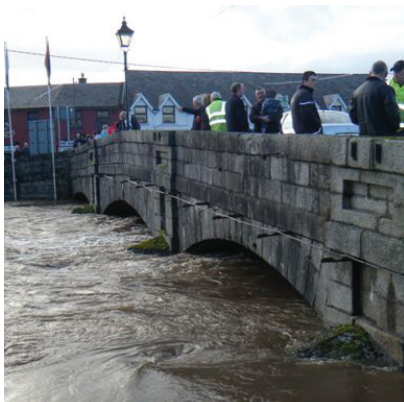
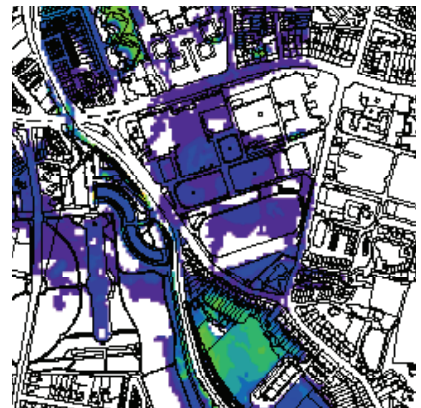
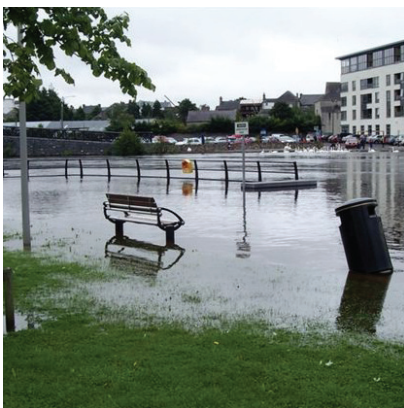
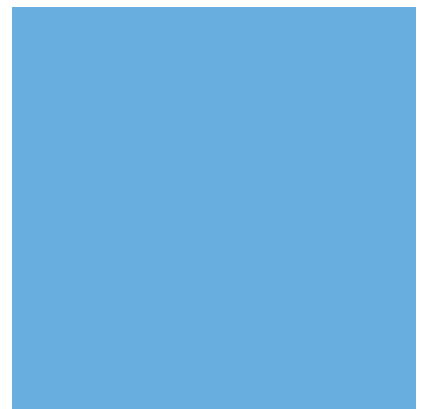




South Eastern CFRAM Study

HA 11, 12 and 13 Hydrology Report

IBE060IRp0012





South Eastern CFRAM Study

HA11, 12 and 13 Hydrology

DOCUMENT CONTROL SHEET

| | | | | | | |
|----------------------------|--|-----|------|----------------|-----------------|----------------------|
| Client | OPW | | | | | |
| Project Title | South Eastern CFRAM Study | | | | | |
| Document Title | IBE0601Rp0012_HA11, 12 and 13_Hydrology Report_F03 | | | | | |
| Document No. | IBE0601Rp0012 | | | | | |
| This Document Comprises | DCS | TOC | Text | List of Tables | List of Figures | No. of Appendices |
| | 1 | 1 | 149 | 1 | 1 | 4 |

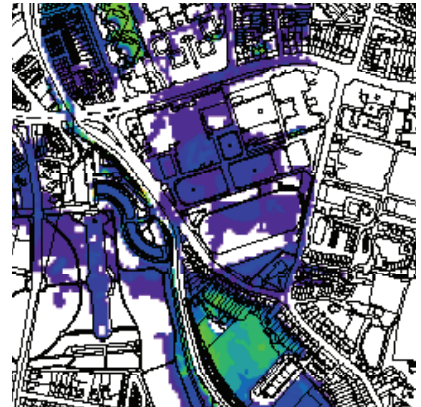
| Rev. | Status | Author(s) | Reviewed By | Approved By | Office of Origin | Issue Date |
|------|-------------|--|-------------|-------------|------------------|------------|
| D01 | Draft | B. Quigley U. Mandal L. Arbuckle | M. Brian | G. Glasgow | Belfast | 02/09/13 |
| F01 | Draft Final | B. Quigley U. Mandal L. Arbuckle | M. Brian | G. Glasgow | Belfast | 17/01/14 |
| F02 | Draft Final | B. Quigley U. Mandal L. Arbuckle | M. Brian | G. Glasgow | Belfast | 11/02/14 |
| F03 | Draft Final | B. Quigley U. Mandal L. Arbuckle | M. Brian | G. Glasgow | Belfast | 14/08/15 |
| F04 | Final | B. Quigley U. Mandal L. Arbuckle | M. Brian | G. Glasgow | Belfast | 20/06/16 |



South Eastern CFRAM Study

HA 11, 12 and 13 Hydrology Report

IBE060IRp0012





Copyright

Copyright - Office of Public Works. All rights reserved. No part of this report may be copied or reproduced by any means without prior written permission from the Office of Public Works.

Legal Disclaimer

This report is subject to the limitations and warranties contained in the contract between the commissioning party (Office of Public Works) and RPS Group Ireland

TABLE OF CONTENTS

| | |
|--|------------|
| LIST OF FIGURES..... | IV |
| LIST OF TABLES | VII |
| APPENDICES | X |
| ABBREVIATIONS..... | XI |
| 1 INTRODUCTION | 1 |
| 1.1 OBJECTIVE OF THIS HYDROLOGY REPORT | 3 |
| 1.2 SUMMARY OF THE AVAILABLE DATA | 4 |
| 1.2.1 Summary of Available Hydrometric Data | 4 |
| 1.2.2 Additional Simulated Flow Data | 6 |
| 1.2.3 Summary of Available Meteorological Data | 8 |
| 1.2.4 Rainfall Radar..... | 10 |
| 2 METHODOLOGY REVIEW..... | 11 |
| 2.1 HYDROLOGICAL ANALYSIS..... | 11 |
| 2.2 METEOROLOGICAL ANALYSIS | 12 |
| 2.3 DESIGN FLOW ESTIMATION | 12 |
| 2.3.1 Index Flood Flow Estimation | 12 |
| 2.3.2 Growth Curve / Factor Development..... | 14 |
| 2.3.3 Design Flow Hydrographs | 14 |
| 2.4 HYDROLOGY PROCESS REVIEW | 15 |
| 2.5 CATCHMENT BOUNDARY REVIEW..... | 17 |
| 3 HYDROMETRIC GAUGE STATION RATING REVIEWS..... | 19 |
| 3.1 METHODOLOGY | 19 |
| 3.3 RATING REVIEW RESULTS..... | 20 |
| 3.4 IMPACT OF RATING REVIEWS ON HYDROLOGICAL ANALYSIS..... | 23 |
| 4 INDEX FLOOD FLOW ESTIMATION | 25 |
| 4.1 HA11 MODEL 1 - COURTOWN | 27 |
| 4.2 HA 11 MODEL 2 - BLACKWATER | 30 |
| 4.3 HA11 MODEL 3 - GOREY | 32 |
| 4.4 HA12 MODEL 1 – BALTINGLASS | 34 |
| 4.5 HA12 MODEL 2 TULLOW (INCL. TULLOWPHELM) | 37 |
| 4.6 HA12 MODEL 3 - BUNCLODY..... | 40 |
| 4.7 HA12 MODEL 4 – ENNISCORTHY (FAIRFIELD / CHERRYORCHARD) | 43 |
| 4.8 HA12 MODEL 5 - WEXFORD..... | 46 |
| 4.9 HA13 MODEL 1 – KILMORE | 49 |
| 4.10 INDEX FLOOD FLOW CONFIDENCE LIMITS..... | 51 |
| 4.10.1 Gauged Q_{med} | 51 |
| 4.10.2 Ungauged Q_{med} | 52 |

| | | |
|----------|---|-----------|
| 5 | FLOOD FREQUENCY ANALYSIS AND GROWTH CURVE DEVELOPMENT | 53 |
| 5.1 | OBJECTIVE AND SCOPE..... | 53 |
| 5.2 | METHODOLOGY | 53 |
| 5.2.1 | Selection of Statistical Distribution | 53 |
| 5.2.2 | Forming a Pooling Region and Groups..... | 53 |
| 5.2.3 | Growth Curve Development..... | 53 |
| 5.2.4 | Limitations in the FEH and FSU Studies..... | 54 |
| 5.3 | DATA AND STATISTICAL PROPERTIES..... | 54 |
| 5.3.1 | Flood Data..... | 54 |
| 5.3.2 | Pooling Region Catchment Physiographic and Climatic Characteristic Data | 59 |
| 5.3.3 | Statistical Properties of the AMAX series..... | 60 |
| 5.4 | STATISTICAL DISTRIBUTION | 61 |
| 5.5 | GROWTH CURVE ESTIMATION POINTS | 63 |
| 5.6 | POOLING REGION AND GROUP FOR GROWTH CURVE ESTIMATION | 66 |
| 5.6.1 | Pooling Region..... | 66 |
| 5.6.2 | Pooling Group..... | 66 |
| 5.7 | GROWTH CURVE ESTIMATION | 67 |
| 5.7.1 | Choice of Growth Curve Distributions | 67 |
| 5.7.2 | Estimation of Growth Curves..... | 67 |
| 5.7.3 | Examination of Growth Curve Shape..... | 69 |
| 5.7.4 | Recommended Growth Curve Distribution for HA 11, 12, 13 | 72 |
| 5.8 | RATIONALISATION OF GROWTH CURVES | 75 |
| 5.8.1 | Relationship of Growth Factors with Catchment Characteristics | 75 |
| 5.8.2 | Generalised Growth Curves | 77 |
| 5.8.3 | Comparison of the at-site growth curves with the pooled growth curves..... | 84 |
| 5.8.4 | Growth factors for all HEPs in HA11, 12 and 13..... | 86 |
| 5.9 | COMPARISON WITH FSR AND SUIR CFRAM STUDY GROWTH FACTORS..... | 91 |
| 5.10 | GROWTH CURVE DEVELOPMENT SUMMARY | 93 |
| 6 | DESIGN FLOWS..... | 95 |
| 6.1 | DESIGN FLOW HYDROGRAPHS | 95 |
| 6.1.1 | Rainfall Runoff (NAM) modelling and HWA | 95 |
| 6.1.2 | FSU Hydrograph Shape Generator..... | 96 |
| 6.1.3 | FSSR 16 Unit Hydrograph Method..... | 96 |
| 6.2 | COASTAL HYDROLOGY..... | 97 |
| 6.2.1 | ICPSS Levels | 97 |
| 6.2.2 | ICWWS Levels | 99 |
| 6.2.3 | Consideration of ICPSS and ICWWS Outputs..... | 100 |
| 6.3 | JOINT PROBABILITY..... | 102 |
| 6.3.1 | Fluvial – Fluvial..... | 102 |
| 6.3.2 | Fluvial – Coastal..... | 102 |

| | | |
|-----------|--|------------|
| 7 | FUTURE ENVIRONMENTAL AND CATCHMENT CHANGES..... | 108 |
| 7.1 | CLIMATE CHANGE | 108 |
| 7.1.1 | HA11, 12 and 13 Context | 108 |
| 7.1.2 | Sea Level Rise | 110 |
| 7.2 | AFFORESTATION | 110 |
| 7.2.1 | Afforestation in HA11,12 & 13 | 110 |
| 7.2.2 | Impact on Hydrology | 113 |
| 7.3 | LAND USE AND URBANISATION | 115 |
| 7.3.1 | Impact of Urbanisation on Hydrology | 119 |
| 7.4 | HYDROGEOMORPHOLOGY | 122 |
| 7.4.1 | Soil Type..... | 122 |
| 7.4.2 | Channel Typology | 123 |
| 7.4.3 | Land Use and Morphological Pressures | 128 |
| 7.4.4 | Arterial Drainage..... | 130 |
| 7.4.5 | River Continuity | 132 |
| 7.4.6 | Localised Pressures | 133 |
| 7.5 | FUTURE SCENARIOS FOR FLOOD RISK MANAGEMENT..... | 134 |
| 7.6 | POLICY TO AID FLOOD REDUCTION | 134 |
| 8 | SENSITIVITY AND UNCERTAINTY | 136 |
| 8.1 | UNCERTAINTY / SENSITIVITY ASSESSMENT MODEL BY MODEL..... | 138 |
| 8.2 | CONCLUSIONS OF SENSITIVITY ANALYSIS..... | 143 |
| 9 | CONCLUSIONS..... | 144 |
| 9.1 | SUMMARY OF THE RESULTS AND GENERAL PATTERNS | 145 |
| 9.2 | RISKS IDENTIFIED | 145 |
| 9.3 | OPPORTUNITIES / RECOMMENDATIONS | 146 |
| 10 | REFERENCES:..... | 148 |

LIST OF FIGURES

| | | |
|--------------|--|----|
| Figure 1.1: | HA11, 12 and 13 AFA Locations | 2 |
| Figure 1.2: | Hydrometric Data Availability..... | 4 |
| Figure 1.3: | Water mass balance between observed and simulated catchment at Rathvilly (12013) 7 | |
| Figure 1.4: | Observed and simulated flow trace for catchment at Rathvilly (12013 - OPW) | 8 |
| Figure 1.5: | Meteorological Data Availability..... | 9 |
| Figure 2.1: | Hydrology Process Flow Chart..... | 16 |
| Figure 2.2: | Comparison of FSU and RPS Catchment Boundaries..... | 18 |
| Figure 4.1: | HA11, 12 and 13 Watercourses to be modelled..... | 26 |
| Figure 4.2: | HA11 Model 1, HEPs and Catchment Boundaries..... | 28 |
| Figure 4.3: | HA11 Model 2 HEPs and Catchment Boundaries..... | 31 |
| Figure 4.4: | HA11 Model 3 HEPs and Catchment Boundaries..... | 33 |
| Figure 4.5: | HA12 Model 1 HEPs and Catchment Boundaries..... | 35 |
| Figure 4.6: | HA12 Model 2 HEPs and Catchment Boundaries..... | 38 |
| Figure 4.7: | HA12 Model 3 HEPs and Catchment Boundaries..... | 41 |
| Figure 4.8: | HA12 Model 4 HEPs and Catchment Boundaries..... | 44 |
| Figure 4.9: | HA12 Model 5 HEPs and Catchment Boundaries..... | 47 |
| Figure 4.10: | HA13 Model 1 HEPs and Catchment Boundaries..... | 49 |
| Figure 5.1: | Locations of 92 Gauging Stations..... | 58 |
| Figure 5.2: | Relative frequencies of catchments sizes (AREA) within the selected 92 stations..... | 59 |
| Figure 5.3: | Relative frequencies of the SAAR values within the selected 92 stations | 60 |
| Figure 5.4: | Relative frequencies of the BFI values within the selected 92 stations..... | 60 |
| Figure 5.5: | L-Moment Ratio Diagram (L-CV versus L-Skewness) for 92 AMAX series | 61 |
| Figure 5.6: | Spatial distribution of the HEPs on the modelled watercourses in HA11, 12 and 13.... | 65 |

| | |
|--|-----|
| Figure 5.7: L-moment ratio diagram (L-skewness versus L-kurtosis) | 67 |
| Figure 5.8: Pooled Growth Curve No. 50 in HA12 - (a) EV1 and GEV distributions; (b) GLO distributions | 71 |
| Figure 5.9: Comparison of EV1, GEV and GLO growth curves on the EV1-y probability plot (Growth Curve No. 50 in HA12) | 73 |
| Figure 5.10: GLO growth curves for 68 HEPs in the Slaney River catchment (HA12)..... | 74 |
| Figure: 5.11: GLO growth curves for 23 HEPs within HA11 | 74 |
| Figure 5.12: GLO growth curve for HA13 | 75 |
| Figure 5.13: Relationship of growth factors with catchment areas for 68 HEPs in HA12 | 76 |
| Figure 5.14: Relationship of growth factors with SAAR for 68 HEPs in HA12 | 76 |
| Figure 5.15: Relationship of growth factors with BFI for 68 HEPs in HA12..... | 77 |
| Figure 5.16: Relationship of growth factors with catchment areas (for 256 growth curve estimation points in HA12) | 78 |
| Figure 5.17: GLO growth curves for all Growth Curve Groups (6 No.) – HA12 | 82 |
| Figure 5.18: Growth Curve for GC Group No. 4 with 95% confidence limits (HA12) | 83 |
| Figure 5.19: The at-site and pooled frequency curves along with the 95% confidence intervals – HA12 | 85 |
| Figure 6.1: 1% AEP Hydrographs for the small urban tributaries in Bunclody AFA..... | 97 |
| Figure 6.2: Location of ICPSS Nodes in Relation to Coastal AFAs..... | 98 |
| Figure 6.3: Draft ICWWS potential areas of vulnerable coastline | 100 |
| Figure 6.4: Typical 1% AEP Coastal Boundary Makeup (to Staff Gauge Zero) | 101 |
| Figure 6.5: Coastal WL @ Dublin Port versus River Level on Slaney and Owenavorrhagh..... | 105 |
| Figure 6.6: Coastal WL @ Wexford versus Flow on Slaney and Owenavorrhagh..... | 106 |
| Figure 7.1: CORINE 2006 Forest Coverage in HA11, 12 &13 Compared to the rest of Ireland ... | 111 |
| Figure 7.2: Forest Coverage Changes in HA11, 12 &13 | 112 |
| Figure 7.3: HA11, 12 &13 CORINE Artificial Surfaces (2000 / 2006)..... | 117 |

| | | |
|-------------|---|-----|
| Figure 7.4: | HA 11, 12 and 13 Soil Types (Source: Irish Forest Soils Project, FIPS – IFS, Teagasc, 2002) | 123 |
| Figure 7.5: | WFD Channel Typology HA11, 12 &13 | 125 |
| Figure 7.6: | Changes in Channel Slope HA11, 12 &13 | 127 |
| Figure 7.7: | HA11, 12 &13 Land Use (CORINE 2006) | 129 |
| Figure 7.8: | Modelled Watercourses affected by arterial drainage in HA11, 12 &13..... | 131 |

LIST OF TABLES

| | | |
|-------------|---|----|
| Table 1.1: | Fluvial and Coastal Flood Risk at each AFA | 1 |
| Table 2.1: | Summary of Catchment Boundary Review | 17 |
| Table 3.1: | Existing Rating Quality Classification for Rating Review Stations in HA11 and 12 (none specified in HA13) | 20 |
| Table 3.2: | AMAX Series Data Before and After Rating Review | 21 |
| Table 3.3: | Summary of Rating Review Effects and Mitigation | 23 |
| Table 4.1: | Q_{med} Values for HA11 Model 1 | 29 |
| Table 4.2: | Q_{med} Values for HA11 Model 2 | 30 |
| Table 4.3: | Q_{med} Values for HA11 Model 3 | 32 |
| Table 4.4: | Q_{med} Values for HA12 Model 1 | 36 |
| Table 4.5: | Q_{med} Values for HA12 Model 2 | 39 |
| Table 4.6: | Q_{med} Values for HA12 Model 3 | 42 |
| Table 4.7: | Q_{med} Values for HA12 Model 4 | 44 |
| Table 4.8: | Q_{med} Values for HA12 Model 5 | 48 |
| Table 4.9: | Q_{med} Values for HA13 Model 1 | 50 |
| Table 4.10: | Calibrated NAM Model Q_{med} Accuracy | 51 |
| Table 5.1: | Hydrometric Station Summary..... | 54 |
| Table 5.2: | Summary of Catchment physiographic and climatic characteristics of Pooling Region | 59 |
| Table 5.3: | Statistical properties of 92 AMAX Series..... | 61 |
| Table 5.4: | Summary results of probability plots assessments (EV1, GEV & GLO distributions) for all 92 AMAX series | 62 |
| Table 5.5: | Summary of the catchment characteristics associated with HA11, 12 and 13 HEPs ... | 63 |
| Table 5.6: | Summary of the catchment characteristics associated with the 108 HEPs in HA12 | 64 |
| Table 5.7: | Summary of the catchment characteristics associated with the 1 HEP in HA13 | 64 |

| | | |
|-------------|--|-----|
| Table 5.8: | Growth curves shape summary | 69 |
| Table 5.9: | Catchment descriptors for all pooled sites for Growth curve No. 50 in HA12 | 70 |
| Table 5.10: | Frequency curve shapes of the individual site's AMAX series associated with the pooled group No. 50 in HA12 | 71 |
| Table 5.11: | Estimated growth factors for Growth Curve No. 50 in HA12 | 72 |
| Table 5.12: | Growth curve estimation summary | 79 |
| Table 5.13: | Growth Curve (GC) Groups | 81 |
| Table 5.14: | Growth factors for range of AEPs | 81 |
| Table 5.15: | Estimated percentage standard errors for growth factors (XT) for a range of AEPs (source FSU Work- Package 2.2 "Frequency Analysis" Final Report – Section 13.3) | 83 |
| Table 5.16: | Hydrometric gauging stations located on the modelled watercourses in HA11, 12 and 13 hydrometric area | 84 |
| Table 5.17: | Growth factors for all HEPs for a range of AEPs for HA11 River catchments (Blackwater & Owenavorrigh Rivers) | 87 |
| Table 5.18: | Growth factors for all 108 HEPs for a range of AEPs for the subject watercourses with HA12 (Slaney River and its tributaries) | 88 |
| Table 5.19: | Growth factors for the subject HEP for a range of AEPs for the Ballyteigue River catchment (HA13) | 91 |
| Table 5.20: | Study growth factors compared with FSR, growth factors | 92 |
| Table 6.1: | ICPSS Level in Close Proximity to HA11, 12 and 13 AFAs | 99 |
| Table 6.2: | Initial Screening for Relevance of Joint Probability | 103 |
| Table 7.1: | Afforestation from 2000 to 2006 in HA11, 12 and 13 | 113 |
| Table 7.2: | Allowances for Effects of Forestation / Afforestation (100 year time horizon) | 114 |
| Table 7.3: | Population Growth in the Counties of HA11, 12 and 13 (Source: CSO) | 115 |
| Table 7.4: | Population Growth within Urban AFAs (Source: CSO) | 116 |
| Table 7.5: | Historic Urbanisation Growth Indicators | 118 |

| | | |
|------------|--|-----|
| Table 7.6: | Potential Effect of Urbanisation on Q_{med} Flow in HA12 | 119 |
| Table 7.7: | Potential Effect of Urbanisation on Q_{med} Flow in HA11 and HA12..... | 121 |
| Table 7.8: | Channel Types and Associated Descriptors | 124 |
| Table 7.9: | HA11, 12 and 13 Allowances for Future Scenarios (100 year time horizon) | 134 |
| Table 8.1: | Assessment of contributing factors and cumulative effect of uncertainty / sensitivity in the hydrological analysis | 138 |

APPENDICES

| | | |
|-------------------|--|-----------------|
| APPENDIX A | HA11, 12 and 13 Hydrometric Data Status Table | 1 Page |
| APPENDIX B | Rating Reviews | 12 Pages |
| APPENDIX C | Design Flows for Modelling Input | 28 Pages |
| APPENDIX D | NAM Outputs | 20 Pages |

ABBREVIATIONS

| | |
|---------|--|
| AEP | Annual Exceedance Probability |
| AFA | Area for Further Assessment |
| AFF | At-site Flood Frequency |
| AMAX | Annual Maximum flood series |
| AREA | Catchment Area |
| BFI | Base Flow Index |
| CFRAM | Catchment Flood Risk Assessment and Management |
| C4i | Community Climate Change Consortium for Ireland |
| CORINE | Coordination of Information on the Environment |
| CSO | Central Statistics Office of Ireland |
| DTM | Digital Terrain Model |
| ERBD | Eastern River Basin District |
| EV1 | Extreme Value Type 1 (distribution) (=Gumbel distribution) |
| EPA | Environmental Protection Agency |
| FARL | Flood Attenuation for Rivers and Lakes |
| FEH | Flood Estimation Handbook |
| FRA | Flood Risk Assessment |
| FRMP | Flood Risk Management Plan |
| FSR | Flood Studies Report |
| FSSR 16 | Flood Studies Supplementary Report No. 16 |
| FSU | Flood Studies Update |
| GC | Growth Curve |
| GEV | Generalised Extreme Value (distribution) |
| GLO | General Logistic (distribution) |
| GSI | Geological Survey of Ireland |
| HA | Hydrometric Area |
| HEFS | High End Future Scenario (Climate Change) |
| HEP | Hydrological Estimation Point |
| HPW | High Priority Watercourse |

| | |
|------------------|--|
| HWA | Hydrograph Width Analysis |
| IH124 | Institute of Hydrology Report No. 124 |
| IPCC | Intergovernmental Panel on Climate Change |
| LA | Local Authority |
| LN2 | 2 Parameter Log Normal (distribution) |
| L-CV | Coefficient of L variation |
| MPW | Medium Priority Watercourse |
| MRFS | Mid Range Future Scenario (Climate Change) |
| NDTM | National Digital Terrain Model |
| OD | Ordnance Datum |
| OPW | Office of Public Works |
| OSi | Ordnance Survey Ireland |
| PCD | Physical Catchment Descriptor |
| PFRA | Preliminary Flood Risk Assessment |
| Q_{med} | median of AMAX flood series |
| Q_{bar} / QBAR | mean average of AMAX flood series |
| RBD | River Basin District |
| RFF | Regional Flood Frequency |
| ROI | Region of Influence |
| SAAR | Standard Average Annual Rainfall (mm) |
| SERBD | South Eastern River Basin District |
| SuDS | Sustainable Urban Drainage |
| UAF | Urban Adjustment Factor |
| UoM | Unit of Management |

1 INTRODUCTION

The Office of Public Works (OPW) commissioned RPS to undertake the South Eastern Catchment Flood Risk Assessment and Management Study (South Eastern CFRAM Study) in July 2011. The South Eastern CFRAM Study was the third catchment flood risk management study to be commissioned in Ireland under the EC Directive on the Assessment and Management of Flood Risks 2007 as implemented in Ireland by SI 122 of 2010 European Communities (Assessment and Management of Flood Risks) Regulations 2010.

The South Eastern CFRAM Study covers an area of approximately 12,857 km² and includes six Units of Management / Hydrometric Areas (Unit of Management Boundaries match the Hydrometric Area boundaries within the SECFRAM Study area). These are HA/UoM 11 (Owenavorrhagh), HA/UoM 12 (Slaney and Wexford Harbour), HA/UoM 13 (Ballyteigue - Bannow), HA/UoM 14 (Barrow), HA/UoM 15 (Barrow), HA/UoM 16(Suir), and HA17 (Colligan – Mahon). HA16 (Suir) is covered by the Suir pilot CFRAM Study and covers an area of approximately 3,452 km². There is a high level of flood risk within the South Eastern CFRAM Study area with significant coastal and fluvial flooding events having occurred in the past.

HA11, 12 and 13 are covered together in this hydrology report. They are predominantly rural catchments in an Irish context, with the largest urban areas being Wexford and Enniscorthy in HA12; and Gorey and Courtown in the case of HA11. Smaller towns and villages include Baltinglass in county Wicklow; Tullow in county Carlow; and Bunclody, Blackwater and Kilmore (HA13) in county Wexford. The rich soils are particularly suitable for agriculture and much of the area is given over to tillage and grassland.

Within HA11, 12 and 13 there are 11 Areas for Further Assessment (AFA) as shown in Table 1.1 and Figure 1.1.

Table 1.1: Fluvial and Coastal Flood Risk at each AFA

| AFA | Fluvial | Coastal | AFA | Fluvial | Coastal |
|----------------------------|---------|---------|--------------|---------|---------|
| Baltinglass | ✓ | - | South Slobs | - | ✓ |
| Tullow (Incl Tullowphelim) | ✓ | - | Kilmore | ✓ | ✓ |
| Bunclody | ✓ | - | Gorey | ✓ | - |
| Enniscorthy and Environs | ✓ | - | Courtown | ✓ | ✓ |
| Wexford | ✓ | ✓ | Blackwater | ✓ | ✓ |
| North Slobs | - | ✓ | | | |
| | | | Total | 9 | 6 |

The principal source of flood risk within HA11, 12 and 13 is fluvial flooding at nine of the 11 AFAs. However coastal flood risk is also a risk at six of the AFAs, and is the only source of flood risk for the North and South Slobs AFAs.



Figure 1.1: HA11, 12 and 13 AFA Locations

1.1 OBJECTIVE OF THIS HYDROLOGY REPORT

The principal objective of this Hydrology Report is to provide detail on the outputs from the processes of hydrological analysis and design flow estimation. The details of the methodologies used and the preliminary hydrological analysis are provided in the Inception Report 'IBE0601Rp0007_HA11, 12 and 13 Inception Report_F02' (RPS, 2012). This report provides a review and summary of the methodologies used as well as details of any amendments to the methodologies since completion of the Inception Report. The report provides details of the results of the hydrological analysis and design flow estimation and summarises the outputs from the analysis which will be taken forward as inputs for the hydraulic modelling. Discussion is provided within this report on the outputs in terms of the degree of confidence which can be attached to the outputs and the opportunities for providing greater certainty for future studies, including opportunities for improving the observed data used to inform the study.

This report does not include details of the data collection process, flood history within the AFAs or methodology and results from the historic flood analysis (except where this is used to inform the design flow estimation) as this is contained within the Inception Report for HA11, 12 and 13.

1.2 SUMMARY OF THE AVAILABLE DATA

1.2.1 Summary of Available Hydrometric Data

Hydrometric data is available at 21 river hydrometric gauge station locations within HA11, 12 and 13 as shown in Figure 1.2 below. There are also five tidal stations and two lake stations as shown on Figure 1.2.

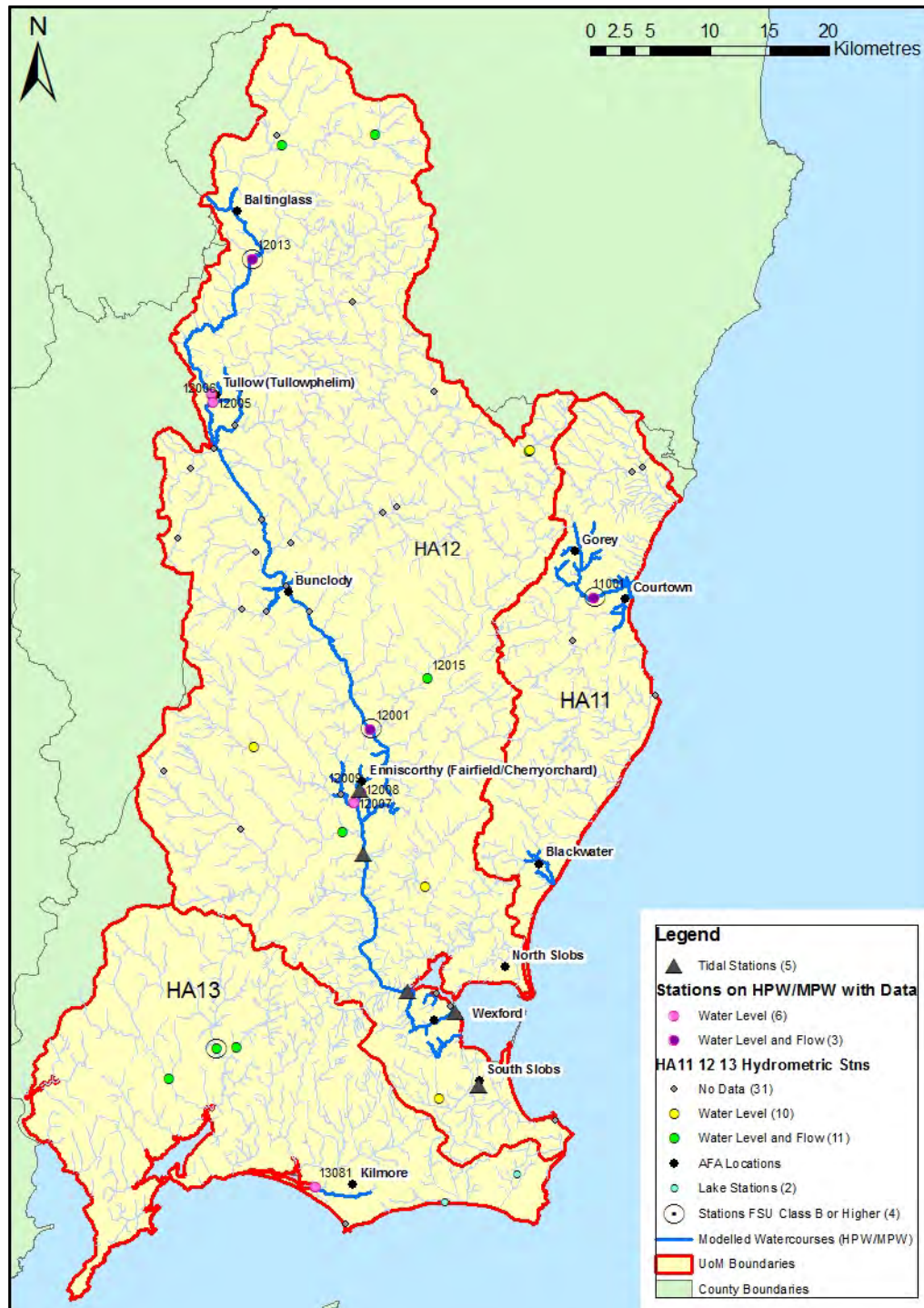


Figure 1.2: Hydrometric Data Availability

Nine of the river hydrometric stations are located on the watercourses to be modelled (HPW/MPW), three of which have flow data available and are shown on Figure 1.2 (Stations 11001, 12001 and 12013).

Four stations within HA11, 12 and 13 were classed as B or higher under the FSU in 2004 meaning that there is confidence in flow data up to the value of Q_{med} at least. These stations are circled on Figure 1.2. Three of these stations are located on watercourses to be modelled (HPW//MPW).

There are two hydrometric stations located on the River Slaney (HA12) that have flow data available to various extents for use in this study:

- Scarawalsh (12001– OPW) has continuous flow data available from 1955 to 2011. It was classified as A2 under the FSU in 2004 with a Q_{med} value of $152\text{m}^3/\text{s}$.
- Rathvilly (12013 – EPA) has continuous flow data available for 1976 to 2005. It is classified as B under FSU but it is noted that additional high flow gaugings are required to confirm the rating.

There is one hydrometric station located within HA11 on the Owenavorrhagh River that has flow data available for use in this study:

- Boleany (11001 – OPW) has continuous flow data available from 1972 to 2009. The AMAX series is split pre and post 1991 due to differing flow gauging trends although it is not clear why this is the case. The FSU classification for both AMAX series was initially A2 but final classification is B. The control is a flat V weir which drowns out due to back water effects during high flow events. The post 1991 AMAX series was adopted for use in the FSU database where the A2 classification is still stated. The adopted Q_{med} value is $45.75\text{m}^3/\text{s}$. However there is uncertainty with this data given the change in FSU classification and also that the FSU predicted Q_{med} based on catchment descriptors is considerably lower $24.67\text{m}^3/\text{s}$.

There are no hydrometric stations with flow data available located on the watercourse to be modelled within HA13.

The two lake stations are located in HA13 at Ladys Island and Tacumshin Lake. The five tidal stations are located at Enniscorthy, Edermine Bridge, Assaly, Ferrycarrig Bridge and Wexford Harbour (inactive) are all within HA12 (refer to Chapter 6).

In the South East CFRAM Study project brief (2200/RP/001 March 2011), three hydrometric stations within HA11, 12 and 13 were recommended for CFRAM Study rating review which is discussed further in Chapter 3 and are listed below:

- 11001 Boleany - outlined above and shown on Figure 1.2
- 12001 Scarawalsh - outlined above and shown on Figure 1.2

- 12015 Ferns - not located on HPW/MPW but is located on the Bann River which is a tributary of the River Slaney. Not classified under FSU at present. Refer to Figure 1.2 for location.

HA13 is essentially ungauged for the purposes of this Study. HA11 has one gauging station on the Owenavorrhagh River. HA12 is moderately gauged in terms of the River Slaney itself with two of the five models containing hydrometric stations class B or above. Further details on the data availability at hydrometric gauge stations within HA11, 12 and 13 can be found in Appendix A.

1.2.2 Additional Simulated Flow Data

As discussed in the Inception Report and in various sections of this report additional flow data has been simulated at various HEPs through the application of rainfall data (radar data calibrated to rain gauges, or rain gauges where radar is not available, refer to Section 1.2.4) in catchment scale runoff models. This additional simulated layer of flow data has been used to aid design flow estimation. This flow data will also be used during the hydraulic modelling calibration phase in order to provide simulated historic flood hydrographs where no flood event flow data currently exists which can be matched against recorded levels and / or mapped flood extents. Each model has been considered on an individual basis against the available flow data and calibration has been achieved based on a range of goodness of fit measures (refer to Appendix D) and on visual inspection of the mass balance and flow trace graphs, examples of which are shown in Figure 1.3 and Figure 1.4 for the modelled catchment to (12013, Rathvilly – OPW) hydrometric gauging station (refer to Appendix D).

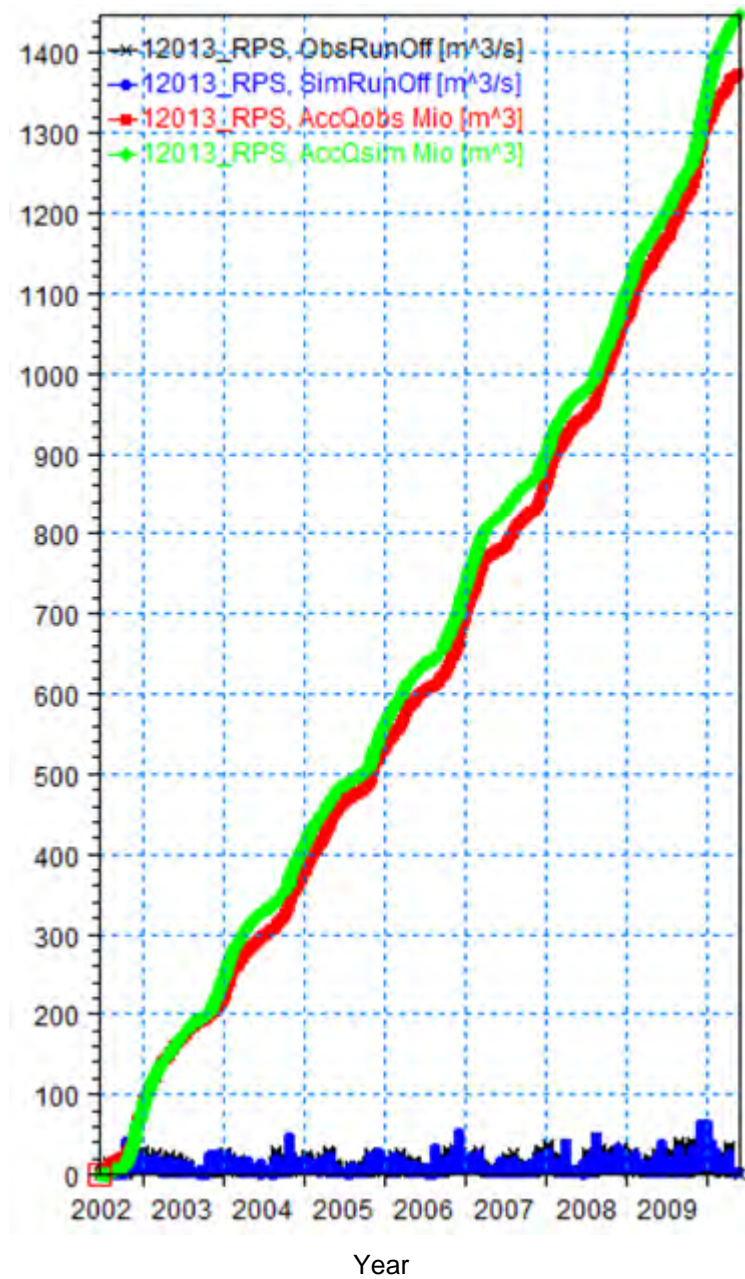


Figure 1.3: Water mass balance between observed and simulated catchment at Rathvilly (12013)

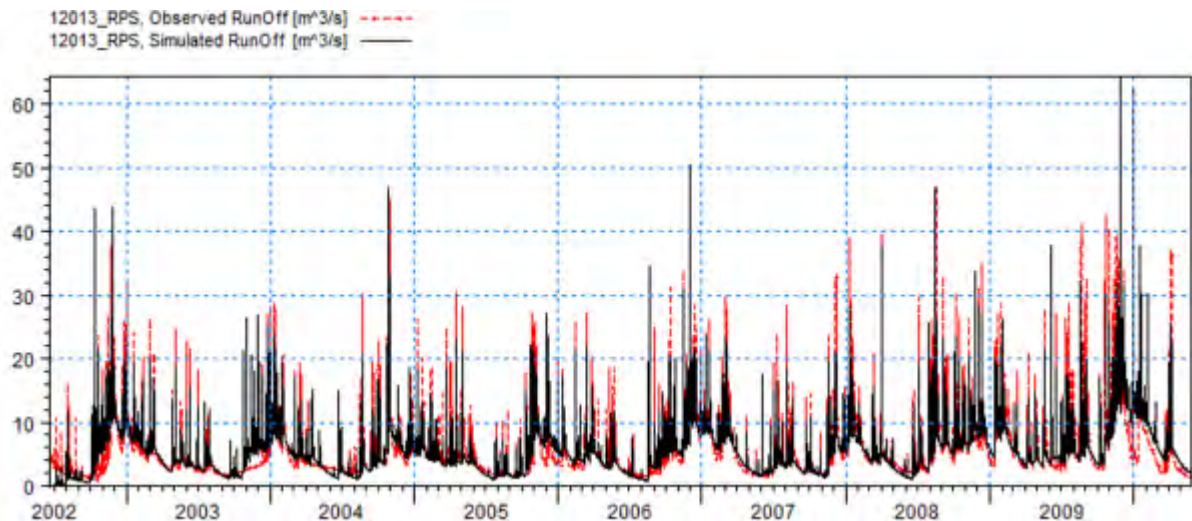


Figure 1.4: Observed and simulated flow trace for catchment at Rathvilly (12013 - OPW)

Issues with the rating curve or gaps in flow data can lead to erroneous goodness of fit measures. It is therefore not possible to make a meaningful summary of the calibration of this simulated data against available flow data from all hydrometric gauging stations and each model must be considered on an individual basis. Results of the calibration process and a summary of the output flow data are contained within Appendix D.

1.2.3 Summary of Available Meteorological Data

Meteorological data is available from a number of Met Éireann daily and hourly rain gauges within the South Eastern RBD and beyond (refer to Figure 1.5) which has the potential to be used within the hydrological analysis. In particular, within the RPS methodology the historical time series data can be used as an input to catchment scale hydrological rainfall runoff models to simulate a continuous flow record within a catchment. High resolution temporal data is required to achieve the required accuracy within the hydrological models and as such hourly time series data is required. There are two Met Éireann hourly rain gauges within HA12 at Johnstown Castle and Rosslare. There is also one in HA14 at Oak Park and in Kilkenny in HA15. Combinations of data from these stations can be used as inputs to hydrological modelling by using the area weighted Thiessen polygons method to interpolate data at geographical locations between the stations. Daily rainfall data is not considered to be of a high enough temporal resolution to be used as direct input for hydrological modelling on its own but can be used along with the hourly data to inform the spatial distribution of hourly rainfall data within the catchments.

In addition to the observed historical rainfall data available at the aforementioned rain gauge locations, further meteorological information is required as input to hydrological models namely observed evaporation, soil moisture deficits and potential evapotranspiration data. Historical time series data is available for these parameters at Met Éireann synoptic weather stations. The locations at which historical data is available is generally the same as for hourly rainfall data and is available at Kilkenny,

Oak Park, Johnstown Castle and Rosslare. This additional meteorological data was found to be of sufficient availability to be used as input to the hydrological models. **Error! Reference source not found.** Figure 1.5 shows the locations of all of the rain gauges available and the availability of historic information at the hourly rainfall gauges.



Figure 1.5: Meteorological Data Availability

1.2.4 Rainfall Radar

A data collection meeting held at the beginning of the Eastern CFRAM Study (between RPS, HydroLogic, OPW and Met Éireann) identified an opportunity for exploring the use and benefits of rainfall radar data in hydrological analysis. A radar trial was undertaken on the Dodder catchment and is reported in 'IBE0600Rp0007 Eastern CFRAM Study, Dublin Radar Data Analysis for the Dodder Catchment, Stage 1' (RPS / Hydrologic, 2012) whereby data from the Dublin radar was adjusted against the available rain gauge data to produce an adjusted hourly gridded time series of rainfall data. When compared to the area-weighted derived rainfall series from the gauge data alone, the use of the radar data was shown to bring significant improvements to the rainfall data for rainfall runoff modelling input in terms of spatial distribution of the rainfall, the peak discharges and the timing of the peak discharges. Simulated hydrograph shapes and the overall water balance error margins were also shown to be significantly improved. A further analysis was also undertaken remote from the Dublin radar in order to quantify the benefits at a location further away from the radar. The Athboy River within HA07 was chosen as a suitable location for the trial and the results of the analysis are presented in the report 'IBE0600Rp0013 Athboy Radar Analysis' (RPS).

Subsequently OPW approved the processing of historical data from the Met Éireann radar stations located at Dublin Airport and Shannon for the entire South Eastern CFRAM Study area for information that was received covering the time period from January 1998 to May 2010. Following initial screening of both the radar information and the available rain gauge information which is required for adjustment of the radar observed rainfall sums; the following dataset was processed for use in the South East CFRAM Study:

- Hourly PCR (Pulse Compression Radar) data on a 1 x 1 km grid (480km x 480km total grid) covering the entire calendar years 1998 –2009.

Following processing of this radar dataset rainfall sums are available for every hour, for the majority of 1km² grid squares of the South Eastern CFRAM Study area for the calendar years 1998 - 2009. There is a limitation to the extent of radar coverage from Dublin and/or Shannon in the South Eastern CFRAM Study Area. The south east corner is covered by neither. In fact the radar data blockages are such that it is not available for any of the NAM models in HA11, 12 and 13. Therefore it is not discussed any further in this report. Further details on the use of rainfall radar data in hydrological modelling for the South Eastern CFRAM Study as a whole can be found in the Hydrology Reports for HA14 and HA15 (IBE0601Rp 00010 and 00011 respectively).

2 METHODOLOGY REVIEW

The methodologies for hydrological analysis and design flow estimation were developed based on the current best practice and detailed in the HA11, 12 and 13 Inception Report. In the intervening period there have been a number of developments both in best practice, and the hydrological analysis tools which are available such that it is prudent that the overall methodology is reviewed and discussed. As well as a review of the methodology this chapter seeks to identify changes to the catchment that have become apparent and must be considered in the hydrological analysis.

2.1 HYDROLOGICAL ANALYSIS

The main tasks of hydrological analysis of existing gauge data have been undertaken based on the best practice guidance for Irish catchments contained within the Flood Studies Update. The analysis of the data available from the hydrometric gauge stations shown in Figure 1.2 has been carried out based on the guidance contained within FSU Work Packages 2.1 'Hydrological Data Preparation' and 2.2 'Flood Frequency Analysis' and is detailed in Chapter 4. This analysis was undertaken prior to the receipt of survey information which would have allowed the progression of the South Eastern CFRAM Study gauge station rating reviews identified within the HA11, 12 and 13 Inception Report. Following completion of the rating reviews at the two stations identified there was shown to be uncertainty in the ratings at neither of them. The rating reviews, the new rating relationships and the consequences of the rating reviews for hydrological analysis are discussed in detail in chapter 3 of this report. The following elements of hydrological analysis have been assessed against the potential impact of uncertainty in the rating and mitigation measures and / or re-analysis undertaken to ensure the robustness of the hydrological analysis:

- Gauged Index Flood Flow (Q_{med}) – Where there has been shown to be uncertainty in the rating within the range of flows up to and around Q_{med} , the Annual Maxima (AMAX) flow series has been re-processed using the revised rating. The use of the gauged Q_{med} in design flow estimation is further discussed in 2.2.1.
- Single site (historic) flood frequency analysis – As the estimated frequency of a flood event is a function of the ranking of the event within the AMAX series, and this will not change following re-processing of the AMAX series, this will have little impact on the outputs of this study.
- Growth Curve Development – The inclusion of gauge years within pooled flood frequency analysis that have a high degree of uncertainty could have a skewing effect within the frequency analysis but the effect will be diluted within a group (where it is assumed other gauge years have a high degree of confidence). The cumulative effect of uncertainty in both directions at multiple gauges may also have a cancelling out effect within a pooling group and as such it is not necessary to re-analyse the pooling groups. However where growth curves are based on a single site analysis where it has been shown that there is uncertainty in the

rating, the single site analysis has been re-analysed with the re-processed AMAX data based on the revised rating relationship.

2.2 METEOROLOGICAL ANALYSIS

Sections 1.2.2 and 1.2.3 discuss how a wide range of meteorological data, both rain gauge and radar based, has been brought together to cover the entire South Eastern CFRAM Study area such that all areas are covered by high resolution spatial and temporal historical rainfall data. The methodology does not seek to analyse the raw rainfall sums which have been produced from the processing of the data but rather seeks to interpret this data through rainfall runoff modelling and build simulations of the resulting flows in the catchments and sub-catchments. The modelling techniques used results in a wealth of additional (simulated) historical flow data within the catchments which is directly relevant to fluvial modelling and which therefore adds statistical robustness to the traditional analysis techniques.

2.3 DESIGN FLOW ESTIMATION

The estimation of design flows is based on a methodology combining the available best practice guidance for Irish catchments and hydrological catchment rainfall runoff modelling to augment the available gauged data with simulated flow data. The methodologies for estimation of the various elements which make up the design flow estimates to be used for modelling are detailed below.

2.3.1 Index Flood Flow Estimation

Estimation of the Index Flood Flow is required for all catchments and sub-catchments to be analysed under the CFRAM Study with each sub-catchment defined by a Hydrological Estimation Point (HEP). The methodologies for estimation of design flow vary depending on whether or not the catchment is gauged and also based on how the runoff from the catchments impacts upon the Area for Further Assessment (AFA). The hierarchy of methodologies is discussed below.

2.3.1.1 Gauged Index Flood Flow (Q_{med})

HEPs have been located at all hydrometric gauging stations where flow data is available and these HEPs are subject to hydrological catchment scale rainfall runoff modelling, where it is deemed that an improvement in the AMAX series and flow trace can be gained from the rainfall runoff model output. The methodology for this is described in detail within the HA11, 12 and 13 Inception Report. The gauged Q_{med} to be used for design flow estimation is improved using simulated data from the AMAX series derived from the rainfall runoff model constructed for the catchment at the gauge station as appropriate. This has a number of advantages:

- An AMAX series is simulated for the duration of the meteorological records which are generally between 50 – 70 years in length giving greater statistical confidence in the Q_{med} value.

- The modelled catchment characteristics reflect present day (derived from the CORINE 2006 land use and Geological Survey of Ireland (GSI) datasets) conditions and as such are not subject to changes in flood flow behaviour over time due to changing catchment conditions (as may be the case within historic gauge records).

It must be noted however that the runoff models are calibrated against the gauge records so in theory there is the potential for any error in the gauge records to be carried over into the rainfall runoff models. As such the following mitigation measure has been taken to ensure that the effect of uncertainty at the hydrometric gauging station is not replicated in the rainfall runoff model:

- Catchment scale rainfall runoff (NAM) models are calibrated only to the range of the flow trace at gauging stations where there is certainty in the rating. For example where there is an FSU A2 classification of the rating the rainfall runoff model will be calibrated on the flow values up to 1.3 times Q_{med} only. Where there is no FSU classification the calibration will be carried out on the range of flows for which spot gaugings are available (i.e. not on flows based on an extrapolated rating curve).

Conversely to this potential for error in the rainfall runoff model, if the calibration is carried out against a period for which there is certainty in the gauged flows then it is possible that the model will replicate historic event flood flows which are beyond the confidence of the gauging station rating (i.e. based on an extrapolated relationship between water level and flow) more accurately than the gauge station has recorded (where there is uncertainty in the rating).

The simulated AMAX series and subsequent Q_{med} will be considered alongside the existing AMAX series and Q_{med} to achieve the most robust estimate of the gauged Q_{med} . Where for example there is confidence in the rating at Q_{med} (FSU A1, A2 & B classification or post rating review) and the gauge record is sufficiently long such that the statistical standard error as detailed in FSU WP 2.3, Table 2 is lower than that of the rainfall runoff models within the catchment (Appendix D) then the Q_{med} at the gauge is preferred.

2.3.1.2 Ungauged Index Flood Flow (Q_{med})

At all catchments the ungauged catchment descriptor based method **FSU WP 2.3 'Flood Estimation in Ungauged Catchments'** has been used for all catchments, to derive estimates of Q_{med} , including small ungauged catchments. This is in accordance with recently published guidance "Guidance Note 21 - *CFRAM guidance note on flood estimation for ungauged catchments*". This guidance note drew on the finding that alternative methods for small catchments (Flood Studies Report, NERC, 1975; IH Report 124, Marshall and Baylis, 1994) do not have enough empirical support in Ireland and draw on older and cruder datasets than FSU. Therefore, in the first instance, the FSU 7-variable ungauged catchment descriptor equation (Work Package 2.3) is used to calculate an estimate of the Index Flood Flow at all HEPs and where available, gauge records or catchment runoff models are used to adjust / improve the estimate as the design flow estimation is developed.

The FSU methodology outlined in WP 2.3 recommends that all estimates based on the seven parameter catchment descriptor equation are adjusted based on the most hydrologically similar gauged site. The adjustment factor is applied to the regression equation estimate at the subject catchment and can be described in simple terms as the gauged Q_{med} divided by the regression equation estimated Q_{med} at the most hydrologically similar gauged site. Hydrological analysis tools developed by OPW as part of the FSU identify 216 gauge locations which are described as 'Pivotal Sites' following analysis of the data available as part of FSU WP 2.1 'Hydrological Data Preparation'. Rather than be restricted to the list of Pivotal Sites RPS has used the results of the rainfall runoff modelling at gauging stations to build a higher density of gauge sites for which data is available upon which to base adjustment. As such the adjustment of ungauged estimates of Q_{med} is based on the rainfall runoff (NAM) model results discussed in 2.3.1.1 where these are available upstream or downstream of the subject site. Where a rainfall runoff (NAM) modelled gauged HEP is not available on the modelled watercourse upon which to base the adjustment RPS have reverted to using the FSU pool of Pivotal Sites based on hydrological similarity.

2.3.2 Growth Curve / Factor Development

Growth curves have been developed based on single site and pooled analysis of gauged hydrometric data based on the FSU methodology set out in Work Packages 2.1 and 2.2. Due to CFRAM Study programme constraints it was not possible to include the simulated AMAX series years at gauging stations within the analysis and as such all analysis is based on the recorded data only. Full details and discussion of the results can be found in Chapter 4.

2.3.3 Design Flow Hydrographs

The design flow hydrograph methodology for the South Eastern CFRAM Study centres around FSU Work Package 3.1 'Hydrograph Width Analysis' and uses the tools developed by OPW for analysing flood hydrographs at gauged sites supplemented with the additional simulated continuous flow data derived from the catchment rainfall runoff (NAM) models if considered appropriate. Since the completion of the Inception Report, the methodology for deriving design flow hydrographs has been developed further following the release of the FSU Hydrograph Shape Generator version 5.

As such the hydrograph shapes are generated based on the following methods:

1. At all rainfall runoff modelled HEPs simulated continuous flow records are now available such that a range of past flood events can be analysed. The method utilises the Hydrograph Width Analysis (HWA) software developed as part of FSU WP 3.1 to analyse these simulated flow records to produce median width, semi-dimensionless hydrographs for design events. The methodology requires the conversion of the continuous flow trace data into the required HWA specific format (.tsf file) before historic events are isolated and analysed. This methodology will provide the larger inflow hydrographs which will drive the hydraulic models.

2. At most other HEPs within HA11, 12 and 13 hydrographs will be generated using the recently released FSU Hydrograph Shape generator version 5 developed by OPW. This tool increases the list of Pivotal Sites from which median hydrograph shape parameters can be borrowed based on the hydrological similarity of the Pivotal Site when compared to the subject site. The release of version 5 of this tool has increased the pool of Pivotal Sites to over 150. RPS trialling of this version of the FSU Hydrograph Shape Generator in CFRAMS has found that the generated hydrograph shapes provide a reasonably good fit when compared to the observed and simulated (NAM) hydrographs within the catchment.
3. In some locations it may not be possible to find a suitable Pivotal Site from which a comparable hydrograph shape can be borrowed, particularly for the very small sub-catchments. In this instance hydrograph shapes have been generated using the Flood Studies Supplementary Report (FSSR) 16 Unit Hydrograph method.

Design hydrographs are being developed at all HEPs. It was originally intended at the smallest inflow / tributary HEPs that continuous point flows could be input. However it is now envisaged that the hydrograph will be critical in some of the smallest watercourses which are restricted by culverts / bridges where flood volume as opposed to flood flow becomes the critical characteristic of a flood. One example of this may be the small urban HPWs in the Wexford (HA12, Model 5) where application of continuous point flows at the upstream limit of the hydraulic model could lead to an unrealistic build up of water behind culvert structures where this is the critical flood mechanism.

2.4 HYDROLOGY PROCESS REVIEW

Following developments in best practice and guidance documents and the refinement of RPS methodology through its application on the South Eastern CFRAM Study the hydrology process has been amended slightly from that which has been presented in the HA11, 12 and 13 Inception Report (summarised previously in Figure 5.2 of report IBE0601Rp0005_HA11, 12 and 13 Inception Report_F02). The revised process flow chart which has been applied in carrying out the hydrological analysis and design flow estimation for HA11, 12 and 13 is presented in Figure 2.1.

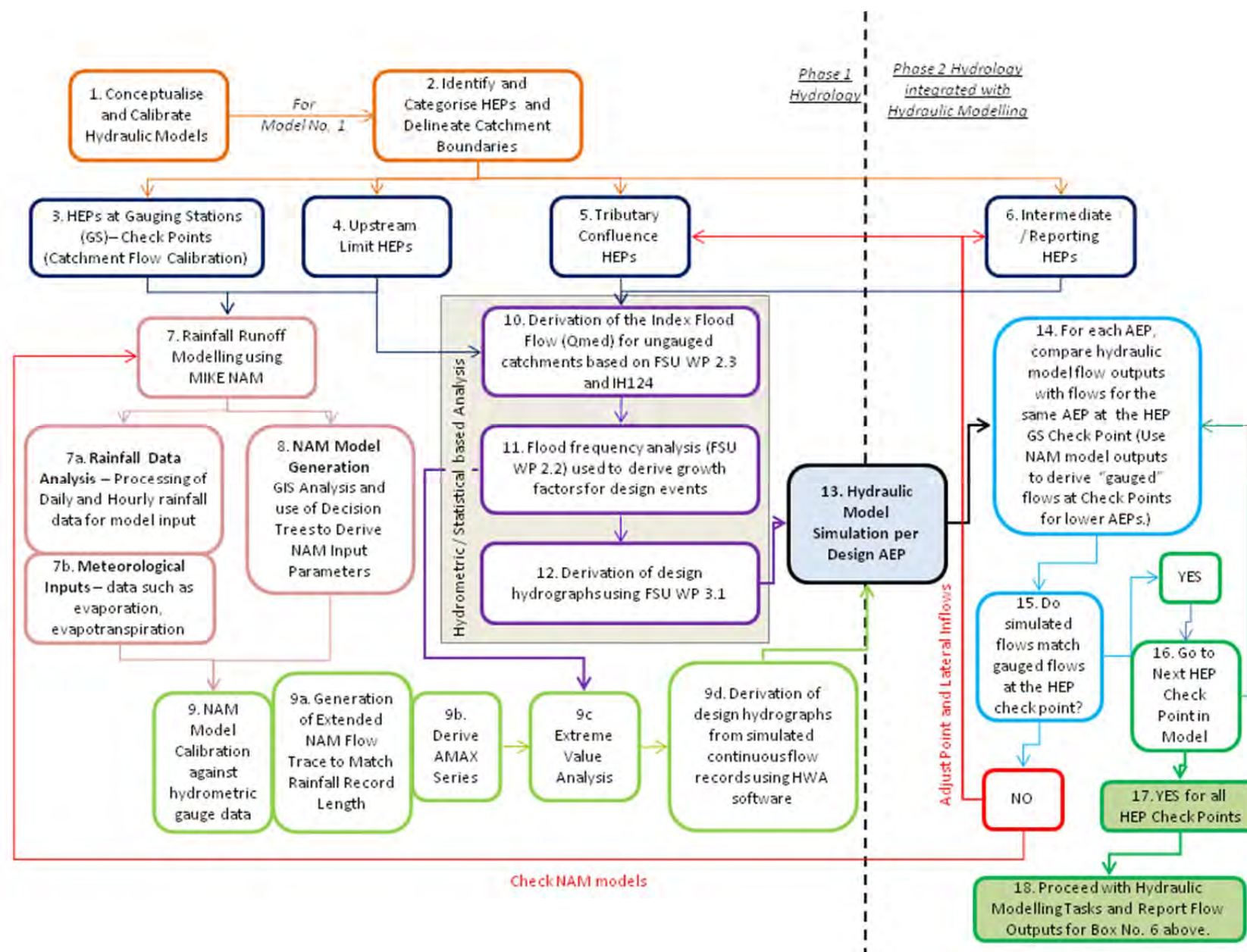


Figure 2.1: Hydrology Process Flow Chart

2.5 CATCHMENT BOUNDARY REVIEW

In line with the CFRAM Study Stage 1 Project Brief (ref. 2149/RP/002/F, May 2010) section 6.3, RPS have delineated the catchment boundaries at HEPs using the FSU derived ungauged and gauged catchment boundaries as a starting point. For details of the full methodology for undertaking this review see HA11, 12 and 13 Inception Report, Section 5.3.2. Following the completion of this process a number of the catchment boundaries were amended and in a number of catchments the boundaries were amended significantly. Table 2.1 gives a summary of the changes in the catchment area at CFRAMS HEP points when compared to the equivalent FSU catchment from which they were derived.

Table 2.1: Summary of Catchment Boundary Review

| Change in Catchment Area | Number of HEPs HA11 | Number of HEPs HA12 | Number of HEPs HA13 |
|---------------------------------|----------------------------|----------------------------|----------------------------|
| New Catchment Delineated | 22 | 23 | 0 |
| No change | 11 | 17 | 1 |
| 0 – 10% | 9 | 60 | 1 |
| Greater than 10% | 0 | 8 | 1 |
| Total | 42 | 108 | 3 |

Not all the catchments related to HEPs that are required to be considered within HA11, 12 and 13 were previously delineated. Some of the catchments relate to small streams and land drains which were previously too small to be considered under FSU and as such RPS delineated these catchments using a combination of mapping, aerial photography and the National Digital Height Model (NDHM). In four cases, original FSU nodes were moved to HEP locations to pick up tributaries observed via walkover survey that were in the wrong location on the Rivers polyline GIS layer (OSI 50k mapping). In 12 cases, river splitting / converging was the reason behind catchment boundary amendment. The review concluded that 48% of catchments were already accurately delineated or were newly delineated but 52% of the catchments delineated under FSU were found not to be representative of the NDHM, the mapping or draft survey information. The most common reason for amendment in HA11, 12 and 13 was due to inspection of topography from the aforementioned sources. Nine of the catchments (6%) were found to have margins of error of over 10%. These catchments ranged from 0.006 to 1034.5 km² in area.

Figure 2.2 shows the original merged FSU river catchments with a red outline. These have been overlain by the corresponding revised RPS merged river catchments which are outlined in blue.

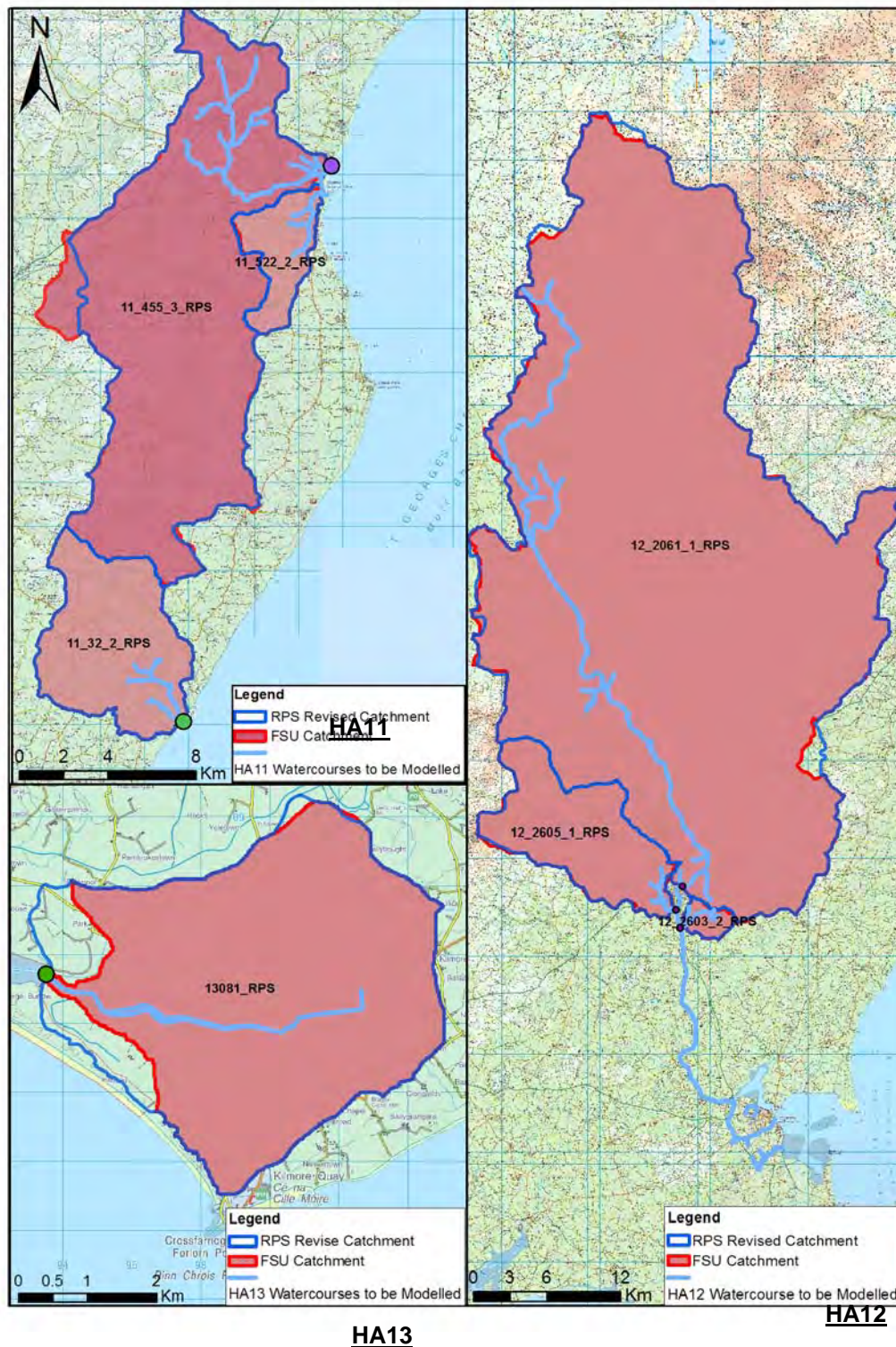


Figure 2.2: Comparison of FSU and RPS Catchment Boundaries

The overall catchment boundaries for HA11, HA12 and HA13 differ slightly as a result of the catchment delineation process which was provided at project commencement as the Unit of Management Boundaries. The RPS catchments were subsequently used to redefine the UoM boundaries for each hydrometric area, the shapefiles of which will be provided to OPW upon completion of the Study.

3 HYDROMETRIC GAUGE STATION RATING REVIEWS

As a follow on from the recommendations of Work Package 2.1 of the FSU (Reference 5), a task was included in the South Eastern CFRAM Study brief to undertake further rating review of a subset of hydrometric stations. Following the completion of the risk review stage and finalisation of the AFA locations a total of three hydrometric stations were specified for rating review. These stations were chosen for rating review by OPW as they had available continuous flow data, were located on watercourses to be modelled and were deemed under FSU Work Package 2.1 as currently having a rating quality classification that could be improved upon (i.e. there may be some uncertainty in the rating at extreme flood flows).

3.1 METHODOLOGY

The methodology for carrying out rating reviews entails the following general steps:

1. Gauge station reach of watercourse is surveyed in detail (site visit, cross sections and LiDAR survey). Rating review survey is prioritised ahead of survey required for hydraulic modelling.
2. A hydraulic model is constructed of the reach of the watercourse from sufficient distance upstream to a sufficient distance downstream of the gauge station.
3. Spot gauged flows are replicated within the model and the model calibrated in order to achieve the observed measured water levels at the gauge station location.
4. When calibration is achieved flows are increased from zero to above the highest design flow (>0.1% AEP event) and the corresponding modelled water levels at the gauge location are recorded.
5. The stage (water level minus gauge station staff zero level) versus discharge results are plotted to determine the modelled stage discharge (Q-h) relationship.
6. The existing Q-h relationship is reviewed in light of the modelled relationship and the existing reliable limit of the Q-h relationship is extended up to the limit of the modelled flows. In some cases where the existing Q-h relationship has been extrapolated beyond the highest gauged flow (for practical reasons) the modelled Q-h relationship may vary significantly and as such the reliability of the existing gauged flood flows is called into question.

The hydrometric stations specified for this analysis within HA11, 12 and 13 are shown in Table 3.1.

3.3 RATING REVIEW RESULTS

The current rating quality classification assigned under the FSU for each station (if available) and whether the rating review indicated that there is significant uncertainty in the existing rating, defined as a difference in Q_{med} of more than 10%, is stated in Table 3.1.

Table 3.1: Existing Rating Quality Classification for Rating Review Stations in HA11 and 12 (none specified in HA13)

| Station Number | Station Name | FSU Station Rating Quality Classification | Significant Uncertainty Identified in current rating |
|----------------|--------------|---|--|
| 11001 | BOLEANY | A2/B | No |
| 12001 | SCARAWALSH | A2 | No |
| 12015 | FERNS | NOT RATED UNDER FSU | Yes |

A1 sites – Confirmed ratings good for flood flows well above Q_{med} with the highest gauged flow greater than $1.3 \times Q_{med}$ and/or with a good confidence of extrapolation up to 2 times Q_{med} , bank full or, using suitable survey data, including flows across the flood plain.

A2 sites – ratings confirmed to measure Q_{med} and up to around 1.3 times the flow above Q_{med} . Would have at least one gauging to confirm and have a good confidence in the extrapolation.

B sites – Flows can be determined up to Q_{med} with confidence. Some high flow gaugings must be around the Q_{med} value. Suitable for flows up to Q_{med} . These were sites where the flows and the rating was well defined up to Q_{med} i.e. the highest gauged flow was at least equal to or very close to Q_{med} , say at least $0.95 Q_{med}$ and no significant change in channel geometry was known to occur at or about the corresponding stage.

C sites – possible for extrapolation up to Q_{med} . These are sites where there was a well defined rating up to say at least $0.8 \times Q_{med}$. Not useable for the FSU.

U sites – sites where the data is totally unusable for determining high flows. These are sites that did not possess 10 years of data or more, had water level only records or sites where it is not possible to record flows and develop stage discharge relationships. Not useable for FSU.

As well as the uncertainty in the existing ratings some gauging station ratings are limited such that they do not cover the range of flood flows other than through extrapolation of the stage discharge relationship. As a result of this all of the AMAX series level data has been re-processed into AMAX flow data using the revised rating derived from the rating review models and the revised AMAX series flow data presented in Table 3.2 below. Full details of the individual rating reviews can be found in Appendix B.

Table 3.2: AMAX Series Data Before and After Rating Review

| | BOLEANY 11001 | | SCARAWALSH 12001 | | FERNES 12015 | |
|------|---------------------------|------------------------|---------------------------|------------------------|---------------------------|------------------------|
| | Exist (m ³ /s) | RR (m ³ /s) | Exist (m ³ /s) | RR (m ³ /s) | Exist (m ³ /s) | RR (m ³ /s) |
| 1940 | | | | | | |
| 1941 | | | | | | |
| 1942 | | | | | | |
| 1943 | | | | | | |
| 1944 | | | | | | |
| 1945 | | | | | | |
| 1946 | | | | | | |
| 1947 | | | | | | |
| 1948 | | | | | | |
| 1949 | | | | | | |
| 1950 | | | | | | |
| 1951 | | | | | | |
| 1952 | | | | | | |
| 1953 | | | | | | |
| 1954 | | | | | | |
| 1955 | | | 106.83 | | | |
| 1956 | | | 201.71 | | | |
| 1957 | | | 227.28 | | | |
| 1958 | | | 158.43 | | | |
| 1959 | | | 145.61 | | | |
| 1960 | | | 246.25 | | | |
| 1961 | | | 139.35 | | | |
| 1962 | | | 179.58 | | | |
| 1963 | | | 166.11 | | | |
| 1964 | | | 158.43 | | | |
| 1965 | | | 399.12 | | | |
| 1966 | | | 166.11 | | | |
| 1967 | | | 106.83 | | | |
| 1968 | | | 153.04 | | | |
| 1969 | | | 156.27 | | | |
| 1970 | | | 93.15 | | | |
| 1971 | | | 189.94 | | | |
| 1972 | | 29.21 | 29.21 | | | |
| 1973 | | 47.16 | 47.16 | | | |
| 1974 | | 33.30 | 33.30 | | | |
| 1975 | | 23.40 | 23.40 | | | |
| 1976 | | 36.01 | 36.01 | | | |
| 1977 | | 50.58 | 50.58 | | 22.94 | |
| 1978 | | 28.04 | 28.04 | | 12.34 | |
| 1979 | | 41.56 | 41.56 | | 19.21 | |
| 1980 | | 39.50 | 39.50 | | 18.43 | |
| 1981 | | 46.21 | 46.21 | | 20.65 | |
| 1982 | | 47.16 | 47.16 | | 24.23 | |
| 1983 | | 27.76 | 27.76 | | 18.40 | |
| 1984 | | 39.50 | 39.50 | | 20.02 | |
| 1985 | | 130.22 | 130.22 | | 35.03 | |
| 1986 | | 33.14 | 33.14 | | 21.03 | |
| 1987 | | 55.17 | 55.17 | | 21.92 | |
| 1988 | | 28.62 | 28.62 | | 17.48 | |
| 1989 | | 36.66 | 36.66 | | 15.83 | 15.84 |
| 1990 | | 26.53 | 26.53 | | 12.86 | 12.86 |

| | BOLEANY 11001 | | SCARAWALSH 12001 | | FERNS 12015 | |
|------------------|---------------------------|------------------------|---------------------------|------------------------|---------------------------|------------------------|
| | Exist (m ³ /s) | RR (m ³ /s) | Exist (m ³ /s) | RR (m ³ /s) | Exist (m ³ /s) | RR (m ³ /s) |
| 1991 | 45.32 | 41.39 | 117.30 | | 14.15 | 14.15 |
| 1992 | 38.63 | 43.15 | 205.29 | | 21.27 | 46.20 |
| 1993 | 43.78 | 52.59 | 188.77 | | 21.93 | 52.22 |
| 1994 | 46.17 | 55.43 | 227.28 | | 23.19 | 65.29 |
| 1995 | 48.03 | 58.89 | 205.29 | | 22.72 | 60.15 |
| 1996 | 50.79 | 64.16 | 153.04 | | - | - |
| 1997 | 47.17 | 57.28 | 241.14 | | - | - |
| 1998 | 30.05 | 30.99 | 214.96 | | - | - |
| 1999 | 23.19 | 23.19 | 101.27 | 84.82 | 12.23 | 12.22 |
| 2000 | 70.76 | 105.76 | 337.82 | 413.97 | 33.39 | 271.56 |
| 2001 | 54.82 | 72.08 | 121.20 | 102.01 | - | - |
| 2002 | 64.84 | 92.92 | 221.09 | 206.66 | 27.65 | 130.58 |
| 2003 | 39.96 | 43.86 | 116.33 | 97.81 | 14.76 | 14.76 |
| 2004 | 44.06 | 51.58 | | 248.36 | 22.66 | 59.48 |
| 2005 | | 43.68 | | 120.31 | 18.33 | 25.26 |
| 2006 | | 77.64 | | 156.11 | 21.54 | 48.56 |
| 2007 | | 72.08 | | 175.53 | | 98.23 |
| 2008 | | 57.81 | | 144.44 | | 44.13 |
| 2009 | | 75.58 | | 266.56 | | |
| 2010 | | | | 84.82 | | |
| Q _{med} | 45.75 | 45.0 | 156.27 | 156.11 | 20.84 | 47.38 |
| % Diff. | | -1.6% | | 0.0% | | +127.4% |

Note – cells in blue denote FSU AMAX series

The rating review at the Boleany gauge (11001) exhibited good agreement between the modelled and existing rating curve. At Q_{med} there was found to be less than 2% difference and as such the observed FSU Q_{med} value can be taken forward for design flow estimation with confidence.

The rating review at Scarawalsh (12001) exhibited very good agreement between the modelled and existing rating curve. At Q_{med} there was found to be no difference and as such the observed FSU Q_{med} value can be taken forward for design flow estimation with confidence.

The rating review at Ferns (12001) exhibited good agreement between the modelled and existing rating curve up to the highest spot gauging which is less than the Q_{med} value. However beyond this point the curves diverge rapidly with the modelled rating indicating that the observed Q_{med} is much higher than that which would be estimated using the existing extrapolated EPA rating curve. The revised Q_{med} based on the modelled rating curve is over double that of the Q_{med} derived from the extrapolation of the EPA rating and as such there is high uncertainty in the Q_{med} value. It is difficult to take either flow value forward with confidence given that the modelled rating value cannot be verified through spot flow gaugings, however this reach of the River Bann is not directly analysed in relation to the flood risk affecting an AFA.

3.4 IMPACT OF RATING REVIEWS ON HYDROLOGICAL ANALYSIS

As discussed in Chapter 2, Methodology Review much of the hydrological analysis was undertaken prior to survey information at the relevant gauging stations being available such that the rating reviews can be carried out. As such it is necessary to quantify the potential impact on the hydrological analysis and identify where re-analysis or mitigation to minimise the potential impact is required. The various elements of the hydrological analysis and design flow estimation are listed below and a summary of the potential impact and the proposed mitigation measures is detailed.

Table 3.3: Summary of Rating Review Effects and Mitigation

| Hydrological Analysis | Potential Effects of Uncertainty in the Rating | Potential Impact | Mitigation |
|---|--|------------------|---|
| Gauged Q_{med} | Most uncertainty with poor rating likely at flood flows and as such there could be uncertainty in AMAX series. Will affect Q_{med} at sites with a classification lower than B. Not critical under RPS methodology as NAM model Q_{med} will be taken forward. Gauged Q_{med} used for verification purposes. | Medium | Re-assess Q_{med} for FSU classified sites of C or U for verification of NAM Q_{med} |
| Ungauged Q_{med} | An issue where an ungauged catchment is adjusted based on a pivotal site with high uncertainty. As Pivotal Sites are taken from A1, A2 & B classification they are unlikely to be affected. | Low | None required |
| Historic flood frequency analysis | Flood frequency is a function of the ranking of events within the AMAX series, the position in the ranking is unlikely to be affected by adjusting all the values of the series (i.e. unless just adjusting a specific gauge period) but the flood flow figure must be revised used for calibration. | Medium | Frequency re-analysis not required. Where event flows are used for hydraulic model calibration historic flows must be re-calculated |
| Growth curve development | The inclusion of gauge years within pooled flood frequency analysis that have a high degree of uncertainty could skew the pooled frequency analysis but the effect will be diluted within a group (where it is assumed other gauge years have a high degree of confidence). The cumulative effect of uncertainty in both directions at multiple gauges may also have a cancelling out effect within a pooling group. | Medium / Low | At gauges where there has been shown to be uncertainty, re-assess single site analysis to check that it is within 95th percentile confidence limits of the pooled analysis. |
| Rainfall runoff / NAM model calibration | Catchment scale rainfall runoff or NAM models are calibrated to the flow trace at gauging stations. If there is uncertainty in the flow trace (most likely at higher flood flows) then this could lead to poor calibration and the error carried over to the runoff model. | Medium | At gauges where there has been shown to be uncertainty, calibrate the rainfall runoff (NAM) model to the medium or low flows. |

| Hydrological Analysis | Potential Effects of Uncertainty in the Rating | Potential Impact | Mitigation |
|-----------------------------|---|------------------|--|
| Hydraulic model calibration | Calibration of hydraulic models is undertaken at extreme flood flows where highest degree of uncertainty could be present. Model calibration therefore dependent on upper limits of gauge rating. | High | Reassess calibration event flows where necessary |
| Hydrograph Shape Generation | Uncertainty would affect values but semi-dimensionless shape will not change (Q is expressed factorially from 0 to 1). | Low | None required |

4 INDEX FLOOD FLOW ESTIMATION

The first component in producing design flows within the majority of best practice methods widely used in the UK and Ireland is to derive the Index Flood Flow which within the FSU guidance is defined as the median value of the annual maximum flood flow series or Q_{med} . The methodologies being used in this study are detailed in the HA11, 12 and 13 Inception Report and are reviewed in chapter 2 of this report. As discussed the methods combine best practice statistical methods with rainfall runoff (NAM) modelling techniques. This chapter details the Index Flood Flow estimation at each of the HEPs within HA11, 12 and 13 on a model by model basis, including a discussion on the confidence and comparison of the outputs from the considered methodologies.

HA11, 12 and 13 has been divided into nine hydrodynamic models, primarily based on the requirement within the modelling software to have only one continuous modelled floodplain per model. These were identified in the HA11, 12 and 13 Inception Report (IBE0601Rp0008). The nine models included in HA11, 12 and 13 are shown in Figure 4.1.

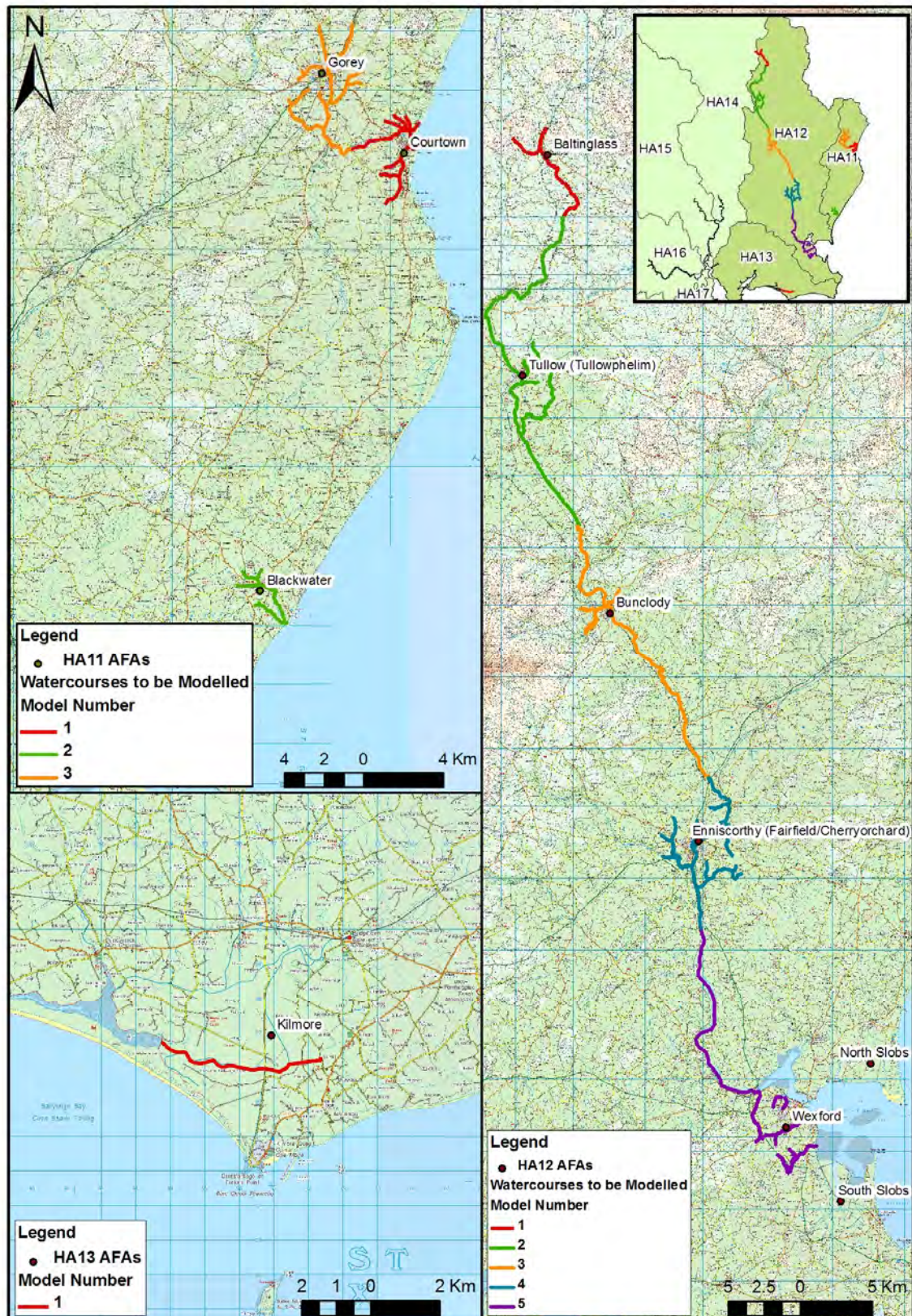


Figure 4.1: HA11, 12 and 13 Watercourses to be modelled

4.1 HA11 MODEL 1 - COURTOWN

HA11 Model 1 constitutes High Priority Watercourses (HPWs) within Courtown AFA. It includes the Owenavorrhagh River from Boleany Bridge to its mouth at Foot Bridge on the coast; and its tributaries. The Aughboy River flows from south to north towards Courtown before joining the Sea at Breanoge Head. The Aughboy River and its tributaries are also part of Model 1. The contributing catchment to Model 1 is 156km² (Owenavorrhagh) and 15km² (Aughboy). Both the Owenavorrhagh and Aughboy catchments are predominantly rural (1.7% and 6.7% urbanised respectively).

The Owenavorrhagh model has one gauging station located at Boleany Bridge, Station 11001. It has an FSU classification of B and therefore has a reliable rating up to Q_{med} which is 45.75 m³/s based on the FSU adopted AMAX series post 1991. The CFRAMS rating review of Station 11001 provided further confidence in the FSU Q_{med} value as discussed in Chapter 3. The HEPs and associated sub-catchments of the Courtown model are shown in Figure 4.2.

Rainfall runoff models (NAM) have been developed of the contributing catchments to selected gauging stations throughout HA11, 12 and 13 in order to simulate longer AMAX series and increase confidence in the Q_{med} where required. The NAM models were calibrated against the low to mid-range continuous flow traces at each gauging station where corresponding gauge adjusted radar based hourly rainfall sums for the catchment are available. Using the adjusted radar based rainfall sums and observed rainfall sums from surrounding rain gauges a continuous flow trace was simulated, generally for the period 1954 to 2010. An AMAX series was extracted from the continuous flow trace and the simulated Q_{med} calculated for each station.

This process was undertaken for Station 11001 (refer to Appendix D). Radar data was not available in the locality so temporal profiles were derived from area-weighted data at Rosslare, Johnstown Castle and Oak Park hourly rainfall stations (refer to Appendix D, NAM Outputs for weighting). The resulting NAM model was calibrated to the hydrometric data (particularly medium to low flows) but yielded a slightly lower Q_{med} value of 43.25m³/s. However the NAM Q_{med} output for the FSU AMAX period of record (1991 – 2004) is almost 28% higher at 58.48m³/s. The uncertainty on the magnitude of Q_{med} is compounded by the significantly lower Q_{med} predicted value based on FSU catchment descriptors (24.67m³/s). Given this uncertainty it was decided to adopt the observed Q_{med} value of 45.75m³/s for subsequent analysis. The completed rating review (Chapter 3) yielded a very similar Q_{med} result and increased confidence in the adoption of the FSU observed Q_{med} value for design flow estimation.

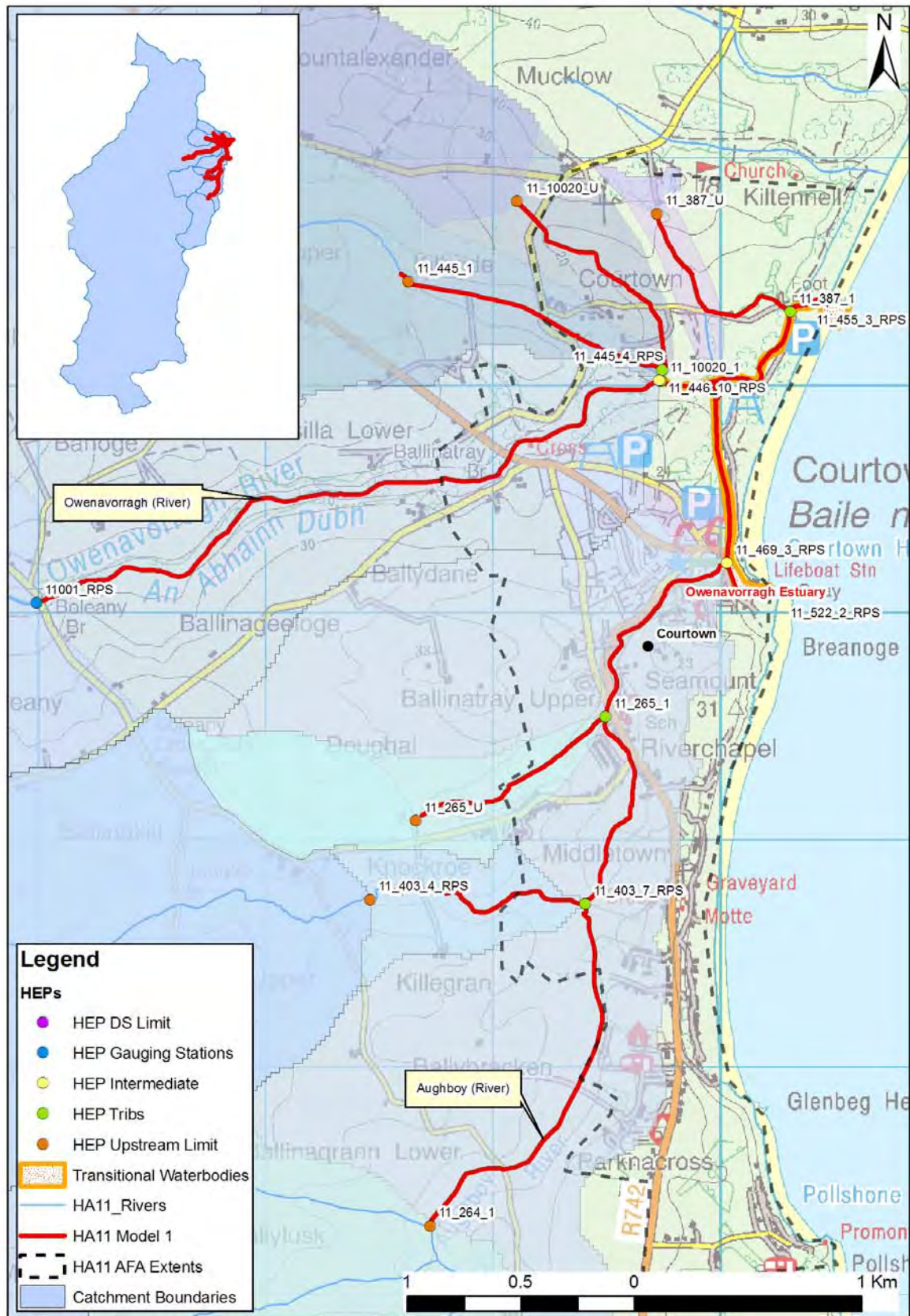


Figure 4.2: HA11 Model 1, HEPs and Catchment Boundaries

The gauged Q_{med} values at Station 11001 were then used to adjust FSU predicted values at each HEP within Model 1 as appropriate. The estimated Q_{med} values for the various HEPs within Model 1 are shown in Table 4.1.

Table 4.1: Q_{med} Values for HA11 Model 1

| Node ID_CFRAMS | AREA (km ²) | Q_{med} (m ³ /s) | Preferred Estimation Methodology |
|----------------|-------------------------|-------------------------------|----------------------------------|
| 11001_RPS | 148.73 | 45.75 | Gauge |
| 11_446_10_RPS | 151.95 | 47.74 | FSU |
| 11_10020_U | 0.80 | 0.24 | FSU |
| 11_445_1 | 1.29 | 0.31 | FSU |
| 11_445_4_RPS | 1.70 | 0.49 | FSU |
| 11_10020_1 | 2.87 | 0.79 | FSU |
| 11_387_U | 0.04 | 0.02 | FSU |
| 11_387_1 | 0.17 | 0.06 | FSU |
| 11_455_3_RPS | 155.59 | 48.27 | FSU |
| 11_264_1 | 5.97 | 1.41 | FSU |
| 11_403_4_RPS | 3.59 | 0.8 | FSU |
| 11_403_7_RPS | 3.98 | 0.94 | FSU |
| 11_265_U | 0.39 | 0.11 | FSU |
| 11_265_1 | 0.70 | 0.18 | FSU |
| 11_469_3_RPS | 14.77 | 3.32 | FSU |
| 11_522_2_RPS | 14.87 | 3.42 | FSU |

Note: Flow highlighted in yellow represent total flows at that point in the model rather than input

The use of Station 11001 as a pivotal station in Model 1 has a significant effect on Q_{med} since the adjustment factor is relatively high due to the difference between Q_{med} rural (predicted) and Q_{med} gauged (24.67m³/s versus 45.75m³/s). For example, in the case of smaller HPW tributaries entering the Owenavorrhagh such as HEP 11_445_1, it has the effect of increasing Q_{med} from 0.31m³/s (FSU predicted) to 0.64m³/s (adjusted). A pivotal site review was undertaken to compare results using other pivotal site options. It was found that the value of 0.64 is just inside the 95%ile upper limit of confidence of the Q_{med} rural estimation. However, the most hydrologically similar site (Station 9011) also yields a high Q_{med} value of 0.61m³/s. Indeed four of the seven hydrologically similar pivotal site options yield values above the 95%ile upper limit. Station 11001 is the closest site geographically to these tributaries albeit not directly upstream or downstream. The second closest station geographically is Station 10028 (Aughrim) which virtually keeps the Q_{med} value for HEP 11_445_1 the same as Q_{med} rural (0.32m³/s).

It has been decided to proceed with the use of Station 11001 as the pivotal station for the main channel HEPs on the Owenavorrhagh only but not for the smaller tributaries since they are less hydrologically comparable in terms of area and profile despite being close geographically. It is noted that this may need to be revisited during the hydraulic modelling calibration phase but that confidence in its use has been increased by the CFRAM rating review outputs (Chapter 3). Transitional Water

Bodies are also shown on Figure 4.2 illustrating the extent of tidal influence on HA11 Model 1. Coastal Hydrology and Joint Probability Analysis for Fluvial-Tidal flood events are discussed further in Sections 6.2 and 6.3 respectively.

4.2 HA 11 MODEL 2 - BLACKWATER

The Blackwater model is located on the River Blackwater which is named after the village it flows through and discharges to the sea at Blackwater Harbour. It is a small coastal river system with a total catchment area of 45km² at its mouth. HA11 Model 2 includes the Blackwater and its tributaries that affect the Blackwater AFA. There are no gauging stations located within the Model.

The Blackwater model, its HEPs and catchment boundaries are shown in Figure 4.3 overleaf.

No rainfall runoff models have been developed for HA11 Model 2 due to the lack of gauged data upon which to calibrate. An appropriate pivotal site was selected from a list of geographical and hydrologically similar options. Station 11001 is closest but yields high Q_{med} values beyond the 95%ile upper limit. Since this station is not located within the Model it was decided to select the most hydrologically similar instead (Station 25034, Rochfort). The resulting Q_{med} values are well within the confidence limits and are similar to the results from 5 out of 7 geographically close stations.

The estimated Q_{med} values for the various HEPs within Model 2 are shown in Table 4.2.

Table 4.2: Q_{med} Values for HA11 Model 2

| Node ID_CFRAMS | AREA (km ²) | Q_{med} (m ³ /s) | Preferred Estimation Methodology |
|----------------|-------------------------|-------------------------------|----------------------------------|
| 11_188_1_RPS | 17.75 | 3.47 | FSU |
| 11_326_U | 0.44 | 0.11 | FSU |
| 11_483_1 | 0.89 | 0.22 | FSU |
| 11_481_1_RPS | 18.13 | 3.26 | FSU |
| 11_481_3_RPS | 19.16 | 3.87 | FSU |
| 11_25_3_RPS | 40.48 | 7.72 | FSU |
| 11_197_U | 0.46 | 0.17 | FSU |
| 11_198_U | 0.04 | 0.02 | FSU |
| 11_198_1 | 0.06 | 0.02 | FSU |
| 11_32_2_RPS | 44.57 | 8.51 | FSU |

Note: Flow highlighted in yellow represent total flows at that point in the model rather than input

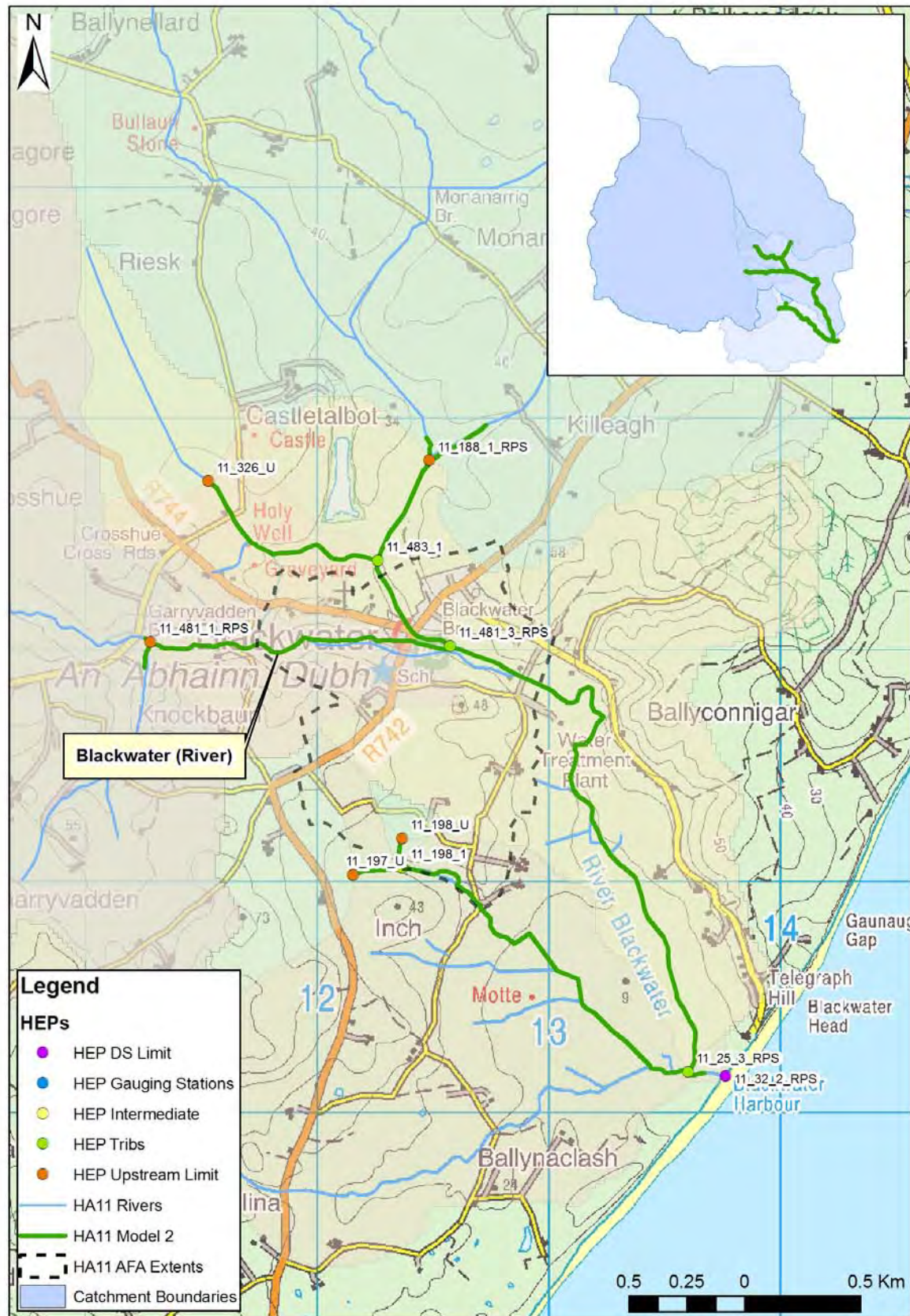


Figure 4.3: HA11 Model 2 HEPs and Catchment Boundaries

4.3 HA11 MODEL 3 - GOREY

The Gorey model is located on the Banoge River and its tributaries which directly affect Gorey AFA. The Banoge is an upper tributary of the Owenavorrhagh River. The gauging station at Boleany Bridge (11001) denotes the downstream limit of HA11 Model 3 (refer to Section 4.1).

The contributing catchment area at the downstream limit of the model is 149km². The HEPs and catchment boundaries are shown in Figure 4.4.

The gauged Q_{med} value at Station 11001 was used to adjust FSU predicted values. A pivotal site review was undertaken. Taking Station HEP 11_441_1_RPS as a typical example, Station 11001 yields a Q_{med} result above the 95%ile upper limit of the Q_{med} rural (predicted) estimate, as do six of the seven hydrologically similar pivotal site options. Station 25034 is the most hydrologically similar and yields a Q_{med} value of 0.984m³/s which is within the confidence limits. However, Station 11001 is at the downstream end of this model and if the gauged data is correct, the high adjustment factor is likely to be needed across the catchment to ensure the Q_{med} predicted from catchment descriptors does not fall short. If the catchment descriptors for Model 3 yield Q_{med} results that are too low, it is considered prudent to adjust them using the observed data from Station 11001. This will be reviewed at the hydraulic modelling stage but confidence in its use has been increased by the CFRAM rating review outputs (Chapter 3).

The estimated Q_{med} values for the various HEPs within Model 3 are shown in Table 4.3.

Table 4.3: Q_{med} Values for HA11 Model 3

| Node ID_CFRAMS | AREA (km ²) | Q_{med} (m ³ /s) | Preferred Estimation Methodology |
|----------------|-------------------------|-------------------------------|----------------------------------|
| 11_441_1_RPS | 3.49 | 1.44 | FSU |
| 11_10010_U | 0.78 | 0.33 | FSU |
| 11_10010_1 | 4.39 | 1.66 | FSU |
| 11_118_U | 0.62 | 0.36 | FSU |
| 11_23_U | 0.41 | 0.24 | FSU |
| 11_23_1 | 0.45 | 0.26 | FSU |
| 11_438_1 | 2.69 | 1.24 | FSU |
| 11_474_2 | 1.53 | 0.49 | FSU |
| 11_281_U | 0.18 | 0.08 | FSU |
| 11_281_1 | 0.41 | 0.18 | FSU |
| 11_110_4 | 5.65 | 2.28 | FSU |
| 11_289_U | 0.28 | 0.14 | FSU |
| 11_289_1 | 0.65 | 0.3 | FSU |
| 11_285_U | 0.50 | 0.19 | FSU |
| 11_303_3_RPS | 5.50 | 2.09 | FSU |
| 11_259_6_RPS | 117.63 | 33.26 | FSU |
| 11001_RPS | 148.73 | 45.75 | NAM |

Note: Flow highlighted in yellow represent total flows at that point in the model rather than input flows

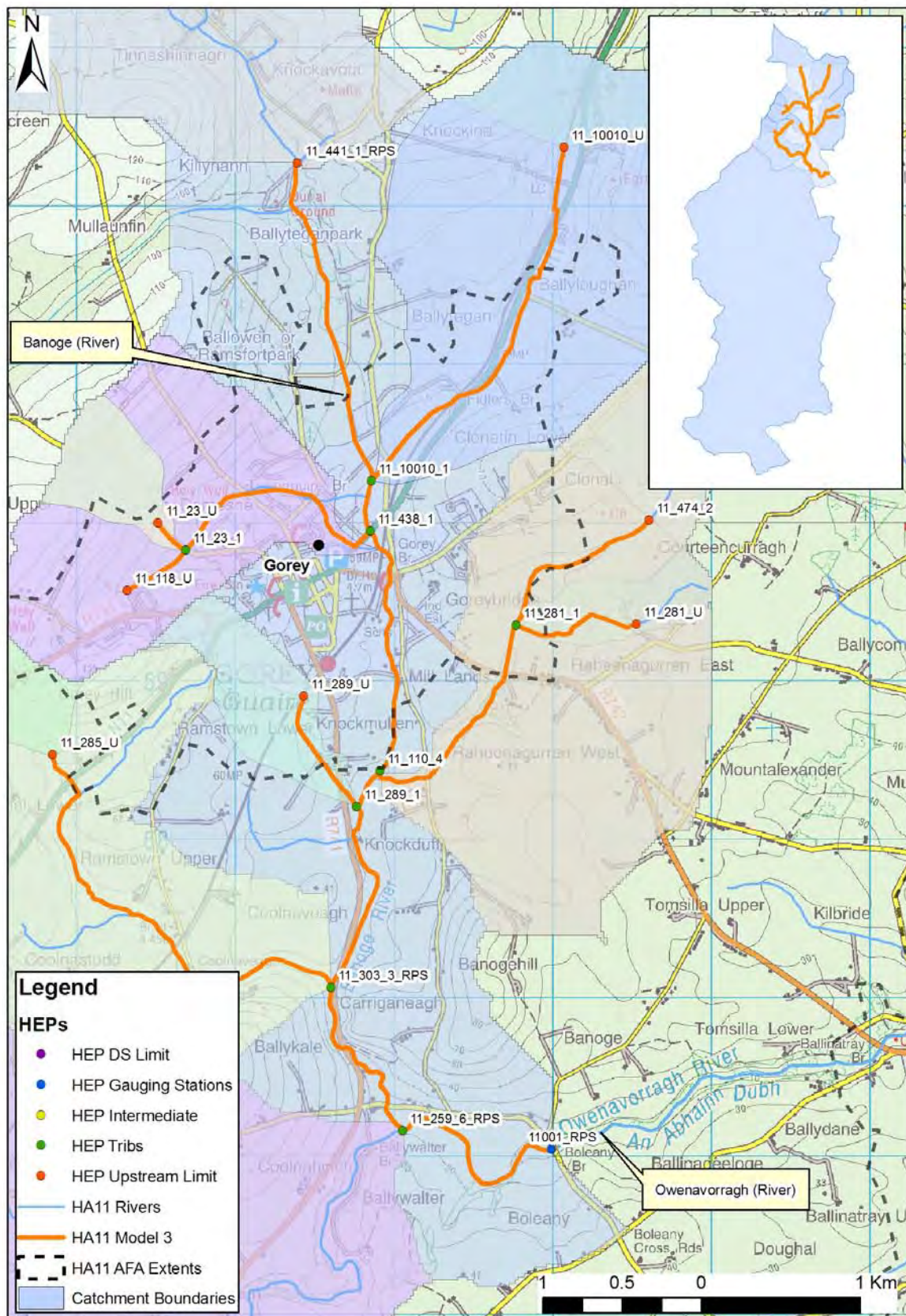


Figure 4.4: HA11 Model 3 HEPs and Catchment Boundaries

4.4 HA12 MODEL 1 – BALTINGLASS

The Baltinglass model is located on the upper reaches of the River Slaney approximately 20km downstream from where it rises in the Glen of Imaal in the Wicklow Mountains. The model also includes the small tributary the Knockanreagh River which enters the Slaney from the west within Baltinglass AFA. There is one gauging station located on the Slaney at the downstream limit of HA12 Model 1:

Rathvilly (12013 – EPA) - FSU Classification B, 28 years of data. So there is confidence in flow values up to and including the Q_{med} gauged value of $43.55\text{m}^3/\text{s}$ (up to 2004).

Approximately 9.5km upstream of the modeled extent, a hydrometric station is located on the Slaney at Castleruddery (Station 12037 – EPA). The station is now inactive but intermittent flow data is available from September 1995 to August 1998 and June 2011 to August 2011. An AMAX series for the station is not available. The only two years of complete data are 1996 and 1997 for which QMAX is $83.6\text{ m}^3/\text{s}$ (recorded on 25th October 1996), and $67.3\text{ m}^3/\text{s}$ (recorded on 18th Dec 1997) respectively. However both of these values are extrapolated well beyond the upper water level limit of the EPA rating curve and are treated with caution. This station was not reviewed under the FSU.

The total contributing catchment area at the downstream limit of the model (Station 12013) is 210km^2 . The HEPs and catchment boundaries are shown in Figure 4.5.

A rainfall runoff model was constructed for Station 12013 and calibrated against observed medium to low flows to increase confidence in the Q_{med} value and provide a median hydrograph shape. Radar data was not available in the locality so daily rainfall data from four suitable stations was used with temporal profiles derived from area-weighted data at Oak Park and Casement Park hourly rainfall stations (refer to Appendix D, NAM Outputs for weighting). The resulting NAM model was well calibrated to the hydrometric data (particularly medium to low flows) and yielded a similar Q_{med} value of $43.88\text{m}^3/\text{s}$. Since the NAM model calibration was satisfactory and increases the length of the AMAX series from 1964 to 2010, it was decided to adopt the Q_{med} value of $43.88\text{m}^3/\text{s}$ for subsequent analysis.

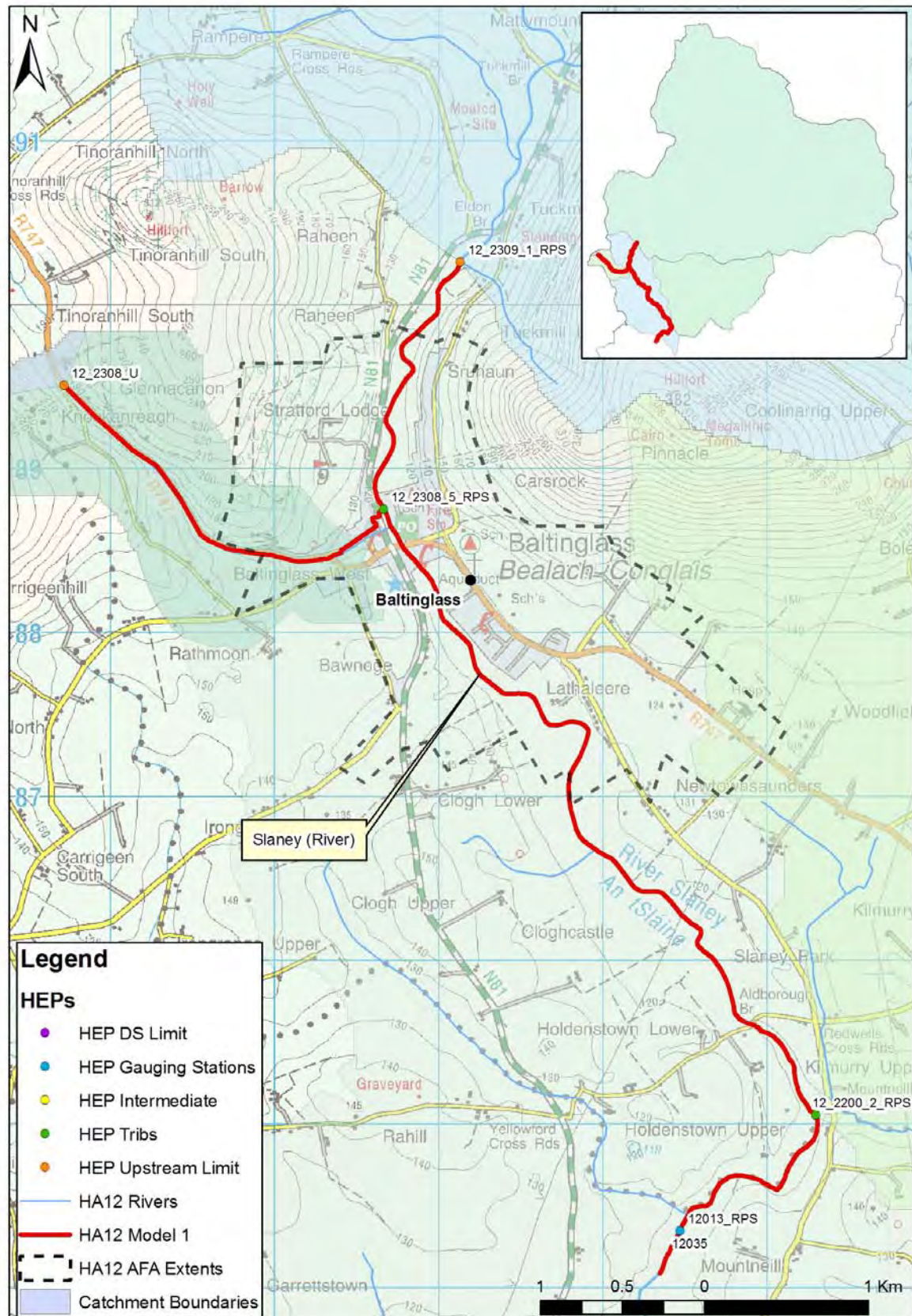


Figure 4.5: HA12 Model 1 HEPs and Catchment Boundaries

The NAM outputs from Station 12013, was used to adjust index flow estimations within HA12 Model 1 as appropriate. The estimated Q_{med} values for the various HEPs within Model 4 are shown in Table 4.4.

Table 4.4: Q_{med} Values for HA12 Model 1

| Node ID_CFRAMS | AREA (km ²) | Qmed (m ³ /s) | Preferred Estimation Methodology |
|----------------|-------------------------|--------------------------|----------------------------------|
| 12_2309_1_RPS | 164.62 | 37.5 | FSU |
| 12_2308_U | 0.11 | 0.03 | FSU |
| 12_2308_5_RPS | 2.52 | 0.76 | FSU |
| 12_2200_2_RPS | 26.56 | 8.57 | FSU |
| 12013_RPS | 209.89 | 43.88 | NAM |

Note: Flow highlighted in yellow represent total flows at that point in the model rather than input flows

At the beginning of the South Eastern CFRAM Study, the team were advised that there was some historical evidence from the 1940s that snow melt had caused flooding in Baltinglass and as such could be a contributing factor to flood risk in this AFA. The historical review of flood events undertaken at project inception (refer to Inception Report IBE0601Rp0007) did not identify any specific events within available historical flood information that were attributed to snow melt in Baltinglass. There is no observed flow data for the 1940s when a snow melt induced flood event is believed to have taken place. A review of the available hydrometric data at the Castleruddery Hydrometric Station (Stn 12027 – EPA), in conjunction with corresponding daily rainfall totals as recorded at the Glen Imaal station (Stn no. 2415) was undertaken to determine if any recorded flood peaks could be not be attributed to high rainfall therefore suggesting snow melt as a possible contributor. No such occurrences were identified within the observed record. This is a potential source of uncertainty with respect to flood mechanisms affecting Baltinglass AFA. As such it is recommended that the hydrometric station at Castleruddery is reinstated, or a new gauge installed on the Slaney within Baltinglass itself so that this localised flood mechanism can be captured if it occurs in the future.

4.5 HA12 MODEL 2 TULLOW (INCL. TULLOWPHELM)

HA 12 Model 2 represents the River Slaney as it flows from Rathvilly gauging station, through Tullow AFA. It includes the Derreen River and a tributary of the Derreen; and two urban tributaries of the Slaney that flow through Tullow.

The total contributing area at the downstream limit of the model is 564km². The Derreen River catchment area is 236km² accounting for just over 40% of the overall model. There are three stations located within HA12 Model 2 on the River Slaney, but only one has flow data available, the aforementioned Rathvilly Station (12013 – EPA) which denotes the upstream limit of the model (refer to Section 4.4 for details).

The extent of HA12 Model 2, its catchment boundaries and HEPs are shown in Figure 4.6 overleaf.

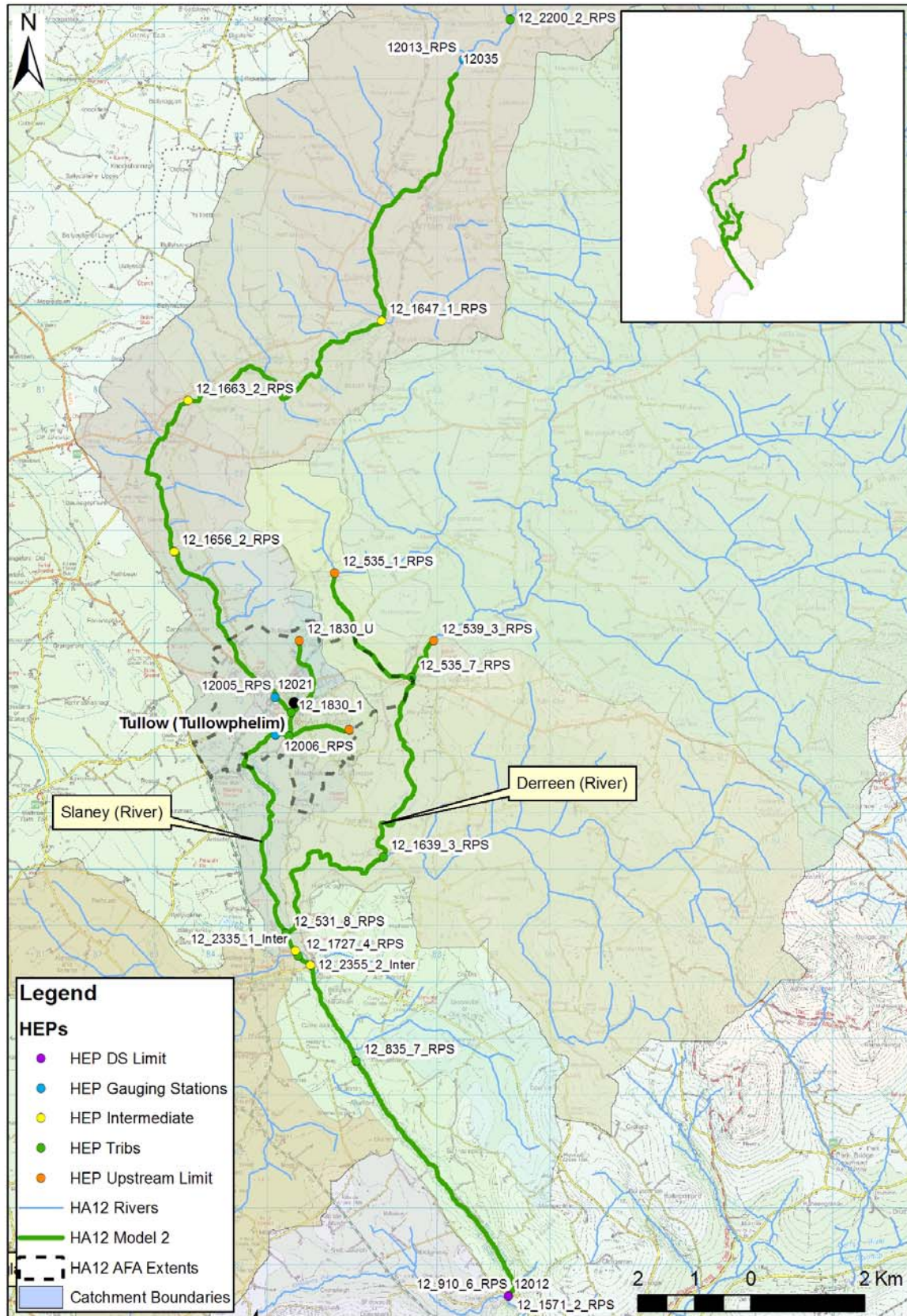


Figure 4.6: HA12 Model 2 HEPs and Catchment Boundaries

The NAM model outputs for Station 12013 were used in subsequent index flow estimation for the Model. The estimated Q_{med} values for the various HEPs within HA12 Model 2 are shown in Table 4.5.

Note the identical Q_{med} values for the first five HEPs. These are all Intermediate HEPs located on the River Slaney main channel. Initial Q_{med} estimates using FSU regression equation resulted in Q_{med} values that decreased in a downstream direction. This is not hydrologically correct and was found to be a function of the SAAR value used in the FSU regression equation. It tends to decrease in a southerly direction and was reducing Q_{med} values as a consequence. In reality flow will not decrease for this reason and as such the higher Q_{med} values from upstream are held constant moving downstream until they begin to rise again. In this case the estimates have been adjusted such that they match the observed Q_{med} at the Rathvilly gauging station 12013. These values are not model inputs, rather check flows.

Table 4.5: Q_{med} Values for HA12 Model 2

| Node ID_CFRAMS | AREA (km ²) | Q_{med} (m ³ /s) | Preferred Estimation Methodology |
|-----------------|-------------------------|-------------------------------|----------------------------------|
| 12013_RPS | 209.89 | 43.88 | NAM |
| 12_1647_1_RPS | 229.97 | 43.88 | FSU |
| 12_1663_2_RPS | 242.18 | 43.88 | FSU |
| 12_1656_2_RPS | 249.22 | 43.88 | FSU |
| 12005_RPS | 254.05 | 43.88 | FSU |
| 12_1830_U | 0.07 | 0.01 | FSU |
| 12_1830_1 | 1.13 | 0.15 | FSU |
| 12_1707_U | 0.26 | 0.04 | FSU |
| 12_1707_2_RPS | 1.59 | 0.28 | FSU |
| 12006_RPS | 257.23 | 44.57 | FSU |
| 12_539_3_RPS | 186.59 | 42.65 | FSU |
| 12_535_1_RPS | 2.86 | 0.47 | FSU |
| 12_535_7_RPS | 5.21 | 0.85 | FSU |
| 12_1639_3_RPS | 36.66 | 7.06 | FSU |
| 12_531_8_RPS | 235.67 | 45.56 | FSU |
| 12_2335_1_Inter | 499.59 | 85.12 | FSU |
| 12_1727_4_RPS | 42.66 | 5.82 | FSU |
| 12_2355_2_Inter | 542.47 | 89.02 | FSU |
| 12_835_7_RPS | 6.69 | 1.21 | FSU |
| 12_1571_2_RPS | 564.04 | 90.10 | FSU |

Note: Flow highlighted in yellow represent total flows at that point in the model rather than input flows

4.6 HA12 MODEL 3 - BUNCLODY

Bunclody AFA is represented by HA12 Model 3. Its largest component is the River Slaney as it flows in a southerly direction through Bunclody and includes the Clody River and Barkers Stream. An additional urban tributary of the Slaney is also included. The total contributing catchment area at the downstream end of the model is 1036km².

The extent of HA12 Model 3, its HEPs and catchments are shown in Figure 4.7.

There is one gauging station located at the downstream limit of the Model. Station 12001, Scarawalsh is classified as A2 under FSU with continuous flow data available from 1955. The FSU gauged Q_{med} from 1955 to 2003 is 156.27m³/s.

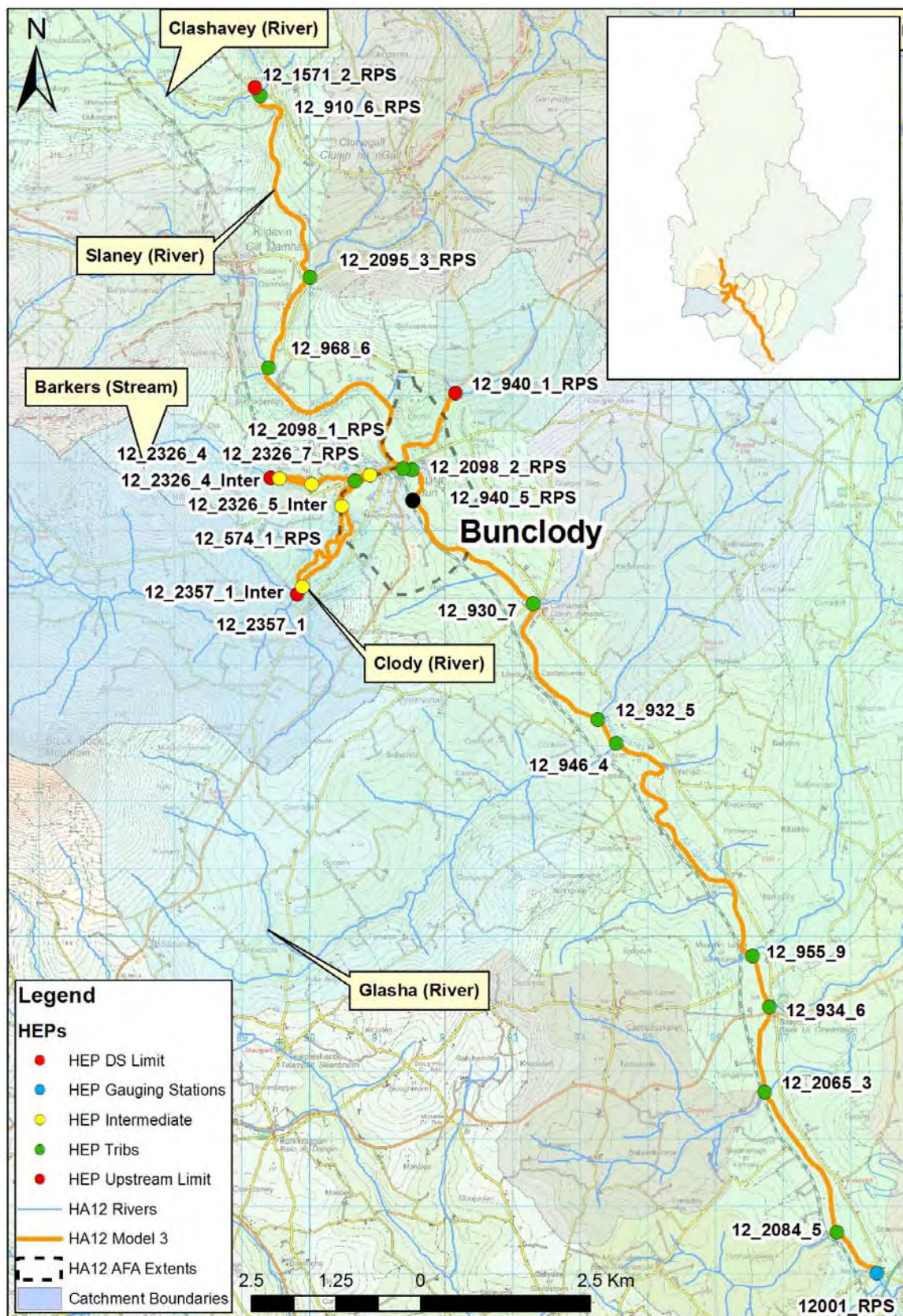


Figure 4.7: HA12 Model 3 HEPs and Catchment Boundaries

A NAM model was constructed for Station 12001 and its contributing catchment. Radar data was not available for use as rainfall input data so spatial and temporal data was derived on an area weighed basis from three hourly stations, Oak Park, Rosslare and Casement (refer to Appendix D for weightings used). Calibration in terms of mass-balance (between 1996 and 2010) was not considered robust with simulated water mass lower than observed. Calibration to observed flow was not strong resulting in a Q_{med} value of $143\text{m}^3/\text{s}$. Whilst this is in between the FSU predicted value of $138\text{m}^3/\text{s}$ and gauge value of $156.27\text{m}^3/\text{s}$ it is considered appropriate to proceed with the gauged value given that the station is already FSU A2 classified with a 48 year record.

The NAM model outputs for Station 12013 and the FSU gauged Q_{med} value at Station 12001 were used in subsequent index flow estimation for the Model HEPs as appropriate.

The estimated Q_{med} values for the various HEPs within HA12 Model 3 are shown in Table 4.6.

Table 4.6: Q_{med} Values for HA12 Model 3

| Node ID_CFRAMS | AREA (km^2) | Q_{med} (m^3/s) | Preferred Estimation Methodology |
|-----------------|------------------------|-------------------------------------|----------------------------------|
| 12_1571_2_RPS | 564.04 | 90.10 | FSU |
| 12_910_6_RPS | 17.93 | 4.17 | FSU |
| 12_2095_3_RPS | 246.67 | 43.72 | FSU |
| 12_968_6 | 14.73 | 3.86 | FSU |
| 12_2357_1 | 29.59 | 10.50 | FSU |
| 12_2357_1_Inter | 29.67 | 10.52 | FSU |
| 12_574_1_RPS | 31.91 | 9.93 | FSU |
| 12_2326_4 | 2.66 | 1.04 | FSU |
| 12_2326_4_Inter | 2.68 | 1.05 | FSU |
| 12_2326_5_Inter | 3.06 | 1.11 | FSU |
| 12_2326_7_RPS | 3.58 | 1.35 | FSU |
| 12_2098_1_RPS | 35.81 | 10.91 | FSU |
| 12_2098_2_RPS | 35.98 | 10.99 | FSU |
| 12_940_1_RPS | 4.52 | 1.28 | FSU |
| 12_940_5_RPS | 5.62 | 1.61 | FSU |
| 12_930_7 | 5.32 | 1.26 | FSU |
| 12_932_5 | 13.32 | 3.37 | FSU |
| 12_946_4 | 27.71 | 6.84 | FSU |
| 12_955_9 | 21.98 | 4.20 | FSU |
| 12_934_6 | 22.00 | 3.71 | FSU |
| 12_2065_3 | 11.46 | 2.93 | FSU |
| 12_2084_5 | 5.12 | 1.37 | FSU |
| 12001_RPS | 1036.43 | 156.27 | FSU Gauged |

Note: Flow highlighted in yellow represent total flows at that point in the model rather than input flows

4.7 HA12 MODEL 4 – ENNISCORTHY (FAIRFIELD / CHERRYORCHARD)

HA12 Model 4 represents the Enniscorthy AFA including Fairfield and Cherryorchard. It encompasses the River Slaney as it flows through the AFA becoming tidally influenced as it makes the transition to Upper Slaney Estuary. The model also includes the River Urrin from the west as it enters the AFA and joins the River Slaney south of the town after passing beneath the N30 road. There are also several HPW tributaries of the Slaney and Urrin within Model 4 including those at Ballycoory, Killagoley, Kilpierce and Blackstoops, all of which directly affect the AFA.

The total contributing area at the downstream limit of the model is 1646km². The catchment area of The River Urrin is 115km². The Bann River enters the Model near the upstream limit and accounts for 182km² of the contributing area although it is not a modelled watercourse itself.

There are six gauging stations located along the length of the Model but only one of these has flow data available, the aforementioned Station 12001 (Scarawalsh) (refer to Section 4.6). Two of the remaining five stations are tidal (St Johns Bridge on the Urrin and Enniscorthy Station on the Slaney).

The modelled extents and HEPs are shown in Figure 4.8. It should be noted that since completion of the hydrology analysis, OPW have advised that construction of a flood defence scheme is soon to commence in Enniscorthy. To this end, there is no longer a requirement to produce flood maps for the River Slaney through Enniscorthy. However, flood risk to Fairfield and Cherryorchard as identified by the Local Authority arising from the River Urrin and any backwater effect from the Slaney will be assessed through the South Eastern CFRAM Study hydraulic modelling.

Q_{med} estimates at the various HEPs were adjusted based on the Gauge at Scarawalsh (refer to Section 4.6). The estimated Q_{med} values for the various HEPs are shown in Table 4.7.

Note the identical Q_{med} values for HEPs 12_2604_2_RPS and 12007_RPS on the River Urrin. These are intermediate HEPs located on the River Slaney main channel. Initial Q_{med} estimates using FSU regression equation resulted in Q_{med} values that decreased in a downstream direction. This is not hydrologically correct and was found to be a function of the SAAR value used in the FSU regression equation. It tends to decrease in a southerly direction and was reducing Q_{med} values as a consequence. In reality flow will not decrease for this reason and as such the higher Q_{med} values from upstream are held constant moving downstream until they begin to rise again. These are not input flows to the model.

Transitional Water bodies are also shown on Figure 4.8 illustrating the extent of tidal influence on HA12 Model 4 (Upper Slaney Estuary). Coastal Hydrology and Joint Probability Analysis for Fluvial-Tidal flood events are discussed further in Sections 6.2 and 6.3 respectively.

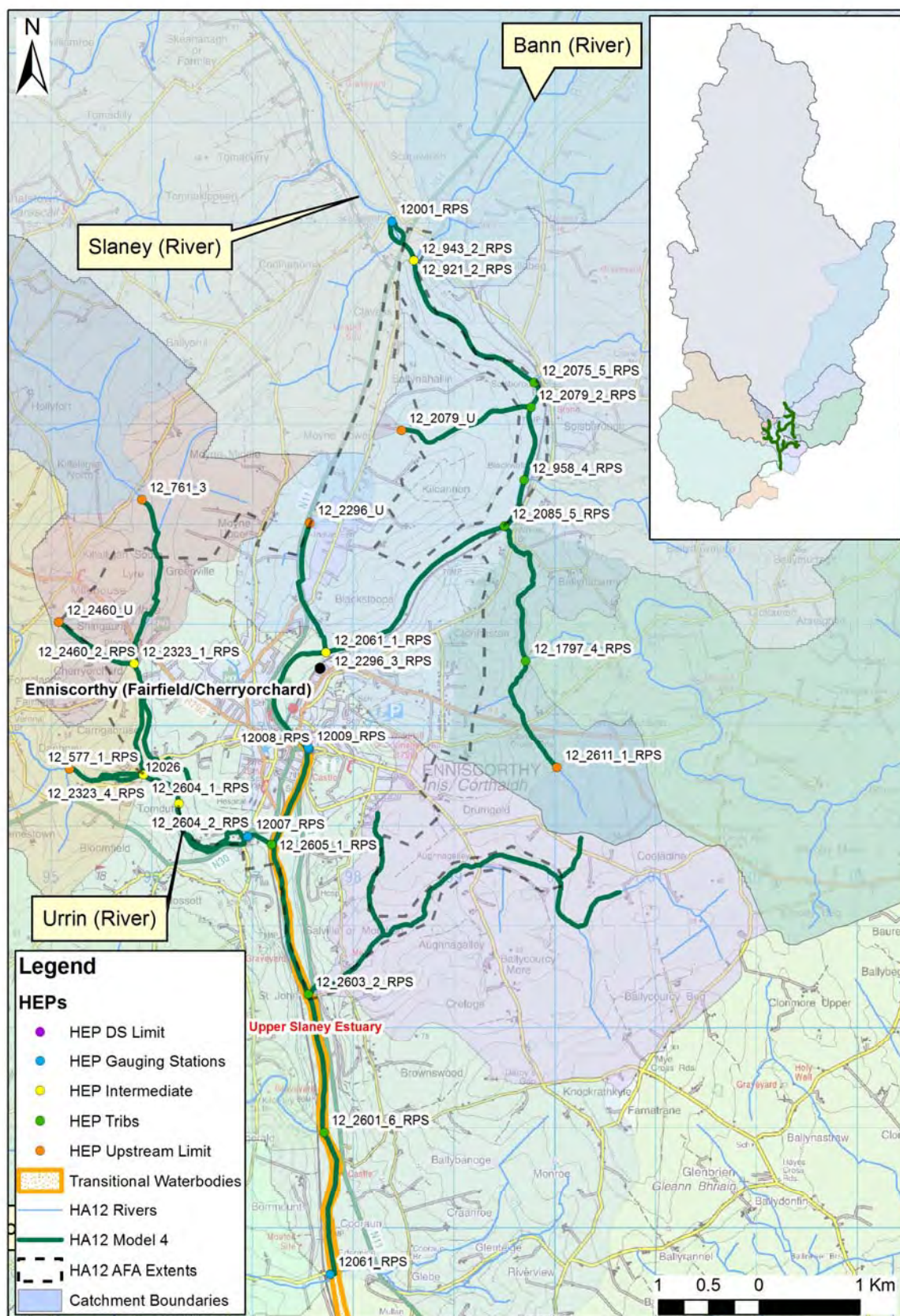


Figure 4.8: HA12 Model 4 HEPs and Catchment Boundaries - UPDATE

Table 4.7: Q_{med} Values for HA12 Model 4

| Node ID_CFRAMS | AREA (km ²) | Q _{med} (m ³ /s) | Preferred Estimation Methodology |
|-------------------|-------------------------|--------------------------------------|--|
| 12001_RPS | 1036.43 | 156.27 | FSU Gauge |
| 12_921_2_RPS | 181.52 | 30.49 | FSU |
| 12_943_2_RPS | 1221.62 | 176.27 | FSU |
| 12_2075_5_RPS | 37.76 | 6.25 | FSU |
| 12_2079_2_RPS | 0.99 | 0.33 | FSU |
| 12_958_4_RPS | 5.69 | 1.41 | FSU |
| 12_2085_5_RPS | 55.50 | 9.19 | FSU |
| 12_2296_U | 0.35 | 0.13 | FSU |
| 12_2296_3_RPS | 1.55 | 0.79 | FSU |
| 12_2061_1_RPS | 1328.71 | 182.25 | FSU |
| 12002_RPS | 1330.66 | 183.25 | FSU |
| 12009_RPS | 1330.71 | 183.26 | FSU |
| 12008_RPS | 1330.72 | 183.26 | FSU |
| 12_577_1_RPS | 103.03 | 22.23 | FSU |
| 12_2323_4_RPS | 0.36 | 0.10 | FSU |
| 12_2604_1_RPS | 103.94 | 22.23 | FSU |
| 12_761_3 | 4.40 | 1.09 | FSU |
| 12_2460_U | 0.78 | 0.16 | FSU |
| 12_2460_2_RPS | 1.44 | 0.30 | FSU |
| 12_2323_1_RPS | 8.47 | 1.98 | FSU |
| 12_2604_2_RPS | 113.51 | 22.99 | FSU |
| 12007_RPS | 114.76 | 22.98 | FSU |
| 12_2605_1_RPS | 114.90 | 23.00 | FSU |
| 12_2603_2_RPS | 9.51 | 2.26 | FSU |
| 12_2601_6_RPS | 179.56 | 30.90 | FSU |
| 12061_RPS | 1646.29 | 219.33 | FSU |

Note: Flow highlighted in yellow represent total flows at that point in the model rather than input flows

4.8 HA12 MODEL 5 - WEXFORD

The Wexford model is located on the River Slaney as it makes the transition from Upper to Lower Slaney Estuary and on to Wexford Harbour. It is tidally influenced along its length. Additional HPWs directly affecting Wexford AFA are also part of Model 5. These include an urban watercourse originating in Hayestown which joins the Slaney at Ferrycarrig Bridge; two small urban watercourses at Carricklawn which enter the Lower Slaney Estuary directly; the Bishops Water which flows through Wexford town and enters the Lower Slaney Estuary; and three small relatively steep watercourses to the south of the AFA at Latimerstown, Sinnottstown and Coolballow. The Sinnottstown watercourse enters Lower Slaney Estuary approximately 1km north of Wexford Harbour.

There are no gauging stations with available flow data located on the watercourses within HA12 Model 5. Station 12064 at Ferrycarrig Bridge is tidal with only water level data available.

The total contributing catchment area at the downstream limit of the Slaney part of the model is 1753km², which covers the entire Slaney catchment. The individual watercourses which directly affect the AFA all have catchment areas less than 10km².

The HEPs and catchment boundaries are shown in Figure 4.9. The extent of transitional waterbodies is also shown, illustrating the tidal influence. Coastal Hydrology and Joint Probability Analysis for Fluvial-Tidal flood events are discussed further in Sections 6.2 and 6.3 respectively.

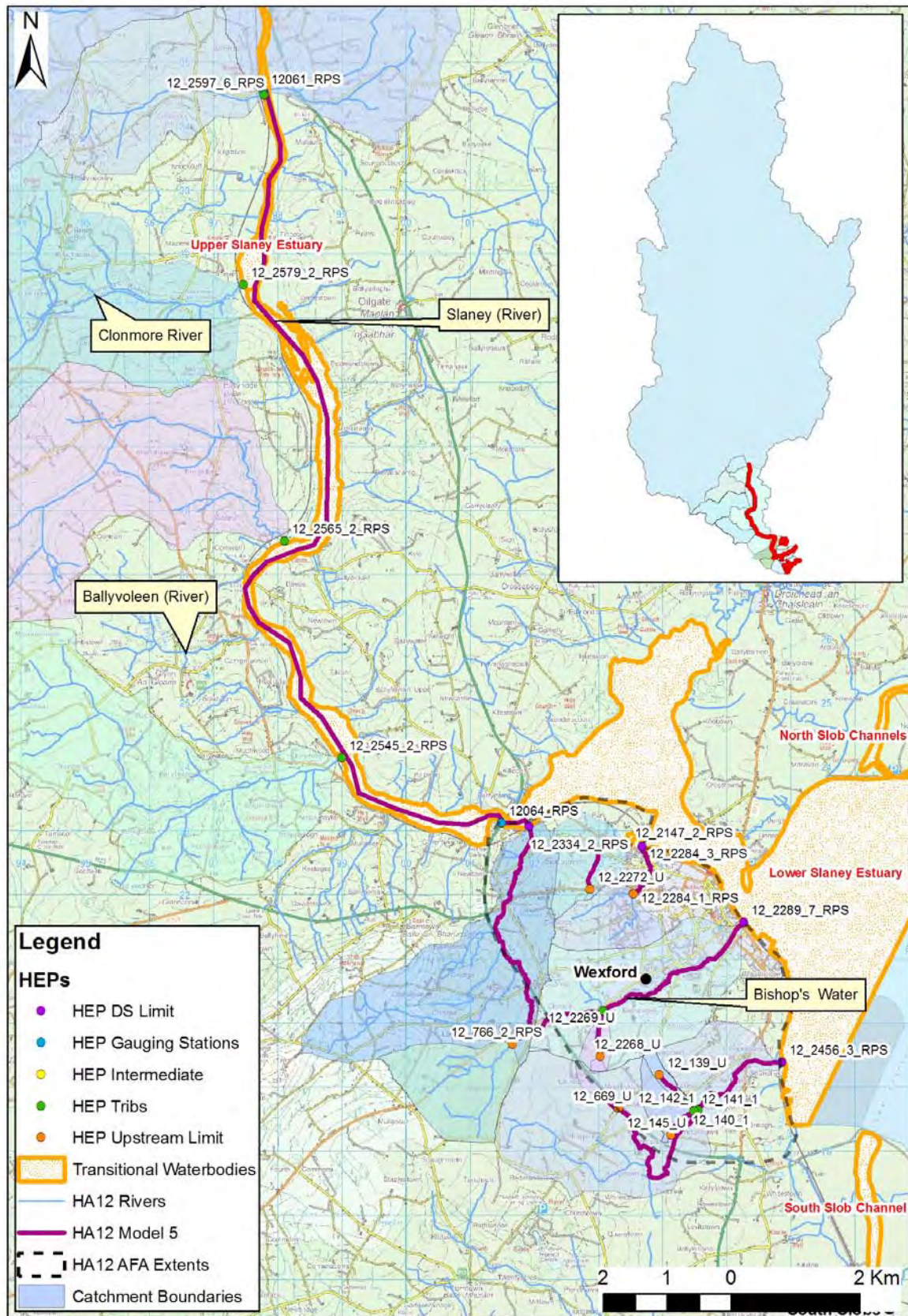


Figure 4.9: HA12 Model 5 HEPs and Catchment Boundaries

No rainfall runoff models have been developed for HA12 Model 5 due to the lack of gauged data upon which to calibrate. Q_{med} estimates at the various HEPs were adjusted based on the Hydrometric Station 12001, Scarawalsh (refer to Section 4.6). Checks were performed on each of the smaller watercourses with respect to suitability of Station 12001 as a pivotal site. Given their small catchment area, the options for hydrologically similar pivotal sites are limited (refer to Section 4.10.2). A comparison of Q_{med} results was undertaken and it was decided to proceed with using Station 12001, the result of which was in keeping with those hydrologically similar sites that were within the 68%ile confidence limits.

The estimated Q_{med} values for the various HEPs within HA12 Model 5 are shown in Table 4.8.

Table 4.8: Q_{med} Values for HA12 Model 5

| Node ID_CFRAMS | AREA (km ²) | Q_{med} (m ³ /s) | Preferred Estimation Methodology |
|----------------|-------------------------|-------------------------------|----------------------------------|
| 12061_RPS | 1646.29 | 219.33 | FSU |
| 12_2597_6_RPS | 5.54 | 1.22 | FSU |
| 12_2579_2_RPS | 15.44 | 3.85 | FSU |
| 12_2565_2_RPS | 22.52 | 5.46 | FSU |
| 12_2545_2_RPS | 12.54 | 4.14 | FSU |
| 12064_RPS | 1752.65 | 232.58 | FSU |
| 12_766_2_RPS | 2.30 | 0.95 | FSU |
| 12_2334_2_RPS | 9.06 | 3.72 | FSU |
| 12_2272_U | 0.01 | 0.01 | FSU |
| 12_2147_2_RPS | 1.29 | 0.54 | FSU |
| 12_2284_1_RPS | 1.27 | 1.22 | FSU |
| 12_2284_3_RPS | 1.67 | 1.68 | FSU |
| 12_2269_U | 0.06 | 0.04 | FSU |
| 12_2268_U | 0.04 | 0.03 | FSU |
| 12_2268_1 | 0.31 | 0.17 | FSU |
| 12_2289_7_RPS | 5.19 | 2.66 | FSU |
| 12_669_U | 0.09 | 0.04 | FSU |
| 12_145_U | 0.01 | 0.01 | FSU |
| 12_139_U | 0.05 | 0.02 | FSU |
| 12_140_U | 0.04 | 0.02 | FSU |
| 12_140_1 | 0.05 | 0.02 | FSU |
| 12_142_1 | 0.20 | 0.08 | |
| 12_142_1 | 0.66 | 0.26 | FSU |
| 12_2456_3_RPS | 7.44 | 2.09 | FSU |

Note: Flow highlighted in yellow represent total flows at that point in the model rather than input flows.

4.9 HA13 MODEL 1 – KILMORE

HA13 contains one fluvial model representing Kilmore AFA. The Kilmore watercourse is a small low slope coastal watercourse with a total catchment area of 21km² at the downstream limit. A gauging station is located at the downstream end (Station 13081) but flow data is not available. The watercourse is tidally influenced along most of the reach as it makes the transition from fluvial to tidal along one of the Ballyteigue Channels before reaching Bridgetown Estuary. The HEPs and catchment boundaries are shown in Figure 4.10. The extent of transitional waterbodies is also shown, illustrating the tidal influence.

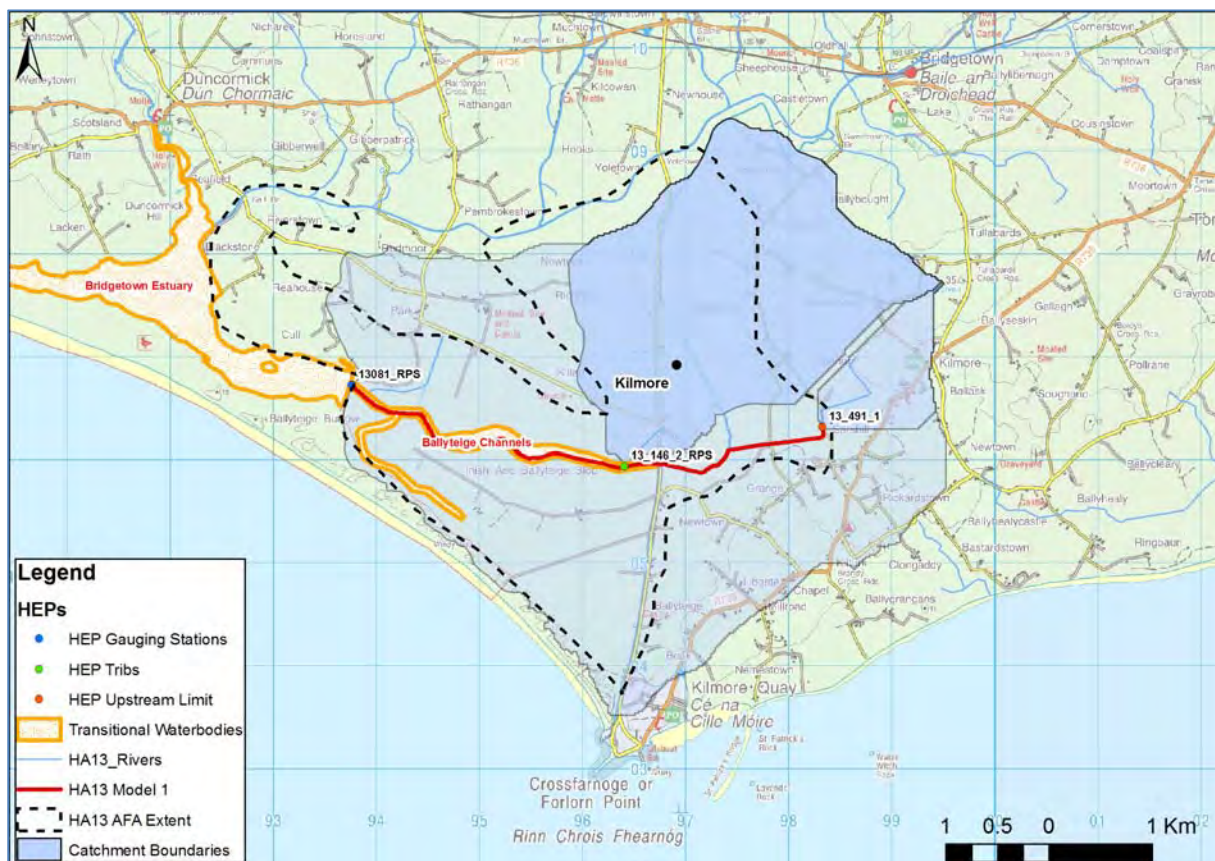


Figure 4.10: HA13 Model 1 HEPs and Catchment Boundaries

No rainfall runoff models were constructed due to the lack of gauged data upon which to calibrate. Initial Q_{med} estimates at the various HEPs were undertaken using the FSU Q_{med} regression equation with a review of pivotal site options so that the estimates could be adjusted based on suitable observed data. Given small catchment area, the options for hydrologically similar pivotal sites are limited (refer to Section 4.10.2). Furthermore, the extent of Arterial Drainage within the Model is 100%. For example at Site 13_146_2, only one of the geographically and hydrologically similar pivotal site options has been arterially drained (Station 25034, Rochfort in the Shannon catchment). In addition, nine of the 14 pivotal site options yielded Q_{med} values either above or below the 95%ile confidence limits. That in itself indicates a high degree of scatter amongst the results with no clear trend emerging for a suitable adjustment factor. The pivotal site options that yield results within the

confidence limits have a range of adjustment factors with an average value of 0.996. On this basis, it was decided not to adjust the Q_{med} estimates using a pivotal site. Furthermore, this catchment is somewhat controlled since there is a flap valve at the downstream limit where the Ballyteigue Channels are separated from the Bridgetown Estuary. Coastal water levels may be the dominating factor in dictating the critical flood mechanism if the flap valves at the estuary remain submerged for long periods. In this scenario flood volume rather than flood peak may be the critical fluvial flood mechanism. Coastal Hydrology and Joint Probability Analysis for Fluvial-Tidal flood events are discussed further in Sections 6.2 and 6.3 respectively.

The estimated Q_{med} values for the various HEPs within HA13 Model 1 are shown in Table 4.9.

Table 4.9: Q_{med} Values for HA13 Model 1

| Node ID_CFRAMS | AREA (km²) | Q_{med} (m³/s) | Preferred Estimation Methodology |
|---------------------------|------------------------------|---|---|
| 13_491_1 | 1.02 | 0.22 | FSU (PCDs) |
| 13_146_2_RPS | 6.74 | 0.63 | FSU (PCDs) |
| 13081_RPS | 20.93 | 2.37 | FSU (PCDs) |

Note: Flow highlighted in yellow represent total flows at that point in the model rather than input flows.

4.10 INDEX FLOOD FLOW CONFIDENCE LIMITS

4.10.1 Gauged Q_{med}

As has been shown previously HA13 is essentially ungauged for the purposes of this Study. HA11 has one gauging station on the Owenavorrigh River. HA12 is moderately gauged in terms of the River Slaney itself with two of the five models having some gauge data available upon which flood flow estimation can be based. The use of rainfall runoff modelling techniques can bring additional confidence at stations where the station rating is questionable at Q_{med} , the length of AMAX series is short such that statistical confidence in the Q_{med} value is diminished or where the behaviour of the catchment may have changed over time.

Rainfall run off models within HA11 and HA12 have been considered by RPS in order to measure their accuracy at predicting Q_{med} . Models representing catchments at hydrometric gauging stations which were considered A1 or A2 under FSU (see FSU WP 2.1) had the NAM model simulated Q_{med} values compared against the station observed Q_{med} values for the same AMAX time series to see if the calibrated NAM models were replicating the gauged Q_{med} values. The results of the comparable simulated and observed Q_{med} values are shown in Table 4.10 below.

Table 4.10: Calibrated NAM Model Q_{med} Accuracy

| Station Number | Station Name | FSU AMAX Years | FSU Classification | Observed Q_{med} Value (for available AMAX years) | Simulated Q_{med} Value (for corresponding AMAX Years) | % Error |
|----------------------|--------------|----------------|--------------------|---|--|-------------|
| 11001 | Boleany | 1991 - 2004 | B | 45.75 | 58.48 | 27.8 |
| 12001 | Scarawalsh | 1955 - 2003 | A2 | 156 | 141.55 | 9.3 |
| 12013 | Rathvilly | 1975 - 2004 | B | 43.55 | 48.81 | 12.07 |
| Average Error | | | | | | 16.4 |

*Note Station 14022 is not a FSU pivotal site at present but has a classification of A2 for available AMAX

As indicated by Table 4.10 the average percentage error is 16.4% when comparing Q_{med} values taken from corresponding AMAX years. A contributing factor to the loss of accuracy in these areas is the lack of radar data to use as rainfall input in the NAM models. In addition, Stations 11001 and 12013 have lower confidence in the observed flow records as reflected by their B classifications under FSU.

As discussed in Section 4.6, the NAM outputs for Station 12001 were not adopted for subsequent analysis given the difference in Q_{med} values and the fact that the station already had robust flow records since 1955. The ration review outputs supported this (Chapter 3).

Station 11001 carries a degree of uncertainty within the flow records themselves but also in the difference between Q_{med} predicted (24.67m³/s) and Q_{med} gauged 45.75m³/s. The NAM model outputs

did not reduce this uncertainty given the 28% difference in Q_{med} values for the FSU AMAX period of record, albeit the overall Q_{med} value for the augmented AMAX series was similar to the gauged value. However the CFRAMs rating review outputs increased confidence in the FSU gauged Q_{med} value (Chapter 3) and therefore it was adopted for subsequent design flow estimation.

Station 12013 is an A2 rated station for which the NAM model achieved satisfactory calibration results at low to medium flows. The percentage error shown in Table 4.10 is 9.3%. However the overall Q_{med} value based on an augmented AMAX series from 1694 is $43.88\text{m}^3/\text{s}$, which is very similar to the gauged Q_{med} value of $43.55\text{m}^3/\text{s}$. The NAM output was adopted for subsequent analysis but the difference between using the gauged Q_{med} and the overall NAM Q_{med} is negligible in this case.

For details on the calibration process for NAM models refer to Appendix D1.

4.10.2 Ungauged Q_{med}

The estimation of Q_{med} for the ungauged catchments within this study focuses on the FSU (WP 2.3) statistical based method where a regression equation is used based on catchment descriptors.

The FSU method for Flood Estimation in ungauged Catchments (WP 2.3) is based on a regression equation derived from data from 190 hydrometric gauge stations across Ireland, only eight of which are for catchments less than 25km^2 . The factorial standard error (FSE) associated with Q_{med} estimation using FSU (WP 2.3) is 1.37. The IH124 method has traditionally been preferred for catchments less than 25km^2 in area as the data upon which the regression equation was derived is much more weighted towards smaller catchments. This has a higher factorial standard error of 1.64. However recent guidance has shifted towards the use of FSU WP 2.3 for all Irish ungauged catchments as discussed in Section 2.3.1.2 (based on recent CFRAM Study Guidance), and as such it has been applied to all ungauged catchments in this Study.

5 FLOOD FREQUENCY ANALYSIS AND GROWTH CURVE DEVELOPMENT

5.1 OBJECTIVE AND SCOPE

This chapter deals with the estimation of flood growth for a number of river catchments located within the Hydrometric Areas HA11 (Owenavorrhagh), HA12 (Slaney and Wexford Harbour) and HA13 (Ballyteigue-Bannow). The estimated growth curves will be used in determining the peak design flood flows for all Hydrological Estimation Points (HEP) located on the modelled tributary and main river channels within these Hydrometric Areas.

The scope of this chapter includes:

- (i) Selection of a statistical distribution suitable for regional flood frequency analysis,
- (ii) Selection of pooling region and groups, and
- (iii) Growth curve estimation,

5.2 METHODOLOGY

5.2.1 Selection of Statistical Distribution

The suitable distributions for the Annual Maximum (AMAX) series for all hydrometric gauging sites located within HA11, 12 and 13 were determined based on the statistical distribution fitting technique described in the Flood Studies Update (FSU) Programme Work Package 2.2 “Frequency Analysis” (OPW, 2009), UK Flood Estimation Handbook (FEH) (Institute of Hydrology, 1999) and 1975 Flood Studies Report (NERC, 1975).

5.2.2 Forming a Pooling Region and Groups

The pooling group associated with each of the growth curves was formed based on the Region-of-Influence (ROI) approach (Burn, 1990) recommended in FSU (2009). The region from which the AMAX series were pooled to form a pooling group for each of the growth curves was selected based on the similarity in catchment characteristics (both in terms of climatic and physiographic) in the neighbouring geographical region.

5.2.3 Growth Curve Development

Growth curves for each of the HEP locations were developed / estimated in accordance with the methodologies set out in the FSU, FSR and FEH studies. The Hosking and Wallis (1997) proposed L-Moment theories were used in estimating the parameters of the statistical distributions. The growth curve estimation process was automated through development of a FORTRAN 90 language based computational program.

5.2.4 Limitations in the FEH and FSU Studies

There is no explicit guidance provided in FEH or FSU for dealing with the issues surrounding production of a large number of growth factors within a river system and the associated problems with consistency and transition from growth curve to growth curve. For the subject river catchments located within HA11, HA12 & HA13, a catchment characteristic based generalised growth curve estimation method, as discussed later in Sections 5.7.4 and 5.8, was used to deal with this real world problem.

5.3 DATA AND STATISTICAL PROPERTIES

5.3.1 Flood Data

The AMAX series for all hydrometric gauging sites located within HA11, HA12 & HA13 were obtained from the OPW and the EPA. In addition to these, flow records from neighbouring catchments were also collected to form a pooling region for growth curve analysis. The AMAX series and continuous flood records for 92 gauging sites were obtained for up to year 2011. Table 5.1 presents the locations details, record lengths and some of the catchment characteristics of these hydrometric stations, while Figure 5.1 overleaf illustrates their spatial distributions in the region. The majority of the 92 stations have A1 & A2 rating quality classification (refer to Section 3.2 for definitions). The record lengths in these gauging stations vary from 9 to 70 years with a total of 3,336 station-years of AMAX series. The Slaney River catchment in HA12 has 121 station-years of AMAX series from three hydrometric gauging sites. In HA11, the Owenavoragh River catchment has 38 station-years (one station located at Boleany); while in HA13 the Corock River at Foulk's Mill has 25 station-years of AMAX series.

There are climatic differences between the eastern and other parts of the country and restricting the choice of pooling stations to the eastern and south-eastern regions along with HA06, should ensure an additional degree of homogeneity. In particular, it was felt that the catchments of the Shannon hydrometric areas, many of which are large and flat, would not necessarily be homogeneous with the Eastern and South-Eastern HAs and therefore would not make any additional useful contribution to the development of their growth curves. In light of the large number of AMAX values (3,336 station-years) available in the eastern and south-eastern HAs, it is not considered necessary to extend the pooling region to the entire country.

Table 5.1: Hydrometric Station Summary

| Stations | Waterbody | Location | Record Length (Years) | Area (Km ²) | SAAR (Mm) | BFI | FARL | FSU Gauge Rating Classification |
|----------|-----------|-------------------|-----------------------|-------------------------|-----------|-------|-------|---------------------------------|
| 6011 | Fane | Moyle's Mill | 51 | 229.19 | 1028.98 | 0.708 | 0.874 | A1 |
| 6012 | Annalong | Subsidiary Intake | 53 | 162.80 | 1046.24 | 0.680 | 0.831 | Not Classified |
| 6013 | Dee | Charleville | 35 | 309.15 | 873.08 | 0.617 | 0.971 | A1 |
| 6014 | Glyde | Tallanstown | 35 | 270.38 | 927.45 | 0.634 | 0.927 | A1 |

| Stations | Waterbody | Location | Record Length (Years) | Area (Km ²) | SAAR (Mm) | BFI | FARL | FSU Gauge Rating Classification |
|----------|----------------------|-------------------|-----------------------|-------------------------|-----------|-------|-------|---------------------------------|
| 6025 | Dee | Burley | 36 | 175.98 | 908.31 | 0.615 | 0.956 | A1 |
| 7001 | Tremblestown | Tremblestown | 42 | 151.31 | 913.24 | 0.700 | 0.996 | A2 |
| 7002 | Deel [Raharney] | Killyon | 51 | 284.97 | 920.53 | 0.780 | 0.929 | A2 |
| 7003 | Blackwater (Enfield) | Castlerickard | 51 | 181.51 | 809.22 | 0.649 | 1.000 | A1 & B |
| 7004 | Blackwater (Kells) | Stramatt | 53 | 245.74 | 1007.88 | 0.619 | 0.772 | A2 |
| 7005 | Boyne | Trim | 52 | 1332.17 | 879.71 | 0.721 | 0.983 | A1 |
| 7006 | Moynalty | Fyanstown | 49 | 177.45 | 936.67 | 0.552 | 0.990 | A2 |
| 7007 | Boyne | Boyne Aqueduct | 50 | 441.18 | 870.98 | 0.663 | 1.000 | A1 & B |
| 7009 | Boyne | Navan Weir | 34 | 1658.19 | 868.55 | 0.713 | 0.911 | A1 |
| 7010 | Blackwater (Kells) | Liscartan | 51 | 699.75 | 948.29 | 0.658 | 0.798 | A1 & A2 |
| 7011 | Blackwater (Kells) | O'daly's Br. | 49 | 281.74 | 1003.32 | 0.678 | 0.965 | A2 & B |
| 7012 | Boyne | Slane Castle | 70 | 2460.27 | 890.06 | 0.678 | 0.893 | A1 |
| 7017 | Moynalty | Rosehill | 11 | 70.64 | 991.74 | 0.516 | 0.993 | Not Classified |
| 7023 | Athboy | Athboy | 9 | 100.10 | 950.81 | 0.717 | 0.995 | Not Classified |
| 7033 | Blackwater (Kells) | Virginia Hatchery | 30 | 124.94 | 1032.22 | 0.439 | 0.893 | A2 |
| 8002 | Delvin | Naul | 24 | 33.43 | 791.12 | 0.597 | 1.000 | A1 |
| 8003 | Broadmeadow | Fieldstown | 18 | 83.59 | 826.00 | 0.466 | 0.880 | B |
| 8005 | Sluice | Kinsaley Hall | 23 | 9.17 | 710.76 | 0.523 | 1.000 | A2 |
| 8007 | Broadmeadow | Ashbourne | 21 | 37.94 | 845.02 | 0.399 | 1.000 | B |
| 8008 | Broadmeadow | Broadmeadow | 28 | 107.92 | 810.61 | 0.487 | 0.999 | A2 |
| 8009 | Ward | Balheary | 15 | 61.64 | 767.09 | 0.545 | 0.999 | A1 |
| 8010 | Garristown St. | Garristown S.W. | 13 | 1.13 | 818.92 | 0.682 | 1.000 | Not Classified |
| 8011 | Nanny | Duleek D/S | 28 | 181.77 | 819.49 | 0.520 | 0.999 | B |
| 8012 | Stream | Ballyboghill | 17 | 25.95 | 798.70 | 0.524 | 0.999 | B |
| 9001 | Ryewater | Leixlip | 54 | 209.63 | 783.26 | 0.507 | 1.000 | A1 |
| 9002 | Griffeen | Lucan | 25 | 34.95 | 754.75 | 0.674 | 0.958 | A1 |
| 9010 | Dodder | Waldron's Bridge | 57 | 94.26 | 955.04 | 0.561 | 0.993 | A1 |
| 9011 | Slang | Frankfort | 19 | 5.46 | 772.95 | 0.563 | 0.986 | B |
| 9024 | Morell | Morell Bridge | 9 | 98.75 | 851.99 | 0.705 | 0.987 | Not Classified |
| 9035 | Camac | Killeen Road | 15 | 37.14 | 794.21 | 0.673 | 0.932 | B |
| 9048 | Ryewater | Anne's Bridge | 10 | 59.35 | 805.54 | 0.474 | 1.000 | Not Classified |
| 9049 | Lyreen | Maynooth | 10 | 87.52 | 768.17 | 0.473 | 1.000 | Not Classified |
| 10002 | Avonmore | Rathdrum | 52 | 230.89 | 1530.19 | 0.538 | 0.986 | B |
| 10004 | Glenmacnass | Laragh | 14 | 30.57 | 1700.39 | 0.436 | 0.997 | Not Classified |
| 10021 | Shanganagh | Common's Road | 30 | 32.51 | 799.07 | 0.654 | 0.997 | A1 |

| Stations | Waterbody | Location | Record Length (Years) | Area (Km ²) | SAAR (Mm) | BFI | FARL | FSU Gauge Rating Classification |
|----------|--------------|---------------------|-----------------------|-------------------------|-----------|-------|-------|---------------------------------|
| 10022 | Cabinteely | Carrickmines | 17 | 12.94 | 821.92 | 0.600 | 1.000 | A1 |
| 10028 | Aughrim | Knocknamohill | 22 | 202.92 | 1396.92 | 0.788 | 0.999 | B |
| 10038 | Stream | Druids Glen | 10 | 16.14 | 914.40 | 0.618 | 1.000 | Not Classified |
| 11001 | Owenavorragh | Boleany | 38 | 155.11 | 931.07 | 0.489 | 0.999 | A1 |
| 12001 | Slaney | Scarawalsh | 55 | 1030.75 | 1167.31 | 0.716 | 0.999 | A2 |
| 12002 | Slaney | Enniscorthy | 31 | 1319.92 | 1129.33 | 0.714 | 1.000 | Not Classified |
| 12013 | Slaney | Rathvilly | 35 | 204.39 | 1383.48 | 0.743 | 0.999 | B |
| 13002 | Corock | Foulk's Mill | 25 | 62.96 | 1043.79 | 0.733 | 1.000 | Not Classified |
| 14003 | Barrow | Borness | 27 | 206.73 | 1160.51 | 0.532 | 1.000 | Not Classified |
| 14004 | Figile | Clonbulloge | 53 | 268.85 | 838.67 | 0.537 | 1.000 | Not Classified |
| 14005 | Barrow | Portarlinton | 53 | 405.48 | 1014.90 | 0.501 | 1.000 | A2 |
| 14006 | Barrow | Pass Br | 56 | 1063.59 | 899.07 | 0.571 | 1.000 | A1 |
| 14007 | Stradbally | Derrybrock | 30 | 118.59 | 814.07 | 0.642 | 1.000 | A1 |
| 14009 | Cushina | Cushina | 30 | 68.35 | 831.24 | 0.667 | 1.000 | A2 |
| 14011 | Slate | Rathangan | 31 | 162.30 | 806.97 | 0.600 | 0.999 | A1 |
| 14013 | Burren | Ballinacarrig | 55 | 154.40 | 887.98 | 0.701 | 0.999 | A2 |
| 14018 | Barrow | Royal Oak | 67 | 2419.40 | 857.46 | 0.665 | 1.000 | A1 |
| 14019 | Barrow | Levitstown | 57 | 1697.28 | 861.46 | 0.624 | 0.999 | A1 |
| 14022 | Barrow | Barrow New Bridge | 12 | 2069.53 | 855.63 | 0.652 | 0.999 | Not Classified |
| 14029 | Barrow | Graiguenamanagh U/S | 52 | 2778.15 | 876.50 | 0.688 | 0.999 | A2 |
| 14031 | Tully | Japanese Gdns | 10 | 13.00 | 826.06 | 0.650 | 1.000 | Not Classified |
| 14033 | Owenass | Mountmellick | 10 | 78.89 | 1145.22 | 0.454 | 0.999 | B |
| 14034 | Barrow | Bestfield Lock | 17 | 2057.36 | 856.05 | 0.652 | 0.999 | A2 |
| 14101 | Boghlone | Kyleclonhobert | 9 | 9.60 | 929.15 | 0.554 | 1.000 | Not Classified |
| 15001 | Kings | Annamult | 48 | 444.35 | 935.24 | 0.514 | 0.997 | A2 |
| 15002 | Nore | John's Br. | 53 | 1644.07 | 945.44 | 0.625 | 0.730 | A2 |
| 15003 | Dinin | Dinin Br. | 56 | 299.17 | 933.86 | 0.381 | 0.998 | A2 |
| 15004 | Nore | Mcmahons Br. | 56 | 491.38 | 1067.46 | 0.594 | 0.999 | A2 |
| 15005 | Erkina | Durrow Ft. Br. | 55 | 379.37 | 884.96 | 0.712 | 0.999 | B |
| 15006 | Nore | Brownsbarn | 54 | 2418.27 | 941.92 | 0.633 | 0.997 | Not Classified |
| 15007 | Nore | Kilbricken | 35 | 339.76 | 1123.04 | 0.594 | 1.000 | A2 |
| 15008 | Nore | Borris In Ossory | 35 | 116.22 | 943.75 | 0.533 | 0.993 | Not Classified |
| 15009 | Kings | Callan | 54 | 203.14 | 940.19 | 0.540 | 1.000 | Not Classified |
| 15010 | Goul | Ballyboodin | 31 | 159.06 | 886.97 | 0.657 | 0.997 | Not Classified |
| 15011 | Nore | Mount Juliet | 57 | 2225.79 | 938.02 | 0.618 | 0.999 | Not Classified |
| 15012 | Nore | Ballyragget | 16 | 1056.80 | 974.00 | 0.682 | 0.999 | B |
| 15021 | Delour | Annagh | 11 | 67.05 | 1358.56 | 0.651 | 1.000 | Not Classified |

| Stations | Waterbody | Location | Record Length (Years) | Area (Km ²) | SAAR (Mm) | BFI | FARL | FSU Gauge Rating Classification |
|----------|------------|---------------|-----------------------|-------------------------|-----------|-------|-------|---------------------------------|
| 15041 | Goul | Ballinfrase | 9 | 135.39 | 889.60 | 0.634 | 0.996 | Not Classified |
| 16001 | Drish | Athlummon | 38 | 135.06 | 916.42 | 0.606 | 1.000 | A2 |
| 16002 | Suir | Beakstown | 56 | 485.70 | 932.15 | 0.634 | 0.999 | A2 |
| 16003 | Clodiagh | Rathkennan | 56 | 243.20 | 1192.01 | 0.550 | 1.000 | A2 |
| 16004 | Suir | Thurles | 55 | 228.74 | 941.36 | 0.579 | 1.000 | A2 |
| 16005 | Multeen | Aughnagross | 35 | 84.00 | 1153.57 | 0.560 | 0.994 | A2 |
| 16006 | Multeen | Ballinaclogh | 38 | 75.80 | 1115.82 | 0.587 | 0.999 | B |
| 16007 | Aherlow | Killardry | 56 | 273.26 | 1330.55 | 0.578 | 0.999 | B |
| 16008 | Suir | New Bridge | 56 | 1090.25 | 1029.63 | 0.635 | 0.998 | A2 |
| 16009 | Suir | Caher Park | 57 | 1582.69 | 1078.57 | 0.631 | 0.998 | A2 |
| 16010 | Anner | Anner | 38 | 437.10 | 985.24 | 0.624 | 0.999 | Not Classified |
| 16011 | Suir | Clonmel | 71 | 2143.67 | 1124.95 | 0.670 | 0.993 | A1 |
| 16012 | Tar | Tar Br. | 46 | 229.63 | 1320.79 | 0.628 | 0.999 | B |
| 16013 | Nire | Fourmilewater | 45 | 93.58 | 1471.29 | 0.539 | 0.993 | B |
| 16051 | Rossestown | Clobanna | 13 | 34.19 | 895.27 | 0.676 | 1.000 | B |
| 17002 | Tay River | Fox Castle | 10 | 33.50 | 1554.00 | n.a. | n.a. | Not Classified |

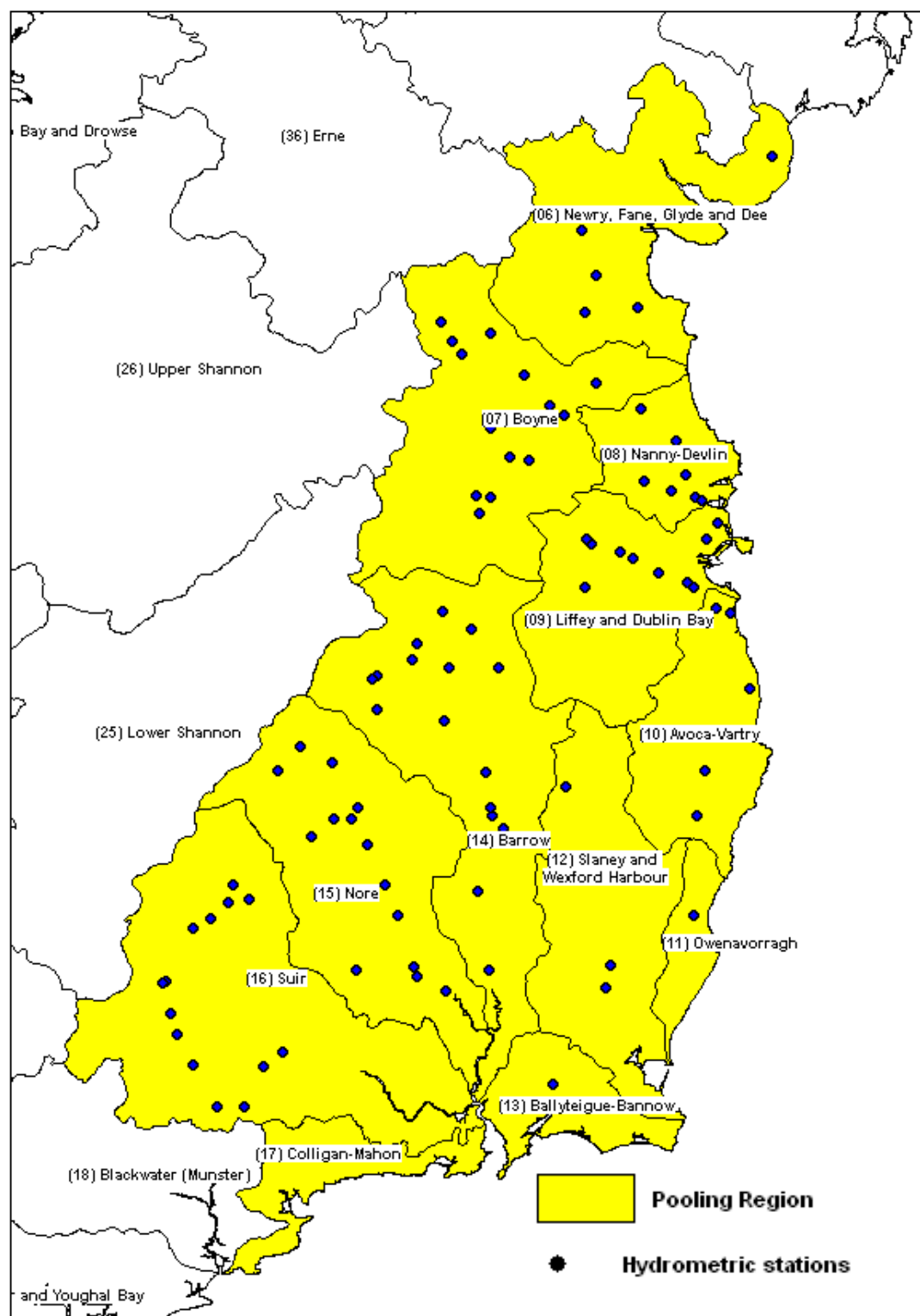


Figure 5.1: Locations of 92 Gauging Stations

5.3.2 Pooling Region Catchment Physiographic and Climatic Characteristic Data

In addition to the AMAX series, some catchment physiographic and climatic characteristics information including the catchment sizes (AREA), Standard Average Annual Rainfall (SAAR), catchment Base Flow Index (BFI) and the Flood Attenuation by Reservoirs and Lakes (FARL) Index for all 92 stations were also obtained from OPW. Table 5.2 presents a summary of these catchment characteristics. Catchment sizes range from 1.13 to 2778.15 km² with a median value of 182 km², SAAR values range from 711 to 1700 mm with a median value of 927 mm. The BFI values vary from 0.381 to 0.788, while the FARL values range from 0.730 to 1.0.

Table 5.2: Summary of Catchment physiographic and climatic characteristics of Pooling Region

| Characteristics | Minimum | Maximum | Average | Median |
|-------------------------|---------|---------|---------|--------|
| AREA (km ²) | 1.13 | 2778.15 | 489.17 | 181.77 |
| SAAR (mm) | 710.76 | 1700.39 | 967.15 | 927.45 |
| BFI | 0.381 | 0.788 | 0.608 | 0.624 |
| FARL | 0.730 | 1.000 | 0.979 | 0.999 |

Furthermore the relative frequencies of the AREA, SAAR and BFI values within the 92 stations are also presented in Figure 5.2, Figure 5.3 and Figure 5.4 respectively. It can be seen from Figure 5.2 that the majority of the catchment areas in the selected sites fall in the range of 100 to 500 km². Figure 5.3 shows that the SAAR values in majority of the stations range from 800 to 1000 mm and very few stations have SAAR values more than 1400 mm. Similarly, Figure 5.4 shows the relative frequency of the BFI values within the 92 catchments. It can be seen from this figure that the BFI values in the majority of the 92 catchment areas range from 0.5 to 0.75.

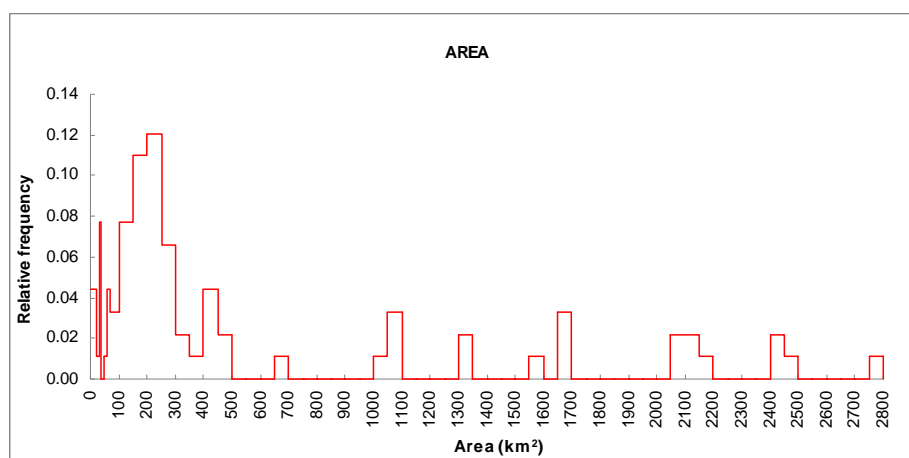


Figure 5.2: Relative frequencies of catchments sizes (AREA) within the selected 92 stations

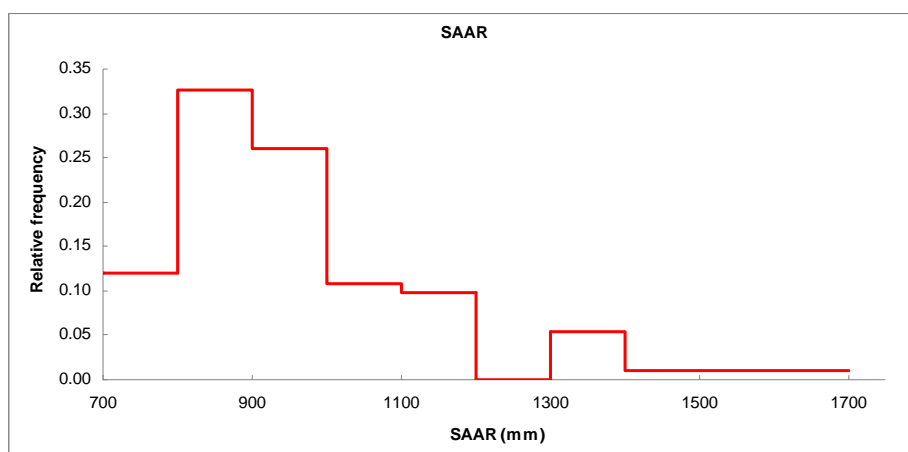


Figure 5.3: Relative frequencies of the SAAR values within the selected 92 stations

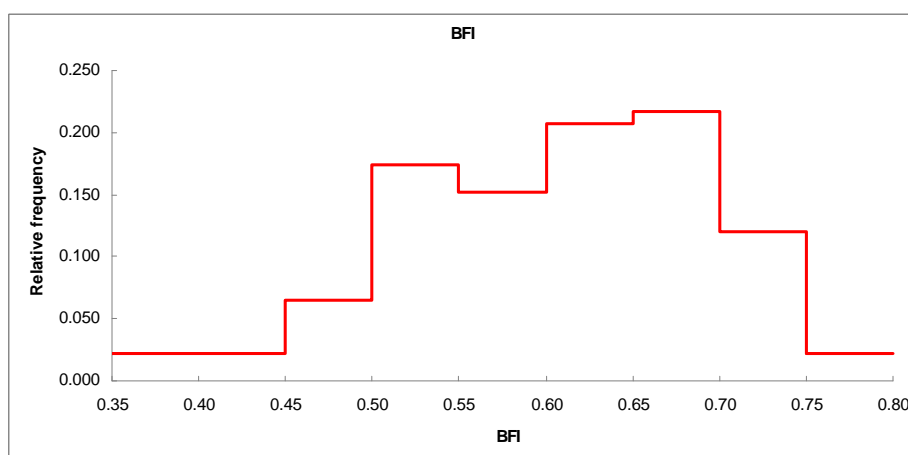


Figure 5.4: Relative frequencies of the BFI values within the selected 92 stations

There are five gauges in the pooling group located within areas that have karst aquifers. The BFI values at these gauges have been accounted for in the pooling group - aquifer type is a contributing factor in this index and is therefore inherently taken into account. The associated BFI values are in keeping with the rest of the pooling group as shown above indicating that the karst element is not significant. Furthermore, the karst areas do not cover significant parts of the catchment areas associated with these gauging sites. Any impacts on the estimated growth curves due to the inclusion of these sites in the pooling group would be minimal and so they have been retained in the pooling group.

5.3.3 Statistical Properties of the AMAX series

Table 5.3 provides a summary of the statistical properties of the AMAX series for all 92 gauging sites. The median annual maximum flows (Q_{med}) range from 0.47 to 299.32 m³/s with an average value of 53.83 m³/s. The L-CV values range from 0.052 to 0.415 with an average value of 0.198, while the L-Skewness values range from -0.181 to 0.488 with an average value of 0.166 which is approximately equal to the theoretical L-Skewness of EV1 distribution. Figure 5.5 shows the L-CV versus L-

Skewness diagram for the 92 AMAX series with the values associated with the HA 11, 12 and 13 river catchments highlighted as shown.

Table 5.3: Statistical properties of 92 AMAX Series

| Parameters | Minimum | Maximum | Average | Median |
|---------------------------------|---------|---------|---------|--------|
| Record Lengths (years) | 9 | 71 | 37 | 35 |
| Mean Flow (m ³ /s) | 0.49 | 303.45 | 56.56 | 27.16 |
| Median Flow (m ³ /s) | 0.47 | 299.32 | 53.83 | 25.42 |
| L-CV | 0.052 | 0.415 | 0.198 | 0.182 |
| L-skewness | -0.181 | 0.488 | 0.166 | 0.163 |
| L-kurtosis | -0.127 | 0.426 | 0.155 | 0.139 |

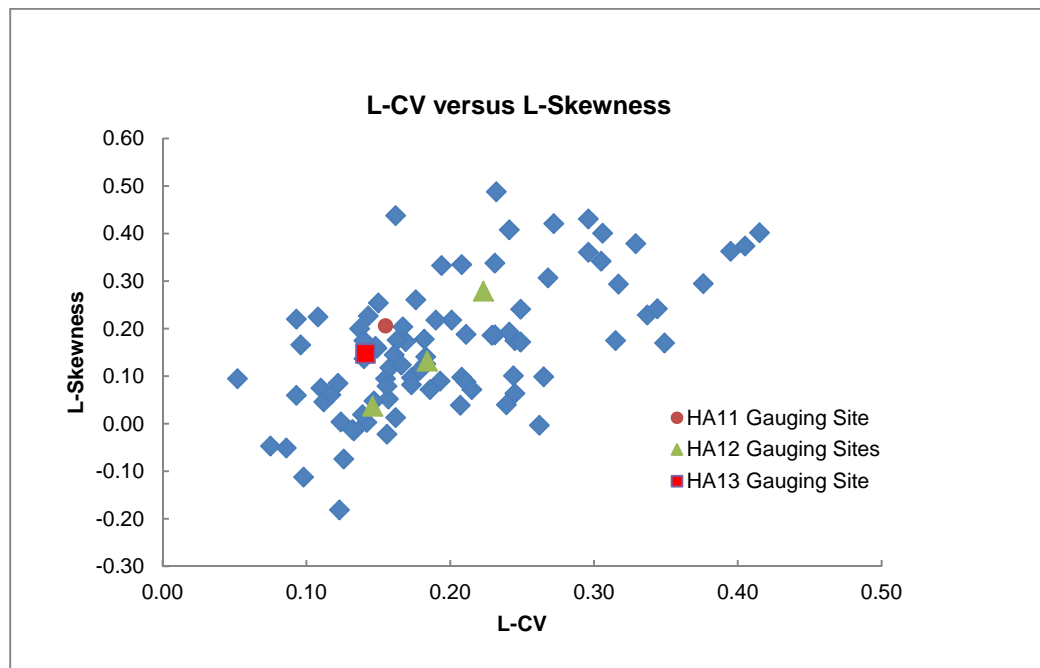


Figure 5.5: L-Moment Ratio Diagram (L-CV versus L-Skewness) for 92 AMAX series

5.4 STATISTICAL DISTRIBUTION

The individual gauging site's AMAX series were fitted to four flood like distributions, namely EV1, GEV, GLO and LN2 distributions. The EV1 and LN2 distributions are two-parameter distributions while the GLO and GEV distributions each have three-parameters.

The choice of distributions used for this study was guided by the findings in FSU Report (September, 2009). In the case of 2-parameter distributions, the FSU Work Package 2.2 report states (Section 4.2, page 40) "*It can be deduced from the linear patterns that Irish flood data are more likely to be distributed as EV1 or LN2 rather than Logistic distribution (LO) among 2-parameter distributions*".

Therefore the elimination of LO as a 2-parameter distribution is robustly based on a study of all relevant Irish data. Also, FSU concentrated on GEV and GLO from among the available 3-parameter distributions. The lack of emphasis on LN3 by FSU was possibly based on the L-kurtosis vs. L-skewness moment ratio diagram (FSU WP 2.2 Report, Figure 3.10, page 30) and that one could be used as a surrogate for the other. Then, because of the overwhelmingly central role, traditionally played by GEV in flood frequency analysis, the FSU decided to base its analysis using the GEV rather than LN3. The same reasoning was adopted for the present study.

Based on the visual inspections of the probability plots of all 92 AMAX series, it was found that the three-parameter distributions (GLO and GEV) provide better fits to the majority of the 92 AMAX series. For the GLO distribution, out of 92 frequency curves, 80 showed concave upward shape, 5 concave downward and 7 straight lines. For the 35 showed concave upward shape, 41 showed concave downward and 16 are of straight line type. In the Slaney River catchment (HA12), the GLO distribution was found to be the best suited to all three AMAX series (all concave upward). In the case of GEV distribution, 2 concave upward shape, one concave downward. The both AMAX series of HA11 & HA13 are also best fitted to the GLO distribution. Both the GLO and GEV curves are of concave upward shaped in both AMAX series. Table 5.4 presents the summary results of the visual assessments of the probability plots for all 92 AMAX series. It should be noted here that one reason for the change of concave / convex upwards shapes seen in GEV and GLO is due to the difference in abscissa used in the probability plots i.e. $EV1y = -\ln\{-\ln(1-1/T)\}$ for the GEV distribution and the $GLOy = -\ln\{1/(T-1)\}$ for GLO distribution.

Table 5.4: Summary results of probability plots assessments (EV1, GEV & GLO distributions) for all 92 AMAX series

| Distribution | No. distribution in each quality ranks (1, 2 & 3) | | | Fitted line type |
|--------------|--|------------------|------------------|---|
| | Rank 1 (very good) | Rank 2 (good) | Rank 3 (fair) | |
| EV1 | 18 | 12 | 62 | All straight line |
| LN2 | 18 | 33 | 41 | All concave upward (At Log n scale) |
| GEV | 20 | 56 | 16 | 16 – straight line (GEV type I) 35 – concave upward (GEV Type II) 41 – concave downward GEV Type III) |
| GLO | 54 | 24 | 14 | 7 – straight line, 80 – concave upward & 5 – concave downward |

A study carried out in University College Dublin (UCD) by S. Ahilan et al. (2012) on 143 stations countrywide in Ireland found that the AMAX series of the majority of hydrometric stations located in the Eastern and South Eastern regions follow the GEV Type III distribution. Section 5.7 discusses the choice of growth curve distributions taken forward in the analysis.

5.5 GROWTH CURVE ESTIMATION POINTS

In order to estimate the peak design flows for each of the HEPs located on the modelled watercourses in HA11 (23 HEPs), HA12 (108 HEPs) & HA13 (1 HEP) using the 'index-flood' method (FEH, 1999; FSU, 2009), growth curves for each of the HEPs are required. The selection of the HEPs was initially derived in accordance with the project brief and further categorised and developed based on the hydraulic model conceptualisation of the modelled watercourses within each of the AFAs. For the integration of hydrological input to the hydraulic model and also for the calibration and verification of the hydraulic models the HEPs were identified at the following locations on the modelled watercourses:

- HEPs at the upstream limit of model;
- HEPs where tributaries greater than 5km² enter the modelled channels;
- HEPs at gauged stations on modelled channels;
- HEPs at intermediate points on the modelled channels, and
- HEPs at the downstream limit of model.

The details of the selection process for the HEPs are discussed in the HA11, HA12 & HA13 Inception Report (Section 5.3). Tables 5.5, 5.6 & 5.7 present a summary of the catchment characteristics associated with all HEPs in HA11, HA12 & HA13 respectively. In HA11, the catchment areas vary from 1 to 160.96 km². The SAAR values range from 881 to 962 mm while the BFI values vary from 0.480 to 0.719. In the Slaney River catchment (HA12), the catchment areas range from close to 0 (at the top of modelled tributaries) to 1753 km², while the SAAR values range from 898 to 1430 mm and the BFI values from 0.523 to 0.743. In HA13, the catchment area, SAAR and BFI values associated with the selected HEP are 18.65 km², 861mm and 0.612 respectively.

Table 5.5: Summary of the catchment characteristics associated with HA11, 12 and 13 HEPs

| Catchment descriptors | Minimum | Maximum | Average | Median |
|-------------------------|---------|---------|---------|--------|
| AREA (km ²) | 1.03 | 160.96 | 22.71 | 5.65 |
| SAAR (mm) | 881 | 962 | 908 | 903 |
| BFI | 0.480 | 0.719 | 0.571 | 0.538 |

Table 5.6: Summary of the catchment characteristics associated with the 108 HEPs in HA12

| Catchment descriptors | Minimum | Maximum | Average | Median |
|-------------------------|---------|---------|---------|--------|
| AREA (km ²) | 0.01 | 1753 | 181 | 12.54 |
| SAAR (mm) | 898 | 1430 | 1124 | 1129 |
| BFI | 0.523 | 0.743 | 0.675 | 0.690 |

Table 5.7: Summary of the catchment characteristics associated with the 1 HEP in HA13

| Catchment descriptors | Value |
|-------------------------|-------|
| AREA (km ²) | 18.65 |
| SAAR (mm) | 861 |
| BFI | 0.612 |

Based on the similarity of the catchment characteristics of these HEPs with the selected gauging sites located within the pooling region, growth curves for all HEPs with areas greater than 5 km² were estimated. Almost 95% of the selected gauging sites in the pooled region have catchment areas more than 5 km². Therefore, the pooling groups for the HEPs with catchment areas less than 5 km² would not be the homogeneous groups and therefore the errors in the estimated growth curves would be larger. All HEPs with catchment areas less than 10 km² are considered to have the same growth curve. Based on these considerations, for HA11, 13 HEPs (out of 23) were selected. While in HA12, 68 HEPs (out of 108) were initially selected as points for the estimation of growth curves but as will be discussed in Section 5.8.2 this was extended to with the additional of a further 188 Growth Curve Estimation Points (GC_EPs) in order to aid rationalisation of the growth factors. The selected HEP in HA13 has an associated catchment area of 18.65km². Because of the small number of HEPs in HA11 & HA13, no further rationalisation of growth curves were considered. Figure 5.6 shows the spatial distribution of all HEPs on the modelled watercourses in HA12.

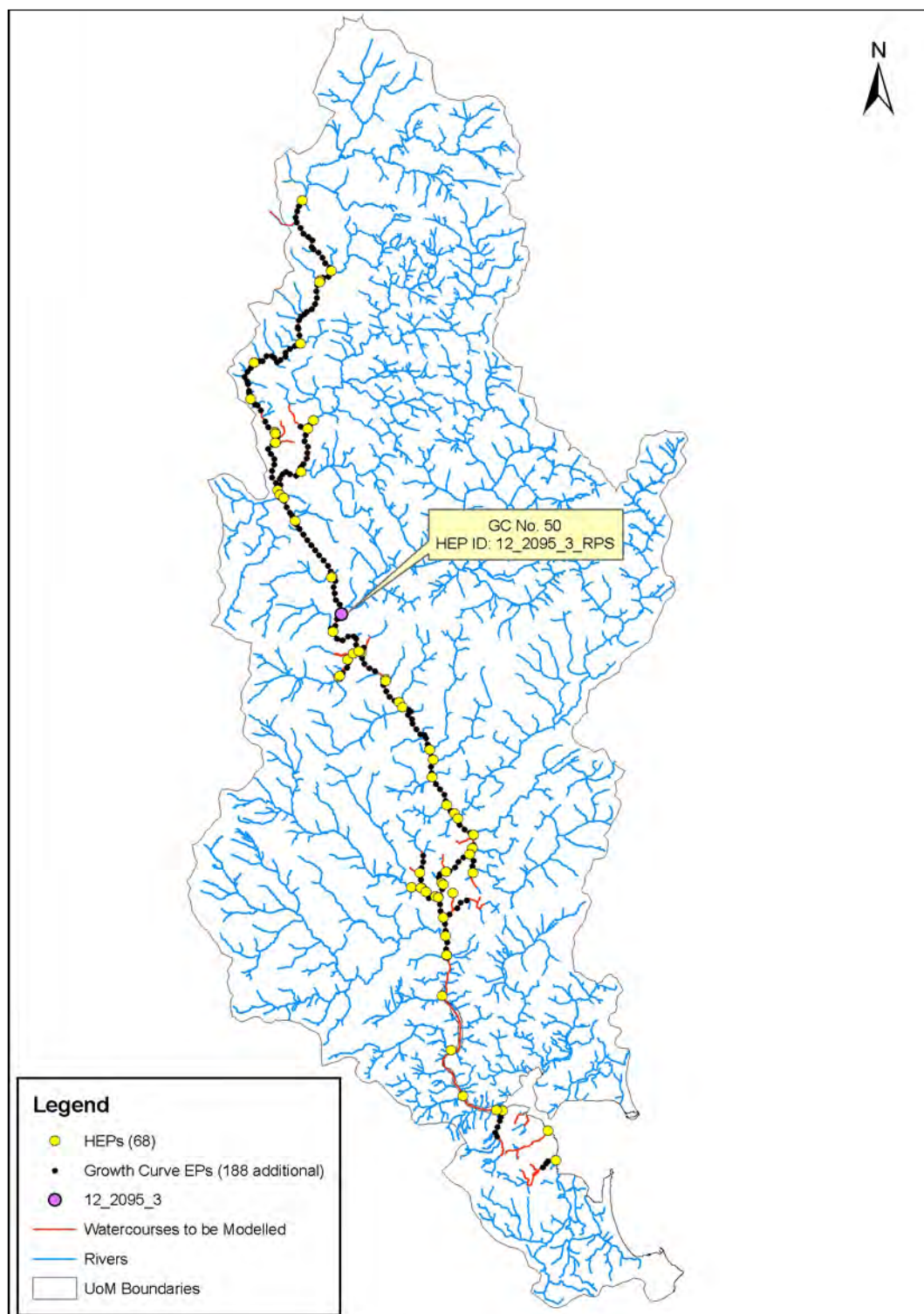


Figure 5.6: Spatial distribution of the HEPs on the modelled watercourses in HA11, 12 and 13

5.6 POOLING REGION AND GROUP FOR GROWTH CURVE ESTIMATION

5.6.1 Pooling Region

Based on the similarity of climatic characteristics, it has been decided that the AMAX series from both the Eastern and South-eastern CFRAM study areas and also from the hydrometric area 06 (HA06 – Newry, Fane, Glyde and Dee) will be pooled to form a pooling group for growth curve estimation for HA11, 12 and 13. (The similarity in the hydrological and physiographic characteristics was taken into account in the dij value calculation when records were pooled from the selected pooling region). The pooling region for this study therefore covers the eastern and south-eastern parts of Ireland. Figure 5.1 illustrates the extent of the pooling region. A summary of the statistical properties of all AMAX series and their associated catchment characteristics is presented in Table 5.3 and 5.2 respectively.

The values of AREA, SAAR and BFI encountered in the subject HEPs are summarised by their minimum, maximum, average and median values in Table 5.5.

Comparison of these with the histograms of AREA, SAAR and BFI for the 92 stations selected for pooling purposes (Figure 5.2 to Figure 5.4) show a good overlap, which indicates that the 92 stations provide good coverage for the range of catchments encountered in the HEPs in HA11, 12 and 13.

5.6.2 Pooling Group

Pooling groups can be formed on the basis of geographical proximity to the subject site. However in the UK FEH study (1999) it was found that such pooling groups were less homogeneous than those formed by Region of Influence (ROI) approach of the type proposed by Burn (1990). The ROI approach selects stations, which are nearest to the subject site in catchment descriptor space, to form the pooling group for that subject site. The FSU approach uses a distance measure in terms of three catchment descriptors of AREA, SAAR and BFI to form a pooling group. The recommended distance measure in the FSU studies is:

$$d_{ij} = \sqrt{1.7 \left(\frac{\ln AREA_i - \ln AREA_j}{\sigma_{\ln AREA}} \right)^2 + \left(\frac{\ln SAAR_i - \ln SAAR_j}{\sigma_{\ln SAAR}} \right)^2 + 0.2 \left(\frac{BFI_i - BFI_j}{\sigma_{BFI}} \right)^2} \quad (5.1)$$

Where i is the subject site and j=1,2,...,M are the donor sites.

In this study, the pooling group was formed based on the above distance measure. The size of the pooling groups was determined based on the FEH recommended 5T rules (i.e. the total number of station-years of data to be included when estimating the T-year flood should be at least 5T). The donor sites associated with this pooling group size are selected based on the lowest distance measures among the available gauging sites in the pooling region. Individual pooling groups have been developed and growth curve have been estimated for every HEP. However, the estimated pooled growth factors/curves have been generalised further based on a range of catchment sizes as discussed later in Section 5.8.2.

5.7 GROWTH CURVE ESTIMATION

5.7.1 Choice of Growth Curve Distributions

In the ‘index-flood’ method one of the major assumptions is that the frequency distributions at different sites in the pooled group are identical apart from a scale factor, which is the median flow (Q_{med}).

As discussed in Section 5.4, the three-parameter GEV and GLO distributions were found to be the better suited distribution for most of the 92 AMAX series than the two-parameter distributions. Furthermore, it can be seen from the L-moment ratio diagram for these 92 AMAX series as shown in Figure 5.7 that the GEV distribution is providing better fits than the GLO distribution, since the theoretical values of the GEV distribution’s L-Skewness and L-Kurtosis pass centrally through the observed L-moments ratios of the 92 AMAX series.

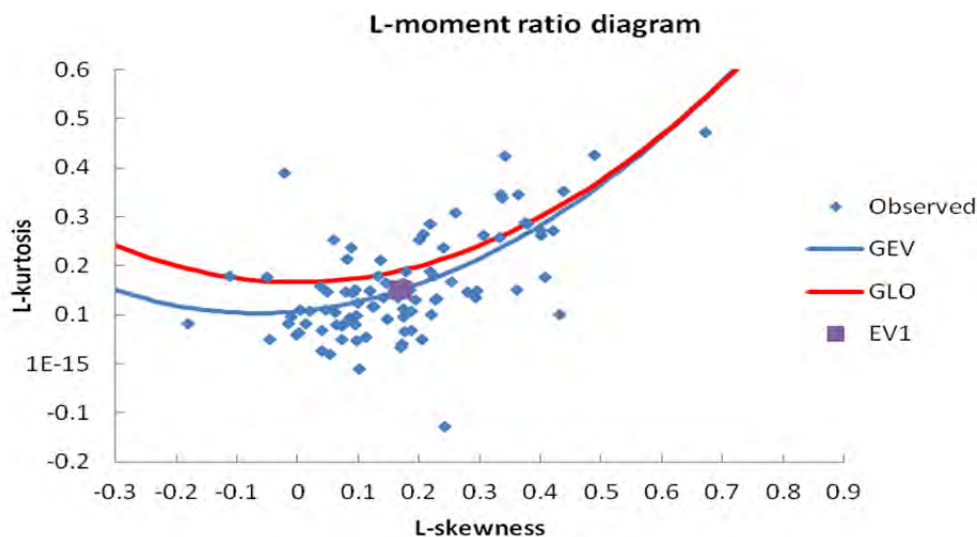


Figure 5.7: L-moment ratio diagram (L-skewness versus L-kurtosis)

Based on the above, the GEV distribution can be adopted as the best candidate distribution for the regional growth curves for the subject river catchments in HA11, HA12 & HA13. However, since the probability plots show that the GLO distribution is also suitable, this distribution is also considered as a candidate distribution for the regional growth curve estimation. Although the two-parameter distributions exhibit more bias in the regional flood frequency estimates as compared to the three-parameter distributions, the two-parameter EV1 distribution is also used in the growth curve estimation process for comparison purposes and to replace the GEV or GLO growth curve when the shape displayed by either of these two distributions is concave downward in order to avoid potential underestimation of extreme event growth factors.

5.7.2 Estimation of Growth Curves

The algebraic equations of the EV1, GEV and GLO growth curves and associated parameters are given below:

EV1 distribution:

$$\text{Growth Curve: } x_T = 1 + \beta(\ln(\ln 2) - \ln(-\ln(1 - 1/T))) \quad (5.2)$$

$$\text{Parameter: } \beta = \frac{t_2}{\ln 2 - t_2[\gamma + \ln(\ln 2)]} \quad (5.3)$$

where, t_2 is the L-coefficient of variation (L-CV) and γ is Euler's constant = 0.5772.

GEV distribution:

$$\text{Growth Curve: } x_T = 1 + \frac{\beta}{k} \left((\ln 2)^k - \left(\ln \frac{T}{T-1} \right)^k \right), \quad k \neq 0 \quad (5.4)$$

The parameters k and β are estimated from sample t_2 =L-CV and sample t_3 =L-skewness as follows:
[Hosking & Wallis (1997, p.196)]

$$k = 7.8590c + 2.9554c^2 \text{ where } c = \frac{2}{3+t_3} - \frac{\ln 2}{\ln 3} \quad (5.5)$$

$$\beta = \frac{kt_3}{t_2(\Gamma(1+k) - (\ln 2)^k) + \Gamma(1+k)(1 - 2^{-k})} \quad (5.6)$$

GLO distribution:

$$\text{Growth Curve: } x_T = 1 + \frac{\beta}{k} (1 - \{T-1\}^{-k}), \quad k \neq 0 \quad (5.7)$$

The parameters k and β are estimated from sample t_2 =L-CV and sample t_3 =L-skewness as follows
[Hosking & Wallis (1997, p.197)]:

$$k = -t_3 \text{ and } \beta = \frac{kt_2 \sin(\pi k)}{k\pi(k+t_2) - t_2 \sin(\pi k)} \quad (5.8)$$

The pooled regional values of the t_2 (L-CV) and t_3 (L-skewness) have been estimated as the weighted average values of corresponding at-site sample values weighted by the at-site record lengths. These values were equated to the expressions for these quantities written in terms of the distribution's unknown parameters as given above and the resulting equations are solved for the unknown parameters.

5.7.3 Examination of Growth Curve Shape

Growth curves for all of the selected HEPs within HA11, HA12 & HA13 for a range of Annual Exceedance Probabilities (AEPs) were estimated in accordance with the above methodologies. An examination of the derived shapes of the growth curves showed that, because of the fixed shape distribution, the EV1 growth curves are of straight-line type for all HEPs, while in the GEV and GLO distribution cases growth curves take either the concave upwards (upward bend) or concave downwards (downward bend) shapes based on the skewness of the pooled group. In the GEV distribution case, out of 68 curves in HA12, 29 showed concave downward shape, 19 showed concave upward shape and 20 showed almost a straight line; while in the GLO distribution case, all 68 curves showed the concave upward shape (Table 5.8). In HA11, 11 out of 13 GEV growth curves showed concave upward and the remaining two showed concave downward shape. The HA13 GEV growth curve showed a concave upward shape curve. All GLO growth curves within HA11 & HA13 are of concave upward shape.

Table 5.8: Growth curves shape summary

| Distribution | Growth Curve Shape |
|--------------|---|
| EV1 | All straight lines |
| GEV | 46 - convex upward 76 – concave upward 24 – straight line |
| GLO | All concave upward |

An assessment of the suitability of the above three growth curve distributions was carried out by examining the suitability of these distributions in fitting the AMAX series in the pooling groups associated with all HEPs in HA11, HA12 & HA13. In other words, for a particular HEP, the pooled growth curves, based on EV1, GEV and GLO, were superimposed on the standardised probability plots of the AMAX series which form the pooling group (typically 10 to 12 such series). A visual comparison of the suitability of the growth curves was made and recorded, as done in Figure 5.8 for example, for HEP No. 50 of the 68 HEPs selected for the growth curve analysis in HA12. The HEP No. 50 was selected to illustrate the composition of one pooling group.

In estimating the pooled growth curve for HEP/Growth Curve No.50, 508 station-years of records from 11 sites were pooled. Figure 5.6 shows the location of this HEP. Table 5.9 shows the catchment characteristics, statistical properties and estimated distance measures for each of the sites from the subject HEP.

Table 5.9: Catchment descriptors for all pooled sites for Growth curve No. 50 in HA12

| Hydrometric stations | Record length (years) | AREA (km ²) | SAAR (mm) | BFI | Qmean (m ³ /s) | Specific Qmean (m ³ /s/km ²) | L-CV | L-skew | L-kur | dij |
|--|-----------------------|-------------------------|----------------|--------------|---------------------------|---|---------------|---------------|-------|-------|
| 06011 | 51 | 229.19 | 1028.98 | 0.708 | 15.91 | 0.069 | 0.110 | 0.075 | 0.080 | 0.372 |
| 06012 | 53 | 162.8 | 1046.24 | 0.680 | 15.27 | 0.094 | 0.169 | 0.173 | 0.112 | 0.418 |
| 07011 | 49 | 281.74 | 1003.32 | 0.678 | 26.71 | 0.095 | 0.245 | 0.175 | 0.096 | 0.479 |
| 07004 | 53 | 245.74 | 1007.88 | 0.619 | 19.82 | 0.081 | 0.149 | 0.159 | 0.151 | 0.521 |
| 15007 | 35 | 339.76 | 1123.04 | 0.594 | 46.53 | 0.137 | 0.098 | -0.112 | 0.180 | 0.530 |
| 15004 | 56 | 491.38 | 1067.46 | 0.594 | 37.13 | 0.076 | 0.158 | 0.118 | 0.150 | 0.723 |
| 16010 | 38 | 437.1 | 985.24 | 0.624 | 44.76 | 0.102 | 0.117 | 0.061 | 0.105 | 0.792 |
| 16003 | 56 | 243.2 | 1192.01 | 0.550 | 30.94 | 0.127 | 0.093 | 0.220 | 0.100 | 0.839 |
| 14003 | 27 | 206.73 | 1160.51 | 0.532 | 33.71 | 0.163 | 0.112 | 0.046 | 0.109 | 0.843 |
| 06014 | 35 | 270.38 | 927.45 | 0.634 | 22.30 | 0.082 | 0.143 | 0.227 | 0.130 | 0.950 |
| 16004 | 55 | 228.74 | 941.36 | 0.579 | 21.84 | 0.095 | 0.122 | 0.085 | 0.093 | 0.972 |
| Subject site (Growth Curve EP-50) | - | 246.67 | 1086.51 | 0.673 | - | - | 0.140* | 0.120* | - | - |

*Pooled regional values

It can be seen from the above table that the subject site's catchment characteristics are well placed within the pooled sites' catchment descriptor space. The subject site has an upstream catchment area of 246.67 km², SAAR and BFI values of 1086.51 mm and 0.673 respectively which are located approximately at the median locations of the pooled sites' corresponding values.

The estimated pooled average L-CV and L-Skewness are 0.140 and 0.120 respectively. This suggests that the pooled growth curve would follow a distribution which has L-Skewness slightly less than that of the EV1 distribution (0.167). Figure 5.8 shows the estimated EV1, GEV and GLO growth curves for the growth curve No. 50. The GEV growth curve is a convex upward shaped curve while the GLO one is a concave upward shaped curve.

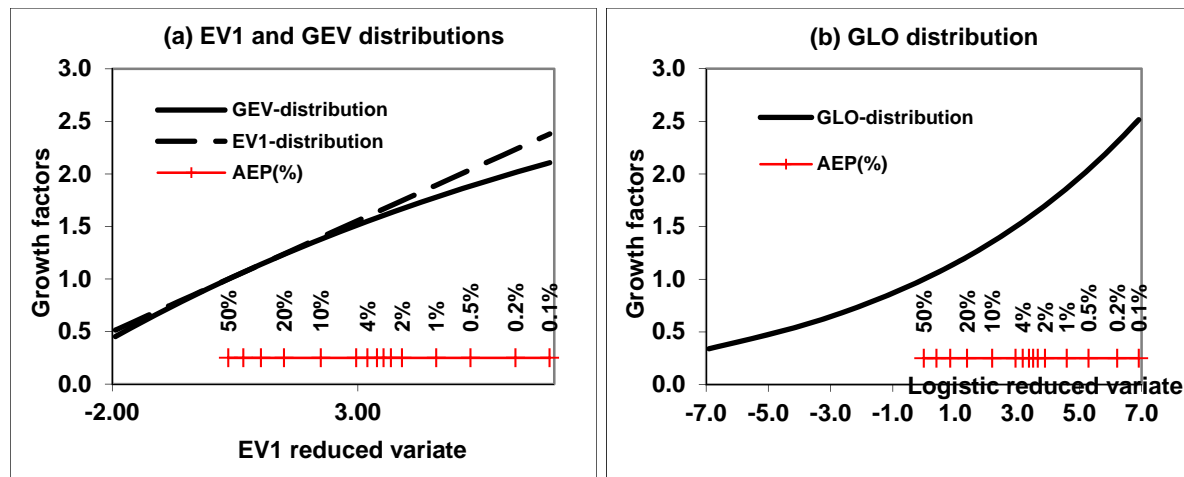


Figure 5.8: Pooled Growth Curve No. 50 in HA12 - (a) EV1 and GEV distributions; (b) GLO distributions

An assessment of the at-site GEV and GLO growth curves was carried out through a visual inspection of their individual probability plots. A summary of this assessment is provided Table 5.10.

Table 5.10: Frequency curve shapes of the individual site's AMAX series associated with the pooled group No. 50 in HA12

| Hydrometric stations | Individual at-site growth curves | | |
|----------------------|----------------------------------|-------------------------|---|
| | GEV (EV1y Plot) | GLO (Loy Plot) | Comparison of performances (visual) |
| 06011 | Straight line | Mild concave upward | Both fit equally well to the observed records |
| 06012 | Mild concave upward | Moderate concave upward | GLO fits slightly better |
| 07011 | Straight line | Moderate concave upward | GLO fits slightly better |
| 07004 | Straight line | Mild concave upward | GLO fits slightly better |
| 15007 | Moderate concave downward | Mild concave downward | GLO fits slightly better |
| 15004 | Mild concave downward | Mild concave upward | Both fit equally well to the observed records |
| 16010 | Mild concave downward | Mild concave upward | Both fit equally well to the observed records |
| 16003 | Mild concave upward | Mild concave upward | Both fit equally well to the observed records |
| 14003 | Mild concave downward | Mild concave upward | GEV fits slightly better |
| 06014 | Mild concave upward | Mild concave upward | Both fit equally well to the observed records |
| 16004 | Mild concave downward | Mild concave upward | GLO fits slightly better |

This assessment shows that both the GEV and GLO distributions fit the observed at-site records quite well at all eleven sites with a slightly better performance by the GLO distribution. In the case of GEV distribution five sites showed concave downward shaped curves (mild to moderate), two concave upward and four sites showed straight lines. While in the GLO distribution case, ten showed concave upward and the remaining site showed concave downward shaped curve. This suggests that, the shape of the pooled growth curves in the case of GEV distribution can be expected as concave downward while for the GLO distribution case it would be concave upward. Similar results were also found in the case of the HA11 & HA13 growth curves.

Table 5.11 shows the estimated growth factors for a range of AEPs for Growth Curve No. 50. The estimated 1% AEP growth factors for the EV1, GEV and GLO distributions are 1.894, 1.780 and 1.863 respectively.

Table 5.11: Estimated growth factors for Growth Curve No. 50 in HA12

| AEP (%) | EV1 | GEV | GLO |
|---------|-------|-------|-------|
| 50 | 1.000 | 1.000 | 1.000 |
| 20 | 1.239 | 1.235 | 1.212 |
| 10 | 1.398 | 1.380 | 1.354 |
| 5 | 1.550 | 1.510 | 1.497 |
| 2 | 1.746 | 1.669 | 1.698 |
| 1 | 1.894 | 1.780 | 1.863 |
| 0.5 | 2.041 | 1.885 | 2.041 |
| 0.1 | 2.381 | 2.107 | 2.515 |

5.7.4 Recommended Growth Curve Distribution for HA 11, 12, 13

The following factors were considered to select an appropriate growth curve distribution for the subject river catchments within HA11, HA12 & HA13:

Suitability of a distribution in fitting the individual at-site records,

- (i) No. of distribution parameters, and
- (ii) Shape of the pooled growth curve

A visual examination of the at-site frequency curves for all 92 gauging sites showed that the AMAX series for most of these sites can be described slightly better by the GLO distribution than by the EV1 and GEV distributions.

The number of distribution parameters also plays an important role in deriving an appropriate growth curve. The fixed skewness two-parameter distributions generally suffer from large biases, particularly at the upper tail of the distribution. The three-parameter distributions, in contrast, suffer from larger standard error though they are less biased. However this standard error is generally reduced by the pooled estimation process. The use of two-parameter distributions such as the Gumbel distribution is not therefore recommended in regional frequency analysis (Hosking and Wallis, 1996). The use of a two-parameter distribution is beneficial only if the investigator has complete confidence that the 'at site' distribution's L-Skewness and L-kurtosis are close to those of the frequency distributions. As discussed in Section 5.7.1, the L-CV and L-Skewness of most of the sites in the Pooling Region differ from those of the theoretical values of the EV1 distribution. This suggests that a three-parameter distribution would be more appropriate to describe the growth curves for the subject watercourses within HA11 (Owenavorrach), HA12 (Slaney and Wexford Harbour) and HA13 (Ballyteigue-Bannow).

The shape of the growth curve also plays an important role in the design and operation of the flood management scheme for a river catchment. It is generally not considered appropriate to have a growth curve concave downward shape. A significant number of the GEV growth curves showed concave downward shape (29 out of 68 in HA12, 2 out of 23 in HA11). In contrast, all GLO growth curves in all HAs are of concave upward shape.

The estimated 1%-AEP GLO growth factor is slightly greater than the GEV growth factor, for almost all growth curves by an amount of 0.1 to 5% (see Table 5.11 for growth curve No. 50 for HA12). This is largely due to the concavity noted above. Figure 5.9 shows a comparison of the GEV, GLO and EV1 growth curves for growth curve No. 50 in HA12, all plotted in the EV1 probability plot. Similar results were found in the cases of HA11 & HA12 river catchments.

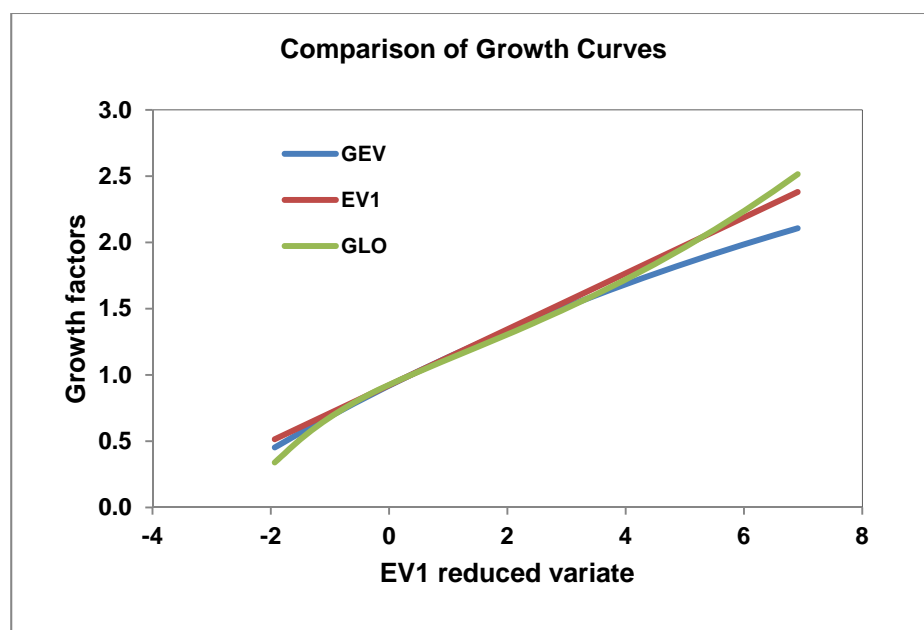


Figure 5.9: Comparison of EV1, GEV and GLO growth curves on the EV1-y probability plot (Growth Curve No. 50 in HA12)

Based on the above, it is recommended to adopt the GLO distribution derived concave upward shape growth curves for the subject river catchments within HA11, HA12 & HA13. Figure 5.10 shows the estimated 68 GLO growth curves for the Slaney River catchment (HA12), while Figure 5.11 shows the estimated GLO growth curves associated with the 13 HEPs in HA11 and Figure 5.12 shows corresponding growth curve for the selected HEP in HA13.

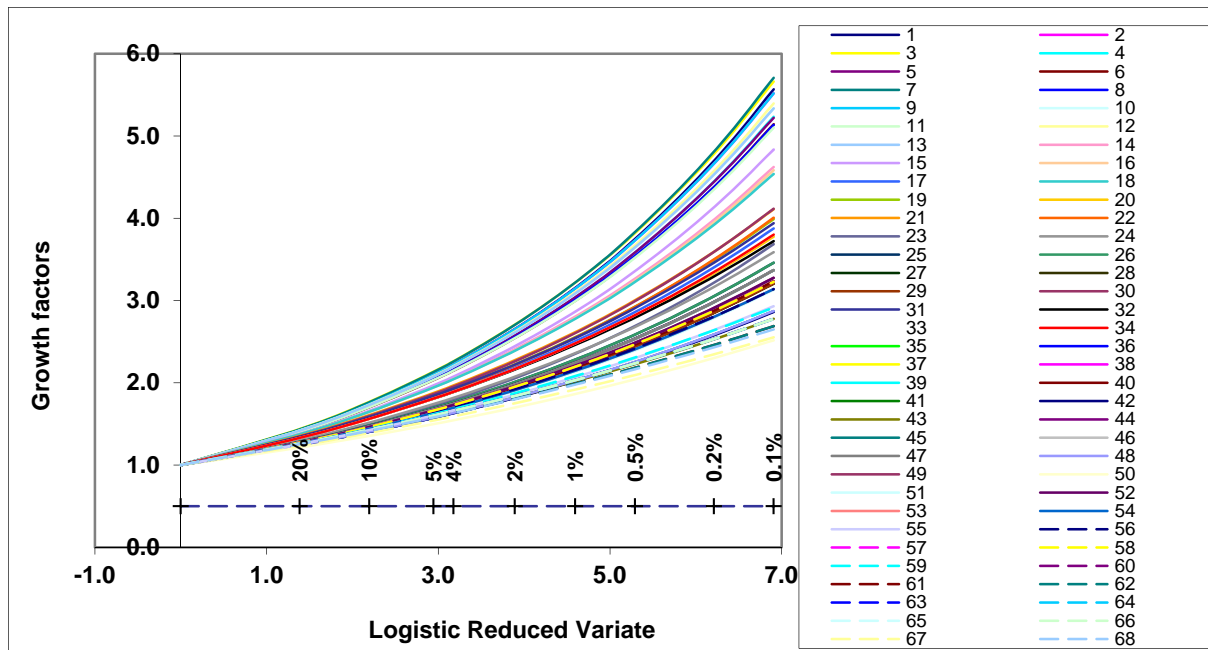


Figure 5.10: GLO growth curves for 68 HEPs in the Slaney River catchment (HA12)

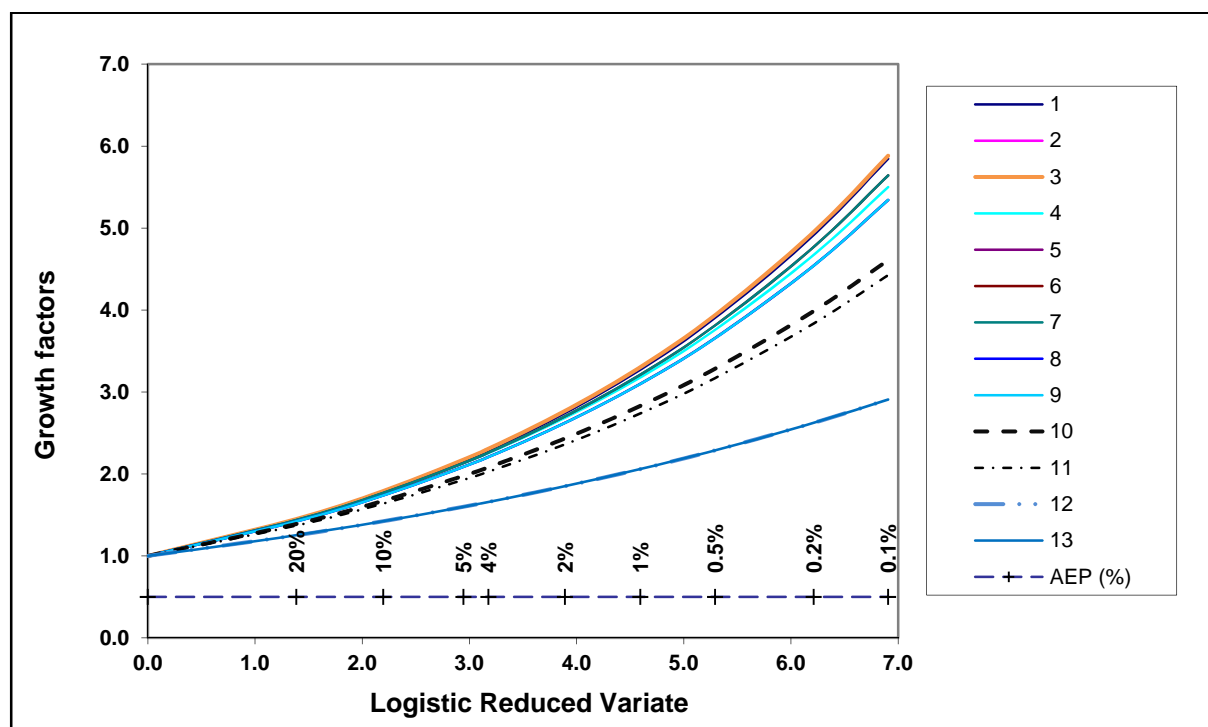


Figure: 5.11: GLO growth curves for 23 HEPs within HA11

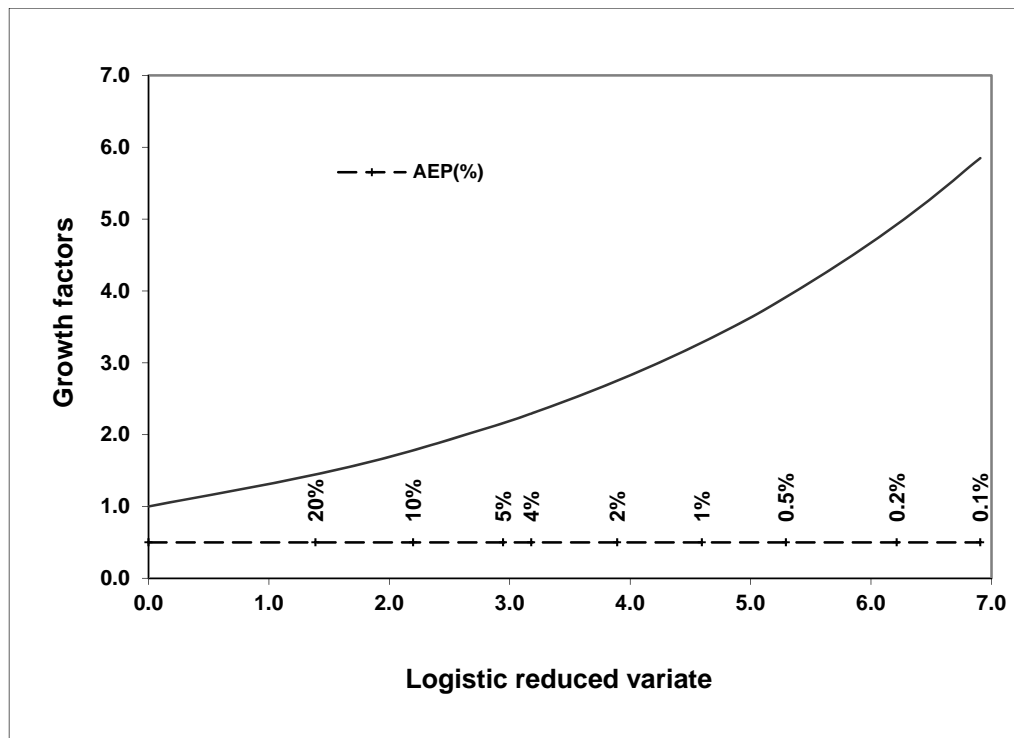


Figure 5.12: GLO growth curve for HA13

5.8 RATIONALISATION OF GROWTH CURVES

5.8.1 Relationship of Growth Factors with Catchment Characteristics

In order to reduce the number of growth curves to a practicable number, the relationship between the estimated growth factors for a range of AEPs and the relevant catchment descriptors were examined. The catchment descriptors used were the AREA, SAAR and BFI. Figures 5.13, 5.14 & 5.15 show the variations of growth factors with AREA, SAAR and BFI respectively for all 68 HEPs within HA12. Because of the small number of HEPs in HA11 & HA13, no rationalisation of growth curves were considered. In these cases, the estimated individual GLO growth curve for each HEP was recommended to use as the design growth curves.

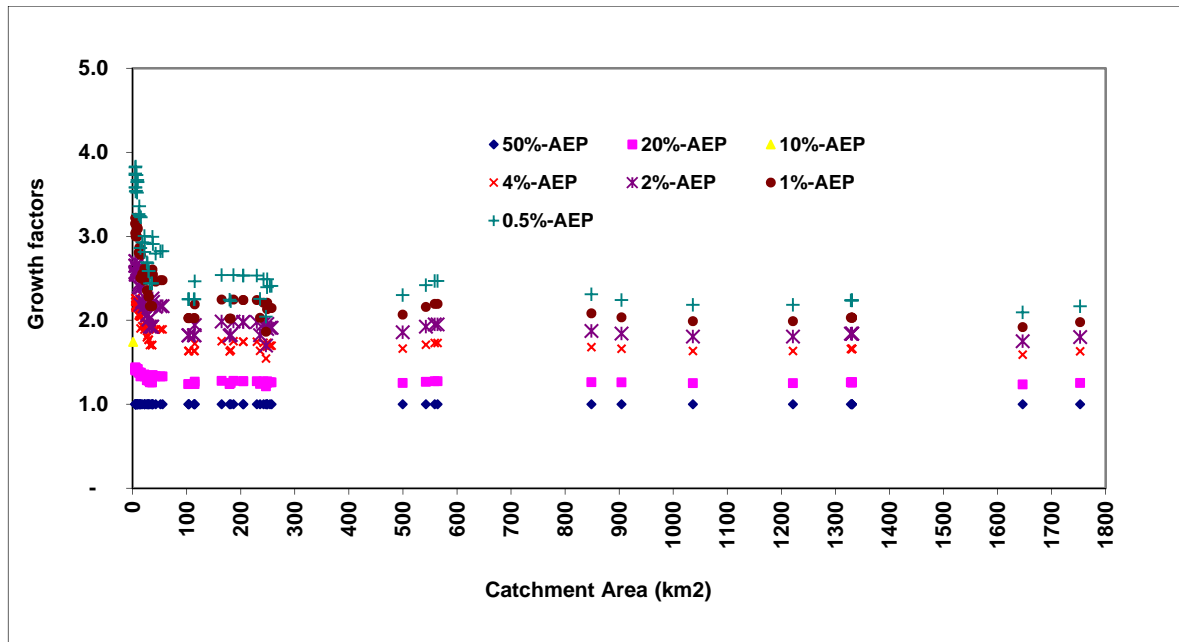


Figure 5.13: Relationship of growth factors with catchment areas for 68 HEPs in HA12

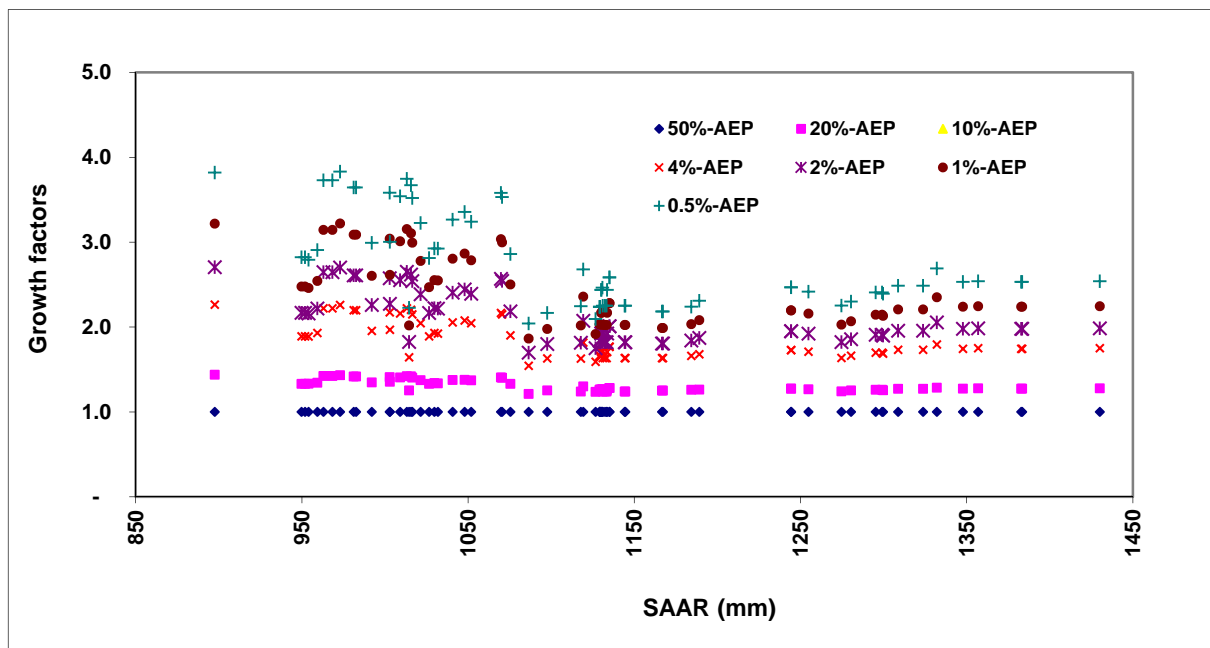


Figure 5.14: Relationship of growth factors with SAAR for 68 HEPs in HA12

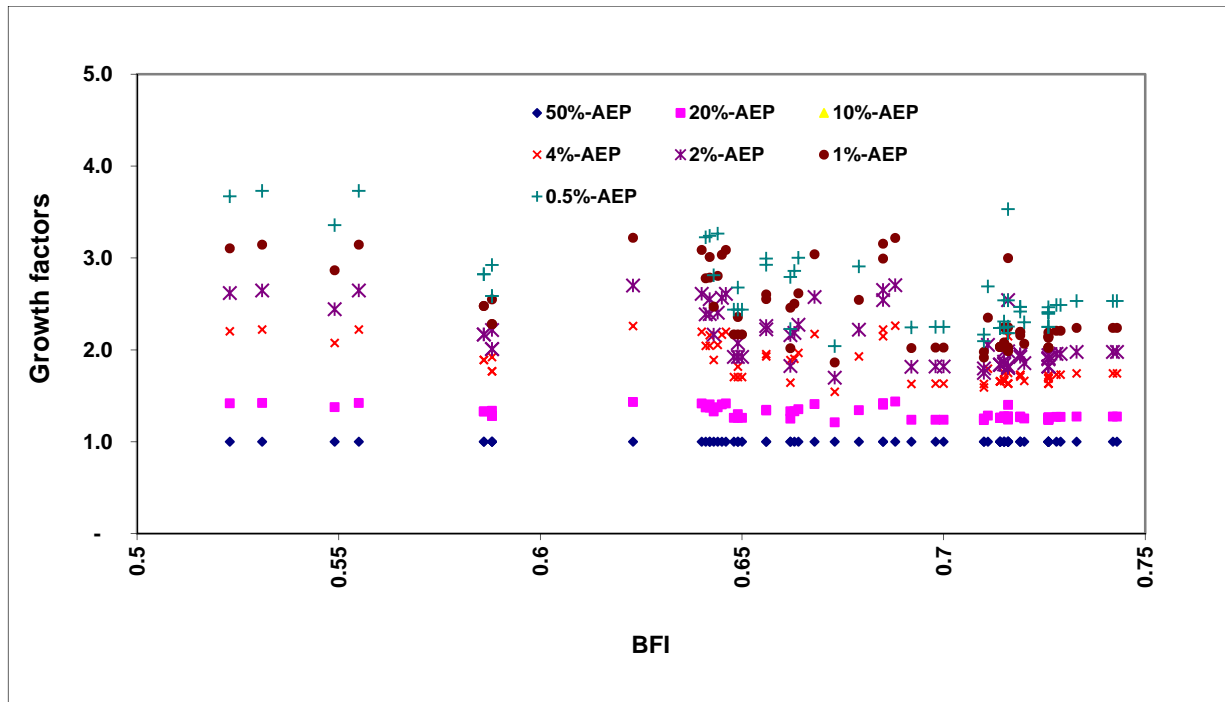


Figure 5.15: Relationship of growth factors with BFI for 68 HEPs in HA12

It can be seen from the above figures that the growth factors generally increase with a decrease in catchment sizes. However this rate of increase is larger for the catchment areas less than 300 km² and also for the larger AEPs growth factors. This can be attributed to the smaller upland catchment areas where catchment response time is shorter and where no flow attenuation is available. For the larger catchments flow attenuation is generally provided by lakes and wider downstream channels. For catchment areas larger than 850 km² the growth factors do not change noticeably with the further increase in catchment area. No particular patterns in the relationships of the growth factors with the SAAR and BFI values were found.

5.8.2 Generalised Growth Curves

Based on the findings discussed in Section 5.8.1, growth curves for the subject river catchments within HA12 were further generalised based on catchment size. To examine further the relationship of the catchment size with the growth factors and also to generalise the growth factor estimates, an additional 188 growth curve estimation points with various catchment sizes were selected on the modelled watercourses. Figure 5.6 shows the spatial distribution of these points. The catchment physiographic and climatic characteristics data associated with these additional growth curve estimation points were obtained from the OPW.

Figure 5.16 shows the variation of the estimated growth factors for a range of AEPs and catchment sizes for all 256 HEPs (68 HEPs plus 188 additional points). Similar catchment size-growth factor relationships were found in this case as were found in the 68 HEPs case. It can be seen from this figure that the growth factors for catchment areas greater than 900 km² do not change appreciably with

the increase in catchment sizes. However, the variations in growth factors for the smaller catchment sizes are very significant.

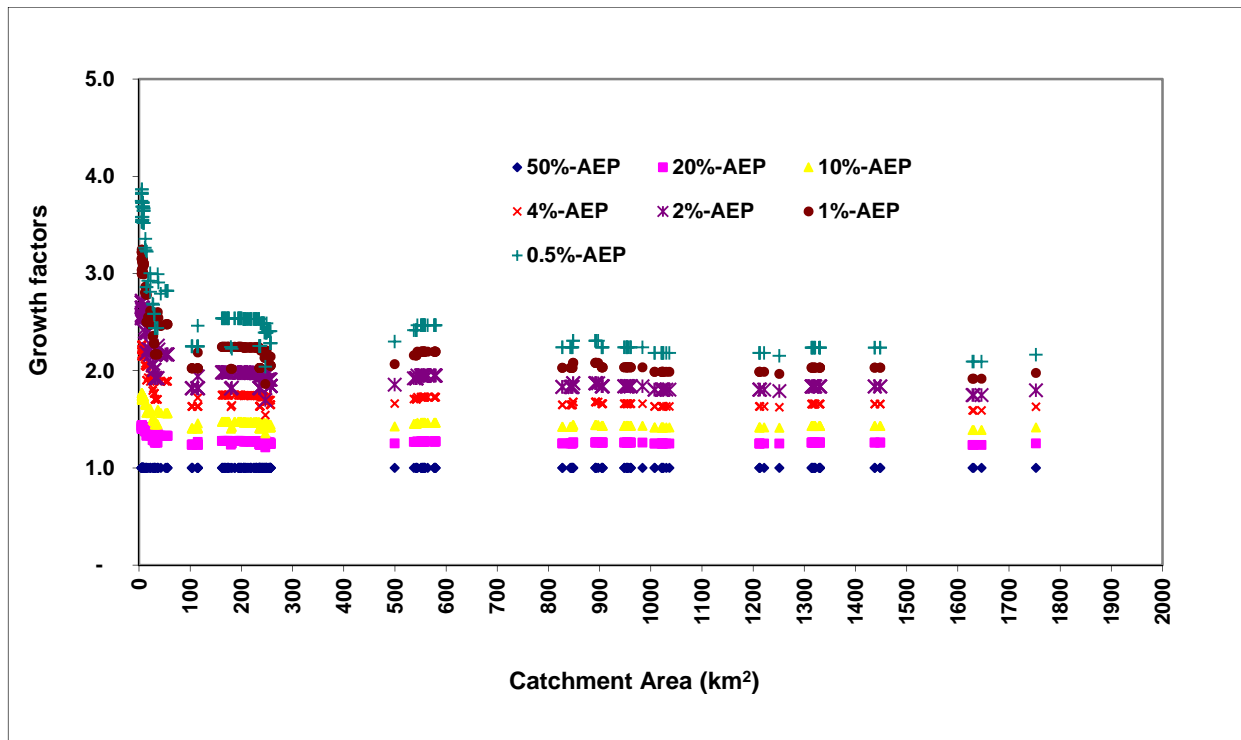


Figure 5.16: Relationship of growth factors with catchment areas (for 256 growth curve estimation points in HA12)

As a result of the above growth curves are generalised based on ranges of catchment size as shown below:

1. AREA < 10 km²
2. 10 < AREA ≤ 25 km²
3. 25 < AREA ≤ 50 km²
4. 100 < AREA ≤ 150 km²
5. 150 < AREA ≤ 200 km²
6. 200 < AREA ≤ 400 km²
7. 400 < AREA ≤ 800 km²
8. 800 < AREA ≤ 1200 km²
9. 800 < AREA ≤ 1200 km²

Table 5.12 shows the estimated average and median growth factors for the above nine categories of growth curves along with their associated group standard deviations for a range of AEPs. The number of HEPs used for the standard deviation calculation in each of the catchment size categories is presented in column 2.

Table 5.12: Growth curve estimation summary

| Catchment size range | No of HEPs in size range | | Growth factors | | | | | | | | |
|--------------------------------------|--------------------------|-----------------------|----------------|-------|-------|-------|-------|-------|-------|-------|-------|
| | | AEP (%) | 50% | 20% | 10% | 5% | 2% | 1% | 0.50% | 0.20% | 0.10% |
| | | Return Period (years) | 2 | 5 | 10 | 20 | 50 | 100 | 200 | 500 | 1000 |
| 1. AREA < 10 km ² | 35 | Average | 1.000 | 1.417 | 1.731 | 2.078 | 2.615 | 3.099 | 3.664 | 4.565 | 5.385 |
| | | Median | 1.000 | 1.418 | 1.733 | 2.081 | 2.619 | 3.104 | 3.670 | 4.572 | 5.394 |
| | | St. dev | 0.000 | 0.012 | 0.022 | 0.035 | 0.058 | 0.081 | 0.110 | 0.160 | 0.210 |
| | | | | | | | | | | | |
| 2. 10 < AREA <= 25 km ² | 10 | Average | 1.000 | 1.352 | 1.607 | 1.880 | 2.287 | 2.642 | 3.047 | 3.670 | 4.220 |
| | | Median | 1.000 | 1.347 | 1.595 | 1.858 | 2.248 | 2.584 | 2.964 | 3.546 | 4.057 |
| | | St. dev | 0.000 | 0.021 | 0.040 | 0.065 | 0.107 | 0.150 | 0.203 | 0.294 | 0.383 |
| | | | | | | | | | | | |
| 3. 25 < AREA <= 50 km ² | 13 | Average | 1.000 | 1.289 | 1.494 | 1.712 | 2.032 | 2.307 | 2.616 | 3.086 | 3.496 |
| | | Median | 1.000 | 1.281 | 1.481 | 1.694 | 2.009 | 2.280 | 2.585 | 3.052 | 3.459 |
| | | St. dev | 0.000 | 0.032 | 0.055 | 0.080 | 0.117 | 0.150 | 0.189 | 0.249 | 0.303 |
| | | | | | | | | | | | |
| 4. 50 < AREA <= 150 km ² | 14 | Average | 1.000 | 1.274 | 1.465 | 1.664 | 1.953 | 2.198 | 2.470 | 2.877 | 3.227 |
| | | Median | 1.000 | 1.240 | 1.405 | 1.575 | 1.820 | 2.025 | 2.250 | 2.584 | 2.868 |
| | | St. dev | 0.000 | 0.044 | 0.076 | 0.113 | 0.169 | 0.220 | 0.278 | 0.371 | 0.453 |
| | | | | | | | | | | | |
| 5. 150 < AREA <= 200 km ² | 27 | Average | 1.000 | 1.275 | 1.468 | 1.673 | 1.972 | 2.228 | 2.516 | 2.951 | 3.328 |
| | | Median | 1.000 | 1.277 | 1.473 | 1.680 | 1.984 | 2.245 | 2.538 | 2.983 | 3.369 |
| | | St. dev | 0.000 | 0.009 | 0.017 | 0.027 | 0.044 | 0.060 | 0.081 | 0.115 | 0.147 |
| | | | | | | | | | | | |

| Catchment size range | No of HEPs in size range | | Growth factors | | | | | | | | |
|---|--------------------------|-----------------------|----------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|
| | | AEP (%) | 50% | 20% | 10% | 5% | 2% | 1% | 0.50% | 0.20% | 0.10% |
| | | Return Period (years) | 2 | 5 | 10 | 20 | 50 | 100 | 200 | 500 | 1000 |
| 6. 200 < AREA ≤ 400 km² | 65 | Average | 1.000 | 1.264 | 1.449 | 1.644 | 1.929 | 2.172 | 2.443 | 2.853 | 3.207 |
| | | Median | 1.000 | 1.271 | 1.462 | 1.663 | 1.956 | 2.207 | 2.487 | 2.909 | 3.275 |
| | | St. dev | 0.000 | 0.012 | 0.022 | 0.034 | 0.054 | 0.073 | 0.097 | 0.135 | 0.171 |
| | | | | | | | | | | | |
| 7. 400 < AREA ≤ 800 km² | 26 | Average | 1.000 | 1.271 | 1.459 | 1.656 | 1.942 | 2.183 | 2.451 | 2.853 | 3.198 |
| | | Median | 1.000 | 1.273 | 1.463 | 1.662 | 1.951 | 2.195 | 2.467 | 2.875 | 3.226 |
| | | St. dev | 0.000 | 0.004 | 0.008 | 0.013 | 0.021 | 0.028 | 0.037 | 0.051 | 0.065 |
| | | | | | | | | | | | |
| 8. 800 < AREA ≤ 1200 km² | 41 | Average | 1.000 | 1.258 | 1.428 | 1.599 | 1.837 | 2.031 | 2.239 | 2.539 | 2.787 |
| | | Median | 1.000 | 1.258 | 1.428 | 1.599 | 1.837 | 2.031 | 2.239 | 2.539 | 2.787 |
| | | St. dev | 0.000 | 0.005 | 0.009 | 0.013 | 0.021 | 0.029 | 0.040 | 0.056 | 0.072 |
| | | | | | | | | | | | |
| 9. AREA > 1200 km² | 25 | Average | 1.000 | 1.255 | 1.421 | 1.588 | 1.819 | 2.006 | 2.205 | 2.490 | 2.724 |
| | | Median | 1.000 | 1.260 | 1.430 | 1.601 | 1.839 | 2.031 | 2.237 | 2.532 | 2.775 |
| | | St. dev | 0.000 | 0.008 | 0.014 | 0.020 | 0.031 | 0.039 | 0.050 | 0.065 | 0.079 |

It can be seen from this that the standard deviations in the 1% AEP growth factors in these catchment size categories range from 2.8% to 22%. The highest variations were found in the catchment size categories of 2, 3, 4 and 5. Hence, it is recommended that the growth factors for all HEPs with catchment sizes falling in these catchment area categories (i.e. from 10 to 200 km²) be estimated from the separate growth curve estimation process. In other words, separate growth curves should be estimated for all HEPs with the catchment areas falling in range of 10 to 200 km². All HEPs with catchment areas less than 10 km² are considered to have the same growth curve. For the remaining categories the median growth curves will be used.

Thus for the study catchments the above mentioned nine categories of catchment size have been reduced to six categories (hereafter called Growth Curve Groups) as presented in Table 5.13. The estimated growth curve types in each category are also presented in Table 5.13.

Table 5.13: Growth Curve (GC) Groups

| Growth Curve Group No. | Catchment size range | Growth curves type / estimation process |
|------------------------|--|---|
| 1 | AREA \leq 10km ² | Use median growth curve |
| 2 | 10 < AREA \leq 200 km ² | Use individual growth curve |
| 3 | 200 < AREA \leq 400 km ² | Use median growth curve |
| 4 | 400 < AREA \leq 800 km ² | Use median growth curve |
| 5 | 800 < AREA \leq 1200 km ² | Use median growth curve |
| 6 | AREA > 1200 km ² | Use median growth curve |

Table 5.14 presents the estimated growth factors for a range of AEPs for each of the above growth curve groups.

Table 5.14: Growth factors for range of AEPs

| GC Group No. | Catchment size range | GLO - Growth factors | | | | | | | | | |
|--------------|--|----------------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|
| | | AEP 50% | AEP 20% | AEP 10% | AEP 5% | AEP 4% | AEP 2% | AEP 1% | AEP 0.5% | AEP 0.2% | AEP 0.1% |
| 1 | AREA \leq 10km ² | 1.000 | 1.418 | 1.733 | 2.081 | 2.203 | 2.619 | 3.104 | 3.670 | 4.572 | 5.394 |
| 2 | 10 < AREA \leq 200 km ² | 1.000 | 1.239 to 1.377 | 1.403 to 1.659 | 1.572 to 1.968 | 1.629 to 2.076 | 1.815 to 2.442 | 2.018 to 2.865 | 2.226 to 3.356 | 3.226 to 3.356 | 2.777 to 4.834 |
| 3 | 200 < AREA \leq 400 km ² | 1.000 | 1.271 | 1.462 | 1.663 | 1.731 | 1.956 | 2.207 | 2.487 | 2.909 | 3.275 |
| 4 | 400 < AREA \leq 800 km ² | 1.000 | 1.273 | 1.463 | 1.662 | 1.729 | 1.951 | 2.195 | 2.467 | 2.875 | 3.226 |
| 5 | 800 < AREA \leq 1200 km ² | 1.000 | 1.258 | 1.428 | 1.599 | 1.655 | 1.837 | 2.031 | 2.239 | 2.539 | 2.787 |
| 6 | AREA > 1200 km ² | 1.000 | 1.260 | 1.430 | 1.601 | 1.658 | 1.839 | 2.031 | 2.237 | 2.532 | 2.775 |

Figure 5.17 shows the estimated growth curves (GLO) for all growth curve groups.

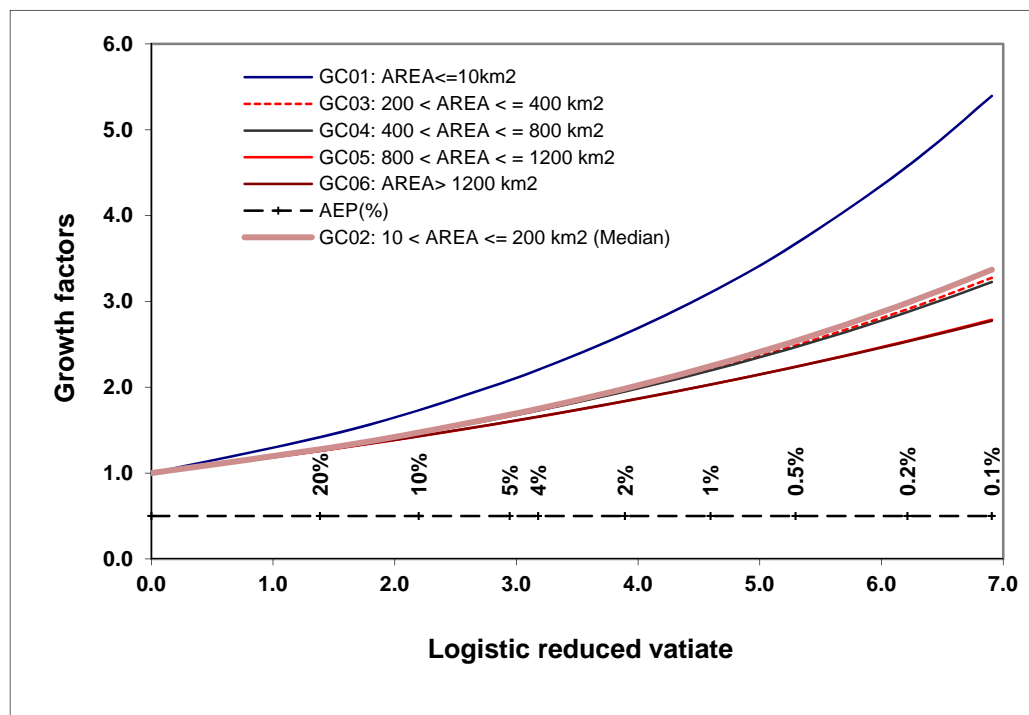


Figure 5.17: GLO growth curves for all Growth Curve Groups (6 No.) – HA12

The uncertainties associated with the above growth curve estimates are expressed in terms of 95% confidence interval of these estimates and were estimated from the following relationship:

$$X_T(95\%ile) = X_T \pm 1.96 \times se(X_T) \quad (5.8)$$

The standard error (se) of the growth curves is estimated in accordance with the FSU recommended methodology.

Table 5.15 presents the estimated standard errors in terms of percentage of the estimated growth factor for a range of AEPs. The upper and lower limits of the confidence interval were estimated using the above mentioned Eq. 5.8. For example, for the GC Group No. 4, the estimated 1%-AEP growth factor is 2.195 and the associated 95% upper and lower confidence limits are 2.410 and 1.980 respectively.

Table 5.15: Estimated percentage standard errors for growth factors (X_T) for a range of AEPs (source FSU Work- Package 2.2 “Frequency Analysis” Final Report – Section 13.3)

| Return periods (years) | Annual Exceedance probabilities (%) | Se (X_T) % |
|------------------------|-------------------------------------|----------------|
| 2 | 50% | 0.60 |
| 5 | 20% | 1.00 |
| 10 | 10% | 1.80 |
| 20 | 5% | 2.77 |
| 25 | 4% | 3.00 |
| 50 | 2% | 3.90 |
| 100 | 1% | 5.00 |
| 200 | 0.5% | 5.94 |
| 500 | 0.2% | 7.30 |
| 1000 | 0.1% | 8.30 |

Figure 5.18 shows the estimated growth curve along with the 95% upper and lower confidence limits for GC Group No. 4.

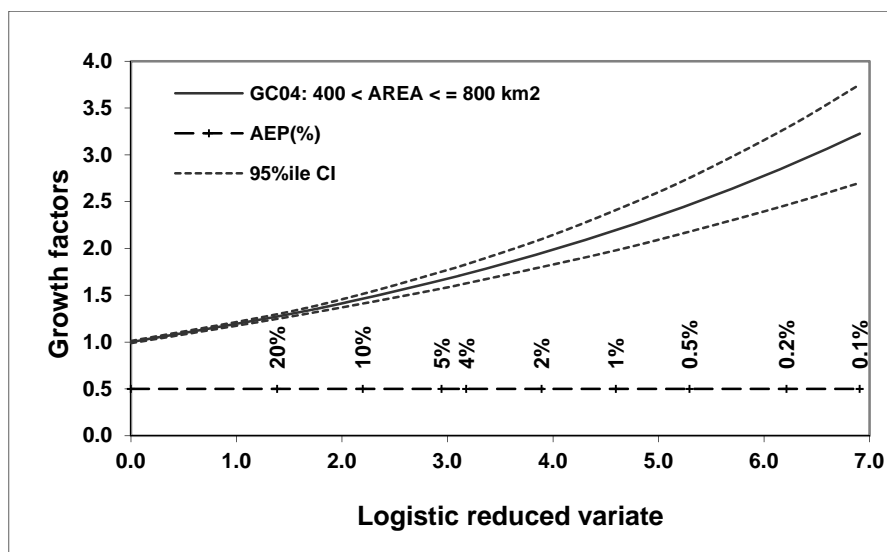


Figure 5.18: Growth Curve for GC Group No. 4 with 95% confidence limits (HA12)

5.8.3 Comparison of the at-site growth curves with the pooled growth curves

The FSU programme recommended that *“in the event that the at-site estimate of Q-T relation is steeper than the pooled one then consideration will have to be given to using a combination of the at-site estimate and the pooled estimate for design flow estimation”*. In light of this, the at-site frequency curves (Q-T) for each of the gauging sites located only on the modelled watercourses in HA11, 12 and 13 were examined and compared with the relevant pooled frequency curves. In the case where the pooled frequency curve is flatter than the at-site curve, the design growth curves/factors should be estimated from the at-site records. If the pooled growth curve is convex upwards then a two parameter distribution should be fitted to the pooled growth curve so as to avoid the upper bound.

Furthermore the FSU study recommended that *“If a very large flood is observed during the period of records the question arises as to whether it should over-ride any more modest estimate of Q_T obtained by a pooling group approach or whether a weighted combination of the pooling group estimate and the at-site estimate should be adopted. If a combination is used the weights to be given to the two components of the combination cannot be specified by any rule based on scientific evidence but must be chosen in an arbitrary, however one would hope a reasonable way.”*

There are three gauging sites located on the modelled river channels within HA12 suitable for use in this analysis, while none of the modelled rivers channels within the HA11 & HA13 are gauged. Table 5.16 shows the hydrometric gauges (10 gauging sites) located on the HA11, 12 and 13 modelled watercourses. The estimated pooled growth curves associated with these gauges are also included therein.

Table 5.16: Hydrometric gauging stations located on the modelled watercourses in HA11, 12 and 13 hydrometric area

| Stations | Waterbody | Location | Approx. Catchment Area (km ²) | Growth Curve Group No. |
|----------|-----------|-------------|---|------------------------|
| 12001 | Slaney | Scarawalsh | 1030.75 | GC05 |
| 12002 | Slaney | Enniscorthy | 1319.92 | GC06 |
| 12013 | Slaney | Rathvilly | 204.39 | GC03 |

Figure 5.19 shows the comparisons of the At-site and Regional Flood Frequency (AFF & RFF) curves for the above mentioned hydrometric gauging sites. The EV1 distribution was used for these comparisons. In addition to the frequency curves, the 95%ile confidence intervals associated with the regional estimates were also included in these plots. The EV1 straight line was used as an indicative descriptor of the at-site distribution, rather than a GEV or GLO curve, because the latter when fitted at-site, is liable to be misleading because of the large standard error involved in the shape parameter particularly. This was used for those stations where the individual AMAX series standardised growth curves were different considerably, in some cases, from the pooling growth curve. In such cases, EV1 regional growth curves were used instead of GLO curves; because the nature of the adjustment implies that an appropriate curved shape could not be determined with more accuracy than that of a straight line i.e. persevering with a curved growth curve in such cases would be an “illusion of accuracy”.

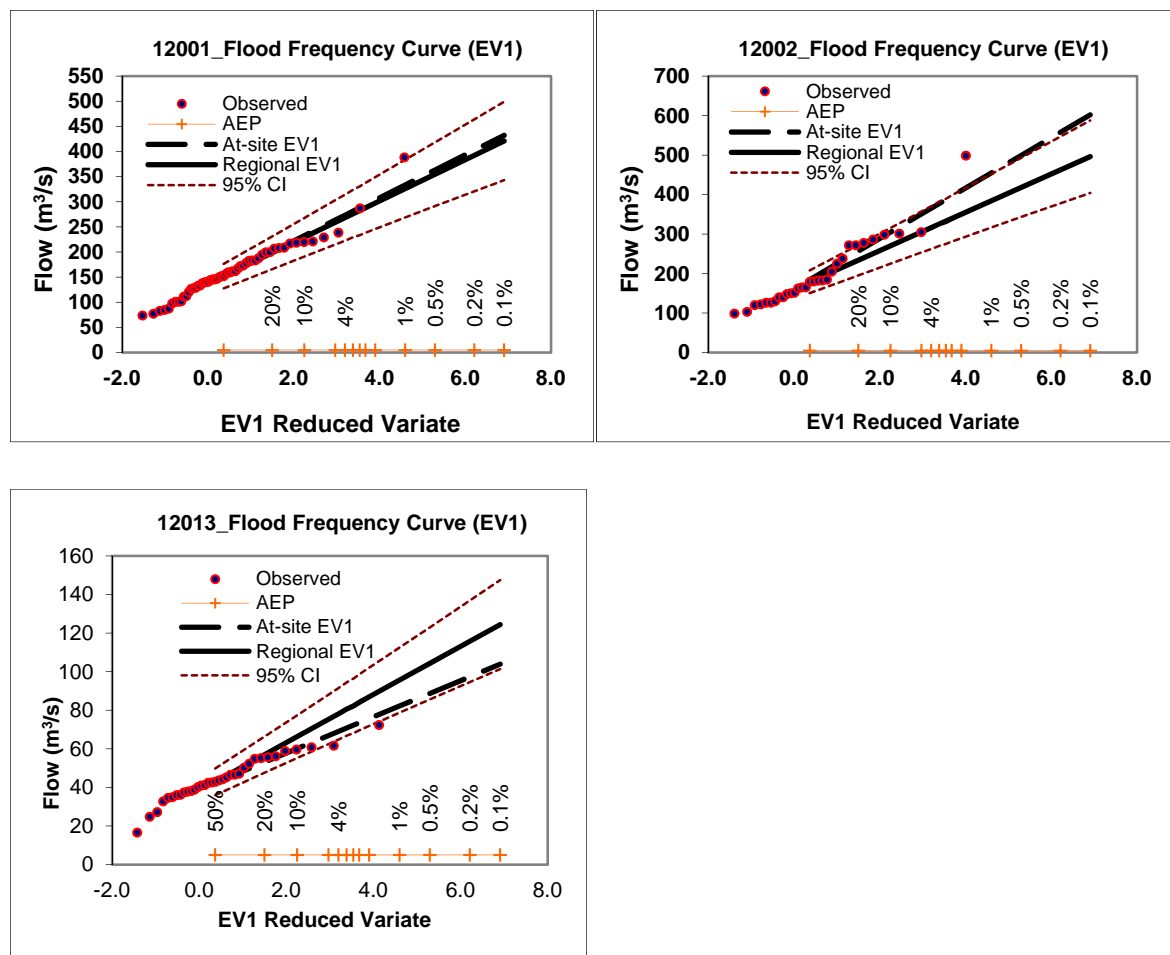


Figure 5.19: The at-site and pooled frequency curves along with the 95% confidence intervals – HA12

It can be seen from the above frequency curves that at station 12001, the AFF and RFF are similar. At station 12002, the AFF curve is steeper than the RFF curve, suggesting that the RFF slightly underestimates when compared with a number of observed floods at this station. However, the at-site growth curve does fall within the 95%ile confidence limits of the estimated associated regional growth

curves. At station 12013, the AFF curve is shallower than the RFF curve but again is within the 95%ile confidence limits.

If an AFF curve lies below the confidence limits of the RFF curve then we consider it prudent to adopt the RFF curve as the design curve, on the basis that the observed flood record has, by chance, fallen below the regional average and that there is a chance or possibility that the record of the next 20 or 30 years will revert to resembling the RFF curve rather than reproduce a re-occurrence of the recent past. It has to be acknowledged that this type of decision may lead to a degree of over-design but it is recommended that this be knowingly accepted.

On the other hand if an AFF curve lies above the RFF curve, then we consider it prudent to take account of both when deciding on the design curve/flood. This could be done by calculating a weighted average of the two curves. The relative weights should be decided, on a case by case basis, following examination of the degree of difference between the two curves, including consideration of the confidence limits of the RFF curve, shape of the at-site probability plot and the number of observed large outliers in the data series.

However an additional consideration is the data quality at the hydrometric stations for which AFF curves are developed. Only stations with FSU classification A1 or A2 are considered robust enough to warrant accounting for the AFF curve when deciding on the design curve/flood. This is in keeping with the FSU frequency analysis method. In the case of stations 12002 and 12013, neither have an A1 or A2 classification and as such it was decided that design growth curves for all HEPs located in close proximity to these stations are estimated from their relevant regional growth curves. Since the AFF and RFF curves are similar for Station 12001, the regional growth curve was also used.

5.8.4 Growth factors for all HEPs in HA11, 12 and 13

Based on the catchment sizes associated with each of the HEPs within HA11, HA12 & HA13, the relevant estimated growth factors for a range of AEPs are presented in Table 5.17, 5.18 and 5.18 respectively.

Table 5.17: Growth factors for all HEPs for a range of AEPs for HA11 River catchments (Blackwater & Owenavorrhagh Rivers)

| Node No. | Node ID_CFRAMS | AREA (km ²) | Growth factors (X _T) | | | | | | | | |
|----------|----------------|-------------------------|----------------------------------|----------------|--------------|--------------|----------------|--------------|--------------|----------------|--------------|
| | | | 1% AEP | | | 0.2% AEP | | | 0.1% AEP | | |
| | | | Lower 95%ile | X _T | Upper 95%ile | Lower 95%ile | X _T | Upper 95%ile | Lower 95%ile | X _T | Upper 95%ile |
| 1 | 11_442 | 1.03 | 2.954 | 3.275 | 3.596 | 4.212 | 4.915 | 5.618 | 4.894 | 5.845 | 6.796 |
| 2 | 11_445 | 1.29 | 2.954 | 3.275 | 3.596 | 4.212 | 4.915 | 5.618 | 4.894 | 5.845 | 6.796 |
| 3 | 11_172 | 1.47 | 2.954 | 3.275 | 3.596 | 4.212 | 4.915 | 5.618 | 4.894 | 5.845 | 6.796 |
| 4 | 11_474 | 1.53 | 2.954 | 3.275 | 3.596 | 4.212 | 4.915 | 5.618 | 4.894 | 5.845 | 6.796 |
| 5 | 11_445 | 1.70 | 2.954 | 3.275 | 3.596 | 4.212 | 4.915 | 5.618 | 4.894 | 5.845 | 6.796 |
| 6 | 11_403 | 3.94 | 2.954 | 3.275 | 3.596 | 4.212 | 4.915 | 5.618 | 4.894 | 5.845 | 6.796 |
| 7 | 11_32 | 44.59 | 2.471 | 2.739 | 3.007 | 3.287 | 3.836 | 4.385 | 3.706 | 4.426 | 5.146 |
| 8 | 11_110 | 5.65 | 2.981 | 3.305 | 3.629 | 4.243 | 4.952 | 5.661 | 4.925 | 5.882 | 6.839 |
| 9 | 11_170 | 21.54 | 2.554 | 2.831 | 3.108 | 3.417 | 3.987 | 4.557 | 3.858 | 4.608 | 5.358 |
| 10 | 11_199 | 4.03 | 2.954 | 3.275 | 3.596 | 4.212 | 4.915 | 5.618 | 4.894 | 5.845 | 6.796 |
| 11 | 11_279 | 18.99 | 2.796 | 3.100 | 3.404 | 3.891 | 4.541 | 5.191 | 4.473 | 5.342 | 6.211 |
| 12 | 11_303 | 5.43 | 2.954 | 3.275 | 3.596 | 4.212 | 4.915 | 5.618 | 4.894 | 5.845 | 6.796 |
| 13 | 11_439 | 13.36 | 2.798 | 3.102 | 3.406 | 3.892 | 4.542 | 5.192 | 4.473 | 5.342 | 6.211 |
| 14 | 11_455 | 160.80 | 1.857 | 2.059 | 2.261 | 2.249 | 2.624 | 2.999 | 2.435 | 2.908 | 3.381 |
| 15 | 11_455_3 | 160.96 | 1.857 | 2.059 | 2.261 | 2.249 | 2.624 | 2.999 | 2.435 | 2.908 | 3.381 |
| 16 | 11_469 | 13.11 | 2.868 | 3.180 | 3.492 | 4.004 | 4.672 | 5.340 | 4.605 | 5.500 | 6.395 |
| 17 | 11_522 | 14.65 | 2.898 | 3.213 | 3.528 | 4.087 | 4.769 | 5.451 | 4.724 | 5.642 | 6.560 |
| 18 | 11_140 | 3.49 | 2.954 | 3.275 | 3.596 | 4.212 | 4.915 | 5.618 | 4.894 | 5.845 | 6.796 |
| 19 | 11_403 | 3.56 | 2.954 | 3.275 | 3.596 | 4.212 | 4.915 | 5.618 | 4.894 | 5.845 | 6.796 |
| 20 | 11_264 | 5.97 | 2.981 | 3.305 | 3.629 | 4.243 | 4.952 | 5.661 | 4.925 | 5.882 | 6.839 |
| 21 | 11_188 | 17.75 | 2.796 | 3.100 | 3.404 | 3.891 | 4.541 | 5.191 | 4.473 | 5.342 | 6.211 |

Table 5.18: Growth factors for all 108 HEPs for a range of AEPs for the subject watercourses with HA12 (Slaney River and its tributaries)

| Node No. | Node ID_CFRAMS | AREA (km ²) | Growth factors (X _T) | | | | | | | | |
|----------|-----------------|-------------------------|----------------------------------|----------------|--------------|--------------|----------------|--------------|--------------|----------------|--------------|
| | | | 1% AEP | | | 0.2% AEP | | | 0.1% AEP | | |
| | | | Lower 95%ile | X _T | Upper 95%ile | Lower 95%ile | X _T | Upper 95%ile | Lower 95%ile | X _T | Upper 95%ile |
| 1 | 12_2308_5_RPS | 2.52 | 2.800 | 3.104 | 3.408 | 3.918 | 4.572 | 5.226 | 4.517 | 5.394 | 6.271 |
| 2 | 12_2308_U | 0.11 | 2.800 | 3.104 | 3.408 | 3.918 | 4.572 | 5.226 | 4.517 | 5.394 | 6.271 |
| 3 | 12013_RPS | 204.39 | 1.991 | 2.207 | 2.423 | 2.493 | 2.909 | 3.325 | 2.742 | 3.275 | 3.808 |
| 4 | 12035 | 204.88 | 1.991 | 2.207 | 2.423 | 2.493 | 2.909 | 3.325 | 2.742 | 3.275 | 3.808 |
| 5 | 12_2309_1_RPS | 164.62 | 2.025 | 2.245 | 2.465 | 2.556 | 2.983 | 3.410 | 2.821 | 3.369 | 3.917 |
| 6 | 12_2200_2_RPS | 26.56 | 2.121 | 2.351 | 2.581 | 2.756 | 3.216 | 3.676 | 3.085 | 3.684 | 4.283 |
| 7 | 12_1707_2_RPS | 1.59 | 2.800 | 3.104 | 3.408 | 3.918 | 4.572 | 5.226 | 4.517 | 5.394 | 6.271 |
| 8 | 12_531_8_RPS | 235.67 | 1.991 | 2.207 | 2.423 | 2.493 | 2.909 | 3.325 | 2.742 | 3.275 | 3.808 |
| 9 | 12_535_7_RPS | 5.21 | 2.800 | 3.104 | 3.408 | 3.918 | 4.572 | 5.226 | 4.517 | 5.394 | 6.271 |
| 10 | 12_1830_U | 0.07 | 2.800 | 3.104 | 3.408 | 3.918 | 4.572 | 5.226 | 4.517 | 5.394 | 6.271 |
| 11 | 12_1707_U | 0.26 | 2.800 | 3.104 | 3.408 | 3.918 | 4.572 | 5.226 | 4.517 | 5.394 | 6.271 |
| 12 | 12005_RPS | 254.05 | 1.991 | 2.207 | 2.423 | 2.493 | 2.909 | 3.325 | 2.742 | 3.275 | 3.808 |
| 13 | 12006_RPS | 257.23 | 1.991 | 2.207 | 2.423 | 2.493 | 2.909 | 3.325 | 2.742 | 3.275 | 3.808 |
| 14 | 12012 | 558.79 | 1.980 | 2.195 | 2.410 | 2.464 | 2.875 | 3.286 | 2.701 | 3.226 | 3.751 |
| 15 | 12021 | 248.93 | 1.991 | 2.207 | 2.423 | 2.493 | 2.909 | 3.325 | 2.742 | 3.275 | 3.808 |
| 16 | 12_535_1_RPS | 2.86 | 2.800 | 3.104 | 3.408 | 3.918 | 4.572 | 5.226 | 4.517 | 5.394 | 6.271 |
| 17 | 12_539_3_RPS | 186.59 | 2.025 | 2.245 | 2.465 | 2.556 | 2.983 | 3.410 | 2.821 | 3.369 | 3.917 |
| 18 | 12_1727_4_RPS | 42.66 | 2.218 | 2.459 | 2.700 | 2.820 | 3.291 | 3.762 | 3.116 | 3.721 | 4.326 |
| 19 | 12_835_7_RPS | 6.69 | 2.800 | 3.104 | 3.408 | 3.918 | 4.572 | 5.226 | 4.517 | 5.394 | 6.271 |
| 20 | 12_1639_3_RPS | 36.66 | 2.348 | 2.603 | 2.858 | 3.076 | 3.590 | 4.104 | 3.446 | 4.115 | 4.784 |
| 21 | 12_1663_2_RPS | 242.18 | 1.991 | 2.207 | 2.423 | 2.493 | 2.909 | 3.325 | 2.742 | 3.275 | 3.808 |
| 22 | 12_1656_2_RPS | 249.22 | 1.991 | 2.207 | 2.423 | 2.493 | 2.909 | 3.325 | 2.742 | 3.275 | 3.808 |
| 23 | 12_1830_1 | 1.13 | 2.800 | 3.104 | 3.408 | 3.918 | 4.572 | 5.226 | 4.517 | 5.394 | 6.271 |
| 24 | 12_1647_1_RPS | 229.97 | 1.991 | 2.207 | 2.423 | 2.493 | 2.909 | 3.325 | 2.742 | 3.275 | 3.808 |
| 25 | 12_2335_1_Inter | 499.59 | 1.980 | 2.195 | 2.410 | 2.464 | 2.875 | 3.286 | 2.701 | 3.226 | 3.751 |
| 26 | 12_2355_2_Inter | 542.47 | 1.980 | 2.195 | 2.410 | 2.464 | 2.875 | 3.286 | 2.701 | 3.226 | 3.751 |
| 27 | 12_1571_2_RPS | 564.04 | 1.980 | 2.195 | 2.410 | 2.464 | 2.875 | 3.286 | 2.701 | 3.226 | 3.751 |
| 28 | 12_2326_7_RPS | 3.58 | 2.800 | 3.104 | 3.408 | 3.918 | 4.572 | 5.226 | 4.517 | 5.394 | 6.271 |
| 29 | 12_940_5_RPS | 5.62 | 2.800 | 3.104 | 3.408 | 3.918 | 4.572 | 5.226 | 4.517 | 5.394 | 6.271 |
| 30 | 12_2098_2_RPS | 35.98 | 1.955 | 2.167 | 2.379 | 2.441 | 2.849 | 3.257 | 2.684 | 3.205 | 3.726 |
| 31 | 12_940_1_RPS | 4.52 | 2.800 | 3.104 | 3.408 | 3.918 | 4.572 | 5.226 | 4.517 | 5.394 | 6.271 |
| 32 | 12001_RPS | 1036.43 | 1.832 | 2.031 | 2.230 | 2.176 | 2.539 | 2.902 | 2.333 | 2.787 | 3.240 |
| 33 | 12027 | 904.25 | 1.832 | 2.031 | 2.230 | 2.176 | 2.539 | 2.902 | 2.333 | 2.787 | 3.240 |
| 34 | 12033 | 848.65 | 1.832 | 2.031 | 2.230 | 2.176 | 2.539 | 2.902 | 2.333 | 2.787 | 3.240 |
| 35 | 12_2326_4 | 2.66 | 2.800 | 3.104 | 3.408 | 3.918 | 4.572 | 5.226 | 4.517 | 5.394 | 6.271 |
| 36 | 12_2357_1 | 29.59 | 2.057 | 2.280 | 2.503 | 2.615 | 3.052 | 3.489 | 2.896 | 3.459 | 4.022 |

| Node No. | Node ID_CFRAMS | AREA (km ²) | Growth factors (X _T) | | | | | | | | |
|----------|-----------------|-------------------------|----------------------------------|----------------|--------------|--------------|----------------|--------------|--------------|----------------|--------------|
| | | | 1% AEP | | | 0.2% AEP | | | 0.1% AEP | | |
| | | | Lower 95%ile | X _T | Upper 95%ile | Lower 95%ile | X _T | Upper 95%ile | Lower 95%ile | X _T | Upper 95%ile |
| 37 | 12_910_6_RPS | 17.93 | 2.303 | 2.553 | 2.803 | 2.992 | 3.492 | 3.992 | 3.340 | 3.989 | 4.638 |
| 38 | 12_968_6 | 14.73 | 2.257 | 2.502 | 2.747 | 2.915 | 3.402 | 3.889 | 3.245 | 3.875 | 4.505 |
| 39 | 12_930_7 | 5.32 | 2.800 | 3.104 | 3.408 | 3.918 | 4.572 | 5.226 | 4.517 | 5.394 | 6.271 |
| 40 | 12_932_5 | 13.32 | 2.513 | 2.786 | 3.059 | 3.384 | 3.949 | 4.514 | 3.837 | 4.582 | 5.327 |
| 41 | 12_946_4 | 27.71 | 2.127 | 2.358 | 2.589 | 2.711 | 3.164 | 3.617 | 3.003 | 3.587 | 4.171 |
| 42 | 12_955_9 | 21.98 | 2.228 | 2.470 | 2.712 | 2.852 | 3.328 | 3.804 | 3.161 | 3.775 | 4.389 |
| 43 | 12_2065_3 | 11.46 | 2.530 | 2.805 | 3.080 | 3.411 | 3.981 | 4.551 | 3.870 | 4.622 | 5.374 |
| 44 | 12_934_6 | 22.00 | 2.359 | 2.615 | 2.871 | 3.078 | 3.592 | 4.106 | 3.441 | 4.109 | 4.777 |
| 45 | 12_2084_5 | 5.12 | 2.800 | 3.104 | 3.408 | 3.918 | 4.572 | 5.226 | 4.517 | 5.394 | 6.271 |
| 46 | 12_574_1_RPS | 31.91 | 1.955 | 2.167 | 2.379 | 2.441 | 2.849 | 3.257 | 2.684 | 3.205 | 3.726 |
| 47 | 12_2098_1_RPS | 35.81 | 1.955 | 2.167 | 2.379 | 2.441 | 2.849 | 3.257 | 2.684 | 3.205 | 3.726 |
| 48 | 12_2326_4_Inter | 2.68 | 2.800 | 3.104 | 3.408 | 3.918 | 4.572 | 5.226 | 4.517 | 5.394 | 6.271 |
| 49 | 12_2326_5_Inter | 3.06 | 2.800 | 3.104 | 3.408 | 3.918 | 4.572 | 5.226 | 4.517 | 5.394 | 6.271 |
| 50 | 12_2357_1_Inter | 29.67 | 2.057 | 2.280 | 2.503 | 2.615 | 3.052 | 3.489 | 2.896 | 3.459 | 4.022 |
| 51 | 12_2095_3_RPS | 246.67 | 1.991 | 2.207 | 2.423 | 2.493 | 2.909 | 3.325 | 2.742 | 3.275 | 3.808 |
| 52 | 12_2079_2_RPS | 0.99 | 2.800 | 3.104 | 3.408 | 3.918 | 4.572 | 5.226 | 4.517 | 5.394 | 6.271 |
| 53 | 12_2296_3_RPS | 1.55 | 2.800 | 3.104 | 3.408 | 3.918 | 4.572 | 5.226 | 4.517 | 5.394 | 6.271 |
| 54 | 12_2460_2_RPS | 1.44 | 2.800 | 3.104 | 3.408 | 3.918 | 4.572 | 5.226 | 4.517 | 5.394 | 6.271 |
| 55 | 12_1858_2 | 1.01 | 2.800 | 3.104 | 3.408 | 3.918 | 4.572 | 5.226 | 4.517 | 5.394 | 6.271 |
| 56 | 12_2085_5_RPS | 55.50 | 2.234 | 2.477 | 2.720 | 2.867 | 3.346 | 3.825 | 3.182 | 3.800 | 4.418 |
| 57 | 12_2323_4_RPS | 0.36 | 2.800 | 3.104 | 3.408 | 3.918 | 4.572 | 5.226 | 4.517 | 5.394 | 6.271 |
| 58 | 12_2603_2_RPS | 9.51 | 2.800 | 3.104 | 3.408 | 3.918 | 4.572 | 5.226 | 4.517 | 5.394 | 6.271 |
| 59 | 12_2079_U | 0.04 | 2.800 | 3.104 | 3.408 | 3.918 | 4.572 | 5.226 | 4.517 | 5.394 | 6.271 |
| 60 | 12_2296_U | 0.35 | 2.800 | 3.104 | 3.408 | 3.918 | 4.572 | 5.226 | 4.517 | 5.394 | 6.271 |
| 61 | 12_2460_U | 0.78 | 2.800 | 3.104 | 3.408 | 3.918 | 4.572 | 5.226 | 4.517 | 5.394 | 6.271 |
| 62 | 12_1858_U | 8.39 | 2.800 | 3.104 | 3.408 | 3.918 | 4.572 | 5.226 | 4.517 | 5.394 | 6.271 |
| 63 | 12_1927_U | ?? | 2.800 | 3.104 | 3.408 | 3.918 | 4.572 | 5.226 | 4.517 | 5.394 | 6.271 |
| 64 | 12002_RPS | 1330.66 | 1.832 | 2.031 | 2.230 | 2.170 | 2.532 | 2.894 | 2.324 | 2.775 | 3.226 |
| 65 | 12007_RPS | 114.76 | 1.827 | 2.025 | 2.223 | 2.214 | 2.584 | 2.954 | 2.401 | 2.868 | 3.335 |
| 66 | 12008_RPS | 1330.72 | 1.832 | 2.031 | 2.230 | 2.170 | 2.532 | 2.894 | 2.324 | 2.775 | 3.226 |
| 67 | 12009_RPS | 1330.71 | 1.832 | 2.031 | 2.230 | 2.170 | 2.532 | 2.894 | 2.324 | 2.775 | 3.226 |
| 68 | 12026 | 104.00 | 1.827 | 2.025 | 2.223 | 2.214 | 2.584 | 2.954 | 2.401 | 2.868 | 3.335 |
| 69 | 12061_RPS | 1646.29 | 1.832 | 2.031 | 2.230 | 2.170 | 2.532 | 2.894 | 2.324 | 2.775 | 3.226 |
| 70 | 12_2052_3_RPS | 1.73 | 2.800 | 3.104 | 3.408 | 3.918 | 4.572 | 5.226 | 4.517 | 5.394 | 6.271 |
| 71 | 12_2611_1_RPS | 1.06 | 2.800 | 3.104 | 3.408 | 3.918 | 4.572 | 5.226 | 4.517 | 5.394 | 6.271 |
| 72 | 12_761_3 | 4.40 | 2.800 | 3.104 | 3.408 | 3.918 | 4.572 | 5.226 | 4.517 | 5.394 | 6.271 |
| 73 | 12_577_1_RPS | 103.03 | 1.827 | 2.025 | 2.223 | 2.214 | 2.584 | 2.954 | 2.401 | 2.868 | 3.335 |
| 74 | 12_921_2_RPS | 181.52 | 1.820 | 2.018 | 2.216 | 2.165 | 2.527 | 2.889 | 2.325 | 2.777 | 3.229 |
| 75 | 12_2075_5_RPS | 37.76 | 2.294 | 2.543 | 2.792 | 2.964 | 3.459 | 3.954 | 3.298 | 3.939 | 4.580 |

| Node No. | Node ID_CFRAMS | AREA (km ²) | Growth factors (X _T) | | | | | | | | |
|----------|----------------|-------------------------|----------------------------------|----------------|--------------|--------------|----------------|--------------|--------------|----------------|--------------|
| | | | 1% AEP | | | 0.2% AEP | | | 0.1% AEP | | |
| | | | Lower 95%ile | X _T | Upper 95%ile | Lower 95%ile | X _T | Upper 95%ile | Lower 95%ile | X _T | Upper 95%ile |
| 76 | 12_958_4_RPS | 5.69 | 2.800 | 3.104 | 3.408 | 3.918 | 4.572 | 5.226 | 4.517 | 5.394 | 6.271 |
| 77 | 12_2601_6_RPS | 179.56 | 1.821 | 2.019 | 2.217 | 2.208 | 2.577 | 2.946 | 2.395 | 2.860 | 3.325 |
| 78 | 12_2605_1_RPS | 114.90 | 1.974 | 2.188 | 2.402 | 2.465 | 2.877 | 3.289 | 2.709 | 3.235 | 3.761 |
| 79 | 12_1927_1 | 0.38 | 2.800 | 3.104 | 3.408 | 3.918 | 4.572 | 5.226 | 4.517 | 5.394 | 6.271 |
| 80 | 12_2604_2_RPS | 113.51 | 1.827 | 2.025 | 2.223 | 2.214 | 2.584 | 2.954 | 2.401 | 2.868 | 3.335 |
| 81 | 12_2604_1_RPS | 103.94 | 1.827 | 2.025 | 2.223 | 2.214 | 2.584 | 2.954 | 2.401 | 2.868 | 3.335 |
| 82 | 12_2323_1_RPS | 8.47 | 2.800 | 3.104 | 3.408 | 3.918 | 4.572 | 5.226 | 4.517 | 5.394 | 6.271 |
| 83 | 12_2061_1_RPS | 1328.71 | 1.832 | 2.031 | 2.230 | 2.170 | 2.532 | 2.894 | 2.324 | 2.775 | 3.226 |
| 84 | 12_1797_4_RPS | 51.75 | 2.234 | 2.477 | 2.720 | 2.867 | 3.346 | 3.825 | 3.182 | 3.800 | 4.418 |
| 85 | 12_943_2_RPS | 1221.62 | 1.832 | 2.031 | 2.230 | 2.170 | 2.532 | 2.894 | 2.324 | 2.775 | 3.226 |
| 86 | 12_2284_1_RPS | 1.27 | 2.800 | 3.104 | 3.408 | 3.918 | 4.572 | 5.226 | 4.517 | 5.394 | 6.271 |
| 87 | 12_2268_1 | 0.31 | 2.800 | 3.104 | 3.408 | 3.918 | 4.572 | 5.226 | 4.517 | 5.394 | 6.271 |
| 88 | 12_2284_3_RPS | 1.67 | 2.800 | 3.104 | 3.408 | 3.918 | 4.572 | 5.226 | 4.517 | 5.394 | 6.271 |
| 89 | 12_2289_7_RPS | 5.19 | 2.800 | 3.104 | 3.408 | 3.918 | 4.572 | 5.226 | 4.517 | 5.394 | 6.271 |
| 90 | 12_2334_2_RPS | 9.06 | 2.800 | 3.104 | 3.408 | 3.918 | 4.572 | 5.226 | 4.517 | 5.394 | 6.271 |
| 91 | 12_2272_U | 0.01 | 2.800 | 3.104 | 3.408 | 3.918 | 4.572 | 5.226 | 4.517 | 5.394 | 6.271 |
| 92 | 12_2269_U | 0.06 | 2.800 | 3.104 | 3.408 | 3.918 | 4.572 | 5.226 | 4.517 | 5.394 | 6.271 |
| 93 | 12_2268_U | 0.04 | 2.800 | 3.104 | 3.408 | 3.918 | 4.572 | 5.226 | 4.517 | 5.394 | 6.271 |
| 94 | 12_669_U | 0.09 | 2.800 | 3.104 | 3.408 | 3.918 | 4.572 | 5.226 | 4.517 | 5.394 | 6.271 |
| 95 | 12_139_U | 0.05 | 2.800 | 3.104 | 3.408 | 3.918 | 4.572 | 5.226 | 4.517 | 5.394 | 6.271 |
| 96 | 12_145_U | 0.01 | 2.800 | 3.104 | 3.408 | 3.918 | 4.572 | 5.226 | 4.517 | 5.394 | 6.271 |
| 97 | 12_140_1 | 0.05 | 2.800 | 3.104 | 3.408 | 3.918 | 4.572 | 5.226 | 4.517 | 5.394 | 6.271 |
| 98 | 12_140_U | 0.04 | 2.800 | 3.104 | 3.408 | 3.918 | 4.572 | 5.226 | 4.517 | 5.394 | 6.271 |
| 99 | 12064_RPS | 1752.65 | 1.832 | 2.031 | 2.230 | 2.170 | 2.532 | 2.894 | 2.324 | 2.775 | 3.226 |
| 100 | 12_2597_6_RPS | 5.54 | 2.800 | 3.104 | 3.408 | 3.918 | 4.572 | 5.226 | 4.517 | 5.394 | 6.271 |
| 101 | 12_2579_2_RPS | 15.44 | 2.506 | 2.778 | 3.050 | 3.358 | 3.919 | 4.480 | 3.799 | 4.537 | 5.275 |
| 102 | 12_2565_2_RPS | 22.52 | 2.298 | 2.548 | 2.798 | 2.998 | 3.499 | 4.000 | 3.353 | 4.005 | 4.657 |
| 103 | 12_2545_2_RPS | 12.54 | 2.584 | 2.865 | 3.146 | 3.541 | 4.132 | 4.723 | 4.048 | 4.834 | 5.620 |
| 104 | 12_2147_2_RPS | 1.29 | 2.800 | 3.104 | 3.408 | 3.918 | 4.572 | 5.226 | 4.517 | 5.394 | 6.271 |
| 105 | 12_142_1 | 0.66 | 2.800 | 3.104 | 3.408 | 3.918 | 4.572 | 5.226 | 4.517 | 5.394 | 6.271 |
| 106 | 12_2456_3_RPS | 7.44 | 2.800 | 3.104 | 3.408 | 3.918 | 4.572 | 5.226 | 4.517 | 5.394 | 6.271 |
| 107 | 12_766_2_RPS | 2.30 | 2.800 | 3.104 | 3.408 | 3.918 | 4.572 | 5.226 | 4.517 | 5.394 | 6.271 |
| 108 | 12_141_1 | 0.20 | 2.800 | 3.104 | 3.408 | 3.918 | 4.572 | 5.226 | 4.517 | 5.394 | 6.271 |

Table 5.19: Growth factors for the subject HEP for a range of AEPs for the Ballyteigue River catchment (HA13)

| Node No. | Node ID_CFRAMS | AREA (km ²) | Growth factors (X_T) | | | | | | | | |
|----------|----------------|-------------------------|--------------------------|-------|--------------|--------------|-------|--------------|--------------|-------|--------------|
| | | | 1% AEP | | | 0.2% AEP | | | 0.1% AEP | | |
| | | | Lower 95%ile | X_T | Upper 95%ile | Lower 95%ile | X_T | Upper 95%ile | Lower 95%ile | X_T | Upper 95%ile |
| 1 | - | 18.65 | 2.960 | 3.282 | 3.604 | 4.216 | 4.920 | 5.624 | 4.827 | 5.848 | 6.799 |

The design flood flows for any required AEP are calculated by multiplying the Index Flood, Q_{med} of each HEP by the above estimated relevant growth factors. The Q_{med} at gauged sites are estimated from the observed AMAX series supplemented with additional simulated gauge years through rainfall runoff modelling (MIKE NAM). For the ungauged sites Q_{med} are estimated from the FSU recommended catchment descriptors based methodology and through the use of rainfall runoff (MIKE NAM) modelling to simulate flow records and hence produce a simulated AMAX record at the ungauged site (refer to Chapter 4).

It should be noted here that any uncertainties in the design flood estimates obtained from the index-flood method generally result from the uncertainties associated with both the index-flood (Q_{med}) and growth factor estimates. The uncertainties in the growth factor estimates can result both from the sampling variability and mis-specification of the growth curve distribution. The sampling error is considered to be small due to the larger record lengths (pooled records) used in the estimation process.

Furthermore, it should also be noted here that, any allowances for future climate change in the design flood flow estimate should be applied to the median flow estimates. Any effects of the climate change on the growth curves are expected to be minimal.

5.9 COMPARISON WITH FSR AND SUIR CFRAM STUDY GROWTH FACTORS

A comparison of the estimated growth factors for the HA 11, 12 and 13 was carried out with the FSR and the Suir CFRAM Study growth factors for a range of AEPs as can be seen in Table 5.20. All growth curves were indexed to the median annual maximum flows (Q_{med}).

Table 5.20: Study growth factors compared with FSR, growth factors

| AEP (%) | 50% | 20% | 10% | 4% | 2% | 1% | 0.5% | 0.2% | 0.1% |
|---|-------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|
| Slaney River Catchment (HA12) | 1.000 | 1.293 to 1.418 | 1.403 to 1.733 | 1.629 to 2.203 | 1.815 to 2.619 | 2.018 to 3.104 | 2.226 to 3.670 | 2.527 to 4.572 | 2.775 to 5.394 |
| HA12 (Average) | 1.000 | 1.351 | 1.607 | 1.980 | 2.304 | 2.674 | 3.099 | 3.764 | 4.359 |
| HA11 River Catchments (Blackwater & Owenavorrhagh Rivers) | 1.000 | 1.252 to 1.450 | 1.424 to 1.792 | 1.659 to 2.308 | 1.851 to 2.767 | 2.059 to 3.305 | 2.288 to 3.938 | 2.624 to 4.952 | 2.908 to 5.882 |
| HA11 (Average) | 1.000 | 1.417 | 1.731 | 2.078 | 2.614 | 3.097 | 3.661 | 4.560 | 5.379 |
| HA13 River catchment | 1.000 | 1.444 | 1.783 | 2.293 | 2.748 | 3.282 | 3.911 | 4.920 | 5.848 |
| Suir CFRAM Study (main channel) | 1.00 | 1.22 | 1.35 | - | 1.61 | 1.72 | 1.82 | 1.95 | 2.05 |
| FSR | 1.000 | 1.260 | 1.450 | 1.630 | 1.870 | 2.060 | 2.620 | 2.530 | 2.750 |

Table 5.20 indicates that the study area growth factors (average values) are higher than the FSR growth factors and are similar to the lower growth factors quoted for the Slaney catchment which relate to main river channel. The higher values of growth factors for the study area river catchments can be attributed to the steeper nature of the smaller river catchments and the pooling region from which the AMAX records were pooled. Comparison of the Suir CFRAM Study growth factors for the main channel are comparable with the River Slaney growth factors at the lower end of the range (which relate to main channel) but the Slaney growth curve is steeper at all AEPs with the difference between them increasing with decreasing AEP.

5.10 GROWTH CURVE DEVELOPMENT SUMMARY

Growth curves for all HEPs were estimated from the regional flood frequency analysis technique as recommended in the FEH, FSU and FSR studies (Region of Influence Approach).

Annual Maximum Flow Records (AMAX) from the 92 hydrometric stations located in the Eastern and South Eastern Region of Ireland were pooled for estimating the pooled growth curves for all HEPs in HA11, HA12 & HA13. The selection of this pooling region was based on the similarity of catchment characteristics both in terms of climatic and physiographic characteristics. The size of a pooling group associated with each of the HEPs was determined based on the FEH recommended 5T rule (with a minimum of 500 station-years AMAX series for each pooled growth curve). The pooling process was based on the FSU recommended catchment characteristics based (AREA, SAAR and BFI) distance measures between the subject and donor sites.

The statistical distribution suitable for a pooled growth curve was determined based on a number of factors such as - the suitability of this distribution for fitting the contributory stations' at-site AMAX series, the number of distribution parameters and shape of the growth curves (concave upward or concave downward). Four flood like distributions namely, the EV1, LN2, GEV and GLO distributions were considered. The three-parameter GLO distribution was found to be the best suited distribution in all respects and therefore was chosen as the growth curve distribution for all HEPs in HA11, 12 and 13.

Initially, growth curves for each of the 217 HEPs in HA11, 12 and 13 were estimated separately. Subsequently, the number of growth curves was reduced based on their relationship with the catchment areas. It was found that the growth factors generally increase with the decrease in catchment sizes. T

In the case of HA 12 (Slaney River catchment) the increase rate in growth factors is larger for the catchment areas less than 300 km² and also for the larger AEP growth factors. For any catchment areas larger than 900 km² the growth factors remained unchanged with the further increase in catchment areas. Based on this the following 6 generalised growth curve groups were recommended for the Slaney River catchment:

1. GC group No. 1: AREA < 10 km²
2. GC group No. 2: 10 < AREA ≤ 200 km²
3. GC group No. 3: 200 < AREA ≤ 400 km²
4. GC group No. 4: 400 < AREA ≤ 800 km²
5. GC group No. 5: 800 < AREA ≤ 1200 km²
6. GC group No. 6: AREA > 1200 km²

It was decided that the growth factors for all HEPs with catchment sizes ranging from 10 to 200 km² (Growth Curve Group No. 2) be estimated from the separate growth curve estimation process. For the remaining growth curve groups the median growth curves will be used. HEPs with catchment areas larger than 1200 km² have almost the same growth factors.

Because of a small number of HEPs in HA11 & HA13, no rationalisation of growth curves were considered. In these cases, the estimated individual GLO growth curve for each HEP was recommended to use as the design growth curves.

The estimated 1% AEP growth factors for the Slaney River catchment (HA12) vary from 2.018 to 3.104, while for the Owenovoragh and Blackwater River catchments (HA11) vary from 2.059 to 3.305, depending on the catchment sizes. The estimated 1% AEP growth factor for the selected HEP in HA13 is 3.282. Growth factors for the smaller catchments are larger than those of the larger catchments.

6 DESIGN FLOWS

6.1 DESIGN FLOW HYDROGRAPHS

Following estimation of the Index Flood Flow (Q_{med}) and growth factors for each HEP it is possible to estimate the peak design flows for a range of Annual Exceedance Probabilities (AEPs). All of the design flows which will be used for hydraulic modelling input are detailed in Appendix C. The final component of estimating the fluvial design flows is to ascertain the profile of the design flow hydrograph for each HEP, i.e. the profile of the flow over time as a flood event rises from its base flow to achieve the peak design flow (rising limb) and then as the flood flow rate decreases and the watercourse returns to more normal flows (recession limb). As discussed in Chapter 2 of this report the methodology for this study has been developed further since production of the Inception Report and as such three methodologies have been used within HA11, 12 and 13 to derive the design flow hydrograph shapes (widths) such that these can be applied to a range of design events:

1. Analysis of simulated historic hydrograph width at all rainfall runoff modelling points based on guidance within FSU WP 3.1 'Hydrograph Width Analysis';
2. FSU Hydrograph Shape generation tool (developed from FSU WP 3.1) for all other HEPs with the exception of 3 (below);
3. FSSR 16 Unit Hydrograph method for small (catchment less than 5 km²) where no suitable pivotal site is available.

6.1.1 Rainfall Runoff (NAM) modelling and HWA

As discussed in Chapter 4, the simulated flow traces from rainfall runoff (NAM) modelling were used to derive augmented AMAX series and subsequent Q_{med} values at three locations – Stations 12001, 12013 and 11001. The derived Q_{med} values were not adopted for further analysis in the case of Stations 12001 and 11001, adopting the Q_{med} values taken from the gauged data instead. To this end, Hydrograph Width Analysis was not pursued. These stations are already used as pivotal sites in FSU Hydrograph shape generation and as such median hydrographs derived using Hydrograph Width Analysis are already available through the FSU (WP 3.1). The NAM model outputs were not considered to supplement the flow traces such that an improvement could be achieved particularly since rainfall radar was not available as input data. Similarly, whilst the NAM Q_{med} value for Station 12013 was adopted the simulated flow trace was not used for hydrograph shape. Again, a satisfactory median hydrograph is already derived from the gauged data since it is a Pivotal Site for hydrograph shape generation in FSU WP 3.1.

For further details on Rainfall Runoff (NAM) modelling and HWA as applied elsewhere in the South Eastern CFRAM Study, refer to Hydrology Reports IBE0601Rp0010 and IBE0601Rp0011).

6.1.2 FSU Hydrograph Shape Generator

For all of the HEPs which have not been subject to rainfall runoff modelling and which are not directly upstream or downstream of a NAM modelled HEP node such that the median hydrograph from the neighbouring HEP can be applied, the Hydrograph Shape Generator tool developed as an output from FSU WP 3.1 is used to derive the design hydrograph. The Hydrograph Shape Generator Tool is an Excel spreadsheet containing a library of parametric, semi-dimensionless hydrograph shapes derived from gauge records of pivotal sites using the HWA software previously discussed. Based on hydrological similarity, a pivotal site hydrograph is ‘borrowed’ and applied at the subject site (in this case the CFRAMS HEP) based on catchment descriptors. One potential issue with the use of the Hydrograph Shape Generator tool is the lack of small catchments from which suitably short hydrographs are available. This, along with overly long receding limbs on hydrographs, was particularly noticeable in earlier versions of the software but is much improved with the addition of further pivotal sites to bring the number within the library up to 145. Within HA11, 12 and 13 the latest version of the software (version 5) was found to provide suitable hydrograph shapes for xxx of the HEPs.

6.1.3 FSSR 16 Unit Hydrograph Method

In some instances it was found that Pivotal Sites could not be found which were sufficiently hydrologically similar to the subject catchment such that hydrograph shape parameters could be borrowed and hydrograph generated as per Section 6.1.2. This was particularly the case for some of the very small sub-catchments e.g. the small urban HPWs affecting Bunclody. The FSSR 16 Unit Hydrograph method was used for these catchments whereby semi dimensionless hydrographs were derived with the same time-step as used for the other hydrographs within the model using the ISIS FSSR 16 UH tool.

Following the application of these methodologies hydrographs are then available for application within the hydraulic model. Using the small urban tributaries in Bunclody as an example, the input / check hydrographs at each HEP are shown for the 1% AEP event in Figure 6.1.

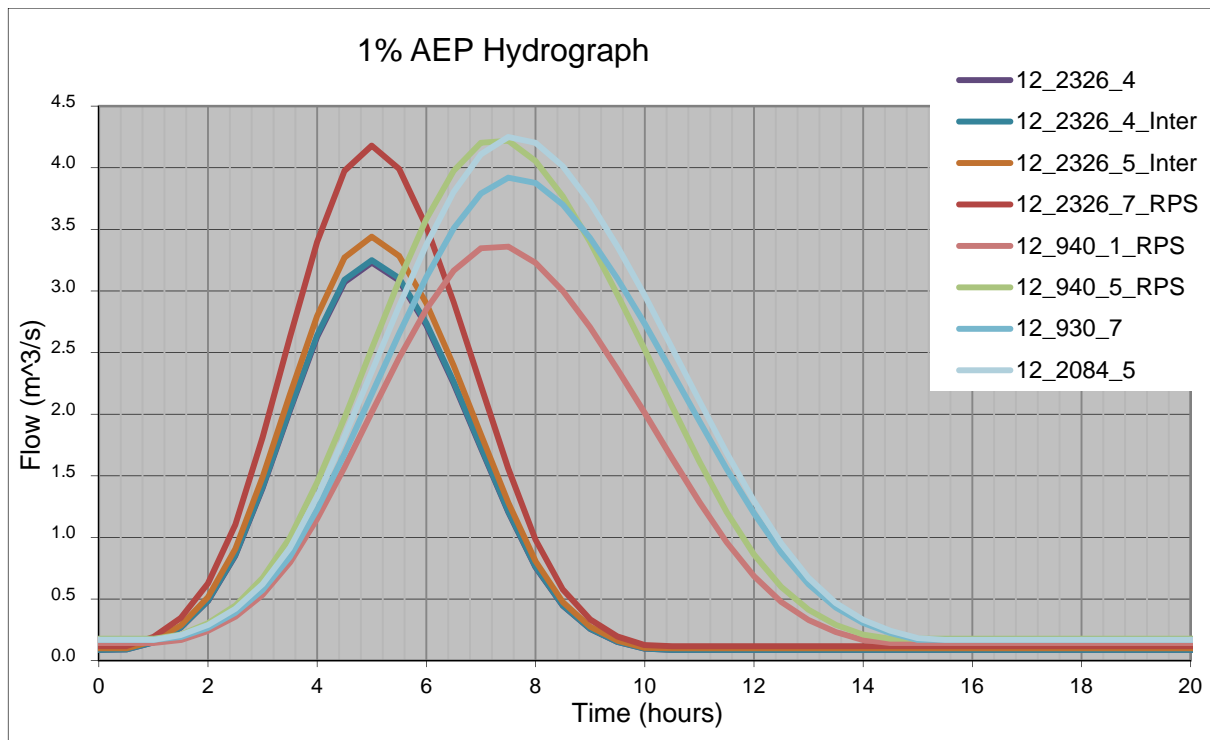


Figure 6.1: 1% AEP Hydrographs for the small urban tributaries in Bunclody AFA.

6.2 COASTAL HYDROLOGY

Analysis of the hydrological elements which contribute to coastal flood risk has been undertaken at a national level through the Irish Coastal Protection Strategy Study (ICPSS) and the Irish Coastal Wave and Water level Study (ICWWS). This study does not seek to re-analyse these elements of coastal flood risk but rather seeks to combine them, along with the fluvial elements where applicable, such that the total combined fluvial and coastal flood risk is assessed on an AFA by AFA basis. In the case of the two AFAs representing Wexford's North and South Slobs the coastal elements (wave, tide and storm surge) only are being considered.

6.2.1 ICPSS Levels

Outputs from the ICPSS have resulted in extreme tidal and storm surge water levels being made available around the Irish coast for a range of Annual Exceedance Probabilities (AEPs). The location of ICPSS nodes are shown in Figure 6.2.

In relation to Courtown and where the Owenavorrhagh River enters the Irish Sea there are two nodes, one to the north (SE22) and one to the south (SE23) which are relevant for determining ICPSS AEP (%) water levels.

Node SE29 lies just to the east of where the River Blackwater (Blackwater AFA) discharges to the Irish Sea.

For Wexford and the North and South Slobs a range of ICPSS nodes are relevant from SE31b to SE35. It is not considered that nodes outside of the harbour are relevant as the Slobs are generally protected by coastal flood embankments along the Irish Sea and flooding is likely to enter these areas via Wexford Harbour.

The Kilmore model encompasses the Bridgetown Estuary with its mouth at the Ballyteigue Bay located between ICPSS nodes S43 & S44.

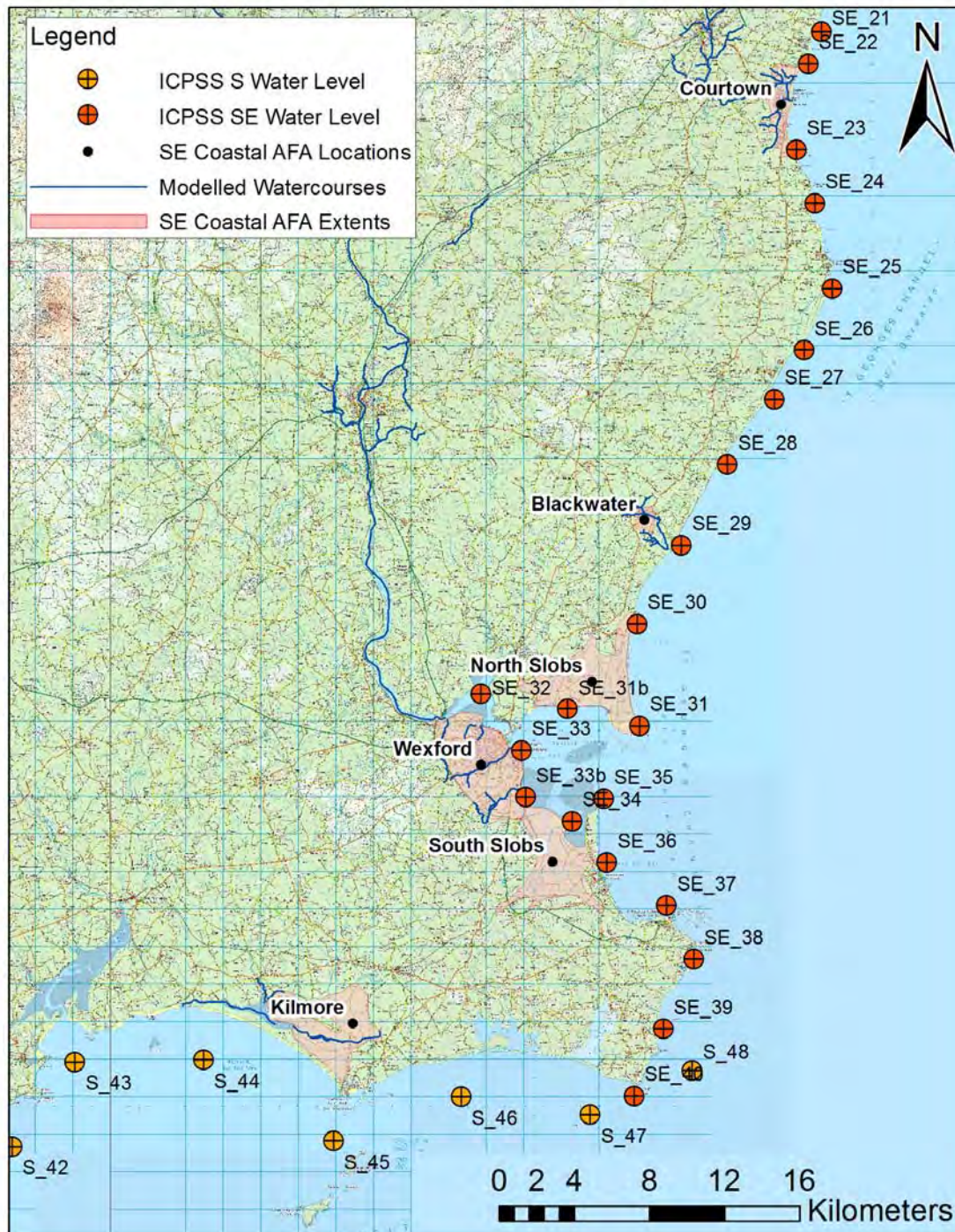


Figure 6.2: Location of ICPSS Nodes in Relation to Coastal AFAs

Levels for a range of AEPs have been extracted from the ICPSS and are shown in Table 6.1.

Table 6.1: ICPSS Level in Close Proximity to HA11, 12 and 13 AFAs

| ICPSS Node | AFA | Annual Exceedance Probability (AEP) % | | | | | | | |
|------------|-------------|---|------|------|------|------|------|------|------|
| | | 2 | 5 | 10 | 20 | 50 | 100 | 200 | 1000 |
| | | Highest Tidal Water Level to OD Malin (m) | | | | | | | |
| SE22 | Courtown | 0.94 | 1.04 | 1.11 | 1.18 | 1.27 | 1.35 | 1.42 | 1.60 |
| SE23 | | 0.93 | 1.03 | 1.10 | 1.16 | 1.25 | 1.32 | 1.39 | 1.55 |
| SE29 | Blackwater | 1.14 | 1.23 | 1.31 | 1.38 | 1.47 | 1.54 | 1.61 | 1.78 |
| SE31B | North Slobs | 1.09 | 1.22 | 1.32 | 1.42 | 1.54 | 1.62 | 1.71 | 1.91 |
| SE32 | Wexford | 1.09 | 1.24 | 1.36 | 1.45 | 1.58 | 1.67 | 1.76 | 1.95 |
| SE33 | | 1.04 | 1.19 | 1.31 | 1.41 | 1.55 | 1.64 | 1.74 | 1.97 |
| SE33b | | 1.02 | 1.15 | 1.26 | 1.36 | 1.50 | 1.60 | 1.70 | 1.93 |
| SE34 | South Slobs | 1.00 | 1.12 | 1.21 | 1.30 | 1.41 | 1.49 | 1.57 | 1.75 |
| S43 | Kilmore | 2.08 | 2.17 | 2.23 | 2.29 | 2.37 | 2.44 | 2.5 | 2.64 |
| S44 | | 2.08 | 2.16 | 2.21 | 2.26 | 2.33 | 2.37 | 2.41 | 2.5 |

(Extracted from: Irish Coastal Protection Strategy Study Phases 2 & 3 – Technical Report ref: IBE0071/June2010 & IBE0104/June2010)

6.2.2 ICWWS Levels

The Irish Coastal Wave and Water level Study (ICWWS) is being progressed by OPW in order to consider the potential risk associated with wave overtopping at exposed coastal locations. The study is currently ongoing but preliminary analysis has been made available for the South Eastern CFRAM Study to identify the areas within HA11, 12 and 13 which have been identified as potentially vulnerable to this flood mechanism. The length of vulnerable coastline and the affected AFAs are shown in Figure 6.3.

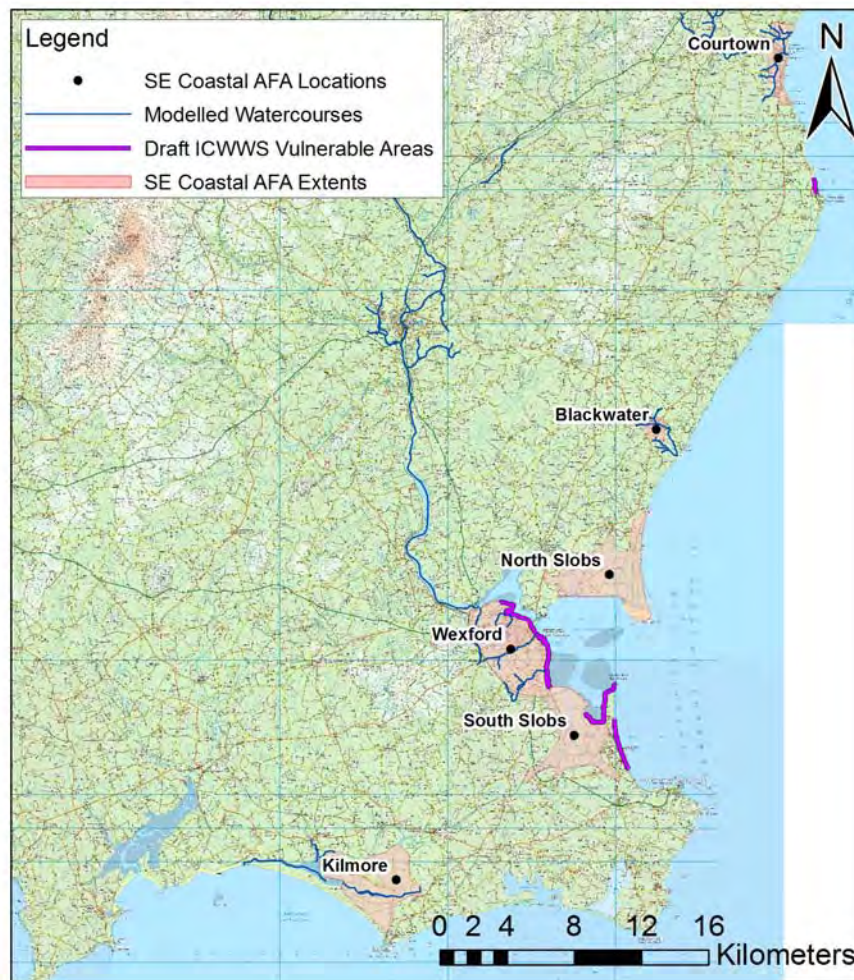


Figure 6.3: Draft ICWWS potential areas of vulnerable coastline

As shown in Figure 6.3, two AFAs are potentially vulnerable to flooding due to wave overtopping. These are Wexford and the South Slobs. The study outputs will be in the form of a range of combinations of water level and wave characteristics (wave height, period, frequency and the joint probability assessed extreme water level) for each AEP %.

6.2.3 Consideration of ICPSS and ICWWS Outputs

It is important to note that the outputs from both the ICPSS and the ICWWS are to be considered separately. The AFAs which have been identified as only to be analysed for coastal flooding will be assessed through 2D modelling of Wexford Harbour. Tidal boundaries will be applied within the 2D models at a scale and distance necessary to capture the complete effects of a dynamic tide and the propagation effects within Wexford Harbour and the watercourse channels to be modelled which have a coastal outfall.

At AFAs where fluvial flooding has also been identified as a consideration within the model the ICPSS levels will be applied considering a range of joint probability scenarios (as detailed in Section 6.3) in order to determine the most onerous flood outline for any AEP. The levels which have been derived

from the ICPSS will be applied within the 2D portion of the hydraulic (hydrodynamic) models. All ICPSS levels (Table 6.1) will be applied as the maximum level on the oscillating average tidal cycle observed at the tidal gauge at Wexford. A typical 1% AEP surge on tidal cycle to staff gauge zero is shown in Figure 6.4 below. Bathymetric and cross sectional survey has been undertaken within the tidal reaches of coastal models in order to accurately capture the effects of tidal propagation within the estuaries and into the tidal reaches of the watercourses where relevant. Full details on the application of the ICPSS levels at the coastal boundaries will be contained within the subsequent Hydraulic Modelling report for HA11, 12 and 13.

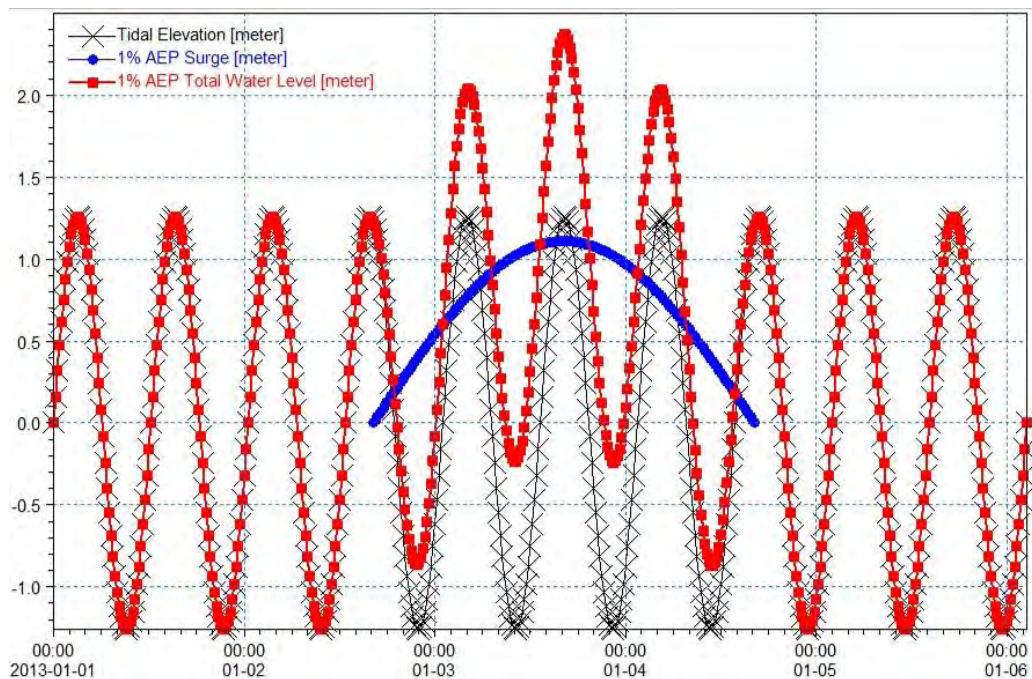


Figure 6.4: Typical 1% AEP Coastal Boundary Makeup (to Staff Gauge Zero)

It is important to note that the outputs from the ICWWS are not directly applicable through the standard 2D hydraulic modelling packages used for coastal flood modelling. The assessment of the volume of flood water from wave overtopping is a function of the outputs from the ICWWS (wave height, period, frequency and the joint probability assessed extreme water level), the duration of the event and the dimensions and hydraulic performance of the sea defence and foreshore. At each of the two AFAs that have been identified as vulnerable to wave overtopping, preliminary analysis will identify the location and length of sea defence / frontage which is vulnerable to wave overtopping. This section will then be assessed against the range of wave / extreme water level combinations for each annual exceedance probability (AEP %) to determine the most critical scenario. The total overtopping volume from the most onerous scenario for each AEP will then be assessed against the digital terrain model (LiDAR based) to ascertain the mapped flood extents, depth and hazard behind the sea defence / frontage within the AFA. Further details of the methodology for assessment and modelling of the wave overtopping flood risk will be contained within the Hydraulic modelling report.

6.3 JOINT PROBABILITY

Joint probability is a consideration in relation to the occurrence of fluvial – fluvial events (where extreme flood events on tributaries and the main channel of rivers coincide) and also at the downstream tidal reaches of the modelled watercourses where tidal – fluvial events become a consideration such as within Wexford Harbour, the tidal reaches of the Owenavorrhagh and Blackwater Rivers and within the Bridgetown Estuary.

6.3.1 Fluvial – Fluvial

There are significant watercourse confluence points on many of the fluvial models within HA11 & 12, with the exception perhaps of Wexford. At these confluence points consideration must be given to the probability of coincidence of flood flows within the model. This is less of a concern on the smaller catchment models (i.e. the Blackwater) where the critical storm in the confluent sub-catchments is likely to be similar. Fluvial to fluvial joint probability is likely to be a significant consideration at confluence points where two catchments with remote catchment centroids meet or where it is apparent that two catchments may have very different response times. Where a small tributary enters a much larger river system such that the increase in flow is small the consideration of joint probability is unlikely to be significant. The models identified where fluvial to fluvial joint probability is likely to be a significant consideration are at Courtown, Bunclody and Enniscorthy.

In order to minimise the need for joint probability analysis within the models RPS has split up the Slaney system into five models and the Owenavorrhagh into two models (the portion of the Blackwater to be modelled is relatively small) such that the hydrological conditions which cause the flood event have a low degree of variance across the model extents. In addition RPS has specified a high number of HEPs such that as we move down the model, i.e. past confluence points, the hydraulic modeller has to hand the design flows downstream of the confluence point such that they can check that the sum of the inflows within the tributary and the main channel are creating the correct frequency conditions downstream of the confluence point. Where these conditions are not being achieved the modeller will adjust the flows depending on the relationship between catchment descriptors of the main channel and tributary such that the joint probability relationship can be determined to create the correct frequency conditions downstream of the confluence point. This is a modelling consideration and may require an iterative approach. These adjustments will be carried out in line with the guidance provided in FSU WP 3.4 'Guidance for River Basin Modelling' and detailed in the Hydraulic Modelling report.

6.3.2 Fluvial – Coastal

In terms of hydrometric areas 11, 12 and 13, this category of joint probability may be relevant to all the fluvial models which are within tidally influenced reaches i.e. Courtown, Blackwater, Wexford, Enniscorthy and Kilmore. The RPS methodology for assessing joint probability for coastal and fluvial flooding is outlined in the CFRAM Study technical note '*NTCG GN20 Joint Probability Guidance (RPS, June 2013)*'. It advocates a stepped approach to the consideration of fluvial coastal joint probability

whereby the relevance is assessed to ascertain at which sites dependence may exist and further analysis needed:

The first stage in any Joint Probability analysis should be to ascertain whether the flooding mechanisms in any particular area, either AFA or MPW, actually warrant the consideration of the joint probability of occurrence. This screening stage should involve a review of all existing information on flooding within the area of interest, such as records of historic events or previous studies including the output from the CFRAM PFRA and the complementary ICPSS data. Where this review identifies either a significant overlap in the areas of fluvial and tidal flood risk or a proven history of significant flooding from both sources, joint probability should be considered. Where the flooding mechanism is heavily dominated by one particular source it is questionable whether joint probability analysis is justified.

An initial screening process has been undertaken on the aforementioned models (excluding previous studies) which have been identified as potentially at risk from fluvial and coastal flooding. The results of this screening are shown in Table 6.2.

Table 6.2: Initial Screening for Relevance of Joint Probability

| HA / Model No. | AFA Name | Evidence / History of Joint Occurrence | Comments | Further JP Analysis |
|----------------|-------------|--|--|-----------------------------------|
| HA11 - Model 1 | Courtown | No | Coastal flood outline extends more than 1km up Owenavorrach channel but no properties affected. | No |
| HA11 - Model 2 | Blackwater | No | Some small overlap of flood outlines in mouth of Blackwater River / harbour but downstream of AFA extents. | No |
| HA12 – Model 4 | Enniscorthy | No | Coastal flood risk is not identified for Enniscorthy but the Slaney is tidally influenced here. JP not required but downstream boundary of the model should be taken from the upstream water levels of the Wexford Model (HA12 Model 5). | No |
| HA12 – Model 5 | Wexford | Yes | Not much overlap in Wexford itself (more the Slobs), but PFRA fluvial flood outline of Slaney does not extend into tidal reaches. Potential significant consequences to joint occurrence. | Yes, consider dependence analysis |
| HA13 – Model 1 | Kilmore | No | Overlap of flood outlines. HPW in Slobs area where closed flap valves due to high | Yes, consider dependence |

| HA / Model No. | AFA Name | Evidence / History of Joint Occurrence | Comments | Further JP Analysis |
|----------------|----------|--|---|---------------------|
| | | | coastal flood levels could be critical mechanism in relation to fluvial flooding. | analysis |

Following initial screening two of the models were removed from the consideration of joint probability of fluvial and coastal flood events. This is not to say there is no evidence of a tidal influence at these locations but rather that there is no known evidence of joint fluvial and coastal flood occurrence and that there are no low lying areas on the lower reaches that would be particularly sensitive to such a joint occurrence, over and above a fluvial or tidally dominant event in isolation. For each of these models suitable conservative tidal downstream boundary conditions will be applied which are relatively conservative such as the highest astronomical tide, oscillating such that there is coincidence between peak tide and hydrograph. It is not thought this will lead to unrealistic downstream flood extents as the overlap of the most extreme 0.1% AEP events, when considering the PFRA and ICPSS outlines, is minimal. Nevertheless this will be reviewed following initial model runs to check that this assumption is valid.

The Wexford and Kilmore models however must consider the occurrence of joint probability further. The result of a joint occurrence of both fluvial and coastal flood conditions would have a significant impact on the harbour / estuary areas of Wexford Town and the Inish and Ballyteige Slob area of Kilmore. There is no documentary evidence of particularly high flows in the Slaney corresponding with coastal flood events but there is evidence of heavy rainfall, generally a condition of extreme fluvial events, jointly occurring at times of high coastal water levels.

The next stage in assessing the joint probability is to review the available data to ascertain if there is a dependence relationship between extreme coastal and fluvial events. There is limited coastal water level data available in close proximity to Wexford Harbour or Bridgetown Estuary. The nearest long term gauge record available for comparison is at Dublin Port over 100km to the north of Wexford. A number of shorter length tidal gauge records (less than ten years) are available in closer proximity to Wexford and Kilmore at Wexford Harbour, Rosslare and Arklow. In terms of fluvial hydrometric gauge records there are no gauging stations located in HA13. Within HA12 the Scarawalsh gauging station (12001 – OPW) is located just outside of the tidal reaches of the River Slaney and the Boleany gauge (11001 – OPW) is located on the Owenavorrhagh, again just outside the tidal reaches. The Boleany gauge (11001 – OPW) on the Owenavorrhagh is worth considering as it represents a smaller catchment (155km²) than the Slaney catchment and will better indicate if there is a dependence relationship between coastal and smaller catchment fluvial flooding. In the first instance regression analysis was undertaken whereby 22 years of high tide values at the Dublin Port tidal gauge were considered along with mean daily level values recorded at both gauges. The results are plotted in Figure 6.5.

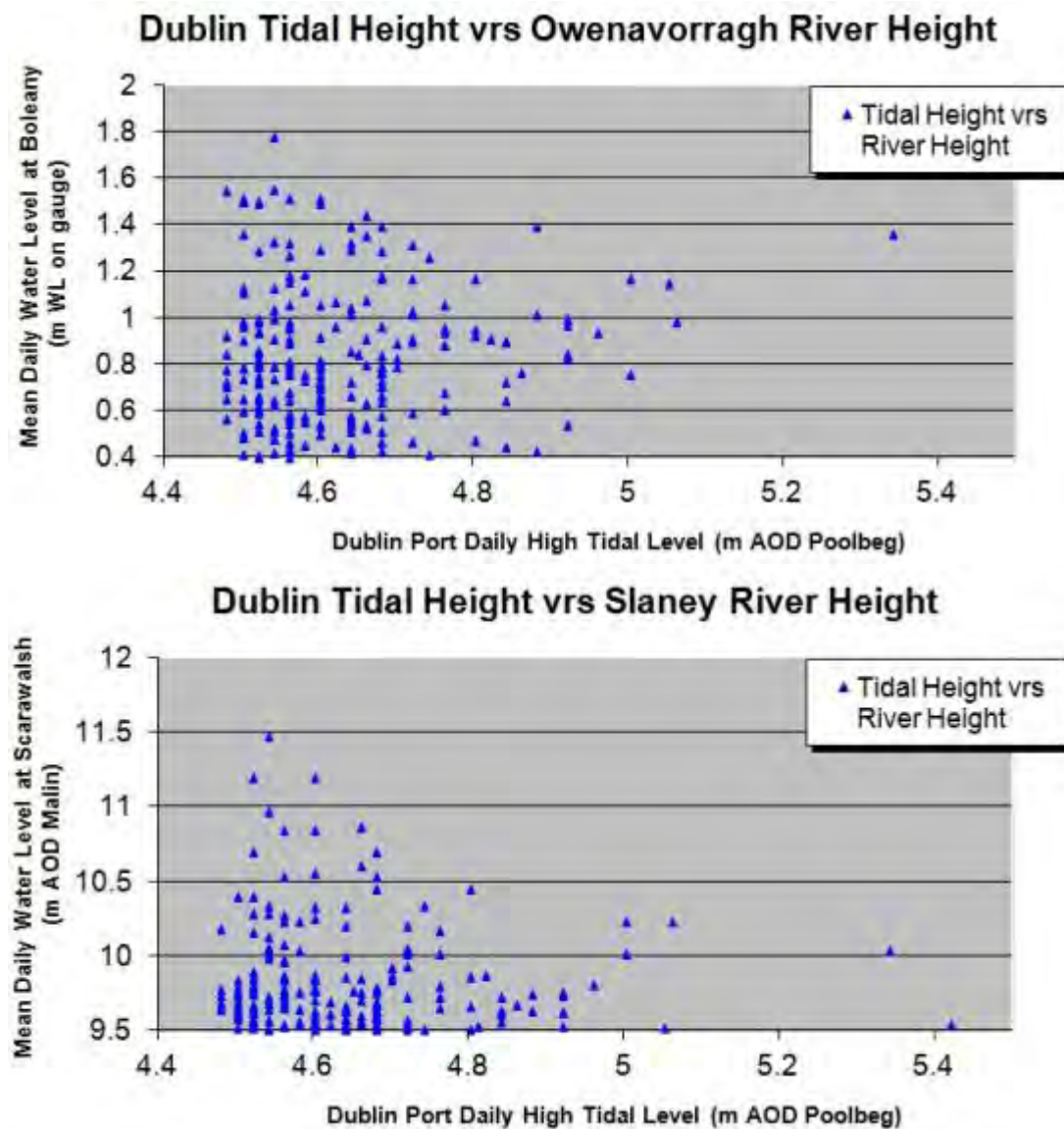


Figure 6.5: Coastal WL @ Dublin Port versus River Level on Slaney and Owenavorrhagh

The scatter diagrams shown in Figure 6.5 indicate no obvious correlation between high tidal levels at Dublin Port and fluvial water levels in the Owenavorrhagh or Slaney Rivers. The use of the Dublin Port gauge in this instance has problems due to its remoteness from the catchment outfalls, particularly in the case of the Slaney and as such this analysis is inconclusive. The shorter but more geographically appropriate water level gauge record from Wexford Harbour (2007 – 2011) was considered against the coinciding flow records from both gauging stations also with the results shown in Figure 6.6.

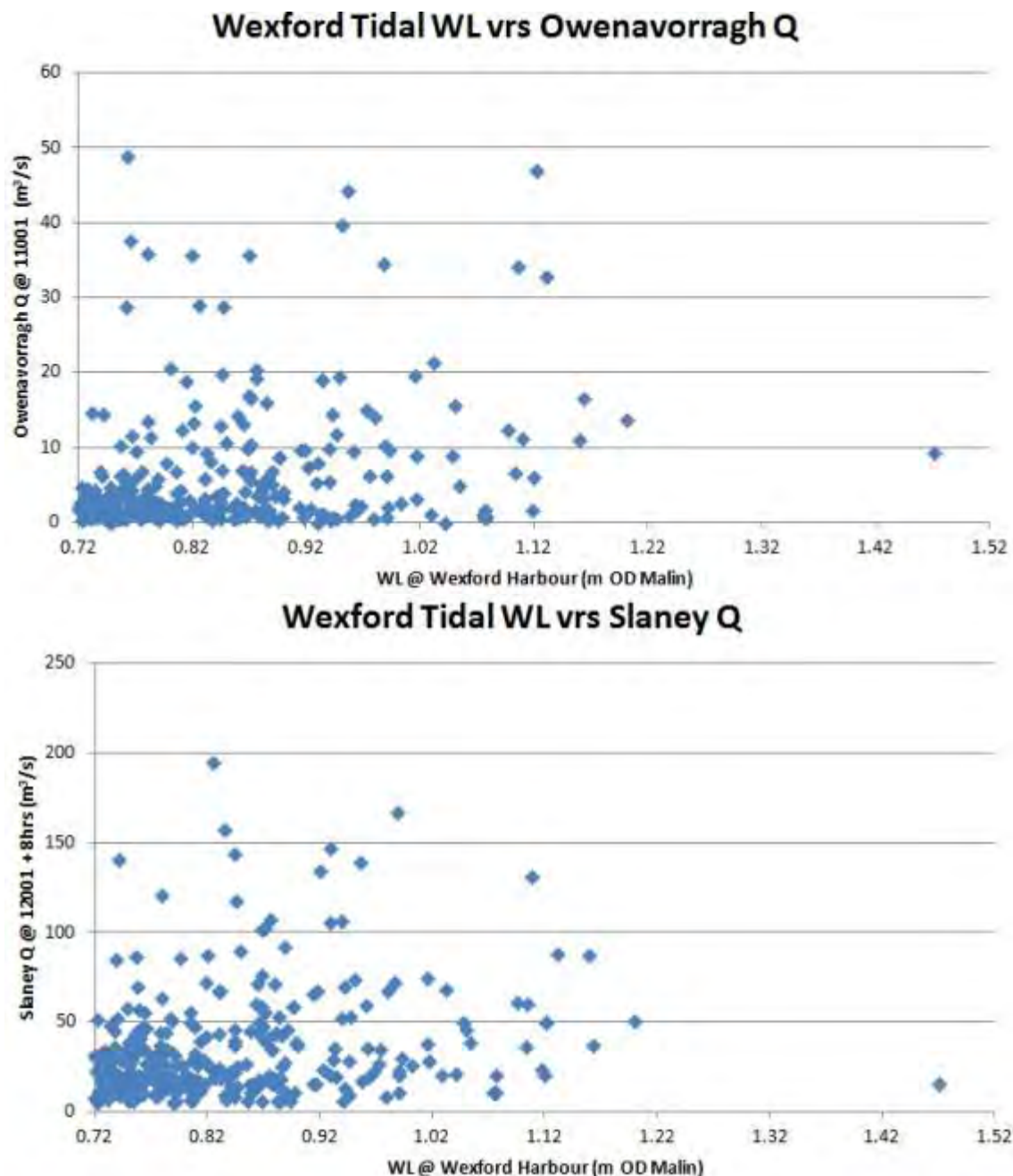


Figure 6.6: Coastal WL @ Wexford versus Flow on Slaney and Owenavorrhagh

The instantaneous flow record from the Scarawalsh gauging station on the Slaney (12001 – OPW) has been transposed in time by eight hours reflecting the approximate delay due to the travel time of the flood hydrograph from Scarawalsh to Wexford Harbour. It was decided not to shift the Boleany data for the Owenavorrhagh as the gauging station is much closer to the coastal outfall and would represent a similar delay to that of the high tide between Wexford and Courtown.

Although this dataset is short, it is appropriate for comparison to both fluvial flow gauges to ascertain whether there is evidence of dependence between Slaney / Owenavorrhagh fluvial flows and coastal water levels. There is no obvious correlation in either of these datasets and as such fluvial flooding and coastal flooding can be considered as independent events in both catchments.

As the two events are considered independent the design event is therefore defined simply by testing the various cumulative probabilities which achieve the required design probability. For example to ascertain the critical 1% AEP event a range of scenarios must be modelled which have a cumulative probability of 1% (50% fluvial and 2% coastal, 2% coastal and 50% fluvial, 20% fluvial and 5% coastal, 5% fluvial and 20% coastal etc.).

7 FUTURE ENVIRONMENTAL AND CATCHMENT CHANGES

There are a number of future potential changes which may affect the outputs of this study and as such it is prudent that they are identified and their potential impact quantified so that the outputs can accommodate these changes as much as practically possible. This chapter outlines potential environmental changes such as climate change and changes to the catchment such as afforestation and changing land uses. HA11, 12 and 13 are predominantly rural catchments with much of the land given over to tillage and grassland. The largest urban area is Wexford town located on the banks of the Slaney Estuary. Urbanisation along with potential management and policy changes are considered in this chapter. The design flow estimations for Mid-Range and High End Future Scenarios (MRFS and HEFS) that have been calculated based on the findings of this chapter are included in Appendix C for each HEP.

7.1 CLIMATE CHANGE

According to the United Nations Intergovernmental Panel on Climate Change (2007) there is “unequivocal” evidence of climate change and furthermore:

"most of the observed increase in global average temperatures since the mid-20th century is very likely due to the observed increase in anthropogenic greenhouse gas concentrations."

(Climate Change 2007, IPCC, Fourth Assessment Report AR4)

Further to this carbon dioxide levels in the atmosphere were observed at over 400 parts per million in Hawaii. This is considered a milestone threshold and is at a level last thought to have occurred several million years ago when the Arctic was ice free and sea levels were up to 40m higher¹.

The effects of climate change on flood risk management are well documented but in terms of fluvial flooding they are not straightforward to quantify. Changes in sea level have direct impact on coastal flooding and a range of predictions on projected rises are available. A number of meteorological projections are also available for changes in rainfall but these have a wide degree of variance particularly from season to season and are difficult to translate into river flow. . A recently completed study by the National University of Ireland, Maynooth (Murphy et al, 2011) provides an indication of the uncertainties associated with standard allowances made for precipitation and river flow in future climates. This is discussed further in Chapter 8.

7.1.1 HA11, 12 and 13 Context

Research into climate change in Ireland is coordinated by Met Éireann through the Community Climate Change Consortium for Ireland (www.c4i.ie). Research summarised in the report ‘Ireland in a

¹ <http://www.theguardian.com/environment/2013/may/10/carbon-dioxide-highest-level-greenhouse-gas>

Warmer World – Scientific Predictions of the Irish Climate in the 21st Century’ (Mc Grath *et al*, 2008) seeks to quantify the impact of climate change on Irish hydrology and considers the impacts of nine Irish catchments all of which were outside HA11, 12 and 13 but includes the Suir (HA16) and the Barrow (HA14). The ensemble scenario modelling from the regional climate change model predicts that between the two periods of 1961 – 2000 and 2021 – 2060 that Ireland is likely to experience more precipitation in autumn and winter (5 – 10%) and less precipitation in summer (5 – 10%). Between the periods of 1961 – 2000 and 2060 – 2099 this trend is likely to continue with increases of 15 – 20% generally, but up to 25% in the northern half of the country in autumn and drier summers of up to 10 – 18%.

The report seeks to further quantify the impact on hydrology in Ireland through the use of a HBV-Light conceptual rainfall runoff model (provided by Prof. Jan Seibert of Stockholm University) to simulate the effects of climate change on stream flow within the nine Irish catchments. The HBV-Light conceptual rainfall runoff model of the Suir catchment (HA16) was calibrated using historical meteorological data against the hydrometric gauge record at the Clonmel gauging station (16011). Validation of the model found that the Suir model was well calibrated when it came to simulating the seasonal cycle of mean monthly and mean winter flow with slight over-estimation but simulated annual maximum daily mean flow is overestimated. Risk outputs from the model can be considered to be over-estimated. The HBV-Light conceptual rainfall runoff model of the Barrow catchment (HA14, was calibrated using historical meteorological data against the hydrometric gauge record at the Royal Oak gauging station (14018). Validation of the model found that the Barrow model was not quite as well calibrated when it came to simulating the mean winter and summer flows. The flows were overestimated when compared against the observed historic data from the gauging station at Royal Oak and as such the risk outputs from the model can be considered to be overestimated. Following simulation of the meteorological climate change ensembles within the runoff models the following observations were made in both catchments for the changes between the periods (1961 – 2000) and (2021 – 2060):

- Reductions in mean daily summer flow of up to 60% and increases in mean winter flow of up to 20% within both catchments;
- The risk of extremely high winter flows is expected to almost double in the Suir. Mixed results were obtained for the Barrow where the flows associated with certain return periods in the past will have a greater return period in the future, which is explained by the effect of damped and even hydrographs resulting in a longer time scale to respond to changes in precipitation than faster responding catchments;
- No definite increase in annual maximum daily mean flow is expected in either the Suir or Barrow catchment.

In addition to the research undertaken by C4i the paper titled ‘Quantifying the cascade of uncertainty in climate change impacts for the water sector’ (Dept. of Geography, National University of Ireland, Maynooth, 2011) seeks to quantify the cumulative effect of uncertainties on catchment scale climate change runoff models from uncertainties in emissions scenarios, climate

model selection, catchment model structure and parameters. This paper concludes that uncertainties are greatest for low exceedance probability scenarios and that there is considerable residual risk associated with allowances of +20% on fluvial flows for climate change, as recommended in 'Assessment of Potential Future Scenarios for Flood Risk Management' (OPW, 2009) for the mid range future scenario. In light of this conclusion there is an even greater weight to be placed on higher end future predictions for climate change. The use of the OPW high end future scenario for fluvial flows of +30% is even more relevant in this context.

7.1.2 Sea Level Rise

Research from c4i summarised in the aforementioned report states that sea levels around Ireland have been rising at an annual rate of 3.5mm per year for the period 1993 – 2003 which is higher than the longer term rate of 1.8mm per year for the period 1963 – 2003. This trend is likely to be reflected in the Southern Region with a 'net trend' (allowing for isostatic adjustment of the earth's crust) of 3.1-3.5mm per year; and more modest in the Irish Sea with a 'net trend' of 2.3 – 2.7mm per year. On top of this the report notes that storm surges are likely to increase in frequency.

7.2 AFFORESTATION

7.2.1 Afforestation in HA11,12 & 13

There is much legislation governing forestry practices in Ireland but it is implemented through the document 'Growing for the Future – A Strategic Plan for the Development of the Forestry Sector in Ireland' (Department for Agriculture, Food & Forestry, 1996). The plan points out that over the period from 1986 to 1996 afforestation saw quite a dramatic growth in Ireland from a level of approximately 70 km² annually to almost 240 km² annually in 1996 largely driven by a growth in private forestry activities. Within HA11, 12 & 13 the current forest coverage as recorded in the 2006 CORINE land maps for the hydrometric area / UoM is shown in a national context by Figure 7.1.

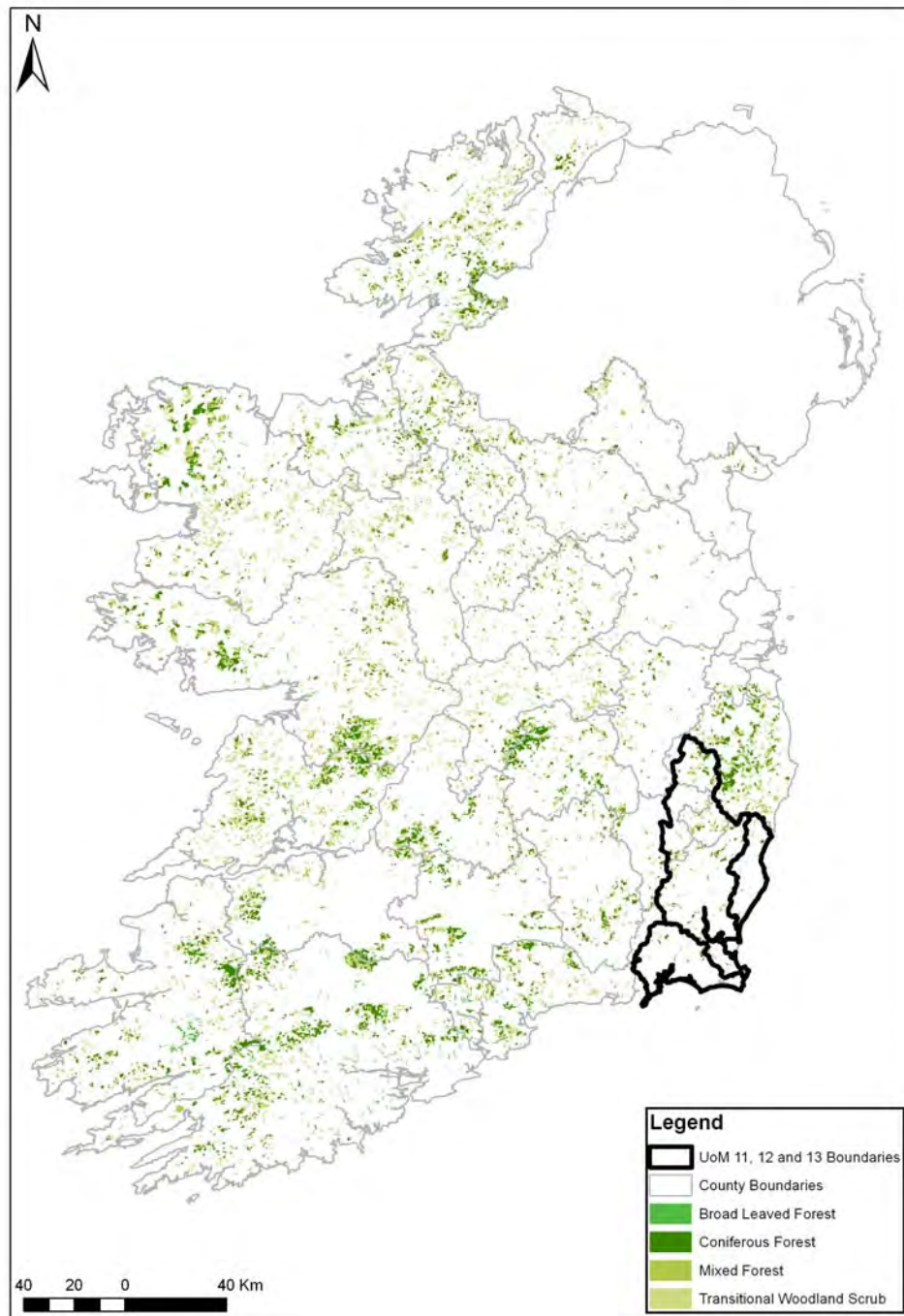


Figure 7.1: CORINE 2006 Forest Coverage in HA11, 12 &13 Compared to the rest of Ireland

The total forested area, including transitional woodland scrub, within HA11, 12 and 13 is 207km² which is approximately 7% of the total area. The average for the country is approximately 10%. The densest forestry coverage is in the north of HA12 within the Wicklow Mountains. Comparison of the CORINE 2006 database to the 2000 database indicates that there has been some increase in the forested area as shown in Figure 7.2.

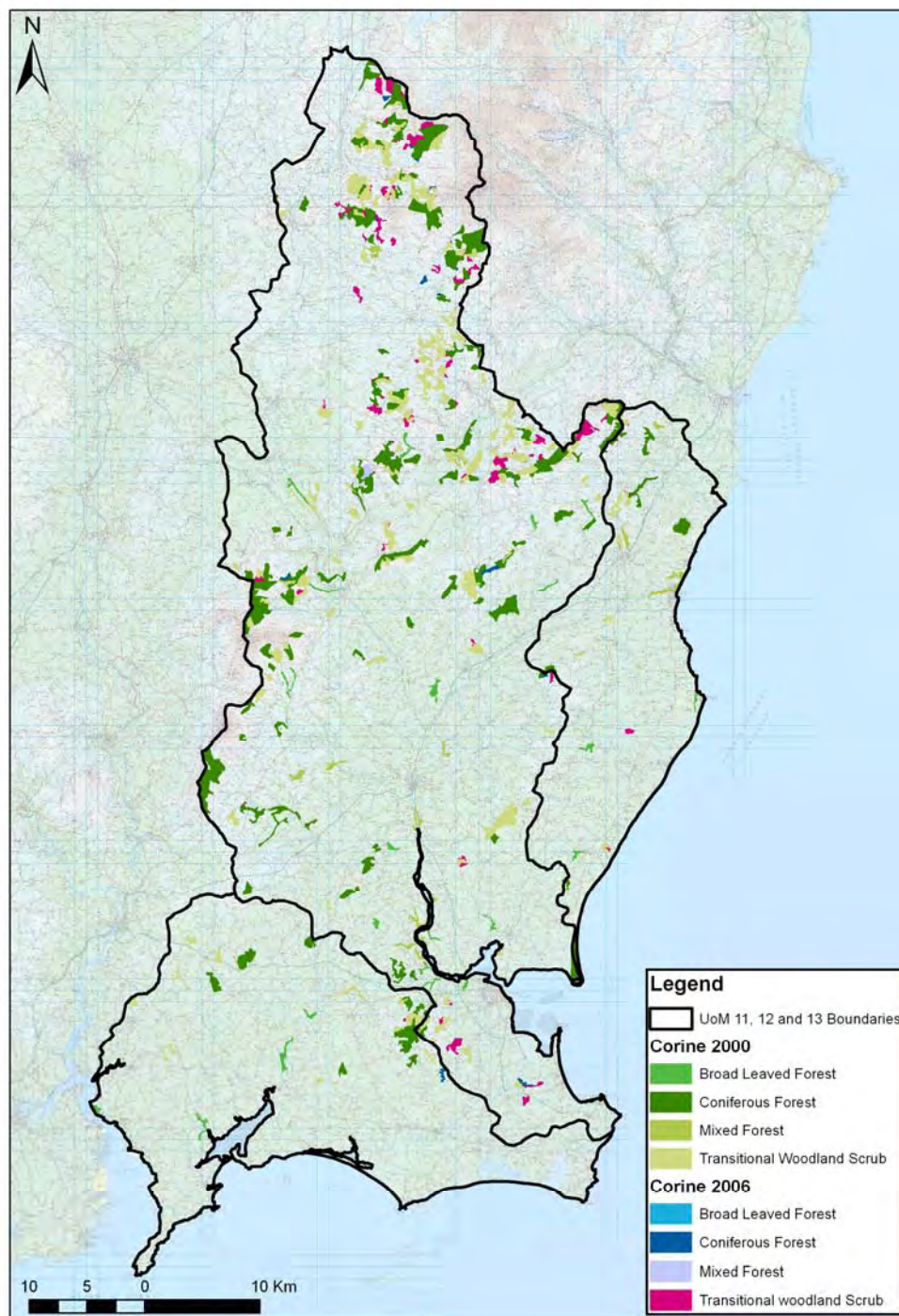


Figure 7.2: Forest Coverage Changes in HA11, 12 & 13

As can be seen from Figure 7.2 there appears to have been an increase in the amount of forested area overall between 2000 and 2006 but the increase has mostly been in transitional woodland scrub as opposed to actual forest. The areas of forest from the two periods of the CORINE 2006 database are broken down further in Table 7.1 where a decrease in coniferous forest coverage is evident. This is not reflective of the national trend during the time period.

Table 7.1: Afforestation from 2000 to 2006 in HA11, 12 and 13

| | CORINE 2000 | | CORINE 2006 | | Change | | Annualised Change | |
|--|----------------------------------|------------------------|----------------------------------|------------------------|----------------------------------|------------------------|----------------------------------|------------------------|
| | Area (km²) | % of catch. | Area (km²) | % of catch. | Area (km²) | % of catch. | Area (km²) | % of catch. |
| Forest | 119.5 | 3.9 | 107.7 | 3.6 | -11.8 | -0.38 | -1.96 | -0.06 |
| Transitional Woodland Scrub | 77.9 | 2.6 | 99.4 | 3.3 | +21.5 | 7.1 | 3.58 | 1.18 |
| Total | 197.4 | 6.5 | 207.1 | 6.9 | +9.7 | 0.32 | 1.6 | 0.05 |
| Total Countrywide | 6,631 | 9.4 | 7,087 | 10.1 | 456 | + 0.65 | 76 | +0.11 |

From Table 7.1 it can be seen that total forest / woodland scrub has increased in HA11,12 &13 between 2000 and 2006 but the actual forest coverage has dropped slightly. However it is worth noting that lowering of actual forest coverage and increase in transitional woodland scrub may be to do with differences in classification methods between CORINE 2000 and 2006.

When considered together the total area of forest / woodland scrub as a proportion of the catchment is lower than the national average of approximately 10%. The rate of increase between 2000 and 2006 is also considerably lower than the national average of + 0.11% per year. If the annualised increase in afforestation were to continue for the next 100 years the woodland ground cover in HA11,12 and 13 would increase from 207km² (6.9%) to 367km² (12.1%).

The Strategic Plan sets out a target for the increase of forest area to 11,890 km² by 2035 in order to achieve a critical mass for a successful high-value added pulp and paper processing industry and this is the main driver behind the increases in forested area. If this value is to be realised nationally the rates of forestation will need to double compared to the change observed between 2000 and 2006. The target increases in the aforementioned Strategic Plan is not borne out by the most recent data for HA11, 12 and 13 and as such increase in forest coverage should only be considered in the High End Future Scenario (HEFS) (refer to Table 7.2).

7.2.2 Impact on Hydrology

A number of studies have been carried out on a range of catchments in an attempt to capture the effects of afforestation on runoff rates and water yields. The DEFRA (UK) report 'Review of impacts of rural land use management on flood generation' (2004) considers a number of case studies where the effects of afforestation on the catchment runoff were considered. The report concluded that the effects

of afforestation are complex and change over time. A summary of the main findings in relation to afforestation are given below in relation to the River Irthing catchment in the north of England:

- Water yield tends to be less from forest than pasture;
- In the Coalburn sub-catchment (1.5 km²) study peak flows were found to increase by 20% in the first 5 years and times to peak decreased, with the effect reducing over time (to 5% after 20 years). The time to peak was also reduced;
- In the overall River Irthing catchment (335 km²) the same effect was observed but to a much smaller degree.

The Coalburn catchment provides lessons which may be relevant to parts of HA11, 12 and 13. The overall impact of afforestation is likely to be negligible in the greater catchment considering the small proportion, and small likely increase in proportion of forest coverage in the catchment. However the models receiving waters from upland areas may be susceptible to the potential affects of afforestation and as such some sensitivity analysis of the effects of afforestation at the HEFS would be prudent. As such it is recommended that sensitivity analysis to quantify the effects of potential afforestation is analysed at:

- HA12 Model 1 – Baltinglass
- HA12 Model 3 - Bunclody

In each of these models the effects of afforestation will be modelled using the following recommended adjustments to the input parameters:

Table 7.2: Allowances for Effects of Forestation / Afforestation (100 year time horizon)

| Mid Range Future Scenario (MRFS) | High End Future Scenario (HEFS) |
|-------------------------------------|---|
| - | - 1/3 Tp ¹ + 10% SPR ² |

Note 1: Reduce the time to peak (Tp) by one sixth / one third: This allows for potential accelerated runoff that may arise as a result of drainage of afforested land

Note 2: Add 10% to the Standard Percentage Runoff (SPR) rate: This allows for increased runoff rates that may arise following felling of forestry

(Extracted from 'Assessment of Potential Future Scenarios for Flood Risk Management' OPW, 2009)

7.3 LAND USE AND URBANISATION

The proportion of people living in urban areas (classified as towns with a population of 1,500 or more) has increased dramatically in recent years with a nationwide increase of over 10% in the total urban population recorded between the 2006 census and the 2011 census. The total population within the HA11, 12 & 13 counties has increased by varying degrees since 1991 as demonstrated by Table 7.3.

Table 7.3: Population Growth in the Counties of HA11, 12 and 13 (Source: CSO)

| | | 1991 | 1996 | 2002 | 2006 | 2011 |
|----------------|--|--------------|------------|-------------|------------|-------------|
| Carlow | Population (Number) | 40,942 | 41,616 | 46,014 | 50,349 | 54,612 |
| | Actual Change Since Previous Census (Number) | -46 | 674 | 4,398 | 4,335 | 4,263 |
| | Population Change Since Previous Census (%) | -0.11 | 1.6 | 10.6 | 9.4 | 8.5 |
| Wexford | Population (Number) | 102,069 | 104,371 | 116,596 | 131,749 | 145,320 |
| | Actual Change Since Previous Census (Number) | -483 | 2,302 | 12,225 | 15,153 | 13,571 |
| | Population Change Since Previous Census (%) | -0.5 | 2.3 | 11.7 | 13 | 10.3 |
| Wicklow | Population (Number) | 97,265 | 102,683 | 114,676 | 126,194 | 136,640 |
| | Actual Change Since Previous Census (Number) | 2,723 | 5,418 | 11,993 | 11,518 | 10,446 |
| | Population Change Since Previous Census (%) | 2.9 | 5.6 | 11.7 | 10 | 8.3 |

As Table 7.3 indicates, counties containing HA11, 12 & 13 AFAs, Carlow, Wexford and Wicklow have seen significant population rise since 1991. In particular Wexford's population has risen by over 10% for the last three record periods.

No county showed an increase in the share of the rural population since 2006 and as such the data would suggest that the population growth within HA11, 12 and 13 has been almost entirely within the urban centres.

Table 7.4 confirms that urban population growth within the urban AFAs (population > 1500) for the period 2006 – 2011 has been significant ranging from 10.5% in Wexford Town to 101.1% in Courtown over the five year census period.

Table 7.4: Population Growth within Urban AFAs (Source: CSO)

| Urban Area | County | Population 2011 | Increase Since 2006 (%) |
|-------------|---------|-----------------|-------------------------|
| Tullow | Carlow | 3,972 | 30.3 |
| Baltinglass | Wicklow | 1,735 | 18.8 |
| Courtown | Wexford | 2,857 | 101.1 |
| Enniscorthy | Wexford | 10,838 | 13.6 |
| Gorey | Wexford | 9,114 | 26.7 |
| Wexford | Wexford | 20,072 | 10.5 |

The total percentage population growth in these AFAs however is 33.5% for the period 2006 – 2011 which equates to an average annual growth rate of approximately 6.7%. To determine if these changes translate into equivalent increases in urbanised areas we must examine the CORINE database within HA11, 12 and 13 and the changes from 2000 to 2006. A simple comparison of the datasets within the HAs appears to show that there has been a modest increase in artificial surfaces within HA11, 12 and 13 from 31.3 km² in 2000 to 40.5 km² in 2006 which represents an increase of just over 29% in six years (see Figure 7.3).

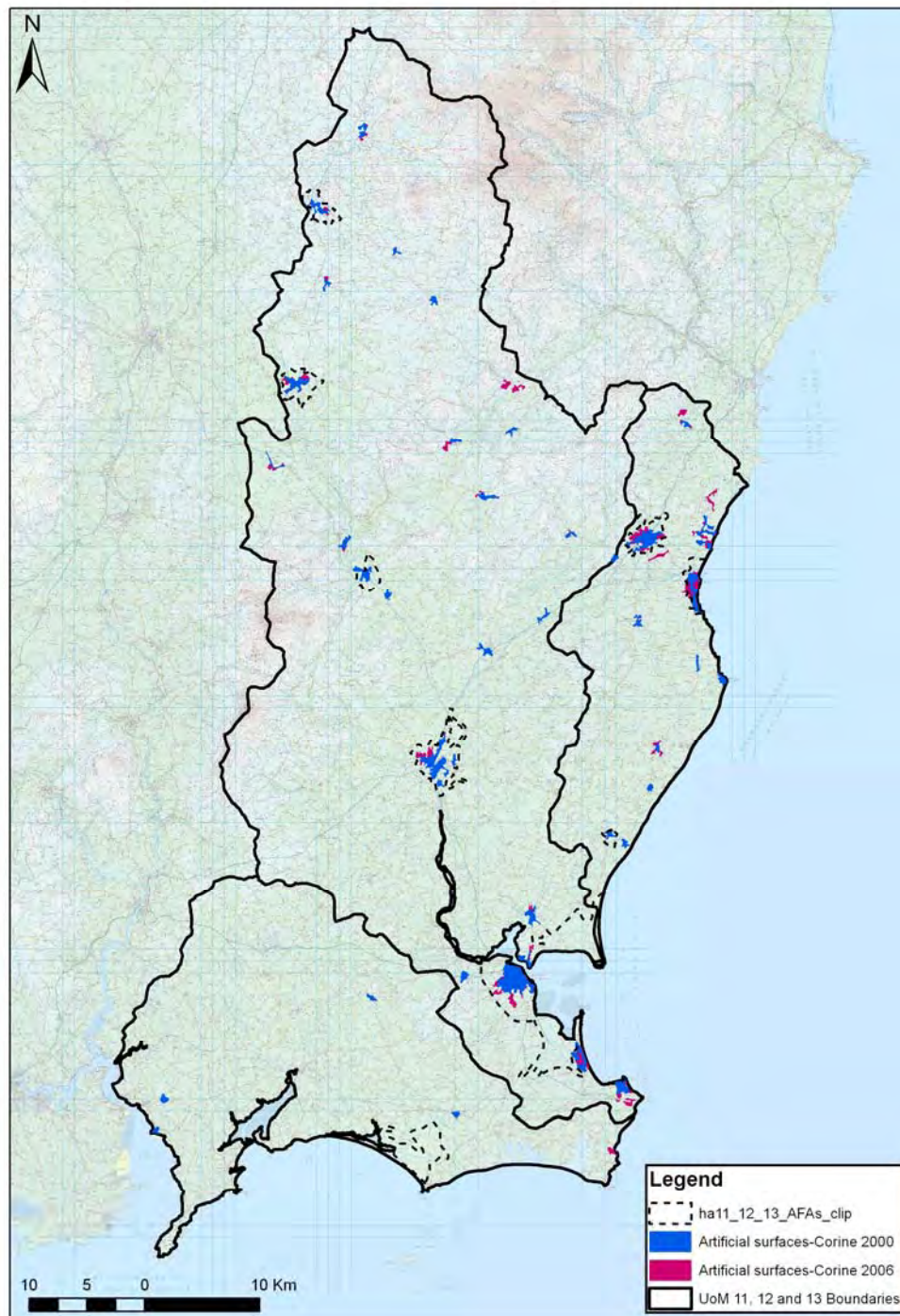


Figure 7.3: HA11, 12 & 13 CORINE Artificial Surfaces (2000 / 2006)

Closer inspection of the CORINE datasets shows that a notable proportion of this growth in artificial surfaces is due to changes outside the AFAs. There are 4.65 km² of additional urban fabric outside the AFAs, a considerable portion of which is classed as Discontinuous Urban Fabric. This denotes development such as private housing estates; scattered blocks of flats with garden areas; cemeteries etc, all of which are typical of having some degree of green space within their periphery. These types of development account for 4.2km² (45.7%) of the additional artificial surfaces. Although they generally have both permeable and impermeable surfaces and may increase runoff they will not affect the AFAs directly and as such for a more representative picture of the increase in urbanisation, the areas of

hardstanding within the AFA extents were compared. The only AFAs with an increase in the extent of artificial surfaces are:

- Baltinglass 10.3% increase (1.7% annually)
- Courtown 58.1% increase (7.9% annually)
- Enniscorthy 21.4% increase (3.3% annually)
- Gorey 42.6% increase (6.1% annually)
- Tullow 29.6% - increase (4.4% annually)
- Wexford 22.1% increase (3.4% annually)

The annual growth rate in the artificial surfaces within all HA11 and HA12 AFA extents is 4.5%.

The CSO has also produced Regional Population Predictions for the period of 2011 - 2026 based on a number of scenarios considering birth rates and emigration. Under all the modelled scenarios the South East region is set to experience strong population growth.

Under the M0F1 Traditional model, which tends to reflect longer term growth trends, the projected rise for the region in the 15 year period equals 8.6% equating to an average annual growth rate of 0.6%. Under the M2F1 Recent model, which tends to reflect more recent growth rates, the projected rise in population is 27% equating to an annual average growth rate of 1.8%.

Any estimation of the rate of urbanisation should consider the three measures of recent growth which have been examined along with the projected population increases from CSO for the region. These are summarised in Table 7.5.

Table 7.5: Historic Urbanisation Growth Indicators

| | Population in HA11/12/13 AFA Counties 1991 - 2011 | Population in HA11/12/13 Urban AFAs 2006 - 2011 | Artificial Surfaces (CORINE) within HA11/12/13 AFA Extent 2000 - 2006 | CSO M0F1 Population Projection 2011 - 2016 | CSO M2F1 Population Projection 2011 - 2016 |
|---|--|--|---|---|---|
| Average Annual Growth Rate (%) | 1.75% | 6.7% | 4.5% | 0.6% | 1.8% |

Table 7.5 indicates a significant spread of growth factors depending on the growth indicator. The high growth rates of population and urban extent within AFAs since 2000 could be considered to be inflated given the strong economic climate during this time period and are unlikely to continue. A more realistic estimate of future urbanisation growth rates in HA11, 12 and 13 are likely to be around 1% per annum. At the high end of projections a rate of approximately 2.5% is selected.

7.3.1 Impact of Urbanisation on Hydrology

The effect of urbanisation on runoff is well documented. The transformation from natural surfaces to artificial surfaces, which in almost all cases are less permeable, increases surface runoff such that it is generally faster and more intense. If we consider the FSU 'URBEXT' catchment descriptor at the most downstream FSU node in the Slaney catchment (downstream of Enniscorthy) currently at 0.68 which represents the percentage of urbanisation within the HA12, the URBEXT could potentially rise to between 1.84% urbanised (based on growth of 1% per annum) and 8% urbanised (based on growth of 2.5% per annum) over a 100 year projection. Applying a growth rate of 6.7% (refer to Table 7.5) over 100 years results in the URBEXT for the Slaney catchment rising to an URBEXT of 445% which clearly is unrealistic. A growth rate of 5.2% per annum would result in 100% urbanisation which again is beyond any reasonable estimate of the HEFS. Since the growth rates of 6.7% and 4.5% per annum are considered unlikely to continue and based on the 100 year URBEXT projections, they are not considered appropriate.

A more realistic estimate of future urbanisation growth rates in HA11, 12 and 13 are likely to be around 1% per annum. At the high end of projections a rate of approximately 2.5% is selected.

Using the FSU equation (WP 2.3) for index flow estimation (Q_{med}) based on catchment descriptors the Urban Adjustment Factor (UAF) for the Slaney catchment at the most downstream FSU node would vary as shown in Table 7.6 for the 100 year high end (HEFS) and mid range (MRFS) future scenarios.

Table 7.6: Potential Effect of Urbanisation on Q_{med} Flow in HA12

| | Growth Rate (per annum) | URBEXT ² | UAFS ¹ | Total Catchment Q_{med} Flow m ³ /s |
|---------------|----------------------------|---------------------|-------------------|---|
| Present Day | n.a. | 0.68 | 1.01 | 217.44 |
| 100 Year MRFS | 1.0% | 1.84 | 1.03 | 221.17 |
| 100 Year HEFS | 2.5% | 8.03 | 1.12 | 241.38 |

Note 1: Urban Adjustment Factor $(UAF) = (1 + URBEXT/100)^{1.482}$

Note 2: URBEXT is the percentage of urbanisation in the catchment

Note 3: Total Catchment – taken as most downstream FSU Node in HA12

Table 7.6 represents the overall Slaney catchment and as such can be considered a more generalised example of the potential effect of urbanisation. At one end of the scale, there are catchments with no existing urbanisation that could remain totally rural. This is likely to be the case in HA13 where URBEXT is currently zero. At the other end of the scale, there are also examples of catchments representing small watercourses on the edges of AFAs which are currently totally rural but which could become totally urbanised in 100 years time if the spatial growth of the urban fabric of the AFA occurs in the direction of that small catchment. In this scenario the application of growth rates to an existing

URBEXT value of zero will have no effect and as such the effect could be missed using a methodology that applies growth factors to the URBEXT values. It must also be considered that any attempts to predict the spatial growth of AFAs on a 100 year time frame would be highly uncertain as growth rates and growth direction are dictated by complex social, economic and cultural factors which cannot be predicted far into the future.

We must also consider the effect of recent developments in sustainable drainage policy and guidance. The move away from conventional drainage systems is likely to gather pace with the aim of these policies and systems to provide drainage for urban areas which recreates the runoff behaviour of the rural catchment in an attempt to mitigate flood risk. Sustainable drainage policy is already being implemented in Dublin through the Greater Dublin Strategic Drainage Strategy (GDSDS). It is largely in its infancy outside the capital but it would be expected to develop greatly throughout time span of the future scenarios. Therefore the current effect of urbanisation on catchment runoff could be expected to reduce over time as sustainable drainage policy and systems develop.

In light of these large uncertainties it is not considered prudent to attempt to predict the varying effects of urbanisation on a HEP by HEP basis and as such it is considered prudent to apply a factor based on the average URBEXT values within the Unit of Management and the growth rates considered above of 1% and 2.5% respectively for the medium and high end future scenarios.

It is still considered prudent though that small urban watercourses with catchments that emanate around the periphery of AFA extents are considered to become much more urbanised and as such will be considered as having URBEXTs of 50% for the mid range and 85% for the high end future scenarios (85% is considered the urban saturation level as some green spaces will always remain). The urban adjustment factors are then moderated by 50% to make allowance for the effect of future sustainable drainage policy in urban areas. This is particularly relevant to two small urban watercourses in Wexford and one in Enniscorthy which currently have an average URBEXT value of 51.9% and range between 30.57 and 70.6% and could become totally urbanised in the future. In cases where URBEXT is already 50% or greater, both MRFS and HEFS will be taken as 85%.

The urban adjustment factors which will therefore be applied to the design flow estimates for the mid range and high end future scenarios are shown in Table 7.7.

Table 7.7: Potential Effect of Urbanisation on Q_{med} Flow in HA11 and HA12.

| | Growth Rate (per annum) | URBEXT ² | UAF ¹ | UAF (adjusted for SuDS) |
|--|-------------------------|---------------------|------------------|-------------------------|
| HEP Average | | 0.48 | 1.01 | n.a. |
| 100 Year MRFS | 1% | 1.3 | 1.02 | n.a. |
| 100 Year HEFS | 2.5% | 5.67 | 1.09 | n.a. |
| Tributary Catchments susceptible to full urbanisation | n.a. | varies | varies | varies |
| 100 Year MRFS | | 50 | 1.82 | 1.412 |
| 100 Year HEFS | | 85 | 2.49 | 1.744 |

Note 1: Urban Adjustment Factor $(UAF) = (1 + URBEXT/100)^{1.482}$

Note 2: URBEXT is the percentage of urbanisation in the catchment

The allowances for urbanisation are based on a robust analysis of population growth, recent increases in artificial surfaces and population projections from CSO. However this is based on extrapolation of current growth rates which are dependent on complex social, economic and environmental factors. Furthermore the estimation of the Urban Adjustment Factor under FSU is based on data from existing urban catchments and therefore does not reflect the impact of recent policy changes and changes to drainage design guidelines where the emphasis is on developments replicating the existing 'greenfield' flow regime through attenuation and sustainable urban drainage systems. An approach has been developed that considers an average adjustment factor for the majority of HEPs across HA11 and HA12. These adjustment factors will translate into increases in flow of approximately 3% and 12% for the mid range and high end future scenarios respectively. Small rural catchments emanating from just outside AFAs which would be susceptible to full urbanisation are to be considered separately and will see their flows increase by up to 41% and 74% for the mid range and high end future scenarios respectively. Small highly urban catchments in Wexford and Enniscorthy which would be susceptible to full urbanisation are to be considered separately and will see their flows increase by up to 21% and 46% for the mid range and high end future scenarios respectively.

There is high uncertainty in all of these allowances as discussed above and it is recommended that they are reviewed at each cycle of the CFRAM Studies.

7.4 HYDROGEOMORPHOLOGY

Hydrogeomorphology refers to the interacting hydrological, geological and surface processes which occur within a watercourse and its floodplain. Erosion and deposition of sediment are natural river processes that can be exacerbated by anthropogenic pressures such as land use practices and arterial drainage.

7.4.1 Soil Type

Figure 7.4 overleaf illustrates the soil types that characterise HA11, 12 and 13. The predominantly flat landscape across HA11, 12 and 13 is reflected by the predominance of deep well drained mineral podzols with interspersed lithosols across HA12 and HA13. The north east corner of HA12 is characterised by peat and peaty podzols where the western edge of the Wicklow Mountains are located. Peaty podzols are also located in the Blackstairs Mountains to the west of HA12 above Bunclody. The eastern seaboard through HA11 is characterised by deep gleys and also shallow well drained mineral lithosols to the north and south of Blackwater. The deep gleys are also predominant to the south west of Wexford and into HA13 as far south as Kimore. The North and South Slob within HA12 are characterised by marine/estuarine sediments.

The predominance of well drained mineral soils is conducive to its agricultural fertility and predominance of tillage land use. To the north east of HA12, the peaty soils would indicate relatively high susceptibility to soil erosion and can be considered a source of sediment which if accelerated due to anthropogenic pressures and given the right pathway (channel typology) can make its way to the watercourse network which drains towards Baltinglass at the upper end of the River Slaney. The deep gleys along the eastern seaboard downstream of Gorey and in the vicinity of Courtown indicate poorly drained soils and higher potential for surface water runoff.

There is currently ongoing research in Ireland and the UK involving modelling the risk of diffuse pollution in river catchments, including sediment transport. Recent research has focussed attention on assessing risk based on erodibility and hydrological connectivity to the river network, with land use/land cover the most common measure of erodibility. While soil type clearly has an influence on erodibility, Reaney et al. (2011) argue that an emphasis upon land cover is warranted as land cover is typically correlated with soil type (refer to Section 7.4.3).

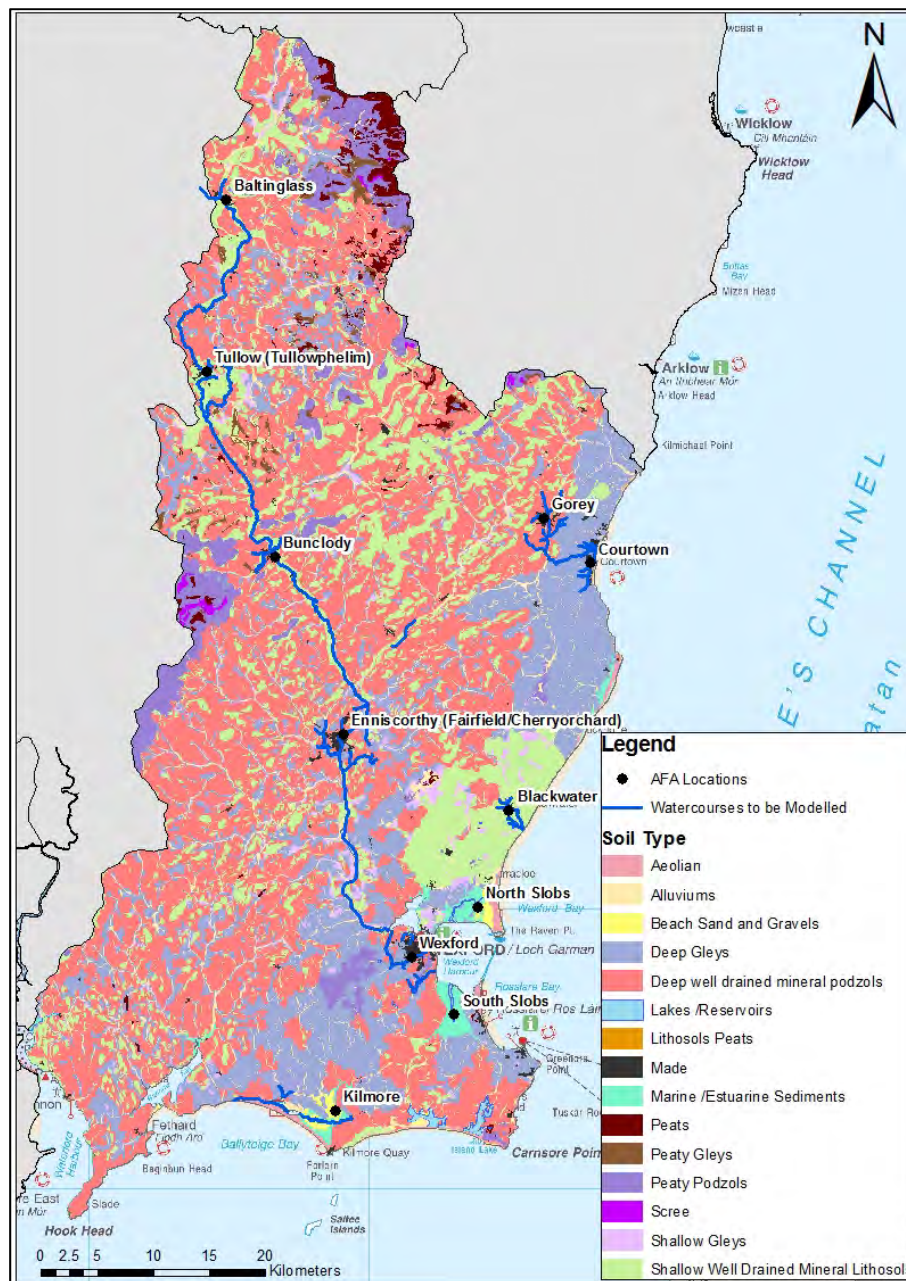


Figure 7.4: HA 11, 12 and 13 Soil Types (Source: Irish Forest Soils Project, FIPS – IFS, Teagasc, 2002)

7.4.2 Channel Typology

As part of national EU Water Framework Directive 2000/60/EC (WFD) studies on hydromorphology through River Basin District projects a national channel typology dataset was defined for Irish rivers². It classified river channels into channel type at 100m node points along each reach. It is based on four key descriptors which categorise rivers according to channel type. Table 7.8 below outlines the four main channel types and how these relate to valley confinement, sinuosity, channel slope and geology.

² (http://www.wfdireland.ie/docs/20_FreshwaterMorphology/CompassInformatics_MorphologyReport)

Table 7.8: Channel Types and Associated Descriptors

| Channel Type | Confinement | Sinuosity | Slope | Geology |
|----------------------------|--------------------|------------------|--------------|------------------|
| Step Pool / Cascade | High | Low | High | Solid |
| Bedrock | High | Low | Variable | Solid |
| Riffle & Pool | Low - Moderate | Moderate | Moderate | Drift / Alluvium |
| Lowland Meander | Low | High | Low | Drift / Alluvium |

Typical undisturbed channel behaviour in terms of flow is described as follows for each of the channel types shown:

Bedrock:

- Boulders and cobbles often exposed, but few isolated pools.
- Overbank flows uncommon.
- Morphology only changes in very large floods.

Cascade and step-pool:

- At low flows, many of the largest particles (boulders, cobbles) may be exposed, but there should be continuous flow with few isolated pools. Valley confinement and low sinuosity associated with this channel type are conducive to erosion processes given the high energy, velocities and steepness of the channels.

Pool-riffle:

- Gravel bars may be exposed in low water conditions, but gravels and cobbles in riffles as well as logs and snags are mainly submerged.

Lowland Meandering:

- In low flow conditions some bars or islands may be exposed, but water fills the majority of the channel. Low valley confinement and high sinuosity associated with this channel type are conducive to sediment deposition as the river slows down, moves laterally within its floodplain and loses energy.

In the national context, the Slaney catchment is a relatively low slope, low energy meandering system through the middle reaches although it is fed by steeper tributaries as it nears the coast. HA11 is characterised by several small relatively steep coastal rivers. The largest system in HA11 is the Owenavorrach which is generally lowland meandering. HA13 is characterised by low slope coastal and tidally influenced channels that are predominantly pool-riffle and lowland meandering. Channel type and slope for HA11, 12 and 13 rivers are indicated by Figure 7.5 and 7.6.

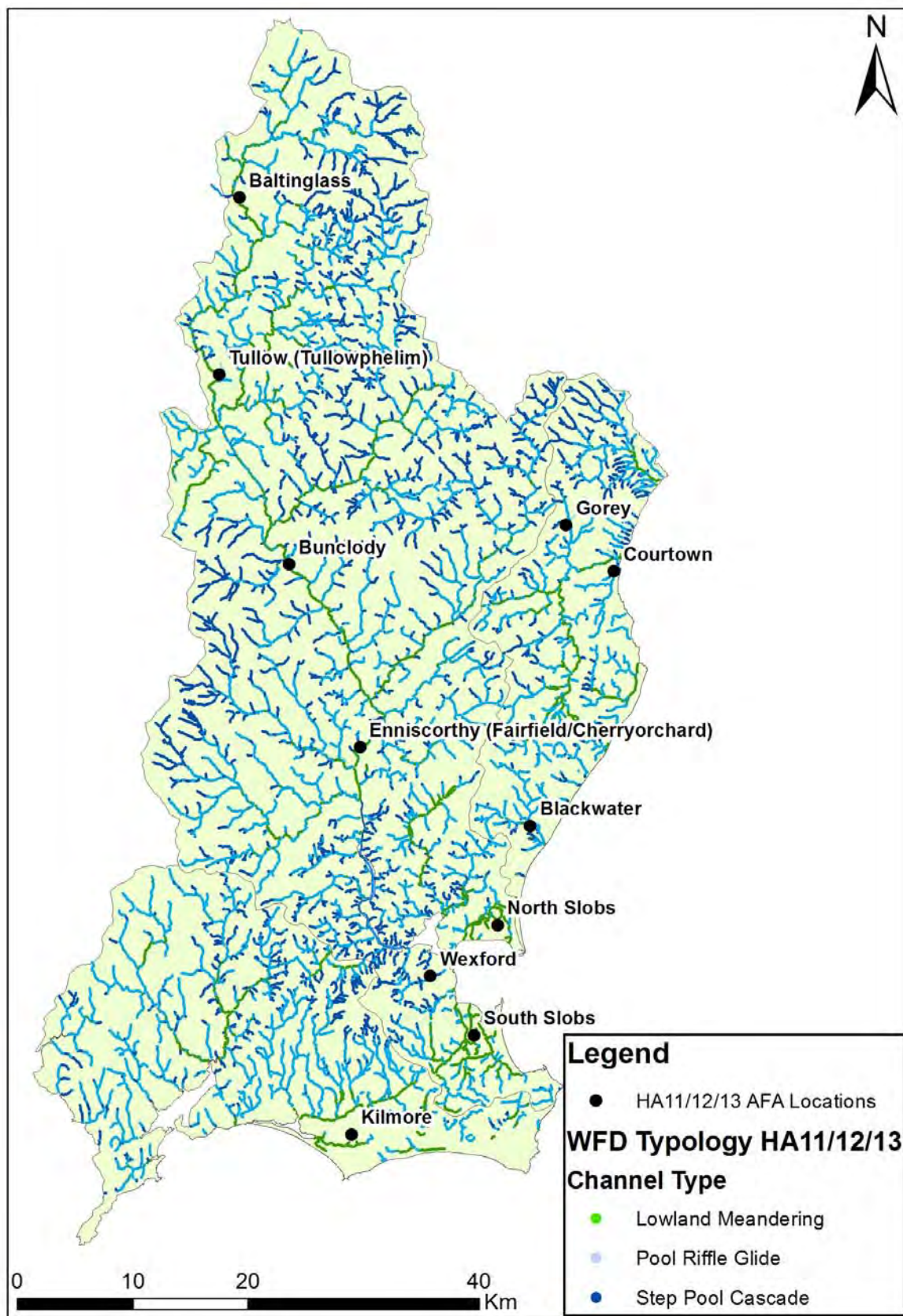


Figure 7.5: WFD Channel Typology HA11, 12 & 13

As indicated by Figure 7.5, the Slaney main channel is classified as lowland meandering for all modelled reaches from Baltinglass to Enniscorthy. From Enniscorthy to Wexford, the Slaney is still lowland meandering but it is also tidally influenced, meaning that it is not included in this rivers only dataset. Modelled tributaries of the River Slaney are predominantly pool riffle glide as far downstream as Enniscorthy. Downstream of Enniscorthy, tributaries are predominantly higher energy step-pool cascade as they drain smaller steeper catchments before joining the Upper Slaney Estuary.

These channel types also represent the change in channel slope from relatively steep to relatively shallow moving downstream. Figure 7.6 indicates the change in channel steepness across HA11, 12 and 13. It can be seen that the steepest channels are located to the north east of HA12 within the Wicklow Mountains with a maximum slope of 0.332 (in other words 1 in 3). To the east, north of Gorey and Courtown the headwaters from Croaghan Mountain are the steepest within HA11 with a maximum slope of 0.195 (1 in 5). Similarly headwaters rising in the Blackstairs Mountains to the west have a maximum slope of 0.229 (1 in 4). These steeper channels are the upper reaches of tributaries that meet the River Slaney at Bunclody and Enniscorthy approximately 7km and 17km downstream respectively. The smaller catchments feeding upper Slaney Estuary north of Wexford have a maximum slope of 0.17 (1 in 6). The remainder of HA11, 12 and 13 is characterised by relatively low energy low slope channels, particularly HA13 which is very flat for much of its area.

These channel types are typical of Irish catchments. Sediment transport, erosion and deposition are natural morphological processes. It is expected that the upper reaches will be more dynamic and as the river moves to the lower lands, sediment is accumulated and transported. Sediment deposition is expected where the channel meanders and loses energy. Based on Figure 7.5 and 7.6, the AFAs that could be affected by sediment deposition are:

- Baltinglass
- Bunclody
- Enniscorthy
- Wexford

This only becomes an issue if too much sediment is transported from the upper reaches and deposited causing channel capacity issues or localised damage to flood defence structures from scour.

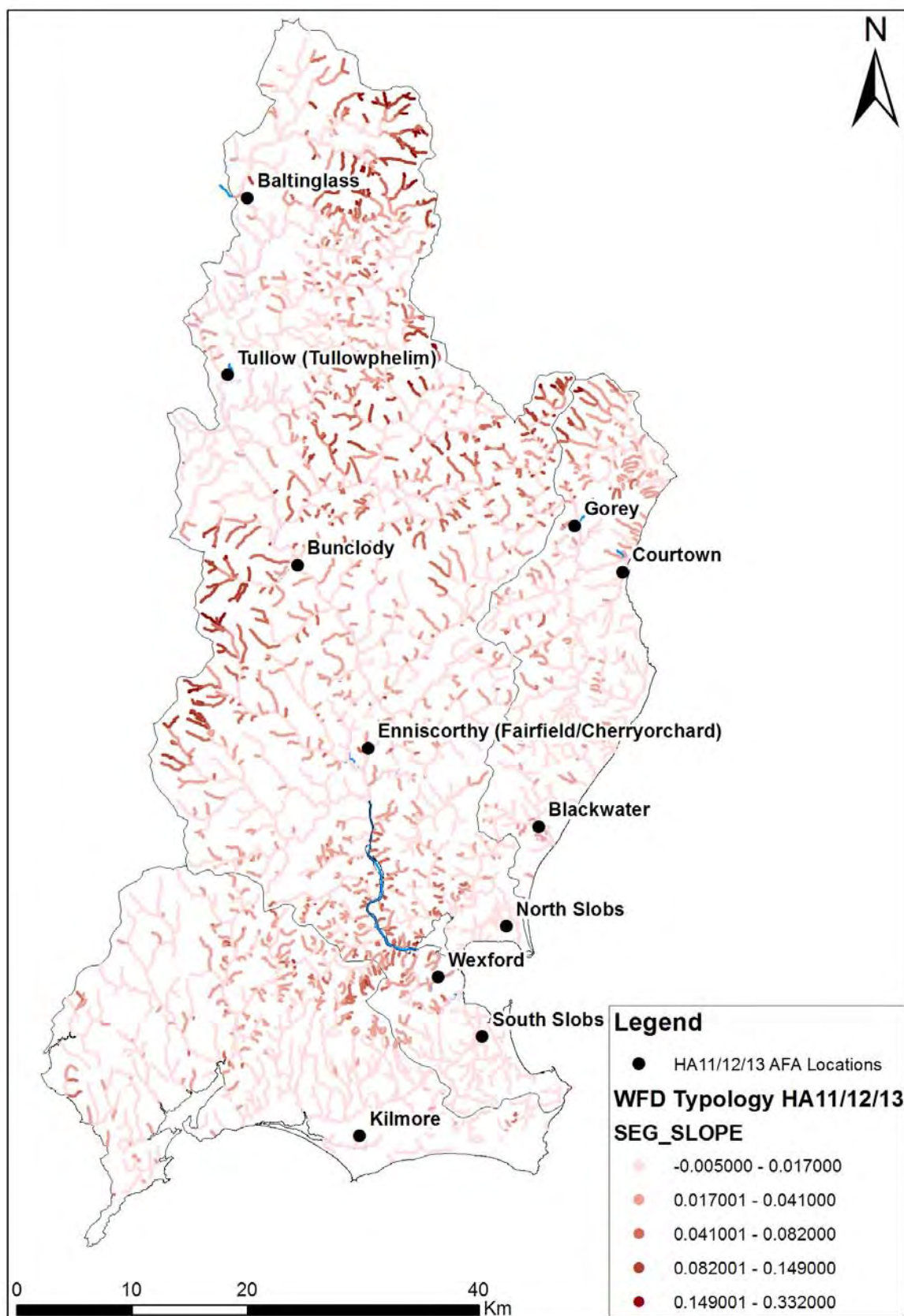


Figure 7.6: Changes in Channel Slope HA11, 12 & 13

7.4.3 Land Use and Morphological Pressures

A sediment study on the River Nore has recently been undertaken by the Environmental Protection Agency (Walsh et al, 2012) with one of the key aims of measuring silt accumulation along the River during base flow conditions. Whilst this study was primarily focussed on freshwater pearl mussel preservation, fisheries and water quality of the River Nore (HA 15) the report also provides mean suspended solid concentrations of several river systems including the River Slaney.

Suspended solid results for the River Slaney from January to March 2012 showed a mean concentration of 7mg/l which was stated as being well below the standard of 25mg/l in the Freshwater Fish Directive and Irish Salmonid Regulations suggesting that siltation is not an issue. However, we must take a look at anthropogenic pressures within the Study Area to ascertain potential impact on flood risk due to increased sediment load within the river systems. As discussed in Section 7.4.1 land use/land cover is becoming the most common measure of soil erodibility in national research.

Figure 7.7 illustrates the land use types within HA11, 12 and 13. It is essentially a rural catchment with 30% arable land coverage and 50% pasture coverage.

Urban fabric accounts for 1.2% of the total area of HA11, 12 and 13. There are pockets of peat bog to the north east and west of HA12 accounting for 2.9% of the overall area.

7.4.3.1 Peat Extraction

Drainage of bog lands and peat extraction activities potentially lead to large quantities of peat silt being discharged to the receiving waters. This may be a consideration in Baltinglass which is located downstream of the peat bogs in the Wicklow Mountains; and Bunclody and Enniscorthy, which are downstream of the Blackstair Mountains peat bogs.

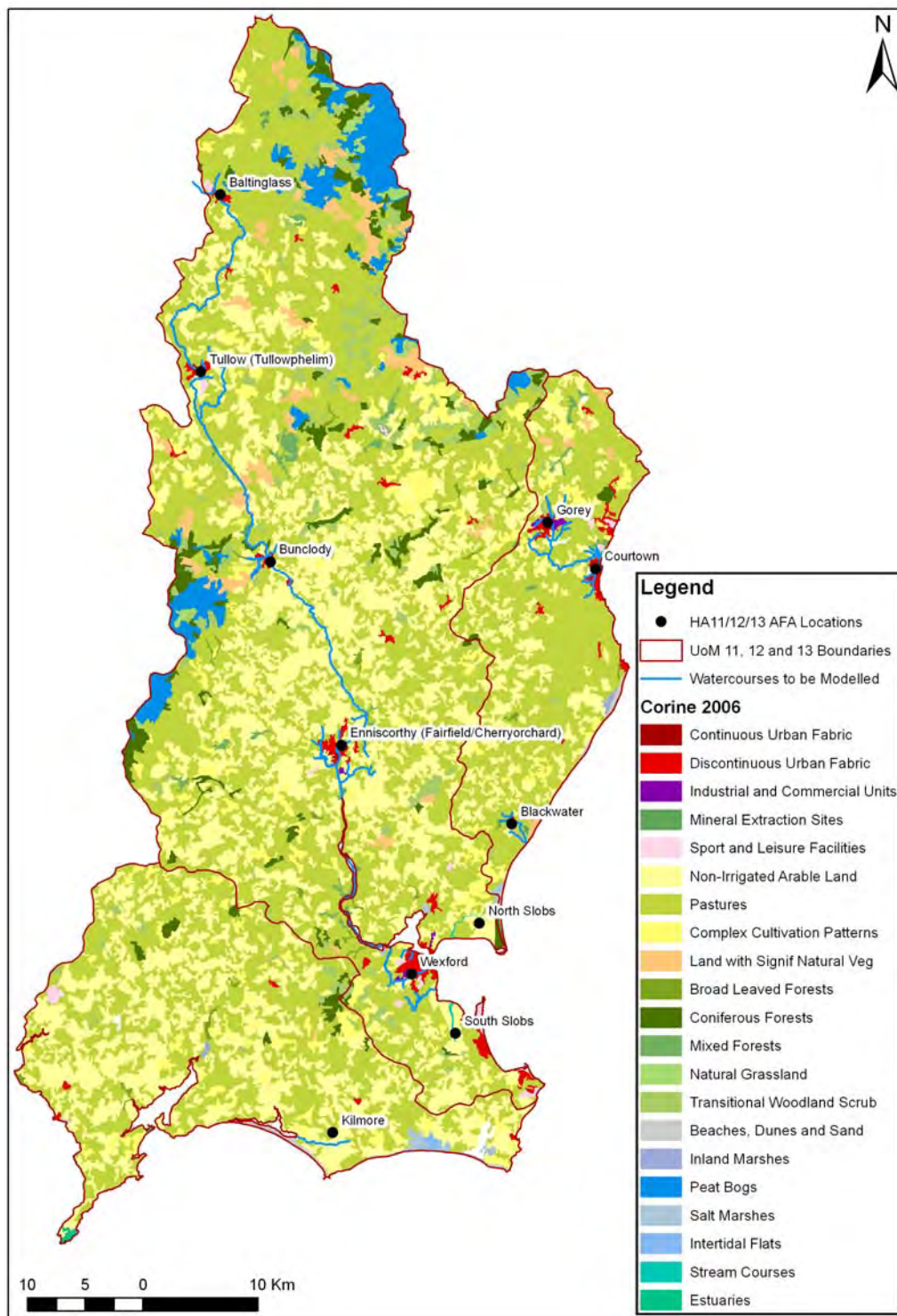


Figure 7.7: HA11, 12 & 13 Land Use (CORINE 2006)

7.4.3.2 Arable Land

Overall the extensive coverage of pasture (grassland) suggests that in general, the level of exposed soil is limited within the catchment. However there is a significant presence of arable land, particularly in close proximity to modelled watercourses as shown on Figure 7.7. Closer inspection of the CORINE dataset reveals that HPWs/MPWs flow through almost 320km² of arable land partially or

wholly affecting all Models within HA11, 12 and 13. Depending on agricultural practices, farming of arable land can lead to increased soil loss to receiving watercourses through ploughing and extensive exposure of soils, which will be exacerbated if environmental measures such as buffer strips along river banks are not employed. At a localised scale, this can increase flood risk due to silting up of smaller channels and loss in channel capacity, on a catchment scale the extent of arable land throughout the Study Area warrants further consideration. In addition, increased sediment causing scour of flood defences within AFAs must be considered.

7.4.3.3 Impact of Land Use and Morphological Pressures

The impact of hydro-geomorphological changes ultimately applies to the performance of flood risk management options. The impact of sediment transport and deposition will be considered further under the hydraulic modelling of options stage of the CFRAM Study for all Models since there is the potential for changes to channel capacity due to fluctuations in sediment load. A previous example of this is in Enniscorthy where a flood relief scheme is soon to commence construction. A report prepared by OPW describing the scheme³ indicates that during option development it was found that a meandering reach of the Slaney located 1km upstream of the town acted as a sediment trap whereby it deposited out transported sediment from upstream and formed a river island. It was concluded that proposed river widening along the reach would increase flow velocities and possibly result in the loss of this natural deposition area during a flood event, with sediment then transported further downstream compromising the flood relief scheme. As a result, supplementary measures (additional widening around the island to negate flood velocity and bed protection to reduce erosion) were identified to ensure sediment deposition would still take place upstream of the town. The report also indicates that debris such as tree branches is a flood feature of the Slaney which should be considered in option development.

7.4.4 Arterial Drainage

A further consideration in HA11, 12 and 13 is the potential effect of arterial drainage on watercourse channel and floodplain geo-morphology. The original Arterial Drainage Act, 1945 was a result of the Browne Commission which examined the issue of flooding and the improvement of land through drainage works and was mainly focussed on the agricultural context. Following flood events in the mid to late 80s the emphasis on flood management shifted to the protection of urban areas and as such the Arterial Drainage Amendment Act was passed in 1995. This widened the scope of the act to cover the provision of localised flood relief schemes. The OPW have used the Arterial Drainage Acts to implement various catchment wide drainage and flood relief schemes. Arterial drainage scheme works may consist of dredging of the existing watercourse channels, installation of field drains / drainage

³ 2425/RP/002/A (May 2012) – River Slaney (Enniscorthy Town) Drainage Scheme – Description of the Scheme

ditches and the construction of earthen embankments using dredged material to protect agricultural land.

The extent of the watercourses affected by arterial drainage within HA11, 12 and 13 is captured in the FSU physical catchment descriptors defined under FSU Work Package 5.3. The catchment descriptor nodes which have a length of arterial drainage defined within the catchment are shown in Figure 7.8.



Figure 7.8: Modelled Watercourses affected by arterial drainage in HA11, 12 & 13

As indicated by Figure 7.8, modelled watercourses affected by arterial drainage are the Kilmore/Ballyteigue Watercourse in HA13 and the Owenavorrigh at Courtown in HA11.

The Ballyteigue/Kilmore Minor Arterial Drainage Scheme took place between 1959 and 1961 and included the entire reach of HPW in HA13. The Owenavorrigh Minor Arterial Drainage Scheme took place between 1968 and 1970.

7.4.4.1 The Impact of Arterial Drainage Scheme on HA11, 12 and 13 Hydrology

The effect of arterial drainage relates to the River Owenavorrigh in Courtown (HA11) and the HPW flowing through Kilmore AFA (HA13). Both schemes were minor in terms of acreage of benefitting land involving river widening and deepening and in the case of Kilmore, construction of flood embankments. The long term effect of the schemes is to increase channel conveyance capacity.

The effect of arterial drainage schemes across Ireland was considered in FSU WP 2.3 Flood Estimation in Ungauged Catchments through the analysis of gauging station records where there was a pre and post arterial drainage scheme record. Analysis of the gauge station record showed a wide degree of variance in the pre and post arterial drainage index flood flow (Q_{med}) values but the average change was to increase the Q_{med} value by approximately 50%⁴. This is in line with previous research carried out on Irish catchments which suggested that arterial drainage schemes can lead to significant changes in peak discharge of up to 60% (Bailey and Bree 1981).

Hydrometric data is not available to compare pre and post drainage Q_{med} values for either drained watercourse. The hydrometric station located on the Owenavorrigh (11001 – OPW at Boleany) only has records as far back as 1972, whilst the scheme was completed in 1970. There are no hydrometric stations on the Kilmore watercourse.

The hydrological analysis and design flow estimation undertaken as part of this study seek to represent as accurately as possible the present day scenario. The ARTDRAIN2 FSU catchment descriptor is included in the ungauged index flow estimation equation where applicable. As such the initial Q_{med} estimates based on catchment descriptors have the effect of arterial drainage built in. When choosing a pivotal site with which to donate gauged data for adjustment of the initial estimate, the selection process included consideration of the arterial drainage history of pivotal candidates so that the most appropriate choice was made.

7.4.5 River Continuity

River continuity is primarily an environmental concept relating to the linear nature of the river eco system and its disruption due to manmade structures such as weirs and dams which alter river flow and can impede fish migration. It is a morphological pressure which has been given consideration

⁴ Extracted from Table 13 of FSU Work Package 2.3

under the Water Framework Directive. Any collated data is of use from a flood risk management perspective as it provides information on such structures and as such can be accounted for in terms of flow regulation in hydraulic modelling.

The risk of impassability may also be an indication of significant hydraulic control and as such is useful in hydraulic modelling. The channel and structure survey undertaken specifically for the South Eastern CFRAM Study includes full geometric survey of these structures and as such ensure their inclusion in the hydraulic modelling phase.

7.4.6 Localised Pressures

As well as the catchment based pressures discussed in this report, localised morphological changes can have an impact on channel capacity and the structural integrity of flood defences due to the effects of scour from high sediment loads within rivers. For example known areas of bank erosion within AFAs can undermine existing channel structures. At this stage of the study, data relating to such localised effects within AFAs has not been received for inclusion in this analysis. Localised areas of bank erosion caused by e.g. cattle poaching were recorded and photographed within AFAs during CFRAM Study team site audits. These are documented and will be fed into the option development process so that such localised risks in terms of channel capacity issues or adverse effects on channel structures can be mitigated. It is also recommended that Progress Group members confirm if such data is available within their organisations that could be of use in the options development process.

7.5 FUTURE SCENARIOS FOR FLOOD RISK MANAGEMENT

OPW does not have a specific policy for the design of flood relief schemes but has produced a draft guidance note 'Assessment of Potential Future Scenarios for Flood Risk Management' (OPW, 2009). The document gives guidance on the allowances for future scenarios based on climate change (including allowing for the isostatic movement of the earth's crust), urbanisation and afforestation. Table 1 from the guidance has been adapted for the purposes of this study to take into account catchment specific effects and is presented here as the basis (Table 7.9) for the design flow adjustment for the mid range (MRFS) and high end (HEFS) future scenarios.

Table 7.9: HA11, 12 and 13 Allowances for Future Scenarios (100 year time horizon)

| | MRFS | HEFS |
|--------------------------------|---|---|
| Extreme Rainfall Depths | + 20% | + 30% |
| Flood Flows | + 20% | + 30% |
| Mean Sea Level Rise | + 500mm | + 1000mm |
| Urbanisation | UAF ³ of 1.03 Urban W.C. UAF ⁴ of 1.41 | UAF ³ of 1.12 Urban W.C. UAF ⁴ of 1.74 |
| Afforestation | - | - 1/3 Tp ¹ + 10% SPR ² |

Note 1: Reduce the time to peak (Tp) by one sixth / one third: This allows for potential accelerated runoff that may arise as a result of drainage of afforested land

Note 2: Add 10% to the Standard Percentage Runoff (SPR) rate: This allows for increased runoff rates that may arise following felling of forestry

Note 3: UAF (Urban Adjustment Factor) to be applied to 'greenfield' flow estimates.

Note 4: UAF (Urban Adjustment Factor) for small urban tributaries within AFA extents. To be assessed on a case by case basis.

7.6 POLICY TO AID FLOOD REDUCTION

Considering the projected growth in population predicted within HA11, 12 and 13 the main future change which could increase flood risk is urbanisation of the catchment. If not managed correctly rapid urbanisation could lead to large swathes of the catchment becoming hard paved and drained through conventional drainage systems which are designed to remove water from the urban area quickly and efficiently. This could have potentially significant implications for fluvial flooding as the flood flows in the watercourses and rivers would intensify. Some of the smaller watercourses in particular could become prone to flash flooding if they become urbanised.

Sustainable Urban Drainage (SuDS) policy has been about for over a decade now in the UK and Ireland. It is a key concept in OPW's "The Planning System and Flood Risk Management Guidelines for Planning Authorities" as published in November 2009. The term covers a range of practices and design options that aim to replicate the pre-development surface water runoff characteristics of the undeveloped catchment following development both in terms of water quality but more importantly, from the perspective of flood risk management, in terms of runoff peak flow, intensity and volume. Typical measures include soft engineered solutions such as filter strips, swales, ponds and wetlands and hard engineered solutions such as permeable paving, 'grey water' recycling underground storage and flow control devices. The implementation of successful SuDS requires a joined up policy that covers planning, design, construction and maintenance. One of the biggest issues surrounding SuDS implementation is long term ownership and maintenance although the long term benefits of SuDS can be shown to outweigh the costs associated with these issues.

If a comprehensive SuDS policy is implemented covering planning, implementation and maintenance, then the impacts of urbanisation on flood flows can be substantially mitigated.

8 SENSITIVITY AND UNCERTAINTY

Hydrological analysis and design flow estimation are probabilistic assessments which originate from observed data. The long term conditions which affect the observations, whether they are climatic or catchment, have been shown to varying degrees to be changing over time. Further to this the degree of uncertainty within the sub-catchments analysed under the South Eastern CFRAM Study varies greatly due to the quality and availability of observed data. The following factors which may affect the quality of both the analysed historic events and the estimation of the future design events are listed below:

- Hydrometric data record length and gaps
- Hydrometric data quality (classified in terms of the rating confidence under FSU WP 2.1)
- High quality meteorological data availability
- Calibration quality of hydrological models (generally a result of all of the above)
- Standard error of flow estimation (catchment descriptor based) techniques
- Future catchment changes, urbanisation, afforestation etc.
- Climate change

The above list is not exhaustive but seeks to identify the main potential sources of uncertainty in the hydrological analysis. In terms of climate change, National University of Ireland, Maynooth recently completed a study entitled “Stress Testing Design Allowances to Uncertainties in Future Climate: The Case of Flooding” (Murphy et al, 2011). The aim of the study was to undertake a sensitivity analysis on the uncertainty inherent in estimates of future flood risk. The estimate concerned is the use of a +20% factor to increase peak flows under the MRFS. Four case study catchments were looked at, the Moy and Suck in the west, the Boyne in the East and the Munster Blackwater in the South East. The Study concluded that the inherent uncertainty associated with this +20% factor is greatest for flood events of lower AEP (higher return period), and that this has design implications for flood protection infrastructure e.g. culverts, flood bridges, since they are designed for lower frequency events e.g. 1% AEP. The Study also noted that there was a variation between study catchments in the percentage change in peak flows associated with 20%, 4%, 2% and 1% AEP events under climate change compared with present day scenarios. The western catchments (Moy and Suck) experienced greater magnitudes of changes in flood frequency than those in the east (Boyne) and South West (Munster Blackwater). This would indicate a greater level of uncertainty associated with the +20% MRFS factor for climate change when applied in the west of the country.

Further to these the list of factors which could potentially affect the uncertainty and sensitivity of the assessment of flood risk under the South Eastern CFRAM Study is subject to further uncertainties and sensitivities related to the hydraulic modelling and mapping stages. Examples of some of the modelling considerations which will further affect the sensitivity / uncertainty of the CFRAM Study outputs going forward from the hydrological analysis are past and future culvert blockage and survey error (amongst others). These considerations will be considered through the hydraulic modelling and

mapping report along with the hydrological considerations listed here to build a complete picture of uncertainty / sensitivity of Study outputs.

It is not possible to make a quantitative assessment of all of the uncertainties as some of the factors are extremely complex. Nevertheless it is important that an assessment is made such that the results can be taken forward and built upon through the subsequent phases of the study. It is also important that the potential sources of uncertainty in the hydrological analysis and design flow estimation are flagged such that the integrated process of refining the hydrological inputs and achieving model calibration can be achieved more efficiently through a targeted approach. A qualitative assessment has therefore been undertaken to assess the potential for uncertainty / sensitivity for each of the models and is provided in this chapter (Table 8.1 overleaf). The assessed risk of uncertainty is to be built upon as the study progresses through the hydraulic modelling and mapping stages. Following completion of the present day and future scenario models the assessed cumulative uncertainties can be rationalised into a sensitivity / uncertainty factor for each scenario such that a series of hydraulic model runs can be performed which will inform the margin of error on the flood extent maps.

8.1 UNCERTAINTY / SENSITIVITY ASSESSMENT MODEL BY MODEL

Table 8.1: Assessment of contributing factors and cumulative effect of uncertainty / sensitivity in the hydrological analysis

| Model No. | Model Name | Uncertainty / Sensitivity – Present Day Scenario | | | | Uncertainty / Sensitivity – Future Scenarios | | | | Notes |
|-----------|------------|--|----------------------------------|-----------------------------|--------------------------------------|--|---------------------------|-----------------------------|-----------------------|--|
| | | Observed Flow Data ¹ | Simulated Flow Data ² | Catchment Data ³ | Ungaaged Flow Estimates ⁴ | Forestation ⁵ | Urbanisation ⁶ | Climate Change ⁷ | Sediment ⁸ | |
| HA11 1 | Courtown | Medium / Low | n.a. | Medium | Medium | Low | Medium | Medium | Medium | Uncertainty with Hydrometric Station 11001 arising from short period of useable record, unsatisfactory calibration of NAM model (no rainfall radar available for input) so it was not used for further analysis. Significant difference between FSU Qmed pcd and Qmed gauged but rating review increased confidence in gauged value. Flows may be high given high adjustment factor used. Review during modelling phase. Medium risk of sensitivity to sediment – at downstream end of steep catchment with arable land use that may exacerbate soil erosion in an area of poorly drained soils. |
| HA11 2 | Blackwater | n.a. | n.a. | Low | Medium | Low | Low | Medium | Medium/Low | No gauged data or simulations. Ungaaged catchment Qmed estimate uses data from Stn 25034 as pivotal site. This is not geographically closest (11001 is buy yields results above confidence limit and is not within the catchment), 25034 yields results well within the limit and similar to the result given by 5 out of 7 pivotal site options. Medium/Low risk of sensitivity to sediment, well drained soils with |

| Model No. | Model Name | Uncertainty / Sensitivity – Present Day Scenario | | | | Uncertainty / Sensitivity – Future Scenarios | | | | Notes |
|-----------|-------------|--|----------------------------------|-----------------------------|--------------------------------------|--|---------------------------|-----------------------------|-----------------------|--|
| | | Observed Flow Data ¹ | Simulated Flow Data ² | Catchment Data ³ | Ungauged Flow Estimates ⁴ | Forestation ⁵ | Urbanisation ⁶ | Climate Change ⁷ | Sediment ⁸ | |
| | | | | | | | | | | little arable land near channel, no other exacerbating land uses. |
| HA11 3 | Gorey | Medium / Low | High | Medium | Medium | Low | Medium | Medium | Medium | <p>Uncertainty with Hydrometric Station 11001 arising from short period of useable record, unsatisfactory calibration of NAM model (no rainfall radar available for input) so it was not used for further analysis. Significant difference between FSU Qmed pcd and Qmed gauged but rating review increased confidence in gauged value. Flows may be high given high adjustment factor used but 11001 is at d/s end of model and so has been used. Review during modelling phase</p> <p>Medium sensitivity to sediment - Downstream of relatively steep high energy watercourse network which can act as a pathway. Arable land upstream of AFA.</p> |
| HA12 1 | Baltinglass | Medium / Low | Medium/Low | Low | Medium/Low | Medium/Low | Low | Medium | Medium | <p>NAM output for Stn 12013 in keeping with gauged data. The Station is B rated so confidence in flow values is only up to Qmed. NAM increases statistical certainty due to augmented AMAX series – this station is used as a pivotal site for ungauged estimates.</p> <p>Medium sensitivity to sediment - Downstream of peat bog but small in area. Downstream of relatively steep high energy watercourse network which can act as a pathway. Arable land downstream</p> |

| Model No. | Model Name | Uncertainty / Sensitivity – Present Day Scenario | | | | Uncertainty / Sensitivity – Future Scenarios | | | | Notes |
|-----------|------------|--|----------------------------------|-----------------------------|--------------------------------------|--|---------------------------|-----------------------------|-----------------------|--|
| | | Observed Flow Data ¹ | Simulated Flow Data ² | Catchment Data ³ | Ungauged Flow Estimates ⁴ | Forestation ⁵ | Urbanisation ⁶ | Climate Change ⁷ | Sediment ⁸ | |
| | | | | | | | | | | of AFA. |
| HA12 2 | Tullow | Medium / Low | Medium/Low | Low | Medium/Low | Low | Low | Medium | Medium | <p>NAM output for Stn 12013 in keeping with gauged data. The Station is B rated so confidence in flow values is only up to Qmed. NAM increases statistical certainty due to augmented AMAX series – this station is used as a pivotal site for ungauged estimates. Ungauged Qmed estimates decrease moving downstream on Slaney, a function of PCD SAAR decreasing in a southerly direction. This was manually rectified.</p> <p>Medium/Low sensitivity to sediment -. Downstream of relatively steep high energy watercourse network which can act as a pathway. Arable land upstream of AFA.</p> |
| HA12 3 | Bunclody | Low | n.a. | Low | Medium/Low | Medium/Low | Low | Medium | Medium | <p>NAM output for Station 12001 not adopted for further analysis due to lack of certainty in calibration. NAM output from 12013 and Gauged data for 12001 used in adjusting ungauged estimates. 12001 is an A2 station so high confidence in flow values.</p> <p>Medium sensitivity to sediment - Downstream of peat bog but small in area. Downstream of relatively steep high energy watercourse network which can act as a pathway. Arable land downstream of AFA.</p> |

| Model No. | Model Name | Uncertainty / Sensitivity – Present Day Scenario | | | | Uncertainty / Sensitivity – Future Scenarios | | | | Notes |
|-----------|-------------|--|----------------------------------|-----------------------------|--------------------------------------|--|---------------------------|-----------------------------|-----------------------|--|
| | | Observed Flow Data ¹ | Simulated Flow Data ² | Catchment Data ³ | Ungaaged Flow Estimates ⁴ | Forestation ⁵ | Urbanisation ⁶ | Climate Change ⁷ | Sediment ⁸ | |
| | | | | | | | | | | |
| HA12 4 | Enniscorthy | Low | n.a. | Low | Medium/Low | Low | Medium | Medium | High / Medium | <p>NAM output for Station 12001 not adopted for further analysis due to lack of certainty in calibration. NAM output from 12013 and Gauged data for 12001 used in adjusting ungaaged estimates. 12001 is an A2 station so high confidence in flow values.</p> <p>High/Medium sensitivity to sediment - Downstream of peat bog but small in area. Downstream of relatively steep high energy watercourse network which can act as a pathway. Extensive arable land along channel upstream of AFA.</p> |
| HA12 5 | Wexford | n.a. | n.a. | Low | Medium/Low | Low | High/ Medium | Medium | High/Medium | <p>Ungaaged catchment.</p> <p>At downstream end of River Slaney and tidally influenced, high/medium risk of sediment deposition from upstream.</p> |
| HA13 1 | Kilmore | n.a. | n.a. | Medium | Medium | Low | Low | Medium | Medium | <p>Ungaaged catchment, no pivotal site adjustments made due to high degree of scatter in results, and average adjustment factor of 0.996 of the values within confidence limits.</p> <p>Medium risk of sensitivity to sediment -shallow catchment with arable land use that may exacerbate soil erosion in an area of poorly drained soils and low</p> |

| Model No. | Model Name | Uncertainty / Sensitivity – Present Day Scenario | | | | Uncertainty / Sensitivity – Future Scenarios | | | | Notes |
|-----------|------------|--|----------------------------------|-----------------------------|---------------------------------------|--|---------------------------|-----------------------------|-----------------------|---|
| | | Observed Flow Data ¹ | Simulated Flow Data ² | Catchment Data ³ | Ungaugged Flow Estimates ⁴ | Forestation ⁵ | Urbanisation ⁶ | Climate Change ⁷ | Sediment ⁸ | |
| | | | | | | | | | | energy channel flowing through the AFA. |

- ¹ Observed flow data marked n.a. where there is no gauged data within the modelled catchment to inform the flood flow estimation for the model. Low to high reflects uncertainty in the gauged data at Qmed if available.
- ² Simulated data refers to data output from rainfall runoff models. This has not been possible on totally ungauged catchments.
- ³ Catchment data refers to delineated catchment extents or catchment descriptors. Low to high reflects uncertainty in physical catchment descriptors or catchment delineation. May have been subject to change since FSU due to urbanisation, afforestation, arterial drainage scheme
- ⁴ Ungaugged flow estimates based on FSU WP 2.3 methodology. Dependent on 1,2 & 3 above. Where high quality gauge data is available along modelled reach upon which adjustment can be performed then uncertainty is considered low. Where no gauge data is available within catchment then certainty is considered medium to high. Uncertainty greater in smaller, urbanised catchments where ungaugged estimation methodologies are considered to be more sensitive.
- ⁵ See Section 7.2 Considered to be low risk of uncertainty to hydrological analysis in HA11, 12 and 13 with the exception of Baltinglass and Bunclody
- ⁶ See Section 7.3 Considered generally to be a medium to high risk of uncertainty to hydrological analysis in urban areas where potential significant, dense urbanisation is possible which would make up a significant proportion of the catchment. High risk where small catchments largely contained within the AFA extents and potentially subject to high risk of urbanisation.
- ⁷ See Section 7.1 Considered a high risk of uncertainty to hydrological analysis in all cases due to the large range of projections and higher inherent uncertainty associated with the +20% MRFS for lower AEP events (Murphy et al, 2011).
- ⁸ Sedimentation of channels causing capacity issues or localised impacts on channel structures are to be considered in options development phase of CFRAM Study where relevant. Degree of uncertainty indicated here is based on qualitative assessment of accelerated soil erosion risk due to land use pressures and pathways to watercourses. Considered under future scenarios only as present day sediment conditions are reflected by recently captured channel survey data.

8.2 CONCLUSIONS OF SENSITIVITY ANALYSIS

The assessment of uncertainty and sensitivity in each category is relative within HA11, 12 and 13. The assessment of uncertainty as being medium or high does not suggest that the analysis is poor but rather in the context of the full suite of design flow estimation techniques being employed in the South Eastern CFRAM Study that uncertainty in that category is towards the higher end of the range. For example the modelled watercourses which affect the Blackwater AFA are small ungauged and mainly urban but are well defined in terms of catchment data. However the ungauged flow estimates have been designated as having a medium uncertainty as the FSU ungauged catchment index flow estimate has been adjusted using a gauge in HA25 as opposed to within the catchment itself since there are none available, and the nearest Station at Boleany has a very high adjustment factor, pushing results above the confidence limit. The ungauged estimates have therefore been labelled as having a medium degree of uncertainty yet the procedure for estimating and adjusting is in line with best practice and would be consistent with the recommended estimation methodology for a typical ungauged rural Irish catchment. The largest degree of uncertainty for the present day scenarios is attributed to the smaller ungauged catchments.

In the future scenarios climate change has been defined as potential source of medium uncertainty due to the inherent uncertainties surrounding climate change science and how these will translate into changes in fluvial flood flows in Ireland. It has not been assigned risk as it is not considered to be any more uncertain than urbanisation which is generally a source of medium uncertainty in the prediction of future flood flows. Enniscorthy, Courtown and Gorey AFAs have been attributed medium uncertainty based on observed higher growth rates and the high density of small urban HPWs that would be more sensitive to urbanisation. Wexford AFA has been attributed High/Medium uncertainty due to the potential for complete urbanisation of HPWs within the town itself. The factors which affect urbanisation are difficult to predict for a 100 year time horizon due to the complex social, cultural and economic factors which affect it. However there is also the affect of sustainable drainage to consider which adds a further degree of uncertainty depending on the extent to which it is successfully implemented. There is a high degree of certainty that there will be little afforestation within HA11, 12 and 13 catchments and as such this is only a significant source of uncertainty in Baltinglass and Bunclody where forestry already exists in the upper catchment.

9 CONCLUSIONS

Moderate hydrometric data exists for the main channel of the Slaney whilst HA11 (Owenavorrach) has one gauge with a high degree of uncertainty associated with it and HA13 is ungauged. High quality meteorological data in the form of rainfall radar is not available for application in the hydrological analysis of HA11, 12 and 13. A comprehensive methodology has been applied combining the latest FSU statistically based and modelling based techniques for analysis. Catchment rainfall runoff modelling has been applied in addition to the FSU statistically based method such that an additional layer of simulated historic data is available. The results from both approaches are cross checked against one another such as to provide the most robust analysis possible to take forward for design flow estimation. However in two of the three cases, the hydrological model outputs were not adopted for further analysis due to lack of certainty with the results (due to calibration and lack of rainfall radar as input data).

There is a fair degree of potential uncertainty within the ungauged tributary catchments where estimates of flood flow are derived from catchment descriptor based estimates and direct adjustment based on gauge data within the sub-catchment is not possible. Geographically closest gauging stations with high confidence in the data or improved certainty due to rainfall runoff modelling have been used to adjust index flow estimates at these catchments and therefore provide some improvement. However in the case of HA11, there is a sizeable difference between the predicted and gauged Q_{med} values at the candidate pivotal station, 11001 at Boleany. This results in a high adjustment factor and possible overestimation of index flows. This is acknowledged and will be closely observed at the hydraulic analysis stage. The calibration of the hydraulic models to historic flood data and observed evidence will further help to screen out design flow estimates which are not reflective of the actual behaviour of these sub-catchments.

There are many potential future changes to the catchment, margins of error and uncertainties which must be considered within the study. However the cumulative application of worst case scenarios, one on top of the other could lead to erroneous flood extents which do not take into account the diminishing cumulative joint probability of these factors. For this reason this report has separated future HA11, 12 and 13 changes that have a high degree of certainty in the projections from those changes which are less certain. Future changes which have a relatively higher degree of uncertainty, along with margins of error and other uncertainties have been risk assessed individually. This risk assessment is to be taken forward and built upon through the hydraulic modelling phase with the ultimate goal of providing a single error margin for the flood extent maps on an AFA by AFA basis. This rationalised single error margin is designed to inform end users in a practical way as to the varying degree of caution to which mapped flood extents are to be treated.

9.1 SUMMARY OF THE RESULTS AND GENERAL PATTERNS

The catchment can be characterised hydrologically as follows:

- The catchment has a wide range of climatic and physiographic characteristics. The drier, lowland areas to the centre moving towards the coast have SAAR values as low as 711mm while the upper catchment to the north has SAAR values of up to 1700mm.
- Hydrometric data is moderate but variable quality and availability, mainly focused on the Slaney main channel and significant tributaries. 60% of models have hydrometric data of varying quality to work with.
- Meteorological data is limited to rain gauge data across the catchment. The processing of rainfall data from the Dublin and Shannon Airport radar is not of benefit since it does not cover any of the Models in HA11, 12 and 13.
- Flood behaviour when defined in terms of the growth curve, i.e. in orders of magnitude greater than the median event, on average is slightly higher than would have been thought based on older methodologies (FSR).
- The 1% AEP flood event ranges from approximately 2.00 (Slaney and Owenavorrhagh main channel) to approximately 3.2 times larger than the median flood flow depending on catchment size. This compares to approximately 2 under FSR.
- Growth factor increases with decreasing catchment size.

Design flow estimation is the primary output of this study and has been developed based on the analysis contained in this report. This analysis is based on previous observed data and estimation / modelling techniques. This analysis will require further validation through the calibration of the hydraulic models. As modelling progresses there may be some elements of the hydrological analysis that might need to be questioned and interrogated further. This is reflective of best practice in hydrology / hydraulic modelling for flood risk assessment. RPS believe that through complementing statistical analysis techniques with rainfall runoff modelling that the design flow estimation has as high a degree of certainty as is possible prior to calibration / validation and that this will save time and increase accuracy as HA11, 12 and 13 moves into the hydraulic modelling phase of the CFRAM Study process. Nevertheless the modelling may necessitate the adjustment of some of the design flows and as such any adjustments made will be summarised within the Hydraulic Modelling Report.

9.2 RISKS IDENTIFIED

The main potential source of uncertainty in the analysis is due to a lack of hydrometric gauge data in the smaller ungauged catchments which are the main source of fluvial flood risk in many of the AFAs. This has been mitigated as much as possible by the use of a comprehensive range of analysis and

estimation techniques from statistical, catchment descriptor based estimates in line with the most recent CFRAM guidance to the use of rainfall runoff modelling.

Following this cycle of the South Eastern CFRAM Study the main potential adverse impact on the hydrological performance of the catchments is the effect of future changes and in particular the scope for rapid urbanisation of towns such as Enniscorthy and Wexford. Further rapid urbanisation of the tributary catchments around these towns could significantly increase flood risk if this leads to development which is unsustainable from a drainage perspective.

9.3 OPPORTUNITIES / RECOMMENDATIONS

This study presents two potential opportunities to improve the hydrological analysis further in the next cycle of the South Eastern CFRAM Study:

1. Three hydrometric gauging stations were identified for rating review in HA11, 12 and 13 yet survey information and hydraulic models will be available for one more station upon completion of the study. This station would benefit to some degree by carrying out a rating review using the hydraulic models / survey, if only to bring confidence to future extreme flood flow measurement. At best it may be possible to estimate historic flows at gauging stations which are currently water level only.

Recommending that new gauging stations are installed on all of the ungauged models (or branches of models) is a long term goal but probably unrealistic within the timeframe of this or even the next CFRAM Study cycle. Multiplied up nationally this would lead to a long list of gauging stations which would likely remain unrealised at a time when many organisations are rationalising their existing networks and may even obscure the case for those gauging stations which are more acutely needed. A more focussed exercise to identify the most acutely needed gauging stations would be more effectively undertaken following hydraulic modelling and consultation such that the AFAs which are at greatest risk, are most affected by uncertainty in the design flow estimates and which would significantly benefit from additional calibration data are identified as priorities. As such it is recommended that this exercise is undertaken following the hydraulic modelling stage. In the interim improvements to the existing hydrometric gauge network should focus on improving the ratings through the collection of additional spot flow gaugings at flood flows at existing stations. Furthermore there is a shortage nationally of very small and / or heavily urbanised catchment gauge data and as such new gauging stations on this type of catchment, ideally within a CFRAM Study AFA, could be progressed immediately.

2. The rainfall runoff modelling carried out as part of this study has, due to programme and data constraints, been carried out following hydrological analysis of the gauge station data. The runoff modelling has effectively created a layer of additional simulated historic gauge station years for all of the gauge stations. This data has been utilised in one case in the index flow

estimation but could potentially be used to provide further statistical confidence to estimates of historic flood frequency.

10 REFERENCES:

1. EC Directive on the Assessment and Management of Flood Risks (2007/60/EC)
2. South Eastern CFRAM Study HA11, 12 and 13 Inception Report F02 (RPS, OPW, 2012)
3. Eastern CFRAM Study, Dublin Radar Analysis for the Dodder Catchment, Stage 1 (RPS, HydroLogic, OPW, 2012)
4. Eastern CFRAM Study, Athboy Radar Analysis (RPS, HydroLogic, 2013)
5. CFRAM Guidance Note 21, Flood Estimation for Ungauged Catchments (OPW, 2013)
6. S. Ahilan, J.J. O'Sullivan and M. Bruen (2012): Influences on flood frequency distributions in Irish river catchments. Hydrological Science Journal, Vol. 16, 1137-1150, 2012.
7. J.R.M. Hosking and J.R.W. Wallis (1997): Regional Frequency Analysis – An approach based on L-Moments. Cambridge University Press.
8. Flood Studies Update Programme – Work Package 2.1 – Review of Flood Flow Ratings for Flood Studies Update – Prepared by Hydrologic Ltd. for Office of Public Works (March 2006)
9. Flood Studies Update Programme – Work Package 2.2 – “Frequency Analysis” – Final Report – Prepared by the Department of Engineering Hydrology of National University of Ireland, Galway for Office of Public Works (September 2009).
10. Flood Studies Update Programme – Work Package 2.3 – Flood Estimation in Ungauged Catchments – Final Report – Prepared by Irish Climate Analysis and Research Units, Department of Geography, NUI Maynooth (June 2009)
11. Flood Studies Update Programme – Work Package 3.1 – Hydrograph Width Analysis – Final Report – Prepared by Department of Engineering Hydrology of National University of Ireland, Galway for Office of Public Works (September 2009)
12. Flood Studies Update Programme – Work Package 3.4 – Guidance for River Basin Modelling – prepared by JBA for Office of Public Works (May 2010)
13. Flood Studies Update Programme – Work Package 5.3 – Preparation of Digital Catchment Descriptors – Pre-Final Draft Report – Prepared by Compass Informatics for Office of Public Works (January 2009)
14. Michael Bruen and Fasil Gebre (2005). An investigation of Flood Studies Report – Ungauged catchment method for Mid-Eastern Ireland and Dublin. Centre for Water Resources Research, University College Dublin.

- 15.** Flood Estimation Handbook- Statistical Procedures for Flood Frequency Estimation, Vol. 3. Institute of Hydrology, UK (1999).
- 16.** NERC, 1975. Flood Studies Report. Natural Environment Research Council.
- 17.** Institute of Hydrology Report No. 124 – Flood Estimation for Small Catchments (D.C.W. Marshall and A.C. Bayliss, June 1994)
- 18.** Ireland in a Warmer World, Scientific Predictions of the Irish Climate in the Twenty First Century Prepared by Met Éireann and UCD (R. McGrath & P. Lynch, June 2008)
- 19.** Stress Testing Design Allowances to Uncertainties in Future Climate: The Case of Flooding (Murphy, Bastola and Sweeney, NUI Maynooth, 2011)
- 20.** Growing for the Future – A Strategic Plan for the Development of the Forestry Sector in Ireland (Department for Agriculture, Food and Forestry, 1996)
- 21.** Review of Impacts of rural land use management on flood generation (DEFRA, 2004)
- 22.** Reaney, S.M. Lane, S.N. Heathwaite, A.L. Dugdale. L.J. 2011. Risk-based modelling of diffuse land use impacts from rural landscapes upon salmonid fry abundance. *Ecol Model*, 222; pp. 1016–1029.
- 23.** OPW, 2012. 12425/RP/002/A– River Slaney (Enniscorthy Town) Drainage Scheme – Description of the Scheme
- 24.** The Planning System and Flood Risk Management, Guidelines for Local Authorities, (OPW, 2007)
- 25.** 'Quantifying the cascade of uncertainty in climate change impacts for the water sector' (Dept. of Geography, National University of Ireland, Maynooth, 2011).

APPENDIX A

HA11, 12 AND 13 HYDROMETRIC DATA STATUS TABLE

Hydrometric Data Status Table
HA11, HA12 HA13 - Hydrometric Stations

| Station Name | Station ID | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | Station ID | Provider |
|---------------------|------------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------------|-----------------------------|
| BALLYVAUGHAN | 11934 | | | | | | | | | | | | | | | | | | | | | 11934 | Wickford Co Co |
| BEL EASY | 11931 | | | | | | | | | | | | | | | | | | | | | 11931 | OPW |
| CANOE RIVER | 11981 | | | | | | | | | | | | | | | | | | | | | 11981 | OPW |
| CLOUGH BR | 11932 | | | | | | | | | | | | | | | | | | | | | 11932 | Wickford Co Co |
| MACOYLE | 11933 | | | | | | | | | | | | | | | | | | | | | 11933 | Wickford Co Co |
| ASSALY | 12063 | | | | | | | | | | | | | | | | | | | | | 12063 | OPW |
| HALLOW | 12022 | | | | | | | | | | | | | | | | | | | | | 12022 | Campan Co Co |
| BARNSHAW BR | 12041 | | | | | | | | | | | | | | | | | | | | | 12041 | Wickford Co Co |
| BUNGLOOY | 12033 | | | | | | | | | | | | | | | | | | | | | 12033 | Wickford Co Co |
| CARLEYS BR | 12036 | | | | | | | | | | | | | | | | | | | | | 12036 | Environmental Research Unit |
| CARNEW | 12017 | | | | | | | | | | | | | | | | | | | | | 12017 | Wickford Co Co |
| CASTLEBORO | 12030 | | | | | | | | | | | | | | | | | | | | | 12030 | Wickford Co Co |
| CASTLEGRACE | 12029 | | | | | | | | | | | | | | | | | | | | | 12029 | Campan Co Co |
| CASTLERODDERY | 12037 | | | | | | | | | | | | | | | | | | | | | 12037 | Wickford Co Co |
| CLOHAMON | 12027 | | | | | | | | | | | | | | | | | | | | | 12027 | Wickford Co Co |
| CLOMOM | 12004 | | | | | | | | | | | | | | | | | | | | | 12004 | Campan Co Co |
| CRAN | 12030 | | | | | | | | | | | | | | | | | | | | | 12030 | Wickford Co Co |
| CROGHORN | 12018 | | | | | | | | | | | | | | | | | | | | | 12018 | Wickford Co Co |
| DUNMORE | 12016 | | | | | | | | | | | | | | | | | | | | | 12016 | Wickford Co Co |
| EDERVINE BRIDGE | 12061 | | | | | | | | | | | | | | | | | | | | | 12061 | OPW |
| ENNSCORTHY | 12002 | | | | | | | | | | | | | | | | | | | | | 12002 | OPW |
| PERNS | 12015 | | | | | | | | | | | | | | | | | | | | | 12015 | Wickford Co Co |
| FLINTCARRIG BR | 12094 | | | | | | | | | | | | | | | | | | | | | 12094 | OPW |
| FRISKE BR | 12040 | | | | | | | | | | | | | | | | | | | | | 12040 | Wickford Co Co |
| HACKETTOWN | 12003 | | | | | | | | | | | | | | | | | | | | | 12003 | Campan Co Co |
| KILCARRY | 12012 | | | | | | | | | | | | | | | | | | | | | 12012 | Campan Co Co |
| KILDAVN | 12034 | | | | | | | | | | | | | | | | | | | | | 12034 | Campan Co Co |
| KNOCKREEN FORD | 12030 | | | | | | | | | | | | | | | | | | | | | 12030 | Wickford Co Co |
| KNOCKLOE | 12023 | | | | | | | | | | | | | | | | | | | | | 12023 | Campan Co Co |
| MANGAN | 12036 | | | | | | | | | | | | | | | | | | | | | 12036 | Wickford Co Co |
| MYSHALL | 12024 | | | | | | | | | | | | | | | | | | | | | 12024 | Campan Co Co |
| PALLIS BR | 12014 | | | | | | | | | | | | | | | | | | | | | 12014 | Wickford Co Co |
| PALLIS NEW | 12036 | | | | | | | | | | | | | | | | | | | | | 12036 | Wickford Co Co |
| RATFER BR DS | 12030 | | | | | | | | | | | | | | | | | | | | | 12030 | OPW |
| RATFER BR US | 12030 | | | | | | | | | | | | | | | | | | | | | 12030 | OPW |
| RATHGLASS BRIDGE | 12031 | | | | | | | | | | | | | | | | | | | | | 12031 | Wickford Co Co |
| RATHVELLY | 12013 | | | | | | | | | | | | | | | | | | | | | 12013 | Campan Co Co |
| RATHVELLY DS | 12035 | | | | | | | | | | | | | | | | | | | | | 12035 | Campan Co Co |
| ROSSLARE | 12005 | | | | | | | | | | | | | | | | | | | | | 12005 | Harold Brown |
| SCARAWAL SH | 12001 | | | | | | | | | | | | | | | | | | | | | 12001 | OPW |
| SLEVEBAUN | 12020 | | | | | | | | | | | | | | | | | | | | | 12020 | Wickford Co Co |
| ST JOHN'S BR | 12007 | | | | | | | | | | | | | | | | | | | | | 12007 | OPW |
| TRAHELY | 12019 | | | | | | | | | | | | | | | | | | | | | 12019 | Wickford Co Co |
| TULLOW | 12021 | | | | | | | | | | | | | | | | | | | | | 12021 | Campan Co Co |
| TULLOW TOWN BR U.S. | 12025 | | | | | | | | | | | | | | | | | | | | | 12025 | OPW |
| TULLOWECO | 12006 | | | | | | | | | | | | | | | | | | | | | 12006 | OPW |
| WEXFORD | 12060 | | | | | | | | | | | | | | | | | | | | | 12060 | Wickford Co Co |
| WEXFORD HARBOUR | 12062 | | | | | | | | | | | | | | | | | | | | | 12062 | OPW |
| WEXFORD TOWN | 12066 | | | | | | | | | | | | | | | | | | | | | 12066 | Marine Institute |
| WHITESTOWN | 12028 | | | | | | | | | | | | | | | | | | | | | 12028 | Wickford Co Co |
| WOODLANDS | 12038 | | | | | | | | | | | | | | | | | | | | | 12038 | Wickford Co Co |
| BALLYTEGE DS | 13062 | | | | | | | | | | | | | | | | | | | | | 13062 | OPW |
| BALLYTEGE US | 13034 | | | | | | | | | | | | | | | | | | | | | 13034 | OPW |
| O'LEARY | 13061 | | | | | | | | | | | | | | | | | | | | | 13061 | OPW |
| POUL'S MILL | 13002 | | | | | | | | | | | | | | | | | | | | | 13002 | Wickford Co Co |
| GOFF'S BR | 13001 | | | | | | | | | | | | | | | | | | | | | 13001 | Wickford Co Co |
| LADY'S ISLAND | 13070 | | | | | | | | | | | | | | | | | | | | | 13070 | OPW |
| MULLINCERRY | 13003 | | | | | | | | | | | | | | | | | | | | | 13003 | Wickford Co Co |
| TAUMSHIN LAKE | 13071 | | | | | | | | | | | | | | | | | | | | | 13071 | OPW |

Key
Annual Max Data
Daily Data
15 Min Data

APPENDIX B

RATING REVIEWS

BOLEANY (11001)

The gauging station at Boleany (11001) is located on the Owenavorragh river south east of Gorey, County Wexford approximately 4km upstream from where it discharges to the Irish Sea. The staff gauge and recorder house are located on the right hand bank of an open channel section downstream of a bridge. The channel is approximately 16m wide with a minimum bed level of 5.62m OD Malin and bank levels of 8.39m OD Malin (Left bank) and 8.33m OD Malin (Right bank). The current OPW ordnance level of the gauge zero is 8.63m OD Poolbeg. The surveyed gauge zero level is 5.995m OD Malin.



Figure 1: Modelled Watercourse and Gauge Station Location

The gauge is operated by the OPW and was installed and automated in 1972. A flat vee-weir structure acts as low flow control however this drowns out due to backwater effects during high flow events. There are 84 spot water level and flow gaugings recorded for the site from the 13th September 1972 to the 4th March 2011. The largest spot gauging is 55.6m³/s recorded on the 10th January 1974. The FSU estimation of Q_{med} for this site is 47.2m³/s.

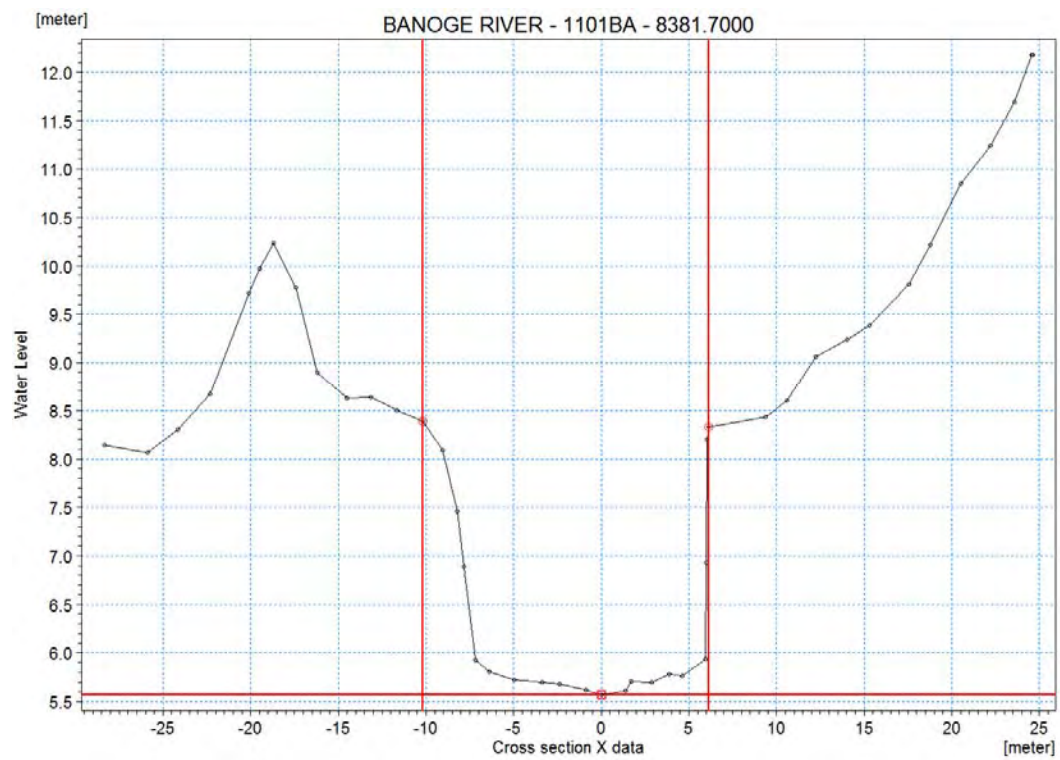


Figure 2: Model cross-section at gauge location (Top); Photo of weir looking upstream (Staff gauge and recorder hut located upstream of weir, Boleany road bridge visible in background) (Bottom)

The study reach in the hydraulic model extends approximately 8.4km in the upstream direction and 2.0km in the downstream direction of the gauge. There are 18 bridge structures and 3 weirs along this reach, including 1 rail bridge, 11 road bridges, 2 access bridges, 1 foot bridge, 3 culverts. The two dimensional hydraulic model uses information from 182 cross-sections on the Banoge and Owenavooragh Rivers including 18 bridges and 3 weirs. The downstream boundary condition applied to the model was calculated as the critical flow Q-h relationship, with the upstream boundary consisting of a hydrograph with a peak flow of $8.4\text{m}^3/\text{s}$, equivalent to an estimated 0.1% AEP event.

A national review under FSU classified the station at Boleany as a B quality rating, meaning flows can be determined up to Q_{med} with confidence. The upper confidence limit of the existing OPW rating curve is at a staff gauge level of 2.450m, and there are two spot gaugings which correspond to stage heights approximately equal to this level. This first has a flow of $55.62\text{m}^3/\text{s}$ and was recorded in January 1974. The second has a flow of $36.99\text{m}^3/\text{s}$ and was recorded in December 2000. The OPW rating curve appears to disregard the spot gauging recorded in 1974, however the reason for the discrepancy between the two values is unknown.

The results of the rating review are shown below in Figure 3 and Table 1. The graph demonstrates the RPS model curve and shows the comparison between the OPW rating curve (which consists of 2 equations) and spot gaugings.

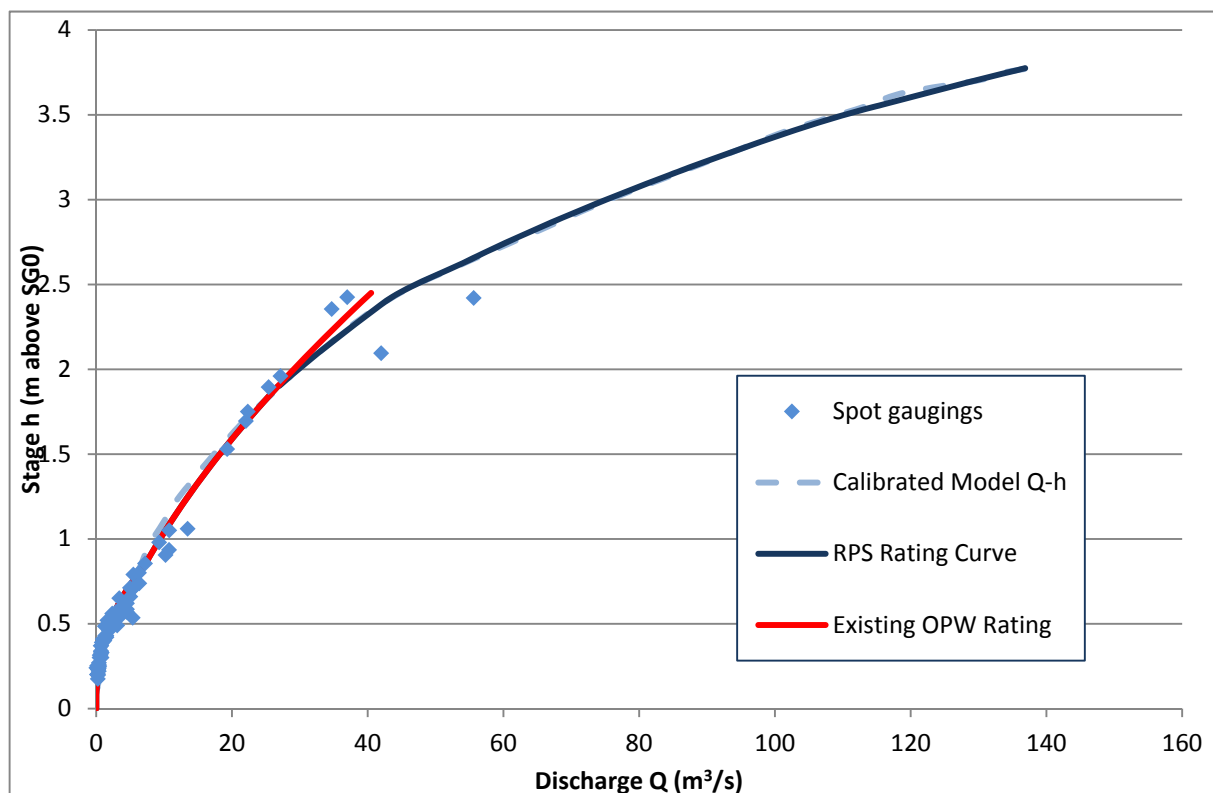


Figure 3: Comparison of Existing OPW Rating Curve and RPS Rating Curve for all flows

| Section | Min Stage (m) | Max Stage (m) | C | a | b |
|---------|------------------|------------------|-------|--------|-------|
| 1 | 0.000 | 0.835 | 11.00 | 0.000 | 2.500 |
| 2 | 0.835 | 1.900 | 9.40 | 0.000 | 1.630 |
| 3 | 1.900 | 2.450 | 8.00 | -0.038 | 1.951 |
| 4 | 2.450 | 3.400 | 8.00 | -0.283 | 2.241 |
| 5 | 3.400 | 3.775 | 8.00 | -0.549 | 2.424 |

Where: $Q = C(h+a)^b$ and h = stage readings (metres)

Note: Sections 1 and 2 are existing OPW rating curve segments

Table 1: Rating equation values for gauge 11001

Figure 3 shows that both the RPS model curve and the existing OPW rating equation are well calibrated up to a stage height of 1.900m. The model rating curve at this point was found to deviate from the current OPW rating curve, leading to a difference in the ratings at Q_{med} of up to $10m^3/s$. However when applied over the entire period of record the resulting Q_{med} is in good agreement with the value taken forward for the FSU. An in-channel Manning's n value of 0.04 was applied to the cross section at the gauge location, with a value of 0.07 used on the channel banks in order to achieve calibration. This is within the range of values expected for clean, winding natural channels with medium to dense brush on the banks. A Manning's n value of 0.013 was used at the v notch weir structure which is typical for a concrete channel. Manning's n values of 0.045 were used downstream of the weir structure as the channel included additional stones and weeds. The combination of these resistance values resulted in the closest fitting rating curve.

Scarawalsh (12001)

The gauging station at Scarawalsh (12001) is located on the River Slaney north of Enniscorthy, County Wexford approximately 2585m upstream of its confluence with Kilcannon River. The staff gauge is located immediately downstream of bridge 2863D. The channel is approximately 63m wide with a minimum bed level of 8.325mOD Malin and bank levels of 12.73mOD Malin (Left bank) and 11.79mOD Malin (Right Bank). The current OPW ordnance level of the gauge zero is 11.44mOD Malin. The rating review has been conducted on MIKE 11 software and is modelled as 1D only. Surveyed staff gauge zero was measured at 8.73 mOD Malin and the OPW staff gauge zero was given as 8.74mOD Malin. The surveyed staff gauge zero was used as the basis for this review; however variance between the gauging was almost negligible at only 10mm. Therefore, the model rating curve is considered relative to the OPW spot gauging and rating curve.

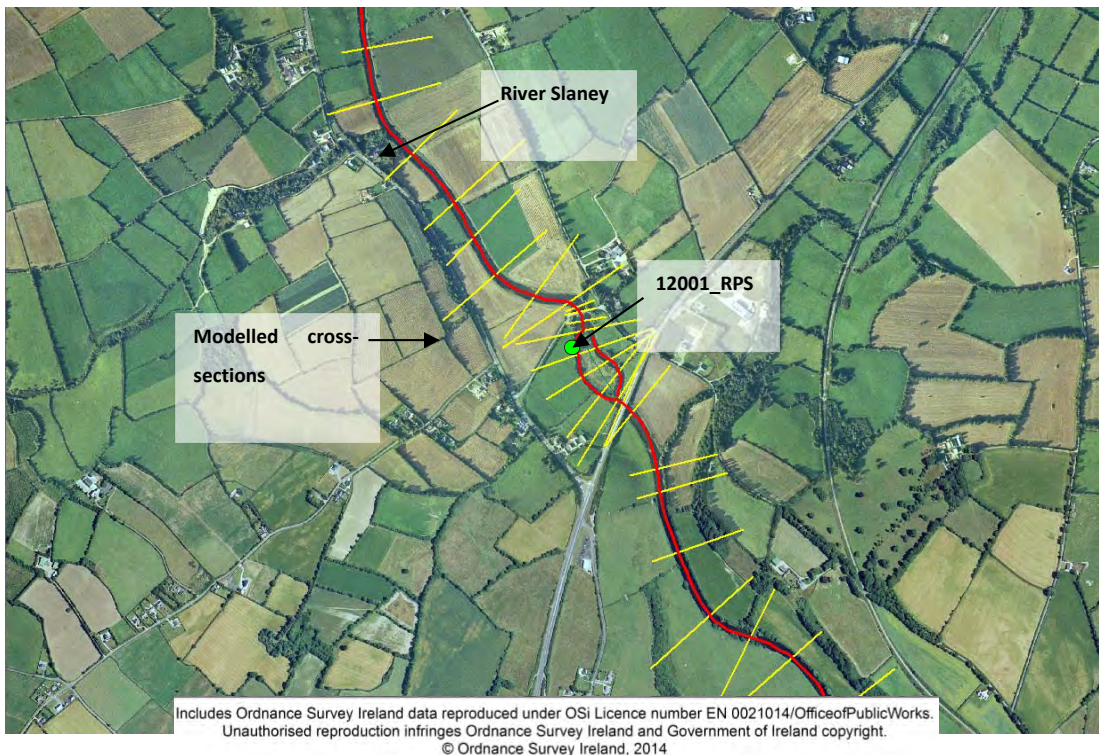


Figure 1. Location of Gauging Station 12001_RPS at Scarawalsh

The gauge is operated by the OPW and was installed and automated in 1955. The gauge is situated in a section of natural channel with a stable gravel bed and natural channel control. There are 55 spot water level and flow gaugings recorded for the site from the 14th December 1955 to the 16th January 2010. There is a range in the staff gauge zero history of 40mm throughout the period over which spot gaugings have been taken but all have been retained here for the purposes of model calibration as there are no obvious significant shifts. Q_{med} for this site is estimated to be 161m³/s.

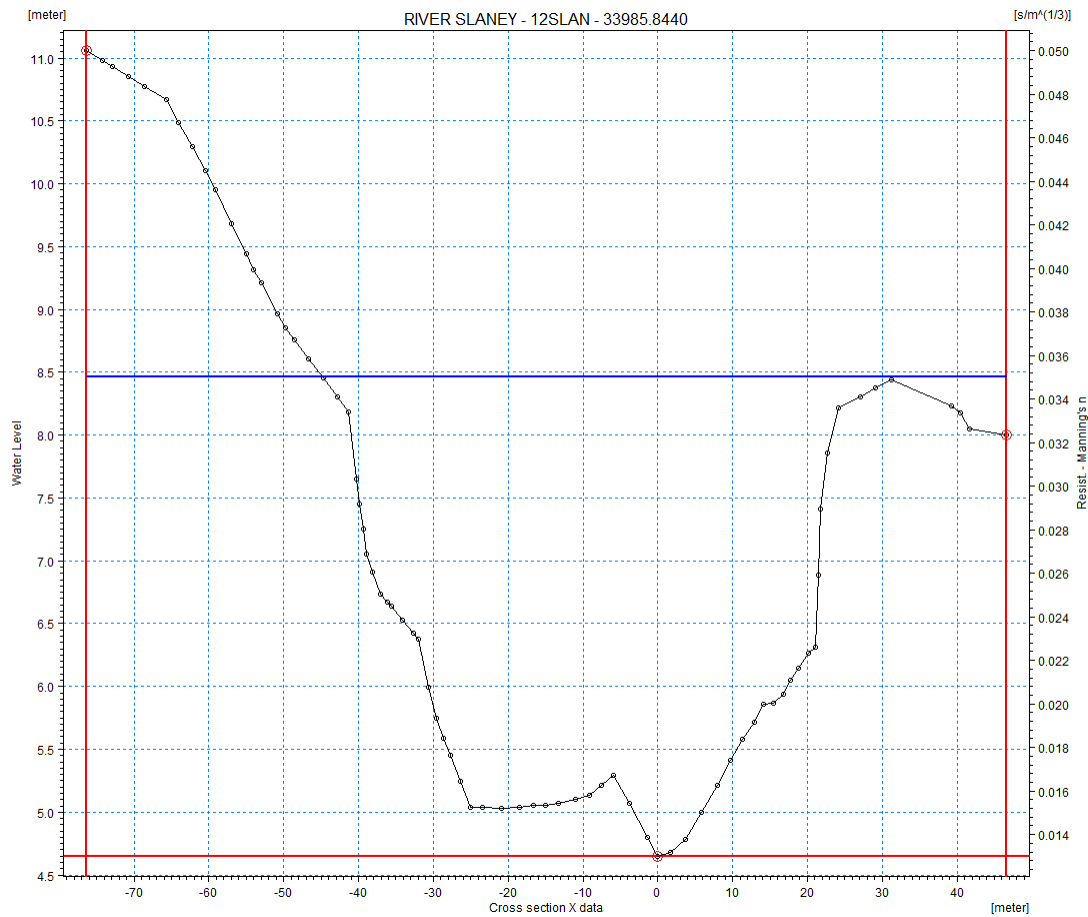


Figure 2. Model cross-section for gauge (Top); Gauge staff located at downstream face of bridge (L) ; Photo of bridge (Looking upstream) (R)

The study reach extends approximately 3.05km in the upstream direction and approximately 15.2km in the downstream direction from the gauge. There are two bridge structures along this reach, both are road bridges. One incorporates 6 arches immediately upstream from the gauge (Figure 2.) and the next is a single span road bridge approximately 320m downstream. The one dimensional hydraulic model uses information from 107 Cross-Sections and 6 bridge structures. The downstream boundary condition applied to the model was calculated as the critical flow Q-h relationship, with the upstream

boundary consisting of a hydrograph with a peak flow of $435.39\text{m}^3/\text{s}$ equivalent to an estimated 0.1% AEP event.

The gauging station rating was given an A2 classification under FSU, suggesting there is confidence in the rating up to 1.3 times Q_{med} . The RPS modelled Q-h relationship envelops the OPW curve with the rising limb falling mostly below the OPW rating curve and the falling limb above the OPW curve. A hysteresis effect can be observed and it is considered that this is due to the attenuating effect of the restrictive bridge cross-section immediately upstream of the gauging station. The rating review match was achieved by the entry of a weir immediately downstream of the bridge, modelled 6m away, with a lowered section included 4m downstream of the bridge face for model run purposes. The weir, a slightly distorted section that does not run in a straight line across the channel, can be observed in photographs (Figure 2. Bottom left picture) but was not included in the original survey. For the purposes of inclusion in the 1D portion of the model, the weir is modelled as a straight section to include the crest over the full width of the channel. An appropriate weir level with a channel bed rise of 0.397m was calculated from the offset of the initial rating curve and confirmed to be consistent. This weir also contributes to the attenuating effect of the bridge with a further hold back of water in the channel. The results of the rating review can be seen below in Figure 3 and Table 1. The graph demonstrates the derived RPS rating curve and shows the comparison between the OPW rating curve (which consists of two equations) and spot gaugings. The first two equations of the revised rating have been retained from the existing OPW rating curve, albeit to slightly below the previous upper limit of 2.95m to achieve intersection with the extended curve section which is considered a better fit to the highest spot gaugings.

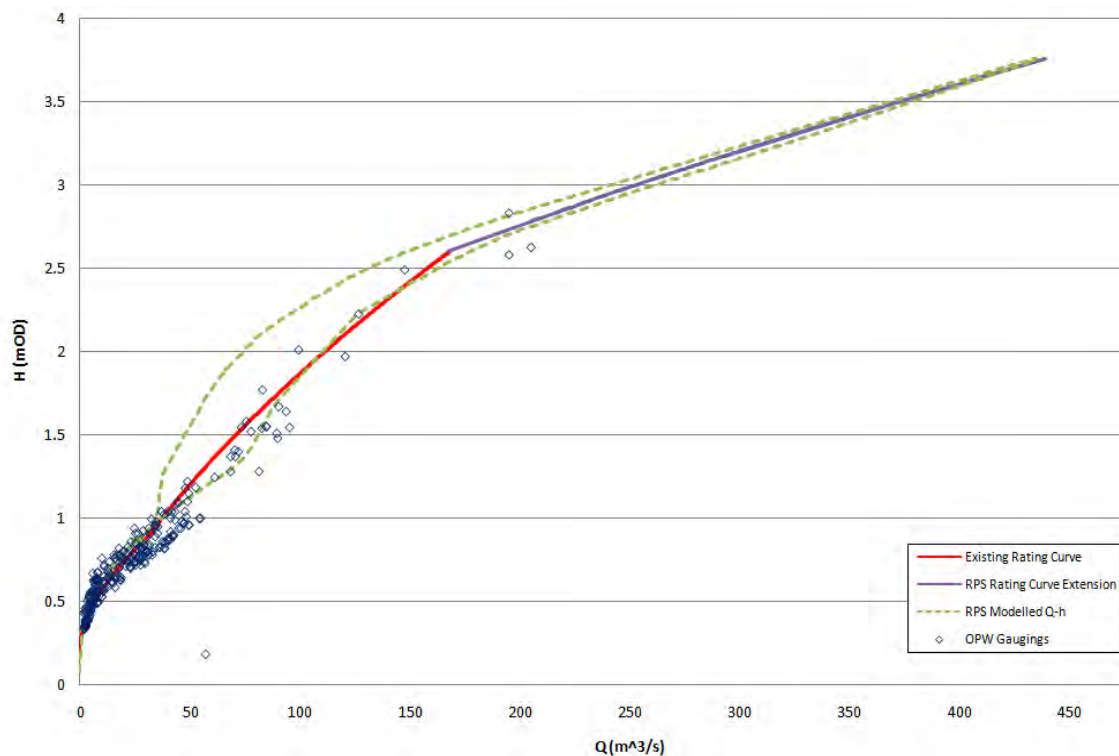


Figure 3. Comparison of existing OPW Rating Curve and RPS Rating Curve for all flows

| Section | Min Stage (m) | Max Stage (m) | C | a | b |
|---------|------------------|------------------|---------|--------|--------|
| 1 | 0 | 0.902 | 60 | -0.2 | 1.775 |
| 2 | 0.902 | 2.609 | 37.636 | 0 | 1.5663 |
| 3 | 2.609 | 3.758 | 135.201 | -1.436 | 1.4 |

Where: $Q = C(h+a)^b$ and h = stage readings (metres)

Shading represents segments of the existing rating which have been retained

Table 1. Rating equation values for gauge 12001

Figure 3 shows that the modelled curve matches the spot gaugings very well at initial flows right up to the highest spot gaugings at over 2.5m stage height with only a low level of variance between the rising limb of the modelled Q-h relationship (relating to the rising limb of the 0.1% AEP flood hydrograph). A large degree of variance can be seen from 2.95m to 5m between the receding limb of the modelled Q-h and the spot gaugings where a hysteresis effect causes a very different relationship to be shown on the falling limb of the 0.1% AEP flood hydrograph. There may therefore be multiple flow values possible for any given stage height at flows above 35 m³/s when hysteresis develops. The RPS rating curve extension was taken from the intersection point at 2.609m, equating to approximately 169m³/s in both equations, plotting through the centre of the rising and falling limbs from the hysteresis effect where it narrows at flood flows. It was found that this gauge station data is suitable for model calibration, however, the model will only be seen to follow the reported flows at low levels and a large degree of variance may be observed at flood flows. The rating curve extension is a best fit representation of the estimated flow captured within the hysteresis effect curvature.

FERNS (12015)

The gauging station at Ferns (12015) is located on the River Bann. South East of Ferns, County Wexford approximately 7.5km upstream of its confluence with the River Slaney. The staff gauge and recorder house are located on the right bank of an open channel section approximately 74m downstream of a bridge. The channel is approximately 19.3m wide with a minimum bed level of 19.565m OD Malin and bank levels of 21.02m OD Malin (right bank) and 21.70m OD Malin (left bank). The rating review has been conducted on Mike 11 software and is modelled as 1D only. The full extent of the surveyed cross sections at the gauging station is 324m wide with a level of 24.58m OD Malin (right bank) and 35.4m OD Malin (left bank). As stated on the HydroNet website the gauge zero ordnance level used by EPA is currently 19.708m. The staff gauge zero level was originally surveyed as 19.56m OD Malin but was resurveyed as 19.609m OD Malin on 14/10/13. The EPA gauge zero level has been used as the basis for this review such that the model rating curve is considered relative to the EPA spot gaugings and rating curve.

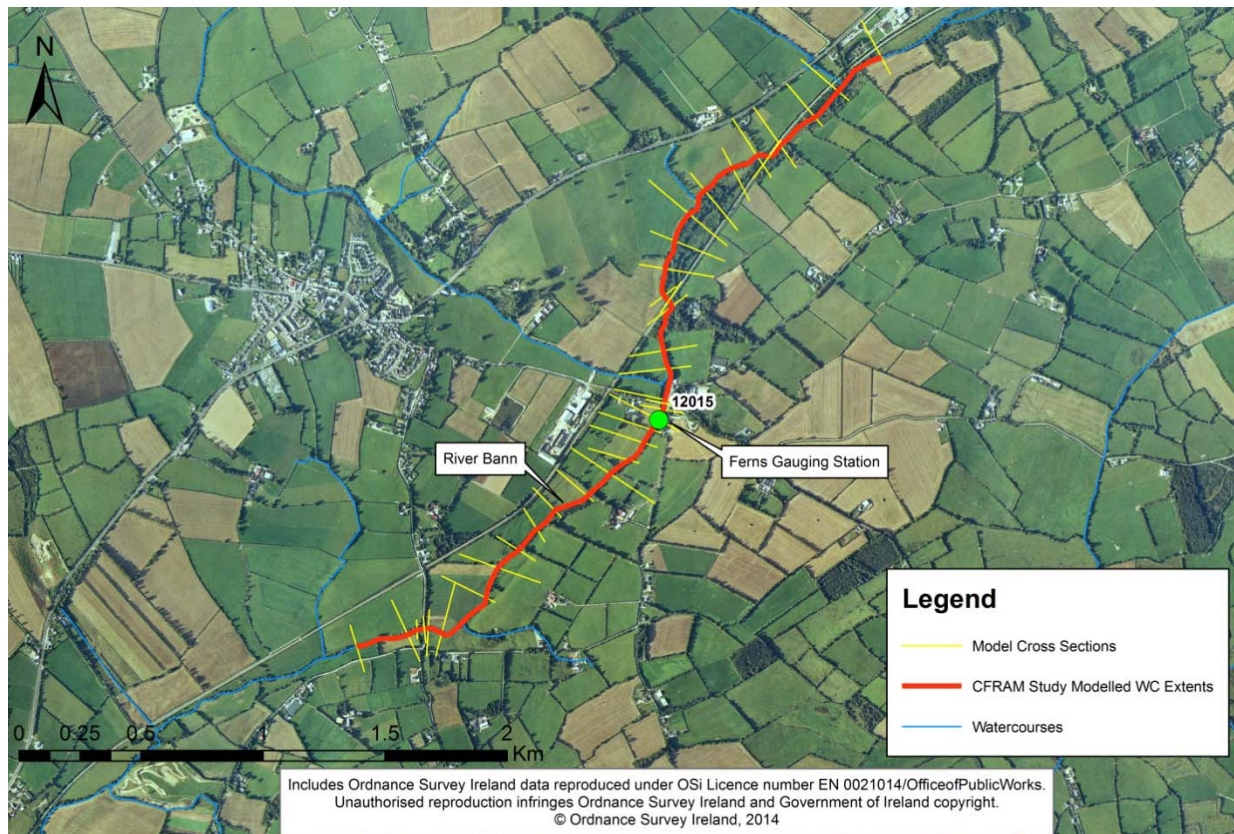


Figure 1: Location of the Ferns Gauging Station

The gauge is managed by the EPA but is currently inactive. Water level and derived flow records have been provided from June 1976 to August 2004. The latest rating has been effective since September 1989 and as such gaugings from this period were initially preferred for calibration. Initial review of the spot gaugings also identified a high degree of scatter at lower flows due to seasonal vegetation. A

review of spot gaugings with the summer flows omitted revealed a much lower degree of scatter and as such summer spot gaugings were excluded from further analysis.

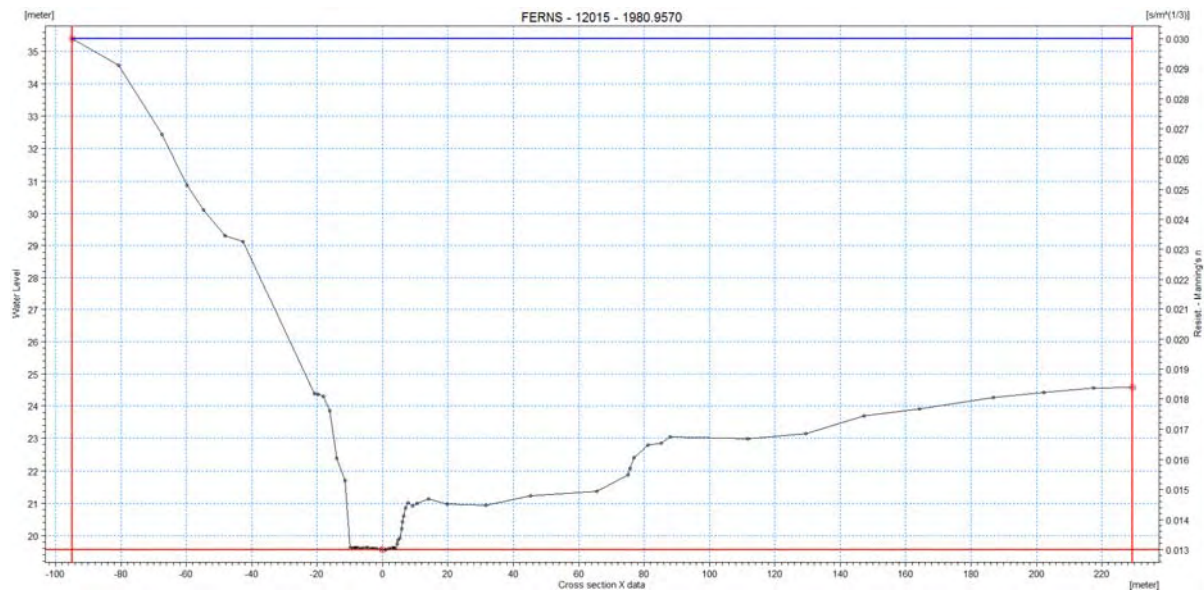


Figure 2: Model Cross-Section at Gauge Location (Top); Photo of gauge location (Bottom)

The rating review reach extends approximately 2km upstream of the gauge and 1.7km downstream. There are 3 bridge structures located upstream of the gauge within the modelled reach approximately 70m, 517m and 1350m upstream. There is 1 additional bridge structure approximately 1380m

downstream of the gauge station. The upstream and downstream approaches to the gauge are relatively straight. There are 42 cross sections included in the 1D hydraulic model for the Bann reach.

The upstream boundary input was set with a hydrograph with a peak flow of $84.62 \text{ m}^3/\text{s}$ equivalent to an estimated 0.1% AEP event. Manning's n values were adjusted to describe the channel and flood plain roughness to replicate vegetation growth and produce a realistic model of the flow conditions. As the model was calibrated to reflect the period with reduced weed growth a lower Manning's n was applied.

The EPA have described the rating standard at Ferns as 'fair - Badly affected by weeds' on the HydroNet website. The National Review under FSU Work Package 2.1 did not assign a rating classification to the Ferns Gauge Station. An observed Q_{med} value is not available from the gauge record but it is estimated to be approximately $30 \text{ m}^3/\text{s}$ based on physical catchment descriptors. The highest spot flow gauging is $16.4 \text{ m}^3/\text{s}$ and dates from 1984 and as such there is no confidence in the rating at Q_{med} . The model and survey do not suggest that there is potential for flow to bypass the gauge and immediate floodplain.

The results of the rating review are shown below in Figure 3 and Table 1. The graph demonstrates the derived RPS rating curve and shows the comparison between the EPA rating curve (which consists of two equations) and spot gaugings. The first two equations on the RPS curve have been taken from the existing EPA rating curve.

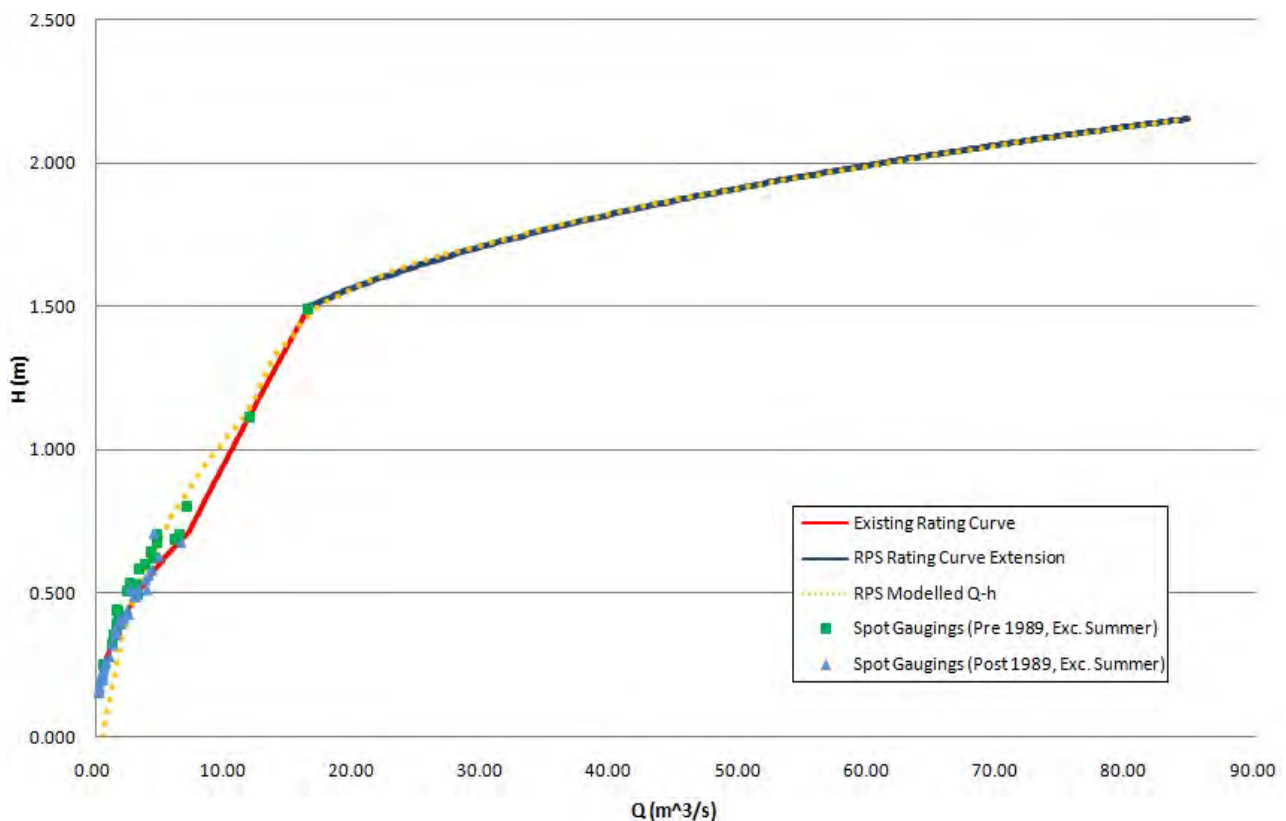


Figure 3: Comparison of Existing OPW Rating Curve and RPS Rating Curve for all flows

| Section | Min Stage (m) | Max Stage (m) | C | a | b |
|---------|---------------|---------------|---------|---------|---------|
| 1 | 0.153 | 0.714 | 15.2438 | 0 | 2.22486 |
| 2 | 0.714 | 1.490 | 10.5057 | 0 | 1.11916 |
| 3 | 1.491 | 2.152 | 6.1160 | -0.2158 | 3.9792 |

Where: $Q = C(h+a)^b$ and h = stage readings (metres)

Shaded area represents segments of the existing rating which have been retained

Table 1: Rating equation values for gauge 12015

Figure 3 shows that the model accurately represents the existing rating curve based and spot gaugings up to the last gauging at 16.4 m³/s although below 10m³/s the model tends to fit the spot gaugings more so than the existing rating. Aside from this divergence which is less than 200mm the RPS modelled curve and the EPA rating curve match well from 1.15 m³/s upwards however there is some evidence that a low flow control is not represented within the model below this. A Manning's 'n' value of 0.03 was applied to the cross section which resulted in the best fit rating curve. The results show that the floodwaters exceed top of bank level at approximately 16.5m³/s, which is less than Q_{med} .

Weed growth during summer months has had a significant hydraulic influence on the Q-h relationship at the gauge station location.

APPENDIX C

DESIGN FLOWS FOR MODELLING INPUT

Model 01 - Courtown

| Node ID_CFRAMS | AREA (km ²) | Qmed | Flows for AEP | | | | | | | | Model number |
|---|----------------------------|-------|---------------|---------|-------------|---------|---------|-------------|---------------|----------------|-----------------|
| | | | 50% (2) | 20% (5) | 10% (10) | 5% (20) | 2% (50) | 1% (100) | 0.5% (200) | 0.1% (1000) | |
| 11001_RPS | 148.73 | 45.75 | 45.75 | 57.28 | 65.15 | 73.20 | 84.68 | 94.20 | 104.68 | 133.04 | Model 1/2 |
| 11_446_10_RPS | 151.95 | 47.74 | 47.74 | 59.77 | 67.98 | 76.39 | 88.37 | 98.30 | 109.23 | 138.83 | Model 1 |
| Top-up between 11001 & 11_446_10_RPS | 3.22 | 1.29 | 1.29 | 1.62 | 1.84 | 2.07 | 2.39 | 2.66 | 2.96 | 3.76 | Model 1 |
| 11_10020_U | 0.80 | 0.24 | 0.24 | 0.34 | 0.42 | 0.51 | 0.65 | 0.78 | 0.93 | 1.40 | Model 1 |
| 11_445_1 | 1.29 | 0.31 | 0.31 | 0.45 | 0.56 | 0.67 | 0.86 | 1.03 | 1.22 | 1.83 | Model 1 |
| 11_445_4_RPS | 1.70 | 0.49 | 0.49 | 0.70 | 0.86 | 1.05 | 1.33 | 1.59 | 1.90 | 2.84 | Model 1 |
| Top-up between 11_445_1 & 11_445_4_RPS | 0.41 | 0.13 | 0.13 | 0.19 | 0.23 | 0.28 | 0.35 | 0.42 | 0.50 | 0.76 | Model 1 |
| 11_10020_1 | 2.87 | 0.79 | 0.79 | 1.14 | 1.41 | 1.71 | 2.17 | 2.60 | 3.10 | 4.64 | Model 1 |
| Top-up between 11_10020_U & 11_10020_1 | 0.37 | 0.12 | 0.12 | 0.17 | 0.21 | 0.25 | 0.32 | 0.38 | 0.46 | 0.68 | Model 1 |
| 11_387_U | 0.04 | 0.02 | 0.02 | 0.02 | 0.03 | 0.03 | 0.04 | 0.05 | 0.06 | 0.09 | Model 1 |
| 11_387_1 | 0.17 | 0.06 | 0.06 | 0.08 | 0.10 | 0.12 | 0.15 | 0.18 | 0.22 | 0.32 | Model 1 |
| Top-up between 11_387_u & 11_387_1 | 0.12 | 0.04 | 0.04 | 0.06 | 0.07 | 0.09 | 0.11 | 0.14 | 0.16 | 0.24 | Model 1 |
| 11_455_3_RPS | 155.59 | 48.27 | 48.27 | 60.43 | 68.74 | 77.23 | 89.35 | 99.39 | 110.44 | 140.37 | Model 1 |
| Top-up between 11_446_10_RPS & 11_455_3_RPS | 0.61 | 0.27 | 0.27 | 0.33 | 0.38 | 0.43 | 0.49 | 0.55 | 0.61 | 0.77 | Model 1 |
| 11_264_1 | 5.97 | 1.41 | 1.41 | 2.05 | 2.54 | 3.08 | 3.91 | 4.68 | 5.57 | 8.32 | Model 1 |
| 11_403_4_RPS | 3.59 | 0.80 | 0.80 | 1.15 | 1.42 | 1.71 | 2.18 | 2.61 | 3.11 | 4.65 | Model 1 |
| 11_403_7_RPS | 3.98 | 0.94 | 0.94 | 1.36 | 1.68 | 2.04 | 2.59 | 3.09 | 3.69 | 5.52 | Model 1 |
| Top-up between 11_403_4_RPS & 10_403_7_RPS | 0.38 | 0.11 | 0.11 | 0.15 | 0.19 | 0.23 | 0.29 | 0.35 | 0.41 | 0.62 | Model 1 |
| 11_265_U | 0.39 | 0.11 | 0.11 | 0.15 | 0.19 | 0.23 | 0.29 | 0.35 | 0.42 | 0.63 | Model 1 |
| 11_265_1 | 0.70 | 0.18 | 0.18 | 0.27 | 0.33 | 0.40 | 0.51 | 0.60 | 0.72 | 1.08 | Model 1 |
| Top-up between 11_265_U & 11_265_1 | 0.31 | 0.09 | 0.09 | 0.12 | 0.15 | 0.18 | 0.23 | 0.28 | 0.33 | 0.50 | Model 1 |

Model 01 - Courtown

| Node ID_CFRAMS | AREA (km ²) | Qmed | Flows for AEP | | | | | | | | Model number |
|--|----------------------------|------|---------------|---------|-------------|---------|---------|-------------|---------------|----------------|-----------------|
| | | | 50% (2) | 20% (5) | 10% (10) | 5% (20) | 2% (50) | 1% (100) | 0.5% (200) | 0.1% (1000) | |
| 11_469_3_RPS | 14.77 | 3.32 | 3.32 | 4.77 | 5.86 | 7.06 | 8.90 | 10.54 | 12.46 | 18.24 | Model 1 |
| Top-up between 11_264_1 & 11_469_3_RPS | 4.13 | 1.00 | 1.00 | 1.45 | 1.78 | 2.14 | 2.70 | 3.19 | 3.78 | 5.52 | Model 1 |
| 11_522_2_RPS | 14.87 | 3.42 | 3.42 | 4.91 | 6.04 | 7.30 | 9.23 | 10.98 | 13.03 | 19.29 | Model 1 |
| Top-up between 11_469_3_RPS & 11_522_2_RPS | 0.10 | 0.03 | 0.03 | 0.04 | 0.06 | 0.07 | 0.08 | 0.10 | 0.12 | 0.18 | Model 1 |

| Node ID_CFRAMS | AREA (km ²) | MRFS Flows for AEP | | | | | | | | HEFS Flows for AEP | | | Model number |
|--|----------------------------|--------------------|------------|-------------|------------|------------|-------------|---------------|----------------|--------------------|-------------|----------------|-----------------|
| | | 50% (2) | 20% (5) | 10% (10) | 5% (20) | 2% (50) | 1% (100) | 0.5% (200) | 0.1% (1000) | 10% (10) | 1% (100) | 0.1% (1000) | |
| 11001_RPS | 148.73 | 57.18 | 71.59 | 81.43 | 91.49 | 105.85 | 117.74 | 130.84 | 166.29 | 107.99 | 156.15 | 220.54 | Model 1 |
| 11_446_10_RPS | 151.95 | 59.79 | 74.85 | 85.13 | 95.66 | 110.66 | 123.10 | 136.79 | 173.86 | 113.86 | 164.64 | 232.53 | Model 1 |
| Top-up between 11001 & 11_446_10_RPS | 3.22 | 1.62 | 2.03 | 2.30 | 2.59 | 2.99 | 3.33 | 3.70 | 4.70 | 3.39 | 4.90 | 6.92 | Model 1 |
| 11_10020_U | 0.80 | 0.30 | 0.43 | 0.53 | 0.64 | 0.82 | 0.98 | 1.16 | 1.74 | 0.65 | 1.20 | 2.14 | Model 1 |
| 11_445_1 | 1.29 | 0.39 | 0.56 | 0.69 | 0.84 | 1.07 | 1.28 | 1.53 | 2.28 | 0.85 | 1.57 | 2.81 | Model 1 |
| 11_445_4_RPS | 1.70 | 0.61 | 0.87 | 1.08 | 1.31 | 1.66 | 1.99 | 2.37 | 3.55 | 1.33 | 2.44 | 4.36 | Model 1 |
| Top-up between 11_445_1 & 11_445_4_RPS | 0.41 | 0.16 | 0.23 | 0.29 | 0.35 | 0.44 | 0.53 | 0.63 | 0.94 | 0.35 | 0.65 | 1.16 | Model 1 |
| 11_10020_1 | 2.87 | 0.99 | 1.43 | 1.76 | 2.13 | 2.71 | 3.24 | 3.87 | 5.79 | 2.16 | 3.98 | 7.11 | Model 1 |
| Top-up between 11_10020_U & 11_10020_1 | 0.37 | 0.15 | 0.21 | 0.26 | 0.31 | 0.40 | 0.48 | 0.57 | 0.85 | 0.32 | 0.59 | 1.04 | Model 1 |
| 11_387_U | 0.04 | 0.05 | 0.07 | 0.08 | 0.10 | 0.13 | 0.16 | 0.18 | 0.28 | 0.09 | 0.17 | 0.30 | Model 1 |
| 11_387_1 | 0.17 | 0.17 | 0.24 | 0.29 | 0.36 | 0.45 | 0.54 | 0.64 | 0.97 | 0.32 | 0.59 | 1.05 | Model 1 |

| Node ID_CFRAMS | AREA (km ²) | MRFS Flows for AEP | | | | | | | | HEFS Flows for AEP | | | Model number |
|---|----------------------------|--------------------|------------|-------------|------------|------------|-------------|---------------|----------------|--------------------|-------------|----------------|-----------------|
| | | 50% (2) | 20% (5) | 10% (10) | 5% (20) | 2% (50) | 1% (100) | 0.5% (200) | 0.1% (1000) | 10% (10) | 1% (100) | 0.1% (1000) | |
| Top-up between 11_387_u & 11_387_1 | 0.12 | 0.12 | 0.18 | 0.22 | 0.27 | 0.34 | 0.41 | 0.48 | 0.72 | 0.24 | 0.44 | 0.79 | Model 1 |
| 11_455_3_RPS | 155.59 | 60.39 | 75.61 | 86.00 | 96.63 | 111.78 | 124.34 | 138.17 | 175.62 | 114.54 | 165.62 | 233.91 | Model 1 |
| Top-up between 11_446_10_RPS & 11_455_3_RPS | 0.61 | 0.33 | 0.42 | 0.47 | 0.53 | 0.62 | 0.69 | 0.76 | 0.97 | 0.63 | 0.91 | 1.29 | Model 1 |
| 11_264_1 | 5.97 | 1.77 | 2.56 | 3.16 | 3.84 | 4.89 | 5.84 | 6.95 | 10.39 | 3.89 | 7.17 | 12.76 | Model 1 |
| 11_403_4_RPS | 3.59 | 0.99 | 1.43 | 1.77 | 2.14 | 2.72 | 3.25 | 3.88 | 5.81 | 2.17 | 4.00 | 7.14 | Model 1 |
| 11_403_7_RPS | 3.98 | 1.18 | 1.70 | 2.10 | 2.54 | 3.23 | 3.86 | 4.61 | 6.89 | 2.58 | 4.75 | 8.47 | Model 1 |
| Top-up between 11_403_4_RPS & 10_403_7_RPS | 0.38 | 0.23 | 0.33 | 0.41 | 0.50 | 0.63 | 0.76 | 0.90 | 1.35 | 0.61 | 1.12 | 2.00 | Model 1 |
| 11_265_U | 0.39 | 0.13 | 0.19 | 0.24 | 0.29 | 0.37 | 0.44 | 0.52 | 0.78 | 0.29 | 0.54 | 0.96 | Model 1 |
| 11_265_1 | 0.70 | 0.40 | 0.58 | 0.72 | 0.87 | 1.11 | 1.32 | 1.58 | 2.36 | 1.06 | 1.95 | 3.49 | Model 1 |
| Top-up between 11_265_U & 11_265_1 | 0.31 | 0.19 | 0.27 | 0.33 | 0.40 | 0.51 | 0.61 | 0.73 | 1.09 | 0.49 | 0.90 | 1.61 | Model 1 |
| 11_469_3_RPS | 14.77 | 4.62 | 6.65 | 8.17 | 9.84 | 12.40 | 14.69 | 17.36 | 25.41 | 16.35 | 29.40 | 50.85 | Model 1 |
| Top-up between 11_264_1 & 11_469_3_RPS | 4.13 | 1.97 | 2.83 | 3.48 | 4.19 | 5.28 | 6.26 | 7.40 | 10.83 | 4.95 | 8.91 | 15.40 | Model 1 |
| 11_522_2_RPS | 14.87 | 4.77 | 6.86 | 8.44 | 10.18 | 12.89 | 15.33 | 18.19 | 26.92 | 16.98 | 30.86 | 54.19 | Model 1 |
| Top-up between 11_469_3_RPS & 11_522_2_RPS | 0.10 | 0.08 | 0.12 | 0.15 | 0.18 | 0.23 | 0.27 | 0.32 | 0.48 | 0.16 | 0.29 | 0.52 | Model 1 |

| |
|--|
| |
| |
| |

Input flows

Top-up flows. These flows should be entered laterally

Check flows. Modellers should check to make sure these flows are being reached at each HEP

Some of these flows may be put in at the US point due to a small difference between US & DS flows.

Model 02 - Blackwater

| Node ID_CFRAMS | AREA (km ²) | Qmed | Flows for AEP | | | | | | | | Model number |
|---|----------------------------|------|---------------|------------|-------------|------------|------------|-------------|---------------|----------------|-----------------|
| | | | 50% (2) | 20% (5) | 10% (10) | 5% (20) | 2% (50) | 1% (100) | 0.5% (200) | 0.1% (1000) | |
| 11_188_1_RPS | 17.75 | 3.47 | 3.47 | 4.94 | 6.03 | 7.24 | 9.10 | 10.76 | 12.69 | 18.54 | Model 2 |
| 11_326_U | 0.44 | 0.11 | 0.11 | 0.16 | 0.20 | 0.24 | 0.31 | 0.37 | 0.44 | 0.65 | Model 2 |
| 11_483_1 | 0.89 | 0.22 | 0.22 | 0.31 | 0.39 | 0.47 | 0.60 | 0.72 | 0.85 | 1.28 | Model 2 |
| Top-up between 11_326_U & 11_483_1 | 0.46 | 0.12 | 0.12 | 0.17 | 0.21 | 0.25 | 0.32 | 0.38 | 0.46 | 0.68 | Model 2 |
| 11_481_1_RPS | 18.13 | 3.26 | 3.26 | 4.63 | 5.66 | 6.79 | 8.54 | 10.10 | 11.91 | 17.40 | Model 2 |
| 11_481_3_RPS | 19.16 | 3.87 | 3.87 | 5.50 | 6.73 | 8.07 | 10.15 | 12.00 | 14.16 | 20.68 | Model 2 |
| Top-up between 11_188_1_RPS & 11_481_3_RPS | 0.52 | 0.12 | 0.12 | 0.17 | 0.21 | 0.26 | 0.32 | 0.38 | 0.45 | 0.65 | Model 2 |
| 11_25_3_RPS | 40.48 | 7.72 | 7.72 | 10.58 | 12.65 | 14.88 | 18.22 | 21.13 | 24.46 | 34.15 | Model 2 |
| Top-up between 11_481_1_RPS & 11_25_3_RPS | 3.19 | 0.71 | 0.71 | 0.98 | 1.17 | 1.38 | 1.69 | 1.96 | 2.26 | 3.16 | Model 2 |
| 11_197_U | 0.46 | 0.17 | 0.17 | 0.25 | 0.31 | 0.37 | 0.48 | 0.57 | 0.68 | 1.01 | Model 2 |
| 11_198_U | 0.04 | 0.02 | 0.02 | 0.03 | 0.03 | 0.04 | 0.05 | 0.06 | 0.07 | 0.11 | Model 2 |
| 11_198_1 | 0.06 | 0.02 | 0.02 | 0.03 | 0.04 | 0.05 | 0.07 | 0.08 | 0.09 | 0.14 | Model 2 |
| 11_32_2_RPS | 44.57 | 8.51 | 8.51 | 11.67 | 13.96 | 16.42 | 20.10 | 23.32 | 26.99 | 37.69 | Model 2 |
| Top-up between 11_197_U & 11_32_2_RPS | 3.57 | 0.80 | 0.80 | 1.10 | 1.31 | 1.54 | 1.89 | 2.19 | 2.53 | 3.54 | Model 2 |

| Node ID_CFRAMS | AREA (km ²) | MRFS Flows for AEP | | | | | | | | HEFS Flows for AEP | | | Model number |
|--|----------------------------|--------------------|------------|-------------|------------|------------|-------------|---------------|----------------|--------------------|-------------|----------------|--------------|
| | | 50% (2) | 20% (5) | 10% (10) | 5% (20) | 2% (50) | 1% (100) | 0.5% (200) | 0.1% (1000) | 10% (10) | 1% (100) | 0.1% (1000) | |
| 11_188_1_RPS | 17.75 | 4.33 | 6.16 | 7.53 | 9.04 | 11.36 | 13.43 | 15.85 | 23.15 | 9.25 | 16.50 | 28.44 | Model 2 |
| 11_326_U | 0.44 | 0.14 | 0.20 | 0.25 | 0.30 | 0.38 | 0.46 | 0.54 | 0.81 | 0.30 | 0.56 | 1.00 | Model 2 |
| 11_483_1 | 17.75 | 0.27 | 0.39 | 0.48 | 0.59 | 0.75 | 0.89 | 1.06 | 1.59 | 0.60 | 1.10 | 1.95 | Model 2 |
| Top-up between 11_326_U & 11_483_1 | 0.44 | 0.25 | 0.37 | 0.45 | 0.55 | 0.70 | 0.84 | 1.00 | 1.49 | 0.67 | 1.24 | 2.20 | Model 2 |
| 11_481_1_RPS | 17.747 | 4.07 | 5.78 | 7.07 | 8.48 | 10.66 | 12.60 | 14.87 | 21.72 | 8.68 | 15.49 | 26.69 | Model 2 |
| 11_481_3_RPS | 0.44 | 4.78 | 6.80 | 8.31 | 9.98 | 12.54 | 14.83 | 17.50 | 25.56 | 10.22 | 18.22 | 31.40 | Model 2 |
| Top-up between 11_188_1_RPS & 11_481_3_RPS | 17.75 | 0.27 | 0.38 | 0.46 | 0.55 | 0.70 | 0.82 | 0.97 | 1.42 | 0.68 | 1.22 | 2.10 | Model 2 |
| 11_25_3_RPS | 0.435 | 9.51 | 13.04 | 15.59 | 18.33 | 22.45 | 26.05 | 30.14 | 42.09 | 19.15 | 32.00 | 51.71 | Model 2 |
| Top-up between 11_481_1_RPS & 11_25_3_RPS | 17.75 | 0.88 | 1.21 | 1.44 | 1.70 | 2.08 | 2.41 | 2.79 | 3.89 | 1.77 | 2.96 | 4.78 | Model 2 |
| 11_197_U | 0.44 | 0.21 | 0.31 | 0.39 | 0.47 | 0.59 | 0.71 | 0.85 | 1.26 | 0.47 | 0.87 | 1.55 | Model 2 |
| 11_198_U | 17.75 | 0.04 | 0.06 | 0.07 | 0.09 | 0.11 | 0.13 | 0.16 | 0.23 | 0.11 | 0.19 | 0.35 | Model 2 |
| 11_198_1 | 0.44 | 0.05 | 0.08 | 0.09 | 0.11 | 0.14 | 0.17 | 0.20 | 0.31 | 0.14 | 0.25 | 0.45 | Model 2 |
| 11_32_2_RPS | 17.747 | 10.51 | 14.40 | 17.22 | 20.26 | 24.80 | 28.78 | 33.30 | 46.50 | 21.16 | 35.35 | 57.13 | Model 2 |
| Top-up between 11_197_U & 11_32_2_RPS | 0.44 | 0.99 | 1.35 | 1.62 | 1.90 | 2.33 | 2.70 | 3.12 | 4.36 | 1.98 | 3.32 | 5.36 | Model 2 |

| |
|--|
| |
| |
| |

Input flows

Top-up flows. These flows should be entered laterally

Check flows. Modellers should check to make sure these flows are being reached at each HEP

Some of these flows may be put in at the US point due to a small difference between US & DS flows.

Model 03 -Gorey

| Node ID_CFRAMS | AREA (km2) | Qmed | Flows for AEP | | | | | | | | Model number |
|--|------------|------|---------------|---------|----------|---------|---------|----------|------------|-------------|--------------|
| | | | 50% (2) | 20% (5) | 10% (10) | 5% (20) | 2% (50) | 1% (100) | 0.5% (200) | 0.1% (1000) | |
| 11_441_1_RPS | 3.49 | 1.44 | 1.44 | 2.08 | 2.56 | 3.10 | 3.95 | 4.72 | 5.62 | 8.42 | Model 3 |
| 11_10010_U | 0.78 | 0.33 | 0.33 | 0.47 | 0.59 | 0.71 | 0.90 | 1.08 | 1.29 | 1.92 | Model 3 |
| 11_10010_1 | 4.39 | 1.66 | 1.66 | 2.41 | 2.98 | 3.61 | 4.59 | 5.49 | 6.54 | 9.77 | Model 3 |
| Top-up between 11_10010_U & 11_10010_1 | 3.61 | 1.38 | 1.38 | 2.00 | 2.48 | 3.00 | 3.82 | 4.57 | 5.44 | 8.13 | Model 3 |
| 11_118_U | 0.62 | 0.36 | 0.36 | 0.52 | 0.64 | 0.77 | 0.98 | 1.17 | 1.40 | 2.09 | Model 3 |
| 11_23_U | 0.41 | 0.24 | 0.24 | 0.35 | 0.43 | 0.52 | 0.67 | 0.80 | 0.95 | 1.42 | Model 3 |
| 11_23_1 | 0.45 | 0.26 | 0.26 | 0.38 | 0.47 | 0.57 | 0.72 | 0.87 | 1.03 | 1.55 | Model 3 |
| 11_438_1 | 2.69 | 1.24 | 1.24 | 1.77 | 2.16 | 2.59 | 3.26 | 3.85 | 4.55 | 6.63 | Model 3 |
| Top-up between 11_118_U & 11_438_1 | 1.62 | 0.77 | 0.77 | 1.10 | 1.34 | 1.61 | 2.03 | 2.40 | 2.83 | 4.13 | Model 3 |
| 11_474_2 | 1.53 | 0.49 | 0.49 | 0.71 | 0.87 | 1.06 | 1.35 | 1.61 | 1.92 | 2.87 | Model 3 |
| 11_281_U | 0.18 | 0.08 | 0.08 | 0.12 | 0.15 | 0.18 | 0.23 | 0.27 | 0.32 | 0.48 | Model 3 |
| 11_281_1 | 0.41 | 0.18 | 0.18 | 0.25 | 0.31 | 0.38 | 0.48 | 0.58 | 0.69 | 1.03 | Model 3 |
| Top-up between 11_281_U & 11_281_1 | 0.23 | 0.10 | 0.10 | 0.15 | 0.18 | 0.22 | 0.28 | 0.34 | 0.40 | 0.60 | Model 3 |
| 11_110_4 | 5.65 | 2.28 | 2.28 | 3.30 | 4.08 | 4.95 | 6.31 | 7.53 | 8.97 | 13.40 | Model 3 |
| Top-up between 11_474_2 & 11_110_4 | 3.72 | 1.54 | 1.54 | 2.23 | 2.76 | 3.35 | 4.26 | 5.09 | 6.06 | 9.05 | Model 3 |
| 11_289_U | 0.28 | 0.14 | 0.14 | 0.20 | 0.24 | 0.29 | 0.38 | 0.45 | 0.53 | 0.80 | Model 3 |
| 11_289_1 | 0.65 | 0.30 | 0.30 | 0.43 | 0.53 | 0.65 | 0.82 | 0.98 | 1.17 | 1.75 | Model 3 |
| Top-up between 11_289_U & 11_289_1 | 0.37 | 0.18 | 0.18 | 0.25 | 0.31 | 0.38 | 0.48 | 0.58 | 0.69 | 1.03 | Model 3 |
| 11_285_U | 0.50 | 0.19 | 0.19 | 0.27 | 0.34 | 0.41 | 0.52 | 0.62 | 0.74 | 1.11 | Model 3 |
| 11_303_3_RPS | 5.50 | 2.09 | 2.09 | 3.01 | 3.71 | 4.49 | 5.72 | 6.83 | 8.15 | 12.20 | Model 3 |
| Top-up between 11_285_U & 11_303_3_RPS | 5.00 | 1.91 | 1.91 | 2.75 | 3.39 | 4.11 | 5.23 | 6.25 | 7.45 | 11.15 | Model 3 |

Model 03 -Gorey

| Node ID_CFRAMS | AREA (km ²) | Qmed | Flows for AEP | | | | | | | | Model number |
|-------------------------------------|-------------------------|-------|---------------|---------|----------|---------|---------|----------|------------|-------------|--------------|
| | | | 50% (2) | 20% (5) | 10% (10) | 5% (20) | 2% (50) | 1% (100) | 0.5% (200) | 0.1% (1000) | |
| 11_257_4 | 29.54 | 8.37 | 8.37 | 11.48 | 13.72 | 16.14 | 19.76 | 22.93 | 26.53 | 37.05 | Model 3 |
| Top-up between 11_441_1 & 11_257_4 | 7.18 | 2.22 | 2.22 | 3.05 | 3.64 | 4.29 | 5.25 | 6.09 | 7.05 | 9.84 | Model 3 |
| 11_259_6_RPS | 117.63 | 33.26 | 33.26 | 41.64 | 47.36 | 53.21 | 61.56 | 68.48 | 76.10 | 96.72 | Model 3 |
| 11001_RPS | 148.73 | 45.75 | 45.75 | 57.28 | 65.15 | 73.20 | 84.68 | 94.20 | 104.68 | 133.04 | Model 3 |
| Top-up between 11_257_4 & 11001_RPS | 1.56 | 0.53 | 0.53 | 0.67 | 0.76 | 0.85 | 0.99 | 1.10 | 1.22 | 1.55 | Model 3 |

| Node ID_CFRAMS | AREA (km ²) | MRFS Flows for AEP | | | | | | | | HEFS Flows for AEP | | | Model number |
|--|-------------------------|--------------------|---------|----------|---------|---------|----------|------------|-------------|--------------------|----------|-------------|--------------|
| | | 50% (2) | 20% (5) | 10% (10) | 5% (20) | 2% (50) | 1% (100) | 0.5% (200) | 0.1% (1000) | 10% (10) | 1% (100) | 0.1% (1000) | |
| 11_441_1_RPS | 3.49 | 1.80 | 2.59 | 3.20 | 3.87 | 4.93 | 5.89 | 7.02 | 10.51 | 3.93 | 7.24 | 12.92 | Model 3 |
| 11_10010_U | 0.78 | 0.41 | 0.59 | 0.72 | 0.88 | 1.12 | 1.33 | 1.59 | 2.38 | 0.89 | 1.64 | 2.92 | Model 3 |
| 11_10010_1 | 4.39 | 2.05 | 2.98 | 3.68 | 4.47 | 5.68 | 6.79 | 8.09 | 12.08 | 4.52 | 8.34 | 14.84 | Model 3 |
| Top-up between 11_10010_U & 11_10010_1 | 3.61 | 3.00 | 4.35 | 5.37 | 6.52 | 8.29 | 9.91 | 11.80 | 17.63 | 7.94 | 14.64 | 26.06 | Model 3 |
| 11_118_U | 0.62 | 0.65 | 0.93 | 1.15 | 1.40 | 1.78 | 2.12 | 2.53 | 3.79 | 1.52 | 2.79 | 4.98 | Model 3 |
| 11_23_U | 0.41 | 0.44 | 0.63 | 0.78 | 0.95 | 1.21 | 1.44 | 1.72 | 2.57 | 1.03 | 1.90 | 3.38 | Model 3 |
| 11_23_1 | 0.45 | 0.48 | 0.69 | 0.85 | 1.03 | 1.31 | 1.57 | 1.87 | 2.79 | 1.12 | 2.06 | 3.68 | Model 3 |
| 11_438_1 | 2.69 | 2.09 | 2.97 | 3.63 | 4.36 | 5.48 | 6.48 | 7.64 | 11.15 | 5.49 | 9.79 | 16.86 | Model 3 |
| Top-up between 11_118_U & 11_438_1 | 1.62 | 1.33 | 1.89 | 2.31 | 2.77 | 3.48 | 4.12 | 4.86 | 7.09 | 3.42 | 6.09 | 10.49 | Model 3 |
| 11_474_2 | 1.53 | 0.61 | 0.88 | 1.09 | 1.32 | 1.68 | 2.01 | 2.40 | 3.59 | 1.34 | 2.47 | 4.41 | Model 3 |
| 11_281_U | 0.18 | 0.10 | 0.15 | 0.19 | 0.22 | 0.29 | 0.34 | 0.41 | 0.61 | 0.26 | 0.48 | 0.85 | Model 3 |
| 11_281_1 | 0.41 | 0.22 | 0.32 | 0.40 | 0.48 | 0.61 | 0.73 | 0.87 | 1.31 | 0.56 | 1.03 | 1.84 | Model 3 |

| Node ID_CFRAMS | AREA (km ²) | MRFS Flows for AEP | | | | | | | | HEFS Flows for AEP | | | Model number |
|--|----------------------------|--------------------|---------|----------|---------|---------|----------|------------|-------------|--------------------|----------|-------------|-----------------|
| | | 50% (2) | 20% (5) | 10% (10) | 5% (20) | 2% (50) | 1% (100) | 0.5% (200) | 0.1% (1000) | 10% (10) | 1% (100) | 0.1% (1000) | |
| Top-up between 11_281_U & 11_281_1 | 0.23 | 0.13 | 0.19 | 0.23 | 0.28 | 0.36 | 0.42 | 0.51 | 0.76 | 0.32 | 0.60 | 1.06 | Model 3 |
| 11_110_4 | 5.65 | 2.85 | 4.13 | 5.10 | 6.19 | 7.88 | 9.41 | 11.21 | 16.75 | 6.74 | 12.44 | 22.14 | Model 3 |
| Top-up between 11_474_2 & 11_110_4 | 3.72 | 2.13 | 3.09 | 3.82 | 4.64 | 5.90 | 7.05 | 8.40 | 12.54 | 4.55 | 8.40 | 14.95 | Model 3 |
| 11_289_U | 0.28 | 0.19 | 0.27 | 0.34 | 0.41 | 0.52 | 0.62 | 0.74 | 1.11 | 0.40 | 0.74 | 1.32 | Model 3 |
| 11_289_1 | 0.65 | 0.42 | 0.60 | 0.74 | 0.90 | 1.14 | 1.36 | 1.62 | 2.43 | 0.88 | 1.62 | 2.90 | Model 3 |
| Top-up between 11_289_U & 11_289_1 | 0.37 | 0.51 | 0.74 | 0.91 | 1.11 | 1.41 | 1.68 | 2.01 | 3.00 | 0.99 | 1.82 | 3.25 | Model 3 |
| 11_285_U | 0.50 | 0.24 | 0.34 | 0.42 | 0.51 | 0.65 | 0.77 | 0.92 | 1.38 | 0.52 | 0.95 | 1.69 | Model 3 |
| 11_303_3_RPS | 5.50 | 2.60 | 3.75 | 4.62 | 5.60 | 7.13 | 8.51 | 10.15 | 15.19 | 5.68 | 10.46 | 18.67 | Model 3 |
| Top-up between 11_285_U & 11_303_3_RPS | 5.00 | 2.38 | 3.43 | 4.23 | 5.12 | 6.52 | 7.78 | 9.28 | 13.89 | 5.19 | 9.56 | 17.07 | Model 3 |
| 11_257_4 | 29.54 | 11.81 | 16.19 | 19.36 | 22.77 | 27.89 | 32.35 | 37.44 | 52.28 | 40.32 | 67.37 | 108.87 | Model 3 |
| Top-up between 11_441_1 & 11_257_4 | 7.18 | 3.14 | 4.30 | 5.14 | 6.05 | 7.41 | 8.59 | 9.95 | 13.89 | 10.71 | 17.90 | 28.92 | Model 3 |
| 11_259_6_RPS | 117.63 | 41.30 | 51.70 | 58.81 | 66.08 | 76.44 | 85.03 | 94.49 | 120.09 | 72.25 | 104.47 | 147.55 | Model 3 |
| 11001_RPS | 148.73 | 57.20 | 71.62 | 81.45 | 91.52 | 105.88 | 117.78 | 130.88 | 166.34 | 108.02 | 156.20 | 220.60 | Model 3 |
| Top-up between 11_257_4 & 11001_RPS | 1.56 | 0.67 | 0.83 | 0.95 | 1.07 | 1.23 | 1.37 | 1.52 | 1.94 | 1.26 | 1.82 | 2.57 | Model 3 |

| |
|--|
| |
| |
| |

Input flows

Top-up flows. These flows should be entered laterally

Check flows. Modellers should check to make sure these flows are being reached at each HEP

Some of these flows may be put in at the US point due to a small difference between US & DS flows.

Model 1 Baltinglass

| Node ID_CFRAMS | AREA (km ²) | Qmed | Flows for AEP | | | | | | | | Model number |
|--|-------------------------|-------|---------------|---------|----------|---------|---------|----------|------------|-------------|--------------|
| | | | 50% (2) | 20% (5) | 10% (10) | 5% (20) | 2% (50) | 1% (100) | 0.5% (200) | 0.1% (1000) | |
| 12_2309_1_RPS | 164.62 | 37.50 | 37.50 | 47.88 | 55.23 | 63.00 | 74.39 | 84.18 | 95.17 | 126.33 | Model 1 |
| 12_2308_U | 0.11 | 0.03 | 0.03 | 0.05 | 0.06 | 0.07 | 0.08 | 0.10 | 0.12 | 0.17 | Model 1 |
| 12_2308_5_RPS | 2.52 | 0.76 | 0.76 | 1.08 | 1.32 | 1.58 | 1.99 | 2.36 | 2.79 | 4.10 | Model 1 |
| Top-up between 12_2308_U & 12_2308_5_RPS | 2.42 | 0.73 | 0.73 | 1.03 | 1.26 | 1.52 | 1.91 | 2.26 | 2.68 | 3.94 | Model 1 |
| 12_2200_2_RPS | 26.56 | 8.57 | 8.57 | 11.01 | 12.80 | 14.72 | 17.62 | 20.15 | 23.06 | 31.58 | Model 1 |
| 12013_RPS | 209.89 | 43.88 | 43.88 | 55.77 | 64.15 | 72.97 | 85.83 | 96.84 | 109.13 | 143.71 | Model 1 |
| Top-up between 12_2309_1_RPS & 12013_RPS | 16.19 | 3.98 | 3.98 | 5.05 | 5.81 | 6.61 | 7.78 | 8.78 | 9.89 | 13.02 | Model 1 |

| Node ID_CFRAMS | AREA (km ²) | MRFS Flows for AEP | | | | | | | | HEFS Flows for AEP | | | Model number |
|--|-------------------------|--------------------|---------|----------|---------|---------|----------|------------|-------------|--------------------|----------|-------------|--------------|
| | | 50% (2) | 20% (5) | 10% (10) | 5% (20) | 2% (50) | 1% (100) | 0.5% (200) | 0.1% (1000) | 10% (10) | 1% (100) | 0.1% (1000) | |
| 12_2309_1_RPS | 164.62 | 46.80 | 59.76 | 68.94 | 78.62 | 92.85 | 105.07 | 118.78 | 157.67 | 84.69 | 129.08 | 193.71 | Model 1 |
| 12_2308_U | 0.11 | 0.04 | 0.06 | 0.07 | 0.08 | 0.10 | 0.12 | 0.15 | 0.22 | 0.09 | 0.15 | 0.26 | Model 1 |
| 12_2308_5_RPS | 2.52 | 0.95 | 1.45 | 1.77 | 2.13 | 2.68 | 3.17 | 3.75 | 5.51 | 3.16 | 5.65 | 9.82 | Model 1 |
| Top-up between 12_2308_U & 12_2308_5_RPS | 2.42 | 0.91 | 1.39 | 1.70 | 2.04 | 2.57 | 3.05 | 3.60 | 5.30 | 3.03 | 5.43 | 9.43 | Model 1 |
| 12_2200_2_RPS | 26.56 | 10.70 | 13.75 | 15.97 | 18.37 | 21.98 | 25.15 | 28.78 | 39.41 | 19.62 | 30.90 | 48.42 | Model 1 |
| 12013_RPS | 209.89 | 54.77 | 69.13 | 79.51 | 90.44 | 106.38 | 120.03 | 135.26 | 178.12 | 97.69 | 147.47 | 218.83 | Model 1 |
| Top-up between 12_2309_1_RPS & 12013_RPS | 16.19 | 4.96 | 9.40 | 10.81 | 12.29 | 14.46 | 16.32 | 18.39 | 24.21 | 16.05 | 24.22 | 35.94 | Model 1 |

| | |
|--|--|
| | Input flows |
| | Top-up flows. These flows should be entered laterally |
| | Check flows. Modellers should check to make sure these flows are being reached at each HEP |
| | Some of these flows may be put in at the US point due to a small difference between US & DS flows. |

Model 2 - Tullow

| Node ID_CFRAMS | AREA (km ²) | Qmed | Flows for AEP | | | | | | | | Model number |
|---|----------------------------|-------|---------------|------------|-------------|------------|------------|-------------|---------------|----------------|-----------------|
| | | | 50% (2) | 20% (5) | 10% (10) | 5% (20) | 2% (50) | 1% (100) | 0.5% (200) | 0.1% (1000) | |
| 12013_RPS | 209.888 | 43.88 | 43.88 | 55.77 | 64.15 | 72.97 | 85.83 | 96.84 | 109.13 | 143.71 | Model 1 |
| 12_1647_1_RPS | 229.973 | 43.88 | 43.88 | 55.77 | 64.15 | 72.97 | 85.83 | 96.84 | 109.13 | 143.71 | Model 2 |
| Top-up between 12013_RPS & 12_1647_1_RPS | 20.085 | 4.41 | 4.41 | 5.61 | 6.45 | 7.34 | 8.63 | 9.74 | 10.97 | 14.45 | Model 2 |
| 12_1663_2_RPS | 242.181 | 43.88 | 43.88 | 55.77 | 64.15 | 72.97 | 85.83 | 96.84 | 109.13 | 143.71 | Model 2 |
| Top-up between 12_1647_1_RPS & 12_1663_2_RPS | 12.208 | 2.59 | 2.59 | 3.29 | 3.79 | 4.31 | 5.07 | 5.72 | 6.44 | 8.49 | Model 2 |
| 12_1656_2_RPS | 249.219 | 43.88 | 43.88 | 55.77 | 64.15 | 72.97 | 85.83 | 96.84 | 109.13 | 143.71 | Model 2 |
| Top-up between 12_1663_2_RPS & 12_1656_2_RPS | 7.038 | 1.53 | 1.53 | 1.94 | 2.23 | 2.54 | 2.99 | 3.37 | 3.80 | 5.00 | Model 2 |
| 12005_RPS | 254.053 | 43.88 | 43.88 | 55.77 | 64.15 | 72.97 | 85.83 | 96.84 | 109.13 | 143.71 | Model 2 |
| Top-up between 12_1656_2_RPS & 12005_RPS | 4.834 | 1.07 | 1.07 | 1.36 | 1.57 | 1.78 | 2.09 | 2.36 | 2.66 | 3.51 | Model 2 |
| 12_1830_U | 0.074 | 0.01 | 0.01 | 0.02 | 0.02 | 0.02 | 0.03 | 0.04 | 0.04 | 0.06 | Model 2 |
| 12_1830_1 | 1.133 | 0.15 | 0.15 | 0.22 | 0.26 | 0.32 | 0.40 | 0.47 | 0.56 | 0.82 | Model 2 |
| Top-up between 12_1830_U & 12_1830_1 | 1.059 | 0.14 | 0.14 | 0.20 | 0.25 | 0.30 | 0.37 | 0.44 | 0.52 | 0.77 | Model 2 |
| 12_1707_U | 0.26 | 0.04 | 0.04 | 0.05 | 0.07 | 0.08 | 0.10 | 0.12 | 0.14 | 0.21 | Model 2 |
| 12_1707_2_RPS | 1.59 | 0.28 | 0.28 | 0.39 | 0.48 | 0.58 | 0.73 | 0.86 | 1.02 | 1.50 | Model 2 |
| Top-up between 12_1707_U & 12_1707_2_RPS | 1.33 | 0.24 | 0.24 | 0.33 | 0.41 | 0.49 | 0.62 | 0.73 | 0.86 | 1.27 | Model 2 |
| 12006_RPS | 257.234 | 44.57 | 44.57 | 56.65 | 65.16 | 74.12 | 87.18 | 98.37 | 110.85 | 145.97 | Model 2 |

Model 2 - Tullow

| Node ID_CFRAMS | AREA (km ²) | Qmed | Flows for AEP | | | | | | | | Model number |
|--|----------------------------|-------|---------------|------------|-------------|------------|------------|-------------|---------------|----------------|--------------|
| | | | 50% (2) | 20% (5) | 10% (10) | 5% (20) | 2% (50) | 1% (100) | 0.5% (200) | 0.1% (1000) | |
| Top-up between 12005_RPS & 12006_RPS | 0.458 | 0.12 | 0.12 | 0.15 | 0.17 | 0.20 | 0.23 | 0.26 | 0.29 | 0.39 | Model 2 |
| 12_539_3_RPS | 186.593 | 42.65 | 42.65 | 54.46 | 62.82 | 71.64 | 84.61 | 95.74 | 108.23 | 143.67 | Model 2 |
| 12_535_1_RPS | 2.858 | 0.47 | 0.47 | 0.67 | 0.82 | 0.98 | 1.23 | 1.46 | 1.73 | 2.54 | Model 2 |
| 12_535_7_RPS | 5.212 | 0.85 | 0.85 | 1.20 | 1.47 | 1.76 | 2.22 | 2.63 | 3.11 | 4.57 | Model 2 |
| Top-up between 12_535_1_RPS & 12_535_7_RPS | 2.354 | 0.40 | 0.40 | 0.57 | 0.70 | 0.84 | 1.05 | 1.25 | 1.48 | 2.17 | Model 2 |
| 12_1639_3_RPS | 36.656 | 7.06 | 7.06 | 9.51 | 11.27 | 13.15 | 15.95 | 18.38 | 21.12 | 29.05 | Model 2 |
| 12_531_8_RPS | 235.671 | 45.56 | 45.56 | 57.91 | 66.62 | 75.77 | 89.12 | 100.56 | 113.32 | 149.22 | Model 2 |
| Top-up between 12_539_3_RPS & 12_531_8_RPS | 7.21 | 1.74 | 1.74 | 2.21 | 2.54 | 2.89 | 3.40 | 3.83 | 4.32 | 5.69 | Model 2 |
| 12_2335_1_Inter | 499.594 | 85.12 | 85.12 | 108.36 | 124.54 | 141.48 | 166.08 | 186.85 | 210.00 | 274.61 | Model 2 |
| Top-up between 12006_RPS & 12_2335_1_Inter | 6.689 | 1.50 | 1.50 | 1.90 | 2.19 | 2.49 | 2.92 | 3.28 | 3.69 | 4.82 | Model 2 |
| 12_1727_4_RPS | 42.656 | 5.82 | 5.82 | 7.76 | 9.11 | 10.52 | 12.58 | 14.32 | 16.26 | 21.67 | Model 2 |
| 12_2355_2_Inter | 542.468 | 89.02 | 89.02 | 113.33 | 130.24 | 147.96 | 173.69 | 195.41 | 219.62 | 287.19 | Model 2 |
| Top-up between 12_2335_1_Inter & 12_2355_2_Inter | 0.218 | 0.06 | 0.06 | 0.07 | 0.09 | 0.10 | 0.11 | 0.13 | 0.14 | 0.19 | Model 2 |
| 12_835_7_RPS | 6.688 | 1.21 | 1.21 | 1.72 | 2.10 | 2.52 | 3.17 | 3.76 | 4.45 | 6.54 | Model 2 |
| 12_1571_2_RPS | 564.041 | 90.10 | 90.10 | 114.70 | 131.82 | 149.75 | 175.79 | 197.78 | 222.28 | 290.67 | Model 2 |
| Top-up between 12_2335_2_Inter & 12_1571_2_RPS | 14.885 | 2.99 | 2.99 | 3.81 | 4.37 | 4.97 | 5.83 | 6.56 | 7.38 | 9.64 | Model 2 |

| Node ID_CFRAMS | AREA (km ²) | MRFS Flows for AEP | | | | | | | | HEFS Flows for AEP | | | Model number |
|--|----------------------------|--------------------|------------|-------------|------------|------------|-------------|---------------|----------------|--------------------|-------------|----------------|-----------------|
| | | 50% (2) | 20% (5) | 10% (10) | 5% (20) | 2% (50) | 1% (100) | 0.5% (200) | 0.1% (1000) | 10% (10) | 1% (100) | 0.1% (1000) | |
| 12013_RPS | 209.888 | 54.39 | 69.13 | 79.51 | 90.44 | 106.38 | 120.03 | 135.26 | 178.12 | 97.69 | 147.47 | 218.83 | Model 1 |
| 12_1647_1_RPS | 229.973 | 54.39 | 69.13 | 79.51 | 90.44 | 106.38 | 120.03 | 135.26 | 178.12 | 105.93 | 159.91 | 237.29 | Model 2 |
| Top-up between 12013_RPS & 12_1647_1_RPS | 20.085 | 5.46 | 6.94 | 7.98 | 9.08 | 10.68 | 12.05 | 13.58 | 17.88 | 9.81 | 14.80 | 21.97 | Model 2 |
| 12_1663_2_RPS | 242.181 | 54.39 | 69.13 | 79.51 | 90.44 | 106.38 | 120.03 | 135.26 | 178.12 | 97.69 | 147.47 | 218.83 | Model 2 |
| Top-up between 12_1647_1_RPS & 12_1663_2_RPS | 12.208 | 3.21 | 4.08 | 4.69 | 5.34 | 6.28 | 7.08 | 7.98 | 10.51 | 5.76 | 8.70 | 12.91 | Model 2 |
| 12_1656_2_RPS | 249.219 | 54.39 | 69.13 | 79.51 | 90.44 | 106.38 | 120.03 | 135.26 | 178.12 | 97.69 | 147.47 | 218.83 | Model 2 |
| Top-up between 12_1663_2_RPS & 12_1656_2_RPS | 7.038 | 1.89 | 2.40 | 2.76 | 3.14 | 3.70 | 4.17 | 4.70 | 6.19 | 3.40 | 5.13 | 7.61 | Model 2 |
| 12005_RPS | 254.053 | 54.39 | 69.13 | 79.51 | 90.44 | 106.38 | 120.03 | 135.26 | 178.12 | 97.69 | 147.47 | 218.83 | Model 2 |
| Top-up between 12_1656_2_RPS & 12005_RPS | 4.834 | 1.32 | 1.68 | 1.94 | 2.20 | 2.59 | 2.92 | 3.29 | 4.34 | 2.38 | 3.59 | 5.33 | Model 2 |
| 12_1830_U | 0.074 | 0.02 | 0.02 | 0.03 | 0.03 | 0.04 | 0.05 | 0.06 | 0.09 | 0.05 | 0.09 | 0.16 | Model 2 |
| 12_1830_1 | 1.133 | 0.31 | 0.44 | 0.53 | 0.64 | 0.81 | 0.95 | 1.13 | 1.66 | 0.79 | 1.41 | 2.45 | Model 2 |
| Top-up between 12_1830_U & 12_1830_1 | 1.059 | 0.29 | 0.41 | 0.50 | 0.60 | 0.76 | 0.90 | 1.06 | 1.56 | 0.74 | 1.32 | 2.30 | Model 2 |
| 12_1707_U | 0.26 | 0.05 | 0.07 | 0.09 | 0.11 | 0.14 | 0.16 | 0.19 | 0.28 | 0.17 | 0.30 | 0.52 | Model 2 |
| 12_1707_2_RPS | 1.59 | 0.56 | 0.79 | 0.97 | 1.16 | 1.46 | 1.73 | 2.04 | 3.01 | 1.43 | 2.56 | 4.44 | Model 2 |
| Top-up between 12_1707_U & 12_1707_2_RPS | 1.33 | 0.47 | 0.67 | 0.82 | 0.98 | 1.23 | 1.46 | 1.73 | 2.54 | 1.21 | 2.16 | 3.76 | Model 2 |
| 12006_RPS | 257.234 | 54.83 | 69.69 | 80.16 | 91.18 | 107.25 | 121.01 | 136.36 | 179.57 | 98.49 | 148.67 | 220.62 | Model 2 |
| Top-up between 12005_RPS & 12006_RPS | 0.458 | 0.35 | 0.44 | 0.51 | 0.58 | 0.68 | 0.77 | 0.87 | 1.14 | 0.55 | 0.83 | 1.23 | Model 2 |
| 12_539_3_RPS | 186.593 | 52.97 | 67.64 | 78.02 | 88.98 | 105.08 | 118.91 | 134.43 | 178.44 | 95.85 | 146.09 | 219.23 | Model 2 |
| 12_535_1_RPS | 2.858 | 0.59 | 0.83 | 1.02 | 1.22 | 1.54 | 1.83 | 2.16 | 3.17 | 1.25 | 2.24 | 3.90 | Model 2 |
| 12_535_7_RPS | 5.212 | 1.05 | 1.50 | 1.83 | 2.19 | 2.76 | 3.27 | 3.87 | 5.69 | 2.25 | 4.02 | 6.99 | Model 2 |

| Node ID_CFRAMS | AREA (km ²) | MRFS Flows for AEP | | | | | | | | HEFS Flows for AEP | | | Model number |
|--|----------------------------|--------------------|------------|-------------|------------|------------|-------------|---------------|----------------|--------------------|-------------|----------------|-----------------|
| | | 50% (2) | 20% (5) | 10% (10) | 5% (20) | 2% (50) | 1% (100) | 0.5% (200) | 0.1% (1000) | 10% (10) | 1% (100) | 0.1% (1000) | |
| Top-up between 12_535_1_RPS & 12_535_7_RPS | 2.354 | 0.88 | 1.24 | 1.52 | 1.83 | 2.30 | 2.73 | 3.22 | 4.74 | 2.25 | 4.03 | 7.00 | Model 2 |
| 12_1639_3_RPS | 36.656 | 8.81 | 11.87 | 14.07 | 16.41 | 19.90 | 22.94 | 26.36 | 36.26 | 17.29 | 28.18 | 44.55 | Model 2 |
| 12_531_8_RPS | 235.671 | 56.65 | 72.00 | 82.82 | 94.21 | 110.81 | 125.03 | 140.89 | 185.53 | 101.75 | 153.61 | 227.94 | Model 2 |
| Top-up between 12_539_3_RPS & 12_531_8_RPS | 7.21 | 2.33 | 2.96 | 3.41 | 3.87 | 4.56 | 5.14 | 5.79 | 7.63 | 5.15 | 7.78 | 11.54 | Model 2 |
| 12_2335_1_Inter | 499.594 | 105.1 8 | 133.8 9 | 153.8 8 | 174.81 | 205.21 | 230.87 | 259.48 | 339.31 | 189.05 | 283.64 | 416.87 | Model 2 |
| Top-up between 12006_RPS & 12_2335_1_Inter | 6.689 | 1.85 | 2.35 | 2.70 | 3.07 | 3.61 | 4.06 | 4.56 | 5.96 | 3.32 | 4.98 | 7.32 | Model 2 |
| 12_1727_4_RPS | 42.656 | 7.20 | 9.59 | 11.26 | 13.01 | 15.55 | 17.70 | 20.10 | 26.79 | 13.83 | 21.75 | 32.91 | Model 2 |
| 12_2355_2_Inter | 542.468 | 110.0 0 | 140.0 3 | 160.9 3 | 182.82 | 214.61 | 241.45 | 271.37 | 354.86 | 197.72 | 296.64 | 435.98 | Model 2 |
| Top-up between 12_2335_1_Inter & 12_2355_2_Inter | 0.218 | 0.07 | 0.09 | 0.11 | 0.12 | 0.14 | 0.16 | 0.18 | 0.23 | 0.13 | 0.20 | 0.29 | Model 2 |
| 12_835_7_RPS | 6.688 | 1.51 | 2.14 | 2.62 | 3.15 | 3.96 | 4.69 | 5.55 | 8.16 | 3.22 | 5.77 | 10.02 | Model 2 |
| 12_1571_2_RPS | 564.041 | 111.3 8 | 141.7 9 | 162.9 5 | 185.11 | 217.30 | 244.48 | 274.78 | 359.31 | 200.20 | 300.36 | 441.45 | Model 2 |
| Top-up between 12_2335_2_Inter & 12_1571_2_RPS | 14.885 | 3.70 | 4.70 | 5.41 | 6.14 | 7.21 | 8.11 | 9.12 | 11.92 | 6.64 | 9.97 | 14.65 | Model 2 |

| | |
|--|--|
| | Input flows |
| | Top-up flows. These flows should be entered laterally |
| | Check flows. Modellers should check to make sure these flows are being reached at each HEP Some of these flows may be put in at the US point due to a small difference between US & DS flows. |

Model 03 - Buncloody

| Node ID_CFRAMS | AREA (km ²) | Qmed | Flows for AEP | | | | | | | | Model number |
|---|----------------------------|-------|---------------|------------|-------------|------------|------------|-------------|---------------|----------------|-----------------|
| | | | 50% (2) | 20% (5) | 10% (10) | 5% (20) | 2% (50) | 1% (100) | 0.5% (200) | 0.1% (1000) | |
| 12_1571_2_RPS | 564.04 | 90.10 | 90.10 | 114.70 | 131.82 | 149.75 | 175.79 | 197.78 | 222.28 | 290.67 | Model 2 |
| 12_910_6_RPS | 17.93 | 4.17 | 4.17 | 5.58 | 6.59 | 7.67 | 9.26 | 10.64 | 12.19 | 16.62 | Model 3 |
| 12_2095_3_RPS | 246.67 | 43.72 | 43.72 | 55.57 | 63.92 | 72.71 | 85.52 | 96.50 | 108.74 | 143.20 | Model 3 |
| 12_968_6 | 14.73 | 3.86 | 3.86 | 5.14 | 6.06 | 7.02 | 8.44 | 9.67 | 11.05 | 14.98 | Model 3 |
| 12_2357_1 | 29.59 | 10.50 | 10.50 | 13.45 | 15.55 | 17.79 | 21.09 | 23.94 | 27.14 | 36.32 | Model 3 |
| 12_2357_1_Inter | 29.67 | 10.52 | 10.52 | 13.48 | 15.59 | 17.83 | 21.14 | 24.00 | 27.21 | 36.41 | Model 3 |
| 12_574_1_RPS | 31.91 | 9.93 | 10.52 | 13.48 | 15.59 | 17.83 | 21.14 | 24.00 | 27.21 | 36.41 | Model 3 |
| 12_2326_4 | 2.66 | 1.04 | 1.04 | 1.48 | 1.80 | 2.17 | 2.73 | 3.23 | 3.82 | 5.62 | Model 3 |
| 12_2326_4_Inter | 2.68 | 1.05 | 1.05 | 1.49 | 1.82 | 2.18 | 2.74 | 3.25 | 3.85 | 5.65 | Model 3 |
| 12_2326_5_Inter | 3.06 | 1.11 | 1.11 | 1.57 | 1.92 | 2.30 | 2.90 | 3.44 | 4.06 | 5.97 | Model 3 |
| Top-up between 12_2326_4_Inter & 12_2326_5_Inter | 0.37 | 0.15 | 0.15 | 0.22 | 0.27 | 0.32 | 0.40 | 0.48 | 0.57 | 0.83 | Model 3 |
| 12_2326_7_RPS | 3.58 | 1.35 | 1.35 | 1.91 | 2.33 | 2.80 | 3.53 | 4.18 | 4.94 | 7.27 | Model 3 |
| Top-up between 12_2326_5_Inter & 12_2326_7_RPS | 0.52 | 0.22 | 0.22 | 0.31 | 0.38 | 0.46 | 0.58 | 0.69 | 0.81 | 1.19 | Model 3 |
| 12_2098_1_RPS | 35.81 | 10.91 | 10.91 | 13.76 | 15.78 | 17.89 | 20.99 | 23.64 | 26.60 | 34.97 | Model 3 |
| Top-up between 12_574_1_RPS & 12_2098_1_RPS | 0.32 | 0.13 | 0.13 | 0.17 | 0.19 | 0.22 | 0.25 | 0.28 | 0.32 | 0.42 | Model 3 |
| 12_2098_2_RPS | 35.98 | 10.99 | 10.99 | 13.85 | 15.89 | 18.02 | 21.14 | 23.81 | 26.78 | 35.21 | Model 3 |
| Top-up between 12_2098_1_RPS & 12_2098_2_RPS | 0.17 | 0.07 | 0.07 | 0.09 | 0.10 | 0.12 | 0.14 | 0.16 | 0.17 | 0.23 | Model 3 |
| 12_940_1_RPS | 4.52 | 1.28 | 1.28 | 1.82 | 2.23 | 2.67 | 3.36 | 3.99 | 4.71 | 6.93 | Model 3 |
| 12_940_5_RPS | 5.62 | 1.61 | 1.61 | 2.28 | 2.79 | 3.35 | 4.22 | 5.00 | 5.91 | 8.68 | Model 3 |

Model 03 - Buncloody

| Node ID_CFRAMS | AREA (km ²) | Qmed | Flows for AEP | | | | | | | | Model number |
|--|----------------------------|--------|---------------|------------|-------------|------------|------------|-------------|---------------|----------------|-----------------|
| | | | 50% (2) | 20% (5) | 10% (10) | 5% (20) | 2% (50) | 1% (100) | 0.5% (200) | 0.1% (1000) | |
| Top-up between 12_940_1_RPS & 12_940_5_RPS | 1.10 | 0.35 | 0.35 | 0.50 | 0.61 | 0.73 | 0.91 | 1.08 | 1.28 | 1.88 | Model 3 |
| 12_930_7 | 5.32 | 1.26 | 1.26 | 1.79 | 2.19 | 2.63 | 3.31 | 3.92 | 4.64 | 6.82 | Model 3 |
| 12_932_5 | 13.32 | 3.37 | 3.37 | 4.63 | 5.55 | 6.55 | 8.07 | 9.40 | 10.93 | 15.46 | Model 3 |
| 12_946_4 | 27.71 | 6.84 | 6.84 | 8.89 | 10.36 | 11.90 | 14.17 | 16.12 | 18.30 | 24.52 | Model 3 |
| 12_955_9 | 21.98 | 4.20 | 4.20 | 5.58 | 6.56 | 7.59 | 9.09 | 10.37 | 11.81 | 15.85 | Model 3 |
| 12_934_6 | 22.00 | 3.71 | 3.71 | 5.02 | 5.96 | 6.95 | 8.43 | 9.70 | 11.14 | 15.24 | Model 3 |
| 12_2065_3 | 11.46 | 2.93 | 2.93 | 4.03 | 4.83 | 5.71 | 7.04 | 8.21 | 9.55 | 13.53 | Model 3 |
| 12_2084_5 | 5.12 | 1.37 | 1.37 | 1.94 | 2.37 | 2.85 | 3.59 | 4.25 | 5.03 | 7.39 | Model 3 |
| 12001_RPS | 1036.43 | 156.27 | 156.27 | 196.52 | 223.10 | 249.80 | 287.04 | 317.38 | 349.90 | 435.48 | Model 3 |
| Top-up between 12_1571_2_RPS & 12001_RPS | 62.47 | 11.24 | 11.24 | 14.14 | 16.05 | 17.97 | 20.65 | 22.83 | 25.17 | 31.33 | Model 3 |

| Node ID_CFRAMS | AREA (km ²) | MRFS Flows for AEP | | | | | | | | HEFS Flows for AEP | | | Model number |
|-----------------|----------------------------|--------------------|------------|-------------|------------|------------|-------------|---------------|----------------|--------------------|-------------|----------------|-----------------|
| | | 50% (2) | 20% (5) | 10% (10) | 5% (20) | 2% (50) | 1% (100) | 0.5% (200) | 0.1% (1000) | 10% (10) | 1% (100) | 0.1% (1000) | |
| 12_1571_2_RPS | 564.04 | 111.38 | 141.79 | 162.95 | 185.11 | 217.30 | 244.48 | 274.78 | 359.31 | 200.20 | 300.36 | 441.45 | Model 2 |
| 12_910_6_RPS | 17.93 | 5.20 | 6.97 | 8.23 | 9.57 | 11.56 | 13.28 | 15.21 | 20.75 | 10.11 | 16.31 | 25.49 | Model 3 |
| 12_2095_3_RPS | 246.67 | 54.20 | 68.88 | 79.23 | 90.13 | 106.01 | 119.61 | 134.79 | 177.49 | 97.35 | 146.95 | 218.06 | Model 3 |
| 12_968_6 | 14.73 | 4.82 | 6.42 | 7.56 | 8.77 | 10.54 | 12.07 | 13.79 | 18.70 | 9.29 | 14.83 | 22.97 | Model 3 |
| 12_2357_1 | 29.59 | 13.11 | 16.79 | 19.41 | 22.20 | 26.33 | 29.88 | 33.88 | 45.34 | 23.85 | 36.71 | 55.70 | Model 3 |
| 12_2357_1_Inter | 29.67 | 13.14 | 16.83 | 19.46 | 22.26 | 26.40 | 29.96 | 33.96 | 45.45 | 23.91 | 36.80 | 55.83 | Model 3 |
| 12_574_1_RPS | 31.91 | 13.12 | 16.80 | 19.43 | 22.22 | 26.35 | 29.91 | 33.91 | 45.37 | 23.87 | 36.74 | 55.74 | Model 3 |

| Node ID_CFRAMS | AREA (km ²) | MRFS Flows for AEP | | | | | | | | HEFS Flows for AEP | | | Model number |
|--|----------------------------|--------------------|------------|-------------|------------|------------|-------------|---------------|----------------|--------------------|-------------|----------------|-----------------|
| | | 50% (2) | 20% (5) | 10% (10) | 5% (20) | 2% (50) | 1% (100) | 0.5% (200) | 0.1% (1000) | 10% (10) | 1% (100) | 0.1% (1000) | |
| 12_2326_4 | 2.66 | 1.30 | 1.84 | 2.25 | 2.70 | 3.40 | 4.03 | 4.77 | 7.01 | 2.77 | 4.96 | 8.61 | Model 3 |
| 12_2326_4_Inter | 2.68 | 1.31 | 1.86 | 2.27 | 2.72 | 3.43 | 4.06 | 4.80 | 7.06 | 2.79 | 4.99 | 8.67 | Model 3 |
| 12_2326_5_Inter | 3.06 | 1.38 | 1.96 | 2.40 | 2.88 | 3.62 | 4.29 | 5.07 | 7.46 | 2.94 | 5.27 | 9.16 | Model 3 |
| Top-up between 12_2326_4_Inter & 12_2326_5_Inter | 0.37 | 0.19 | 0.27 | 0.33 | 0.40 | 0.50 | 0.60 | 0.71 | 1.04 | 0.41 | 0.73 | 1.28 | Model 3 |
| 12_2326_7_RPS | 3.58 | 1.84 | 2.61 | 3.19 | 3.83 | 4.82 | 5.71 | 6.76 | 9.93 | 5.99 | 10.73 | 18.65 | Model 3 |
| Top-up between 12_2326_5_Inter & 12_2326_7_RPS | 0.52 | 0.45 | 0.63 | 0.77 | 0.93 | 1.17 | 1.39 | 1.64 | 2.41 | 1.14 | 2.05 | 3.56 | Model 3 |
| 12_2098_1_RPS | 35.81 | 13.48 | 16.99 | 19.49 | 22.10 | 25.93 | 29.20 | 32.86 | 43.19 | 23.94 | 35.88 | 53.07 | Model 3 |
| Top-up between 12_574_1_RPS & 12_2098_1_RPS | 0.32 | 0.28 | 0.36 | 0.41 | 0.47 | 0.55 | 0.62 | 0.69 | 0.91 | 0.29 | 0.43 | 0.64 | Model 3 |
| 12_2098_2_RPS | 35.98 | 13.57 | 17.11 | 19.62 | 22.25 | 26.10 | 29.40 | 33.07 | 43.48 | 24.55 | 36.79 | 54.42 | Model 3 |
| Top-up between 12_2098_1_RPS & 12_2098_2_RPS | 0.17 | 0.15 | 0.19 | 0.22 | 0.25 | 0.30 | 0.33 | 0.38 | 0.49 | 0.33 | 0.49 | 0.73 | Model 3 |
| 12_940_1_RPS | 4.52 | 1.60 | 2.27 | 2.78 | 3.34 | 4.20 | 4.98 | 5.88 | 8.65 | 3.41 | 6.11 | 10.62 | Model 3 |
| 12_940_5_RPS | 5.62 | 1.99 | 2.83 | 3.46 | 4.15 | 5.22 | 6.19 | 7.32 | 10.75 | 4.29 | 7.69 | 13.36 | Model 3 |
| Top-up between 12_940_1_RPS & 12_940_5_RPS | 1.10 | 0.75 | 1.07 | 1.30 | 1.56 | 1.97 | 2.33 | 2.76 | 4.05 | 1.93 | 3.45 | 5.99 | Model 3 |
| 12_930_7 | 5.32 | 1.57 | 2.23 | 2.72 | 3.27 | 4.11 | 4.88 | 5.76 | 8.47 | 3.34 | 5.99 | 10.41 | Model 3 |
| 12_932_5 | 13.32 | 4.21 | 5.78 | 6.93 | 8.18 | 10.07 | 11.74 | 13.65 | 19.30 | 8.52 | 14.42 | 23.71 | Model 3 |
| 12_946_4 | 27.71 | 8.53 | 11.10 | 12.93 | 14.86 | 17.69 | 20.12 | 22.85 | 30.61 | 15.88 | 24.72 | 37.60 | Model 3 |
| 12_955_9 | 21.98 | 5.24 | 6.97 | 8.19 | 9.47 | 11.35 | 12.95 | 14.74 | 19.79 | 10.06 | 15.91 | 24.31 | Model 3 |
| 12_934_6 | 22.00 | 4.63 | 6.27 | 7.44 | 8.68 | 10.52 | 12.11 | 13.90 | 19.03 | 9.14 | 14.88 | 23.38 | Model 3 |

| Node ID_CFRAMS | AREA (km ²) | MRFS Flows for AEP | | | | | | | | HEFS Flows for AEP | | | Model number |
|--|----------------------------|--------------------|------------|-------------|------------|------------|-------------|---------------|----------------|--------------------|-------------|----------------|--------------|
| | | 50% (2) | 20% (5) | 10% (10) | 5% (20) | 2% (50) | 1% (100) | 0.5% (200) | 0.1% (1000) | 10% (10) | 1% (100) | 0.1% (1000) | |
| 12_2065_3 | 11.46 | 3.65 | 5.03 | 6.04 | 7.13 | 8.79 | 10.25 | 11.92 | 16.89 | 7.41 | 12.59 | 20.75 | Model 3 |
| 12_2084_5 | 5.12 | 1.71 | 2.43 | 2.96 | 3.56 | 4.48 | 5.31 | 6.28 | 9.23 | 3.64 | 6.52 | 11.33 | Model 3 |
| 12001_RPS | 1036.43 | 187.52 | 235.83 | 267.72 | 299.76 | 344.45 | 380.85 | 419.88 | 522.58 | 290.04 | 412.59 | 566.13 | Model 3 |
| Top-up between 12_1571_2_RPS & 12001_RPS | 62.47 | 13.91 | 17.49 | 19.86 | 22.24 | 25.55 | 28.25 | 31.15 | 38.77 | 24.40 | 34.71 | 47.63 | Model 3 |

| | |
|--|--|
| | Input flows |
| | Top-up flows. These flows should be entered laterally |
| | Check flows. Modellers should check to make sure these flows are being reached at each HEP |
| | Some of these flows may be put in at the US point due to a small difference between US & DS flows. |

Model 4 - Enniscorthy (Fairfield & Cherryorchard)

| Node ID_CFRAMS | AREA (km ²) | Qmed | Flows for AEP | | | | | | | | Model number |
|--|----------------------------|--------|---------------|------------|-------------|------------|------------|-------------|---------------|----------------|--------------|
| | | | 50% (2) | 20% (5) | 10% (10) | 5% (20) | 2% (50) | 1% (100) | 0.5% (200) | 0.1% (1000) | |
| 12001_RPS | 1036.43 | 156.27 | 156.27 | 196.52 | 223.10 | 249.80 | 287.04 | 317.38 | 349.90 | 435.48 | Model 4 |
| 12_921_2_RPS | 181.52 | 30.49 | 30.49 | 38.18 | 43.30 | 48.42 | 55.65 | 61.53 | 67.88 | 84.68 | Model 4 |
| 12_943_2_RPS | 1221.62 | 176.27 | 176.27 | 222.10 | 252.07 | 282.21 | 324.16 | 358.01 | 394.32 | 489.16 | Model 4 |
| Top-up between 12001_RPS & 12_943_2_RPS | 3.67 | 0.76 | 0.76 | 0.96 | 1.09 | 1.22 | 1.41 | 1.55 | 1.71 | 2.12 | Model 4 |
| 12_2075_5_RPS | 37.76 | 6.25 | 6.25 | 8.39 | 9.90 | 11.50 | 13.86 | 15.88 | 18.15 | 24.60 | Model 4 |

Model 4 - Enniscorthy (Fairfield & Cherryorchard)

| Node ID_CFRAMS | AREA (km ²) | Qmed | Flows for AEP | | | | | | | | Model number |
|--|----------------------------|--------|---------------|------------|-------------|------------|------------|-------------|---------------|----------------|-----------------|
| | | | 50% (2) | 20% (5) | 10% (10) | 5% (20) | 2% (50) | 1% (100) | 0.5% (200) | 0.1% (1000) | |
| 12_2079_2_RPS | 0.99 | 0.33 | 0.33 | 0.47 | 0.57 | 0.69 | 0.86 | 1.02 | 1.21 | 1.78 | Model 4 |
| 12_958_4_RPS | 5.69 | 1.41 | 1.41 | 2.00 | 2.44 | 2.93 | 3.69 | 4.37 | 5.17 | 7.60 | Model 4 |
| 12_2085_5_RPS | 55.50 | 9.19 | 9.19 | 12.22 | 14.35 | 16.61 | 19.92 | 22.76 | 25.93 | 34.91 | Model 4 |
| 12_2296_U | 0.35 | 0.13 | 0.13 | 0.18 | 0.23 | 0.27 | 0.34 | 0.40 | 0.48 | 0.70 | Model 4 |
| 12_2296_3_RPS | 1.55 | 0.79 | 0.79 | 1.11 | 1.36 | 1.63 | 2.06 | 2.44 | 2.88 | 4.24 | Model 4 |
| Top-up between 12_2296_U & 12_2296_3_RPS | 1.20 | 0.66 | 0.66 | 0.94 | 1.15 | 1.38 | 1.74 | 2.06 | 2.43 | 3.58 | Model 4 |
| 12_2061_1_RPS | 1328.71 | 182.25 | 182.25 | 229.64 | 260.62 | 291.78 | 335.16 | 370.15 | 407.70 | 505.75 | Model 4 |
| Top-up between 12_943_2_RPS & 12_2061_1_RPS | 5.60 | 1.08 | 1.08 | 1.37 | 1.55 | 1.74 | 1.99 | 2.20 | 2.42 | 3.01 | Model 4 |
| 12008_RPS | 1330.72 | 183.26 | 183.26 | 230.90 | 262.06 | 293.40 | 337.01 | 372.20 | 409.95 | 508.54 | Model 4 |
| Top-up between 12_2061_1_RPS & 12008_RPS | 2.00 | 0.42 | 0.42 | 0.53 | 0.60 | 0.67 | 0.77 | 0.85 | 0.94 | 1.16 | Model 4 |
| 12_577_1_RPS | 103.03 | 22.23 | 22.23 | 27.57 | 31.24 | 35.02 | 40.46 | 45.02 | 50.02 | 63.76 | Model 4 |
| 12_2323_4_RPS | 0.36 | 0.10 | 0.10 | 0.15 | 0.18 | 0.22 | 0.27 | 0.32 | 0.38 | 0.56 | Model 4 |
| 12_2604_1_RPS | 103.94 | 22.23 | 22.23 | 27.57 | 31.24 | 35.02 | 40.46 | 45.02 | 50.02 | 63.76 | Model 4 |
| Top-up between 12_577_1_RPS & 12_2604_1_RPS | 0.55 | 0.16 | 0.16 | 0.20 | 0.22 | 0.25 | 0.29 | 0.32 | 0.36 | 0.46 | Model 4 |
| 12_761_3 | 4.40 | 1.09 | 1.09 | 1.54 | 1.89 | 2.27 | 2.85 | 3.38 | 4.00 | 5.87 | Model 4 |
| 12_2460_U | 0.78 | 0.16 | 0.16 | 0.23 | 0.29 | 0.34 | 0.43 | 0.51 | 0.60 | 0.89 | Model 4 |
| 12_2460_2_RPS | 1.44 | 0.30 | 0.30 | 0.42 | 0.52 | 0.62 | 0.78 | 0.93 | 1.09 | 1.61 | Model 4 |
| Top-up between 12_2460_U & 12_2460_2_RPS | 0.66 | 0.16 | 0.16 | 0.23 | 0.28 | 0.33 | 0.42 | 0.49 | 0.58 | 0.86 | Model 4 |
| 12_2323_1_RPS | 8.47 | 1.98 | 1.98 | 2.81 | 3.43 | 4.12 | 5.19 | 6.15 | 7.27 | 10.68 | Model 4 |
| Top-up between 12_761_3 & 12_2323_1_RPS | 2.62 | 0.66 | 0.66 | 0.94 | 1.14 | 1.37 | 1.73 | 2.05 | 2.42 | 3.56 | Model 4 |

Model 4 - Enniscorthy (Fairfield & Cherryorchard)

| Node ID_CFRAMS | AREA (km ²) | Qmed | Flows for AEP | | | | | | | | Model number |
|--|-------------------------|--------|---------------|---------|----------|---------|---------|----------|------------|-------------|--------------|
| | | | 50% (2) | 20% (5) | 10% (10) | 5% (20) | 2% (50) | 1% (100) | 0.5% (200) | 0.1% (1000) | |
| 12_2604_2_RPS | 113.51 | 22.99 | 22.99 | 28.50 | 32.29 | 36.20 | 41.83 | 46.55 | 51.72 | 65.92 | Model 4 |
| Top-up between 12_2323_1_RPS & 12_2604_2_RPS | 1.11 | 0.30 | 0.30 | 0.37 | 0.42 | 0.47 | 0.55 | 0.61 | 0.68 | 0.86 | Model 4 |
| 12007_RPS | 114.76 | 22.98 | 22.98 | 28.49 | 32.28 | 36.19 | 41.82 | 46.53 | 51.70 | 65.90 | Model 4 |
| Top-up between 12_2604_2_RPS & 12007_RPS | 1.25 | 0.33 | 0.33 | 0.41 | 0.47 | 0.53 | 0.61 | 0.68 | 0.75 | 0.96 | Model 4 |
| 12_2605_1_RPS | 114.90 | 23.00 | 23.00 | 28.52 | 32.32 | 36.23 | 41.86 | 46.58 | 51.75 | 65.97 | Model 4 |
| 12_2603_2_RPS | 9.51 | 2.26 | 2.26 | 3.21 | 3.92 | 4.71 | 5.93 | 7.02 | 8.30 | 12.21 | Model 4 |
| 12_2601_6_RPS | 179.56 | 30.90 | 30.90 | 38.28 | 43.35 | 48.57 | 56.08 | 62.38 | 69.33 | 88.37 | Model 4 |
| 12061_RPS | 1646.29 | 219.33 | 219.33 | 276.35 | 313.64 | 351.14 | 403.34 | 445.45 | 490.63 | 608.63 | Model 4 |
| Top-up between 12008_RPS & 12061_RPS | 11.61 | 2.11 | 2.11 | 2.66 | 3.02 | 3.38 | 3.89 | 4.29 | 4.73 | 5.86 | Model 4 |

| Node ID_CFRAMS | AREA (km ²) | MRFS Flows for AEP | | | | | | | | HEFS Flows for AEP | | | Model number |
|---|-------------------------|--------------------|---------|----------|---------|---------|----------|------------|-------------|--------------------|----------|-------------|--------------|
| | | 50% (2) | 20% (5) | 10% (10) | 5% (20) | 2% (50) | 1% (100) | 0.5% (200) | 0.1% (1000) | 10% (10) | 1% (100) | 0.1% (1000) | |
| 12001_RPS | 1036.43 | 193.32 | 243.12 | 276.00 | 309.02 | 355.10 | 392.62 | 432.86 | 538.73 | 339.10 | 482.38 | 661.89 | Model 4 |
| 12_921_2_RPS | 181.52 | 37.66 | 47.15 | 53.48 | 59.81 | 68.73 | 76.00 | 83.84 | 104.59 | 65.70 | 93.37 | 128.49 | Model 4 |
| 12_943_2_RPS | 1221.62 | 218.07 | 274.77 | 311.84 | 349.13 | 401.03 | 442.90 | 487.82 | 605.14 | 383.12 | 544.14 | 743.47 | Model 4 |
| Top-up between 12001_RPS & 12_943_2_RPS | 3.67 | 0.95 | 1.19 | 1.35 | 1.51 | 1.74 | 1.92 | 2.12 | 2.62 | 1.66 | 2.36 | 3.22 | Model 4 |
| 12_2075_5_RPS | 37.76 | 7.79 | 10.47 | 12.35 | 14.36 | 17.30 | 19.82 | 22.66 | 30.70 | 15.18 | 24.35 | 37.72 | Model 4 |
| 12_2079_2_RPS | 0.99 | 0.68 | 0.97 | 1.19 | 1.42 | 1.79 | 2.12 | 2.51 | 3.69 | 1.75 | 3.14 | 5.46 | Model 4 |
| 12_958_4_RPS | 5.69 | 1.76 | 2.49 | 3.05 | 3.66 | 4.60 | 5.46 | 6.45 | 9.48 | 3.74 | 6.70 | 11.65 | Model 4 |
| 12_2085_5_RPS | 55.50 | 11.43 | 15.20 | 17.85 | 20.66 | 24.78 | 28.31 | 32.25 | 43.43 | 21.93 | 34.78 | 53.36 | Model 4 |

| Node ID_CFRAMS | AREA (km ²) | MRFS Flows for AEP | | | | | | | | HEFS Flows for AEP | | | Model number |
|---|----------------------------|--------------------|------------|-------------|------------|------------|-------------|---------------|----------------|--------------------|-------------|----------------|-----------------|
| | | 50% (2) | 20% (5) | 10% (10) | 5% (20) | 2% (50) | 1% (100) | 0.5% (200) | 0.1% (1000) | 10% (10) | 1% (100) | 0.1% (1000) | |
| 12_2296_U | 0.35 | 0.25 | 0.35 | 0.43 | 0.52 | 0.65 | 0.78 | 0.92 | 1.35 | 0.50 | 0.90 | 1.56 | Model 4 |
| 12_2296_3_RPS | 1.55 | 1.58 | 2.24 | 2.74 | 3.29 | 4.14 | 4.90 | 5.80 | 8.52 | 2.97 | 5.31 | 9.23 | Model 4 |
| Top-up between 12_2296_U & 12_2296_3_RPS | 1.20 | 1.24 | 1.76 | 2.15 | 2.58 | 3.25 | 3.85 | 4.56 | 6.70 | 2.33 | 4.18 | 7.26 | Model 4 |
| 12_2061_1_RPS | 1328.71 | 225.33 | 283.92 | 322.23 | 360.76 | 414.39 | 457.65 | 504.07 | 625.30 | 395.88 | 562.27 | 768.24 | Model 4 |
| Top-up between 12_943_2_RPS & 12_2061_1_RPS | 5.60 | 2.35 | 2.96 | 3.36 | 3.76 | 4.32 | 4.77 | 5.25 | 6.52 | 4.97 | 7.05 | 9.64 | Model 4 |
| 12008_RPS | 1330.72 | 226.28 | 285.11 | 323.58 | 362.27 | 416.13 | 459.57 | 506.18 | 627.92 | 397.54 | 564.62 | 771.46 | Model 4 |
| Top-up between 12_2061_1_RPS & 12008_RPS | 2.00 | 0.91 | 1.14 | 1.30 | 1.45 | 1.67 | 1.84 | 2.03 | 2.52 | 1.92 | 2.73 | 3.72 | Model 4 |
| 12_577_1_RPS | 103.03 | 27.75 | 34.41 | 38.99 | 43.70 | 50.50 | 56.19 | 62.43 | 79.58 | 47.90 | 69.04 | 97.77 | Model 4 |
| 12_2323_4_RPS | 0.36 | 0.13 | 0.19 | 0.23 | 0.27 | 0.34 | 0.41 | 0.48 | 0.70 | 0.30 | 0.54 | 0.93 | Model 4 |
| 12_2604_1_RPS | 103.94 | 27.75 | 34.41 | 38.99 | 43.70 | 50.50 | 56.19 | 62.43 | 79.58 | 47.90 | 69.04 | 97.77 | Model 4 |
| Top-up between 12_577_1_RPS & 12_2604_1_RPS | 0.55 | 0.20 | 0.25 | 0.28 | 0.31 | 0.36 | 0.40 | 0.44 | 0.57 | 0.34 | 0.49 | 0.70 | Model 4 |
| 12_761_3 | 4.40 | 1.36 | 1.93 | 2.35 | 2.83 | 3.56 | 4.22 | 4.99 | 7.33 | 2.89 | 5.18 | 9.00 | Model 4 |
| 12_2460_U | 0.78 | 0.21 | 0.29 | 0.36 | 0.43 | 0.54 | 0.64 | 0.75 | 1.11 | 0.44 | 0.78 | 1.36 | Model 4 |
| 12_2460_2_RPS | 1.44 | 0.41 | 0.58 | 0.71 | 0.86 | 1.08 | 1.28 | 1.51 | 2.22 | 1.12 | 2.00 | 3.48 | Model 4 |
| Top-up between 12_2460_U & 12_2460_2_RPS | 0.66 | 0.25 | 0.36 | 0.43 | 0.52 | 0.66 | 0.78 | 0.92 | 1.35 | 0.74 | 1.32 | 2.29 | Model 4 |
| 12_2323_1_RPS | 8.47 | 2.44 | 3.46 | 4.23 | 5.08 | 6.39 | 7.57 | 8.95 | 13.16 | 5.19 | 9.30 | 16.17 | Model 4 |

| Node ID_CFRAMS | AREA (km ²) | MRFS Flows for AEP | | | | | | | | HEFS Flows for AEP | | | Model number |
|--|----------------------------|--------------------|------------|-------------|------------|------------|-------------|---------------|----------------|--------------------|-------------|----------------|-----------------|
| | | 50% (2) | 20% (5) | 10% (10) | 5% (20) | 2% (50) | 1% (100) | 0.5% (200) | 0.1% (1000) | 10% (10) | 1% (100) | 0.1% (1000) | |
| Top-up between 12_761_3 & 12_2323_1_RPS | 2.62 | 1.43 | 2.02 | 2.47 | 2.97 | 3.73 | 4.42 | 5.23 | 7.69 | 3.65 | 6.54 | 11.36 | Model 4 |
| 12_2604_2_RPS | 113.51 | 28.57 | 35.43 | 40.14 | 45.00 | 52.00 | 57.85 | 64.28 | 81.94 | 49.32 | 71.08 | 100.67 | Model 4 |
| Top-up between 12_2323_1_RPS & 12_2604_2_RPS | 1.11 | 0.66 | 0.81 | 0.92 | 1.03 | 1.19 | 1.33 | 1.48 | 1.88 | 1.36 | 1.96 | 2.78 | Model 4 |
| 12007_RPS | 114.76 | 28.53 | 35.37 | 40.08 | 44.93 | 51.92 | 57.76 | 64.18 | 81.81 | 49.24 | 70.97 | 100.51 | Model 4 |
| Top-up between 12_2604_2_RPS & 12007_RPS | 1.25 | 0.73 | 0.90 | 1.02 | 1.14 | 1.32 | 1.47 | 1.63 | 2.08 | 1.51 | 2.17 | 3.08 | Model 4 |
| 12_2605_1_RPS | 114.90 | 28.56 | 35.41 | 40.12 | 44.98 | 51.97 | 57.83 | 64.25 | 81.90 | 49.29 | 71.04 | 100.62 | Model 4 |
| 12_2603_2_RPS | 9.51 | 2.79 | 3.96 | 4.84 | 5.81 | 7.32 | 8.67 | 10.25 | 15.07 | 6.04 | 10.82 | 18.79 | Model 4 |
| 12_2601_6_RPS | 179.56 | 38.56 | 47.78 | 54.10 | 60.62 | 69.99 | 77.86 | 86.54 | 110.29 | 66.47 | 95.66 | 135.50 | Model 4 |
| 12061_RPS | 1646.29 | 271.01 | 341.48 | 387.55 | 433.89 | 498.39 | 550.43 | 606.26 | 752.06 | 476.14 | 676.25 | 923.97 | Model 4 |
| Top-up between 12008_RPS & 12061_RPS | 11.61 | 4.58 | 5.77 | 6.55 | 7.33 | 8.42 | 9.30 | 10.24 | 12.70 | 9.68 | 13.74 | 18.78 | Model 4 |

| |
|--|
| |
| |
| |

Input flows

Top-up flows. These flows should be entered laterally

Check flows. Modellers should check to make sure these flows are being reached at each HEP

Some of these flows may be put in at the US point due to a small difference between US & DS flows.

Model 05 - Wexford

| Node ID_CFRAMS | AREA (km ²) | Qmed | Flows for AEP | | | | | | | | Model number |
|---|----------------------------|--------|---------------|------------|-------------|------------|------------|-------------|---------------|----------------|--------------|
| | | | 50% (2) | 20% (5) | 10% (10) | 5% (20) | 2% (50) | 1% (100) | 0.5% (200) | 0.1% (1000) | |
| 12061_RPS | 1646.29 | 219.33 | 219.33 | 276.35 | 313.64 | 351.14 | 403.34 | 445.45 | 490.63 | 608.63 | Model 5 |
| 12_2597_6_RPS | 5.54 | 1.22 | 1.22 | 1.73 | 2.11 | 2.53 | 3.19 | 3.78 | 4.47 | 6.56 | Model 5 |
| 12_2579_2_RPS | 15.44 | 3.85 | 3.85 | 5.28 | 6.33 | 7.47 | 9.18 | 10.68 | 12.40 | 17.45 | Model 5 |
| 12_2565_2_RPS | 22.52 | 5.46 | 5.46 | 7.29 | 8.61 | 10.01 | 12.10 | 13.91 | 15.96 | 21.87 | Model 5 |
| 12_2545_2_RPS | 12.54 | 4.14 | 4.14 | 5.70 | 6.87 | 8.15 | 10.11 | 11.86 | 13.89 | 20.01 | Model 5 |
| 12064_RPS | 1752.65 | 232.58 | 232.58 | 293.05 | 332.59 | 372.36 | 427.71 | 472.37 | 520.28 | 645.40 | Model 5 |
| Top-up between 12061_RPS & 12064_RPS | 50.32 | 8.35 | 8.35 | 10.52 | 11.94 | 13.37 | 15.36 | 16.96 | 18.68 | 23.18 | Model 5 |
| 12_766_2_RPS | 2.30 | 0.95 | 0.95 | 1.35 | 1.65 | 1.98 | 2.49 | 2.95 | 3.49 | 5.13 | Model 5 |
| 12_2334_2_RPS | 9.06 | 3.72 | 3.72 | 5.27 | 6.45 | 7.74 | 9.74 | 11.55 | 13.65 | 20.06 | Model 5 |
| Top-up between 12_766_2_RPS & 12_2334_2_RPS | 6.76 | 2.83 | 2.83 | 4.01 | 4.90 | 5.88 | 7.40 | 8.77 | 10.37 | 15.25 | Model 5 |
| 12_2272_U | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.02 | 0.02 | 0.03 | 0.04 | Model 5 |
| 12_2147_2_RPS | 1.29 | 0.54 | 0.54 | 0.77 | 0.94 | 1.13 | 1.42 | 1.69 | 2.00 | 2.93 | Model 5 |
| Top-up between 12_2272_U & 12_2147_2_RPS | 1.28 | 0.54 | 0.54 | 0.76 | 0.93 | 1.12 | 1.41 | 1.67 | 1.98 | 2.91 | Model 5 |
| 12_2284_1_RPS | 1.27 | 1.22 | 1.22 | 1.73 | 2.12 | 2.54 | 3.20 | 3.79 | 4.48 | 6.59 | Model 5 |

Model 05 - Wexford

| Node ID_CFRAMS | AREA (km ²) | Qmed | Flows for AEP | | | | | | | | Model number |
|---|----------------------------|------|---------------|------------|-------------|------------|------------|-------------|---------------|----------------|-----------------|
| | | | 50% (2) | 20% (5) | 10% (10) | 5% (20) | 2% (50) | 1% (100) | 0.5% (200) | 0.1% (1000) | |
| 12_2284_3_RPS | 1.67 | 1.68 | 1.68 | 2.38 | 2.90 | 3.49 | 4.39 | 5.20 | 6.15 | 9.04 | Model 5 |
| Top-up between 12_2284_1_RPS & 12_2284_3_RPS | 0.40 | 0.50 | 0.50 | 0.70 | 0.86 | 1.03 | 1.30 | 1.54 | 1.82 | 2.67 | Model 5 |
| 12_2269_U | 0.06 | 0.04 | 0.04 | 0.05 | 0.06 | 0.08 | 0.10 | 0.12 | 0.14 | 0.20 | Model 5 |
| 12_2268_U | 0.04 | 0.03 | 0.03 | 0.04 | 0.04 | 0.05 | 0.07 | 0.08 | 0.09 | 0.14 | Model 5 |
| 12_2268_1 | 0.31 | 0.17 | 0.17 | 0.24 | 0.29 | 0.35 | 0.44 | 0.52 | 0.61 | 0.90 | Model 5 |
| Top-up between 12_2268_U & 12_2268_1 | 0.26 | 0.15 | 0.15 | 0.21 | 0.25 | 0.30 | 0.38 | 0.45 | 0.53 | 0.78 | Model 5 |
| 12_2289_7_RPS | 5.19 | 2.66 | 2.66 | 3.77 | 4.61 | 5.54 | 6.97 | 8.26 | 9.76 | 14.35 | Model 5 |
| Top-up between 12_2269_U & 12_2289_7_RPS | 4.82 | 2.61 | 2.61 | 3.70 | 4.53 | 5.44 | 6.84 | 8.11 | 9.59 | 14.09 | Model 5 |
| 12_669_U | 0.09 | 0.04 | 0.04 | 0.06 | 0.07 | 0.09 | 0.11 | 0.13 | 0.15 | 0.22 | Model 5 |
| 12_145_U | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.02 | 0.02 | 0.02 | 0.03 | Model 5 |
| 12_139_U | 0.05 | 0.02 | 0.02 | 0.03 | 0.04 | 0.05 | 0.06 | 0.07 | 0.09 | 0.13 | Model 5 |
| 12_140_U | 0.04 | 0.02 | 0.02 | 0.03 | 0.03 | 0.04 | 0.05 | 0.06 | 0.07 | 0.11 | Model 5 |
| 12_140_1 | 0.05 | 0.02 | 0.02 | 0.04 | 0.04 | 0.05 | 0.06 | 0.08 | 0.09 | 0.13 | Model 5 |
| 12_141_1 | 0.20 | 0.08 | 0.08 | 0.12 | 0.15 | 0.18 | 0.22 | 0.26 | 0.31 | 0.46 | Model 5 |

Model 05 - Wexford

| Node ID_CFRAMS | AREA (km ²) | Qmed | Flows for AEP | | | | | | | | Model number |
|--|----------------------------|------|---------------|------------|-------------|------------|------------|-------------|---------------|----------------|-----------------|
| | | | 50% (2) | 20% (5) | 10% (10) | 5% (20) | 2% (50) | 1% (100) | 0.5% (200) | 0.1% (1000) | |
| Top-up between 12_139_U & 12_141_1 | 0.09 | 0.04 | 0.04 | 0.06 | 0.07 | 0.09 | 0.11 | 0.13 | 0.16 | 0.23 | Model 5 |
| 12_142_1 | 0.66 | 0.26 | 0.26 | 0.37 | 0.45 | 0.54 | 0.68 | 0.81 | 0.96 | 1.40 | Model 5 |
| Top-up between 12_145_U & 12_142_1 | 0.45 | 0.18 | 0.18 | 0.26 | 0.31 | 0.38 | 0.47 | 0.56 | 0.67 | 0.98 | Model 5 |
| 12_2456_3_RPS | 7.44 | 2.09 | 2.09 | 2.96 | 3.62 | 4.34 | 5.47 | 6.48 | 7.66 | 11.26 | Model 5 |
| Top-up between 12_669_U & 12_2456_3_RPS | 6.69 | 1.89 | 1.89 | 2.68 | 3.28 | 3.93 | 4.95 | 5.87 | 6.94 | 10.19 | Model 5 |

| Node ID_CFRAMS | AREA (km ²) | MRFS Flows for AEP | | | | | | | | HEFS Flows for AEP | | | Model number |
|---|----------------------------|--------------------|------------|-------------|------------|------------|-------------|---------------|----------------|--------------------|-------------|----------------|-----------------|
| | | 50% (2) | 20% (5) | 10% (10) | 5% (20) | 2% (50) | 1% (100) | 0.5% (200) | 0.1% (1000) | 10% (10) | 1% (100) | 0.1% (1000) | |
| 12061_RPS | 1646.29 | 271.06 | 341.53 | 387.61 | 433.96 | 498.47 | 550.51 | 606.35 | 752.18 | 476.21 | 676.35 | 924.12 | Model 5 |
| 12_2597_6_RPS | 5.54 | 1.52 | 2.15 | 2.63 | 3.16 | 3.98 | 4.71 | 5.57 | 8.19 | 3.23 | 5.79 | 10.07 | Model 5 |
| 12_2579_2_RPS | 15.44 | 4.80 | 6.60 | 7.91 | 9.32 | 11.46 | 13.33 | 15.48 | 21.78 | 9.71 | 16.38 | 26.76 | Model 5 |
| 12_2565_2_RPS | 22.52 | 6.82 | 9.11 | 10.75 | 12.50 | 15.10 | 17.37 | 19.92 | 27.30 | 13.20 | 21.33 | 33.53 | Model 5 |
| 12_2545_2_RPS | 12.54 | 5.17 | 7.12 | 8.57 | 10.17 | 12.62 | 14.80 | 17.34 | 24.98 | 10.53 | 18.19 | 30.69 | Model 5 |
| 12064_RPS | 1752.65 | 306.67 | 386.41 | 438.54 | 490.98 | 563.97 | 622.85 | 686.03 | 851.02 | 504.98 | 717.22 | 979.95 | Model 5 |
| Top-up between 12061_RPS & 12064_RPS | 50.32 | 11.01 | 13.88 | 15.75 | 17.63 | 20.25 | 22.37 | 24.63 | 30.56 | 18.13 | 25.75 | 35.19 | Model 5 |
| 12_766_2_RPS | 2.30 | 1.19 | 1.68 | 2.06 | 2.47 | 3.11 | 3.69 | 4.36 | 6.41 | 2.53 | 4.53 | 7.87 | Model 5 |
| 12_2334_2_RPS | 9.06 | 4.64 | 6.58 | 8.05 | 9.66 | 12.16 | 14.41 | 17.04 | 25.05 | 9.89 | 17.71 | 30.77 | Model 5 |
| Top-up between 12_766_2_RPS & 12_2334_2_RPS | 6.76 | 3.53 | 5.00 | 6.11 | 7.34 | 9.24 | 10.95 | 12.95 | 19.03 | 7.51 | 13.46 | 23.38 | Model 5 |
| 12_2272_U | 0.01 | 0.01 | 0.01 | 0.02 | 0.02 | 0.02 | 0.03 | 0.03 | 0.05 | 0.02 | 0.04 | 0.08 | Model 5 |
| 12_2147_2_RPS | 1.29 | 0.80 | 1.13 | 1.38 | 1.66 | 2.09 | 2.48 | 2.93 | 4.31 | 2.67 | 4.78 | 8.31 | Model 5 |
| Top-up between 12_2272_U & 12_2147_2_RPS | 1.28 | 1.03 | 1.46 | 1.79 | 2.15 | 2.70 | 3.20 | 3.79 | 5.57 | 2.64 | 4.74 | 8.23 | Model 5 |

| Node ID_CFRAMS | AREA (km ²) | MRFS Flows for AEP | | | | | | | | HEFS Flows for AEP | | | Model number |
|--|----------------------------|--------------------|------------|-------------|------------|------------|-------------|---------------|----------------|--------------------|-------------|----------------|-----------------|
| | | 50% (2) | 20% (5) | 10% (10) | 5% (20) | 2% (50) | 1% (100) | 0.5% (200) | 0.1% (1000) | 10% (10) | 1% (100) | 0.1% (1000) | |
| 12_2284_1_RPS | 1.27 | 1.77 | 2.51 | 3.07 | 3.68 | 4.64 | 5.49 | 6.50 | 9.55 | 3.32 | 5.95 | 10.34 | Model 5 |
| 12_2284_3_RPS | 1.67 | 2.27 | 3.21 | 3.93 | 4.72 | 5.94 | 7.04 | 8.32 | 12.23 | 4.26 | 7.62 | 13.25 | Model 5 |
| Top-up between 12_2284_1_RPS & 12_2284_3_RPS | 0.40 | 0.59 | 0.84 | 1.03 | 1.24 | 1.56 | 1.84 | 2.18 | 3.20 | 1.12 | 2.00 | 3.47 | Model 5 |
| 12_2269_U | 0.06 | 0.05 | 0.07 | 0.08 | 0.10 | 0.12 | 0.15 | 0.17 | 0.25 | 0.10 | 0.18 | 0.31 | Model 5 |
| 12_2268_U | 0.04 | 0.03 | 0.04 | 0.05 | 0.07 | 0.08 | 0.10 | 0.12 | 0.17 | 0.07 | 0.12 | 0.21 | Model 5 |
| 12_2268_1 | 0.31 | 0.21 | 0.29 | 0.36 | 0.43 | 0.54 | 0.65 | 0.76 | 1.12 | 0.44 | 0.79 | 1.38 | Model 5 |
| Top-up between 12_2268_U & 12_2268_1 | 0.26 | 0.18 | 0.26 | 0.31 | 0.38 | 0.48 | 0.56 | 0.67 | 0.98 | 0.39 | 0.69 | 1.20 | Model 5 |
| 12_2289_7_RPS | 5.19 | 4.66 | 6.60 | 8.07 | 9.69 | 12.19 | 14.45 | 17.08 | 25.11 | 8.74 | 15.65 | 27.20 | Model 5 |
| Top-up between 12_2269_U & 12_2289_7_RPS | 4.82 | 4.35 | 6.16 | 7.53 | 9.04 | 11.38 | 13.49 | 15.95 | 23.44 | 8.16 | 14.61 | 25.40 | Model 5 |
| 12_669_U | 0.09 | 0.05 | 0.07 | 0.09 | 0.11 | 0.13 | 0.16 | 0.19 | 0.28 | 0.11 | 0.20 | 0.34 | Model 5 |
| 12_145_U | 0.01 | 0.01 | 0.01 | 0.01 | 0.02 | 0.02 | 0.02 | 0.03 | 0.04 | 0.02 | 0.03 | 0.05 | Model 5 |
| 12_139_U | 0.05 | 0.07 | 0.10 | 0.12 | 0.15 | 0.19 | 0.22 | 0.26 | 0.38 | 0.13 | 0.24 | 0.42 | Model 5 |
| 12_140_U | 0.04 | 0.02 | 0.04 | 0.04 | 0.05 | 0.06 | 0.08 | 0.09 | 0.13 | 0.05 | 0.09 | 0.16 | Model 5 |
| 12_140_1 | 0.05 | 0.03 | 0.04 | 0.05 | 0.06 | 0.08 | 0.10 | 0.11 | 0.17 | 0.07 | 0.12 | 0.20 | Model 5 |

| Node ID_CFRAMS | AREA (km ²) | MRFS Flows for AEP | | | | | | | | HEFS Flows for AEP | | | Model number |
|---|----------------------------|--------------------|------------|-------------|------------|------------|-------------|---------------|----------------|--------------------|-------------|----------------|-----------------|
| | | 50% (2) | 20% (5) | 10% (10) | 5% (20) | 2% (50) | 1% (100) | 0.5% (200) | 0.1% (1000) | 10% (10) | 1% (100) | 0.1% (1000) | |
| 12_141_1 | 0.20 | 0.11 | 0.15 | 0.18 | 0.22 | 0.28 | 0.33 | 0.39 | 0.57 | 0.23 | 0.40 | 0.70 | Model 5 |
| Top-up between 12_139_U & 12_141_1 | 0.09 | 0.09 | 0.13 | 0.16 | 0.19 | 0.24 | 0.29 | 0.34 | 0.50 | 0.24 | 0.42 | 0.74 | Model 5 |
| 12_142_1 | 0.66 | 0.33 | 0.46 | 0.56 | 0.68 | 0.85 | 1.01 | 1.19 | 1.75 | 0.69 | 1.24 | 2.15 | Model 5 |
| Top-up between 12_145_U & 12_142_1 | 0.45 | 0.40 | 0.56 | 0.69 | 0.83 | 1.04 | 1.23 | 1.46 | 2.14 | 1.02 | 1.82 | 3.16 | Model 5 |
| 12_2456_3_RPS | 7.44 | 2.60 | 3.69 | 4.51 | 5.42 | 6.82 | 8.09 | 9.56 | 14.05 | 5.55 | 9.93 | 17.26 | Model 5 |
| Top-up between 12_669_U & 12_2456_3_RPS | 6.69 | 2.44 | 3.46 | 4.23 | 5.07 | 6.39 | 7.57 | 8.95 | 13.15 | 5.83 | 10.44 | 18.14 | Model 5 |

| | |
|--|--|
| | Input flows |
| | Top-up flows. These flows should be entered laterally |
| | Check flows. Modellers should check to make sure these flows are being reached at each HEP Some of these flows may be put in at the US point due to a small difference between US & DS flows. |

Model 01 - Kilmore

| Node ID_CFRAMS | AREA (km ²) | Qmed | Flows for AEP | | | | | | | | Model number |
|-------------------------------------|----------------------------|------|---------------|------------|-------------|------------|------------|-------------|---------------|----------------|--------------|
| | | | 50% (2) | 20% (5) | 10% (10) | 5% (20) | 2% (50) | 1% (100) | 0.5% (200) | 0.1% (1000) | |
| 13_491_1 | 1.02 | 0.22 | 0.22 | 0.31 | 0.38 | 0.47 | 0.59 | 0.71 | 0.84 | 1.26 | Model 1 |
| 13_146_2_RPS | 6.74 | 0.63 | 0.63 | 0.91 | 1.13 | 1.37 | 1.74 | 2.08 | 2.47 | 3.70 | Model 1 |
| 13081_RPS | 20.93 | 2.37 | 2.37 | 3.43 | 4.23 | 5.12 | 6.52 | 7.78 | 9.28 | 13.87 | Model 1 |
| Top-up between 13_491_1 & 13081_RPS | 13.17 | 1.54 | 1.54 | 2.22 | 2.74 | 3.32 | 4.22 | 5.04 | 6.01 | 8.99 | Model 1 |

| Node ID_CFRAMS | AREA (km ²) | MRFS Flows for AEP | | | | | | | | HEFS Flows for AEP | | | Model number |
|-------------------------------------|----------------------------|--------------------|------------|-------------|------------|------------|-------------|---------------|----------------|--------------------|-------------|----------------|--------------|
| | | 50% (2) | 20% (5) | 10% (10) | 5% (20) | 2% (50) | 1% (100) | 0.5% (200) | 0.1% (1000) | 10% (10) | 1% (100) | 0.1% (1000) | |
| 13_491_1 | 1.02 | 0.27 | 0.39 | 0.48 | 0.58 | 0.74 | 0.88 | 1.05 | 1.58 | 0.59 | 1.09 | 1.94 | Model 1 |
| 13_146_2_RPS | 6.74 | 0.79 | 1.14 | 1.41 | 1.71 | 2.17 | 2.59 | 3.09 | 4.62 | 1.73 | 3.18 | 5.67 | Model 1 |
| 13081_RPS | 20.93 | 2.96 | 4.28 | 5.28 | 6.40 | 8.14 | 9.72 | 11.58 | 17.32 | 6.49 | 11.94 | 21.27 | Model 1 |
| Top-up between 13_491_1 & 13081_RPS | 13.17 | 1.92 | 2.77 | 3.42 | 4.14 | 5.27 | 6.30 | 7.50 | 11.22 | 4.20 | 7.73 | 13.78 | Model 1 |

| |
|--|
| |
| |
| |

Input flows

Top-up flows. These flows should be entered laterally

Check flows. Modellers should check to make sure these flows are being reached at each HEP

Some of these flows may be put in at the US point due to a small difference between US & DS flows.

APPENDIX D

NAM MODELLING OUTPUTS

Appendix D1

Calibration methodology for the NAM models

A tool based on global optimization techniques was used for calibrating NAM models (Figure). This calibration tool has seven global/evolutionary optimization algorithms, including Genetic Algorithm. Two of them, namely ACCO (Adaptive Cluster Covering Optimization) and ACD (Adaptive Cluster Descent) were mostly utilized for the NAM model calibration because these optimization algorithms can converge faster and obtain a reliable optimal solution.

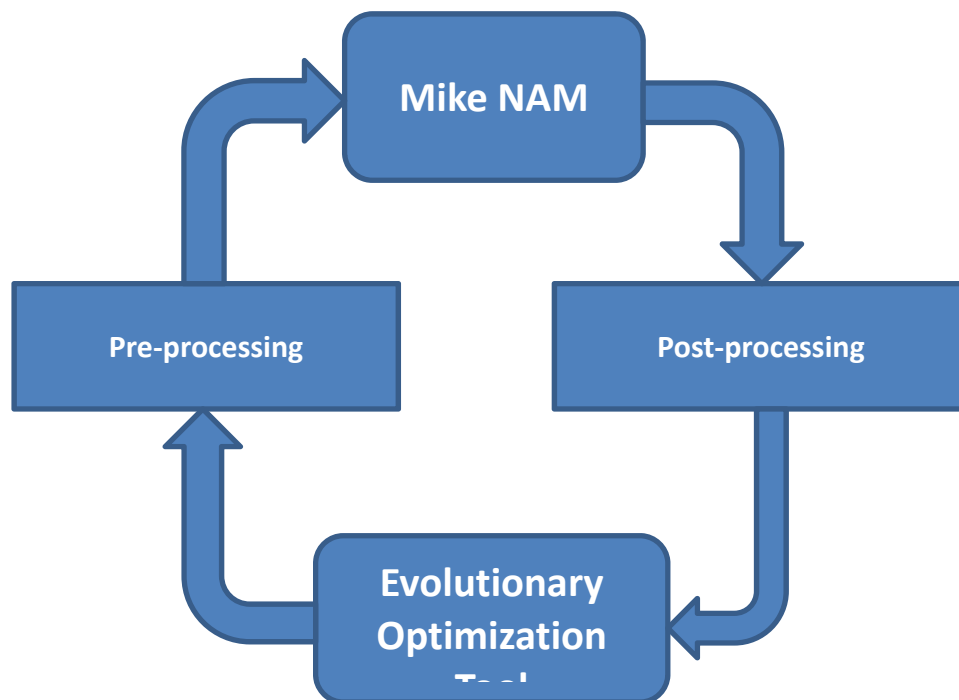


Figure D1: A schematic diagram of Mike NAM model calibration using evolutionary optimization tool

Ten decision variables (NAM model parameters) were adjusted and required to be optimized: Umax, Lmax, CQOF, CKIF, CK1, CK2, TOF, TIF, TG, CBKF.

The default value ranges for these decision variables were set as follows:

| | | |
|-----|------|---------|
| 5 | 35 | {Umax} |
| 50 | 400 | {Lmax } |
| 0 | 1 | {CQOF} |
| 200 | 2000 | {CKIF } |
| 3 | 72 | {CK1 } |
| 3 | 72 | {CK2 } |
| 0 | 0.99 | {TOF} |
| 0 | 0.99 | {TIF} |
| 0 | 0.99 | {TG} |
| 500 | 5000 | {CKBF } |

Appendix D2

Derivation of NAM Parameters

The NAM models were built based on the provided GIS, precipitation and flow data as well as the decision tree (refer to Inception Reports), which determine the initial parameter values of the built NAM models. Four parameters (UMAX, CQOF, CKIF, CKBF) were calculated based on a decision tree using the provided hydro-geological data. In most cases, the built NAM models with the initial parameter values were not good and required for calibration. The calibration tool finds the optimal parameter values of the NAM models given the precipitation and flow data. The initial values of the decision variables to be calibrated were the same as the initial parameter values of the built NAM models so that the parameter values determined by the decision tree and hydro-geological data had been included and evaluated as one candidate of the optimal solution during calibration process.

The parameters, CK1 and CK2 determine the shape of hydrograph peaks as these parameters represent the time constants of the overland flows for two connected serial reservoirs. Therefore, the parameter CK2 was activated in NAM model setup and became part of the decision variables to be calibrated. The lower bounds of parameters CKIF, Umax and Lmax were extended to 1 because in some cases of the NAM model calibrations, these parameter values of the initial calibrated NAM models were found in the lower bounds. The calibrated parameter value nearby the bounds indicates that the value range of a decision variable needs to be extended. The parameter TOF determines the start of runoff as overland flows and was set as the maximum TOF value of 0.99 as the upper bound, in order to allow the calibration tool for evaluating and finding the optimal TOF parameter value in wider value range.

Appendix D3**MET EIREANN RAINFALL STATIONS KEY**

| STN NO. | NAME | Type |
|----------------|---------------------|-------------|
| 375 | OAK PARK | Hourly |
| 475 | JOHNSTOWN CASTLE | Hourly |
| 1475 | GURTEEN | Daily |
| 1715 | DONARD GS | Daily |
| 2415 | GLEN IMAAL | Daily |
| 2615 | ROSSLARE | Hourly |
| 2922 | MULLINGAR II | Hourly |
| 3613 | KILKENNY | Hourly |
| 3723 | CASEMENT | Hourly |
| 4919 | BIRR | Hourly |
| 9915 | M.GLEN IMAAL | Daily |

Appendix D4

| NAM Model Number | Calibration Performance of NAM Models | | | | | | |
|------------------|---------------------------------------|--|--------------------------------|--------------------|--|---------------|-----------------|
| | Correlation Coefficient (CC) | Coefficient of Determination (r^2) | Root Mean Squared Error (RMSE) | Peak-Weighted RMSE | QMAX (from FSU or Local Authority AMAX series) | (RMSE/QMAX) % | (PW-RMSE/QMAX)% |
| 11001_RPS | 0.69 | 0.47 | 3.11 | 13.33 | 120.70 | 2.58 | 11.04 |
| 12001_RPS | 0.60 | 0.36 | 15.77 | 36.88 | 399.12 | 3.95 | 9.24 |
| 12013_RPS | 0.85 | 0.73 | 2.40 | 4.48 | 72.30 | 3.32 | 6.20 |
| 14003_RPS | 0.70 | 0.49 | 3.55 | 8.35 | 48.26 | 7.36 | 17.30 |
| 14004_RPS | 0.73 | 0.54 | 2.28 | 3.55 | 38.40 | 5.94 | 9.23 |
| 14005_RPS | 0.83 | 0.69 | 3.77 | 10.47 | 80.42 | 4.69 | 13.02 |
| 14006_RPS | 0.85 | 0.73 | 7.00 | 14.23 | 137.38 | 5.10 | 10.36 |
| 14011_RPS | 0.66 | 0.44 | 1.30 | 2.72 | 18.74 | 6.95 | 14.51 |
| 14014_Rev01 | 0.71 | 0.50 | 0.34 | 0.69 | 4.52 | 7.53 | 15.27 |
| 14019_RPS | 0.86 | 0.75 | 10.89 | 19.08 | 164.50 | 6.62 | 11.60 |
| 14022_RPS | 0.92 | 0.85 | 11.22 | 18.61 | 184.81 | 6.07 | 10.07 |
| 14029_RPS | 0.88 | 0.78 | 16.62 | 28.34 | 206.21 | 8.06 | 13.74 |
| 14033_RPS | 0.76 | 0.57 | 1.90 | 6.57 | 33.00 | 5.76 | 19.91 |
| 14101_RPS | 0.65 | 0.43 | 0.46 | 0.63 | 4.32 | 10.65 | 14.58 |
| 14105_RPS | 0.83 | 0.68 | 11.22 | 21.38 | 149.64 | 7.50 | 14.29 |
| 14107_RPS | 0.73 | 0.54 | 5.79 | 11.18 | 56.59 | 10.23 | 19.76 |
| 15004_RPS | 0.54 | 0.29 | 6.63 | 8.99 | 74.96 | 8.84 | 11.99 |
| 15007_RPS | 0.76 | 0.58 | 5.51 | 11.10 | 70.56 | 7.81 | 15.73 |
| 15008_RPS | 0.87 | 0.76 | 3.92 | 6.50 | 27.26 | 14.38 | 23.84 |
| 15009_RPS | 0.80 | 0.63 | 3.58 | 13.52 | 60.17 | 5.95 | 22.47 |
| 15011_RPS | 0.82 | 0.67 | 23.55 | 45.62 | 444.39 | 5.30 | 10.27 |
| 15012_RPS | 0.83 | 0.69 | 17.83 | 29.02 | 133.00 | 13.41 | 21.82 |
| 15050_RPS | 0.82 | 0.67 | 0.90 | 21.78 | 67.14 | 1.35 | 32.44 |

Appendix D3 – NAM Model Outputs**Calibrated Mike NAM Model****Catchment code = 11001_RPS****Catchment name = Gorey/Courtown**

Catchment_Name = '11001_RPS'

Catchment_Model =

'NAM'

Catchment_Area = 144.17

Parameter settings

U_Max = 3.06

L_Max = 15

CQOF = 0.727

CKIF = 125.1

CK1 = 19.7

CK12_DIF =

true

CK2 = 3.8226

TOF = 0.244

TIF = 0

TG = 0

CKBF =

633.288

Calibration period

start = 2002, 1, 16, 17, 0, 0

end = 2010, 8, 29, 0, 0, 0

Precipitation data source

| | | % |
|---------|------|-------|
| station | 2615 | 0.5 |
| station | 375 | 0.055 |
| | | 0.445 |

| | |
|---------|-----|
| station | 475 |
|---------|-----|

Error measures with missing values (as shown in the figures overleaf)

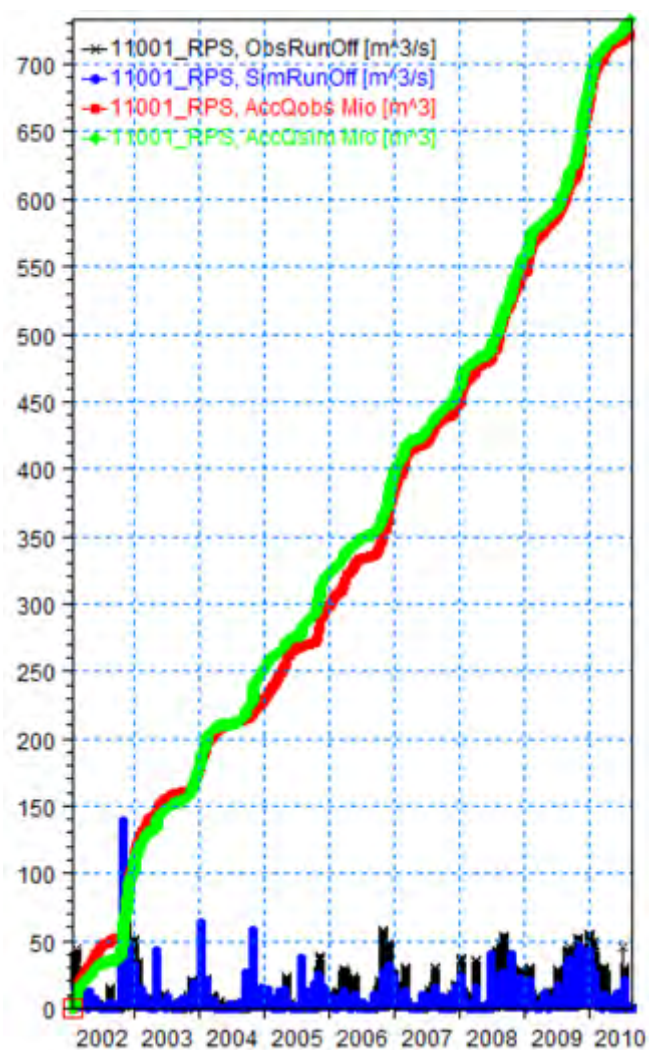
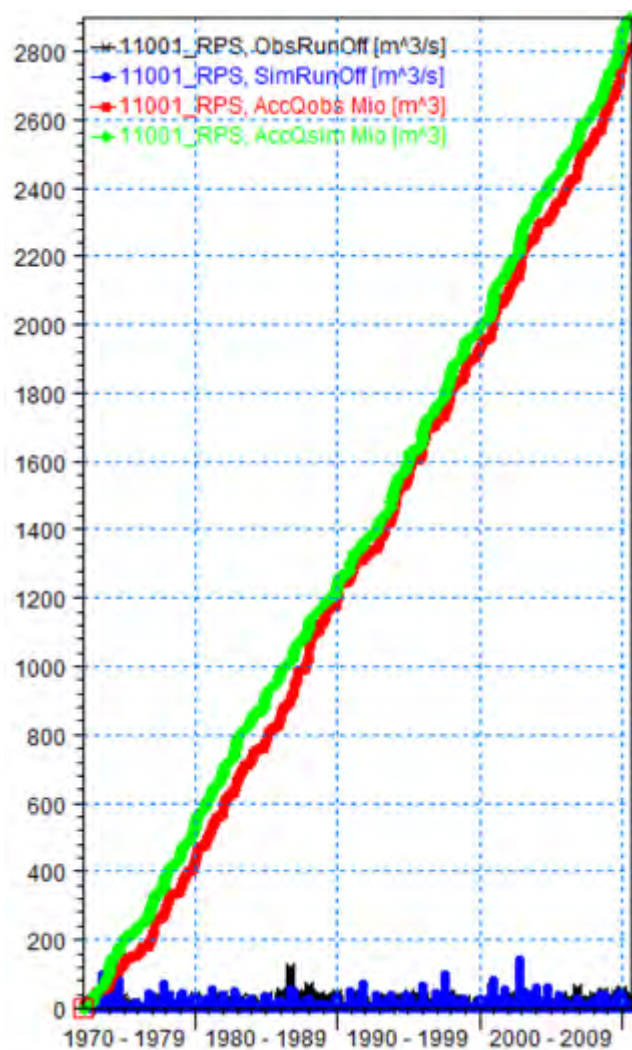
R2 = 0.449

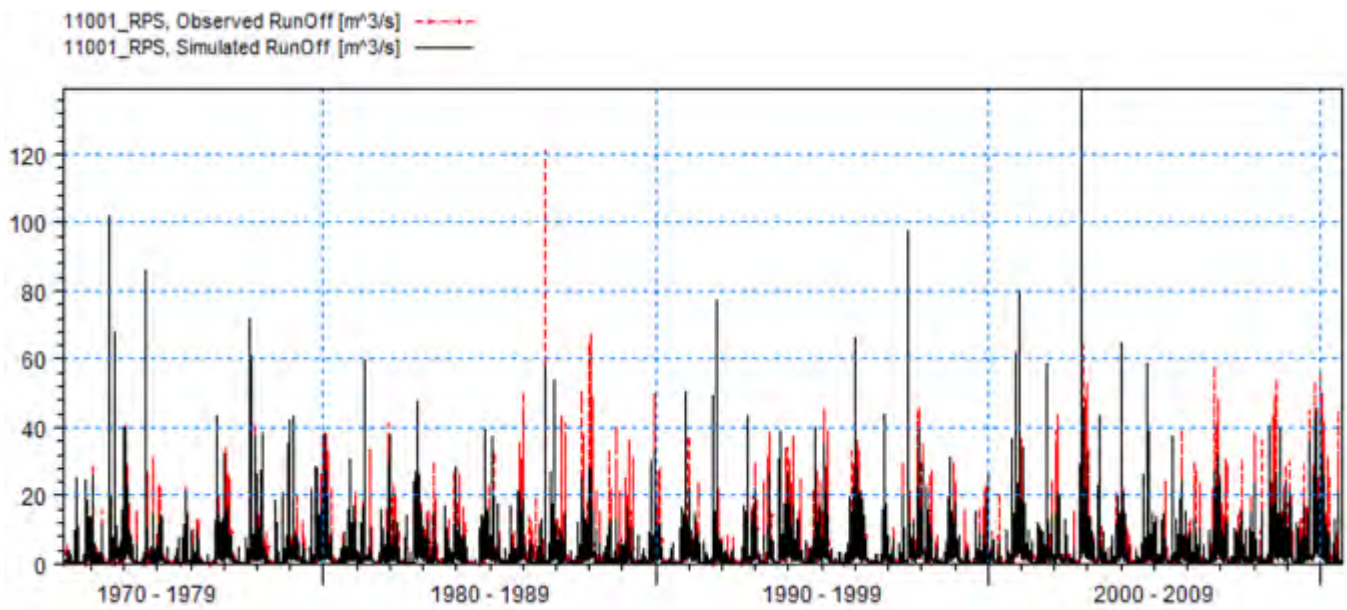
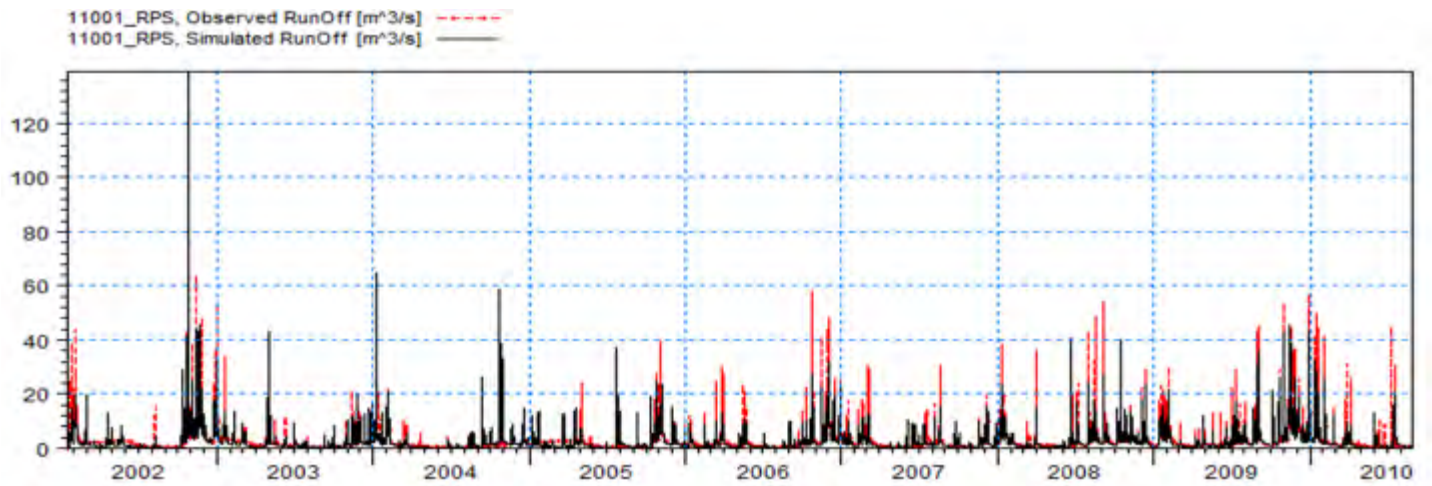
Error measures without missing values

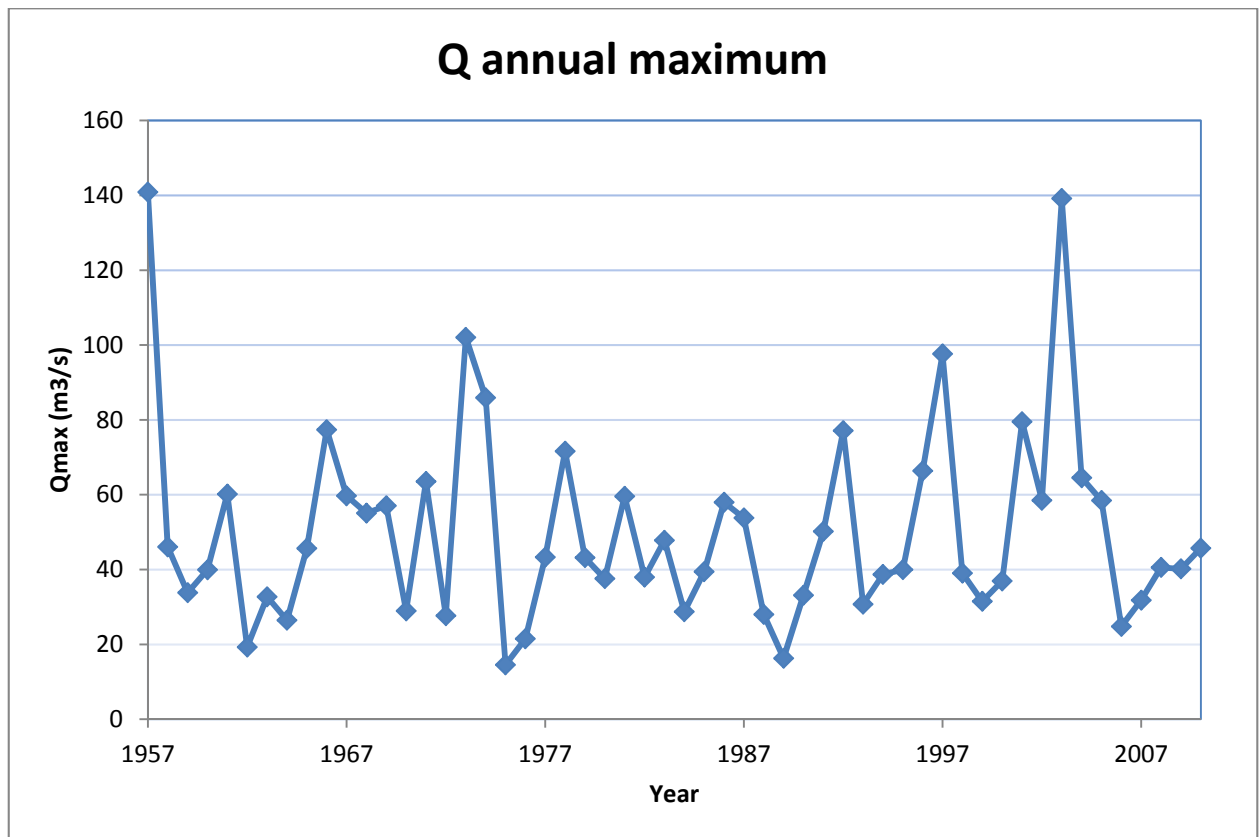
RMSE(Q) = 3.11

Peak-weighted RMSE(Q) = 13.33

R2 = 0.471







Q annual maximum
(1st October - 30th September)

| Datetime | Qmax | Year | NAM Qmed | 43.25 |
|------------------|--------|------|------------|--------------|
| 25/09/1957 09:30 | 140.86 | 1957 | FSU Qmed | 24.57 |
| 25/06/1958 23:00 | 46.07 | 1958 | Gauge Qmed | 45.75 |
| 22/01/1959 12:00 | 33.81 | 1959 | | |
| 17/10/1959 22:00 | 39.94 | 1960 | | |
| 02/10/1960 16:30 | 60.17 | 1961 | | |
| 30/09/1962 04:15 | 19.27 | 1962 | | |
| 06/02/1963 14:30 | 32.73 | 1963 | | |
| 28/11/1963 11:45 | 26.45 | 1964 | | |
| 13/12/1964 00:30 | 45.68 | 1965 | | |
| 18/11/1965 00:30 | 77.37 | 1966 | | |
| 10/10/1966 12:30 | 59.71 | 1967 | | |
| 07/11/1967 17:45 | 55.09 | 1968 | | |
| 20/01/1969 20:15 | 57.04 | 1969 | | |
| 11/11/1969 18:00 | 28.95 | 1970 | | |
| 17/11/1970 18:15 | 63.53 | 1971 | | |
| 02/12/1971 06:15 | 27.67 | 1972 | | |
| 16/07/1973 19:00 | 102.06 | 1973 | | |
| 01/09/1974 03:30 | 85.90 | 1974 | | |
| 23/11/1974 12:30 | 14.56 | 1975 | | |
| 11/11/1975 12:45 | 21.50 | 1976 | | |
| 23/10/1976 14:30 | 43.31 | 1977 | | |
| 07/10/1977 03:15 | 71.63 | 1978 | | |
| 01/02/1979 14:45 | 43.20 | 1979 | | |
| 19/01/1980 19:30 | 37.58 | 1980 | | |
| 22/03/1981 03:30 | 59.56 | 1981 | | |
| 08/01/1982 23:15 | 37.96 | 1982 | | |
| 06/11/1982 11:15 | 47.81 | 1983 | | |
| 20/12/1983 22:15 | 28.75 | 1984 | | |
| 12/11/1984 02:45 | 39.43 | 1985 | | |
| 25/08/1986 19:45 | 57.99 | 1986 | | |
| 08/12/1986 11:30 | 53.79 | 1987 | | |
| 19/01/1988 01:00 | 28.03 | 1988 | | |
| 24/02/1989 12:15 | 16.30 | 1989 | | |
| 14/12/1989 14:00 | 33.12 | 1990 | | |
| 25/11/1990 22:00 | 50.22 | 1991 | | |
| 31/10/1991 10:15 | 77.11 | 1992 | | |
| 19/09/1993 22:15 | 30.77 | 1993 | | |
| 06/10/1993 11:45 | 38.71 | 1994 | | |
| 22/10/1994 10:30 | 39.96 | 1995 | | |
| 04/01/1996 13:15 | 66.38 | 1996 | | |
| 04/08/1997 08:15 | 97.61 | 1997 | | |
| 25/11/1997 19:15 | 39.04 | 1998 | | |

| | | |
|------------------|--------|------|
| 09/11/1998 01:15 | 31.49 | 1999 |
| 30/09/2000 09:30 | 36.96 | 2000 |
| 08/12/2000 04:00 | 79.52 | 2001 |
| 07/10/2001 20:15 | 58.51 | 2002 |
| 25/10/2002 00:30 | 139.16 | 2003 |
| 08/01/2004 09:15 | 64.55 | 2004 |
| 22/10/2004 20:30 | 58.45 | 2005 |
| 24/10/2005 09:00 | 24.81 | 2006 |
| 03/12/2006 05:30 | 31.82 | 2007 |
| 21/06/2008 15:00 | 40.57 | 2008 |
| 14/10/2008 21:30 | 40.19 | 2009 |
| 14/11/2009 01:30 | 45.73 | 2010 |

Calibrated Mike NAM Model**Catchment code = 12001_RPS****Catchment name = Enniscorthy**

Catchment_Name = '12001_RPS_NAM'
Catchment_Model = 'NAM'
Catchment_Area = 1025.43
Catchment_Name = '12001_RPS_URBAN'
Catchment_Model = 'Urban'
Catchment_Area = 10.93
Catchment_Name = '12001_RPS'
Catchment_Model = 'Combined'
Catchment_Area = 1036.36

Parameter settings

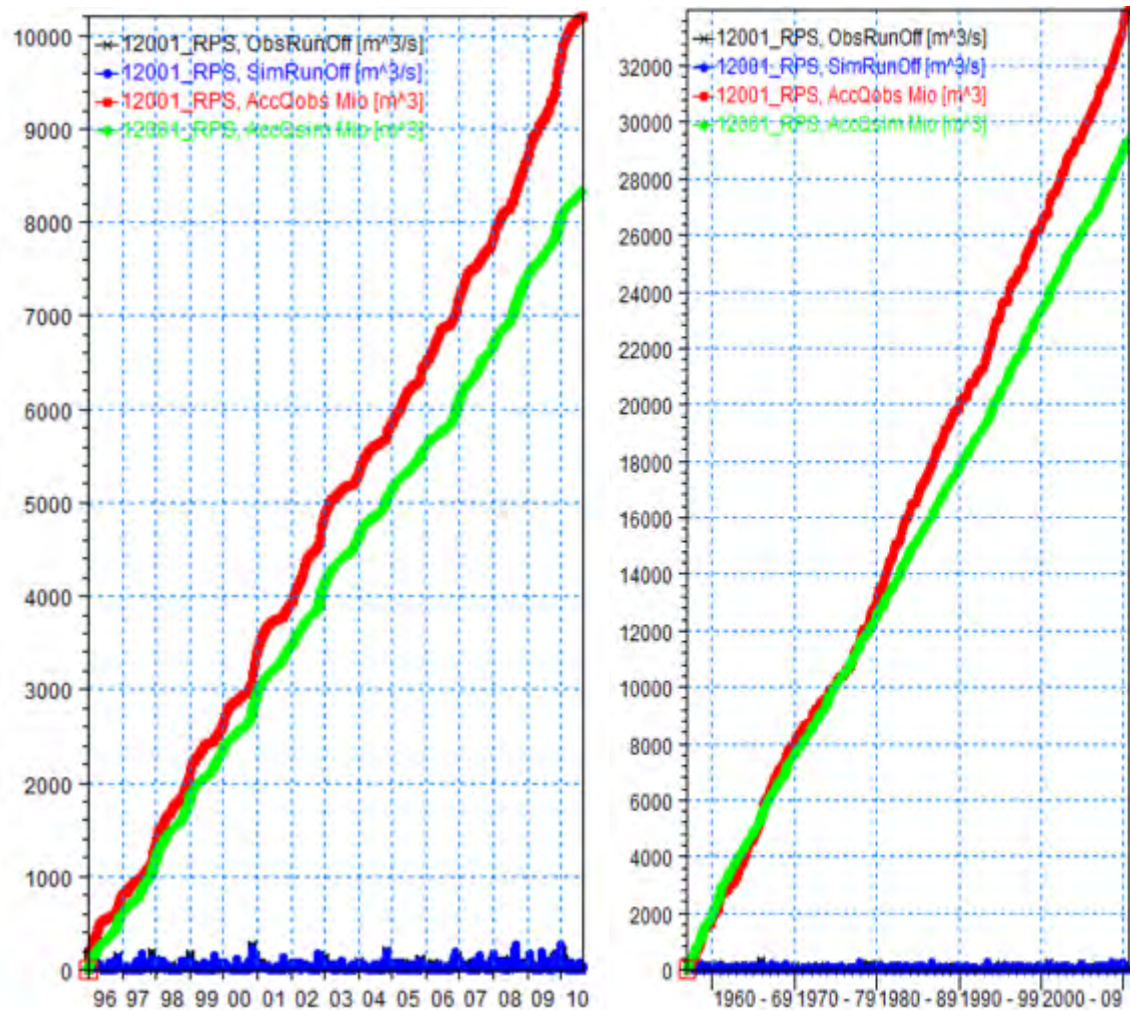
U_Max = 1
L_Max = 1
CQOF = 0.487
CKIF = 43.84
CK1 = 5.5
CK12_DIF =
true
CK2 =
19.6377
TOF = 0.99
TIF = 0
TG = 0.0001
CKBF =
1046.18

Calibration period

start = 1996, 1, 1, 0, 0, 0
end = 2010, 8, 29, 0, 0, 0

Precipitation data source

| | | |
|---------|------|----------|
| station | 3723 | 0.329746 |
| station | 3613 | 0.534462 |
| station | 2615 | 0.135792 |



Error measures with missing values (as shown in the figures)

$R^2 = 0.352$

Error measures without missing values

$RMSE(Q) = 15.77$

Peak-weighted $RMSE(Q) = 36.88$

$R^2 = 0.359$

Error measures with missing values (as shown in the figures)

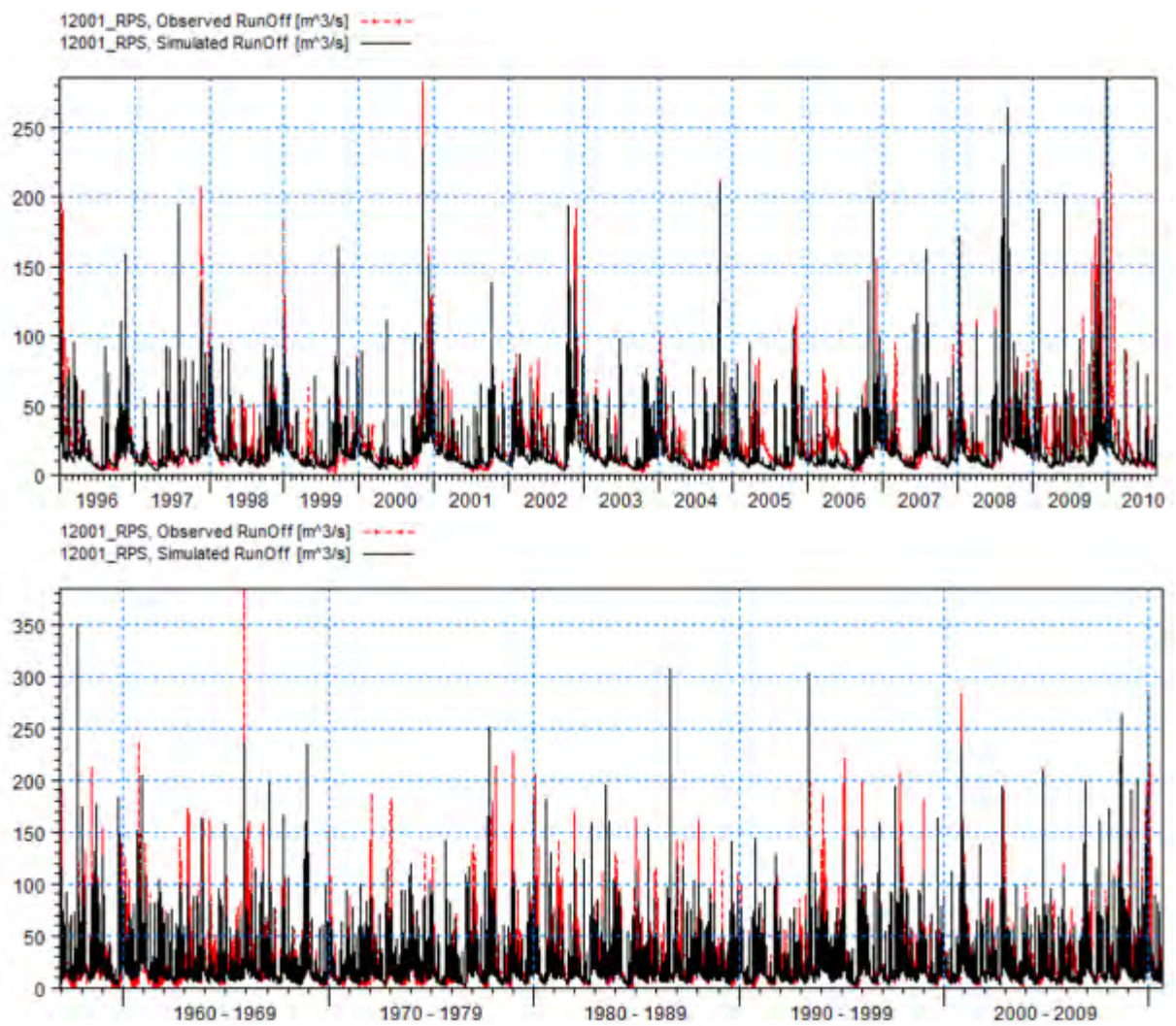
$R^2 = 0.349$

Error measures without missing values

$RMSE(Q) = 15.11$

Peak-weighted $RMSE(Q) = 36.02$

$R^2 = 0.361$

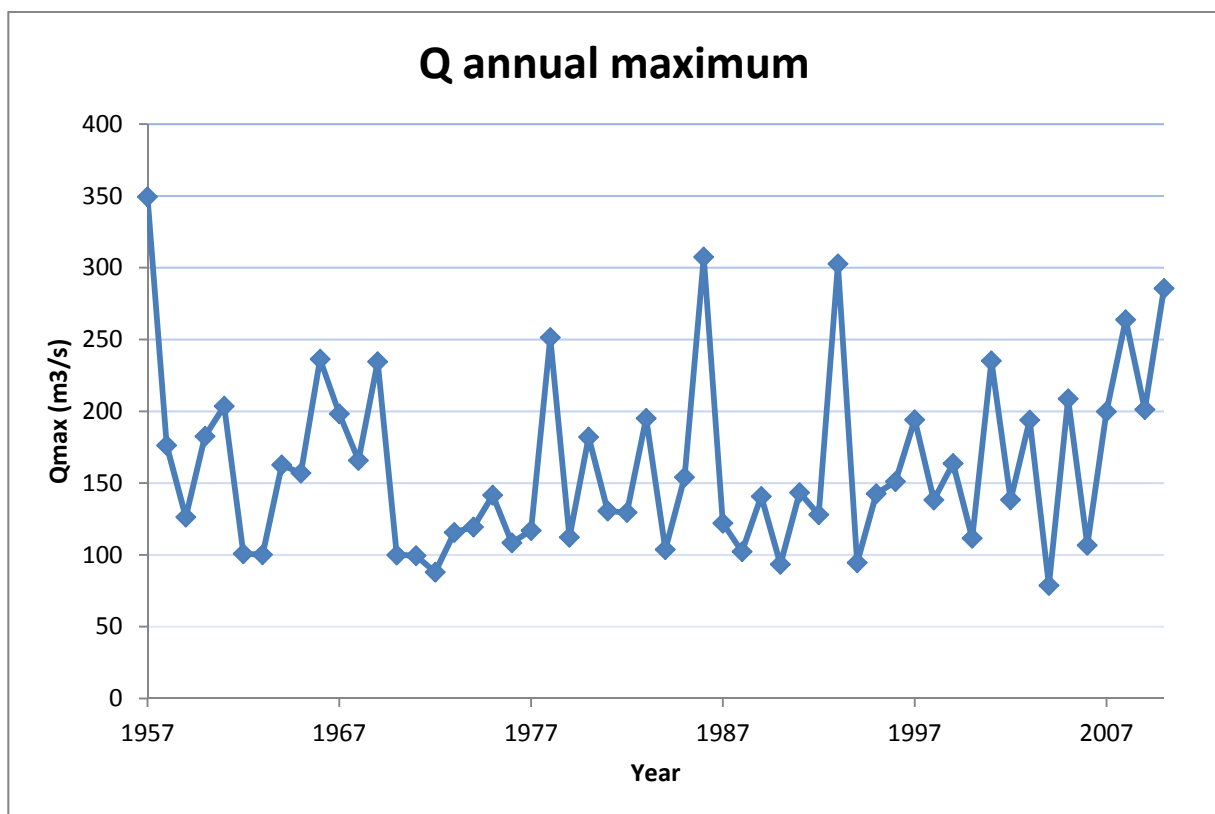


Q annual maximum
(1st October - 30th September)

| Datetime | Qmax | Year |
|------------------|--------|------|
| 25/09/1957 06:15 | 349.41 | 1957 |
| 03/09/1958 04:30 | 176.27 | 1958 |
| 19/12/1958 19:30 | 126.30 | 1959 |
| 10/10/1959 18:15 | 182.66 | 1960 |
| 04/12/1960 03:15 | 203.60 | 1961 |
| 30/09/1962 05:30 | 100.76 | 1962 |
| 06/02/1963 15:15 | 100.09 | 1963 |
| 30/10/1963 18:30 | 162.65 | 1964 |
| 13/12/1964 03:30 | 156.96 | 1965 |
| 17/11/1965 20:15 | 236.32 | 1966 |
| 22/02/1967 23:15 | 198.24 | 1967 |
| 17/10/1967 00:30 | 165.83 | 1968 |
| 24/12/1968 20:30 | 234.55 | 1969 |
| 04/11/1969 05:30 | 99.97 | 1970 |
| 01/08/1971 21:30 | 99.46 | 1971 |
| 03/02/1972 05:15 | 87.96 | 1972 |
| 12/11/1972 19:15 | 115.67 | 1973 |
| 08/01/1974 13:30 | 119.47 | 1974 |
| 18/09/1975 02:30 | 141.55 | 1975 |
| 25/09/1976 03:30 | 108.38 | 1976 |
| 23/10/1976 16:45 | 117.02 | 1977 |
| 31/10/1977 04:15 | 251.39 | 1978 |
| 28/12/1978 03:45 | 112.24 | 1979 |
| 07/08/1980 13:15 | 182.05 | 1980 |
| 22/10/1980 16:30 | 130.53 | 1981 |
| 14/12/1981 15:15 | 129.56 | 1982 |
| 17/07/1983 13:45 | 195.13 | 1983 |
| 09/12/1983 09:45 | 103.72 | 1984 |
| 26/07/1985 06:15 | 154.05 | 1985 |
| 25/08/1986 23:30 | 307.41 | 1986 |
| 08/12/1986 19:15 | 122.12 | 1987 |
| 21/10/1987 15:45 | 102.23 | 1988 |
| 30/08/1989 14:30 | 140.76 | 1989 |
| 13/12/1989 22:00 | 93.40 | 1990 |
| 16/10/1990 00:30 | 143.42 | 1991 |
| 31/10/1991 09:15 | 127.95 | 1992 |
| 11-Jun-93 | 302.65 | 1993 |
| 04/02/1994 02:45 | 94.52 | 1994 |
| 25/01/1995 20:30 | 142.59 | 1995 |
| 24/10/1995 19:30 | 151.12 | 1996 |
| 04/08/1997 07:30 | 194.15 | 1997 |
| 17/11/1997 23:00 | 138.22 | 1998 |

| | | |
|------------------|--------|------|
| 21/09/1999 03:30 | 163.72 | 1999 |
| 16/05/2000 21:30 | 111.62 | 2000 |
| 06/11/2000 08:30 | 235.12 | 2001 |
| 07/10/2001 21:00 | 138.35 | 2002 |
| 21/10/2002 16:15 | 193.88 | 2003 |
| 08/01/2004 14:45 | 78.77 | 2004 |
| 28/10/2004 23:45 | 208.66 | 2005 |
| 24/10/2005 10:30 | 106.72 | 2006 |
| 15/11/2006 19:15 | 199.81 | 2007 |
| 05/09/2008 13:45 | 263.74 | 2008 |
| 06/06/2009 23:15 | 201.28 | 2009 |
| 30/12/2009 21:15 | 285.57 | 2010 |

| | |
|-------|--------|
| NAM | |
| Qmed | 143.01 |
| FSU | |
| Qmed | 138.03 |
| Gauge | |
| Qmed | 156.00 |



Calibrated Mike NAM Model

Catchment code = 12013_RPS

Catchment name = Baltinglass

Catchment_Area = 207.55

Parameter settings

U_Max = 1.2

L_Max = 11.9

CQOF = 0.213

CKIF = 98.11

CK1 = 3.13

CK12_DIF =

true

CK2 = 9.7206

TOF = 0.418

TIF = 0

TG = 0.5223

CKBF =

992.212

Calibration period

start = 2002, 6, 20, 0, 0, 0

end = 2010, 5, 27, 23, 30, 0

Precipitation data source

Daily

raingauge

| | | |
|---------|------|----------|
| station | 9915 | 0.178857 |
|---------|------|----------|

| | | |
|---------|------|----------|
| station | 3715 | 0.283022 |
|---------|------|----------|

| | | |
|---------|------|----------|
| station | 1715 | 0.320161 |
|---------|------|----------|

| | | |
|---------|------|----------|
| station | 2415 | 0.217959 |
|---------|------|----------|

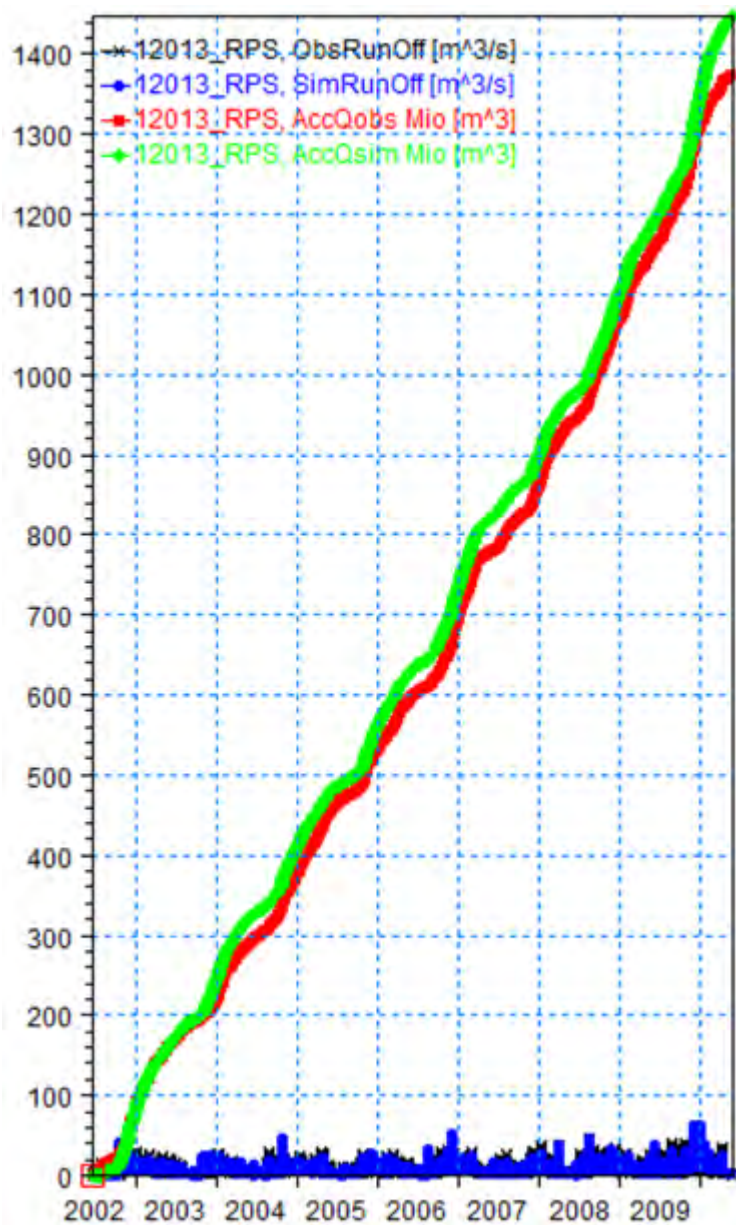
Dissaggregation patterns

Hourly

raingauge

| | | |
|---------|------|----------|
| station | 3723 | 0.068708 |
|---------|------|----------|

| | | |
|---------|-----|----------|
| station | 375 | 0.931292 |
|---------|-----|----------|



Error measures with missing values (as shown in the figures)

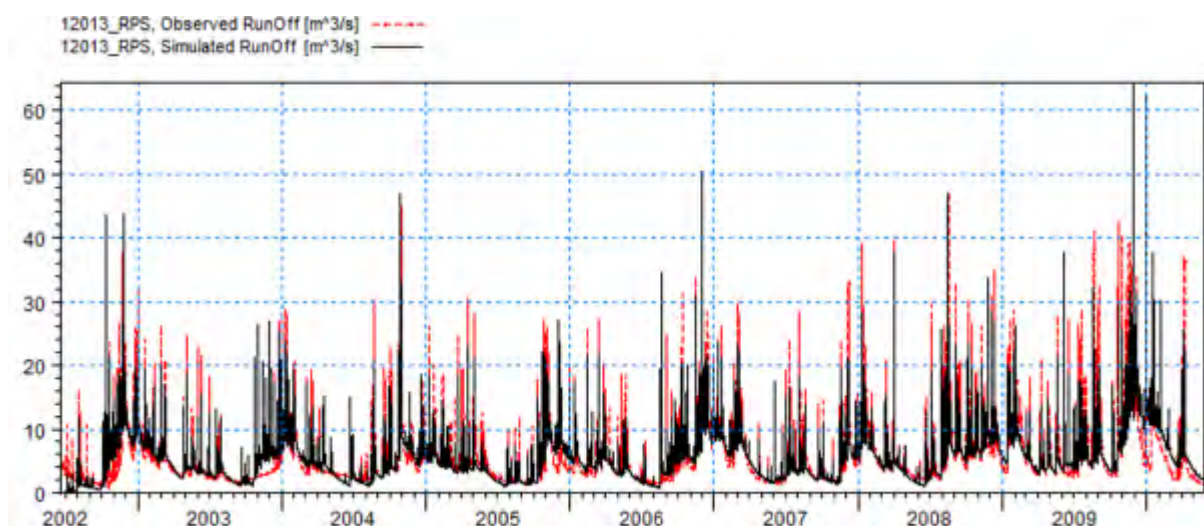
$R^2 = 0.673$

Error measures without missing values

$RMSE(Q) = 2.3978$

Peak-weighted $RMSE(Q) = 4.48$

$R^2 = 0.725$



Q annual maximum

(1st October - 30th September)

| Datetime | Qmax | Year |
|------------------|--------|------|
| 18/03/1964 17:00 | 20.10 | 1964 |
| 12/12/1964 00:30 | 31.33 | 1965 |
| 17/11/1965 19:30 | 88.17 | 1966 |
| 18/10/1966 02:00 | 40.52 | 1967 |
| 30/10/1967 22:15 | 33.87 | 1968 |
| 17/12/1968 06:15 | 31.58 | 1969 |
| 15/08/1970 23:15 | 31.87 | 1970 |
| 18/03/1971 20:45 | 23.47 | 1971 |
| 16/02/1972 16:15 | 53.44 | 1972 |
| 17/09/1973 00:45 | 31.15 | 1973 |
| 01/02/1974 00:45 | 37.71 | 1974 |
| 25/01/1975 01:30 | 35.10 | 1975 |
| 24/09/1976 21:45 | 24.84 | 1976 |
| 22/10/1976 22:15 | 35.96 | 1977 |
| 31/10/1977 03:00 | 108.55 | 1978 |
| 31/12/1978 13:15 | 51.20 | 1979 |
| 26/12/1979 21:15 | 66.26 | 1980 |
| 27/12/1980 16:15 | 51.46 | 1981 |
| 20/12/1981 08:15 | 50.79 | 1982 |
| 19/05/1983 05:45 | 67.09 | 1983 |
| 08/12/1983 20:30 | 44.24 | 1984 |
| 12/11/1984 00:15 | 53.48 | 1985 |
| 26/08/1986 00:15 | 39.44 | 1986 |
| 03/04/1987 03:15 | 43.44 | 1987 |
| 01/09/1988 06:30 | 27.43 | 1988 |
| 30/08/1989 14:45 | 36.07 | 1989 |
| 08/11/1989 14:15 | 20.93 | 1990 |

| | | |
|------------------|-------|------|
| 28/09/1991 11:45 | 68.53 | 1991 |
| 31/10/1991 10:45 | 22.27 | 1992 |
| 30/03/1993 03:45 | 52.97 | 1993 |
| 03/02/1994 22:15 | 55.20 | 1994 |
| 10/03/1995 09:15 | 46.83 | 1995 |
| 12/03/1996 11:45 | 40.73 | 1996 |
| 19/11/1996 12:15 | 74.45 | 1997 |
| 17/11/1997 22:30 | 66.93 | 1998 |
| 20/09/1999 18:45 | 71.30 | 1999 |
| 01/10/1999 20:15 | 30.72 | 2000 |
| 06/11/2000 15:45 | 74.20 | 2001 |
| 07/10/2001 21:15 | 50.81 | 2002 |
| 27/11/2002 15:30 | 43.88 | 2003 |
| 29/11/2003 13:00 | 26.99 | 2004 |
| 28/10/2004 01:30 | 46.88 | 2005 |
| 19/08/2006 06:15 | 34.55 | 2006 |
| 30/11/2006 21:30 | 50.47 | 2007 |
| 16/08/2008 13:30 | 46.86 | 2008 |
| 06/06/2009 21:15 | 37.78 | 2009 |
| 29/11/2009 13:30 | 64.39 | 2010 |

NAM

Qmed 43.8803

FSU

Qmed 43.55