GLENTIES FLOOD RELIEF SCHEME

Hydrology Report

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1 INTRODUCTION

Glenties lies at the junction of the two largest sub-catchments which make up the Owenea catchment; the Owenea and the Stracashel, with the smaller Gortnamucklagh watercourse discharging into the Owenea to the southwest of Glenties town. The Stracashel drains a glen to the north-east of Glenties, before flowing through the town. The Gortnamucklagh watercourse drains an area to the north and, like the Stracashel discharges into the Owenea River downstream of Glenties. The hydrological analysis for the Glenties Flood Relief Scheme (FRS) will consider the flood risk emanating from the Owenea, Stracashel, and Gortnamucklagh watercourses, and any drainage channels which flow through the Glenties study area that have been identified as potentially causing risk to Glenties. The Glenties study area and the watercourses affecting Glenties are shown in Figure 1.1.

1.1 CFRAM Study Hydrological Analysis

The hydrological analysis undertaken as part of the North-Western Neagh-Bann (NWNB) CFRAM Study utilised the latest Flood Studies Update (FSU) methodologies and the best available gauge data at the time (up to the end of the hydrological year 2013). The hydrological analysis was validated through a review of the modelled flood extents against observed data on the Owenea River. In light of this, ungauged catchment descriptor-based FSU estimates of the Index Flood Flow (Q_{med}) were reduced by 20% on the Owenea and Stracashel Rivers due to over-estimation. Ungauged catchment descriptor-based estimates on the smaller Gortnamucklagh watercourse were not adjusted.

Given that the Owenea River is gauged downstream of Glenties, and the observed flows are considered robust at Q_{med}, the design flows are tied to observed data. For that reason, the hydrological analysis for this project must consider the impact of additional years of data on the assumptions regarding flood frequency inherent in the CFRAM Study analysis. The August 2019 flood represents a significant event that when considered within an 'at-site' flood frequency analysis may alter the understanding of flood risk at Glenties. The additional data may also inform understanding of the timing of hydrographs. Furthermore, other improvements could be made to enhance the robustness of the analysis at scheme level, including the potential to increase the resolution of Hydrological Estimation Points (HEPs).

1.2 Catchment Review

The Owenea catchment downstream of Glenties town (at the Clonconwall Ford gauging station; including the Gortnamucklagh tributary catchment) is approximately 111km^2. The most upstream extents of the catchment are located at the source of the tributaries of the Owenea River in the Bluestack Mountains to the west of Ballybofey and the source of the Stracashel River to the west of Aghla Mountain. The Glenties study area includes the three main watercourses considered to represent fluvial flood risk: the Owenea River, Stracashel River, and Gortnamucklagh watercourse as shown in Figure 1.1.

The catchments are defined within the FSU datasets. These have been checked through re-delineation using the automated catchment delineation tools available in ArcHydro and the best available digital terrain models. ArcHydro is a suite of hydrological GIS tools that use processing algorithms to determine watershed and flow paths from rasterised digital terrain datasets such as LiDAR and digital height models.

The Owenea River catchment is predominantly rural with several significant attenuating features (reservoirs and lakes) including Lough Ea and Lough Anna. The catchment is relatively impermeable with some peat coverage on high ground with restricted development of river alluvium in valleys. The catchment experiences high levels of rainfall annually, typically 1800mm. These physiographic and meteorological characteristics result in relatively high flood flows and a flashy response within this medium-sized catchment.

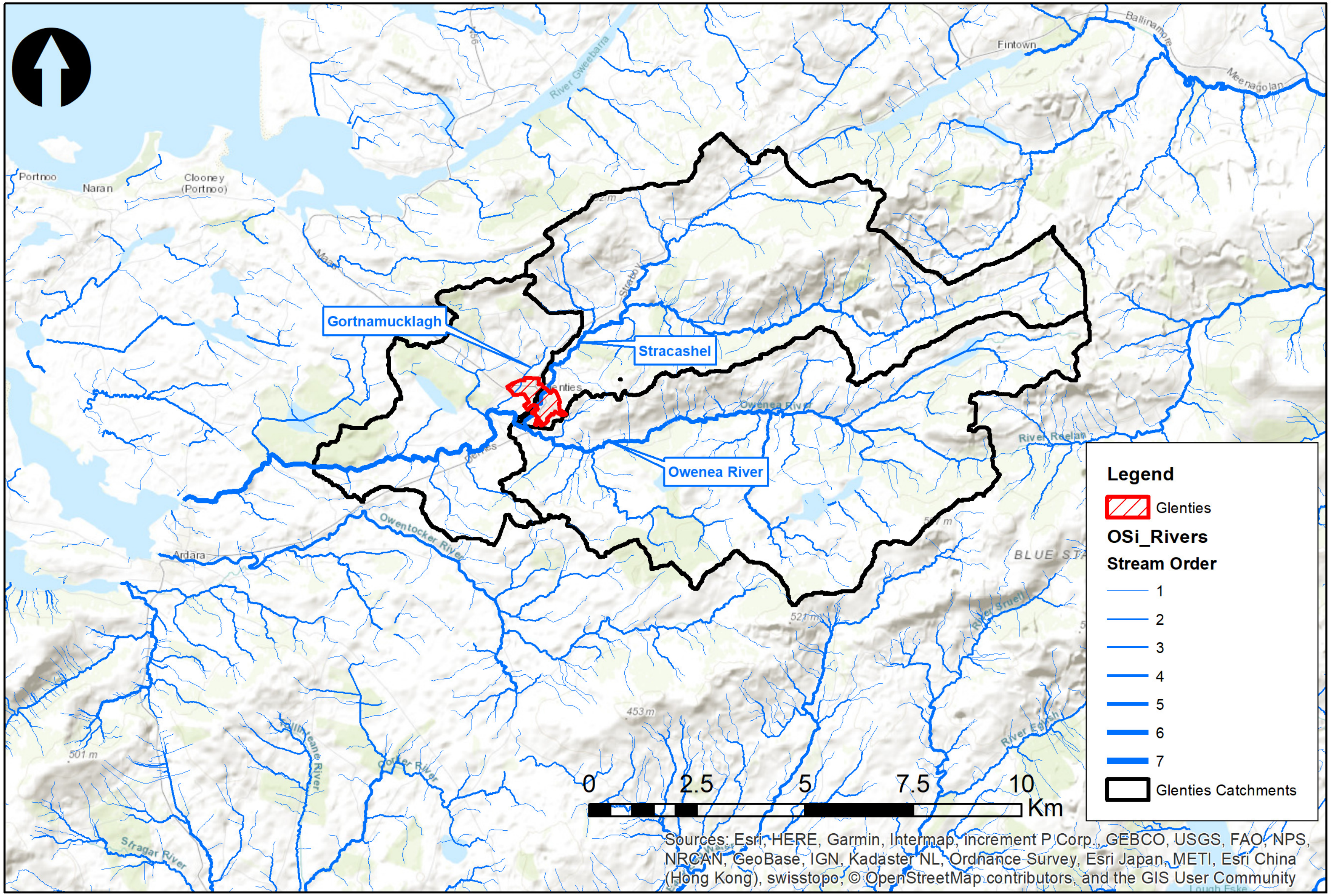


Figure 1.1 Glenties FRS Main Catchments

1.3 Available hydrometric data

The main data which underpins the hydrological analysis is the hydrometric data available on the Owenea River at Clonconwall Ford upon which statistical flood frequency analysis has been conducted. Another recently installed Office of Public Works (OPW) gauging station is present on the Stracashel River, which is a water level (WL) and flow gauging station.

The OPW was consulted for the most up-to-date hydrometric data for the Glenties study area. Hydrometric data was provided for two gauging stations identified within the Glenties study area (Table 1.1 and Figure 1.2)

Table 1.1 Hydrometric Gauging station record considered for hydrological analysis

Station No.	Station Name	Waterbody	Catch Area (Km^2)	Operator	Record Start	Record End	Data
38100	Clonconwall Ford	Owenea	126	OPW	12/11/1972	30/09/2020	WL & Flow
38010	Glenties	Stracashel	49	OPW	29/11/2019	01/10/2021	WL & Flow

Rating reviews were conducted at both gauging stations. The rating review analysis was conducted to provide greater confidence in the flood flow data used to inform the design flow estimation at Glenties. The full details of both rating reviews are detailed in Chapter 2.

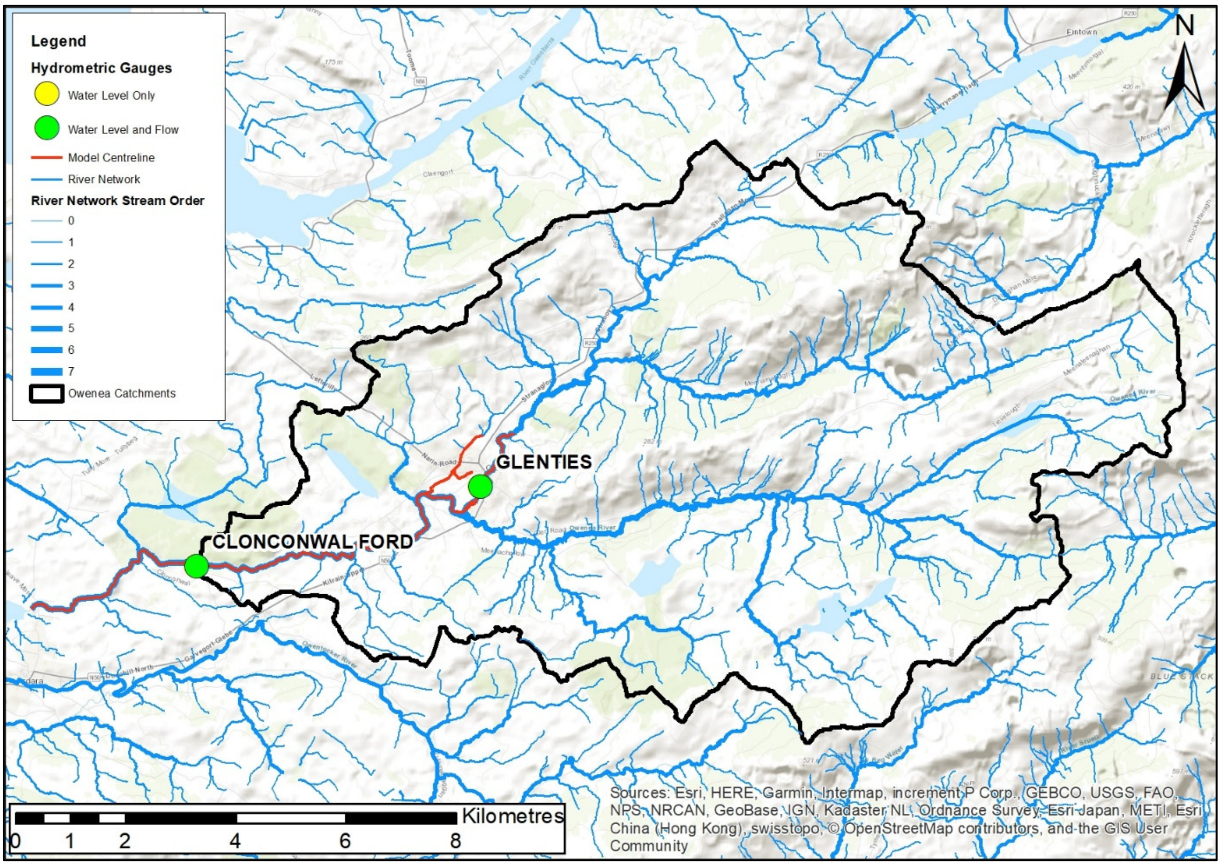


Figure 1.2 Hydrometric Gauging Station Locations

1.4 Flood event history

Recently, the study area has been subject to fluvial flooding in March 2021, as well as a major flood event that was recorded in Glenties in October 1989. A summary of the flood history affecting Glenties is presented in Table 1.2.

Table 1.2 Flood History at Glenties

Event Date	Source	Summary of Reports
March 2021	Fluvial	Flooding was reported in the Glenties area following heavy rainfall over the 27th and 28th March. This was reported to have led to the flooding of local agricultural land at Mulantyboyle and the stranding of livestock in the agricultural fields until flood waters receded.
August 2019	Fluvial	Flooding occurred in the Glenties area following a heavy rainfall event on the 28th August 2019. It was reported that many areas in the Clós Naomh Chonaill housing estate flooded including properties and private gardens. Flooding was also noted at the local GAA pitch (Davy Brennan Memorial Park), as well as at Ardara. It was reported that the council issued sandbags to help stop the advancing waters and protect property. A site visit report from the OPW detailed the flooding observed by DCC staff at Glenties which included photos of the flooding at Mulantyboyle, Davy Brennan Memorial Park, and Clós Naomh Chonaill. Other areas that flooded within the study area including the Glen Tavern (upstream of Glenties) and at Derries (downstream of Glenties) were also captured in the report.
December 2015	Fluvial	Flooding was reported in the Glenties area following a heavy rainfall event on the 4th/5th of December 2015. Flooding was reported at the local GAA pitch (Davy Brennan Memorial Park). This led to a storage shed and the club amenities flooding. The pitch was also impacted, and the ground remained closed until a major clean-up was completed.
January 2012	Fluvial	Flooding occurred in Glenties on 4th January 2012 due to a heavy rainfall event. There were several local reports of flooding to many major roads with the Gardaí issuing warnings in Glenties. Met Éireann's Monthly Weather Bulletin for January 2012 states that 86.1mm of rainfall was recorded at climatological station 'Glenties Hatchery' between 1st and 10th January 2012.
December 2011	Fluvial	Flooding occurred in Glenties throughout December 2011. There were reports of flooding on 13th December and 30th December, which were both due to heavy rainfall events. It was reported that many roads in the Glenties area became impassable.

Event Date	Source	Summary of Reports
October 2011	Fluvial	Flooding occurred across Donegal County including Glenties due to a heavy rainfall event on 23rd October, where 40mm of rain fell in 24 hours.
October 1989	Fluvial	Flooding occurred in Glenties on 28th October 1989. It was reported that the flooding of roads and agricultural farmland was extensive in the Glenties area. It was also reported that roads became impassable and lead to closures of roads from Letterkenny to Dungloe and Glenties.
Recurring	Fluvial	www.floodinfo.ie indicates that there is recurring flooding in the Glenties study area; two sources from the Owenea at Kilrean and Mulantyboyle and one from the Stracashel at Glenties Town. There is no further information on flooding in these areas.

2 RATING REVIEWS

RPS has conducted two separate rating reviews on two hydrometric gauges within the Glenties study area:

- Glenties (38010) gauging station on the Stracashel River, located within the town of Glenties.
- Clonconwall Ford (38001) gauging station on the Owenea River, located downstream of Glenties.

The rating reviews have been conducted as part of the hydrological and hydraulic analysis for the FRS at Glenties to validate (or otherwise) the Index Flood Flow (Q_{med}) and design flow estimation on both the Stracashel and Owenea Rivers.

The general form of any rating equation is:

$$Q = C(h + a)^{\beta}$$

Where;

Q = river flow (m^3/s)

C, a, β = rating equation constants

h = stage height (m)

The rating equation constants have physical significance and are originally derived from hydraulic theory. Rating equation constants have been derived using an iterative process and setting a number of constraint conditions on these physical constants. This helps to generate optimal parameters such that it limits the sum of the squared residuals (Chi Squared) of the observed and predicted flows.

2.1 Clonconwall Ford (38001)

An assessment of the rating at Clonconwall Ford on the Owenea River was conducted as part of the hydrological analysis for the Glenties FRS. Rating equation parameters have been derived using the stage heights relative to the staff gauge zero level at the gauging station. The most recent OPW record for the staff gauge zero level is 26.225 metres above ordnance datum (mAOD Poolbeg). The survey undertaken as part of this project found the staff gauge zero level to be 23.535 metres above ordnance datum (mAOD Malin OSGM15). The two levels are in very good agreement with a difference of less than 10mm when the OPW value is converted to the latest datum (Malin - OSGM15). The staff gauge zero level was taken as 23.535m (mAOD Malin OSGM15) for this project.

2.1.1 Spot Gauging History

RPS has analysed the spot gauging history at the Clonconwall Ford gauging station (38001). Figure 2.1 shows the full available spot gauge record from 1972 – 2021, as received from the OPW. Initial analysis suggested there was a wide spread of spot gaugings across the record period. There is also a shift in the trend of the spot gaugings from 1992 onwards, which is due to a shift in staff gauge in August 1992 (see Figure 2.1).

Figure 2.2 shows the spot gauge record plotted to total water level (mAOD) for the entire 1972-2021 record period. This shows a stable rating when allowing for the shift in the staff gauge.

A new rating review of the Clonconwall Ford gauging station has been conducted by RPS in light of an increased number of spot gaugings since the CFRAM Study.

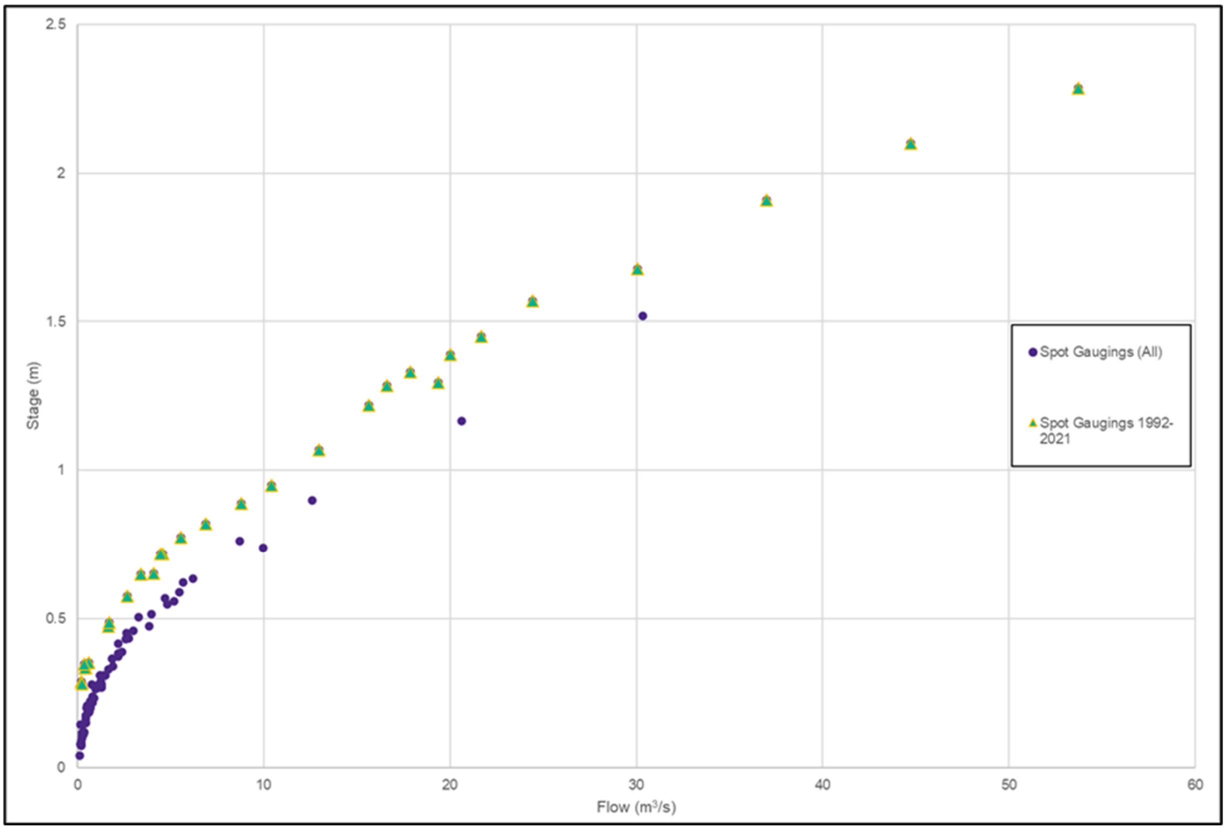


Figure 2.1 Spot Gauging History 1972 - 2021, Clonconwall Ford

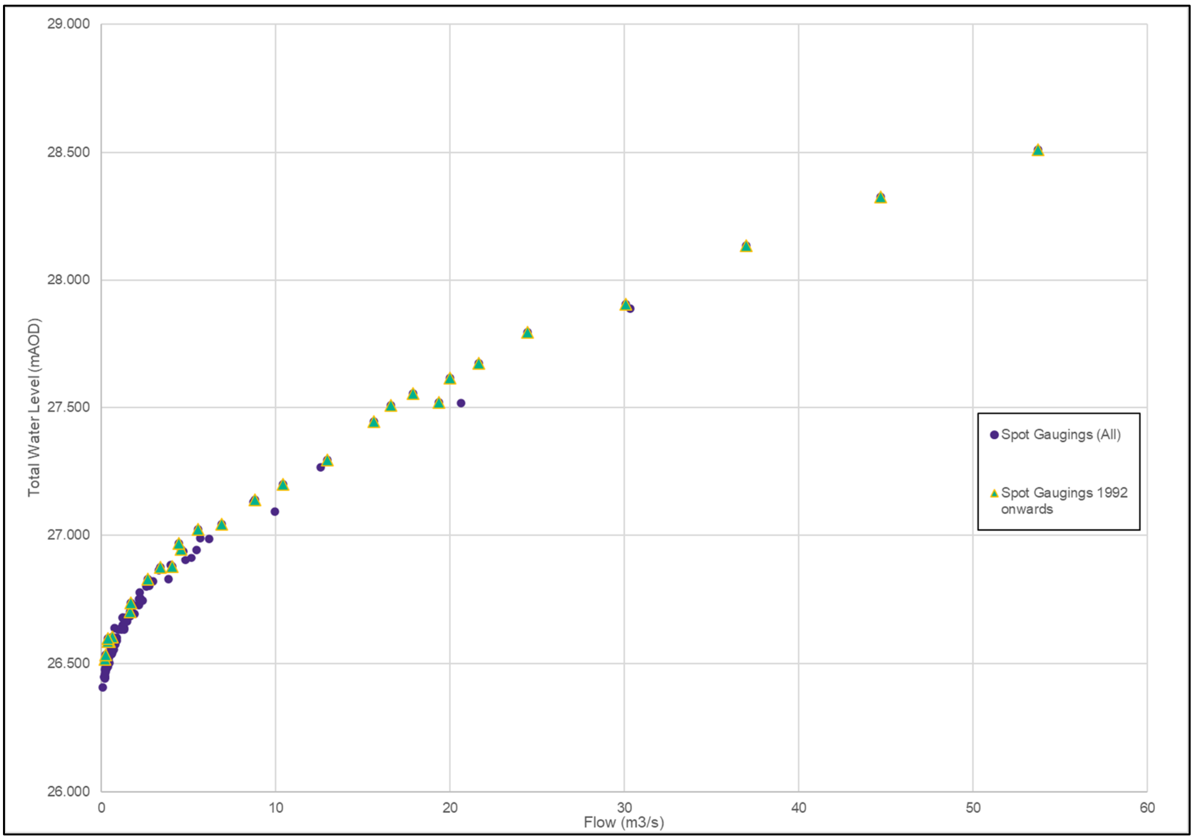


Figure 2.2 Spot Gauging History plotted to Total Water Level (mAOD), Clonconwall Ford, 1972 – 2021

2.1.2 Hydraulic Model Development

The rating review modelling was carried out within the full Glenties FRS hydraulic model. The Owenea River reach is rural and the topography flat, with adjacent land, used primarily for agriculture and forestry. The river cross-section measures approximately 23.9m wide, with a small and rudimentary footbridge immediately downstream of the gauge location. Furthermore, a series of historic stepping-stones exist downstream of the footbridge, acting as a downstream control to flow, similar in function to a weir.

Figure 2.3 Looking downstream from Clonconwall Ford gauging station, with rudimentary footbridge and stepping-stones

Figure 2.4 De facto weir created by stepping-stones, downstream of Clonconwall Ford gauging station

Survey data obtained during the CFRAM Study was noted as lacking in resolution to sufficiently represent the profile and crest height of the weir, with future detailed survey of the position of the individual stones (and gaps) subsequently recommended. Re-survey as part of the current analysis in 2021 was carried out in a period of high flow with the weir in a drowned condition and as such it was not possible to safely attain accurate survey data of the crest profile in this instance. High-resolution survey of this section is currently outstanding.

With a lack of high-resolution survey data, a mixture of imagery captured during the CFRAM Study and most recent survey periods was used to inform manual manipulation of the channel cross-section, such that the hydraulic effect of the weir be accurately represented.

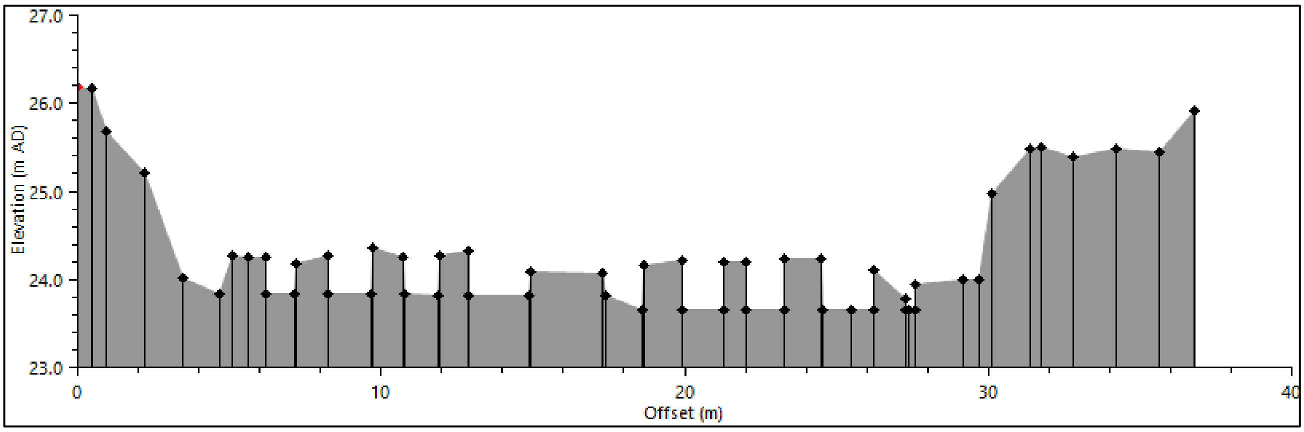


Figure 2.5 Manually manipulated weir cross-section

The downstream boundary assumed by the model is that of a normal condition river reach outlet, owing to the distant and thus non-influential littoral boundary. The upstream boundary consists of a hydrograph with a peak flow of 202 m^3/s, representing an estimated 0.1% Annual Exceedance Probability (AEP) flood event with the flood event baseflow removed from the hydrograph such that the very lowest flows were simulated (i.e., starting and returning to 0 m^3/s). The model was calibrated by comparing the model Q-h (flow and stage) relationship with the range of observed spot gaugings and adjusting model parameters as required, within appropriate bounds, until the Q-h and spot gaugings aligned.

2.1.3 Hydraulic Model Calibration and Sensitivity

After initial hydraulic modelling, a number of sensitivity tests were carried out on the Owenea River at the gauging station to inform the decision on a potential new rating. These sensitivity tests included hydraulic model runs of a range of model parameters in relation to the Manning's (n) coefficient, bridge coefficients, and weir coefficients.

Calibration is an iterative process that seeks to adjust the conditions of the model such that the hydraulic function of the reach in question is, as closely as possible, replicated. This is visualised by the Q-h relationship (flow and stage) and identifies which parameters and physical characteristics are most and least hydraulically significant in a particular instance. By modifying parameters individually and in-line with all available information it is possible to identify the impact on the river reach hydraulics of a specific modification through observation of the change in Q-h relationship relative to the observed spot gauging record.

In the instance of the Clonconwall Ford gauging station, iterative development determined that the hydraulic significance of the footbridge located downstream of the gauge and upstream of the weir was low. This was established by modelling the feature as a bridge unit, by modelling the central pier as an irregular weir (such that any assumed head loss generated by the deck be negated), and by removing the bridge from the model altogether. In all instances minimal impact on the Q-h relationship was noted and as such the bridge unit was retained for completeness.

Manipulation of the cross-section invert was found to induce significant changes in the Q-h relationship, with modification by smaller margins across the entirety of the crest profile offering the most control in calibrating the low flow Q-h relationship to the gauge record. It was found that by incrementally increasing the invert of the gaps between the stepping-stones that significant control could be had over the low flow relationship, however at the cost of significantly steepening the Q-h relationship relative to the high flow spot gaugings. Figure 2.6 shows the impact and sensitivity of the invert level within the hydraulic model on the Q-h relationship at the gauge cross-section.

Reducing the discharge co-efficient of the weir from the default 1.7 offered by the model (InfoWorks ICM) mainly controls the flow condition beyond low flows when the weir has been observed as drowned. This offers significant control over the Q-h relationship in the range of mid to high flows, without significant impact on the low flow relationship. Figure 2.7 shows the sensitivity of the discharge co-efficient on the Q-h relationship at the gauge cross-section.

Increasing the Manning's co-efficient of roughness (n) values served to imply a rougher and less-efficient reach condition, steepening the resulting Q-h plot across the range of flows and generating a slightly higher stage for a given flow. Conversely, by reducing the *n* value (representative of a smoother and more-efficient reach) the steepness of the curve was reduced, with a lower stage observed for the same flow. Modification of the n value to both extremes of the permissible range (based on survey images of the bed and banks) across the rating review reach gave some ability to influence the Q-h relationship, albeit minimally and as such was used at the latter stages of calibration for minor adjustment of the entire curve.

Model outputs of each of the hydraulic sensitivity runs were analysed and the final hydraulic model parameters used on the Owenea River at the gauging station are shown in Table 2.1.

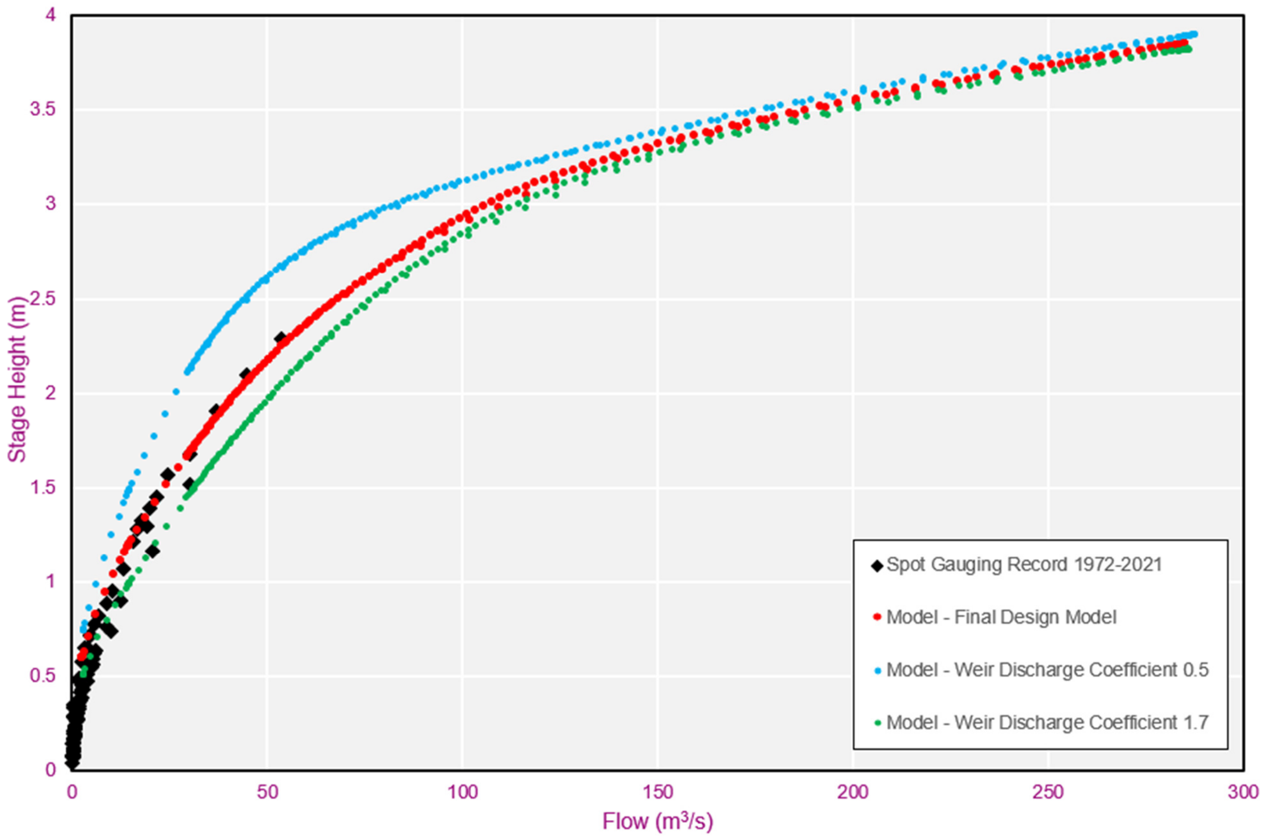


Figure 2.6 Sensitivity of Invert Levels, Clonconwall Ford

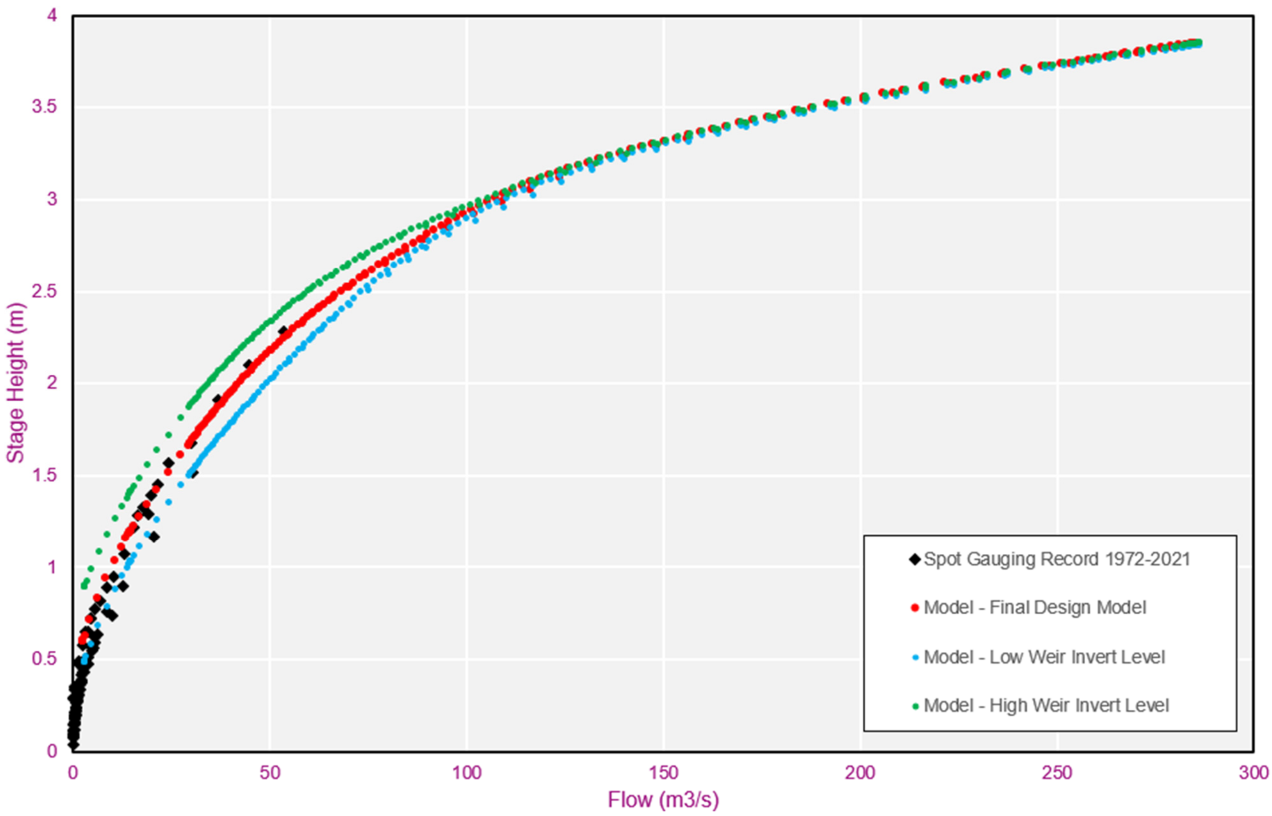


Figure 2.7 Sensitivity of Discharge Co-Efficient, Clonconwall Ford

Table 2.1 Final Hydraulic Model Parameters following Sensitivity Analysis, Clonconwall Ford

Section ID	Manning's Coefficient (N)	Bridge Coefficient	Weir Coefficient
0112M00380D **(40 metres downstream of the gauging station)**	0.04 (channel) 0.06 (banks) 0.011 (openings)	Discharge co-efficient 1.70 Modular Limit 0.90	-
0112M00377W **(60 metres downstream of the gauging station)**	0.02 (channel) 0.035 (banks)	-	Discharge co-efficient 0.87 Modular Limit 0.90

The in-channel Manning's at the weir (0112M00377W) is lower (0.02) than that of the other sections which make up the river reach (typically 0.04). Similarly, the bank Manning's at the weir is 0.035 but there is only a very limited portion of the cross-section at this value within the weir cross-section. This reflects the very localised conditions of large boulders which themselves have been represented in the cross-section profile but would be expected to have a smooth surface. Ultimately these low values were chosen based on the calibration of the model to the low – medium spot gaugings and are considered reasonable.

2.1.4 Rating Curve Development

Following data collection in conjunction with the OPW Hydrometrics Team, and further analysis of the full spot gauging history, the data suggests that there is no significant rating shift throughout the history of the Clonconwall Ford gauging station, but rather there are a number of noted periods of shifting staff gauge zero levels across the same 1972 – 2021 record period.

The most recently approved OPW rating at the gauging station was derived in 2019. The physical constant rating parameters of the rating equation are shown in Table 2.2. The rating is illustrated in Figure 2.8.

Table 2.2 OPW Rating Physical Constant Parameters, Clonconwall Ford (2019 onwards)

Limb	Min Stage (m)	Max Stage (m)	C	a	B
01	0.00	0.52	18	-0.05	2.86
02	0.52	1.02	13.3	-0.05	2.48
03	1.02	3.60	13.17	-0.05	1.77

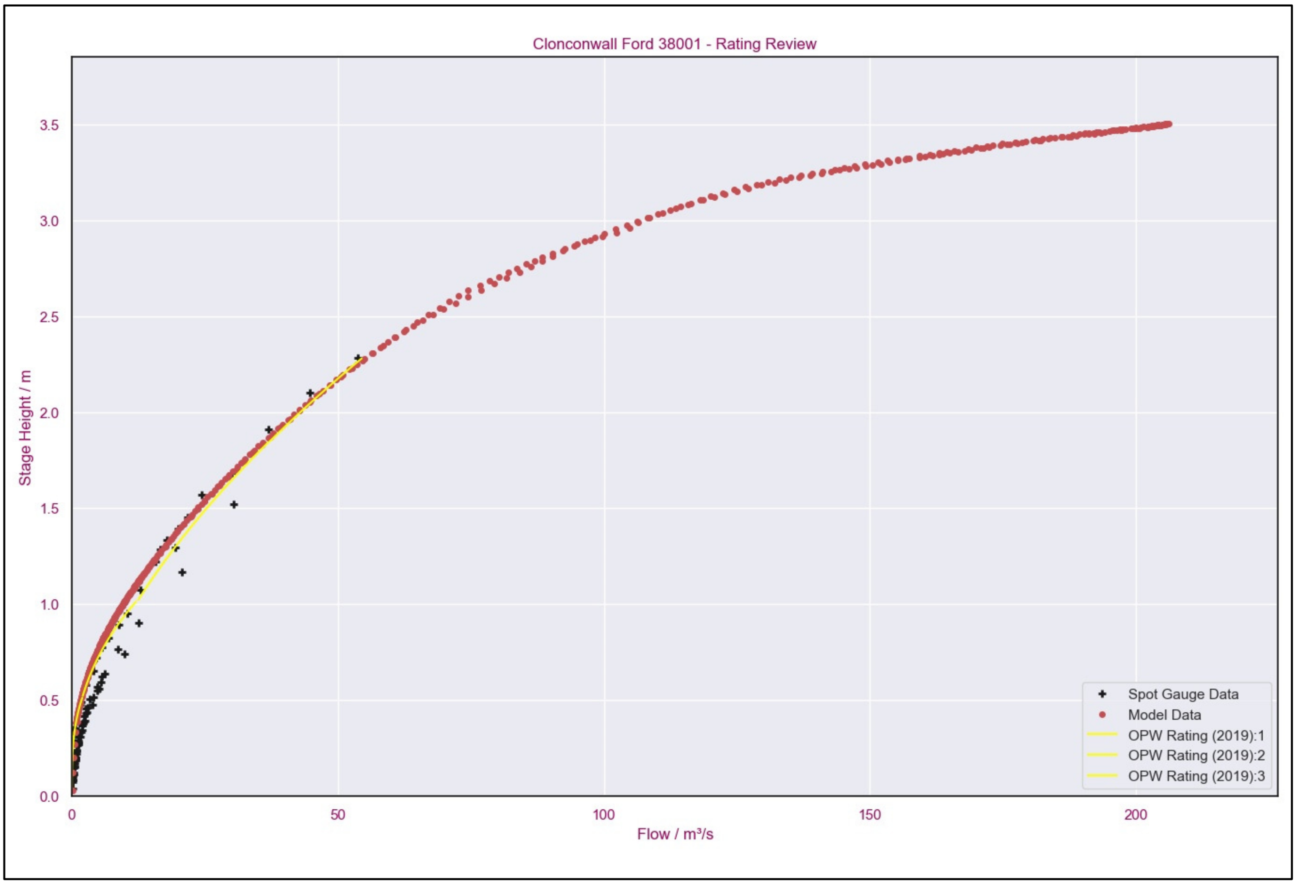


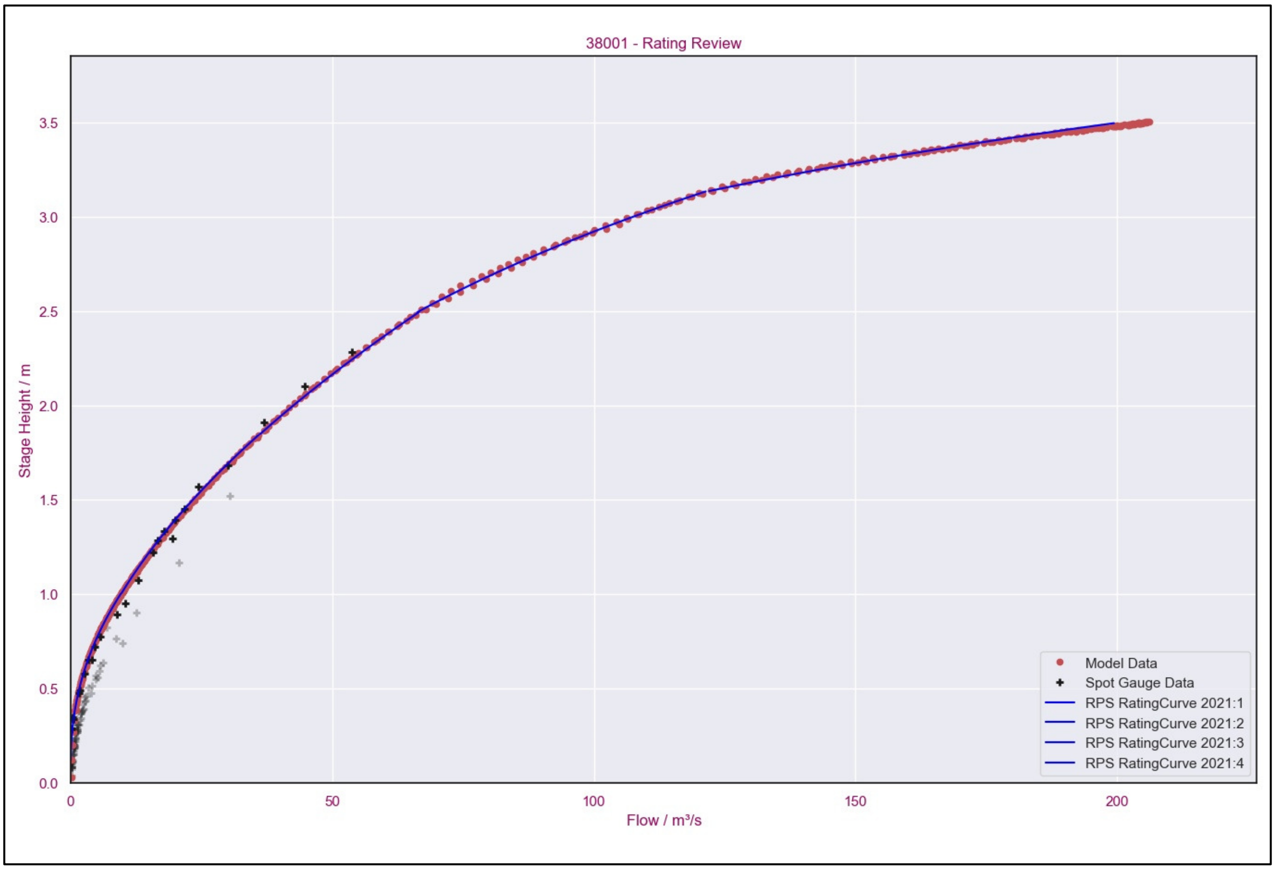
Figure 2.8 Existing OPW Rating, Clonconwall Ford

The proposed RPS rating curve is shown in Figure 2.9. also shows the cross section from the hydraulic model of the Clonconwall Ford gauging station. The physical constant parameters derived for each limb are shown in Table 2.3.

Table 2.3 Proposed RPS Rating (2021) Physical Constant Parameters, Clonconwall Ford

Limb	Min Stage (m)	Max Stage (m)	C	a	B
01	0	1.097	10.827	-0.048	2.359
02	1.097	2.519	12.33	-0.101	1.937
03	2.519	3.131	0.027	2.464	4.886
04	3.131	3.6	34.7130	-1.511	2.572

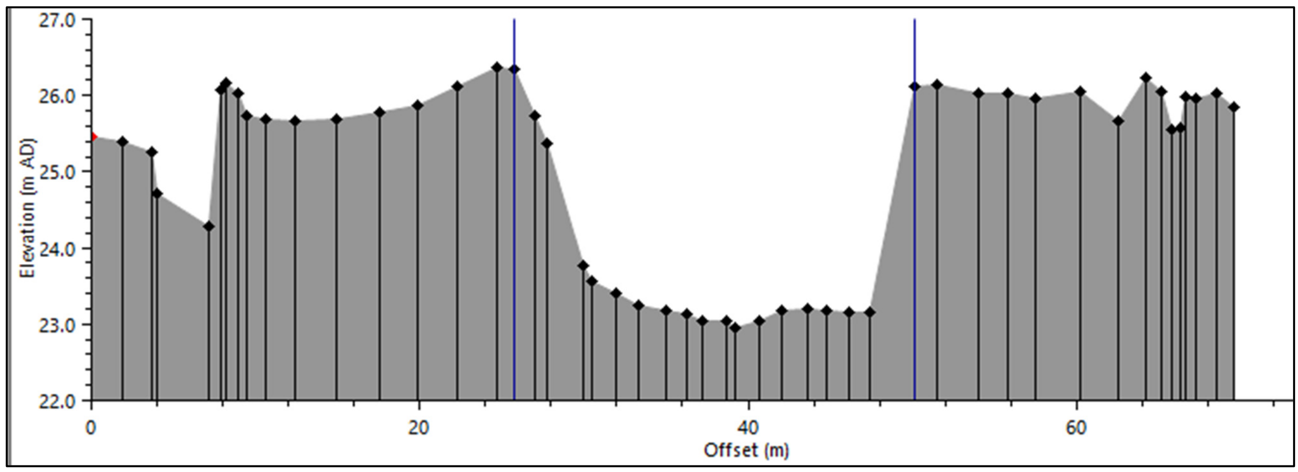
The newly proposed rating shows a good fit to the current hydraulic model of the Owenea River at the Clonconwall Ford gauging station. It also provides a good fit to the entire spot gauging history from 1972-2021 when they are plotted against the total water level (mAOD OSGM15).



*grey crosses indicate spot gaugings taken prior to the most recent staff gauge zero shift in 1992.

Figure 2.9 Proposed RPS Rating, Clonconwall Ford

(a)



(b)

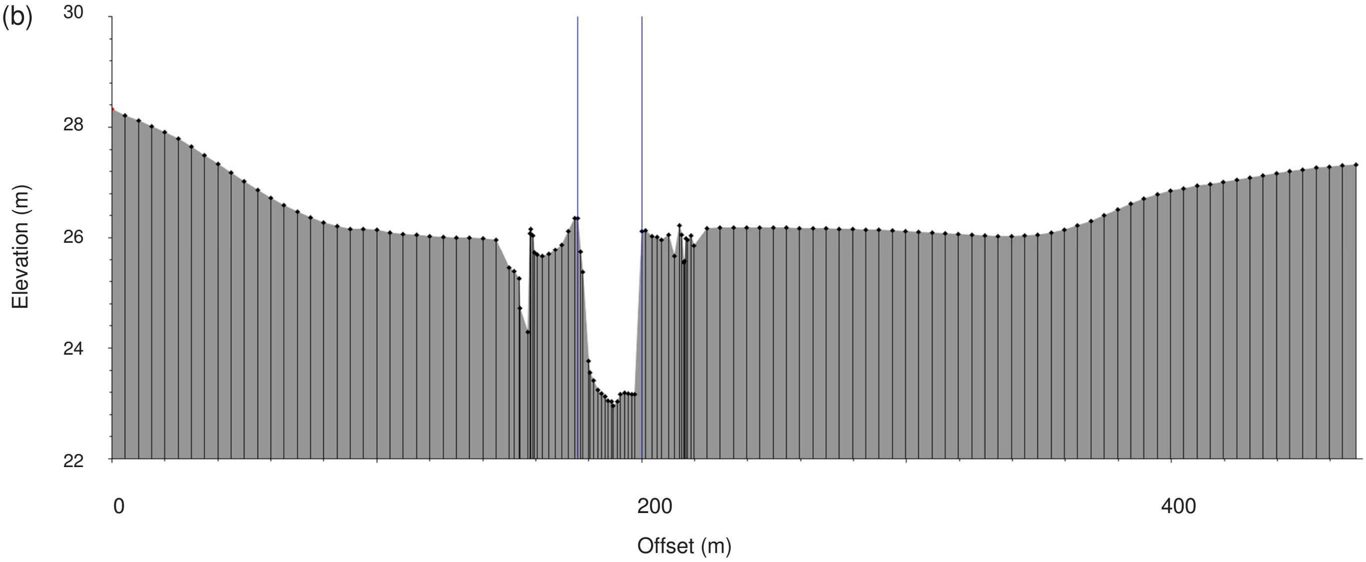


Figure 2.10 Clonconwall Ford Gauging Station Cross Section (a) 1D model (between blue vertical lines) slightly extended, and (b) widely extended to capture the 2D model.

2.1.5 Rating Review Conclusions

RPS conducted the rating review to use the available hydrometric data at the Clonconwall Ford gauging station to inform and validate the hydrological analysis and hydraulic model build for the Glenties FRS. Before the newly proposed RPS rating detailed in Section 0, the rating in use was the current OPW rating which has been valid since 2019. Table 2.4 compares the results of the proposed RPS rating against the OPW's current rating at the Clonconwall Ford gauging station and the impact this has on the Q_{med} and the re-processed annual maximum (AMAX) series. It should be noted that the entire record period was reprocessed through the proposed RPS rating, with adjustments also made to the OPW published stage heights to make them relative to the current staff gauge zero level at Clonconwall Ford.

Table 2.4 Comparison of Q_{med} and AMAX Events between OPW and RPS Rating, Clonconwall Ford

Event	Date	Adjusted Stage Height (m)	OPW Rating (from 2019)	Proposed RPS Rating (2021)	Percentage Difference
Q_{med}*	-	-	70.87	77.55	**+ 9.4**
AMAX01	9th Nov 1993	3.445	113.38	189.35	**+ 67.0**
AMAX02	31st Aug 2019	3.314	107.14	158.09	**+ 47.6**
AMAX03	15th Nov 2015	3.290	105.75	152.74	**+ 44.4**

***Q_{med} and rating applied over the full record period of 1972-2021.**

The proposed RPS rating has resulted in an increase in Q_{med} at Clonconwall Ford by 9.4%. This rating has been applied back across the full record period at the gauging station from 1972 – 2021. This was deemed appropriate to apply the rating across the full record period, using adjustments to account for changes in the staff gauge zero level, given that there is no obvious shift in the rating when analysing the spot gauging history plotted to total water level (mAOD). This increase in Q_{med} is used to inform the updating of the Clonconwall Ford gauging station adjustment factor which is used through the design flow estimation.

The proposed RPS rating has also resulted in much higher flows across the reprocessed AMAX series. The top three AMAX events have increased by 67%, 48%, and 44%, respectively. The large increases in the AMAX events are due to a number of reasons. The proposed RPS rating has a less steep trajectory than the current OPW rating (see Figure 2.8 and Figure 2.9) which results in the larger high flows at the top end of the proposed RPS rating. The proposed RPS rating is based on a model of the hydraulic characteristics of the river reach including its floodplain performance. Flattening of the rating curve is expected when water breaks out of bank and flows across the floodplain. As a result, the flow cross-section becomes wider but represents reality. The OPW rating beyond the top of bank is based on an extrapolation of the in-channel Q-h relationship, given that there are no spot gaugings taken during high flows / out of bank flow, and no modelled representation of the floodplain. Therefore, the flattening effect of the rating curve is not captured. The RPS rating can therefore be considered to be the rating best anchored to the physical characteristics of the flow cross-section.

2.2 Glenties at Stracashel (38010)

The Glenties at Stracashel is a relatively newly installed water level and flow gauging station in the centre of Glenties town. The most recent survey of the gauging station in 2021 indicates the staff gauge zero level is 41.955mAOD Malin (OSGM15).

2.2.1 Raw Data Analysis

Given this station is relatively newly installed and currently has no OPW-derived rating, which is classified as under-development on the waterlevel.ie website, a review of the available data at the gauging station was conducted.

The station records water levels at 15-minute intervals (WL15). The station has recorded data available for analysis from 29th November 2019 to 1st October 2021. Figure 2.11 shows the water level record at the gauging station. There are no significant data gaps within the record period.

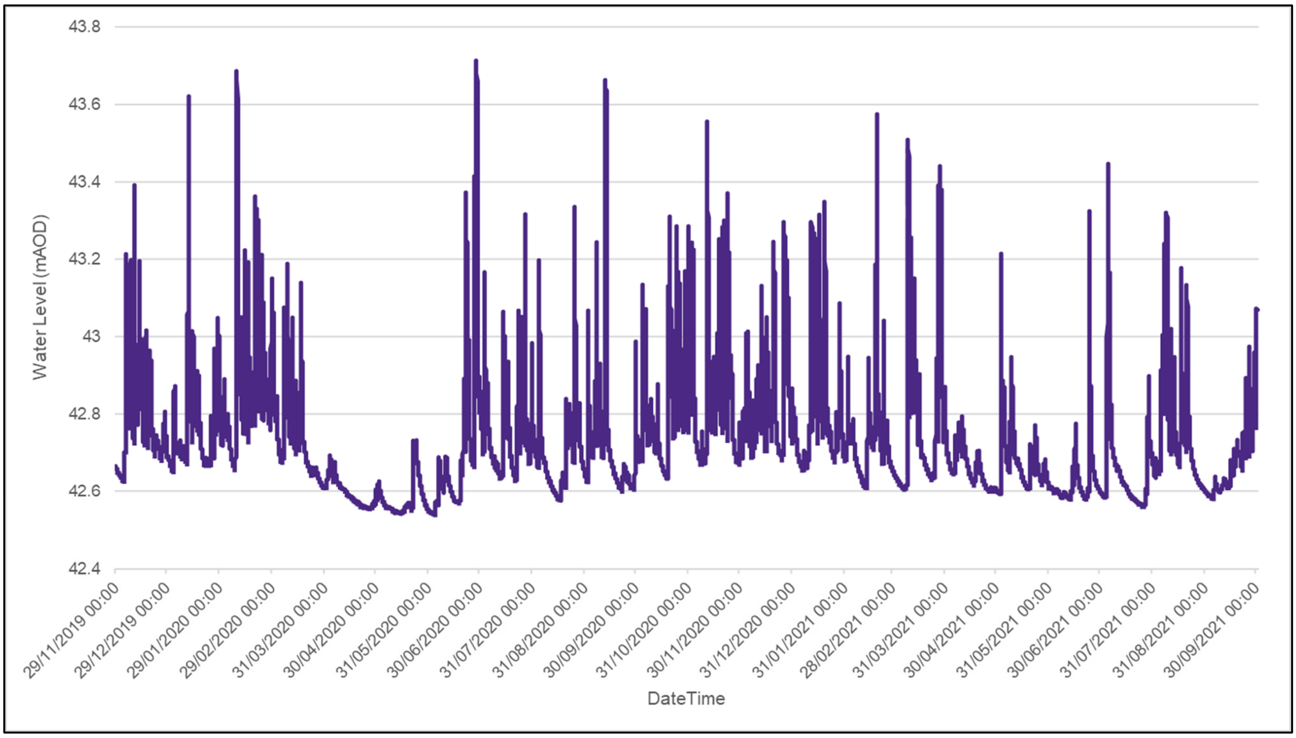


Figure 2.11 Glenties at Stracashel (38010) Water Level Record, 2019-2021

While it is apparent that there is an extremely short record period (nearly two complete hydrometric years of 2019 and 2020), this can still provide enough data to estimate a Q_{med} value, albeit with high statistical uncertainty, on the Stracashel River at Glenties that can be used as a means of validation.

2.2.2 Spot Gauging History

The spot gauge history for the Glenties at Stracashel gauging station was received from the OPW Hydrometrics section. There are a limited number of spot gaugings over the 2019 – 2021 record period. Figure 2.12 shows the full spot gauge history for the gauging station. While the spot gauging record is extremely limited, it allows a rating to be developed initially for the station to provide a provisional estimate of Q_{med} that can be used to validate the design flow estimation.

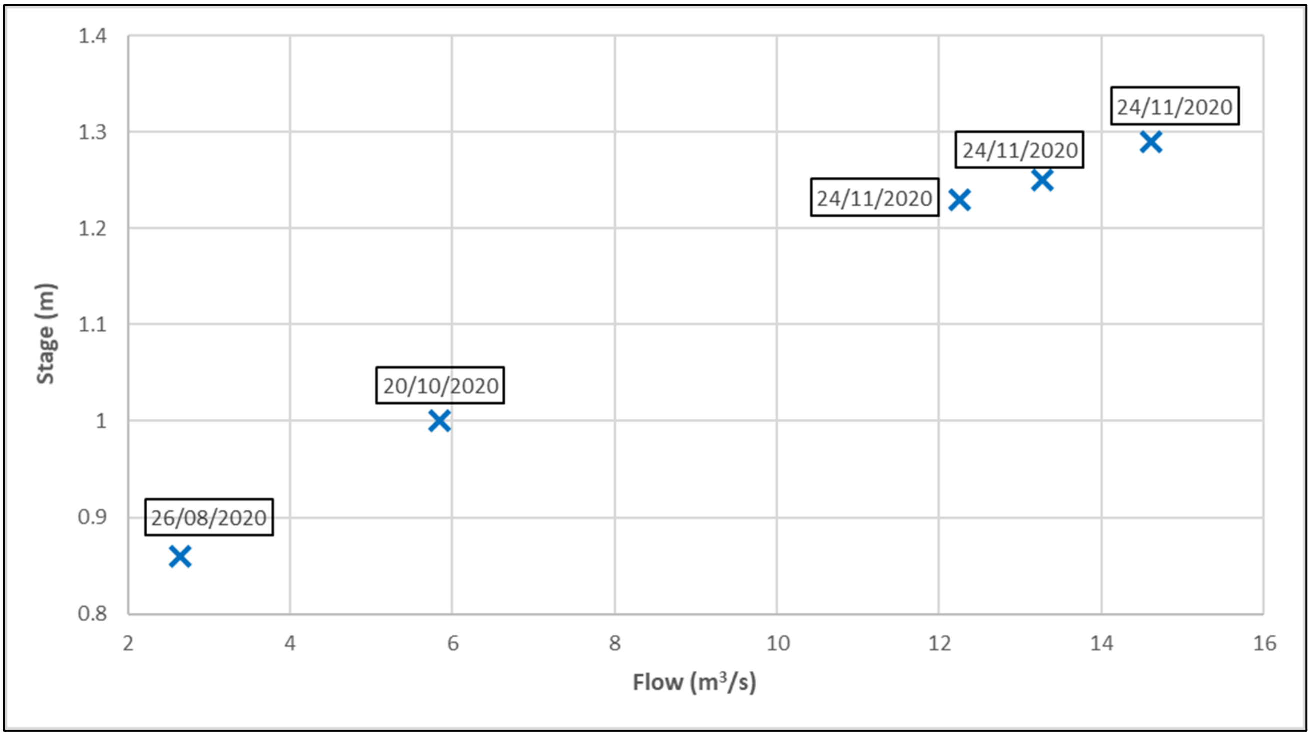


Figure 2.12 Spot Gauging History, Glenties at Stracashel, 2019 – 2021

2.2.3 Hydraulic Model Development

The rating review modelling was carried out within the full Glenties FRS hydraulic model. The Stracashel River reach is mainly rural but does include most of the urban area that makes up Glenties town. The topography is relatively flat around the lower reaches of the Stracashel River and the location of the gauging station. The topography is much steeper upstream to the north-east of Glenties town. The land around the gauging station is pastures, scrub, and a number of residential properties. The river cross-section measures approximately 22.5m wide, with a small bridge immediately upstream of the gauge location.

Survey data obtained during the CFRAM Study was noted as lacking in resolution to sufficiently represent the profile of the watercourse around this gauge. Re-survey as part of the current analysis in 2021 was carried out to obtain cross sections in the vicinity of the gauge location, which was installed in 2019, and upstream and downstream of the gauge at approximately 6m intervals. This higher resolution gave a better profile of the channel around the gauging station.

Also crucial to the hydraulic model development for the gauging station was weir and sluice gates located approximately 100m downstream. The weir is crucial as this sets the minimum level of the river and impacts the levels recorded at the gauge. This weir was also re-surveyed to ensure the minimum level of the structure was available for modelling. The crest level was surveyed to be 42.531mAOD.

The sluice gates were also important as these are located beside the weir along a small mill race. These sluice gates are in poor condition and have not been in use for many years. Figure 2.13 shows the mill race sluice gates in relation to the Stracashel River weir.

Figure 2.13 Location of the mill race sluice gates in relation to Stracashel River weir

2.2.4 Hydraulic Model Calibration and Sensitivity

After initial hydraulic modelling, a number of sensitivity tests were carried out on the Stracashel River downstream of the gauging station in order to inform the decision on a potential new rating. These sensitivity tests included hydraulic model runs of a range of model parameters in relation to the Manning's (n) coefficient, sluice gate coefficients, and weir coefficients.

For the Stracashel at Glenties (38010) gauging station, it was determined that the weir located downstream of the gauge was hydraulically significant. This was established by modelling the feature and altering the discharge coefficients for the structure within the model. In all instances, the impact on the Q-h relationship was noted and as such the discharge coefficient of the structure was altered both up and down over a number of calibration runs to obtain the most realistic value.

By increasing the discharge co-efficient of the weir from the standard 1.7 offered by InfoWorks ICM, a better-calibrated crest condition is achieved. The Glenties gauge has limited observed data and the data available represents low flows.

Increasing the Manning's coefficient of roughness (n) value served to imply rougher and less-efficient reach conditions, steepening the resulting Q-h plot across the range of flows and generating a slightly higher stage for a given flow. Conversely, by reducing the n value (representative of smoother and more-efficient conditions) the steepness of the curve was reduced, with a lower stage observed for the same flow. Modification of the n value to both extremes of the permissible range (based on survey images of the bed and banks) across the rating review reach had a minimal impact on the Q-h relationship. Therefore, no adjustments were made to the manning's n coefficient from that determined from photographs of the reach.

Changing the opening height of the two sluice gates on the mill race had the impact of flattening and curving the resulting Q-h plot across the range of flows. When the gates were fully open this resulted in a flatter curve which prevented the Q-h relationship indicated from matching the limited spot gaugings. As the gates were iteratively closed over a number of runs the Q-h relationship became more favourable, especially in lower flow scenarios. From this information and based on their observed condition in the survey photographs it was decided that the gates should be modelled as fully closed.

Changing the discharge coefficient of the sluice gates also impacted the Q-h relationship. The discharge coefficient relates to flow over the structure and how efficiently this can occur. By reducing and increasing these values the impacts on the Q-h were noted. Given the poor condition of the sluice gates, the value was reduced rather than increased. It was concluded that a coefficient of 0.5 was the most appropriate for the gates.

Model outputs of each of the hydraulic sensitivity runs were analysed and the final hydraulic model parameters used on the Stracashel River at the gauging station are shown in Table 2.5. The output cross-section of the hydraulic model for the weir and sluice gate are also displayed in Figure 2.14 and Figure 2.15, respectively.

Table 2.5 Final hydraulic model parameters following sensitivity analysis, Glenties (38010)

Section ID	Manning's Coefficient (N)	Weir Crest Level	Weir Coefficient	Sluice Gate Coefficient	Opening Height (m)
01GORT00274	0.015 (channel) 0.06 (banks)	42.531mOD	2.7	-	-
0112A00022	0.04 (channel) 0.06 (banks)	-	-	0.5	0

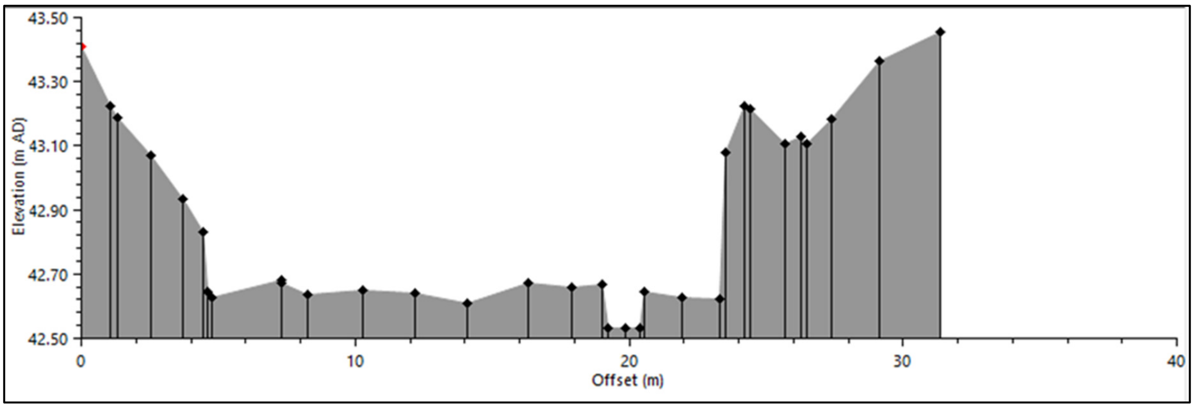


Figure 2.14 Cross Section of Weir, Stracashel River, Glenties (01GORT00274)

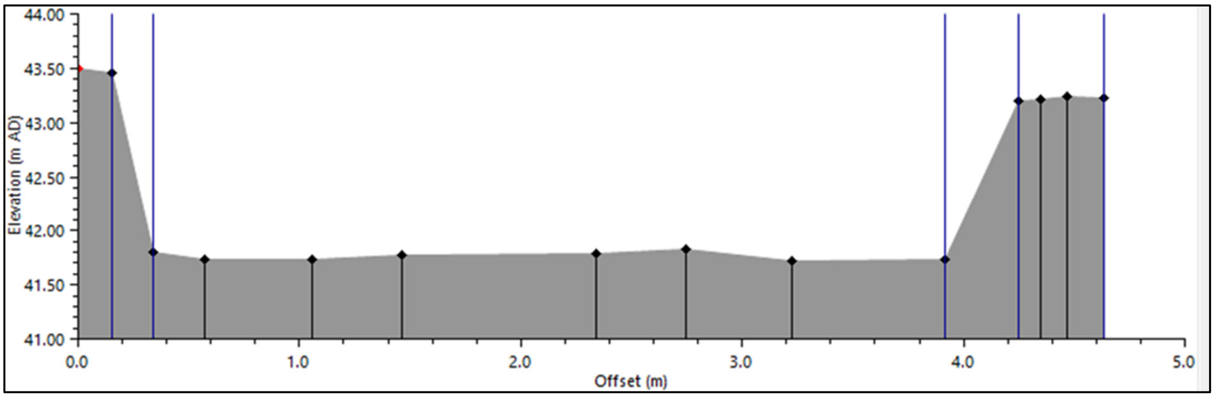


Figure 2.15 Cross Section of Sluice Gate, Stracashel River, Glenties (0112A00022)

2.2.5 Rating Curve Development

A new rating curve was developed using an iterative process to develop the most appropriate physical constant parameters to define the Q-h relationship at the Glenties at Stracashel gauging station. The physical constant parameters are shown in Table 2.6 and the new rating curve is plotted alongside the spot gaugings at the station in Figure 2.16.

The rating has been derived through 100,000 iterations and represents the most accurate and robust physical constant parameters possible given the limited amount of data for both model and rating calibration.

Table 2.6 Proposed RPS Rating (2021) Physical Constant Parameters, Glenties at Stracashel (38010)

Limb	Min Stage (m)	Max Stage (m)	C	a	b
1	0.000	1.115	26.82	-0.656	1.444
2	1.115	1.610	19.946	-0.458	1.980
3	1.610	2.067	0.017	1.808	5.976
4	2.067	2.510	31.752	-0.775	2.210

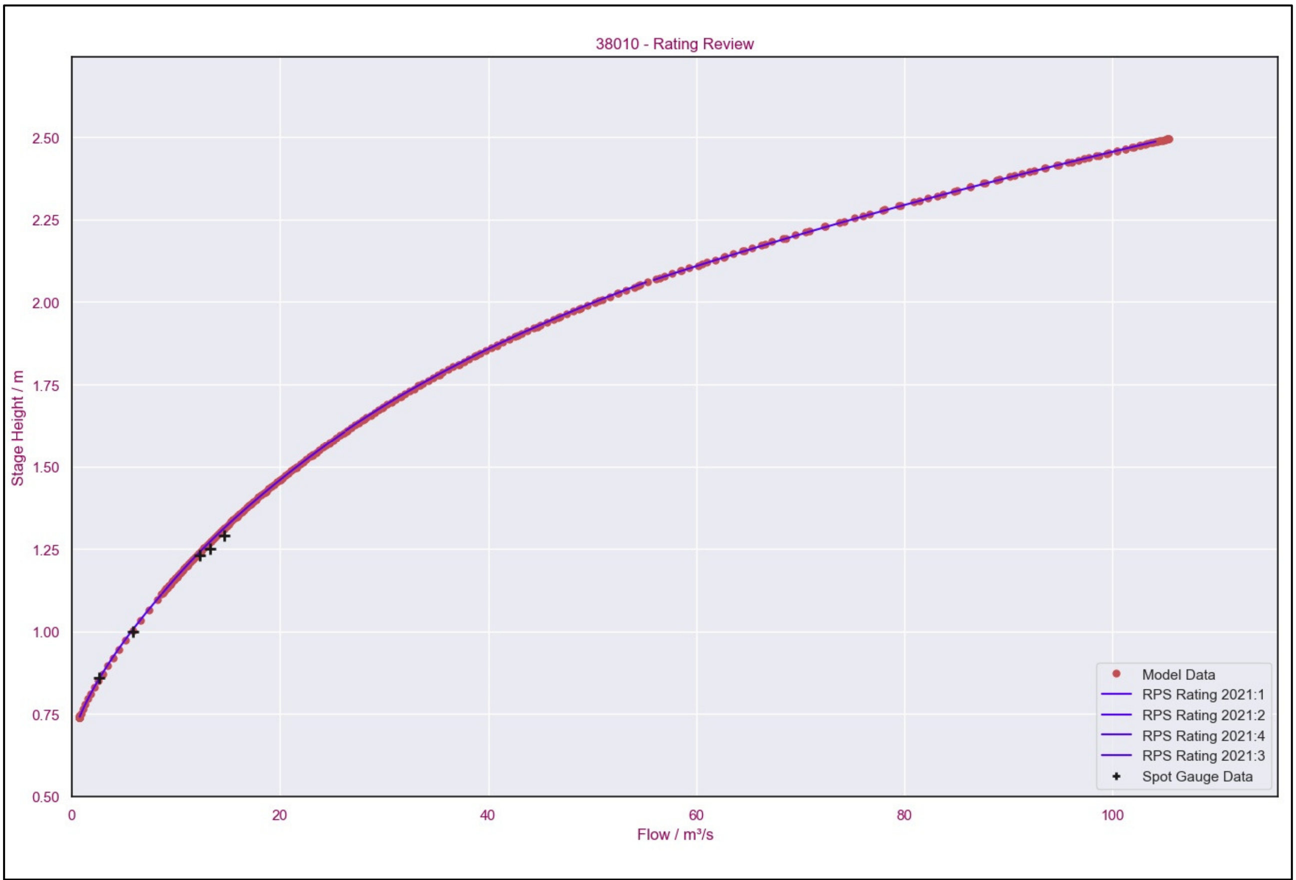


Figure 2.16 Proposed RPS Rating, Glenties at Stracashel (38010)

The development of this rating equation allowed for the extraction of AMAX values for the two available hydrometric years (2019 and 2020). The 2-year AMAX series that was processed is shown in Table 2.7.

Table 2.7 Processed 2-Year AMAX, Glenties at Stracashel (38010)

Hydrometric Year	QMAX Record Date	S.G. Reading (m)	Estimated Flow (m^3/s)
2019	28/06/2020	1.758	33.907
2020	19/02/2021	1.620	26.783

This produces a Q_{med} estimate of 30.36 m^3/s which is approximately 27% below the initial design flow estimate (38 m^3/s) derived from the FSU7 variable regression equation (see Section 4.3.5, Table 4.15). However, the estimation of this Q_{med} based on AMAX data over a 2-year data period is highly uncertain.

2.2.6 Peaks Over Threshold Analysis

Peaks Over Threshold (POT) analysis consists of the abstraction of distinct peaks in water level or flow data that are greater than a selected threshold level. In general, POT estimates give an improved estimation of Q_{med}, especially in short record periods such as the Stracashel at Glenties gauging station.

In line with guidance set out in Volume 3, Chapter 12 of the Flood Estimation Handbook (FEH), Q_{med} estimation using POT analysis is appropriate when:

- The POT record is as long as the AMAX record (in this case 2 years); and
- There are fewer than 14 years of record (in this case, there are 2 years of record).

A POT extraction was conducted using MIKE 11 software on the complete hydrometric years within the WL15 water level record period i.e., 2019 and 2020. During POT analysis, there are key considerations in terms of independence rules which determine what is a distinct peak, and threshold level which defines what level above which peaks are extracted. The chosen parameters of the POT extraction are shown in Table 2.8.

Table 2.8 Input Parameters into MIKE 11 EVA Editor, Glenties at Stracashel, 2019 - 2021

Parameter	Input into EVA for POT Analysis
Partial Duration Series (PDS)	Seasonal where the year runs 01/10 to 30/09 to reflect a hydrometric water year
Record Length	2 full water years
Threshold Level	43.4 metres
Inter-Event Time	6 hours (to ensure enough time that 2 peaks within the same storm were not selected).

After an initial analysis of the raw water level data (Figure 2.11) a threshold of 43.4 metres was deemed appropriate. FEH guidance states that POT analysis should allow for the extraction of at least four peaks in each full water year. The analysis met this criterion allowing for 10 peaks to be extracted over the two water years of data. The proposed rating curve (Section 2.2.4) was then applied to the extracted peaks to allow an estimate of flow to be assigned. The extracted peak water levels and estimated flows are shown in Table 2.9.

Table 2.9 Extracted POT water levels and estimated flows, Glenties at Stracashel (38010)

Date Time	Total Water Level (mAOD)	Stage (m)	Estimated Flow (m^3/s)
28/06/2020 21:00	43.713	1.758	33.907
08/02/2020 23:15	43.686	1.731	32.401
12/09/2020 22:45	43.663	1.708	31.163
11/01/2020 10:15	43.621	1.666	29.003
19/02/2021 05:45	43.575	1.620	26.783
11/11/2020 18:15	43.556	1.601	25.989

Date Time	Total Water Level (mAOD)	Stage (m)	Estimated Flow (m^3/s)
09/03/2021 22:15	43.509	1.554	23.916
29/06/2020 03:15	43.475	1.520	22.469
05/07/2021 02:30	43.447	1.492	21.311
28/03/2021 01:45	43.441	1.486	21.067

Q_{med} can then be estimated using this POT data using the following equation:

$$Qmed = w\,Q_i + (1 - w)\,Q_{i+1}$$

The constant parameters are defined in Volume 3, Chapter 12, Table 12.1 of the FEH. These parameters are displayed below in Table 2.10. Table 2.10 has been adapted to show the parameters up to a 3-year record period.

Table 2.10 Summary information for POT analysis, extracted and adapted from Volume 3, Chapter 12, Table 12.1 of FEH guidance

POT record length (Years)	i	i+1	Weight (w)
1	1	2	0.602
2	2	3	0.895
3	2	3	0.100

The POT parameters used to derive an observed Q_{med} estimate at Glenties at Stracashel gauging station are shown in Table 2.11.

Table 2.11 POT Parameters, Glenties at Stracashel (38010)

POT Parameters	Value	Flow from extracted POT series (m^3/s)
i	2	32.401
i + 1	3	31.163
w	0.895	N/A

The POT analysis produced a Q_{med} of 32.27 m^3/s. This estimate is approximately 18% below the design flow estimation at the Stracashel at Glenties gauging station within the hydraulic model (see Section 4.3.5, Table

4.15). Despite the lower estimate of the observed Q_{med}, this is deemed to provide validation of the estimation of Q_{med} provided within the model inputs using the FSU7 variable regression equation. The POT-derived value provides a more statistically robust estimate of Q_{med} when compared to that produced through AMAX analysis. This analysis can be revisited as more full water years are added to the record period at the Stracashel at Glenties gauging station during the lifespan of the project.

3 FLOOD EVENT ANALYSIS

The first step to understanding the flood frequency behaviour in relation to the subject catchment and its sub-catchments is conducting statistical analysis of the at-site flood flow records for the watercourses which represent the main drivers for flood risk in the study area. EVA has been carried out in line with the procedures set out in the FSU[1], using the AMAX and continuous series records supplied by the OPW. The at-site flood frequency analysis of the flood event history has been conducted post-rating review at both the Clonconwall Ford and Glenties gauging stations.

3.1 Owenea at Clonconwall Ford (38001)

The Owenea at Clonconwall Ford (38001) gauging station is located on the Owenea River (Glen_21), downstream of the confluence with the Stracashel River and Gortnamucklagh watercourse and downstream of Glenties Town. The gauging station has a long-standing, continuous flow record that extends back from 1972 to the present day (01/10/1972 to 30/09/2020). The gauging station is the only gauging station in the area of Glenties town that provides a significant period of 15-minute (Q15) flow and water level data to capture and estimate extreme event frequencies. A review of the spot gauging record for the station shows that the highest spot gauging captured was at 53.70m^3/s on 29/03/2021, which is approximately 30% lower than Q_{med} (77.55m^3/s). The rating curve at the gauging station was reviewed during the CFRAM Study. The rating curve was further analysed and updated as part of the current analysis and is presented in full in Section 2.1. The updated AMAX derived using the project rating curve is shown in Figure 3.1.

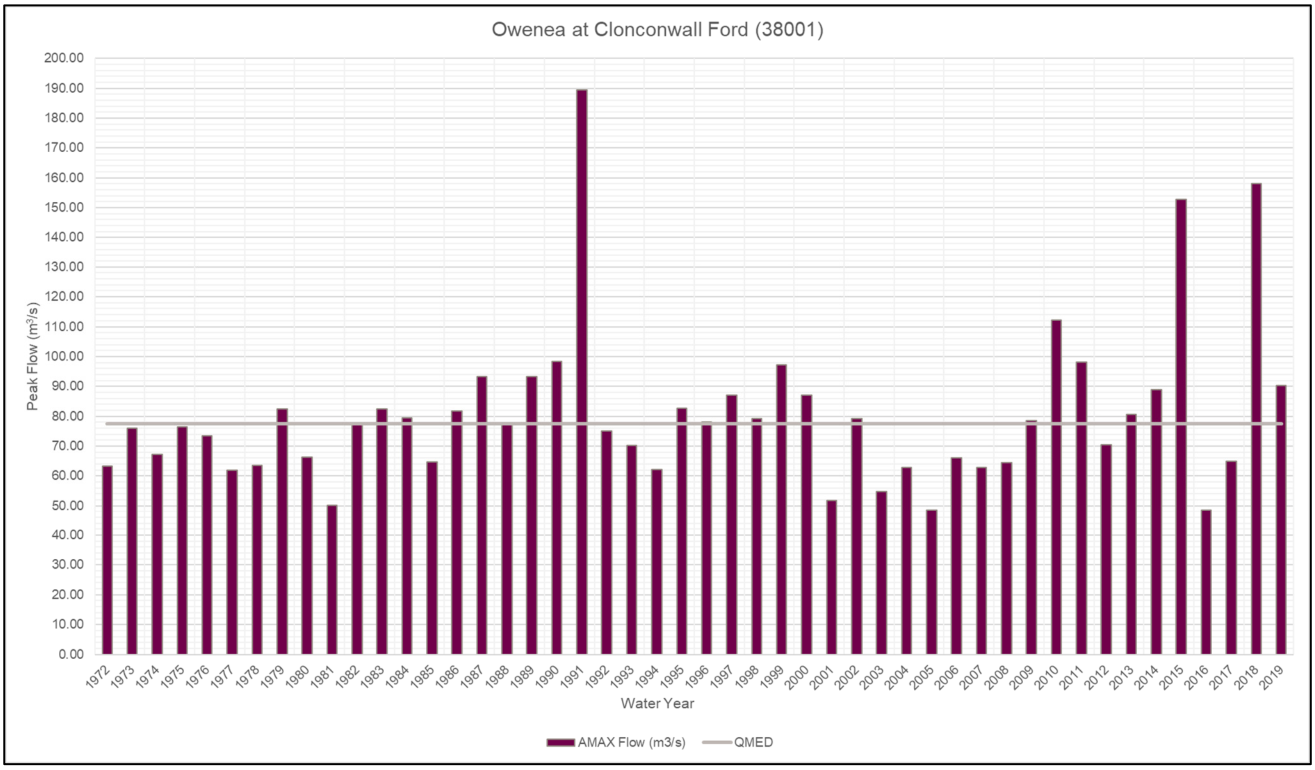


Figure 3.1 Owenea at Clonconwall Ford (38001) – AMAX series

[1] FSU Technical Research Reports Volume II, Flood Frequency Estimation available at http://opw.hydronet.com/default.aspx?page=11

At-site flood frequency analysis was performed on this record. A number of flood-like distributions were fitted to the AMAX data as part of the flood frequency analysis and the Generalised Logistic (GLO) distribution was found to be the best fit for the data available at the Owenea at Clonconwall Ford (38001) gauging station. The at-site flood frequency curve is shown in Figure 3.2.

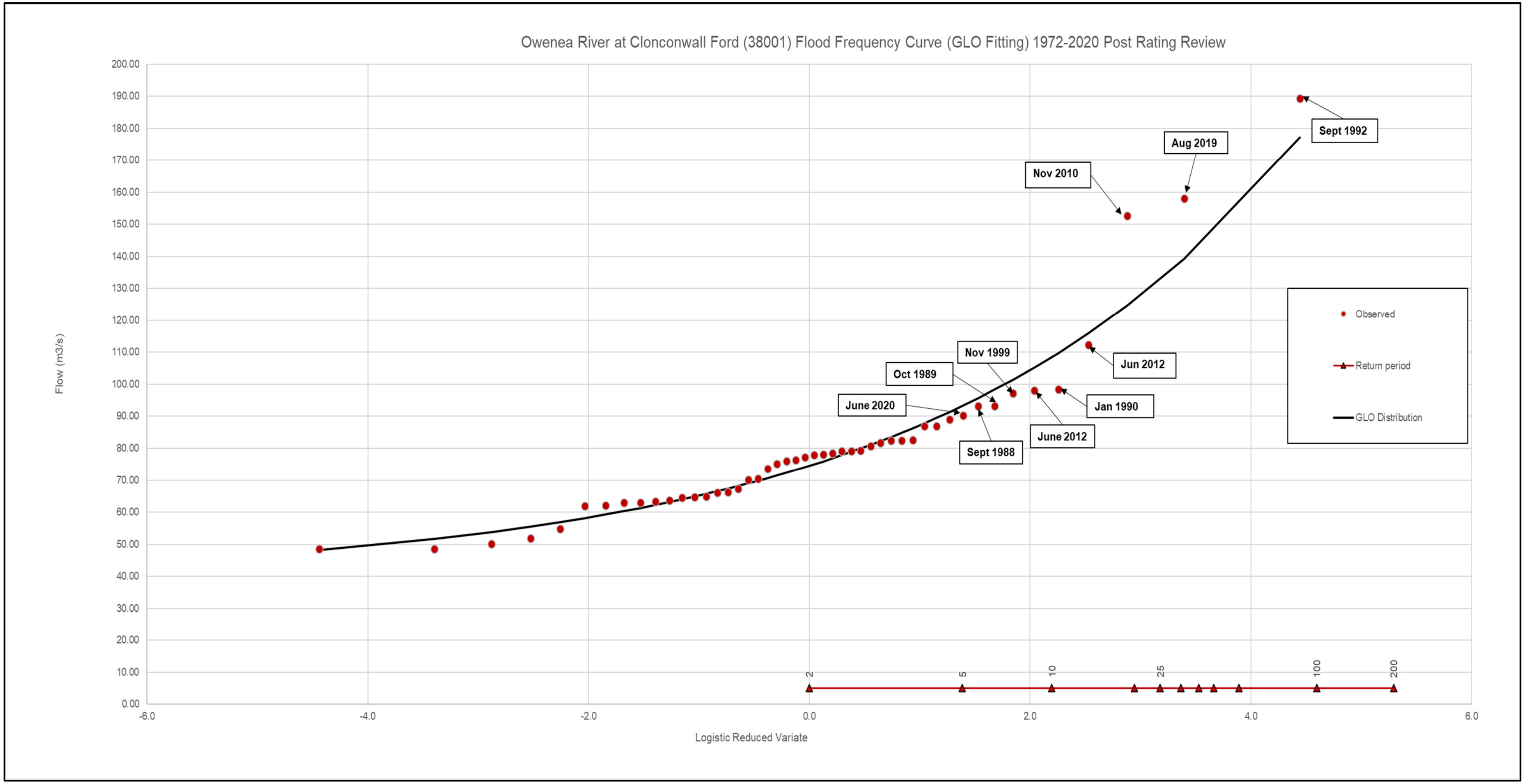


Figure 3.2 Flood frequency curve fitted to AMAX data for Owenea at Clonconwall Ford (38001)

The largest flood events recorded that have had an impact on Glenties are shown in Table 3.1, with the peak flow, rank of the event within the AMAX series and the estimated return period given.

Table 3.1 Estimated return period for flood events, Owenea at Clonconwall Ford (38001)

Event Date	Hydrological Year	Peak Flow (m^3/s)	Rank	Estimated Return Period (Years)
11/09/1992	1991	189.35	1	100
31/08/2019	2018	158.09	2	50
15/11/2015	2015	152.74	3	38
08/11/2010	2010	112.28	4	15
01/01/1990	1990	98.46	5	10
09/06/2012	2011	98.10	6	9
01/11/1999	1999	97.21	7	7
29/10/1989	1989	93.19	T-8	6
02/09/1988	1987	93.19	T-8	6
29/06/2020	2019	90.22	10	5

* 11/09/1992 event estimated return period of 100 years is greater than the record length of 46 years.

Notably, there have been a number of extreme events within the record period, most notably September 1992 and November 2015 where no flood event report is available (Section 1.4). This may reflect a low risk from fluvial flooding within the scheme area yet there are numerous records of flooding in the south of Glenties (Table 1.2), at Mulantyboyle, Davy Brennan Memorial Park (GAA pitch), and Clós Naomh Chonaill. The inconsistency in the occurrence of these events with the peak flow record at Clonconwal Ford may be due to a number of factors:

- the distance of the gauge downstream of the scheme area
- the presence of other flood mechanisms in past events
- inconsistency in the reporting of flood events

3.2 Stracashel at Glenties (38010)

The Stracashel at Glenties (38010) gauging station is located on the Stracashel River, just downstream of Glenties and upstream of the confluence with the Owenea River (Glen_05). The gauging station is a water level only gauging station. There are just under two full hydrometric years of continuous 15-minute water level data from 29/11/2019 – 01/10/2021. There is no historic rating at the station.

RPS derived a rating at the gauging station over the short record period and conducted an analysis on the Q_{med} (Section 2.2). The observed Q_{med} extracted at the gauging station is 32.27m^3/s. The highest spot gauged flow is 14.62m^3/s, which is approximately 45% of Q_{med}. Despite the extraction of an observed Q_{med}, the data period is not considered sufficient to capture and estimate accurate at-site flood frequency conditions on the Stracashel River.

With every hydrometric year of data that becomes available statistical confidence in the observed Q_{med} value will increase as well as the ability to estimate the frequency of events recorded.

4 DESIGN FLOW ESTIMATION

The design flow estimation process entails reviewing all available/useable hydrological data and employing FSU techniques to derive estimates of peak flows across the range of return periods at various locations across the modelled watercourses within the Glenties study area.

The techniques employed in Glenties are anchored to the long-term hydrometric data at the Clonconwall Ford gauging station downstream. The potential for the application of the Stracashel at Glenties gauging station has also been analysed post-rating review.

4.1 HEP Physical Catchment Descriptors

A detailed hydrological analysis was undertaken to determine the flood flow hydrographs and peak design flows for the Glenties study area. The design flow estimation requires a comprehensive understanding of the physical catchment characteristics/descriptors (PCDs) throughout the Glenties study area. Hydrological Estimation Points (HEPs) have been specified at the locations where peak design flows have been estimated.

HEPs have been established at the most upstream and downstream extremities of the Glenties hydraulic model i.e., at the upstream extents of the Stracashel River and the Gortnamucklagh watercourse and the downstream extents of the Owenea River at the Clonconwall Ford gauging station (Glen_21). The Stracashel at Glenties gauging station has also been assigned a HEP (Glen_05) for design flow estimation.

There are also intermediate HEPs along the main channel watercourses (Owenea River, Stracashel River, and Gortnamucklagh watercourse) to fully capture the flood flow estimation as the catchment land-use and physical characteristics change moving from the upstream to downstream of each of the modelled watercourses. The intermediate HEPs act as checkpoints along the modelled main channel watercourses to ensure that the Glenties hydraulic model is anchored to the hydrological analysis.

Tributary HEPs have been specified downstream of tributary watercourses that flow through the Glenties study area; one on the Stracashel River at its confluence with the incoming Owenea River, three in the Gortnamucklagh watercourse, and three in the downstream reaches of the modelled Owenea River.

Subject to the availability of appropriate catchment data, PCDs have also been updated from the FSU-defined PCDs. For example, the extent of urbanisation (URBEXT), drainage density (DRAIND), and mean average slope (S1085) were updated for each individual sub-catchment throughout the Glenties study area. DRAIND was re-calculated following the review of the catchment delineation. S1085 was re-calculated using the LiDAR coverage for the Glenties study area. Finally, a PCD that can significantly influence the hydrological analysis is URBEXT. This was updated through an analysis of the most up-to-date CORINE Land Use Mapping. This allowed the URBEXT PCD to be updated to capture the most recent changes in urban extent in the Glenties study area.

The specification of HEPs are presented in Figure 4.1. Table 4.1 details the PCDs assigned to each HEP to describe the physical catchment characteristics moving through the Glenties study area.

Reporting nodes can be added post modelling in addition to HEPs if required.

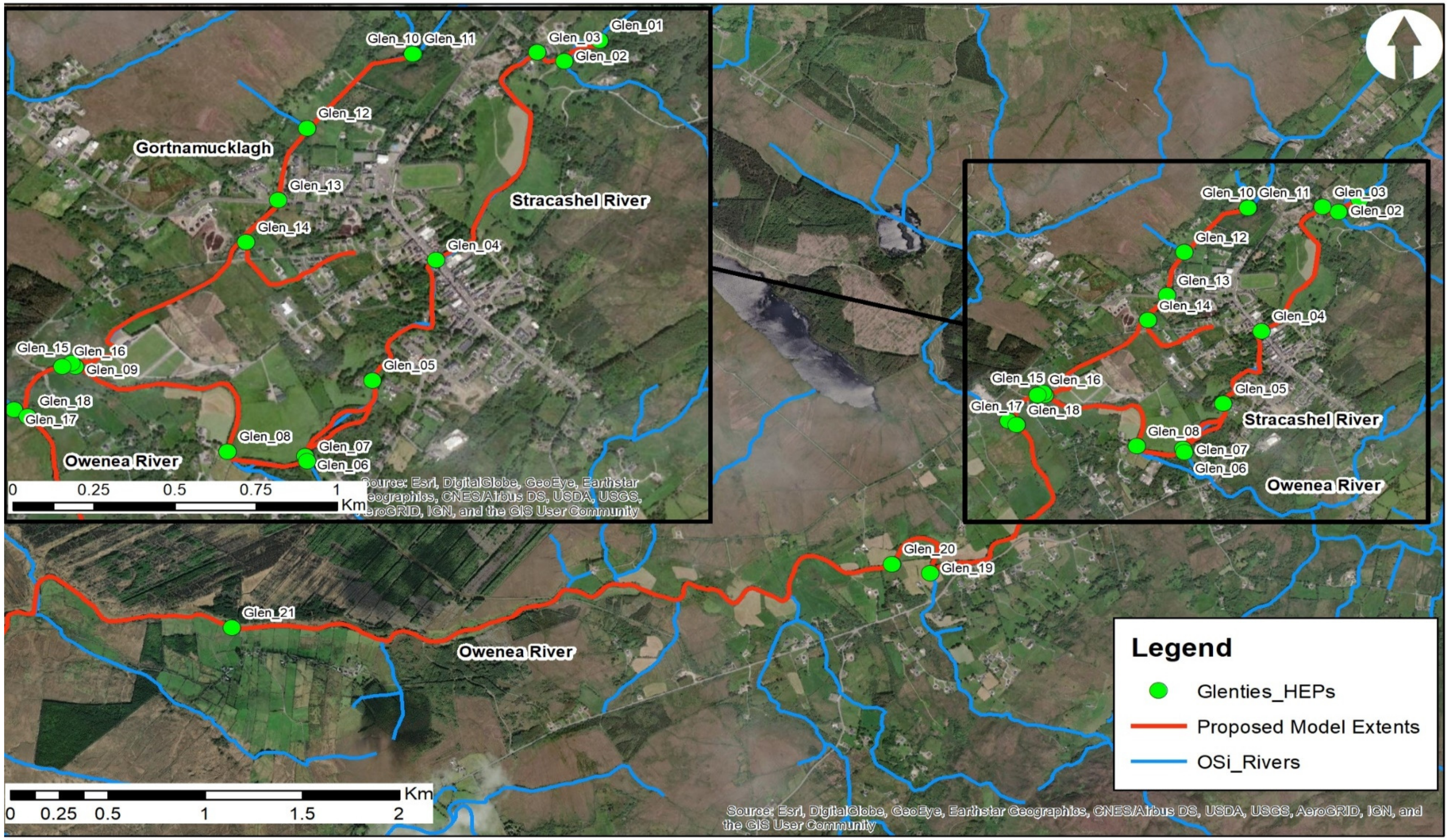


Figure 4.1 Hydrological Estimation Points (HEPs) and schematisation

Table 4.1 Physical Catchment Descriptors for Glenties

HEP	Location	Area (km^2)	Centroid X	Centroid Y	SAAR (mm)	FARL	BFISoil	URBEXT
Glen_01	Start of model: Stracashel River	41.00	586984	897145	1781	0.962	0.284	0.0000
Glen_02	Unnamed Tributary of Stracashel River	0.63	582912	894644	1779	0.962	0.284	0.0000
Glen_03	D/S of confluence on Stracashel River	41.70	586913	897104	1779	0.962	0.284	0.0000
Glen_04	Stracashel at N56	42.11	586866	897079	1777	0.963	0.284	0.0012
Glen_05	Stracashel at Glenties (38010) gauging station	42.40	586826	897054	1776	0.963	0.284	0.0060
Glen_06	Stracashel U/S of Owenea River	42.49	586802	897039	1803	0.963	0.285	0.0069
Glen_07	Owenea River	49.23	587503	893035	1828	0.880	0.346	0.0700
Glen_08	D/S of confluence of Stracashel and Owenea River	91.80	587173	894896	1803	0.918	0.285	0.0032
Glen_09	Intermediary: Owenea U/S of Gortnamucklagh	91.99	587160	894894	1803	0.918	0.285	0.0032
Glen_10	U/S Gortnamucklagh	1.25	581964	895949	1559	1.000	0.299	0.0000
Glen_11	Unnamed Tributary, Gortnamucklagh	0.13	581567	895282	1559	1.000	0.299	0.0000
Glen_12	Unnamed Tributary, Gortnamucklagh	0.05	581254	894951	1554	1.000	0.300	0.0175

HEP	Location	Area (km²)	Centroid X	Centroid Y	SAAR (mm)	FARL	BFISoil	URBEXT
Glen_13	Intermediary: Gortnamucklagh at N56	1.72	581841	895674	1554	1.000	0.300	0.0587
Glen_14	Unnamed Tributary, Gortnamucklagh	0.21	581448	894308	1552	1.000	0.299	0.6322
Glen_15	D/S of Gortnamucklagh	2.47	581623	895302	1547	1.000	0.299	0.1554
Glen_16	Intermediary: Owenea D/S of Gortnamucklagh	94.46	587015	894904	1796	0.920	0.285	0.0072
Glen_17	Unnamed Tributary of Owenea River	4.75	580436	895695	1485	0.936	0.285	0.0260
Glen_18	Intermediary: Owenea River	99.27	586696	894942	1781	0.921	0.285	0.0080
Glen_19	Unnamed Tributary of Owenea River	1.39	580668	892168	1546	1.000	0.296	0.0000
Glen_20	Intermediary: Owenea River	102.07	586531	894880	1774	0.923	0.285	0.0078
Glen_21	End of Model: Clonconwall Ford (38001)	110.99	585913	894739	1753	0.922	0.285	0.0072

Where;

FARL – Index of flood attenuation by reservoirs and lakes;

SAAR – Standard average annual rainfall (mm);

URBEXT – Proportional extent of catchment area mapped as urbanised;

AREA – Individual area of each catchment computed based on GIS based catchment delineation (km²);

BFI_{SOIL} – Soil Base Flow Index (estimate of BFI derived from soils, geology and climate data).

4.2 Index Flood Flow (Q_{med}) Estimation

The first step in determining the design flows for the various HEPs will be the estimation of the Index Flood Flow (Q_{med}) at each HEP. The Index Flood Flow is a crucial flood statistic as it can be robustly determined from suitable gauged locations with a significant record length (more than seven years).

For the Glenties study area along the modelled extents of the Stracashel, Gortnamucklagh, and Owenea River an observed Q_{med} is available for the Clonconwall Ford gauging station on the Owenea River in the downstream extents of the hydraulic model at Glen_21. This observed Q_{med} has been interrogated as part of the rating review at the station (Section 2.1). This allows for the anchoring of the hydrological analysis to robust observed data within the model extents.

The analysis of the rating at the Stracashel at Glenties gauging station represents the first estimate of an observed Q_{med} on the Stracashel River. Q_{med} was extracted from two years of hydrometric data through a POT method. This is a noted improvement on the CFRAM Study which had no observed estimate of Q_{med} on the Stracashel River. Design flow estimates of Q_{med} on the Stracashel River are estimated using the ungauged approach to Q_{med} estimation under FSU. This is due to the high uncertainty in basing design flows on a POT Q_{med} derived from only 2 years of hydrometric data.

In estimating Q_{med} in the tributaries (including the Gortnamucklagh watercourse), there is no observed Q_{med} available. Therefore, these watercourses adopted the ungauged approach to Q_{med} estimation under FSU.

4.2.1 Q_{med} at gauged locations

Table 4.2 shows the observed Q_{med} and the available record period for hydrometric data at the Clonconwall Ford gauging station.

Table 4.2 Observed Q_{med} at Clonconwall Ford (38001)

River	Gauge Location	Number	Q_{med} (m^3/s)	Q_{med} Record Period
Owenea	Clonconwall Ford	38001	77.55	12/11/1972 – 30/09/2020

The observed Q_{med} has increased by 9.4% from the Q_{med} adopted in the CFRAM Study. This is a result of the rating review at the gauging station (section 2.1). This represents a robust estimation of Q_{med} in the Owenea River. The rating review has increased the confidence in the rating at the gauging station at higher flows and validated the observed Q_{med} to be used during the current hydrological analysis.

Table 4.3 shows the extracted observed Q_{med} and the available record period for the hydrometric data at the Stracashel at Glenties gauging station.

Table 4.3 Observed Q_{med} at Stracashel at Glenties (38010)

River	Gauge Location	Number	Q_{med} (m^3/s)	Q_{med} Record Period
Stracashel	Glenties	38010	32.27	29/11/2019-01/10/2021

Despite the extraction of a Q_{med} from the Stracashel gauging station which represents the first observed estimate on the watercourse at Glenties, there is high uncertainty in using this value as the basis for design flows.

4.2.2 Q_{med} at ungauged locations

While the presence of the Clonconwall Ford gauging station on the Owenea allows the peak design flow estimates to be anchored to observed data, the estimation of Q_{med} using ungauged methods is required on the Stracashel River and Gortnamucklagh watercourse and all HEP checkpoints along the modelled watercourses. These estimates are initially treated as ungauged but receive a pivotal site adjustment to ensure the peak design flows are informed by the gauged data within the Glenties study area.

Ungauged estimates involve the estimation of Q_{med} in its rural form, referred to henceforth as $Q_{med\ rural}$. These will initially be based on the FSU methods for ungauged catchments, i.e., using regression equations derived from FSU Work Package 2.3 and for the smaller catchments from FSU Work Package 4.2. The five variable equation set out in FSU Work Package 4.2 ‘Flood Estimation in Small and Urbanised Catchments’ is an alternative method suitable for small catchments, particularly those where the physical catchment descriptors such as drainage density are poorly defined.

Other methods of interrogating the estimation of flood flows in smaller catchments were also considered. This includes methods such as IH124, ADAS, the Rational Method, as well as the FSU 5 variable equation. The FSU 5 Variable equation was chosen as the main small catchment analysis tool. This is because the alternative methods presented above are conducted on lower resolution datasets and/or on datasets that are now considered old and outdated. These alternative methods are also considered to be much cruder in terms of their input parameters and their ability to capture the nuances of a changing catchment at the small scale. Finally, FSU Work Package 4.2 highlights that the FSU5 Variable equation has the lowest factorial standard equation in terms of estimation at the small catchment scale.

FSU7 Variable (standard method):

$$\mathbf{Q_{med\ rural} = 1.237{*}I0^{-5}{*}AREA^{0.937}{*}BFI_{SOIL}^{-0.922}{*}SAAR^{1.306}{*}FARL^{2.217}{*}DRAIND^{0.341}{*}S1085^{0.185}{*}(1+ ARTDRAIN2)^{0.408}}$$

FSU5 Variable (small catchments):

$$\mathbf{Q_{med\ rural} = 2.0951{*}10^{-5}{*}AREA^{0.9245}{*}BFI_{SOIL}^{-0.9030}{*}SAAR^{1.2695}{*}FARL^{2.3163}{*}S1085^{0.2513}}$$

The FSU5 variable equation was not used on the Owenea or Stracashel Rivers. The FSU7 and FSU5 methods were both interrogated on the smaller tributary inflows and Gortnamucklagh watercourse to compare the outputs of both methods. The method deemed most appropriate has been carried forward for design flow estimation.

4.2.3 Pivotal Site Adjustment

FSU recommends that the ungauged Q_{med} estimates (i.e., $Q_{med\ rural}$) are adjusted using a ‘pivotal site’; a geographically close or hydrologically similar gauged catchment that can be used to reduce the error and level of uncertainty in the estimates. The basis of this adjustment is grounded in the fact that Q_{med} estimation based purely on the physical catchment descriptor regression equations can be highly uncertain as it has been generalised for application across a wide range of catchments nationally.

However, this estimation can be improved, and the uncertainty reduced by using data transfer methods from other nearby or hydrologically similar gauged catchments. This approach borrows observed flood flow data from an appropriately gauged subject catchment, which is known as the ‘pivotal site’ in FSU methodologies.

A comprehensive review of nearby and hydrologically similar gauging stations was conducted in relation to the Glenties study area. At the time of the CFRAM Study, the Clonconwall Ford gauging station was used as the pivotal site adjustment on the Stracashel and Owenea River main channels. The tributaries including the Gortnamucklagh did not receive any pivotal site adjustment in the CFRAM Study.

The Stracashel at Glenties gauging station is not considered appropriate as a pivotal site. Adjusting the peak design flows based on a site that is only gauged for two full hydrometric years does not improve the statistical confidence; a Q_{med} based on only two years of data has a similar Factorial Standard Error (FSE) to an ungauged FSU estimate. Following the rating review at the Clonconwall Ford gauging station, there is increased certainty with the observed Q_{med} value and hence the pivotal site adjustment factor. Clonconwall Ford is the obvious choice of pivotal site adjustment for the Glenties study area (Stracashel and Owenea).

The adjustment is considered in relation to the catchments in their rural state such that the effects of urbanisation from the pivotal site are not transferred. In light of this, the estimated effect of urbanisation may need to be stripped from the observed Q_{med} value by dividing the observed value by the UAF. However, in the case of the Clonconwall Ford gauging station, urbanisation is approximately 1% and therefore is not considered to have a significant effect on the observed Q_{med} value. The observed and FSU7 variable equation predicted Q_{med} values, and the resulting pivotal site adjustment factor is shown in Table 4.4.

Table 4.4 Pivotal Site Adjustment Factor (AdjFac) for Glenties study area

River	Gauge Location	Number	Q_{med} Observed (m^3/s)	$Q_{med\ rural}$ Predicted (m^3/s)	Adjustment Factor (AdjFac)
Owenea	Clonconwall Ford	38001	77.55	87.26	**0.889**

Table 4.4 suggests that the FSU7 variable catchment descriptor equation is slightly overestimating the Q_{med} on the Owenea River. This suggests that the $Q_{med\ rural}$ estimates require a downwards adjustment of approximately 11%, given the adjustment factor of 0.889.

However, there is uncertainty in applying this adjustment factor to the smaller Gortnamucklagh watercourse, its tributaries, and the smaller tributaries entering the Owenea River in the downstream extents of the Glenties study area. Given Clonconwall Ford gauging station is the only potential pivotal site available within the Owenea catchment, it would seem appropriate to apply the adjustment globally. However, the catchment represented by the Clonconwall Ford gauging station is significantly larger, slightly wetter, more attenuated, and flatter than the Gortnamucklagh watercourse, its tributaries, and the tributaries of the Owenea River.

A further review of available small catchment hydrometric gauging stations which are geographically close enough and hydrologically similar enough for use as a pivotal site for the tributaries was conducted. This review identified a relatively new gauging station operated by the EPA; Gortinlieve at Carrigans (Station No.: 01016) as the most appropriate pivotal site for the Gortnamucklagh watercourse and the remaining tributaries. This gauging station is in northwest Donegal, approximately 60km from Glenties, on a small tributary of the River Foyle. The station has been operational since 2010 with 11 years of continuous data available. The station was not available at the time of FSU and did not have sufficient data to be considered relevant at the time of the CFRAM Study. Although the highest gauged flow is significantly lower than the Q_{med} value, the gauge is contained within a concrete channel with a flat V-weir providing the control. The high flow rating is described as excellent by the EPA and RPS has deemed it suitable for Q_{med}. The catchment is one of the closest stations to the tributary catchments with the other closer sites representing much larger catchments and therefore lower hydrological similarity. The Gortinlieve station has a fairly high hydrological similarity to all of the tributary catchments. A summary of the main tributary catchment descriptors with the Gortinlieve gauged catchment descriptors is shown in Table 4.5.

Table 4.5 Comparison of Gortinlieve gauging station to tributary catchments, Glenties

HEP	Location (EPA Name)	Area (km^2)	SAAR (mm)	FARL	BFI_{SOIL}	S1085 (m/km)	URBEXT (%)
Glen_02	Unnamed Tributary of Stracashel	0.63	1779	0.962	0.284	8.053	0.000
Glen_10	U/S Gortnamucklagh watercourse	1.25	1559	1.000	0.299	51.469	0.000
Glen_11	Unnamed Tributary at U/S of	0.13	1559	1.000	0.299	51.469	0.000

HEP	Location (EPA Name)	Area (km^2)	SAAR (mm)	FARL	BFI_{SOIL}	S1085 (m/km)	URBEXT (%)
	Gortnamucklagh watercourse						
Glen_12	Unnamed Tributary on Gortnamucklagh watercourse	0.05	1554	1.000	0.300	38.279	0.018
Glen_13	Gortnamucklagh at N56	1.72	1554	1.000	0.300	38.279	0.059
Glen_14	Unnamed Tributary on Gortnamucklagh watercourse	0.21	1552	1.000	0.299	29.361	0.632
Glen_15	D/S Gortnamucklagh watercourse	2.47	1547	1.000	0.299	23.981	0.155
Glen_17	Unnamed Tributary of Owenea River	4.75	1485	0.9360	0.285	7.704	0.026
Glen_19	Unnamed Tributary of Owenea River	1.39	1546	1.000	0.296	75.469	0.000
Gortinlieve Gauging Station	**Carrigans**	**0.96**	**1042**	**1.000**	**0.346**	**75.071**	**0.000**

Table 4.6 illustrates the observed and predicted Q_{med} values and the resulting pivotal site adjustment factor for the Gortinlieve at Carrigans gauging station.

Table 4.6 Pivotal Site Adjustment Factors (AdjFac), Gortinlieve at Carrigans (01016)

River	Gauge Location	Gauge Number	Q_{med} Observed (m^3/s)	$Q_{med\ rural}$ FSU7 Predicted (m^3/s)	$Q_{med\ rural}$ FSU5 Predicted (m^3/s)	FSU7 Adjustment Factor (AdjFac)	FSU5 Adjustment Factor (AdjFac)
Carrigans	Gortinlieve	01016	0.910	0.596	1.054	1.527	0.864

Table 4.6 suggest that the FSU7 variable equation is significantly underestimating Q_{med} by approximately 53%. Conversely, the FSU5 variable equation is suggested to be overestimating Q_{med} by approximately 14%. The FSU5 variable equation estimate of $Q_{med\ rural}$ was used with the observed Q_{med} at Gortinlieve as the basis of the pivotal site adjustment of Q_{med} on the ungauged tributary catchments within the Glenties study area including the Gortnamucklagh watercourse. The FSU5 variable estimate was considered more appropriate given the small nature of the catchments, the uncertainty in the drainage-related catchment descriptors (i.e.,

drainage density (DRAIND)), and the fact that this method at the small catchment scale was found to have produced a lower statistical error within FSU Work Package 4.2 than the FSU7 variable equation.

4.2.4 Urban Adjustment

This $Q_{med\ rural}$ value does not consider the effects of urbanisation which is considered separately through an Urban Adjustment Factor (UAF) calculated as follows:

$$\mathbf{UAF = (1+URBEXT)^{1.482}}$$

The final Q_{med} which considers the effect of urbanisation is then calculated:

$$\mathbf{Q_{med\ urban} = UAF * Q_{med\ rural}}$$

The urban adjustment was not applied on the Stracashel or Owenea River main channels as the level of urbanisation in both main channel catchments is considered to be sufficiently low (~1%). This means that urbanisation has a negligible effect on the peak design flows on the Stracashel or Owenea Rivers.

However, the urban adjustment has been applied to the tributaries in the Glenties study area where the level of urbanisation is deemed to have a potential impact on run-off and the peak design flows. In general, any tributary catchment that has an URBEXT value of greater than 2.5% (0.025) has had the urban adjustment factor applied.

Table 4.7 illustrates the tributary catchments in the Glenties study area that meet the 2.5% urbanisation threshold and the effect of the urban adjustment on the rural, catchment descriptor based FSU5 variable Q_{med} estimates.

Table 4.7 Urban Adjustment, Glenties

HEP	Location (EPA Name)	Area (km^2)	$Q_{med\ rural}$ (m^3/s)	URBEXT %	Urban Adjustment Factor	$Q_{med\ urban}$ (m^3/s)
Glen_13	Gortnamucklagh at N56	1.72	2.89	0.059	1.09	2.72
Glen_14	Unnamed Tributary on Gortnamucklagh watercourse	0.21	0.38	0.632	2.07	0.68
Glen_15	D/S Gortnamucklagh watercourse	2.47	3.57	0.155	1.24	3.82
Glen_17	Unnamed Tributary of Owenea River	4.75	4.19	0.026	1.04	3.76

4.2.5 Final Q_{med} Design Flow Estimates

Following the urban adjustment procedure, the $Q_{med\ urban}$ estimates for each sub-catchment then had their pivotal site adjustment applied to give the final Q_{med} estimate ($Q_{med\ urban\ adj.}$). Table 4.8 provides the final Q_{med} design flow estimates for the Glenties study area.

Table 4.8 Final Q_{med} Design Flow Estimates, Glenties

HEP	Flood Estimation Method	$Q_{med\ rural}$ (m^3/s)	Pivotal Site (Gauging Station No.)	Urban Adjustment Factor	Pivotal Site Adjustment Factor	Final Q_{med} (m^3/s)
Glen_01	FSU7	41.61	Clonconwall Ford (38001)	1.00	0.89	36.98
Glen_02	FSU5	0.88	Gortinlieve (01016)	1.00	0.86	0.76
Glen_03	FSU7	41.87	Clonconwall Ford (38001)	1.00	0.89	37.21
Glen_04	FSU7	42.71	Clonconwall Ford (38001)	1.00	0.89	37.96
Glen_05	FSU7	42.74	Clonconwall Ford (38001)	1.01	0.89	37.99
Glen_06	FSU7	43.60	Clonconwall Ford (38001)	1.01	0.89	38.75
Glen_07	FSU7	38.76	Clonconwall Ford (38001)	1.11	0.89	38.19
Glen_08	FSU7	80.71	Clonconwall Ford (38001)	1.00	0.89	71.73
Glen_09	FSU7	80.87	Clonconwall Ford (38001)	1.00	0.89	71.87
Glen_10	FSU5	2.33	Gortinlieve (01016)	1.00	0.86	2.01
Glen_11	FSU5	0.30	Gortinlieve (01016)	1.00	0.86	0.26
Glen_12	FSU5	0.11	Gortinlieve (01016)	1.03	0.86	0.10
Glen_13	FSU5	2.89	Gortinlieve (01016)	1.09	0.86	2.72
Glen_14	FSU5	0.38	Gortinlieve (01016)	2.07	0.86	0.68
Glen_15	FSU5	3.57	Gortinlieve (01016)	1.24	0.86	3.82
Glen_16	FSU7	81.97	Clonconwall Ford (38001)	1.01	0.89	72.85
Glen_17	FSU5	4.19	Gortinlieve (01016)	1.04	0.86	3.76

HEP	Flood Estimation Method	$Q_{med\ rural}$ (m^3/s)	Pivotal Site (Gauging Station No.)	Urban Adjustment Factor	Pivotal Site Adjustment Factor	Final Q_{med} (m^3/s)
Glen_18	FSU7	84.20	Clonconwall Ford (38001)	1.01	0.89	74.83
Glen_19	FSU5	2.83	Gortinlieve (01016)	1.00	0.86	2.44
Glen_20	FSU7	85.98	Clonconwall Ford (38001)	1.01	0.89	76.42
Glen_21	FSU7	87.26	Clonconwall Ford (38001)	1.01	0.89	77.55

4.3 Growth Curve Development

To derive design event peak flows for the range of probabilities / return period (50%, 20%, 10%, 5%, 2%, 1%, 0.5% and 0.1% AEP), a growth curve must be developed. The growth curve defines the relationship between Q_{med} and the various event probability peak flows (QT).

With observed data, a growth curve can be defined from available AMAX data from a reliable gauging station. This applies to the Owenea River given the presence of the Clonconwall Ford gauging station. However, in the absence of observed hydrometric data (i.e., in an ungauged catchment such as the Gortnamucklagh watercourse) the development of a growth curve relies on pooled analysis. This involves forming an estimated growth curve using key statistical characteristics of observed AMAX data from a pooled group of hydrologically similar gauged catchments.

4.3.1 CFRAM Study Growth Curve Development

Growth curve development was previously undertaken as part of the CFRAM Study based on the FSU methodologies to determine growth factors for a range of design events. The growth factors derived for the Glenties hydraulic model from the CFRAM Study are presented in Table 4.9.

Table 4.9 CFRAM Study Growth Curves

Glenties Model Reach	Growth Factors at AEP (Return Period)							
	50% (2)	20% (5)	10% (10)	5% (20)	2% (50)	1% (100)	0.5% (200)	0.1% (1000)
Stracashel	1.00	1.25	1.43	1.63	1.92	2.18	2.47	3.33
Gortnamucklagh	1.00	1.30	1.52	1.76	2.13	2.47	2.86	4.02
Owenea (entering Stracashel)	1.00	1.26	1.45	1.66	1.97	2.24	2.56	3.49
Owenea River (Clonconwall Ford)	1.00	1.26	1.45	1.65	1.94	2.19	2.48	3.29

4.3.2 At-Site Growth Curve

A single site analysis was conducted at the Clonconwall Ford gauging station post-rating review (see Section 3). The at-site growth curve is extracted from the flood frequency curve by taking the ratio of estimated peak flow to the observed Q_{med} value. The GLO was the best performing distribution during the at-site analysis. The at-site GLO growth curve for the Clonconwall Ford gauging station is shown in Figure 4.2.

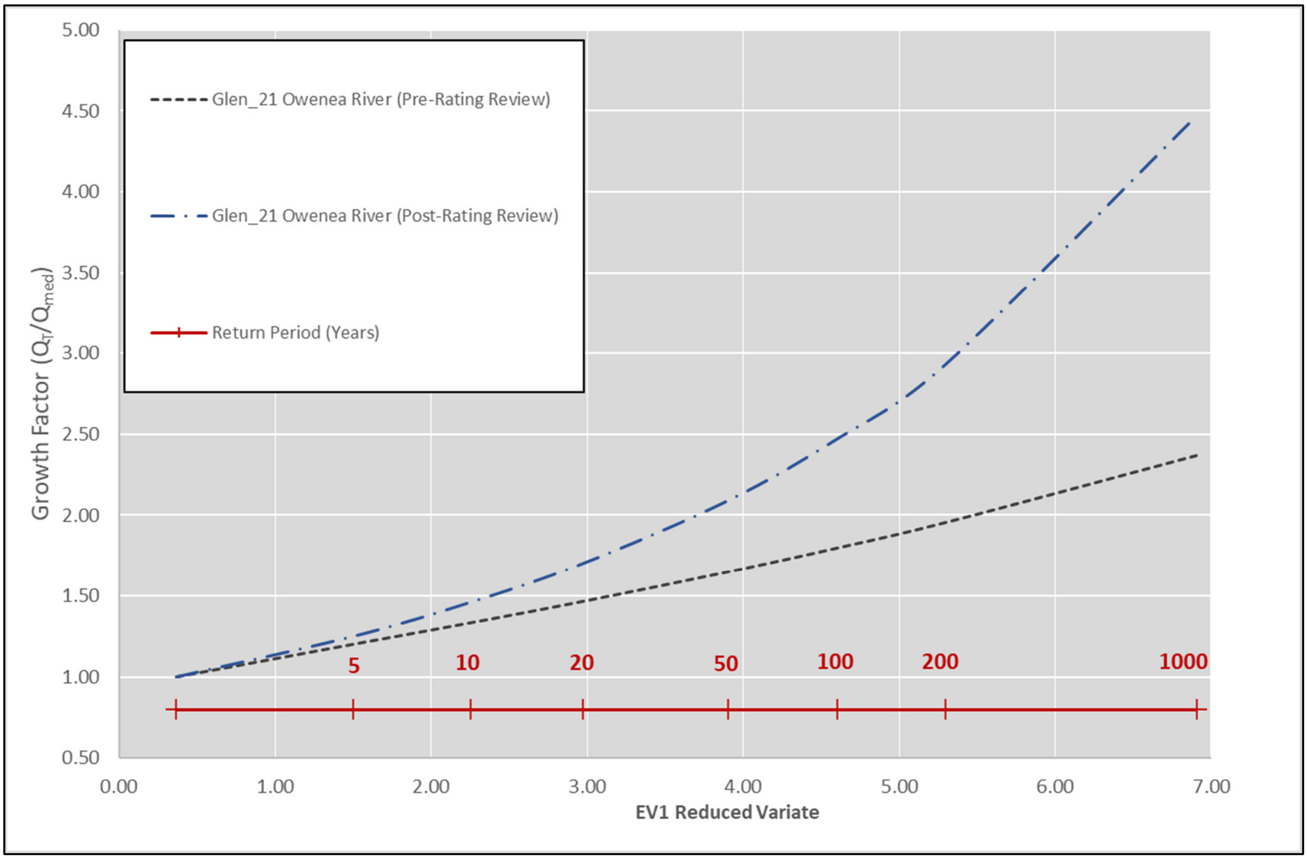


Figure 4.2 At-Site Growth Curve Pre- and Post-Rating Review, Clonconwall Ford (38001)

Post rating review the at-site growth curve is much steeper resulting in higher growth factors than the pre-rating review at-site curve. It is also steeper than the growth curve adopted on the Owenea River in the CFRAM Study.

The at-site growth curve developed for the Clonconwall Ford gauging station is based on 49 years of AMAX flood flow data. Following the rating review, the AMAX values are considered to be more robust and the flood frequency curve is suitable for the basis of flood flow estimation. However, as noted in Table 4.10, it is only recommended that the at-site analysis is used as the basis for design flow estimation if there are more than *T* years of AMAX data, where *T* is the design return period. In other words, the Clonconwall Ford at-site analysis is only recommended for use as the basis for design flow estimation up to the 49-year return period (i.e., for Q2, Q5, Q10, Q20).

Table 4.10 Selection of Growth Curves methodology, adapted from FEH Volume 3 Tables 8.2 and 8.3

Record Length	At-Site Analysis	Pooled Analysis	Preferred Method
< T/2 or 14 years	No	Yes	Pooled
T/2 to T years	For confirmation	Yes	Pooled
T to 2T years	Yes	Yes	Joint
> 2T years	Yes	For confirmation	At-Site

An at-site growth curve was not constructed for the Stracashel at Glenties gauging station. With only two years of current hydrometric data, it is not appropriate to develop an at-site growth curve or at-site growth factors.

4.3.3 Development of Pooled Growth Curves

The pooled analysis has been updated and re-analysed for the Glenties study area. There were limitations to the current FSU database from which pooled gauged stations are derived. The FSU database has not been updated since it was developed and therefore was limited to AMAX years up to 2004.

An update of the FSU database was conducted to include all hydrometric data and AMAX years up to the latest hydrometric year (end of the hydrometric year 2019 / 2020). This update was conducted on sites that were included in the pooling group for Glenties (i.e., based on hydrological similarity). This was to ensure the updated pooled analysis was pooling the most recent hydrometric data to inform the development of new growth curves. Additional stations were also added to the pooled database which was previously unaccounted for including potentially relevant Northern Ireland gauging stations to ensure the most hydrologically similar pooling group could be formed. The addition of Northern Irish stations was included to add an extra layer of data to the analysis by including all appropriate geographically close sites that may have been excluded due to jurisdictional boundaries.

This update was applied to FSU sites which have recently been determined to be robust for pooling group analysis by the OPW. This was to ensure the updated pooled analysis included the most recent, robust hydrometric data to inform the development of new growth curves. FSU sites not included within the list were assumed to be robust up to 2004 (as per the original FSU classification) and were retained.

Pooled analysis and pooled growth curves were developed at multiple locations across the Glenties study area to fully capture the changing flood frequency conditions. Pooled growth curves were developed at the following locations:

- The Stracashel River at Glen_06 represents the main channel of the Stracashel;
- The Owenea River at Glen_07 to represent the Owenea River where it joins the Stracashel;
- The Owenea River at Glen_08 to represent the Owenea River post-confluence with the Stracashel;
- The Gortnamucklagh watercourse at Glen_15 represents the main channel of the Gortnamucklagh and the similar tributary watercourses included in the hydraulic model; and
- The Owenea River at Glen_21 represents the downstream reaches of the hydraulic model at the Clonconwall Ford gauging station.

The final pooled stations for each location are provided in Table 4.11.

Table 4.11 Sites included within the Pooling Groups, Glenties

Glen_06	Glen_07	Glen_08	Glen_15	Glen_21
New Mills (39001)	New Mills (39001)	Clonconwall Ford (38001)	Kiltybardan (36021)	Clonconwall Ford (38001)
Clonconwall Ford (38001)	Louisbeg Weir (32011)	New Mills (39001)	Inch Bridge (27001)	Glenamoy (33001)
Glenamoy (33001)	Clonconwall Ford (38001)	Glenamoy (33001)	New Mills (39001)	New Mills (39001)
Louisbeg Weir (32011)	Kiltybardan (36021)	Louisbeg Weir (32011)	Louisbeg Weir (32011)	Ballybofey (01043)
Kiltybardan (36021)	Inch Bridge (27001)	Ballybofey (01043)	Glenamoy (33001)	Louisbeg Weir (32011)
Inch Bridge (27001)	Ballycarroon (34007)	Ballycarroon (34007)	Clonconwall Ford (38001)	Ballycarroon (34007)
Ballycarroon (34007)	Duncannon (18016)	Inch Bridge (27001)	Duncannon (18016)	Duarrigle (18050)
Duncannon (18016)	Gartan Bridge (39008)	Ennistimon (28001)	Ballymullen (23012)	Ennistimon (28001)
Ballybofey (01043)	Glenamoy (33001)	Duarrigle (18050)	Laragh (10004)	Inch Bridge (27001)
Ennistimon (28001)	Cartronbower (30001)	Duncannon (18016)	Ballycarroon (34007)	Duncannon (18016)
Duarrigle (18050)	Ennistimon (28001)	Kiltybardan (36021)	Gartan Bridge (39008)	Kiltybardan (36021)
Sandy Mills (01041)	Aghawoney (39009)	Sandy Mills (01041)	Agivey at Whitehall (NI) (03028)	Sandy Mills (01041)
Gartan Bridge (39008)	Dromcarra (19014)	Aghawoney (39009)	Ennistimon (28001)	Aghawoney (39009)
	Sandy Mills (01041)		Mountmellick (14033)	
			Lagan at Drumiller (NI) (05008)	

Table 4.12 provides a summary of the pooling group analysis and summary statistics for each of the locations where pooled growth curves were developed.

Table 4.12 Pooling Summary Statistics, Glenties

HEP	Final Pooling Group Total Years	Number of Stations Removed from Original Pooling Group	L-Skewness	L-Kurtosis	Preferred Distribution (GLO or GEV)
Glen_06	502	0	0.150	0.149	**GLO**
Glen_07	536	0	0.165	0.169	**GLO**
Glen_08	515	0	0.164	0.168	**GLO**
Glen_15	530	0	0.146	0.168	**GLO**
Glen_21	515	0	0.164	0.169	**GLO**

The pooling groups formed were found to be hydrologically similar and did not require any adjustments in terms of removing stations that were not representative. The GLO was the preferred growth curve distribution across the Glenties study area.

4.3.4 Finalising Growth Curves

The final growth factors/curves for each of the five locations where growth curves were developed are presented in Table 4.13 and illustrated in Figure 4.3 and Figure 4.4.

Table 4.13 Finalised Growth Factors, Glenties

Glenties Model Reach (HEP)	Growth Factors at AEP (Return Period)							
	50% (2)	20% (5)	10% (10)	5% (20)	2% (50)	1% (100)	0.5% (200)	0.1% (1000)
Glen_06	1.00	1.25	1.43	1.61	1.87	2.09	2.34	3.01
Glen_07	1.00	1.28	1.47	1.68	1.97	2.23	2.51	3.31
Glen_08	1.00	1.25	1.42	1.60	1.86	2.08	2.33	3.03
Glen_15	1.00	1.25	1.43	1.62	1.90	2.15	2.42	3.20
Glen_21	1.00	1.25	1.44	1.64	1.97	2.27	2.62	3.73

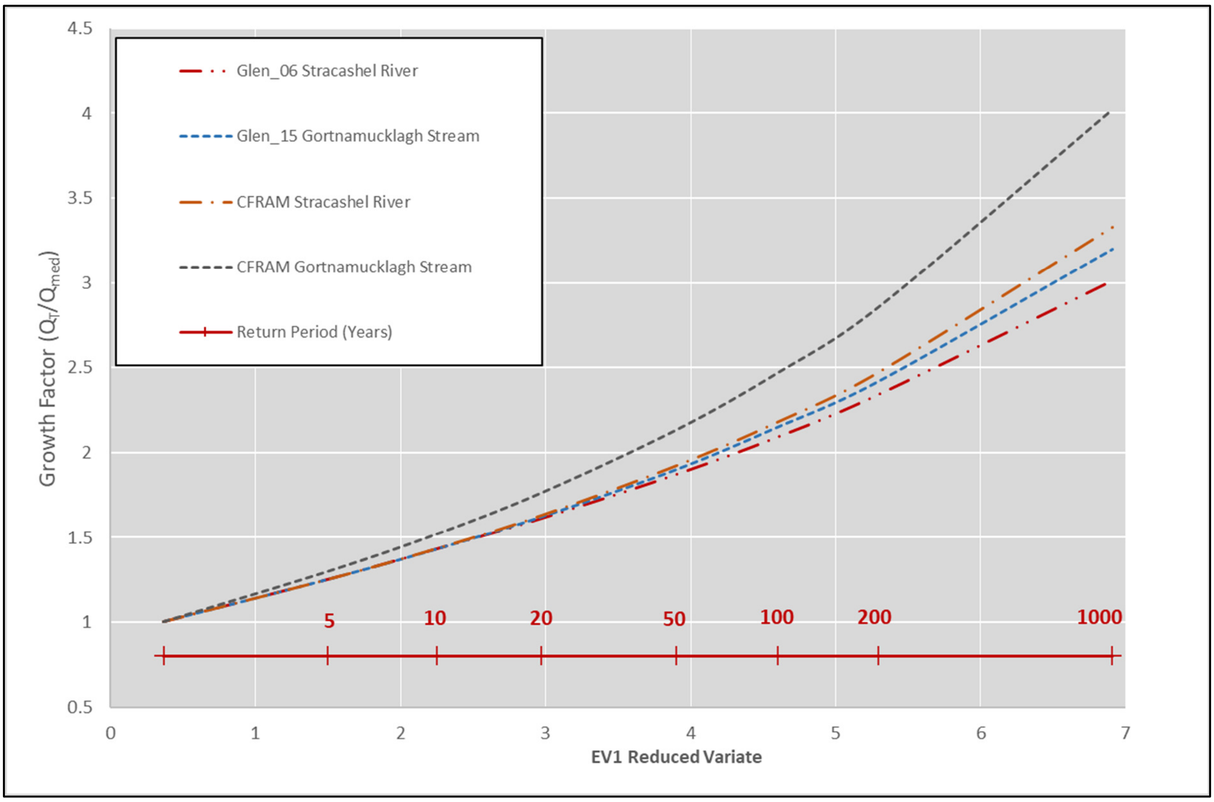


Figure 4.3 Final Growth Curves, Stracashel River and Gortnamucklagh

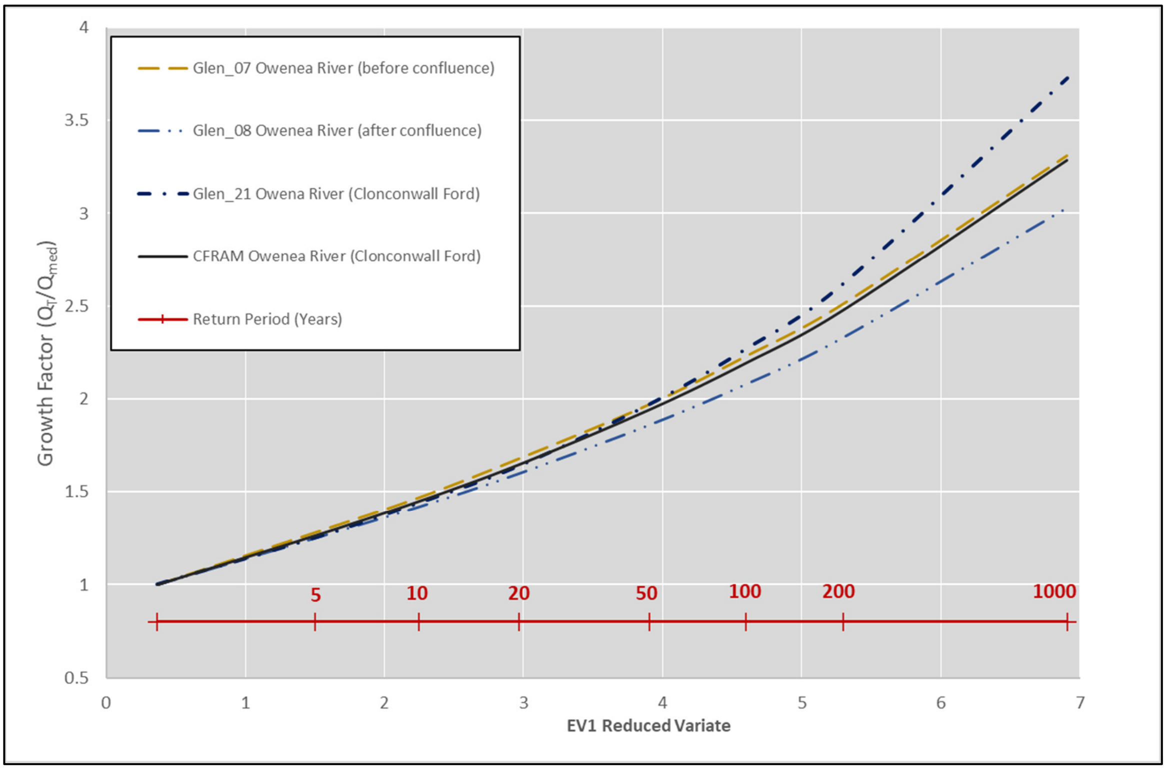


Figure 4.4 Final Growth Curves, Owenea River

The finalised growth curve that has been used on the downstream extents of the Owenea River (Glen_21) at the Clonconwall Ford gauging station is a composite growth curve that is an average of the post-rating at-site growth curve and the pooled growth curve.

Each of the design growth curves across Glenties was applied to the hydrologically similar sub-catchments to enable the derivation of the final peak design flow estimates. Table 4.14 outlines the growth curve application across the Glenties study area.

Table 4.14 Growth Curve Application, Glenties

Glen_06 (Stracashel River)	Glen_07 (Owenea River prior to confluence)	Glen_08 (Owenea River post-confluence with Stracashel)	Glen_15 (Gortnamucklagh watercourse)	Glen_21 (Owenea River, Clonconwall Ford gauging station)
Glen_01 Glen_02 Glen_03 Glen_04 Glen_05	N/A	Glen_09	Glen_10 Glen_11 Glen_12 Glen_13 Glen_14	Glen_16 Glen_17 Glen_18 Glen_19 Glen_20

4.3.5 Glenties FRS Final Design Flows

The final peak design flow estimates for each of the HEPs in the Glenties study area are presented in Table 4.15.

Table 4.15 Final Peak Design Flow Estimates, Glenties

Glenties Model Reach (HEP)	Flows for AEP							
	50% (2)	20% (5)	10% (10)	5% (20)	2% (50)	1% (100)	0.5% (200)	0.1% (1000)
Glen_01	36.98	46.07	53.08	60.79	72.77	83.85	96.86	137.97
Glen_02	0.76	0.95	1.09	1.25	1.49	1.72	1.99	2.83
Glen_03	37.21	46.36	53.41	61.17	73.22	84.37	97.47	138.83
Glen_04	38.00	47.34	54.54	62.46	74.77	86.15	99.53	141.77
Glen_05	37.99	47.32	54.52	62.44	74.75	86.13	99.50	141.73
Glen_06	38.75	48.27	55.62	63.70	76.25	87.86	101.50	144.57
Glen_07	38.19	47.58	54.81	62.77	75.15	86.59	100.03	142.48
Glen_08	71.73	89.36	102.95	117.90	141.14	162.63	187.87	267.61
Glen_09	71.87	89.54	103.16	118.14	141.42	162.95	188.25	268.14

Glenties Model Reach (HEP)	Flows for AEP							
	50% (2)	20% (5)	10% (10)	5% (20)	2% (50)	1% (100)	0.5% (200)	0.1% (1000)
Glen_10	2.01	2.52	2.88	3.26	3.82	4.33	4.87	6.44
Glen_11	0.26	0.32	0.36	0.41	0.48	0.55	0.62	0.82
Glen_12	0.10	0.12	0.14	0.15	0.18	0.21	0.23	0.31
Glen_13	2.72	3.40	3.89	4.40	5.16	5.84	6.58	8.70
Glen_14	0.68	0.85	0.97	1.10	1.29	1.46	1.64	2.17
Glen_15	3.82	4.78	5.47	6.19	7.26	8.22	9.25	12.23
Glen_16	72.85	90.75	104.56	119.74	143.34	165.16	190.81	271.79
Glen_17	3.76	4.67	5.31	5.97	6.94	7.77	8.68	11.26
Glen_18	74.83	93.22	107.40	123.00	147.24	169.66	196.00	279.18
Glen_19	2.44	3.03	3.44	3.88	4.51	5.04	5.64	7.30
Glen_20	76.42	95.20	109.68	125.61	150.36	173.26	200.16	285.11
Glen_21	77.55	96.61	111.31	127.47	152.59	175.83	203.12	289.33

4.3.6 Comparison of Design Flows with CFRAM Study

Table 4.16 presents a summary of the comparison between the final design flows area in the present hydrological analysis against the CFRAM Study at comparable HEPs across the Glenties study area.

Table 4.16 Comparison of Glenties FRS Design Flows vs CFRAM Study (comparable HEPs)

CFRAM Study HEP	Area	Qmed (m^3/s)	Q100 (m^3/s)	Glenties FRS HEP	Area	Qmed (m^3/s)	Q100 (m^3/s)	% Change Qmed	% Change Q100
38_3761_2	41.04	33.46	73.92	**Glen_01**	40.99	36.97	77.41	10%	5%
38_3822_4	49.25	39.53	88.71	**Glen_07**	49.07	38.08	84.42	- 4%	- 5%
38_23_1	1.32	1.53	3.78	**Glen_10**	1.25	2.01	4.33	31%	15%
38001	111.25	70.14	153.82	**Glen_21**	110.99	77.55	175.83	9%	14%

There are significant differences with the current hydrological analysis when compared to the design flows at the time of the CFRAM Study. In general, there has been an increase in the resolution of the analysis in terms of HEPs, catchment delineation, pooled analysis, growth curve development, and rating reviews associated with the gauging stations within the Glenties study area. Catchment delineation was reviewed using 2m LiDAR where available in comparison with the widespread use of the 5m National Digital Height Model (NDHM) during the CFRAM Study.

The changes shown on the Stracashel River (Glen_01) and Owenea River (Glen_21) are due to the knock-on effect of the rating review at Clonconwall Ford. This has resulted in an uplift in Q_{med} and the adjustment factor at the gauging station by 9.4% (approximately the uplift at each location from the CFRAM Study). The changes at the Q100 are due to small differences in the growth curves (Figure 4.4) between the two analyses.

The differences on the Gortnamucklagh (Glen_10) and the Owenea River entering the Stracashel (Glen_07) deviate from the general rise of around 10%. These differences, seen at Q_{med} and the Q100, are due to an over-generalisation of the PCDs used on these river reaches during the CFRAM Study. The application and assignment of PCDs were revisited and updated during the current hydrological analysis of PCDs which better characterise the catchments. In effect, the revised flows taken forward for this project are due to improved resolution and accuracy of the analysis.

4.4 Design Hydrograph Estimation

The previous sections discussed the process of arriving at peak design flow estimates. Before being applied within a hydraulic model these must be coupled to a hydrograph such that they provide a true representation of the rising and falling of a flood flow over time. The approach adopted is the FSU-based approach set out in the FSU Technical Research Report Volume III[2]. The method is similar in principle to the estimation of the Q_{med} in that it uses PCDs to arrive at an initial estimate of the hydrograph shape, defined in three parameters, and then uses a pivotal site to adjust the shape based on observed data.

4.4.1 Hydrograph Width Analysis

The approach used leans heavily on the method developed by Archer *et al.* (2000) and as set out in FSU under Technical Research Report Volume III. The method used is based on principles of Hydrograph Width Analysis (HWA). HWA aims to define the shape of the design flood hydrograph based on observed flood hydrographs which have occurred. The premise is that hydrographs of floods occurring at a particular station are broadly similar in character and that the typical shape of the hydrograph of a future flood - embodied in the design flood hydrograph – can be expected to reflect the general features of those which have already occurred.

The approach considers all the observed hydrographs represented within the AMAX series for the gauged catchment. Firstly, hydrographs are analysed to isolate the individual event shape with data from before and after this point removed. Hydrograph width is then determined for each 10th percentile of the peak flow and median widths are determined for each percentile. This is then used to determine a median width hydrograph reflecting the AMAX data based on three shape parameters:

n – Shape parameter of Gamma distribution (and of UPO-ERR-Gamma model)

T_r – Rise time (=translation parameter) of UPO-ERR-Gamma model)

C - Recession parameter of UPO-ERR-Gamma model (hours)

For the Glenties analysis this approach has been applied to a number of nearby gauging stations which were not included in the original FSU Hydrograph Width Analysis or have since been updated with a longer record period that may impact the Glenties study area significantly. These stations include:

- Carrigans at Gortinlieve (01016)

[2] http://opw.hydronet.com/data/files/Technical%20Research%20Report%20-%20Volume%20III%20-%20Hydrograph%20Analysis%281%29.pdf

- Owenea at Clonconwall Ford (38001)
- Stracashel at Glenties (38010)

The HWA hydrographs when applied at each of the HEPs may not accurately capture the baseflow characteristics for each catchment. This will be estimated based on catchment descriptors from the Flood Studies Supplementary Report No. 16 and as restated in the FEH Volume 4, equation 2.19 and is as follows:

$$BF = \{33(CWI - 125) + 3.0\,SAAR + 5.5\}10^{-5} AREA$$

Where:

BF = Baseflow (m^3/s)

CWI = Catchment Wetness Index

SAAR = Standard Average Annual Rainfall (mm)

4.4.2 Design hydrographs at Gauged Locations

The HWA was undertaken at the Clonconwall Ford gauging station as the basis for the design inflow hydrographs on the Owenea River. It was also undertaken on the record at the Stracashel water level only gauge in an attempt to validate the design hydrograph shape along the upper reaches of the model in the vicinity of Glenties. The FSU hydrograph shape generator was used at all ungauged locations to derive statistically informed catchment responses.

To validate the HWA output hydrographs at gauged locations, a data analysis process of event extraction, normalisation and superimposition was undertaken. This process involved the following steps:

1. Locate all AMAX events in the continuous records,
2. Extract the events by taking a window of 24hrs preceding and succeeding the event peak flow,
3. Overlay events with their mean and median traces to generalise complexities in observed hydrographs affected by compounded rainfall events and antecedent conditions,
4. Superimpose the design outputs from the HWA exercise.

4.4.2.1 Hydrograph Width Analysis for Owenea River at Glen_21 (Clonconwall Ford)

The HWA validation process was conducted on the entire Q15 flow record at Clonconwall Ford. The flow record is derived from the water level record at the gauge. Therefore, the Q15 flow record was reprocessed following the rating review. This was done by applying the new rating to the 15-minute water level file to produce an updated flow record using the new rating.

The outputs of the HWA are compared to the design hydrograph derived with the focus solely on shape in terms of key hydrograph characteristics (ascending and receding limb and time to peak). A total of 46 AMAX years were extracted from the continuous flow record from 1972-2020 (water years 2004 and 2005 are missing).

The extracted AMAX events were extracted, normalised, and superimposed with the design hydrograph generated by HWA. Mean and median observed hydrographs were also generated to aid comparison. Figure 4.5 shows the outputs of the HWA at Clonconwall Ford.

The design hydrograph output following HWA appears to be slightly wider than the average event hydrographs (mean and median hydrographs). The average event hydrographs are more heavily influenced by the more complex observed hydrographs, which is noticeable on the receding limb when compared to the receding limb of the design hydrograph.

The overall shape and timing associated with the design hydrograph are considered a good representation of the observed behaviour, albeit leaning towards a conservative interpretation of the receding limb and volume.

The design hydrograph was used for design flow estimation and hydraulic modelling (as a check flow hydrograph) at Clonconwall Ford.

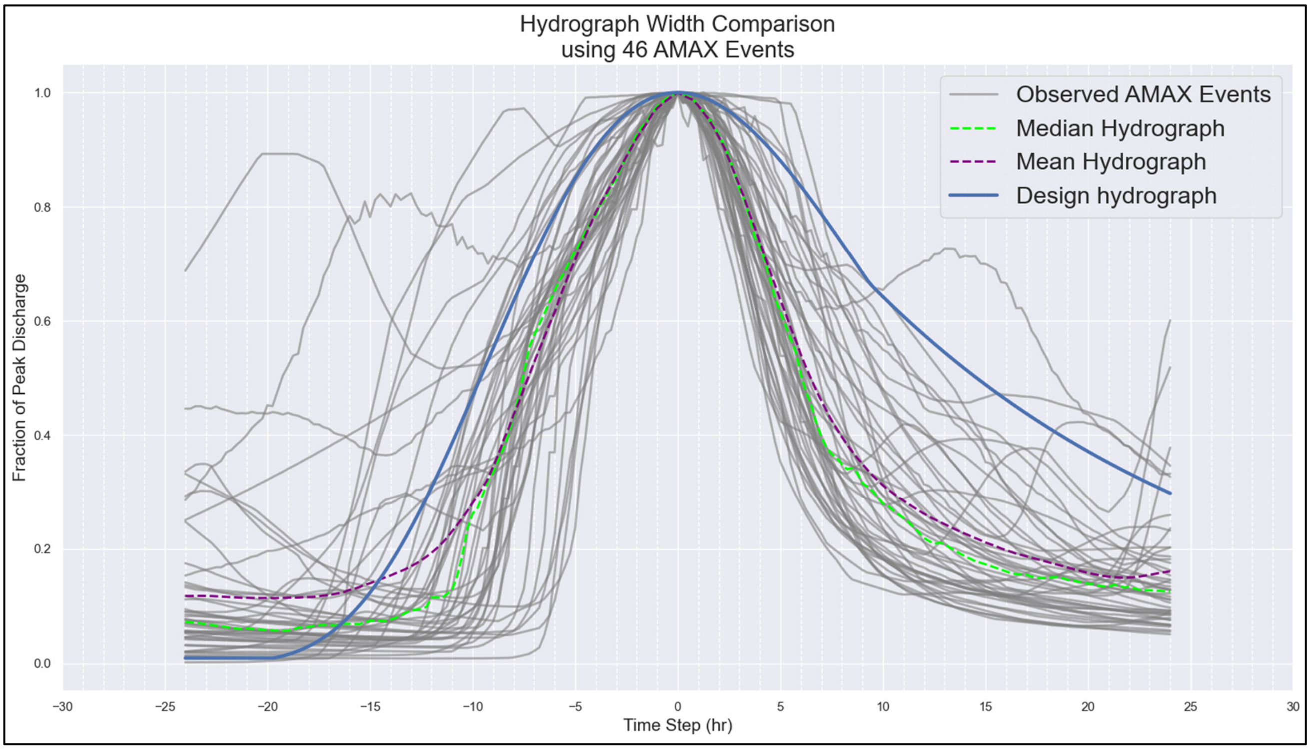


Figure 4.5 Clonconwall Ford Hydrograph Shape Validation

4.4.2.2 Hydrograph Width Analysis of Stracashel River at Glen_05 (Glenties WL)

HWA validation was also conducted on the Stracashel River at the Glenties water level only gauging station (Glen_05). Similar to the Clonconwall Ford HWA, the flow record is derived from the water level record at the gauge. The input Q15 flow record was processed post-rating review by applying the new derived rating (0) to the Q15 water level record.

The outputs of the HWA are compared to the design hydrograph derived with the focus solely on shape in terms of key hydrograph characteristics (ascending and receding limb and time to peak). A total of three AMAX years were extracted from the continuous flow record from 2019-2021. The water year 2021 is noted as being incomplete but has been included within the analysis as a means of validation purposes only.

The AMAX events were extracted, normalised, and superimposed with the design hydrograph generated by HWA. Mean and median observed hydrographs were also generated to aid comparison. Figure 4.6 shows the outputs of the HWA at Glenties gauging station on the Stracashel River.

The design hydrograph output following HWA appears to be slightly wider than the average event hydrographs (mean and median hydrographs). The average event hydrographs are heavily influenced by the more complex observed hydrographs, which is noticeable on the receding limb whereas the design hydrograph is slightly wider on the receding limb.

The overall shape and timing associated with the design hydrograph displays a good representation of the observed events. The design hydrograph was used for design flow estimation and hydraulic modelling (as a check flow hydrograph) along the Stracashel River reaches.

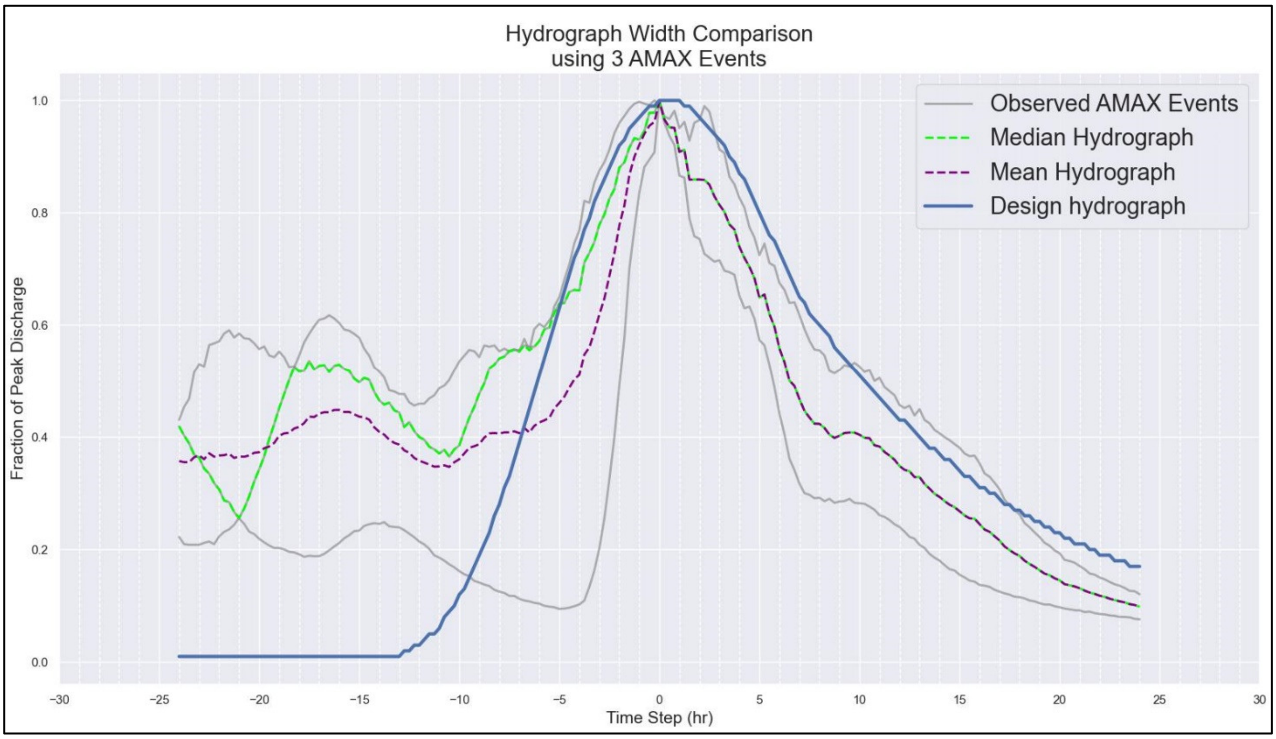


Figure 4.6 Stracashel at Glenties Hydrograph Shape Validation

4.4.3 Design hydrographs at ungauged locations

The design hydrographs at ungauged locations have been generated using the FSU Shape Generator that derives hydrograph shape parameters based on PCDs and adjusted based on pivotal site adjustment, like the method used during Q_{med} estimation.

The update of the FSU database for the hydrograph shape library was conducted to allow further refinement of the design hydrographs such that the FSU Shape Generator tool produced acceptable answers.

The main focus of the design hydrograph development was on the inflows to the Stracashel River and Gortnamucklagh watercourse (which also represents the tributaries throughout the Glenties study area) and the upstream catchment (Glen_06) of the Owenea River in the Glenties study area.

4.4.4 Design Hydrograph Pivotal Site Adjustment

Analysis of the Glenties hydrographs and the updated FSU pivotal site database found that the best choice of sites upon which to base a pivotal site adjustment are:

- Carrigans at Gortinlieve (01016), which was introduced during this study as a new gauging station.
- Deele at Sandy Mills (01041) given its geographical closeness and hydrological similarity to the Glenties study area.
- Owenea at Clonconwall Ford (38001) given its location within the Glenties study area on the modelled extents of the Owenea River at Glen_21.

Table 4.17 indicates the design hydrograph shapes at the ungauged locations within the Glenties study area.

Table 4.17 Pre- and Post-Pivotal Site Adjustment on Design Hydrograph Shape Parameters, Glenties

Watercourse	Pre-Pivotal Site Adjustment			Post-Pivotal Site Adjustment			Pivotal Sites used for Adjustment
	N	Tr	C	N	Tr	C	
Glen_01 (U/S Stracashel River)	11.43	23.21	5.01	**10.51**	**15.55**	**3.35**	**Deele at Sandy Mills (01041)** **Owenea at Clonconwall Ford (38001)**
Glen_07 (Owenea River at confluence with Stracashel)	7.33	18.95	14.97	**7.29**	**16.65**	**37.38**	**Owenea at Clonconwall Ford (38001)**
Glen_15 (Gortnamucklagh watercourse) *	12.30	15.347	4.88	**10.47**	**4.29**	**3.81**	**Carrigans at Gortinlieve (01016)** **Owenea at Clonconwall Ford (38001)**
Glen_16 (Owenea River, d/s of Gortnamucklagh watercourse)	10.05	27.51	6.22	**9.99**	**24.18**	**15.53**	**Owenea at Clonconwall Ford (38001)**

*representative of the hydrographs used for the tributary inflows across the Glenties study area

4.4.5 Final Design Hydrograph Shapes

The final output semi-dimensional hydrographs that have been taken forward for flow estimation and input into the hydraulic model are presented in Figure 4.7.

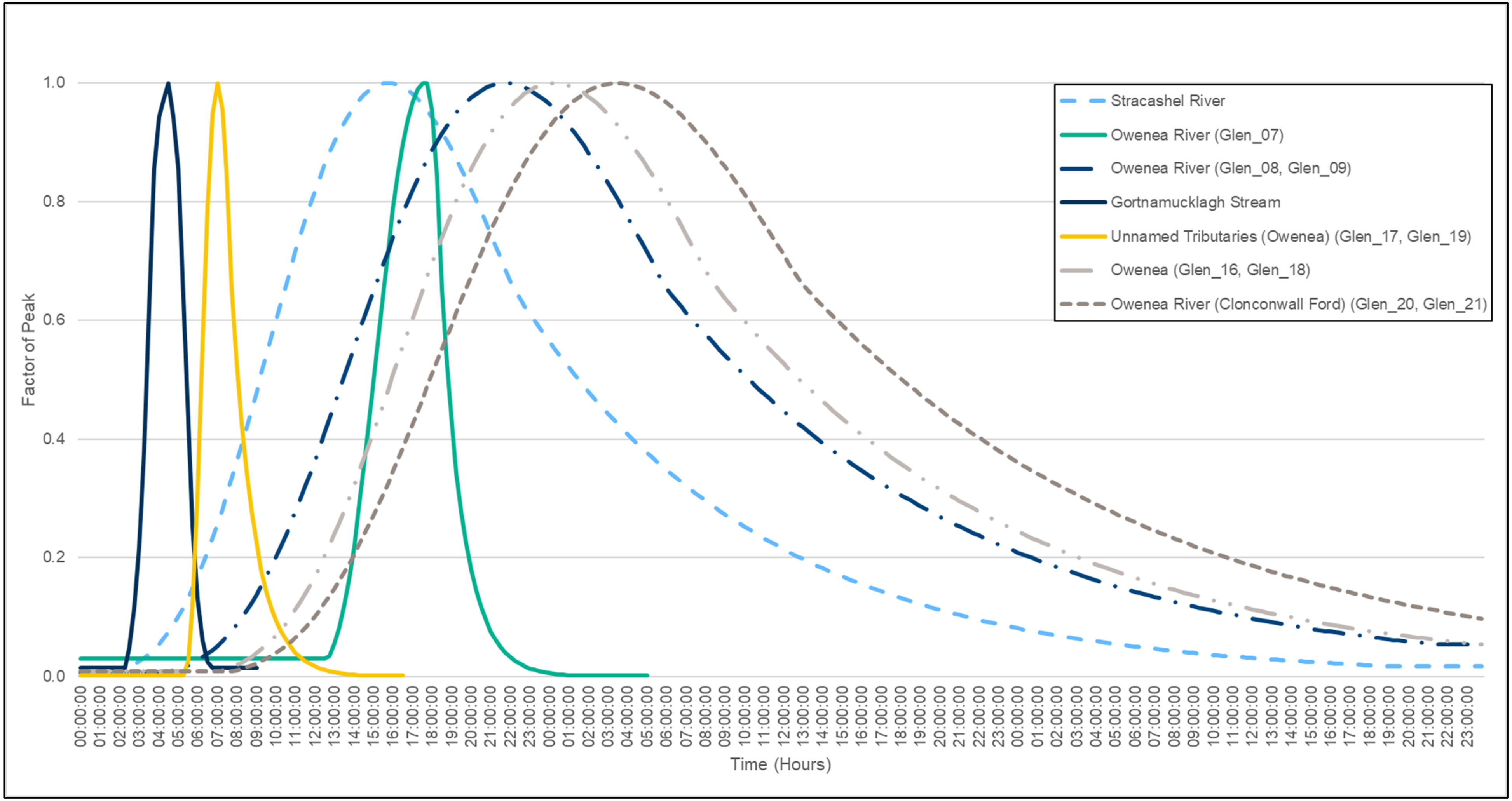


Figure 4.7 Design Hydrograph Shapes, Glenties

4.5 Design Flow Reconciliation and Hydraulic Model Inputs

Peak design flows have been estimated following the statistical methods set out in the FSU. Significant efforts were made to update the existing FSU datasets in terms of pivotal sites (and pivotal site adjustment), pooled analysis, growth curve development, and derivation of design hydrograph widths.

Pivotal site adjustments have been implemented to the peak design flow estimates and design hydrograph widths. The output design semi-dimensional hydrographs were then scaled to the statistical peak flow estimates across the range of return periods (50%, 20%, 10%, 5%, 2%, 1%, 0.5% and 0.1% AEP).

4.5.1 Lateral inflow generation

The preferred approach for the Glenties study area is to estimate the lateral inflow hydrograph by scaling the downstream HEP hydrograph to the lateral catchment area (between the subject HEP and the next HEP upstream).

$$Lateral\ Inflow = \frac{Lateral\ Catchment\ Area}{Downstream\ HEP\ Area} \times Downstream\ Check\ Flow$$

As an initial check before modelling, the sum of the inflow hydrographs is calculated at each of the intermediate and downstream HEPs to check the total inflow to the model at that point. This approach cannot account for the hydraulic effects on flows within the model such as flood peak travel time and attenuation but provides a check before modelling.

Glenties initial sum of inflows at Glen_21 (Clonconwall Ford gauging station and the outflow of the hydraulic model) at the Q_{med} event is 79.54m^3/s. This is an approximate 2.6% overestimation of the peak flows at Glen_21 in the Q_{med} event. This small difference is deemed within acceptable limits at the gauging station as the check flow at the end of the hydraulic model, anchoring the hydraulic model to hydrological estimates.

A complete check on whether appropriate lateral inflows have been estimated can only be made following hydraulic modelling of the inflows and as such the lateral inflows to the model may be amended following initial hydraulic modelling as part of the integrated approach to hydrological and hydraulic analysis.

5 SENSITIVITY ANALYSIS

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-based, have been shown to varying degrees to be changing over time. 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)
- Standard error of flow estimation (catchment descriptor-based) techniques
- Future catchment changes, urbanisation, afforestation, sedimentation, etc.
- Climate change

The above list is not exhaustive but seeks to identify the main potential sources of uncertainty in the hydrological analysis. It is not possible to make a quantitative assessment of all 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 in the hydraulic modelling phase. 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 been undertaken to assess the potential for uncertainty/sensitivity.

The assessment of uncertainty is used to derive a score for the uncertainty in the hydrological analysis for the Glenties River based on the approach adopted for the CFRAM Studies. The parameters affecting uncertainty are assessed out of a possible maximum score dependent on the likely impact of the source of uncertainty. Uncertainty scores out of a maximum of 20 were assigned to the main inflows to the model in the CFRAM Studies.

The CFRAM Study Guidance Note 22 derived a range of uncertainty factors associated with the FSU methodologies for deriving peak flows. The uncertainty associated with Q_{med} for ungauged catchments is 1.37 but for well-gauged catchments with long records can be as low as 1.06. It is appropriate therefore that the higher end of this range of error (1.37) is applied as a sensitivity factor to the Q_{med} flows for the Glenties study area for the ungauged HEPs where there is high uncertainty. The guidance note also suggests that for more extreme design flood events where the uncertainty is inherently higher a further factor should be applied based on the known uncertainties. The recommended uncertainty factors were adapted for CFRAM Study into recommendations to be applied to the 10% and 1% AEP design events as shown in Table 5.1.

Table 5.1 Example of uncertainty factors derived under the CFRAM Study

<table>
<tr><th rowspan="2">Event AEP%</th><th colspan="20">Summed Score</th></tr>
<tr><th>1</th><th>2</th><th>3</th><th>4</th><th>5</th><th>6</th><th>7</th><th>8</th><th>9</th><th>10</th><th>11</th><th>12</th><th>13</th><th>14</th><th>15</th><th>16</th><th>17</th><th>18</th><th>19</th><th>20</th></tr>
<tr><td>10%</td><td colspan="4">1.06</td><td colspan="6">1.14</td><td colspan="5">1.21</td><td colspan="3">1.29</td><td colspan="2">1.37</td></tr>
<tr><td>1%</td><td colspan="6">Use 10% uncertainty factor x 1.1</td><td colspan="6">Use 10% uncertainty factor x 1.2</td><td colspan="6">Use 10% uncertainty factor x 1.3</td><td colspan="2">Use 10% factor x 1.5</td></tr>
</table>

Uncertainty factors have been derived based on the quality of the available hydrometric data, the uncertainty in the catchment data, and the application of the chosen design flow method. The scores for the various aspects of uncertainty for each HEP, the summed score, and uncertainty factors and flows to be modelled are shown in Table 5.2 (see Section 3.5 in the Glenties Hydraulics Report for full information on the sensitivity analysis).

Table 5.2 Comprehensive Summary of Uncertainty Scores

Reach	HEP	Observed Data (Out of 10)	Catchment Data (Out of 5)	Ungauged Flow Estimates (Out of 5)	Comments	Summed Score (Out of 20)	10% AEP Uncertainty Factor	10% AEP Uncertainty Flow	1% AEP Uncertainty Factor	1% AEP Uncertainty Flow
Stracashel River	Glen_01	4	2	2	The Stracashel is well-defined under FSU in terms of PCDs and catchment delineation. FSU7 estimation methods was used on the main channel. Stracashel at Glenties water level only gauging station increased certainty in flows.	8	1.14	60.51	1.37	188.75
Unnamed Tributary	Glen_02	10	5	5	Not defined under FSU. FSU5 methods used for ungauged estimates. High uncertainty.	20	1.37	1.49	2.06	5.82
Stracashel River	Glen_03	4	2	2	The Stracashel is well-defined under FSU in terms of PCDs and catchment delineation. FSU7 estimation methods was used on the main channel. Stracashel at Glenties water level only gauging station increased certainty in flows.	8	1.14	60.89	1.37	189.93
	Glen_04	4	2	2		8	1.14	62.18	1.37	193.94
	Glen_05	4	2	2		8	1.14	62.16	1.37	193.88
	Glen_06	4	2	2		8	1.14	63.4	1.37	197.78
Owenea River	Glen_07	6	2	2	Owenea River is well-defined under FSU. It is anchored to the Clonconwall Ford gauging station in the lower reaches. FSU7 estimation methods were used.	8	1.14	62.49	1.37	194.92
	Glen_08	6	2	2		8	1.14	117.36	1.37	366.09
	Glen_09	6	2	2		8	1.14	117.6	1.37	366.82
Gortna-mucklagh Watercourse	Glen_10	8	3	3	Gortnamucklagh main channel is defined under FSU. The incoming tributaries not defined and are highly uncertain which is reflected in the uncertainty factors.	14	1.21	3.48	1.57	10.13
	Glen_11	8	5	5		18	1.29	0.47	1.68	1.37
	Glen_12	8	5	5		18	1.29	0.18	1.68	0.51
	Glen_13	8	3	3		14	1.21	4.7	1.57	13.68
	Glen_14	8	5	5		18	1.29	1.25	1.68	3.63
	Glen_15	8	3	3		14	1.21	6.62	1.57	19.24

Owenea River	Glen_16	2	2	1	Owenea lower reaches are well defined under FSU and are anchored to the Clonconwall Ford gauging station.	4	1.06	110.83	1.17	316.91
Unnamed Tributary	Glen_17	8	5	5	Not defined under FSU. FSU5 methods used for ungauged estimates. High uncertainty.	18	1.29	6.85	1.68	18.88
Owenea River	Glen_18	1	2	1	Owenea lower reaches are well defined under FSU and are anchored to the Clonconwall Ford gauging station.	4	1.06	113.85	1.17	325.53
Unnamed Tributary	Glen_19	8	5	5	Not defined under FSU. FSU5 methods used for ungauged estimates. High uncertainty.	18	1.29	4.44	1.68	12.25
Owenea River	Glen_20	1	2	1	Anchored to the Clonconwall Ford gauging station.	4	1.06	116.26	1.17	332.43
	Glen_21	1	2	1		4	1.06	117.99	1.17	337.36

Key

- Low uncertainty
- Medium / Low Uncertainty
- Medium Uncertainty
- Medium / High Uncertainty
- High Uncertainty

6 DESIGN RAINFALL

It may be necessary to drive portions of the hydraulic model with pluvial inputs. This will be the case where there is evidence of significant pluvial flooding from direct runoff or where the performance of the urban drainage sub-catchments needs to be modelled to determine the level of existing or residual flood risk. There may be no apparent risk from the drainage system presently, but this may need to be tested in the post scheme model to assess the level of residual flood risk and to design secondary mitigation (e.g., flap valves, pumps).

Where this is the case design rainfall inputs must be derived to use as boundary conditions within rainfall-driven hydraulic models/calculations. These are extracted from the FSU DDF model. Rainfall sums for a range of durations are extracted from the DDF model for the relevant sub-catchment or point which best represents the drainage sub-catchment in question.

6.1 Design Rainfall Sums

Design rainfall sums have been extracted from the FSU DDF model[3] for the suite of return periods. Rainfall sums have been extracted as point data from the FSU 2km grid point closest to the Glenties study area. FSU design rainfall sums (mm) are presented in Table 6.1.

Table 6.1 FSU Rainfall Sums, Glenties

Event Duration Hours	AEP (%) / Return Period (Year)							
	50% (2)	20% (5)	10% (10)	5% (20)	2% (50)	1% (100)	0.5% (200)	0.1%* (1000)
0.25	7.30	9.30	10.70	12.20	14.40	16.30	18.40	24.70
0.5	9.90	12.60	14.50	16.50	19.40	21.90	24.80	34.18
1	13.30	16.90	19.50	22.20	26.20	29.60	33.40	44.76
2	17.90	22.80	26.20	29.90	35.20	39.80	45.00	32.70
3	21.30	27.10	31.20	35.60	42.00	47.40	53.60	72.11
4	24.10	30.70	35.40	40.30	47.50	53.70	60.60	81.68
6	28.70	36.60	42.10	47.90	56.50	63.90	72.10	97.27
9	34.20	43.50	50.10	57.10	67.30	76.10	85.90	115.67
12	38.70	49.30	56.70	64.60	76.20	86.10	97.20	130.92
18	46.10	58.60	67.50	76.90	90.70	102.50	115.70	155.44
24	53.80	68.00	78.00	88.60	104.00	117.10	131.90	176.30

*The 0.1% AEP frequency event has had rainfall depths calculated by extrapolation from the depth values in the FSU DDF grid and the estimates provided for the various rainfall frequencies (50% - 0.5% AEP).

[3] FSU Technical Research Report Volume II Rainfall Frequency

6.2 Design Rainfall Profiles

Design rainfall sums are disaggregated over the FSR summer and winter rainfall profiles[4] depending on an assessment of the likely seasonality of a drainage system flood event. Both summer and winter profiles will be tested due to the variation in flooding reports in terms of seasonality at Glenties. The FSR summer and winter rainfall profiles across which the rainfall sums are applied are shown in Figure 6.1.

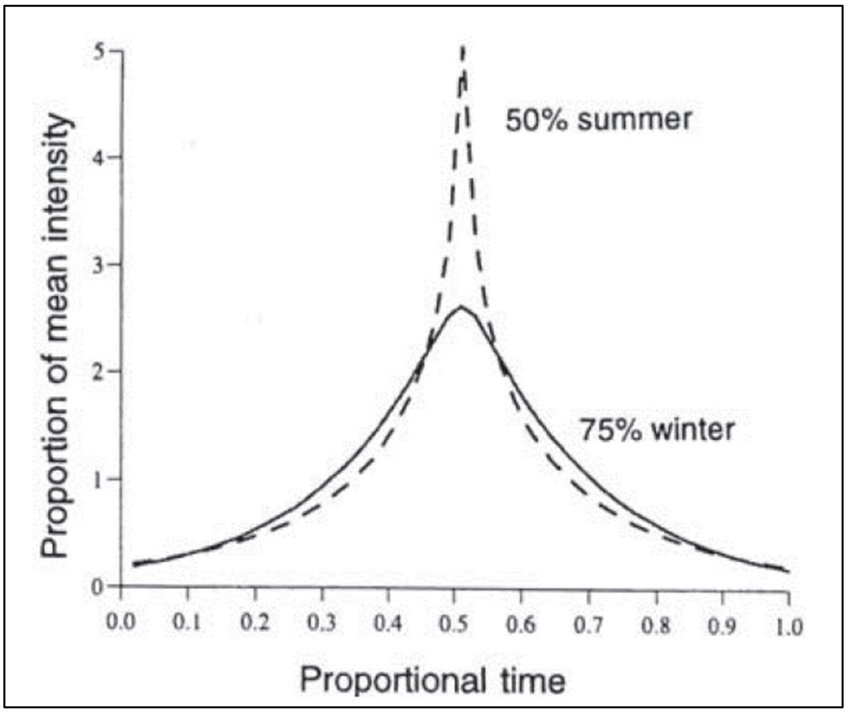


Figure 6.1 FSR Rainfall Profiles, extracted from FEH Volume 2, Chapter 4 (1999)

Where the pluvial analysis is used to test behind defence drainage, the critical event duration and season may need to be considered against the fluvial critical storm duration and seasonality where the critical mechanism is locked out of the drainage system due to high levels in the receiving river/watercourse.

The range of event durations will be tested within the model to determine the critical event in relation to the sub-catchment / drainage system and the full range of current and future scenario design events run for that duration.

[4] See Flood Estimation Handbook Volume 2, Chapter 4 (Institute of Hydrology, 1999)

7 FUTURE SCENARIOS

There are a number of potential future changes which could impact the effectiveness of any flood management measures proposed. It is prudent that the potential impacts are identified and quantified such that effective planning and design for adaptation can be accommodated. The adjustments applied to the design flow estimates are outlined in 'Flood Risk Management, Climate Change Sectoral Adaptation Plan' (OPW, 2019)[5] and are reproduced in Table 7.1.

Rates of urbanisation were assessed under the CFRAM Study and are reported in the CFRAM Study Hydrology Report[6]. The Owenea River main catchment is predominantly rural however the smaller tributary catchments are partially urbanised and susceptible to significant future urbanisation if the Glenties settlement expands. Therefore, it is predicted that within these smaller, partially urbanised catchments there will be a greater impact on future flood flows. The growth rates shown in Table 7.1 are applied to the catchment descriptors describing urban fabric within the relevant catchment for Glenties and the effect on Q_{med} applied through the FSU methods calculated and applied to the design flows.

Table 7.1 Allowances for Future Scenarios for 100-year time horizon considering urbanisation growth rates reported in the CFRAM Hydrology Report

Parameter	Mid-Range Future Scenario (MRFS)	High-End Future Scenario (HEFS)
Extreme Rainfall Depths	+ 20%	+ 30%
Peak Flood Flows	+ 20%	+ 30%
Mean Sea Level Rise	+ 500 mm	+ 1000 mm
Urbanisation	1% per annum	2.5% per annum
Forestation	Reduce time to peak by 1/6	Reduce time to peak by 1/3 + 10% on SPR (Standard Percentage Runoff)

For the Stracashel catchment (GLEN_09) it is anticipated that peak flows will increase by 22% in the MRFS. 20% of this compound growth[7] is attributable to climate change and a further 2% is attributable to future urbanisation of the catchment which is expected to be high in this small catchment. For the HEFS, peak flows are projected to increase by 42% with 30% attributable to climate change and 19% attributable to urbanisation.

For the Gortnamucklagh catchment (GLEN_15) it is anticipated that peak flows will increase by 32% in the MRFS. 20% of this compound growth is attributable to climate change and a further 10% is attributable to future urbanisation of the catchment which is expected to be high in this small catchment. For the HEFS, peak flows are projected to increase by 72% with 30% attributable to climate change and 43% attributable to urbanisation.

[5] Accessed at:

https://www.gov.ie/en/publication/97984b-climate-change-and-sectoral-adaptation-plan/

[6] NWNB CFRAM Study UoM01 Hydrology Report

[7] Note compound growth is calculated by multiplying the components of growth, e.g. 4% growth on top of 20% growth = 1.04 x 1.20 = 1.25, i.e. 25%

For the Owenea catchment (GLEN_21) it is anticipated that peak flows will increase by 22% in the MRFS. 20% of this compound growth is attributable to climate change and a further 2% is attributable to future urbanisation of the catchment which is expected to be high in this small catchment. For the HEFS, peak flows are projected to increase by 41% with 30% attributable to climate change and 18% attributable to urbanisation.

8 CONCLUSIONS

Glenties lies at the junction of the two largest sub-catchments which make up the Owenea catchment; the Owenea and the Stracashel, with the smaller Gortnamucklagh watercourse discharging into the Owenea to the southwest of Glenties town. The Stracashel drains a glen to the north-east of Glenties, before flowing through the town. The Gortnamucklagh watercourse drains an area to the north and discharges with the Stracashel into the Owenea River downstream of Glenties.

There are two gauging stations within the Glenties study area. Stracashel at Glenties gauging station is a recently installed water level and flow gauging station located within Glenties town. The Owenea at Clonconwall Ford gauging station is a long-standing hydrometric gauge located downstream of Glenties. Rating reviews were conducted at both gauging stations to help increase the confidence in the design flow estimation across the Glenties study area. The key outcomes of the rating reviews were:

- An initial rating was developed for the Stracashel at Glenties gauging station which allowed the estimation of a Q_{med} flood flow. This provided some validation of the design flow estimate of Q_{med}.
- Stracashel at Glenties gauging station was not used as the basis of design flow estimation or flood frequency conditions on the Stracashel River due to the limited data period available
- The Owenea at Clonconwall Ford gauging station was subject to the development of a newly proposed rating curve that deviated from the current OPW curve, particularly at the high flows. This has led to a 9.4% increase in Q_{med} as well as an increase in the recorded peak flows across the AMAX record.
- The increase at Q_{med} at Owenea at Clonconwall Ford gauging station formed the basis of the design flow estimation on the Owenea including Q_{med} estimation and pivotal site adjustment.

The hydrological analysis relies on the statistical methods for flood flow estimation set out in the FSU. Namely the standard FSU 7 variable equation for ungauged catchment but also the FSU 5 variable equation optimised for small Irish catchments. The ungauged estimates are anchored to the rating reviewed gauge data as recommended within the FSU.

The updating of the hydrological analysis through the rating reviews, pooled analysis updates and pivotal site adjustment has led to slight increases across the Glenties study area at comparable HEPs from the time of the CFRAM Study.

There is high certainty in the flood flow estimates for the Stracashel and Owenea reaches owing to their size and gauged nature, particularly following the rating reviews. The smaller, ungauged Gortnamucklagh watercourse has much higher uncertainty.

8.1 Recommendations for Data Collection

Data collection remains vital in understanding flood frequency conditions and estimating design flow estimates at any site. The presence of gauged data lessens the margin of uncertainty that is associated within ungauged estimates.

The following recommendations for data collection should be considered:

- There is no available rainfall data within the Glenties study area. A high-resolution rainfall gauge at Glenties would assist in the analysis of the frequency of future flood events which may occur and the validation (or otherwise) of the Glenties FRS Stage 1 analysis.

The presence of the Stracashel at Glenties gauging station allows for the estimation of flows on the Stracashel River. To fully understand the flood behaviour on the Stracashel River an increased data collection programme of spot gauging measurements should be the main focus of hydrometric activities in the coming years at Glenties. The spot gaugings should continue to be captured across the range of flow events, with a particular focus on the high flows, if possible, to help validate the preliminary rating developed as part of this project.