Coirib go Cósta
Scéim Faoisimh Tuilte Chathair na Gaillimhe
Galway City Flood Relief Scheme

Galway City Flood Relief Scheme
Hydrology Report

January 2023

Tionscadal Éireann
Project Ireland
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OPW
Oifig na nOibreacha Poiblí
Office of Public Works

Comhairle Cathrach na Gaillimhe
Galway City Council

ARUP

GALWAY CITY

FLOOD RELIEF SCHEME

HYDROLOGY REPORT

JANUARY 2023

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Abbreviations

AEP	Annual Exceedance Probability
AFA	Area of Further Assessment
ALLUV	Proportional extent of floodplain alluvial deposit
ALTBAR	Mean elevation of catchment (m)
AM	Annual Maximum
AREA	Catchment Area (km^2)
ARTDRAIN2	Fraction of Catchment that has undergone OPW arterial drainage
BFISOIL	Soil baseflow index (estimate of BFI derived from soils, geology and climate data)
CFRAM	Catchment Flood Risk Assessment Management
C.I.	Confidence interval
CV	Coefficient of Variation
CWI	Catchment wetness index
D_{ij}	Euclidean distance measure from the FSU
DRAIND	Drainage Density km/km^2
DTM	Digital Terrain Map
EDA	Exploratory data analysis
EPA	Environmental Protection Agency
ESB	Electricity Supply Board
EU	European Union
EV1	Extreme Value Type 1 = Gumbel (a 2-parameter distribution)
FAI	Flood attenuation index
FARL	Index of flood attenuation by reservoirs and lakes
FEH	Flood Estimation Handbook
FLATWET	PCD summarising proportion of time soils expected to be typically quite wet
FOREST	Proportional extent of forest cover FSE Factorial standard error
FRMP	Flood Risk Management Plan
FRS	Flood Relief Scheme
FSE	Factorial standard error
FSR	Flood Studies Report
FSSR	Flood Studies Supplementary Report
FSU	Flood Studies Update

GCC	Galway City Council
GCoCo	Galway County Council
GEV	Generalised Extreme Value (a 3-parameter distribution)
GLO	Generalised Logistic (a 3-parameter distribution)
HA 25	Hydrological Area 26 (Upper Shannon)
HA 26	Hydrological Area 30 (Corrib)
HEC	Hydrological Engineering Centre US Army Corp of Engineers
HEFS	High-End Future Scenario
HEL	Hydro Environmental Ltd.
HEP	Hydrological Estimation Point
HGF	Highest gauged flow
H-skew	Hazen-corrected skewness
iid	Independently and identically distributed
LA	Local Authority
L-CV	Coefficient of L-variation (Hosking and Wallis, 1997)
L-Kurtosis	Coefficient of L-kurtosis (Hosking and Wallis, 1997)
L-Kkewness	Coefficient of L-skewness (Hosking and Wallis, 1997)
LN2	2-parameter lognormal (a distribution)
LN3	3-parameter lognormal (a distribution)
LO	Logistic (a 2-parameter distribution)
LP3	Log Pearson Type 3
Malin	OS Malin Head Datum (Mean Sea level)
mOD	Metres Over Datum (Malin)
MRFS	Mid-Range Future Scenario
MSL	Mainstream length (km)
NERC (UK)	Natural Environment Research Council
NETLEN	Total length of river network above gauge (km)
NWRM	Natural Water Retention Measure
OSi	Ordnance Survey Ireland
OGSM02	Ordnance Survey Geoid Model 2002
OGSM15	Ordnance Survey Geoid Model 2015
OPW	Office of Public Works
PASTURE	Proportional extent of catchment area classed as grassland/pasture/agriculture

PDF	Probability density function
PEAT	Proportional extent of catchment area classified as peat bog
PCD	Physical Catchment Descriptor
Poolbeg	OSi Poolbeg Datum (Lowest Astronomical Tide at Poolbeg Lighthouse)
POT	Peaks Over Threshold series
QBAR	Mean annual maximum flood flow
Qmed	Median annual maximum flood flow
QT	T-year flood
ROI	Region of influence
S1085	Slope of main stream excluding the bottom 10% and top 15% of its length (m/km)
SAAPE	Standard-period average annual potential evapotranspiration (mm)
SAAR	Standard Annual Average Rainfall
SE,se	Statistical standard error (of an estimate)
SOIL	FSR Soil index based on WRAP classifications
SPR	Standard Percentage Runoff
Tb	Time of Base
Tp	Time to peak
Tc	Time of Concentration
TUH	FSR Triangular Unit Hydrograph
UoM	Unit of Management
URBANEXT	Urban Fraction of Catchment
UAF	Urban adjustment factor
UoM	Unit of Management
WI	Waterways Ireland
WRAP	FSR Winter Rainfall Acceptance Potential - soil class

1 Executive Summary

1.1 Introduction

The hydrology study for the proposed Corrib go Cósta (Galway City) Flood Relief Scheme established the best estimates of design return period flood flow magnitudes and associated flood hydrographs within the Galway City Flood Relief Scheme (FRS) Area for the River Corrib and associated local tributaries of the Terryland and Sruffaunacashlaun Streams. Hydrological calculations were completed using best practice FSU methodologies. For this process, suitable HEP locations have been selected and their PCD data updated where required.

The study also examined the tidal flood levels in Inner Galway Bay in respect to extreme storm surge tidal flood events and evaluated combined probabilities with fluvial and pluvial flood events. These fluvial, pluvial and tidal flood estimates are required as inputs to the hydraulic flood model of the estuary, river network and floodplain areas within the FRS area in order to determine the respective return period design flood levels, flow depths and velocities and flood duration .

1.2 Flood Flow Rating Review of Key Hydrometric Stations

A flow rating review of the Wolfe Tone and Claregalway hydrometric stations was carried out to improve the reliability of the flood flow estimates for these stations and to update their respective AM flow series. This rating review was supported by topographic survey and hydraulic modelling. The Wolfe Tone Gauge represents an important hydrometric gauging station for estimating River Corrib flows. The Rating relationship was revised with various ratings produced for different time periods when the stage was measured downstream of the bridge, upstream and more recently reinstalled downstream. The gauge is tidally influenced and extraction of the fluvial component is required at non-tidal periods. The gauge also suffers fluctuations in water level due to turbulence effects particularly towards low tide. The reliability of the flood rating for this site is assessed as moderate. A rating review of the Dangan Gauge on the Corrib as an upstream alternative was carried out for the flood flow range, when all barrage sluice gates are opened. This was found to be generally the case at the annual maximum flow rates. A reliable AM flood flow series for Dangan gauge was produced for the period 1986 to 2020. The index Q_{MED} flow rate measured at Dangan and Wolfe Tone gauges for the same period were within 2.26% of each other, which is within acceptable range of measurement accuracy.

1.3 Hydrological Estimation Points

A total of 22 Hydrological Estimation Points within the Flood Relief Scheme area, 15 on the Corrib River, 5 on the Terryland River and 2 on the Sruffaunacashlaun Stream were selected at key locations for flood flow estimation and input to the hydraulic model. All catchment PCD's at these estimation points were reviewed and revised as necessary.

1.4 Return period flood flows

Return period flood flow estimates for the Corrib were obtained using the FSU index flood method with a pooled flood growth curve. The Flood Studies Update PCD equation was used with a pivotal adjustment to the Q_{MED} value using the gauged Q_{MED} for Dangan and WolfeTone stations. The QMED estimate for the Corrib to Galway City (HEP 30_3419_2 located 290m upstream of the Salmon Weir Barrage) is 255.7cumec with a S.E. of 9.2 cumec (or 3.6% of Q_{MED}). This estimate is based on combining the gauged Q_{MED} from Wolfe Tone (Q_{MED} = 250.6 cumec for AM period 1972 – 2020) and from Dangan (Q_{MED} = 260.8 cumec for AM period 1986 – 2020). This represents a FSU pivotal adjustment factor of 1.608 ($QMED_{gauged}/QMED_{PCD}$) for all of the Corrib HEPs within the scheme area.

The recommended flood growth curve for the Corrib is obtained from a 513 station-year pooling group of 9 stations selected using Euclidean distance based on modified FSU method using 4 PCD parameters , namely, AREA, SAAR, BFISOIL and FARL and fitting an EV1 probability distribution. This gives a growth curve very similar to the average of the at-site, Corrib regional, and FSU pooling group growth curves. The growth factor for the 100year flood is 1.704, giving a Q_{100} of 435.7 cumec with an estimated statistical error of 8.31%. It is expected that the design flows developed by fitting an EV1 distribution will be reasonably conservative for the Corrib due to the attenuating effect from Lough Corrib and its extensive regionally important karst aquifer on the eastern side of Lough Corrib, which limits peak flow rates discharging from the lake.

On the small ungauged sub-catchments, peak flow estimation is less certain as Qmed has been estimated using ungauged catchment methodology. A suite of hydrological estimation methodologies has been used. The IH124 and Rational methods are recommended for the Terryland and Sruffaunacashlaun streams. Flood flow estimates from both methods are recommended for consideration in the hydraulic modelling of these streams. Hydraulic sensitivity analysis should reflect the high degree of uncertainty associated with the design flood flows for these small, highly urbanised ungauged catchments.

1.5 Design Flood Hydrographs

The design hydrograph for the Corrib was developed using the FSU Hydrograph width method using an UPO Gamma Curve shape with a shape parameter n = 1.9 and a shift parameter Tr = 460hours, commencing at a flow rate of 40% of the design flow (i.e. F = 0.4) and the standardized ordinates multiplied by the required design flood peak magnitude to produce the design flood hydrograph. The FSR design storm with unit triangular hydrograph method is recommended for small urbanized catchments of the Sruffaunacashlaun Stream and the Terryland River.

1.6 Tidal Flood Analysis

Tidal flood analysis was carried out to provide design tidal flood levels and tidal flood elevation profiles as input to the coastal tide inundation and wave overtopping model analysis for the Flood Relief Scheme. The highest astronomical tide this century occurred on the 29/09/2015 having an estimated astronomical tide height of 2.895m OGSM15 based on the Marine Institute astronomical tide forecast model for Galway Port. The lowest astronomical tide based on the Marine Institute model for the record period 2007 to 2022 was found to be -2.967m OD.

The critical larger tidal flooding is produced by Atlantic storm surge events that coincide with higher astronomical spring tide periods. Storm surges of significance occur when an Atlantic depression system is backed by strong gale force westerly winds raising locally the sea water level due to reduced atmospheric pressure and the associated wind shear that tilts the water surface and seiching effects within Inner Galway Bay. This surge can be further pronounced by local wind direction coming around from west to the south towards the peak of the event. Storm surge effects along the West Coast of Ireland can in the more extreme cases increase the normal high-water level by well over 1.5m. From the Galway Port 15year gauge record (2007 to 2022) the estimated maximum surge height of 1.74m occurred on the 18 December 2019.

The ICWWS (2020) estimates the 200year and 1000year coastal flood levels for node W6 (adjacent to Mutton Island) at 4.01m and 4.26m OD Malin respectively. The statistical analysis of the gauged AM tidal flood series gives 200year and 1000year elevations of 3.96m OD and 4.24m OD respectively. The ICWWS predictions includes a flat rate of +0.15m across all of the return periods for local wind/wave and seiching effects on tidal flood levels within inner Galway Bay and recommends an additional model error of 0.15m.

1.7 Storm Surge Design Profile

Analysis of the surge profiles from 17 storm surges exceeding 1m during the record period analysed 2007 to 2022 was carried out to define a design profile shape for the surge event. These surge profiles show considerable variation in shape, some short and sharp and others prolonged. Given the irregularity of the surge profiles and variation between events it is recommended that a smooth, wide profile is used to represent the design surge profile. Different functions, including sine, polynomial and Gamma functions was applied to the data to produce a robust and realistic profile. The selected function was a sine curve to define the sharper section of the profile and the tails of the profile defined by an exponential decay function. The recommended tidal flood profile that retains a degree of conservatism but is not overly conservative is the combination of storm surge profile that peaks at mid-ebb stage coinciding with high spring tides. This profile raises the low water and next high water which may also be important for pumping considerations behind flood defences.

1.8 Joint Probability Analysis

Joint probability analysis was carried out between tidal and Corrib Flood Events giving a 200-year combined probability of a 200-year tidal flood peak of 3.98mOD with a Corrib flow of 145m^3/s or a 100year Corrib flood of 435.65m^3/s with a 3.01mOD Tidal highwater. Joint probability analysis was also carried out between short duration rainstorm events and Corrib flows and also with tidal highwater levels. The analysis found that there is low correlation between the short duration hourly maximum rainfall and River Corrib flood flows. There is poor to moderate correlation between the short duration hourly maximum rainfall and tidal high tide levels.

1.9 Trend Analysis of Corrib Flows

The Wolfe Tone AM flood flow series record suggests that there is significant increasing trend in the AM flows in the Corrib from the 1950's to present time. However, examination of record from 1972 onwards does not suggest any significant change, which is the record period post the majority of the Arterial drainage works on the Corrib Catchment. On the River Clare, the Corrofin gauge AM flood flow record from 1954 onwards suggests significant increasing trend most likely due to the Arterial Drainage Works. However, the Ballygaddy gauge on the Clare (for the period 1974 onwards) post arterial drainage, suggests no significant trend in the AM series and the Claregalway gauge record is too short to draw any conclusions. The Lough Corrib lake gauges which are post drainage scheme (Cong and Annaghdown provide records from 1972 onwards) and the Dangan River Corrib gauge (1986 onwards) show no significant trend at the 90-percentile or greater significance.

In conclusion, the time series of annual maximum floods both parametric (flood level and flow rate magnitude) and non-parametric (flood ranking index) for the AM series examined generally display increasing trends in the flood magnitude with time. In many of the AM series that captured both pre and post arterial drainage works some of this increasing trend is clearly due to these drainage works. However, the continued trend in increased flood events and their magnitudes in the post arterial drainage record period suggests that other sources, such as, land-use changes (agricultural drainage of the catchment, forestry loss of peatlands, etc.) and climate change are having an influence. Statistically the significance of this more recent trend post arterial drainage works cannot be proved at 90% or greater significance without a longer record period.

The record period for gauged tidal flood levels within inner Galway Bay was too short to establish any significance trend. However, it is noted that the three largest tidal floods have occurred in the past decade.

1.10 Recommendations

It is recommended that the climate change allowances of 20% and 30% increase at the MRFS and the HEFS be included for both storm rainfall and flood runoff in assessing the adaptation of the proposed flood relief scheme to future change. The sea level rise of 500mm and 1000mm associated with the MRFS and the HEFS cases be included in assessing the adaptation of the proposed coastal and estuarine flood relief measures. Future potential catchment land-use changes, agriculture and forestry are not considered for the Corrib catchment to be significant drivers for increase in the design flood magnitudes and changes to the hydrograph shape through Galway City. The potential impact of local urbanisation to runoff rates within potential defended lands will require careful consideration, particularly where temporary storage or pumping of storm flows from the defended areas might be required.

It is recommended to include for hydrological uncertainty in respect to Corrib design flows and the tidal flood levels allowances based on measurement, model and statistical error. These increases in the design flood flow and tidal height magnitudes should be tested in the sensitivity analysis of the hydraulic design.

Table 1-1 Return Period Design Corrib Flood Flows and Tidal Flood Level

Return Period T years	**2**	**5**	**10**	**20**	**50**	**100**	**200**	**1000**
Corrib Flood Flow QT (m^3/s)	255.7	304	335.7	366.4	406	435.7	465.3	533.8
Q_T Uncertainty allowance (m^3/s)	34.8	46.9	54.8	62.4	72.4	79.7	87.2	104.3
Tidal Flood Level H_T (m OSGM15)	3.19	3.37	3.49	3.60	3.76	3.87	3.98	4.25
H_T Uncertainty allowance (m)	0.11	0.13	0.14	0.16	0.18	0.19	0.21	0.25

2 Introduction

2.1 Background

The Office of Public Works (OPW), in partnership with Galway City Council (GCC) have completed a Catchment Flood Risk Assessment and Management Study (CFRAMS) for the Corrib Catchment, which includes the Galway City Area. The Catchment Flood Risk Management Plan (CFRMP), which was published in 2018, concluded that a flood relief scheme for Galway City would be viable and effective.

Arising from the CFRMP, Galway City Council in association with the OPW have commissioned Arup to develop a flood relief scheme for Galway City. The project will consist of five stages as follows:

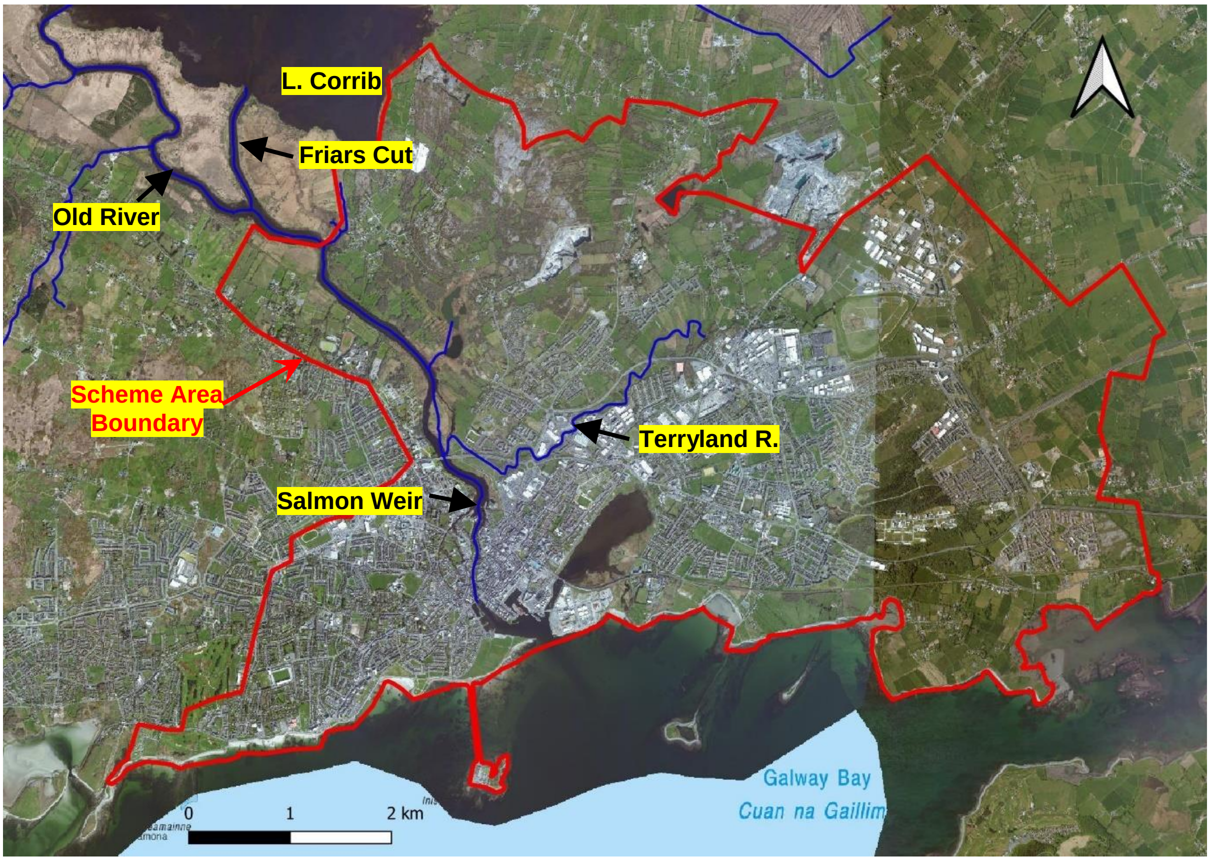
- Stage I: Identification and Development of a Preferred Scheme
- Stage II: Public Exhibition/ Planning Process
- Stage III: Detailed Construction Design, Compilation of Work Packages and the Preparation of Tenders for Contracts and Confirmation Documents
- Stage IV: Construction Supervision & Project Management Services
- Stage V: Handover of Works

The project title of the Galway City Flood Relief Scheme (FRS) is Corrib go Cósta and the Hydrology Report is produced as part of Stage I of the project. The Hydrology Report provides the design flood conditions for the Flood Relief Scheme in respect to identifying and developing the preferred scheme under Stage I of the project. Hydro Environmental Ltd. In association with ARUP was responsible for the preparation of the hydrology report.

The hydrological analysis in combination with the hydraulic flood modelling considers the flood risk emanating from the River Corrib, its local tributaries, drainage areas, estuary and coastal waters on the city of Galway. The hydrology study establishes best estimates of return period flood flow magnitudes and associated flood hydrographs within the Galway City Flood Relief Scheme Area from the Corrib and associated tributaries. The study also examines the tidal risk on the city from Galway Bay in respect to extreme storm surge levels and potential combination effects with fluvial and pluvial flood and storm events. These fluvial, pluvial and tidal flood estimates are required as inputs to the hydraulic flood model of the estuary, river network and floodplain areas within the FRS area to determine the respective flood levels, flow depths and velocities and flooding duration. The FRS area is the area within the red line boundary presented in Background Map Data © 2023 Google, DigitalGlobe

Figure 2-1 and extends upstream to the outlet from Lough Corrib.

Please note for clarity that all levels stated as m OD Malin are to the current OGSM15 geoid model datum unless otherwise stated. Other datums referred to in the report for historical reasons are Poolbeg datum and OGSM02.



Background Map Data © 2023 Google, DigitalGlobe

Figure 2-1 Galway City Flood Relief Scheme Area Boundary

2.2 Corrib Catchment

2.2.1 General description

The main river flowing through Galway City is the River Corrib which flows from Lough Corrib southwards to sea at Galway Port. The lower reach of the Corrib downstream of the OPW salmon weir barrage in Galway City is tidally influenced. The estuarine / transitional reach of the Corrib open to the sea is downstream of Wolfe Tone Bridge in the Claddagh basin, refer to Figure 2-2. The tidal backwater from the claddagh basin impacts water levels in the river reach from Wolfe Tone Bridge to upstream of the Salmon Weir Bridge and just downstream of the OPW Sluice Barrage.

The River Corrib channel from the Lough Corrib to the sea is a significantly modified channel through human engineering intervention and is very much canalised through Galway City. The Corrib Navigation and Drainage Works in the period 1848 to 1858 excavated a new wide outlet channel from Lough Corrib known as “The Friar’s Cut” which provides a more direct shorter and deeper channel (1.3km in length) to drain the lake than the former, meandering old channel of almost 3.8km in length, which is still present today. The “Friar’s Cut” channel is the main flow conduit from the Lake, refer to Figure 2-4. The Friar’s Cut” extends into the lake to meet the deeper navigable waters. As part of the Corrib Navigation and Drainage Works (1848 to 1858) the canal system in Galway was constructed including the main Eglington Canal.

Significant excavation of the River Corrib channel has taken place both during the original Corrib Drainage and Navigation Scheme (1848-1858) and also during the OPW Corrib-Clare Arterial Drainage Scheme (in the late 1950’s and early 1960’s). The River Corrib channel is a navigation channel and is reasonably wide, varying typically from 80m to 130m between riverbanks and typically 3 to 4m deep in the navigation section of the channel. It is an impounded channel with levels maintained generally close to 6m OD Malin throughout the year by gated sluices at the Salmon Weir barrage that is operated by the OPW Arterial Drainage Section.

The catchment area of the River Corrib based on the EPA Hydrotool and the OPW FSU Physical Catchment Descriptor Data (based on DTM elevation data) is estimated at 3,136km^2 to Wolfe Tone Bridge, 3121km^2 to the Dangan Slip Hydrometric gauge, refer to Figure 2-3 for catchment map. This catchment is quite large by Irish standards and is the biggest river system in the Western River Basin District and is the sixth largest river catchment on the island of Ireland (i.e., Shannon(15,700km^2), Bann (5,810 km^2), Erne (4,370 km^2), Suir (3,610km^2), Blackwater (3,330km^2) and Corrib(3,140km^2)).

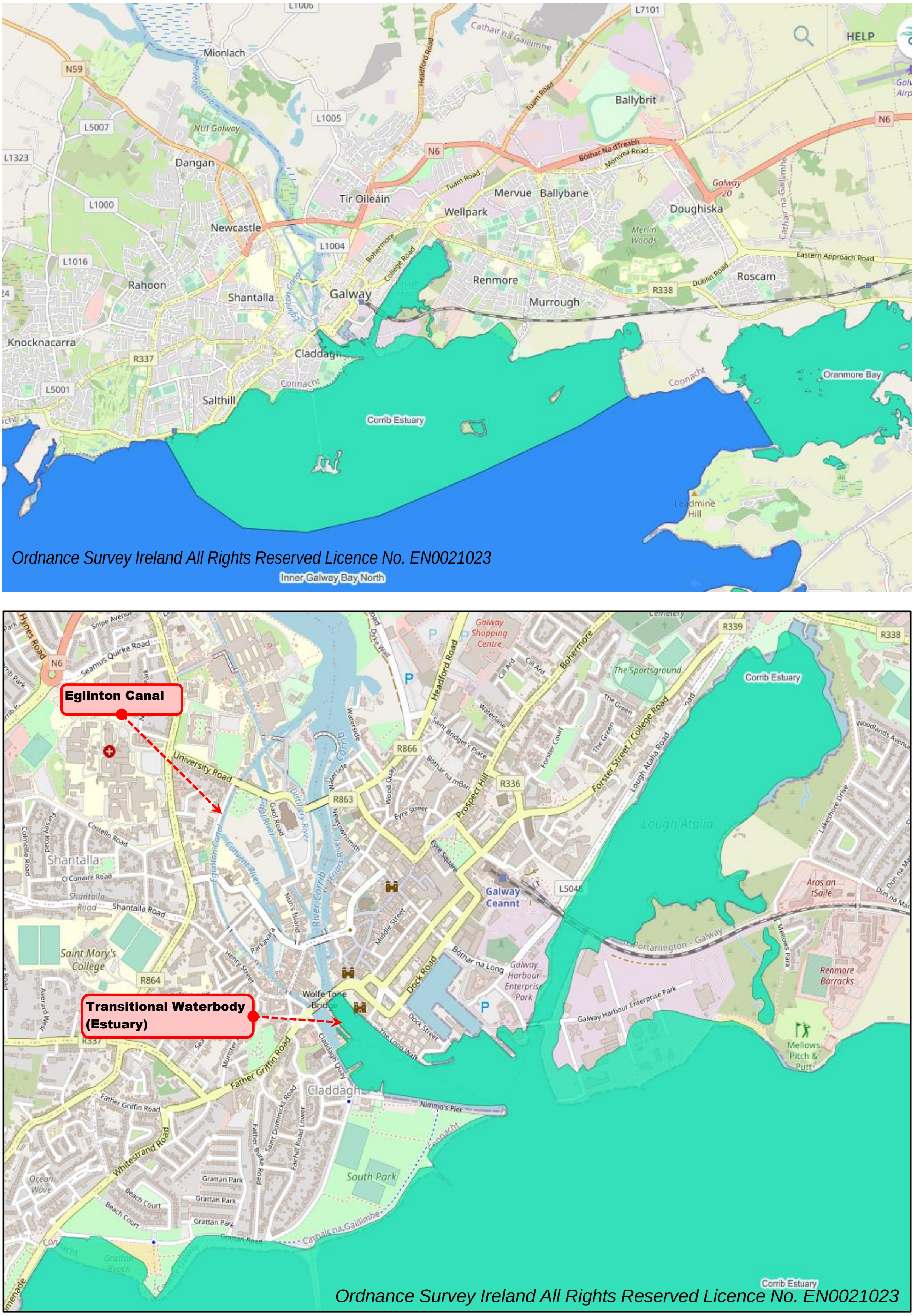


Figure 2-2 EPA Designated Coastal (Navy Blue) and Transitional / Estuarine (Green) waters at Galway City

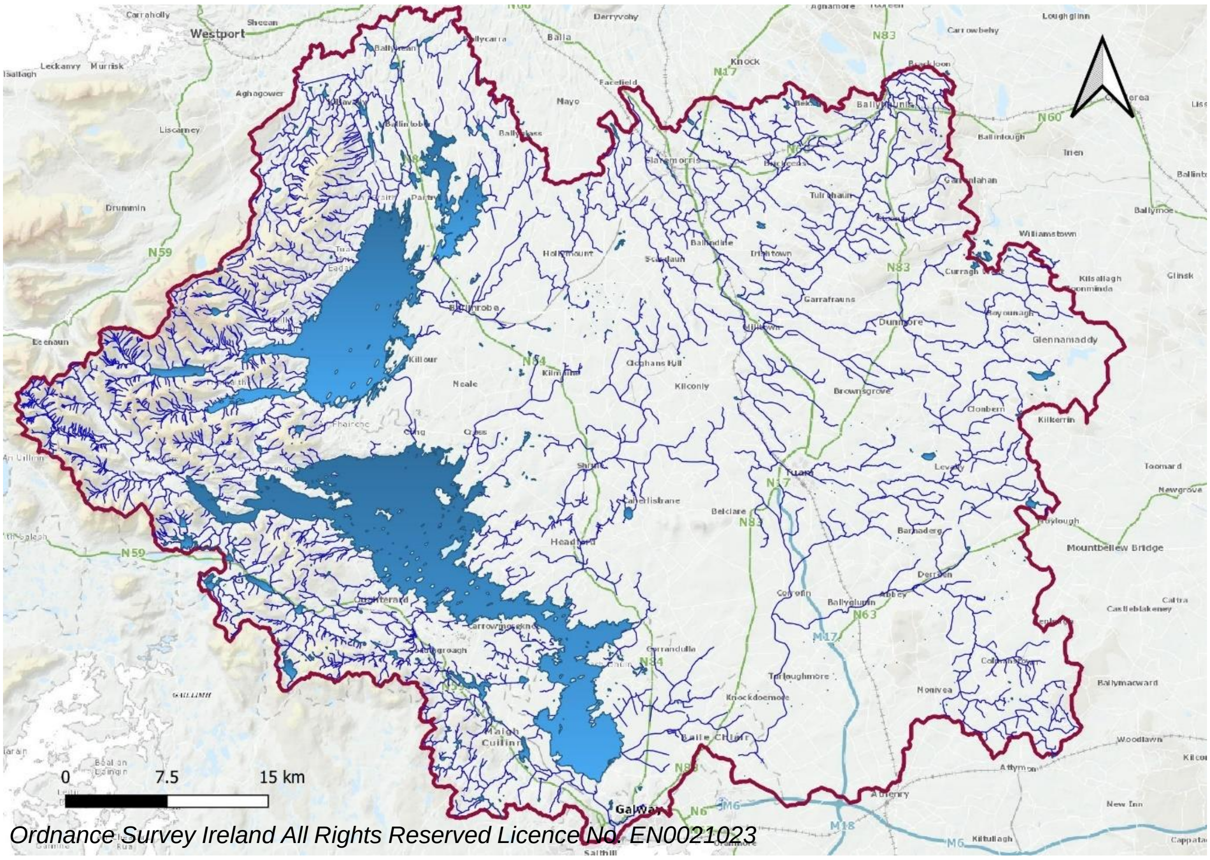
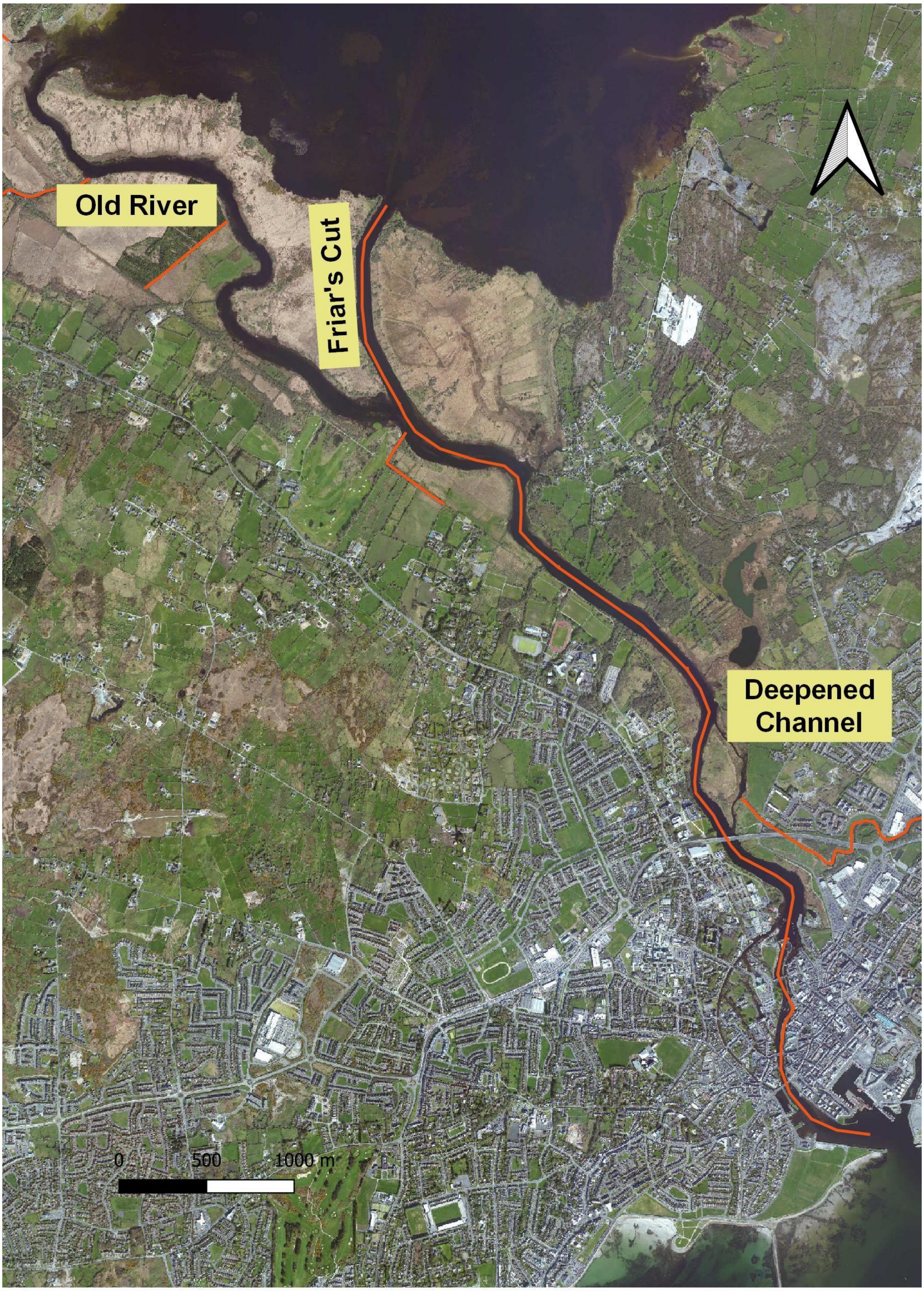


Figure 2-3 River Corrib Catchment Map to Wolfe Tone Bridge



Background Map Data © 2023 Google, DigitalGlobe

Figure 2-4 Corrib Arterial Drainage Channel

The EPA register of hydrometric gauges gives a catchment area to Wolfe Tone Bridge of 3111km^2 which is less than the FSU/EPA catchment estimate of 3136 km^2. The catchment extents were reviewed as part of this study and currently the catchment estimate of 3136 km^2 (EPA Hydro Catchments estimate from the EPA Water Maps) which includes the small Terryland stream catchment of 9.04km^2 in area, refer to Figure 2-5. This basin area should be excluded as the Terryland stream drains underground via karst swallow-holes at Castlegar Galway City, through the karst limestone bedrock to the sea and does not contribute to the Corrib river flow at Terryland water intake. In fact, the Corrib contributes a small abstraction to the Terryland Stream via the public water intake channel at the Dike Road near Jordan's Island which supplies the water treatment plant and any excess flow discharges to the Terryland River. A review of the mapped catchment area of the River Corrib to Wolfe Tone Bridge estimates a catchment area of 3,126.2 km^2 when Terryland catchment is removed and slight adjustments to the watershed boundary are made.

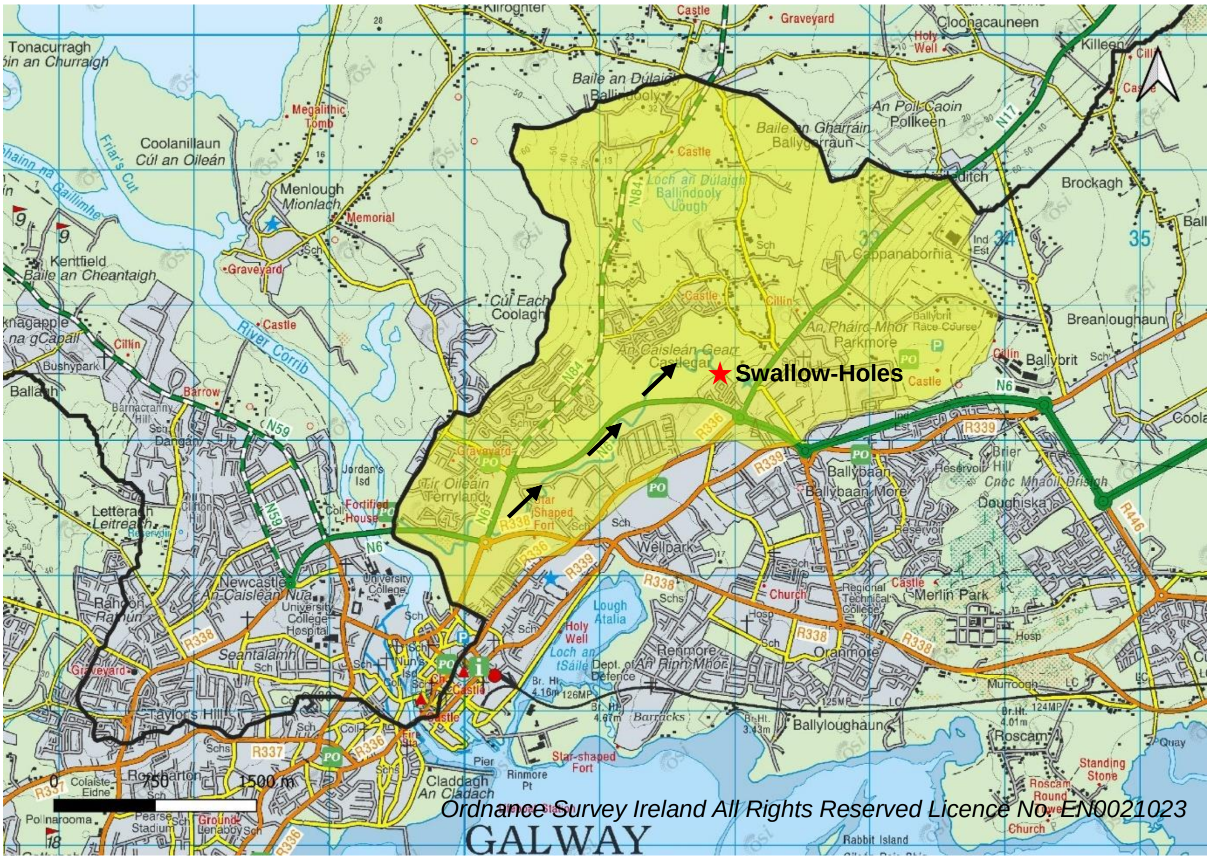


Figure 2-5 ***Terryland Stream catchment area of 9km2 discharging to the sea via swallow-holes at Castlegar.***

The River Corrib channel acts as a short outflow channel from Lough Corrib to the sea at the Claddagh Basin measuring just under 6.4km in length from the lake outlet at Friar's Cut to Wolfe Tone Bridge at the Claddagh Basin. The tidally influenced section extends from the downstream of the Salmon Weir to the Galway Port navigation channel south of Nimo's Pier. The downstream channel from the Salmon Weir to Claddagh basin was excavated into the bedrock as part of the arterial drainage scheme to convey Corrib flow and prevent backwatering of the weir under design flood conditions. This reach section is much steeper than the upstream channel section at a typical bed gradient of fall of 1m in 275m.

2.3 Galway Salmon Weir Sluice Barrage

The River Corrib flow is regulated by the Salmon Weir Sluice Barrage located opposite Earl's Island and Woodquay area of Galway City. The barrage was constructed by the OPW as part of the Corrib-Clare Arterial drainage scheme in 1959 and consists of 14 steel hydraulic gates along with 2 older wooden lift gates from the previous weir control. The weir is an arc of 114.8m in length and total gate openings width of 91.7m (c. 80% of the length). The weir discharges to a sloping concrete spillway apron which is designed as an energy dissipator to generate a hydraulic jump within the protected apron area downstream of the weir crest. The 14 gates are hinge gates that are lowered by tilting forward from their sill and are operated hydraulically.

A detailed paper on the Galway Salmon Weir Sluice Barrage by Arthure (1960) describes the design and construction of the new barrage which was completed in 1959 and gives details of the previous weir which was constructed in 1852 by the Board of Public Works (triangular plan weir) as part of the original Corrib drainage and navigation scheme. The former weir was a massive structure built from limestone blocks and had a total length of 607 feet (185m) and an average crest level of 27.7 ft OD Poolbeg (c. 5.702m OGSM15) in a triangular plan profile. Falling boards, 15inches in depth, were provided over 190ft of the weir and two 10ft vertical lift timber sluice gates (which are still present today) formed the western terminus.

The new barrage as constructed consisted of 14no. leaf type steel sluice gates which are arranged in a circular arc. The gates measure 20ft in width (6.096m) and 5ft in height (1.524m). The crest level of the weir when the gates fully closed is set at 28ft O.D Poolbeg (*c.* 5.79m OD Malin OGSM15) and when fully opened the gates are hinged at their base and are reclined to the horizontal where they fit into a recess in the concrete floor. The crest level of the weir when gates are fully open (i.e., recessed into the gate bucket) is 23 ft Poolbeg (4.269m OGSM15). Murphy Survey as part of the infill topographical survey for the project confirmed that the crest level of the gates when fully closed varied very slightly over the 14 gates with crests levels measured at 5.76 to 5.79m OGSM15.

The two 10ft vertical lift timber sluice gates and masonry abutments from the former regulating weir were retained at the western terminus. The invert level of these timer gates was surveyed by Murphy Surveys at 4.37m OGSM15. A fish pass and two elver passes were incorporated in the weir configuration. The gates are operated by means of hydraulic rams and when in the desired position a hydro-loc valve is applied which prevents the gate from opening further. A gate can be opened or closed in 3.5minutes. Essentially the function of the weir control is to open-up to allow floodwaters pass downstream without causing upstream flooding and to close in non-flood periods in order to maintain upstream river and lake levels for navigation purposes and also to maintain water levels in the canals for hydropower (milling).

Arthure described in his detailed paper the design requirements of the weir (14 steel and 2 timber gates) to discharge a peak of 10,000cusec (283cumec) and maintain the upstream water level at the weir at 28ft Poolbeg. A full-scale physical model was developed of a single full gate with abutments and half gates on either side. Based on the results from the physical model a total flow 9000 ft^3/s (254cumec) discharging through the 14 gates would require an upstream water level of 28ft Poolbeg. Based on the critical depth equation for a broad crested weir, which would represent the gate when fully opened, gives a coefficient of discharge Cd of 0.93 which is reasonably consistent with the literature.

A report by the Farrell et al of the OPW (May 1987) into the operation of the Galway Sluice barrage states that the design was to maintain the water level in Lough Corrib at or above 28ft OD Poolbeg (i.e., 5.79m OGSM15) and at or below 30ft OD Poolbeg (i.e., 6.403m OGSM15). This paper also showed that maintaining levels below 30ft OD in Lough Corrib could not be achieved with only 4years out of 27years examined achieving this upper limit. The conclusion of the study found that the fault of such exceedances in lake flood levels did not lie with the capacity of the Weir gates but with the capacity of the Corrib channel between the Lake and the gates requiring a sufficient flow depth and fall between the lake and the weir to discharge flood flows from Lough Corrib.

Plate 1 View of Salmon Weir taken on the 11 December 2015 during flood conditions with all gates opened

Plate 2 ***View of the two timber lift/drop gates taking during flood flows on the 11th December 2015***

2.4 Lough Corrib

2.4.1 Lakes within the Corrib Catchment

The Corrib River system includes a total lake surface area of approximately 285km^2. The larger lakes are Lough Corrib (166km^2), Lough Mask (82km^2) and Lough Carra (15.6km^2) and smaller lakes of, Nafooey(2.5km^2), Ross(1.4km^2), Bofin (0.9km^2) and Lettercraffroe (0.8km^2) loughs and a further 465 smaller lakes from 0.1ha to 70ha within the catchment. The combined effect of these lakes provides significant attenuation storage limiting winter flood flows and sustaining summer low flows in the Corrib.

2.4.2 Inflow Tributaries to Lough Corrib

The main river tributaries discharging into Lough Corrib are presented below and their catchment extents are presented in Figure 2-6:

- Lough Mask Outflow via the Cong Canal (also potential for significant groundwater flow in the epi-karst between the Mask and Corrib (catchment area 892 km^2 of Mask outflow)

Eastern Side of Corrib with the Limestone Bedrock area

- Cross River (66.2km^2)
- The Black River which flows through Shrule Village (Catchment Area 204km^2)
- The Headford River (Catchment Area 45km^2)
- The Cregg River (Catchment Area 61 km^2)
- Clare River flows through Claregalway Village Catchment Area 1108 km^2 to Lough Corrib and 1083.1km^2 to Claregalway Bridge)

Western Side of Corrib from the igneous bedrock formations

- Habhain Cor Na Mona River (Catchment Area 26km^2)
- Habhain Thir Na Cille (Catchment Area 85km^2)
- Owenree River (Catchment Area 23km^2)
- Owenriff River through Oughterard (Catchment Area 67km^2)
- Aughnanum River (Catchment Area 29km^2)
- Loch an Chip River (Catchment Area 89km^2)

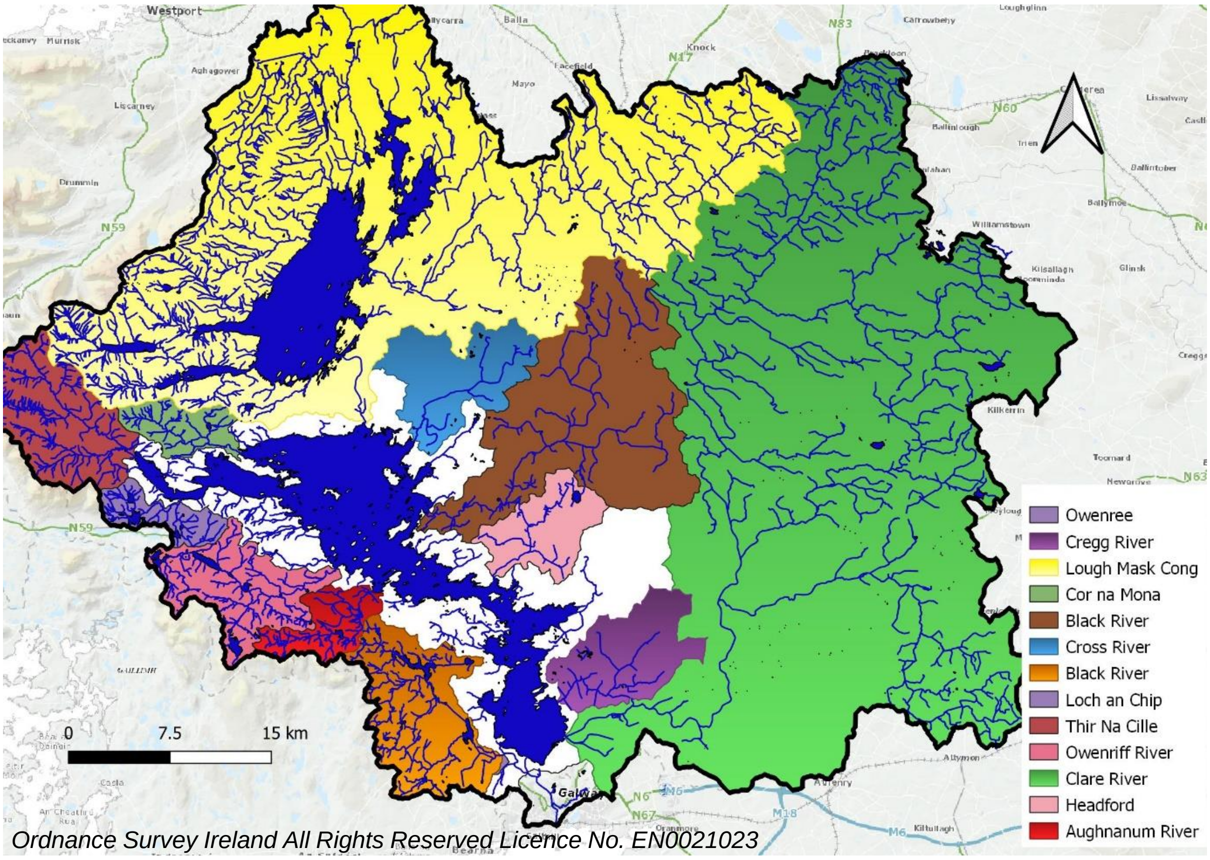


Figure 2-6 Main Catchments to Lough Corrib

2.5 Tributaries discharging to the River Corrib downstream of the Lake

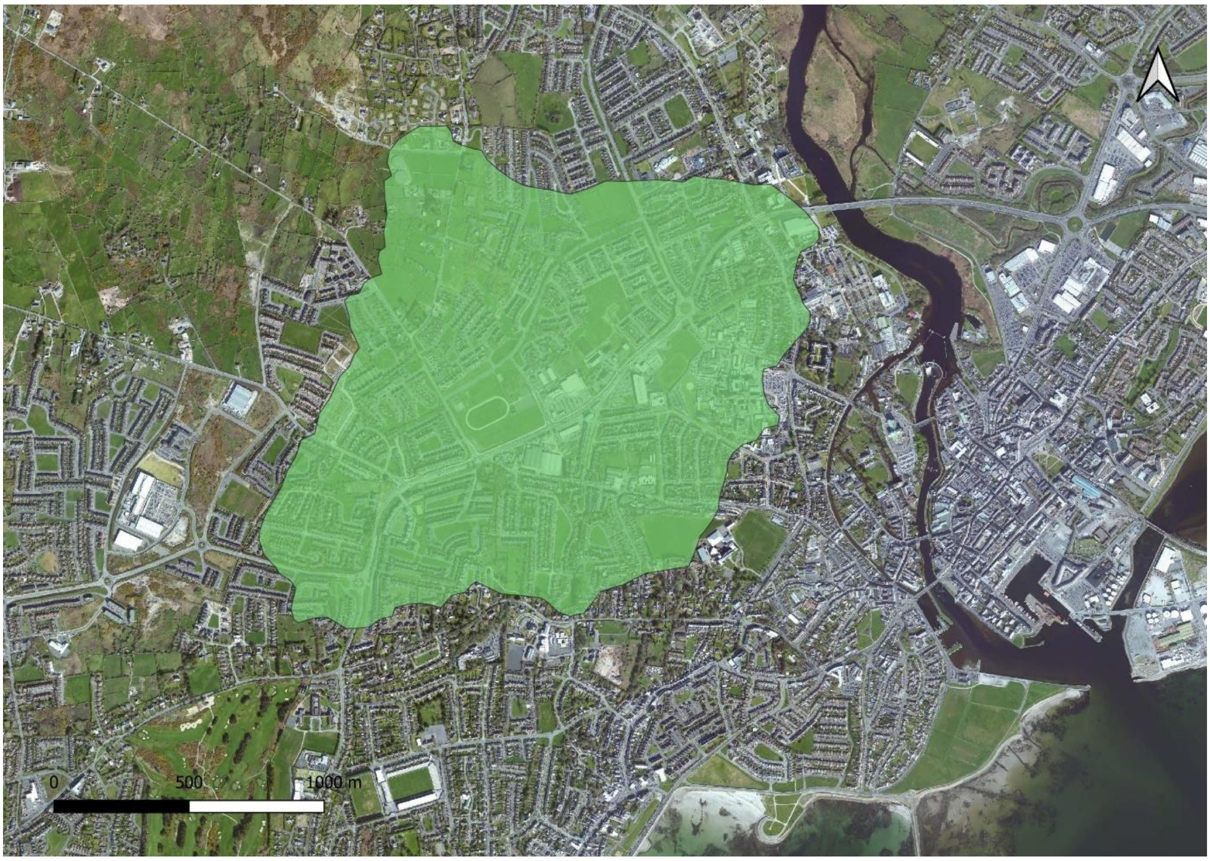
There are no major tributaries discharging to the Corrib within the scheme area downstream of Lough Corrib with the Corrib catchment area from the old river confluence with Friars Cut to Wolfe Tone Bridge only increasing by 7km^2 which represents an increase of 0.6% in total catchment area. The catchment area discharging to the old River between the Lake and the confluence with the Friars Cut channel is estimated to be 97 km^2 in area which includes Lough Kip River and the much smaller Drum and Gortatleva Streams. Small local inflows occur from karst groundwater fed springs at Menlough and from the Coolagh Lakes and at Dangan from the Bushypark stream.

The canal system in Galway city is principally fed by the River Corrib upstream of the Salmon Weir with no other major tributary inflowing to the canal system except for a number of small storm pipes. The Distillery channel though the University is fed by Sruffaunacashlaun Stream that drains the Rahoon, Shantalla and Westside area of Galway City, and also fed by a number of storm sewers from the upper Newcastle area and the Dangan Area. The Sruffaunacashlaun Stream has, based on lidar and the drainage network extracted from historical 25inch mapping, a catchment area to the Distillery Stream of *c.* 2.5km^2. The catchment for this stream to its confluence with the Distillery Stream is presented in Background Map Data © 2023 Google, DigitalGlobe

Figure 2-7. This catchment is now completely urbanised, and its runoff features dictated by the Galway City stormwater drainage network. The Distillery Stream through the University campus also receives inflow from the Corrib via the Kingfisher channel which is controlled by Penstocks and also downstream of Earl's Island by the Huntsman canal discharge. The distillery channel which historically was channelised for milling is contained within its own walled channel discharging to the Corrib River in the reach downstream of the Salmon Weir Bridge and just upstream of O'Brien's Bridge.

The Terryland Stream also known as the Sandy River has an estimated catchment area of 9km^2, which is karstic and this small river is principally fed by the groundwater table and by storm sewer outfalls from the Lisbaun and Terryland urban areas and the Tuam Road and Twomileditch area. Originally before the Corrib drainage and navigation scheme in the 1850's the Corrib would have flooded into the Terryland basin, but this connection has since been cut off by the Dike Road embankment, constructed originally in the 1850's and improved by the OPW as part of the Corrib-Clare arterial drainage scheme. The Terryland River channel is an OPW maintained drainage channel that discharges to swallow-holes at Castlegar.

A large section of the mapped drainage catchment area in Figure 2-5 in the vicinity of Ballindooley Lake basin and the Ballybrit, Parkmore and Twomileditch area are not very well connected to the Terryland Stream with these areas draining slowly to the regional groundwater table and therefore not contributing significantly to flood flows in the Terryland stream, refer to Figure 2-8. These areas potentially only contribute as general groundwater baseflow to the Terryland Basin. As a consequence, the effective surface runoff catchment of the Terryland Stream is only 4.58km^2 (i.e., over 50% reduction in the mapped total drainage area), refer to Figure 2-9.



Background Map Data © 2023 Google, DigitalGlobe

Figure 2-7 Sruffaunacashlaun Stream catchment area from Lidar mapping

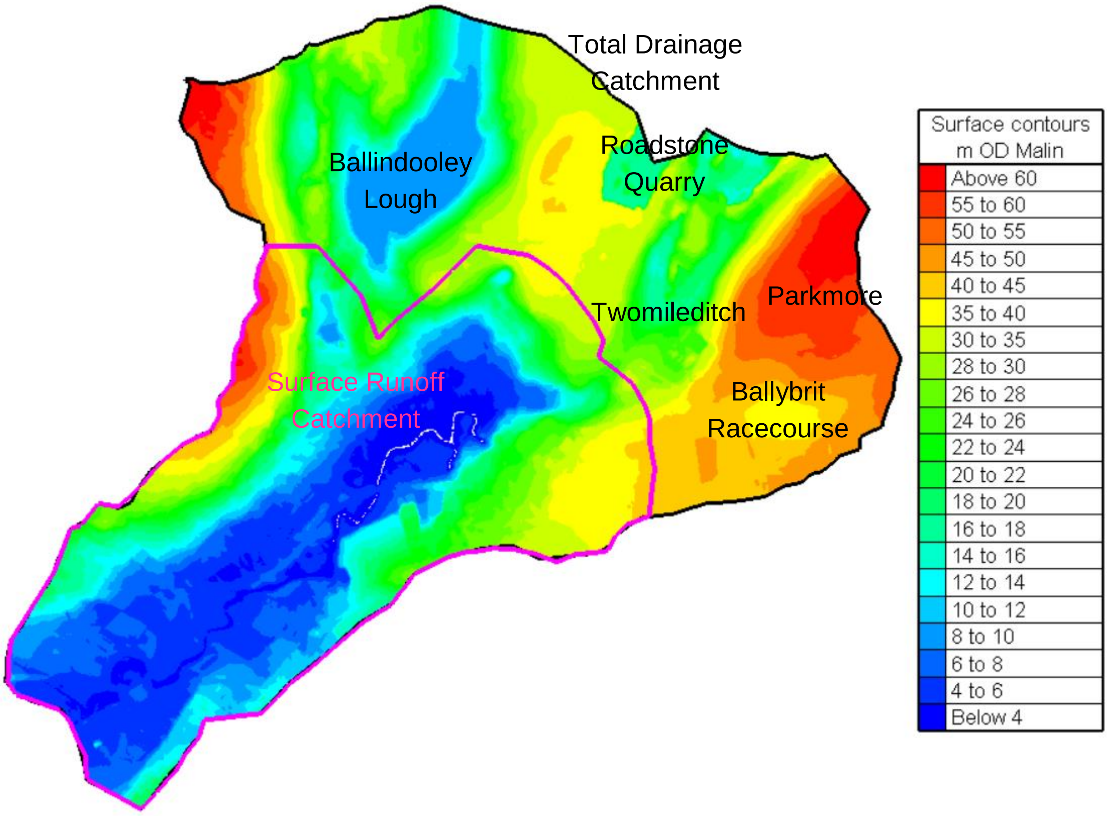


Figure 2-8 Terryland Drainage Basin Contour Map and Features

Figure 2-9 Terryland Stream Surface Drainage Area Contributing to flood flows

3 Data Collection

3.1 Introduction

Various datasets relevant to catchment hydrology of the Corrib have been collated for inclusion in the hydrological assessment of catchment flood flows within the Study Area. These datasets are summarised as follows:

<u>EPA</u>

EPA hydrometric data sets

EPA river network mapping (OSi Geometric River Network)

Corine Land-use mapping (2018)

<u>EU</u>

Copernicus EMS mapping

<u>Geological Survey of Ireland</u>

Soils and subsoil mapping

Bedrock mapping

Groundwater recharge mapping

Aquifer mapping

Aquifer vulnerability mapping

Karst features mapping

Groundwater Flooding Mapping

Recharge Rate Mapping

<u>Local Authority – Galway City Council (GCC)</u>

Historical flood information

Storm drainage catchments and storm, foul and combined sewer network details

Planning and development information in respect to current and urban footprint

<u>Met Eireann</u>

Gauged rainfall data from Synoptic Stations and daily rainfall gauging stations for the Corrib–Hydrometric Area 30 and Galway and Mayo areas

Seasonal Average Annual Rainfall (SAAR) – 2km grid model

Storm Rain Depth-Duration-Frequency model – 2km grid dataset

<u>OPW</u>

OPW hydrometric data at relevant gauges described latter refer to Section 4.3 for list of gauging stations

OPW FSU Physical Catchment Descriptor data set

OPW gauged hydrometric catchment boundaries

OPW CFRAM river survey cross-section data

OPW CFRAM reports for the Western Basin units of management 29, 30 and 31 and Galway City AFA.

OPW historical flood data flood inundation mapping ()

OPW Lidar Digital Terrain Mapping (DTM) 2m, 5m and 10m grids for the Galway City area

<u>OSI</u>

Vector mapping datasets

Historical OSI mapping

Orthographic mapping

OSi PRIME-2 dataset

OSI Geometric River Network: 24/02/2020 GIS shapefile

<u>Local Authorities</u>

Galway City Council

- City Development Plan
- Planning Application web site
- Urban Storm Drainage network

Galway Co. Council

- County Development Plan
- Planning Application web site

<u>Other Bodies</u>

Galway Port Company

- Wave and Tide data

NUI Galway

Strategic Flood Risk Assessment of University Campus

Marine Institute

Tide data and astronomical tidal Predictions

Irish Water

Foul and combined Sewer network

Terryland abstraction and proposed Corrib new Abstraction

3.2 Hydrometric Gauges

The Corrib catchment has numerous hydrometric gauges present within its catchment refer to Figure 3-1 below. Many of these gauges provide level only data generally associated with the various lake gauges. Hydrometric stage and flow gauging stations are present on the Corrib at Wolfe Tone Bridge, on the Clare River at Claregalway, Corofin and Ballygaddy Tuam, on the Owenriff at Oughterard and on the Cong Canal at Cong Weir. Within the Galway City Scheme Area there are a number of water level (Stage) stations present which provide relevant water level data for the hydraulic model calibration and validation exercise, refer to Figure 3-2 for their general location. These gauges are located at Galway Port, Wolfe Tone Bridge, upstream of the Salmon Weir Barrage and a recently installed recorder at the Quincentennial Bridge and the existing hydrometric station at Dangan Slip and at Angligham in Lough Corrib near the lake's outflow at Friar's Cut. A water level recorder as part of this project has recently been installed by the OPW on the Terryland Stream which picks up the tidal response of the Terryland from its swallow holes and confirms groundwater connection to Galway Bay. A new water level recorder as part of this study has been installed by the OPW in the Corrib River channel a short distance downstream of the Salmon Weir Barrage (30097) adjacent to Earl's Island.

The available Met Eireann rain gauges for the Corrib Catchment are presented in Figure 3-3. These are daily read recorders and have different start and end periods. The daily rainfalls from these gauges is extracted for the more significant historical flood events where coverage is available, and the rainfall return periods for such events are estimated.

The majority of rain gauges are only daily read gauges, with hourly records only available at two gauges, Mace Head Gauge in Connemara and at Athenry Gauge.

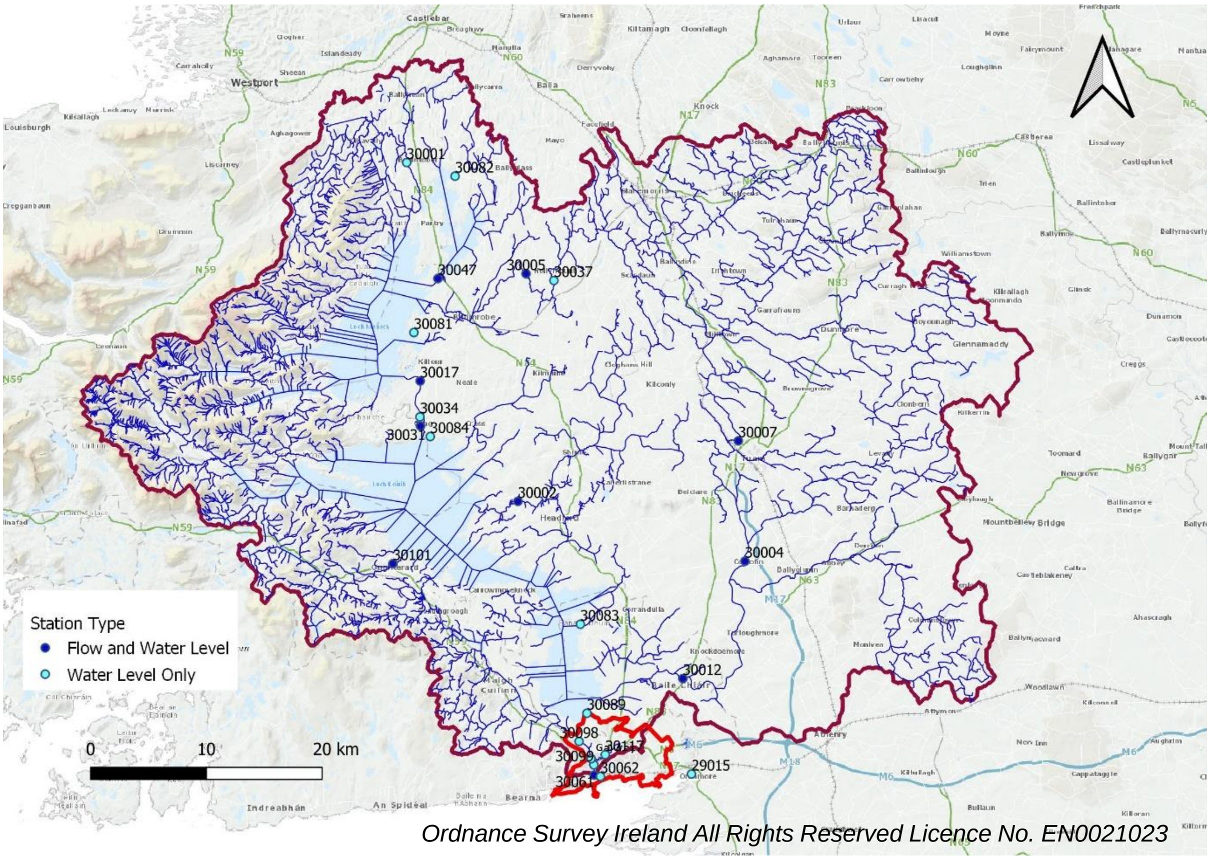


Figure 3-1 Relevant Hydrometric flow and water level only Gauging Stations within Corrib Catchment

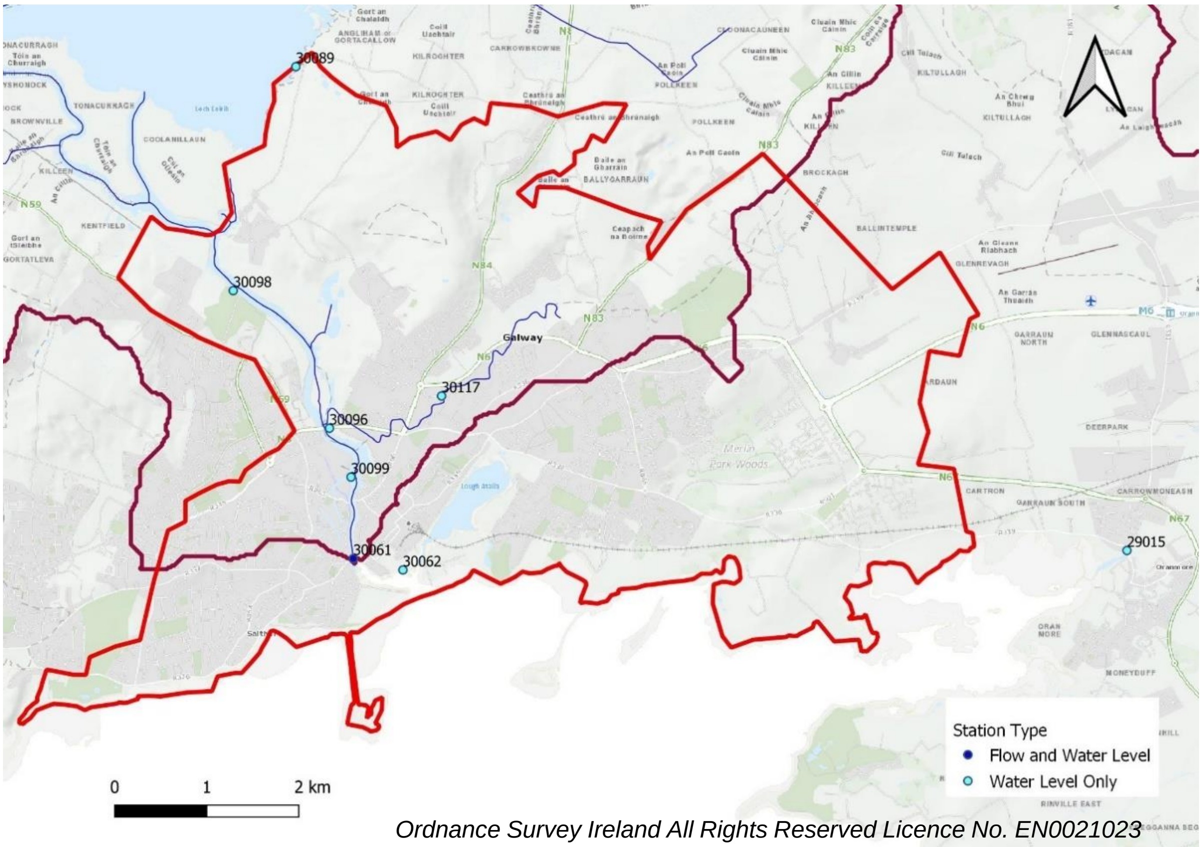


Figure 3-2 Hydrometric flow and water level only Gauging Stations within Galway City Scheme Area

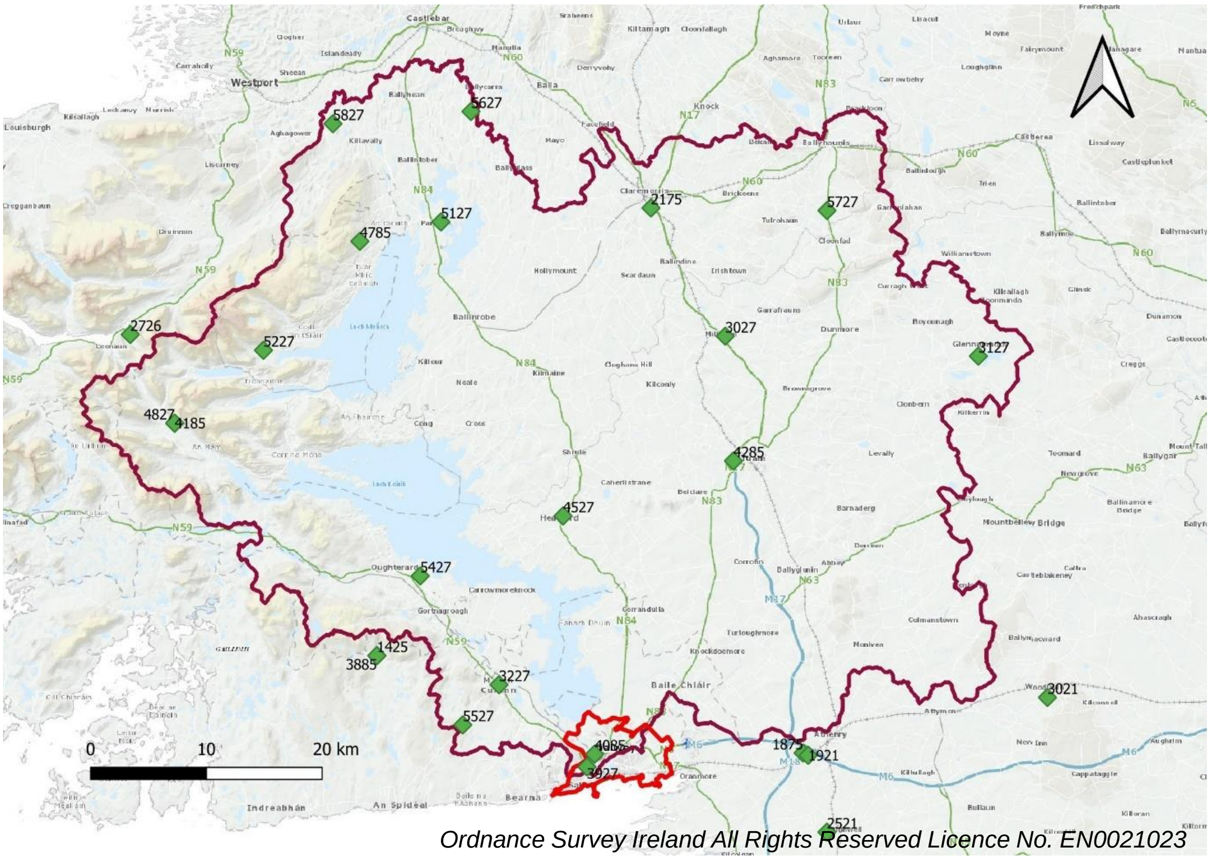


Figure 3-3 Daily Read Rain Gauges for the Corrib Catchment

3.3 Review of Physical Catchment Descriptor datasets

The OPW Flood Study Update (FSU) physical catchment descriptors data set for gauged and ungauged river nodal points has been provided along with catchment and sub-catchment boundaries and the OSI river channel network. As per Section 2.4.2 and 2.4.4 of the hydrology brief all of the relevant data bases have been included with their most up to data versions, including the OSI Geometric River Network: 24/02/2020 GIS shapefile. This data was reviewed for any significant discrepancies which may be present due to mapping error or catchment land use changes or temporal changes in a data set such as changes in the long-term rainfall. The Catchment boundaries have been checked against DTM and the OSI drainage network polylines checked for inconsistencies. These have been found to be generally suitable for the large-scale catchment of the River Corrib to Galway, but at the smaller local scale significant revisions to the catchment extents and watershed boundary have been applied in respect to the Terryland Stream and Sruffaunacashlaun Stream and the resultant changes to the Corrib catchment at the various selected HEP nodal Points.

The selected HEP's for the Scheme area have been presented latter in Section 11 and involve 22 nodal points, with 15 on the Corrib River, 5 on the Terryland River and 2 on the Sruffaunacashlaun Stream, refer to Background Map Data © 2023 Google, DigitalGlobe

Figure 11-1.

The PCDs were checked for consistency within the Scheme area between upstream and downstream HEPs and slight adjustments were made for the Corrib in respect to catchment Area. The river mainline slope parameter S1085 was found to fluctuate somewhat between nodes within the study reach which will cause a fluctuation in the estimated design flow magnitudes as all other PCD parameters used in the FSU PCD flood estimation equation are relatively constant with catchment area only slightly increasing in the downstream direction. This jumpiness in flow rate between nodes is not considered realistic for such an attenuated catchment. This is examined further in in Section 11 with a recommendation to use a constant average S1085 value over the study reach to eliminate inconsistency in the estimated flows between nodes.

For the Terryland and Sruffaunacashlaun Streams the FSU PCD's values had to be completely revised from available mapping as the Terryland actually flows in the opposite direction than assumed in the FSU and Sruffaunacashlaun Stream was never included. The revised PCD values for all 22 HEPs are presented in Table 11-1 and Table 11-2.

3.4 CFRAM review

The Western Catchment Flood Risk Assessment and Management (CFRAM) Study was one of seven River Basin District studies carried out across the Republic of Ireland from 2011 to 2016 carried out nationally to meet the requirements of the EU Floods Directive (Directive

2007/60/EC) and the 2004 Flood Policy Review Report. The Galway City Area was included in the CFRAM assessment under Unit of Management (UoM) 30 (Corrib Catchment, Hydrometric Area 30). The CFRAM study included detailed hydrological and hydraulic modelling assessments to quantify the flood risk from fluvial and coastal sources and to identify management measures to protect vulnerable receptors within the AFAs.

The following Table 3-3 presents the return period design flows produced by the CFRAM study for the Corrib at Galway City based on the FSU physical catchment descriptor (PCD) Median flood flow equation and using the FSU pooled growth curve and fitted by a three parameter GLO distribution. The pivotal gauged site used in the CFRAM study was the Wolfe Tone Station (30061) with a QMED = 248cumec based on the available 31-year record from 1972 to 2002. The CFRAM pooling group was selected based on the FSU methodology from the most hydrologically similar gauged stations to the subject site using the PCD descriptors of AREA (3136km2), SAAR (1422mm) and BFIsoil (0.81) to produce 500station years of AM flows. The distribution was fitted by the method of l-moments. This gave a 100year flood growth curve of 1.78 and 2.33 for the 1000year return period.

The CFRAM study concluded that single at-site analysis of the Corrib AM series at Wolfe Tone Bridge with 31years of AM flows available was not suitable for estimating the larger return period flood flows as the record available was from hydrometric year 1972 to 2002 which missed the 1968 flood and the more recent large floods including 2006 and 2009 flood. The Wolfe Tone bridge gauge was also not included in the CFRAM pooling group selection due to it relatively short record length of 31years and poor flood rating.

Table 3-1 CFRAM Statistical Distribution Type and parameters for River Corrib at Galway

Distribution	**Location**	**Scale**	**Shape**	**100yr Growth factor**
Pooled GLO (L-moments)	1.000	0.132	-1.04	1.780

Table 3-2 Pooling Group Selected by the CFRAM study for the River Corrib (it is based on the FSU web portal selection of sites)

Station ref	Rank	Watercourse Location	Years
34001	1	Moy Rahans	37
34003	2	Moy Foxford	36
12002	3	Slaney Enniscorthy	31
12001	4	Slaney Scarawalsh	55
27002	5	Fergus Ballycorey	56
35073	6	Lough Gill	30
16011	7	Suir Clonmel	57
26108	8	Boyle Abbey Bridge	20
35012	9	Garvogue New Bridge	10
16009	10	Suir Caher Park	57
35005	11	Ballysadare	62
25017	12	Banagher	39
26005	13	Suck Derrycahill	56
		Station years	546

Table 3-3 CFRAM estimated Return Period flows and Growth Factor for the Corrib at Wolfe Tone Bridge

Return Period (years)	**2**	**5**	**10**	**20**	**50**	**100**	**200**	**1000**
AEPs	50%	20%	10%	5%	2%	1%	0.5%	0.1%
Flow (cumec)	248	296.8	328.8	360.8	405.0	440.9	479.1	579.0
Growth Factor	1.00	1.20	1.33	1.45	1.63	1.78	1.93	2.33

The CFRAM study noted the following in respect to the selected pooling group:

"*The Corrib catchment at Galway is unusual as it is very large and subject to extremely large flood attenuation due to the size of Loughs Corrib and Mask immediately upstream. For this reason, it is difficult to have much confidence that many of the gauges in the pooling group are representative of the hydrological response of the Corrib catchment. The top-ranking gauges in the group are both on the Moy, which has a similar size to the Corrib and is also subject to major influence from loughs, although a substantial part of the Moy catchment does not drain through the loughs*."

The CFRAM study has a high degree of uncertainty associated with its return period flood estimates due to using a QMED estimate based on the Wolfe Tone gauge whose rating relationship was not reviewed and since considered no longer valid by OPW hydrometric, and which ceased in 2002 missing out on the more recent decades of larger flood events. This uncertainty was compounded by the pooling group selection which had a wide variety of catchment types in the group, the majority of which did have significant lake attenuation within their catchments. A GLO frequency distribution was selected, which is unclear from the study whether it was the best choice of distribution for the pooling group. It is demonstrated later in Section 5 of this report that Qmed for the Corrib is actually higher than CFRAM estimate, at 265.25cumec and that the recommended pooled flood growth curve is milder and that the most suitable statistical fit to the pooling group is produced by a 2-parameter EV1 distribution as opposed to a GLO distribution.

The design flood hydrograph developed in the CFRAM study for the Corrib at Galway used the FSU hydrograph width method with the width set to the median width of the observed hydrographs for the pivotal gauged site at Wolfe Tone Bridge. This method included 20 flood events from the recorded period of 1972 to 2002 with the largest event producing an estimated peak flow of 441cumec on the 25 January 1975. The hydrograph parameters produced by this method gave a n value of 2.20 and a Tr of 101hours.

Station 30061	Corrib @ Galway (Wolfe Tone Bridge) (3136km^2)

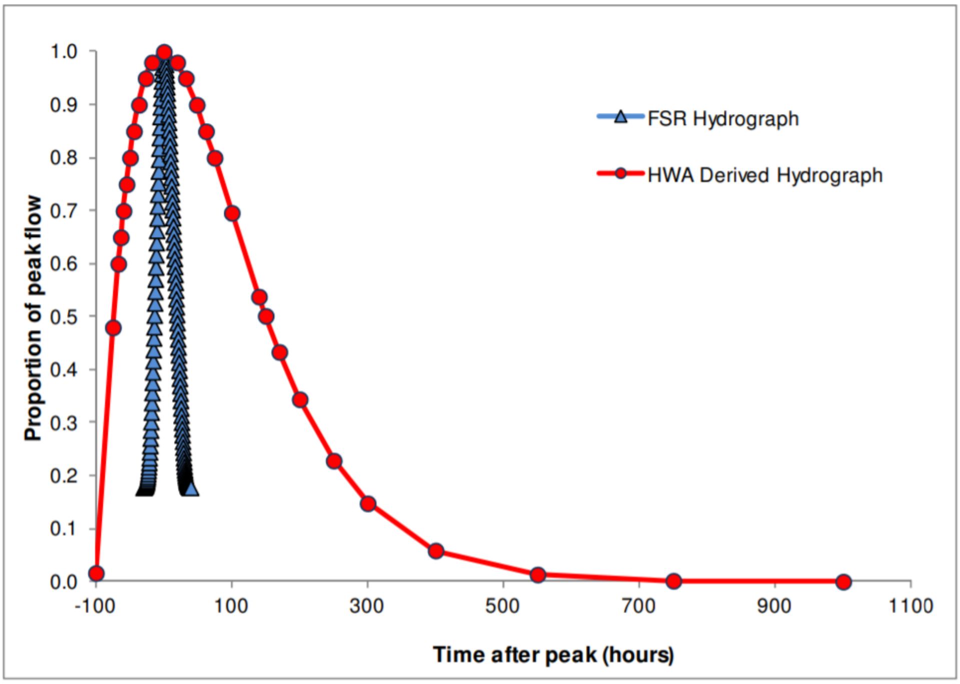


Figure 3-4 CFRAM Design Hydrograph Shape for the Corrib at Wolfe Tone Bridge from HWA and the FSR time to peak and design storm method included for comparison

This hydrograph Shape developed by the CFRAM study is not very realistic for the River Corrib which is significantly slower to rise and recede with the peak flow almost steady over many days due to the attenuating effect of its Lakes and the karst groundwater catchments to the east. A more realistic longer duration hydrograph in this study was produced and validated against the more recent large floods of 2009, 2015/2016 and 2020, refer to Section 9.

3.5 Hydrogeology and Groundwater

The Geological Survey of Ireland groundwater mapping provides information on bedrock, aquifers, aquifer vulnerability, quaternary sediments and groundwater recharge which are presented for the Catchment in Figure 3-5 to Figure 3-8. The Corrib catchment primarily consists of Limestone Bedrock formations representing 81% of the catchment area and the remaining 19% is underlain by the more impervious igneous bedrock located on the western side of the Corrib. The Geological Survey of Ireland Aquifer classification indicates that 67% of the total catchment area is underlain by a regionally important karstified Limestone Bedrock with conduit flow. This karstified bedrock provides for high groundwater recharge and storage within the bedrock which generally attenuates the shorter duration flashier floods with flooding in the turloughs and rivers associated with the more prolonged rainfall events that generally peak between late autumn and early spring. Presented in Figure 3-9 is the Corine 2018 Land-use mapping. The OPW Arterial Drainage scheme channels and benefitting lands mapping for the Corrib catchment is presented in Figure 3-10, which shows a significant area of the Corrib catchment being arterially drained.

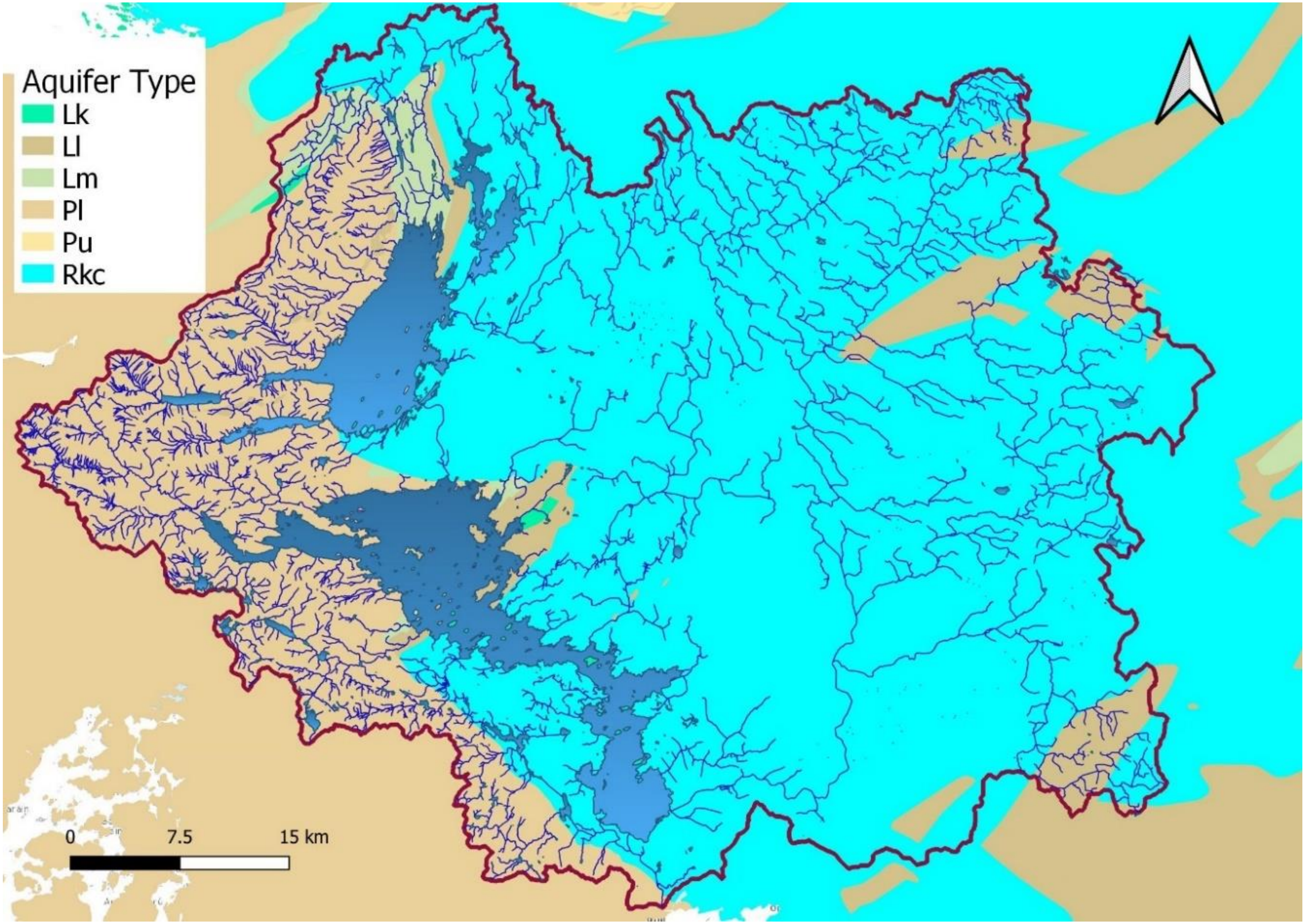


Figure 3-5 Bedrock Aquifer within the Corrib Catchment

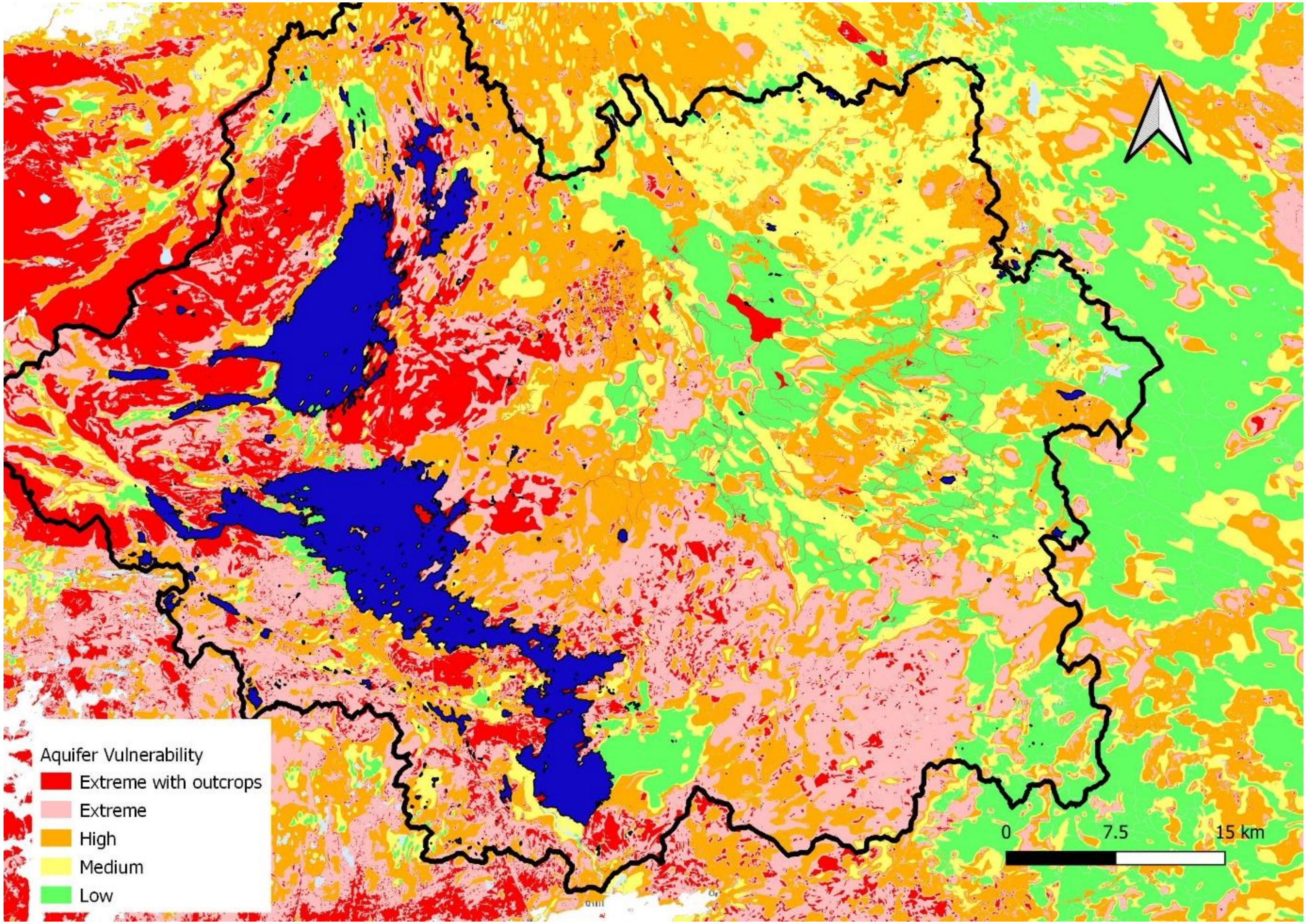


Figure 3-6 Groundwater Vulnerability within the Corrib Catchment

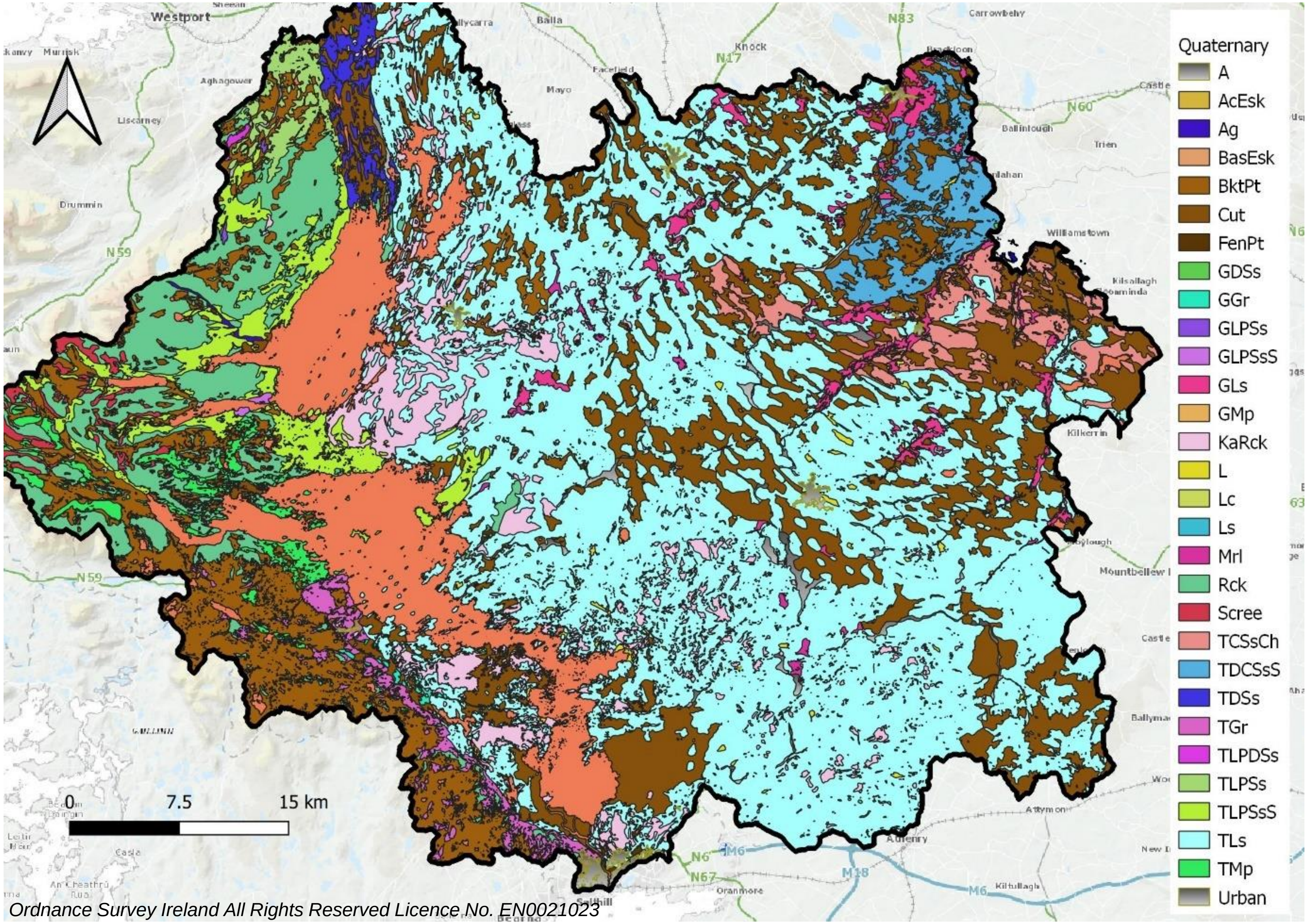


Figure 3-7 Quaternary Geology of the Corrib Catchment

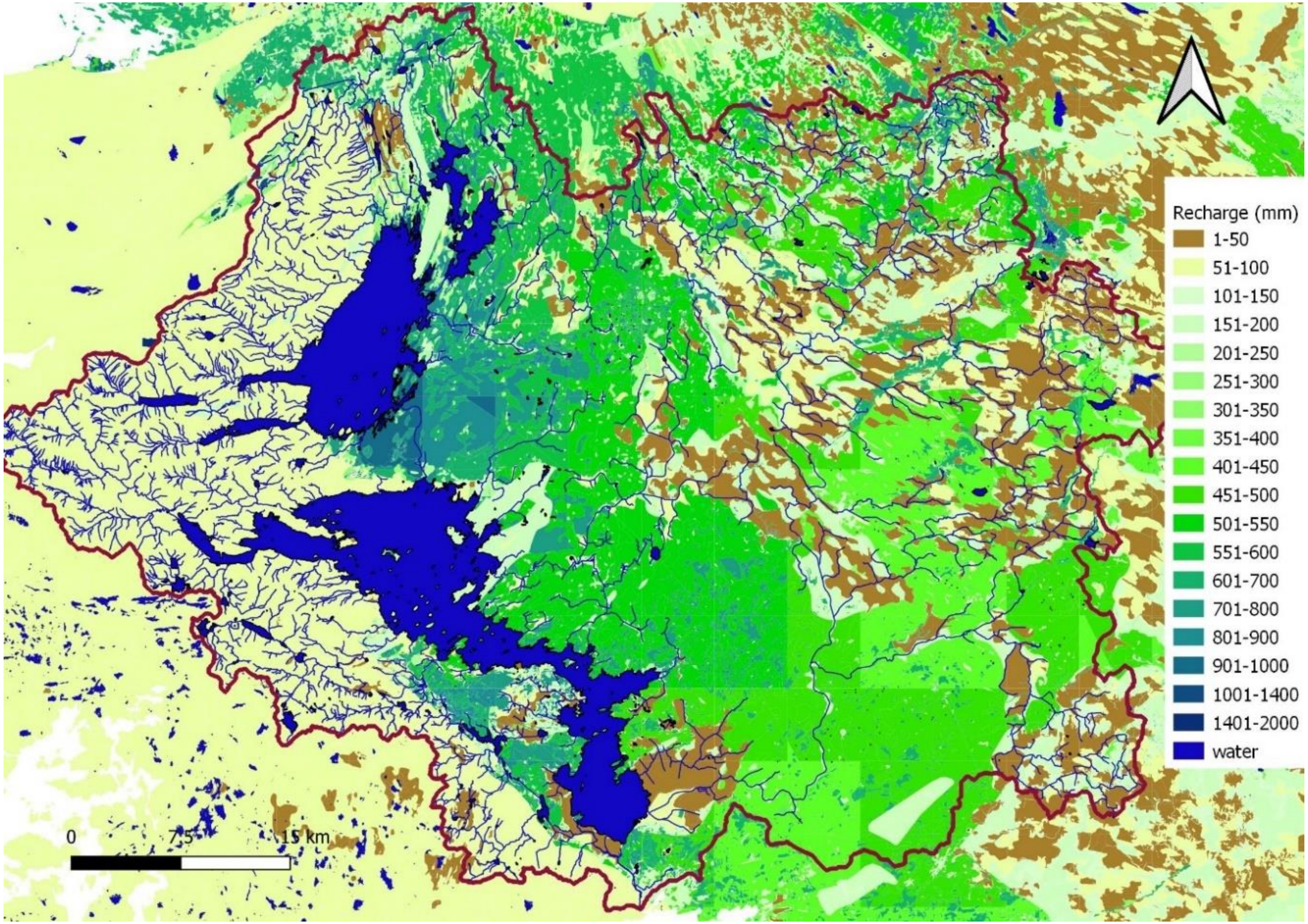


Figure 3-8 Groundwater Recharge mapping for Corrib Catchment (mm per annum)

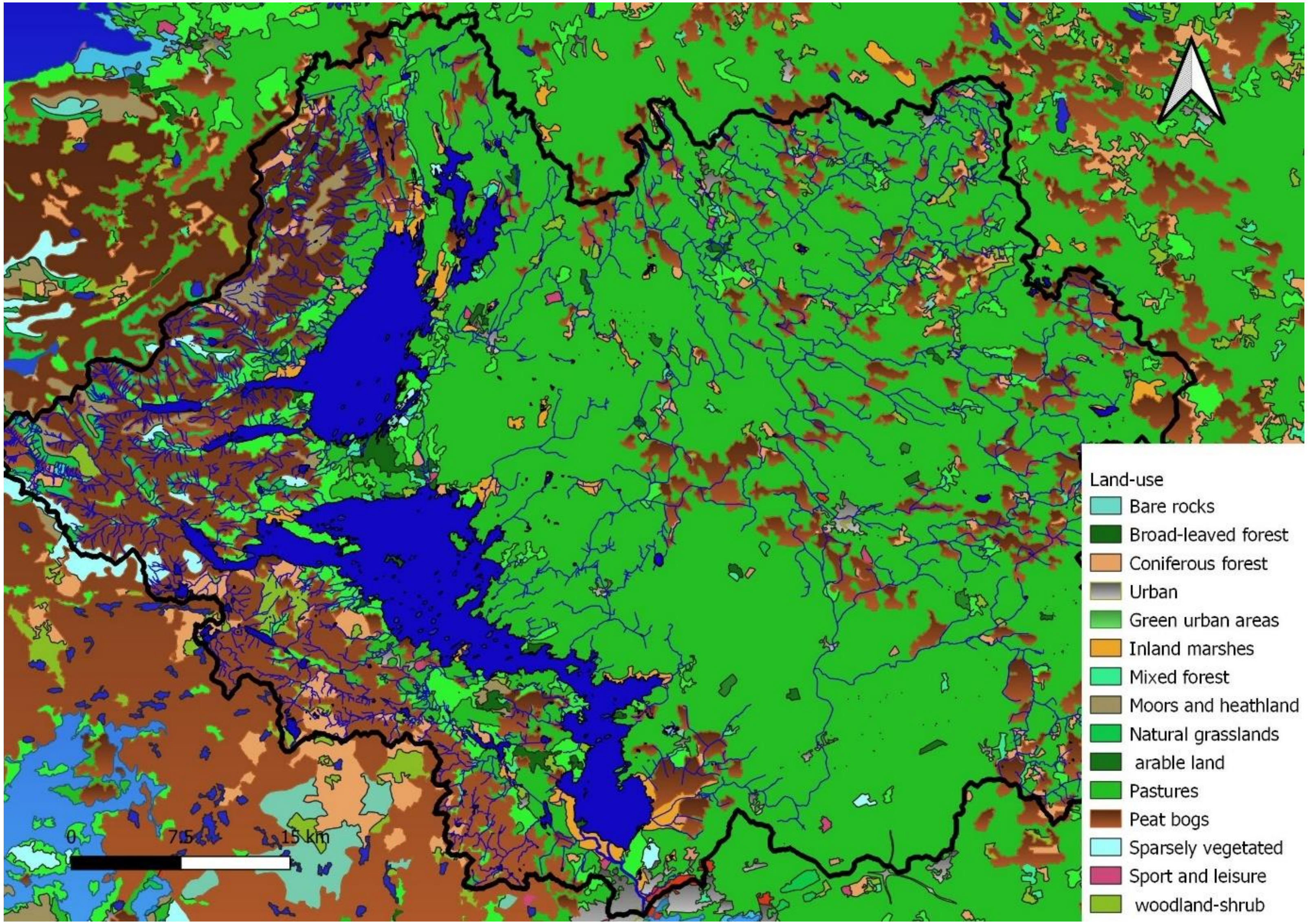


Figure 3-9 Corine 2018 Land Use mapping for Corrib Catchment

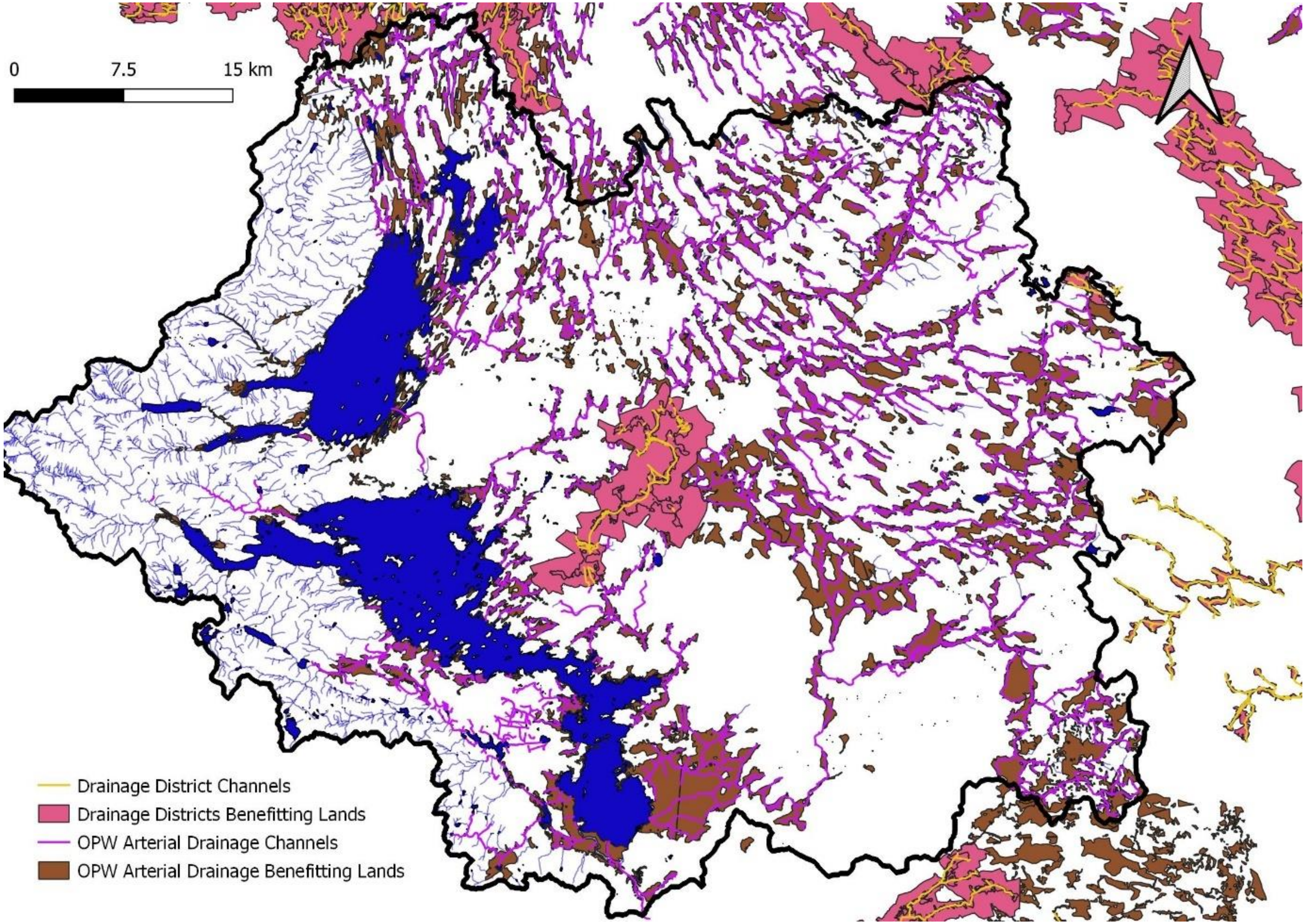


Figure 3-10 OPW Arterial Drainage Channels and benefitting Lands