Uisce Éireann
Irish Water

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Galway Wastewater Strategy

Appendix 4 - Impact on Water Quality

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1. Introduction to this Appendix

1.1 Overview

This appendix forms part of the Galway Wastewater Strategy (GWS) and assesses the potential impact of **current and future** wastewater discharges on freshwater and marine water quality within the study area. The analysis considers existing wastewater assets and treatment infrastructure, projected population growth, and climate change scenarios to evaluate compliance with the Water Framework Directive (WFD), and non-regulatory targets: Urban Pollution Management (UPM) Fundamental Intermittent Standards (FIS) and High Percentile Standards (HPS) standards. The overall modelling approach is discussed in section 2. The performance of wastewater treatment plants discharging to freshwaters, the assimilative capacity of receiving waters, and the implications of intermittent and continuous discharges on WFD objectives are reported in section 3. This includes the potential impact of a new WWTP discharging to the River Corrib, which was also undertaken against WFD standards, as identified through the optioneering process in *Appendix 5*: *Our Approach to Optioneering and Feasible Option Development.*

In addition to freshwater river waterbodies, the assessment evaluates the feasibility of discharges from a proposed new wastewater treatment plant (WWTP) to coastal waters in Galway Bay (section 4). This includes modelling initial dilution and feasible effluent quality requirements and outfall configurations likely to meet WFD objectives.

2. General Modelling Approach

The principal wastewater discharges within the Galway Study Area were assessed. This entailed creating wastewater flow profiles to provide the continuous and intermittent impacts of the discharges, for the current system and predicted future systems including predicted growth and elements of climate change until 2080. In all, five scenarios have been identified that require assessment to identify current and future pressures in the study area.

The assessments were done against WFD Standards and UPM Standards. UPM assessments apply the modelling approaches described in the UPM Manual (FWR, 2018) [1]to investigate and quantify the impacts of intermittent wastewater discharges on a receiving watercourse. Standards for intermittent discharges are not included in UÉ water quality legislation. In this absence, the UPM approach has been adopted for the Strategy to provide a source of such targets for water quality modelling purposes to recognised industry standards. This ensures that there is a basis to assess current and future long-term needs and provide adequate protection to sensitive water bodies that may arise due to Storm Water Overflow (SWO) discharges.

2.1 Modelling Standards

2.1.1. Continuous Discharges - WFD Standards

Table 2-1 summarises the WFD Environmental Quality Standards (EQS), which were used to assess compliance of freshwater waterbodies and the impact the continuous discharges are having within the study area. These were assessed in accordance with Uisce Éireann's the Technical Guidance for Wastewater Water Quality Impact Assessment (Freshwaters)[2] using the UÉ Monte Carlo Assessment (MCA) tool. This provides the understanding of the ability of a waterbody to receive and naturally assimilate wastewater discharges without causing environmental harm.

Table 2-1 WFD Target Concentrations (Ireland, 2019)

Classification	Ammonia mg/l		BOD mg/l		Ortho-P mg/l	
	mean	95%ile	mean	95%ile	mean	95%ile
Good	0.065	0.14	1.5	2.6	0.035	0.075
High	0.04	0.09	1.3	2.2	0.025	0.045

The Monte Carlo assessment provided a robust assessment of the impact of a continuous discharge with a flow and pollutant load into the watercourse. This is undertaken to give potential Emission Limit Values (pELVs) for purposes of strategic planning. It does not replace the statutory process for setting of ELVs undertaken by the Environmental Protection Agency.

[1] UPM Manual (FWR, 2018)

[2] Uisce Éireann (2024), Interim Technical Guidance for Water Quality Impact Assessments (Freshwaters), Revision 1.1

Monte Carlo approaches have been used throughout the UK for setting permit discharges as part of the River Quality Planning (RQP), the SIMCAT-SAGIS suite of tools and is the basis of UPM assessments.

A Monte Carlo assessment models the mixing of a wastewater discharge into a river by explicitly accounting for uncertainty and natural variability in key inputs such as effluent concentration, effluent flow, and river flow.

Rather than using single "worst-case" values, each input is represented by a probability distribution (for example, log-normal concentrations or flow duration curves). Thousands of simulations are then run, with each simulation randomly sampling from these distributions and calculating the resulting mixed river concentration under mass-balance mixing.

The output is a distribution of predicted downstream concentrations, allowing assessment of:

- The probability of exceeding environmental quality standards
- Performance under different flow conditions (e.g. low-flow risk)
- Overall compliance in a risk-based, probabilistic way

The input parameters include a river flow duration curve based on observed data, background water quality taken from upstream and downstream sample sites, effluent timeseries flow and effluent quality data. These various inputs are all parameterised in the spreadsheet as a distribution, typically log-normal and its mean and standard deviation.

A river flow calibration process is undertaken to ensure the model gives the best prediction of the river water quality downstream of the WWTP. A detailed description of this process is provided in section 3.

In all, five scenarios (discussed in section 2.2.4) were investigated to determine the level of treatment required at each WWTP to ensure compatibility with WFD objectives and thus inform potential future ELV limits. This in turn was used as part of Strategy optioneering to understand current and future risks.

Generally, effluent flows increased with growth, but the performance of the WWTP would be unchanged so effluent quality was assumed to be the static for all scenarios. Likewise, it was assumed that the receiving water flows and quality were unchanged for each scenario except the 2080 climate change scenario. This scenario applied receiving water flows which had been modified to account for variations in river flow arising from climate change.

The 2080 flows were developed by transforming the observed flow statistics using climate change factors developed for the Moycullen modelling. This is also discussed further in section 2.2.4.

The Monte Carlo assessment tool determines potential ELVs using a "goal seek" approach, which would maintain WFD good or high status in the receiving water using permitted headroom allowances based on environmental risk and using observed or notionally clean boundary conditions (in line with existing licensing practices and as set out in UÉ Technical Guidance).

The river flow and water quality data was checked for consistency, outliers, drift and step changes to identify any unsuitable data points. Plots in the Monte Carlo assessment tool were used to undertake these checks. For all three agglomerations, the data was consistent throughout the period captured.

2.1.2. Intermittent Discharges - UPM High Percentile Standards (HPS)

HPS (commonly referred to as 99th percentile standards) satisfy a need for separate standards related to the specific quality of a particular river waterbody. Their statistical nature is intended so that they consider the impact of short duration intermittent discharge events. In effect, these intermittent standards are used to provide a measure of and controls for impact of short-term *acute* pollution events, in addition to the long term mean / 95%ile EQS targets which are used as measure of *chronic*, long term pollution sources.

The high-percentile standards (e.g. 99th percentile) were extrapolated from existing 90th /95th percentile EQS. HPS are set on river typology, defined by alkalinity and elevation, the typology is a UK classification system applied to each waterbody[3]. Table 2-2 summarises the values assigned based on river typology. As Claregalway has no intermittent discharges to the river Clare, the river typology is not included.

Table 2-2 High Percentile Standards (FWR, 2018)

Watercourse	River Type (from UK Classification)	Target Class and river type	99%ile BOD mg/l	99%ile ammonia mg/l
Ballycuirke Canal	mean alkalinity of 75 mg/l $CaCO_3$ and an elevation of about 10 m which classes it as a type 3 river.	WFD Good Status	11	1.5
Clarin River	mean alkalinity of 269 mg/l $CaCO_3$ and an elevation of about 28 m which classes it as a type 7 river.	WFD Good Status	5.0	0.7

2.1.3. UPM Fundamental Intermittent Standards (FIS)

FIS are targets designed to protect river ecosystems from stress caused by short-duration, intermittent pollution events - such as Storm Water Overflows (SWOs) during heavy rainfall. They define concentration–duration thresholds (Table 2-3), combined with allowable return periods. In other words, they specify how extreme pollutant levels (e.g. high un-ionised ammonia, low dissolved oxygen) can spike and for how long, within an acceptable frequency to avoid ecological harm. The standards provide protection to all life-stages of all aquatic life (fish, invertebrates, plants) associated with two specified ecosystem types: a sustainable salmonid and a sustainable cyprinid fishery.

[3] Defined in Schedule 2, section 1 of The Water Framework Directive (Standards and Classification) Directions (England and Wales) 2015

Table 2-3 Fundamental Intermittent Standards for a sustainable cyprinid fishery

Return period	Threshold (mg/l) unionised ammonia concentrations		
	1 hr.	6 hr.	24 hr. *
One Month	0.150	0.075	n/a
Three Months	0.225	0.125	n/a
One Year	0.250	0.150	n/a

Return period	Threshold (mg/l) dissolved oxygen concentrations		
	1 hr.	6 hr.	24 hr. *
One Month	4.0	5.0	5.5
Three Months	3.5	4.5	5.0
One Year	3.0	4.0	4.5

* Standard not applicable as retention time does not approach 24 hrs in waterbodies

The fisheries type of the receiving inland waterbody is used to determine the FIS standards used. Neither of the two inland waterbodies which were assessed, the Ballycuirke Canal (also known as Ballyquirke Canal) and the River Clarin were designated as Salmonid under European Communities (Quality of Salmonid Waters) Regulations 1988 (S.I. No. 293/1988)[4], therefore both were assumed to be classified as "sustainable cyprinid".

A UPM assessment was only required for the Athenry SWO discharges. Moycullen did not require an assessment following Technical Guidance for Wastewater Water Quality Impact Assessment (Freshwaters)[5] because the SWO spilled for less than 1% of the time. Claregalway has a fully separated sewerage network and therefore no SWO discharges.

4 Salmonid Water Regs Table

5 Uisce Éireann (2024), Interim Technical Guidance for Water Quality Impact Assessments (Freshwaters), Revision 1.1

2.2 Common Modelling Inputs

Similar datasets or approaches to developing inputs were used for each agglomeration investigated, those common to all are discussed below.

2.2.1. Time Series Rainfall

The Galway City April 2011 – March 2022 Time Series Rainfall (TSR) was applied, this is a 10-year time-series developed for the Galway City DAP Study, generated from a rain gauge at Athenry and applied across the whole study area.

Urban drainage models were simulated for 2055 and 2080 horizons using both climate change emission scenarios (RCP4.5 and RCP8.5). For purpose of water quality modelling the 2080 climate change TSR (RCP8.5) was used as it was the most precautionary to assess future impacts for strategy optioneering purposes.

2.2.2. Urban Drainage Models

A hydraulic sewer model (InfoWorks ICM) of the Galway City, Moycullen, Claregalway and Athenry agglomerations were included as part of the Galway Strategic Model. In Athenry and Moycullen, the representation of the FFT and Formula A flow separation was not represented within the current network model. The models finished at the inlet to the WWTP. The time series of Storm Water Overflow discharges were estimated outside the model based on the volume generated within the models to estimate the volume discharged to the environment. This was done externally to ICM in software designed for this purpose. Historical verification of Athenry discharges was undertaken but was unavailable at Moycullen.

2.2.3. Intermittent Discharge Quality

The intermittent discharges were modelled using typical event mean concentrations taken from Dempsey, 2005[6], listed in Table 2-4.

Table 2-4 Event mean concentration for intermittent discharges

Determinand	Mean (mg/l)
BOD	125
Ammonia	8
DO	6

[6] Dempsey (2005)

2.2.4. Modelling Scenarios and Climate Change Assessment

Five modelling scenarios were assessed, using the modelled 10-year flow series.

Table 2-5 Modelling Scenarios Description

Scenario Number	Scenario	Sewer Network Flows	River Flows
1	Baseline	Baseline Flows	Baseline Flows
2	2040	2040 Growth	Baseline Flows
3	2055	2055 Growth	Baseline Flows
4	2080	2080 Growth	Baseline Flows
5 (a)	2080 (Climate change)	2080 Growth	2080 CC river flows.
5 (b)	2080 (Climate change)[7]	2080 Growth with CC TSR (RCP8.5)	2080 CC river flows.

The Met Eireann produced TRANSLATE 2080[8] climate change rainfall dataset was used with rainfall runoff modelling to produce a 10-year 2080 flow series as part of the study. These were used to drive rainfall run-off models (NAM[9]) to produce representative river flows for scenario five.

The rainfall runoff model developed for the Ballycuirke Canal at Moycullen was run with the baseline and 2080 rainfall series, to develop runoff flow series. The Ballycuirke Canal catchment was chosen out of the three study watercourses because of its smaller size and geology, it was not as large as the River Clare catchment and did not have the complex geology of the River Clarin.

These were processed into flow frequency curves for the baseline. The baseline flow series was calibrated against the Hydrotool[10] flow frequency curve for the catchment. Once a suitable baseline model was developed it was rerun using the 2080 rainfall timeseries to develop the climate change flow series, which was used to create a climate change flow frequency curve. The two curves were compared and a series of flow factors developed, for each percentile, between the baseline and the climate change series providing a single series of percentiles that can be applied to other flow frequency curves.

[7] Note: Scenario 5(b) was only simulated for Athenry agglomeration as a further sensitivity test. The discharge at Moycullen occurred for less than 1 percent of the year for all scenarios and was therefore extremely infrequent and the impact can be considered negligible as it is so infrequent there are not standard/targets to assess against. It was not required for Claregalway as there are no SWOs.

[8] TRANSLATE 2080

[9] NAM is the abbreviation of the Danish "Nedbør-Afstrømnings-Model", meaning precipitation-runoff-model, also named RDII in English standing for Rainfall Dependent Inflow and Infiltration model. This model was originally developed by the Department of Hydrodynamics and Water Resources at the Technical University of Denmark (Nielsen & Hansen, 1973).

[10] Hydrotool

The climate change flow frequency curves were remapped, whereby for instance a Q90 flow was mapped to the Q90 flow in the future scenario. By doing this for all the probabilities a new curve can be produced modelling the range of future flows.

The flow relationship curves were used to modify the flow frequency curves used for the Rivers Clare, Clarin and Corrib.

2.3 Fitness For Use

All modelling undertaken to produce the assessment results in this appendix is fit for purpose in supporting the *strategic* direction and objectives of the Galway Wastewater Strategy (GWS). Each model represents the data available at the time of its development and, as with all modelling exercises, would benefit from enhanced data collection in the future. Nevertheless, the modelling completed for the GWS was appropriate for its strategic intent, and no additional data collection would have altered its overall outcomes or recommendations.

At a more technical level, and as the Strategy progresses into implementation, certain limitations and assumptions within the models may need to be revisited or refined. For further information, please refer to Annex A.

3. Freshwater Assessment Results

3.1 Moycullen – Ballycuirke Canal

Moycullen is an agglomeration to the northwest of Galway City. The Moycullen WWTP discharges to the Ballycuirke Canal (also known as Ballyquirke Canal), which links Ross Lake to Ballycuirke Lough shown in Figure 3-1.

The agglomeration has a combined sewage system with a population equivalent (PE) of 2,490 and is served by Moycullen WWTP which discharges treated effluent to the canal (IE_WE_30B140100) about 500m south of the plant.

The final effluent and storm discharges from Moycullen WWTP are passed through a Nature Based Solution (NBS) area which is used to further improve the quality of the effluent. Regulatory sampling is upstream of the NBS.

The Ballycuirke Canal, Ballycuirke_010 was classified WFD Moderate in the 2019-2024 assessment.

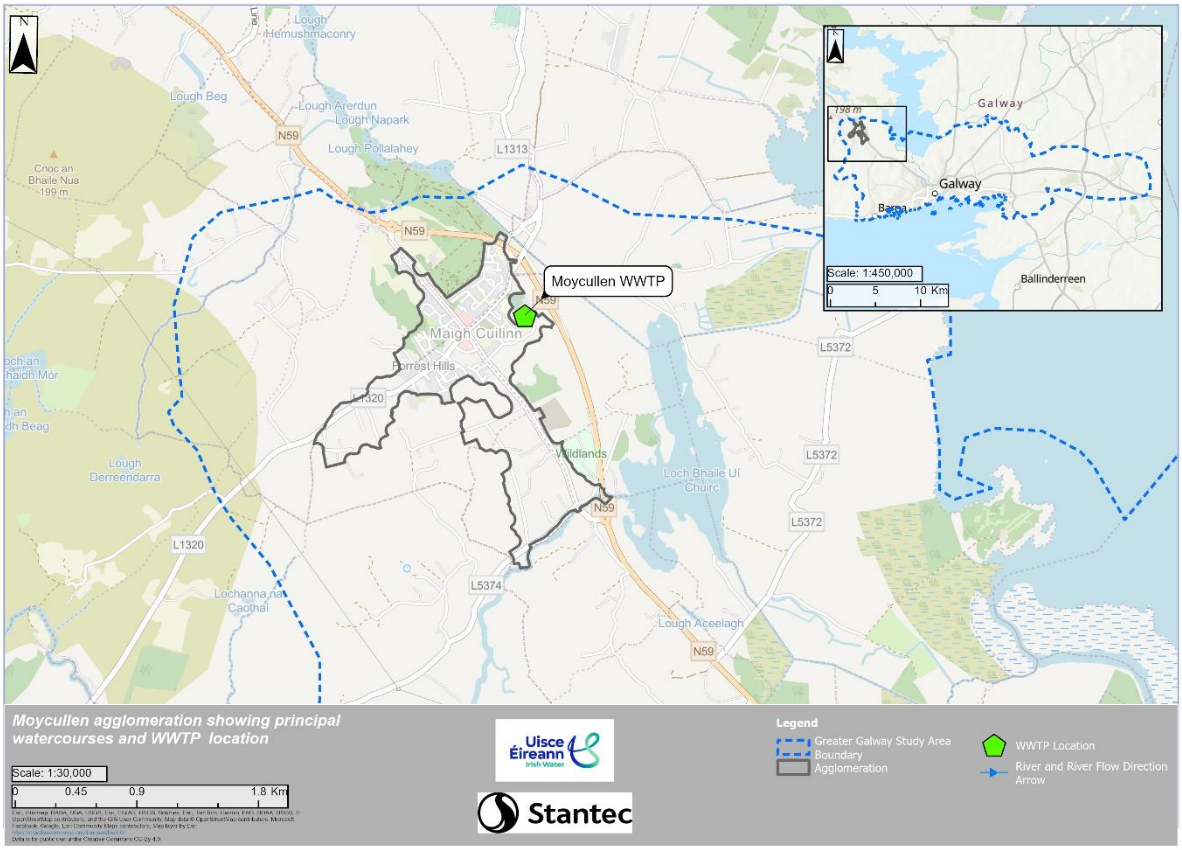

Figure 3-1 Moycullen agglomeration showing principal watercourses (blue) and WWTP location

3.1.1. Study Inputs

3.1.1.1. River Flow Modelling

Hydrological modelling of the Ballycuirke catchment was carried out by using NAM Rainfall-Runoff model module.

The NAM model was run with the catchment TSR to generate a 10-year runoff series for a prescribed set of up to 200 parameters. This generated up to 200 different rainfall runoff series. Each series was analysed to produce a flow frequency curve. Each curve was compared algorithmically against a target curve for the catchment assessing both annual and seasonal comparisons. The curve that fitted best was taken as the model to represent the river flow. The flow series from the chosen model was used as the flow series for the waterbody under investigation. Table 3-1 summarises flow statistics determined for the Ballycuirke Canal at the point of discharge.

A 2080 NAM model was also run for future analysis. This future run used a 2080 TSR model for climate change rainfall, but the same evaporation parameter was used as in the present-day baseline. The climate change rainfall series assumes there will be greater rainfall in the future, however as evaporation is unchanged the results indicate greater mean and standard deviation river flow in 2080 than at the present day, creating in a bigger range, increasing the chances of both higher and lower flows.

Table 3-1 Receiving Waterbody Baseline Scenario Flow Statistics

Site	Flow (m3/s)	
	Annual Mean	Annual Standard Deviation
Ballycuirke Canal - baseline	1.253	1.28
Ballycuirke Canal - 2080	1.619	1.65

3.1.1.2. River Water Quality

The water quality monitoring stations registered with the Environmental Protection Agency (EPA) are identified in Figure 3-2. From the available stations two sites, adjacent to the Moycullen outfall, were selected for use in the assessment. These are identified in Table 3-2. The data was downloaded from the EPA Catchments.ie website and is summarised in Table 3-3, along with the WFD classifications.

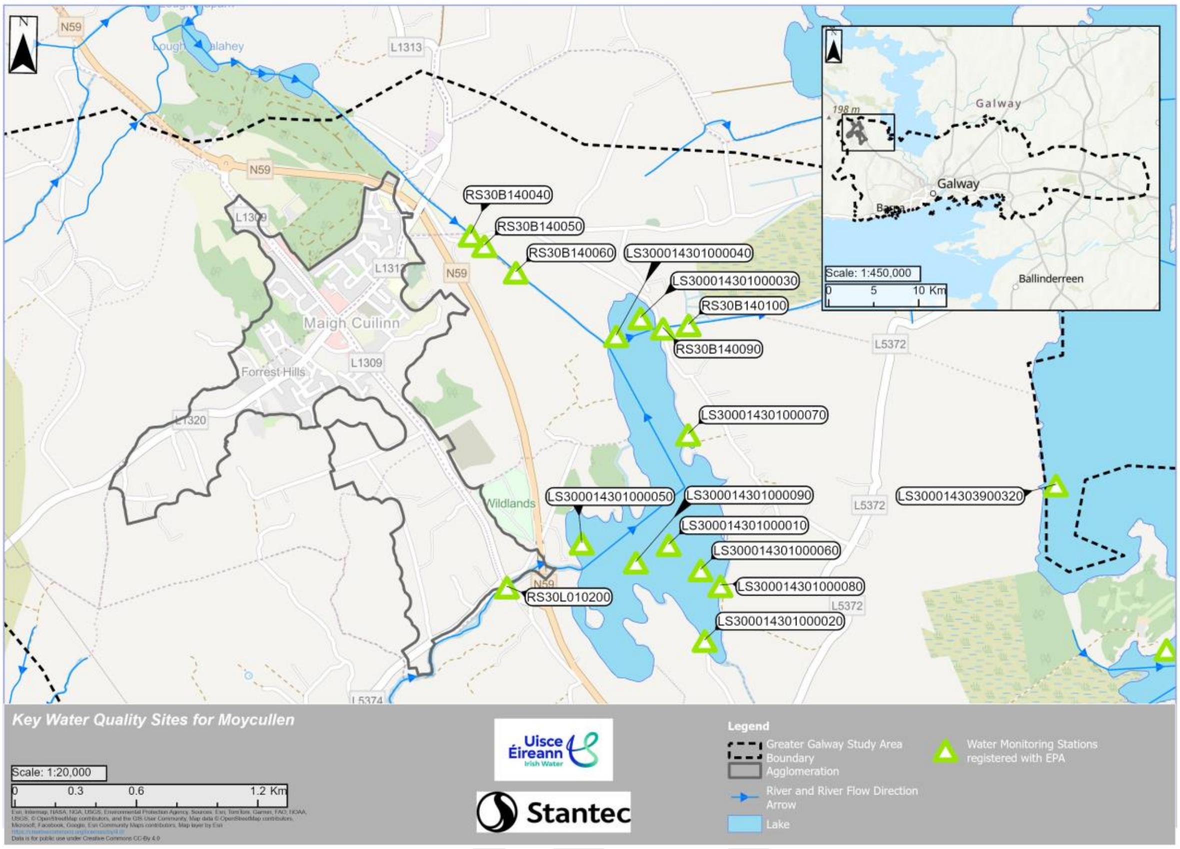

Figure 3-2 EPA Water Quality Sites (green triangles) on the Ballycuirke Canal

Table 3-2 Selected Water Quality Sites

Site	Name	What data used for
RS30B140050	Br u/s Ballycuirke Lough	UPM and WFD U/S boundary
RS30B140060	Downstream Monitoring of TPEFF1200D0191SW001	WFD D/S calibration site

Table 3-3 Observed Water Quality and WFD Classifications (orange <good, green=good, blue=high)

Determinand	Upstream			Downstream		
	Period	Mean mg/l	95%ile mg/l	Period	Mean mg/l	95%ile mg/l
Ammonia	11/06/2013-15/07/2022	0.065	0.218	11/06/2013-23/08/2022	0.114	0.379
BOD	27/09/2017 – 23/08/2022	2.4	5.4	25/07/2017-23/08/2022	2.0	3.7
Ortho-P	14/10/2014-15/07/2022	0.038	0.184	11/06/2013-23/08/2022	0.057	0.202

3.1.1.3. Continuous Discharge Data (WWTP)

The Moycullen Wastewater Treatment Plant (WWTP) site is located to the east of Moycullen village, and discharges to the Ballycuirke Canal part of the Ballycuirke_010 river waterbody. The WWTP performance is described in detail in Appendix 3 and wastewater treatment analysis was used to generate inputs into water quality models.

The effluent flow was taken from the hydraulic sewer model of the Moycullen catchment, the model was used to predict the increase in flows to the WWTP resulting from predicted growth within the agglomeration.

Table 3-4 Modelled Continuous Discharges

Gauged Model Link	Description	Receiving Reach
SM21329601.1	Flow to treatment	BALLYCUIRKE_010

The final effluent flow data used in the modelling are shown in Table 3-5.

Table 3-5 Final Effluent Flow Statistics

Period	Final Effluent			
	Period	Source	Mean l/s	95%ile l/s
Baseline	10-year series	Modelled	12.9	25.6
2040 Growth	10-year series	Modelled	11.9	16.3
2055 Growth	10-year series	Modelled	13.2	17.7
2080 Growth	10-year series	Modelled	13.7	18.2

The data for effluent quality from the WWTP is summarised in Table 3-6, in this case the effluent quality is sampled upstream of the wetland, and the effluent passes through the wetland so it is likely to be treated to a higher quality before discharge.

Table 3-6 Final Effluent Quality Statistics

Determinand	Final Effluent			
	Period	No Records	Mean mg/l	95%ile mg/l
Ammonia	04/01/2019 – 06/10/2023	37	0.473	1.34
BOD	15/03/2019 – 06/10/2023	34	3.8	7.9
Ortho-P	04/01/2019 – 05/12/2023	50	0.277	0.908

3.1.1.4. Intermittent Discharges

The spill summaries in Table 3-7 are based on the hydraulic sewer model outputs processed as outlined in Figure 3-3.

Table 3-7 Modelled Intermittent Spills

	Discharge	Moycullen Baseline	Moycullen 2040	Moycullen 2055	Moycullen 2080
Total Duration (hr/yr)	Storm Tank Spill	12.0	12.2	15.9	17.2
Total Duration (% of the year)	Storm Tank Spill	0.14%	0.14%	0.18%	0.20%

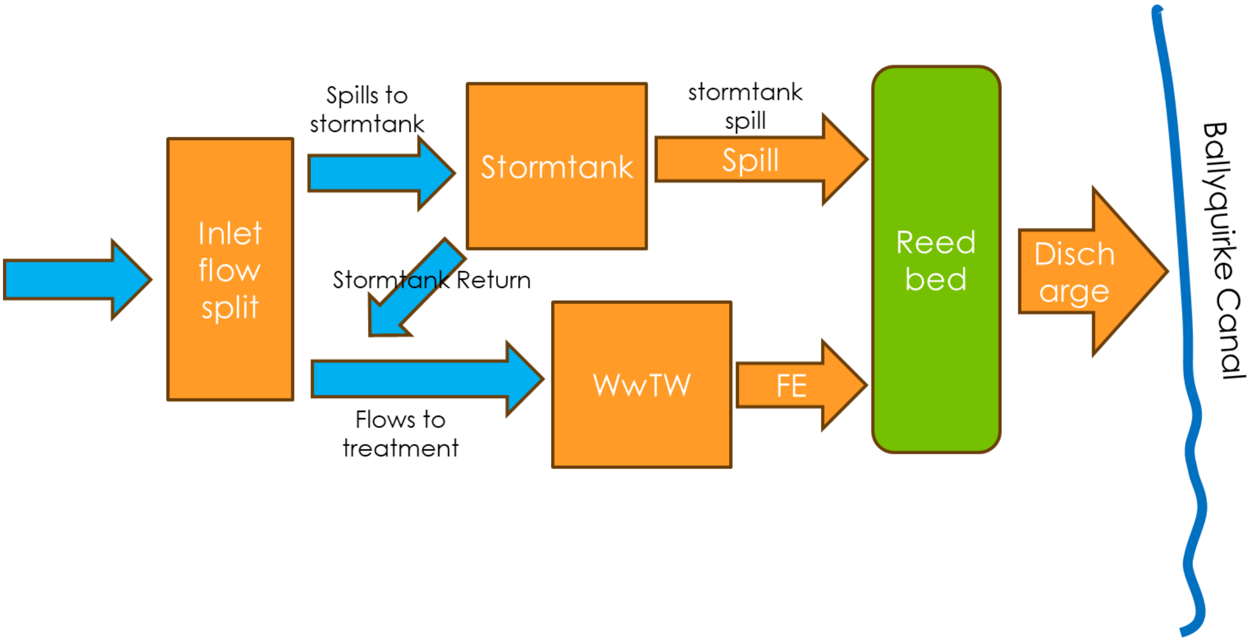

Figure 3-3 Schematic showing the representation of Moycullen WWTP

3.1.2. Model Calibration – WFD Monte Carlo WAC Assessment

The comparison of the upstream, downstream and simulated downstream continuous quality cumulative distribution frequency (CDF) curves (Figure 3-4), showed the downstream curve, which simulated the mixing of the river and the final effluent, was beneath the curve from the observed data. This confirmed the simulated concentration were lower than the observed data, therefore the impact of the final effluent was being underestimated in the monte carlo analysis.

There are three potential sources of sensitivity within the modelling, the receiving water flows, the wastewater discharge and the discharge quality.

The software has a feature where a scaling factor can be applied to the upstream river flow to re-estimate the downstream water quality. Using a value of <1 the flow contribution from the river can be reduced, it was found that by reducing the flow, the fit between the observed and simulated curves could be considerably improved for ammonia and ortho-P. The BOD model could not be improved because the observed upstream BOD concentration was marginally higher than downstream (reflecting variations in sampling).

The calibration demonstrated that the potential ELV concentrations calculated by the tool were sensitive to flow factors. Consequently, sensitivity testing was undertaken to see how the flow factors impact ELVs. Three different factors were applied 1, 0.75 and 0.5 to assess the impacts of changing treatment.

Figure 3-4 shows how the flow factor can be used to adjust the fit for the three determinands. Of the three scaling factors tested the 0.75 scaling factor was used in the water quality assessment, recognising the uncertainty in river flow and not force fitting the data.

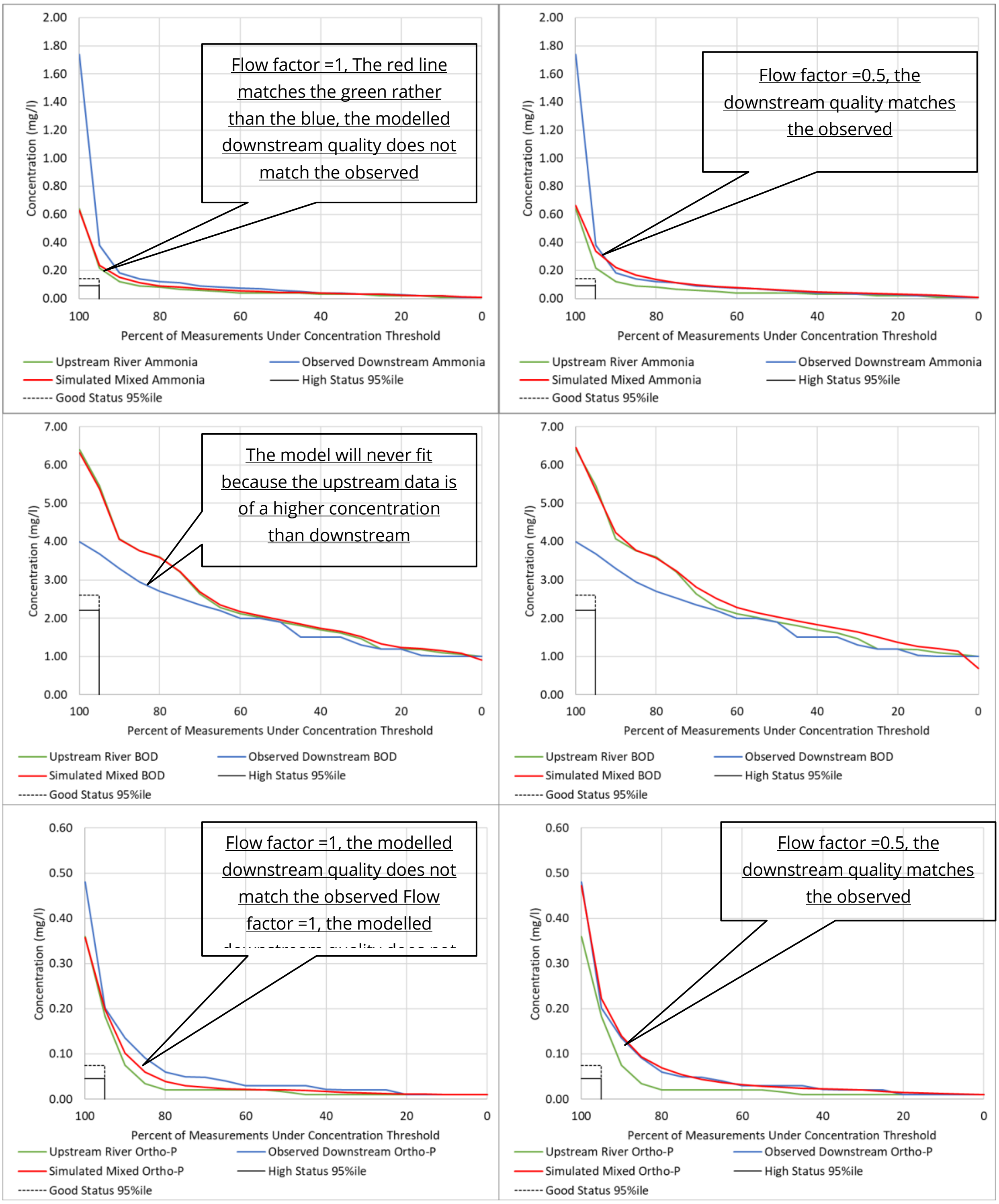

Figure 3-4 Continuous quality distributions, showing (left) using unmodified and (right) modified downstream ambient flows

3.1.3. Model Results

3.1.3.1. Continuous Discharge - WFD Monte Carlo WAC Assessment

Because the quality of the receiving water upstream of the WWTP already exceeds or gets close to the EQS there is insufficient assimilative capacity to calculate a discharge quality. In these cases, a "notionally clean" upstream boundary is applied. The aim of the "notionally clean" scenario is to allow determination of emission limits with due regard to source apportionment of pollution sources in line with the "polluter pays principle" as set out in Article 9 of WFD. The boundary is set by scaling the mean and standard deviation of the upstream ambient pollutant concentrations until both the mean and the 95%ile concentrations are set to 20% of the good/high threshold.

Notionally clean boundaries were required for all three of the water quality determinands for the assessment of the canal.

The effluent quality estimated for the five scenarios, are summarised in Table 3-8. The climate change scenario gave slightly higher proposed Emission Limit Values because the average annual river flows were greater than the average annual river baseline flows providing more dilution to the wastewater effluent.

Table 3-8 Moycullen WWTP - Proposed Emission Limit Values to meet WFD Good (with flow factor 0.75)

Growth Scenario	Ammonia mg/l 95%ile	BOD mg/l 95%ile	Ortho-P mg/l 95%ile	Does effluent need improvement to meet allowable assimilative capacity
Baseline	1.19	28.1	1.29	Yes (Ammonia)
2040	1.24	28.9	1.40	Yes (Ammonia)
2055	1.11	27.5	1.26	Yes (Ammonia)
2080	1.09	25.7	1.18	Yes (Ammonia)
2080 CC	1.35	31.8	1.52	No

Although a tightening of the proposed ELV for Ammonia is identified, there has been an identified need to assess the current plant for performance for this determinand. This is discussed further in Appendix 3.

3.1.3.2. Intermittent Discharges - UPM Model Analysis

As the storm tank SWO spills less than 1% of the time a UPM model was deemed unnecessary for this location. This is because if the discharge frequency is less than 99% of the time, then the discharge will not affect water body compliance with current EQS standards for mean and 95%ile conditions and the impact can be considered as negligible (as per UÉ, 2024[11]). The discharge also could not be assessed against a UPM HPS 99%ile standard.

3.1.4. Conclusions

The Ballycuirke Canal is of Moderate ecological status in the 2019-2024 assessment upstream of the discharge from Moycullen WWTP. The waterbody currently has no assimilative capacity due to the upstream water quality to receive wastewater discharges, therefore, a notionally clean boundary analysis was used to determine appropriate future levels of treatment in line with polluter pays principle, as set out in Article 9 of WFD.

In summary the analysis concluded:

- **Upstream Water Quality -** Upstream of Moycullen WWTP, the Ballycuirke Canal is classified as not achieving Good Status against WFD standards for ammonia, BOD and Ortho-P. The Ballycuirke Canal cannot achieve WFD good status without a significant improvement in the upstream water quality.
- **Downstream Water Quality -** Downstream of the WWTP, the canal is not achieving Good Status against WFD standards for ammonia, BOD and Ortho-P.
- **Intermittent Discharge Impacts -** The hydraulic sewer model outputs estimate that the storm tanks at the WWTP discharge for less than 1 percent of the year for all current and future scenarios. These discharges are infrequent and the impact can be considered as negligible. Furthermore, assessment is not possible against proposed standards/targets to assess compliance, as the discharges are so infrequent.
- **Continuous Discharge Impacts -** The results of the WFD WAC (Wastewater Assimilative Capacity) assessment using the Monte Carlo assessment tool demonstrated that WAC and consequently the proposed ELVs for the WWTP are sensitive to the modelling of the receiving watercourse.The proposed ELVs in Table 3-8 are less onerous than the licenced ELVs for the WWTP which are 1:10:0.5 mg/l respectively for Ammonia: BOD :ortho-phosphate. The WWTP performs well but there are unexpected instances of high ammonium levels exceeding ELV limits, which require further investigation.
- **Recommendations -** More comprehensive modelling and asset assessments are advised to ensure no process optimisation is necessary prior to the 2055 design horizon and to ensure the assets operate in a manner compatible with WFD objectives. It does not affect strategy recommendations to maintain the asset and keep treatment in-situ as any proposed standards are treatable with current technologies.

[11] Uisce Éireann (2024), Technical Guidance for Wastewater Impact Assessments (Freshwater Environments), Revision 02

3.2 Claregalway – River Clare

The Baile Chláir (Claregalway) agglomeration is a village to the northeast of Galway City. The village is situated alongside the River Clare, which flows in a south westerly direction into Loch Corrib.

The agglomeration has a separate sewage system with a population equivalent (PE) of 2,408 (2024 AER) and is served by Claregalway WWTP which discharges treated effluent to the River Clare adjacent to the plant as identified in Figure 3-5.

The River Clare reach CLARE (GALWAY)_100 was classified WFD Poor in the 2019-2024 assessment on grounds of Invertebrate Status or Potential.

Figure 3-5 Claregalway showing principal watercourses (blue) and WWTP location

3.2.1. Study Inputs

3.2.1.1. River Flow Modelling

Observed flow data was available local to the WWTP discharge. The river flow information was described with flow frequency curves. Flow statistics were taken from records for the flow measurement station, 30012 at the Tuam Road bridge in the centre of the village, shown in Figure 3-6.

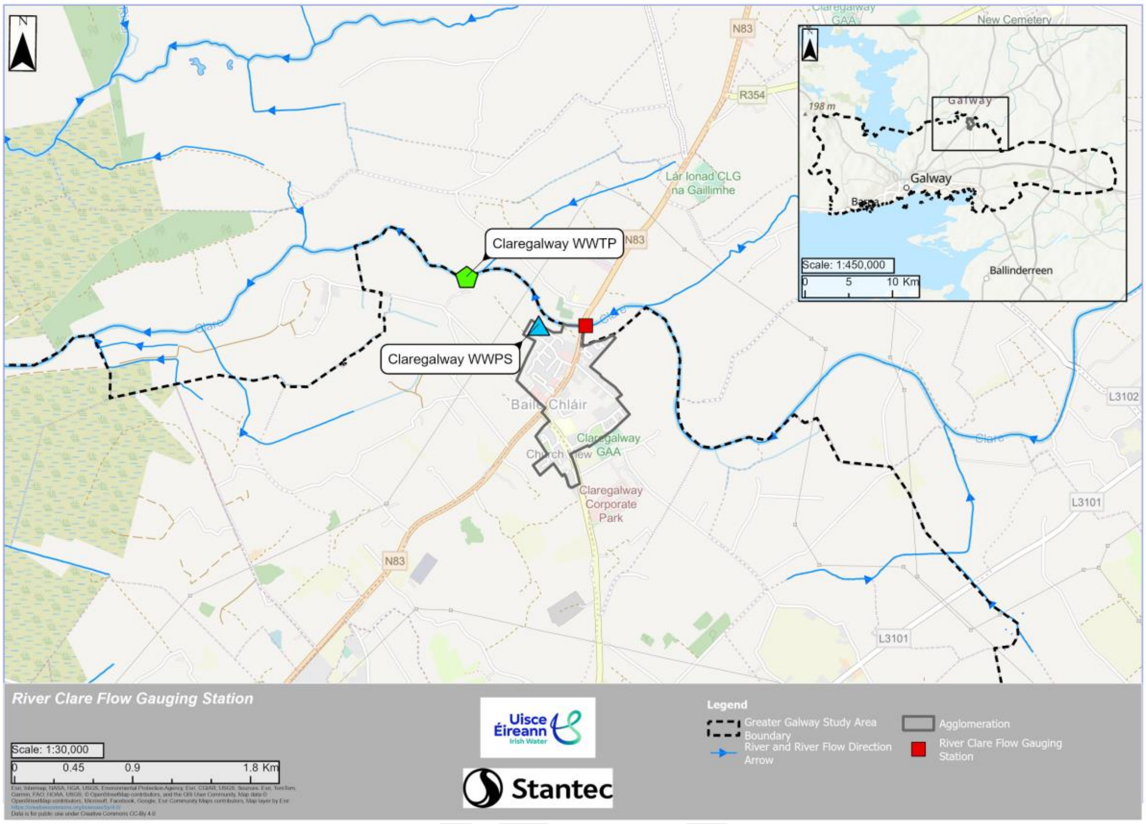

Figure 3-6 River Clare Flow Gauging Station

Summary statistics (Table 3-9) were developed from daily mean flow data from 1996 to 2023, which is 90% complete.

Table 3-9 Receiving Water Flow Statistics

Statistic	Flow m³/s
1 percent exceedance (Q1)	103
5 percent exceedance (Q5)	71.0
10 percent exceedance (Q10)	53.6
20 percent exceedance (Q20)	36.0
30 percent exceedance (Q30)	25.4
40 percent exceedance (Q40)	18.3
50 percent exceedance (Q50)	13.6
60 percent exceedance (Q60)	9.86
70 percent exceedance (Q70)	7.21
80 percent exceedance (Q80)	5.06
90 percent exceedance (Q90)	3.08
95 percent exceedance (Q95)	2.16
99 percent exceedance (Q99)	1.40

3.2.1.2. River Water Quality

The 2019-2024 WFD assessment for waterbody CLARE (GALWAY)_090 classifies the river as Good.

River water quality data was available for two sites adjacent to the Claregalway outfall, shown in Figure 3-7 and described in Table 3-10. The data was downloaded from the EPA Catchments website and is summarised in Table 3-11, along with the WFD classifications. The analysis shows that the river upstream of the WWTP discharge is high for BOD and ammonia but only marginally achieves WFD good for Ortho-P.

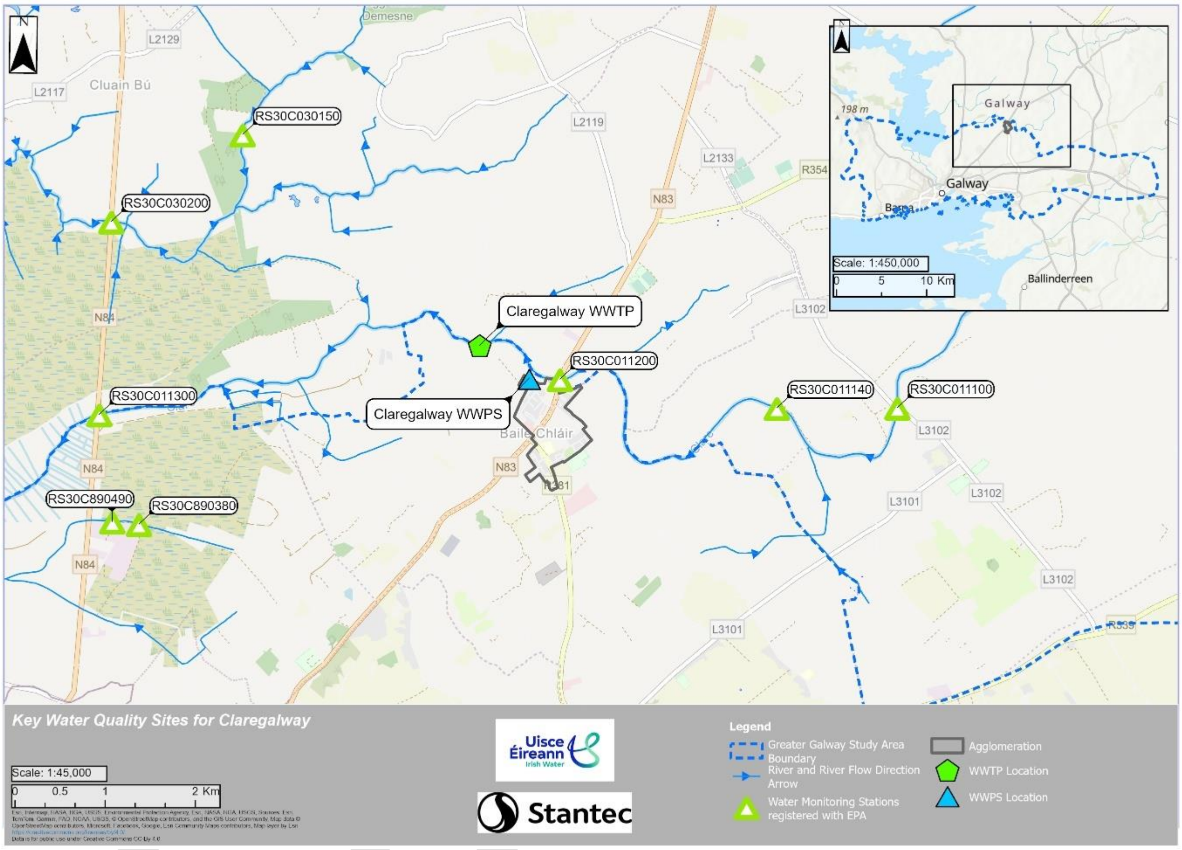

Figure 3-7 Key Water Quality Sites on the River Clare

Table 3-10 Available Water Quality Sites on River Clare

Site	Name	What data used for
RS30C011200	Claregalway Bridge	UPM and WFD U/S boundary
RS30C011300	Curraghmore Bridge	WFD D/S calibration site

Table 3-11 Observed Water Quality and WFD Classifications at Claregalway (orange <good, green=good, blue=high)

	Upstream			Downstream		
Determinand	Period	Mean mg/l	95%ile mg/l	Period	Mean mg/l	95%ile mg/l
Ammonia	15/02/2007-19/10/2023	0.019	0.046	14/02/2007-14/07/2022	0.020	0.050
BOD	15/02/2007-19/10/2023	0.923	2.1	14/02/2007-14/07/2022	0.894	2.300
Ortho-P	15/02/2007-19/10/2023	0.020	0.047	14/02/2007-14/07/2022	0.020	0.048

3.2.1.3. Continuous Discharge Data (WWTP)

Claregalway WWTP is located to the northwest of the village as shown in Figure 3-5. The agglomeration had a PE of 2,408 in 2024 and has tertiary treatment with N and P removal. The WWTP discharges to the River Clare in river waterbody Clare (Galway)_100. The WWTP performance is described in detail in Appendix 3 and wastewater treatment analysis was used to generate inputs into water quality models

The final effluent flow was estimated using desktop calculations for the Claregalway catchment. These were deemed more representative than the hydraulic model for Claregalway which has not been calibrated so the desktop calculations were used so that modelling undertaken was precautionary in nature (Table 3-12). The data for effluent quality from the WWTP is summarised in Table 3-13.

Table 3-12 Final Effluent Flow Statistics

Period	Final Effluent		
	Source	Mean l/s	95%ile l/s
Baseline	Desktop Calc	8.8	18.0
2040 Growth	Desktop Calc	16.9	34.5
2055 Growth	Desktop Calc	20.8	42.5
2080 Growth	Desktop Calc	21.8	44.5

3.2.2. Model Calibration – WFD Monte Carlo WAC Assessment

As high-quality observed river flow data from a site very close to the discharge was used and there was little additional dilution other than the final effluent discharge between the upstream and downstream water quality sampling sites a flow scaling factor of 1 was applied. The results are shown in Figure 3-8.

The observed upstream and downstream curves are reasonably similar showing that the WWTP does not have a large impact on the river, because the river is large providing considerable dilution. The model fits in Figure 3-8 show a good agreement in terms of both shape and values i.e. the red simulated mixed values match the blue observed downstream curves.

The BOD modelling performance is weak. Observed upstream BOD concentrations are very low and combined with the high river dilution and low effluent BOD, the model predicts downstream concentrations that closely match the upstream values. As a result, the simulated mixed concentration essentially overlays the observed upstream concentration. Although the downstream BOD is also low, the model cannot reproduce it.

The model provides a reliable representation of ammonia and orthophosphate mixing, correctly reflecting the effluent-to-river flow ratio. The model can still be used to develop proposed effluent quality for BOD, provided that the upstream BOD concentrations are considered representative.

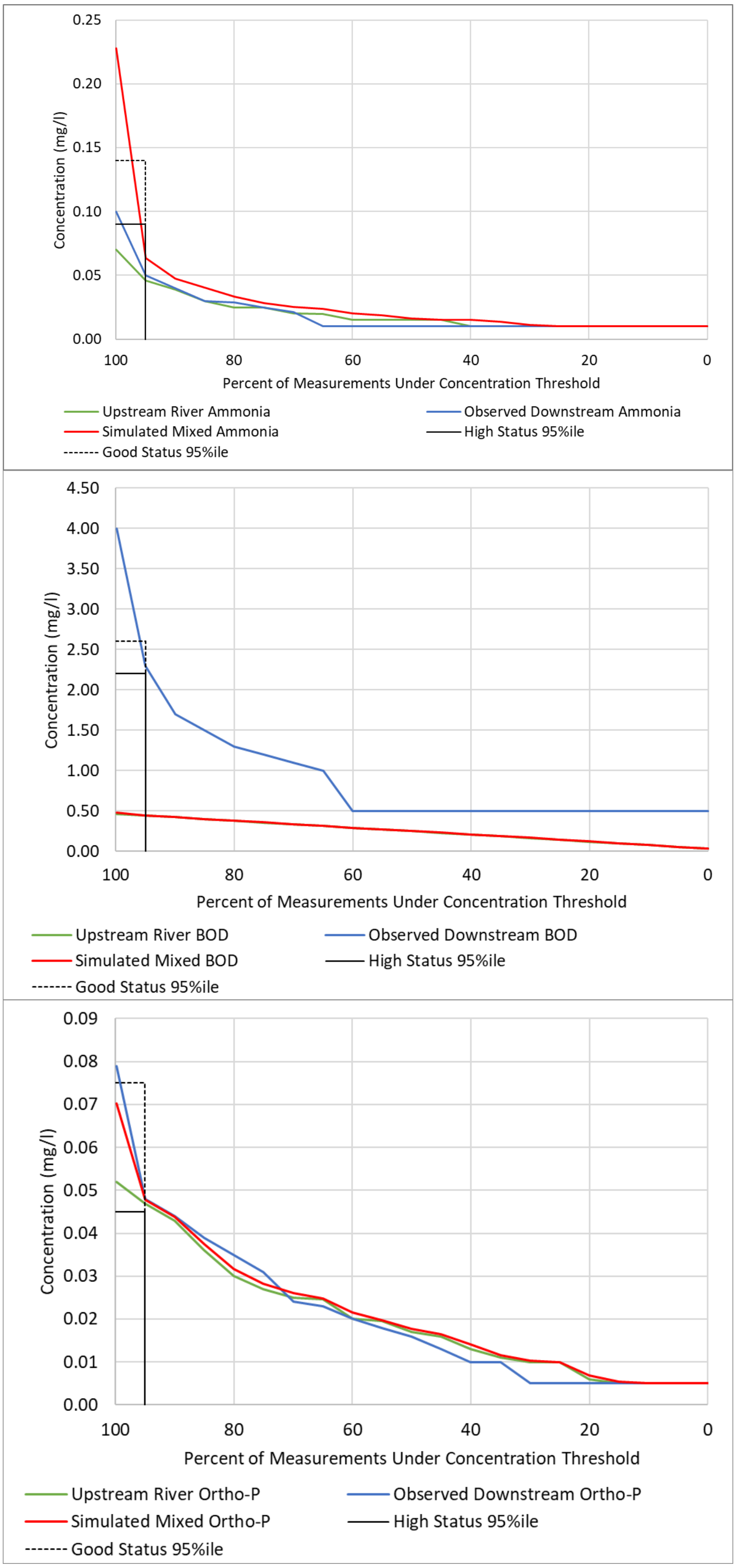

Figure 3-8 Non-exceedance probability curves for observed and modelled data from the monte Carlo assessment tool

3.2.3. Model Results

3.2.3.1. Continuous Discharge - WFD Monte Carlo WAC Assessment

The tool was run to determine the potential ELVs that would maintain WFD good and high status in the River Claire.

For all three determinands the proposed ELVs (Table 3-13 and Table 3-14) are larger than the current performance of the WWTP. This demonstrates that the watercourse has adequate capacity to comply relevant water quality standards provided the Claregalway WWTP maintains current levels of performance to 2080.

Table 3-13 Proposed Emission Limit Values to meet WFD Good

Growth Scenario	Ammonia mg/l 95%ile	BOD mg/l 95%ile	Ortho-P mg/l 95%ile	Does effluent need improvement to meet allowable assimilative capacity
Baseline	47	1010	34	No, Effluent meets EQS
2040	25	572	20	No, Effluent meets EQS
2055	21	408	17	No, Effluent meets EQS
2080	20	420	13	No, Effluent meets EQS
2080 (CC)	25	498	19	No, Effluent meets EQS

Table 3-14 Proposed Emission Limit Values to meet WFD High

Growth Scenario	Ammonia mg/l 95%ile	BOD mg/l 95%ile	Ortho-P mg/l 95%ile	Does effluent need improvement to meet allowable assimilative capacity
Baseline	28.8	909	8.2*	No, Effluent meets EQS
2040	13.9	445	5.5*	No, Effluent meets EQS
2055	12	383	5.7*	No, Effluent meets EQS
2080	11.7	368	5.1*	No, Effluent meets EQS
2080 CC	15.1	416	8.4*	No, Effluent meets EQS

*Achieving 95th percentile WFD High compliance for Ortho-P was not possible, as the upstream river does not meet WFD Good standards at this percentile. Compliance has only been reported based on the ELV using the mean value.

3.2.4. Conclusions

A modelling exercise has been undertaken investigating the water quality impacts of Claregalway agglomeration.

In summary the analysis concluded:

- **Upstream & Downstream Water Quality -** The River Clare in Claregalway has a large flow and consequently a large assimilative capacity. The River Clare at Claregalway maintains a WFD good water quality both upstream and downstream of the WWTP, classifying high for BOD and ammonia. The River Clare does not comply with WFD High for the 95% classification for Molybdate Reactive Phosphorus (ortho-phosphate) upstream of the WWTP.
- **Intermittent Discharge Impacts** - There are no intermittent discharges from the Claregalway agglomeration from UÉ assets to the River Clare.
- **Continuous Discharge Impacts** - Modelling showed that the river would comply with WFD high for ammonia and BOD, based on current ELVs. A climate change model was applied to create a flow duration curve for the River Clare for the year 2080. The assessment with the 2080 catchment growth and 2080 climate change river flows demonstrated that, provided the WWTP maintains its current performance, the river will maintain its current WFD water quality classification.
- **Recommendations -** The growth modelling shows that if the Claregalway WWTP maintains its current performance with predicted flows for 2040, 2055 and 2080 it will still enable the river to maintain its current water quality status.

3.3 Athenry – River Clarin

Athenry is a town located approximately 22km kilometres east of Galway City and situated on the River Clarin. The River Clarin is formed by two adjoining tributaries, the Graigabbey and Cloonkeen Rivers. The River Clarin flows south-westwards until it meets the sea at Dunbaulkin Bay which forms part of the Galway Bay Complex Special areas of conservation (SAC) and Inner Galway Bay Special protected areas (SPA).

The agglomeration operates a combined sewage system with a AER2024 PE of 6,206. It is served by the WWTP, which discharges treated effluent into the Clarin River. The agglomeration and the WWTP are shown in Figure 3-9.

The WWTP discharges to the beginning of waterbody Clarinbridge_030 (IE_WE_29C020300) just below the Clarinbridge_020 (IE_WE_29C020200) waterbody. The Clarin River was classified WFD Moderate ecological status in the 2019-2024 assessment.

The 2021 Biological Quality Assessment rated the river 3-4 upstream (Clarinbridge_020) of the WWTP and 3-4 downstream (Clarinbridge_030). Table 3-15 shows key findings from the 2019-2024 Catchment Assessment which does not show a decline in river quality from the point of the principal sanitary determinands. The table also includes the waterbody Clarinbridge_040 which shows a further decrease in ecological status or potential to Poor. In all three waterbodies the classification is driven by Invertebrate Status or Potential.

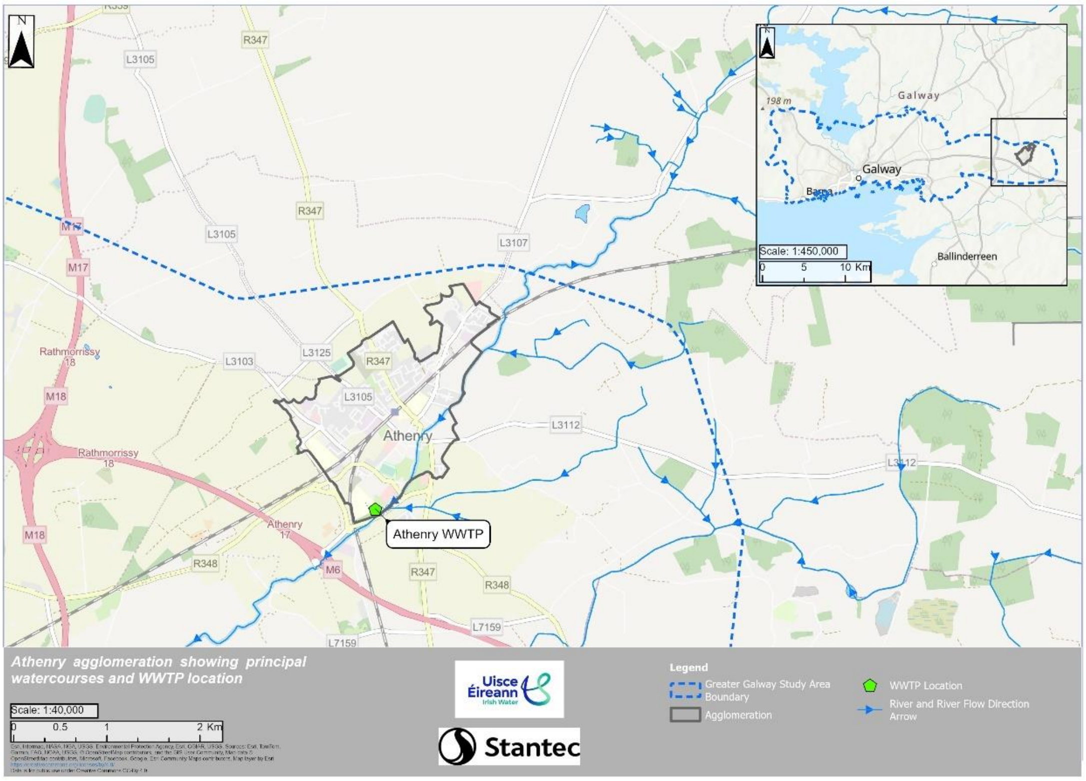

Figure 3-9 Athenry showing principal watercourses (blue) and WWTP location

Table 3-15 2019-2024 WFD Catchment Assessment

Model	CLARINBRIDGE_020	CLARINBRIDGE_030	CLARINBRIDGE_040
Ecological Status or Potential	Moderate	Moderate	Poor
Invertebrate Status or Potential	Moderate	Moderate	Poor
Dissolved Oxygen (% Sat)	Pass	Pass	Pass
Other determinand for oxygenation	High	High	High
Ammonium	High	High	High
Orthophosphate	High	High	High

3.3.1. Study Inputs

3.3.1.1. River Flow Modelling

The study requires a representation of the river flow entering the study reach at the upstream boundary. The waterbody is in the Galway Bay Southeast, WFD catchment, within the Clarinbridge_20 Sub Basin (area 24 km^2). The Clarin catchment is Karst and there is considerable interaction with ground water, which makes the Hydrotool model unreliable for predicting river flows (this was factored into the calibration discussed in section 3.3.2 to ensure model was fit for purpose). The only appropriate flow gauging station was the Office of Public Works (OPW) site more than 12km downstream of Athenry in Clarinbridge (Figure 3-10).

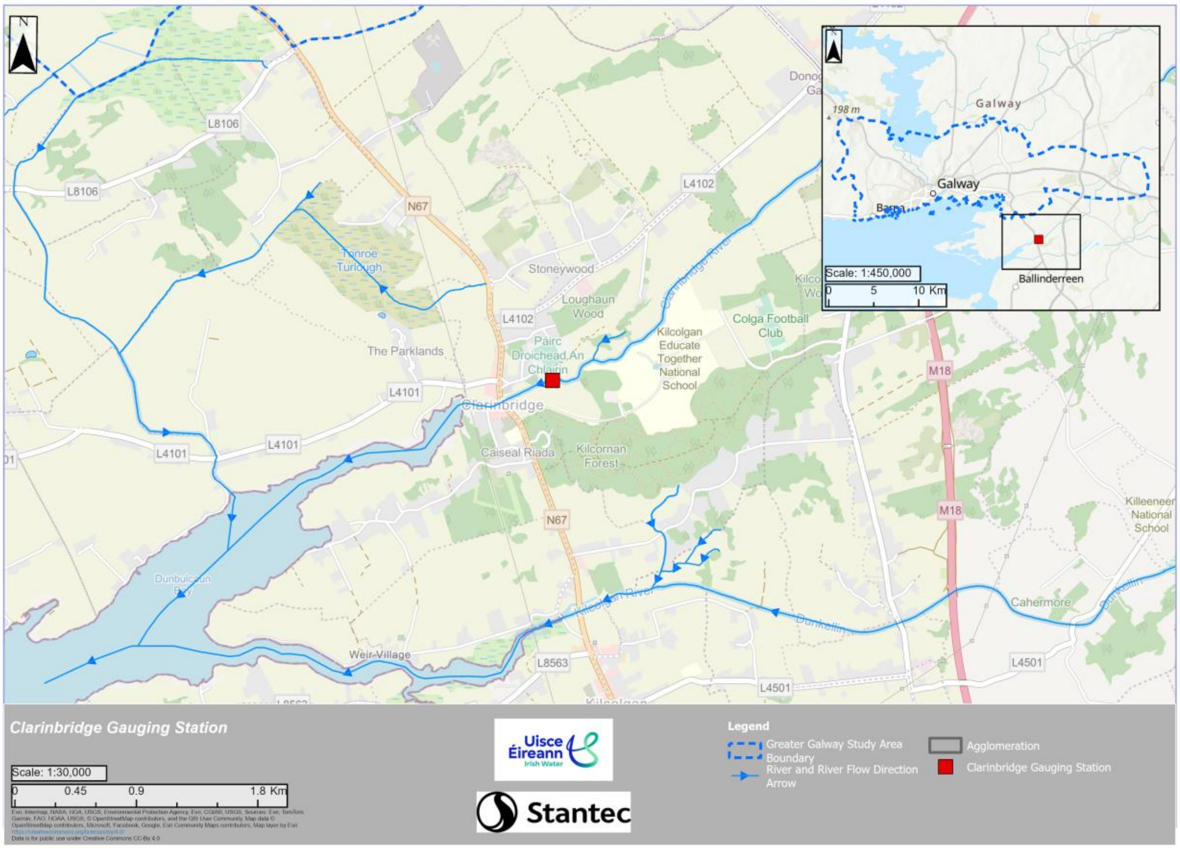

Figure 3-10 The Clarinbridge Gauging Station

The River Clarin at Clarinbridge drains an area of 123 km^2, but only 39 km^2 at the Athenry WwTP discharge point. The flow duration curves for the Hydrotool flow prediction (29_359) for the Clarin at Athenry, the measured flows at the OPW Clarinbridge gauge and area scaled flows based on Clarinbridge were compared (Figure 3-11). The scaled flows and Hydrotool predictions match for flows above Q50 but deviated for lower flows.

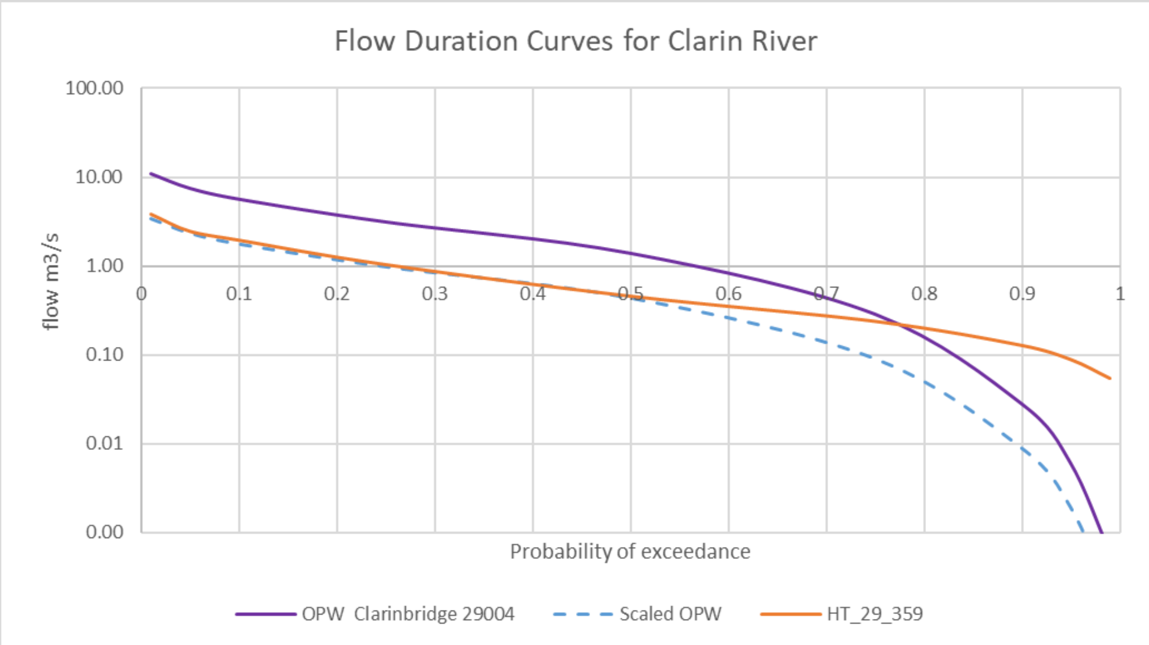

Figure 3-11 Generating a flow distribution for upstream of Athenry WWTP.

The Karst maps provided by Tailte Éireann (2025)[12] and shown in Figure 3-12, show very complex hydrological interaction with the geology downstream of Athenry, with most features on the river between Athenry and Clarinbridge. It was concluded that the Hydrotool model should be used to produce a more rational description of the flows at Athenry.

There were also concerns that wastewater discharges might impact ground water quality, but these were discounted because, although the Clarin River's interaction with the Karst network complicates flow balancing at certain points, the river's flow remains fast-moving, akin to a surface water flow network, with minimal interaction with deeper aquifers. Consequently, the WFD and UPM assessments, which provide ecological protection for surface water, also offer appropriate protection for these disappearing and resurgent streams.

[12] Tailte Éireann (2025)

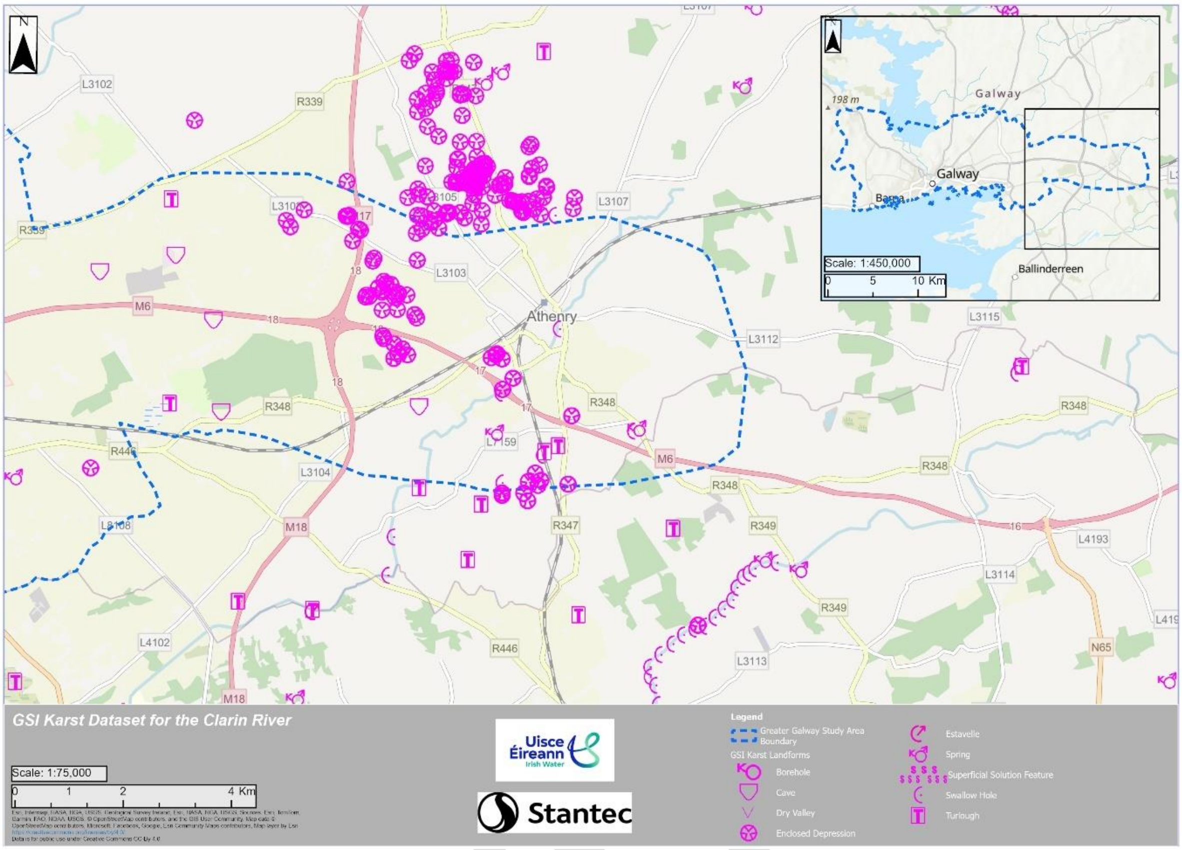

Figure 3-12 GSI Karst Dataset for Clarin River (Tailte Éireann 2025).

For the Clarin River, the flows were taken from observed flow records as described. The river flows were modelled using a Level 1 UPM approach, flows were drawn randomly from the flow distribution, to produce a 10-year set of river flows.

The UPM FIS analysis is generally undertaken when the environment is more susceptible to intermittent discharges, the low dilution, higher temperature summer period. To account for seasonality, a separate summer time-series was generated, this generation was scaled from the annual on the seasonal information in Hydrotool for the river, May-September mean flow was approximately 50% smaller than the annual mean flow. The river flow was thus decreased by 50% to produce a summer flow series.

The summary statistics are provided in Table 3-16.

Table 3-16 Receiving Water Flow Statistics

Site	Flow (m3/s)			
	Annual Mean	Annual Standard Deviation	Summer Mean	Summer Standard Deviation
River Clarin	0.622	0.679	0.311	0.340

A Simplified River Model is required for the UPM assessment to simulate DO and ammonia concentrations at points along the river which can then be assessed against the UPM standards. A model was used which accounts for channel hydraulics, flow, depth and velocity and concentrations of BOD, ammonia, pH temperature and DO. It simulates reaeration, BOD decay, ammonia release from BOD and ammonia decay. The model was developed in accordance with guidance contained within the UPM manual and the CIWEM River Modelling Guide (CIWEM, 2017)[13].

The waterbody considered in this study is represented as a single reach. The reach is described in Table 3-17.

Table 3-17 Reach Physical Characteristics

Physical characteristics	Reach
Length (km)	14.784
Slope (m/km)	1.89
Typical Width (m)	4.57
Manning's n	0.08

The parameters used in modelling water quality processes are listed in Table 3-18. The chosen water quality parameter values are typical values taken from standard guidance.

[13] River Modelling Guide (CIWEM, 2017).

Table 3-18 Water Quality Process Parameters

Parameter	All reaches
BOD Decay (/day)	0.3
Ammonia Decay (/day)	1.0
Ammonia Release from BOD Decay (/day)	0.3
Ammonia Yield Factor	4.47
Re-aeration Parameter A	3.9
Re-aeration Parameter B	0.5
Re-aeration Parameter C	-1.5

3.3.1.2. River Water Quality

River water quality data was available for two sites adjacent to the Athenry outfall, shown in Figure 3-13 and described in Table 3-19. The data was downloaded from the EPA Catchments.ie website and is summarised in Table 3-20, along with the WFD classifications for BOD, ammonia and Molybdate Reactive Phosphorus (MRP). The classifications are set out in the European Union Environmental Objectives (Surface Waters) (Amendment) Regulations, European Union (2019).[14]

[14] Surface Water Regulations (2019)

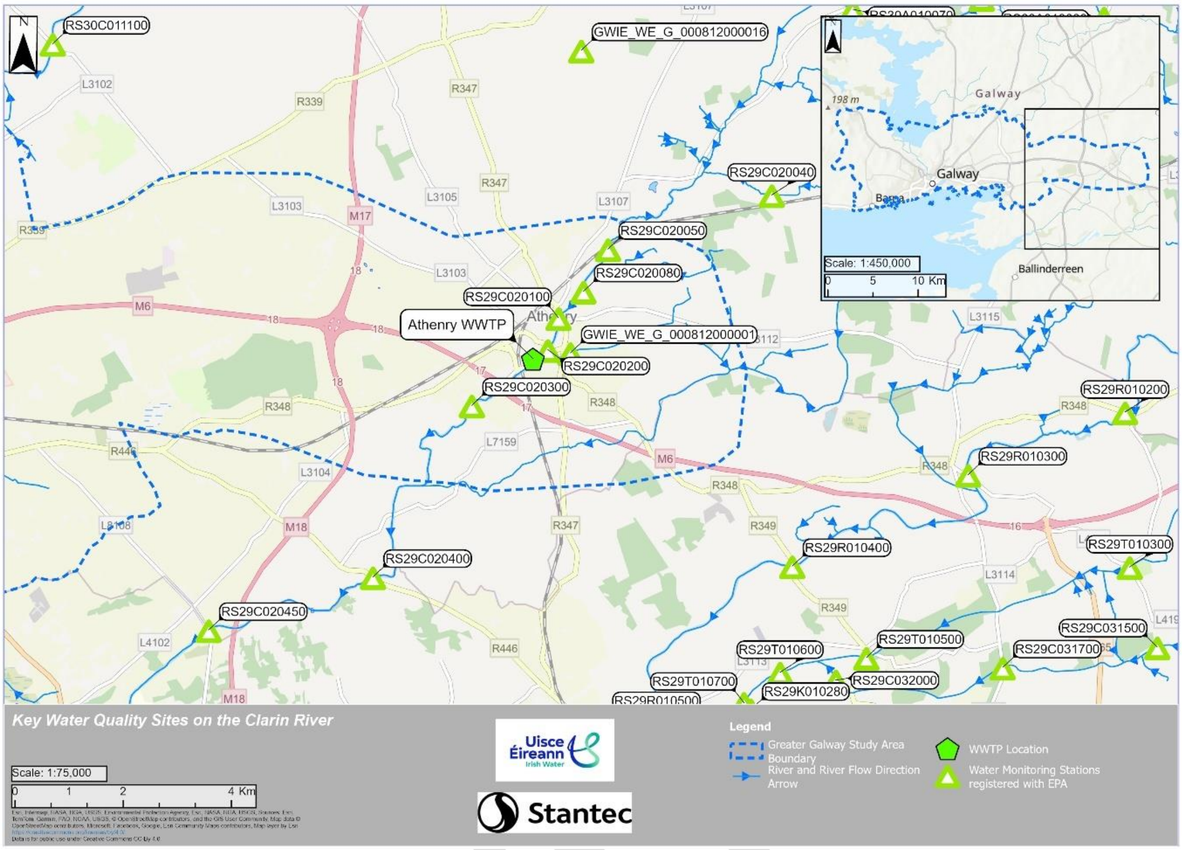

Figure 3-13 Key Water Quality Sites on the Clarin River

The annual and summer data sources used in the UPM analysis are summarised in Table 3-21 respectively. The annual statistics used for the WFD WAC assessment and the UPM FIS are slightly different because they were summarised over different periods but do show that the concentrations of BOD and ammonia upstream of Athenry WwTW are not seasonally variable.

Table 3-19 Water Quality Sites

Site	Name	What data used for
RS29C020200	Athenry: South Bridge	UPM and WFD U/S boundary
RS29C020300	Br N Mulpit	WFD D/S calibration site

Table 3-20 Observed Water Quality and WFD Classifications (orange = less than good, green=good, blue=high)

Determinand	Upstream - RS29C020200			Downstream - RS29C020300		
	Period	Mean mg/l	95%ile mg/l	Period	Mean mg/l	95%ile mg/l
Ammonia	21/05/2019-11/10/2024	0.036	0.043	05/02/2019-11/10/2024	0.045	0.175

Determinand	Upstream - RS29C020200			Downstream - RS29C020300		
	Period	Mean mg/l	95%ile mg/l	Period	Mean mg/l	95%ile mg/l
BOD	21/05/2019 – 11/10/2024	0.78	1.30	12/03/2019-11/10/2024	0.87	1.53
Ortho-P	21/05/2019-11/10/2024	0.017	0.029	14/03/2019-11/10/2024	0.102	0.069

The concentrations observed at the downstream site RS29C020300, show that for certain determinands and statistics the river water quality is not better than good contradicting the physico-chemical elements of the classification for CLARINBRIDGE_020 in Table 3-15. There are at least three monitoring sites in the waterbody so the classification may not be directly related to this single site.

Table 3-21 Water Quality Parameters used in the UPM HPS and FIS Analysis

Site	Years	Season	Determinand	Count	Mean (mg/l)	SD (mg/l)	Type
RS29C020200 Athenry: South Bridge	2007 – 2014	Annual HPS	Ammonia	80	0.032	0.077	Lognormal
			BOD	79	0.8	0.4	Lognormal
		Summer FIS	Ammonia	45	0.039	0.101	Lognormal
			BOD	45	0.8	0.5	Lognormal
			DO	23	10.20	1.05	Normal
			Temp	45	14.1	2.0	Normal
			pH	46	8.146	0.174	Normal

3.3.1.3. Continuous Discharge Data (WWTP)

The WWTP performance is described in detail in Appendix 3 and wastewater treatment analysis was used to generate inputs into water quality models. The treated effluent flow was taken from the hydraulic sewer model and are detailed in Table 3-22. The data for effluent quality from the WWTP was supplied by UÉ and summarised in Table 3-23.

Table 3-22 Athenry Final Effluent Flow Statistics

Model	Final Effluent			
	Period	Source	Mean l/s	Pass Forward Flow l/s
Baseline	10-year series	Modelled	11	66
2040 Growth	10-year series	Modelled	24	66
2055 Growth	10-year series	Modelled	28	66
2080 Growth	10-year series	Modelled	29	66
2080 Growth with 2080 CC Rainfall	10-year series	Modelled	30	66

Table 3-23 Athenry WWTP Final Effluent Quality Statistics

Determinand	Final Effluent			
	Period	No Records	Mean mg/l	95%ile mg/l
Ammonia	08/01/2019–05/12/2023	52	0.37	1.0
BOD	02/04/2019 – 05/12/2023	22	2.8	6.1
Ortho-P	08/01/2019 – 05/12/2023	56	0.26	0.69

3.3.1.4. Intermittent Discharges

The Athenry hydraulic sewer model was simulated to produce flows arriving at the inlet to the Athenry WWTP. The sewer model did not extend into the inlet works of the WWTP and did not represent all the intermittent discharges that may occur from the WWTP, notably discharges from the stormtanks and the greater than Formula A overflow. On review, the orifice setting on the inlet SWO did not match the current configuration on site, therefore modifications were required to simulate observed discharge frequencies using historical verification. This configuration is illustrated in Figure 3-14.

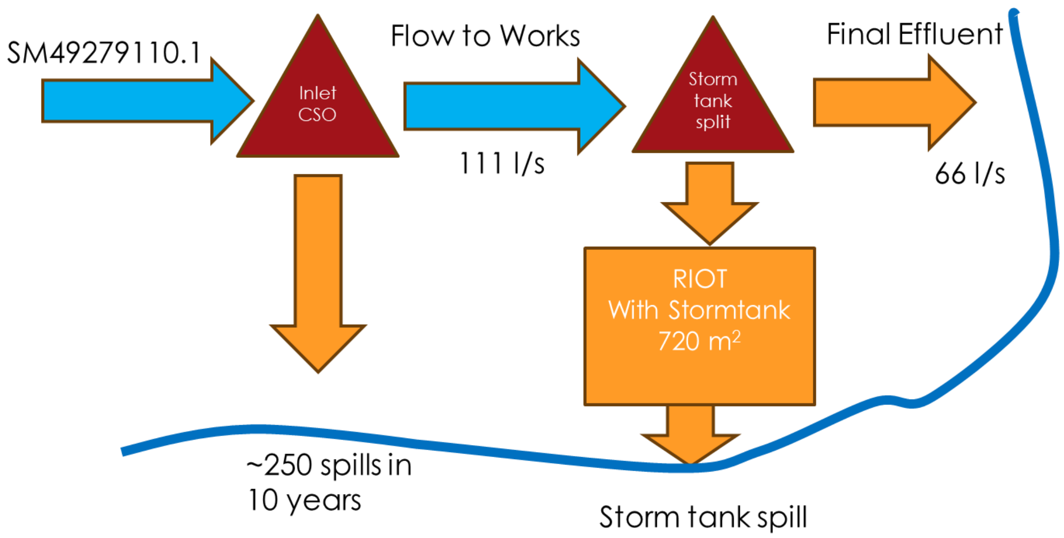

Figure 3-14 Flow configuration used for the UPM assessment

Consequently, the time-series flow to the inlet works was taken from the model and split into a pass-forward flow (PFF) to the WWTP and discharges at both the inlet and to the storm tanks. A 111 l/s pass-forward flow at the inlet resulted in an average of 25 spills per year. From the 111 l/s passed forward to preliminary treatment 66l/s went to full treatment (FFT). Any flows more than this flow were discharged to the stormtanks.

A stormtank storage and drawdown model was used, whereby flow discharging to the stormtanks were either:

1) stored in the 720 m^3 tank and returned to treatment sometime after the storm had abated (i.e. The stormtanks were assumed to drawdown two hours after they had stopped receiving an inflow from the inlet works. A real-time control was set at a discharge rate of 25 l/s, this resulted in a storm tank drain down time of 8 hours.) or;

2) discharged to the river if the tank had filled completely.

The resultant discharge data is illustrated in Table 3-24 from the drawdown model.

Table 3-24 Modelled Intermittent Discharges at Athenry WWTP

Parameter	Overflow	Baseline	Athenry 2040	Athenry 2055	Athenry 2080	2080 Climate Change*
Average No. Spills per year	Inlet SWO	252	440	468	479	439
	Storm Tank Spill	1.6	7.0	8.5	9.4	11.3
Ave. Duration per year (hr)	Inlet SWO	116	271	315	325	101
	Storm Tank Spill	7	30	37	43	46
Ave % of year spills	Inlet SWO	1.3%	3.1%	3.6%	3.7%	1.15%
	Storm Tank Spill	0.1%	0.3%	0.4%	0.5%	0.5%
Spill Volume Per Year (m^3)	Inlet SWO	1,944	4,089	4,378	4,485	8,782
	Storm Tank Spill	6,252	25,667	31,848	35,362	4,187

*The 2080 climate change spills analysis was based on a single typical wet year run, whereas all the other analyses were run with 10 years.

3.3.2. Model Calibration – WFD Monte Carlo WAC Assessment

The comparison of the upstream, downstream and simulated downstream continuous quality curves (Figure 3-15) showed the simulated downstream curve slightly underestimated the observed data for ammonia and Ortho-P but under predicted BOD, which indicated the impact of the effluent was being underestimated.

The tool has a feature where a factor can be applied to scales the contribution from the upstream flow, prior to the mass-balance. Using a scale factor to modify flows, the fit between the observed and simulated curves was considerably improved for ammonia and ortho-p, albeit with limited improvement for BOD.

Because the simulated and observed curves fitted so well for ammonia and ortho-P it was concluded that the flows in River Clarin had been over-estimated in the river flow modelling. A more rational and precautionary estimate of the true flow in the river was achieved by applying a scale factor of 0.8.

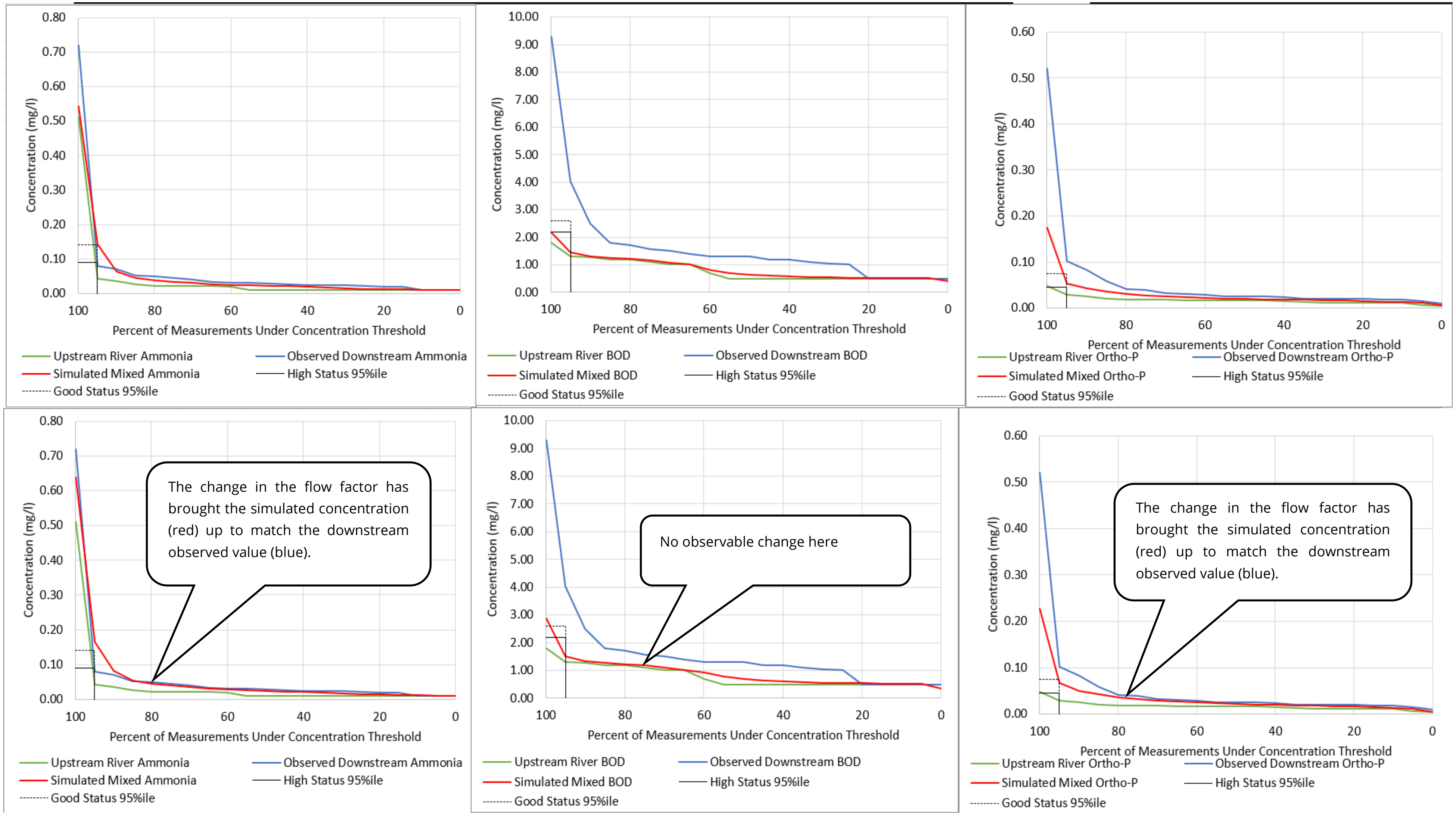

Figure 3-15 Comparison of upstream and downstream curves at scale factor 1 (top) and 0.8 (bottom)

3.3.3. Model Results

3.3.3.1. Continuous Discharge - WFD Monte Carlo WAC Assessment

The effluent quality estimated for the five scenarios, are summarised in Table 3-25.

Table 3-25 Proposed Emission Limit Values to meet WFD Good

Growth Scenario	Ammonia mg/l 95%ile	BOD mg/l 95%ile	Ortho-P mg/l 95%ile	Does effluent need improvement to meet allowable assimilative capacity
Baseline	0.3	18	0.5	Yes (ammonia and ortho-P)
2040	0.1	5	0.2	Yes (ammonia, BOD and ortho-P)
2055	0.1	4	0.1	Yes (ammonia, BOD and ortho-P)
2080	0.1	4	0.1	Yes (ammonia, BOD and ortho-P)
2080 Climate Change	0.1	4	0.1	Yes (ammonia, BOD and ortho-P)

3.3.3.2. Intermittent Discharges - UPM Model Analysis

The modelled spills were analysed, and the results summarised in Table 3-26 and Table 3-27. The system spills sufficiently often (i.e. > 1% of year) to warrant a UPM assessment.

Both a Fundamental Intermittent Standards (FIS) and High Percentile Standards (HPS) model were assessed. For the FIS modelling a 1 hour and 6-hour assessment was undertaken. The FIS assessment generally only looks at summer flows, which are most onerous with less precipitation, lower river flows, with higher temperature. HPS modelling analyses was for the whole year.

The FIS assessments all pass, as shown in Table 3-26, having fewer than 1 exceedance per year for dissolved oxygen and unionised ammonia. These results indicate that the intermittent discharges from the Athenry do not cause ecological harm.

A WFD mean, 95-percentile and a UPM High Percentile (99-percentile) assessment was undertaken. The 99-percentile assessment is not required in Ireland but provides a further means to assess the potential impacts of the Athenry intermittent discharges. The Athenry system does not comply with the WFD (mean and 95-percentile) and UPM (99-percentile) HPS for ammonia for all scenarios and all the growth scenarios for BOD (Table 3-27).

Table 3-26 FIS Results for Athenry Model (green = pass, red = fail)

Scenario	Duration	Threshold (Exceedances per year)	1 hour		6 hours		Overall performance against standards
			Dissolved Oxygen (Exceedances per year)	Unionised Ammonia (Exceedances per year)	Dissolved Oxygen (Exceedances per year)	Unionised Ammonia (Exceedances per year)	
Baseline	One Month	5	0	1.86	0	0.27	Pass
	Three Months	1.7	0	0.45	0	0.05	
	One Year	1	0	0.3	0	0.02	
2040	One Month	5	0	2.37	0	0.56	Pass
	Three Months	1.7	0	0.75	0	0.09	
	One Year	1	0	0.48	0	0.06	
2055	One Month	5	0	2.53	0	0.45	Pass
	Three Months	1.7	0	0.56	0	0.15	
	One Year	1	0	0.34	0	0.06	
2080	One Month	5	0.02	2.94	0	0.47	Pass
	Three Months	1.7	0	0.78	0	0.08	
	One Year	1	0	0.52	0	0.06	
2080 with CC River	One Month	5	0.01	3.05	0	0.33	Pass
	Three Months	1.7	0	0.70	0	0.09	
	One Year	1	0	0.53	0	0.05	
2080 with CC Network and River	One Month	5	0.35	2.8	0	0.31	Pass
	Three Months	1.7	0.26	0.92	0	0.05	
	One Year	1	0.21	0.69	0	0.03	

Table 3-27 WFD Percentile and HPS (99%ile) Results for Athenry Model (Blue= High, Green = pass/good, Red = fail)

Scenario	Mean BOD mg/l*	Target Mean BOD mg/l	95%ile BOD mg/l*	Target 90%ile BOD mg/l	99%ile BOD mg/l¥	Target 99%ile BOD mg/l
Baseline	0.87	1.5	1.52	2.6	4.48	5.0
2030 Growth	1.30		2.91		5.61	
2055 Growth	1.34		3.06		5.85	
2080 Growth	1.34		2.96		5.82	
2080 Growth + CC River	1.30		2.95		5.72	
2080 with CC Network and River	1.31¥		3.12¥		7.08	

Scenario	Mean TA mg/l*	Target Mean TA mg/l	95%ile TA mg/l*	Target 90%ile TA mg/l	99%ile TA mg/l¥	Target 99%ile TA mg/l
Baseline	0.047	0.06	0.169	0.14	0.82	0.7
2030 Growth	0.125		0.443		0.96	
2055 Growth	0.132		0.435		1.02	
2080 Growth	0.136		0.457		1.06	
2080 Growth + CC River	0.124		0.420		1.01	
2080 with CC Network and River	0.11¥		0.41¥		1.14	

*Taken from the WFD Monte Carlo analysis, ¥Taken from the UPM HPS analysis

3.3.4. Conclusions

A modelling exercise has been undertaken investigating the water quality impacts of Athenry agglomeration.

In summary the analysis concluded:

- **Upstream Water Quality -** Upstream of Athenry WWTP, the River Clarin is classified as 'high' against WFD standards for ammonia, BOD and Ortho-P

- **Downstream Water Quality -** Downstream of the WWTP, ammonia and orthophosphate decline to below good status, modelling demonstrates that growth in the catchment and climate change will make this situation worse.

- **Intermittent Discharge Impact** - the inlet SWO currently spills for more than 1% of the year and proposed growth will increase the duration three-fold. The storm tanks as modelled do not spill more than 1% of the year and are not expected to, as a result of growth scenarios or climate change scenarios.

  The UPM FIS scenarios (present day through to 2080 climate change plus growth), did not show the intermittent discharges exceeding the standards for sustainable Cyprinid fishery, implying that the intermittent discharges are not at risk of causing ecological harm to the River Clarin. However, the UPM HPS (which may not apply in Ireland) suggest that the intermittent discharges may potentially have an ecological impact on the receiving watercourse.

- **Continuous Discharge Impact** - The results indicate that WWTP final effluent improvement is necessary. For the present-day analysis both ammonia and orthophosphate require improvement, but with BOD meeting the estimated ELV. However, in all growth scenarios all the determinands fail the proposed ELVs and the WWTP final effluent will require further improvement.

- **Recommendations -** Given the sensitive nature of the receiving watercourse and the treatment standards proposed it is not feasible to have a WWTP discharging to this watercourse in the medium to long term.

3.4 New WWTP – River Corrib Discharge

An assessment was carried out to support the determination of indicative ELVs for a proposed WWTP discharging to the River Corrib. This was for purposes of assessing a new WWTP discharge location as part of the optioneering process carried out in Appendix 5, to be subject to Multi-Criteria Decision Analysis (MCDA). A continuous discharge water quality impact assessment was carried out for this purpose.

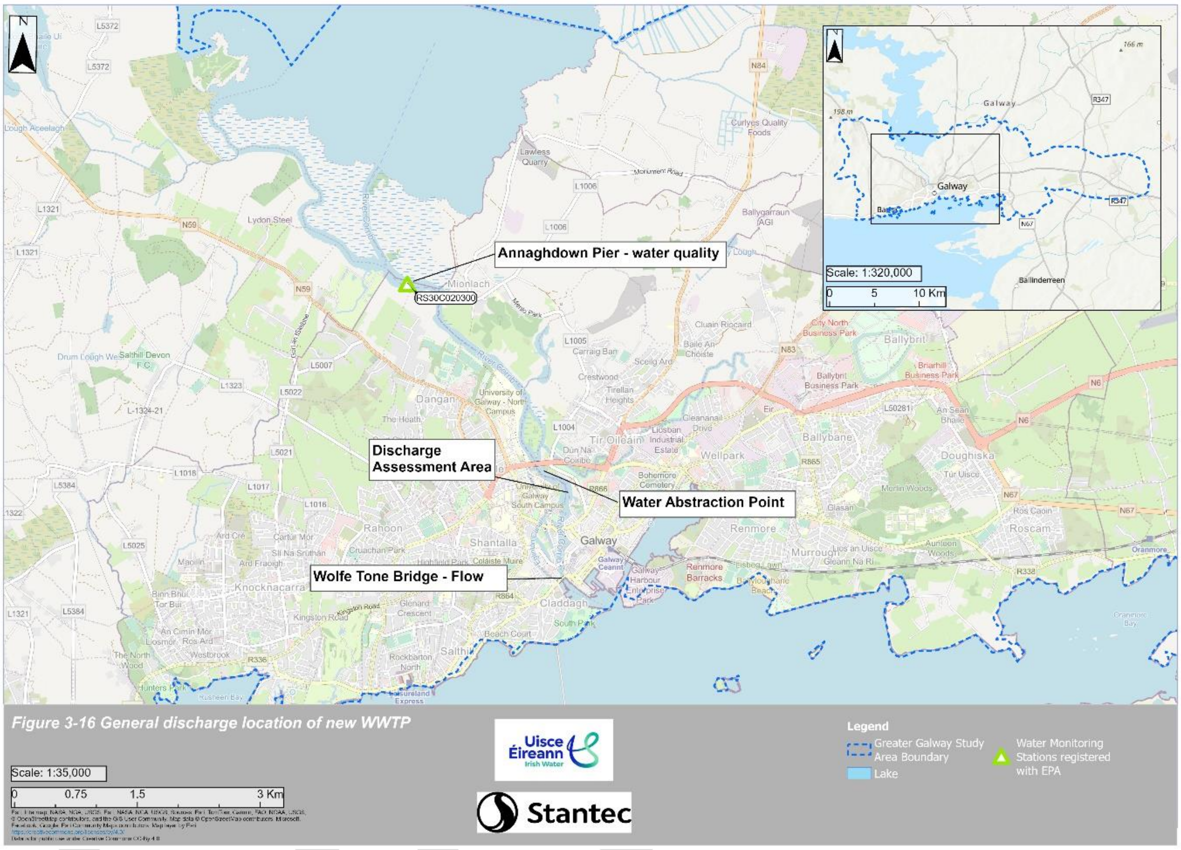

Figure 3-16 General discharge location of new WWTP

3.4.1. Study Inputs

3.4.1.1. River Flow Modelling

An OPW flow gauging station at Wolf Tone Bridge (Figure 3-16) on the River Corrib was used to assess the ambient flow conditions. Percentile analysis for the flow frequency is summarised in Table 3-28

Table 3-28 Flow Frequency Curve for Wolf Tone Bridge

Percentile	Flow [m^3/s]
1	103
5	71
10	53.6
20	36

Percentile	Flow [m³/s]
30	25.4
40	18.34
50	13.6
60	9.856
70	7.21
80	5.06
90	3.08
95	2.16
99	1.4029

3.4.1.2. River Water Quality

River water quality was taken from the site at Annaghdown Pier (RS30C020300) shown in Figure 3-16. This site was upstream of the proposed discharge site and as such considered to be representative of upstream river water quality.

Data for the monitoring station showed that the River Corrib is classified as WFD High for ammonia and BOD but Good for Ortho-P as there was a marginal exceedance of the 95%ile threshold of 0.045 mg/l, as shown in Table 3-29.

The receiving waterbody Corrib_020, classified as Good ecological status for both the 2013-2018 and the 2019-2024 assessments.

Table 3-29 Summary Statistics for River Corrib at Annaghdown Pier, RS30C020300 (orange <good, green=good, blue=high)

Determinand	Mean (mg/l)	95%ile (mg/l)
Ammonia	0.026	0.059
BOD	0.251	0.441
Ortho-P	0.021	0.048

3.4.2. Continuous Discharge Data (New WWTP)

The flow for the new WWTP proposed is summarised in Table 3-30. The Monte Carlo assessment requires a distribution of the treated effluent flows. The flow distribution for Athenry was used and scaled until the flows met the average flows for the new WWTP. The average and peak flows were obtained from growth projections outlined within *Appendix 1: Managing Growth* to estimate the flows at the 2080 horizon for the new WWTP for modelling purposes.

Table 3-30 Treatment flows for potential new WWTP

	Average Flow (l/s)	FFT (l/s)
New WWTP	786	1664

3.4.3. WFD Monte Carlo WAC Assessment

A Monte Carlo analysis was undertaken to investigate the assimilative capacity of the river to receive the effluent of the proposed new WWTP. This was undertaken to give indicative ELVs for purposes of assessing its viability as a treatment location for strategy optioneering purposes (without further MCDA assessment).

The tool was run to calculate effluent concentrations that would meet available assimilative capacity and maintain upstream water quality status. The River Corrib was generally classified "high" for the three key determinands of interest. The proposed effluent quality was estimated which would meet both High and Good status downstream of the discharge location.

As this is a theoretical scenario, there was no downstream data with which to calibrate the model against.

3.4.4. Model Results

Table 3-31 summarises the indicative ELVs that would be required for a discharge to meet various WFD standards for the River Corrib.

Table 3-31 Proposed ELV to meet WFD standards in the River Corrib.

Scenario	Ammonia mg/l	BOD mg/l	Ortho-P mg/l	Comments
WFD Good	2.1	65	0.8	
WFD High	0.9	54	0.3*	Requires a notionally clean boundary for ortho-P to meet threshold

3.4.5. Conclusions

- The River Corrib has sufficient assimilative capacity. It is feasible to discharge effluent from a new WWTP into the River Corrib and comply with current WFD standards.
- If WFD standards were to tighten, to meet high status, this discharge location may have insufficient capacity, lack resilience and increase vulnerability of such a WWTP.

4. Transitional and Coastal Waterbody Assessment Results

An assessment of potential future marine outfall locations at two areas at the eastern end of Galway Bay (as shown in Figure 4-1) was undertaken to support the determination of indicative ELVs for a new proposed WWTP discharging to the marine environment. One outfall option was to the west, where the bed slopes rapidly down to a depth of 12-15m below Mean Low Water Springs (MLWS). The other outfall option, to the east, where the bed slopes more gradually and reaches depths of 9-12m below MLWS but at a much further distance from the shore, in comparison to the western area. The eastern area is within the Galway Bay Complex SAC and the Inner Galway Bay SPA, which overlay one another as illustrated in Figure 4-2.

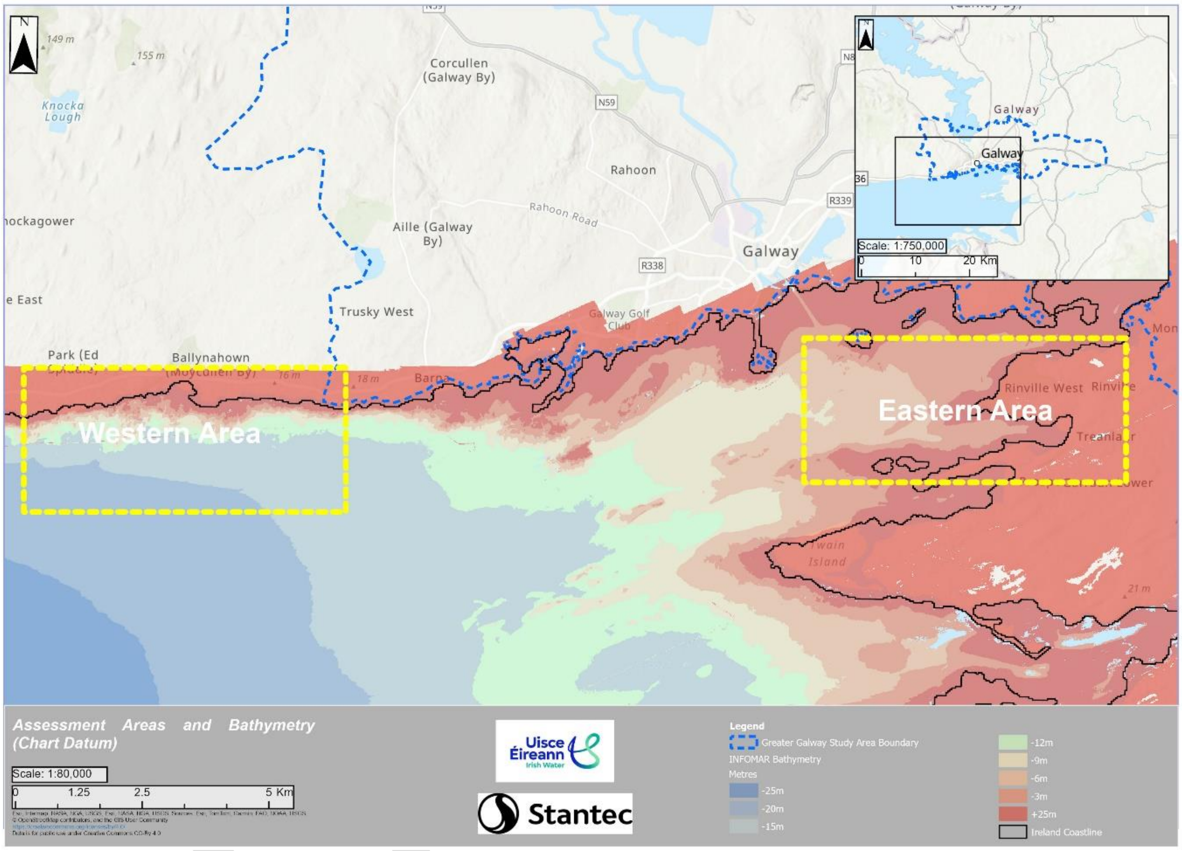

Figure 4-1 Galway Bay, showing assessment areas and bathymetry (Chart Datum)

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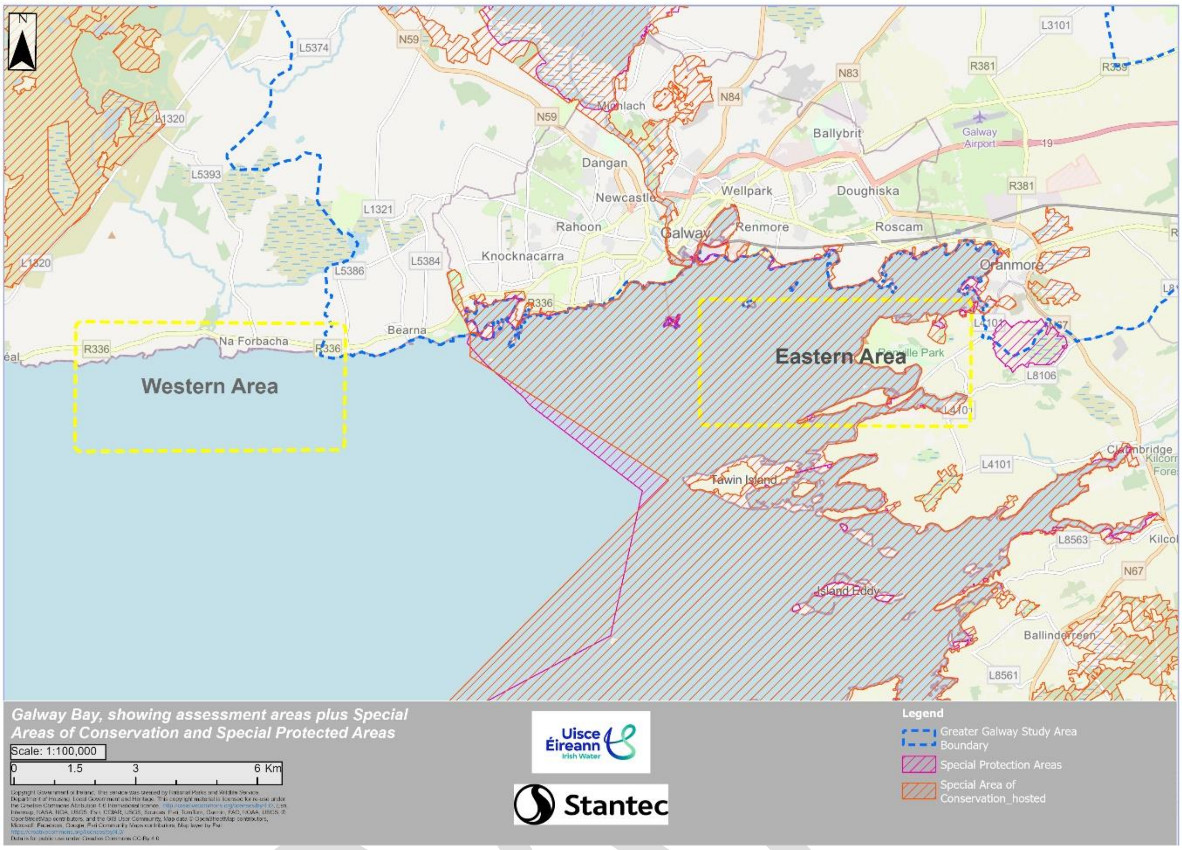

Figure 4-2 Eastern Galway Bay, showing assessment areas plus Special Areas of Conservation and Special Protection Areas.

4.1 Study Inputs

4.1.1. Current, Depth and Level Data

The Marine Institute provided a 1-hour time step series for one year of simulated water levels and currents from their high resolution (66m grid) model of the Galway Bay for a series of points located in Galway Bay and the two study areas.

Data was extracted from the Galway Bay 3D ROMS model (Nagy et al, 2020)[15]. This data was processed to provide depths and currents through a spring and a neap tide, by extracting values for 13-hour periods coinciding with the spring and neap tides. This information was used as input for the initial dilution calculations. The data for the Bay shows that the currents are much higher in the deeper water to the west of bay, and this is where the greatest mixing of discharges will occur.

4.1.2. Discharge Flows and Outfall Configuration

The 95th percentile initial dilution was calculated for each site for outfalls with a range of diffuser port arrangements. The range of diffuser ports considered was informed by average flows for the wastewater discharge. Locations and optimal configurations are summarised in section 4.3.1.

[15] Galway Bay 3D ROMS model (Nagy et al, 2020)

4.1.3. Screening Initial Dilution Targets

An initial screening was undertaken using an indicative target of 50:1 dilution at the 95th percentile in line with UÉ Marine Modelling Technical Guidance (UÉ, 2022), which proposes this as a minimum dilution target for secondary treated effluent for new discharges only. This is in line with guidance from Scottish Environmental Protection Agency (SEPA) to avoid oils slicks and odour nuisance. This was used to screen potential discharge locations for further analysis against relevant WFD targets.

4.1.4. WRc Equations

The WRc equations (WRc 1990)[16] were used to estimate initial dilution. These use spring and neap tidal conditions (current velocity and depth) combined with outfall configuration, number of ports and effluent flow to estimate the minimum initial dilution at time-steps throughout spring and neap tides above the outfall.

These equations are programmed into a spreadsheet which calculates the dilutions at half hour stages in the tide between high water –6 hours to high water +6 hours. The spreadsheet provides summary statistics from these calculations as well as pertinent hydraulic information to the outfall design. Examples of the initial dilution calculations are shown in Figure 4-3.

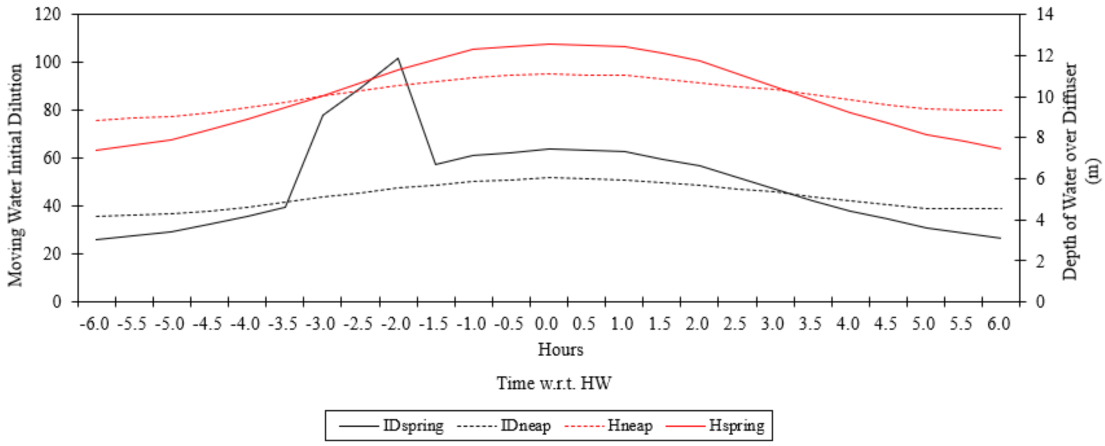

Figure 4-3 Initial dilution and depth over diffuser over spring and neap tides (WRc 1990).

4.1.5. Ambient Water Quality

The assessment was extended further, to determine the levels of treatment that would be required were a marine discharge to be implemented which met the initial screening criteria. This was a strategic level assessment to consider the constraints and technical practicalities associated with a proposed outfall within the two areas to inform the optioneering process.

The assessment required ambient water quality with which to estimate potential levels of treatment to meet WFD targets for the potential marine outfalls. The water quality sites used for the assessment are detailed in Table 4-1.

[16] WRc equations (WRc 1990)

Table 4-1 New WWTP Proposed Marine Outfall Water Quality Sites

Site	Water Body	Water Quality Site	Record
Western Area	Outer Galway Bay	GY220 - Furbo	2013-2025
Eastern Area	Inner Galway Bay North	GY160 - SE of Hare Island	2013-2025

The parameters and associated data are set out in Table 4-2. The values are largely consistent between sites.

Table 4-2 Representative water quality statistics

Parameter	Units	Statistic	GY220 - Furbo	GY160 - SE of Hare Island	GY140 - Mutton Island Buoy CIL	Season
DIN	mg/l	Median	0.022	0.024	0.032	summer
	mg/l		0.133	0.032	0.15	winter
TA (Total ammonia)	mg/l	Median	0.017	0.019	0.020	summer
UIA (Un-ionised ammonia)	mg/l	Median	0.0005	0.0006	0.0006	summer
BOD	mg/l	Median	0.5	0.5	0.50	annual
MRP	mg/l	Median	0.006	0.007	0.01	summer
	mg/l		0.011	0.008	0.01	winter
temp	°C	Median	15.3	15.8	15.7	summer
	°C		8.6	8.6	8.8	winter
salinity	PSU	Mean	34.0	31.9	33.1	summer
	PSU		32.9	30.2	32.0	winter
pH		Median	8.1	8.1	8.10	summer
			8.0	8.1	8.00	winter
%age UIA		Median	2.8%	3.0%	2.9%	summer
			1.4%	1.8%	1.4%	Winter

4.1.6. Environmental Quality Standards and Targets

The assessment utilised EQS or non-regulatory targets to estimate the WWTP effluent quality which would align with WFD objectives. These standards were compared with the likely level of treatment that would be required under the recast Urban Wastewater Treatment Directive (rUWWTD)[17], to determine the overall viability of the discharge location. The EQS are listed in Table 4-3

The targets for DIN and MRP are applied on a seasonal basis using salinity-adjusted EQS targets. Consequently, DIN targets are less onerous for the proposed eastern marine outfall discharge as it is in a transitional water, with significant freshwater inputs.

Table 4-3 Water Quality Targets and EQS to meet WFD Good status

Determinand	Target or EQS West	Target or EQS East	Units	Statistic	Transitional Water	Coastal Water
DIN summer	0.28	0.42	mg/l	median	-	EQS
DIN winter	0.35	0.56	mg/l	median	-	EQS
BOD	4	4	mg/l	median	EQS	-
MRP summer	0.041	0.043	mg P/l	median	EQS	-
MRP winter	0.042	0.046	mg P/l	median	EQS	-

Total ammonia (TA) is used as an indicator of the quantity of the toxic form of ammonia, unionised ammonia (UIA). In saline water the fraction of unionised ammonia in TA is lower than in freshwater. To develop a target for TA, the UK WFD legislation (UK Government, 2015) provides a standard for unionised ammonia (Table 4-4) in saline water. The fraction of UIA, in TA can be determined based on ambient temperature and salinity at the discharge.

Table 4-4 Non-Regulatory Water Quality Targets taken from UK WFD legislation

Determinand	Target or EQS West	Target or EQS East	Units	Statistic	Source
UIA	0.021	0.021	mg/l	mean	Target

4.1.6.1. Faecal Bacteria Modelling

The initial dilution assessment cannot assess the impact of bacteria on key receptors such as bathing waters within the study area. The modelling undertaken for the Strategy could not

[17] recast Urban Wastewater Treatment Directive (rUWWTD)

investigate the transport and fate of faecal indicator organisms. The primary receptors for faecal bacterial impact are located at a distance of 1.5km (or greater) from discharge points and require a pollutant transport and dispersion model to assess the impact to key receptors.

All sites assessed have the potential to influence designated bathing waters, including Trá na bhForbacha, Silverstrand Beach, Salthill Beach, Grattan Road Beach, and Ballyloughane Beach. The transport and fate of bacteria will have to be considered in any future assessment. UÉ is developing a Strategic water quality model of Galway Bay and it is recommended that this is used to determine whether further treatment to reduce faecal bacteria concentrations is required.

4.2 Initial Dilution Assessment

The methodology calculates the initial dilutions for the effluent discharge and port configuration using the WRc Equations (WRc, 1990). Multiple locations were selected within the western and eastern area in order to optimise the outfall location against the screening criteria. The outfall length was estimated based on the distance from the nearest point on the coastline to the site where the optimal level of dilution could be achieved.

The method entailed, processing the Marine Institute model output, extracting sea level and current speeds, for spring and neap periods. The depth of water over the seabed was derived from the vertical layers in the Marine Institute model output, and to calculate the depth of water over the outfall.

With the current speeds and depths derived, the initial dilution values for different effluent flow and ports configurations were tested, to find the optimum configuration to meet the initial dilutions screening criteria. The initial dilutions statistics from the selected configurations were used with the ambient water quality conditions and targets to calculate the level of treatment required to meet the EQS or targets with a 20% headroom.

4.3 Results

4.3.1. Initial Dilutions

The initial screening considered different combinations of flows and port configurations and the optimal locations and configurations are shown in Table 4-5.

Table 4-5: Optimal outfall configurations

Site	Length of outfall m	Depth above diffusers at spring low tide m	No Ports	ADWF m^3/s	FFT m^3/s	Port Diameter m
Western Area	600	12.3	10	0.786	1.664	0.2
Eastern Area	2500	8.6	16	0.786	1.664	

The study has identified the potential for a WWTP with a western outfall to discharge to the Outer Galway Bay coastal waterbody. An initial assessment based on targeting a mean initial dilution of 50 times has identified that a 600m outfall, with 10 diffusers will provide sufficient dilution.

The study has also identified the potential for a WWTP with an eastern outfall to discharge to the Inner Galway Bay North waterbody. An initial assessment based on targeting a mean initial dilution of 50 times has identified that a 2500m outfall, with 16 diffusers will provide sufficient dilution.

Further assessment has been undertaken to determine the effluent quality required to achieve WFD good status with a 20% headroom at each outfall. These values are presented in Table 4-6 and could be achieved by a WWTP with quaternary treatment as would be required by the rUWWTD.

4.3.2. Indicative effluent concentrations

The modelled output was presented as minimum required effluent values in Table 4-6 the values chosen complied with the EQS or targets with 20% of headroom, after also considering ambient conditions. These values are indicative minimum values, based on initial dilution modelling which applied conservative parameters, high effluent flows and targets with a 20% headroom.

The values presented could reasonably be achieved by a new WWTP of the size required which would have mandatory tertiary and quaternary treatment as would be required by the rUWWTD.

Table 4-6 Minimum effluent concentrations to meet EQS/Non-Regulatory Targets at the point of mixing

Parameter	Units	Compliant Effluent Values West	Compliant Effluent Values East
DIN	mg/l (as N)	12.0*	25.0
TA	mg/l (as N)	3.4	3.0
UIA	mg/l	0.02	0.02
BOD	mg/l	160	130*
MRP	mg P/l	1.9	2.2*

*EQS

5. Conclusions

5.1 Current Status of Receiving Waters

- The Ballycuirke Canal and River Clarin are classified as Moderate ecological status under the WFD, with upstream and downstream water quality failing to achieve Good Status for key parameters (ammonia, BOD, and orthophosphate in Ballycuirke; declining orthophosphate downstream in Clarin).

- The River Clare at Claregalway maintains Good to High status for BOD and ammonia, with ortho-phosphate marginally achieving Good.

5.2 Performance of Wastewater Treatment Plants – Continuous Discharges

- Moycullen WWTP would warrant further modelling and asset performance assessment. This does not affect strategy recommendations to maintain the asset and keep treatment in-situ as any proposed standards undertaken through sensitivity testing are treatable with current technologies. There are no strategic needs at the asset, however, process optimisation may be needed prior to 2055 to achieve the desired ELV limit, subject to a more comprehensive modelling and asset assessment.

- Claregalway WWTP performs well and modelling indicates compliance with WFD standards under future growth and climate change scenarios if current performance is maintained.

- For Athenry WWTP, baseline analysis for both ammonia and orthophosphate require improvement to meet the allowable assimilative capacity. However, in all growth scenarios all the determinands exceed the allowable assimilative capacity and the WWTP processes will require improvement. Given the sensitive nature of the receiving watercourse and the treatment standards proposed it is not feasible to have a WWTP discharging to this watercourse in the medium to long term.

5.3 Impact of Intermittent Discharges

- Intermittent discharges from Moycullen are negligible (<0.2% of the year). These discharges are extremely infrequent, and the impact can be considered as negligible. Furthermore, because they are so infrequent the assessment is not possible against proposed standards/targets.

- There are no SWOs present in the Claregalway agglomeration, therefore there are no impacts from intermittent discharges.

- Athenry intermittent discharges exceed 1% of the year and required a UPM assessment. The FIS modelling indicates no impact from intermittent discharges, but HPS suggests there may be a potential risk and needs to be considered as part of the Strategy development.

5.4 New WWTP

- Strategic assessment indicates that discharges from a new WWTP via marine outfalls to Galway Bay (East and West) and to the River Corrib are viable and would be able to meet WFD Good status with appropriate outfall design and quaternary treatment.

- Vertical mixing at proposed discharge locations is generally insufficient to meet bacterial targets at the surface, above the proposed outfall locations. Dispersion modelling is often required to understand impact on spatially specific receptors such as Bathing or Shellfish waters. Although proposed sites have potential to impact designated bathing waters. Given the high level of treatment proposed, the risk is considered low. However, comprehensive dispersion investigations will be required to confirm this.

5.5 Key Points

- It is viable for treatment to be retained at Moycullen WWTP. Further modelling is recommended to ascertain the level of treatment required to meet future ELVs and identify the timeframe of process optimisation interventions. Even if this were achieved, the Ballycuirke Canal may not achieve WFD Good without upstream improvements to the waterbody.

- It is viable for treatment to be retained at Claregalway WWTP. There is sufficient assimilative capacity in the receiving water which can maintain its WFD status if current treatment performance is sustained through to 2080.

- It is not viable for treatment to be retained at Athenry WWTP. The continuous discharge poses a significant environmental risk to the River Clarin in the future, and the treatment standards are not viable. The optioneering process should take this outcome into account throughout its course.

- The proposed new WWTP for Galway will require to have tertiary and quaternary treatment alongside an appropriate outfall design. The three marine outfall locations identified (Galway Bay east, west and River Corrib) are viable locations to be considered in the optioneering process and are compatible with current WFD objectives through to 2080. The optioneering process should take this outcome into account throughout its course.

Annex A - Modelling Limitations and Assumptions

MARINE CURRENTS AND DEPTHS

The currents and depths within Galway Bay were derived from grid points from the Marine Institute hydrodynamic model. This model is validated by the Marine Institute and provides the best available information about flows and depths within the Bay for the strategic level of this study. A pollution transport model may be required for any future dispersion modelling required as part of the implementation of the options identified in this strategy.

TARGETS FOR MARINE ASSESSMENT

The Irish surface water regulations legislate for certain determinands, such as DIN in coastal water bodies and MRP and BOD in transitional water. The assessments considered discharges to coastal waters against non-legislative targets based on the EQS for transient waters and vice versa.

The study also considered non-legislative targets for unionised ammonia to identify any ecotoxicological risk from wastewater discharges. Un-ionised ammonia target in salt water were taken from guideline values published by SEPA/EA and which have been used previously by UÉ in consultation with the EPA and used to set rational ammonia targets based on salinity and temperature of the receiving water.

RIVER FLOW DATA

Hydrotool tool predictions have been used in the absence of observed flow data. Hydrotool provides robust river flow predictions for Ireland by integrating physically based hydrological models with comprehensive national datasets, enabling consistent and credible estimates.

Hydrotool has known limitations in karstic catchments because the underlying assumptions of its hydrological models are less well suited to the highly heterogeneous and non-linear behaviour of karst systems. In practice, Hydrotool remains useful in karst regions for broad-scale assessment, but its outputs should be treated as indicative and augmented with karst-specific data and expertise wherever decisions are sensitive to flow extremes or groundwater–surface water interactions.

MOYCULLEN MODELLING

It should be noted that the sewer network and river water quality model for Moycullen is of lower confidence than other agglomerations modelled. Further modelling work and data collection is recommended. The sensitivity tests conducted during model calibration demonstrated that lower river flows i.e. using the 0.5 factor resulted in proposed ELVs which were tighter than the current performance of the WWTP for both ammonia and Ortho-P. These sensitivity tests do not affect strategy outcomes as any tightening of proposed ELVs are within treatable limits with known technology. Both the sewer network model and water quantity model would benefit from extra data collection to gain a better understanding of impacts and optimise the proposed ELVs to support value engineering and detailed appraisal in due course. Additionally, the treatment benefits of the reed bed could not be taken into consideration as there was no data available with which to represent it accurately in the model.

ATHENRY MODELLING

It should be noted that the sewer network model of Athenry would benefit from further data collection The flow in the River Clarin at Athenry is uncertain, there are no direct flow measurements in Athenry with the nearest site being the OPW station downstream at Clarinbridge, and the complex karst geology with a network of underground rivers makes this challenging to determine. The WFD Monte Carlo calibration suggested that the flows could be 80% of the values originally assumed.

It is assumed that the WFD surface water standards and UPM standards will also provide an adequate level of protection to the underground karst river system.

SURFACE WATER OUTFALLS

Discharges from urban runoff generated in separate surface water systems were not explicitly represented in the impact assessment where the discharges occur into the reach assessed.