IT Sligo
An Institiúid Teicneolaíochta, Sligeach
CERIS
Centre for Environmental Research
Innovation and Sustainability

A real-time alert system for predicting and managing short-term pollution and bathing water quality at Enniscrone beach

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Submitted for the Degree of Master of Science (Research)

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Submitted to the Institute of Technology, Sligo, September 2019

Declaration:

I certify that the content of this project is entirely my own work. Any material adopted from other sources is duly cited and referenced and acknowledged as such.

Signed: W Egan ………………Date: 30/09/19 ……………….

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Abbreviations

ACP	African, Caribbean and Pacific Group of States
BBC	British Broadcasting Corporation
Cfu	Colony forming units
DHI	Dansk Hydraulisk Institut
EA	Environment Agency
EC(c)	*Escherichia coli*
EC	European Commission
EEA	European Economic Area
EEC	European Economic Community
EPA	Environmental Protection Agency
EU	European Union
EWS	Early Warning System
FIO	Faecal Indicator Organisms
GSM	Global System for Mobile communications
HSE	Health Service Executive
IE	Intestinal enterococci
ITC	Intelligent Top Cap
MDL	Minimum Detection Limit
MP	Monitoring Point
MPN	Most Probable Number
PIP	Pollution Impact Potential
SEPA	Scottish Environment Protection Agency
SCADA	Supervisory Control and Data Acquisition
SI	Statutory Instrument
SIM	Subscriber Identity Module
SMS	Short Message Service
STP	Short-term pollution
TBM	Temporary Bench Mark
TC	Total coliforms
TNTC	Too numerous to count
UN	United Nations
UN/ISDR	United Nations Inter-Agency Secretariat of the International Strategy for Disaster Reduction
UWWTP	Urban Waste Water Treatment Plant
UTC	Coordinated Universal Time
WFD	Water Framework Directive
WHO	World Health Organisation

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Abstract

Under the Bathing Water Directive [2006/7/EC] there is a new highest microbiological quality classification of “Excellent” that is much more stringent than the highest standard of the old directive. This has serious implications for some beach resorts in Ireland as they may now struggle to meet this classification which is also required to qualify for a *Blue Flag* eco label.

Enniscrone, a major sea-side resort in Co. Sligo has failed to attain this highest classification and has also lost its *Blue Flag*. The cause was a large flux of faecal indictor organisms (*E. coli*) from an inputting river which grossly affected a compliance sample in 2014, and consequently the current overall classification. These events are defined in the directive as predictable “short-term pollution” (STP).

The directive with its stronger focus on protecting public health encourages beach managers to be much more pro-active in managing bathing water quality. In Enniscrone’s case, to attain “Excellent” status appropriate early-warning systems to predict and manage health hazards like STP must be established. The incentive for managers if such systems exist, are permitted deviations in compliance monitoring which will shield the water’s classification from the impact of the STP.

This study utilised innovative new techniques to create maps to identify the critical source areas for *E. coli* in the contributing local river catchment. These were then used to identify the key locations for monitoring fluxes of *E. coli* generated in the catchment. Automatic hydrometric monitoring stations were installed at these locations in the river catchment to measure the related flux in river flow and level. Using the conceptual model, hydrometric instrumentation was configured to predict STP events and automatically communicated real-time alerts to the author. These measured hydrographs were compared to *E. coli* levels analysed in the river and bathing water to develop and confirm the operational model.

This study developed and ran real-time bathing water predictions for Enniscrone Beach for the 2016 and 2017 bathing seasons. The *E. coli* results confirmed a 100% prediction rate for STP with no false positives or missed events. From the summer of 2018 this system has used Twitter® to disseminate bathing water predictions to the public. This is the first operational automatic real-time bathing water prediction system in Ireland.

This risk management method will help ensure that bathers’ health at this beach will be protected and that Enniscrone regains and retains a *Blue Flag*.

The approach adopted in this study of using a localised conceptional and operational model could act as a template for environmental management solutions at the many other beaches in Ireland whose bathing waters are affected by diffuse STP.

Acknowledgements

I would like to express my deep gratitude to my supervisor Declan Feeney. His encouragement, guidance and support from the very beginning enabled me to gain a deeper understanding of this project and our environment. I would like to thank Frances Lucey and the staff of the Department of Environmental Science, IT Sligo and the Centre for Environmental Research Innovation and Sustainability (CERIS) for their support.

I am indebted to my colleagues in the Environmental Protection Agency for their assistance. To Conor Quinlan, Matt Craig, Andy Fanning, Matt Crowe, Hugh McGinley, Pat Durkin, Rebecca Quinn, Robert Wilkes, Lil Gormally, Bríd Farragher, Alan Stephens, Peter Webster, Brigid Flood, Marie Archbold and Nigel Hayes I say a big thank you.

I am also grateful to Enda Mulrooney of Enniscrone Golf Club, Liam Hallinan, Chair of the Carns Shrine Committee, Ciaran Duffy and Michael Jones of EPS and Rosie Morrissey of Sligo County Council for their assistance.

I would like to thank Mum and Dad, Evanne, Ciarán and Luke, and Máire, Richard and Ruairí for their love, help and encouragement.

Finally, I would like to thank Lisa, Caoimhe, Fiachna and Róise for all their love, support, fun, help and patience.

1 Introduction

1.1 Background

Enniscrone is a popular tourist seaside resort situated on the shores of Killala Bay in County Sligo (Figs. 1 & 2). Enniscrone beach is approximately 5 km long and consists of firm sand backed by large sand dunes. The beach forms part of the Killala Bay/Moy Estuary Special Area of Conservation and Special Protection Area (www.npws.ie). It has a north-westerly aspect. The town of Enniscrone has a population of over 1200 people and is situated adjacent to the beach. It is served by a modern urban wastewater treatment plant (Fig. 3). The nearest large town, Ballina, County Mayo is 12 km away. The Bellawaddy River drains a catchment of approximately 19 km^2 and discharges over the beach to the sea (Figs. 3,4, 5 & 6).

The development of Enniscrone as a seaside resort dates to the 1840s when sea bathing was made fashionable by the British royal family and was also encouraged as a healthy pursuit by the medical profession. This led to the building of lodges and hotels in the locality to accommodate the numbers of visiting bathers. In the 1850s the local landlord (Orme) built a seawater bath-house to help encourage tourism. By the 1860s Enniscrone was a bathing village that was densely populated in the summer (Mac Hale, 1985).

Today, the tourism industry is Enniscrone's main employment generator (Sligo County Council, 2014). Developments include hotels with a 156-bedroom capacity. Other attractions include a twenty-seven-hole golf course, seawater baths, surf schools, paddle-boarding, aqua-centre and caravan park.

Enniscrone tourism is based on the same principle as when it began long ago: that it is a place with healthy bathing water.

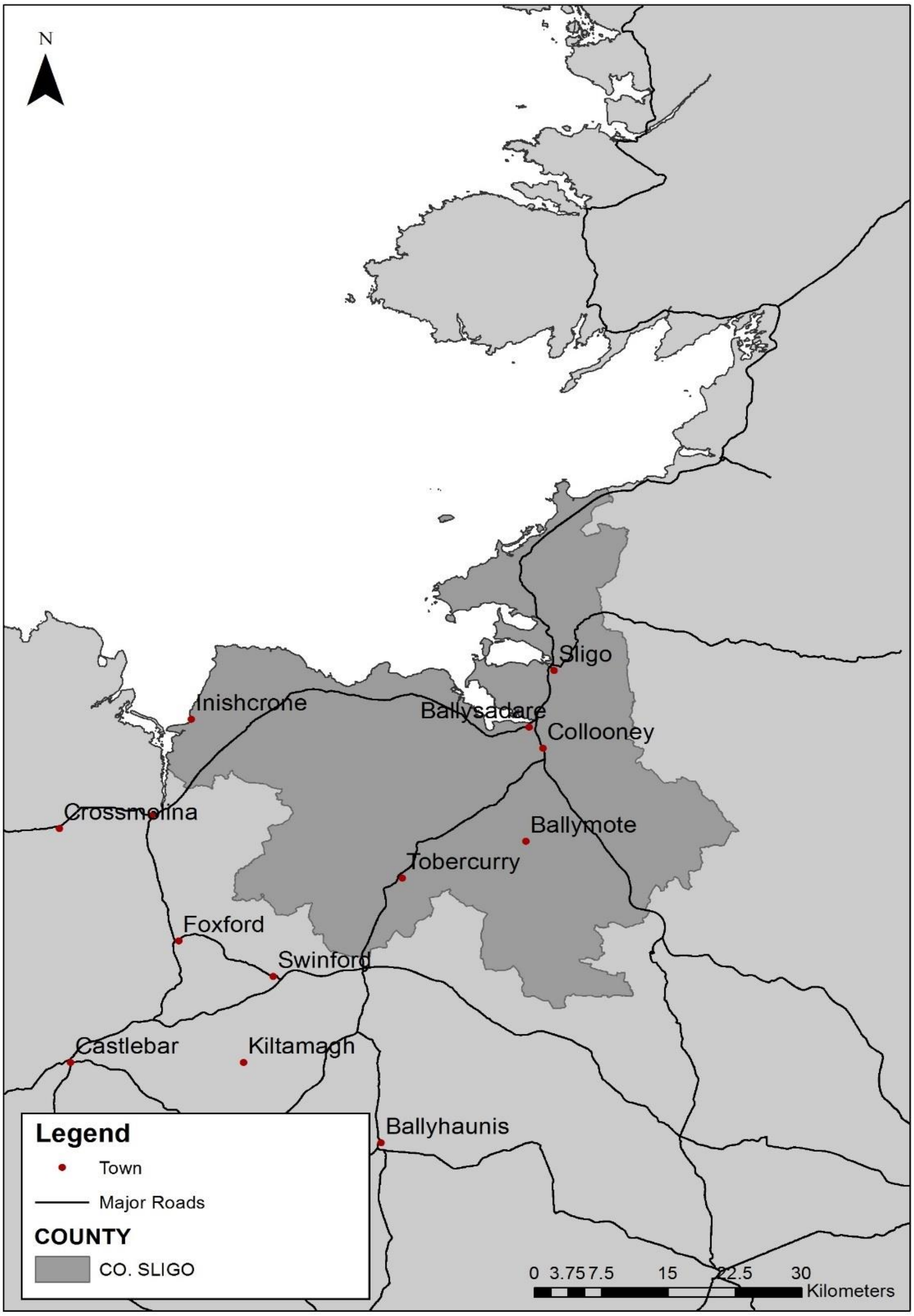


Figure 1: Location of Enniscrone (Inishcrone), County Sligo

In modern times the importance of clean bathing water nationally and internationally has been equally recognised. Efforts to ensure clean and healthy bathing waters started with the first EU Bathing Water Directive in 1975 (EEA, 2013). Its main objectives were to safeguard public health and protect the aquatic environment at bathing places from pollution. Together with other European legislation which lead to investment in urban wastewater treatment systems and the reduction of pollution from farms, Europe's bathing water is much cleaner than forty years ago. By 2015 96% of European bathing water sites met the minimum quality requirement with 84% reaching the top classification standard (EEA, 2016).

A new European Bathing Water Directive was adopted in 2006 which came into force at designated sites for the 2015 bathing season (Webster, 2017). This new directive updates the measures of the 1975 legislation and simplifies management and surveillance methods. This is achieved by prioritising the assessment of faecal indicator bacteria in the water whose presence strongly indicate pathogens that cause disease to humans. These bacteria are also known as Faecal Indicator Organisms (FIO).

It also prioritises a focus on public health by providing for more, better and earlier public information about bathing water quality. It does this by requiring responsible authorities to study and profile their individual beaches to greater understand how microbial pollution impacts their beach. For prescribed situations that threaten bathers' health the authorities are required to establish measures and procedures to warn and protect them. The focus of these new management methods is on predictable episodic fluxes of microbial pollution that discharge to bathing waters. These fluxes are defined as *short-term pollution* or STP.

There are three direct consequences for regulatory authorities caused by the new Directive:

1. There is a new method to calculate bathing water classification
2. There is a new highest category of bathing water classification (*Excellent*) that is more difficult to achieve
3. Forecasting methods and models that identify STP episodes are required for bathing places affected by these events

This increased focus on the connection between the environment and public health was recognised by Laura Burke the Director-General of the Irish Environmental Protection Agency (EPA) when she stated in the *EPA Strategic Plan 2016 – 2020 Our Environment, Our Wellbeing* "*clear, accurate and timely information is a vital component in raising awareness about the environment among the public and key policy and decision makers. As part of our strategic priorities we will be accelerating the development of new approaches and tools, with a particular emphasis on the provision of accessible information to allow people to make informed choices for themselves, their families, their communities and their businesses*."

Prior to the implementation in 2015 of the new Bathing Water Directive in Ireland a study was carried out by the EPA in 2013 which reviewed projected bathing water assessments post 2014 under the new classification method. This evaluation was based on bathing water data from Ireland for the 2009-2012 period. It demonstrated that some of the bathing waters that had previously achieved the top-quality status under the old directive would unlikely achieve the new top *Excellent* classification under the new directive and would instead be classified in the second tier as *Good*. This report projected Enniscrone to be classified as *Good* and "v*ulnerable*' to being reclassified lower because of its *E. coli* parameter results. It further warned for bathing waters identified in this "*vulnerable*" category "*that local authorities be advised of the findings* *of this study and asked to review the management measures set out in their bathing water profiles for effectiveness in mitigating pollution pressures*" (Webster, 2013).

Enniscrone, having previously achieved the top category under the old classification system, will now struggle to attain this again. It has remained in the second-tier quality category since the new assessment method started in 2015 (www.beaches.ie). This failure was caused by a STP event in 2014 which affected the new calculation (1.) and thus the new classification (2.) mentioned above.

This has added implications for beaches like Enniscrone who participate in the *Blue Flag* Eco–Label programme. This programme is one of the main devices seaside resorts use to attract potential tourists and to indicate clean water quality. To qualify, a series of stringent environmental, educational, safety-related and access-related criteria must be met and maintained. At beaches, the bathing water quality must comply with the new highest standard of *Excellent* in accordance with the 2006 EU Bathing Water Directive. (Foundation for Environmental Education, 2018). Enniscrone lost its *Blue Flag* in 2015 because it failed to achieve this new highest water quality standard.

Enniscrone's bathing water is subject to STP episodes that are now affecting its classification, and which originate from the adjacent river catchment (Egan, 2015).

There is little evidence that environmental management measures as required by the directive or requested by the EPA above for *vulnerable* bathing waters have been implemented in Ireland.

To overcome the challenges set by the new directive new environmental management tools such as a STP forecasting method and model are required for bathing waters like Enniscrone.

Current methods for determining levels of FIO in bathing water produce a result 36 hours after sample collection. This is of little value to bathers or to beach managers at sites where water quality can vary due to STP. Real time information is required to protect bathers' health and to fulfil the directive.

Figure 2: Enniscrone beach is a popular seaside resort.

Figure 3: Aerial photograph of Enniscrone beach showing the river flowing from a south-easterly direction before flowing over the strand to the sea.

Secondary treatment is provided by a modern urban wastewater treatment plant (UWWTP) situated 1.5 km north of the bathing water with an outfall to the sea. Source: [*www.Beaches.ie*](http://www.Beaches.ie)

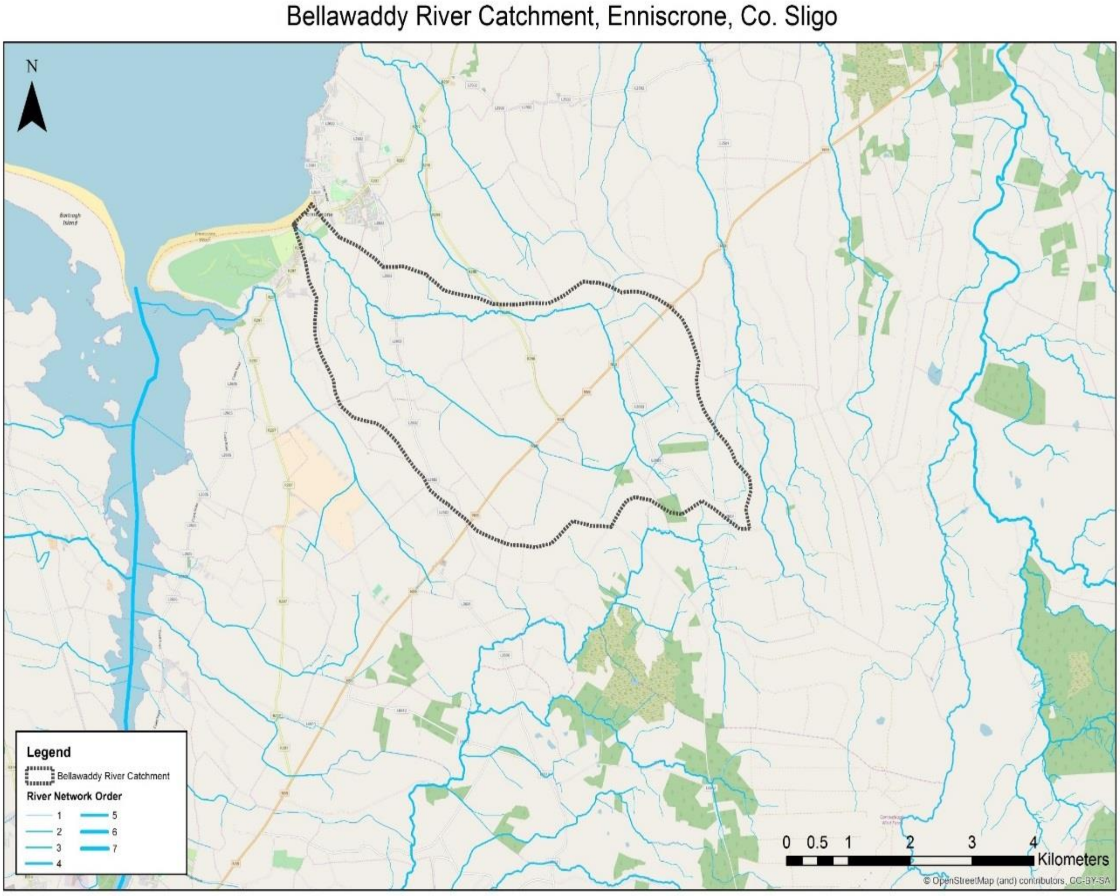


Figure 4: Map showing the Bellawaddy river in blue and its catchment in black.

The river drains from the SE to the NW and discharges to the sea at Enniscrone beach (yellow). The river drains a catchment area of 18.6 km² and has a length of 29.6 km. The catchment is rural in nature with mixed farming practised. The River Moy enters Killala Bay 3 km to the west of the bathing area.

Figure 5: Bellawaddy river discharging over Enniscrone beach. The river can be seen entering the bathing water in the background

Figure 6: Another view of the Bellawaddy river discharging over Enniscrone beach towards the bathing water.

1.2 Changes to bathing water monitoring and management

The occurrence of these FIO in bathing waters signal the presence of microbial pollution of human or animal origin which may contain pathogens harmful to human health. The analysis results are used to classify the quality of the bathing water and to inform the public of the condition of the beaches they are using.

Faecal contamination because of the risk of diseases such as viral gastroenteritis (Pruss, 1998; Kay 2010) can impact bathing water quality making it unsafe for swimming, paddling, etc. Pathogenic bacteria are the principal cause for spreading disease and associated health related problems in bathing water (Lin et al., 2008).

Sources of this contamination include:

- discharges from urban wastewater treatment plants (UWWTP) and their associated networks
- run-off from land in river catchments with diffuse sources such as livestock, septic tanks and slurry

The measurement of individual types of pathogens (infectious hazardous microorganisms) in bathing water is difficult and expensive. Since the introduction of the first *European Bathing Water Directive of 1976* (76/160/EEC) indicator bacteria have been used as environmental markers whose manifestation indicate the possibility of the presence of pathogens. This was achieved by measuring for Total and Faecal Coliforms as well as a range of physio-chemical parameters (faecal streptococci were also an option). Bathing water monitoring in Ireland was regulated by the *Quality of Bathing Waters Regulations 1992* (S.I. 155 of 1992) which transposed into Irish law the first *European Bathing Water Directive of 1976* (76/160/EEC).

World Health Organisation (WHO) studies have established stronger links between public health and bathing waters. Following these, new Irish legislation governing bathing water quality was fully implemented from 2015. These *Bathing Water Quality Regulations 2008* (S.I. 79 of 2008) transpose into Irish Law the revised *Bathing Water Directive* (2006/7/EC).

These new standards with the focus on public health are based on the risk of contracting gastrointestinal illness from pathogens. This has resulted in a halving of the risk to bathers from 12-15% under the old directive to 6% (and 3% for the new highest classification standard).

As a result, under the new directive and regulations there are new areas of focus for beach managers:

- Analysis of the bathing water during the summer now concentrates on two different types of FIO. These are *Escherichia coli* (*E. coli*) and intestinal enterococci (IE) which are regulated at a stricter standard (i.e. nearly twice as difficult to attain). Classification is also now based on the analysis of a rolling four-year data set rather than on a single year's results.
- To better protect bathers' health there is a change of emphasis from retrospective assessment of the bathing water to a much stronger focus on proactive management of the bathing water quality. Greater stress is placed on the development of systems for the management of bathing waters and notification of bathing water quality to the public (Environmental Protection Agency, 2014), particularly on the risks that bathers may face from pollution (Scottish Environment Protection Agency, 2013).

- Prediction of *short-term pollution* (STP). STP is significant microbiological contamination whose source has been clearly identified and which does not affect bathing water quality for more than approximately 72 hours.

1.3 Need for research into the development of STP prediction models

It has become apparent to scientists that expenditure on urban wastewater sources of faecal bacteria will not ensure compliance with bathing water standards (Kay et al., 1998). Indeed, Enniscrones's urban wastewater treatment plant was upgraded in 2008 at a cost of €5 million. Installed in isolation these infrastructural solutions have proven ineffective in attaining microbiological water quality standards at many beaches because the non-human contribution remains unchanged and can be sufficient to cause non-compliance (Kay et al., 2010a). Scientists have now turned their attention to diffuse catchment sources of these bacteria.

As Kay et al., (2007a) and Kay et al., (2010b) discuss, in rural catchments that are dominated by livestock farming the principal source of Faecal Indicator Organisms (FIO) originates from the animal population. The FIO output from sheep and cattle is much greater per head than for humans and directly impacts the land surface and streams. Livestock populations will also be much higher than the associated human population in a rural catchment.

As demonstrated by Crowther et al., (2001, 2003), Wyer et al., (2010), Kay et al., (2008) and McPhail and Stidson, (2009) antecedent rainfall and river flow correspond closely with consistent and significant increases in concentrations of FIO in surface water streams. A stream hydrograph event in response to intense rainfall in a catchment will deliver a large flux of FIO to connected bathing waters, potentially affecting FIO levels in that water. Ghimire and Deng,

(2013) point out in their paper that storm events can cause the export of up to 98% of the annual load of *E. coli* in a river. They further observe that peak concentrations of bacteria occur during the rising limb of a storm hydrograph. Kay et al., (2008) talk about the highly episodic nature of FIO pollution in catchment systems characterised by a ˜ 3 $\log_{10}$ orders change in concentration during rainfall-induced storm events when flow may increase in small catchment streams by >1 $\log_{10}$ order. The effect of this pattern is to produce >97% of the FIO flux from rural livestock farming areas in very short episodes (<10% flow time series) when streams display elevated flows caused by rainfall.

Enniscrone beach is impacted by STP flux events caused by a river with a rural catchment entering the bathing water (Egan, 2015). Methods that can identify and evaluate these episodic dips in quality can be utilised to regain the top water quality standard, protect against status vulnerability and protect public health.

Much of the current research into forecasting STP events focuses on statistical regression models or artificial neural networks (Crowther et al., 2001; Olyphant, 2005; Lin et al., 2008; Thou et al., 2012; Bedri et al., 2016). The further focus on catchment management has led to research on quantifying FIO flux in catchments, microbial source apportionment, farm management practices and run-off modelling and source tracking of FIO (Kay et al., 2010b).

Often the prime aim of all this research was to greater understand the processes involved at a beach or catchment rather than prior prediction of inferior water quality events (Stidson, 2012) which is required to protect bathers' health. Currently, there no real-time automatic STP forecast models or systems operational in Ireland

Additionally, as noted before, one of the main criteria to attain *Blue Flag* status is achievement of the top *Excellent* water quality classification standard (Foundation for Environmental Education, 2018). Enniscrone lost its *Blue Flag* status in 2015 due to a failure to meet the criteria for this standard alone. It also received much adverse publicity (Farry, 2015; Hutton, 2015; Siggins, 2015). There is a possibility that Enniscrone could regain its *Blue Flag* if STP is managed correctly. To ensure and maintain this, management systems need to be put in place to ensure *Excellent* water quality and protect bathers' health. Furthermore, *Blue Flag* designation plays a very positive role in the improvement of beach management and hence the visitor experience since they focus attention and bring resources to bear on desirable goals such as water quality improvement, cleanliness and environmental education. They are used as management programmes where on average €40,000 is used to maintain a *Blue Flag* (McKenna et al., 2011; Kay et al., 2010a). There is a risk Enniscrone will miss out on this type of investment.

Conversely, there is a potentially large economic risk in trying to attain the environmental management elements of the new directive. Kay et al., (2013) estimate that to keep the current *Blue Flag* numbers in the United Kingdom £1.5 – £5.4 billion will be required for real-time prediction methods (black box and hydrodynamic models). They go on however to say that this data will be needed for mitigation strategies in agricultural catchments under the Water Framework Directive and that the net benefit of investment will be positive. This does highlight that for public health and directive purposes any model or system used must be relatively cost effective for authorities to deploy across numerous bathing sites.

Wyer et al., (2010) point out that eco-labels such as the *Blue Flag* award are driven by compliance with the Bathing Water Directive and that the loss of such a designation can have a significant impact on local tourist economies. They go on to say that understanding water quality variation and real-time prediction of FIO at a bathing beach is a key component of the revised Bathing Directive.

To protect bathers' health and to ensure the achievement of *Excellent* water quality this thesis promulgates a new real-time bathing water quality forecasting method and model for use at Enniscrone.

The model applied in this study is based on the hydrograph response of the stream that flows to Enniscrone beach. The core idea of this approach is based on the relationship between the main explanatory variables of localised rainfall and river flow and FIO levels in the bathing water. This is similar to the system successfully deployed by the Scottish Environment Protection Agency (SEPA) (McPhail and Stidson, 2009). SEPA further state that to be successful the model must provide reliable advance prediction of compliance failure events and recognise that a failure to predict poor water quality is more damaging than a failure to predict good water quality (Stidson, 2012).

To test this solution for Enniscrone this study applied novel methods to locate telemerised hydrometric instrumentation in the river catchment to capture the source of the greatest potential flux of FIO in a timely manner. Stream flow trigger levels were developed to indicate to the author when storm hydrographs were taking place. Levels and concentrations of FIO were measured throughout the river catchment and at the bathing water during the summers of 2016 and 2017. This was done to determine concentrations and loadings during low-flow and storm hydrograph events in the river catchment and to determine the relationship with levels in the bathing water during these events. The relationship between rainfall and stream hydrographs in the river catchment was also examined. Trigger alarms were set to indicate when regulatory FIO thresholds for the bathing water would be breached. The forecasting system that was developed monitors the hydrometric data in real time. If triggered, and a dip in bathing water is predicted, a notification is disseminated to the public. The forecast system monitors on a continuous 24/7 basis.

Stidson, (2013) noted that to be successful, a model as put forward in this thesis needed to meet the following operational requirements for predicting STP:

1. Accurate model for predicting bathing water quality
2. Run the model in near real time during the bathing season
3. Disseminate water quality information to the public in real time
4. Meet directive requirements for replacement samples
5.

The primary objective of this study is to present a simple but effective approach to modelling STP at a bathing water. This will further provide an operational, accurate, automatic, real-time STP forecasting system at the study site. If successful, it will be the first operating system of this type in Ireland. Based on current research and the issues facing Enniscrone beach and others like it in Ireland, this project aims to:

- Develop an environmental management method that can predict and indicate STP at Enniscrone Beach.
- Run real-time predictions of bathing water quality at Enniscrone Beach for the 2016 and 2017 bathing seasons.
- Develop a method to disseminate water quality information to the public.

2 Literature review

2.1 Initial scoping of literature

2.1.1 Bathing water legislation

The purpose of this section is to review the development of relevant legislation with regards to bathing waters. The first legislation brought in for bathing water in Europe was in 1976. *The Bathing Water Directive* [76/160/EEC] (Council of the European Communities, 1976), defined bathing waters as "*those fresh or sea waters where bathing is either explicitly authorised or is not prohibited, and is traditionally practised by large numbers of bathers*". This directive listed a total of 19 parameters (microbiological, physical and chemical) which had limits defined depending on what classification was being sought. The minimum standard were the *Mandatory* values while the higher *Guide* values were desirable targets. Sampling frequencies and reference methods of analysis were also specified.

When this older directive was adopted large quantities of untreated or partially treated municipal wastewaters were being discharged to surface waters. Tackling coastal pollution has been addressed by tools like the *EU Urban Waste Water Treatment Directive* [91/271/EEC] (Council of the European Communities, 1991) which focused on point source discharges and technical solutions. In many bathing waters, however these were ineffective with relation to microbial water quality as they focused on discharges from human agglomerations but did not consider the human and non-human element coming from river catchments. In many cases fluxes of faecal indicator organisms (FIO) in catchment streams are greater causes of non-compliance.

Under the *European Union Water Framework Directive* (WFD) [20/60/EC] (Council of the European Communities, 2000), management of water quality in river catchments has changed from regulating point source inputs to a more integrated approach that takes into account both diffuse and point source inputs. As bathing water condition is linked to the quality of other water bodies in the catchment around it, integrated catchment management as promulgated in the directive will be essential in managing and protecting them. Bathing waters are categorised as protected areas under the WFD. These areas are identified as requiring special protection as they may be sensitive to pollution or because of their environmental, social or economic importance. The aim of the WFD is that all water bodies achieve and maintain *Good* status. Protected areas must comply with the standards and objectives set under their own directive.

Concurrently, the World Health Organisation (WHO) developed *Guidelines for Safe Recreational Water Environments* (World Health Organization, 2003). The WHO process involved expert consultations at Valetta in 1989 (protocol presented), Athens in 1991 (protocol approved), Athens 1994 (results presented), Bad Elster 1996 (research review), Jersey 1997 (guideline principles), Farnham 1998 (draft refined), Annapolis 1999 (beach management) and Farnham 2001 (guidelines finalised) (Kay et al., 2013). The WHO guidelines and approach are based on the beach management protocol adopted in Annapolis above. *The Annapolis Protocol* (World Health Organisation, 1999) is an improved approach to the classification and regulation of recreational water that better reflects health risk and provides enhanced scope for effective management intervention. Previously regulation was based on retrospective numerical compliance assessment. The Protocol suggests the use of relevant information to facilitate real-time environmental management and public health protection (Cronin, 2006). The Protocol which was incorporated into the new bathing water directive (below) is based on the following observations and principles:

- Gross pollution of bathing waters by human sewage from combined sewer and storm-tank overflows and from casual discharge should be controlled and regulated.
- There will always be fluxes of FIOs from river catchments even in the absence of humans i.e. the catchment FIO loading from 100 sheep is approximately equivalent to the FIO output from a secondary level treatment plant serving 1 million people.
- The catchment derived flux is highly episodic and driven by rainfall events reflected in high stream flows impacting on bathing waters – thus the event period is often short, clearly defined and predictable.
- The appropriate regulatory response to this episodic pollution exposure was to:
    - predict the risk in real time
    - develop a management system to inform the public and ensure an informed choice to bathe
    - use the data to inform the regulatory response to catchment pollution

(Kay et al., 2010b)

The new *Bathing Water Directive* [2006/7/EC] (Council for the European Communities, 2006) was transposed into Irish Law as the *Bathing Water Quality Regulations 2008* [S.I. 79 of 2008] (Minister for the Environment Heritage and Local Government, 2008) . It came into full force on the 31st December 2014. The following are some of the key points of the new directive especially from an environmental management point of view:

Preamble

In the preamble in paragraph 8 it states "*Appropriate information on planned measures and progress on implementation should be disseminated to stakeholders. The* ***public should receive appropriate and timely information on the results*** *of the monitoring of bathing water quality and* ***risk management measures*** *in* ***order to prevent health hazards****,* ***especially in the context of predictable short-term pollution*** *or abnormal situations****.*** ***New technology*** *that allows the public to be informed in an efficient and comparable way on bathing waters across the Community should be applied.*"

In paragraph 10 of the preamble it states "***Compliance should be a matter of appropriate management measures and quality assurance, not merely of measuring and calculation.*** *A system of bathing water profiles is therefore appropriate to provide a better understanding of risks as a basis for management measures.*"

The above demonstrates the much stronger focus of the new directive on the protection of public health and the pro-active approach to bathing water quality management.

General Provisions of the Directive

Purpose:

The purpose of the directive is to preserve, protect and improve the quality of the environment and to protect human health by complementing the *Water Framework Directive* 2000/60/EC (Cronin, 2006). It provides for this by the:

a. monitoring and classification of bathing water quality

b. management of bathing water quality

c. provision of information to the public on bathing water quality

Definitions:

"***pollution***" means the presence of microbiological contamination (Intestinal enterococci and *Escherichia coli*) affecting bathing water quality and presenting a risk to bathers' health (other types are referenced without value criteria)

"***bathing season***" means the period during which large numbers of bathers can be expected. The Irish regulations define this as the 1 June to the 15 September.

"***management measures***" means the following measures undertaken with respect to bathing water:

(a) establishing and maintaining a bathing water profile

(b) establishing a monitoring calendar

(c) monitoring bathing water

(d) assessing bathing water quality

(e) classifying bathing water

(f**) identifying and assessing causes of pollution that might affect bathing waters and impair bathers' health**

(g) giving information to the public

(h) **taking action to prevent bathers' exposure to pollution**

(i) **taking action to reduce the risk of pollution** "***short-term pollution***" is defined as microbiological contamination (Intestinal enterococci and *Escherichia coli*) that has clearly identifiable causes, is not normally expected to affect bathing water quality for more than approximately 72 hours after the bathing water quality is first affected and for which **the competent authority has established procedures to predict and deal with** as set out in Annex II.

Annex II states that the bathing water can be given a bathing water classification if:

- the set of bathing water microbiological quality data for the last assessment period (4 years) achieves the values of that classification, and
- **if the bathing water is subject to *short-term pollution*;**
    - **adequate management measures are being taken, including surveillance, early warning systems and monitoring, with a view to preventing bathers' exposure, by means of a warning** or, where necessary, a bathing prohibition
    - adequate management measures are being taken to prevent, reduce or eliminate the causes of pollution
    - the number of samples disregarded because of short-term pollution during the last assessment period represented no more than 15 % of the total number of samples provided for in the monitoring calendars established for that period, or no more than one sample per bathing season, whichever is the greater

Quality and Management of Bathing Water

Monitoring:

Monitoring is now just carried out for just 2 parameters which are both microbiological. These are *Escherichia Coli* (*E. coli*) and Intestinal Enterococci (IE).

The change to monitoring for these two parameters came following studies that established links between bathing water and public health (World Health Organisation, 1999). These epidemiological studies demonstrated a strong correlation between IE and resultant cases of gastro-intestinal illness from bathing compared to the previous faecal indicator organisms used (Total and Faecal Coliforms). IE is therefore used as an index for faecal pollution especially for seawater. *E. coli,* although better in fresh water has been added as a further indicator of recent faecal pollution in the environment.

Monitoring for these 2 parameters is carried out as follows:

1. One sample taken prior to the bathing season.
2. A monitoring calendar fixing sampling dates for each bathing water shall be established before the start of a bathing season. Monitoring shall take no later than 4 days after the specified date in the calendar.
3. Minimum of 4 samples per bathing season.
4. Sampling dates distributed evenly throughout the bathing season with the interval between these dates never exceeding 1 month.
5. If a *short-term pollution* (STP) event as defined in the directive occurs another sample is taken to confirm the event is over. This end of event sample is not used

for classification purposes**. If scheduled compliance sampling coincides with the STP event, the result can be disregarded and replaced with the result of another sample taken 7 days after the event has ended** (subject to the limitations above). This allowed derogation is important which will become apparent later.

Bathing Water Quality Assessment:

Assessment is carried out for each bathing water at the end of the season and based on the set of quality monitoring data for that season and the preceding 3 bathing seasons on a rolling basis. This means that the assessment data set comprises at least 16 samples (4 per season over 4 years). In practice in Enniscrone assessment sampling is scheduled every two weeks over the bathing season meaning that data from 36 sampling occasions are assessed (further information is given in Appendix A).

Classification and quality status of bathing waters:

The new directive classifies bathing waters in 4 new categories:

1. ***Excellent***
2. ***Good***
3. ***Sufficient***
4. ***Poor***

The criteria for each classification are given below in Table 1 for **coastal bathing waters** (different standards apply for freshwater):

Table 1: Coastal bathing water classification criteria. Calculation results must be equal or better than the value shown

	Classification			
	Excellent	Good	Sufficient	Poor
Parameter				
E. coli (cfu/100 ml)	250*	500*	500**	Does not meet Sufficient standards
Intestinal Enterococci (cfu/100 ml)	100*	200*	185**	Does not meet Sufficient standards

*Based on a 95-percentile calculation **Based on a 90-percentile calculation

NB: Under the old directive (76/160/EEC) 95% of microbiological samples for 1 year needed to comply with the required standard for the old *Mandatory* classification. Under this new directive compliance is based on a 95-percentile or 90-percentile evaluation depending on the classification category. The classifications are normally calculated for 4 years of monitoring data using the 2 parameters above to give a more consistent picture of the water quality condition of the bathing water. This is done by taking the monitoring results for 4 years and calculating the arithmetic mean (μ) and standard deviation (σ) – the spread, for both *E. coli* and IE using the $\log_{10}$ of the reported measurements.

(If a zero value is obtained, take the $\log_{10}$ value of the minimum detection limit of the analytical method used instead).

The 95 and 90-percentile evaluations for *E. coli* and IE are then calculated as specified in the directive:

Upper 95-percentile = antilog ($\mu + 1.65\ \sigma$).

Upper 90-percentile = antilog ($\mu + 1.282\ \sigma$).

The calculated value is then used to assign overall classification as per the criteria in *Table 1* above.

Both the *E. coli* and IE percentiles must be equal to, or lower than the respective classification thresholds as shown below in Table 2. If the 2 parameters fall into separate classifications than the lower classification is assigned to the bathing water.

Table 2: Status definition of bathing waters considering all combinations of achieved IE and E. coli statuses

Parameter status (2006/7/EC)	**IE: Excellent**	**IE: Good**	**IE: Sufficient**	**IE: Poor**
***E. coli*: Excellent**	Excellent	Good	Sufficient	Poor
***E. coli*: Good**	Good	Good	Sufficient	Poor
***E. coli*: Sufficient**	Sufficient	Sufficient	Sufficient	Poor
***E. coli*: Poor**	Poor	Poor	Poor	Poor

Note: (Globevnik et al., 2016)

Bathing water profiles:

As well as establishing the general characteristics of the bathing water and its catchment this profiling consists also of an assessment of potential sources and causes of pollution at the bathing water. If this assessment shows that there is a risk of *short-term pollution* the **management measures taken during *short-term pollution*** and **the identity and contact details of bodies responsible for taking such action** are required for the Profile.

Exchange of Information

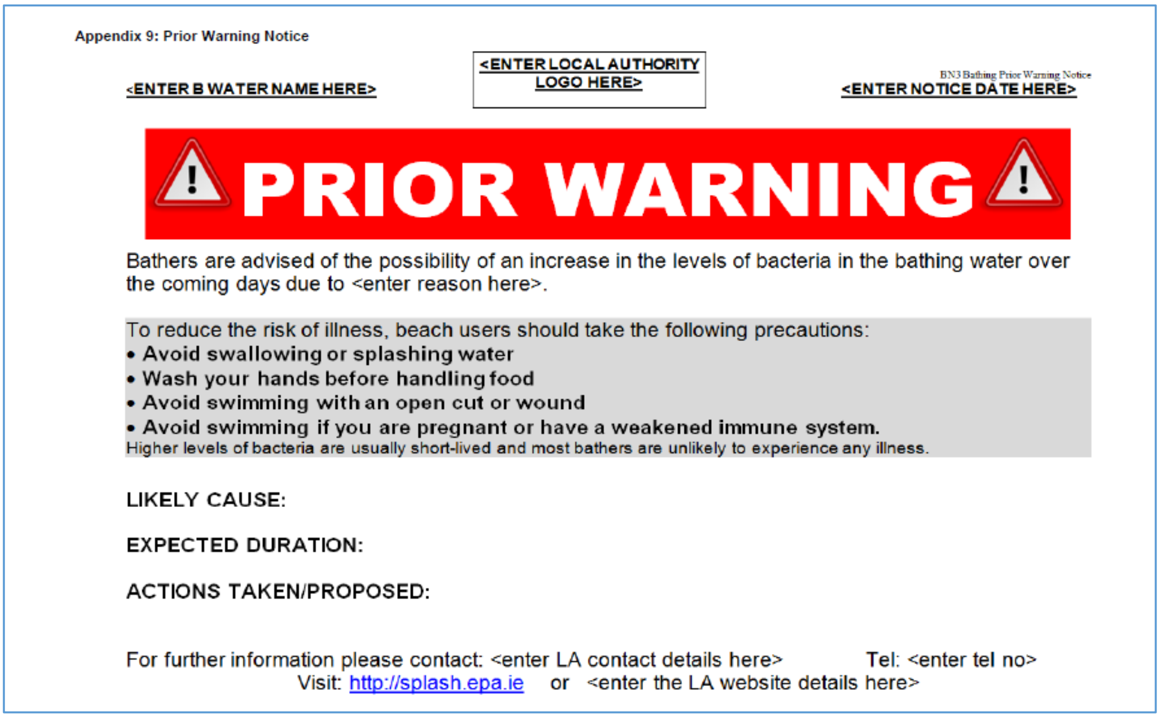
Information to the public

Where bathing waters are subject to *short-term pollution* it should be ensured that a **warning** be given to the public whenever **such pollution is predicted or present**.

New signage was introduced by the Environmental Protection Agency in 2014 (in conjunction with the Health Service Executive) to inform the public of a deterioration of water quality. These 3 signs cover the following scenarios:

1. where a deterioration in water quality was predicted, or likely to occur [***Prior Warning***] as shown in Fig. 7 below.
2. when routine sampling showed a deterioration in water quality which indicated that bathing was not advisable [***Warning – Advice Not To Swim***]
3. when bacterial pollution is detected at concentrations which present an acute health risk and a bathing prohibition is required [***Advice – Do Not Swim***]

(Webster and Lehane, 2015).



Appendix 9: Prior Warning Notice

<ENTER B WATER NAME HERE>

<ENTER LOCAL AUTHORITY LOGO HERE>

BN3 Bathing Prior Warning Notice
<ENTER NOTICE DATE HERE>

PRIOR WARNING

Bathers are advised of the possibility of an increase in the levels of bacteria in the bathing water over the coming days due to <enter reason here>.

To reduce the risk of illness, beach users should take the following precautions:
- **Avoid swallowing or splashing water**
- **Wash your hands before handling food**
- **Avoid swimming with an open cut or wound**
- **Avoid swimming if you are pregnant or have a weakened immune system.**

Higher levels of bacteria are usually short-lived and most bathers are unlikely to experience any illness.

LIKELY CAUSE:

EXPECTED DURATION:

ACTIONS TAKEN/PROPOSED:

For further information please contact: <enter LA contact details here> Tel: <enter tel no>
Visit: http://splash.epa.ie or <enter the LA website details here>

Figure 7: Prior Warning notice used for predicted short-term pollution [STP] (Health Service Executive, 2016).

The 2 other signs can be seen in Appendix G.

One of the criteria for discounting a predicted STP result is that the *Prior Warning* sign above must be erected before official compliance sampling.

In Ireland, local authorities have the primary responsibility for the management and monitoring of bathing waters and for the implementation of management measures to reduce or eliminate sources of pollution (Webster, 2017). They undertake the official compliance sampling and analysis of bathing waters as well as the day to day practical aspects of litter removal, maintenance of facilities, and the investigation of pollution events. The EPA's role as regulator, is to ensure that the local authorities carry out these functions in accordance with the Bathing Water Regulations (Directive). It collates the monitored data and undertakes the formal assessment and classification of water quality together with reviewing actions taken by local authorities in relation to pollution incidents. The EPA report this data to the European Commission in December of each year.

2.1.2 Overall trends in previous publications of this topic

Kay et al. (1994), Prüss (1998) and Kay and Dufour (2000) have shown that faecal indicator organisms (FIO) can be used to predict health outcomes in bathers. The World Health Organisation (WHO) outline in their *Safe Management of Shellfish and Harvest Waters* (Kay et al, 2010) how their *Guidelines for Safe Recreational Water Environments* of 2003 developed two guiding principles for recreational water management, based on research. One of these is that the microbiological standards should be based on epidemiological evidence of health risk, the other that the indicator organisms used should reflect current environmental conditions present in the bathing water. These guiding principles have led to major revision of the regulations covering the management of bathing water.

As stated previously the new *Bathing Water Directive* has introduced 2 new parameters (*E. coli* and Intestinal Enterococci) along with new assessment and management methods. Another dimension highlighted in the literature is the tightening of the limits. The 1976 *Bathing Water Directive* set microbiological criteria for coliforms based on an estimated risk factor of approximately 5% (1 in 20) potential risk of contracting gastro-intestinal illness because of bathing in waters of *Good* quality and 12-15% if waters were of *Sufficient* quality. The revised bathing water standards have been developed on a significantly reduced risk of approximately 3% for *Excellent* waters, ca. 5% for *Good*, and ca. 8-9% for *Sufficient* waters thus strengthening the protection of public health by approximately a factor of two-fold (Environmental Protection Agency, 2014). In other words, the new top *Excellent* classification is twice as stringent as the top standard in the old directive. Additionally, attainment of the top standard for water quality is necessary for *Blue Flag* status.

Furthermore, it should be noted here that monitoring for enterococci (faecal streptococci) was an option under the old directive where there were grounds for believing that water quality had deteriorated because of this parameter. The tightening of the classification for this parameter is represented below in Fig. 8:

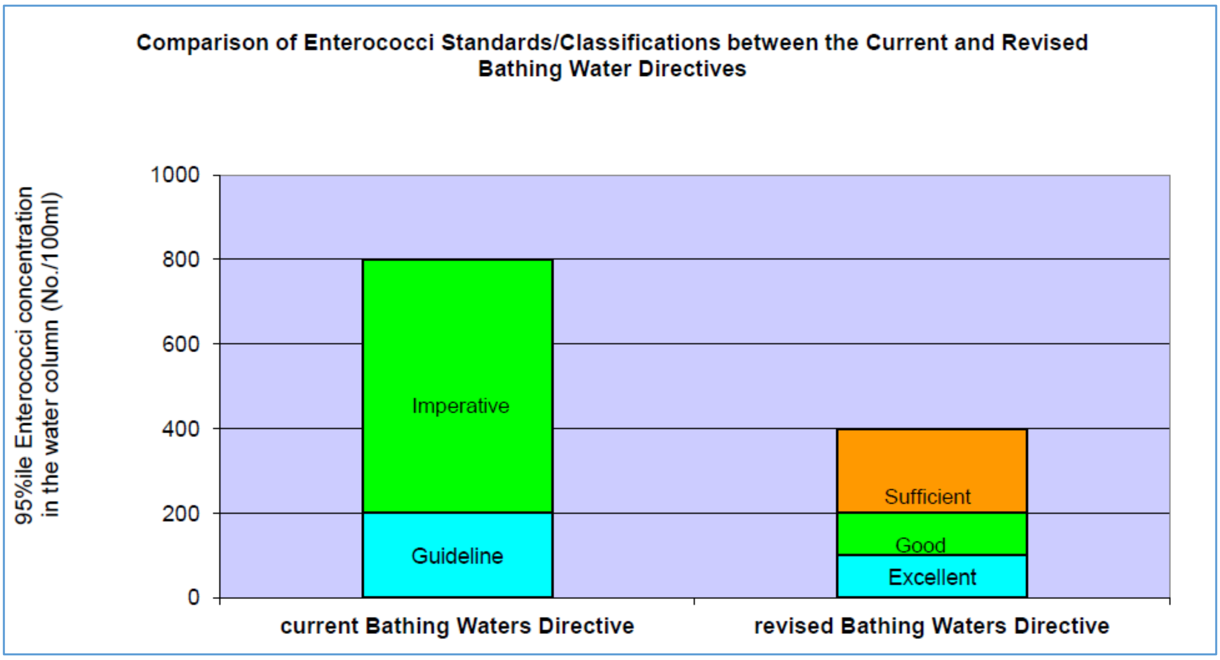


Figure 8: Chart showing the tightening of classification for enterococci from the old directive on the left to the new directive on the right.

It should be noted that meeting the top classification (blue) is one of the criteria that must be met for Blue Flag status (monitoring for enterococci was optional under the old directive but is now mandatory). Taken from Beard, (2013) which was presented before the new (revised) directive was fully in place.

Fig. 8 above further demonstrates how it is now much more difficult to attain the top water quality classification required for *Blue Flag* status. To help attain this desirable top classification the tools that are available in the Directive should be utilised (Scottish Environment Protection Agency, 2015). These include:

- predict and protect systems
- communication at times of incidents or *short-term pollution*
- key role for digital functionality

Investigations carried out in the United Kingdom and the States of Jersey Kay et al., (1998) conclude that many bathing beach locations exhibit non-compliance after rainfall when stream inputs, rather than sewerage inputs, commonly dominate the loadings of faecal indicator bacteria. They conclude that the implication of this input pattern is that previous routine monitoring data of riverine bacterial sources may not provide information relevant to new infrastructure planning designed to achieve bathing beach compliance. Wyer et al. (1994, 1996 and 1997a.) provide evidence that the treatment of municipal wastewater plant effluent alone will not ensure compliance with microbiological standards at many coastal bathing waters. Kay et al. (2006) observe that historically there has been very little effort to measure or indeed regulate indicator bacteria in catchment streams such as those that discharge to bathing water. This is important, as bathing waters are regulated using faecal indicator organisms. Stapleton et al. (2006) note that the inclusion of the *Bathing Water Directive* under the list of "protected areas" in the *EU Water Framework Directive 20/60EC* places a requirement to control sources of faecal indicator organisms within catchments to achieve the objectives of both directives. Thou et al., (2012) discuss the increasing trend internationally of using statistical or data-driven models to provide short-term forecasts of bathing water quality to assist in beach management. They go on to say that water quality forecasting at marine beaches has received less investigation. This forecasting or predictive modelling is seen as a good method for the management of bathing water. This reflects the change of emphasis of legislation governing bathing water from a retrospective management regime to a proactive one. Further investigations have taken place on the modelling concept (Crowther et al., 2002, 2003; Vinten et al., 2004; Kay et al., 2005; Olyphant., 2005; Stapleton et al., 2006; Wyer et al., 2010).

2.1.3 Criteria for reviewing literature

The purpose of this review is to establish what research had taken place into bathing water contamination and the protection of human health.

The review will look at how faecal indicator bacteria get into bathing water. Emphasis was placed on stream and river inputs to bathing waters, what aspects affect the bathing water and stream, what methods were employed to monitor the environment and collect data, and what methods were employed to interpret and use the data.

Any research that assists beach managers to interpret the existence of conditions where there would be a risk of contamination by FIO will also be reviewed.

The relevant criteria used for the literature review were separated into 3 broad areas:

- sources of FIO at bathing waters
- streams discharging to bathing waters
- environmental management of FIO at bathing waters

2.2 Main areas of previous study

2.2.1 Sources of faecal indicator organisms in bathing waters

According to the European Environment Agency's bathing water quality report of 2012 (EEA, 2013), Europe's bathing waters are much cleaner today than they were thirty years ago due to many years' investment in sewage systems and better wastewater treatment.

However, Kay et al., (1998) state that many bathing water locations demonstrate non-compliance after rainfall when stream inputs rather than sewage inputs commonly dominate the loadings of faecal indicator bacteria. The implication of this input pattern is that previous routine monitoring data of riverine bacterial sources may not provide information that is relevant to new infrastructure planning designed to achieve bathing water compliance. A major threat to a local tourist industry in northern England according to Kashefipour et al., (2002) is the continued failure of its bathing waters to comply with the EC mandatory water quality standards, even though over £600 million has been invested in upgrading wastewater treatment plants and reducing storm water discharges. It is demonstrated that diffuse sources to a river was one of the main reasons for non-compliance of the bathing water.

Crowther et al., (2001) list the sources of faecal indicator organisms in coastal waters as:

- discharges of untreated or treated sewage
- runoff from adjacent land areas, particularly those used for livestock farming
- birds

They go on to say that the specific causes of variability in bathing water quality are poorly understood at most beaches and this impedes the development of effective strategies to improve bathing water quality.

2.2.2 *Impact of streams discharging to bathing waters*

Kay et al., (1998) caution that evidence is mounting that attention to the sewage sources of faecal indicator bacteria in recreational waters will not be sufficient to ensure bathing water compliance with EU standards. They discuss the reasons for continued non-compliance of bathing water locations that have treated sewage effluent. One of the principal reasons given is the input to near-shore recreational waters from rivers and streams. These produce highly episodic bacteria delivery which is driven by the flow regime of the river. They further state that data on high flow bacterial concentrations is vital to understanding non-compliance.

Wyer et al., (1996) and Crowther et al., (2002, 2003) observed that faecal indicator organisms increased in rivers experiencing a hydrograph event due to rainfall. Wyer et al., (2010) further noted that *Blue Flag* status of a bathing beach could be compromised following hydrograph events by up to two days or more. As well as coinciding with the stream input hydrograph event, poor bathing water quality also coincided with high turbidity levels in the sea. Kay et al., (2008) demonstrated in their research that input streams to bathing waters demonstrated consistent and significant increases in concentrations of faecal indicator bacteria during hydrograph response to rainfall, thus threatening compliance with standards.

Ghimire and Deng, (2013) in their study utilise a hydrograph-based approach to predict bacterial concentrations in rivers. Furthermore, they conclude that the most important mechanism for bacterial transport in streams is watershed loading during flood events and hyporheic exchange during low flow periods. They also note that faecal coliforms are mostly associated in streams with fine particulates of low settling velocity.

2.2.3 Environmental management of bathing waters

Kay et al., (1998) argue that the management of bathing waters needs to expand its focus from providing infrastructure, to incorporating management of diffuse sources of faecal indicator loading. As stated earlier, because of the impact of the *EU Water Framework Directive* and the revised daughter *Bathing Water Directive*, “protected areas” like bathing waters must be protected and improved. Statistical models have been developed to investigate the impact of faecal indicator organisms on coastal waters (Kashefipour et al., 2002). Catchment-based tools also have been developed to help protect bathing waters from stream and river inputs (Kay et al., 2006; Kay et al., 2008). In recent years, there appears to be a focus on the development of catchment models to predict fluxes of faecal indicator organisms to recreational waters. However, the study in fluxes of faecal indicator organisms from diffuse sources in a catchment, and subsequent modelling, is not well developed (Crowther et al., 2002; Kay et al., 2006). As Kay et al., note in 2008, such catchment microbial modelling is required to both characterise faecal indicator organisms in streams and fluxes to bathing waters, and to assess the management of land use in the catchment. They go on to say that to further advance the area of modelling, empirically based faecal indicator organism data for different catchments and at different stream flux states (high and base flow) are required.

As Crowther et al., (2001); Kay et al., (2006); Stapleton et al., (2006) and Wyer et al., (2010) discuss, there has been little data generated on the fluxes of faecal indicator organisms in catchment streams and the variability in bathing water quality at the majority of beaches is poorly understood. There is a lack of empirical data for faecal indicator organisms in river catchments on which to assess loads and fluxes.

To understand any non-compliance of a bathing water with a stream input, environmental sampling should be undertaken at high flow events in streams as well as during low flows to characterize faecal indicator loadings. This can form the basis of remedial action (Kay et al., 1998).

Stapleton et al., (2006) state that once the various sources of a pollutant have been determined, more effective management practices can be put in place. They highlight that whilst monitoring and modelling of pollutants like nitrogen and phosphorus are well established, little attention has been given to faecal indicator organisms in river catchments. They conclude that additional sampling effort would be needed to undertake catchment profiling as envisaged by the *Bathing Directive* of 2006 or the WHO (1999, 2003). There is little empirical data on which to base initial assessments of faecal indicator loads (Kay et al., 2007).

Locally at the bathing water of interest at Enniscrone, the previous study of the author (Egan, 2015) demonstrated a clear relationship between rainfall, river discharge, concentrations of indicator bacteria in the Bellawaddy River and levels of bacteria in the bathing waters of Enniscrone. The results revealed that *short-term pollution* events in the bathing water were caused by the hydrograph response of the river in response to local heavy rainfall events. Very high concentrations of indicator bacteria were measured being discharged by the river. Wyer et al., (2010), state that the physical linkage between hydrological inputs and bathing water compliance monitoring sites under high flow response to rainfall is seldom established although such connectivity is central to the EU *Programmes of Measures* under the *Water Framework Directive.*

Samples from bathing waters can take greater than 24 hours to enumerate FIO. Thoe et al., (2014), discuss this issue and that resultant beach management decisions based on out-dated sampling results could lead to health risks for bathers. Furthermore, they discuss the successful use of predictive modelling using hydro-meteorological aspects in Scotland which was the first country in the EU to employ this method. McPhail and Stidson (2009) in their paper on the Scottish system point out that a key factor causing *short-term pollution* is wet weather and particularly the intensity of local rainfall in the period before sampling. However, information such as local rainfall and hydrometric data that the Scottish use may not be available for bathing areas elsewhere. But it does emphasize the need and importance of determining any hydro-meteorological relationship in a locality. Any such data that is readily available locally should be utilised.

2.2.4 Aspects & interpretation of the legislation

As was discussed earlier there are pro-active management tools available under the new directive which can be used to disregard predicted *short-term pollution* (STP) results from the compliance sampling data set (as the public have been warned of an increased risk of poor water quality). To summarise:

- Compliance sampling is carried out as per calendar.
- Results obtained from such STP events will not be used in the overall quality classification (4-year) on the basis that bathing was reduced or absent during the warning period.
- A sample is taken within 72 hours to confirm that the episode is over (but not used for quality classification). NB: This is done for all predicted STP episodes whether compliance sampling is scheduled or not.

- If necessary (i.e. a scheduled sampling event was impacted) the replacement compliance sampling takes place 7 days later after the end of the *short-term pollution* event.
- This discounting is nonetheless limited to 15% of the overall result set or 1 sample per year (whichever is greater).

This discounting limitation might be challenging in certain conditions (i.e. a wet year) as in an Irish context it would normally be allowed once per bathing season if applied. According to Webster, (2013) Irish bathing waters are more susceptible to statistical outliers due to climatic conditions. Even when transformed the spread of results are severely right-skewed; i.e. there is a high proportion of results at the lower values with only a scattering of higher values. This is important, as compliance assessment is a statistical analysis of the results of the previous four years (95 percentile). However, with a bathing water quality system to predict STP, aspects of the directive provide further flexibility for compliance sampling. The Scottish Environment Protection Agency have pioneered the interpretation and use of the 5 day monitoring provisions (Stidson, 2013). The directive provides for compliance monitoring no later than 4 days after the date specified in the calendar. This implies that if you have confidence in your real-time water quality system to predict STP which then coincides with sampling, you can move the compliance monitoring back providing its within 5 days. This can be done to protect the health and safety of the sampler, avoid an STP event and importantly can be done on unlimited occasions.

Very little research has been undertaken into the cost of implementing the new directive and its requirements, against any health benefits from protecting the public to exposure to pathogens. Georgiou and Bateman, (2005) carried out net present value calculations based on figures from the United Kingdom and the Netherlands. Comparing the cost and benefit estimates it appears that for the UK any cost-benefit assessment depends on the level of water quality and associated health risk reduction that compliance will deliver, and with the types of health and other benefits included in the assessment. For example, if the most stringent of the water quality scenarios for the UK is considered along with the widest measure of benefits for the UK then the Directive delivers positive net benefits (£12,983 million in benefits—£9,119 million in costs). However, if any of the more conservative measures of benefits are considered instead, then there are overall net costs associated with the Directive. In the case of the single Dutch revision scenario considered, the benefits easily outweigh the costs of compliance (£3,413 million in benefits—£31 million costs). Thus, he argues that, although not unequivocal, there does appear to be some support for the Commission's desire to see a tightening of bathing water standards in terms of the economic costs and benefits of the new Directive. In an Irish context Hynes et al., (2013) illustrate that further research is needed in this area. The cost of improving a bathing water to *Sufficient* status may be more than the benefits. Individual assessments should be carried out at beaches. They caution that if it is found in a national assessment that aggregate benefits are substantially less than aggregate costs that this would imply more attention will be needed to find more cost-effective ways of achieving target improvements in water quality. They also note that water quality is not of major concern to many users unless there is a significant impact. Kay et al., (2013) estimate that in a British context real-time prediction of bathing water that is hydrodynamic and black box will cost £1.5 – £5.4 billion just to maintain present *Blue Flag* numbers.

As stated previously the Directive/Regulations establish a new classification system for bathing water quality based on four classifications; "*Poor*", "*Sufficient*", "*Good*" and "*Excellent*" and require that a classification of at least *Sufficient* be achieved by 2015 for all bathing waters. Local authorities must take appropriate measures with a view to improving waters which are classified as *Poor* and increasing the number of bathing waters classified as *Good* or *Excellent*. If a bathing water receives a *Poor* status during any given 4-year assessment period, the bathing water will require to be subject to restrictions on bathing and monitored for the following season. In the event of a bathing water being classified as *Poor* for 5 consecutive years it must be permanently closed (Health Service Executive, 2016).

2.2.5 Forecasting systems

The new Directive is very clear that bathing places like Enniscrone which are impacted by *short-term pollution* must have established procedures put in place to predict and deal with it. To achieve this there must be adequate management measures, including surveillance, early warning systems and monitoring, with a view to preventing bathers' exposure. This requires that a form of forecasting element is established to predict *short-term pollution*. But what is an effective forecasting or warning system? Traditionally, bathing water quality assessments are based on microbiological analyses for indicators of pathogen bacteria. A significant drawback of these analyses is the time lag until results are available and their limited representation in time and space. The introduction of a bathing water quality forecast system will greatly improve the assessment of human health risks. The core of the forecasting system is hydrodynamic model simulation and forecasting the physical conditions and the water quality at the bathing water sites (1D, 2D or 3D i.e. becoming more complex). The system ensures that managers and bathers are warned when the water is unsafe to swim in. Furthermore, the tool provides quantitative assessments of the impact of pollution sources and provides a basis for reviewing the monitoring programs and identifying mitigation measures. This provides a strong management tool for identification of the most effective measures to reduce contamination – an important element of the new *Bathing Water Directive* (Mark and Erichsen, 2007).

Whilst there is literature pertaining to the modelling of bathing water pollution there is very little literature available regarding the *structure* of bathing water quality early warning systems.

There are no guidelines about the complexity of bathing early warnings systems but with less knowledge of today's bacterial pollution some conservatism needs to be included to account for the lack of knowledge compared to more precise management tools (Mark and Erichsen, 2007).

In 2006 the United Nations produced its *Global Survey of Early Warning Systems* which identified 4 elements that should be combined in natural hazard early warning systems along with the judgment that to be effective they need to be people focused (United Nations Inter-Agency Secretariat of the International Strategy for Disaster Reduction (UN/ISDR), 2006). These elements are shown in the diagram (Fig. 9) below.

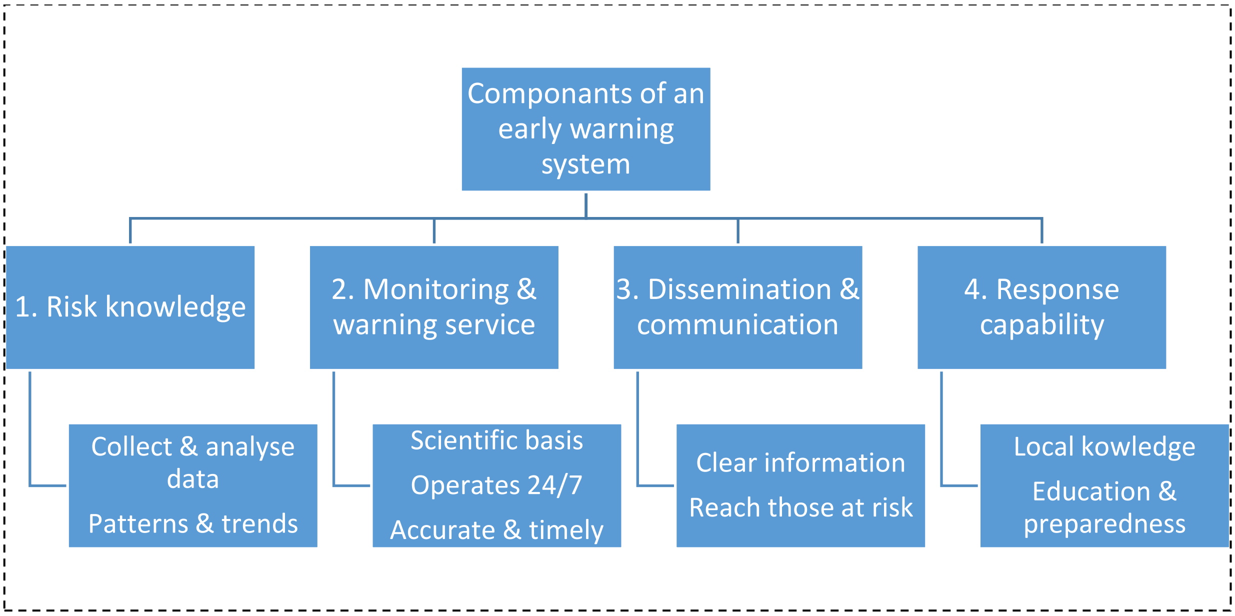


Figure 9: The 4 inter-related elements contained in an effective early warning system (United Nations Inter-Agency Secretariat of the International Strategy for Disaster Reduction (UN/ISDR), 2006)

The UN/ISDR go on further to state that a weakness in any one part could result in a failure of the whole system. The process diagram shown in Fig. 10 below shows how the 4 elements in Fig. 9 above can be used to set up and operate a local early warning system. Some stages may operate in parallel and not sequentially. This example of an effective system described below is taken from the *Caribbean Handbook on Risk Information Management* which was developed by an EU funded consortium led by the University of Twente. It is used for flood forecasting but can be applied to any other natural hazard (ACP-EU Natural Disaster Risk Reduction Program, 2014). As was described earlier in the literature, hydro-meteorological conditions analogous to those that can cause flooding events (intense rainfall etc.) influence strongly the fluxes of faecal indicator organisms from catchments to bathing waters which cause the hazard to bathing.

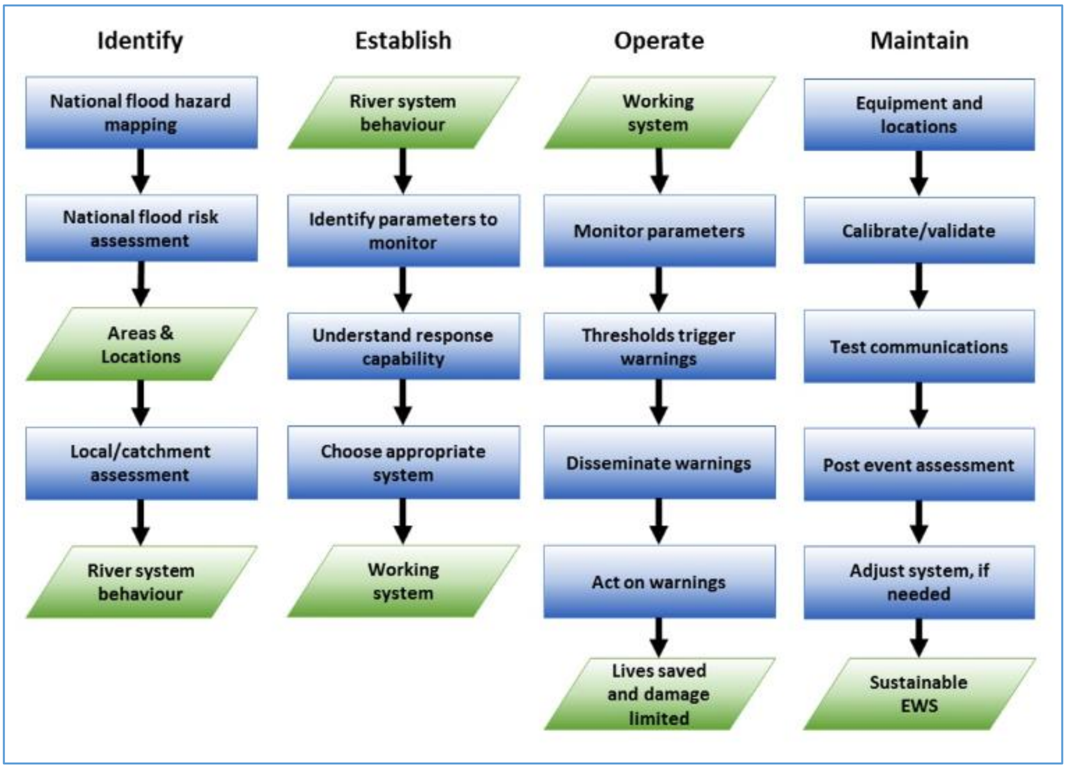


Figure 10: Schematic representation of the 4 elements and their components in use in an early warning system (Caribbean Handbook on Risk Information Management ACP-EU Natural Disaster Risk Reduction Program, 2014)

The following is a description on how the 4 elements and their components in an Early Warning System can operate:

1. **Identify need for system:** The first step is to identify the need for the Early Warning System (EWS). Both the supervisory authority (Sligo County Council, 2016) and the author (Egan, 2015) have concluded that Enniscrone Beach is subject to *short-term pollution*. In cases such as these the *Bathing Water Directive* (Council for the European Communities, 2006) instructs that adequate management measures such as early warning systems must be put in place.

Location/Catchment Assessment: This means establishing how the hazard is most likely to occur and what its characteristics are. This will allow an appropriate EWS to be established. The location specific context is established through a catchment or location assessment. It should be noted here that although there may be similarities between catchments, local conditions and characteristics often make a hazard a particularly local phenomenon, which means this level of assessment is essential otherwise there is a risk that the EWS will be implemented poorly. The outcomes of the local assessment will form the basis for the design and implementation of the EWS. It should identify:

a. What conditions give rise to an event? There may be more than one mechanism that gives rise to risk. This will make it clear what should be monitored to get an early indication that an event is imminent.
b. What explicit parameters to monitor, where to measure them, and how frequently to measure them?
c. The physical flow paths and timings of events, possibly with intensity. This will make it clear who will need warning and how quickly. The understanding of the timing is crucial for an EWS. Smaller steeper catchments will respond to rainfall within an hour or so, whereas large river systems may take from multiple hours to days to respond.

2. **Establish & 3. Operate System:**

Monitoring parameters and thresholds: Once an understanding of the river system and what is likely to occur in an event has been ascertained, then it is possible to design and build an appropriate system. It should be clear from this knowledge, which specific locations will be best for monitoring relevant parameters, for example rainfall higher up in the catchment, upstream and local water levels and so on. Measuring rainfall & river levels form the core monitoring system for an EWS.

Dissemination and action: Typically for an EWS, when monitored parameters exceed predetermined thresholds (determined from local assessment described above) this triggers the next stage of the system, which involves informing someone that this has occurred and putting into action the predetermined plan of disseminating warnings and acting on those warnings. The responsible parties for each of these stages can vary depending upon local capabilities and legal responsibilities. How messages and warnings will be practically disseminated is of critical importance and should be studied in detail, including having backup alternative forms of communication in case the primary system fails. As well as physical systems in place to monitor, and communicate warnings, it is also important that a clear procedure is established so that responsible parties understand what they need to do at each stage of an event. These procedures should be documented in a clear, easy to understand way. It is common for an EWS to be established that uses several levels of increasingly urgent warnings, with each level increasing the urgency and escalating the warning to more people to take further actions. This multi-tiered approach is sometimes referred to as the “Ready, Set, Go” concept which conveys the severity and timing of a forecast hazard and the level of forecaster confidence. This is typically to allow for the fact that an EWS is most effective if warnings are given as early as possible but offset by the fact that very early warnings can be unreliable due to uncertainties of an event actually happening. False warnings can have a very counterproductive effect in that too many will lead communities to ignore future warnings. The final stage in the warning process is action based on the warnings. This can involve persons who ensure action is taking place which can further reinforce the message for people who may not have received the initial warnings. This can involve responsible officials and/or community members.

4. **Maintain system:**

   An extremely important part of the design of an EWS is to consider the long-term sustainability of the system. It is surprisingly common for well-designed and expensive systems to fail due to a lack of basic maintenance, for example. Events requiring warnings may be infrequent enough that equipment can fail, unnoticed by operators until an event occurs, and then it is too late. Long term funds and procedures need to be provided so that regular checks on equipment are conducted and any deficiencies repaired. For remote gauges, this can involve field vehicles and fuel costs as well as staff time and replacement equipment. The simpler the system is, the less expensive this process is, but this will not negate the need for regular checks. Automatic equipment will also require calibration and checks to ensure it is reporting correct values. Primary and backup communications systems will need to be checked to ensure they will operate correctly during an event. Another useful aspect of maintaining a system is to carry out a post-event assessment to see if the EWS can be improved. For example, by adjusting warning thresholds or to increase the warning area to cover people who were exposed to risk that the initial location assessment failed to identify.

As the system required for this project will be based on hydro-meteorological conditions locally certain conditions as outlined above will apply. The atmospheric system is chaotic with convective rainfall causing some of greatest challenges to rainfall forecasting, and consequently the ability of the weather forecast system to detect and predict such events is a major issue

(Hénonin et al., 2010). Schuurmans, (2008) states one system that can be used is Numerical Weather Prediction models which are good when you want to increase the forecast lead time. However, these systems capture the physics of large systems quite well but lack local detail because of their limited spatial resolution. Schuurmans also determines that *now-casting* which involves the interrogation of real-time data, captures the initial information almost perfectly but the forecast will decrease rapidly with increasing lead time. Any forecasting strategy employed by this project must recognise the limitations of the available data and the feasibility of providing an effective forecast. Events in flashy catchments like the small one examined in this study offer particular challenges to forecasting. (A flashy river catchment is one that reacts rapidly to intense rainfall because of its topography and related geology). Adoption of a simple threshold procedure for formulating watches and warnings is necessitated by the very short lead times allowed by these events for forecasting and response activities (Brown, 2017).

This experience is replicated in the field of economic forecasting. Economists are evaluating why they missed predicting the recent financial crash and some very interesting conclusions are emerging (Johns, 2015). Amongst them are:

- *"A much more elaborate, expensive, exercise might have more intellectual gravitas (than a simpler one) but would reach the same conclusions and involve numbers of dubious if not spurious precision".*
- *"One of the few really interesting innovations in forecasting methods has been the development of something called Now-casting. The future is all very well, but we have an equally tough task in figuring out where the economy is right now – or what it has been doing over the recent past."*

2.2.6 *Real-time early warning systems in-situ*

Denmark:

Copenhagen: Copenhagen and the nearby city of Arhaus have developed a bathing water prediction system for the beaches that are situated beside them. The prediction is based on the impact of heavy rainfall causing overflows from the sewer system or wastewater treatment plants. Sensors are placed throughout the system which calculate storage in the system and rainfall radar now-casts the expected runoff volume from the combined sewer overflows. These results are combined using water modelling software are with other parameters like sea current, predicted rainfall water temperature etc. to produce a forecast. A texting app system notifies subscribers on their phone. (Vezzaro et al., 2014). The bathing forecasting system was developed by DHI in Denmark and it has been in operation since 2002 as a service under DHIs Water Forecast service. The first client was Copenhagen. Since then the system has been expanded to include beaches in 11 Danish and 3 Swedish municipalities. The Danish and Swedish forecasts are disseminated on two websites, one for Denmark and one for Sweden (Kaas et al., 2011)

Australia: The New South Wales Government provides daily bathing water pollution forecasts for the Sydney, Hunter, Central Coast and Illawarra regions. The system provides forecasts 7 days a week during the bathing season and is based on rainfall thresholds (Office of Environment & Heritage New South Wales Government, 2018).

China (SAR Hong Kong)**:** Thoe and Lee, (2014) developed one of the first beach forecast systems in the world and the forecasts for 16 beaches are disseminated by phone apps and an internet webpage. Multiple linear regression models were developed using recent hydro-environmental data. It is intended to be used to supplement regular monitoring.

United States: Thoe et al., (2014) developed artificial neural networks to correlate FIO levels with hydro-environmental factors like rainfall, tide, solar radiation, wind etc. for beaches in California. The pilot test for this ran at 5 beaches during the summer of 2017 (Orange County Health Care Agency, 2018). Statistical models are used at some beaches in the US including Lake Michigan Beaches, Illinois, Lake Erie Beaches, Ohio and Port Washington, Washington. Many other types are in development (United States Environmental Protection Agency, 2010a). An example is the City of Chicago which is piloting a project called *Clear Water* which models near real-time results (2 hour) for *E. coli* at certain beaches, along with previous results, to produce water quality notifications or *beach advisories* for a larger tranche of beaches (City of Chicago, 2018).

United Kingdom: Scotland have led the way in Europe, developing and rolling out a successful system. During the bathing seasons of 2003 and 2004 the Scottish Environment Protection Agency (SEPA) introduced *predict and protect* management tools which inform the public in real-time of bathing water quality forecasts at appropriate beaches. McPhail and Stidson, (2009) go on to say that because SEPA maintain a network of hydrometric and rainfall monitoring stations they were well placed to develop real-time predictions using preceding rainfall and river flow. The system now provides daily forecasts via electronic signage at 23 beaches across Scotland during the bathing season (Scottish Environment Protection Agency, 2013). The prediction of water quality at these bathing locations is based on a daily assessment of hydrometric data. The science of hydrometry is concerned with the measurement of the quantity of water in the environment. The monitoring of river flow and rainfall allows the detection of conditions that are known to increase the risk of pollution entering rivers and coastal waters. Monitoring data is recorded at each station on a data-logger and is then automatically scrutinised using telecommunications systems. The data is interrogated every morning during the bathing water season by hydrometrists who check for irregularities before producing a prediction for bathing water quality. This prediction is then uploaded onto electronic signs at beach locations as well as the internet and smartphone networks. In 2012 the interrogation location was moved from a central location to three regional locations so that hydrometrists with local knowledge of monitoring stations and catchments could give an enhanced interpretation. The Environment Agency of England (EA) developed a method to predict pollution of bathing waters in 2013 with the purpose of warning the public of an increased risk of poor water quality based on antecedent rainfall in catchments draining to bathing waters. Each bathing site was associated with a telemetered rain gauge measurement station. The water quality at a bathing site was considered low risk if the rainfall total at the associated rain gauge station was below a site-specific threshold and increased risk if the threshold was exceeded. The prediction of water quality at each bathing site is displayed via appropriately dated beach signage every morning for the day. To predict the bathing water quality it was decided to setup an operational bathing water quality forecasting system (BWQFS) using modelling software (Dhondia et al., 2014).

Ireland: In Ireland, Kerry Council have led the way in this area. They have developed an innovative risk matrix to proactively manage their beaches (Lenihan, 2014). With a constraint on resources they developed their risk matrix based on historical rainfall and microbiological data for each beach. They then ranked the vulnerability of each beach to non-comply with the regulations according to rainfall amounts. They use predicted rainfall as a basis to manage their beaches, i.e. prior notice warning for *short-term pollution* events. This type of method may be the basis for the management of *short-term pollution* at many bathing places around Ireland going forward (Environmental Protection Agency, 2014).

In its *Information Note on the Management of Short-Term Pollution (STP) Events specified in the 2008 Bathing Water Quality Regulations (SI No, 79 of 2008)* issued in June 2015 the Environmental Protection Agency strongly recommends that local authorities adopt the above risk matrix linking it to forecasted rainfall from sites like www.met.ie www.passageweather.com www.xcweather.co.uk and www.magicseaweed.com. It also states that whilst the above sites carry some degree of uncertainty nonetheless they do provide an insight into probable meteorological conditions that can trigger a STP event. Furthermore, it gives the European Commission's updated view that predictability of a STP event refers to prior knowledge of conditions (such as heavy rainfall) that can trigger STP events. The Note is promoting the use of these forecasts along with individual beach matrixes to predict STP (Office of Environmental Assessment (OEA) Bathing Water Unit, 2015). It does mention that these forecasts carry some degree of uncertainty but do afford an insight into probable meteorological conditions. This is evidenced however in the data for the 2016 and 2017 bathing seasons. In 2016 there were 24 precautionary STP notifications but pollution was confirmed as occurring on only 2 occasions (Webster, 2017). For 2017 where it was anticipated that a STP event may occur only 2 out of 120 actually resulted in any increase in bacterial levels (Webster, 2018b). This is despite the acknowledgement in the Bathing Water Quality Report for 2014 (Webster and Lehane, 2015) that "*there is however, a need to ensure that any assessment criteria provide an appropriate balance between the risk of not identifying potential problems and the imposition of unnecessary bathing restrictions*".

As far as the author is aware this model is only one in official use in Ireland however few local authorities have availed of the approach (Environmental Protection Agency, 2014).

Bedri et al., (2016) undertook a study to try and predict water quality at Bray Beach in Co. Wicklow. This study used the MIKE model developed in Denmark (referenced above) and catchment and coastal hydro-meteorological data. There were 2 elements to this study with the model using real-time data performing better than the model that utilised forecasts from the Norwegian Meteorological Institute and the Norwegian Broadcasting Corporation namely www.yr.no (79% as against 77% correct predictions for *E. coli*). This study used the *Sufficient* classification under the new directive as the bar for compliance for water quality. In December 2017 this system was launched as an EU Research Interreg (SWIM) Project for 6 beaches in Northern Ireland and 2 in the Republic of Ireland (including Enniscrone) with a completion date of 2020 (Keep Northern Ireland Beautiful, 2017).

2.3 Conclusion of review

2.3.1 Summary of findings

The conclusions of the investigations into bathing waters, associated streams and early warning real-time bathing water quality systems can be summarized as follows:

- Input streams can carry a variable and large load of faecal indicator organisms to a bathing water.
- The bathing waters are regulated by using faecal indicator organisms. Stream inputs of bacteria from diffuse sources can have a significantly greater impact on bathing waters than sewerage sources.

- Even after the completion of new sewerage infrastructure, bathing waters can still demonstrate non-compliance with the regulations.
- Loadings and fluxes of bacteria in streams are influenced by local hydro-meteorological conditions.
- To understand what is happening at a bathing water with a stream input local investigations should take place.
- To protect public health and concur with the Directive/Regulations a real-time bathing water quality information system is required for bathing waters impacted from STP.
- Little research has been carried out on beaches with *Good* status that are trying to achieve the top *Excellent* status (the focus has been on avoiding "*Poor*" status or improving from *Sufficient* status).
- Little research has been carried out on the structure of real-time bathing water quality systems.
- Systems will cost money.
- The only system used in Ireland (risk matrix) is applied sporadically.
- The system that is used in Ireland is inaccurate and imprecise.
- Inaccurate and imprecise systems will damage local tourism industries.
- Systems should be based on local knowledge and data.

This review shows the increasing importance of the study of faecal indicator organisms in streams and rivers discharging to bathing waters. As Kay et al., (2006) note, the *European Union Water Framework Directive* of 2000 is the most significant piece of environmental legislation the EU has produced. It has shifted the focus of water quality from point sources of pollution to the integrated catchment management of water resources. Water resource management is outlined by them as a set of coordinated technical interventions in the hydrological cycle, to regulate water supplies for human use. River basin planning goes on further to integrate the above interventions into the whole inter-relationship of social and environmental issues. It internalises many of the externalities of water resource management. In the United Kingdom and Ireland this new approach has been promoted as the *Integrated Catchment Management Approach* (Deakin and Daly, 2013). The simple concept is that all upstream point and diffuse pollution in a catchment must be managed to achieve a target water quality at a downstream point of use. Kay et al., (2006) further point out that to implement this approach new science and understanding is necessary as a basis for potential remedial actions. Harmonised decision-support tools are also needed to predict downstream water quality for various parameters.

3 Site Description

3.1 Description of study area

3.1.1 Detail of Bellawaddy river catchment

A catchment is an area where water is collected by the natural landscape and flows from source through river, lakes and groundwater to the sea (Ferrier and Jenkins, 2010). The Bellawaddy river catchment is small at approximately 19 km² and is situated on an east to west axis. It has a classic "leaf" shape being broader in its upland eastern area and narrowing down to a point where it enters the sea to the west. Elevations range from 90 m in its eastern portion to sea level in the west. The geology is dominated by Dinantian Pure bedded limestones categorised as regionally important karstified aquifer.

The Bellawaddy River's code in the Western River Basin District is 34_3252. It is one of 112 river bodies contained in the Moy Management Water Unit Action Plan

The river is contained within the EPA Hydrometric Area 34. Its EPA River Code is 34B05

The catchment area is 19,097,481 m². The river has a total fluvial habitat of 50,521 m². Total fluvial habitat is defined as the wetted area of a riverine habitat within a given river system except 1st order streams. The wetted area is based on the width of the river water surface measured at right-angles to the direction of flow during low flow conditions.

(Including 1st order streams which are not used above, the total wetted area of the riverine habitat is estimated at 60,000 m²).

The analysis below in Table 3 illustrates that most of the river catchment exhibits a low stream gradient with just over 4 % with a high gradient.

Table 3: Classification of the gradient of the Bellawaddy river's total fluvial habitat

Classification using the Rosgen system			
Rosgen 1	Rosgen 2	Rosgen 3	Rosgen 4
High gradient >>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>→			Low gradient
> 10%	4 - 10%	2 - 4%	< 2%
81 m^2	2,126 m^2	5,342 m^2	42,973 m^2

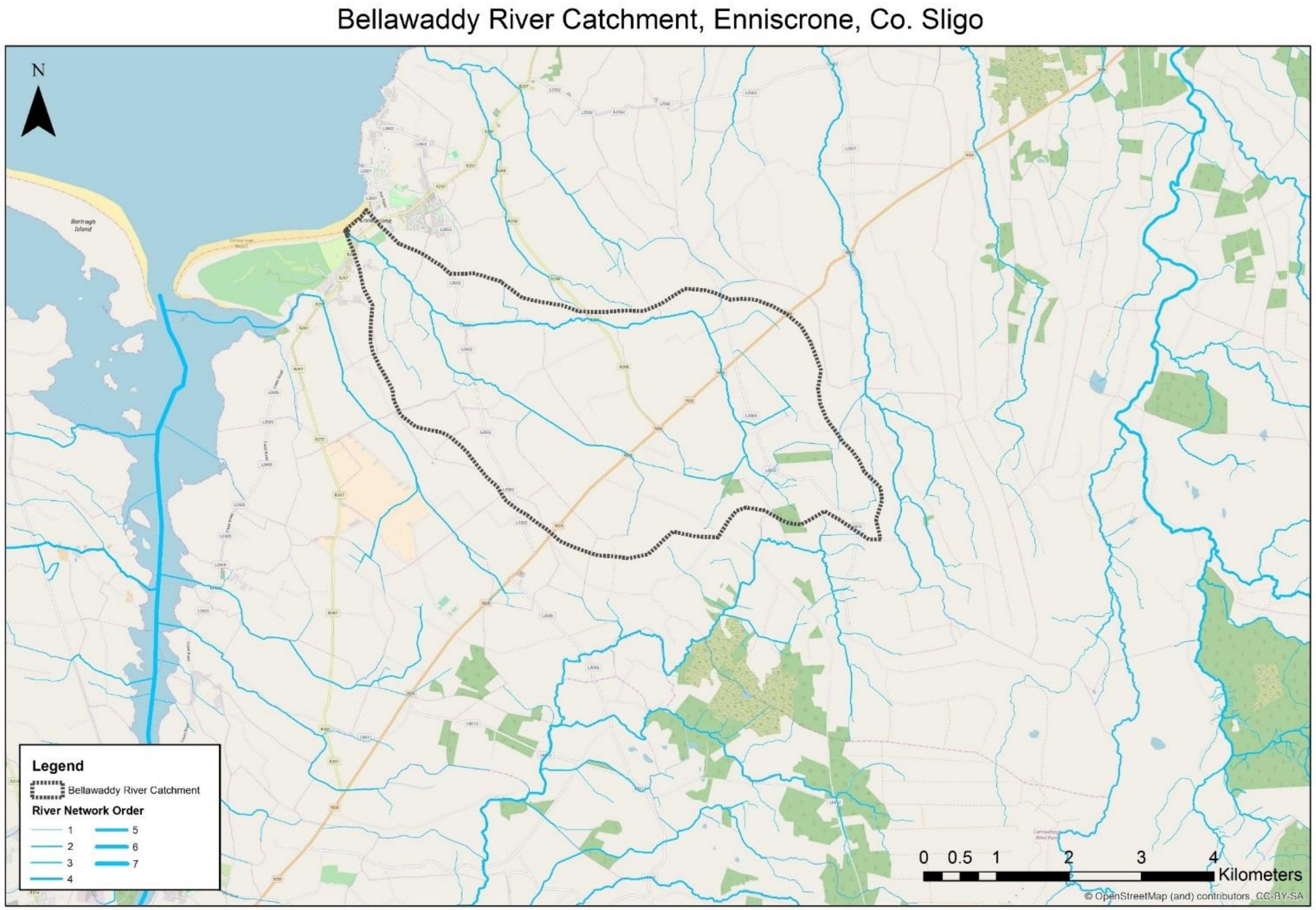


Figure 11: Location of the Bellawaddy catchment above Enniscrone bathing water and beach (yellow)

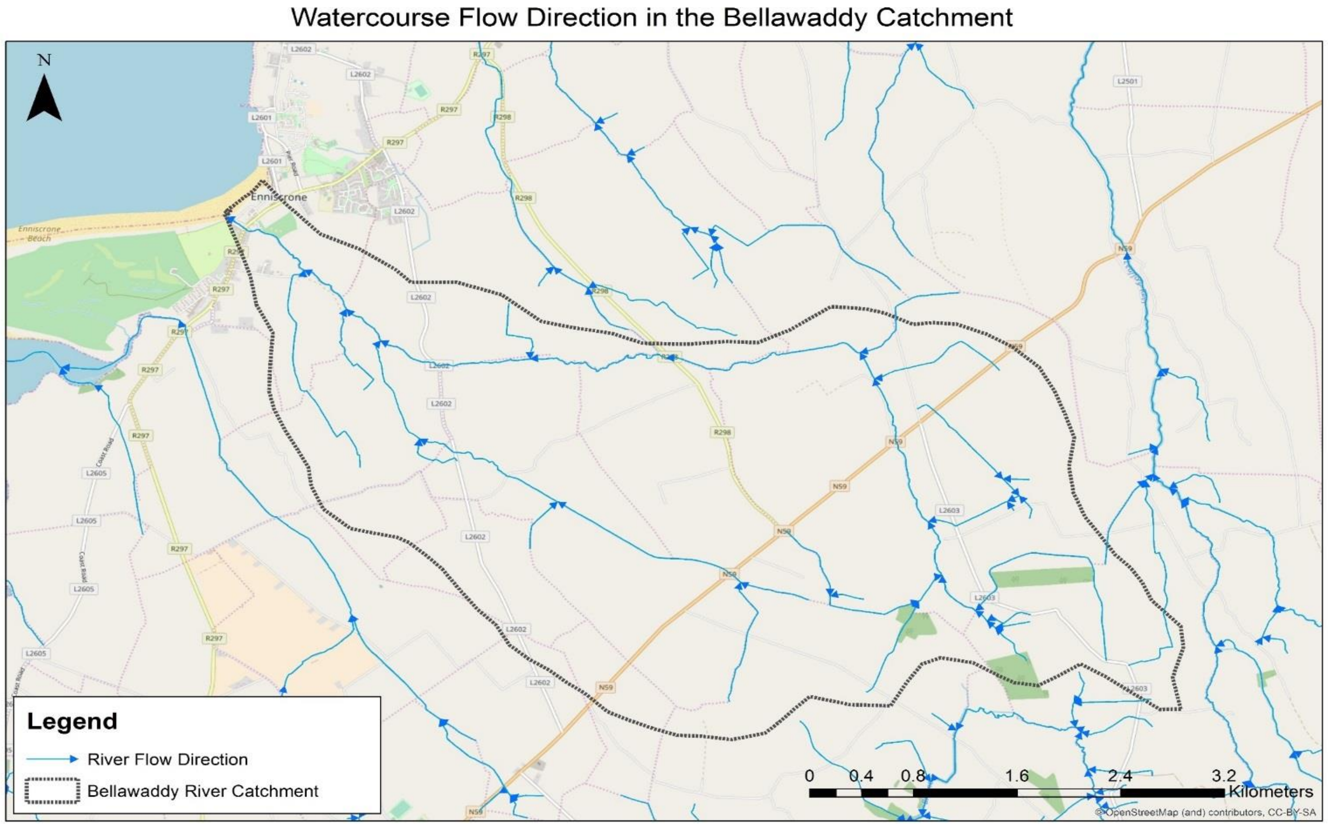


Figure 12: Direction of water flow.

Note the main (northern) channel and the minor (southern) branch which conjoin 1.5 km above Enniscrone. The main drainage of surface water in the catchment is from the SE towards the NW and Enniscrone beach

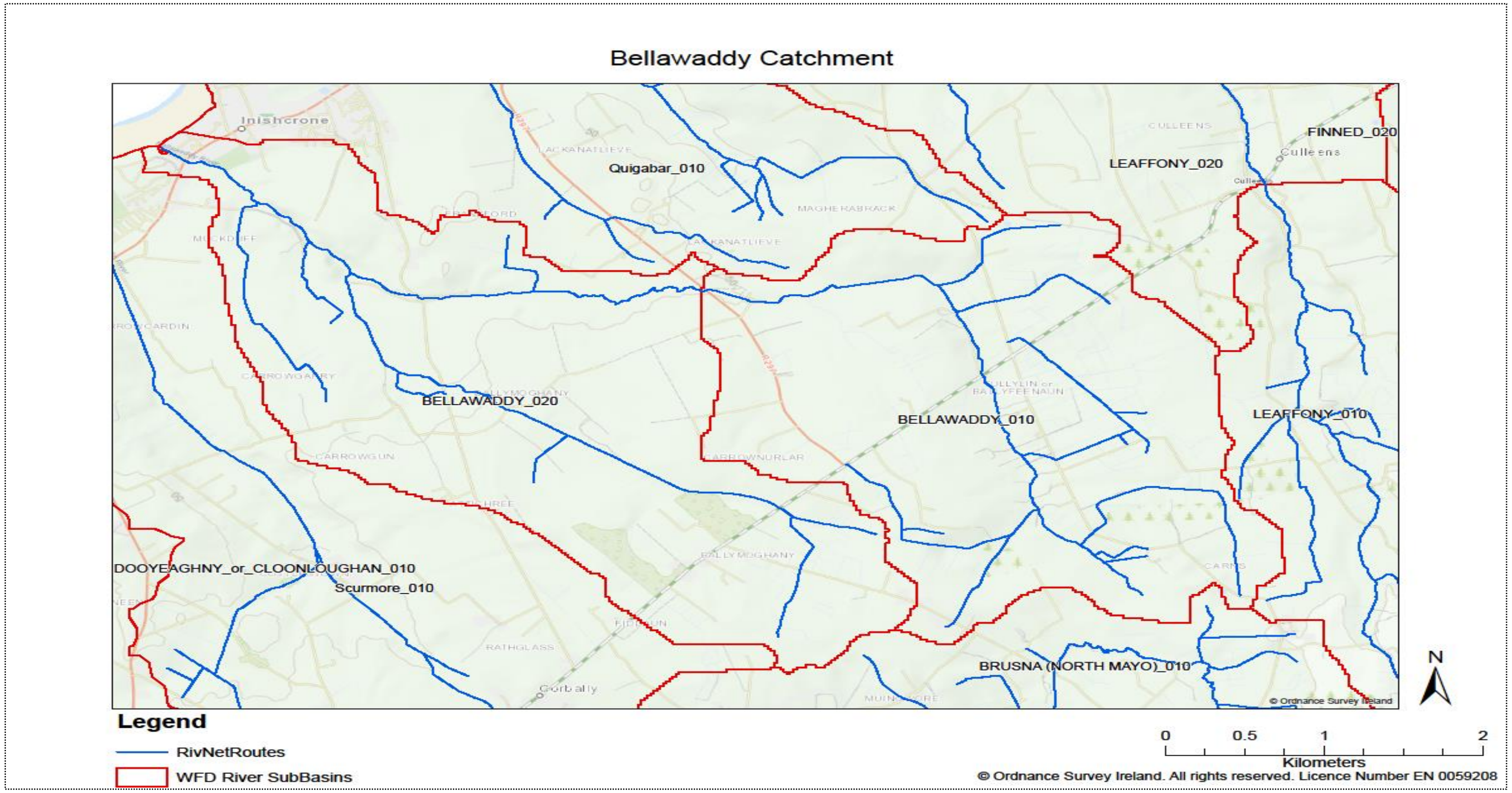


Figure 13: Map of Bellawaddy catchment showing its 2 sub-basins.

The upper (Tullylinn) sub-catchment is labelled Bellawaddy_010 with the lower sub-catchment labelled Bellawaddy_020

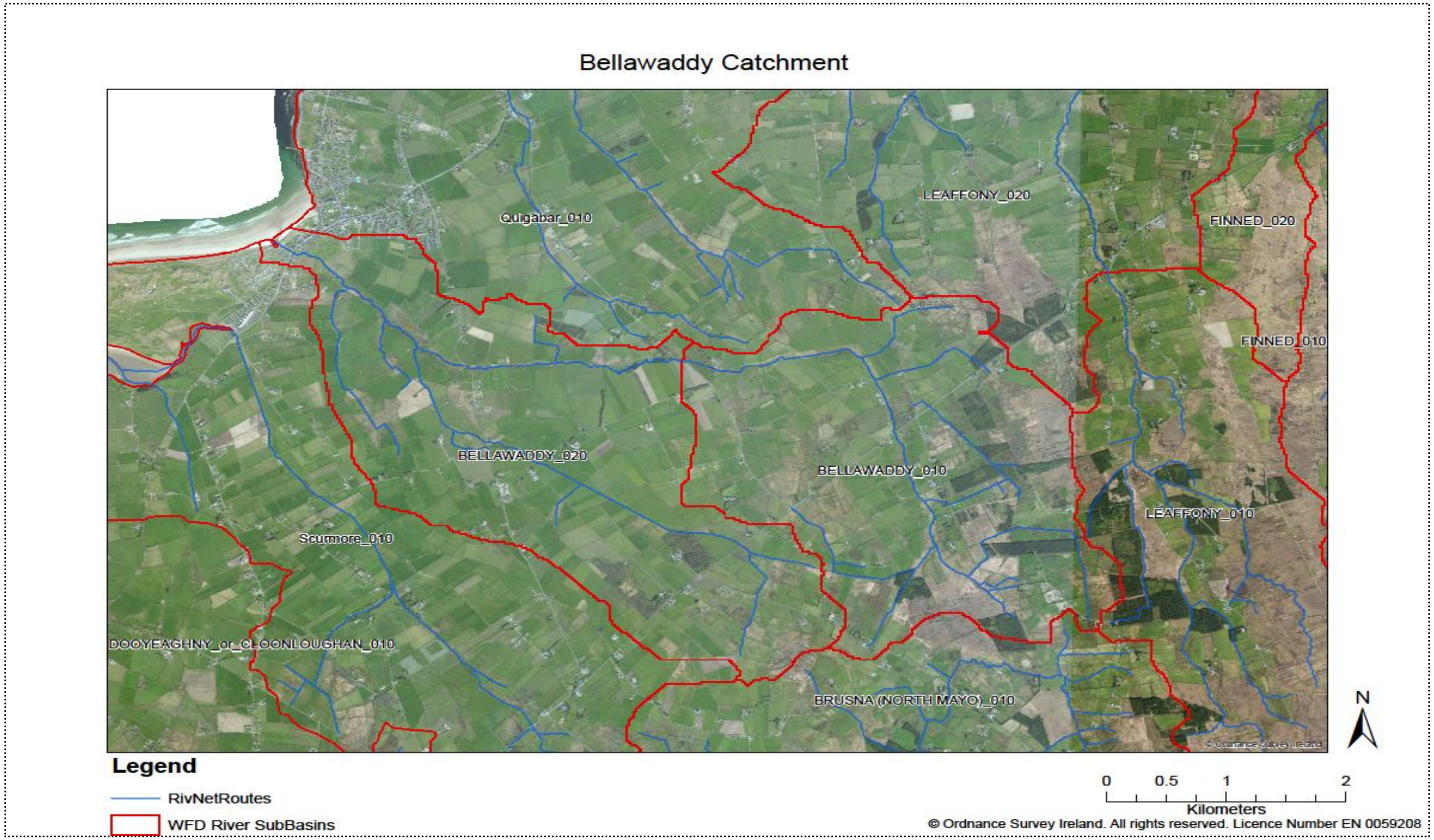


Figure 14: Aerial photograph showing land use overlaid by the Bellawaddy river and its 2 sub-catchments (centre).

The catchment is predominantly rural. Most of the poorer land is in the eastern (010) sub-catchment. Enniscrone town and beach can clearly be seen in the NW corner

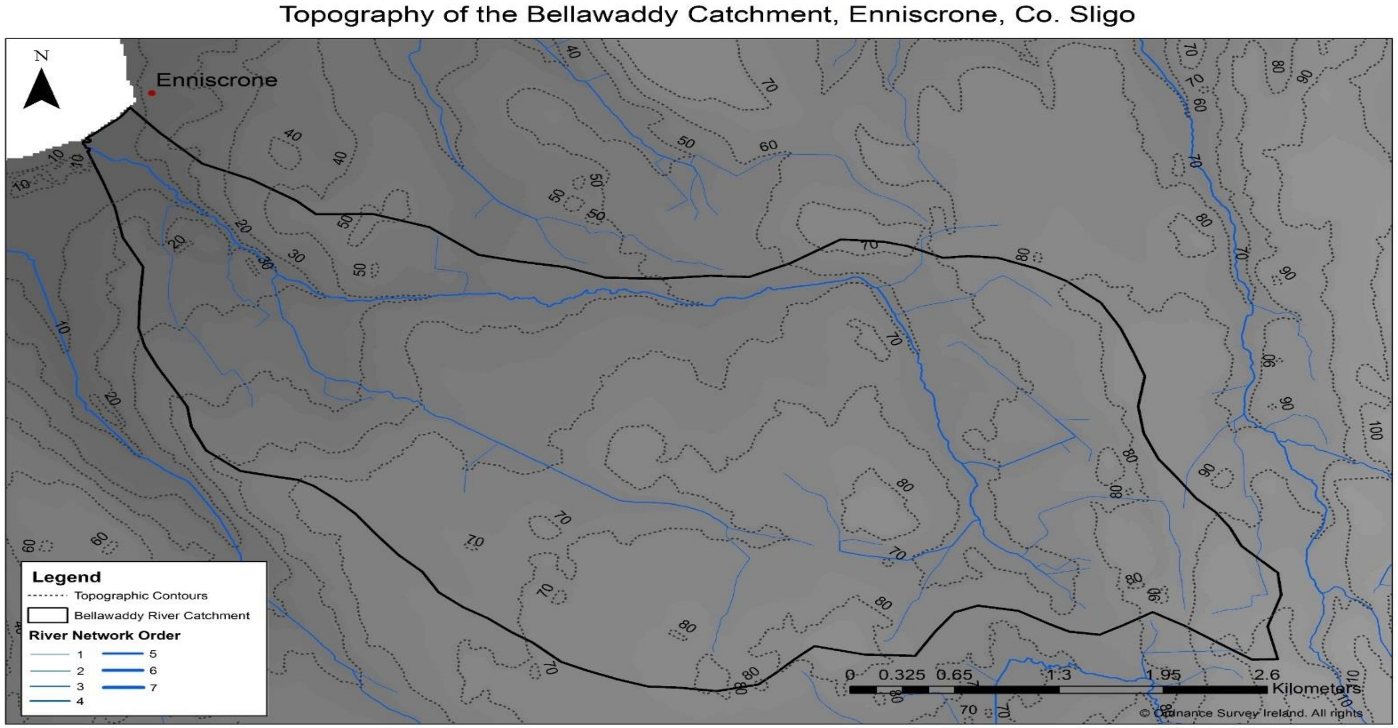


Figure 15: Topography of the Bellawaddy river catchment showing contours in metres.

The catchment gently slopes from east to west. The eastern (01-Tullylinn) sub-catchment contains the steepest gradients

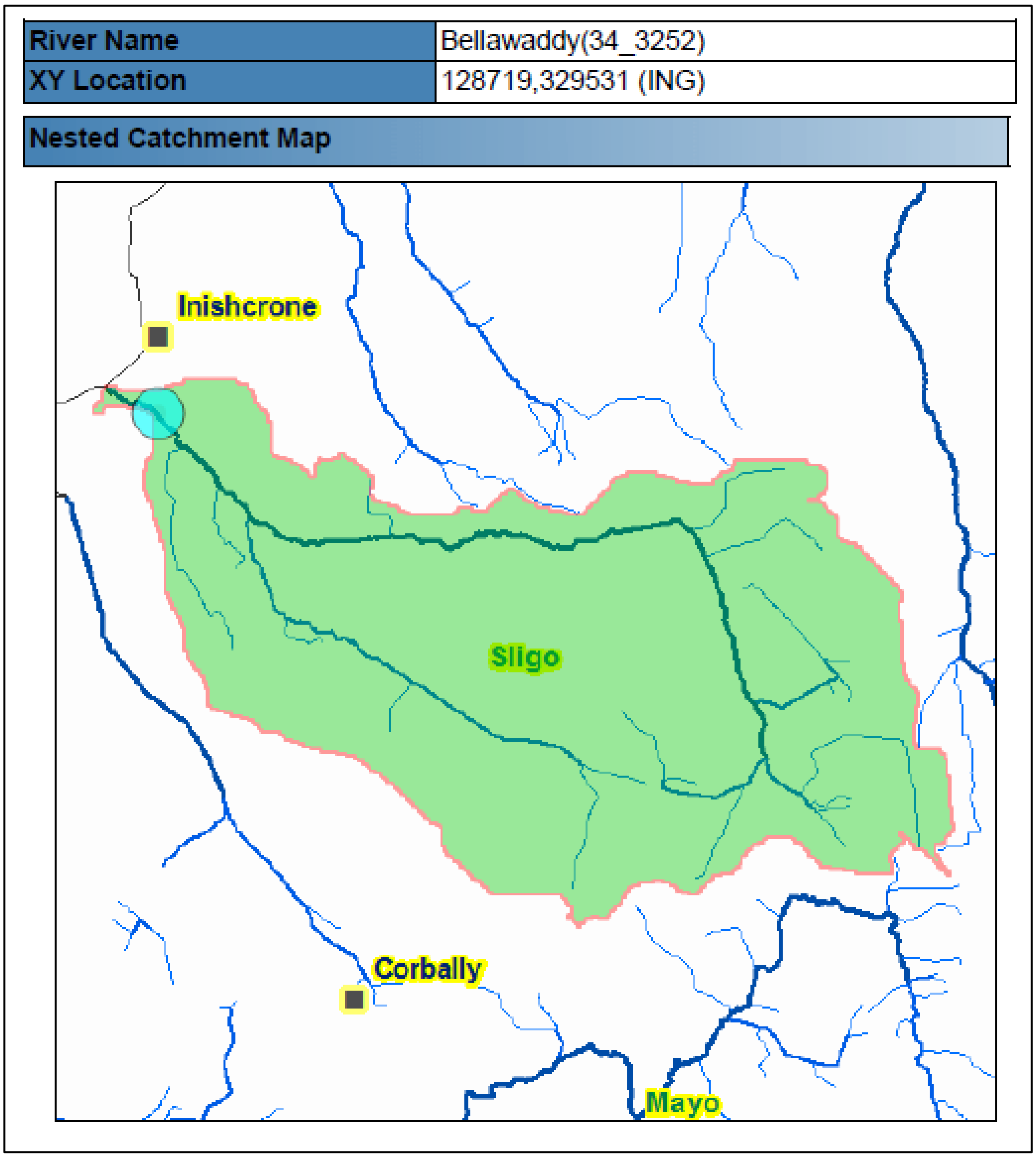
Figure 16: Aerial photograph of beach with river catchment behind.

The Bellawaddy river flows from the dark area in the centre background through the catchment to discharge at the bathing water in the bottom left-hand corner of the picture. The rural nature of the catchment can be clearly seen. Picture © Steve Rogers Photography – by permission

The following is a description and analysis of the Bellawaddy River and its catchment taken from the EPA's *Hydrotool* database. Drainage density points to the number of watercourses in an individual drainage basin (catchment) and is measured by dividing the total length of all watercourses in a catchment by its area. Soil permeability and underlying rock type (Tables 5 & 7) affect the runoff in a catchment with impermeable ground or exposed bedrock leading to a rise in surface water runoff and therefore to more numerous streams. The higher the drainage density the more quickly water drains from a catchment. Generally, values of 2 or greater indicate catchments with greater surface water run-off. Because of this storm hydrographs caused by rainfall events will have a steep falling limb indicative of flashy catchments. The value for drainage density obtained in the Hydrotool model for the overall catchment below (Fig. 17) is given in Table 4 as 1.6. This is less than 2.0 and indicates a catchment that might not be flashy. However, for the sub-catchment above Tullylinn (Fig. 19) that figure rises to 2 in Table 6 which indicates this part of the river will react more quickly to localised intense rainfall.

FARL (Flood Attenuation by Reservoir or Lake) indicates if there is attenuation effect on the movement of water through the stream network by lakes etc. which will slow the surface water response to a rainfall event. Values less than 0.8 indicate a large effect whilst values of 1 indicate none. The surface water response to rainfall events is not slowed by any water storage in this catchment.

A flow duration curve (FDC) represents the relationship between the magnitude and duration of stream flows. Duration in this context refers to the overall percentage of time that a specific flow is exceeded. Therefore, the shape of the FDC for any river strongly indicates the type of flow regime. It is influenced by the character of the upstream catchment including geology, urbanisation, artificial influences and groundwater. The FDCs for the Bellawaddy River at Enniscrone and Tullylinn below (Figs. 18 & 20) exhibit a flashy flow regime with more extreme high and low flows because of its areas of upland topography with steeper gradients in addition to the impermeable nature of the catchment. Catchments with the opposite topography would display a much “flatter” FDC.

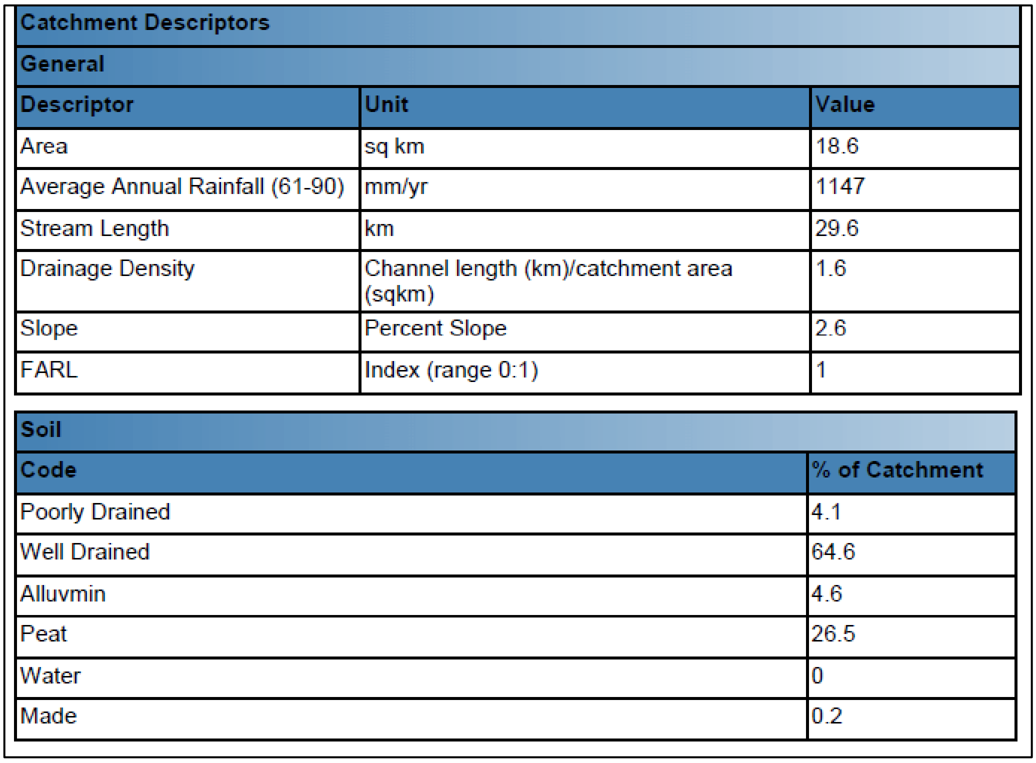


River Name	Bellawaddy(34_3252)
XY Location	128719,329531 (ING)

Nested Catchment Map

Figure 17: Bellawaddy catchment used for EPA Hydrotool Description Model (not to scale)

Table 4: Description of Bellawaddy catchment. Source: EPA Hydrotool



Catchment Descriptors

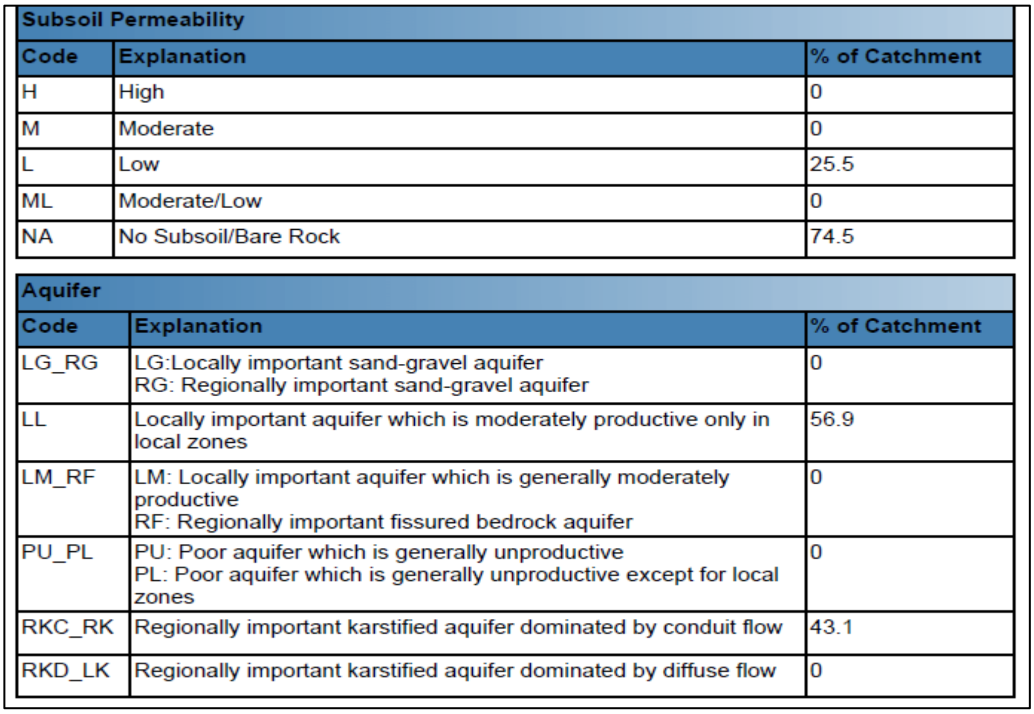
General

Descriptor	Unit	Value
Area	sq km	18.6
Average Annual Rainfall (61-90)	mm/yr	1147
Stream Length	km	29.6
Drainage Density	Channel length (km)/catchment area (sqkm)	1.6
Slope	Percent Slope	2.6
FARL	Index (range 0:1)	1

Soil

Code	% of Catchment
Poorly Drained	4.1
Well Drained	64.6
Alluvmin	4.6
Peat	26.5
Water	0
Made	0.2

Table 5: Description of Bellawaddy catchment. Source: EPA Hydrotool

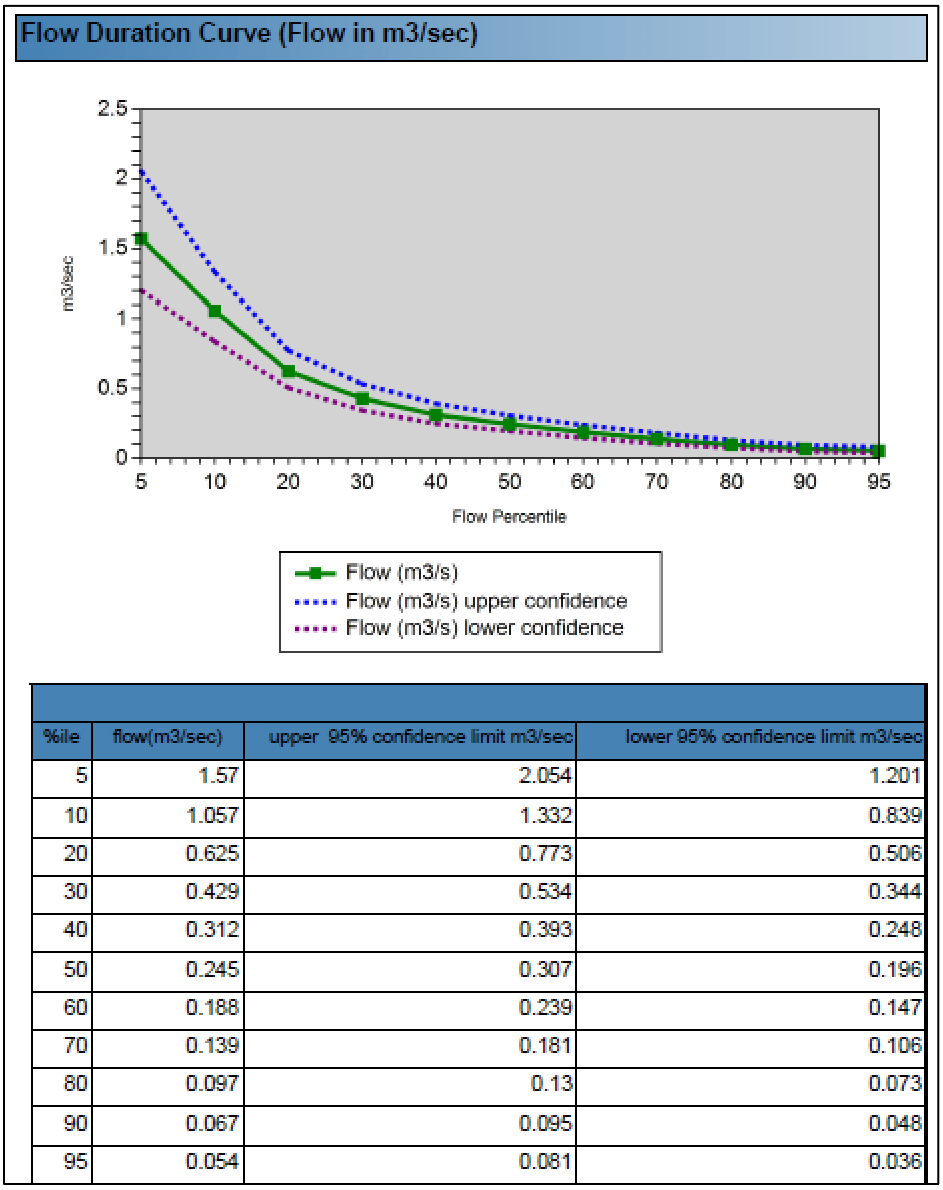


Subsoil Permeability

Code	Explanation	% of Catchment
H	High	0
M	Moderate	0
L	Low	25.5
ML	Moderate/Low	0
NA	No Subsoil/Bare Rock	74.5

Aquifer

Code	Explanation	% of Catchment
LG_RG	LG:Locally important sand-gravel aquifer RG: Regionally important sand-gravel aquifer	0
LL	Locally important aquifer which is moderately productive only in local zones	56.9
LM_RF	LM: Locally important aquifer which is generally moderately productive RF: Regionally important fissured bedrock aquifer	0
PU_PL	PU: Poor aquifer which is generally unproductive PL: Poor aquifer which is generally unproductive except for local zones	0
RKC_RK	Regionally important karstified aquifer dominated by conduit flow	43.1
RKD_LK	Regionally important karstified aquifer dominated by diffuse flow	0



%ile	flow(m3/sec)	upper 95% confidence limit m3/sec	lower 95% confidence limit m3/sec
5	1.57	2.054	1.201
10	1.057	1.332	0.839
20	0.625	0.773	0.506
30	0.429	0.534	0.344
40	0.312	0.393	0.248
50	0.245	0.307	0.196
60	0.188	0.239	0.147
70	0.139	0.181	0.106
80	0.097	0.13	0.073
90	0.067	0.095	0.048
95	0.054	0.081	0.036

Figure 18: Flow duration curve for Bellawaddy river at Enniscrone Co. Sligo

River Name	Bellawaddy(34_2976)
XY Location	133469,327821 (ING)

Nested Catchment Map

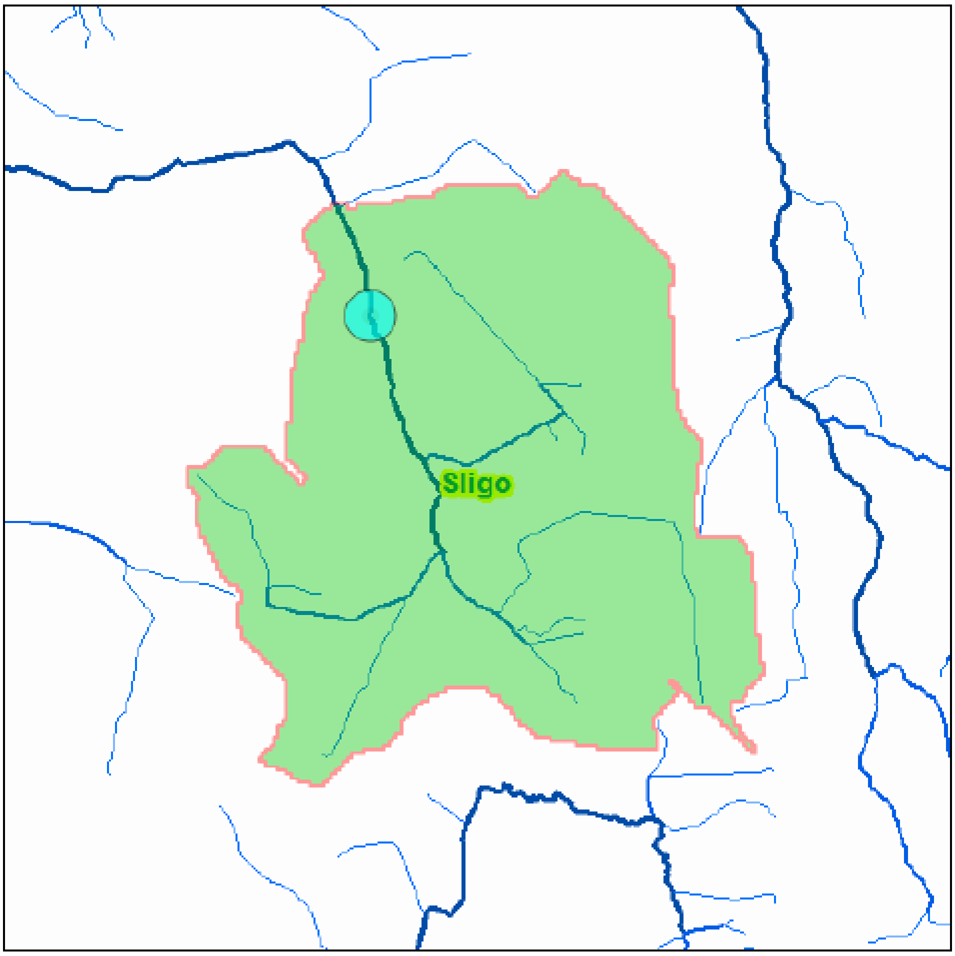
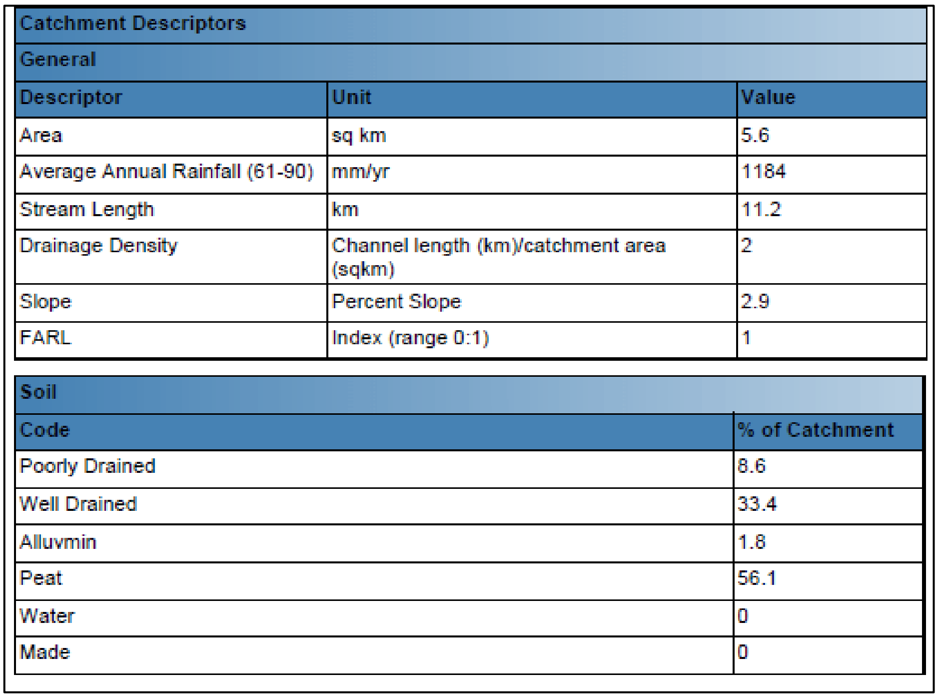


*Figure 19: Bellawaddy river **sub-catchment at Tullylinn** used for EPA Hydrotool Description Model (not to scale)*

Table 6: Description of Bellawaddy ***sub-catchment upstream of Tullylinn****. Source: EPA Hydrotool*



Catchment Descriptors

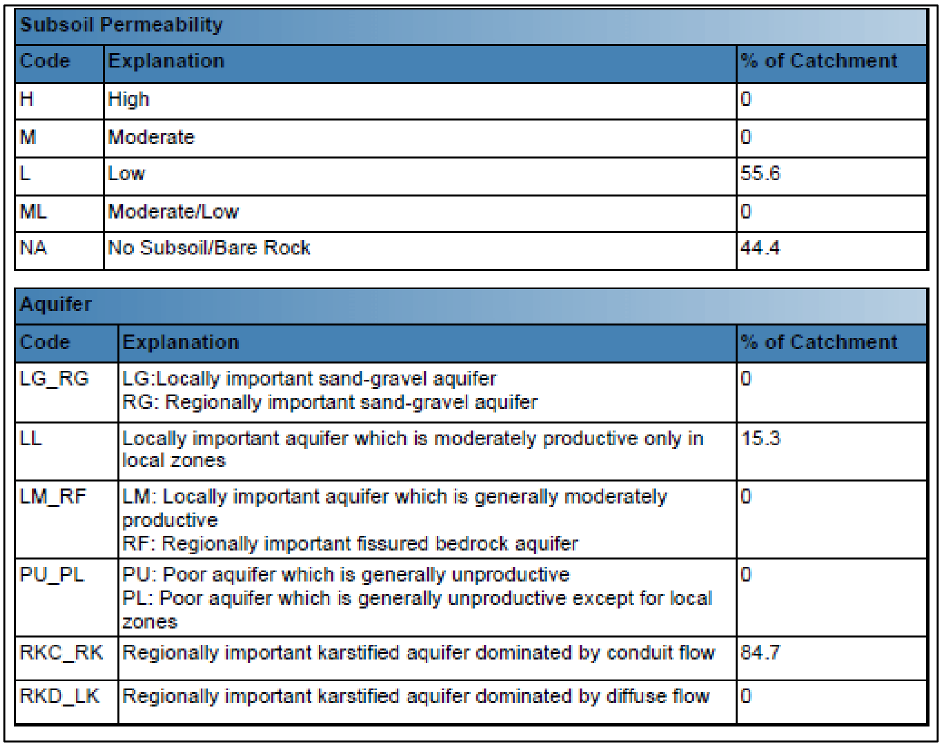
General

Descriptor	Unit	Value
Area	sq km	5.6
Average Annual Rainfall (61-90)	mm/yr	1184
Stream Length	km	11.2
Drainage Density	Channel length (km)/catchment area (sqkm)	2
Slope	Percent Slope	2.9
FARL	Index (range 0:1)	1

Soil

Code	% of Catchment
Poorly Drained	8.6
Well Drained	33.4
Alluvmin	1.8
Peat	56.1
Water	0
Made	0

Table 7: Description of Bellawaddy ***sub-catchment above Tullylinn****. Source: EPA Hydrotool*

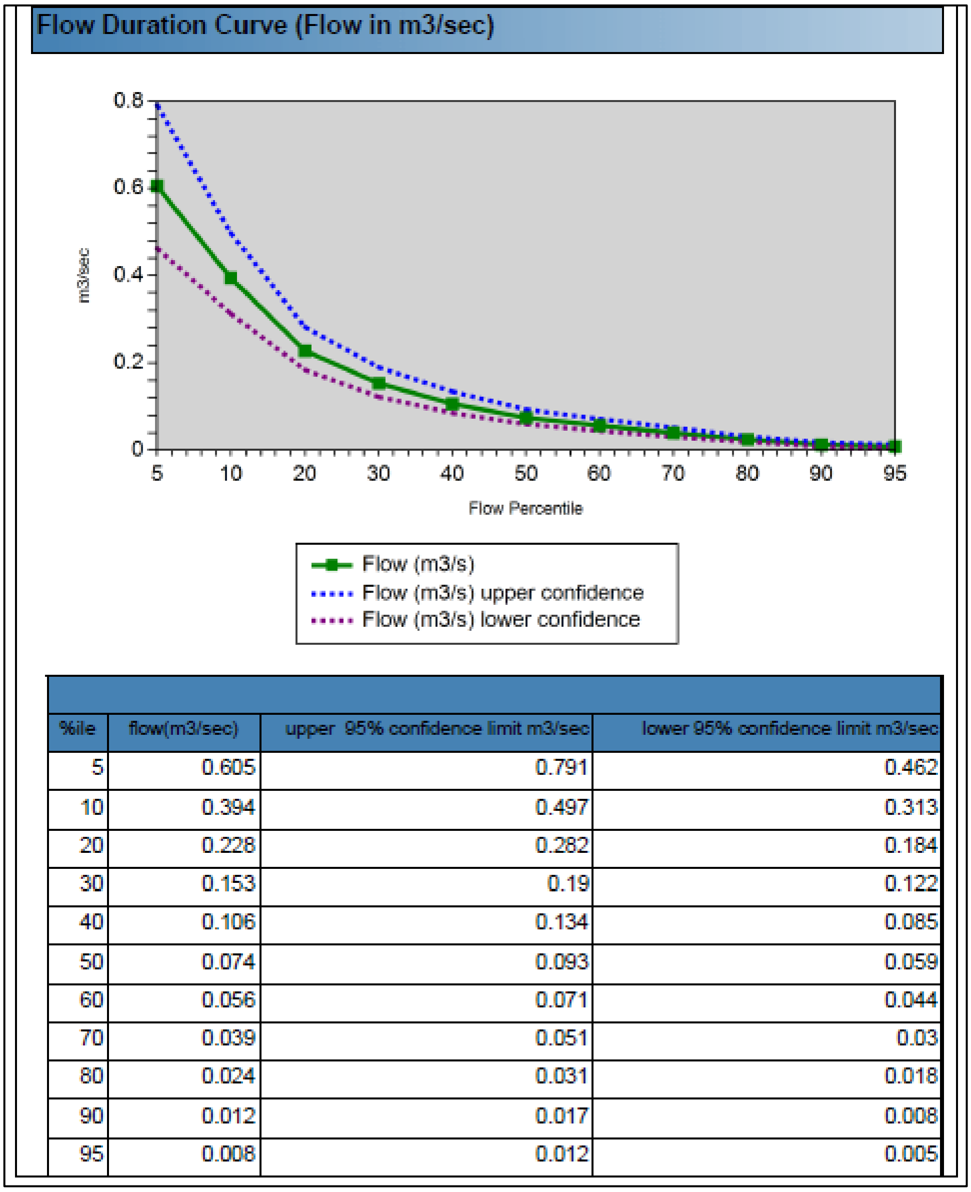


Subsoil Permeability

Code	Explanation	% of Catchment
H	High	0
M	Moderate	0
L	Low	55.6
ML	Moderate/Low	0
NA	No Subsoil/Bare Rock	44.4

Aquifer

Code	Explanation	% of Catchment
LG_RG	LG:Locally important sand-gravel aquifer RG: Regionally important sand-gravel aquifer	0
LL	Locally important aquifer which is moderately productive only in local zones	15.3
LM_RF	LM: Locally important aquifer which is generally moderately productive RF: Regionally important fissured bedrock aquifer	0
PU_PL	PU: Poor aquifer which is generally unproductive PL: Poor aquifer which is generally unproductive except for local zones	0
RKC_RK	Regionally important karstified aquifer dominated by conduit flow	84.7
RKD_LK	Regionally important karstified aquifer dominated by diffuse flow	0


Flow Duration Curve (Flow in m3/sec)

%ile	flow(m3/sec)	upper 95% confidence limit m3/sec	lower 95% confidence limit m3/sec
5	0.605	0.791	0.462
10	0.394	0.497	0.313
20	0.228	0.282	0.184
30	0.153	0.19	0.122
40	0.106	0.134	0.085
50	0.074	0.093	0.059
60	0.056	0.071	0.044
70	0.039	0.051	0.03
80	0.024	0.031	0.018
90	0.012	0.017	0.008
95	0.008	0.012	0.005

*Figure 20: Flow duration curve for **Bellawaddy river at Tullylinn**, Co. Sligo*

3.1.2 Monitoring point locations

As outlined in the introduction and literature review Enniscrone beach is susceptible to fluxes of microbial pollution from a diffuse source i.e. the river catchment (there is no UWWTP or industry located in this river catchment).

As discussed in Section 2.2.5 (Forecasting Systems) the location specific context of a pressure is established through a catchment assessment. Again, conditions and characteristics often make a hazard or pressure a particularly local phenomenon and a focussed local assessment is essential for a properly implemented model and early warning system. The outcomes of the local assessment will form the basis for the design and implementation of the model and system.

To investigate and locate significant pressures on a water body including those from diffuse sources a Catchment Characterisation Tool has been developed by the EPA's Catchment unit (www.catchments.ie). This new tool produces a Pollution Impact Potential (PIP) map that reveals the potential critical source areas for agricultural diffuse nutrients in water bodies and sub-catchments. Critical sources areas are zones that deliver an inordinately higher amount of pollutants compared to other areas of a catchment and signify the areas with the highest risk of impacting a water body. To determine where critical source areas are located, you need to ascertain the hydrogeological susceptibility of the water body and the nutrient loadings applied to that water body. Highly susceptible areas exist where nutrients have a high likelihood of reaching a water body due to the underlying hydrogeological conditions i.e. zones that have significant pathway linkages from the source of pollution or pressure to surface water or groundwater receptors. Susceptibility maps are generated by linking data on soils, subsoils, groundwater vulnerability and aquifer types with nutrient attenuation and transport factors. These maps are newly available for phosphate along the near-surface pathway. The susceptibility maps are combined with nutrient loadings data provided by the Department of Agriculture, Food and the Marine (DAFM) and the Central Statistics Office (CSO) to produce PIP maps. The PIP maps rank the relative risk areas for diffuse phosphorus to surface water and diffuse nitrogen to surface and groundwater. The PIP map for phosphate to surface water for the Bellawaddy catchment is shown below in Figure 22. The darkest blue areas are the critical sources areas (or the highest risk zones) and all areas are ranked relative to this area. These high-risk areas for phosphate to surface water correspond with poorly drained areas, signifying that in these areas phosphate is more likely to flow overland to surface waters instead of being retained in the soil and subsoil. In the assessment of this catchment the diffuse parameter of interest is FIO. There is a proven correlation between faecal indicator bacteria and P surface water run-off (Stout et al., 2005) which is used in this analysis to indicate the critical source areas of FIO in the catchment. The identification of these influential areas formed the basis for the location of the main sampling and hydrometric stations in the catchment. The three areas that emerged from this analysis were all higher up the catchment and are circled red in Figure 22. Two monitoring stations were installed just downstream of these areas as they would measure water which would be most prone to faecal bacterial contamination (Note: MP5 downstream of 2 areas in Tullylinn). The measurement of flow and FIO levels at these precise points means that the zones in the river catchment that potentially produce the most FIO will be monitored. Fluxes (loadings) of bacteria can be determined for low and high flow events which the literature review demonstrated can govern the bathing water quality of the receiving water. The river level and flow which is directly influenced by the rate, timing and volume of surface water run-off will also be monitored.

Two Davis Instruments ®Self-Contained Automatic Logging (metric) rain gauges (hourly) were installed as close as possible to these critical source areas to accurately measure the timing and intensity of rainfall on these important surface water run-off zones.

The other measuring points were the officially designated sampling point for bathing water at Enniscrone and the nearby long-established daily rain gauge at Enniscrone golf club. To measure the final loadings and fluxes of river water FIO entering the bathing water a hydrometric and water sampling monitoring station was re-established at the bottom of the catchment (Enniscrone) where the river outflows to the sea.

Further measuring points of interest were Enniscrone UWWTP's storm-water tank and a control point between the discharge of the UWWTP and the bathing water.

Table 8 below describes the monitoring points and locations for this project. Fig. 21 shows these points on a map in the area of interest. Fig. 24 illustrates the designated bathing area at Enniscrone beach. It extends for approximately 250 m either side of the Bellawaddy River. The official bathing water sampling location is shown by the black dot.

Table 8: Project monitoring locations

Number	Monitoring Location	Site Description	Irish Grid (xy) Coordinates
MP1	Bathing Water	West of river	128040 329830
MP2	Control	End of pier	128396 330697
MP3	Enniscrone Hydrometric Station - Automatic Water Level Data-logger	5 m upstream footbridge-RHS	128368 329710
MP4	Enniscrone Rainfall Station - Daily-manual	Enniscrone Golf Club	127408 329186
MP5	Tullylinn Hydrometric Station – Automatic Water Level Data-logger with Telemetry	Tullylinn Bridge	133475 327811
MP6	Stokane Hydrometric Station – Automatic Water Level Data-logger with Telemetry	Bridge at Stokane	132323 326159
MP7	Carns (Tullylinn) Rainfall Station – Automatic - Hourly	Carns Shrine	134882 326226
MP8	Stokane Rainfall Station – Automatic - Hourly	Old pump site SE of Stokane School	133059 325875
MP9	Storm-water Tank at Enniscrone Urban Waste Water Treatment Plant	Enniscrone UWWTP	128567 331238

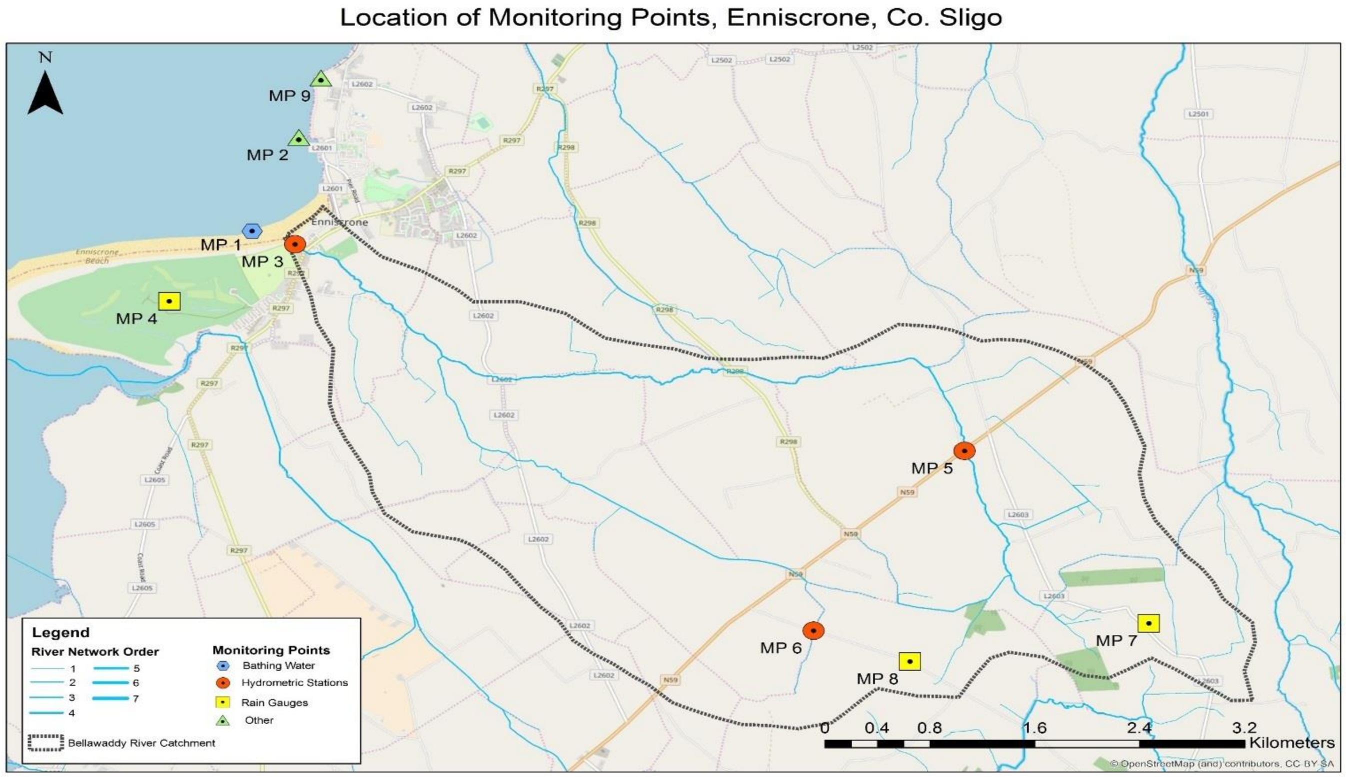


Figure 21: Location of project monitoring points (MP)

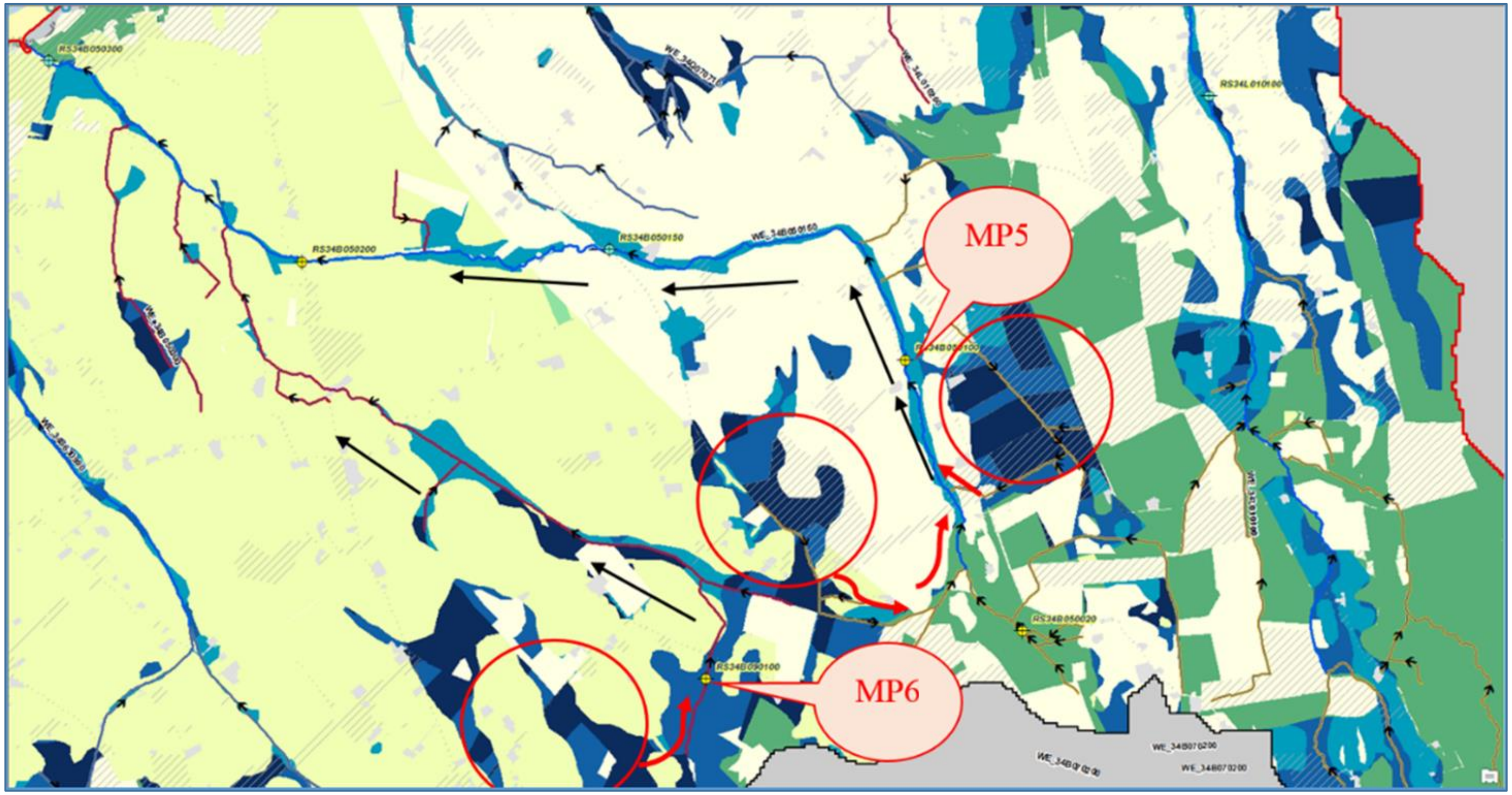


Figure 22: Selection of automatic hydrometric monitoring sites:

Pollution Impact Potential (PIP) map (not to scale) generated based on Bellawaddy catchment map in Fig. 21 above. Enniscrone beach in top left-hand corner. The dark blues areas in the map indicate areas most likely to be susceptible to phosphorous (& faecal bacteria) runoff in surface water. The 3 areas that emerged from this analysis were all higher up the catchment and are circled. 2 monitoring stations were installed just downstream of these areas as they would measure water which would be most prone to faecal bacterial contamination. (MP5 downstream of 2 areas in Tullylinn). Note stream flow direction indicated by arrows. PIP Map © Environmental Protection Agency – Catchment Management Unit

Figure 23: Enniscrone beach with the Bellawaddy river entering the bathing water from the middle-left side of the picture

Figure 24: Aerial photograph showing extent of designated bathing area and location of bathing water monitoring point MP1.

Note the river flowing over the sand in centre of photograph. Source: www.Beaches.ie

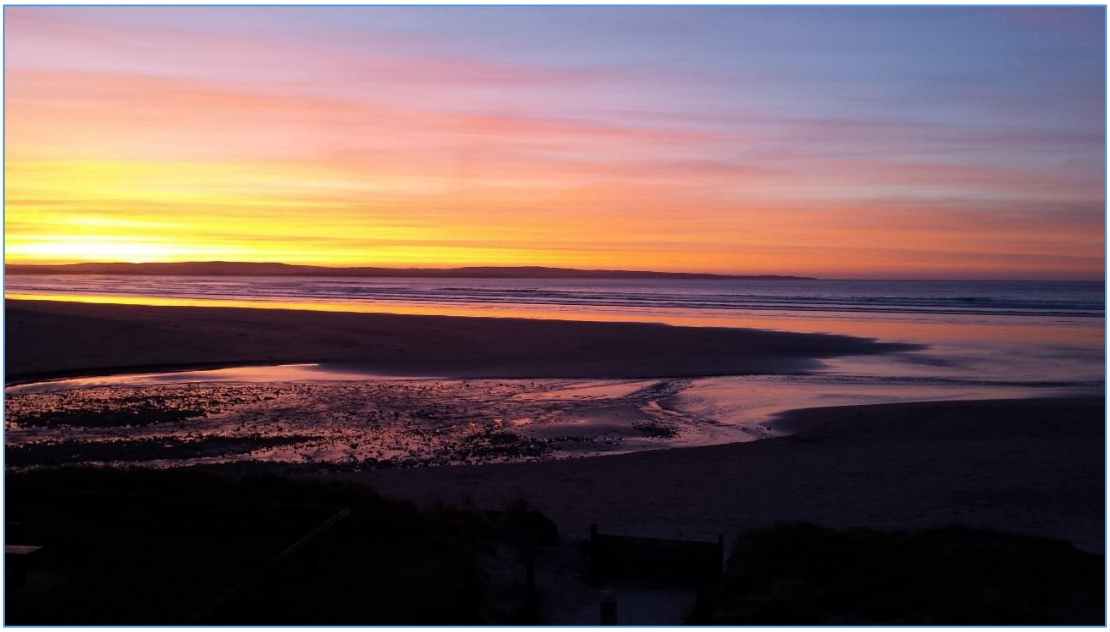


Figure 25: Bellawaddy river at beach with bathing water monitoring point MP1 in centre-left background

Figure 26: Location of MP3 (water quality, level & flow) where the Bellawaddy river discharges to the beach at Enniscrone.

Note: Pipe containing water level data-logger on right hand side of picture. MP1 (bathing water quality) can be seen over the heads of the people on the left-hand side of the image

Figure 27: MP4 (daily rainfall). Enniscrone Golf Club which is the site of a Met Éireann rain gauge. Enniscrone town & beach can be seen in the background

Figure 28: MP5 (water quality, level & flow – main channel) situated at Tullylinn Bridge on the main Ballina to Sligo road

Figure 29: MP6 Bridge at Stokane (water quality, level & flow – river branch)

Figure 30: MP7 Automatic rain gauge (hourly) situated at Carns Shrine (centre-background)

Figure 31: MP8: Automatic rain gauge at Stokane (hourly). Old pump site

Figure 32: MP2. Enniscrone pier. Bathing water control (samples taken from end of pier)

Figure 33: View from MP2 back towards beach, bathing water & town. River can be seen discharging over beach at centre-right of image

Figure 34: Enniscrone waste-water treatment plant where the storm-water tank is located & monitored

4 **Materials & Methods**

4.1 Description of short-term pollution (STP) warning system

The prediction system as devised uses the hydrograph response of the Bellawaddy river to indicate conditions where STP at Enniscrone bathing water are imminent. The hydrograph response is resultant from antecedent rainfall in the catchment. The system uses a derived site-specific river water-level trigger alarm to predict bathing water quality at Enniscrone Beach. The system automatically monitors the river level and is configured to contact the author in real-time when the trigger level is reached.

The automatic water level stations were located at MP5 (main channel) and MP6 (branch) based on the PIP analysis in Section 3.1.2.

Automatic rainfall gauges were then installed in the upper catchment near the water level monitoring points to calculate the lag time between peak hourly rainfall and the peak of the hydrograph (water level) in the river at the automatic water level stations.

The hydrometric station at MP3 (Enniscrone) was used to calculate the travel time of water from the upper catchment to the outfall of the river at Enniscrone beach during these events.

Predictions are based on observed correlations between river water level triggers and measured levels of FIO in the bathing water.

Loadings of FIO were also calculated at the 3 river monitoring stations.

4.2 Hydrometric

4.2.1 Construction & installation

Construction and installation of the hydrometric monitoring station at the river discharge to the beach at Enniscrone (MP1) was undertaken previously in April 2014. The older type data-logger (OTT® Thalimedes) here was replaced by an OTT® Orpheus Mini data-logger in early 2016 for this project. After the monitoring point location (PIP) analysis above, two new hydrometric stations were constructed and installed also in early 2016. One was installed at Tullylinn Bridge on the main (northern) river channel and the other on the much smaller southern branch at Stokane (Figs. 35, 36 & 37 below).

Figure 35: Hydrometric station installed at MP5 (Tullylinn) in early 2016

Figure 36: Construction & installation of new hydrometric station at MP6 (bridge in Stokane) – early 2016.

(2 of these stations were newly constructed for the project with a third upgraded)

Figure 37: Hydrometric installation at MP6 (Stokane)

Monitoring started in May 2016 and continues to the present. The purpose of this assessment was to produce continuous flow data for the river. To do this, two elements were needed:

- the development of a station calibration
- continuous recording of river water levels

4.2.2 Station calibration

The station calibration (or discharge rating curve) was developed by plotting the results of flow measurements that were taken at various water levels and developing a stage-discharge relationship between water level (stage) and river flow (discharge). The method used for flow measurement was the velocity-area method. Velocity was measured by current meter at a number of verticals along a cross-section of the rivers (see Figs. 38 & 40 below).

Figure 38: Velocity measurement by current meter at one of the vertical points along a cross-sectional area of the river

The flow (m³/s) of the river is the result of summing the products of the velocity and corresponding areas along the cross-section of the river. The discharge rating curve relating river level readings to discharge were then generated by regression analysis using the SKED software package. This can be seen in Figure 39 below.

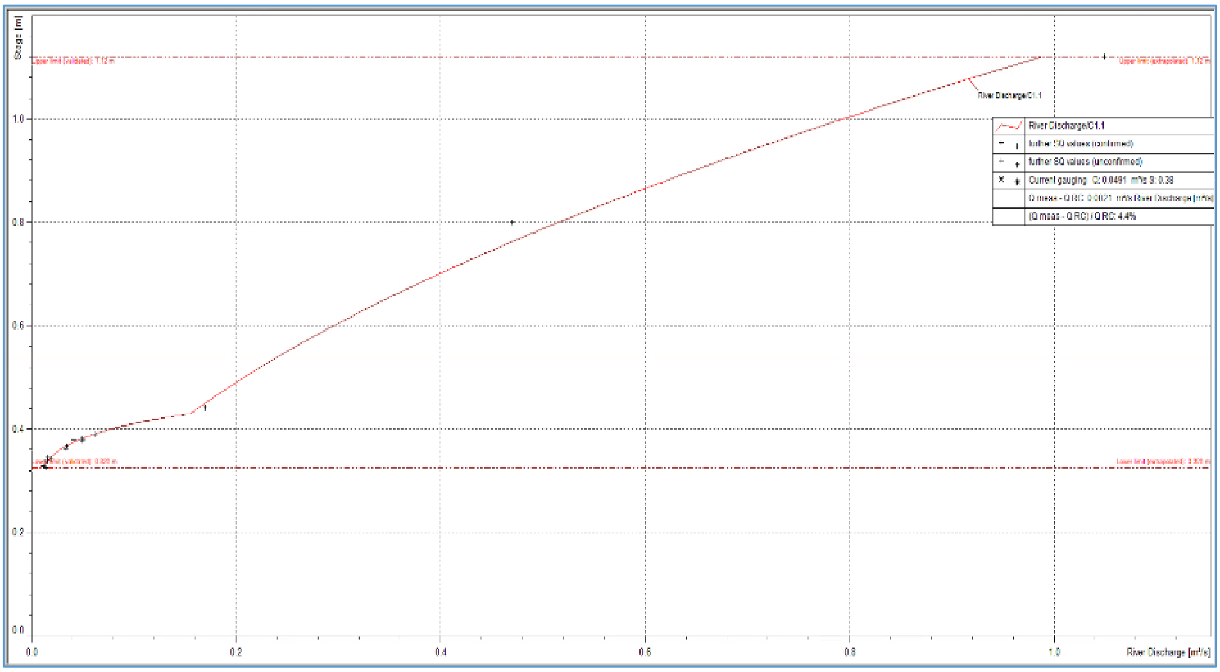


Figure 39: Discharge rating curve for MP 5 at Tullylinn

The rating curve (station calibration) shown above covers the period from May 2016 onwards. The flow measurement results at different levels of stage (water level) can be seen along the line marked with an asterisk. This was repeated at all 3 hydrometric stations.

The purpose of this is to calculate loadings of faecal bacteria from microbiological samples taken at these sites.

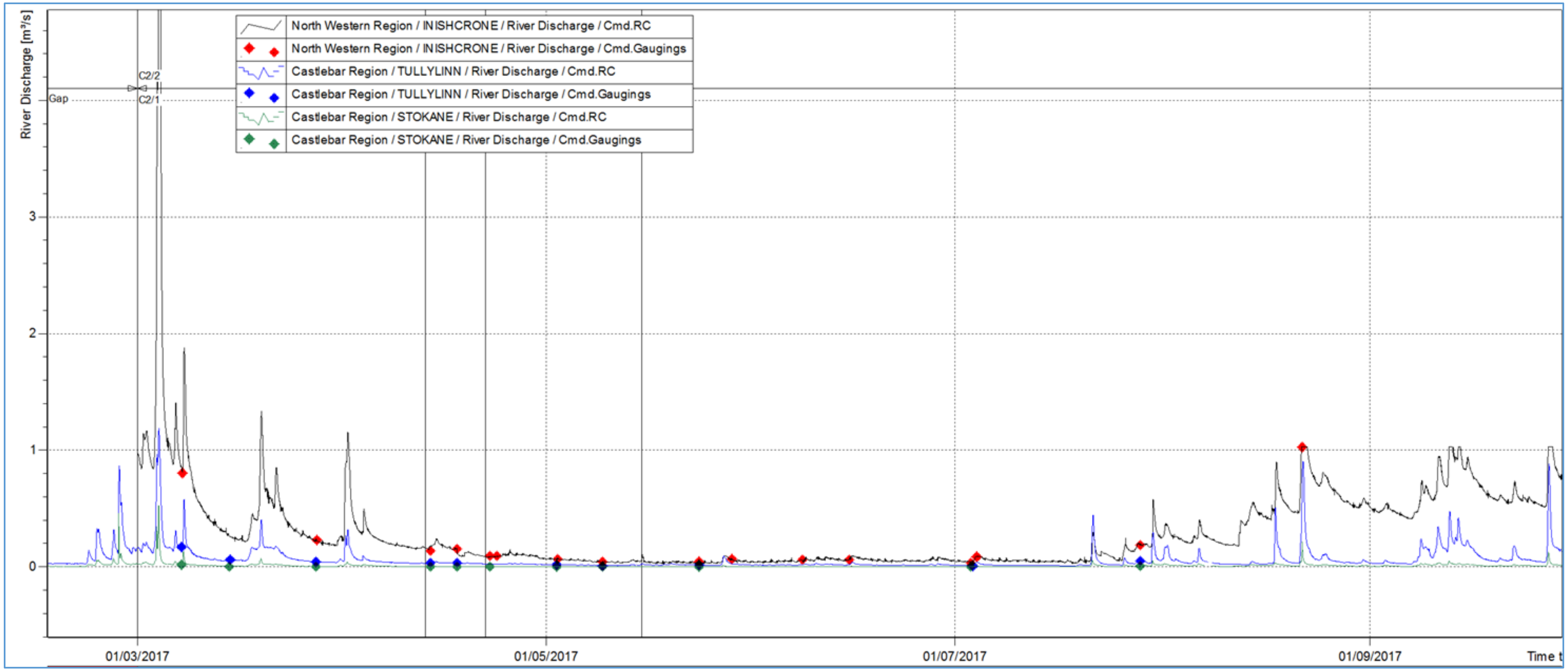


Figure 40: Discharge hydrographs for the 3 river stations MP3(green), MP5(blue) and MP6(black) showing individual flow measurements (icons) for 2017

4.2.3 Continuous recording of river water levels

An OTT® Orpheus Mini Water Level Logger (Fig. 41) was used to measure river water level at all 3 hydrometric sites (MP3, MP5 and MP6) for 2016 and 2017. It is an integrated pressure sensor (pressure level transducer) and data-logger for level measurement in surface or groundwaters.

Figure 41: OTT® Orpheus Mini water level logger. Source OTT®

The data-logger manages and stores water level readings every 15 minutes. Spot checks were carried out weekly to ensure the data logger was recording the correct water level. This was achieved by comparing the data-logger reading to a staff gauge. The staff gauge is a fixed long metal strip with metric graduation marks installed in the river to give a visual indication of water level. The initial water level of the data logger is taken from this. The staff gauge zero graduation was levelled back to a temporary bench mark (TBM) to be able to spot check that the staff gauge position (elevation) in the river had not changed (Figs.48 & 49). These measurements are given in Appendix B. The water level equipment was installed within a stilling well (Fig. 42) so that there would be calm water for measurement and to protect the data-logger. Two of the sites were given a communication housing called an Intelligent Top Cap (ITC) situated on top of the stilling well to allow real-time data transmission of data (Figs. 43 & 44) The data-loggers were configured to record water level every 15 minutes throughout the study period (2016 - 2017). This was achieved by using the OTT® operating programme on a PC in conjunction with an infra-red interface device to communicate with the data-logger (Fig. 46) These records were subsequently processed using the discharge rating curve so that a continuous river flow record was produced.

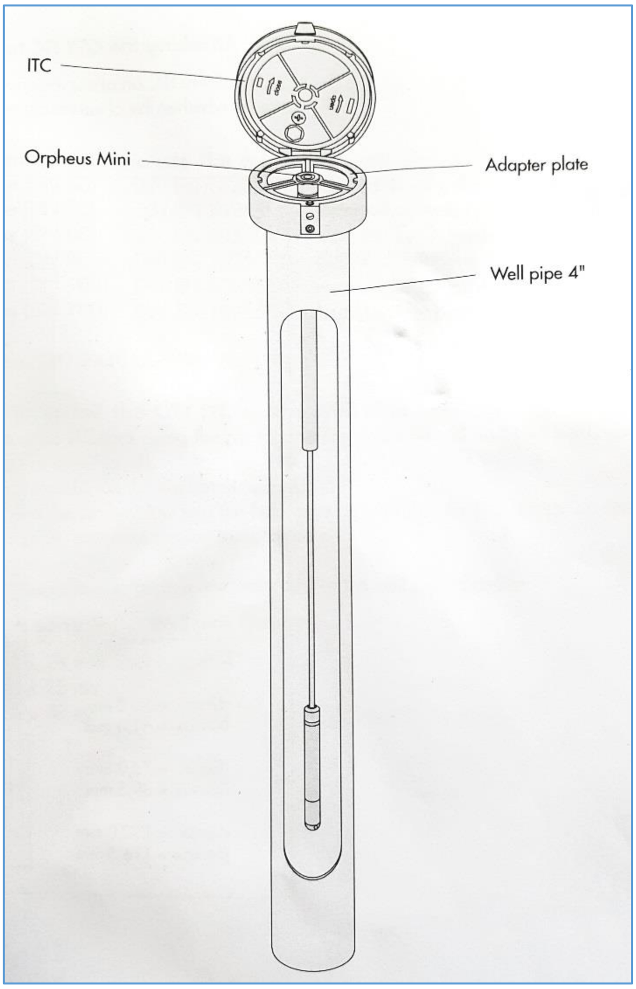


Figure 42: Layout of hydrometric water level stations with Orpheus Mini® data-logger located inside & hanging down the stilling well.

MP5 & MP6 also had the ITC accessory attached for remote data transmission. Source OTT® Operating Instructions Document Number 55.530.010.B.E

Figure 43: MP7 with its water-level data-logger in-situ.

Note it has an ITC attached to the top of the pipe to allow the data-logger remote GSM/SMS data transmission. Note also the staff gauge beside the pipe

Figure 44: ITC in place (& open) at top of pipe.

Top of data-logger can be seen in centre of pipe opening

Figure 46: Set-up & interrogation of the data-logger/ITC using OTT software

Figure 47: Set-up & interrogation of the data-logger/ITC using OTT software

Figure 48: Using a Trimble® receiver & network to survey & establish a temporary bench mark (TBM) at MP7.

This fixed point with a known elevation & position is used to check & confirm the position of the staff gauge. The staff gauge in used to measure water level & the data-logger reading is checked against this. This was done for all 3 hydrometric stations in the project & the measurements are in Appendix B

Figure 49: Surveying with a vertical staff along with a dumpy level & tripod to measure the relative height difference between the base of the staff gauge (staff gauge zero) and the TBM.

This was repeated occasionally to check that the staff gauge was still reading accurately. The elevation of the staff gauge zero above Ordnance Datum was also established. This was repeated at all 3 hydrometric sites with the results in Appendix B

4.2.4 Telemetry

Because of the real-time requirements of the warning system, indications that a significant hydrograph event were occurring at the automatic hydrometric stations monitoring data from the water level measurements on the main river channel at MP5 (&MP6) need to be transmitted swiftly. Telemetry is an automated process for performing measurements and collecting data for sending to receiving equipment for analysis.

The OTT Intelligent Top Cap (ITC) ® was developed to equip the OTT Orpheus Mini data-logger® with remote GSM/SMS data transmission [the use of data collection using methods like short message service (SMS) along digital cellular technologies such as Global System for Mobile communications (GSM)]. The 2 ITCs were installed with SIM cards that were connected to the EPA Hydrometric & Groundwater Unit's Modem. This enabled the configuration of the data-loggers' interface to communicate with the author's mobile phone using SMS text

4.2.5 Hydrograph events & alarms

In order that the author would receive a SMS text from the hydrometric station once certain water levels were reached pre-set alarms were configured in each data-logger software. The pre-set alarms for the main river channel (MP5) & the southern branch (MP6) were to be determined from experience and trial and error. Pre-Alarm trigger levels were also set up to warn the author that a significant hydrograph event was likely to be occurring. This was to allow the author to return to the catchment for sampling purposes. These trigger alarms were set at 0.8 m (Alert) and 0.6 m (pre-Alert) for MP5 (main river channel) and 0.30 m (Alert) and 0.25 m (pre-Alarm) for MP6 (smaller branch).

4.3 Water quality monitoring

Microbiology samples were collected aseptically into 500 ml sterilised Duran glass bottles at elbow depth in the water where possible Samples were transported in a covered cool-box containing ice packs back to the laboratory. All samples were analysed within 24 hours and in chronological order. The total coliforms and *E. coli* were enumerated using the IDEXX Laboratories Colilert method. Intestinal enterococci were detected and enumerated by membrane filtration using the ISO 7899-2 method. Aliquots of 100 ml were used for all tests.

Total coliforms have been superseded by *E. coli* and intestinal enterococci in the new Bathing Water Directive. This is following the WHO studies which showed that total coliforms were not as good an indicator of a risk of illness as previously thought. However, in addition to analysing for the two new indicators, this study continued to analyse for total coliforms. This was done to: (a.) provide further data on the concentration and levels of bacteria present in both the river and sea, and (b.) to facilitate any comparisons between sampling sites. Future analysis with historic data would also be possible.

Individual bathing water samples are assessed using the criteria set down by the EPA in conjunction with the Health Service Executive (HSE) shown in Table 9 below. The official assessment for these individual compliance samples taken during the study period is given in the Results section. A similar assessment is given for the study samples taken during the same period.

Assessment for **annual Bathing Water Classification** is undertaken as per the Directive (2.1.1). The official annual classifications for Enniscrone's bathing water are given in the Results section. These are based on the Directive /Regulations criteria given in Table 1 and are calculated using the 4-year rolling data set of compliance samples. This classification result is reported by the EPA to the European Commission each year and is also used for the separate *Blue Flag* award. Similar assessments using this study's data are also given in the Results section.

Table 9: Thresholds developed by EPA to define ***individual sample status***

	Individual Sample Status (Unit of measurement is No./100 ml)			
Parameter	Excellent	Good	Sufficient	Poor
Escherichia coli	≤250	251 - 500	500 - 1000	>1000
Intestinal enterococci	≤100	101 - 200	201 - 250	>250

4.4 Rainfall

Rainfall is collected and recorded daily at MP 4 by trained staff at Enniscrone Golf Club who use a Met Éireann rain gauge

Rainfall was measured at MP7 and MP8 using 2 Davis Instruments ®Self-Contained Automatic Logging (metric) Rain Gauges. They are a self-emptying tipping-bucket design. They are used in conjunction with Lascar Electronics® EasyLog Data Loggers. They were configured by the author to record rainfall every hour.

Figure 50: Davis Instruments ® self-contained automatic logging rain gauge with rain cone in background and base with bubble level and tipping spoons in foreground. Source: www.weathershop.com

Figure 51: Inserting data-logger into the base of the rain gauge. Source: *www.weathershop.com*

4.5 Statistical and graphical methods

E. coli and enterococci results from regulatory monitoring were collated from the pooled 4-year sets of interest during this study. The average concentration (μ) and the standard deviation (σ) – a measure of the spread of results – was calculated for each parameter using the logarithm of the measurements. The 95 and 90 percentile values were calculated as specified in the directive:

95 percentile = antilog ($\mu + 1.65\ \sigma$)

90 percentile = antilog ($\mu + 1.282\ \sigma$)

The 95 and 90 percentiles were compared against the prescribed quality criteria as given in the directive (Table 1) and the quality classification was assigned according to the parameter with the poorer result. The same statistical analysis was then also carried out incorporating the monitoring data from this study. This analysis is given and discussed in 5.1.9 and 5.1.10 with further analysis in Appendix E.

5 Results

Key results are summarised in the points below followed by a more detailed analysis:

- Results from volumetric flow rate (discharge) and *E. coli* loading measurements demonstrate that MP5 is the most suitable river catchment location to issue the system trigger alert from.
- Loadings of river *E. coli* were shown to change by 10^4 during hydrograph events
- Official compliance monitoring of the bathing water undertaken by the regulatory authority did not reflect or capture periods of inferior water quality at Enniscrone during the study period.
- 4 STP events were predicted, alerted & confirmed by the EWS during the study period with no false positives or missed events. Fortuitously these events did not coincide with any compliance sampling.
- The official bathing water classification result for Enniscrone during the study period was the second tier “Good”.
- Bathers were exposed to inferior water quality.

To produce a model for predicting bathing water quality at Enniscrone a set of site-specific criteria for river level peaks needed to be tested based on bacteriological data from the chosen river monitoring sites and bathing water results. The model is calibrated to issue an alert when a trigger level is reached at the river monitoring point. This model and system does not specify the concentrations of *E. coli* in the bathing water but instead indicates when *E. coli* levels cause STP. Key outcomes are given for each criterion.

5.1 River

Two river monitoring sites (MP5 & MP6) had been chosen for their greater potential to receive large amounts of faecal indicator organisms (FIO) from run-off to the catchment above them. These river sites were assessed to ascertain the impact on the river of FIO (especially *E. coli*) particularly during hydrograph events caused by rainfall. This analysis would be used to assess their suitability for the model's alert triggering point.

5.1.1 River discharge

The volume of water (discharge) was examined at both sites (Figs 52 & 53) along with the final discharge of the river to the beach.

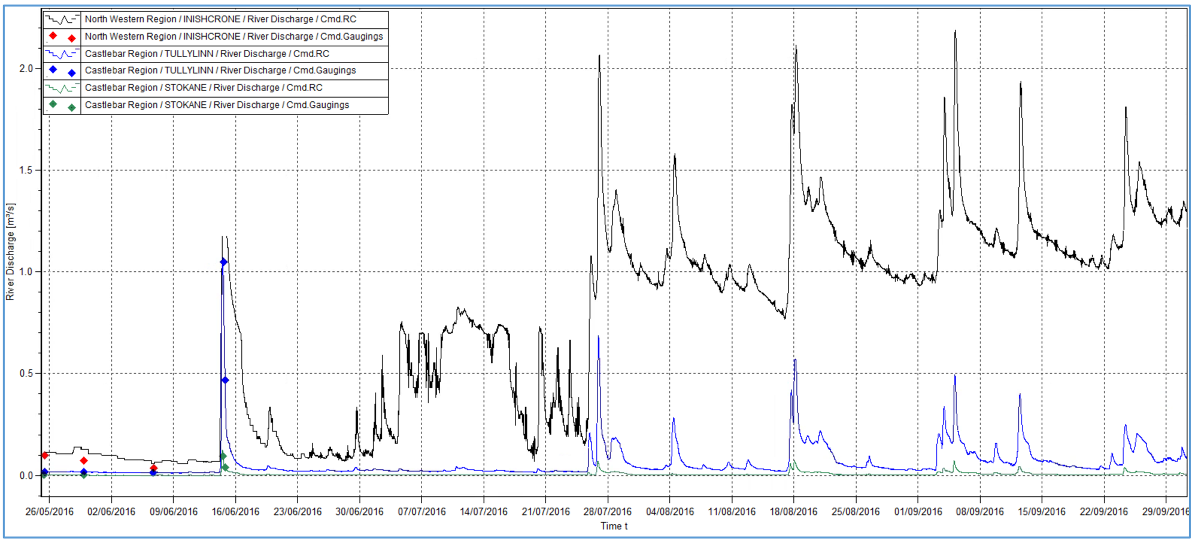


Figure 52: Summer 2016 discharge hydrographs for MP5 (blue) & MP6 (green) overlaid onto the discharge hydrograph for MP3 (black) which is the final flow of the river to the beach.

The largest peak in June was not fully recorded at MP3. Note that the discharge at river MP5 (blue) is much greater than river MP6 (green) which is located on another branch of the river. The contribution of the discharge at MP5 to the overall final discharge of the river is also much larger.

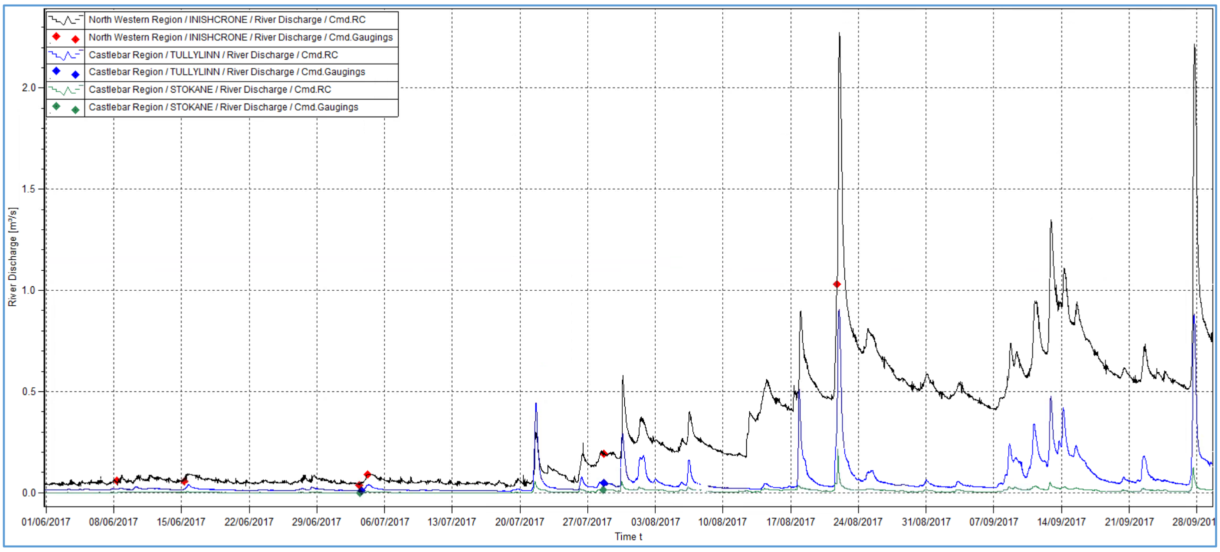


Figure 53: Summer 2017 discharge hydrographs for MP5 (blue) & MP6 (green) overlaid onto the discharge hydrograph for MP3 (black).

Note again that the discharge of the river is much greater at MP5 (blue) than MP6 (green).

Key outcome: It can be seen from the Figs. 52 & 53 above that the discharge of river water passing through MP5 is much greater than the discharge of water passing down the branch of the river at MP6.

5.1.2 Hydrograph events

Water level was recorded at river monitoring points MP5 & MP6 for the 2016 and 2017 bathing seasons. Hydrograph events caused by localised intense rainfall in the river were utilised to trigger alerts. The water level hydrographs recorded for MP5 are shown below with the peak events that triggered alerts. The hydrographs for MP6 are contained in Appendix D.

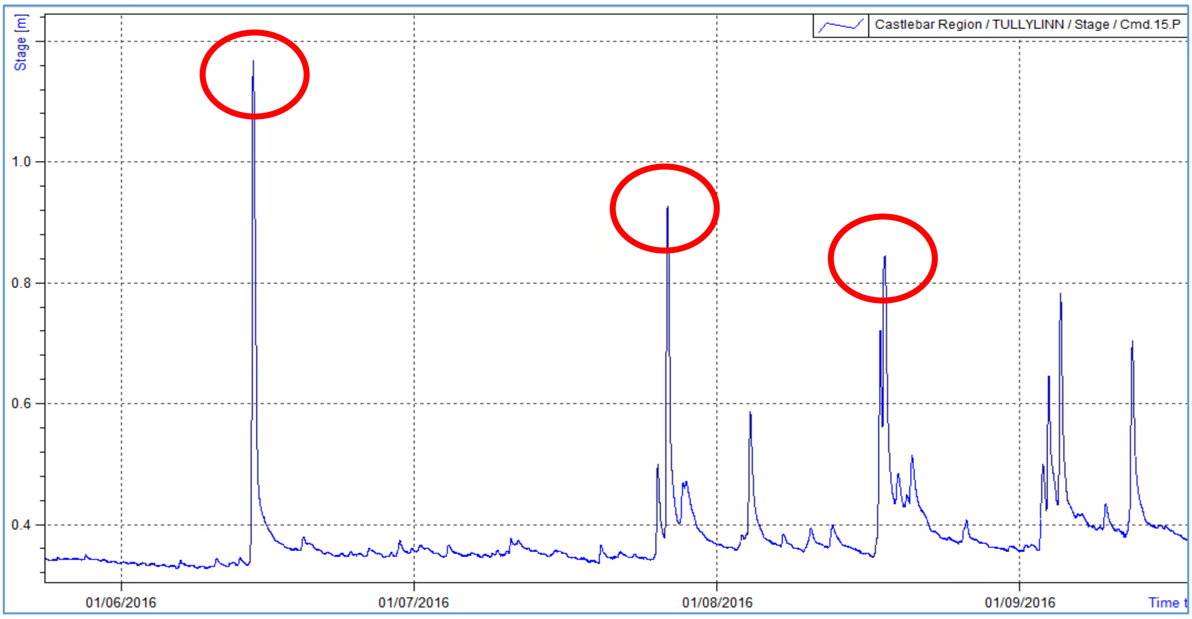


Figure 54: Graphic of continuous water levels at MP5 during the summer of 2016 showing the hydrographic events that triggered an alert.

0.800 m on the x-axis is the alert trigger setting

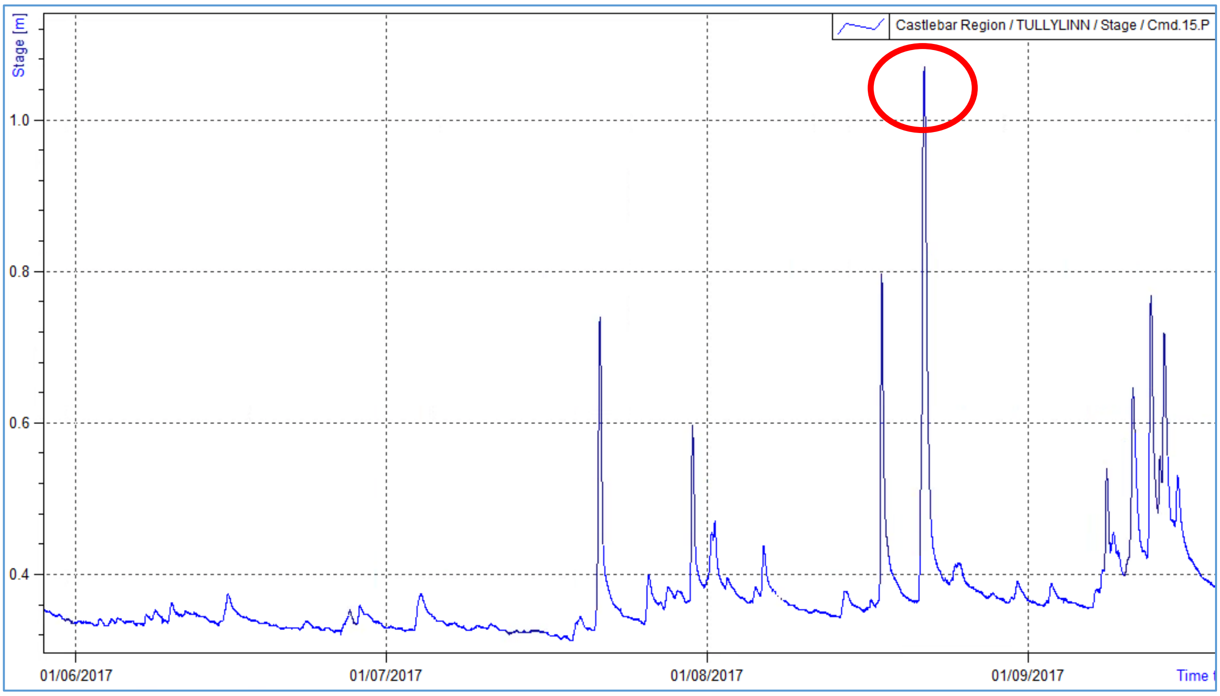


Figure 55: Graphic of continuous water levels at MP5 during the summer of 2017 showing the hydrographic event that triggered an alert.

0.800 m on the x-axis is the alert trigger setting

Key outcome: As shown above in Figs. 54 & 55 above the hydrograph events measured at MP5 in 2017 and 2018 used to trigger the alerts can be clearly seen.

Next, Figs. 10 & 11 present the microbiological results obtained at the 3 measuring points of the river catchment for the 2 years of this study. Emphasis was given to sampling during hydrograph events outlined above to capture FIO runoff to the river.

5.1.3 River water microbiological results

Table 10: Sampling dates and results for bacteriological analysis at MP3, MP5 & MP6 (river water) 2016. E. coli results highlighted

Date	Time UTC	MP6 Total coliforms	MP6 *Escherichia coli*	MP5 Total coliforms	MP5 *Escherichia coli*	MP3 Total coliforms	MP3 *Escherichia coli*
06/06/2016		19863	1616	30000	24192	3448	1467
07/06/2016		30000	30000	30000	12033	14136	6131
14/06/2016	07:00	300000	155307	325500	130900	51720	15530
14/06/2016	08:20	300000	198628	204600	77100	92080	22470
14/06/2016	10:30					173287	57940
14/06/2016	13:00	365400	72300	193500	42600	172200	88000
14/06/2016	15:45					178500	51200
20/07/2016		30000	10462	30000	30000	2382	1081
26/07/2016	20:00	63200	26000	68800	17100	14010	2660
26/07/2016	21:00	55300	29300	62900	20600	15970	6840
26/07/2016	21:45					70800	35800

Note: Total coliforms & *Escherichia coli* = MPN/100 ml. Intestinal enterococci not measured

Table 11: Sampling dates and results for bacteriological analysis at MP3, MP5 & MP6 (river water) 2017

Date	Time UTC	MP6 Total coliforms	MP6 *Escherichia coli*	MP6 Intestinal enterococci	MP5 Total coliforms	MP5 *Escherichia coli*	MP5 Intestinal enterococci	MP3 Total coliforms	MP3 *Escherichia coli*	MP3 Intestinal enterococci
02/05/2017	16:00	1120	31		19863	17329		980	135	
11/05/2017	06:30	6488	1986	10	6488	4611	60	1553	816	30
15/06/2017	07:00							10462	3255	720
27/06/2017	06:40							6488	3255	120
03/07/2017	09:15	2613	41	10	12033	8164	50	5475	1904	55
04/07/2017	06:15							14136	6131	210
13/07/2017	08:00							168	80	
19/07/2017	19:00							12033	3255	290
02/08/2017	09:00	3654	195	73	5475	839	127	3654	669	112
21/08/2017	19:15							TNTC	24192	600
21/08/2017	21:30							TNTC	24192	17200
21/08/2017	10:00	120960	38505	1100	TNTC	120960	1400			
22/08/2017	05:10							120960	34335	800
22/08/2017	16:00							14136	2247	98

Note: Total coliforms & *Escherichia coli* = (MPN/100 ml) Intestinal enterococci = cfu/100 ml. TNTC = Too numerous to count

5.1.4 River indicator bacteria loadings

Loadings of bacteria were calculated by combining the concentration of FIO at the time of sampling (Figs 10 & 11 above) with the corresponding river discharge value taken from the discharge hydrograph time series (Appendix D). These loading results show the amount of FIO that the river is transporting at a given time. Loadings of FIO are shown in the summary tables (Tables 12 & 13) below. Overall loading calculation tables for all FIO are contained in Appendix D.

Table 12: E. coli loadings calculated for each MP for 2016. Loading expressed as E. coli/m^3/s

Date		Time UTC	Loading@MP6 Ec/ m^3/s	Loading @MP5 Ec/ m^3/s	Loading @MP3 Ec/ m^3/s	Prevailing Weather/ Hydrograph state
06/06/2016		17:40	1616	3314304	522252	Dry
07/06/2016		17:40	900000	1528191	4420451	Rain previous evening
14/06/2016		07:00	148162878	1373402800	403904240	Very heavy intense prolonged rain. Start 06:00
14/06/2016		08:20	32574992	114879000	139763400	Very heavy intense prolonged rain. Rising limb
14/06/2016		10:30			570709000	Very heavy prolonged rain. Rising limb
14/06/2016		13:00	79530000	455947800	1284800000	Rain stopped 11:00. Near top of peak
14/06/2016		15:45			436736000	Receding limb
20/07/2016		20:00	41848	5700000	4118610	Dry
26/07/2016		20:00	16120000	78147000	27930000	Heavy intense rain 1600-2100 Rising limb
26/07/2016		21:00	19513800	120716000	97401600	Heavy intense rain 1600-2100 Rising limb
26/07/2016		21:45			619340000	Rising limb

Table 13: E. coli & intestinal enterococci (IE) loadings calculated for each MP for 2017(E. coli highlighted). Loading expressed as FIO/m^3/s

Date	Time UTC	Loading @MP6 Ec/ m^3/s	Loading @MP6 IE/ m^3/s	Loading @MP5 Ec/ m^3/s	Loading @MP5 IE/ m^3/s	Loading @MP3 Ec/ m^3/s	Loading @MP3 IE/ m^3/s	Weather/Hydrograph state
02/05/2017	16:00	217		3292510		92745		Dry
11/05/2017	06:30	2562	13	622255	8097	295800	10875	Very dry
15/06/2017	07:00					1865115	412560	Recent rain
27/06/2017	06:40					1942421	71610	Recent rain
03/07/2017	09:15	123	30	914368	5600	668304	19305	Dry
04/07/2017	06:15					5468852	187320	Recent heavy rain
13/07/2017	08:00					31280		Dry
19/07/2017	19:00					1969275	175450	
02/08/2017	09:00	3026	1133	495010	74930	1795596	300608	Recent Rain Rising limb
21/08/2017	19:15					248935680	6174000	Very heavy rain Rising limb
21/08/2017	21:30					348643008	247869200	Very heavy rain Rising limb
21/08/2017	22:00	4454258	127248	1005419520	11636800			MP6 Hydrograph over MP5 Rising limb
22/08/2017	05:10					644227605	15010400	Falling limb
22/08/2017	16:00					22982316	1002344	End falling limb

E. coli loadings in the river were observed changing by up to a magnitude of 10^4 during hydrograph events. The results above can be analysed (Figs 56 – 68 below) to show the magnitude of these events. They also illustrate which of the 2 selected river MPs capture the largest fluxes of *E. coli* passing down the catchment during the different stages of a hydrograph event.

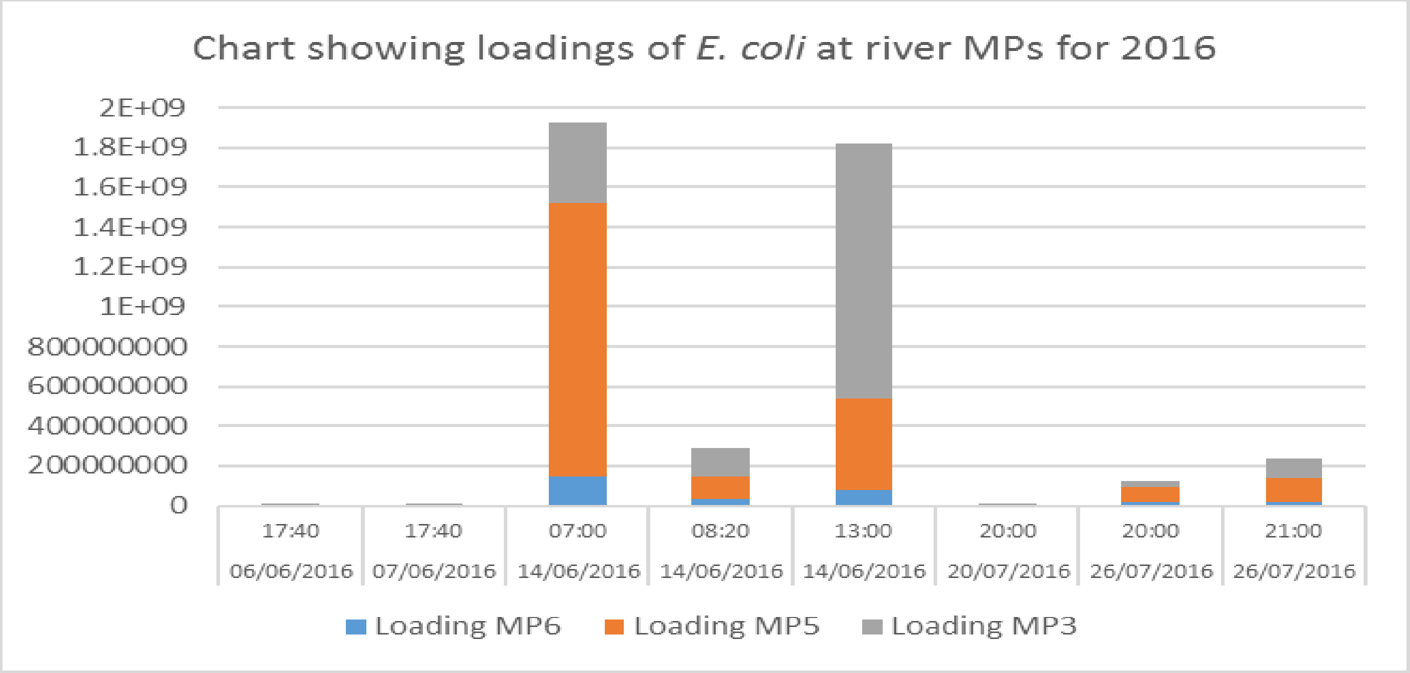


Figure 56:Chart (based on Table 12) of loadings of E. coli at river MPs for 2016.

The targeted hydrograph events are very prominent & as would be expected they dominate the loadings of E. coli calculated. During the event on the 14/06/2016 MP5 (Tullylinn – main channel) dominates the proportion of the very large loadings measured at 0700. After the expected large run-off of E. coli, the loadings at all 3 river stations drops dramatically. By 1300 it can be clearly seen that the whilst the overall loading has returned to a high level MP3 (Enniscrone) now dominates. This illustrates the initial load of E. coli hitting MP5 and then later it reaches MP3. Importantly it shows the huge load of FIO that can be transported to the bathing water during these events compared to benign conditions like the 07/06/16. A similar proportional result can be seen for the 26/07/16

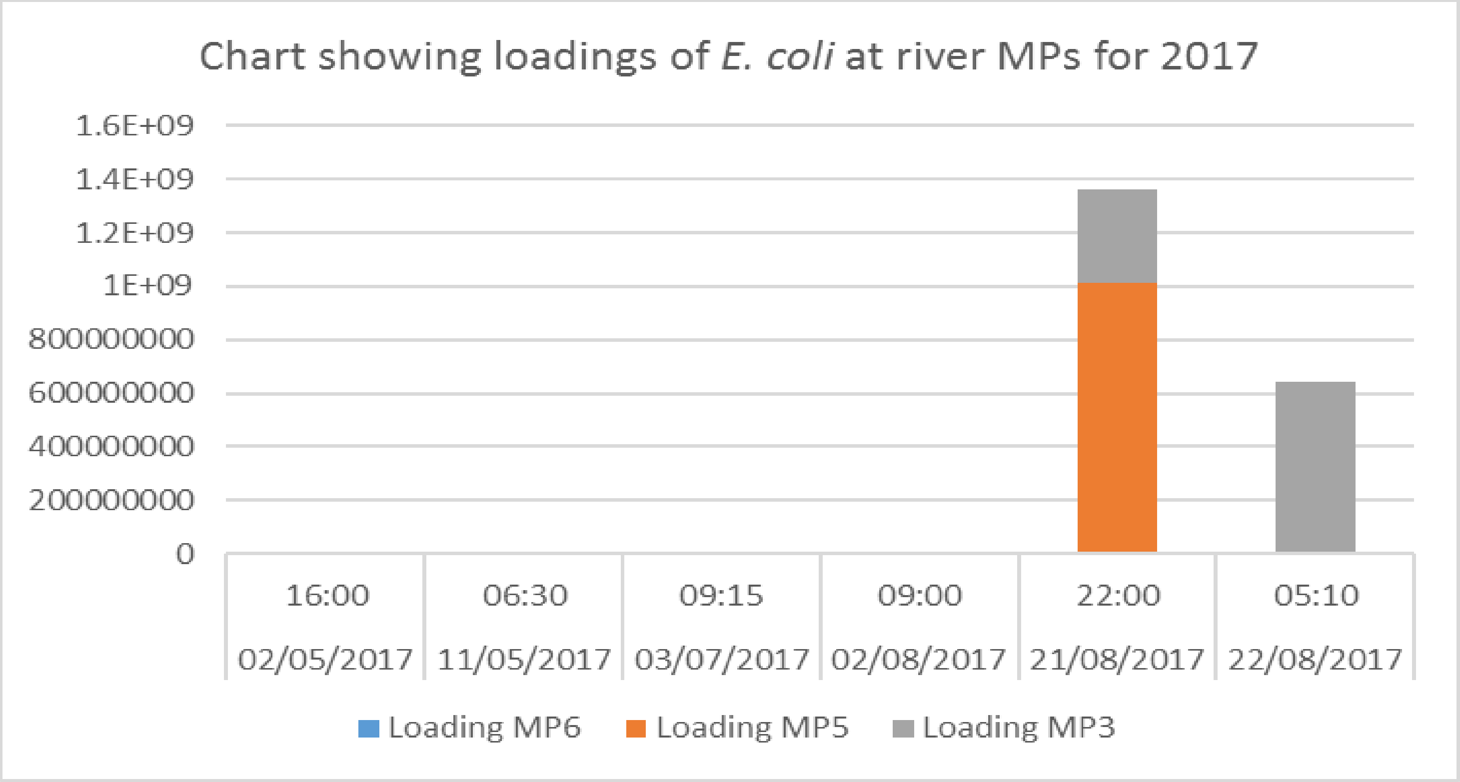


Figure 57: Chart (based on Table 13) of loadings of E. coli at river MPs for 2017.

The only STP event of 2017 in August is prominent. Again, MP5 dominates at the start of the event. The next day the proportion of E. coli loading has risen substantially at MP3 (figure not available for MP5-sample bottle broken). Again, the very large flux of FIO measured during the STP event can be seen compared to the rest of the summer of 2017

Further analysis below demonstrates that MP5 captures the largest proportion of fluxes of *E. coli* when compared to MP6.

(Analysis for intertestinal enterococci (IE) is given in Appendix D. Note that MP3 dominated the IE loadings but did not influence the bathing water quality.)

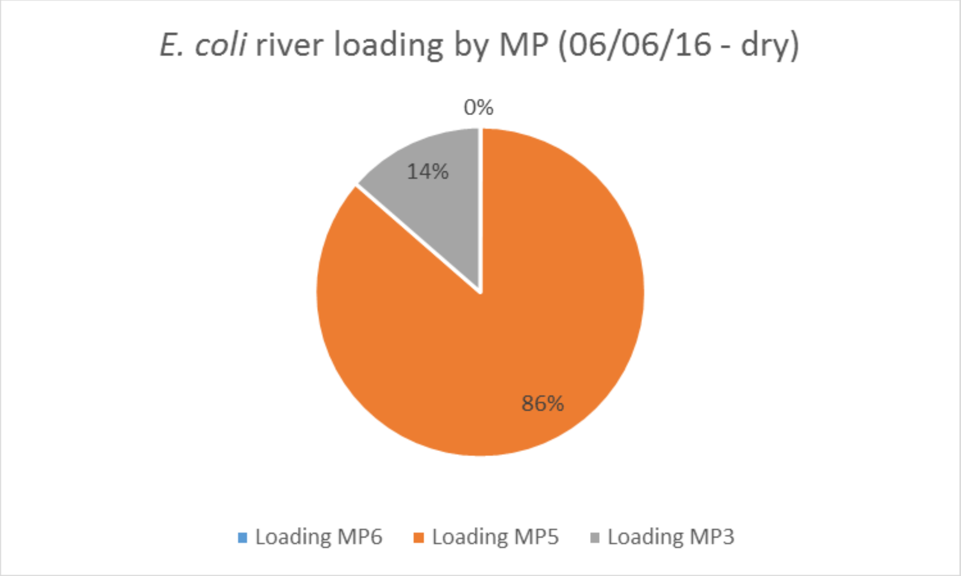


Figure 58: River E. coli loadings during a dry spell.

MP5 (Tullylinn – main channel) dominates. Much smaller loading at MP3 (outflow to beach) indicates probable die off of bacteria between both stations. MP6 (southern branch) negligible

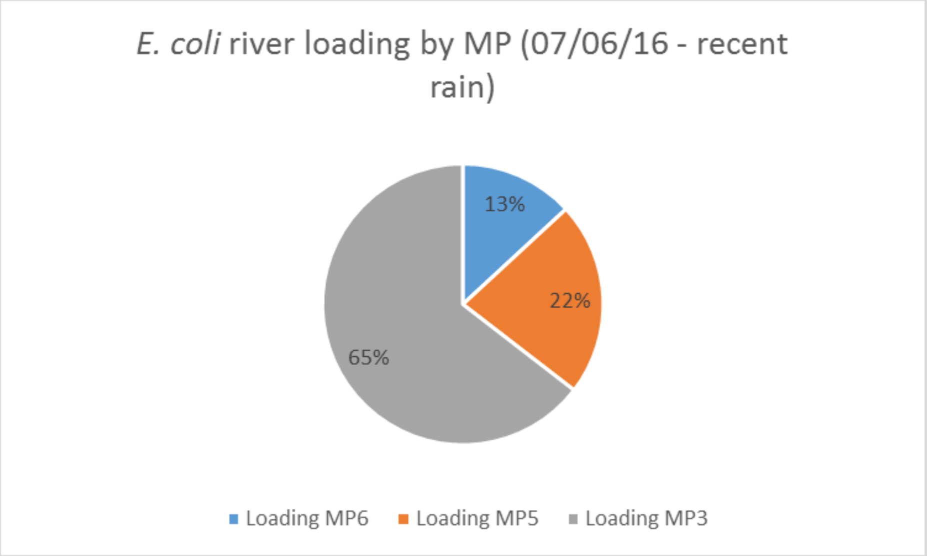


Figure 59: River E. coli loadings after rain in previous days.

MP3 dominates at river outflow to sea

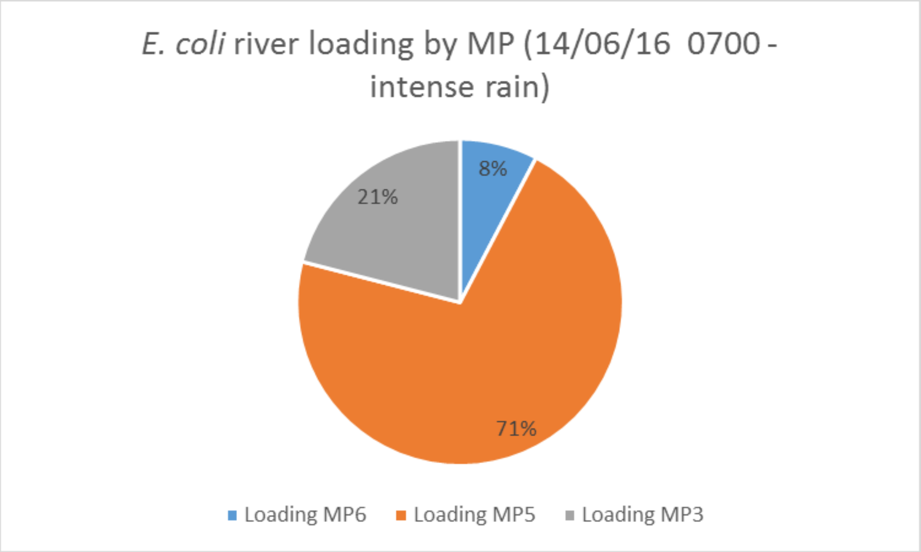


Figure 60: River loadings shortly after the start of the intense rainfall event of 14/06/16.

Rainfall was so intense that the river level hydrographs at all 3 stations started at 0615 and were rising rapidly at 0700. This is when most FIO are driven off the land by surface water run-off. MP5 dominates the loadings at this point as this MP is just downstream of the largest source of potential FIO run-off (as identified by the PIP analysis)

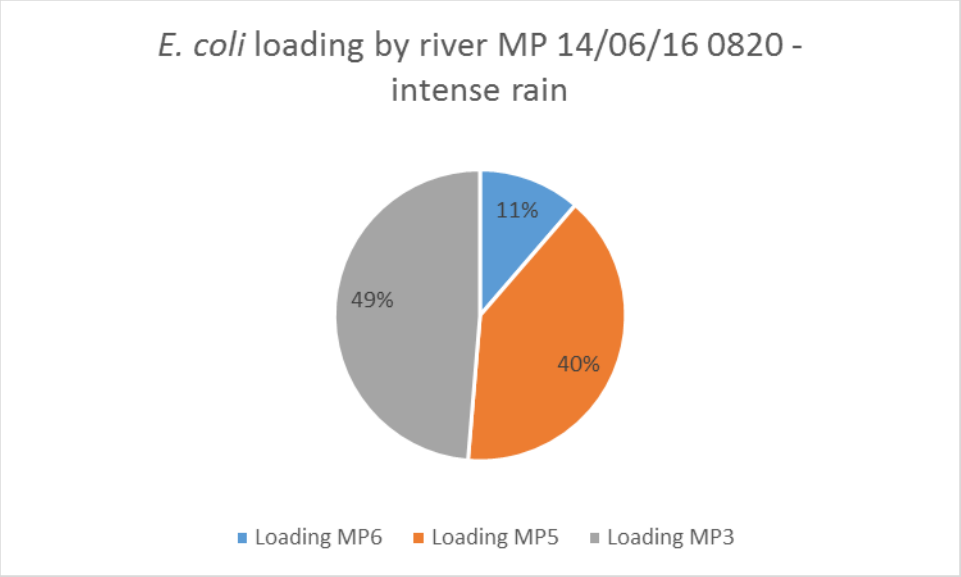


Figure 61: River loading at 0820.

All 3 stations' hydrographs still rising rapidly. As the river basin drains towards MP3 this station now begins to exhibit a higher proportion of the E. coli load

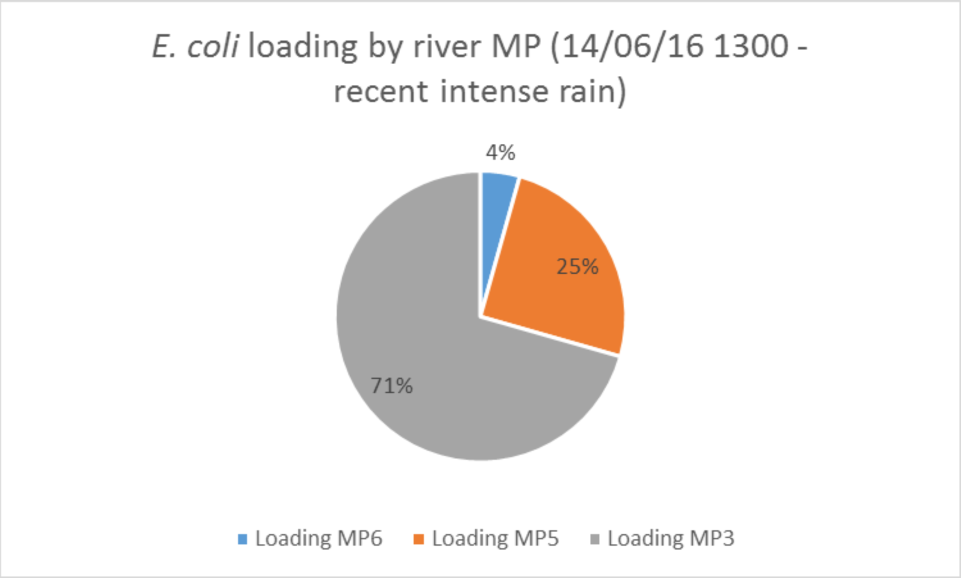


Figure 62: River loadings of E. coli now dominated by MP3 which is the discharge point of the river basin to the sea at Enniscrone.

Initial glut of FIO now being washed from MP5 & MP6 through MP3 to the sea

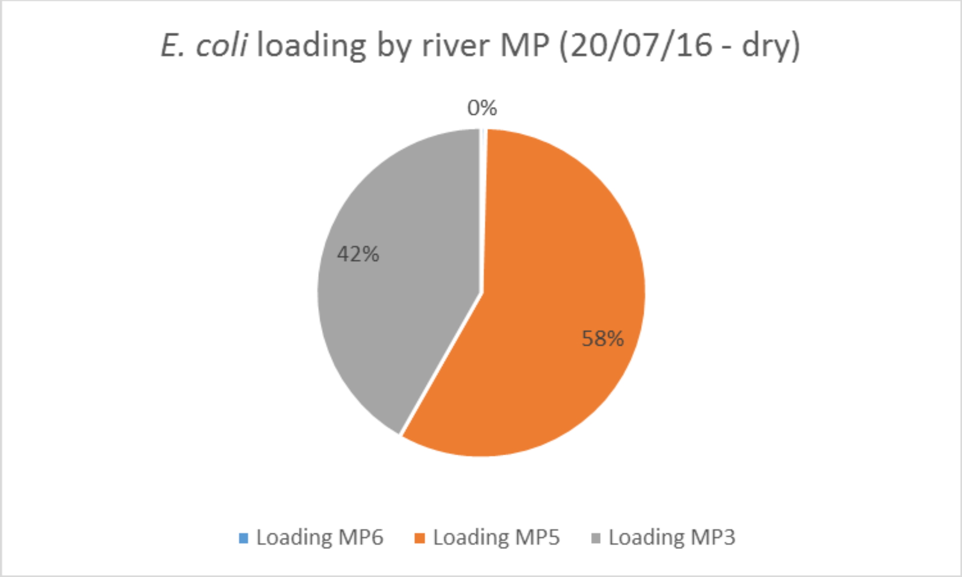


Figure 63: Dry weather river loadings at each MP.

MP5 proportion is larger – MP6 negligible

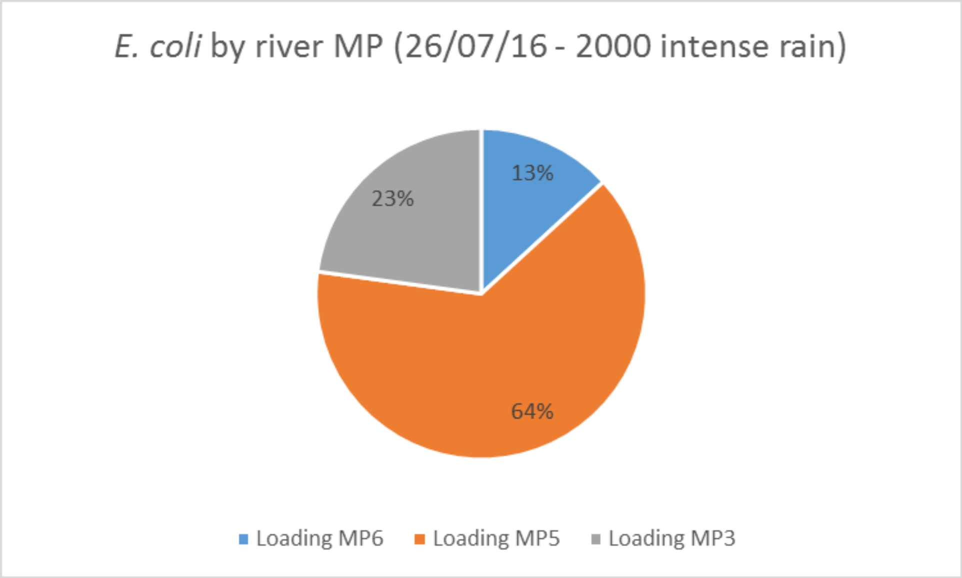


Figure 64: Heavy rain between 1600 & 2100.

MP5 dominates the E. coli load

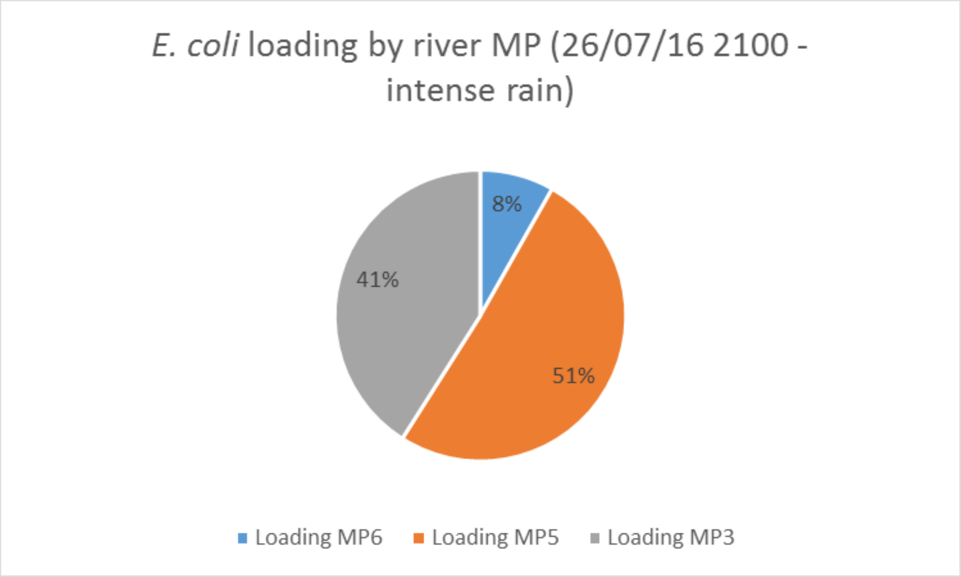


Figure 65: Heavy rain between 1600 & 2100.

MP3 proportion rising as the river water in the catchment reaches the outlet to the sea and the initial glut of FIO at MP5&MP3 wanes

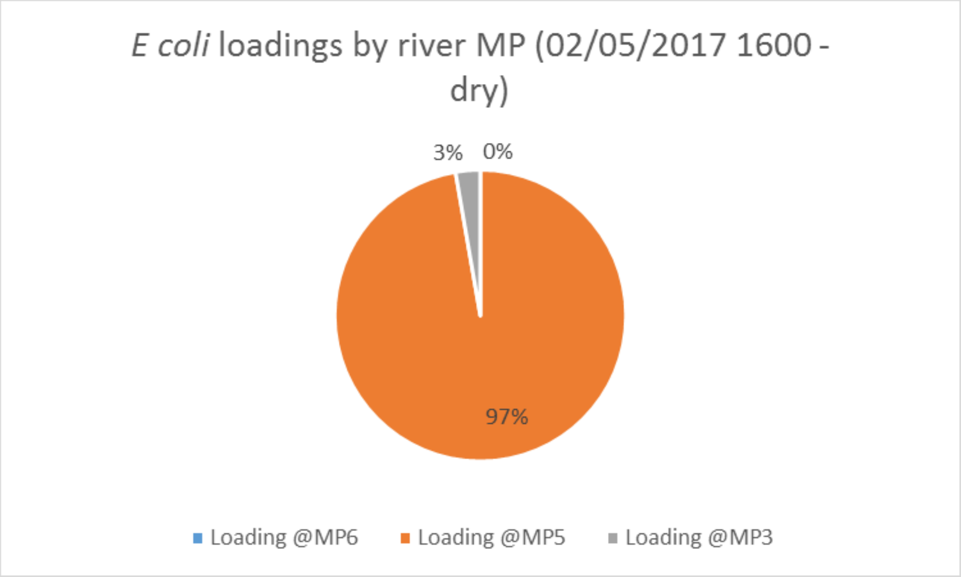


Figure 66: Dry weather 2017.

MP5 (Tullylinn – main channel) dominates

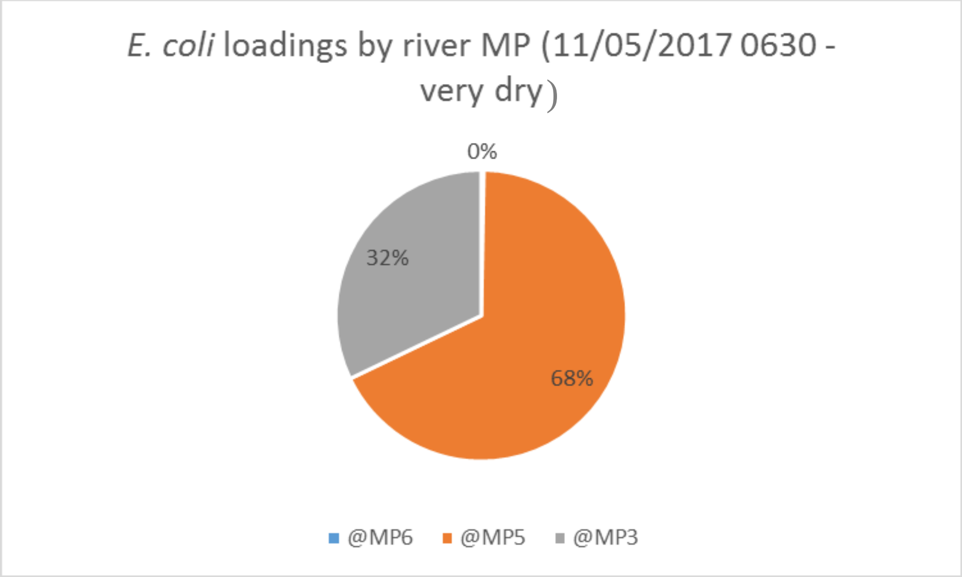


Figure 67: Very dry weather 2017.

MP5 (Tullylinn – main channel) still dominates

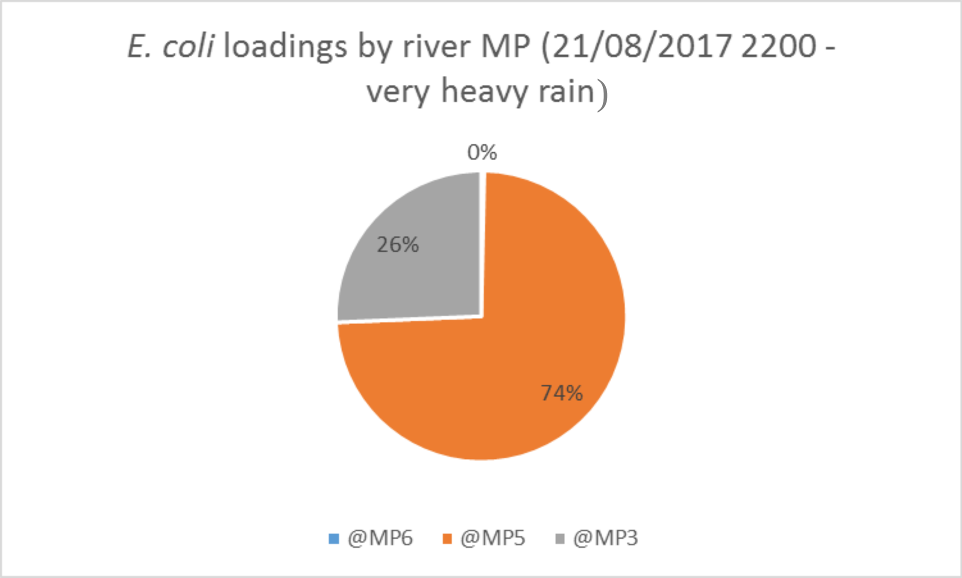


Figure 68: Heavy rain since 1900.

Rising limb of hydrograph at MP5 when most FIO would be expected to be washed into the river due to surface run-off. MP 5 dominates loadings. At 0500 the following day the loading at MP3 has doubled as you would expect as the river basin water reaches the outlet to the sea

Key outcome: Loadings of *E. coli* can change by 10^4 during hydrograph events.

From the analysis above it can be seen that river catchment *E. coli* loadings calculated for MP5 dominated over MP6 and was therefore the most suitable river catchment location for modelling the alert system (MP3 is the discharge to the sea and would not be suitable for an EWS because of its proximity to the target area).

5.2 Bathing water

5.2.1 Individual Sample Results

Table 14 below shows the results of the compliance samples taken for Sligo County Council in the years 2016 and 2017 (study period). It also displays the individual ranking or status for that sample. This ranking uses the result of either *E. coli* or intestinal enterococci, whichever is the lowest for that sample.

Table 15 below shows the results for the three microbiological parameters measured in the bathing water between May and September 2016 for this study. The individual ranking for each sample is also given which is based on the *E. coli* and intestinal enterococci results. Table 16 gives the results and data from this study for the period between May and September 2017. Regulatory and study results for both years are graphed in Figs. 69, 70 & 71. Note that short-term pollution (STP) events were targeted by this study for both bathing seasons.

Key outcome: Official compliance monitoring of the bathing water undertaken by the regulatory authority did not reflect or capture periods of inferior water quality at Enniscrone during the study period. Episodes of gross water pollution were measured during this research. For example, Fig. 69 below illustrates the magnitude of these episodes for 2016.

Table 14: Results of official compliance sampling for the bathing water at Enniscrone beach for the 2016 & 2017 bathing seasons. Source www.beaches.ie

Date	*E. coli* Result/100 ml	Intestinal enterococci Result/100 ml	Individual water sample status *
11/09/2017	100	21	Excellent
04/09/2017	<10	1	Excellent
28/08/2017	30	8	Excellent
14/08/2017	50	21	Excellent
31/07/2017	10	<1	Excellent
17/07/2017	<10	<1	Excellent
03/07/2017	30	<1	Excellent
19/06/2017	40	1	Excellent
06/06/2017	<10	3	Excellent
22/05/2017	<10	<1	Excellent
12/09/2016	<1	26	Excellent
05/09/2016	120	6	Excellent
29/08/2016	<1	<1	Excellent
15/08/2016	<1	<1	Excellent
02/08/2016	<1	<1	Excellent
18/07/2016	<1	<1	Excellent
04/07/2016	<1	<1	Excellent
20/06/2016	60	9	Excellent
07/06/2016	145	200	Good
23/05/2016	200	4	Excellent

* Note: This status is for the assessment of the quality of an **individual sample only** (Table 9 in Section 4.3) - as opposed to the overall water quality classification (Table 1).

Table 15: Results and sampling dates from ***2016*** *for bacteriological analysis of Enniscrone's bathing water for this study (E. coli highlighted). Taken at monitoring location MP1*

Date	Time UTC	Total coliforms	*Escherichia coli*	Int. ent	**Individual** Sample status
06/06/2016		<10	<10		Excellent
07/06/2016		900	158	200	Good
14/06/2016	07:00	1956	275		Good
14/06/2016	08:20	24192	8164		Poor
14/06/2016	10:30	8164	1223		Poor
14/06/2016	13:00	30000	30000		Poor
14/06/2016	15:45	30000	30000		Poor
14/06/2016	18:40	30000	30000		Poor
15/06/2016	05:40	30000	12033		Poor
15/06/2016	19:10	15531	4884		Poor
16/06/2016	07:50	12996	3654		Poor
20/06/2016			60	9	Excellent
04/07/2016		52	<10	<1	Excellent
10/07/2016		51	10		Excellent
18/07/2016		74	<10	<1	Excellent
20/07/2016		586	41		Excellent
26/07/2016	20:00	1019	439		Good
26/07/2016	21:00	744	134		Excellent
26/07/2016	21:45	288	20		Excellent
26/07/2016	22:15	323	74		Excellent
26/07/2016	23:15	413	96		Excellent
27/07/2016	05:50	19862	6488		Poor
27/07/2016	19:45	5172	2063		Poor
28/07/2016		246	31		Excellent
29/07/2016		3255	340		Good
02/08/2016			<10	<1	Excellent
15/08/2016			<10	<1	Excellent
17/08/2016	18:00	2481	189		Excellent
17/08/2016	19:10	3609	609		Sufficient
17/08/2016	21:00	24192	6867		Poor
18/08/2016	06:00	11198	1145		Poor
18/08/2016	10:00	5475	288		Good
19/08/2016	16:00	19862	1081		Poor
19/08/2016	20:00	3282	292		Good
20/08/2016	07:45	2723	262		Good
29/08/2016			<10	<1	Excellent
04/09/2016		1211	74		Excellent
05/09/2016			120	6	Excellent
06/09/2016		1483	146		Excellent
12/09/2016			<10	26	Excellent

Total coliforms & *Escherichia coli* = (MPN/100 ml). Intestinal enterococci (Int. ent.) = cfu/100 ml. Note: some sampling was targeted during predicted short-term pollution (STP)

Table 16: Results and sampling dates from ***2017*** *for bacteriological analysis of Enniscrone's bathing water for this study. Taken at monitoring location MP1*

Date	Time UTC	Total coliforms	*Escherichia coli*	Int. Ent.	**Individual** Sample status
11/05/2017	06:30	<10	<10	<1	Excellent
08/06/2017	07:00	<10	<10	1	Excellent
15/06/2017	07:00	265	31	3	Excellent
27/06/2017	06:40	63	<10	<1	Excellent
03/07/2017	09:15	233	41	2	Excellent
04/07/2017	06:15	426	74	5	Excellent
13/07/2017	08:00	2	<10		Excellent
19/07/2017	19:00	20	<10	1	Excellent
22/07/2017	18:15	1169	155	49	Excellent
31/07/2017	07:00	41	11	11	Excellent
18/08/2017		1069	125	24	Excellent
21/08/2017	19:15	408	31	24	Excellent
21/08/2017	21:30	134	63	6	Excellent
22/08/2017	05:10	4352	959	84	Sufficient
22/08/2017	16:00	2359	471	39	Good
23/08/2017	20:15	9804	95	20	Excellent
04/09/2017	07:00		<10	1	Excellent

Total coliforms & *Escherichia coli* = (MPN/100 ml). Intestinal enterococci (Int. ent.) = cfu/100 ml. Note: some sampling was targeted during predicted short-term pollution (STP)

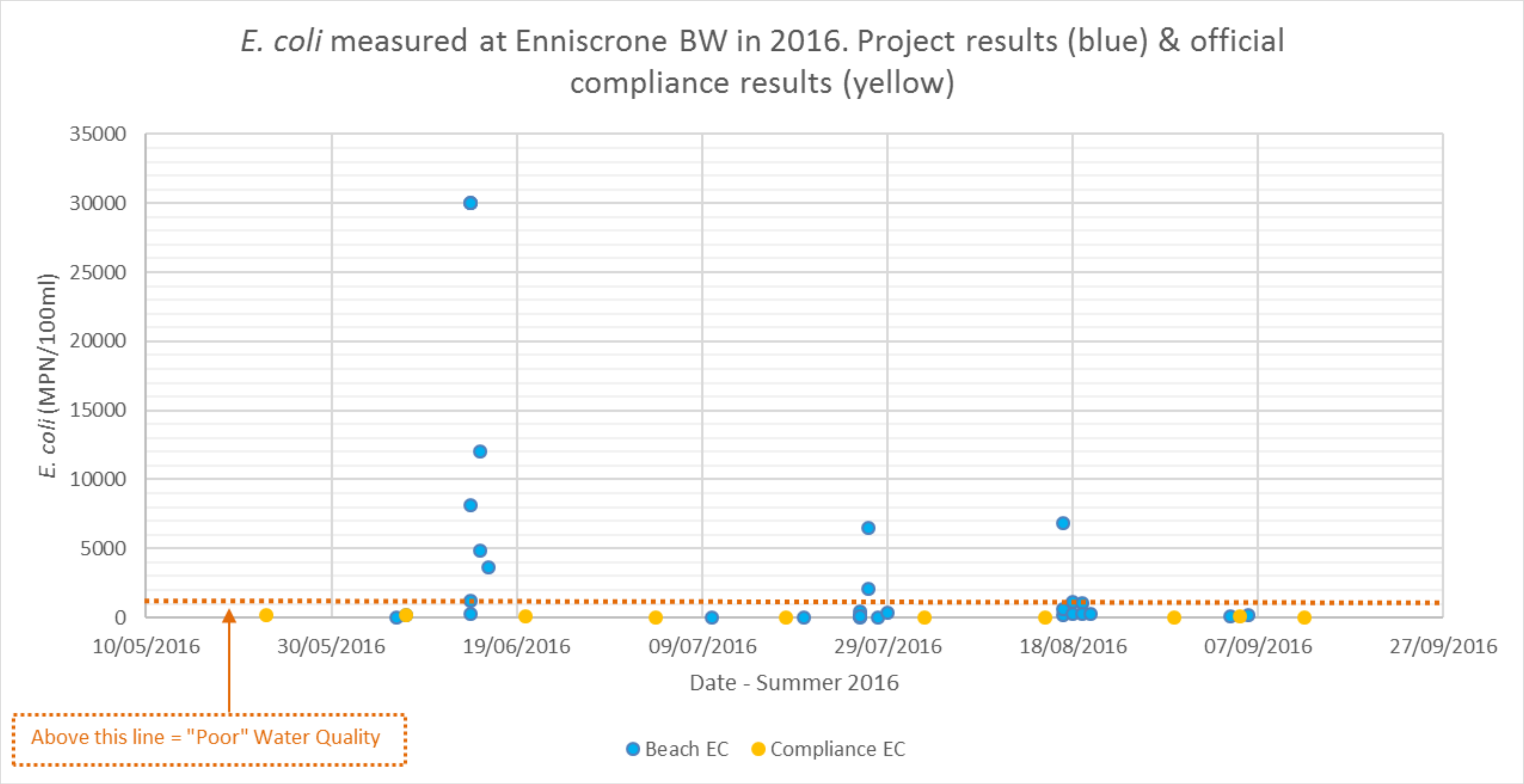


Figure 69: Results for E. coli measured at Enniscrone bathing water in 2016 showing project (blue) & official compliance (yellow) results. Note the 3 STP events. Orange line delineates the "Poor" E. coli limit – 1000 MPN/100 ml for water quality from individual samples

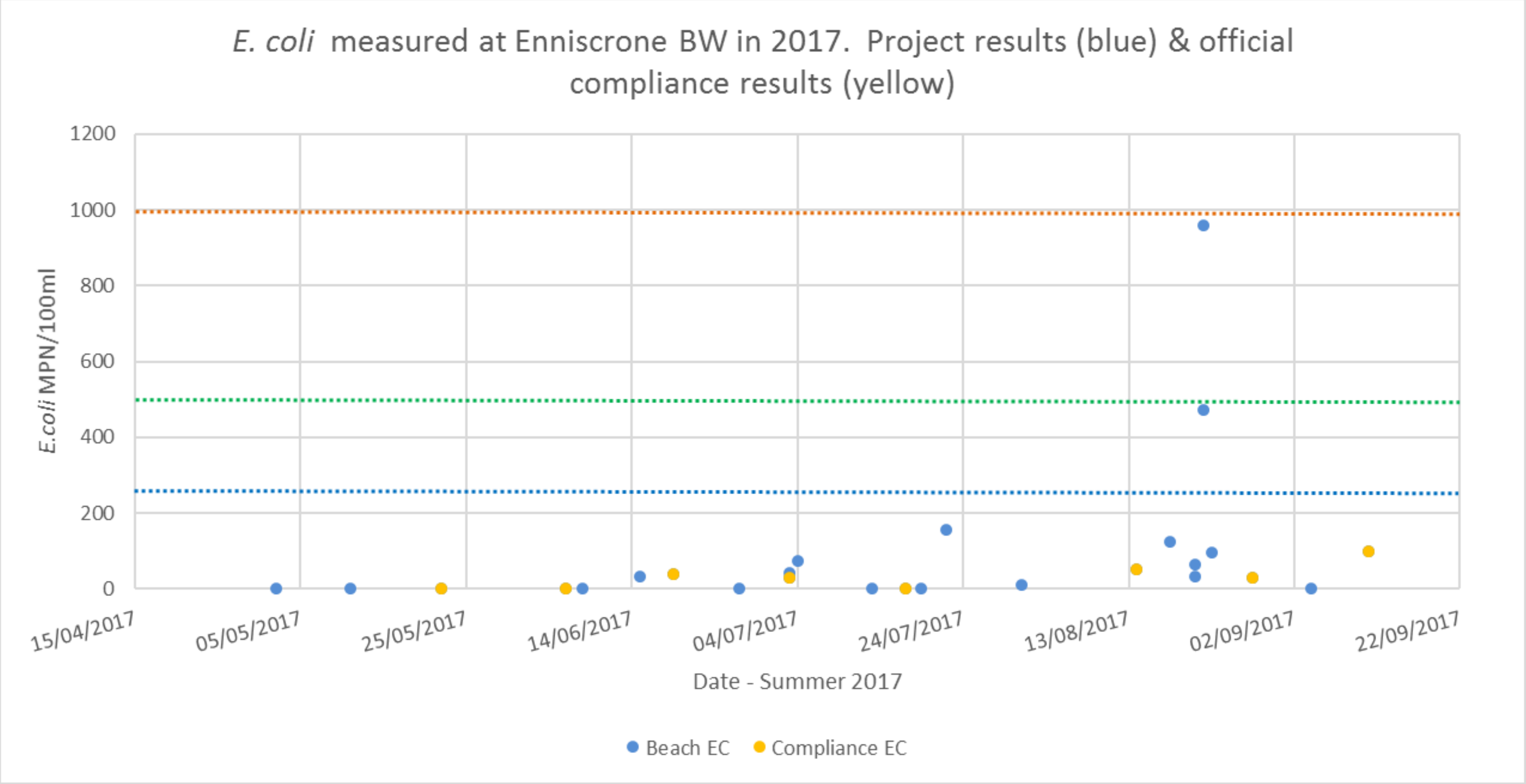


Figure 70: Results for E. coli measured at Enniscrone bathing water in 2017.

Note the STP event in August. Blue line delineates the "Excellent" E. coli limit, the green line the "Good" E. coli limit & the orange line the "Poor" E. coli limit for water quality from individual samples.

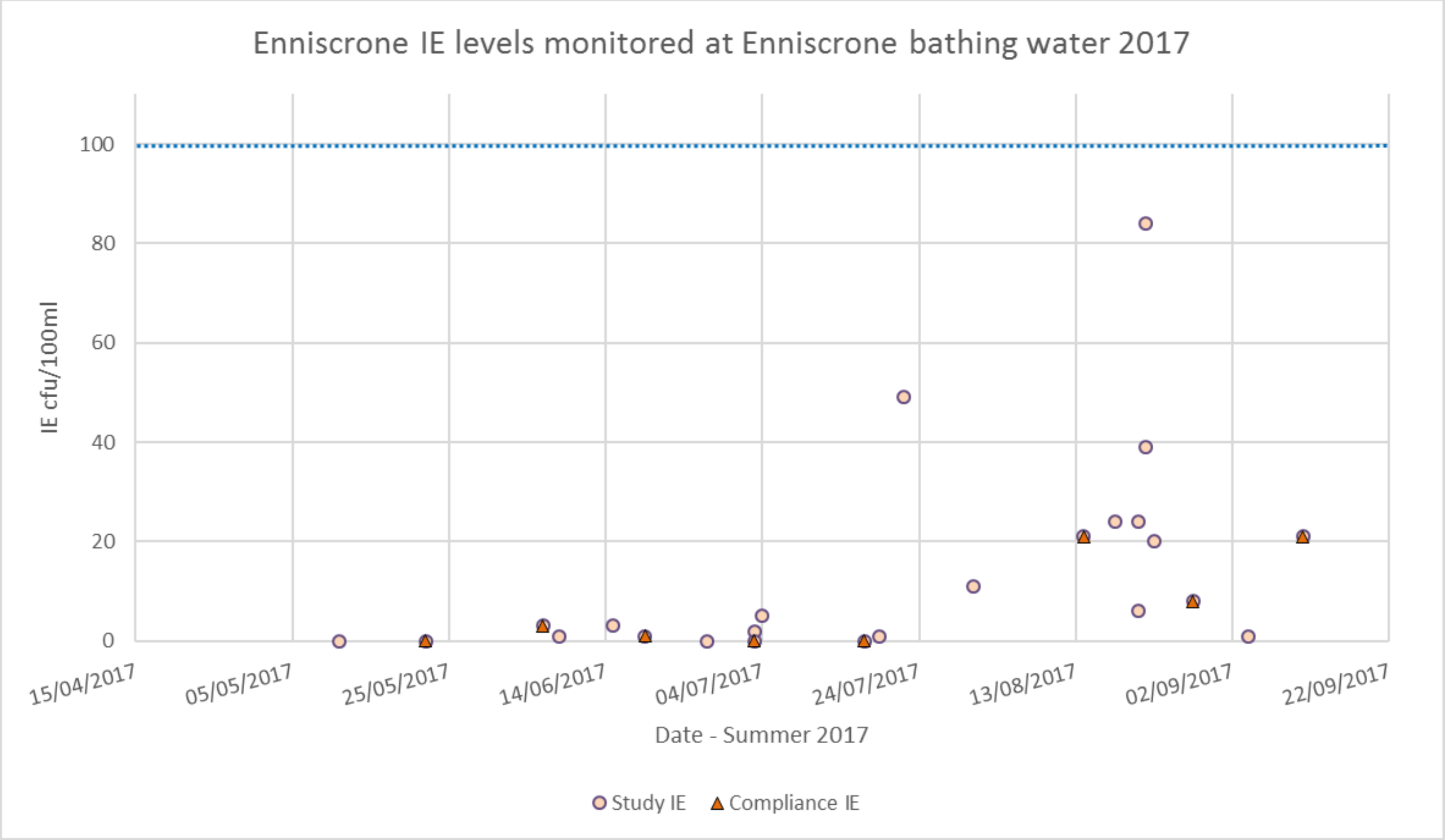


Figure 71: Results for intestinal enterococci (IE) measured at Enniscrone bathing water in 2017.

Blue line delineates the "Excellent" IE limit of 100 cfu/100 ml for water quality from individual samples.

5.2.2 STP warning system alarms

From very early on in the project after initial analyses of the river catchment (Sections 3.1.2 & 5.2), it was evident that MP5 would provide the most accurate and precise indicator of the large fluxes of *E. coli* generated in the catchment. Efforts were then concentrated on checking the calibration of this MP with no effort made to calibrate MP6. The system alerts generated and sent from this station (MP5) during the study period are tabulated below in Table 17.

Table 17: Table showing SMS message alerts sent to authors phone for 2016 & 2017. MP5 highlighted

MP5 (Tullylinn) – Main channel		MP6 (Stokane)	
Alarm Date	Alarm Time (UTC)	Alarm Date	Alarm Time (UTC)
14/06/2016	10:15	14/06/2016	11:00
26/07/2016	21:00	26/072016	Pre-alarm only
18/08/2016	01:30	18/08/2016	Pre-alarm only
21/08/2017	20:15	21/08/2017	19:45

The warning system alerts versus the individual results for *E. coli* (& intestinal enterococci) were then tracked for each bathing season of this study. These results are presented in Section 5.2.3 (Figs 72, 73 & 74) below. They show that 4 STP events occurred and were alerted by the EWS during the study period. Luckily, they did not coincide with regulatory monitoring. Furthermore, the individual *E. coli* results and system alerts for each STP event was also tracked. The results are depicted below (Figs. 75 – 78) in Section 5.2.4. They show the efficacy of the EWS to monitor the occurrence of STP events in the bathing water.

5.2.3 System alerts by bathing season

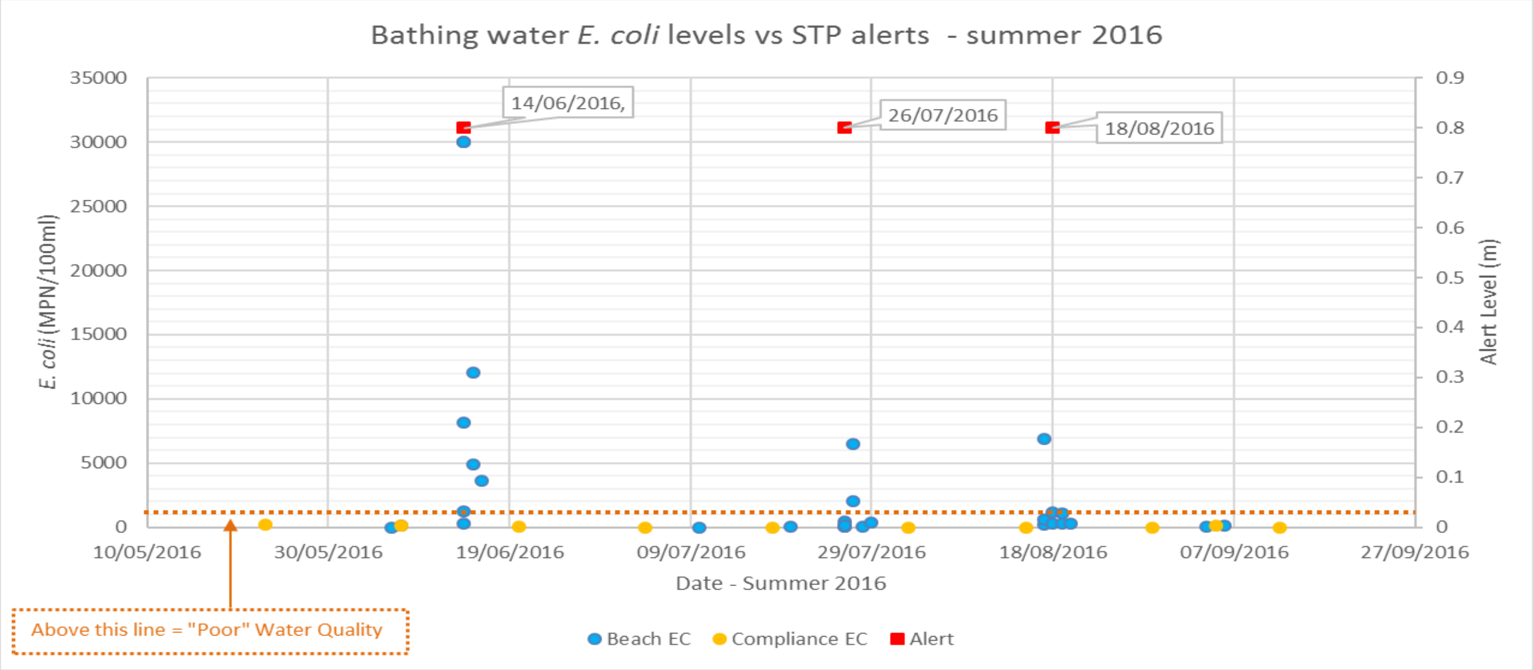


Figure 72: Enniscrone bathing water E. coli levels taken at MP1 for the summer of 2016 versus the 3 automatic warning alerts issued by the system from MP5 (main channel).

Key outcome: *3 STP events were predicted alerted & confirmed with no false positives or missed events. Fortuitously these events did not coincide with any compliance sampling (yellow markers). The E. coli classification delineation for "Sufficient" (individual sample) is shown by the orange line. Anything above this is classified as "Poor" quality bathing water.*

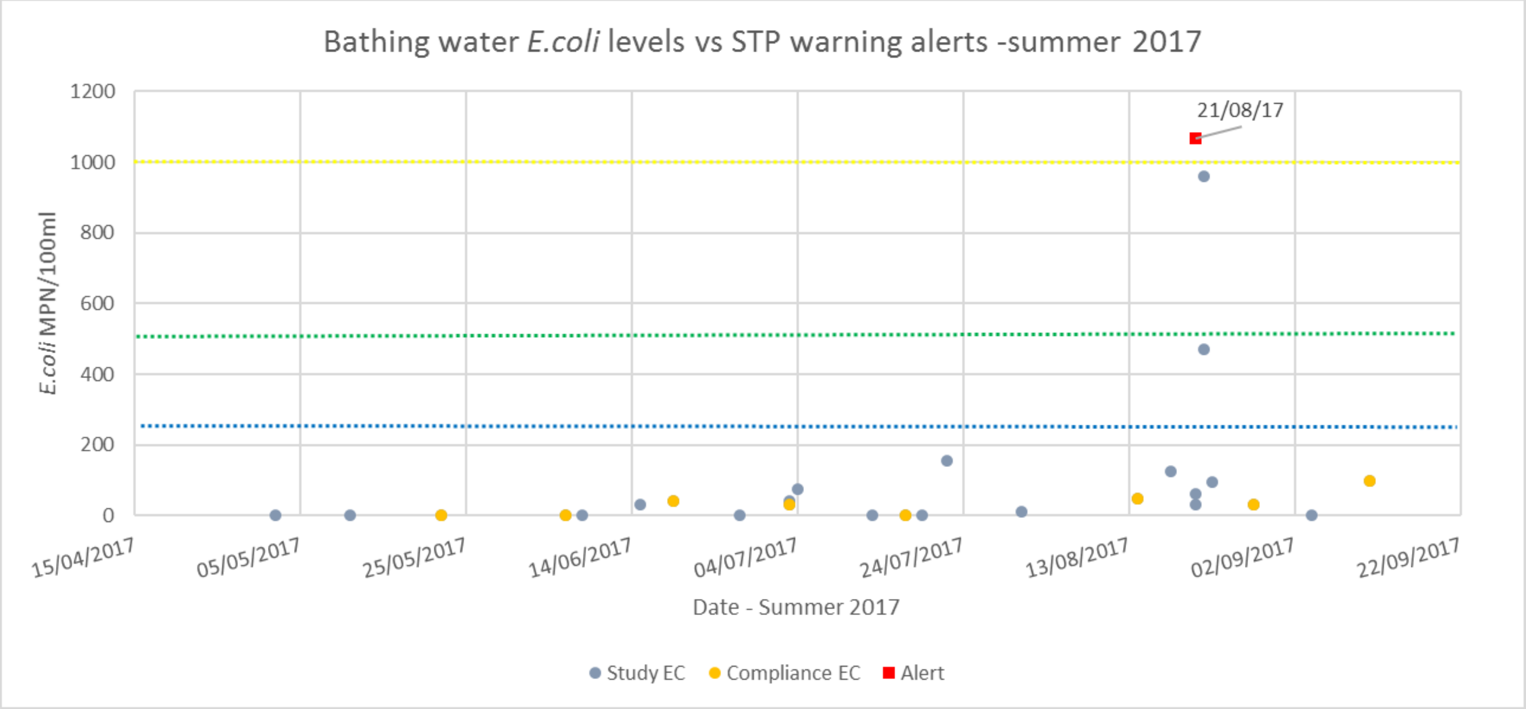


Figure 73: Enniscrone bathing water E. coli results from samples taken at MP1 versus the 1 automatic warning alert issued by the system from MP5 on the 21/08/17.

Study samples (blue) & official compliance sample (yellow) results are both shown from the summer of 2017. ***Key Outcome:*** *One STP event was predicted alerted & confirmed in August with no false positives or missed events. Note that fortuitously it did not coincide with official fortnightly compliance sampling (yellow markers). The classification delineations for individual samples are also shown (under the blue line =" Excellent", under the green = "Good", under the yellow = "Sufficient" above = "Poor").*

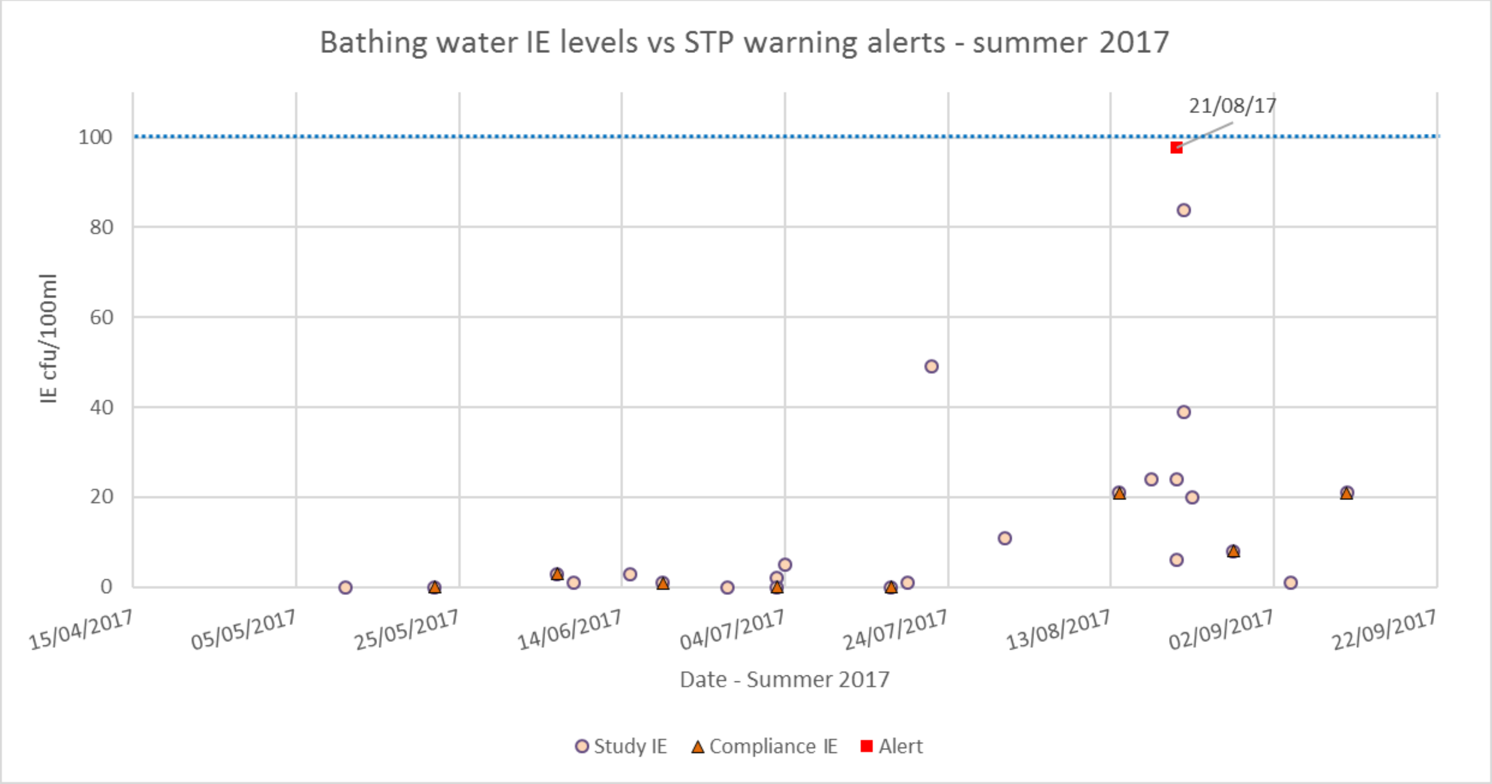


Figure 74: Enniscrone bathing water intestinal enterococci results (IE) from samples taken at MP1 versus automatic alert.

Study samples (pink) & official compliance sample (purple) results are both shown from the summer of 2017. "Excellent" standard for IE is shown by blue line (100 cfu/100 ml). ***Key outcome:*** *All sample results achieved this standard for IE. IE results are not causing the downgrading of Enniscrone's bathing water*

5.2.4 System alerts by STP event

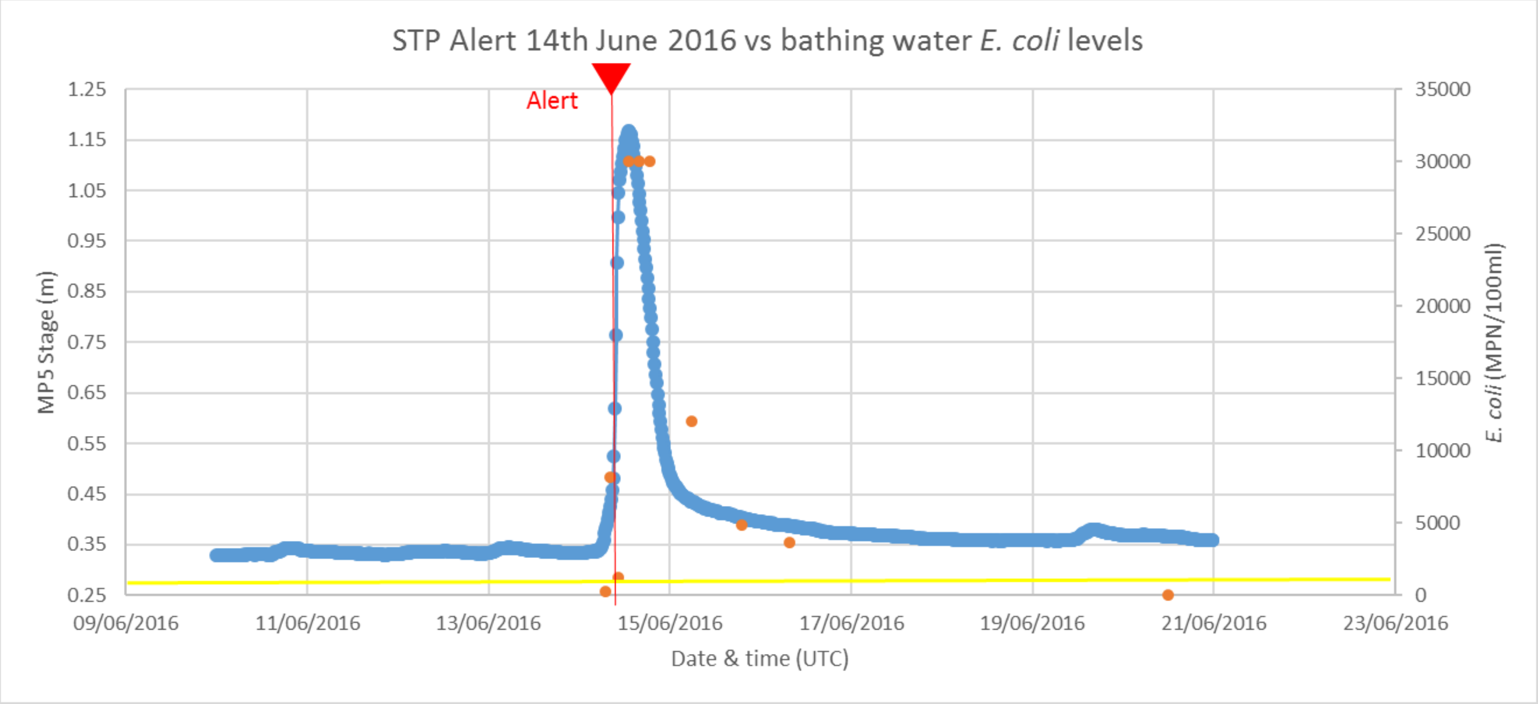


Figure 75: Major STP event of the 14/06/16.

Alert was triggered at 1015. Orange markers denote E. coli sample numbers enumerated during the event whilst the yellow line marks the "Sufficient" water quality limit for individual E. coli results. Above this is classified as "Poor" water quality. The blue line denotes the hydrograph at MP5 where the alert is triggered from. ***Key outcome:*** *STP Alert was precise and accurate*

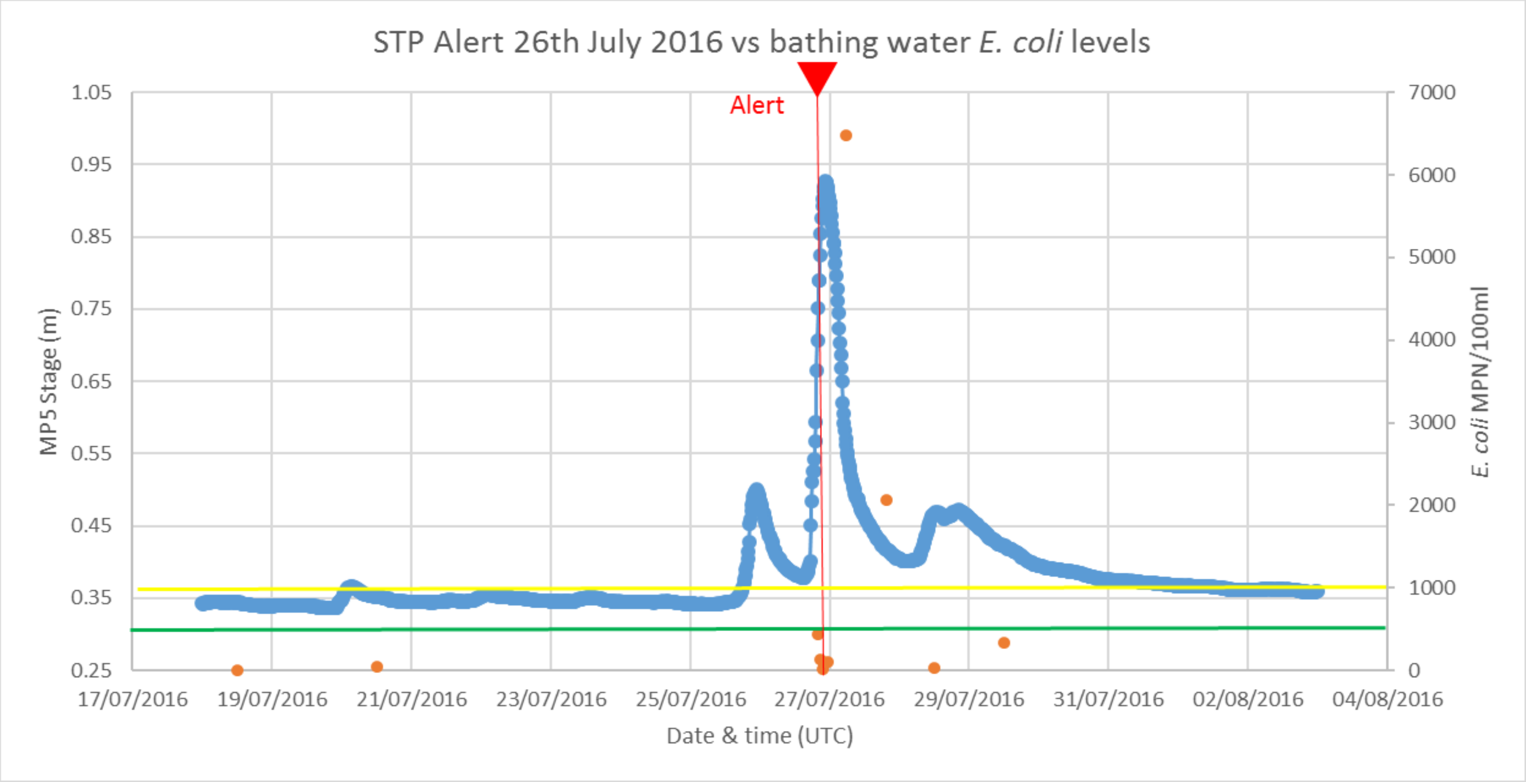


Figure 76: STP event of the 26/07/16.

Alert was triggered at 2100. Orange markers denote E. coli sample numbers enumerated during the event. The green line marks the "Good" water quality limit & the yellow delineates the "Sufficient" water quality limit for individual E. coli results. Above this is classed as "Poor" water quality. The blue line denotes the hydrograph at MP5 where the alert is triggered from. ***Key outcome:*** *STP Alert was precise and accurate*

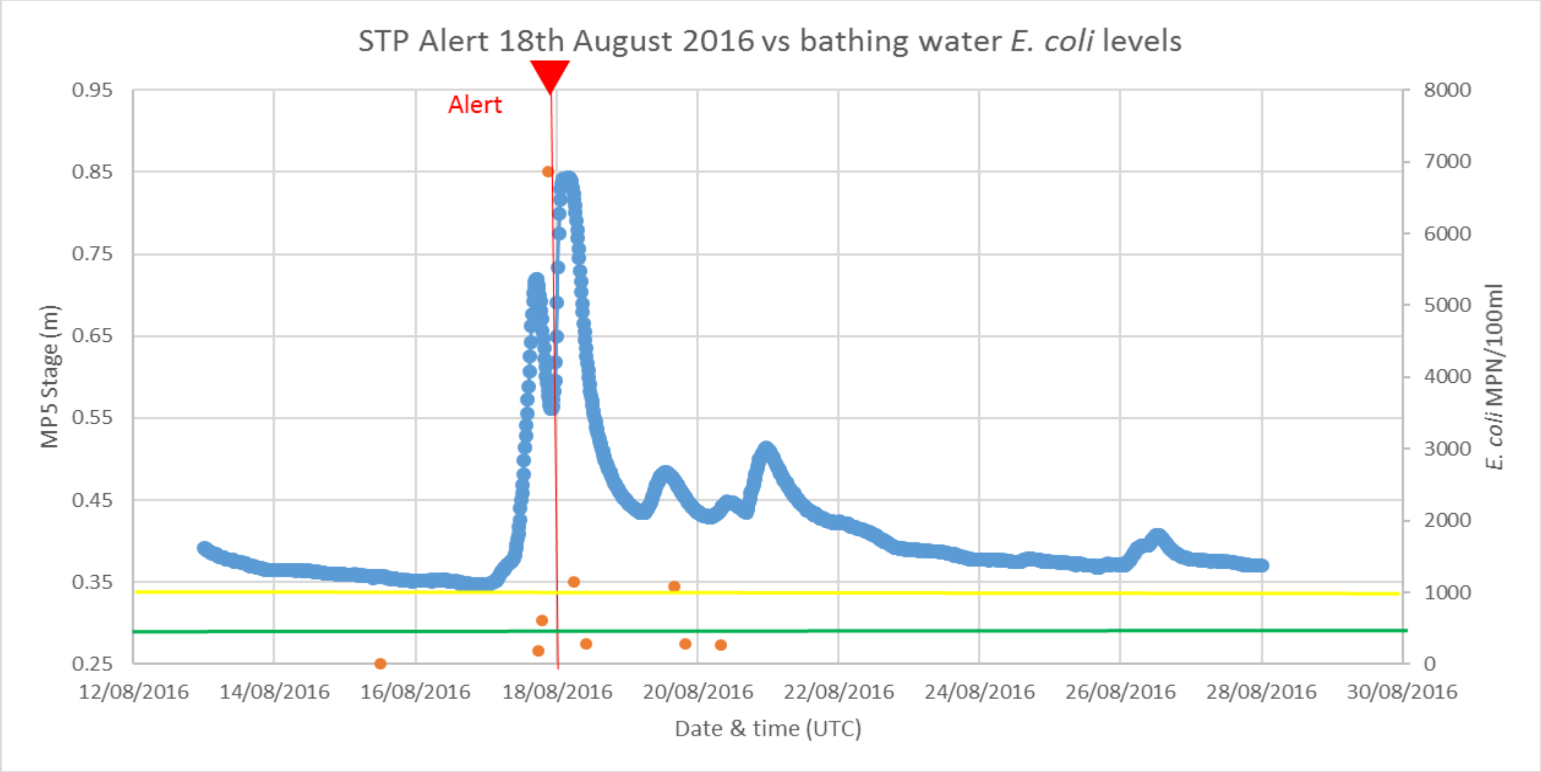


Figure 77: STP event of the 18/08/16.

Alert was triggered at 0130. Orange markers denote E. coli sample numbers enumerated during the event. The green line marks the "Good" water quality limit & the yellow line marks the "Sufficient" water quality limit for individual E. coli results. Above this is classed as "Poor" water quality. The blue line denotes the hydrograph at MP5 where the alert is triggered. ***Key outcome:*** *STP Alert was precise and accurate*

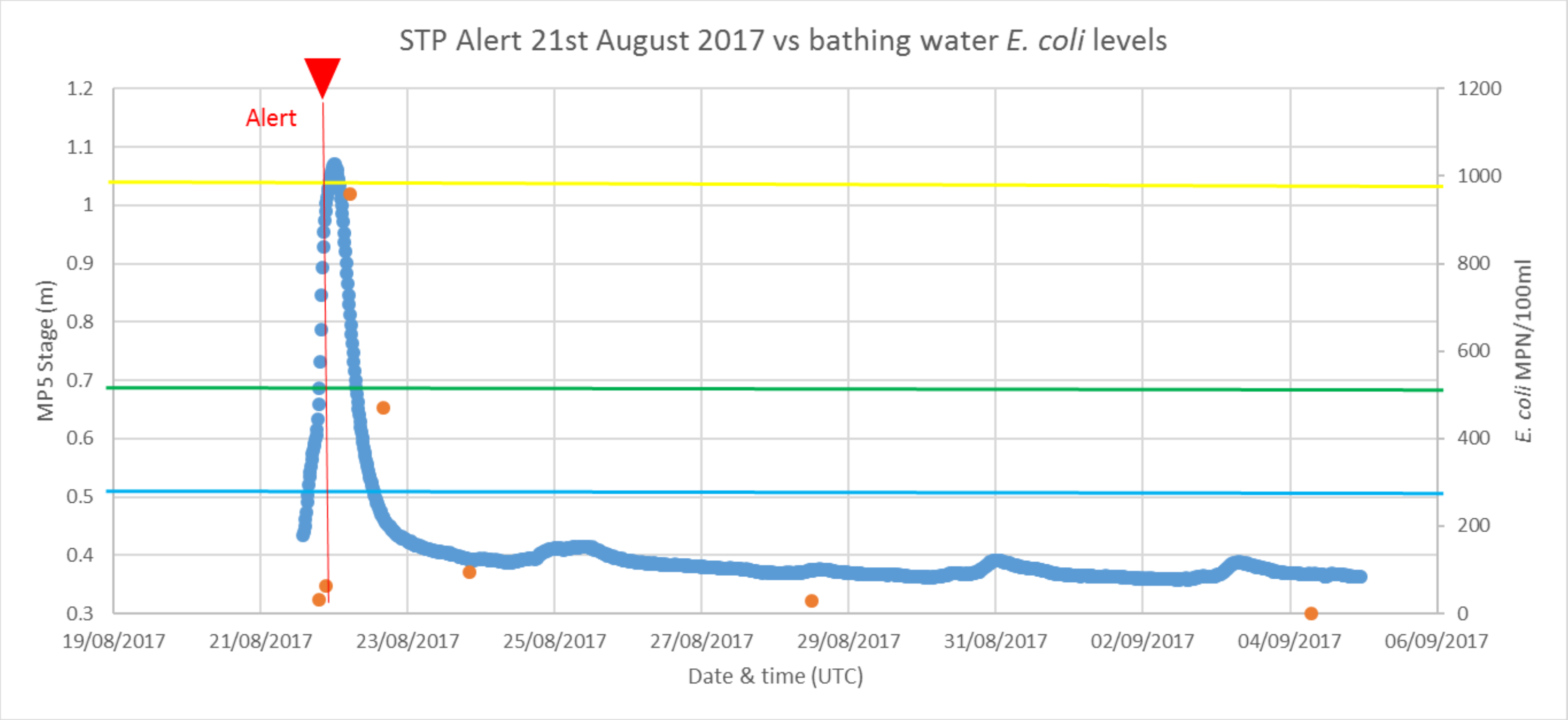


Figure 78: STP event of the 21/08/17.

Alert was triggered at 2015. Orange markers denote E. coli sample numbers enumerated during the event. The green line marks the "Good" water quality limit, the yellow line marks the "Sufficient" water quality limit and the blue line marks the "Excellent" water quality limit for individual E. coli results. Above the yellow line is classed as "Poor" water quality. The dark blue line denotes the hydrograph at MP5 where the alert is triggered from. ***Key outcome:*** *STP Alert was precise and accurate*

Figure 79: Taken on the 18/08/16 after the last (3rd) STP warning alert of 2016 was issued at 0130UTC.

The bathing water was of poor quality & a potential health hazard. As can be seen the weather was good with the beach busy with bathers, surfers / surf schools & paddlers

Figure 80: Safe to swim?

Taken on 18/08/16 after the STP warning alert at 0130UTC. Bathers surfers & beach-goers enjoying the good weather. Water is of poor quality

Figure 81: Taken on the 22/08/17 the day after the only STP alert of 2017 was issued at 2015UTC (21/08/17).

There were many recreational users in the water. The water quality in the morning had dipped to "Sufficient" & nearly "Poor" thus at least doubling the risk of bathers contracting gastro-intestinal illness. This had improved to "Good" by the evening. The Met Éireann rainfall radar for this event can be seen in Appendix H

Key outcome: Figures 79 to 81 above illustrate predicted periods during the study where bathing water quality results demonstrated inferior quality during recreational use.

5.2.5 Annual Classification Results

The **annual classification** of Enniscrone's bathing water from regulatory compliance sampling during the 2-year study period is given in Table 18 below. These are based on the Directive criteria given in Table 1 i.e. calculated from a 4-year data set of the individual compliance results from that year and the preceding 3 years.

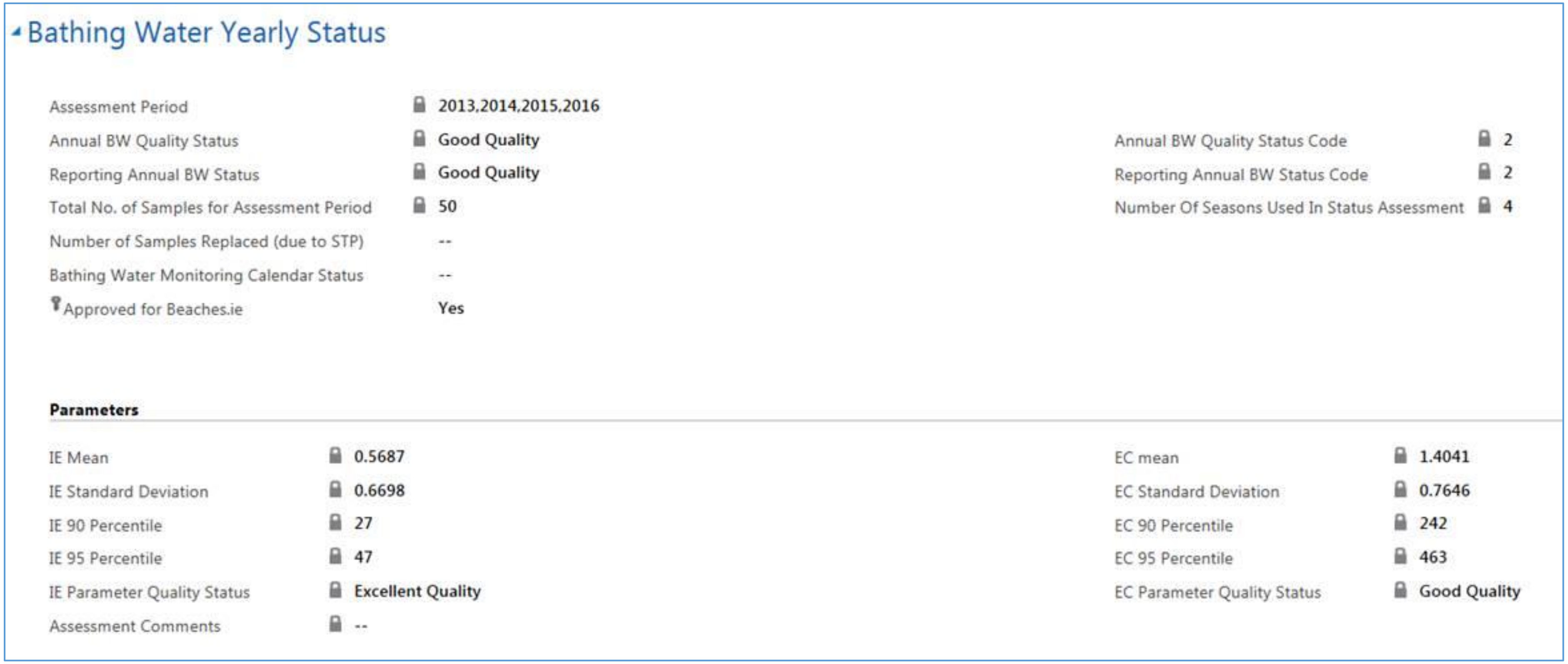
*Table 18: **Annual water quality rating** for Enniscrone beach for the last 4 years. Source www.beaches.ie*

Year	2017	2016
Classification	Good	Good

Note: This is based on the Directive criteria in Table 1 and is the official water quality rating of Enniscrone beach for the years listed.

The official assessment for each of the 2 years above is given in the following tables (Tables 19 & 20). A single year's rating is based on a data set which includes the data of that year, pooled with the previous 3 years' data (i.e. the assessment for 2016's rating would include all compliance data from 2013-2016 inclusive).

Table 19: Enniscrone bathing water quality assessment for ***2016****. Rating “***Good***”. Source: EPA Bathing Water Unit*



Bathing Water Yearly Status

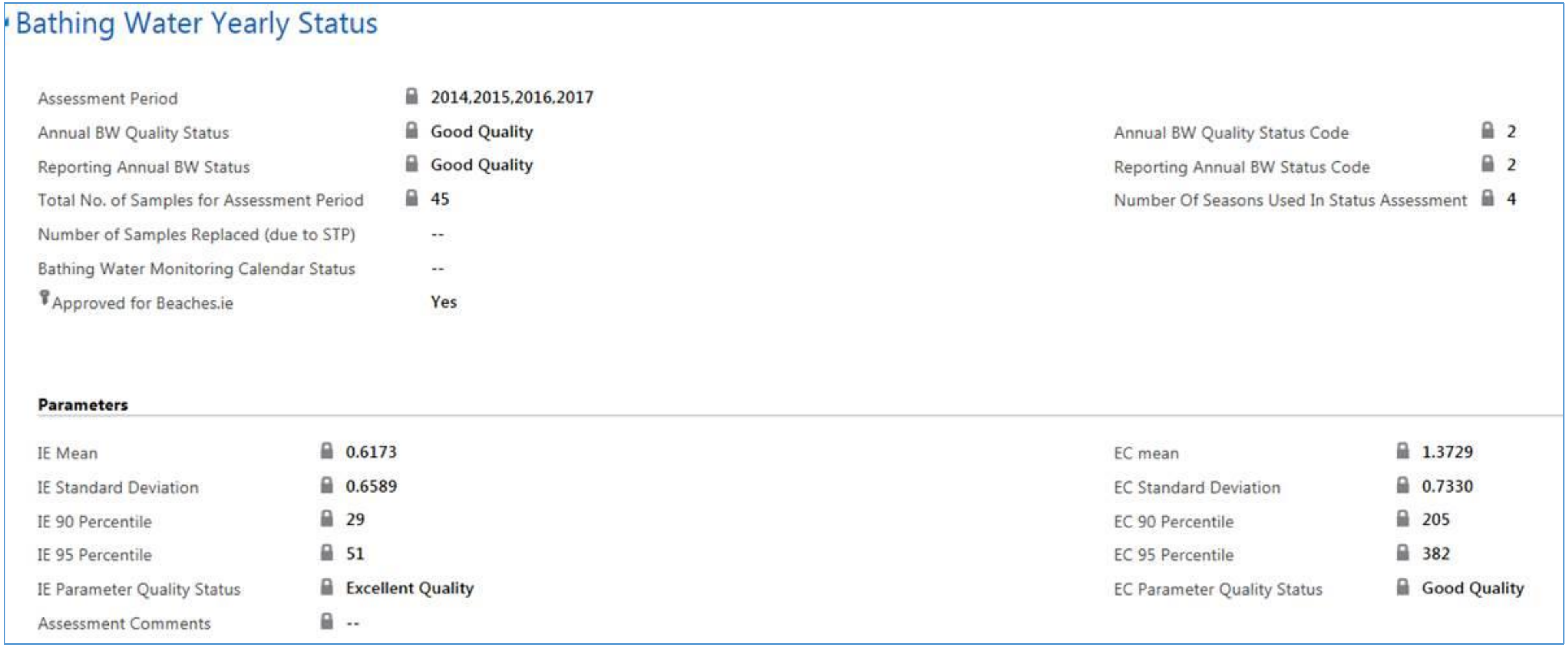
Assessment Period	2013,2014,2015,2016		
Annual BW Quality Status	Good Quality	Annual BW Quality Status Code	2
Reporting Annual BW Status	Good Quality	Reporting Annual BW Status Code	2
Total No. of Samples for Assessment Period	50	Number Of Seasons Used In Status Assessment	4
Number of Samples Replaced (due to STP)	--		
Bathing Water Monitoring Calendar Status	--		
Approved for Beaches.ie	Yes		

Parameters

IE Mean	0.5687	EC mean	1.4041
IE Standard Deviation	0.6698	EC Standard Deviation	0.7646
IE 90 Percentile	27	EC 90 Percentile	242
IE 95 Percentile	47	EC 95 Percentile	463
IE Parameter Quality Status	Excellent Quality	EC Parameter Quality Status	Good Quality
Assessment Comments	--		

Note the 95-percentile result of 47 for intestinal enterococci (IE) ranks as *Excellent* (equal or better than 100). However, the 95-percentile result for *E. coli* (EC) of 463 ranks only as *Good* quality (250 -500). The lowest parameter ranking gives the overall classification – in this case *Good*

Table 20: Enniscrone bathing water quality assessment for ***2017****. Rating "***Good***". Source: EPA Bathing Water Unit*



Bathing Water Yearly Status

Assessment Period	**2014,2015,2016,2017**		
Annual BW Quality Status	**Good Quality**	Annual BW Quality Status Code	**2**
Reporting Annual BW Status	**Good Quality**	Reporting Annual BW Status Code	**2**
Total No. of Samples for Assessment Period	**45**	Number Of Seasons Used In Status Assessment	**4**
Number of Samples Replaced (due to STP)	--		
Bathing Water Monitoring Calendar Status	--		
Approved for Beaches.ie	**Yes**		

Parameters

IE Mean	**0.6173**	EC mean	**1.3729**
IE Standard Deviation	**0.6589**	EC Standard Deviation	**0.7330**
IE 90 Percentile	**29**	EC 90 Percentile	**205**
IE 95 Percentile	**51**	EC 95 Percentile	**382**
IE Parameter Quality Status	**Excellent Quality**	EC Parameter Quality Status	**Good Quality**
Assessment Comments	--		

Note the 95-percentile result of 51 for intestinal enterococci (IE) ranks as *Excellent* (equal or better than 100). However, the 95-percentile result for *E. coli* (EC) of 382 ranks only as *Good* quality (250 -500). The lowest parameter ranking gives the overall classification – in this case *Good*

5.2.5.1 Calculation of Annual Classification Results for *E. coli*

The calculations used for the annual classification of *E. coli* results given above follow below in Figs. 82 & 83. These encompass the 4-year range of regulatory compliance results used to calculate the official classification rating for 2016 and 2017. The regulatory results for the years 2013 – 2017 were obtained at www.beaches.ie.

The upper 95-percentile point of the data probability density function is derived from the following equation given in the Bathing Water Directive:

$$95\%\text{ile} = \text{antilog}\,(\mu + 1{,}65\,\sigma)$$

The upper 90-percentile point of the data probability density function is derived from the following equation given in the Bathing Water Directive:

$$90\%\text{ile} = \text{antilog}\,(\mu + 1{,}282\,\sigma)$$

Key Outcome: The official bathing water classification result for Enniscrone during the study period was the second tier “Good”.

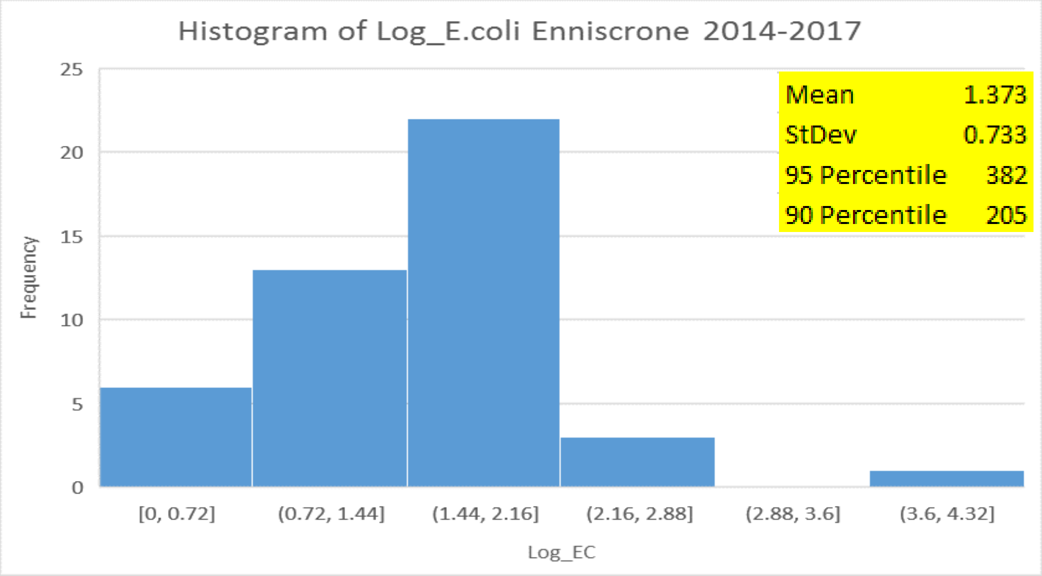


Figure 82: 2017 Annual Classification Result for Ennicrone.

*Histogram of log E. coli & descriptive statistics for compliance samples at Enniscrone (2014 – **2017**). Note 95%ile result of **382** – **"Good"** Water Quality Classification*

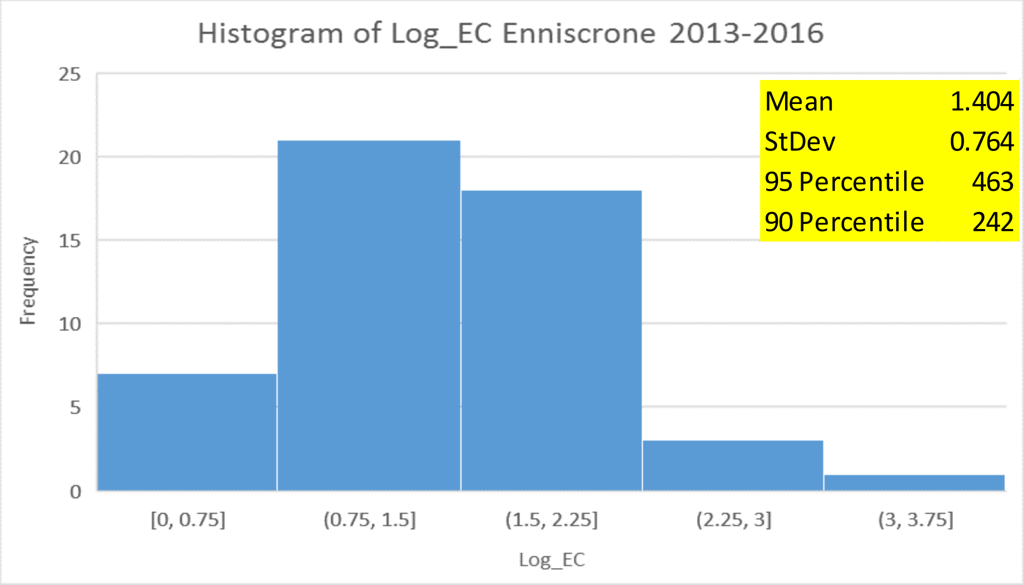


Figure 83: 2016 Annual Classification Result for Ennicrone.

*Histogram of log E. coli & descriptive statistics for compliance samples at Enniscrone (2013 – **2016**). Note 95%ile result of **463** – **"Good"** classification*

5.2.6 Modelling the impact of STP events on bathing water classification

This study provided a much more comprehensive picture of *E. coli* levels at Enniscrone's bathing water during the study period than demonstrated by the results from compliance sampling. Targeted STP episodes were also measured but fortuitously these events did not coincide with the compliance sampling

The *E. coli* data from some of these STP events was than modelled with the compliance results obtained during the 2016 and 2017 bathing seasons. This exercise was carried out to ascertain the potential effects on Enniscrone's annual water quality classification if compliance sampling coincided with some of these events.

The analysis below (Fig. 84) shows what would happen if the STP event measured by the author during this study on the 14/06/2016 had coincided with official compliance sampling. A "normal" *E. coli* compliance result was substituted by one of the results (30,000 *E. coli*/100 ml) obtained during the STP event. The 95-percentile classification result for 2016 would have risen from 463 to 808. This result greater than 500 signifies that the 90-percentile result would have to be used instead, giving an overall classification of *Sufficient* (3rd tier).

A similar result was obtained below using the same STP event for the 2017 classification calculation (Fig. 85).

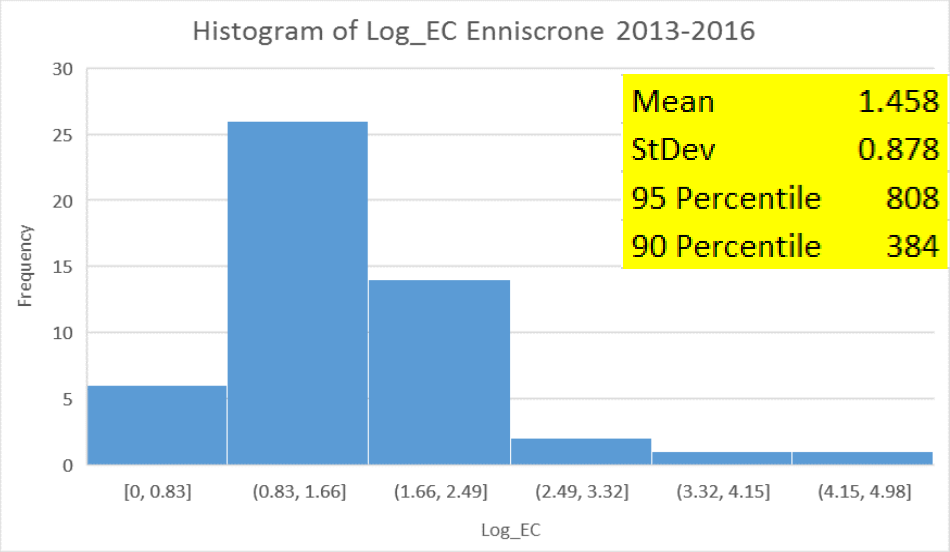


Figure 84: Histogram of log E. coli & descriptive statistics for compliance samples including the STP event of 14/06/16 at Enniscrone measured by the author (2013 – 2016).

Note 95%ile result > 500 denotes use of ***90****%ile result of* ***384.*** *This result would class Enniscrone's bathing waters as the 3*rd *tier "Sufficient"*

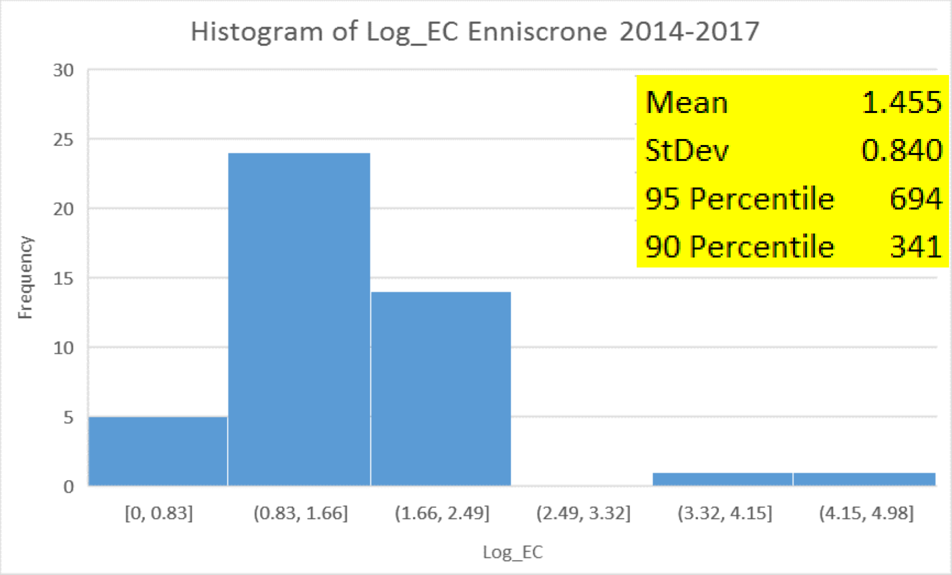


Figure 85: Histogram of log E. coli & descriptive statistics for compliance samples plus the STP event of 14/06/16 at Enniscrone measured by the author (2014 – 2017).

Note 95%ile result > 500 denotes use of ***90****%ile result of* ***341.*** *This result would class Enniscrone's bathing waters as the 3*rd *tier "Sufficient"*

If encountered, this 2016 event would have downgraded the bathing water to the 3rd tier "*Sufficient*" for 2016 *and* 2017 as shown in Table 21 below.

Table 21: Table showing classification results for the last 2 bathing seasons if the STP event measured on the 14/06/16 coincided with compliance sampling. Official results give a "Good" rating

Assessment Period	90%ile Result*	Classification
2014-2017	341	Sufficient
2013-2016	384	Sufficient

*Note use of 90%ile

This demonstrates that STP results will persist into following years.

The inverse approach to this analysis was then undertaken to further illuminate how an STP event from previous years can persistently affect the official classification of Enniscrone's bathing waters during this study period. The 2016 (Fig. 86) and 2017 (Fig. 87) compliance data is now analysed without the compliance sample result impacted by STP in 2014 (a "normal" result was substituted in its place). The data since that event (2014 & 2015) is additionally analysed for completeness in Figs. 88 & 89 respectively.

The results for annual bathing water quality classification for each assessment period since 2014 are shown in Table 22. The results after the analysis above (Figs. 86 - 89) which removes the STP event of 2014 is shown in Table 23.

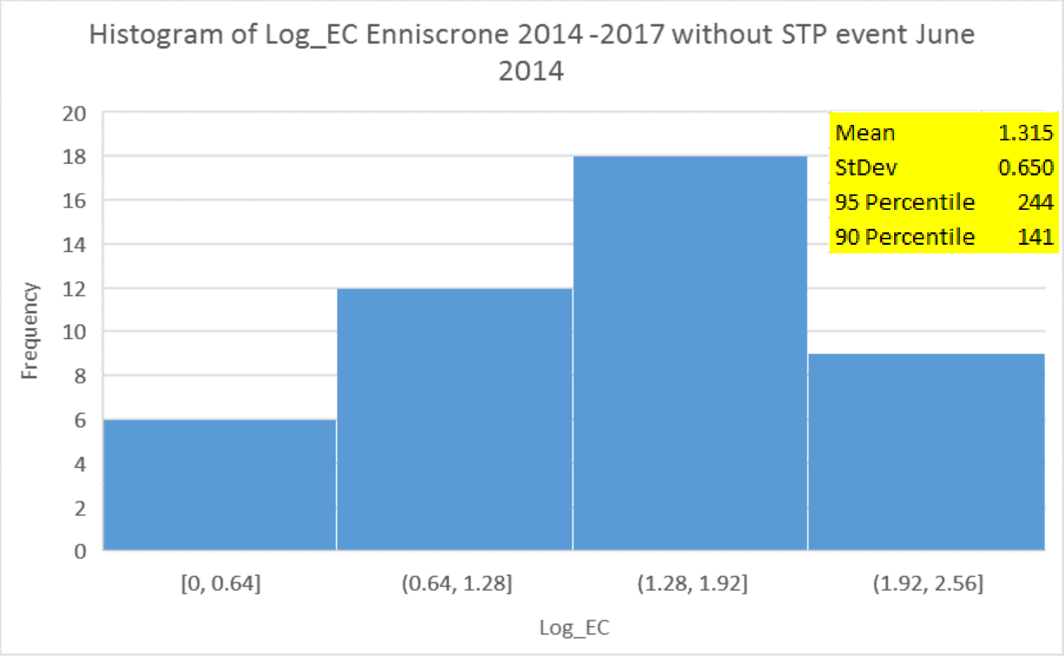


Figure 86: Histogram of log E. coli & descriptive statistics for compliance samples at Enniscrone (2014 – ***2017****) minus result from STP June 2014.*

Note 95%ile result of 244 - ***"Excellent"*** *Water Quality Classification*

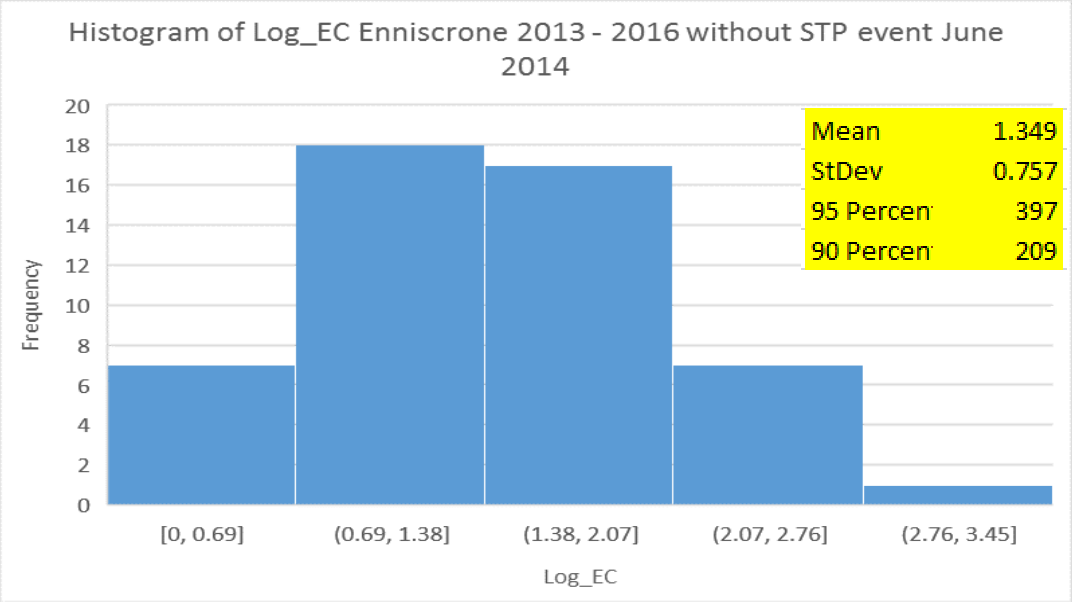


Figure 87: Histogram of log E. coli & descriptive statistics for compliance samples at Enniscrone (2013 – ***2016****) minus result from STP June 2014.*

Note 95%ile result of 397 - ***"Good"*** *Water Quality Classification*

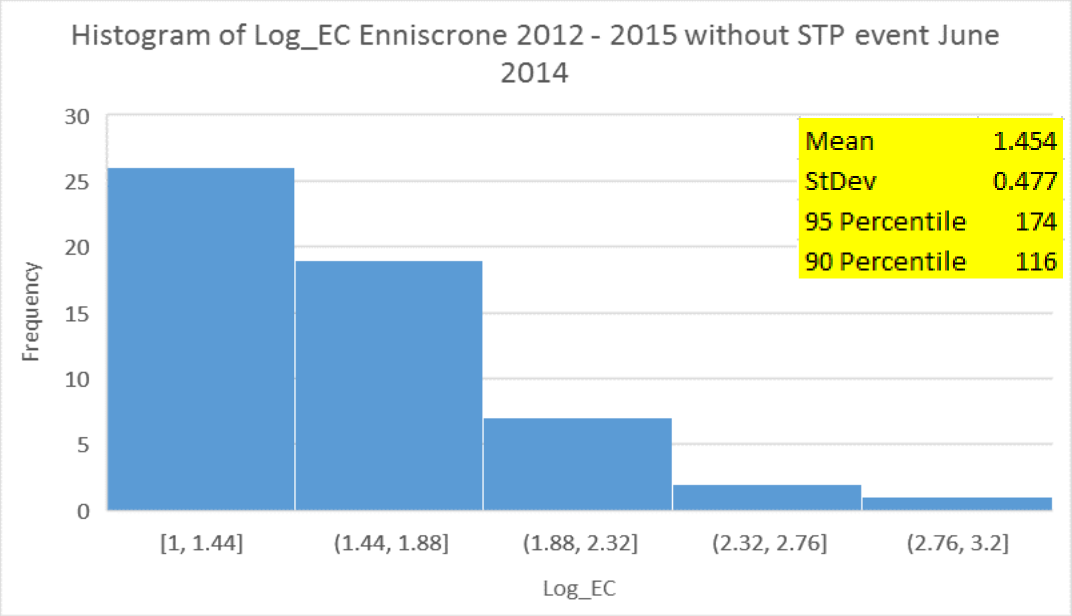


*Figure 88: Histogram of log E. coli & descriptive statistics for compliance samples at Enniscrone (2012 – **2015**) minus result from STP June 2014.*

*Note 95%ile result of 174 - **"Excellent"** Water Quality Classification*

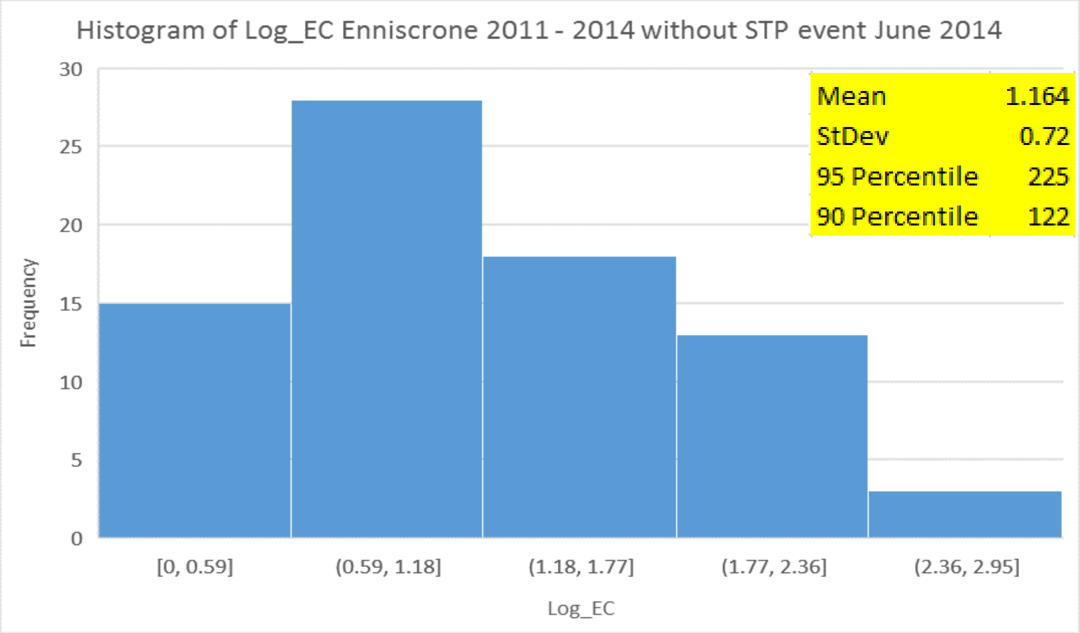


*Figure 89: Histogram of log E. coli & descriptive statistics for compliance samples at Enniscrone (2011 – **2014**) minus result from STP June 2014.*

*Note 95%ile result of 225 - **"Excellent"** Water Quality Classification*

Table 22: Annual bathing water quality classification results based on the E. coli 95%ile for each assessment period

Assessment Period	95%ile Result	Classification
2014-2017	382	Good
2013-2016	463	Good
2012-2015	262	Good
2011-2014	266	Good

Table 23: Annual bathing water quality classification results based on the E. coli 95%ile for each assessment period ***minus the STP event of June 2014****

Assessment Period	95%ile Result	Classification
2014-2017	244	Excellent
2013-2016	397	Good
2012-2015	174	Excellent
2011-2014	225	Excellent

*Note: Replaced by "clean" sample

It can be seen from the analysis above that 1 STP event in 2014 involving *E. coli* affected the bathing water classification at Enniscrone for the following 4 years including the study period. This has meant that the top *Excellent* classification could not be attained. If the bathing water regulations had been fully established by this time and the STP event predicted in advance by a warning system, then this result could have been disregarded and replaced with a clean sample when the event was over. *Excellent* water quality and the *Blue Flag* could have been retained for 3 out 4 of the last 4 years. This highlights the persistent impact a STP event can have when it coincides with compliance monitoring of the bathing water and why management systems are essential to deal with STP.

The impact of the change in the sampling calendar (compliance samples are now taken 1/fortnight compared to 1/week up to and including 2014) can be seen in the 2016 result. This change means that there is less data to calculate the 95-percentile (i.e. in the overall 2016 calculation there is now 2 years with data that use 10 instead of 15 sampling events for the bathing season). The sampling occurrences have dropped from 61 in total over the 4 years to 2014, to 50 in total over the 4 years to 2016 and 45 up to 2017. The significance of this for the future is that any unpredicted STP event that affects a compliance sample will have a much more severe impact on the classification result for years afterwards.

This analysis demonstrates the perils that can befall a bathing water like Enniscrone if no environmental management tools are formulated to deal with STP. Other possible outcomes using STP event data from this study are contained in Appendix E.

Key outcome: STP events that coincide with compliance monitoring will persistently affect the official classification of Enniscrone’s bathing waters.

6 Discussion

6.1 Performance of STP prediction system

This is the crux of this study. As was shown above STP events not only heighten the risk of an impact on public health they also can have a persistent effect on bathing water classification. An accurate STP forecasting system is essential to negate these risks.

The 4 elements of an early warning system (EWS) as described in Section 2.2.5 will be used to assess the performance of the system put in place for this study.

1. Identify the need for a system

Both the supervisory authority Sligo County Council (2016), and the author (Egan, 2015) have concluded that Enniscrone Beach is subject to *short-term pollution* (STP). In cases such as these the *Bathing Water Directive* (Council for the European Communities, 2006) instructs that adequate management measures to predict and deal with STP such as early warning systems must be put in place.

As part of an EWS the locality/catchment should also be assessed. Local conditions and characteristics often make a hazard a local phenomenon. The assessment should identify what conditions give rise to an event. From Egan, (2015) it was evident that local hydro-meteorological conditions were driving the occurrence of STP at Enniscrone beach. This can also be seen in the relationship between rainfall and the river in Sections 5.1.2 and 6.4. and the peaks in the river hydrograph with STP events at the bathing water in Section 5.2.4.

The assessment should also identify what parameters to monitor, where to monitor them and how frequently. From the analysis in Sections 1.1, 5.1.3 and 5.2.1 above it became apparent very early that *E. coli* was the parameter of interest at Enniscrone beach. The analysis in

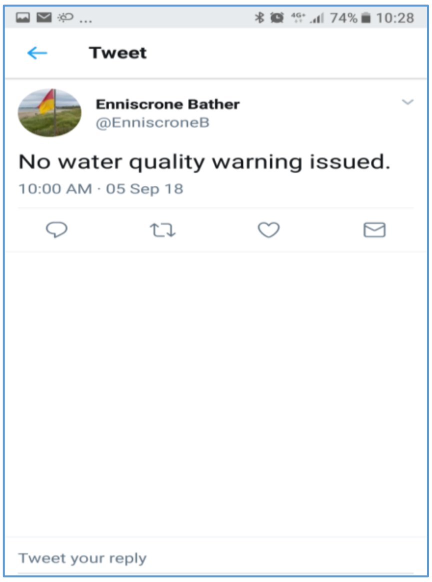
Sections 3.1.2, 5.1.1 and 5.1.4 provided evidence that MP5 would give the most relevant early warning data regarding hydrograph peaks and *E. coli* data. Essentially the critical source areas and surface water linkages for *E. coli* in the catchment were identified and targeted for the installation of the monitoring equipment. This was confirmed by the *E. coli* loadings (concentration and flow) at MP5. As the hydrograph response of the river (Sections 5.1 & 5.2) drives the STP event at the bathing water, continuous water level monitoring at MP5 was identified as data that would be needed in real-time. Finally, the assessment should identify the timing of events as these are crucial to an EWS. These were identified for this system in Section 5.2 and further discussed later in 6.3.1. Overall, the catchment responds very quickly to hydro-meteorological events and this is reflected in the very quick rise in FIO in the bathing water at MP1.

2. Establish & 3. Operate the system

Monitoring parameters and thresholds can be established once a catchment and what occurs within it regarding rainfall, river water level and FIO concentration has been established. As per Section 2.2.5 a monitoring and warning service should be established on a scientific basis, operate 24/7 and be accurate and timely. This EWS identifies STP events in the bathing water rather than model *E. coli* levels in the water. The trigger thresholds were configured as per Section 4.2.5. From the analysis above it could be seen that MP5 was the river catchment site which should be used to produce the alerts. The relationship between its trigger alarms over the 2-year study period (4 alerts for *E. coli* STP with 4 STP events confirmed with no missed events or false positives) corroborates its reliability, precision and accuracy. This is a 100% strike rate for STP events by the system and just as importantly there were no false alerts. This study demonstrated the robustness of the system over a long period of time and in different hydrometeorological conditions. The system was also able to alert in real-time prior to STP events occurring.

The river water level that triggers the alert because of a hydrograph event is monitored by the instrumentation continuously. Alerts are issued in real-time automatically by the instrumentation and a SMS message sent onwards for distribution. An example is given in Appendix F.

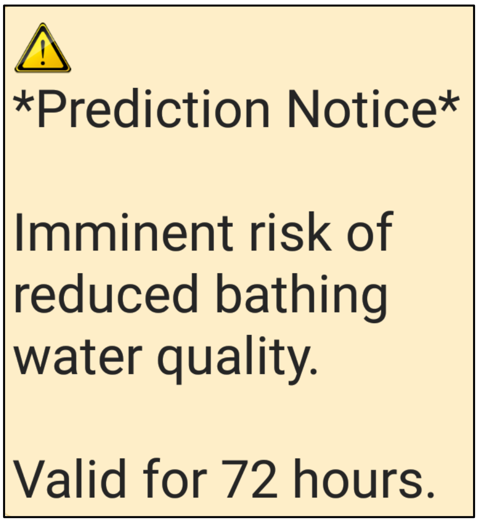
Dissemination of the alerts from the system was achieved by the use of the Twitter® social media platform. Using the Enniscrone Bather (@EnniscroneB) handle a message indicating predicted water quality is issued at 0900 UTC every morning during the bathing season (1st June – 15th September), and for that period that covers the pre-season sample which is taken approximately two weeks before the season starts. When no alert has been received, this message will state "*No water quality warning issued*" as per Fig.96.



No water quality warning issued.

Figure 90: "No water quality warning issued"

When an automatic alert has been received from the system for STP, the following notice (Fig. 97) will be issued promptly:



⚠

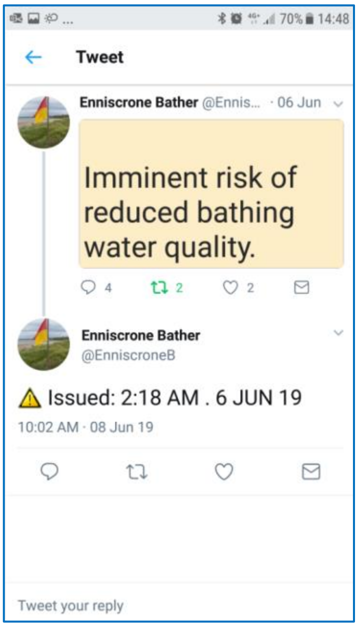
Prediction Notice

Imminent risk of reduced bathing water quality.

Valid for 72 hours.

Figure 91: Notification tweet

The date and time of the alert is embedded in the tweet. This alert tweet will be repeated at 0900UTC on the following 3 mornings with the alert time and date highlighted again also (Fig. 98).



Enniscrone Bather @Ennis... · 06 Jun

Imminent risk of reduced bathing water quality.

Enniscrone Bather
@EnniscroneB

⚠ Issued: 2:18 AM . 6 JUN 19

10:02 AM · 08 Jun 19

Figure 92: Repeat tweet of the Notice

The system will then revert to the original statement unless a fresh warning has been issued or there is additional information available. The twitter page is shown below in Fig. 99.

Enniscrone Bather
@EnniscroneB Follows you

This project has developed a real-time forecast system for water quality at Enniscrone beach during the bathing season.

Enniscrone Co. Sligo

4 Following **19** Followers

Pinned Tweet
Enniscrone Bather @En... · 18 Aug 18

integrated approach based on hydrodynamic modelling using E. coli levels, relevant hydro-meteorological parameters and real-time data-d n hydro-informatic tools.

Disclaimer: This Bathing Water Q
Forecast System is purely for research

Enniscrone Bather
47 Tweets

Enniscrone Bather @En... · 14 Sep 18
No water quality warning issued.

Enniscrone Bather @En... · 13 Sep 18
No water quality warning issued.

Enniscrone Bather @En... · 12 Sep 18
The forecast system monitors on a continuous 24/7 basis. If a dip in bathing water quality at Enniscrone beach is predicted a notification tweet will be issued here immediately.

Enniscrone Bather @En... · 12 S
No water quality warning issued.

Figure 93: Twitter® site used to disseminate real-time water quality information

Further information is also available on a pinned tweet:

"To inform the public, this project has developed a bathing water quality forecast system by predicting temporary dips in water quality at Enniscrone beach. The forecast system is developed from an integrated approach based on hydrodynamic modelling using E. coli levels relevant hydro-meteorological parameters and real-time data-driven hydro-informatic tools".

Another tweet repeats the message that "*The forecast system monitors on a continuous 24/7 basis. If a dip in bathing water quality at Enniscrone beach is predicted a notification tweet will be issued here immediately*."

A disclaimer will be displayed on the profile page and is available in Appendix F.

This is clear information available to those who use or manage the bathing water and is freely disseminated. As accuracy of the prediction is the most important element of this system (public health, tourism) and because of the topography of the catchment involved with its quick effect on the bathing water, a long lead time for the forecast is not appropriate. The system as the results show, indicates the risk of STP accurately and precisely in real-time.

The final stage of the warning process is action based on the alerts. This is the responsibility of the local authority who may choose to use the system. Responses would be based on the provisions of the Water Framework Directive as outlined in Section 2.1.1. with the extra advantages outlined in Section 2.2.4. It would also have to consider any EPA information note that may apply. The EPA's Office of Environmental Assessment produced a *Guidance on Reviewing BW Profiles and Identifying and Assessing Pressures in BW Profiles* in August 2013 for local authorities who manage Ireland's bathing waters. In it they discuss that after reviewing all the bathing water profiles submitted to the EPA, some issues were identified as areas that could be improved. These included:

- that management measures were often more of a wish list than an action list
- that sources like wastewater plants are dealt with but surface waters are omitted from management measures
- mitigation methods are often aspirational

Also, it states that in assessing potential impact sources, the risk assessment should also mention if there are any known correlations between sources and events such as heavy rainfall. Any correlations should ideally be supported by quantitative monitoring data. Local knowledge is also important when managing impacts like STP. It appears there has been little progress on this since 2013.

The EPA prefers if the notice is given the day before any predicted deterioration (Webster, 2018b) but how far in advance depends on the factors that trigger the pollution event. The author would propose that the quickest response to a warning like the one from this study would be the hoisting of the red (no swimming) flag immediately and the positioning of the fixed “Prior Warning” signage indicating that STP is predicted. This gives the benefit of immediately indicating to the public a risk of a dipping in water quality and also means that any sampler taking compliance samples can note the warning and so allow the sample result to be disregarded if needs be. It would also give time for any actions outlined in Section 2.2.4 to be started. If the system is officially used it would be essential that documented procedures with decision tree tools be established to provide effective environmental management to the event.

As was outlined above (Section 2.2.6) there were 24 precautionary STP notifications in Ireland in 2016 but pollution was confirmed as occurring on only 2 occasions (Webster, 2017). For 2017 where it was anticipated that a STP event may occur, only 2 out of 120 resulted in any increase in bacterial levels (Webster, 2018a) This indicates strongly that STP predictive models in Ireland are not working and are inaccurate and imprecise or not robust. The "Prior Warning" notice is being used as a screen for a *possible* deterioration in water quality. As was outlined when reviewing forecasting systems in Section 2.2.5 false warnings damage the local tourist industry and undermine any warning system as people will soon deem it unreliable and ignore it. This approach may also be counter-intuitive to the legal definition of STP in the Directive.

Conversely, no STP Warnings were issued for Enniscrone during the study period (2016 – 2017) even with the author measuring 4 such events. This means that bathers were exposed to a risk of illness because of STP. As was discussed above if any of these STP events occurred during compliance sampling the official annual classification for the next 4 years would have been adversely affected. This would have generated the associated negative publicity which a seaside resort is very sensitive to. The impact on the bathing water classification would again have made the *Blue Flag* unattainable.

The final element of the warning system is that it should be maintained, validated and adjusted if needs be. This could be done by confirmatory samples being taken occasionally by the authority when STP is predicted at a time not scheduled for compliance sampling and also by the *end of event* samples. The hydrometric structures would also need to be maintained and calibrated. Until a more formal structure is put in place the author undertakes to further maintain and validate the system including STP and *end of event* monitoring of *E. coli* in the bathing water. This is not done elsewhere in Ireland. This is important and highlighted by Milly et al in

2008 who state that in a nonstationary world, continuity of observations is critical. Prediction systems for bathing water will have to be sensitive enough to account for further variations in local hydrometeorological conditions caused by climate change. For example, climate change will lead to alterations to the type of rainfall received in the west of Ireland. More short-lived high-intensity showers predicted for the summer months suggests that any EWS for bathing water will need to be adaptable. Water resource management has been based on the idea that natural systems fluctuate within an unchanging envelope of variability but with the magnitude of hydroclimatic change this is not fit for purpose. Water managers who develop systems for their local communities need high resolution data from climate scientists. Climate scientists need explicit data from local water managers to understand climate change. Continuous data is essential for this.

6.2 Statistical anomaly observed

It was noted during this statistical analysis that the minimum detection limit (MDL) of the official *E. coli* results for 2016 and 2017 for Enniscrone has changed from 10 to 1 (Table 14). This is most likely due to a change of *E. coli* enumeration method because of a switch in contracted laboratories i.e. from IDEXX® MPN (MDL 10) to membrane filtration (MDL 1). As was outlined in Section 2.1.1 under *Classification and quality status of bathing waters* where results of zero are obtained in bathing water the MDL is used for the classification calculation. This change to using a different MDL figure could have a serious direct adverse impact on the official results for Enniscrone’s (and others) bathing waters caused by a statistical anomaly (widening of the standard deviation) and not because of STP.

Official assessment results for *E. coli* in 2017 (382) and 2016 (463) are highlighted in yellow below in Table 25.

Table 24: Higher 95 percentile result caused by statistical anomaly with a change of E. coli test method and Lower Detection Limit (LDL)

	Mean of log *E. coli* results		St Dev		95%ILE	90%ILE
E Coli results 2017-14 (Using current LDLs)	1.372851411		0.732996		382	205
E Coli results 2017-14 (Using unchanged LDL)	1.506184744		0.530143		240	153
E Coli results 2016-13 (Using current LDLs)	1.404061663		0.764628		463	242
E Coli results 2016-13 (Using unchanged LDL)	1.524061663		0.590389		315	191

Both years give a result which is in the “Good” annual classification for Bathing Water. However, if the test method (& thus the LDL) had not changed in 2016 the official results would have been 240 for 2017 and 315 for 2016 (highlighted in blue). This would have meant that the bathing water would have achieved “Excellent” annual classification in 2017.

It can be seen that the widening of the standard deviation caused by a lower LDL (that is used in the place of monitoring results of zero – zero cannot be used in the calculation of standard deviation) has given a higher result for the annual (4-year set) classification for 2016 and 2017. The significant consequences of regulatory authorities changing their *E. coli* enumeration methods will be highlighted to them as a result of this research. In addition, any proposed change in enumeration methods in future directives/legislation will need to take this anomaly into account.

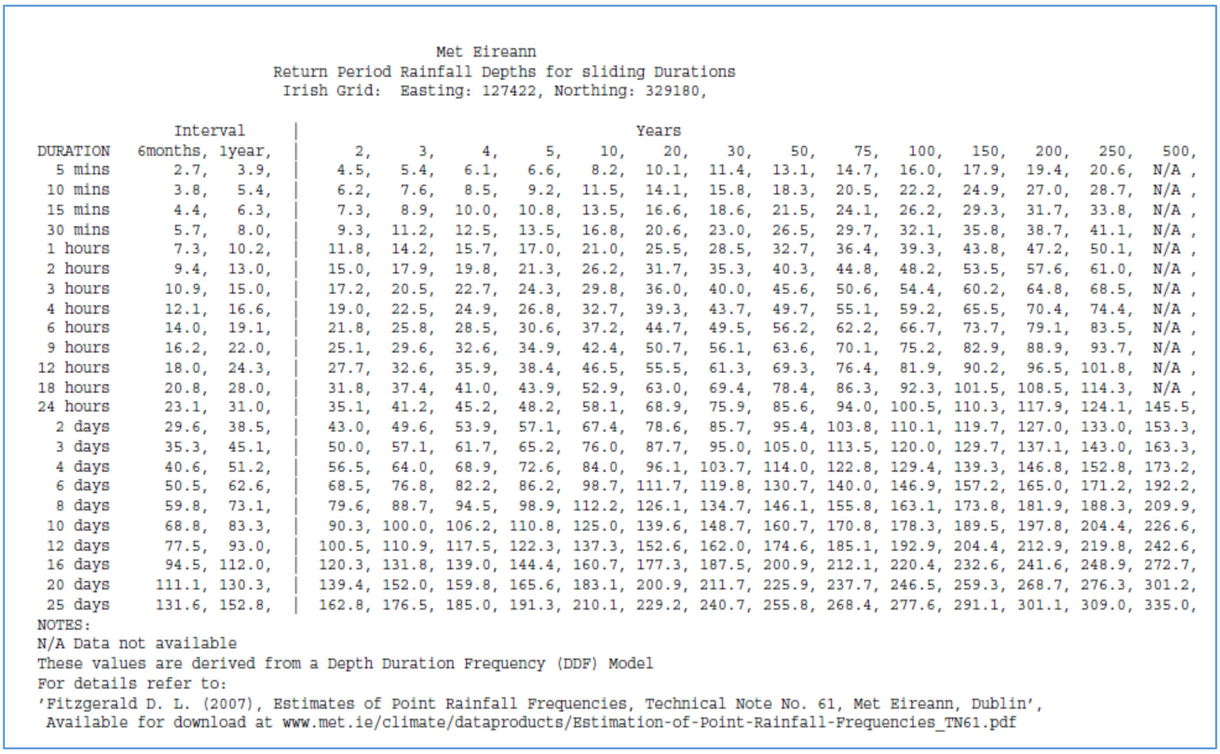
6.3 Rainfall

As was noted earlier, Kay et al., (2008), Wyer et al., (1996) and Crowther et al., (2002, 2003) observed that faecal indicator organism concentrations increase in response to a hydrograph event in a river caused by localised intense rainfall.

On the morning of the 14/06/2016 there was a very intense rain event in the local Enniscrone area. It started at 0600 and finished at 1130 UTC. The most intense period was in the first 3 hours. Daily rainfall at MP4 for the 13/06/2016 was recorded at 44.3 mm and only 7.5 mm for the 14th of June However, the author observed the weather to be dry on the 13/06/2016. The rain gauge was emptied at circa 0900 (UTC) on the 14/06/2016 and so would account for most of the intense period of rainfall in the early morning of 14/06/2016. The rest of the 14/06/2016 was observed to be dry. It would be most probable that the large majority of the 51.8 mm of rainfall fell on that morning. If a round figure of 50 mm is taken for the daily rainfall on the 14th June than this would indicate a 1 in 5-year rainfall event according to Met Éireann figures derived from a Depth Duration Frequency model for MP4 (see below – Table 26). If a conservative figure of 40 mm / 24h is used this would indicate a 1 in 2-year event. However, the rainfall was observed to last about 5.5 hrs which would indicate a 1 in 10-year event. Whatever the intensity there can be no doubt that this was the largest STP event for the 2 years of this study with a peak level of 30,000 *E. coli* /100 ml enumerated from the bathing water. This grossly polluted water posed a health risk. The hourly rain gauges had not been installed at this stage.

The effect of these rainfall events on the river are illustrated in Figs. 90 -93 below.

Table 25: Return period rainfall depths for sliding durations – Enniscrone. Source: Met Éireann



```
                                 Met Eireann
                  Return Period Rainfall Depths for sliding Durations
                   Irish Grid:  Easting: 127422, Northing: 329180,

              Interval     |                                Years
DURATION   6months, 1year, |     2,     3,     4,     5,    10,    20,    30,    50,    75,   100,   150,   200,   250,   500,
  5 mins      2.7,   3.9,  |   4.5,   5.4,   6.1,   6.6,   8.2,  10.1,  11.4,  13.1,  14.7,  16.0,  17.9,  19.4,  20.6,   N/A ,
 10 mins      3.8,   5.4,  |   6.2,   7.6,   8.5,   9.2,  11.5,  14.1,  15.8,  18.3,  20.5,  22.2,  24.9,  27.0,  28.7,   N/A ,
 15 mins      4.4,   6.3,  |   7.3,   8.9,  10.0,  10.8,  13.5,  16.6,  18.6,  21.5,  24.1,  26.2,  29.3,  31.7,  33.8,   N/A ,
 30 mins      5.7,   8.0,  |   9.3,  11.2,  12.5,  13.5,  16.8,  20.6,  23.0,  26.5,  29.7,  32.1,  35.8,  38.7,  41.1,   N/A ,
  1 hours     7.3,  10.2,  |  11.8,  14.2,  15.7,  17.0,  21.0,  25.5,  28.5,  32.7,  36.4,  39.3,  43.8,  47.2,  50.1,   N/A ,
  2 hours     9.4,  13.0,  |  15.0,  17.9,  19.8,  21.3,  26.2,  31.7,  35.3,  40.3,  44.8,  48.2,  53.5,  57.6,  61.0,   N/A ,
  3 hours    10.9,  15.0,  |  17.2,  20.5,  22.7,  24.3,  29.8,  36.0,  40.0,  45.6,  50.6,  54.4,  60.2,  64.8,  68.5,   N/A ,
  4 hours    12.1,  16.6,  |  19.0,  22.5,  24.9,  26.8,  32.7,  39.3,  43.7,  49.7,  55.1,  59.2,  65.5,  70.4,  74.4,   N/A ,
  6 hours    14.0,  19.1,  |  21.8,  25.8,  28.5,  30.6,  37.2,  44.7,  49.5,  56.2,  62.2,  66.7,  73.7,  79.1,  83.5,   N/A ,
  9 hours    16.2,  22.0,  |  25.1,  29.6,  32.6,  34.9,  42.4,  50.7,  56.1,  63.6,  70.1,  75.2,  82.9,  88.9,  93.7,   N/A ,
 12 hours    18.0,  24.3,  |  27.7,  32.6,  35.9,  38.4,  46.5,  55.5,  61.3,  69.3,  76.4,  81.9,  90.2,  96.5, 101.8,   N/A ,
 18 hours    20.8,  28.0,  |  31.8,  37.4,  41.0,  43.9,  52.9,  63.0,  69.4,  78.4,  86.3,  92.3, 101.5, 108.5, 114.3,   N/A ,
 24 hours    23.1,  31.0,  |  35.1,  41.2,  45.2,  48.2,  58.1,  68.9,  75.9,  85.6,  94.0, 100.5, 110.3, 117.9, 124.1, 145.5,
  2 days     29.6,  38.5,  |  43.0,  49.6,  53.9,  57.1,  67.4,  78.6,  85.7,  95.4, 103.8, 110.1, 119.7, 127.0, 133.0, 153.3,
  3 days     35.3,  45.1,  |  50.0,  57.1,  61.7,  65.2,  76.0,  87.7,  95.0, 105.0, 113.5, 120.0, 129.7, 137.1, 143.0, 163.3,
  4 days     40.6,  51.2,  |  56.5,  64.0,  68.9,  72.6,  84.0,  96.1, 103.7, 114.0, 122.8, 129.4, 139.3, 146.8, 152.8, 173.2,
  6 days     50.5,  62.6,  |  68.5,  76.8,  82.2,  86.2,  98.7, 111.7, 119.8, 130.7, 140.0, 146.9, 157.2, 165.0, 171.2, 192.2,
  8 days     59.8,  73.1,  |  79.6,  88.7,  94.5,  98.9, 112.2, 126.1, 134.7, 146.1, 155.8, 163.1, 173.8, 181.9, 188.3, 209.9,
 10 days     68.8,  83.3,  |  90.3, 100.0, 106.2, 110.8, 125.0, 139.6, 148.7, 160.7, 170.8, 178.3, 189.5, 197.8, 204.4, 226.6,
 12 days     77.5,  93.0,  | 100.5, 110.9, 117.5, 122.3, 137.3, 152.6, 162.0, 174.6, 185.1, 192.9, 204.4, 212.9, 219.8, 242.6,
 16 days     94.5, 112.0,  | 120.3, 131.8, 139.0, 144.4, 160.7, 177.3, 187.5, 200.9, 212.1, 220.4, 232.6, 241.6, 248.9, 272.7,
 20 days    111.1, 130.3,  | 139.4, 152.0, 159.8, 165.6, 183.1, 200.9, 211.7, 225.9, 237.7, 246.5, 259.3, 268.7, 276.3, 301.2,
 25 days    131.6, 152.8,  | 162.8, 176.5, 185.0, 191.3, 210.1, 229.2, 240.7, 255.8, 268.4, 277.6, 291.1, 301.1, 309.0, 335.0,
NOTES:
N/A Data not available
These values are derived from a Depth Duration Frequency (DDF) Model
For details refer to:
'Fitzgerald D. L. (2007), Estimates of Point Rainfall Frequencies, Technical Note No. 61, Met Eireann, Dublin',
 Available for download at www.met.ie/climate/dataproducts/Estimation-of-Point-Rainfall-Frequencies_TN61.pdf
```

Data from the individual rain gauges is given in Appendix D.

Figure 94:Benign river discharging to the beach on the 12/06/16

Figure 95: The same view on the 14/06/16 at 1300UTC after rainfall event in the early morning

Figure 96: MP5 (Tullylinn Br. – main channel) on the 12/06/16

Figure 97: MP5 (Tullylinn Br. – main channel) 14/06/16 after rainfall event

6.3.1 Analysis of river hydrograph

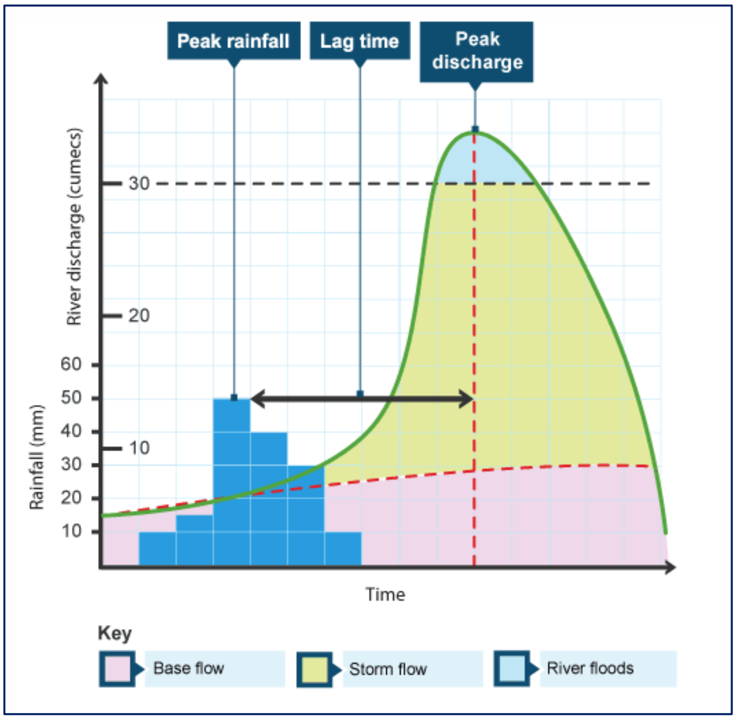


Figure 98: A storm hydrograph is a graph to show how and when a rainfall event affects the discharge of a river. Source: BBC

As was noted earlier intense rainfall events cause the river hydrographs that are used to trigger the STP alert. The purpose of recording hourly rainfall (graphs in Appendix D) was to calculate the lag time between peak rainfall and peak discharge (level) at the river monitoring station. This was done to see how quickly a rainfall event in the catchment affects river discharge as demonstrated in Figure 95. This was averaged at approximately 4 hours as shown in Table 27 below.

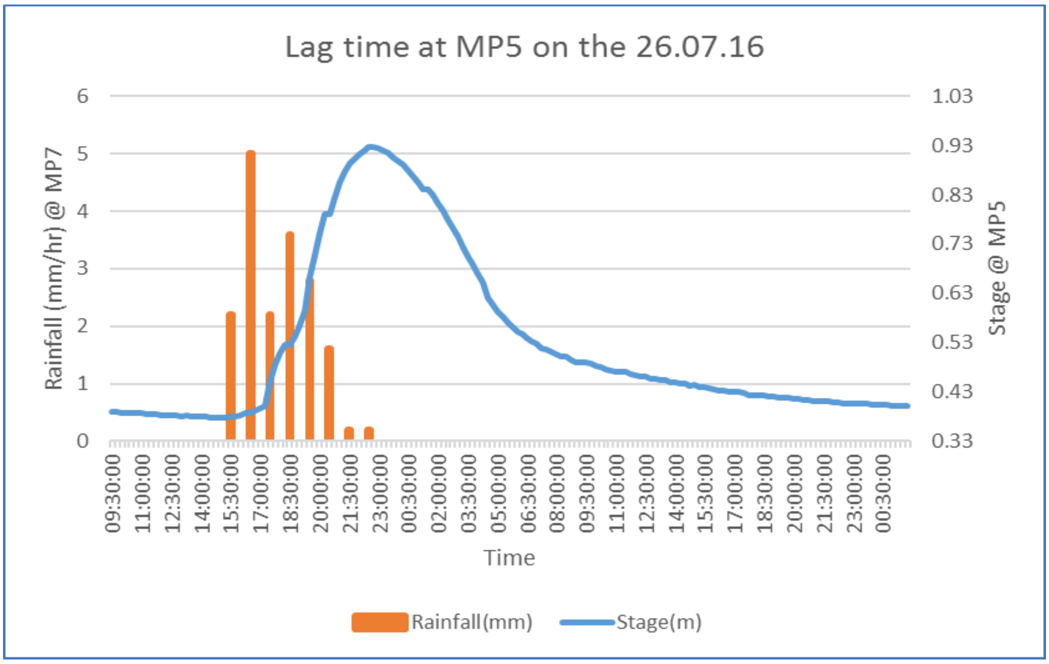


Figure 99: Graphic showing the lag time between peak rainfall at MP7 and peak water level (& so discharge) at MP5 on 26.07.16.

Lag time was calculated at 6 hours

Table 26: Lag times as evaluated above between MP7 (hourly rainfall) & MP5 (main river channel). Calculated for the rainfall events during the study period

Date	Peak rainfall (UTC)	Date	Peak Hydrograph (UTC)	Lag time (hours/minutes)
26/07/2016	16:30	26/07/2016	22:30	6 h
04/08/2016	06:30	04/08/2016	10:15	4 h 45 m
17/08/2016	13:30	17/08/2016	17:00	3 h 30 m
18/08/2016	00:30	18/08/2016	04:15	3 h 45 m
03/09/2016	17:30	03/09/2016	22:45	5 h 15 m
04/09/2016	22:30	05/09/2016	04:00	5 h:30 m
				Average 2016 4.7 h
21/07/2017	09:59	21/07/2017	15:45	5 h 45 m
30/07/2017	10:59	30/07/2017	14:15	3 h 15 m
17/08/2017	16:59	17/08/2017	21:15	4 h 15 m
21/08/2017	19:59	22/08/2017	00:00	4 h 00 m
				Average 2017 4.2 h

Note: Hourly rainfall not available for 14/06/16

The peak river hydrograph data at MP5 is then compared to the river peak hydrograph data at the outfall to the beach (MP3) to calculate how quickly the flux of FIO travels to the bathing waters. Using water level peaks during event hydrographs at MP5 (Tullylinn) and MP3 (Enniscrone), the time-of- travel of run-off water was estimated between the 2 stations. This was averaged at 81 minutes as shown in Table 28 below.

Table 27: Travel time of water level peaks between MP5 & MP3

Date	Time of Peak MP5	Date	Time of Peak MP3	Travel time (hours)
26/07/2016	22:30	27/07/2016	01:15	02:45
14/06/2016	13:15	14/06/2016	13:45*	00:30
04/08/2016	10:15	04/08/2016	13:00	02:45
18/08/2016	04:15	18/08/2016	06:00	01:45
05/09/2016	04:00	05/09/2016	04:30	00:30
04/10/2016	05:30	04/10/2016	06:00	00:30
18/11/2016	18:45	18/11/2016	20:30	01:45
23/12/2016	11:45	23/12/2016	13:15	01:30
26/02/2017	07:30	26/02/2017	08:00	00:30
04/03/2017	06:00	04/03/2017	08:00	02:00
27/05/2017	14:00	27/05/2017	15:15	01:15
21/07/2017	15:45	21/07/2017	16:00	00:15
30/07/2017	14:15	30/07/2017	15:15	01:00
17/08/2017	21:15	18/082017	00:30	03:15
22/08/2017	00:00	22/08/2017	00:45	00:45
27/09/2017	17:15	27/09/2017	18:00	00:45
				Average = 81 minutes

*estimate

The short lag times calculated above displays the flashy nature of the catchment above MP5. This would be caused by the small catchment size at this point (as precipitation falls on the catchment it would have less time to travel to meet the main channel of the river). Also, the general impermeable nature of the sub-soil would have a large influence along with the numerous small surface streams. This is in line with the outcomes from the catchment analysis in Section 3.1.1. The short travel time of water flowing from MP5 near the top of the catchment to the river outlet at MP3 reflects the small catchment size of the Bellawaddy river above Enniscrone. This analysis signifies that a short lead time is necessary for the forecast or prediction of STP.

6.4 Project limitations

There are several limitations to this project. No account was made for the state of the tide, birds, wind speed and direction and currents in the sea. These were beyond the scope of the study. It was envisaged that a real-time corroborative system could be developed using the Supervisory Control and Data Acquisition (SCADA) system at MP9. However, this was not possible due to constraints outside the control of the author. Results using manual recordings of this data at MP9 are given in Appendix C.

7 Conclusion

Under the new Bathing Water Directive (2006/7/EC) EU countries are required to be pro-active in protecting public health at bathing waters by predicting and warning of dips in water quality at beaches where STP events occur. Diffuse sources of FIO in catchments can easily cause non-compliance with the Directive. Furthermore, research recognises that these fluxes of FIO from catchments are highly episodic and driven by rainfall events. This manifests in short-term high stream-flow events that adversely impact bathing water quality. Therefore, the risk period is usually short, clearly defined and predictable. The management methods promulgated by the new directive put an emphasis on the target of the standard (bathers) along with a related flexibility to achieve compliance. This is very important as the European Court of Justice has held that the duty to comply with quality standards is generally an absolute one, and that doing what is reasonably practicable is not enough (Bell et al., 2017).

The aim of this project was to develop an environmental management forecast system that can predict and indicate short term pollution (STP) at Enniscrone beach using local hydro-meteorological data. This was achieved by determining the relationship between levels of *E. coli* in the bathing water and hydrograph events in the Bellawaddy river catchment. The prediction is based on the likelihood of elevated levels of *E. coli* in the bathing water in response to fluxes of faecal indicator bacteria being washed down the catchment by rainfall events. Monitoring sites for this study were based on previous research and new sites were developed that were located after innovative analysis of the catchment. New monitoring infrastructure were installed and configured in conjunction with real-time data-driven hydro-informatic tools.

This project also aimed to run real-time predictions of bathing water quality at Enniscrone Beach for the 2016 and 2017 bathing seasons to test the system. This was successfully completed with a 100% strike rate with no missed events or false positives.

The initial view of the literature confirmed the serious risk of inputting streams causing STP events at beaches. However, the ability to accurately predict these events is difficult and the automated real-time equipment required by good operational warning systems is sparsely used for beaches and very rare in Ireland.

In the spirit of the WFD (involvement of locals and citizen science) the “Hong Kong” approach is adopted where advisory data is freely disseminated (Thoe and Lee, 2014).

The author believes that when this system went “live” for the summer of 2018 it was the first operational automatic real-time bathing water prediction system in Ireland.

The conclusions of the project are:

Assessment of impacts on the bathing water

- The Bellawaddy River is a clear source of STP in Enniscrone's bathing waters.
- Large loadings of FIO are discharged to the bathing water in episodes strongly reflecting local hydro-meteorological events.

Environmental management of the bathing water

- An automatic real-time EWS using local data was devised which could accurately and clearly indicate conditions where there was an imminent risk of STP at Enniscrone Beach.
- Catchment specific investigations and models are essential for developing a robust real-time EWS for the prediction of STP
- For accuracy and precision in predicting STP from a small river catchment, a small forecast lead time is necessary.
- This management method would protect bathers' health at Enniscrone.
- This management method would help ensure that Enniscrone's bathing waters achieve "Excellent" status under the new Bathing Water Regulations.
- This environmental management system would contribute to the economy of the seaside resort of Enniscrone.

Recommendations arising from this project are as follows:

- The 4th element of an EWS (2.2.3) recommends that any system should be maintained validated and adjusted. This can be done using mandatory “end of event” samples which confirm STP events have finished. Some samples could be taken during STP events to validate the alert trigger levels. This could lead to a readjustment of the warning trigger levels giving a longer forecast lead time. To accomplish this more data is needed.
- If used, actions based on the system alerts would need to be agreed and documented by the regulatory authority in a procedure with decision trees where relevant. Ongoing collaboration with the authority will also be essential if the system is consulted by them.
- It is recognised that if a system is employed that predicts STP then more sampling would have to take place to confirm the event has finished. This extra cost would be offset by the current situation where extra samples are taken when a STP event coincides with compliance samples to fulfil HSE and EPA requirements. However, if the techniques in Section 2.2.4 regarding flexibility of sampling if STP is predicted and warned of, then these sampling events will not be necessary. What would be required is not more sampling and sample analysis but more flexible sampling and analysis.
- Local data in conjunction with an assessment of local aspects and impacts should be used in any management method to predict/ascertain STP. As referenced by the directive, investigations should take place for bathing waters individually as each one consists of unique localised characteristics influenced by different topographical and other parameters. Unique models will better serve the aims of the directive rather than a “one size fits all” approach.

- Management tools used need to be accurate and precise. Any major errors could put bathers' health at risk or in the obverse cause undue disruption and economical harm to a bathing water resort.
- A study on the impact of changing the test method (and thus the minimum detection limit) on the statistical analysis of bathing waters in Ireland and the EU should be urgently undertaken

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Appendix A

Literature Review – Bathing water legislation (Section 2.1.1).

Note: The precision of 95-percentile is higher when the sample number is increased. The pooling of results from a rolling 4-year data set gives a better precision in the results. The classification assessment is now based on all the compliance data for the previous 4 bathing seasons (on a rolling basis) as opposed to the old method which assessed the most recent season only. By 2015 EU member states should have ensured that all bathing waters are of *sufficient* quality or better. If a bathing water is classified as *poor* for 5 consecutive years (even with improvement measures) than a permanent advice against bathing must be implemented.

Each bathing water classification will now carry an EU pictogram which is displayed for each beach at www.beaches.ie and locally on a noticeboard to indicate the result of the latest 4-year water quality assessment. They are standard across the EU and are in English and national languages (Webster, 2017).

'Excellent' quality

'Good' water quality

'Sufficient' water quality

'Poor' water quality

Figure 100: EU bathing water classification signs

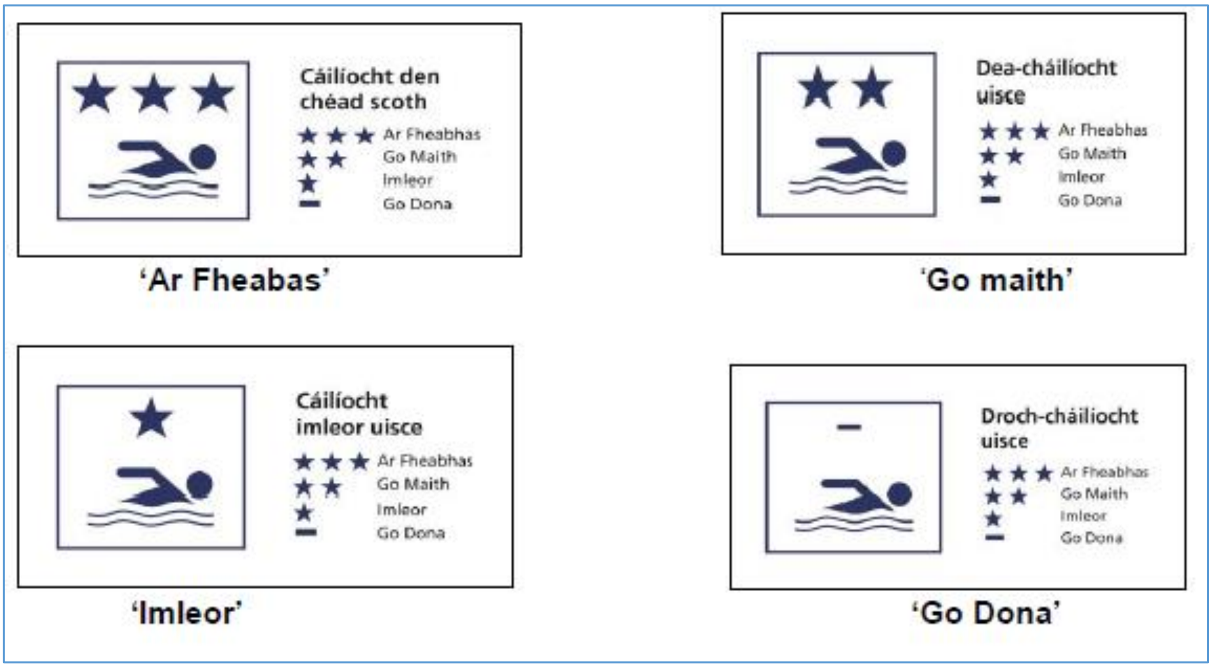


Figure 101: Comharthaí aicmithe uisce snámha

Appendix B

Methods – hydrometric (Section 4.2.3).

Trimble® survey results to establish temporary bench marks (TBM) & subsequent levelling.

MP6 (Stokane)

TBM (located at yellow ↑at hydrant valve LHS Br. XY E 532290.804 m N 826166.549 m) = **72.736 mOD Malin** (OSGM 15)

Staff Gauge Zero = **70.611 mOD** Malin (OSGM 15)

Difference = 2.125 m

MP5 (Tullylinn)

TBM (located at yellow ↑on Br FP d/s. XY E 533433.510 m N 827825.237 m) = **62.607 mOD Malin** (OSGM 15)

Staff Gauge Zero = **59.481 Malin** (OSGM 15)

Difference = 3.126 m

MP3 (Enniscrone)

TBM (located at yellow ↑on concrete seat RHS Br. XY E 528340.690 m N 829715.633 m) = **4.607 mOD Malin** (OSGM 15)

Staff Gauge Zero = **2.2409 mOD Malin** (OSGM 15)

Difference = 2.358 m

Appendix C

Control & possible confirmatory now-casting (Section 6.4).

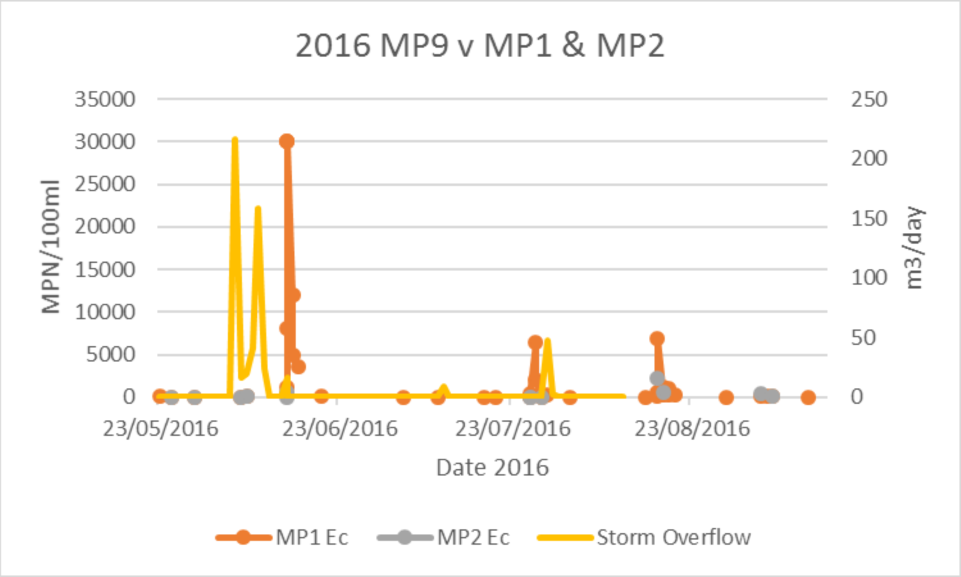


Figure 102: Graph showing discharges from MP9 and E. coli levels in the bathing water (MP1) & the control (MP2) for 2016

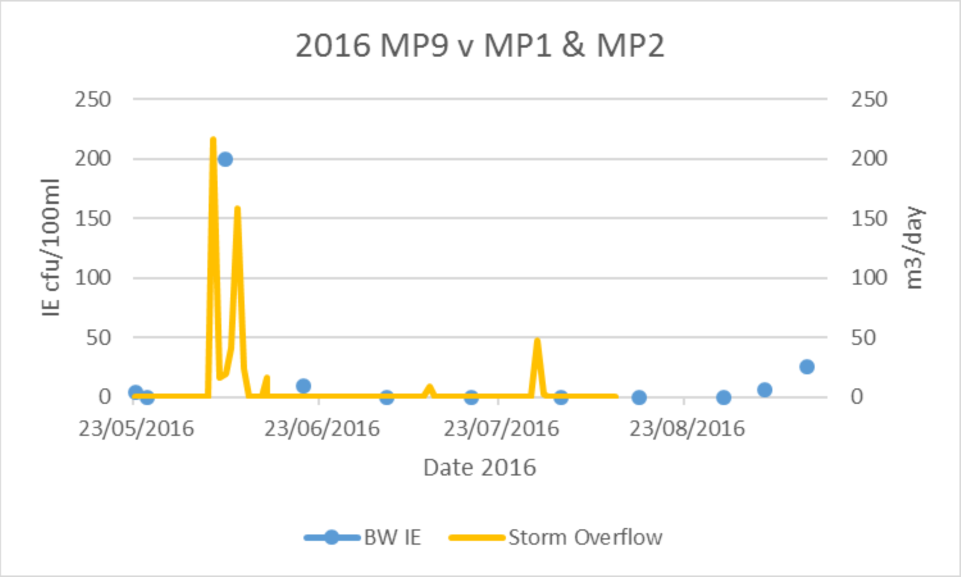


Figure 103: Graph showing discharges from MP9 and intestinal enterococci (IE) levels in the bathing water (MP1) & the control (MP2) for 2016

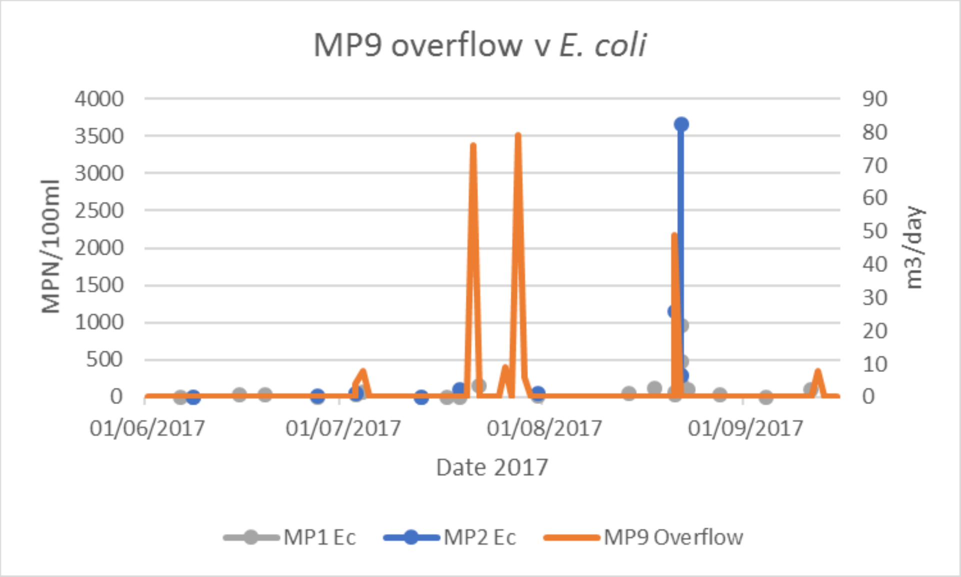


Figure 104: Graph showing storm-tank overflow versus E. coli levels at MP1 (bathing water) & MP2 (control) for 2017

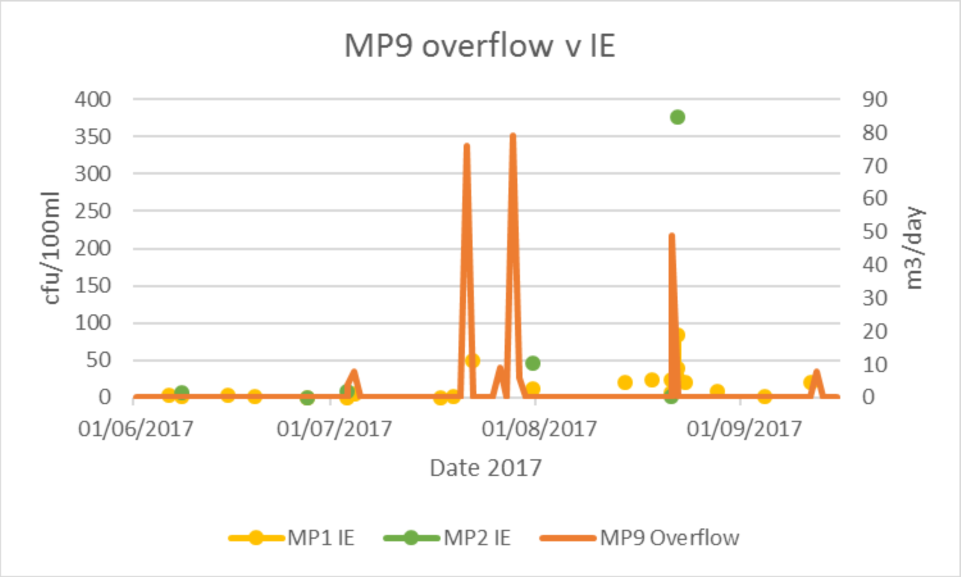


Figure 105: Graph showing storm-tank overflow versus intestinal enterococci (IE) levels at MP1 (bathing water) & MP2 (control) for 2017

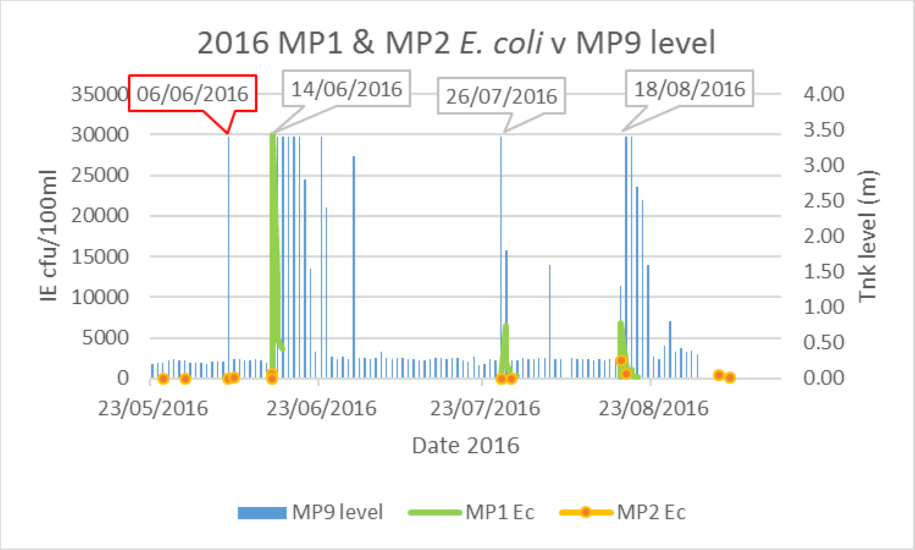


Figure 106: Using MP9 (Storm-water tank level of 3.40 m) to indicate current bathing water conditions (now-cast). However, the method indicated for the 06/06/16 when no E. coli STP event occurred.

Note that the E. coli results for MP2 (control - orange)) situated between the bathing water (MP1- green) & the out flow from the storm-water tank (MP9) graphically demonstrate that the storm-water (or UWWTP waste-water) was not influencing the E. coli levels in the bathing water

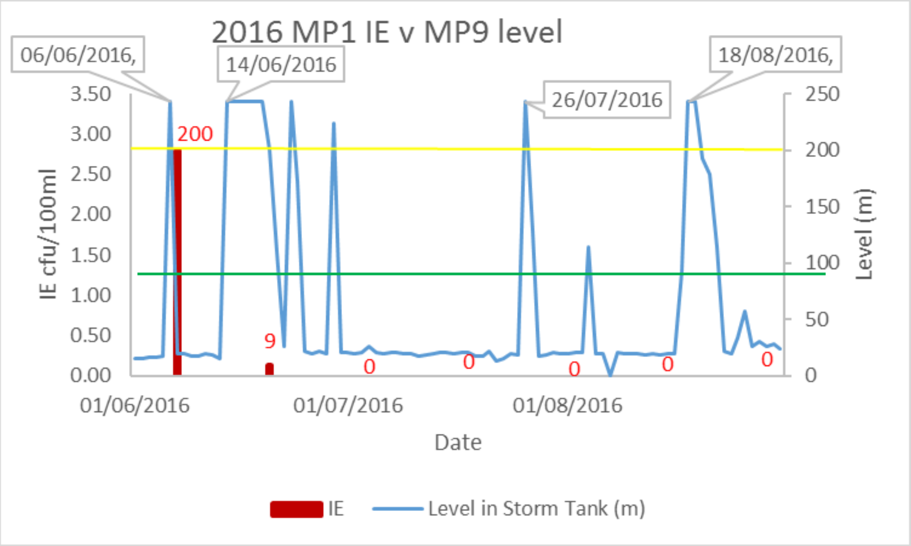


Figure 107: Using the water level in the Storm Water Tank (MP9) to indicate current water quality (now-cast) at Enniscrone bathing water (MP1).

The tank is located at Enniscrone UWWTP. The combined sewer of Enniscrone town collects excess water & sewage caused by any rainfall event which then flows to the tank. The graph showing the 10 official compliance intestinal enterococci (IE) results for 2016 & the level in the storm-water tank. The graph shows the method indicating for the spike of IE levels officially recorded on 07/06/16. Green line=" Excellent "limit. Yellow=" Good". Above yellow=" Sufficient"

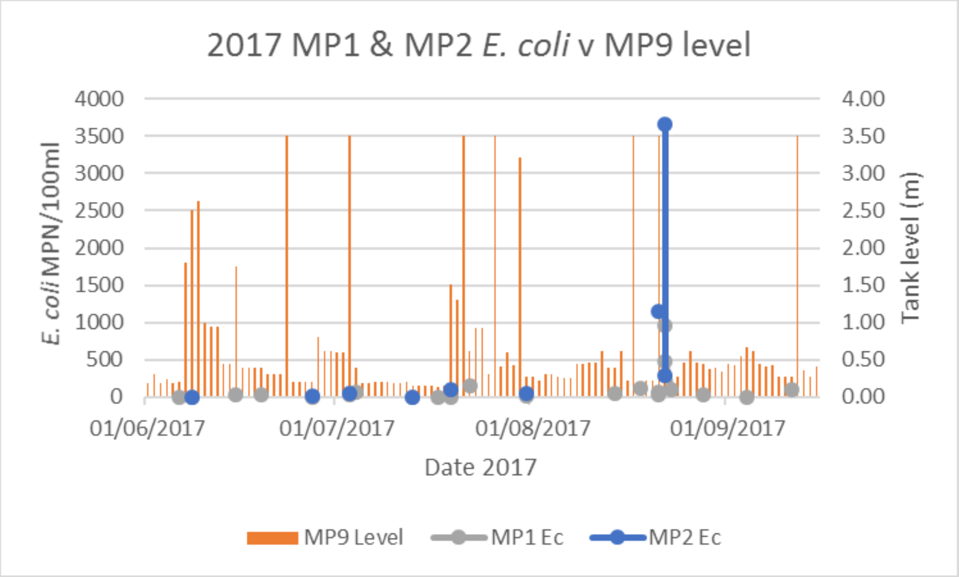


Figure 108: Storm-tank level indicated 7 times for the summer of 2017.

However, there was only 1 STP event for this period. There was a large spike of E. coli at MP2 (control) at that time. It can be concluded that using MP9 (storm-tank level) cannot confirm E. coli STP events at MP1 (bathing water)

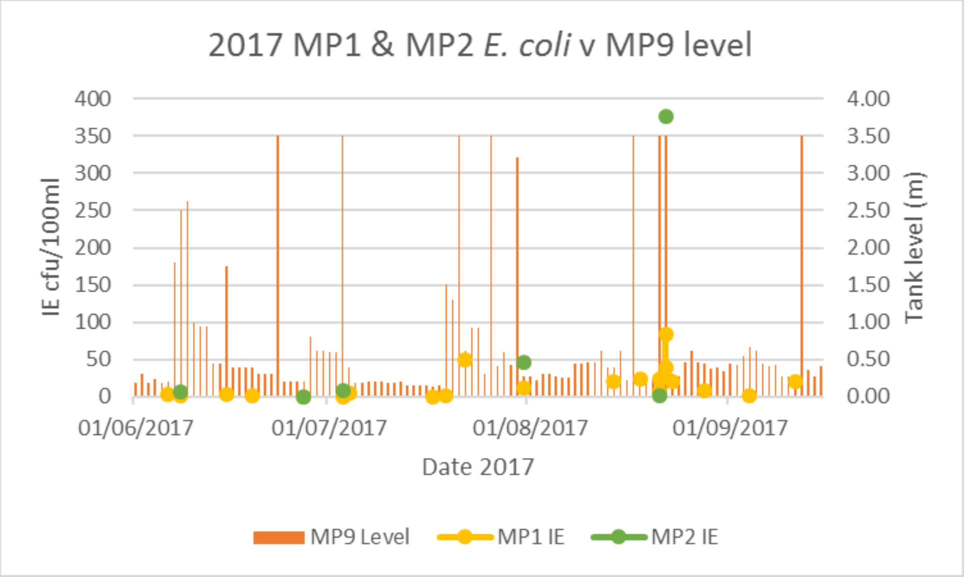


Figure 109: Storm-tank level indicated 7 times for the summer of 2017.

However, there was only 1 STP event for this period. There was a large spike of IE at MP2 (control) at that time. It can be concluded that using MP9 (storm-tank level) cannot confirm IE STP events at MP1 (bathing water)

Appendix D

Results (Section 5).

Table 28: River indicator bacteria loadings for MP6, MP5 & MP3 calculated for targeted sampling dates during the summer of 2016. E. coli highlighted. Loading expressed as FIO/m³/s

		MP6				MP5				MP3				
Date	Time UTC	MP6 T coli	Loading@ MP6 TC/ m³/s	MP6 *E. coli*	Loading@ MP6 Ec/ m³/s	MP5 T coli	Loading@ MP5 TC/ m³/s	MP5 *E. coli*	Loading @MP5 Ec/ m³/s	MP3 T coli	Loading@ MP3 TC/ m³/s	MP3 *E coli*	Loading @MP3 Ec/ m³/s	Prevailing Weather/ Hydrograph state
06/06/2016	17:40	19863	19863	1616	1616	30000	4110000	24192	3314304	3448	1227448	1467	522252	Dry
07/06/2016	17:40	30000	900,000	30000	900000	30000	3810000	12033	1528191	14136	10192056	6131	4420451	Rain previous evening
14/06/2016	07:00	300000	286200000	155307	148162878	325500	3415146000	130900	1373402800	51720	1345133760	15530	403904240	Very heavy intense prolonged rain. Start 06:00
14/06/2016	08:20	300000	49200000	198628	32574992	204600	304854000	77100	114879000	92080	572737600	22470	139763400	Very heavy intense prolonged rain. Rising limb
14/06/2016	10:30									173287	1706876950	57940	570709000	Very heavy prolonged rain. Rising limb
14/06/2016	13:00	365400	401940000	72300	79530000	193500	2071030500	42600	455947800	172200	2514120000	88000	1284800000	Rain stopped 11:00. Near top of peak
14/06/2016	15:45									178500	1522605000	51200	436736000	Receding limb
20/07/2016	20:00	30000	120000	10462	41848	30000	5700000	30000	5700000	2382	9075420	1081	4118610	
26/07/2016	20:00	63200	39184000	26000	16120000	68800	314416000	17100	78147000	14010	147105000	2660	27930000	Heavy intense rain 1600-2100 Rising limb
26/07/2016	21:00	55300	36829800	29300	19513800	62900	368594000	20600	120716000	15970	227412800	6840	97401600	Heavy intense rain 1600-2100 Rising limb
26/07/2016	21:45									70800	1224840000	35800	619340000	Rising limb

Note: Total coliforms (TC) & *Escherichia coli* (Ec) = MPN/100 ml. Intestinal enterococci not measured

Table 29: River indicator bacteria loadings for MP6, MP5 & MP3 calculated for targeted sampling dates during the summer of 2017. E. coli highlighted. Loading expressed as FIO/m³/s

		MP6						MP5						MP3						
Date	Time UTC	MP6 T coli	Loading @MP6 TC/ m³/s	MP6 *E. coli*	Loading @MP6 Ec/ m³/s	MP6 IE	Loading @MP6 IE/ m³/s	MP5 T coli	Loading @MP5 TC/ m³/s	MP5 *E. coli*	Loading @MP5 Ec/ m³/s	MP5 IE	Loading @MP5 IE/ m³/s	MP3 T coli	Loading @MP3 TC/ m³/s	MP3 *E coli*	Loading @MP3 Ec/ m³/s	MP3 IE	Loading @MP3 IE/ m³/s	Weather/Hydrograph state
02/05/2017	16:00	1120	7840	31	217			19863	3773970	17329	3292510			980	673260	135	92745			Dry
11/05/2017	06:30	6488	8369	1986	2562	10	13	6488	875556	4611	622255	60	8097	1553	562963	816	295800	30	10875	Very dry
15/06/2017	07:00													10462	5994726	3255	1865115	720	412560	Recent rain
27/06/2017	06:40													6488	3871714	3255	1942421	120	71610	Recent rain
03/07/2017	09:15	2613	7839	41	123	10	30	12033	1347696	8164	914368	50	5600	5475	1921715	1904	668304	55	19305	Dry
04/07/2017	06:15													14136	12679992	6131	5468852	210	187320	Recent heavy rain
13/07/2017	08:00													168	65688	80	31280			Dry
19/07/2017	19:00													12033	7279965	3255	1969275	290	175450	
02/08/2017	09:00	3654	56711	195	3026	73	1133	5475	3230250	839	495010	127	74930	3654	9807336	669	1795596	112	300608	Recent Rain Rising limb
21/08/2017	19:15													TNTC		24192	248935680	600	6174000	Very heavy rain Rising limb
21/08/2017	21:30													TNTC		24192	348643008	17200	247869200	Very heavy rain Rising limb
21/08/2017	22:00	120960	13992653	38505	4454258	1100	127248	TNTC		120960	1005419520	1400	11636800							MP6 Hydrograph over MP5 Rising limb
22/08/2017	05:10													120960	2269596672	34335	644227605	800	15010400	Falling limb
22/08/2017	16:00													14136	144582301	2247	22982316	98	1002344	End falling limb

Note: Total coliforms (TC) & *Escherichia coli* (Ec) = MPN/100 ml. Intestinal enterococci (IE) = cfu/100 ml

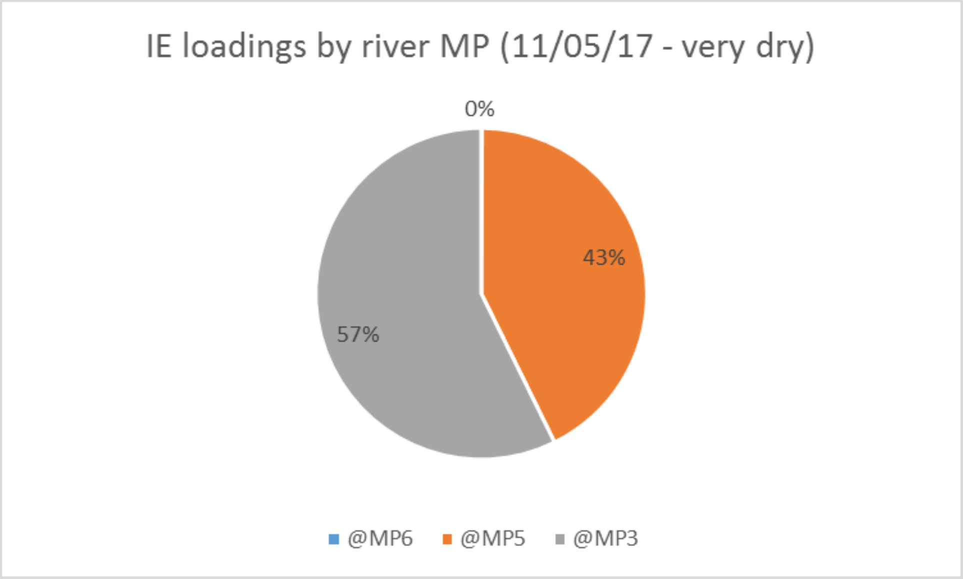


Figure 110: Intestinal enterococci loadings during a dry spell in 2017. MP3 (Enniscrone) is the principal source

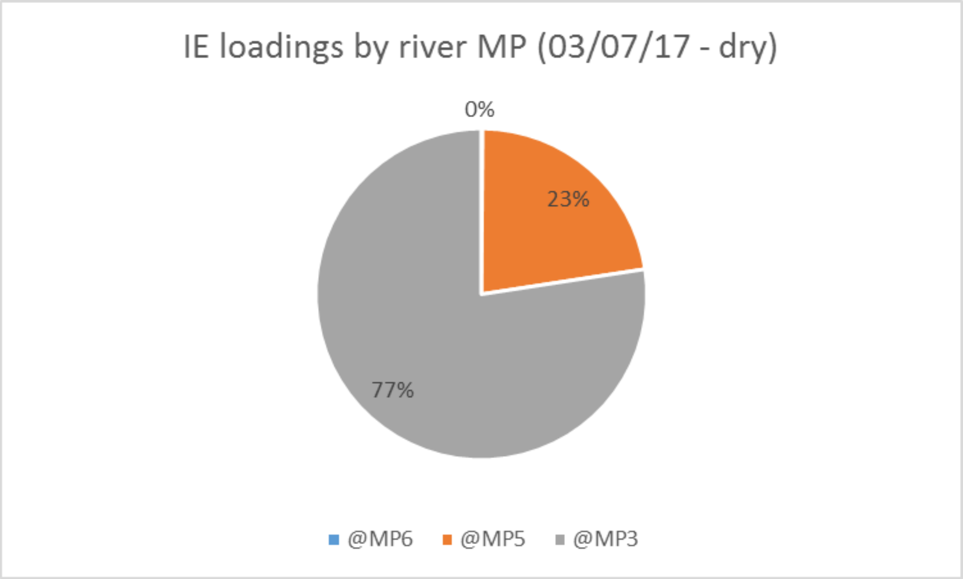


Figure 111: Intestinal enterococci loadings during a dry spell in July 2017. MP3 (Enniscrone) dominates

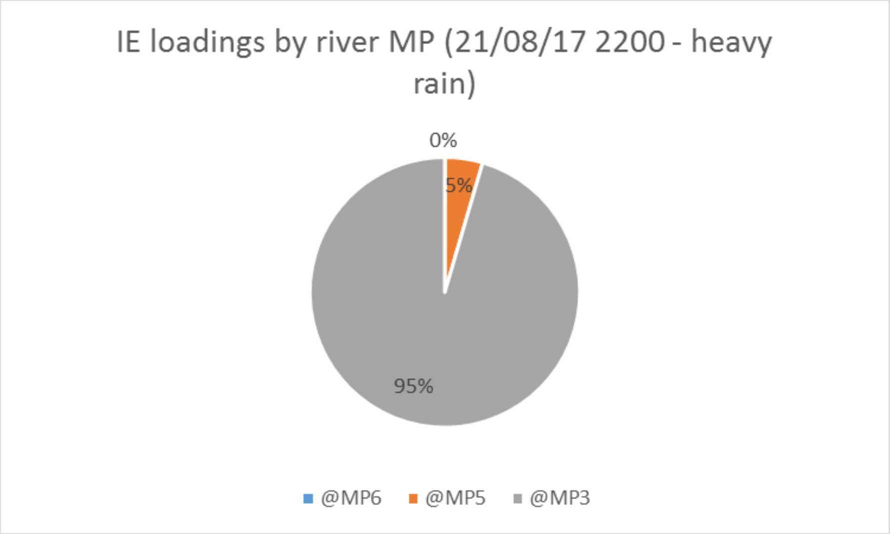


Figure 112: Very heavy rain since 1900.

MP3 (Enniscrone) strongly dominates the intestinal enterococci loading. This could reflect point sources from the urban environment of MP3 (storm-water overflows & missed sewer connections) or the environmental persistence of IE compared to E. coli

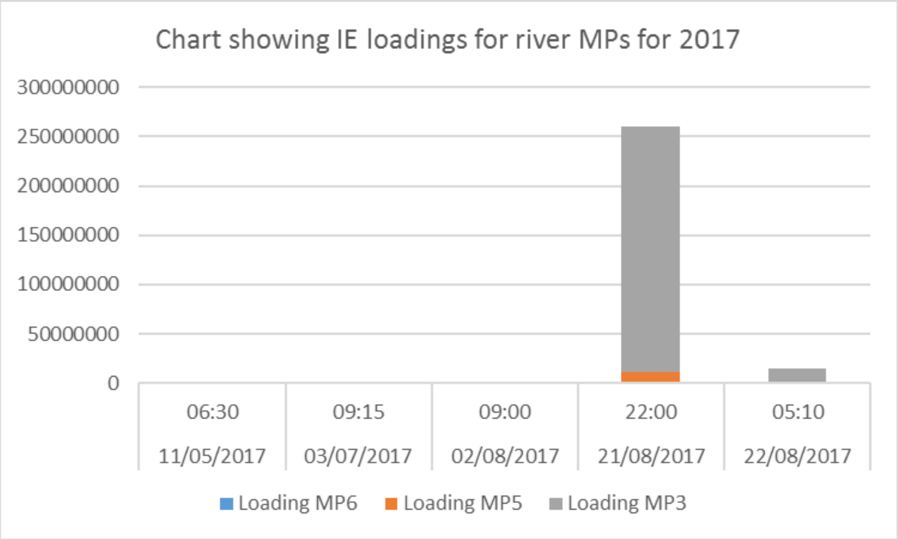


Figure 113: The STP event of the 21/08/17 is very prominent compared to the rest of the summer.

Intestinal enterococci loads are dominated by MP3. Note: The magnitude of the event did not adversely impact on bathing water IE levels

River Hydrographs for 2016 & 2017

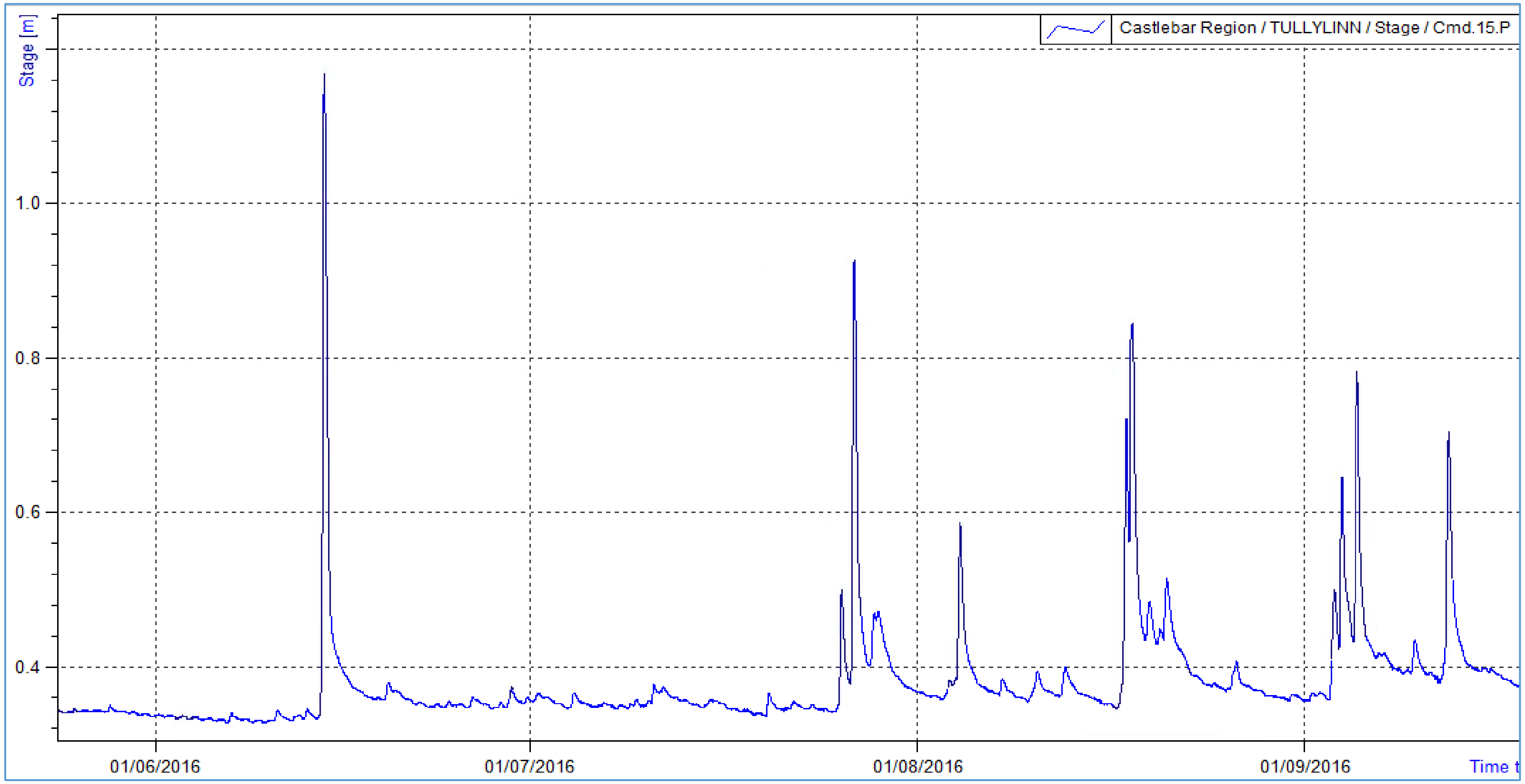


Figure 114: Bellawaddy river water level (stage) hydrograph for the summer of 2016 at MP5 (main channel)

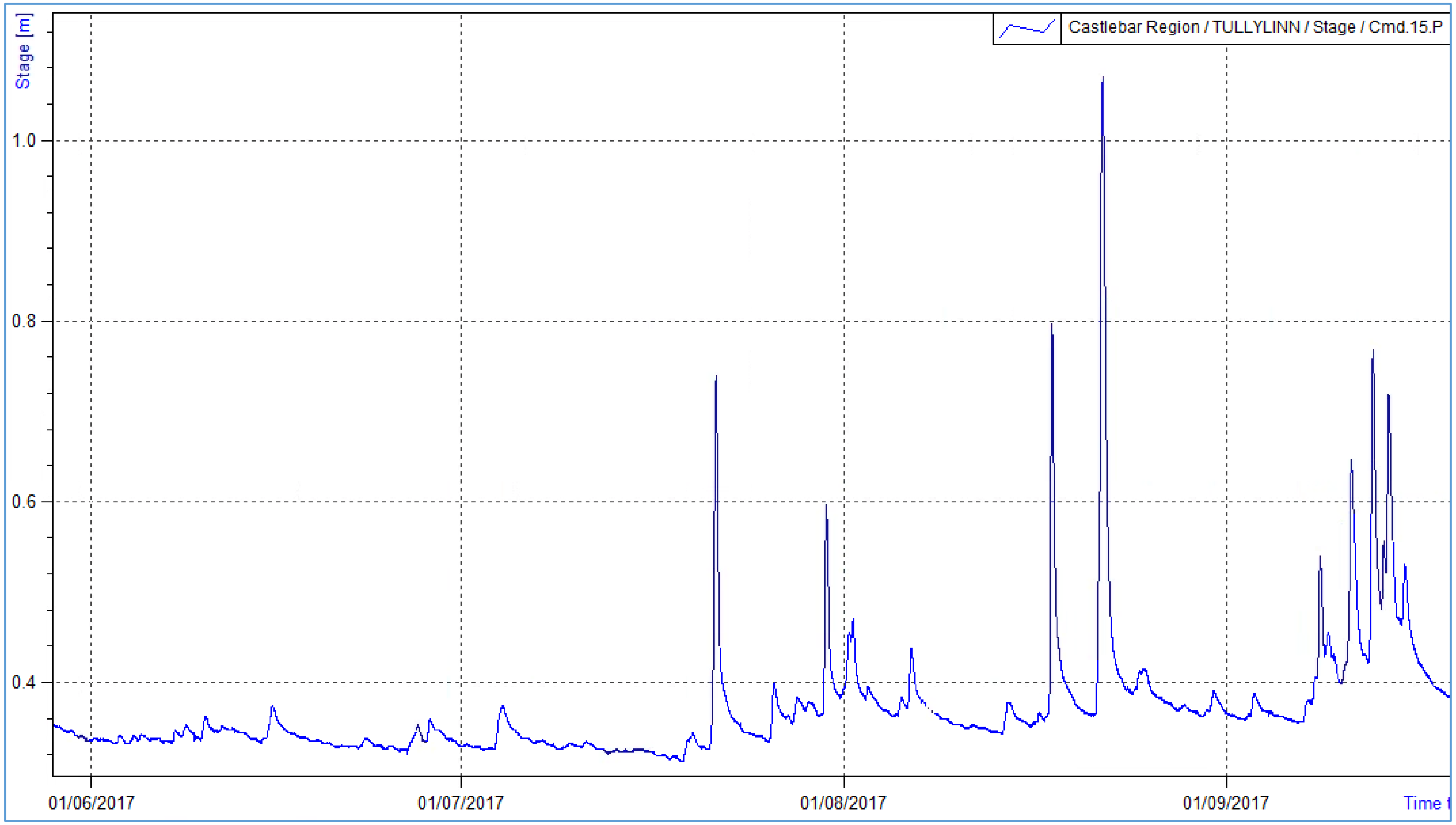


Figure 115: Bellawaddy river water level (stage) hydrograph for the summer of 2017 at MP5 (main channel)

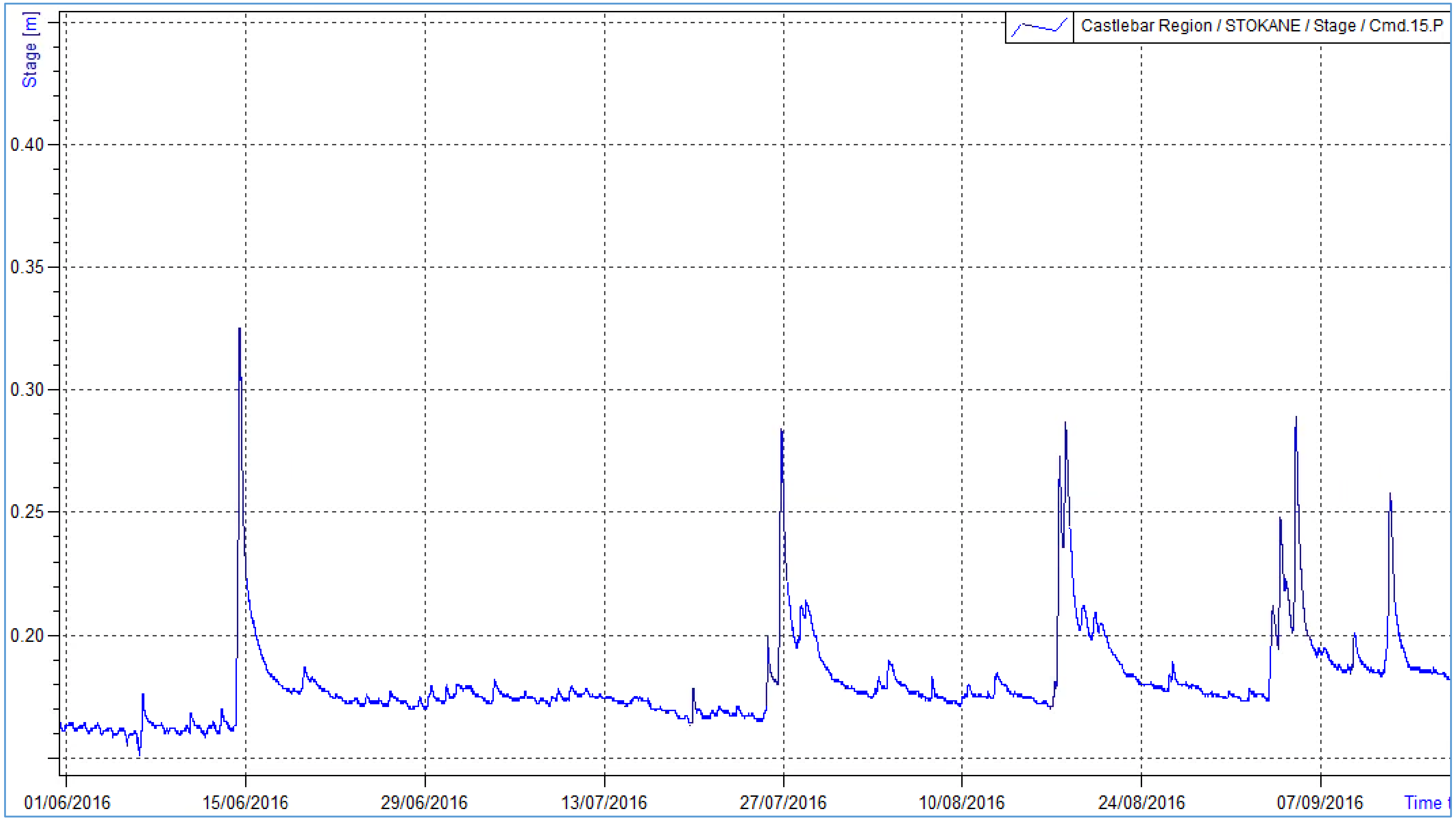


Figure 116: Bellawaddy river water level (stage) hydrograph for the summer of 2016 at MP6

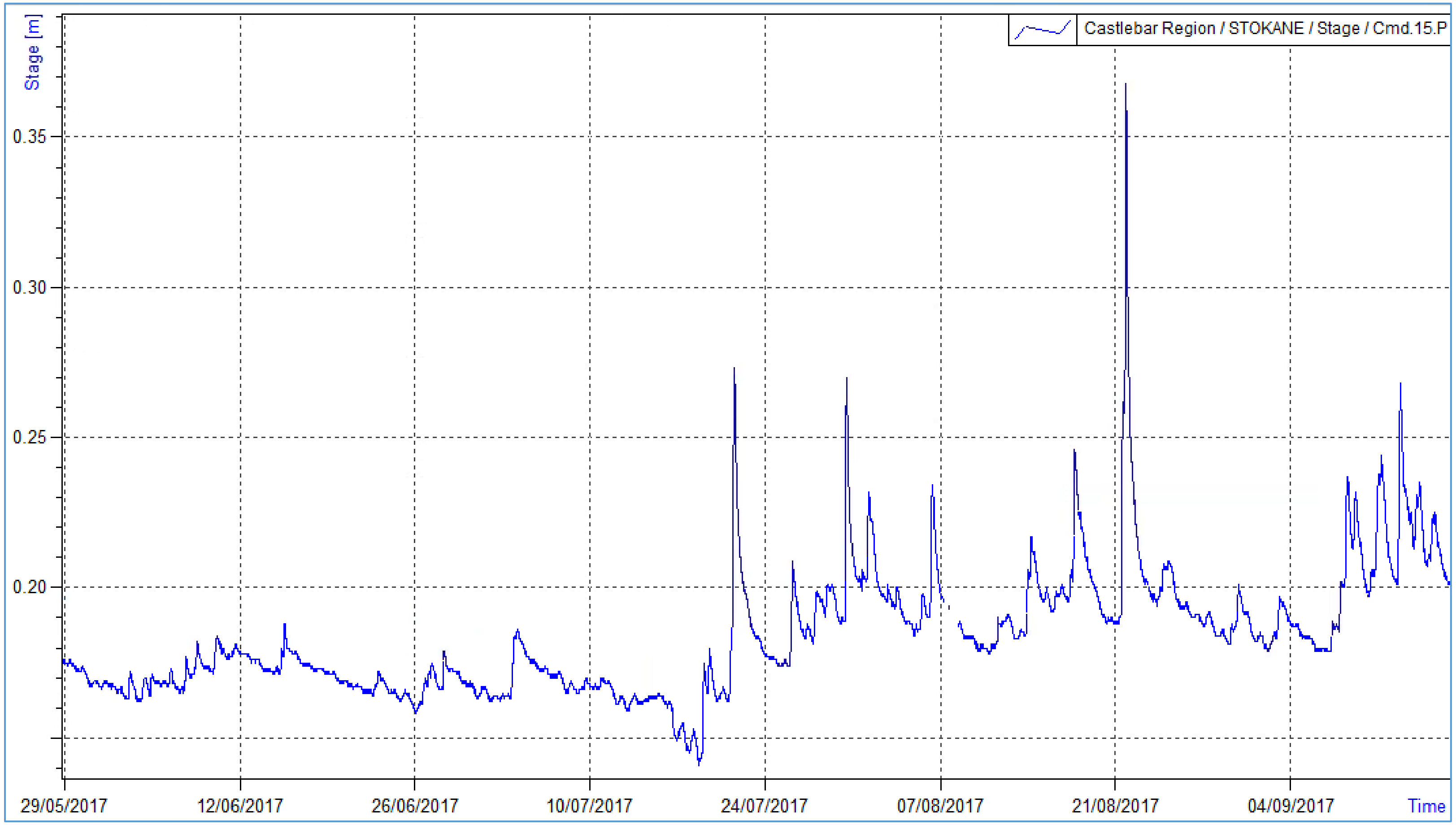


Figure 117: Bellawaddy river water level hydrograph for the summer of 2017 at MP6

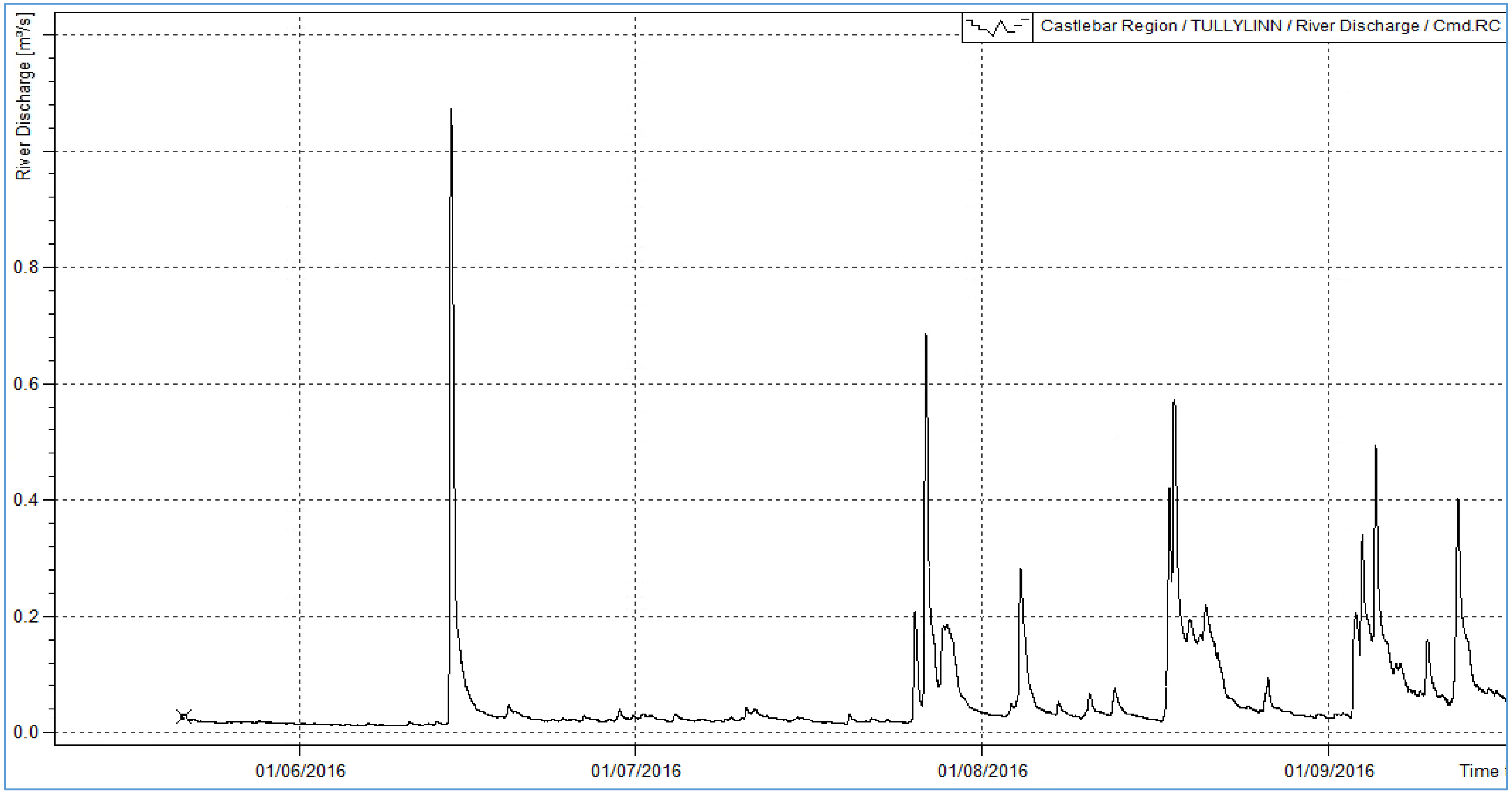


Figure 118: Bellawaddy river discharge hydrograph for the summer of 2016 at MP5(main channel)

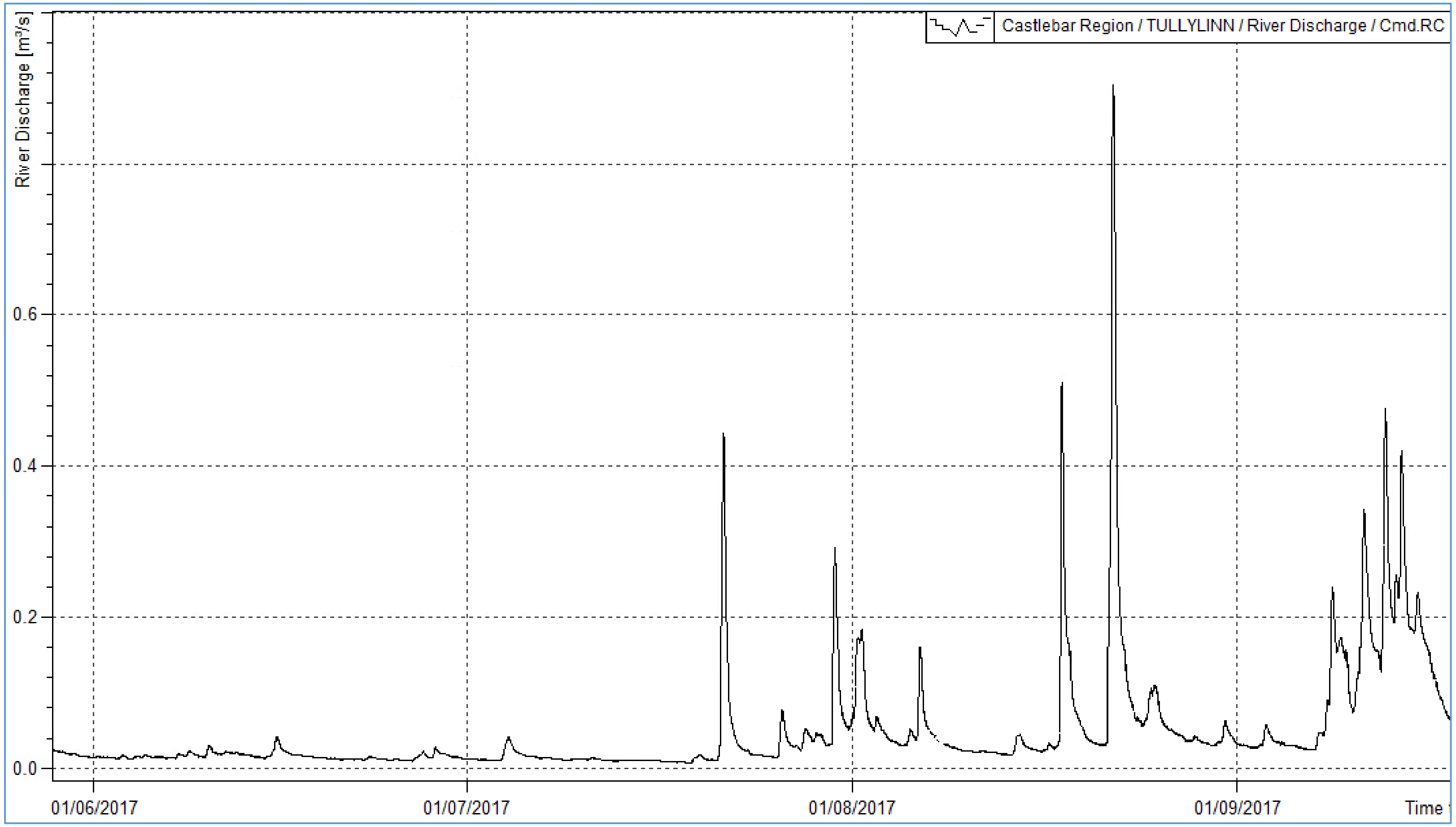


Figure 119: Bellawaddy river discharge hydrograph for the summer of 2017 at MP5(main channel)

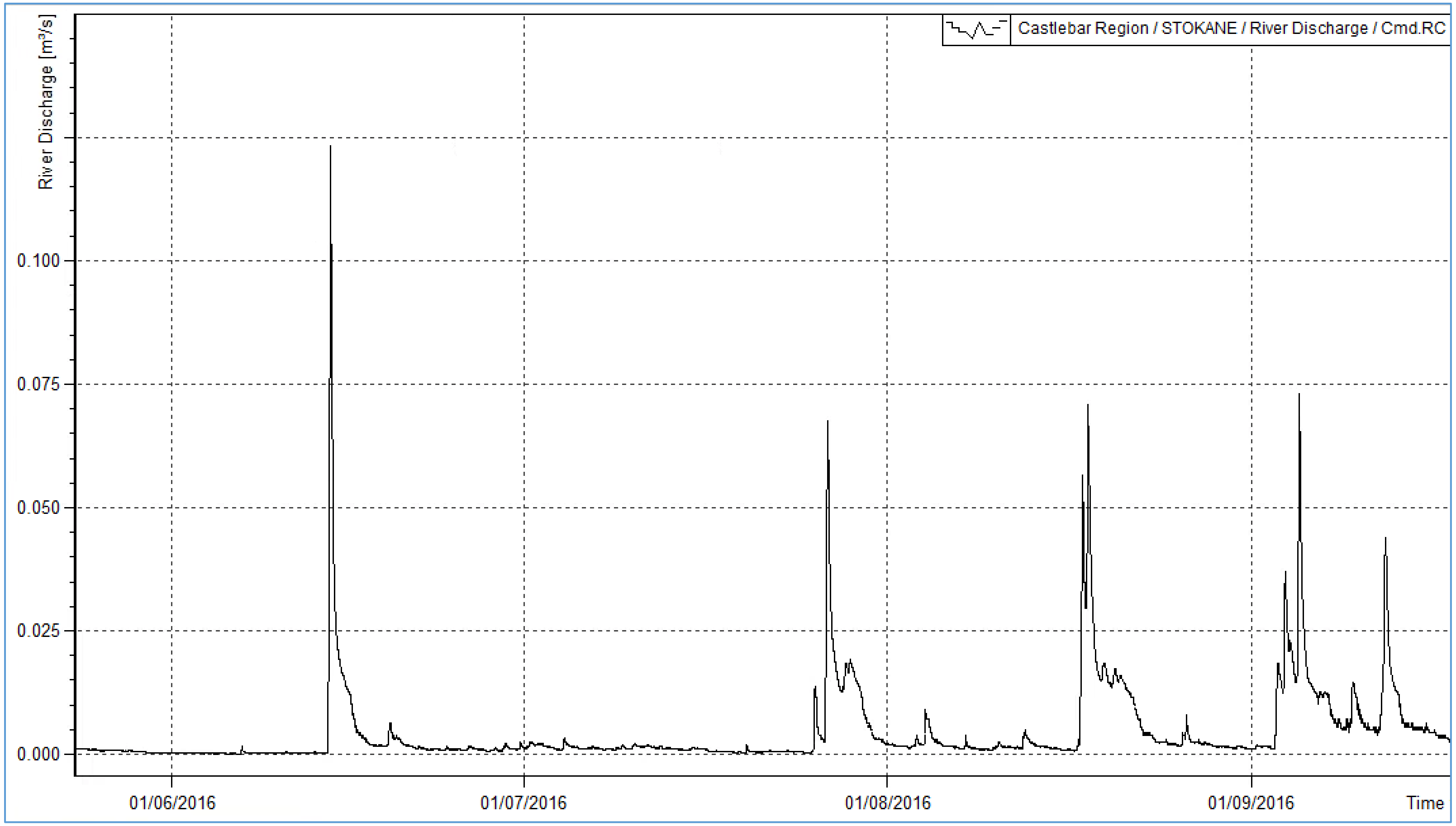


Figure 120: Bellawaddy river discharge hydrograph for the summer of 2016 at MP6

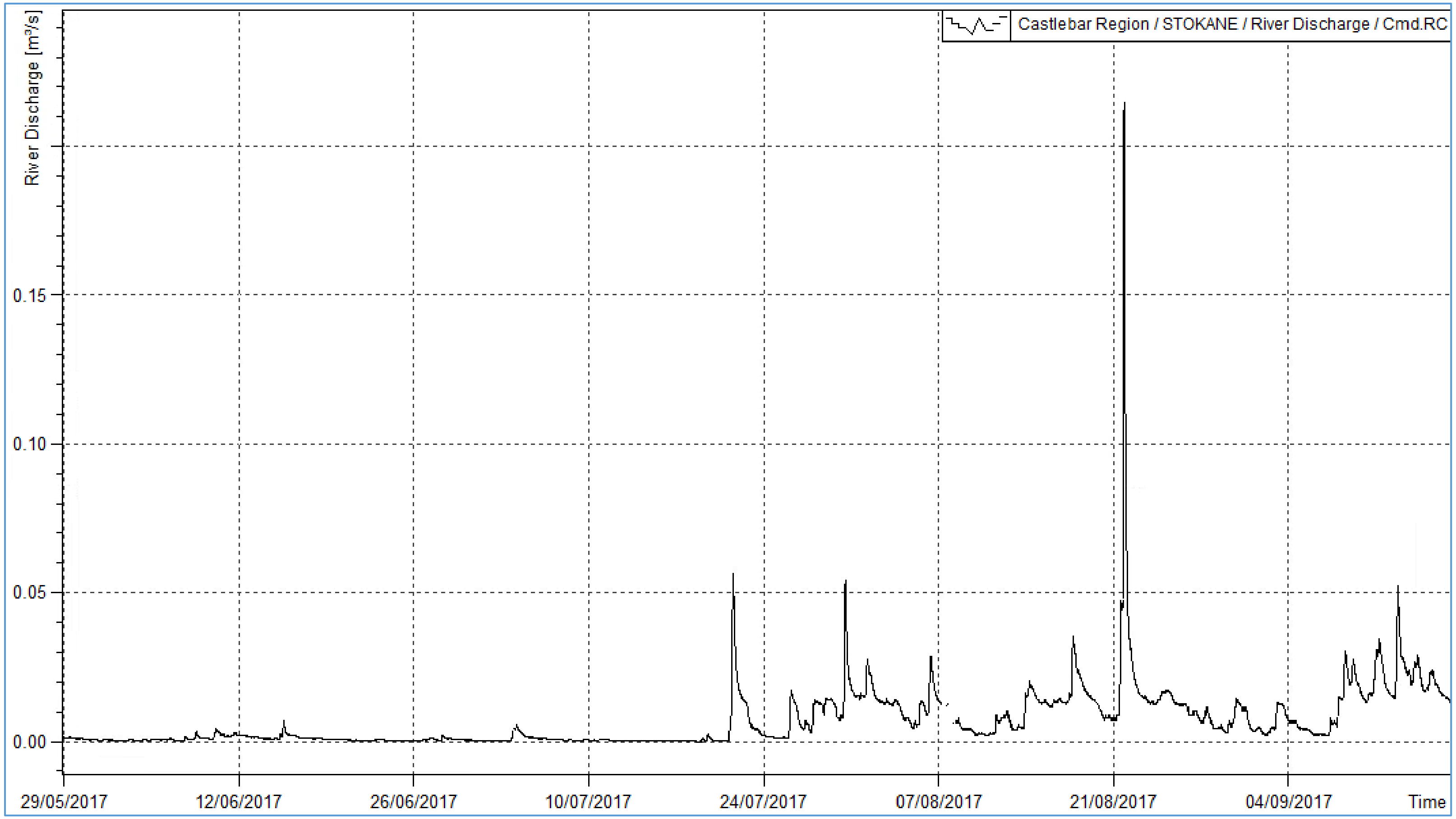


Figure 121: Bellawaddy river discharge hydrograph for the summer of 2017 at MP6

Rainfall (Section 6.3).

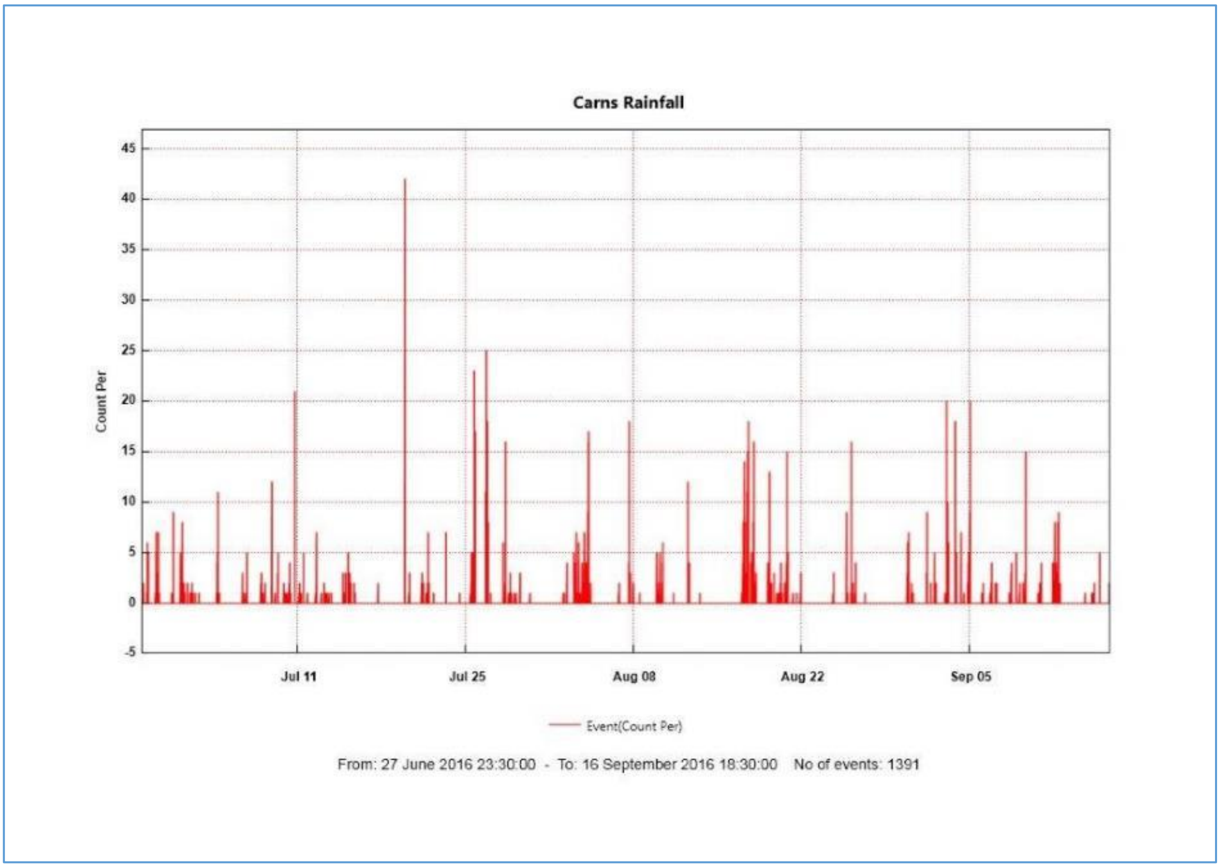


Figure 122: Hourly rainfall recorded by automatic rain gauge at MP7 Carns (Tullylinn) for June – September 2016.

Note: "Count" is equivalent to 0.2 ml of rainfall

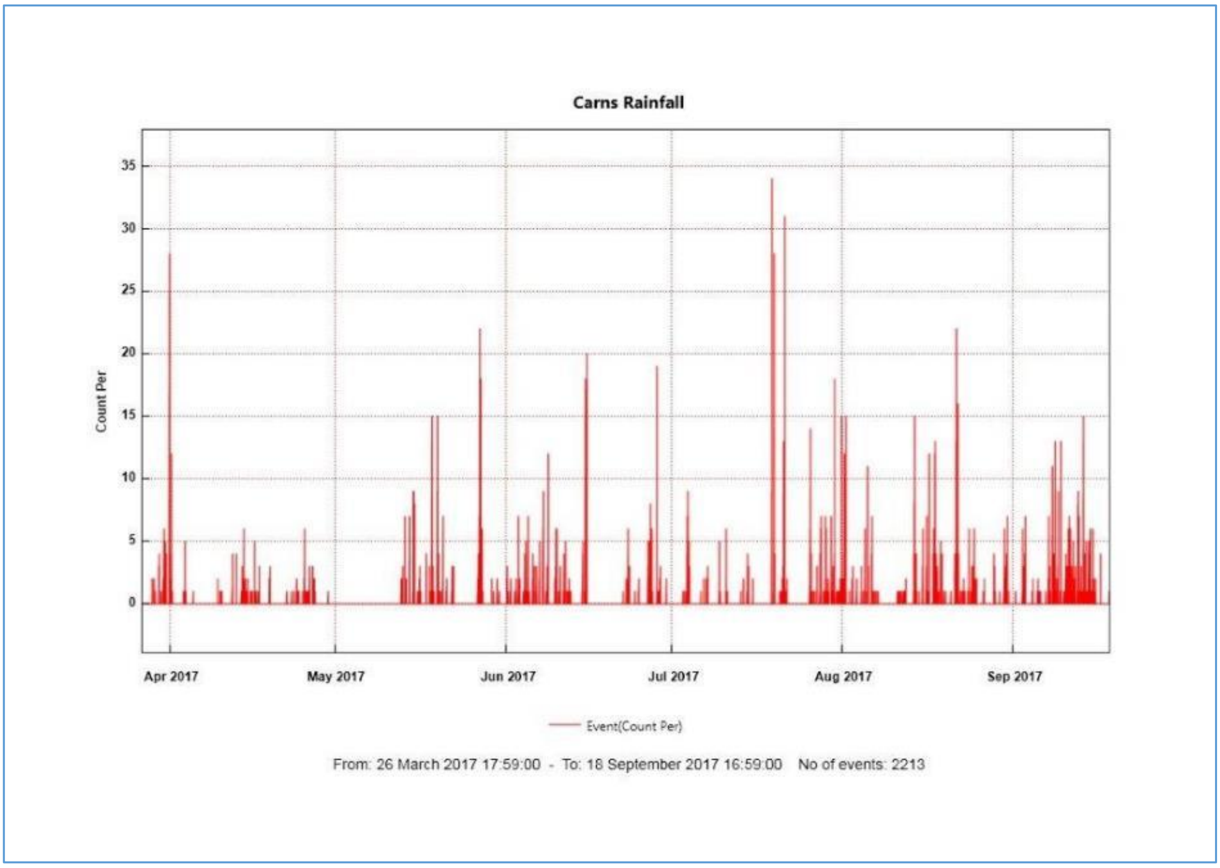


Figure 123: Hourly rainfall recorded by automatic rain gauge at MP 7 Carns (Tullylinn) for the summer of 2017.

Note: "Count" is equivalent to 0.2 ml of rainfall

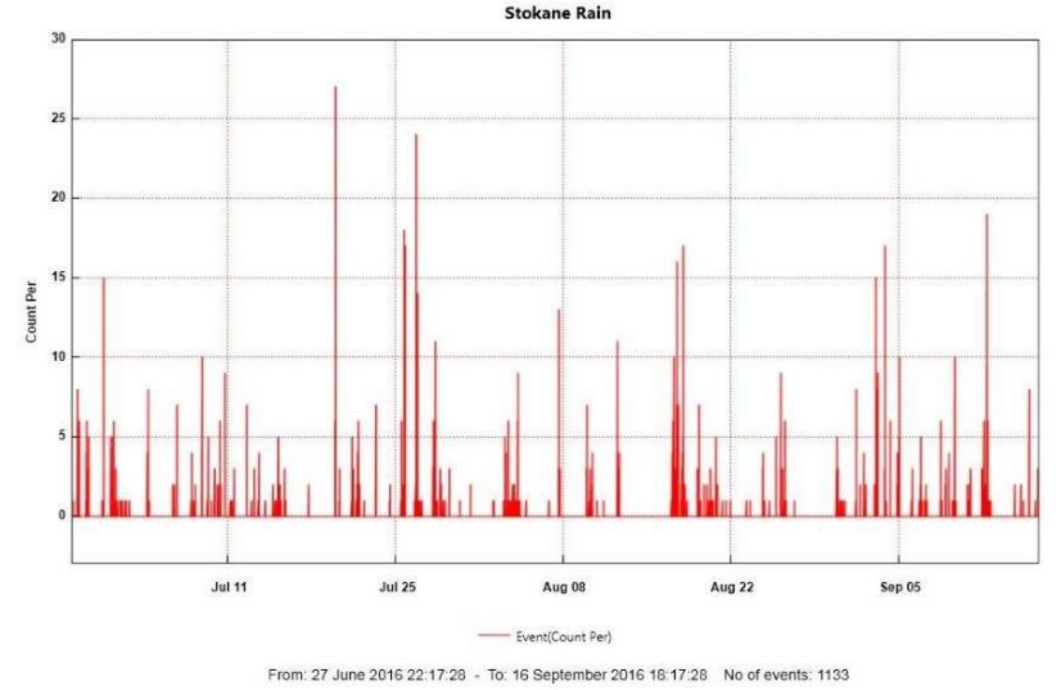


Figure 124: Hourly rainfall recorded by automatic rain gauge at MP8 Stokane for June – September 2016.

Note: "Count" is equivalent to 0.2 ml of rainfall

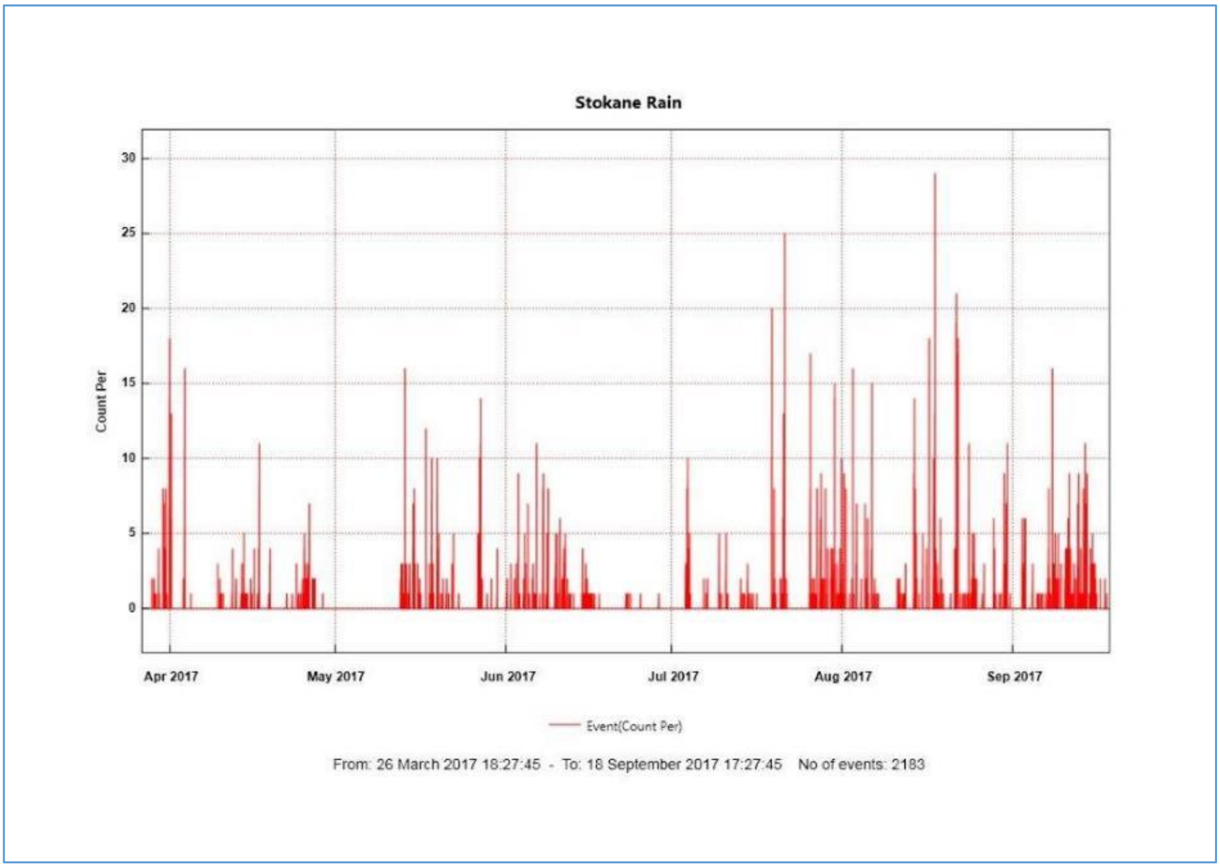


Figure 125: Hourly rainfall recorded by automatic rain gauge at MP8 Stokane for the summer of 2017.

Note: "Count" is equivalent to 0.2 ml of rainfall

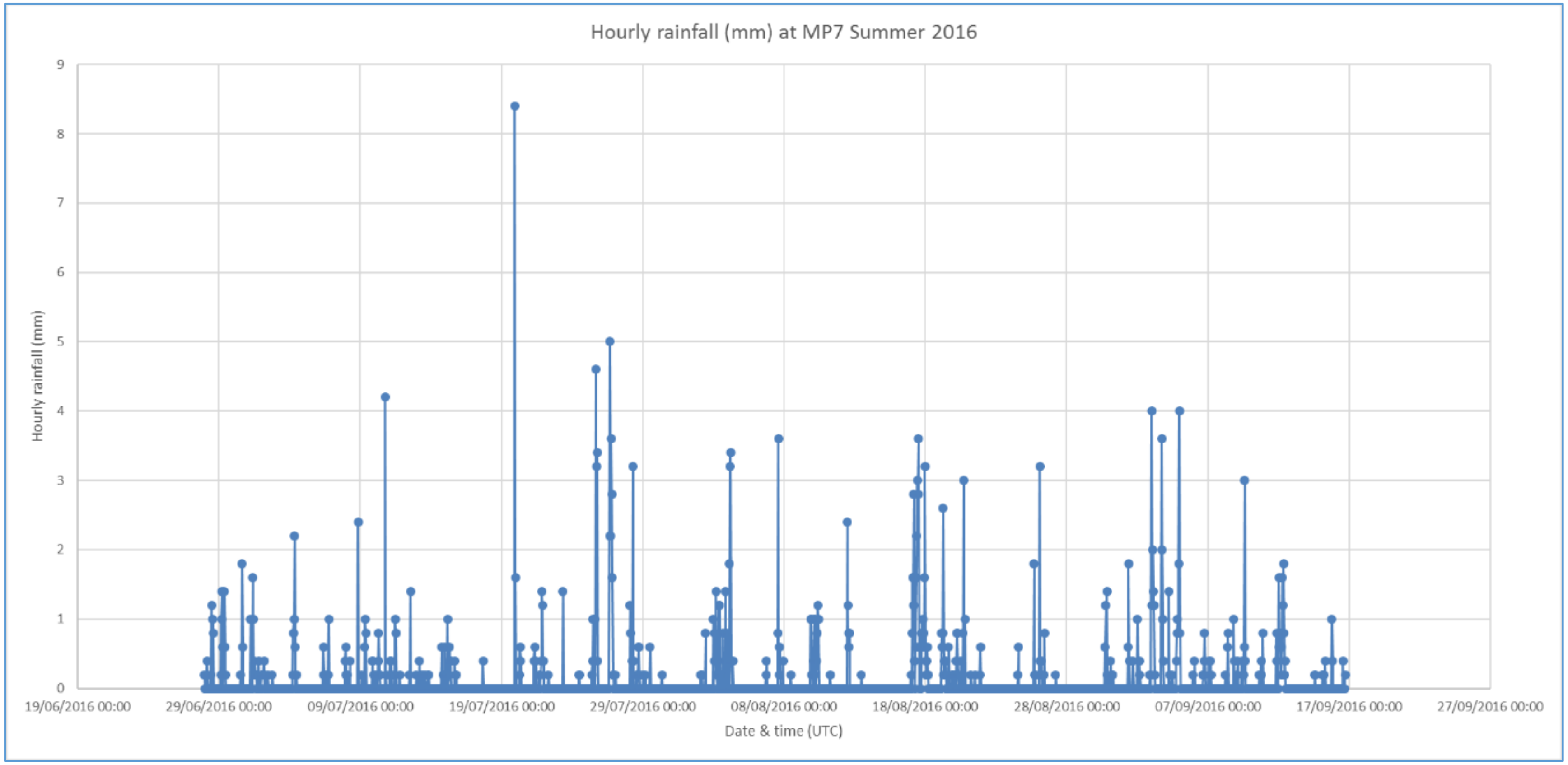


Figure 126: Hourly rainfall at MP7 Carns (Tullylinn) for the Summer of 2016, converted to mm rainfall and UTC (coordinated universal time)

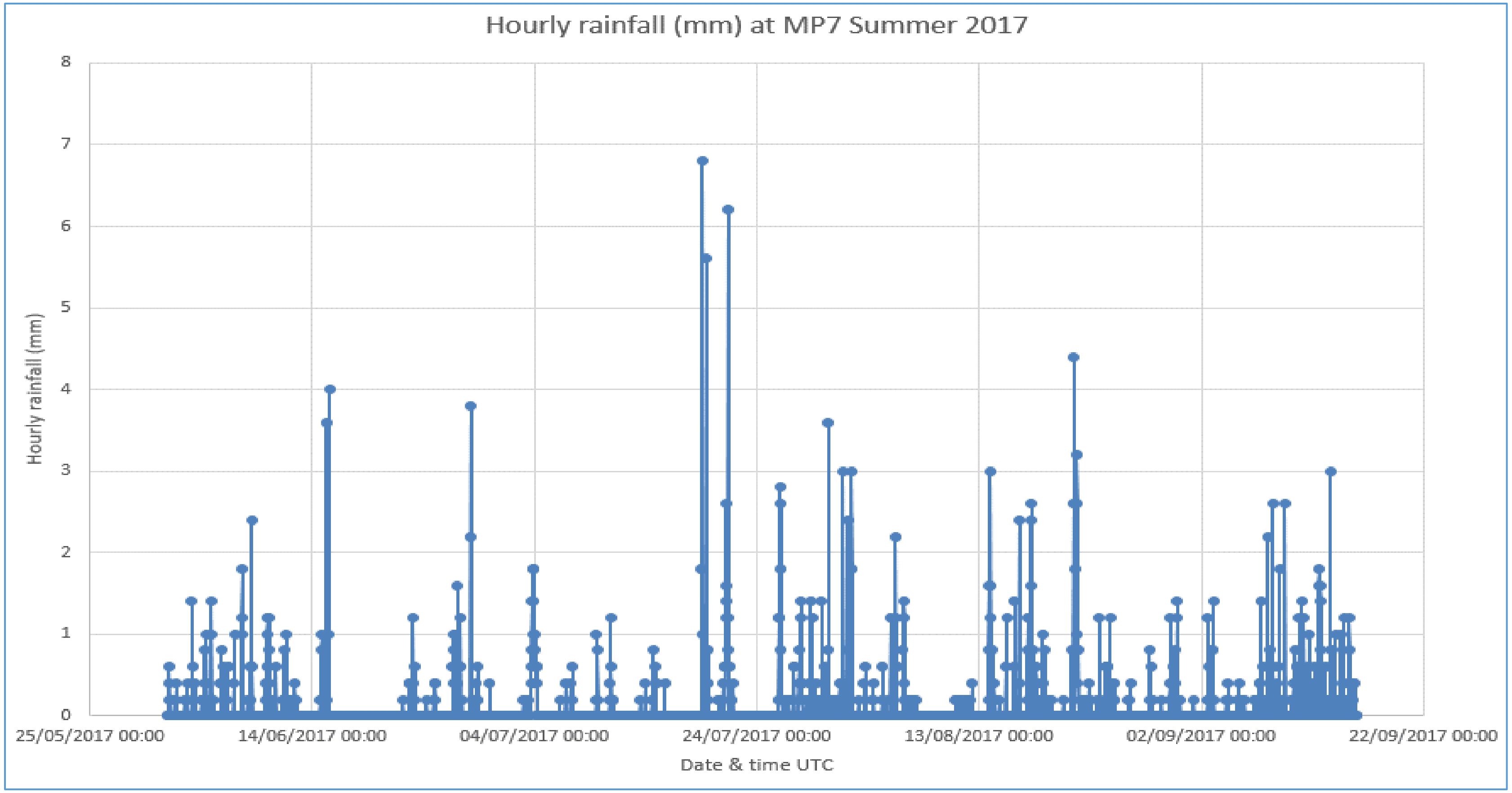


Figure 127: Hourly rainfall at MP7 Carns (Tullylinn) for the Summer of 2017, converted to mm rainfall and UTC (coordinated universal time)

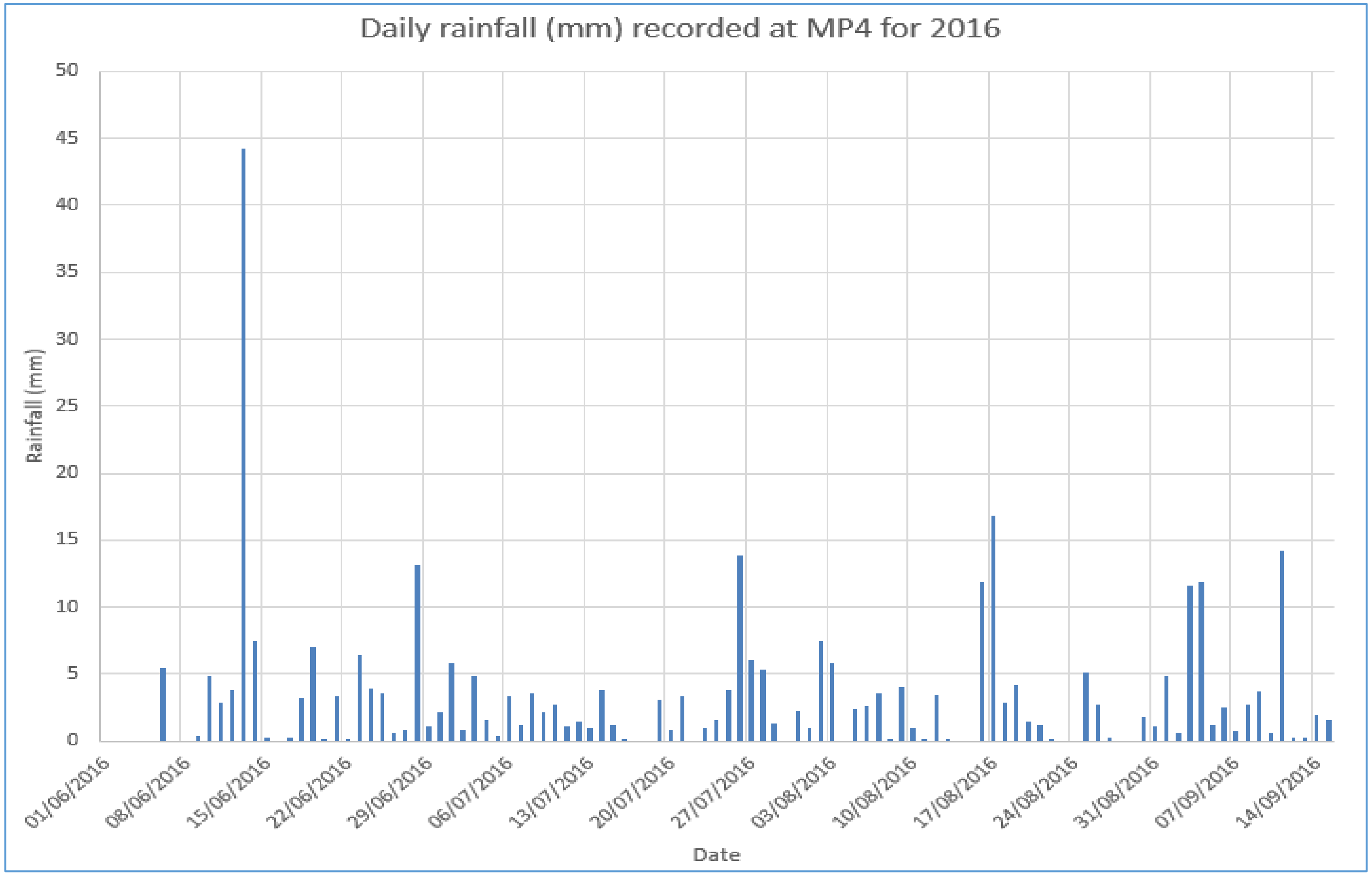


Figure 128: Daily rainfall recorded at MP4 Enniscrone for the summer of 2016

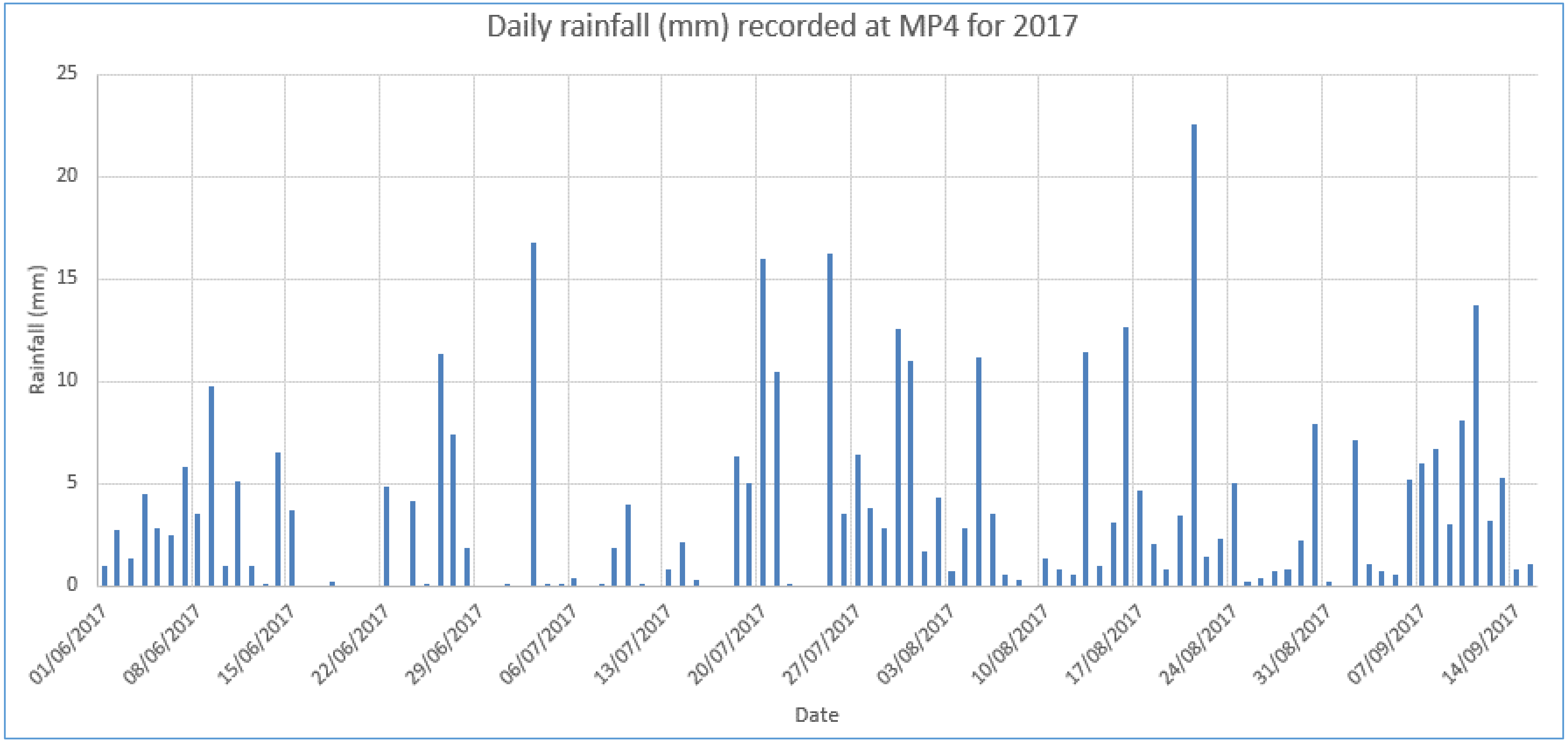


Figure 129: Daily rainfall recorded at MP4 Enniscrone for the summer of 2017

Relationship between rainfall & river water level

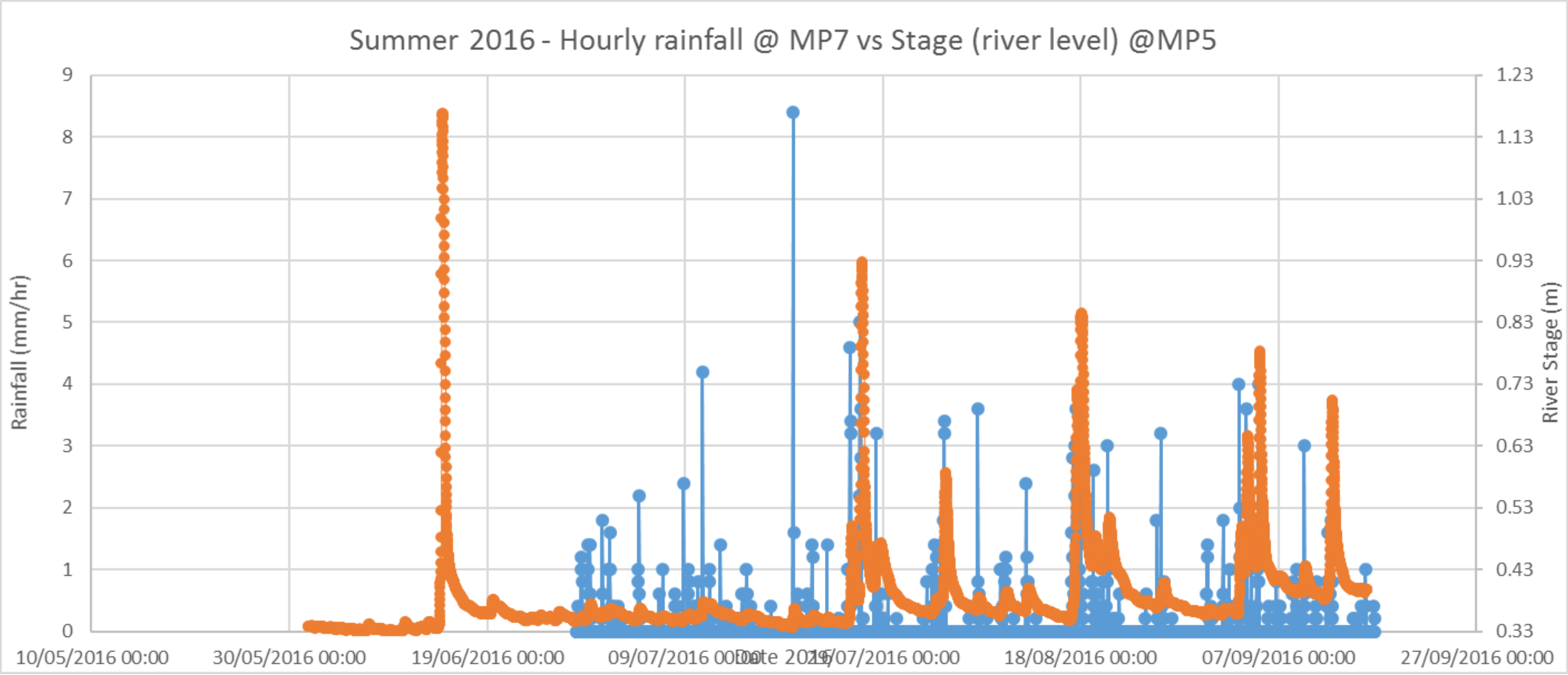


Figure 130: Hourly rainfall at MP7 versus continuous river water level at MP5 (main channel) for the summer of 2016.

Note: hourly recording of rainfall did not commence until the 27th June 2016

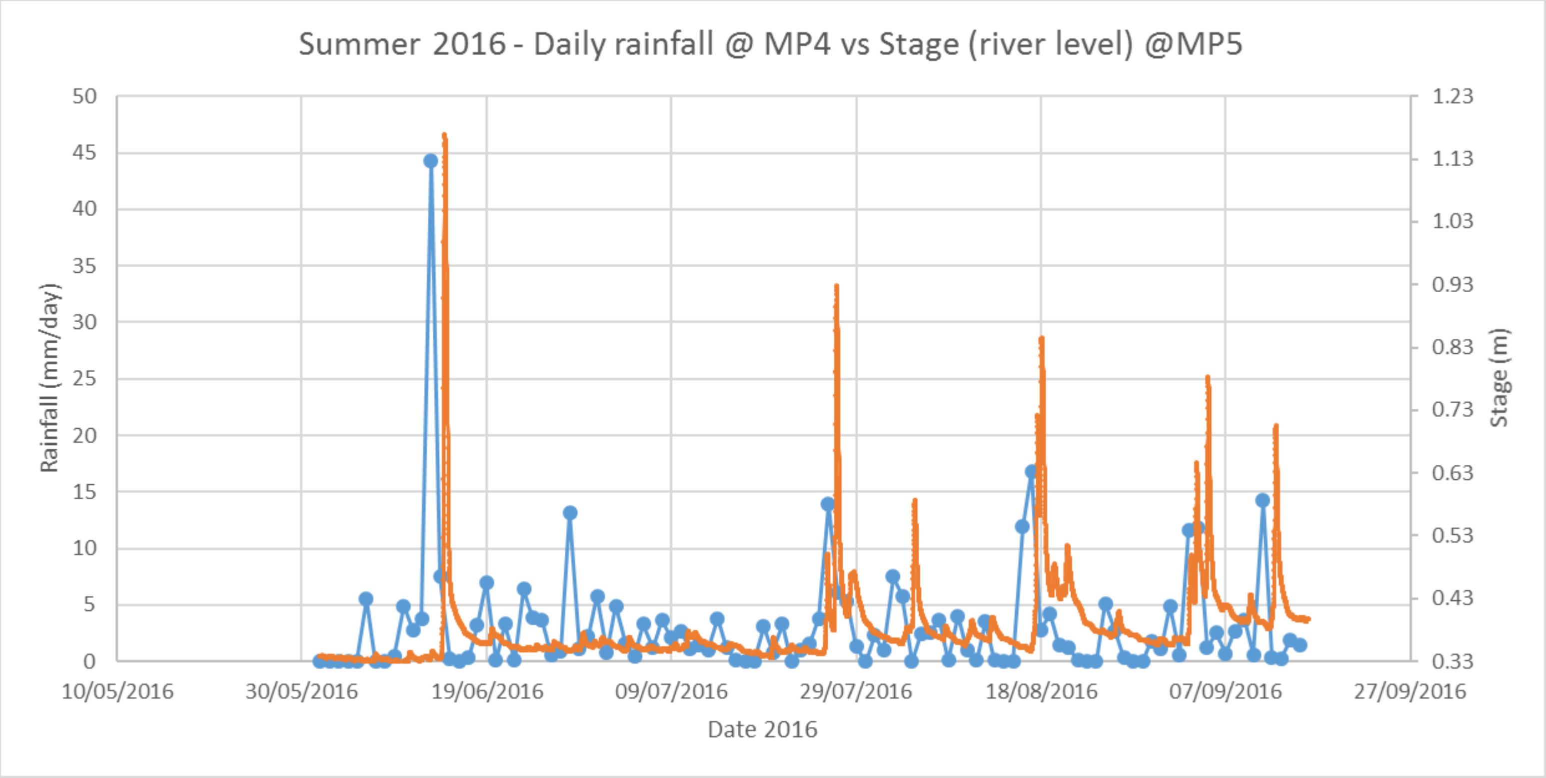


Figure 131: Daily rainfall recorded at MP4 versus continuous river water level at MP5 (main channel) for the summer of 2016.

Note that the relatively large amount of rainfall of the 28th June (13.2 mm) was not registered at either of the automatic rain gauges even though they are within a 10 km radius of MP4. This resulted in no water-level hydrograph being recorded at MP5 reflecting its proximity to the automatic rain gauges

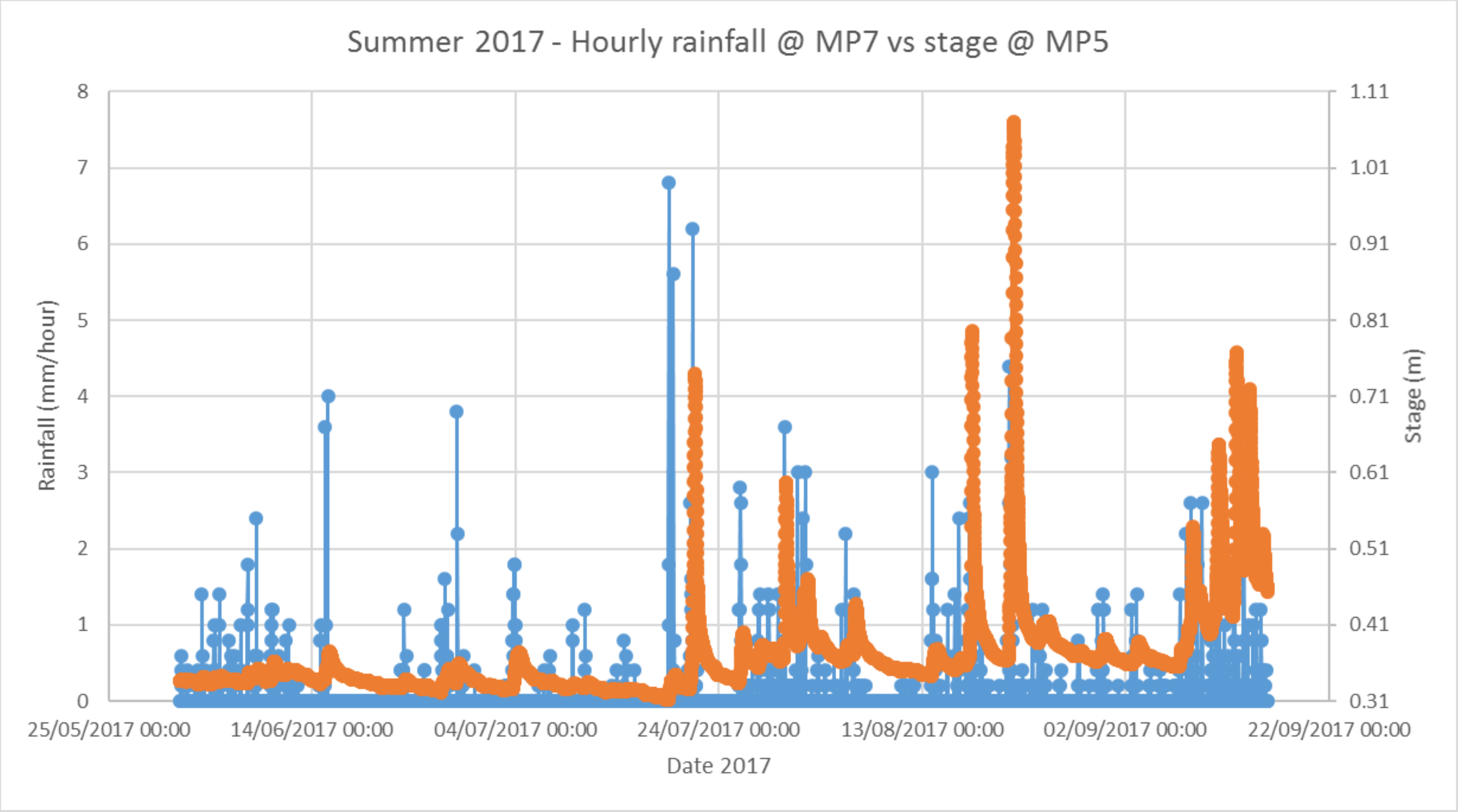


Figure 132: Hourly rainfall at MP7 versus continuous river water level at MP5 (main channel) for the summer of 2017

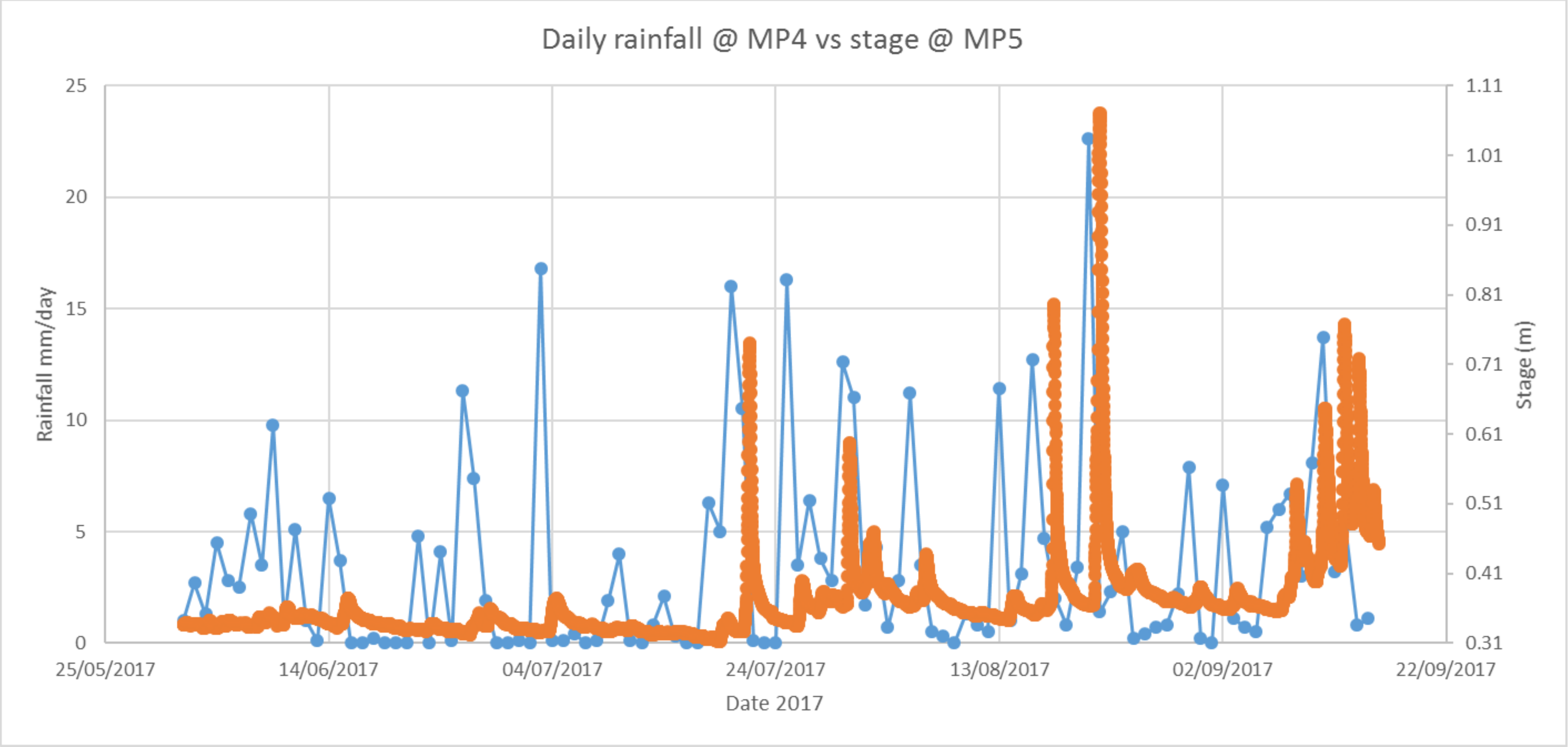


Figure 133: Daily rainfall at MP4 versus continuous river water level at MP5 (main channel) for the summer of 2017

Appendix E

Statistics (Section 4.5).

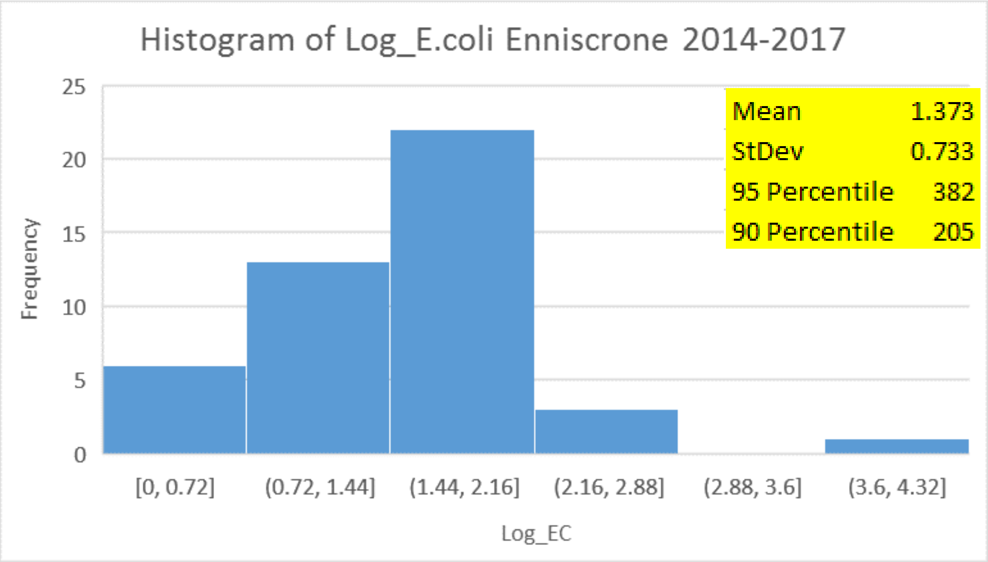


Figure 134: Histogram of log E. coli & descriptive statistics for compliance samples at Enniscrone (2014 – 2017)

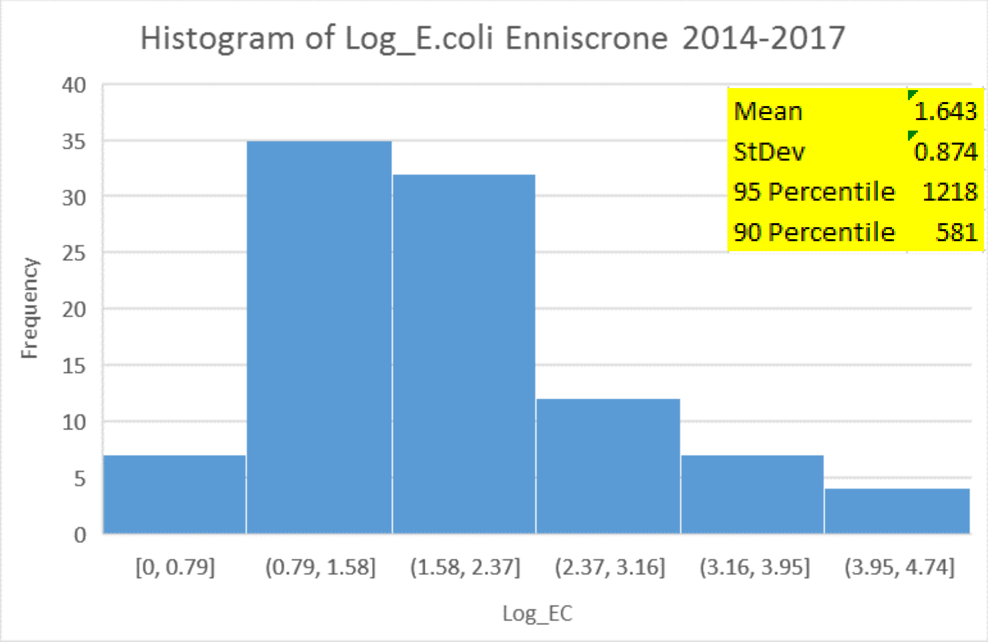


Figure 135: Histogram of log E. coli & descriptive statistics for compliance samples & study samples (including STP events) at Enniscrone (2014 – 2017)

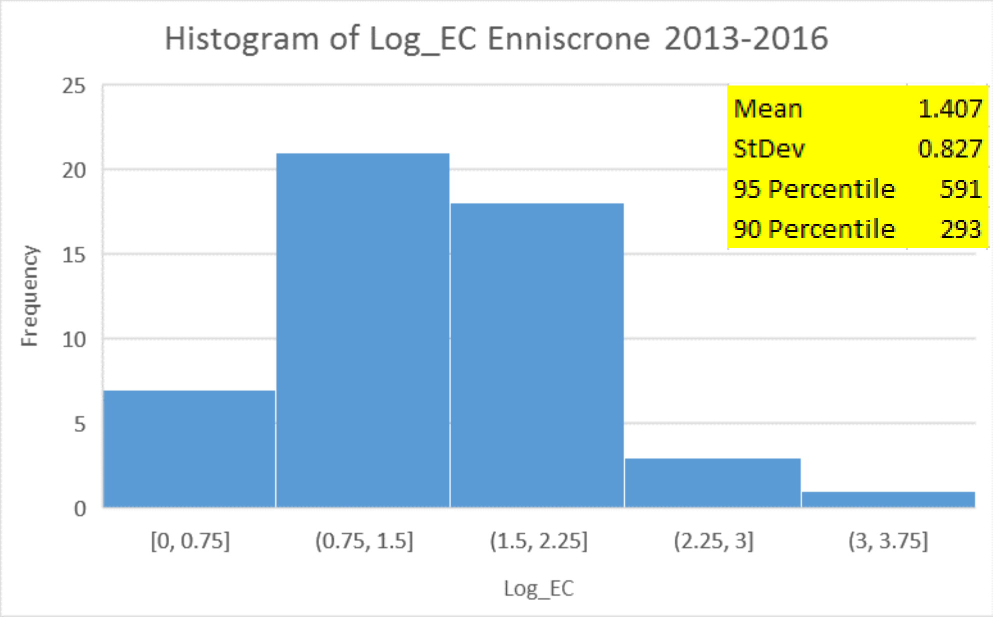


Figure 136: Histogram of log E. coli & descriptive statistics for compliance samples at Enniscrone (2013 – 2016)

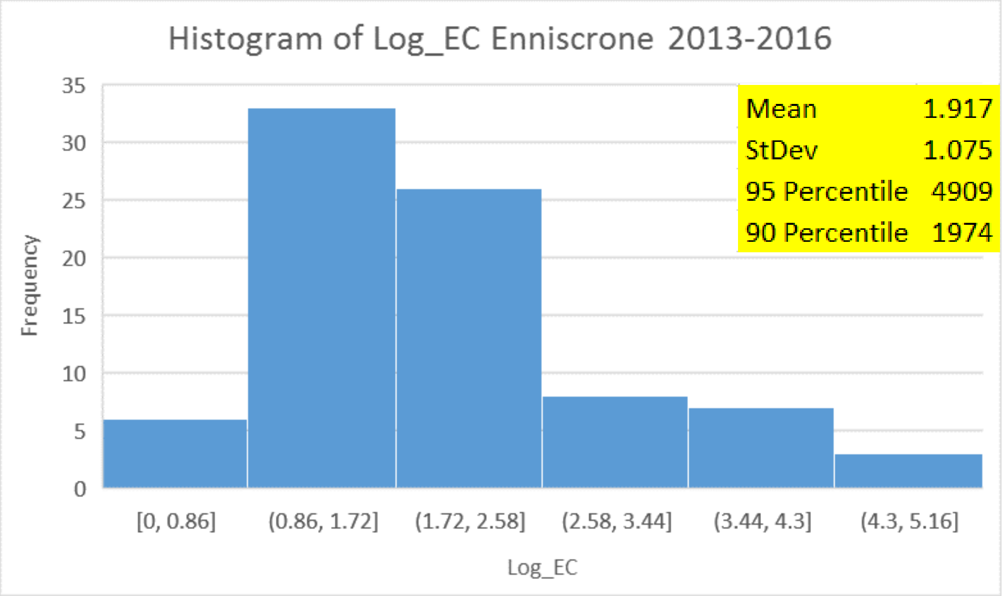


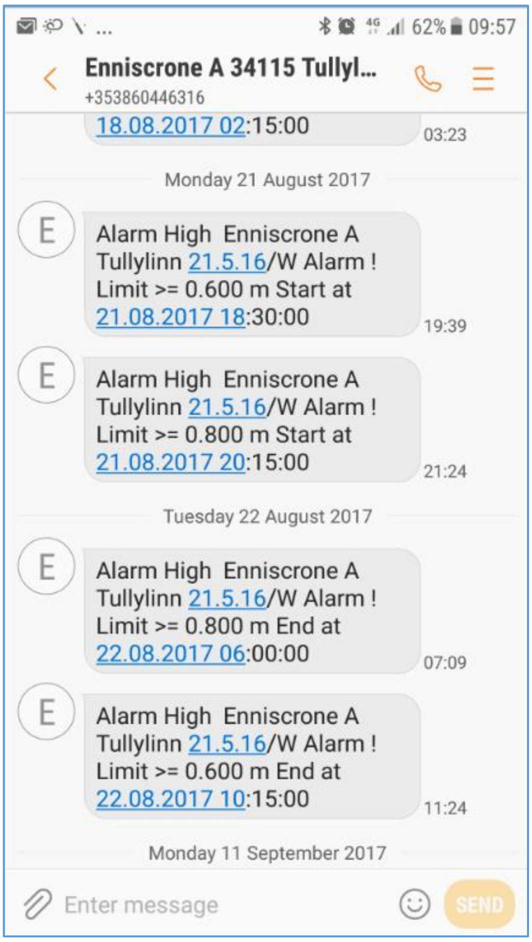
Figure 137: Histogram of log E. coli & descriptive statistics for compliance samples & study samples (including STP events) at Enniscrone (2013 – 2016)

Figures and statistics were generated using Microsoft Excel 2016. Example cell numbers are used here.

Log transformation was carried out by =LOG10(A2). The mean was calculated by =AVERAGE(D2:D46). Standard Deviation by =STDEV.S(D2:D46). The 95 percentile by =10^(F2+1.65*H2) and the 90 percentile by =10^(F2+1.282*H2).

Appendix F

Warning system messages & disclaimer (Section 6.1).



18.08.2017 02:15:00 03:23

Monday 21 August 2017

Alarm High Enniscrone A Tullylinn 21.5.16/W Alarm ! Limit >= 0.600 m Start at 21.08.2017 18:30:00 19:39

Alarm High Enniscrone A Tullylinn 21.5.16/W Alarm ! Limit >= 0.800 m Start at 21.08.2017 20:15:00 21:24

Tuesday 22 August 2017

Alarm High Enniscrone A Tullylinn 21.5.16/W Alarm ! Limit >= 0.800 m End at 22.08.2017 06:00:00 07:09

Alarm High Enniscrone A Tullylinn 21.5.16/W Alarm ! Limit >= 0.600 m End at 22.08.2017 10:15:00 11:24

Monday 11 September 2017

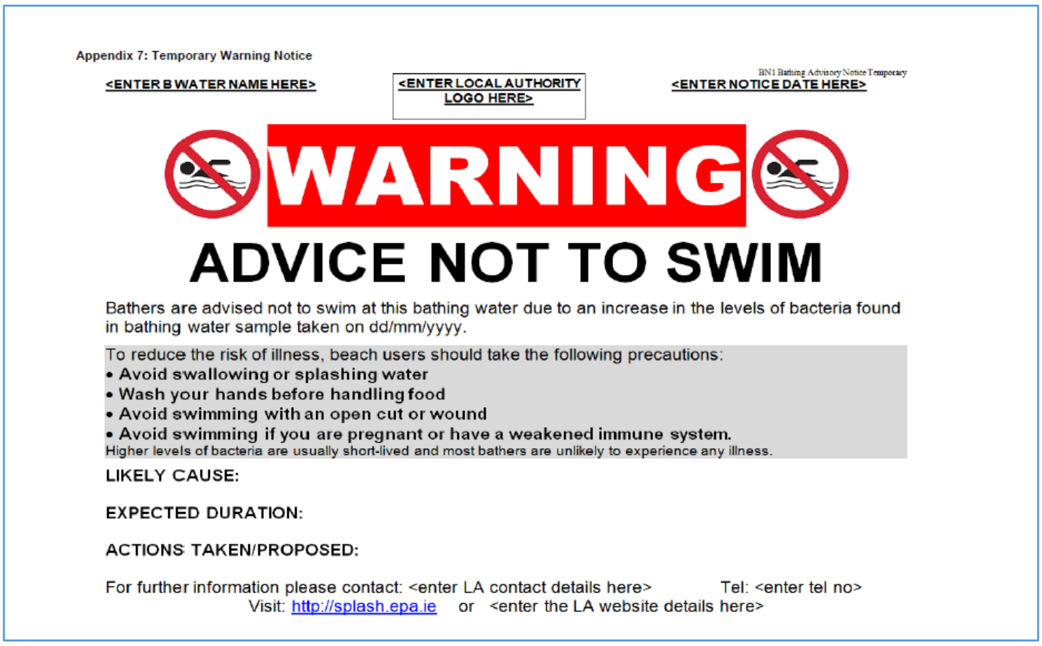
Figure 138: Example of SMS message received from data-logger at MP5

A Disclaimer will also be available on the profile page of the Twitter® site as follows:

This Bathing Water Quality Forecast System is purely for research purposes. Whilst every effort is made to ensure that accurate information is disseminated through this medium Enniscrone Bather makes no representation about the content for any purpose, and assumes no responsibility for anyone's use of the information.

Appendix G

Warning notices (Section 2.1.1).



Appendix 7: Temporary Warning Notice

BN1 Bathing Advisory Notice Temporary

<ENTER B WATER NAME HERE>

<ENTER LOCAL AUTHORITY LOGO HERE>

<ENTER NOTICE DATE HERE>

WARNING

ADVICE NOT TO SWIM

Bathers are advised not to swim at this bathing water due to an increase in the levels of bacteria found in bathing water sample taken on dd/mm/yyyy.

To reduce the risk of illness, beach users should take the following precautions:

- **Avoid swallowing or splashing water**
- **Wash your hands before handling food**
- **Avoid swimming with an open cut or wound**
- **Avoid swimming if you are pregnant or have a weakened immune system.**

Higher levels of bacteria are usually short-lived and most bathers are unlikely to experience any illness.

LIKELY CAUSE:

EXPECTED DURATION:

ACTIONS TAKEN/PROPOSED:

For further information please contact: <enter LA contact details here> Tel: <enter tel no>
Visit: http://splash.epa.ie or <enter the LA website details here>

Figure 139: Temporary Warning Notice

Appendix 8: Temporary Prohibition Notice

BN2 Bathing Prohibition Notice Temporary

<ENTER B WATER NAME HERE>

<ENTER LOCAL AUTHORITY LOGO HERE>

<ENTER NOTICE DATE HERE>

WARNING

DO NOT SWIM

SWIMMING IN THIS WATER MAY CAUSE ILLNESS

BATHING IS PROHIBITED DUE TO:

LIKELY CAUSE:

EXPECTED DURATION:

ACTIONS TAKEN/PROPOSED:

For further information please contact: <enter LA contact details here> Tel: <enter tel no>
Visit: http://splash.epa.ie or <enter the LA website details here>

Figure 140: Temporary Prohibition Notice

Appendix H

Rainfall event in August 2017 (Section 5.2.4).

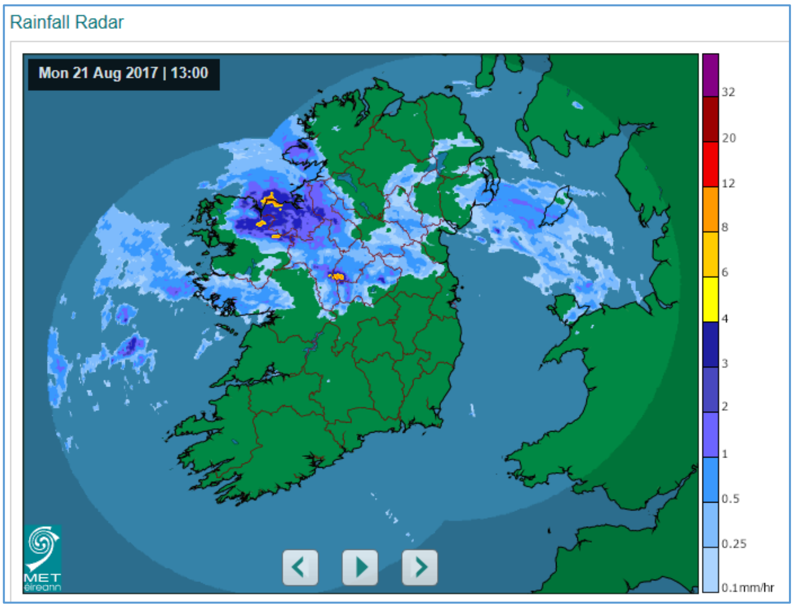


Figure 141: Met Éireann rainfall radar images for the 21/08/2017 – 1200UTC

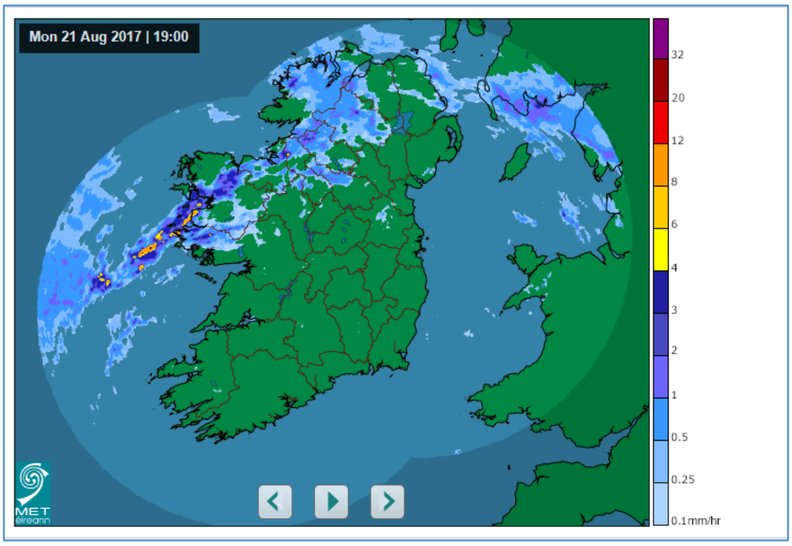


Figure 142: Met Éireann rainfall radar images for the 21/08/2017 – 1800UTC

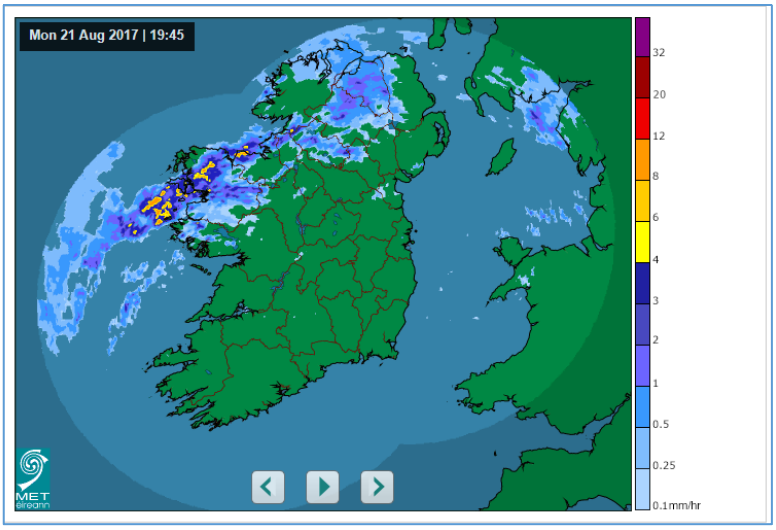


Figure 143: Met Éireann rainfall radar images for the 21/08/2017 – 1845UTC

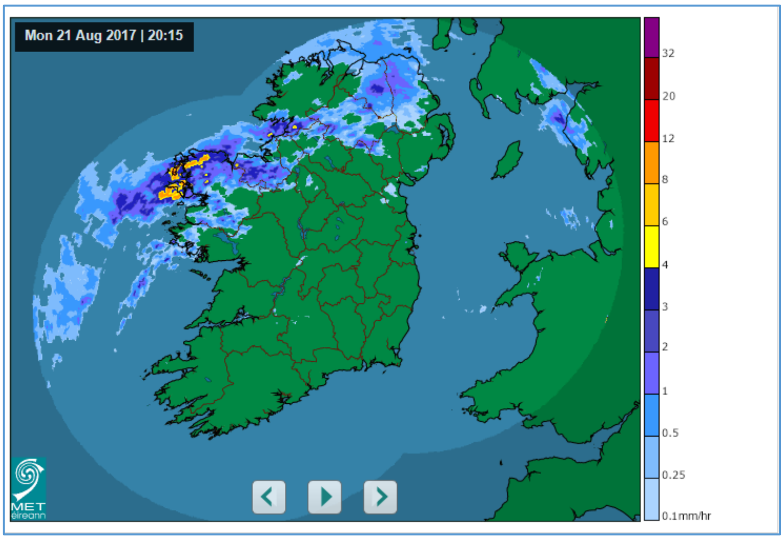


Figure 144: Met Éireann rainfall radar images for the 21/08/2017 – 1915UTC