02 – RIVER RESTORATION AND NATURAL WATER RETENTION MEASURES (NWRM) – A SUSTAINABLE RESPONSE TO CLIMATE CHANGEAND ACHIEVING GOOD STATUS UNDER THE WATER FRAMEWORK DI RECTIVE IN URBAN WATERS
Case Study: The Santry River

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Abstract
A catchment may be defined as any area of land where precipitation collects and drains to a river, lake, groundwater or coastal waterbody. A catchment includes all the surface water from rainfall, snow melt, and nearby streams that run downslope towards the common outlet, as well as the groundwater underneath. Catchments are complex 3-D systems influenced, not only by their topography, but also by the geology underneath.

Urbanisation is the process by which a natural, pervious landscape is converted into one that is hard, sealed and impervious. Before urbanisation, precipitation soaked into the ground, recharging groundwater and feeding the river naturally and slowly. As the water passed through the soil layer, it was purified, resulting in clean water supplying the baseflow of the river. Through urbanisation, precipitation is rapidly moved from the point at which it lands, via drainage infrastructure, to the nearest water course. This is known as urban runoff. The typical movement pattern of storm water in this instance is sheet flow, where rainwater flows rapidly across hard surfaces, polluting water courses and increasing flooding. Urbanisation disturbs the natural water cycle. Short-duration, high intensity storms exacerbate the effects of urban runoff.

The Santry Catchment is approximately 14 km^2 and is situated in north Dublin. Over approximately 200 years, it has developed from an agricultural and afforested catchment to an almost exclusively urban one. The river channel has been heavily modified, and local stormwater drainage infrastructure discharges to the river through approximately 60 pipes along its length. Under Water Framework Directive classification, the river has poor status in the upper reach, and 'unassigned' status in the lower reach (although it can be assumed to have, at best, poor status).

Dublin City Council is proposing a long-term, catchment-scale solution to address matters relating to poor water quality, flooding, biodiversity and ecology, as well as social and amenity use. The solution is based on the renaturalisation, where possible, of the river channel and the introduction of nature-based water retention measures (NWRM; also known as stormwater green infrastructure) along the riparian corridor and at appropriate locations throughout the catchment.

The project includes the first study in Ireland of the effectiveness of NWRM in terms of hydraulic efficacy, biodiversity impacts, and flood defence modelling. As part of the study, 5 carefully selected pilot sites, comprising residential housing estates, have been identified within the Santry Catchment to facilitate this study. A solution for each pilot site, based on NWRM, will be designed to retain 25 mm of rainfall in a 1 - 3-hour time frame, thus minimising pluvial flooding within the pilot sites and reducing the impact of urban runoff on water quality and flow volumes in the River Santry. NWRM also have

tremendous potential to reduce combined sewer overflow spill frequency which will be essential in areas with combined sewer networks. NWRM have many secondary benefits beyond stormwater management, including reduced flood risk and, in the area of climate action, reducing the heat-island effect, and sequestering carbon dioxide.

The success of this proposal will depend on the adoption of a multidisciplinary and inclusive approach. Apart from including a range of City Council Departments and functions, we will need to involve, from the earliest stages, a wide range of stakeholders across state agencies, local communities and commercial interests, as well as environmental groups and other NGOs.

1. INTRODUCTION

Directive 2000/60/EC, the Water Framework Directive, was signed on the 23rd October 2000 and subsequently incorporated into Irish law by SI 722 of 2003, the European Communities (Water Policy Regulations) 2003. The aims of the Water Framework (WFD) are to achieve at least good ecological status in all surface waters, maintaining existing good status, and to protect high status water bodies by 2027 at the very latest. In the case of heavily modified water bodies or artificial water bodies, the goal is to achieve good ecological potential. Achieving good ecological status or potential is to be achieved through River Basin Management Plans (RBMP) and associated Programmes of Measures (POMs), spread over 3 reporting periods, 2010 – 2015, 2015 – 2021, and 2021 – 2027. It is a requirement that RBMPs follow a catchment-based approach.

A catchment, or watershed, is a topographically discrete unit or stream basin, including the headwaters, main channel, slopes from the channel, tributaries, and mouth area, all defined by a common drainage pattern (Benedict and McMahon, 2006). A catchment includes all the surface water from rainfall, snow melt, and nearby streams that run downslope towards a common outlet, as well as the groundwater underneath. Catchments are complex 3-D systems influenced not only by their topography, but also by the geology underneath. When a catchment becomes urbanised, its topography undergoes tremendous change, to the point where it no longer looks or functions like a natural catchment (McGrane, 2016).
One cannot discuss a catchment without considering the water (aka hydrological) cycle, and a discussion of the impact of urbanisation on catchments is effectively a discussion of the impact of urbanisation on the water cycle. The water cycle describes the natural processes by which water moves from one location to another and the pathways which facilitate this movement. The pathways of the natural water cycle are interrupted by urbanisation. Figure 1 illustrates (a) the natural water cycle, (b) the urban water cycle, and (c) an example of a sustainable option for the urban water cycle.

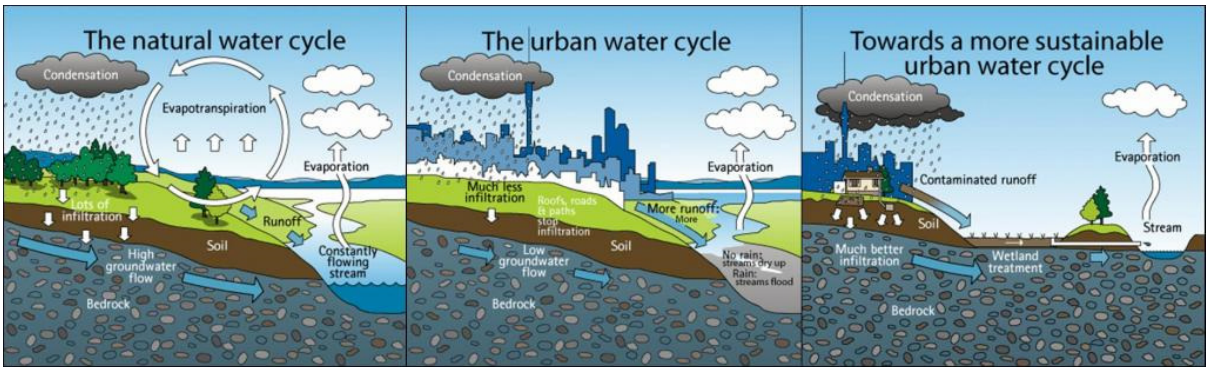

Figure 1: *The natural water cycle and how it is impacted by urbanisation (Source: Auckland City Council)*

In a natural catchment, channel form is governed largely by catchment topography and geology. In an urban catchment, natural topography is heavily altered, and channels are engineered to facilitate development. Channels are typically straightened, diverted, culverted and/or canalised. Furthermore, the area draining to the channel becomes artificial, constrained by drainage infrastructure.

2. WHAT IS URBANISATION?

While an agreed definition of urbanisation remains elusive (McGrane, 2016), for the purpose of this paper, urbanisation may be defined as the process by which a natural, pervious landscape is converted into one that is hard, sealed and impervious. It may also be described as the process by which towns and cities are formed and become larger as more and more people begin living and working in central areas. There are good social and economic reasons for urbanisation (McGranahan and Satterthwaite, 2014). This paper is not intended to demonise urbanisation; however, it is important to sustainably manage the consequences of urbanisation.

Prior to urbanisation, precipitation would have soaked into the ground, recharging groundwater and feeding the river naturally in accordance with the natural water cycle. As the water passed through the soil layer, it was purified, resulting in clean water supplying the baseflow of the river. In the urban context, precipitation is rapidly moved from the point at which it lands, to the drainage infrastructure, and into the nearest water course. This is known as stormwater runoff or urban runoff. The typical movement pattern of storm water in this instance is sheet flow, where rainwater flows rapidly across hard surfaces. In this scenario, water is seen as a waste product to be disposed of quickly, when it should be valued as the asset that it is. When treated as a waste, it exacerbates flooding and becomes contaminated with pollutants.

2.1. URBAN RUNOFF

Urban runoff is precipitation that has collected on roofs, roads, footpaths and other sealed surfaces. It flows directly to the storm water drainage network and into the nearest waterbody. As the storm water drainage network has no treatment processes, pollutants are washed into surface waters.

Stormwater run-off contains a “wide variety of pollutants” often at levels high enough to have a deleterious effect on the ecological health of the river-bodies into which it is discharged (LeFevre et al., 2015; Flint and Davis, 2007, USEPA, 1983). Pollutants such as toxic metals, suspended solids, pathogens, nutrients, and petroleum hydrocarbons are all frequently found at elevated levels (LeFevre et al. 2015). Much of the pollutant mass is delivered within the first flush i.e. the first 25% of the stormwater to reach the river body (Flint and Davis, 2007). This makes intercepting and attenuating the pollutants contained within the first flush of critical importance. As the surface water system is designed to move water rapidly away, it can lead to flooding further downstream.

3. IMPACT OF URBANISATION ON A CATCHMEMT

Urbanisation dramatically changes the landscape of a catchment and disrupts the natural water cycle. Rainfall and other precipitation that would traditionally have been managed by the natural water cycle now becomes stormwater and urban runoff, resulting in flooding and pollution of watercourses (Liu et al., 2015). Figure 2 illustrates the differences between natural cover and impervious cover and Table 1 describes how urbanisation changes a landscape and how these changes can lead to flooding and poor water quality.

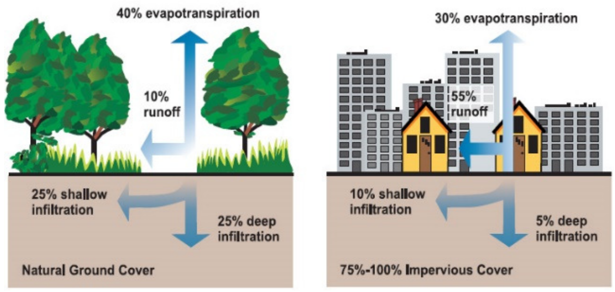

Figure 2: *A comparison between runoff from rural and urban surfaces (source: USEPA)*

Table 1: *Elements and Effects of Urbanisation on a Catchment*

Elements of Urbanisation:

- Removal of trees and vegetation
- Bulldozing of land for infrastructure
- Intensive construction of buildings, car parks, roadways and footpaths and supporting infrastructure
- Filling in of ponds and draining of lands
- Stream diversions and modifications to facilitate development
- Sinking of wells, including industrial capacity wells
- Construction of water supply and distribution systems, including reservoirs
- Construction of wastewater infrastructure, i.e. drainage infrastructure and wastewater treatment plants

Effects of Urbanisation:

- More stormwater runoff and erosion because there is less vegetation to slow water. High stormwater volumes impact waterways by:
    - Damaging the habitat for aquatic animals, such as fish and invertebrates
    - Disturbing the breeding cycles of aquatic animals
    - Eroding stream banks
    - Increasing turbidity and pollution levels
    - Altering natural flood cycles
- Flooding can occur because natural drainage patterns are changed
- More sediment is washed into streams, which increases the risk of flooding and reduces water quality
- Natural land that previously soaked up runoff is replaced by impervious surfaces. More pavement means less soakage into the ground, meaning less recharge of groundwater. This will lower the water table and some existing, shallower wells may dry up
- Base flow in rivers may be reduced and, at certain times of the year, small streams may dry up
- Water quality deteriorates as any sediments and other pollutants collected by stormwater runoff are washed into the river.
- Urbanisation prevents water from soaking into the ground. This can result in low soil moisture content, which can impede healthy growth of plants, thereby increasing the need for artificial irrigation.
- Major loss of biodiversity and ecology as vegetated and is cleared and replaced with impervious surfaces.

Overall, the large-scale interruption of the water cycle through urbanisation reduces groundwater recharge, reduces base flow in rivers and streams, increases the rate of flow of rainwater into the surface water drainage network, increases the 'flashiness' of rivers, can lead to flooding, and impacts the quality of surface waters. Large-scale urbanisation also negatively impacts downwind rainfall proliferation at regional scale as a result of the heat island effect (McGrane, 2016).

4. FLOODING AND WATER QUALITY IN URBAN CATCHMENTS

Urbanisation has a major impact on flow characteristics in a catchment (McGrane, 2016). Urbanisation results in an increase in impervious surfaces and growth of artificial drainage networks that facilitate dramatic changes to the magnitude, pathways and timing of runoff at all scales, from individual buildings to large developments (Walsh *et al*, 2005).

Contamination from both point and diffuse source pollutants can greatly alter the chemical water quality of urban watercourses, often transporting 'dirty' water over vast areas into downstream, estuarine and coastal areas. The mobilisation of contaminants is expedited through increased surface runoff and hydraulic efficiency (McGrane, 2016).

A broad range of contaminants derive from urban areas, including nutrients (Carey *et al*, 2013), volatile organic compounds (VOCs) (Lopes and Bender, 1998), heavy metals (Sorme and Lagerkvist, 2002), and sediment (Bruen *et al*, 2006). Significantly, suspended solids may bind with heavy metals and a significant proportion of the toxins deposited on road surfaces can be transported into the freshwater system in this manner (Zhao et al., 2010). The main route by which sediment is transported to water bodies, particularly in urban areas, is through drainage infrastructure (Lawlor *et al*, 2017).
In recent years, there has been an increasing focus on 'emerging priority pollutants', such as herbicides, microbial contaminants, pharmaceuticals, and polycyclic aromatic hydrocarbons (PAHs). Many of these are experienced at higher concentrations in urban areas. Microbial pollution, for example, has been shown to increase with population, where concentrations are higher in urbanised areas (McGrane, 2014).

5. HABITAT LOSS AND DECLINE IN BIODIVERSITY

Urban development has a major impact on habitat, biodiversity and ecology in an area. Furthermore, the effects of urbanisation on biodiversity are not only likely to persist, but they are likely to expand and threaten other local ecosystems (McKinney, 2002).

Urbanisation and biodiversity interact in multi-faceted and complex ways. Both the size and spatial configuration of urban areas are important factors on the impact of urbanisation on habitats and biodiversity (Seto et al, 2015). Urbanisation impacts biodiversity and ecosystem services both directly and indirectly. Landcover change is the most prevalent direct impact, leading to degradation and loss of habitat, altered disturbance regimes, modified soils and physical transformations caused by urban expansion. Indirect impacts include changes in water and nutrient availability, increases in abiotic stressors (e.g. air pollution), increases in competition from non-native species, and changes in herbivory and predation rates (Seto et al, 2015).

6. A SUSTAINABLE APPROACH TO STORMWATER MANAGEMENT

Traditional stormwater management has treated precipitation as something to be disposed of rather than something from which economic and environmental value can be derived (McGrane, 2016). The consequences are loss of groundwater recharge, reduced base flows in rivers, increased flooding and poorer water quality.

EU Member States are required to address flooding and water quality issues through the Floods Directive and Water Framework Directive, respectively. In addition, EU Member States are required to implement other environmental legislation, including the Birds and Habitats Directives, and achieve specified objectives contained therein. Successful implementation of this broad range of environmental legislation, coupled with delivering additional social and economic benefits to citizens of EU Member States may be best achieved by implementing projects and schemes that deliver multiple benefits. A cross-agency and multi-disciplinary approach is required.

Stormwater can be managed more naturally and in a way that generates increased environmental and economic benefits by restoring the natural water cycle as much as possible. Globally, cities are achieving this using Green Infrastructure (GI). Everybody can, and should, be involved in the management of stormwater, including the private householder, business owners, estate managers, developers and the State Agencies.

GI incorporates both the natural environment and engineered systems to provide clean water, conserve ecosystem values and functions, and provide a wide range of benefits to people and wildlife (Benedict and McMahon, 2006). GI boosts the economy, enhances community health and safety, and provides recreation, wildlife and other benefits. For example, the City of Lancaster, Pa, calculated that their GI plan would provide approximately $4.2 million in energy, air quality and climate related benefits annually, as well as additional, albeit un-costed, benefits associated with reduced heat island effect, increased property value, reduced noise pollution, increased recreational value, habitat improvement, public education, and community cohesion (USEPA, 2014). Table 2 outlines the outcomes of implementing GI throughout a catchment.

Table 2: *Outcomes from the effective use of GI*

Outcomes from the effective use of GI in a catchment
• Reduces runoff volume, peak flow and flow duration • Slows down flow to increase the time of concentration and encourage infiltration and evapotranspiration • Restore groundwater recharge • Protect downstream water resources, including wetlands • Reduce downstream flooding and property damage • Reduce the frequency of operation of combined sewer overflows (CSOs) • Improve water quality by preventing pollution from entering the watercourse • Reduce thermal pollution • Improve habitats, biodiversity and ecology

In 2017, Dublin City Council carried out a study (Stack, et al, 2017) into the effectiveness of the following green infrastructure options to address pollution of surface waters caused by urban runoff:

- Green roofs
- Rain barrels and cisterns
- Bioretention cells
- Bioswales
- Stormwater Wetlands/Integrated Constructed Wetlands
- Permeable paving
- Tree trenches and tree pits.

The study investigated their performance, not only in terms of the primary benefits of stormwater management and pollutant removal, but also from the perspective of property prices, air quality, noise pollution, thermal benefits, biodiversity and cost benefit.

It was clear from this study that, while each of these GI options provide benefits in their own right, the application of GI is best applied at catchment scale, using an integrated suite of natural water retention measures. The environmental benefits of a GI approach to stormwater management are not limited to storm water runoff and pollution of waters; they have additional benefits such as carbon sequestration and linking niche habitat sites within a larger urban area (Ellis, 2013). It must be emphasised that GI is a framework, not a methodology, upon which various ecological and environmental outcomes are achieved. Ellis (2003) emphasises the need for the development planning process to integrate SUDs drainage infrastructure within the context of a multi-purpose greenspace network and to consider infrastructure needs and provision as the first step in the spatial planning process. Therefore, the application of GI cannot be an add-on at a later stage in any design process and must, rather, be the framework upon which land is managed within any development. This is particularly important when working at catchment scale.

Natural Water Retention Measures (NWRM), also known as 'Nature-based Water Retention Measures,' are multi-functional measures intended to protect and manage water resources using natural means and processes, therefore building up green infrastructure, for example, by restoring ecosystems and changing land use (WFD CIS Working Group Programme of Measures, 2014). If GI is the framework, then NWRM are the methodologies used in the implementation of the framework.

In the context of stormwater management, Dunnett and Clayden (2007) refer to the Stormwater Chain and bioretention. Bioretention is a terrestrial-based, water quality and quantity control practice using the physical, chemical and biological characteristics of plants, microbes, and soils for the removal of pollutants from stormwater runoff (Coffman and Winogradoff, 2002). The Stormwater Chain suggests a series of integrated measures that consider how water enters, moves through, and leaves a catchment or area. Coffman (2002) identifies four major categories of technique:

- Techniques that prevent surface runoff
- Techniques that retain water for infiltration or evapotranspiration
- Techniques that detain water temporarily for later release at a measured rate, either to receiving waters or to the next element of the stormwater chain
- Techniques that convey water from where it falls to where it is temporarily retained or detained.

By taking a strategic approach to stormwater management, at catchment scale, each of these techniques can be applied where appropriate. Consequently, a sustainable, catchment-scale stormwater management plan delivers the multiple benefits of water quality improvement, flood resilience, enhanced biodiversity and ecology, climate change mitigation, and the delivery of social and environmental services for people living within the catchment.

Giese *et al* (2019) studied the effectiveness of green infrastructure to manage more intense rainfall events associated with climate change. This study compared the effectiveness of several larger-scale detention ponds (a traditional approach to stormwater management) to the cumulative effectiveness of a large number of smaller-scale GI/NWRM, such as rain gardens, dry detention ponds, and sand filters. This study found that the watershed with more GI/NWRM was better able to buffer and absorb more of the increased rainfall than the more traditionally designed watershed.

7. THE RIVER SANTRY

The River Santry is a relatively small river, approximately 13 km in length, though with a sizeable catchment of approximately 14.25 km^2 relative to its length (figure 3).

Figure 3: *River Santry Catchment*

The river rises in Harristown, near Dublin Airport, which is in the functional area of Fingal County Council. It then flows through Sillogue Golf Course, into Dublin City Council's functional area and, via Ballymun, Santry, Coolock and Raheny, it discharges to the lagoon at the rear of the North Bull Island, a UNESCO Biosphere and major nature reserve. Near the headwaters, a minor tributary, the Dubber, flows into the Santry. At Kilmore, there is a diversion from the Nanniken River for flood relief purposes. Within its catchment, the surface water drainage network discharges to the river (Sweeney et al, 2017).

The river is situated in a largely urban environment, with the exception of approximately the first 3 km of its length. Most of the river flows through a variety of industrial, residential and park land before discharging to the lagoon at the rear or North Bull Island. It is impacted by a broad range of pressures; again, of a predominantly urban nature, with urban runoff discharging to the river via a combination of approximately 60 pipes as well as direct discharge. While most of the river flows in open channel, large sections of this open channel have been heavily modified with concrete walls and base, numerous road crossings and several culverted sections.

Prior to the 1900's, the catchment was largely rural, comprising agricultural lands and mixed, broad-leaf forests. Since then, the catchment has been almost completely urbanised, resulting in significant hydro-morphological change to the river channel and riparian zone, the conversion of land from pervious to impervious, altered flow characteristics in the river, and tremendous loss of biodiversity and ecology throughout the catchment.

For the purpose of WFD, the River Santry is divided into two sections with an operational monitoring point at the downstream end of each. The upstream section (IE_EA_09S010300) runs from Harristown to Clonshaugh, where there is an operational monitoring point. The downstream section (IE-_EA_09S011100) runs from Clonshaugh to the lagoon to the rear of North Bull Island (another operational monitoring point is located at Bettyglen). At present, the upper section is classified as poor, while the downstream section is unassigned (although it can be assumed to have, at best, poor status).

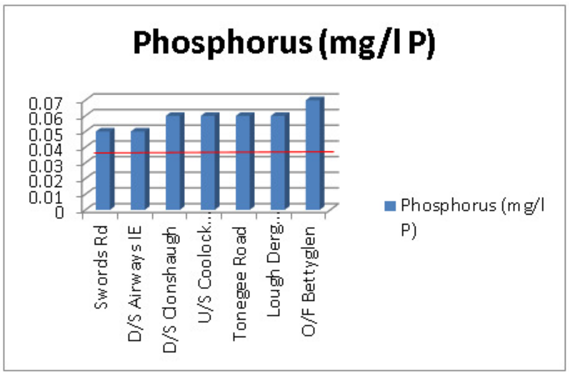

Figure 4 Phosphorus concentration, mg/l P, River Santry, 2007 - 2019

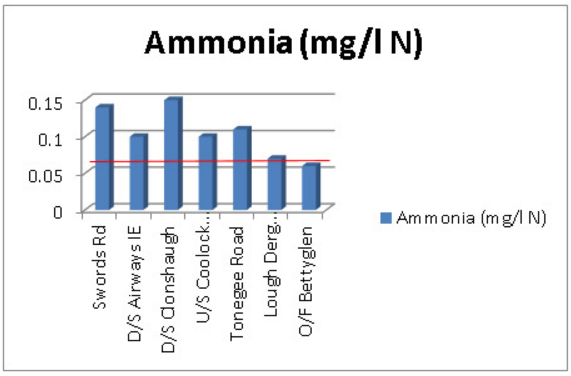

Figure 5 Ammonia concentration, mg/l N River Santry, 2007 – 2019

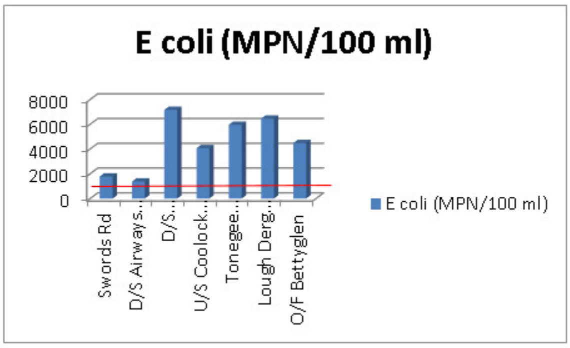

Figure 6 E coli concentration, MPN/100 ml, River Santry, 2007 - 2019

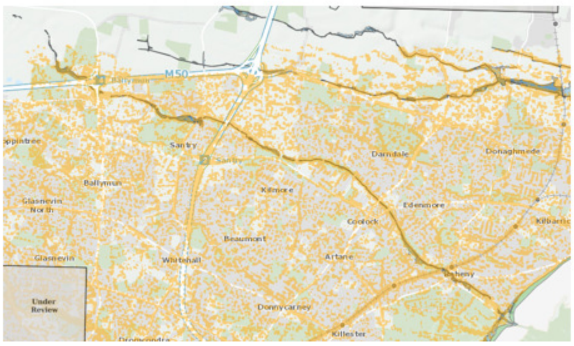

Figure 7 Fluvial and pluvial flood prediction maps, River Santry (www.floodinfo.ie)

Dublin City Council has carried out physico-chemical water quality monitoring in the River Santry, under dry weather conditions, for many years. Figures 4 to 6 show the phosphorus, ammonia, and *E coli* concentrations in the River Santry from 2007 to 2019. The 'Swords Road' monitoring point is the most upstream monitoring point, while 'O/F Bettyglen' is the most downstream monitoring point. The red line on each graph denotes the ELV for that parameter. Figure 7 shows fluvial and pluvial flood prediction maps for the catchment.

The pressures impacting on water quality in the River Santry (and, indeed, most urban rivers) include agriculture (at the headwaters), urban runoff, misconnections, pollution incidents/illegal dumping, and changes to hydro-morphology. Flooding is an issue in the catchment during extreme weather events. Incidents of flooding are projected to increase in the coming years as a result of climate change.

8. SUSTAINABLE STORMWATER MANAGEMENT IN THE SANTRY CATCHMENT

Dublin City Council, in collaboration with Fingal County Council and other stakeholders, propose a catchment-scale stormwater management plan for the Santry catchment. Based on a GI framework, it is proposed to utilise a broad suite of NWRM throughout the catchment to intercept polluted urban runoff, reduce flood risk, and to provide other environmental, ecological, biodiversity, social and economic opportunities within the catchment. The proposal comprises three elements:

1. A river channel and riparian zone restoration project, incorporating a greenway
2. A catchment-scale stormwater management plan, based on GI and NWRM
3. Pilot studies in small sub-catchments to identify optimisations in the application of GI /NWRM in an Irish context with a view to retaining 25 mm of rainfall in a 1 – 3 hour rainfall event.

The aim of the river channel and riparian zone restoration plan is to renaturalise the river channel where possible, provide flood risk benefits and enhance local habitat, biodiversity and public amenity. The project will also incorporate a cycle and pedestrian greenway. In order to maximise ecological and biodiversity potential, the greenway will be designed such that it intersects the river at particular locations rather than running adjacent to and in parallel with the river channel. With regard to public amenity, the greenway will provide sustainable transport options between important locations within the catchment (e.g. residential areas, schools, shopping areas, etc.).

The aim of the catchment-scale stormwater management plan is to address issues relating to poor water quality as a result of urban pressures within the catchment, mitigate flood risk by detaining and slowing down the movement of stormwater throughout the catchment, and to maximise biodiversity, ecological, habitat, social and amenity potential throughout the entire River Santry catchment. This will be achieved using a GI framework and incorporating a broad range of appropriately designed NRWM.
The principal objectives of the GI/NWRM pilot projects are twofold: (i) to demonstrate the effectiveness of GI/NRWM in addressing the problems caused by urbanisation, and (ii) to develop optimisations in the application of GI/NWRM in an Irish context. The outcomes of this process will direct those of the catchment-scale stormwater management plan. In terms of water quality and quantity, the objective of GI/NWRM in this context is to intercept and cleanse the first 25 mm of rainfall in a 1 – 3 hour rainfall event.

The over-arching objective of the plan is to achieve the objectives of several pieces of EU legislation, namely, the Water Framework Directive, the Floods Directive, the Birds Directive, and the Habitats Directive.

This is an ambitious, cross-agency and multi-disciplinary project to be implemented over a multi-year timescale. In the context of Dublin City Council, it is very much an inter-departmental project, requiring input and management from several departments within the organisation. Initial public engagement with elected representatives and communities within the catchment has commenced, and framework documents for the engagement of suitably qualified consultancies are currently being prepared. It is anticipated to go to tender in Q4 of 2019 with a view to appointing consultants in Q1/2 of 2020.

9. CONCLUSIONS

Catchments are complex 3-D systems influenced by their topography, underlying geology and hydrology. Urbanisation severs the natural link between catchment surface and hydrogeology, greatly altering the movement of stormwater through the catchment, and the flow characteristics of receiving waters. Urbanisation results in reduction in water quality of rivers, streams, estuarine, groundwater and coastal waters, increased incidence of flooding, alterations to downwind weather and rainfall patterns, and exacerbation of the impacts of climate change.

EU Member States are required to implement a broad range of environmental legislation simultaneously and synergistically, including the Water Framework Directive, the Floods Directive, the Habitats Directive and Birds Directive. This can only be achieved by implementing projects that deliver multiple benefits. Applying natural water retention measures under a green infrastructure framework is emerging as an appropriate approach to achieving the multiple objectives of these pieces of legislation. The Santry River Restoration scheme is the first of its kind in Ireland whereby a catchment-scale green infrastructure framework, utilising natural water retention measures, will be implemented to achieve these multiple objectives, as well as delivering additional social and economic benefits to communities living within the catchment.

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