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Ollscoil na hÉireann Má Nuad

Climate Change and its Potential Impacts on Construction in Ireland: The Argument for Mitigation and Adaptation

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ABSTRACT

The construction industry makes a significant contribution to Ireland's physical and economic milieu. It is therefore important to investigate the potential impacts of climate change upon it and formulate mitigation and adaptation strategies. Observed and modelled data were used to evaluate possible effects in the following areas: wind-driven rain; domestic wastewater management, in the context of septic tanks; and to analyse their implications for current and future Building Regulations.

Current and projected future wind-driven rain values were calculated. The likely outcomes were found to be greater building deterioration, increased maintenance requirements and a threat to occupant health. The implications of likely increases in precipitation were also examined. Findings indicated that a potentially significant restriction would exist on future construction in areas where septic tank densities were high and where water table levels approached the surface. In the context of both these findings, the Building Regulations were evaluated. For these, and for the general construction environment, it was found that the Regulations were fit for purpose, although the Building Control Regulations and Technical Guidance Documents required modification.

It was concluded that decision makers must factor in these implications when considering construction issues. Closer supervision of current buildings will be required to monitor for signs of accelerated degradation under changed climatic conditions. New builds should be constructed using the modifications recommended in this research, and where possible avoid locations highlighted as being likely to experience more severe climatic conditions.

The over-riding contemporary concern within the industry however is survival, not climate change. This current primary focus on short term concerns will have to be accommodated within a wider long term perspective on climate change before mitigation and adaptation strategies can be effective. This research brings to the attention of decision makers the urgency of doing this.

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1 RESEARCH OVERVIEW

1.1 Motivation for research

The relationship between climate and construction has been studied ever since *Homo sapiens* exchanged caves for mud-huts. Until recently this relationship has been well understood, but with the advent of climate change, the impact that climate will have on construction is changing. This thesis addresses the knowledge gap that exists as a result of this changing relationship.

The outputs of this research will be of interest to bodies such as government agencies and local authorities developing adaptation policies. Making improved information available to decision-makers will aid in the preparation of appropriate mitigation and adaptation strategies, the implementation of which will increase the resilience of the construction sector in vulnerable areas. This research will also serve as a foundation upon which further studies can be based as climate models become more refined.

1.2 Context of the research

Climate change is an important subject in 21st century scientific discourse. It is a key focus for both proponents and detractors, and forms an important part of government policy programmes. The United Nations Framework Convention for Climate Change defines climate change thus (UNFCCC, 2012: 1):

> 'Climate change means a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods.'

Substantiating the anthropogenic component, the Intergovernmental Panel on Climate Change's Fourth Assessment Report concluded with 'very high confidence' that human-induced warming of the climate is occurring (IPCC, 2007a: 37). This is a trend that is likely to continue as global populations and economies expand, increasing the atmospheric concentrations of greenhouse gases. Although climate change effects will be location-specific and diverse (Dessai & Hulme, 2007), the basic understanding of climate change is well established. It is the demand for climate applications knowledge that is now emerging (Dozier in Hey *et al*. (Eds.), 2009). A sector that would benefit from an increase in such applied climate knowledge is the construction industry.

The construction industry is a fundamental component of Ireland's physical and economic environment. It is therefore of great importance to investigate the potential impacts of climate change in this vital sector. Climate has a substantial influence on planning, work practices and cost estimation, and any change in climate could impact upon construction considerably. Losses in productivity due to increased precipitation, temperature fluctuations and high winds could result in serious economic consequences. The impact of projected climate change on existing buildings and infrastructure is also important. Such structures were built on the basis of contemporary codes and standards, which were based on historical climate data that may not be appropriate for changed climatic conditions. An increase in the severity of climate impacts could elevate their exposure to levels where they begin to fail.

The construction industry has long-since recognised the importance of adapting to climatic influences. Materials, technology and techniques have improved considerably, albeit against a background of development centred on current rather than future climate conditions. Climate change is set to test these advancements, and significant climate change threats in many areas of infrastructure and the built environment has already been identified (e.g. Garvin *et al*., 1998; Graves & Phillipson, 2000; Arkell *et al.*, 2007; IAE, 2011; and CCRA, 2012). Nevertheless, there are areas that are under-represented in an Irish context and which will be addressed in this work.

1.3 Research focus

It is anticipated that long-term climate change and extreme weather events will affect infrastructure and the built environment (CCRA, 2012). However, evaluating impacts in both areas is impracticable in one study due to their vast and diverse nature. Given that the construction of buildings is the dominant area in the industry, accounting for 78% of total construction, while infrastructural works constitute the remaining 22% (EC, 2012b), this research focuses on the built environment.

In terms of research scale, refining the focus to the built environment still presents significant considerations. Housing stock alone stands at 2,004,175 (CSO, 2011), and local industrial units for electricity, manufacturing, gas and water number 5,135 (CSO, 2009). In terms of research design, the life-expectancy of buildings is the principal driver. Watton (2000) observed wryly, ‘The expected life of a building is 50 years (the builder), 100 years (the lender), and 400 years (the owner).’ This quote serves to illustrate the temporal scales involved, notwithstanding the rather wide variation. Although the design life of buildings today is assumed by the industry to be 60 years (Nolan, 2009), many existing structures, for example the Georgian houses of Dublin, demonstrate clearly that buildings survive for centuries. An approach to climate change assessment is therefore required that satisfies these temporal scales.

Such an approach is demonstrated in the IPCC adaptation framework. This top-down approach was developed in the early 1990s and is particularly relevant if the concerns are long term and at global or regional scale (Dessai *et al.*, 2005). It utilises climate change scenarios as the main driver of impacts from which adaptation strategies are developed (Parry & Carter, 1998). Conversely, a bottom-up approach such as the United Nations Development Programme’s Adaptation Policy Framework would not be appropriate. Such an approach firmly grounds decisions ‘in the priorities of the present’ (UNDP, 2004: 1), and bases reducing vulnerability to long-term climate change on adapting to short-term climate variability. It could be argued that it does not suit the temporal context presented by the built environment. This thesis will therefore employ a top-down approach as espoused by the IPCC adaptation framework.

1.4 Research aims

This thesis examines potential climate change impacts on the construction industry in Ireland, with a particular focus on vulnerable aspects of the built environment. The research questions are:

- To what extent will climate change affect vulnerable sectors, both temporally and spatially?
- What specific impacts is climate change likely to have within these sectors?
- How can the recommendations developed through this research aid decision-making and adaptation with regard to these vulnerable sectors?

Although the anticipated impacts of climate change in Ireland will lead to conditions no more extreme than those managed successfully in other regions of the world, there are nonetheless circumstances pertinent to Ireland that warrant further investigation. These are identified in the literature review and defined further in the objectives.

1.5 Thesis structure

Chapter 2: Literature review

The Irish construction industry is first set in a global and European context. Subsequently, an overview of the industry in Ireland is given. The relationship between current weather and construction is explored, and the scientific basis for climate change is examined. An introduction to the construction context and a background to the objectives are then presented. Objectives are identified in three areas relevant to construction in Ireland: wind-driven rain; domestic wastewater management; and the

Building Regulations 1997-2012. An overview of the data employed to meet the objectives is also discussed.

Chapter 3: Wind-driven rain

Wind-driven rain (WDR) is rain that is given a horizontal component by wind. WDR's net result is increased vertical surface wetting, which affects U-values and increases wear on components such as building façades, roofs, windows and doors. WDR receipt is calculated herein by employing the latest International Standards Organisation (ISO) standard. Observed and modelled data are utilised to provide a benchmark and future projections of WDR, the first time this has been performed in Ireland at the national scale.

Chapter 4: Domestic wastewater management

Increased winter precipitation as a result of climate change may lead to rising winter water tables. The resulting vulnerability of groundwater to contamination from domestic wastewater from one-off housing is investigated. The impact of this on construction will be assessed in the context of more restrictive planning regimes and the installation, maintenance and/or replacement of over 435,000 domestic wastewater treatment systems currently in use in Ireland. Not analysed previously in such depth, results of wastewater treatment system density analyses are presented, and a vulnerability index to aid spatial awareness of threat levels at county scale is developed. A shift in geographies of construction is also discussed.

Chapter 5: Building regulations

The Building Regulations 1997-2012 are assessed in the context of climate change. Traditionally, historical climate data is used in regulatory development and assessment. This chapter represents the first attempt in Ireland at incorporating climate change projections into building regulation evaluation. Adaptive recommendations are made for the Regulations, Technical Guidance Documents, Codes and Standards reviewed.

Chapter 6: Discussion and conclusions

Observations are discussed that inform the proposed recommendations and adaptation strategies. The key findings of the thesis are then summarised and placed in the context of the international literature. Limitations of the study are considered and areas for further study are outlined.

1.5.1 Conceptual flow

Due to the identification of three significant yet diverse strands of research within the Irish construction industry context, a tripartite thesis structure (as illustrated in Figure 1.1) will be employed. Its design allows the separate assessment of each area, while maintaining feedback paths that enable relevant regulatory themes to be introduced at appropriate junctures.

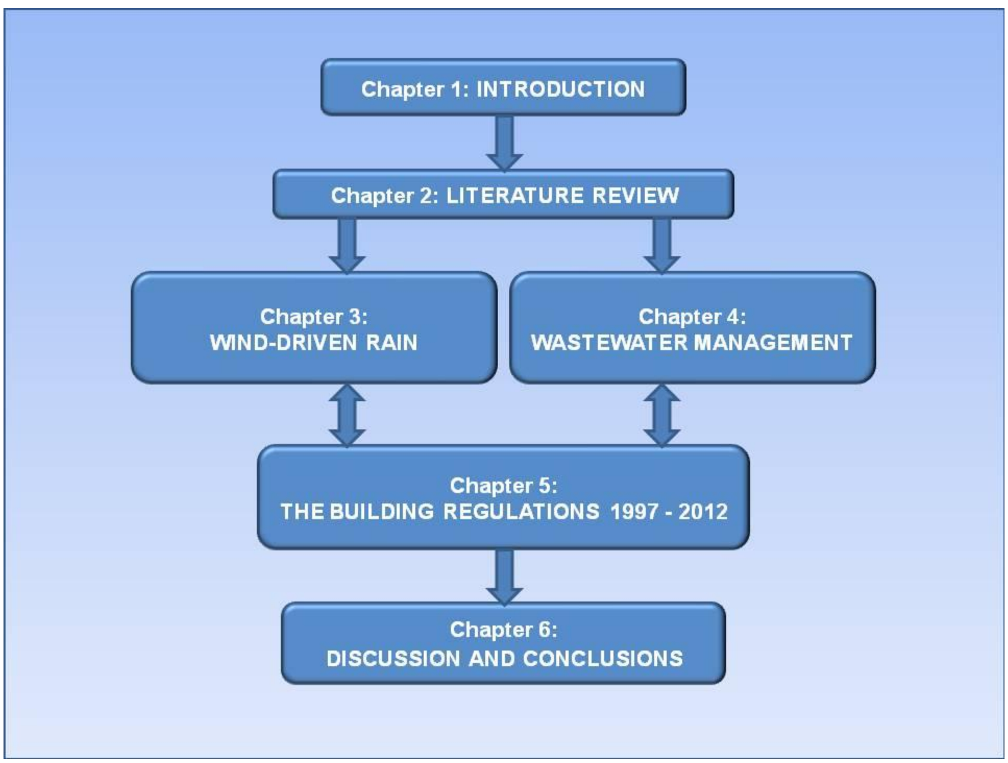


Figure 1.1 Conceptual flow.

CHAPTER 2
THE STATE OF THE ART

2 INTRODUCTION

The construction sector plays a central role in society and is a vast entity. In 2011 it accounted for over 11% of global Gross Domestic Product, representing a value of construction output of €5.8 trillion (UNEP, 2011). In a European context the overall turnover of the construction industry at its peak in 2007 was €2.317 billion. In 2008 it still supported 26 million jobs representing 7.1% of total employment and 29.1% of all industrial employment (CSES, 2011). Although the EU-27 index of production for construction fell by 14.2% between the first quarter of 2008 and the third quarter of 2009, the industry still accounted for around 5% of the EU-27's GDP with estimated investment valued at €1.173 billion (FIEC, 2012). In Q4 2011 European industry output was down at 90.54% of the base year, 2005, but the general rate of decline had levelled out (EC, 2012a). Still, although the mean rate of decline may have levelled out there were significant national variations. Ireland's decline for example was substantially greater than the European average. Nonetheless, while it is anticipated that construction in developed countries over the next decade will be restricted by austerity programmes (UNEP, 2011) it can be seen that the construction industry is an important sector. As such, assessing the impact of climate change upon it is of great importance.

The European construction industry is composed of a high proportion of small companies with less than 50 employees but it is the large corporations that tend to influence practice and dominate the market in areas such as public procurement (CSES, 2011). In terms of sector focus, as noted in Chapter 1, the construction of buildings is the dominant activity. Within this apparently simple divide it can be seen that the industry is very diverse. Construction is divided into several categories in the pan-European *Nomenclature Generale des Activites Economiques dans I`Union Europeenne* (NACE) code classification system, ranging from construction of buildings to site preparation to joinery installation (EC, 2008). The sector can be sub-divided further into construction activities (74%), professional construction services (14%) and manufacturing of building materials (12%) (CSES, 2011). At national scales there is variance in these ratios determined by levels of investment and a nation's individual requirements, but these percentages serve to indicate the relative significance of each division and give context to this multi-billion Euro industry.

2.1.1 The shift towards sustainable construction

As has been demonstrated, the value of the construction industry to society is immense. However, construction is also the biggest user of natural resources and a significant emitter of greenhouse gases and thus assumes an important role in the climate change debate. An area of the construction industry in which climate change assumes a principal role is the continued drive towards sustainable construction. Although the move towards sustainable construction has been described as the most significant recent development in the industry (Domone & Illston, 2010), sustainability is not a new concept in a construction context. Sustainable development represented a core strand of Ireland's development strategy as far back as 1997, when policy stated that 'sustainability principles must underlie the implementation of future strategy for the construction industry' (DOE, 1997: 153). Similarly, Ireland's Guidelines for Planning Authorities (2007: 3) stated that development plans must offer 'clear guidance on sustainable development policies and objectives […] which address the various issues involved, such as climate change'. Extending policy further, Scotland is considering making sustainability 'a factor to be considered in the procurement process' (Scottish Government, 2011a: 7).

The link between sustainability, construction and climate can be considered inextricable. Indeed, 'construction has the greatest impact on sustainability in the world' (CSES, 2011: 145). While sustainable development as a broad term can be defined as 'meeting the needs of the present without compromising the ability of future generations to meet their own needs' (Brundtland, 1987: 15), sustainable construction embraces a range of interpretations (Smith, 2010). However, its aims can probably best be summarised as protecting and enhancing the physical and natural environment and 'using resources and energy as efficiently as possible' (DTI, 2006: 4). Sustainable construction's integrated life-cycle-oriented approach can be seen as complementing the EU's 20-20-20 climate strategy to improve energy efficiency by 20% and cut greenhouse gases by 20% by 2020. An estimated 35% of all greenhouse gas emissions in the EU are attributable to buildings (EC, 2012c), so it can be seen that the shift towards sustainable construction coupled with more efficient building operation will contribute to the achievement of 2020 targets.

The drive towards sustainability will afford opportunities in the construction sector. Some studies (e.g. Tan *et al*., 2011) have concluded that embracing sustainability will increase contribution to business competitiveness, given a long-term view. Additionally, the EU Construction Products Regulations (2011) specify sustainable construction practices. If sustainability can thus be seen as a long-term asset in the commercial reality of construction, it could help overcome the regulatory inertia present in a culture of standardisation not accustomed to reacting to a significantly changing climate (Sanders & Phillipson, 2003).

The importance attributed to sustainable construction resulted in its inclusion in the EU's Lead Market Initiative (LMI). Markets in the LMI have been selected because, amongst other criteria, they provide solutions to broad societal and environmental challenges. Sustainable construction undoubtedly has to address the environmental challenge, upon which climate change has had a considerable impact. Climate change is therefore a key driver in the shift towards sustainable construction, which in turn represents a significant change in the focus of the construction industry itself. As observed in Ireland's Environment (EPA, 2012: 147), 'as Ireland begins to work its way back to economic recovery, it [must go] in a sustainable direction'.

2.2 Overview of the construction industry in Ireland

The construction sector's importance to Ireland is substantial. At its peak in 2006 it contributed to 25% of GNP equating to a value of output of €39 billion (SCSI, 2012). Although its contribution to GNP fell to 23.8% in 2007 and to 12.8% in 2009, this still represented a value of output estimated at €18 billion (DKM, 2010). Between Q2 2009 and Q2 2010 its value of production contracted by 31.8% but it still represented a critical component of the Irish economy. Despite employment in the industry also falling significantly from its peak of 269,600 in 2007 to 125,300 in 2010 it accounted for almost 7% of the Irish workforce (CSO, 2010). However, by 2012 the value of output had declined to €7.5 billion, representing 7% of GNP (SCSI, 2012: 5). As can be seen, from a peak of 25% of GNP in 2006 to 7% of GNP in 2012 the construction industry contracted sharply. However, as an industry it is still substantial: the most recent annual figures available indicate that 107,500 people were employed in the Irish construction sector in 2011 and the value of output was €8.7 billion (CSO, 2011).

The industry can be divided into three sectors comprising housing, civil engineering and non-residential building (Figure 2.1). Housing incorporates all structures intended as dwellings, including one-off rural housing, developer-led housing and city apartments. Civil engineering includes structures such as railways, roads, bridges, airport runways and dams. Non-residential structures are those that have commercial purposes, such as office blocks, or infrastructural purposes such as public buildings and power stations.

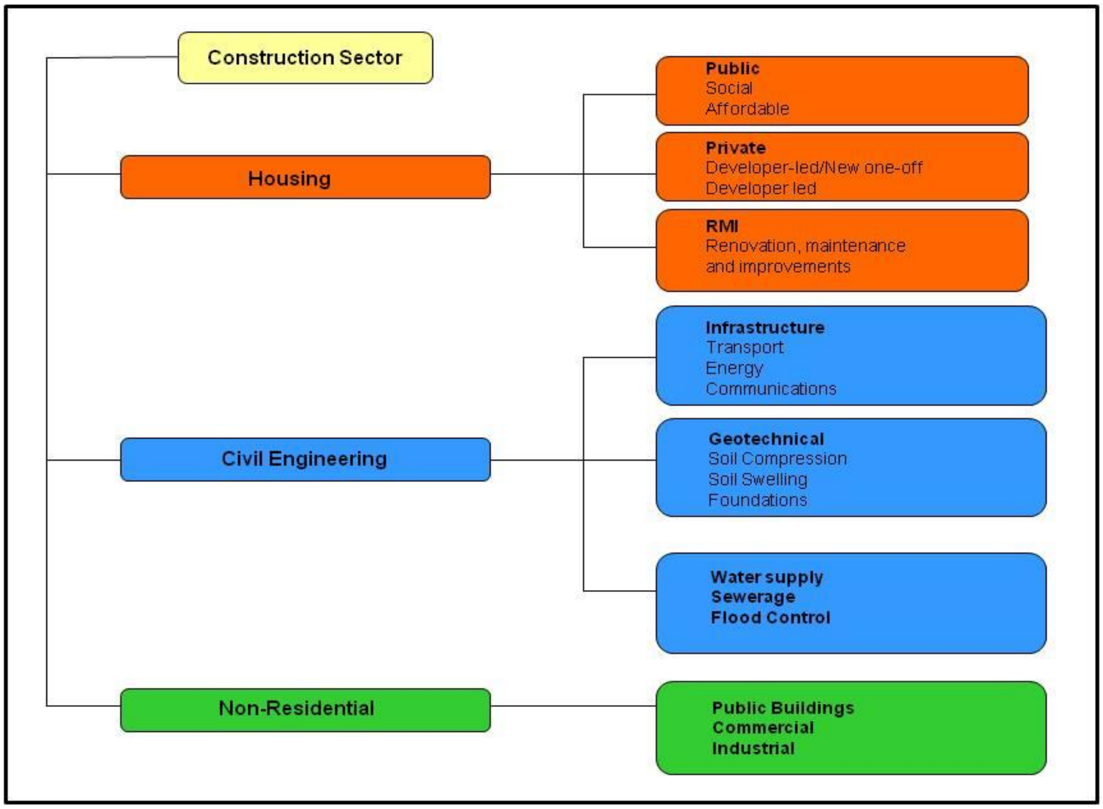


Figure 2.1 Construction Industry sectoral breakdown (adapted from Stafford, 2007).

It can be seen that the construction industry in Ireland exercises a pivotal position in society. It employs a significant proportion of the workforce and represents a sizeable percentage of GNP, which makes it important to estimate the extent to which climate change is likely to impact upon it. Aside from the concern of negative climate impacts, an important consideration for the industry is what positive prospects climate change may present. For example, the emerging Green Economy, and the energy sector, where the Government is committed to improving the energy efficiency of residential building stock, are potential opportunities for construction. Indeed it has been observed that when the industry recovers it will be more focused on ‘ensuring that the building stock is fit for purpose rather than on major new works’ (SCSI, 2012: 42).

2.3 The current relationship between weather and construction

2.3.1 Introduction

Weather conditions affect many aspects of construction projects. From site conditions to construction processes to worker comfort, the construction phase is highly weather-dependent. Infrastructure and buildings are subject to continual exposure, and elements such as precipitation, wind, ultra-violet radiation and temperature have significant impacts over time. However, such issues are addressed in current building regulations, codes and standards. The Building Regulations 1997-2012 Part A, for example, gives guidance on Structure, while Part D gives guidance on Materials and Workmanship. Further guidance in such areas as energy, ventilation, wastewater disposal and resistance to moisture is also available, although it should be noted that the guidance employed in all such documents is based on historical climatic data rather than future projections.

The physical impact of weather on the built environment in general in the temperate European sphere has been well documented (e.g. Lacy, 1966; Smith, 1975; Garvin *et al*., 1998; Graves & Phillipson, 2000; Sanders & Phillipson, 2003; Vivian *et al*., 2005; Arkell *et al*., 2007; Smith, 2010). Table 2.1 outlines the principal processes identified, while the main agents involved include water, ice, wind, salts, thermal changes, atmospheric pollution and microbiological organisms (Pavía and Bolton, 2000).

As can be seen, the construction industry is very much aware of weather impacts. To address the issue, clauses in insurance policies pertaining to adverse weather form an important part of construction contracts. For example, accumulated degree-days above or below an agreed threshold is widely used (Graves & Phillipson, 2000). Assessing weather risk through the most recent information and mitigating for it through weather insurance is *de rigueur*, particularly for large projects. Ensuring that weather delays are excusable, even though usually non-compensable, is critical to avoiding penalties that would otherwise impact negatively on profit margins.

Table 2.1 Principal weather impacts on construction (after Smith, 1975 and Vivian *et al.*, 2005).

Phenomenon:	In conjunction with:	Effect:
Rain		Delays concreting, bricklaying and all external trades. Affects site access and movement. Spoils newly finished surfaces. Delays drying out of buildings. Damages excavations. Damages unprotected materials. Causes discomfort to personnel.
	High wind	Increases rain penetration. Increases site hazards. Reduces protection offered by horizontal covers.
High wind		Limits or prevents operation of tall cranes and cradles. Makes steel erection, roofing, wall sheeting, scaffolding and similar operations hazardous. Damages untied walls, partially fixed cladding and incomplete structures.
Higher summer temperature		Curing of concrete: ideal temperature is *c.* 23˚C. Water scarcity (e.g. for mixing concrete). Health and safety of workforce.
Low and sub-zero temperature		Damages mortar, concrete and brickwork. Slows or stops development of concrete strength. Slows down excavation. Delays painting and plastering.
	High wind	Increases probability of freezing and aggravates all above points.

Insurance is also a recognised tool in mitigating for phenomena such as subsidence. Subsidence is well understood and proper subsoil assessment and foundations will afford protection against it in new-builds. However, for existing buildings and infrastructure vulnerable to climate impacts, insurance policies may have to be revised to exclude claims for subsidence, although this will impact the body responsible for the constructed unit rather than the construction industry *per se*.

In terms of adaptation to weather-related events, retrofitting is gaining considerable momentum within the industry. Indeed, a Department of the Environment, Community and Local Government (DECLG) Code of Practice for Retrofitting is due for publication shortly. This is an important evolution, because aside from affording increased weather protection it is anticipated that retrofitted wall and roof insulation will offer the greatest energy savings, which will in turn make an appreciable contribution to reducing greenhouse gas emissions (CEC, 2006). €880 million was allocated for investment in energy efficiency retrofitting programmes by the Government during the period 2010-2016 (Department of the Taoiseach, 2010), although exchequer funding is now being phased out by the end of 2013 due to the economic downturn (NESC, 2012). Nevertheless, this still demonstrates the scope of opportunity for the industry when the economy improves.

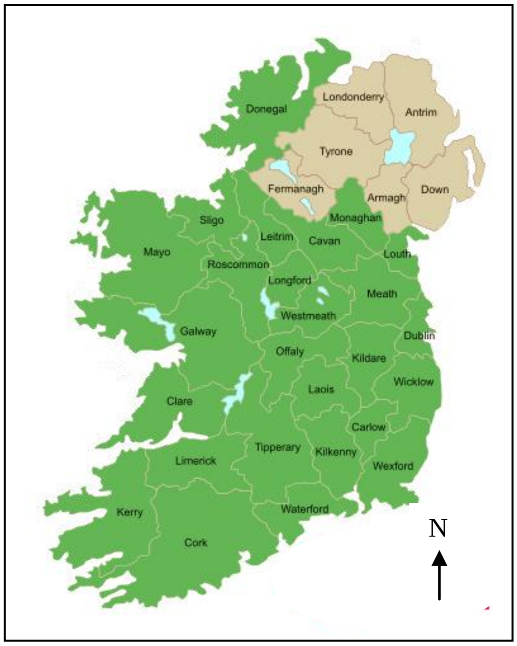
There are many private companies and national weather centres offering the latest available climate data to incorporate into project planning. Frequency and magnitude of construction-critical parameters such as frost days, wet days, wind speeds, humidity and maximum and minimum temperature are the main variables utilised. The key point is that the data used currently in assessing the risks to weather are historical. Because the cost and duration of construction activities are heavily influenced by climatic conditions, it is ever more important that decision-making should be based on future projections as well as past conditions. Nonetheless, it is important that the relationship between current weather conditions and construction is discussed first to establish a baseline condition against which the impacts of climate change can be compared.

To assess the current physical impacts of weather on construction, the Irish climate will be discussed briefly and the phenomena detailed in Table 2.1 above will be examined in more detail. Key factors that have the potential to affect construction are precipitation, wind speed and temperature (Vivian *et al.*, 2005). The contemporary relationship between weather and construction will therefore be evaluated in this context.

2.3.2 The Irish Climate

The two dominant influences that shape Ireland’s climate are the relatively warm winter North Atlantic waters and the general westerly circulation (McElwain & Sweeney, 2004). The Atlantic Ocean tempers Ireland’s climate insofar that it does not suffer the extremes experienced by many countries at similar latitudes, instead experiencing a generally mild and moist climate.

Irish precipitation patterns are largely determined by the westerly winds and orography with the largest rainfall values usually occurring in highland areas (Wang *et al.*, 2006).



Irish Counties. (Source: WesChem, 2013.)

The highland areas, many of which lie near the coast, shelter the more inland areas from the oceanic effects and strong winds, while Ireland's proximity to North Atlantic storm tracks result in increased wind and more frequent rainfall in the northwest (Keane & Sheridan, 2004). The eastern half of Ireland generally receives between 750 mm and 1000 mm of precipitation annually, the west 1000 mm to 1400 mm, and in mountainous areas rainfall can exceed 2000 mm per year (Met Éireann, 2012).

The prevailing wind direction in Ireland currently is between south and west (Met Éireann, 2012). However, seasonal variation is a feature with, for instance, a predominance of easterly winds between February and May and south south-easterlies in January. Topography also affects winds experienced at different locations. For example, the sheltering effect of the Dublin Mountains results in a low frequency of southerly winds at Dublin Airport, while at a more local scale buildings and trees can also affect wind direction (Met Éireann, 2012). In terms of wind speeds in Ireland, averages range from 8m/s in the extreme north down to 3m/s in parts of Carlow and Wexford. Inland locations experience fewer gale force winds. In Kilkenny there are less than 2 days per year featuring gale force winds, while in Malin Head, Donegal, the figure is more than 50 days per year (Met Éireann, 2012).

Temperature in Ireland is moderated by the Atlantic. Consequently, Ireland does not experience the great range of temperatures experienced by much of Continental Europe. In summer air temperatures inland generally peak at between 18 to 20°C, while in winter this figure drops to 8°C. In terms of minima, air temperature falls below 0°C less than 10 days per year in coastal locations and approximately 40 days per year inland (Met Éireann, 2012).

Now that a brief overview of current precipitation, wind and temperature in Ireland has been given, a more detailed examination of these factors will be carried out in the context of their impact on construction.

2.3.3 Precipitation

Precipitation is one of the most disruptive elements on construction activities. Wet weather is often the reason behind contract or budget extension requests (Smith, 1975). In terms of site works, prolonged or intense periods of rainfall can create extremely muddy conditions that preclude heavy machinery from working efficiently and generally hinder access by all building trades. It will also delay general earth moving, paving and foundation work. However, it is not just above ground that precipitation can cause problems. Groundwater levels can be affected, particularly during winter months, and in areas where recharge is fast, water table levels can rise quickly. Flooding can then become an issue especially in trenches and foundation works (DTI, 2004). In the lifetime of the building, permanent waterproofing of affected areas may be required to mitigate for groundwater conditions (Crissinger, 2005). Low or freezing temperatures may also create problems. Temperatures below 10°C reduce the rate of concrete hardening and below -2°C there is a risk of frost damage (Smith, 1975). In addition, concrete may be subjected to chemical attack from groundwater, and corrosion induced by chlorides and carbonation (European Standard EN 206-1, 2000: 15).

Construction materials are also subject to the impacts of precipitation. For example, moisture can penetrate brick through capillary action and the action of wind-driven rain.

Unless these actions are checked by devices such as rain screens, cavity walls and wall-flashings, moisture can reach the interior and condense on interior walls. This can lead to mould growth, deterioration of finishes and potential health problems for occupants (Scottish Government, 2011b). In addition, any imperfections in finish will leave a gap that rain can penetrate. Wind can blow rain through gaps as small as 0.15 mm (Hens, 2010), although if moisture breaches the building shell, drainage provisions such as channels and drains in cavity walls can re-direct it to the exterior. In terms of painting and the application of surface finishes, these and similar actions are also affected by precipitation. It is not possible to perform such operations when rain is directly impacting surfaces.

2.3.4 Wind

Unlike precipitation, the failure of structures to withstand wind can be catastrophic. Although there is 'a great deal of uncertainty about future patterns of wind speed and direction' (Sharples & Lee, 2009: 11), buildings and other structures must still be constructed to withstand the strongest winds that might occur, even though a failure-inducing wind gust may last only a few seconds. That said, in terms of insurance, the 'nightmare scenario' for an insurer with respect to buildings claims is not complete destruction of one building but 'one tile off every roof in the country' (Larkin, 2011 [personal communication]).

The geography of a site also impacts mitigation for wind. Tall buildings in exposed areas require significantly different structural considerations compared to low-rise buildings in sheltered areas (Crissinger, 2005). Furthermore, roof design must consider the immediate surroundings. In particular, height can influence the suction effect of wind passing over peaked roofs. High winds in such cases can provide sufficient vacuums to cause severe damage or complete roof failure. Increased wind suction may also arise from local factors such as the funnelling of wind through gaps between buildings (DECLG, 2011e). Doors and windows may not be as vulnerable to wind as roofs, but nonetheless anticipated wind speeds must be considered as moisture infiltration through joints is dependent largely on pressures induced by wind speed.

In addition to its own direct effects, wind acts as a multiplier in other aspects of construction. For instance, wind accelerates drying by evaporating moisture more rapidly. This can be critical when curing concrete, where incomplete curing may occur due to premature water loss. Studies have indicated that evaporation rates increase approximately fourfold when wind increases in speed from zero to 15km/h (Vivian *et al.*, 2005). Wind also increases rain penetration of materials due to increased pressure on moisture on construction surfaces. In terms of site works, high winds in particular can increase the number of days that cranes are not able to function. It also makes all manner of roofing, sheeting and scaffolding more hazardous, and induces freezing at low temperatures.

2.3.5 Temperature

Temperature is a critical parameter in construction. For example, concrete is one of the most widely used materials and relies on setting and curing within certain temperature parameters. The optimum temperature to cure concrete is 23°C, which gives 80-100% greater strength than concrete which has not been properly cured (Vivian *et al.*, 2005). Rapid evaporation of water due to high temperatures results in concrete with a lower compressive strength (Crissinger, 2005). Another consequence of the rapid evaporation of moisture is the premature setting of cement. In such cases, bricks may not absorb the mortar completely, resulting in a reduction in bond strength between the mortar and brick. In addition, if bricks are dry due to high temperatures when laid they may absorb water from the cement at a rate that also results in a loss of bond strength, the consequence of which may be leaks at weakened joints.

A further effect of temperature on joints is the potential for thermal distortion. Different materials expand and contract at different rates, which can lead to an opening up of joints and seams leading to component and/or structural failure. The expansion and contraction properties of materials used in construction must thus be considered in the context of the temperatures they are likely to be subjected to. However, even if the appropriate seals and sealants are employed, over time UV exposure and freeze-thaw cycles reduce their resiliency. Loss of elasticity and increasing brittleness is the consequence, which eventually results in gaps and the potential of increased moisture ingress.

Low temperatures can have an equally debilitating effect on construction processes. Ice crystals can form which retain the water needed for concrete curing and cement bonding. Curing may be slowed which can affect strength and spoil the finish. Paint finish may also be affected as carriers such as water and solvents thicken or even freeze, retarding the drying process. Conversely, high temperatures and low relative humidity can cause reducers in paint such as solvents to evaporate too fast. In such cases it is evaporation rather than retention that slows the curing process. Blisters, cracking and delamination may result. To mitigate for these eventualities ambient and substrate temperature recommendations are displayed on most paint containers.

In terms of site impacts temperature is important. In long spells of hot dry weather dust becomes a major factor, which could lead to concerns regarding the potential for unsafe working conditions (DTI, 2004). It accumulates on inside and outside surfaces and must be removed regularly before finishes are applied. The situation is further exacerbated if heavy machinery is being employed. Clouds of dust can impact a wide area, particularly if wind is also involved, resulting in a reduction of site efficiency and impaired worker health. Low temperatures also affect site efficiency and induce weather-related delays. Principal impacts include retarded curing times, a reduction in worker comfort and lower viscosity of key liquids such as water and solvents. Each of these factors can lead to a loss of project momentum.

2.3.6 Summary

Construction is highly weather-dependent. Optimal construction conditions require factors such as precipitation, wind, temperature and relative humidity to fall within certain parameters. Indeed, many products are designed to be used within certain boundary conditions, outside of which their performance declines, depending on the severity of the conditions. Nevertheless, the action of weather on construction and its impact on the construction industry is well understood, and technological innovations, insurance and advances in practice and materials are utilised to mitigate for its impacts.

In terms of construction practice, structures should be built of materials that can resist the deteriorating effects of the weather. Some of the principal methods for mitigating for weather impacts are the use of corrosion-resistant metals, decay-resistant wood, UV-resistant finishes and high performance windows and doors. Accurate assessment of local weather patterns will also influence the outcome of construction projects. In large construction projects particularly, weather represents a major factor in timelines and can impact profitability if delays exceed conditions laid out in the project contract.

With the advent of climate change the current relationship between construction and weather is being altered. Indeed, ‘some extreme events are projected to increase in frequency and/or severity during the 21st century’ (IPCC, 2007e: 1), with the result that current construction practice and mitigation and adaptation measures may not withstand the new climate regime. To assess the change in relationship between weather and construction, climate change will now be examined. Objectives will be identified that are relevant to the Irish context and to which recommendations and adaptation strategies can be applied.

2.4 How climate change is altering the relationship between weather and construction

2.4.1 Introduction

As highlighted in section 1.3 the actions of weather on construction and structures are well understood. Moreover, materials and methods are constantly being developed to provide increasing resilience against elements experienced currently. However, it is apparent that most of these developments do not take into account future climate projections (Gething, 2010). Climate change is set to alter some of the relationships discussed previously, and it is therefore imperative to assess the implications for construction in this new context and address the issues that are specifically relevant to Ireland. Without such an assessment, accelerated deterioration of surfaces, interiors and even structural failure itself may occur during the intended lifespan of a structure. It is also important that new structures are designed to take into account the new relationship and mitigation measures incorporated. A brief overview of current climate change literature will therefore be undertaken, from which it will be possible to consider the likely impacts on the construction industry.

2.4.2 The scientific basis for climate change

Since the industrial revolution *c.* 1750 a sustained increase in the use of fossil fuels and change in land use has taken place. This has resulted in an increase in the amount of greenhouse gases emitted, the heating effect of which is estimated to be five times that of the natural causes of climate change (McGrath & Lynch, 2008). Eleven of the twelve years spanning 1995-2006 were among the warmest recorded since 1850, and the 50-year linear warming trend of 0.13ºC per decade from 1956 to 2005 was nearly twice that of the 100-year trend from 1906 to 2005 (IPCC, 2007c). Indeed, less than 5% probability that the observed warming is due to natural climate variability now exists, such that:

> ‘Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice and rising global average sea level’.
>
> (IPCC, 2007c: 1).

Depending on emissions scenario, the best estimate of mean global temperature change for the end of the 21st century ranges from +1.8 to +4°C (McGrath & Lynch, 2008). The result of a warmer atmosphere is that more moisture can be retained. Precipitation in many areas including northern Europe has increased and changes in storm tracks have also been attributed to warming. Additionally, it is very likely that cold spells over land at night will become less frequent and hot spells during the day more frequent (IPCC, 2007c).

In Ireland, autumn and winter are projected to get wetter and windier while spring and summer are expected to get warmer and drier (McGrath & Lynch, 2008). The Community Climate Change Consortium for Ireland (C4I) predict that average temperatures in the period 2021-2060 could be 1-1.5°C higher than 1961-2000. Winters may be up to 15% wetter and 1-2% windier, and summers up to 20% drier particularly in the south east with a slight decrease in wind speed of 2-3% (Figure 2.2 and Figure 2.3).

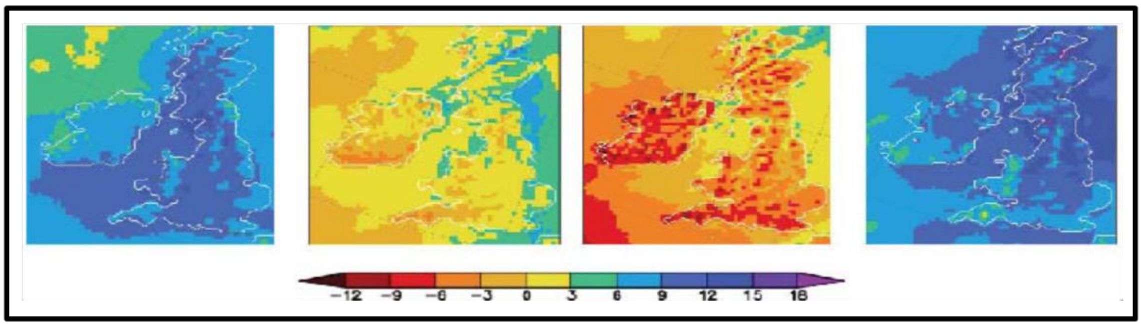


Figure 2.2 Percentage seasonal changes in precipitation. Mean of 8 ENSEMBLE simulations illustrating change between 1961-2000 and 2021-2060 for (left to right) winter, spring, summer and autumn. Increases in winter/autumn in the order: 5-10%. Decreases in summer: 5-10%. Decreases in spring: 2-5% (McGrath & Lynch, 2008).

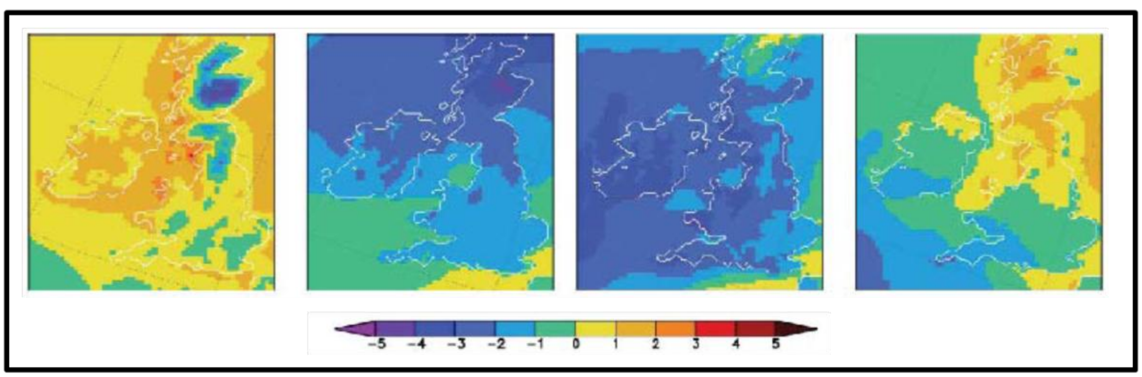


Figure 2.3 Percentage seasonal changes in wind speed. Mean of 8 ENSEMBLE simulations illustrating change between 1961-2000 and 2021-2060 for (left to right) winter, spring, summer and autumn. Increases in winter in the order: 1-2%. Decreases in summer: 2-3% (McGrath & Lynch 2008).

In northern areas more extreme rainfall events are shown to occur in autumn, along with a 20% increase in 2-day extreme rain amounts. Extreme wind speeds also display a higher occurrence under future simulations (Nolan, 2009b). At the regional level, because there can be substantial differences in local climate over distances of even one or two kilometres (Lacy, 1977), plans need to be refined to take into account local factors such as topography. In general, therefore, all sectors impacted by weather in Ireland need to plan for effective long-term action on climate change, and in a global window of opportunity that is 'extraordinarily narrow' (Parry *et al.*, 2009: 1103).

2.4.3 The Irish construction context

As noted previously the impact of weather on construction is well understood in general; what is deficient is an appraisal of the impact of climate change in an Irish construction context. Yet it is important to recognise that potential solutions to Irish issues may already exist in other countries. For example, Scotland is subject to similar synoptic circulation types that influence the Irish climate and has committed considerable resources towards working to mitigate for warmer, wetter winters and hotter, drier summers with an increase in variability of extremes (Scottish Government, 2012). That said, it should be noted that, despite Britain's general proximity to Ireland, notable contrasts in weather can occur in different parts in a single day due to the presence of multiple airflow types (Sweeney & O'Hare, 1992). In the context of building and construction there will also be different impacts depending on building type, scale, construction and location (Camilleri *et al*., 2001). Nonetheless, due to the similar climate change impacts anticipated in the UK it is reasonable to examine the findings of British and Northern Irish studies in an Irish context, and evaluate them alongside Irish studies to identify synergies and adaptive opportunities. As Cassar *et al*. noted (2007: 4):

> '…weather at all UK [and Irish] locations will remain inside the range of existing variability for Europe and North America. Adaptation to climate change is unlikely, for a century at least, to require anything that is not done somewhere else already, either in the UK or in neighbouring countries.'

Similarly, the Royal Academy of Engineers observed that the anticipated impacts of climate change in the British and Irish sphere will lead to conditions ‘no more extreme than those currently experienced and dealt with elsewhere in the world’ (RAE, 2011: 8).

2.4.4 Background to research objectives

The aim of this research is not to evaluate existing adaptive solutions in an Irish context. Rather, it is to identify climate-related construction concerns that are specific to Ireland and which may be used as exemplars in the context of adaptation. Considerable effort on the part of European governments has already been made in the development of methodologies to assess construction projects for climate change risks (OECD, 2010). Irish agencies too have, over the last decade, included climate change as a significant consideration. The need to assess, plan and manage adaptation to climate change impacts is included in the Guidelines for Regional Authorities and Planning Authorities (2004). Furthermore, the Guidelines for Planning Authorities (2007: 24) state that it is ‘imperative that the objectives and strategies set out in development plans are compatible with the Government’s commitment to […] modifying the impacts of climate change’. As such, it can be seen that the principles of climate change adaptation are enshrined in planning policy and legislation. The gaps lie in effective implementation and practice, where all too often it is not carried through (An Taisce, 2012: 1).

Still, identifying adaptation gaps is problematic. As outlined in Chapter 1, comprehensive climate-related research has been published recently in the area of infrastructure. *Ireland at risk: critical infrastructure adaptation for climate change* (IAE, 2009), and the UK’s *Sector resilience plans for critical infrastructure* (Cabinet Office, 2010) are two examples. Scale, too, represents an issue. Assessing climate change impacts on an individual basis is not feasible due to the high number of individual units comprising the built environment. The identification, however, of key vulnerable areas at county level is achievable. By assessing results at this resolution, adaptation proposals can be formulated to inform decision-makers in the regions concerned, at a spatial scale not available previously.

Climate change adaptation also presents a complicated methodological challenge (Brown *et al.*, 2011). It can be considered a 'wicked' problem in that the issues involved are complex, interacting and evolving in a dynamic social context (Richey, 2011). That said, it has been observed that climate change can be considered broadly as having three spheres of impact. Holm (2003) proposed the following categorisation:

- Primary sphere - includes driving rain, wind speed, temperature and water table height.
- Secondary sphere - includes flora, fauna and biological agents.
- Tertiary sphere - includes socio-economic and institutional factors.

In the context of construction all three spheres are relevant. Primary impacts may result in structural failure due to increased wind loading and/or rising water tables, and increases in temperature may impact negatively on finishes and internal environments. Secondary influences such as biological actions and mould growth could affect building materials and occupant health. Tertiary impacts may see shifts in settlement patterns and more restrictive planning policies, the consequence of which will be a change in geographies of construction.

In addition to the more holistic evaluation of the impacts of climate change proposed by Holm above, a large number of studies have been carried out to consider the specific impacts of climate change on the construction process (Arkell *et al*., 2007). Research indicates that the three most important actors on infrastructure and the built environment will result from water, wind and heat (Scottish Government, 2011b). In the context of water, incidences of wind-driven rain are likely to increase with the result that more building envelopes may be breached. In addition, flooding is becoming increasingly severe and frequent with the result that insurance companies are considering not re-insuring property once a flood claim has been made on that property (Larkin, 2011 [personal communication]). Indeed, flooding has cost insurance companies almost €700 million since 2000 (News at 9, 2012). Indeed, zones where the impacts detailed in Table 2.2 below begin to occur more frequently will suffer from increases in premium to a point where a structure may become uninsurable. In the context of heat, warmer conditions and increased relative humidity during winter could result in increased damage to building fabric from damp. More condensation will be probable, which will increase the likelihood of fungus and mould growth and the possibility of health issues for building occupants (Scottish Government, 2011b).

A summary of factors that have been identified as having particularly relevance to construction in the context of climate change are detailed in Table 2.2 (after Garvin *et al*., 1998; Graves & Phillipson, 2000; DTI, 2004; Vivian *et al*., 2005; Arkell, B. *et al*., 2007; Gething, 2010; and Scottish Government, 2011a).

Research in many of the areas listed in Table 2.2 is already extensive. In addition, considerable guidance on designing new buildings that are sustainable in the long term is readily available to professionals (Scottish Government, 2011a). Subsidence and heave is also an issue that is well understood (DTI, 2004). The UK's National House Building Council has provided guidance on issues relating to clay soils and trees for several years (Vivian *et al*., 2005). Improvements in technology too have enhanced climate impact assessment. For example, the development of Building Information Management (BIM) software has enabled designers to incorporate and assess the impact on structures of many parameters at the drawing-board stage. Indeed, a Client BIM Mobilisation and Implementation Group has been formed to drive the adoption of BIM across government in the UK (Cabinet Office, 2011).

Temperature is another area on which considerable research has been focused. The journal *Building and Environment* has featured many studies on the subject that have incorporated temperature and climate change projections into applied situations. The construction industry itself has a vested interest in the research and development of more robust materials. Indeed, advancements in Research and Development and subsequent innovation and diversification have been presented as a means of recovery and growth for the industry (Boran, 2009).

Table 2.2 Climate change factors with particular relevance to construction.

Climate variable	Anticipated impact due to increased intensity, period and/or frequency
Precipitation	Increase in flood events leading to delays and disruption of plant.
	Flood risk from rising groundwater resulting in flooding of sewerage systems and drainage networks, with implications for health.
	Damage to materials on site, increasing costs.
	Reduced weather-tightness of buildings.
	Increased foundation movement from heave.
	More stress on pipes and tunnels from movement in soils.
	Increased threat to foundations from enhanced mobility of water-based contaminants.
Wind	Higher risk of structural damage.
	Storm winds may damage roofs, cladding and infrastructure.
	Higher winter winds will impact the number of days cranes can be in use during construction.
	Risks to pylons, power and communications cables.
	Higher risk to crane operation.
Wind with rain	Wind-driven rain may penetrate walls and apertures leading to deterioration of materials through moisture ingress.
	Buildings compromised by wind-driven rain will suffer from possible increased mould growth and health issues for occupants.
	Wind-driven rain increases weathering, affects the durability of building façades and induces higher maintenance costs.
Temperature	Increased interior overheating in summer leads to increased energy use through air conditioning.
	Higher temperatures impact the placing and curing of concrete.
	Hotter summers will lead to decreased durability of materials.
	Increased solar radiation will degrade materials quicker.
	Milder winters may mean more pest impacts, such as the house longhorn beetle on roof timbers.
	Higher temperatures result in more rapid deterioration of building fabric.
	Frequency of cycling though freezing points will affect durability.

Considering the depth of research outlined briefly above it may appear that there are no gaps in an Irish context. However, there are three areas worthy of investigation that have been identified and which have particular relevance for Ireland. The areas are: wind-driven rain, which is classified by Holm (2003) as being in the Primary climate impact sphere; domestic wastewater management in one-off housing, which lies in the Tertiary sphere; and the Building Regulations 1997-2012, also Tertiary.

Wind-driven rain is an important climatological factor. Identified in Table 2.2 as having a significant potential impact on buildings, the effect of climate change on it is of particular concern (DTI, 2004) and further research is needed in this area (Scottish Government, 2011a). Although a Distribution of Driving Rain in Ireland (Met Éireann, 2010) has been published it does not include a climate change component, leaving a significant gap in wind-driven rain knowledge in the context of climate change. With winter rainfall events anticipated to be more intense, the consequences for buildings are that an increase in moisture penetration problems is likely. Although a building may have been designed for a certain exposure level, with a margin of safety built in, increases in wind-driven rain could raise the exposure to a level where the building envelope begins to fail (Scottish Government, 2011b). As the outer leaves of a building are the primary interface between weather and occupants, it is important that an estimation of increase in wind-driven rain due to climate change is evaluated in an Irish context.

Domestic wastewater management in one-off housing is an area with particular relevance to the construction industry in Ireland. In a country where 38% of the population live in rural areas (CSO, 2011), the building of one-off rural dwellings is important to the industry. Climate change may alter this dynamic, however. One-off dwellings tend to employ septic tanks for onsite wastewater treatment, and rising winter water tables as a result of climate change may lead to increased groundwater pollution. Ireland already faces 'some considerable challenges' to meet the water quality requirements of the Water Framework Directive (EPA, 2012: 56), with pollution from septic tanks identified as one of the principal challenges (Ireland’s Environment, 2012).

The result is the recommendation of a 'precautionary approach' with respect to planning (DEHLG, 2010: 4), which could restrict construction opportunities in rural environments. In terms of research, studies regarding urban wastewater treatment plants were published recently (EPA, 2012), and the Water Services (Amendment) Act (2012) is set to address the legislative aspect. Agriculture has also been the focus of substantial research in this area with legislation such as the Nitrates Directive (EU, 1991) the result. It can therefore be seen that the gap in knowledge lies in domestic wastewater management, specifically septic tanks, and it is important that this is addressed to enable the impact on rural construction to be gauged.

The Building Regulations 1997-2012 are also in need of evaluation in the context of climate change. Currently, the Building Regulations, Codes and Standards are informed by historical climate data, but this may no longer be sufficient to meet the demands placed upon construction and the built environment under a changing climate. Given that builders 'seldom exceed the build quality required by building regulations and codes of practice' (Graves & Phillipson, 2000: 42), if regulations and codes are not updated to take into account climate change new buildings may be under-designed for conditions in the second half of the 21st century. Indeed, it is likely that for many standards the margin for safety is 'no longer adequate to reduce risks to acceptable levels' (Graves & Phillipson, 2000: 45). The Building Regulations in Ireland are reviewed using historical climate data only (Wickham, 2011). It is therefore prudent to examine the current Regulations and propose modifications so that they remain relevant under a changing climate regime. As Innes and le Grand noted (2006: 2), Building Regulations 'are an immediately obvious route for increasing performance standards […] to take account of climate change'.

2.5 The requirement for research

2.5.1 Wind-driven rain

Wind-driven rain (WDR) is a phenomenon that primarily affects the north and west coasts of Ireland, two of the windiest areas in Europe (Met Éireann, 2010). With the climate of Ireland projected to get wetter and slightly windier by mid-century, and with increases in extreme winter wind speeds projected (Nolan, 2009), increases in incidences of WDR can be considered likely.

WDR is one of the most important climatological factors to affect the hygrothermal performance and durability of building envelopes (Karagiozis *et al.*, 1997; Van Mook, 1997; Sanders & Phillipson, 2003; Blocken *et al*., 2010). Indeed, it is considered the most critical exterior environmental load factor in over 90% of building envelopes (Karagiozis, 2003) and can increase the amount of moisture present in a structure by more than 100 times due to vapour diffusion (Karagiozis *et al.*, 1997). In heat-air-moisture numerical simulations WDR is categorised as one of the most important boundary conditions (Blocken & Carmeliet, 2007). With 78% of construction output represented by the built environment, WDR is thus identified as having considerable importance in the context of the construction industry in Ireland.

Increases in WDR may have implications not only for building fabric but also legislative frameworks such as the European Performance of Buildings Directive (EPBD). For example, a building's thermal characteristics are the first aspect to be considered in the EPBD's calculation of energy performance (EPBD, 2010), and an increase in WDR is likely to have a noticeable impact on a building's thermal properties. To identify areas vulnerable to WDR, present and future scenario data were used to construct a new driving rain index (DRI) for the periods 1961-1990, 2021-2040 and 2041-2060. Maps were assessed in the context of an exemplar region and future planning considerations. Recommendations are made for construction in the vulnerable areas identified.

2.5.2 Domestic wastewater management in one-off housing

Domestic wastewater management, specifically septic tank operation, is identified as an issue that warrants particular attention in the context of climate change. Rising winter water tables as a result of changed precipitation regimes may lead to faecal coliforms being introduced directly into groundwater where the water table rises into the septic tank effluent purification zone. Due to the reliance on septic tank systems in rural Ireland the impact on construction is that planning in rural areas is likely to become increasingly restrictive, leading to an increase in peri-urban settlement construction patterns. Thus, construction in rural areas will have to adapt to new geographies defined to a large extent by the vulnerability of groundwater to septic tank effluent.

Almost a third of the population live in one-off housing without access to mains sewerage (EPA, 2009), leading to approximately 435,000 septic tank systems operating in Ireland (CSO, 2011). When sited in a suitable environment they are an efficient method of wastewater treatment. However, conditions for the siting of septic tanks in Ireland vary from 'slightly to seriously inadequate' over an estimated 40% of the country and are considered to be one of the principal sources of groundwater contamination (Daly *et al.*, 1993: 4). This is due to a combination of factors; for example, granite lies very close to the surface in many areas of western Galway, making septic tank construction largely inappropriate, and over 50% of Ireland is underlain by carboniferous limestone that tends to have fissure permeability; contaminants experience little attenuation once percolation through subsoil has occurred (Lee *et al*., 2008).

Recharge coefficients and the permeability of soils and subsoil also determine the extent of vulnerability from precipitation increase. In low permeability settings the likelihood is that increased run-off and ponding will result from increased precipitation, while in high permeability zones it is more likely that water table levels will be affected. This has implications for existing and planned housing in sensitive areas, for example in the vicinity of gravel aquifers featuring high recharge coefficients. Any contamination contravenes the EU Water Framework Directive (2000), which decreed that Member

States' groundwater bodies must have achieved at least Good Status by 2015. It is estimated that 62% of Ireland's groundwater bodies are at risk of not achieving this (EPA, 2008). Failure to address this issue has already led to the threat of severe financial penalties.

To highlight the most vulnerable regions, septic tank densities were calculated by electoral division (ED) and mapped over groundwater levels and areas of projected increased winter rainfall. Maps were constructed on a local authority basis and will be made available to planning authorities for use in risk assessment and Development Planning. Recommendations were made for areas at highest risk from groundwater contamination from partially treated septic tank effluent.

2.5.3 The Building Regulations 1997-2012

Wind-driven rain and domestic wastewater management represent important areas where it is anticipated that climate change will impact the construction industry markedly. However, a key component of any adaptation measures proposed is the legislation with which they are enforced. Without legislation, policy recommendations may not be acted upon.

The Building Regulations 1997-2012 and their associated Technical Guidance Documents (TGDs), fall under the auspices of the Department of the Environment, Community and Local Government (DECLG) and the Building Regulations Advisory Body (BRAB). They are indirectly based on British and European Standards and on Codes produced by other independent bodies such as the UK Construction Industry Research & Information Association (CIRIA), Timber Research and Development Association (TRADA) and other professional bodies such as the Building Research Establishment (BRE). Most new Irish buildings can be expected to have a lifetime of at least 60 years and are constructed on the basis of building standards applying today. It is important therefore that a mechanism for incorporating adaptation related measures is developed to allow such standards to remain relevant in changing climatic conditions.

Standards and Codes of Practice are assessed traditionally through analysis of historical climate data. However, such data may not always be appropriate to contemporary Irish conditions and may be even less appropriate to future climatic conditions. With current advances in climate modelling it is now feasible to analyse the Building Regulations in the light of future climate scenarios as well as past events. Existing provisions for the construction and weather-proofing of buildings in the Building Regulations 1997-2012 and associated TGDs were therefore assessed in the context of climate change. Modifications will be proposed later in this work where appropriate, with particular attention paid to the Regulations relevant to wind-driven rain and domestic wastewater management.

2.6 Data discussion

In order to evaluate climate change impacts on the research areas identified, it was necessary to attempt quantification of the likely changes through the use of suitable climate projections. The climate projections used in this research were taken from the extensive modelling completed by C4I in 2008. The Hadley Centre Global Circulation Model HadCM3, driving the RCA3 Regional Climate Model under an A1B emissions scenario, was employed. The A1B scenario describes a future world of very rapid economic growth, employing a balance of fossil and non-fossil energy resources. A1B projects a mid- to mid-upper range warming scenario as illustrated in Figure 2-4. Model outputs were generated at a horizontal resolution of 14km, although for mapping purposes the data was processed further to produce datasets at 10km resolution, for plotting over Ordnance Survey Ireland's 10km grid. An ensembles approach, employing a combination of model runs, was not possible due to limited computational resources.

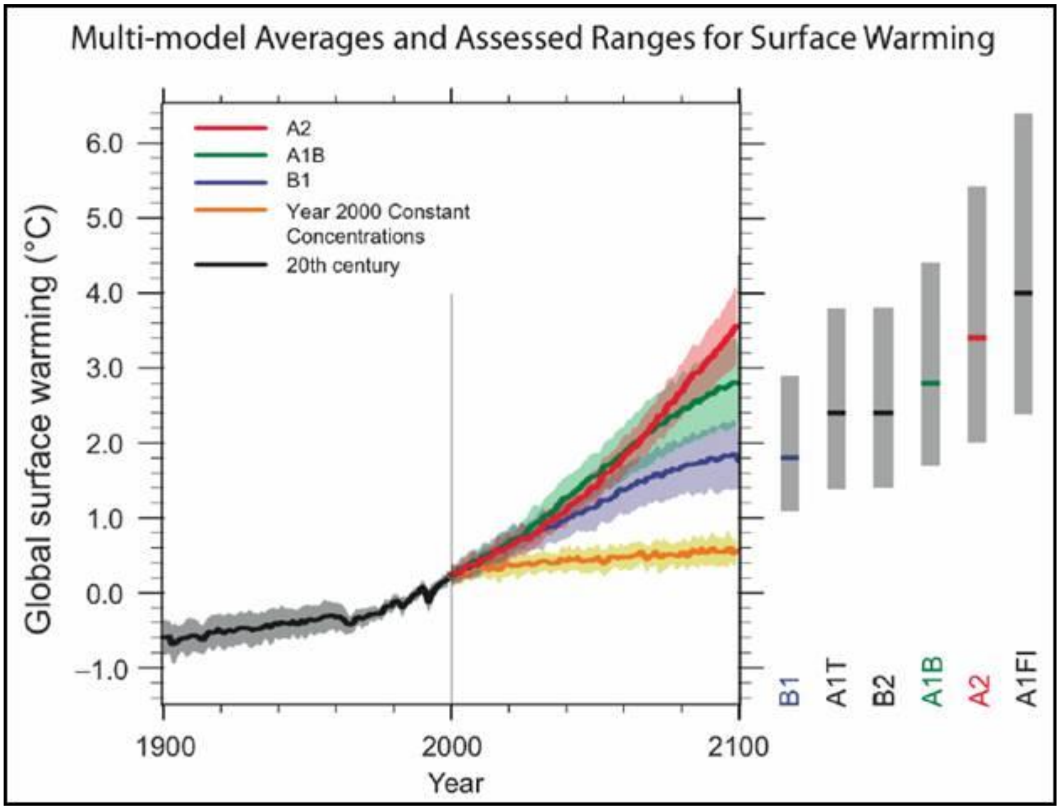


Figure 2.4 Projected temperature trends under different emission scenarios (IPCC, 2007e).

It must be acknowledged that although the use of single models to generate scenarios was common in the literature until recently, reliance on a single GCM means that there is 'significant potential for gross under- or over-estimation of the associated risks' (Fealy, 2010: vii). Caution must therefore be exercised when basing decisions on single model derived climate scenarios. That said, the use of a single climate model can still be considered 'a significant step forward' when used explicitly in situations where no climate change factor has been incorporated previously (Wilby, 2007: 38). Moreover, the model outputs used in this research agree generally with outputs from the most recent Weather Research Forecasting model (WRF). For example, extreme mid-century summer temperatures projected by WRF indicate climate warming of *c.* 2.2ºC, while C4I indicated warming of 1.2–1.6ºC. The difference in magnitude is attributed to the use of an 8.5 W m^{-2} RCP scenario versus the A2 SRES scenario (Teck, 2012).

HadCM3 was employed in the creation of climate scenarios published in the IPCC's TAR and AR4 (IPCC, 2001 & 2007d). RCA3 was selected as the Regional Climate

Model to be driven by all GCMs in the EU ENSEMBLES project (van der Linden and Mitchell, 2009). Indeed, regional climate projections from ENSEMBLES and other RCA3-based scenarios ‘have been widely used in a range of climate impact studies over the past few years’ (Samuelsson *et al*., 2011: 4). HadCM3 and RCA3 therefore have a considerable pedigree, and have generated the most comprehensive outputs available for Ireland pending the development of multi-model ensembles producing higher resolution temporal and spatial datasets. The data discussed in this overview was used to inform the following work on wind-driven rain.

CHAPTER 3
WIND-DRIVEN RAIN

3 INTRODUCTION

Of the three research areas identified in section 2.5, wind-driven rain can probably be considered the most accessible in terms of quantifying impacts. Indeed, it would appear relatively straightforward to study coincident events of rain and wind, versus investigating domestic wastewater treatment that takes place largely below ground and building regulations that usually remain in the sphere of designers, developers and policymakers. It will be shown however that the assessment of wind-driven rain is highly complex, although it is nonetheless important that an evaluation in the context of climate change and construction is carried out. This is due principally to climate projections that tend to describe ever-increasing extreme conditions, and Ireland's location in the path of moisture-laden North Atlantic weather systems.

Wind-driven rain (WDR) is a phenomenon that affects primarily the northern, western and southern coastal regions of Ireland. It is a product of simultaneous wind and rain events, the result being rain that is given a horizontal component that causes it to fall at an angle away from the vertical. This has important implications for construction, and in particular the built environment, due to the potential of increased wetting of vertical surfaces. Although spring and summer precipitation and wind speeds are predicted to decrease in Ireland, autumn and winter are projected to become wetter and windier overall (McGrath & Lynch, 2008). This is particularly important in the Irish context, where it can be seen from Figure 3.1 that Ireland lies in the path of the majority of North Atlantic storms.

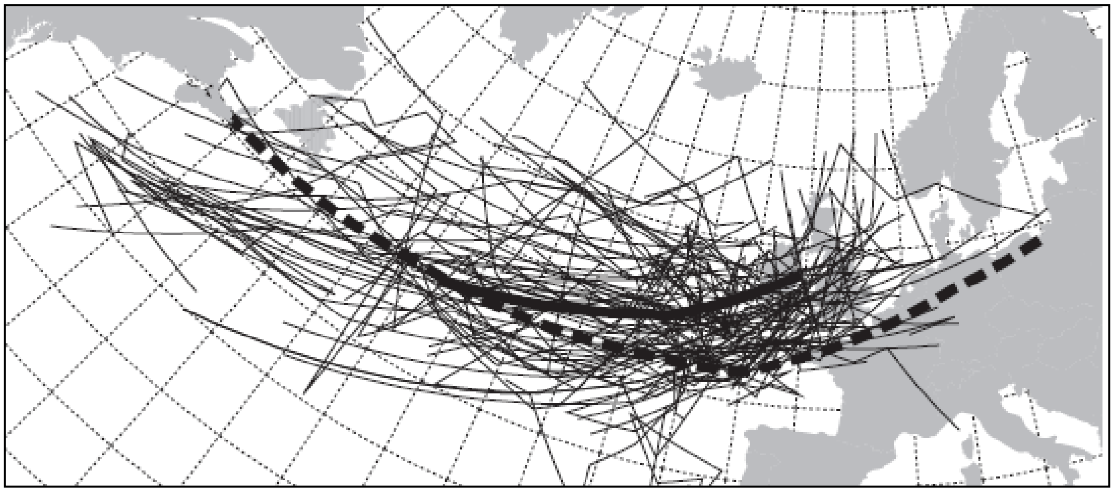


Figure 3.1 North Atlantic storm tracks 1950–1992 causing storm surges in Brest (Betts *et al*., 2004), but which nevertheless demonstrate Ireland's geographic context with respect to North Atlantic weather systems. Dotted line indicates mean jet stream core (500 hPa), thick solid line indicates mean storm track, and thin solid lines indicate storm tracks.

An increase in intensity of WDR, over what has already been designed for, may cause significant damage during the lifetime of a building. Damage to buildings from WDR can be attributed broadly to two processes: penetration of rain water through the building façade, which causes damage inside the building and to building finishes (Figure 3.2); and partial entry of water into the building envelope causing damage to material forming the envelope, such as bricks, cladding and insulation (Figure 3.3).

The first process is usually over a short duration of time and depends on the intensity of WDR, while the second process relates to the total amount of WDR over a longer period (Choi, 1999). Both processes can also lead to variance in heat and moisture. For example, the thermal conductivity of brick when dry is 0.6 W/mK; when wet it rises to 0.9 W/mK, representing an increase of 50% (LEARN, 2004). The implication for energy consumption is that more energy will be needed to heat a given space as surfaces begin to suffer from increased wetting. This has particular resonance with Part L of the Building Regulations 1997–2012, *Conservation of Fuel and Energy*, revisions for which are specifying increasingly restrictive limits for U-values. The intensity of driving rain on a façade depends on several factors including: horizontal rainfall intensity; raindrop size distribution; neighbourhood density; building geometry; wind direction; and local detailing (Hens, 2011).

Figure 3.2 Interior damage due to wind-driven rain penetration. Damp can be observed at lower right.

Figure 3.3 Wind-driven rain on two-year old cladding. Green mould is growing in the vertical seam towards the top-right, circled.

To mitigate for environmental conditions including WDR, the Building Regulations contain regulations governing weatherproofing in buildings. Part C for example relates to resistance to moisture, and Part H to drainage and wastewater. No matter how well a building is constructed however, the envelope is unlikely to be absolutely watertight. Despite Part D of the regulations providing guidance on workmanship there are usually imperfections, and all masonry components are porous (Domone, 2010). There are various methods to limit rain penetration, including the use of a cavity wall, but WDR remains a crucial factor in construction. It therefore merits investigation due to an anticipated increase in incidences of driving rain as a result of climate change. To facilitate evaluation, new driving rain indexes were calculated for current and future scenarios using observed and modelled data to allow assessment at a regional scale. Urban centres in County Mayo on the west coast were then mapped as an exemplar and adaptive strategies proposed.

3.1.1 Definition of wind-driven rain

In its simplest form, wind-driven rain can be described as rain that is given a horizontal velocity component by the wind causing it to fall obliquely onto the building envelope (Van Mook, 1999; Blocken & Carmeliet, 2004). The trajectory angle depends on factors such as the wind vector relative to the horizontal, wind speed change with height and the raindrop size. The impact of these factors is that for wind speeds in excess of only 5m/s, WDR free-field intensity exceeds precipitation intensity (Hens, 2010). Within a building science context, and vertical building façades in particular, the definition of WDR is narrowed to mean the ‘component of the rain intensity vector causing rain flux through a vertical plane’ (Blocken & Carmeliet, 2004: 2). This definition has been adopted by organisations such as the International Council for Building Research, and is one of two principal components of rain intensity; the other component is horizontal rainfall intensity (Figure 3.4). Wind is generally measured at 10 m above ground level for free-field WDR calculation.

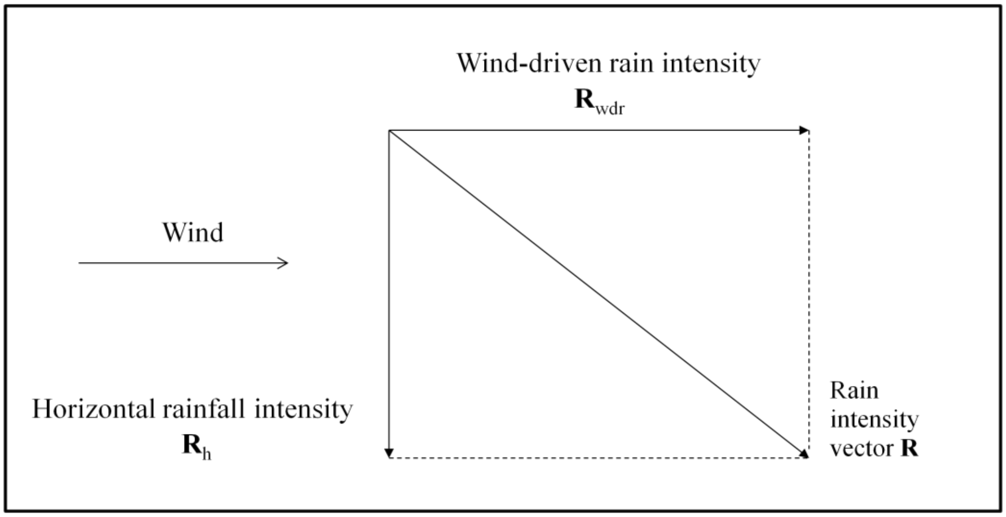


Figure 3.4 Rain intensity vector R and its components: Wind-driven rain intensity R_{wdr} and horizontal rainfall intensity R_h (Blocken and Carmeliet, 2004).

3.2 Methodology discussion

WDR has been researched extensively. For example, Best (1950), Hoppestadt (1955), Lacy (1965), Frank (1973), Prior (1985) and Flori (1988) dealt extensively with the topic and proposed methods for its calculation, while Blocken and Carmeliet's comprehensive review of WDR in building science research (2004) provided a seminal review. Although thorough assessment of the earlier research is difficult because references are not always easily available (van Mook, 1999), tenets such as Lacy's Constant form the building blocks of contemporary WDR science. To complicate matters further, wind and rain data are recorded globally by numerous agencies but their measurements and analysis tend to be done separately. The resulting statistics have a propensity to be unrelated (Choi, 2001).

There are three principal methodologies for assessing WDR in the context of buildings: measurement by observation; numerical simulations based on computational fluid dynamics (CFD); and semi-empirical models. Each methodology has particular strengths and weaknesses, which will now be discussed.

3.2.1 Measurement of WDR by observation

Recent research by Högberg *et al*. (1999), van Mook (2002) and Blocken and Carmeliet (2006) concluded that WDR observational measurements are not easy and errors can be large depending on gauge and rain event type. Teasdale-St-Hilaire and Derome (2006) observed that even experimental settings using wind tunnels posed significant challenges with respect to reproducing environmental conditions found in the field. Observational methods are also expensive and time-consuming, with the further disadvantage that measurements made on a particular building façade have only limited relevance to building surfaces at other sites. Such limitations have resulted in research efforts being concentrated on the development of semi-empirical and CFD methodologies, with the result that WDR calculation is now carried out predominantly using semi-empirical and CFD techniques (Blocken *et al*., 2010). Therefore, as a methodology to calculate a driving rain index in the context of this research, measurement by observation has been discounted.

3.2.2 Measurement of WDR by CFD

Van Mook (1999) noted that one of the most widely used methods for the systematic analysis and calculation of WDR on building faces is the CFD model proposed by Edmund Choi (1993). Choi's model involved two components. Firstly, flow around the building was computed by solving the k-ε two-equation turbulence model, where the transport equation is solved for two turbulent quantities k and ε (where: k = molecular diffusion, in which momentum is transferred to molecules within a slower moving layer of fluid from molecules in the faster moving layer above (Charlton, 2008); and ε = eddy viscosity, which is an apparent viscosity resulting from momentum transfer by turbulent eddies (Charlton, 2008: 87)). Secondly, movements of raindrops in the wind field were calculated by considering the forces acting on the droplets. Raindrop trajectories were calculated by solving the equations of motion (Choi, 1993).

Choi (1999) then used the k-ε turbulent model with a finite volume implementation to solve for the three-dimensional wind flow pattern around a building. Velocities obtained were used for the calculation of raindrop trajectories. Knowing the wind velocities at every point form the k-ε model, raindrop trajectories were computed by solving iteratively the equations of motion. Choi found that WDR intensity varied with the location of the face of a building and that the top of the building experienced much higher intensities of WDR than lower portions. This result reinforced his earlier finding that the upper quarter received much more rainfall than the sum of the remaining three quarters (Choi, 1993), and agreed broadly with Karagiozis *et al* (1997) and Hangan (1999) in that upper portions of buildings are observed to receive greater quantities of WDR than the lower portions.

Subsequent research has sought to build upon the earlier results with regard to their application to the construction industry. For example, Karagiozis *et al* (1997), Hangan (1999), Choi (1999) and Rydock (2007) developed various frameworks for CFD application to a range of building-related simulations. Hangan (1999) used CFD to reproduce wind tunnel experiments on generic buildings. He incorporated two turbulence models; the k-ε and the Reynolds stress (a measure of the anisotropy of the turbulent velocity fluctuations which produces a stress on the mean flow). Generally, the numerical simulation replicated the wind tunnel experiment, although there were discrepancies where a poor fit between numerical and physical simulations was observed. Van Mook (1999) noted too that at low wind speeds some of the simulated driving-rain ratios were well outside the standard deviation of the measured driving-rain ratio. Possible reasons proposed were errors in the calculation of the wind velocity field, the drop trajectories or the chosen raindrop spectra. Building on such earlier research, Blocken and Carmeliet (2002) performed a validation study for WDR simulations on a low-rise test building and found good agreement between the numerical results and the corresponding WDR measurements.

With advances in computer technology, CFD techniques have progressed significantly. Wind tunnel validation studies carried out by Blocken and Carmeliet (2002, 2006, 2007), Tang and Davidson (2004), Abuku *et al*. (2009) and Briggen *et al*. (2009) show that CFD models can provide accurate results. Indeed, the ISO and SB models are evaluated by comparison with CFD simulations, which are treated as the reference case (Blocken *et al*., 2010). However, in the context of construction where relatively swift site-specific evaluation is required, semi-empirical methodologies are easier and faster to apply and thus hold sway.

3.2.3 Measurement of WDR by semi-empirical calculation

Semi-empirical methodologies have a theoretical basis but feature coefficients that are partly derived from measurement. The models that are most advanced and hence most frequently used in contemporary WDR research are the ISO model and the SB model (Blocken *et al*., 2010).

The ISO model is classified as an Irish standard thus: IS EN ISO 15927-3:2009 ‘Hygrothermal performance of buildings – calculation and presentation of climatic data – part 3: Calculation of a driving rain index for vertical surfaces from hourly wind and rain data’ (NSAI, 2009). Based closely on BS 8104:1992, it employs hourly wind and rain data to generate a driving rain index that also takes into account the surrounding environment. For instance there are correction factors to account for topographic features such as hills and valleys and surrounding obstacles. The code specifies the use of hourly data for calculations although Blocken & Carmeliet (2007) suggested that ten-minute data could produce more accurate results. However, Blocken acknowledged that ten-minute data may not always be available, a point made by Rydock (2007) who noted that even hourly data may not be accessible in many regions.

The SB model was developed by Straube and Burnett (2000) and, although based on the same WDR relationship as the ISO standard, it differs in several respects. For example, it utilises a Driving Rain Function rather than a constant free-field WDR coefficient, and provides a maximum and minimum limit for WDR intensity versus the ISO standard’s single result. Another important difference is that the SB model does not provide correction factors for the surrounding environment (Blocken & Carmeliet, 2010). The latter difference is particularly important in the context of a model's applicability to the wider geographic area.

While appearing to represent the most comprehensive approach to WDR estimation and a uniform methodology for calculating WDR at any location, the ISO standard nonetheless raises an important data issue. It requires hourly wind and rain data and thus places significant constraints upon the observations that can be employed. Hourly wind and rain data is not available in all instances meaning that in many countries annually averaged wind and rainfall data has to be used (Rydock, 2007). In addition, the driving rain index calculated for a specific observation point cannot necessarily be applied directly to areas distant from the observing station. Topographical and environmental circumstances may alter the characteristics of localised climate regimes.

Extensive interpolation is therefore needed to generate a national driving rain index using the ISO standard. This will increase uncertainty in the index accuracy, the greater the distance from the data gathering point. The optimal method to improve accuracy is to increase the number of data gathering points but this would require significant investment, and in the current economic climate is highly unlikely. Failing increased investment in the construction of more monitoring stations, employing local knowledge and incorporating the correction factors provided in the ISO standard offer the optimal route to WDR calculation for vertical surfaces not located at observation stations. The aforementioned notwithstanding, the ISO standard has been adopted by the National Standards Authority of Ireland and will therefore be used in this research to calculate a driving rain index for Ireland.

3.2.4 Discussion conclusions

Observational measurement as a methodology is discounted as a viable option for the reasons set out in section 3.2.1 above. Each of the semi-empirical and CFD methodologies has its disadvantages and advantages, which are summarised here.

Semi-empirical methodologies such as the ISO standard and SB model can only provide an approximation of the amount of WDR received by a building surface (Blocken & Carmeliet, 2004). Also, all observations and topographical data provided by the relevant agencies must be assumed to be valid. Furthermore, because height is regarded as the most important parameter and building width is regarded as negligible in the SB model and neglected in ISO, they do not reproduce the wind-blocking effect well. That said, these two semi-empirical methodologies are relatively easy and fast to employ, provide a firm foundation for model development and are 'without any doubt [...] very valuable' (Blocken *et al*., 2010: 1724).

CFD methodologies are skilful in applying comprehensive influencing parameters but the model complexity, and thus the calculation cost, are high relative to semi-empirical methodologies. Moreover, Versteeg and Malalasekera (1995) point out that the reliability of CFD calculations is dependent on the choice of turbulence model, and that the results generated are only as good as the physics employed in the calculation. However, considerable research has been invested in developing CFD methodologies to the point where they are acknowledged to be the most accurate gauge of WDR. Although CFD is generally considered to be impractical for widespread use, in the context of construction it is important for validating semi-empirical models and improving their performance (Blocken & Carmeliet, 2010).

3.3 Operationalisation of IS EN ISO 15927-3:2009

3.3.1 Introduction

The Irish Standard EN ISO 15927-3:2009 (NSAI, 2009) was employed to calculate new driving rain indexes for Ireland. Initially, two indexes were calculated for the period 1961-1990 using hourly records from each of the Irish synoptic stations. The first exercise involved using observed data, the other was based on modelled data. Next, indexes were calculated for 2021-2040 and 2041-2060 using climate data from C4I (McGrath & Lynch, 2008). This involved using modelled hourly data for each of the periods under study. To obtain an estimate of future driving rain that is grounded on the observed baseline data, the differences between the modelled index values were applied to the observed 1961-1990 index. Values were mapped as point data and then converted to a kriged surface for mapping purposes. Subsequent analysis identified the most vulnerable areas to increases in WDR as a result of climate change.

An issue with interpolating points that lie between the synoptic stations is that the change in index between synoptic stations is not linear due to regional meteorological and topographical factors. Variations in driving rain between data points were therefore not accounted for, due mainly to large distances between synoptic stations in the network. While estimates at the regional scale can be inferred by assuming that spatial distribution is proportional to the average annual rainfall and wind speed (Prior, 1985), to derive accurate localised values for construction purposes, site-specific calculations using ISO 15927-3:2009 must be carried out. This was clarified by Sanders (2010), the convener of CEN/TC 89/WG 9 which developed EN ISO 15927-3:2009. He observed that while the standard was not excluded as a valid method for mapping driving rain at the national scale, the committee 'felt it was really oriented towards calculating the driving rain indices at a specific location for which wind and rain data would be available' (Sanders, 2010 [Personal communication]).

In acknowledging the constraints outlined above it can be seen that the primary purpose of the driving rain maps was that they could act as decision support tools, rather than being viewed solely as climatalogical maps.

3.3.2 Data employed

Data used in the baseline index and modelled index calculation were from two sources. Observed data were supplied by Met Éireann while the modelled output was from C4I, generated using RCA3 to dynamically downscale HadCM3 data. For hourly rainfall, 1961-1990 data from 13 synoptic stations (Malin Head; Belmullet; Clones; Claremorris; Mullingar; Dublin Airport; Casement; Birr; Shannon Airport; Kilkenny; Rosslare; Cork

Airport; and Valentia) were used to drive a Bartlett-Lewis Stochastic Rainfall Model. The parameters for each month and station were estimated to account for the temporal and spatial rainfall structure. For hourly mean wind speed, time series were generated by using a sequence of independent random numbers from the normal distribution. Parameters of the normal distribution were the mean and standard deviation (for each hour of a day), and were estimated from the hourly mean wind speed time series (transformed to account for non-normality). For both wind and rainfall bias correction, 3-hourly HadCM3 wind and rainfall were used to modify the generated hourly time series proportionally.

3.3.3 The Airfield Annual Index and Airfield Spell Index

Two indexes can be derived using IS EN ISO 15927-3:2009: the Airfield Annual Index (I_A) and the Airfield Spell Index (I_S).

The Airfield Annual Index is the quantity of driving rain that would occur on a square metre of vertical wall during one year at a height of 10m above the ground if the wall were located in the middle of an airfield (i.e. free from obstructions and sited on flat grassy terrain). It is measured in litres per m^2. It is used as a measure of the moisture content of masonry and has implications for thermal performance, mould growth and building façade durability.

The Airfield Spell Index totals the amount of driving rain over the worst spell likely to occur in any three-year period. A spell can be considered as 'a period in which the input of water due to driving rain exceeds the loss due to evaporation' (NSAI, 2009: 12). As such, a spell influences the likelihood of rain penetration through masonry and features such as cracks in building façades, wall joints and the edges of doors and windows. The higher the spell index, the greater the risk of rain penetration that can be expected. The Spell Index is measured in litres per m^2.

It is important to note that ISO 15927-3:2009 considers a spell in terms of rain penetration through masonry, which requires prolonged water inputs, rather than for rain penetration through gaps in the building façade which depends on heavier rain and higher pressure differences. The result of this focus on penetration through masonry is that a gap between two spells is defined by a period of at least 96 hours (4 days) when there is an absence of the co-occurrence of wind and rain (NSAI, 2009). It should also be emphasised, as Blocken and Carmeliet (2004) observed with respect to BS 8104: 1992, that neither the Airfield nor the Spell Index is precise enough to enable fine distinctions between degrees of exposure. Local knowledge and experience should always be taken into account.

3.3.4 Calculation of the Airfield Annual Index and Airfield Spell Index

To calculate the annual driving rain index utilising IS EN ISO 15927-3:2009, two formulae were employed. The first equation [1] was used to calculate the Airfield Annual Index (I_A). The second equation [2] was used to calculate the Airfield Spell Index (I_S). The indexes are designed to be used in conjunction with Wall equations that employ a terrain roughness coefficient, topography coefficient, obstruction factor and wall factor to derive site-specific values from which informed judgements on construction aspects can be made. It is therefore of value to map the indexes and illustrate values, for ease of incorporation into such equations. For ease of plotting and for use with geographical increments as recommended by IS EN ISO 15927-3:2009 (NSAI, 2009: 13), the Airfield Annual Index is converted into a Map Annual Index (m_A) and the Airfield Spell Index is converted into a Map Spell Index (m_S) using equations [3] and [4] respectively.

The driving rain indexes calculated are omni-directional. The component that accounts for wind direction, $\cos(D\text{-}\Theta)$, is designated the value 1, which is indicative of wind impacting the wall perpendicularly at all times. Although Figure 3.5 illustrates that this is not the case currently in Ireland, where the wind is predominantly but not exclusively south-westerly, calculating for a wind vector that is constantly perpendicular to a vertical surface represents the worst case scenario. Any adaptive actions recommended utilising these outputs will, therefore, be inherently of a no-regrets nature.

Airfield Annual Index

$$I_A = \frac{2}{9}\frac{\Sigma v r^{8/9} \cos(D - \Theta)}{N} \quad [1]$$

Where:

I_A = Airfield Annual Index (l/m^2)

v = Hourly mean wind speed (m/s)

r = Hourly rainfall total (mm)

D = Hourly mean wind direction from north

Θ = Wall orientation relative to north

N = Number of years of available data

Airfield Spell Index

$$I'_S = \frac{2}{9}\Sigma v r^{8/9} \cos(D - \Theta) \quad [2]$$

Where:

I'_S = Spell value from which Airfield Spell Index is derived (l/m^2)

v = Hourly mean wind speed (m/s)

r = Hourly rainfall total (mm)

D = Hourly mean wind direction from north

Θ = Wall orientation relative to north

The 67% percentile (the value for which 33% of values of I'_S are higher) is found from the values of I'_S for all the spells within the data. The 67% percentile defines the Airfield Spell Index I_S (the maximum value of I'_S likely to occur once every three years).

A sample of the numerical values and calculations used to derive the Airfield Annual Index (I_A) and the Annual Map Index (m_A) can be found in Appendix I.

Map Airfield Index

$m_A = 6 + 19.93 \log_{10}(I_A/200)$ [3]

Where:

m_A = Map Airfield Index

I_A = Airfield Annual Index (l/m^2)

Map Spell Index

$m_S = 10 + 19.93 \log_{10}(I_S/20)$ [4]

Where:

m_S = Map Spell Index

I_S = Airfield Spell Index (l/m^2)

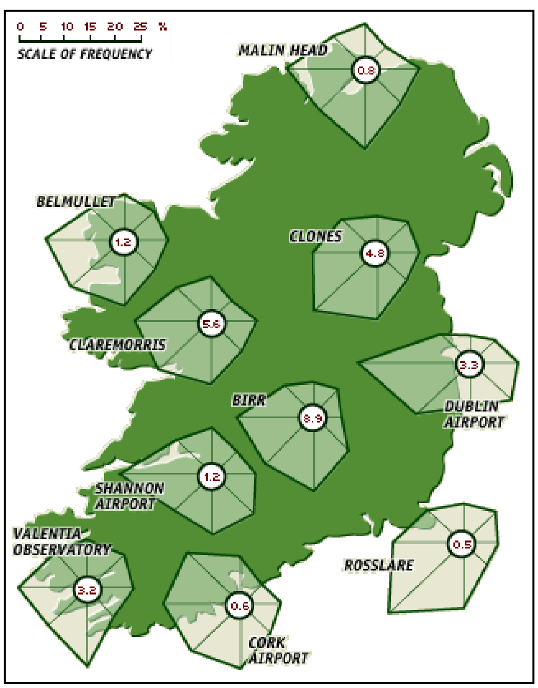


Figure 3.5 Wind direction frequency at synoptic stations (Met Éireann, 2012).

The reasons for calculating for the maximum vulnerability scenario are twofold. The first is that future scenarios point to greater uncertainties regarding wind speed and direction (Sanders & Phillipson, 2003; Sharples & Lee, 2009). Modelled December-January-February (DJF) precipitation over Ireland for the period 2040-2070 indicates a shift towards the north-west, possibly associated with increased frequencies of circulation from this direction (Figure 3.6 (left)). Modelled DJF precipitation for the period 2070-2100 illustrates a further shift towards the north (Figure 3.6 (right)). In addition to climatic considerations, local factors such as new construction could alter the immediate environment and wind patterns, thereby exposing surfaces to more severe conditions from a direction not calculated for originally. Deriving an omni-directional index calculated for a maximum vulnerability scenario mitigates for these risks.

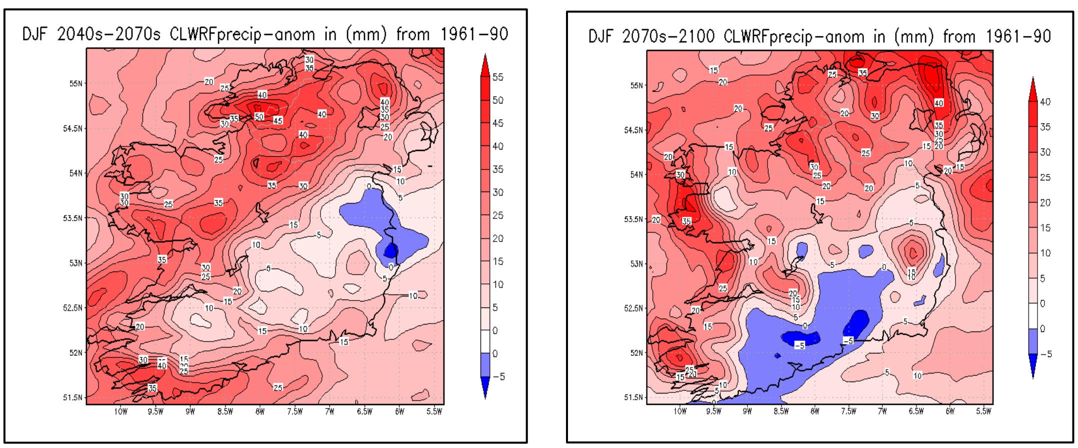


Figure 3.6 Modelled precipitation regimes for 2040-2070 (left) and 2070-2100 (right).

The second reason for calculating for maximum vulnerability is a question over the accuracy of the cosine projection itself. After performing validated CFD simulations on a low-rise cubic model, Blocken and Carmeliet (2006: 1182) observed that as the wind direction from the normal of the wall increased, the cosine projection had a propensity to overestimate the catch ratio. They concluded that 'although generally adopted and used for all wind-driven rain calculations with semi-empirical methods [including IS EN ISO 15927-3:2009], it is strictly not valid and can give rise to significant errors.' Such uncertainties in wind direction can lead to considerable variance in applied situations. For example, some European design wind speed maps have been found not to match at borders. Within relatively short distances variations of up to 100% in design wind load have been observed (Gatey & Miller, 2007). Therefore, considering that new buildings are designed to last 60 years or more and will experience increasingly uncertain climate regimes, it is reasonable to apply a high vulnerability scenario to driving rain calculations to mitigate for impacts. Calculating for the worst-case scenario addresses the considerable uncertainties inherent in modelled values of $\cos(D-\Theta)$. The result should be the development and implementation of no-regrets policies that are more robust to climate change and which will deliver the optimal level of adaptation expected of EU member states (CEC, 2009).

3.4 Results

3.4.1 Driving rain Airfield Annual Index (I_A)

The first column of Table 3.1 overleaf shows the Airfield Annual Index values for the 1961-1990 observed baseline. Values are comparable with the example values given for Aberystwyth in IS EN ISO 15927-3:2009 (NSAI, 2009: 14). Table 3.1 also shows the modelled 2021-2040 and 2041-2060 values resulting from adding the respective modelled climate signals to the observed baseline. They are mapped accordingly (Figures 3.7, 3.8 and 3.9). The white areas on the maps indicate regions that lie outside the kriged zones, and have not been interpolated to avoid speculative values. Appendix I features a sample of the actual numerical values and calculations from which the contour maps are derived.

As expected, the areas showing the most exposure to wind-driven rain are the northern, western and southern fringes of Ireland. 1961-1990 values of driving rain in the order of 887 litres per year are indicated at Malin Head, while Valentia and Belmullet register 794 and 784 respectively. Steadily reducing values characterise the trend towards the inland zones. Kilkenny and Birr show the lowest values; 292 and 309 litres per year, around a third less than those experienced in the more exposed zones.

Modelled Index values for 1961-1990 to 2021-2040 demonstrate increases in the order of 9-16% in inland areas and 7-12% in more exposed areas. However, it is the absolute increases in driving rain that are important rather than the percentages. Increases of 65-108 litres per year are noted for Malin Head, Valentia and Belmullet whereas Kilkenny, despite the largest percentage increase (16%), shows an absolute increase in receipt of driving rain of 55 litres per year. Values do not change significantly between 2021-2040 and 2041-2060. This plateau, attributed to the SRES scenario employed in which fossil fuels are exhausted by this time period, nonetheless features levels of driving rain that will make adaptation to future climate conditions necessary for construction, and the built environment in particular.

Table 3.1 Driving rain Airfield Annual Index (I_A). Units in litres per m^2.

Station Name	1961-1990 Observed I_A	2021-2040 Modelled I_A	2041-2060 Modelled I_A
Valentia	794	864	873
Shannon Airport	485	524	525
Dublin Airport	400	446	440
Malin Head	887	952	922
Belmullet	784	892	894
Clones	420	464	446
Rosslare	543	577	597
Claremorris	543	596	583
Mullingar	423	467	457
Kilkenny	292	347	349
Casement Aerodrome	426	466	454
Cork Airport	697	727	717
Birr	309	347	344

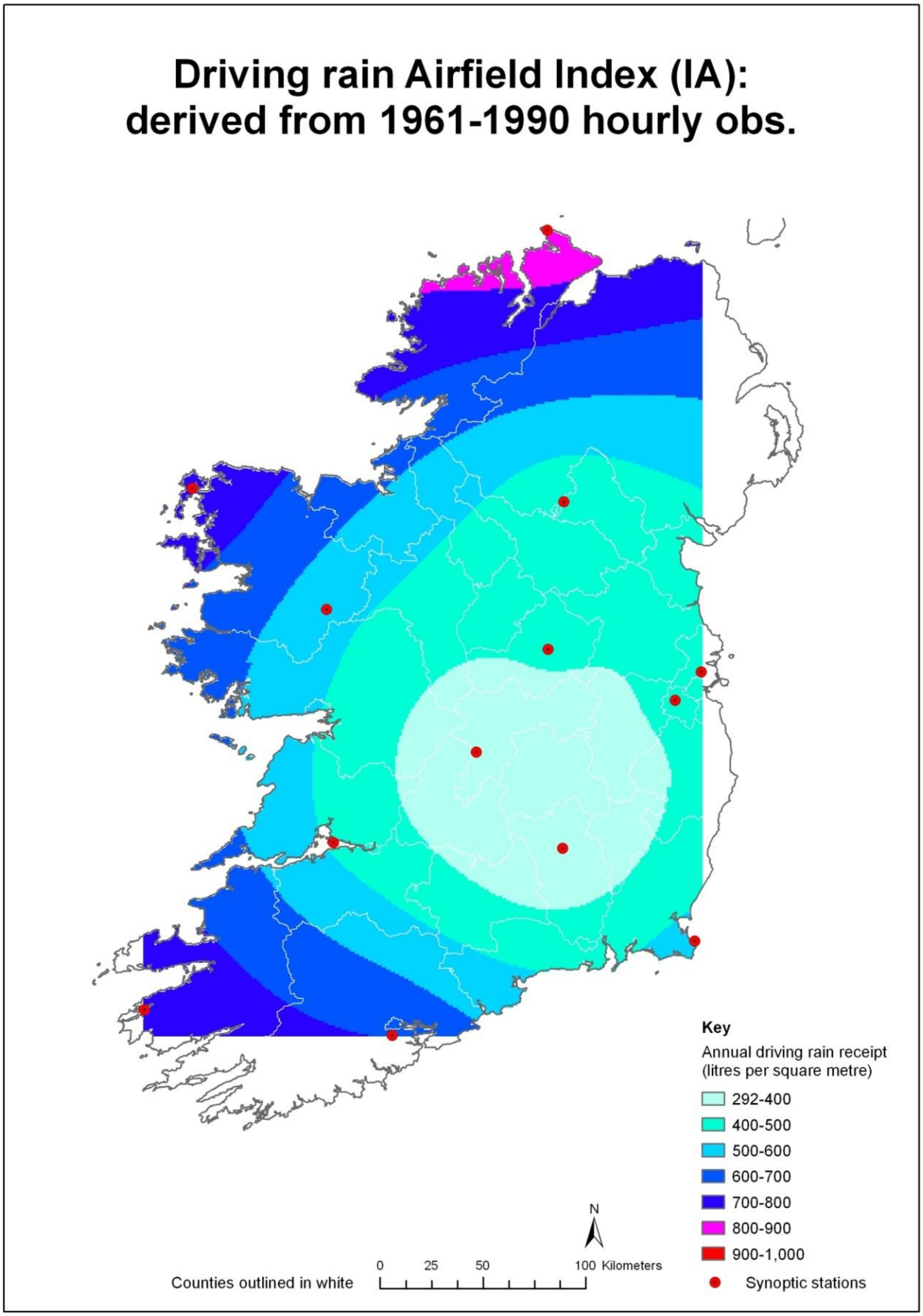


Figure 3.7 Airfield Index (I_A): derived from 1961-1990 hourly synoptic observations.

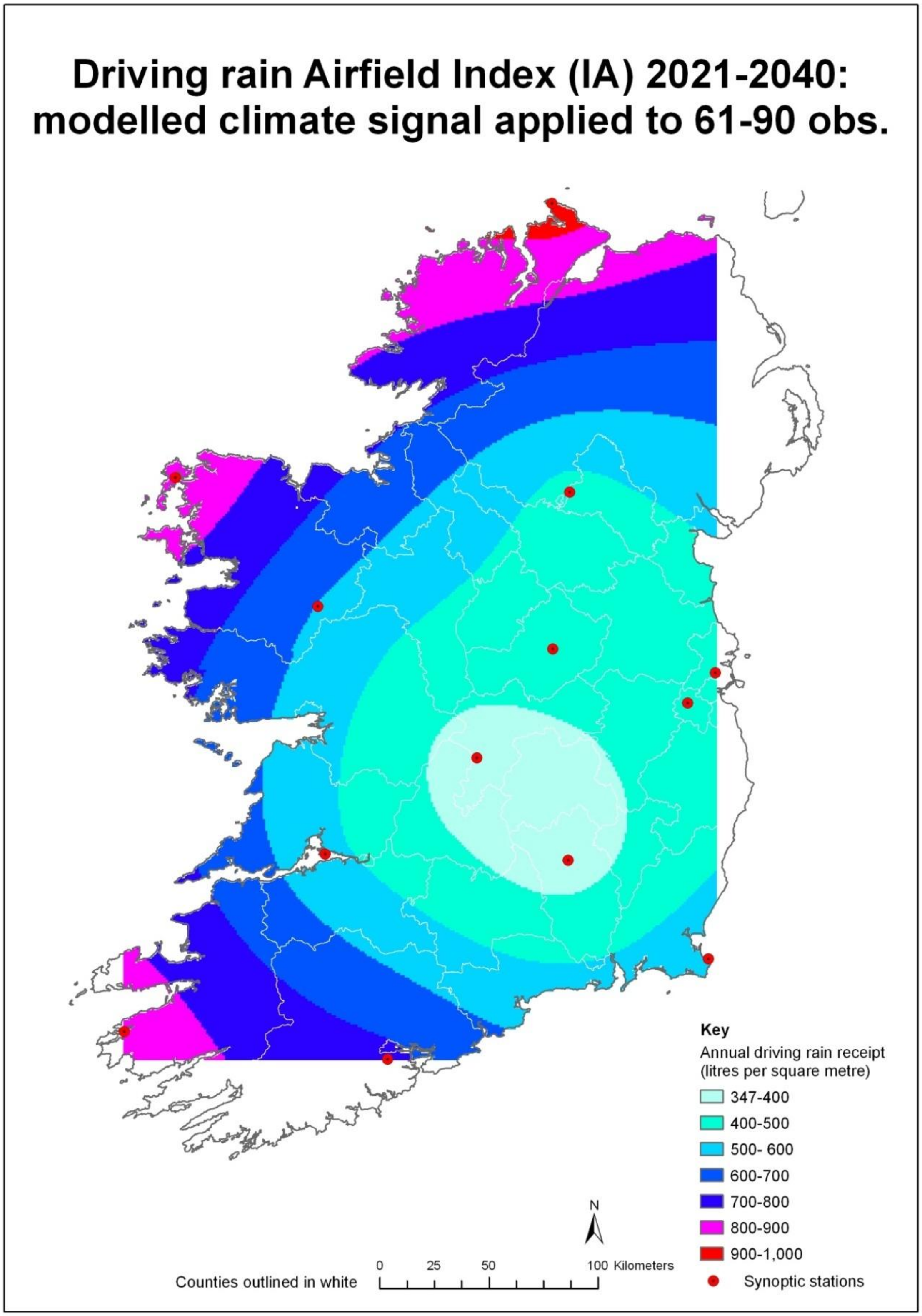


Figure 3.8 Airfield Index (I_A): 2021-2040 climate signal applied to observed synoptic data.

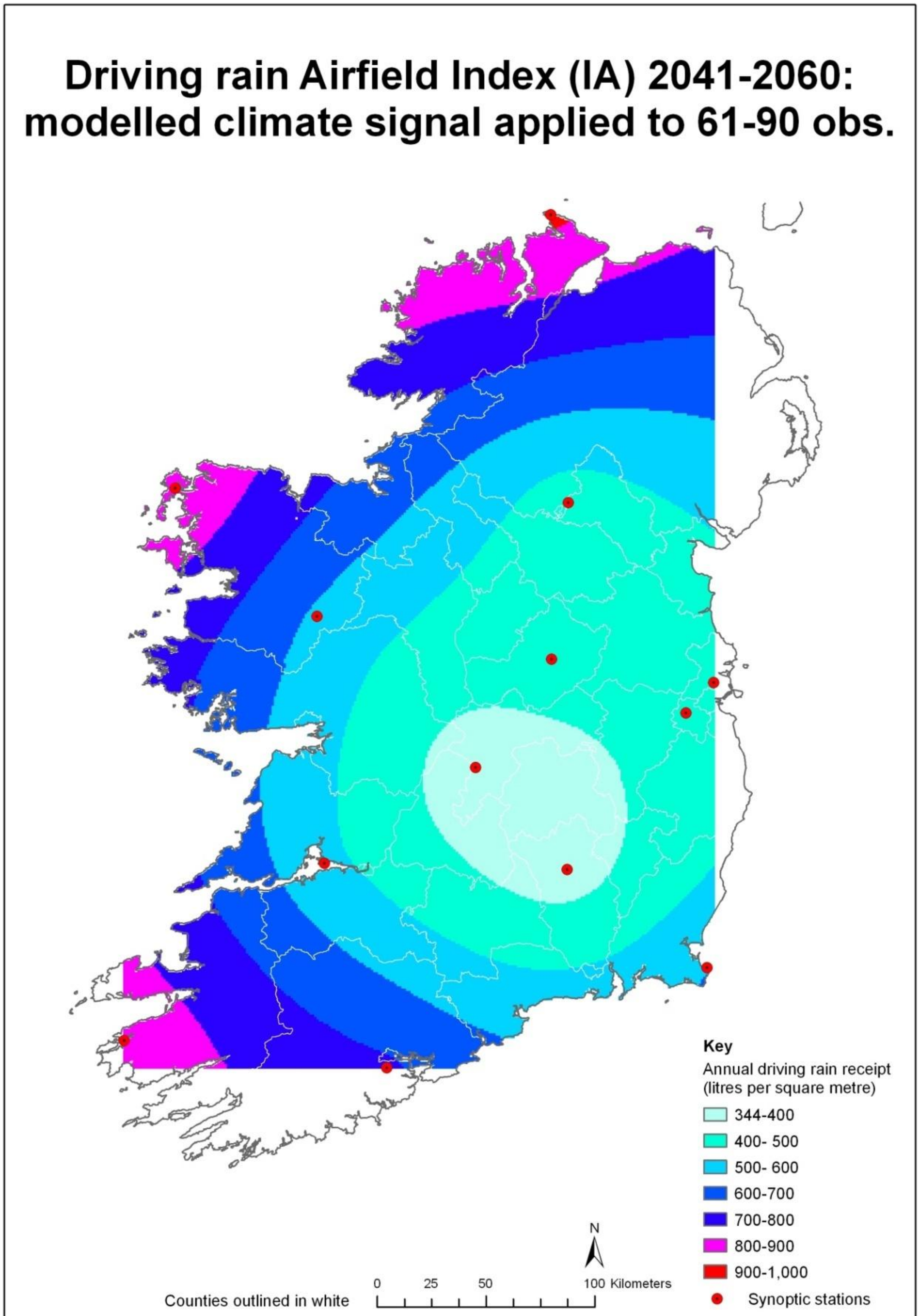


Figure 3.9 Airfield Index (I_A): 2041-2060 climate signal applied to observed synoptic data.

3.4.2 Driving rain Map Airfield Index (m_A)

Table 3.2 shows the annual driving rain Map Airfield Index values, illustrated in Figures 3.10, 3.11 and 3.12. Predictably, the Map Index provides a corroboration for the Airfield Index but when plotted is nonetheless instructive in that it illustrates a spatial shift not apparent when viewing the table in isolation. As a corollary, observed values in the more exposed areas of Ireland agree broadly with those recorded for coastal Northern Ireland contained in BS 8104:1992, upon which the ISO standard is closely based.

While the Airfield Index indicates the actual amounts of driving rain that would be received by an unobstructed vertical surface at 10m height, the Map Index values are employed for their ease of plotting, and for use with geographical increments as recommended by IS EN ISO 15927-3:2009 in the creation of driving rain maps.

Table 3.2 Driving rain Map Airfield Index (m_A).

Station Name	1961-1990 Observed m_A	2021-2040 Modelled m_A	2041-2060 Modelled m_A
Valentia	18	19	19
Shannon Airport	14	14	14
Dublin Airport	12	13	13
Malin Head	19	20	19
Belmullet	18	19	19
Clones	12	13	13
Rosslare	15	15	15
Claremorris	15	15	15
Mullingar	12	13	13
Kilkenny	9	10	10
Casement Aerodrome	13	13	13
Cork Airport	17	17	17
Birr	10	10	10

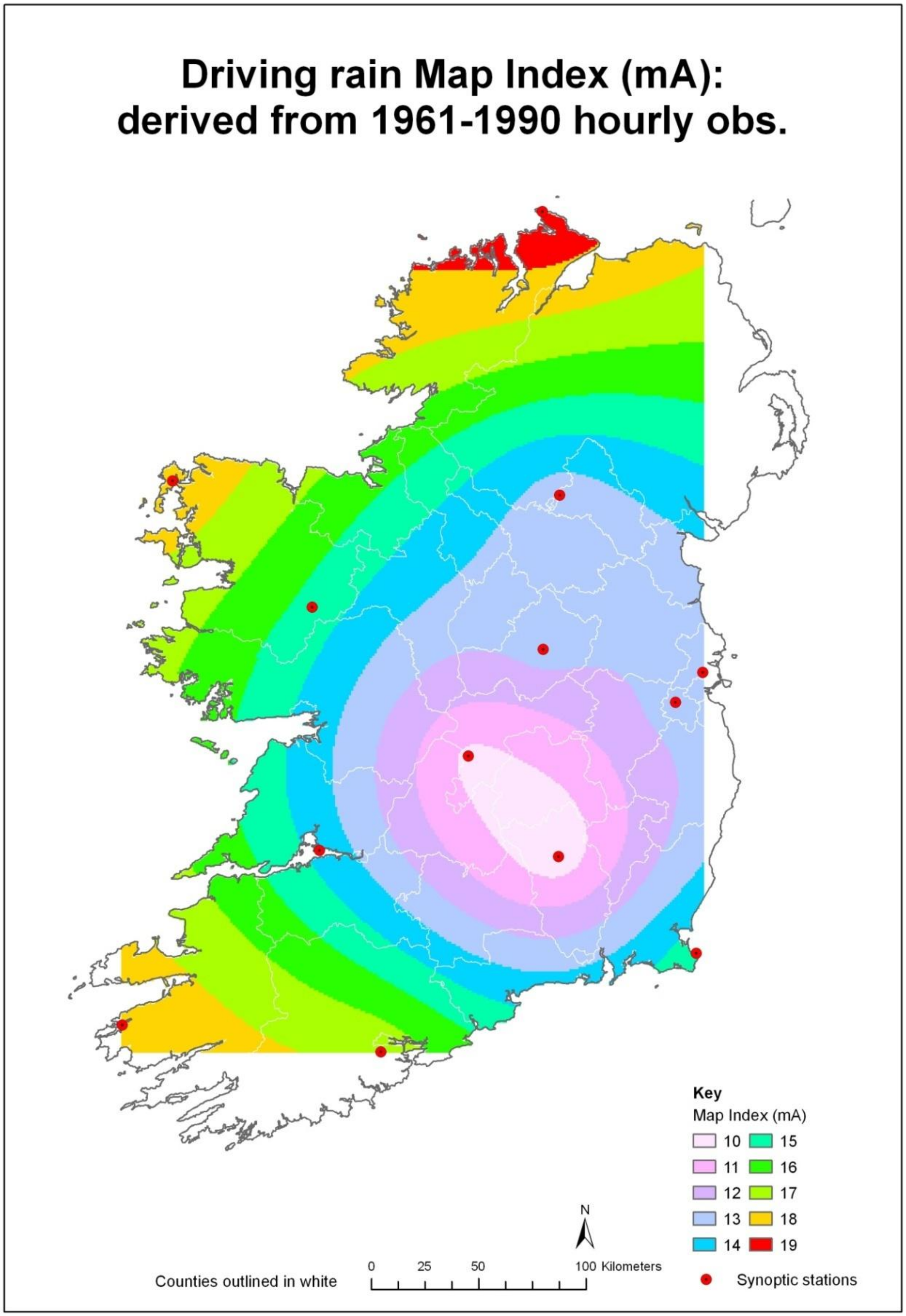


Figure 3.10 Map Index (m_A) derived from 1961-1990 hourly synoptic observations.

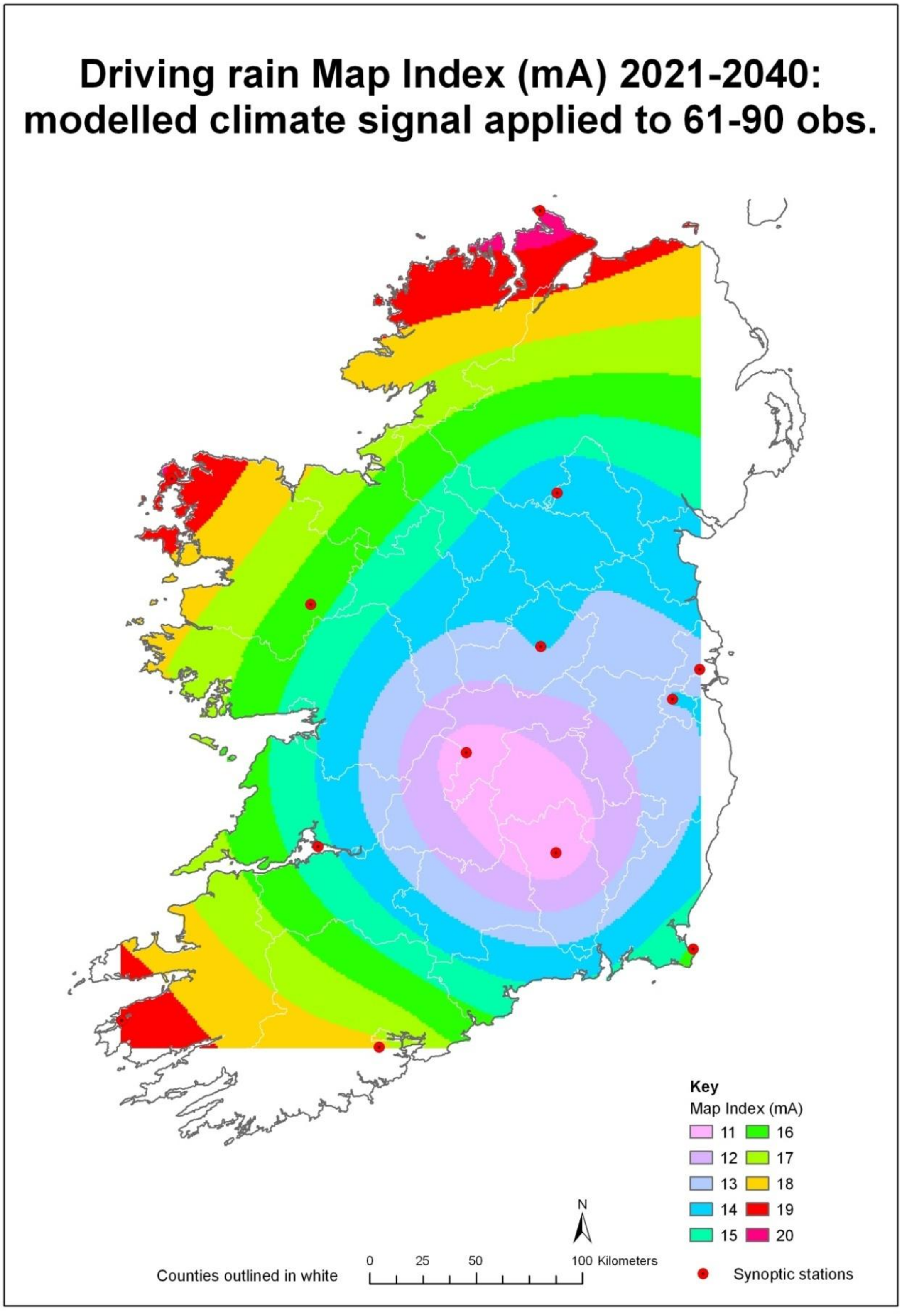


Figure 3.11 Map Index (m_A): 2021-2040 climate signal applied to observed synoptic data.

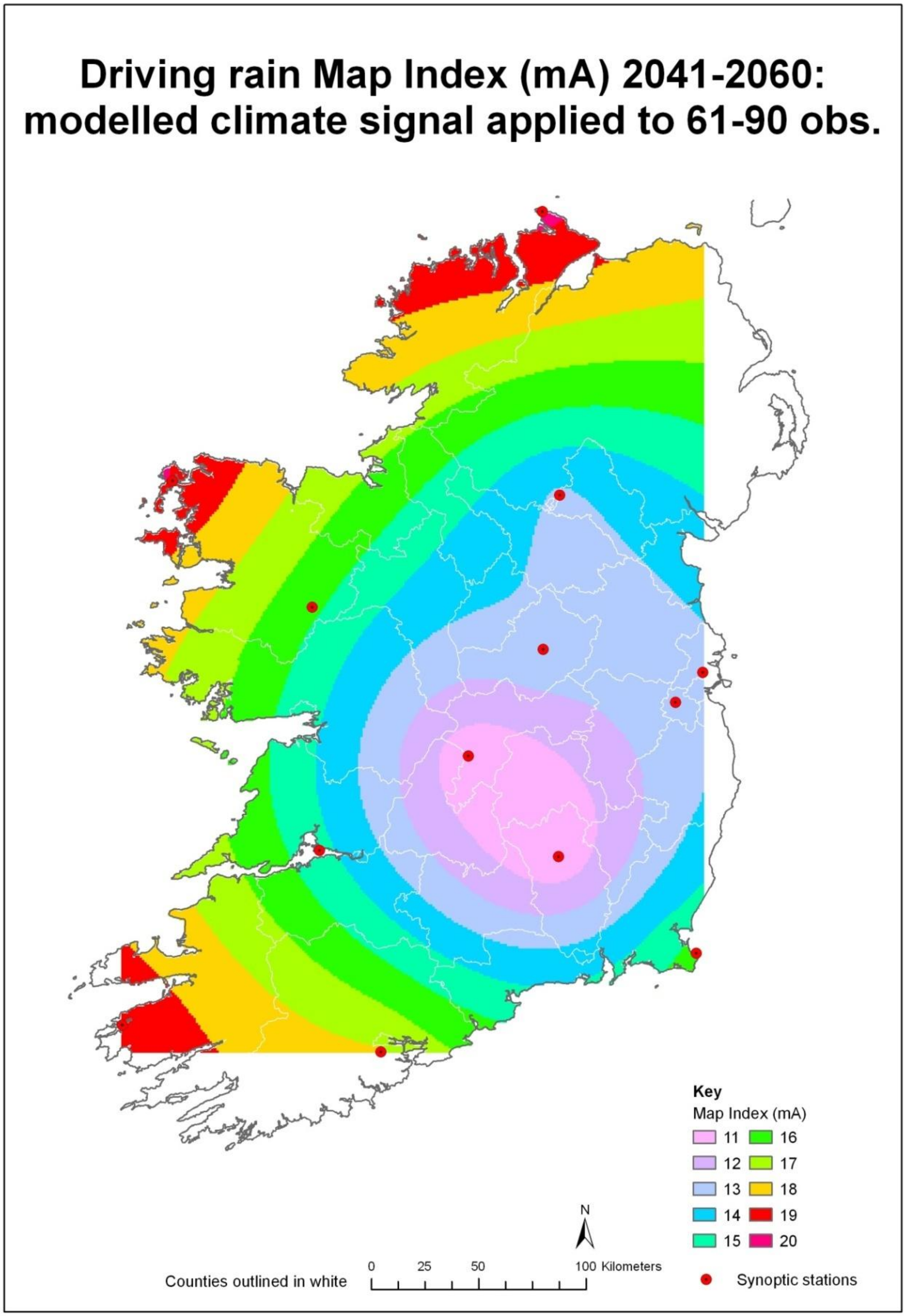


Figure 3.12 Map Index (m_A): 2041-2060 climate signal applied to observed synoptic data.

3.4.3 Driving rain Airfield Spell Index (I_S)

Table 3.3 shows the Airfield Spell Index values for the 1961-1990 observed baseline. It also shows the modelled 2021-2040 and 2041-2060 values resulting from adding the respective modelled climate signals to the observed baseline. Of immediate interest, aside from the high values due to the worst case strategy with respect to wind direction (see section 3.3.4), are the extremely high values for the modelled periods. The 2021-2040 period, in particular, demonstrates unrealistically high variation, from as little as 4 litres per m^2 in Kilkenny to as much as 440 in Belmullet. While Kilkenny is indeed inland and relatively sheltered, and Belmullet is located on the exposed west Mayo coast, the values are beyond the realms of any reasonable margins of error. Similarly extraordinary values are also found in the period 2041-2060, although with not such a low threshold.

Table 3.3 Driving rain Airfield Spell Index (I_S), the maximum value of I'_S likely to occur once every three years, measured in litres per m^2.

Station Name	1961-1990 Observed I_S	2021-2040 Modelled I_S	2041-2060 Modelled I_S
Valentia	200	399	372
Shannon Airport	104	211	327
Dublin Airport	60	137	108
Malin Head	182	238	268
Belmullet	202	440	338
Clones	94	257	217
Rosslare	88	97	138
Claremorris	122	143	328
Mullingar	92	45	487
Kilkenny	53	4	254
Casement Aerodrome	65	154	108
Cork Airport	151	266	476
Birr	65	163	297

The table serves to illustrate shortcomings in precipitation modelling with respect to the Spell Index. The required 96 hours of zero coincidence of rain and wind that bracket a spell do not appear to have been modelled successfully. Visual inspection of the modelled data reveals this to be the case, with stretches of several months often occurring before a gap of 96 hours is reached. All the rain in such extended periods is thus incorporated into the Spell Index equation. Conversely, the observed data contains frequent gaps that enable a spell to be defined with more temporal finesse.

Although the modelled outputs cannot reasonably be used for mapping, it is nonetheless instructive to map the observed values (Figure 3.13). These can then be used, in conjunction with geographical increments, to calculate an Airfield Spell Index for a specific location by using the inverse of equation [4]. As of yet however, geographical increments have not been calculated for Ireland. This work could nonetheless form the basis for further research in this area, whereby site-specific driving rain maps could be created by incorporating geographical factors that can be translated into increments for use with the Map Indexes.

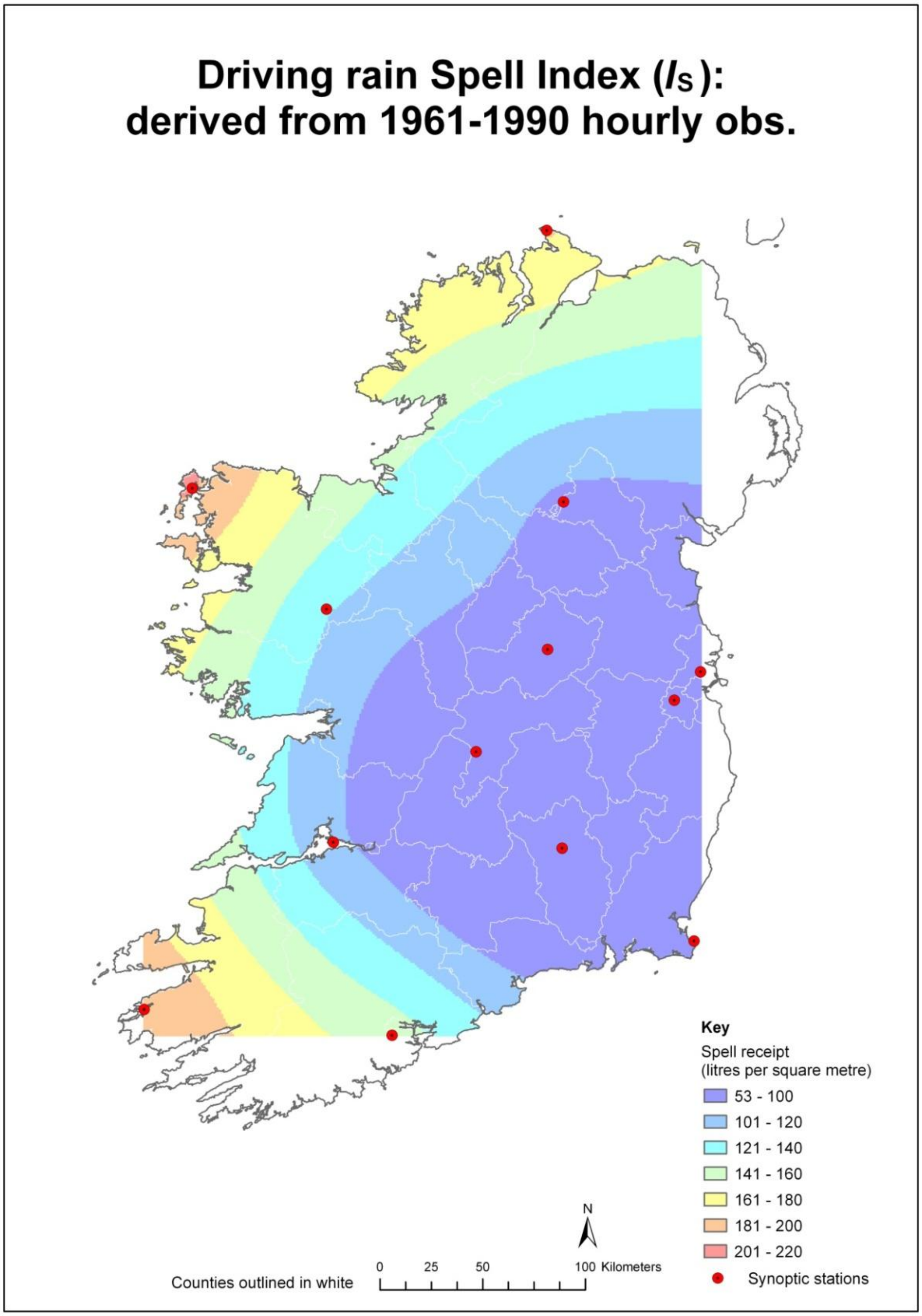


Figure 3.13 Spell Index (I_S), the maximum value of I'_S likely to occur once every three years, derived from 1961-1990 hourly synoptic observations.

3.4.4 Driving rain Map Spell Index (m_S)

Table 3.4 shows the Map Spell Index values for the 1961-1990 observed baseline and the modelled 2021-2040 and 2041-2060 values. As above, only the observed values are mapped (Figure 3.14). Corroborating the assertion made previously that the modelled values lie outside any reasonable margin of error is the value for Kilkenny, 2021-2040. A value of -5, the product of equation [4], is clearly erroneous. The observed values however are comparable with the values given for Aberystwyth (NSAI, 2009: 14). The south-westerly spell rose value for Aberystwyth, which features a similar level of exposure to Valentia, is 29. The Spell Map value for Valentia, even though it was calculated with a no-regrets wind factor, is 30. Investigating this unexpected closeness of values lies outside the remit of this research, although a possible contributing factor could be that only daily rainfall data were available to calculate indexes at UK subsidiary stations. Such data went through an estimation procedure to produce hourly rainfall amounts (NSAI, 2009). As discussed earlier, averaged data may introduce errors, although without further analysis this is purely speculative.

Table 3.4 Driving rain Map Spell Index (m_A).

Station Name	1961-1990 Observed m_S	2021-2040 Modelled m_S	2041-2060 Modelled m_S
Valentia	30	36	35
Shannon Airport	24	30	34
Dublin Airport	20	27	25
Malin Head	29	31	32
Belmullet	30	37	34
Clones	23	32	31
Rosslare	23	24	27
Claremorris	26	27	34
Mullingar	23	17	38
Kilkenny	18	-5	32
Casement Aerodrome	20	28	25
Cork Airport	27	32	37
Birr	20	28	33

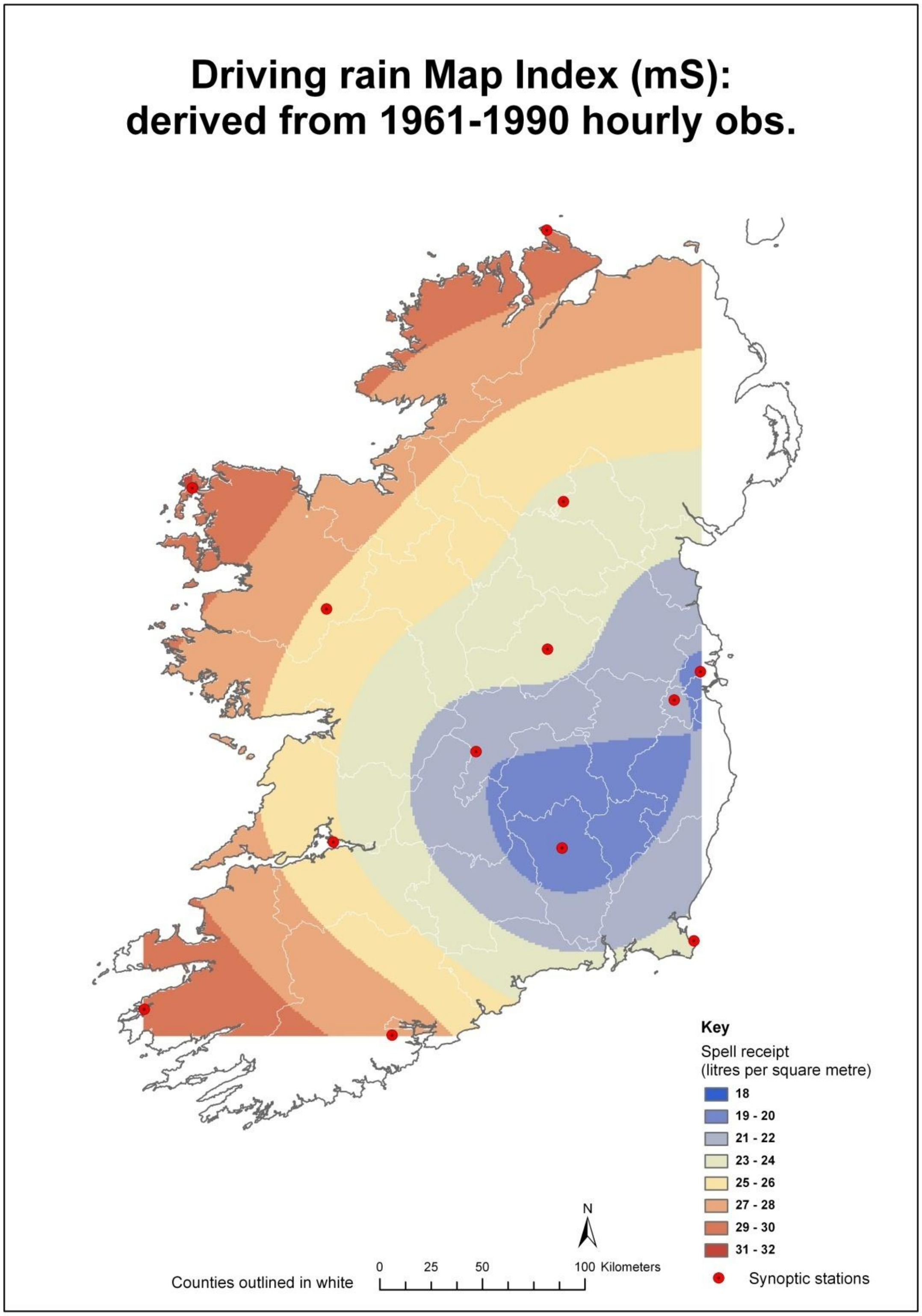


Figure 3.14 Map Index (m_S) derived from 1961-1990 hourly synoptic observations.

3.5 Application of WDR indexes: County Mayo as case-study

3.5.1 Introduction

To assess the application and practical implications of the indexes in the context of construction it was necessary to sharpen the focus to a more regional level. To this end, County Mayo was selected. Due to its location on the western fringes of Ireland, Mayo is exposed to more extreme weather events than many other counties, and consequently its built structures experience proportionally greater weathering than those further inland. The importance of this is that climate change is likely to have a more significant impact on buildings in Mayo than in more eastern and inland areas. Therefore, it is of great importance to quantify likely changes in climatic conditions at the local scale and to identify adaptation strategies to manage them. Due to issues with the Spell Index discussed earlier, only the Airfield Index is used to illustrate potential areas of concern.

3.5.2 County Mayo index and index projections

Current wind-driven rain conditions in Mayo for the period 1961-1990 can be seen in Figure 3.15. Westport, Ballina and Claremorris were subject to annual values of wind-driven rain in the order of 600-700 litres/m^2. Predictably, amounts are greatest on the western seaboard and decrease inland. Using downscaled output from global climate models, projected changes in these quantities can be computed: Figure 3.16 illustrates the projected wind-driven rain amounts for the period 2041-2060. Of particular note is that the principal urban centres of Westport, Ballina and Castlebar are in, or near to, a band of wind-driven rain featuring values between 700-800 litres/m^2 per annum. Also of interest is higher terrain such as the Nephin Beg range prevailing in the west. Increased wind-driven rain intensity with height will mean that any effects are accentuated with altitude, which will necessitate further consideration both in terms of materials used and planning policy. That said, it is anticipated that very little construction will take place in these zones due to planning restrictions and their Natura 2000 status. Overall however, the result is that increases in wind-driven rain in the order of 14% will be experienced by the built environment and infrastructure in County Mayo. Mitigation strategies advocating measures such as stronger roof ties and adaptation strategies recommending the fitting of rain-screens should be formulated.

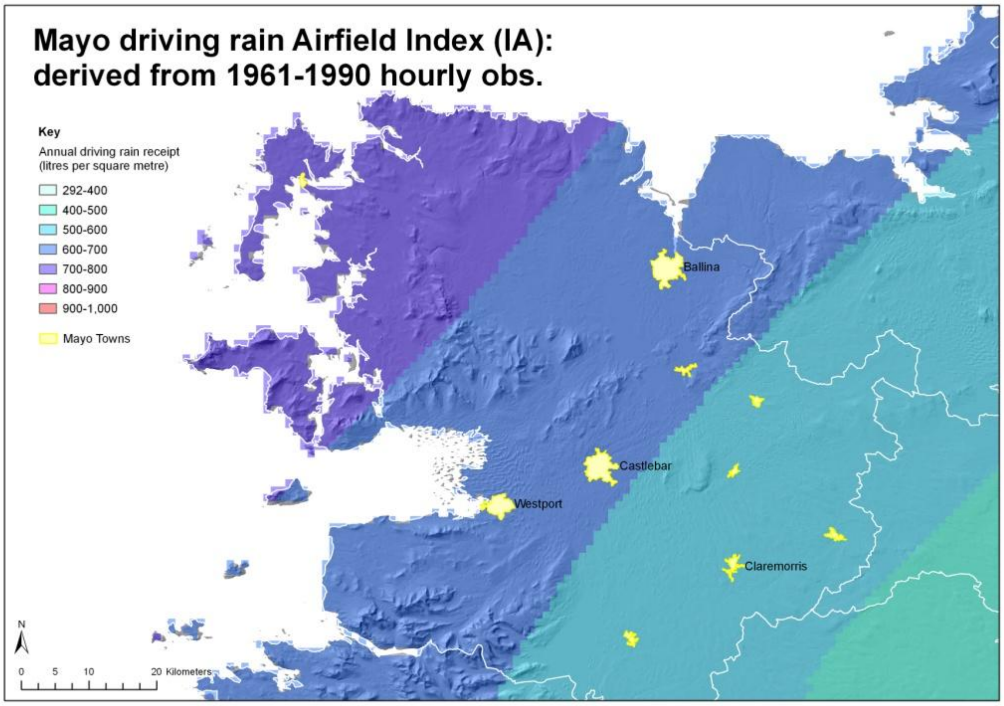


Figure 3.15 Mayo driving rain Airfield Index for 1961-1990.

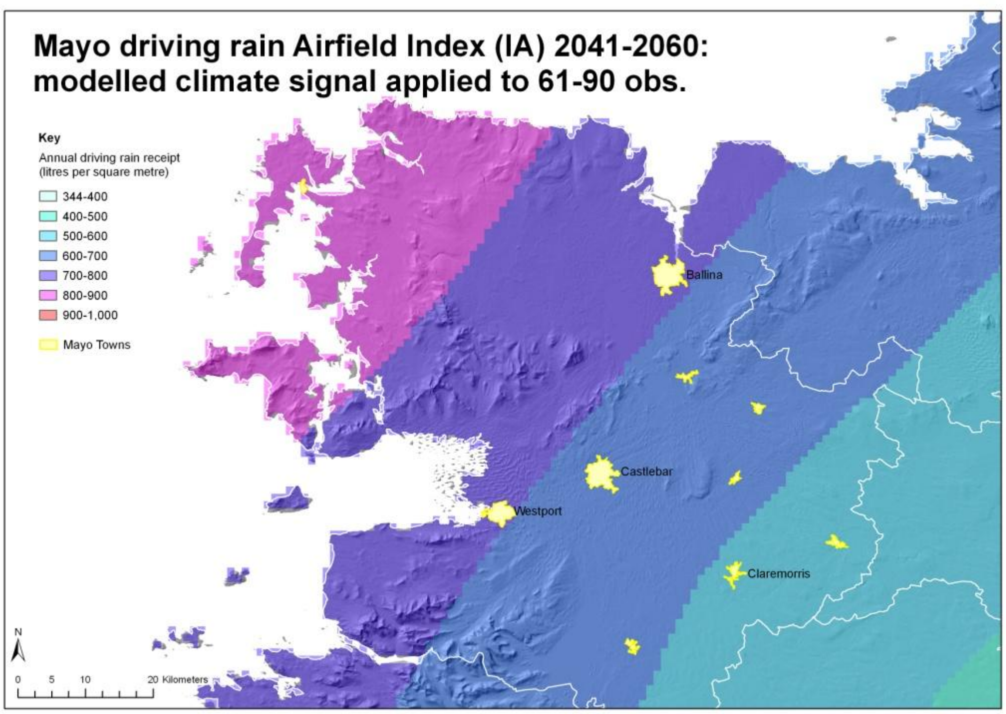


Figure 3.16 Mayo driving rain Airfield Index for 2041-2060.

3.5.3 General remarks

The volume and value of construction in Mayo are not as high as in other, more densely populated areas of Ireland. The built environment and human infrastructure in Mayo are generally more widely dispersed, with 71% of the population of the county currently residing in rural parts (CSO, 2012). However, the region highlights the necessary steps that will ultimately have to be taken by the more inland authorities as climate change impacts resulting from WDR trend eastwards through the present century. While the primary strategies in a construction context revolve around planning regimes and materials usage, governance and responsibility at local level are also as important tools with which to handle climate change issues.

Communication and co-ordination are vital in this regard. Ensuring seamless adaptation management requires strong linkages horizontally between Local Authorities and cooperation vertically with high-level government. If linkages are supported by relevant policies which support the recommendations proposed in section 1.6.2, Mayo can be seen as leading the way in terms of experiencing climate change and implementing national strategies to manage it.

3.6 WDR summary, recommendations and conclusion

3.6.1 Summary

It is important to note that the maps are not intended for climatalogical use. They are designed to act as a decision support tool for groups considering exposure to driving rain in a construction context, such as planning departments in Local Authorities and bodies such as the Building Regulations Advisory Body (BRAB), who are involved in Building Regulations review. In terms of map accuracy, it should also be noted that while the boundaries used are based on calculated index values they are delineated into bands for clarity, and are not intended for strict interpretation. In reality, transitions across boundaries are indistinct, and index values will be affected by factors such as local conditions and topography. Site-specific evaluations that incorporate corrections for topography, local obstructions and building geometry must be carried out to determine driving rain values relevant to individual structures.

The aforementioned notwithstanding, the Airfield Annual Index (I_A) and Map Airfield Index (m_A) show good agreement with wind geography demonstrated by other maps. For example, the Airfield Index derived from 1961-1990 observations is comparable with the NSAI wind derivation map and the UK wind speed map (Figure 3.17). Higher values are seen around the northern, western and southern fringes, while lower values trend towards the midlands and east. While precipitation is not a factor, wind is a common denominator and thus a tentative comparison can be made. For reasons elucidated earlier, the Spell Index is not used for evaluation in this context.

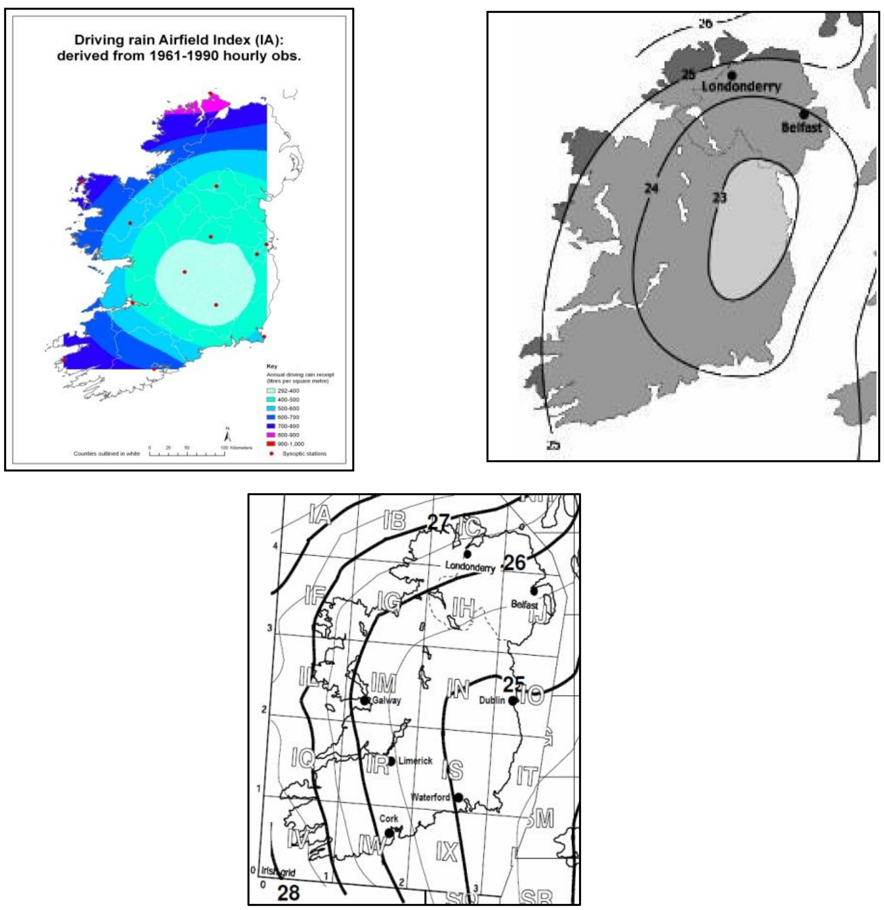


Figure 3.17 Top left: Airfield Index (I_A) derived from 1961-1990 hourly synoptic observations. Top right: UK map of wind speed zones (CTMA, 2006). Bottom: NSAI Wind Derivation Map (DEHLG, 2009b).

Interestingly, the NSAI Driving Rain map and Met Éireann's Distribution of Driving Rain in Ireland (Figure 3.18) do not demonstrate quite as good agreement. A principal reason is proposed for each instance. In the first case, the NSAI map features a topographic and coastal delineation component that acts to separate the northern, western and southern exposure zones and highland areas (Severe Exposure, $\geq 5m^2$/sec/year) from the lowland areas (Low Exposure, $<5m^2$/sec/year). In contrast, the maps generated herein (Figures 3.7 to 3.14) using ISO 15927-3:2009 exclude such a topographic element because topography does not preclude the occurrence of significant driving rain at the site-specific scale. For instance, buildings in an open area may receive forty times more wind-driven rain than buildings located in a clustered setting (Hens, 2011). It can therefore be seen that an exposed west-facing wall in a normal exposure zone such as Offaly may receive considerably more driving rain than an east-facing sheltered wall in one of the most exposed zones. As a corollary, the predecessor of ISO 15927-3:2009, BS8104:1992, excluded all terrain above 427 m r.s.l. (1,400 feet) from driving rain maps. ISO 15927-3:2009 notes that direct measurements of rain impacting on building façades should be made wherever possible 'especially in mountainous areas' (NSAI, 2009: v).

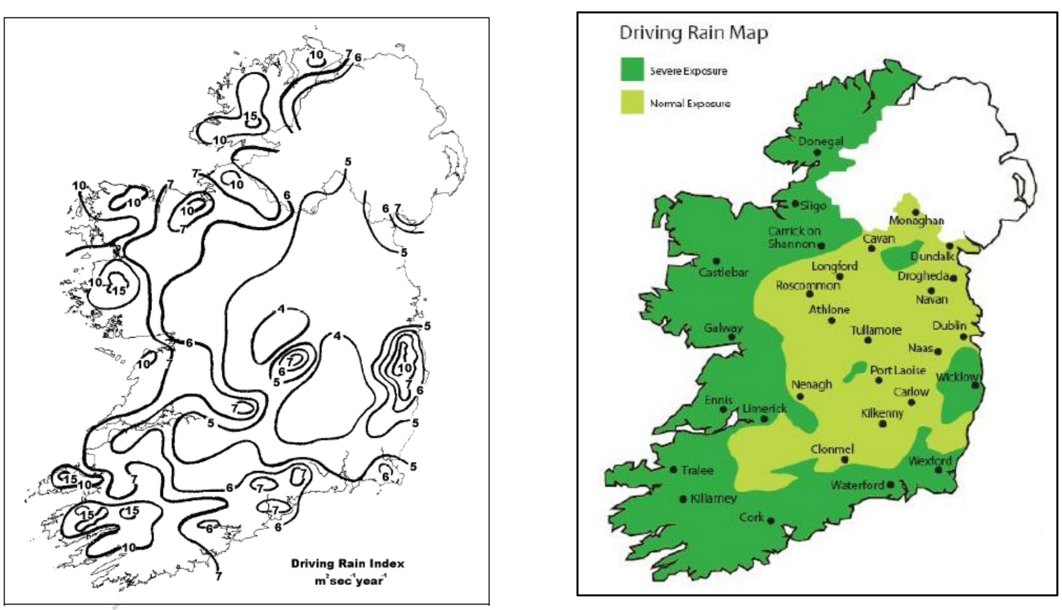


Figure 3.18 Distribution of Driving Rain in Ireland (Met Éireann, 2010) (left) and NSAI Driving Rain Map (2009) (right).

In the second case, Met Éireann's Distribution of Driving Rain in Ireland map is generated using annually averaged data. The annual rainfall field is multiplied by the annual mean wind field to produce the final index field, with the variation of index with height attributed to higher rainfall in upland areas (ME, 2010). However, the use of annually averaged data could result in significantly different index values versus the use of hourly data. Prior (1985) concluded that the use of averaged annual rainfall and long term average wind speed led usually to underestimation of driving rain indices. This was borne out during the development of BS8104: 1992, wherein it was found that values of driving rain calculated using the hourly product method were typically 26% higher, and sometimes 50%, than those obtained by the 'annual product' method (BS8104, 1992: 65). Demonstrating further the importance of temporally fine data, it has been observed that even using arithmetically averaged hourly data can cause 'an important loss of information about the co-occurrence of wind and rain' (Blocken & Carmeliet, 2007: 2335). Thus, the use of hourly synoptic data to calculate the driving rain indexes in this research was always likely to produce results somewhat at variance with maps utilising annually averaged data.

3.6.2 Recommendations

The projected increase in wind-driven rain will impact on construction through a potential reduction in the numbers of sites suitable for construction using contemporary building methods, tighter planning regimes and the necessity of employing increasingly resilient materials. Materials used in construction, particularly in the north west of the county, will need to be appropriate for current and future conditions in terms of maintaining building envelope integrity and resistance to moisture. This has practical implications for the industry in terms of cost, work schedules and maintaining industry best practice.

In terms of planning permissions, a stricter regime is recommended to limit construction in exposed zones to mitigate for climate change impacts. Where construction is permitted, materials of higher specification should be used as prescribed in the Technical

Guidance Documents and work carried out to standards set out in relevant Actual Construction Details. ISO 15927-3:2009 should be used for site-specific WDR evaluation.

Regarding adaptation, no single leaf building construction should be permitted. Double leaf construction, or construction such as meets or exceeds double leaf performance, should be used in all zones unless in an extremely well sheltered environment. Higher tolerances to wind loading and a more integrated materials approach should be incorporated to enhance structural and thermal performance.

In summary, recommendations as a result of this research are:

- ISO 15927-3:2009 must be used for site-specific WDR evaluation.
- Materials for building fabric must be designed and selected for the projected rather than current exposure zone.
- Restrict planning permissions in exposed zones.
- Consider adaptive measures such as the fitting of rain-screens in exposed zones.
- Double-leaf housing construction should be considered for more inland areas. Single-leaf construction should only be used in the least exposed zones.
- Remedial actions such as the application of rendering, dashing or moisture resistant paint should be carried out on single leaf buildings or those whose outer leaf has failed.

3.6.3 Conclusion

Indications of zonal suitability for construction and areas where possible remedial actions on structures may be necessary can be discerned from the maps illustrating the Airfield Index, Spell Index and Map Indexes. However, WDR is characterised by a high temporal and spatial variability (Blocken & Carmeliet, 2010). It is therefore essential that site-specific evaluations using IS EN ISO 15927-3:2009 are carried out for individual construction projects utilising all relevant available rainfall data in conjunction with local wind knowledge (Sanders, 2010). Nevertheless, the plotting of 1961-1990 observed values demonstrates the exposed nature of northern, western and southern zones, while the modelled data projected onto the 1961-1990 baseline provides a new quantification of likely climate regime shifts. An eastwards progression of zones indicating increases in driving rain can be seen. As a corollary, in Scotland 'wind-driven rain is likely to become more prevalent' (Scottish Government, 2011a: 11).

Temporally, the greatest increase in driving rain can be seen between the periods 1961-1990 and 2021-2040. Annual percentage increases in the order of 8-12% on the western and northern fringes indicate a noteworthy increase in the effects of wind and precipitation. Spatially, the areas suffering the more extreme effects lie along the western coastal zones. However, increases are noted throughout inland Ireland, and overall the prognosis is that walls will be wetter for longer with consequent impacts on thermal performance and implications for mould growth and deterioration of surfaces. More rain will penetrate the building envelope during severe spells, with consequences for occupant health and the structural integrity of buildings over their lifespan.

WDR may also have an impact on building insurability. Buildings located in areas of, for example, moderate levels of WDR may experience increasing levels of driving rain. The design resistance performance of external elements, joints and materials may be exceeded and thus no longer provide the protection needed. Retrofitting consequently becomes the only viable solution, which impacts directly on costs and potentially on premiums for other buildings located in the same zone. It is therefore ever more critical that materials selected for new construction are designed for levels of resistance to rain penetration not necessarily being experienced currently, but are being projected for the future.

This research, while not quantifying WDR at local level for reasons given previously, acts as a strong argument for increased materials research and represents a starting point for discussion. It is also the first study in Ireland to complete an overall assessment of climate change impacts on construction in the context of WDR using the latest standard, ISO 15927-3:2009. It is anticipated that designers, planners and developers will be able to use the outputs of this research to evaluate the future construction environment in a spatial and temporal context not available previously.

CHAPTER 4
DOMESTIC WASTEWATER MANAGEMENT

4 INTRODUCTION

While the link between climate change and construction is reasonably clear in the context of wind-driven rain, it is perhaps more obscure in the context of domestic wastewater management in one-off housing. In an Irish context, however, climate change is very likely to have a significant impact on the construction industry in this regard. Construction of one-off housing accounted for a large proportion of construction in Ireland until recently, when the recession impacted it severely. However, post-recovery, it is vital that the issues of construction in rural settings and the relationship with climate change are understood. This is necessary to identify areas of opportunity and areas where it will become increasingly hard for the construction industry to flourish.

Most domestic wastewater in Ireland is managed by public mains sewerage schemes. Out of 1,649,408 households, 1,092,418 are connected to the mains system (CSO, 2011), while the remaining 556,990 rely on other means. The high relative usage of other means compared to mains sewerage exists because almost a third of the population lives in rural one-off housing without access to mains sewerage. For those not connected to mains sewerage, onsite wastewater treatment is the primary treatment option. This fulfils the requirements of Part H of the Building Regulations, which specifies that all buildings must have an adequate drainage system for the hygienic disposal of wastewater (Part H, 2010). Other options outlined in codes such as the EPA's *Wastewater Treatment and Disposal Systems Serving Single Houses* (2009) include storing sewage in cesspools with regular tankering to wastewater treatment plants, but such options are not widespread due to high cost.

Given the number of dwellings relying on onsite treatment, it can be seen that domestic wastewater management is an issue that warrants particular attention in the Irish context. Should onsite systems fail, there can be significant contamination of groundwater and surface waters, and public health may be threatened (Keegan & Clinton, 2009). Indeed, on-site wastewater treatment systems have long been suspected as a primary source of contamination of both ground and surface water bodies (Gill *et al.*, 2007). Changed precipitation regimes as a result of climate change are likely to affect the function of septic tanks in vulnerable areas, as winter water tables rise during precipitation events and compromise the effectiveness of septic tank operation. In such areas, construction is likely to be curtailed as groundwater vulnerability issues may result in fewer planning permissions granted. Consequently, geographies of construction may be altered significantly.

To mitigate for the aforementioned contamination eventualities, the Geological Society of Ireland (GSI), the Department of the Environment and Local Government (DELG) and the EPA developed a methodology for the implementation of groundwater protection schemes (Daly *et al*, 2000: 28). As the name suggests, groundwater protection schemes are designed to protect and maintain groundwater quality. When allied to groundwater protection zones (based on aquifer maps), guidelines for controlling various sources of pollution, including septic tanks, and vulnerability to groundwater pollution (based mainly on the nature and thickness of subsoils), they offer an effective method with which to protect the environment from contamination (Daly *et al*, 2000: 29) .

Onsite wastewater treatment in Ireland creates a challenge to public health and the environment outside the experience of many other developed European countries. For example, in England and Wales there are approximately 800,000 septic tanks equating to 1 septic tank per 65 head of population (UK Census, 2001). In Ireland the figure is 1 in 10. In a broader European context the EU Water Framework Directive (2000/60/EC) requires that groundwater is viewed as a component of the water balance of a river basin. This integrated approach requires that water is managed at the River Basin District (RBD) scale and that the impact of human pressures on groundwater and surface water is also considered. In addition, on-site wastewater treatment and disposal must now have regard to Surface Water (DEHLG, 2009a) and Groundwater (DEHLG, 2010e) Objective Regulations. Moreover, groundwater and surface water must have achieved ‘good status’ by 22 December 2015 (DEHLG, 2010e: 8) if penalties are to be avoided.

The current status of Ireland’s water bodies suggests that meeting the 2015 target for good status will require significant attention. For instance, 87 (17%) of privately-sourced group water schemes were contaminated at least once during 2009 with *E. coli*, which can get into supplies from improperly functioning septic tanks. A group water scheme is where two or more households come together to provide their own common water supply. Usually, group schemes are established in areas where the local authority does not intend to install a water supply system, and get water supplies instead from a private source such as a well or lake. The group water scheme sector was deemed to warrant its continuing year-on-year allocation of €100 million to improve performance under the Rural Water Programme (EPA, 2011: 16). Although group water schemes tend to be the focus of improvement works it is worth noting that public water supplies are not immune to contamination. For example, in November 2009 severe flooding in the west of Ireland led to ‘boil water’ notices being placed on 10 public water supplies serving approximately 70,000 people (EPA, 2011).

The issue of contamination is indeed important but the focus should also be on mitigating the root causes. In this context, climate change and its impact on construction become apparent, in that the siting of potential construction projects is likely to be altered significantly as water body protection issues start to influence the location of future new-builds. It has already been observed that implementation of measures to remedy the situation in poor quality areas may have social and economic costs (Daly & Craig, 2009). To estimate the regions of construction most likely to be affected by the impact of climate change, this strand of the research calculated and mapped septic tank densities and overlaid them with projected winter precipitation changes and current WFD groundwater vulnerability maps. A Groundwater Vulnerability Index was also employed to present a broader picture of high risk zones in a Local Authority context. In addition, an exemplar area located in County Galway was examined to provide an assessment of potential impacts on construction at the local scale.

4.1 Types of domestic wastewater treatment available for dwellings not connected to mains sewerage

There are several types and variations of onsite wastewater treatment system for dwellings not connected to mains sewerage. The most widespread in Ireland is the septic tank system. In 2011 there were 437,652 in operation (CSO, 2012). As the principal system under study in this section of the research the septic tank system will be described. Subsequently, septic tank alternatives such as packaged systems and Low Pressure Pipe (LPP) and Drip Distribution Systems (DDS) will be discussed briefly.

4.1.1 The septic tank system

Contrary to popular perception a septic tank system is not purely a tank in the ground that receives wastewater. Such a system is termed a cesspool, which needs pumping at regular intervals to maintain capacity and prevent overflow. A septic tank system comprises a septic tank and a percolation area (Keegan & Clinton, 2009). The system not only receives domestic wastewater but also purifies it through a series of interlinked processes. The basic procedure is illustrated in Figure 4.1.

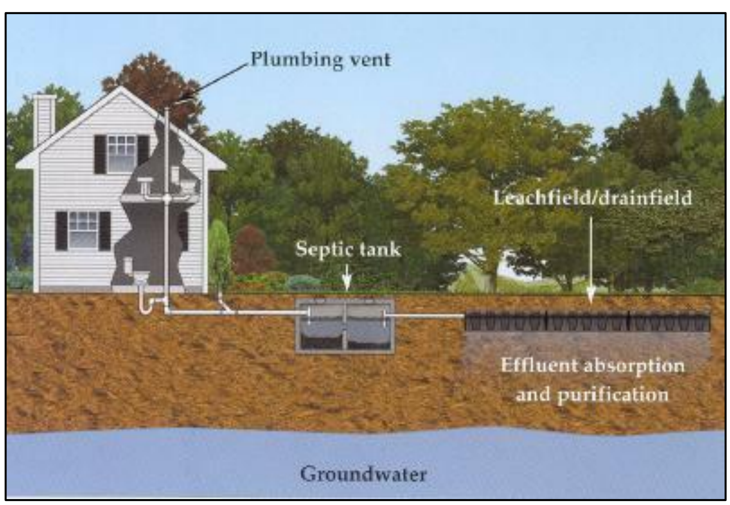


Figure 4.1 Basic septic tank system. (Source: Earnshaw Brothers, 2012.)

Initial treatment, classified as primary treatment, takes place in the septic tank. There are many types of septic tank offering several levels of primary treatment, but the result is the same: solids separate from the wastewater and sink to the bottom to form sludge, while the remaining liquid flows into a second chamber *via* filters. Settling out of the remaining solids occurs in the second chamber. Solids separation is complemented by limited anaerobic digestion. Effluent then flows through pipes into the percolation field, sometimes referred to as the leachfield or drainfield. This is the area where several pipes of determinant length, punctured by holes at regular intervals, introduce the septic tank effluent into the subsoil for purification. It is in this area that the majority of treatment takes place (Keegan & Clinton, 2009).

Purification of septic tank effluent takes place through filtration, straining, physio-chemical interactions and microbial breakdown while percolating through the subsoil. The percolation area is therefore an integral part of the overall on-site treatment system and it is essential that the wastewater remains in it long enough for effective treatment to take place. If the hydraulic load to the percolation area is too great or the subsoil thickness too small, the result may be ponding and/or partially treated effluent entering the bedrock or groundwater. To militate against such events, there should be at least 1.5 m between the bottom of the percolation pipes and water table or bedrock. This should comprise at least 1.2 m of undisturbed subsoil plus 0.3 m of distribution gravel located under the pipe network (Keegan & Clinton, 2009). As an indication of the scale of contamination in Ireland, between 2004 and 2006 approximately 34% of 1,330 samples taken tested positive for faecal coliforms. Faecal coliforms are an indicator that faecal matter from humans and animals may be present the water. 25.4% of samples contained positive faecal coliform counts of which 10.9% had a concentration of more than 10/100 ml, a level which is taken as an indicator of gross contamination. Indeed, faecal coliform counts in excess of 10/100ml were recorded at 37% of monitoring locations on one or more occasions during the reporting period (EPA, 2008). The incidence of a single faecal coliform in drinking water supply is a breach of the Drinking Water Regulations.

In areas where a septic tank system *solo* is not suitable, secondary treatment filters and polishing filters comprising different filtration media may be employed to treat effluent further. For example, a system might incorporate a septic tank followed by a pumping chamber, a constructed wetland or an intermittent filter comprising soil, sand or peat, and a polishing filter. Polishing filters reduce pollutants such as micro-organisms and 'polish' the effluent before discharging it to ground or surface waters. While there are several alternatives and permutations for additional effluent treatment, including soil filter systems, sand filter systems with underlying sand/subsoil polishing filters and mounded intermittent filter systems, it can be seen that the correct choice and installation of an onsite wastewater treatment system is critical to the protection of the environment in dwellings not connected to mains drainage.

4.1.2 Alternative systems

4.1.2.1 Packaged treatment systems

Packaged systems use mechanical parts and different media to treat domestic wastewater. In addition, they require a polishing filter before discharge to groundwater or surface water can take place. Many systems are available incorporating treatment processes such as:

- Activated sludge systems
- Biological/submerged aerated filter systems
- Rotating biological contactor systems
- Sequencing batch reactor systems
- Membrane bioreactor systems

In contrast to basic septic tank systems they require power and regular maintenance due to the use of mechanical and/or electrical components. However, in general they produce a higher quality effluent in terms of organics than septic tanks, although their sensitivity to grease loading means that grease traps may also be required (Keegan & Clinton, 2009).

4.1.2.2 Low Pressure Pipe (LPP) and Drip Distribution Systems (DDS)

LPP and DDS are pressure-dosed wastewater distribution systems suitable for zones of shallow subsoil and/or high water tables. Developed in the USA, they are used successfully throughout many states. Each system allows wastewater from a septic tank or secondary treatment unit to be distributed in regular discharges over a percolation field under pressure from pumps. The controlled rate is important due to the necessity of allowing sufficient treatment to take place in the subsoil and also to avoid ponding. Grass and other foliage aids removal of wastewater *via* evapotranspiration, while the controlled dosing through narrow diameter tubing means that the soil receives smaller averaged volumes rather than larger lower frequency doses associated with normal septic tank systems.

LPP and DDS allow complete treatment of wastewater while preventing the soil from becoming hydraulically overloaded. A further benefit is that due to their use of pumps they can be installed upslope of the septic tank or secondary treatment site. Furthermore, the shallow nature of the percolation field means that less excavation is required than with other systems. However, they are at present undergoing tests in Irish conditions, and until the tests are completed it is not possible to ascertain to what extent they may or may not replace septic tank systems as the preferred method of onsite wastewater treatment.

4.2 Septic tanks systems and vulnerability

As has been highlighted, the most widespread system used to treat domestic wastewater is the septic tank system (herein referred to as a ‘septic tank’ for brevity, unless indicated otherwise). When sited in suitable conditions septic tanks are an efficient method of wastewater treatment. However, conditions for the siting of septic tanks over an estimated 40% of Ireland vary from slightly to seriously inadequate (Daly *et al*., 1993). For example, granite lies very close to the surface in many areas of western Galway making septic tank construction largely unsuitable, and over 50% of Ireland is underlain by carboniferous limestone that tends to have fissure permeability. Contaminants experience little attenuation once percolation through subsoil has occurred and can thus enter groundwater relatively uninhibited. Indeed, septic tanks are considered to be one of the principal sources of groundwater pollution, and in many areas over 30% of private domestic and farm wells have been contaminated by microbiological organisms at some juncture (Daly, 2003). Even if the amount of groundwater polluted is relatively small, the risks to health can be significant.

To analyse septic tank vulnerability, winter precipitation projections were used. The most frequent and intense precipitation events occur in winter, specifically December, January and February. Although a decrease in exposure may occur in summer months, if groundwater is contaminated it could take many years to return to potable status. It is therefore critical to assess groundwater vulnerability during the periods of highest precipitation, when the highest recharge rates and the greatest potential for rising water tables exist.

While the siting and correct construction of septic tanks is critical to their efficacy, the root of the potential contamination issue due to climate change does not lie in current septic tank construction *per se*. If located and constructed within procedures laid down by the Sustainable Rural Housing Guidelines for Planning Authorities (DEHLG, 2005b) and the Code of Practice for Wastewater Treatment and Disposal Systems Serving Single Houses (EPA, 2009), there should be minimal impact on groundwater quality. The principal cause for concern lies in legacy septic tanks. Constructed before current legislation came into force, they operate to variable and questionable degrees of efficacy and impact groundwater quality to the detriment of future construction opportunities.

4.2.1 Legacy septic tanks

The construction of legacy septic tanks took place initially under guidance provided in *Recommendations for septic tank drainage systems suitable for single houses* (IIRS, 1975). This differs substantially from current legislation in several aspects. For example, regarding the critical distance that provides for contaminant attenuation measured from the base of the gravel surrounding the percolation pipes to the water table, it states that 'ideally the distribution pipes plus their surrounding gravel should remain above the water table at all times of the year' (IIRS, 1975: 8). The key term is 'ideally' in this regard in that it obviates the necessity to ensure that percolation pipes are above the water table at all times. Should percolation pipes be at or below the water table at any time, partially treated effluent is being discharged direct to groundwater. In addition, a T value below which a site was deemed to have failed is not proposed. The T value is an indication of the percolation property of the subsoil.

The omission of the minimum T value in the 1975 regulations is critical, particularly for karstic zones where very low T values may be found. In karstic areas, water, and thus effluent, can move rapidly through fissures widened by solution (fissure permeability), and can enter groundwater quickly *via* entry points such as sinking streams. Such streams transit from surface to sub-surface fast and thus provide little or no filtration or attenuation of contaminants. Solution hollows and sinkholes may also provide direct entry routes through vertical shafts. In addition, the characteristic soil cover over karst areas is typically only a few centimetres deep and therefore provides little protection (DELG, 2000).

Another significant factor affecting pollution transfer is variable source areas. In such areas, the water table is relatively shallow, such as in valley bottoms. When the area receives more rainfall than can be infiltrated into the subsoil, a saturated area forms around the river channel. The saturated area increases in size and acts as an extension to the channel network, meaning that a substantial amount of water can be transferred in a short time (Charlton, 2008: 23). Any contaminants contained in the water at such a time will therefore be transferred quickly also, increasing the threat of pollution to surrounding zones.

Subsequent guidelines in *Recommendations for effluent treatment and disposal from a single dwelling house* (EOLAS, 1991) provided more comprehensive guidance yet did not preclude septic tank installation on poorly drained sites. An example of what can occur in a low permeability subsoil setting is illustrated in Figure 4.2, where lack of maintenance combined with poor percolation characteristics led to significant contamination and subsequent pollution.

Appendix C in the aforementioned recommendations offered solutions in these cases but acknowledged that 'such site development is likely to be expensive' and that 'septic systems installed in such sites may prove troublesome in operation' (EOLAS, 1991: 24). In such cases it is doubtful that adequate levels of environmental protection exist. There are many more areas where the 1975 and 1991 guidance are deficient, but it is sufficient to highlight the instances above to give a clear indication of the hazard to the environment that legacy septic tanks may pose. As an indication of the potential scale of the threat to the environment 344,635 septic tanks were in use in 1991 (CSO, 1991).

Figure 4.2 Legacy septic tank sump overflow in a low permeability setting. (Source: Limerick County Council, 2011.)

Onto this current threat to the environment a layer of climate change impacts must be overlaid. Changes in precipitation patterns could result in rising winter water tables, which may encroach into the purification zones of many legacy septic tanks resulting discharge of partially treated effluent direct to groundwater. The consequences for construction are twofold: at local level, many septic tank systems will need upgrading or replacing; at regional level, geographies of construction will change as areas where it is possible to build will become fewer. An exemplar area, the environs of Galway City, is analysed in this context in section 4.8.

4.3 Septic tank density, groundwater monitoring and geological factors

Regardless of septic tank age, numbers and condition, septic tank density (STD) has been recognised as one of the most important factors influencing groundwater contamination (Yates, 1985). Although a properly functioning septic tank system can filter most pathogens, high-density installations can cause nitrogen contamination (Wakida and Lerner, 2005; cited in EPA, 2009). Specific pressures identified also include nutrients from septic tank systems (EPA, 2005), which in conjunction with high septic tank densities can impact groundwater negatively due to cumulative loading (EPA 2009). Further pressures from legacy septic tanks and those located in zones of low permeability subsoils amplify the threat posed to groundwater and surface water by high septic tank densities.

4.3.1 Groundwater monitoring status

Septic tank and subsoil processes are reasonably well understood. However, the assessment of groundwater represents a significant challenge. The record is generally short or incomplete even after the instigation of a hydrometric programme under the EPA Act 1992, with the result that large areas of Ireland are not represented in the data. Even modelled data has considerable limitations due to the absence of comprehensive datasets for model calibration (Daly & Craig, 2009). That said, the groundwater monitoring network was reviewed and updated in 2007 and is now more representative of the hydrogeology and pressures (EPA, 2009). Even so, there are only 344 groundwater monitoring sites throughout Ireland, and these are focused primarily on groundwater bodies classified as 'at risk' from over-abstraction rather than on groundwater bodies whose levels might rise as a result of increased recharge receipt. Crucially, this means that monitoring sites are not distributed evenly, and critically for groundwater just 64 sites monitor levels. The short-term records cover periods variously from 2007-2010 and are recorded at 15-minute intervals. Of the 64 monitoring sites, only five have digitised long-term records. In County Kilkenny: Knocktopher; Oldtown (1980-2008); Rathduff (1981-2008). In County Roscommon: Aghadrestan; Cloonamagaunna (1984-2007).

Groundwater monitoring is important because groundwater accounts for between 20% and 25% of drinking water supplies. In some counties, such as Roscommon, it accounts for approximately 75%, and at least 100,000 wells and springs are in use in rural areas nationwide where groundwater is typically the sole source of drinking water (EPA, 2008). Although septic tank density has the potential to impact groundwater quality, groundwater that encroaches into the 1.5m purification layer of septic tank systems as a result of rising water tables will also expose aquifers to risk of contamination. This was noted in the Rural Planning Guidelines (2005), which pointed out that any locations prone to extremely high water tables should be avoided in the context of septic tank construction. Exacerbating the matter is the issue of potential increases in winter water table levels due to climate change. Changed precipitation regimes could result in an increase in zones of groundwater vulnerability due to groundwater coming into direct contact with partially treated effluent as the water tables rise. This issue is particularly relevant for catchments with fast response times and areas liable to flooding.

4.3.2 Geological factors

The geology of Ireland presents further challenges to effective mitigation and adaptation strategies. Only around 2% of the country features sand and gravel aquifers with intergranular permeability. The remaining aquifers are bedrock aquifers that tend to be unconfined and have fissure permeability only. In addition, most bedrock aquifers are karstified limestone featuring conduit flow (EPA, 2012b). Groundwater velocities are fast in such aquifers, up to several metres per day, and mixing in the top ~60m readily occurs. Consequently, contaminants in bedrock experience little attenuation once percolation through subsoil has occurred (Lee *et al*., 2008) and relatively rapid transportation can take place. This is important due to the majority of aquifers being classified as 'regionally important' (EPA, 2012c).

Due to the effective low porosity in bedrock aquifers, a small change in the volume of groundwater can effect a large change in water table level. However, it should also be noted that the same low porosity could inhibit the potential rise in water table levels. Although winter rainfall is likely to increase, a large proportion of the aquifers will not be able to accept the potential recharge volumes. Additionally, most of Ireland's aquifers are covered with low permeability subsoil, restricting recharge further. That said, there are regions where recharge coefficients of up to 85% are indicated. For example, the Curragh aquifer in County Kildare is considered a 'high permeability, high vulnerability gravel aquifer' (Misstear & Brown, 2007: 29). Gravel aquifers are generally relatively thin, typically featuring between 5-15m of saturated subsoil, and are usually unconfined. Arguably, they would not require a significant increase in precipitation to amplify their vulnerability.

4.4 National vulnerability research methodology

In the context of this research vulnerability can be defined as:

> 'the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes.'
>
> (IPCC AR4, 2007b: 1)

To identify potential zones of vulnerability, a Geographic Information System (GIS) is used to map septic tank densities, winter precipitation regimes and WFD groundwater vulnerability. By layering the three datasets in GIS and correlating with EPA groundwater level data where available, susceptible areas are identified. Strategies are formulated to support the successful achievement of WFD ‘good’ groundwater status by 2015.

Septic tank density was calculated by dividing the number of septic tanks in each Electoral Division (ED) by the total land area of each ED. An ED is the smallest legally defined administrative area for which Small Area Population Statistics are published from the Census. There are 3,440 legally defined EDs in the State. The mean population is 1,223, although figures vary depending on whether urban or rural (CSO, 2006). Initially, data from SAPS Volume 6, Table 13, ‘Private dwellings in permanent housing units in each Province, County and City’ was classified by water supply and sewerage facilities (CSO, 2006). This was joined to the ED shape file attribute table. Subsequently, the number of septic tanks per square kilometre was calculated and the output mapped. The nominal STD threshold to indicate potential vulnerability is 17 septic tanks per square kilometre. This is based on the US EPA designation that any greater density than 16 constitutes a ‘region of potential contamination’ (Yates, 1985). The geological and demographic differences between the USA and Ireland may suggest that critical STD values valid in the USA may not be appropriate in the Irish context: however, Irish local authorities such as Limerick and Wexford consider $8/km^2$ to represent the nominal critical threshold. The density threshold can be considered nominal because although density is a key factor in assessing potential contamination, other factors such as subsoil, bedrock geology and groundwater level are also significant in assessing true vulnerability. Density alone will not determine the extent of potential vulnerability to rising winter water tables.

Gridded precipitation regimes for the periods 1961-1990 and 2041-2060 were obtained, based on dynamically downscaled HadCM3 data and the HIRLAM Regional Climate Model (McGrath & Lynch, 2008). These outputs were interpolated statistically to 10km (Teck & Holman, 2010) and mapped on a 10km OSI grid in ArcGIS. The point data was converted to a Kriged surface to enable clear overviews of areas at national and regional scales. Winter monthly averages (DJF) for 1961-1990 and 2041-2060 were calculated and differences quantified. The modelled DJF 61-90 baseline was subtracted from the DJF 2041-60 averages to obtain percentage increases for the periods in question. Outputs were mapped over septic tank density and WFD groundwater vulnerability to provide a national overview. Results were used to design adaptation strategies to mitigate for climate change in vulnerable areas.

Further to the national septic tank density map, a Groundwater Vulnerability Index was proposed to illustrate high risk zones in a local authority context. Nominal vulnerability thresholds were decided for STD, precipitation increase and WFD risk score and a vulnerability rating for each parameter was determined. Subsequently, a vulnerability index was calculated by totalling the vulnerability ratings for each Local Authority area. Vulnerability to contamination was then inferred, which also acted as a primary indicator of where developers may focus investment for new construction projects.

4.4.1 Exemplar area research methodology

The septic tank density map produced using the methodology discussed above indicated areas of potential vulnerability to climate change at the national scale. However, a more focused approach is necessary to assess the threats posed by climate change at the local scale in the cases of rising winter water tables. To provide a more focused view of issues affecting septic tanks the environs of Athenry, County Galway were assessed. Galway has suffered recently from contamination issues, and its location in a karst region where groundwater is vulnerable due to rapid flow regimes represents an appropriate study area for septic tanks.

Initially, Athenry was mapped to illustrate septic tank density at the regional scale. Subsequently, Athenry was mapped at a local scale to illustrate the variable distribution of septic tank density within an ED and thus demonstrate the wide range of vulnerabilities apparent at a finer resolution. It is worth noting that while local scale vulnerability may be variable, due to its flow characteristics the ultimate receptor, groundwater, may be vulnerable at a more general scale as contamination plumes spread horizontally as well as vertically.

The An Post GeoDirectory, which provides co-ordinates for each address in Ireland, was employed to map individual onsite wastewater systems. The assumption being made is that any mapped location outside a sewered area will of necessity have an onsite wastewater treatment system. Thus, each GeoDirectory data point is assumed for the purposes of this research to represent an onsite wastewater treatment system. Kernel density analysis was employed to identify ‘hotspots’ within the study area. Observations and recommendations were then made with regard to the impact of climate change on the current situation and its likely effect on construction.

4.5 Results: National groundwater vulnerability

4.5.1 Septic tank density

National septic tank densities are illustrated in Figure 4.3. As can be seen, densities are greatest overall in the peri-urban areas of towns and cities. A doughnut effect can be discerned where low densities in the centres are surrounded by higher densities in the suburban environs and commuter belts. It can reasonably be assumed that the central zones are connected to mains sewerage and thus septic tank density is low, while the outer rings of construction have no connection to mains sewerage networks and therefore feature high septic tank densities.

A notable exception is Dublin city centre where several zones of high septic tank density exist (Figure 4.4). For example, Merchant’s Quay has an STD of 80/km^2 and Rotunda 108/km^2. Although the absolute number of septic tanks is only 13 in Merchant’s Quay and 27 in Rotunda, due to the small ED areas of 0.16km^2 and 0.25km^2 respectively the density is high. Nonetheless, despite the relatively low absolute number of septic tanks the tightly grouped treatment systems represent a significant concentrated point source for pollutant loading.

The high densities in Dublin are somewhat surprising given that mains drainage is prevalent in most urban areas. This leads to questions over the accuracy of the Dublin urban census data. One possible explanation is that urban dwellers' knowledge of the sewerage systems connected to their residence is not extensive. There could also be confusion or misunderstanding between the terms used to describe sewerage types on the census form, resulting in erroneous entries. However, why this pattern is not repeated in other urban areas is a matter for conjecture. That said, there may exist historically a large number of septic tanks in the original environs of Dublin city. In this case, STD is indeed a cause for concern, although verification of the data may be troublesome due to the presumed location of many septic tanks under buildings and thus out of sight. Conversely, a strength of the data from the peri-urban and rural zones is that respondents can ascertain visually the presence or otherwise of a septic tank.

Taking the Dublin anomaly into account, and considering that urban septic tanks can be connected to mains drainage relatively easily to mitigate for vulnerability, results identify the primary potential problem areas as being the suburban peripheries of major towns and cities. Here, significant septic tank densities, increased precipitation, a general lack of mains sewerage and the likelihood of further development exist. Zones of particular interest due to size of population lie in the peri-urban areas of Cork, Galway and Limerick (see Figure 4.4). For example, Cahelag (Cork) contains 22 septic tanks per square kilometre; Rahoon (Galway) contains 39/km^2; and Clarina (Limerick) 21/km^2. It is instructive to observe the contrast with suburban Dublin where, notwithstanding the city centre issues discussed above, mains sewerage networks extend into the peripheries where the septic tank density is low. Groundwater is less vulnerable in these areas in the context of septic tank density.

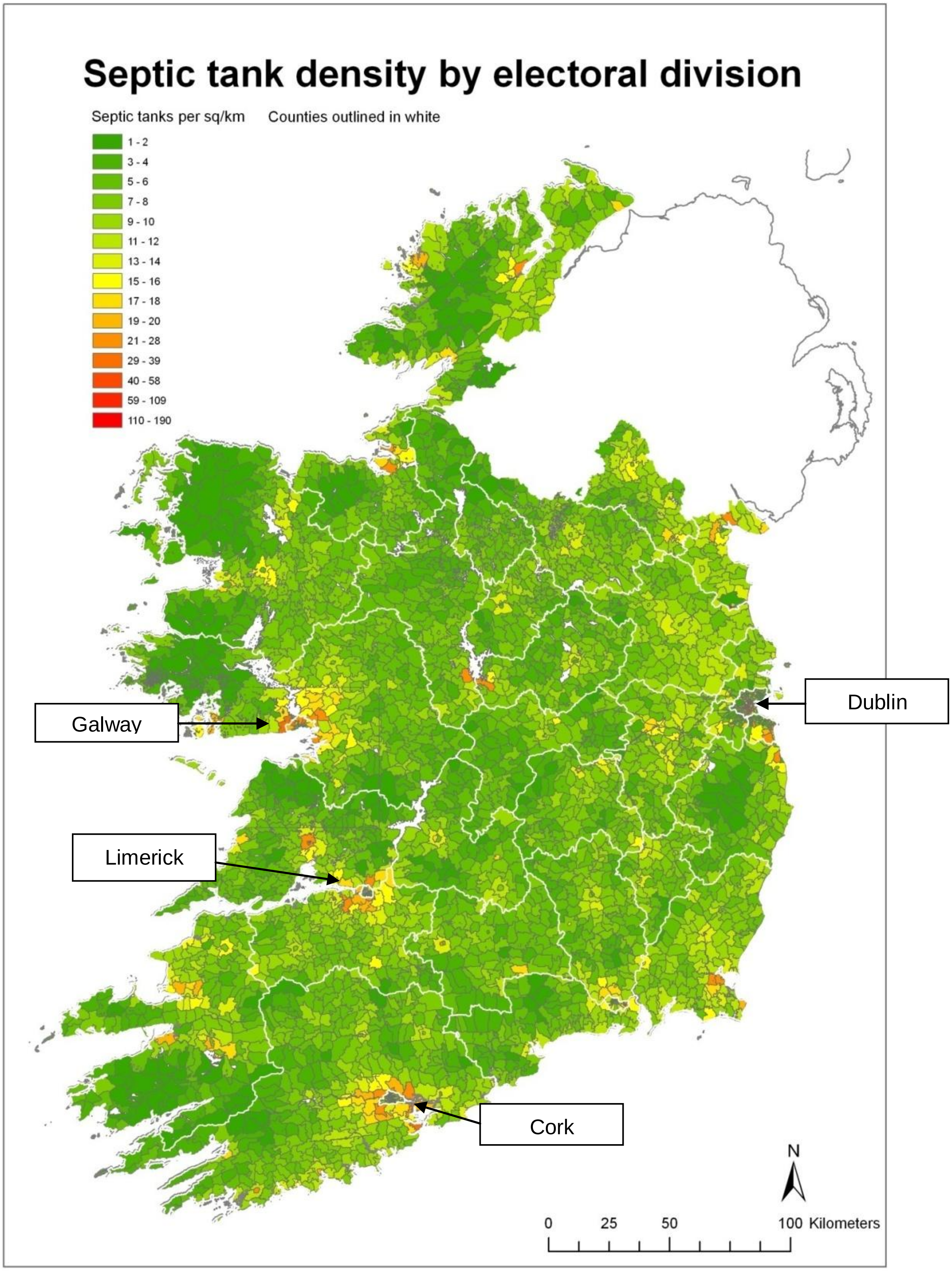


Figure 4.3 National septic tank density by Electoral Division.

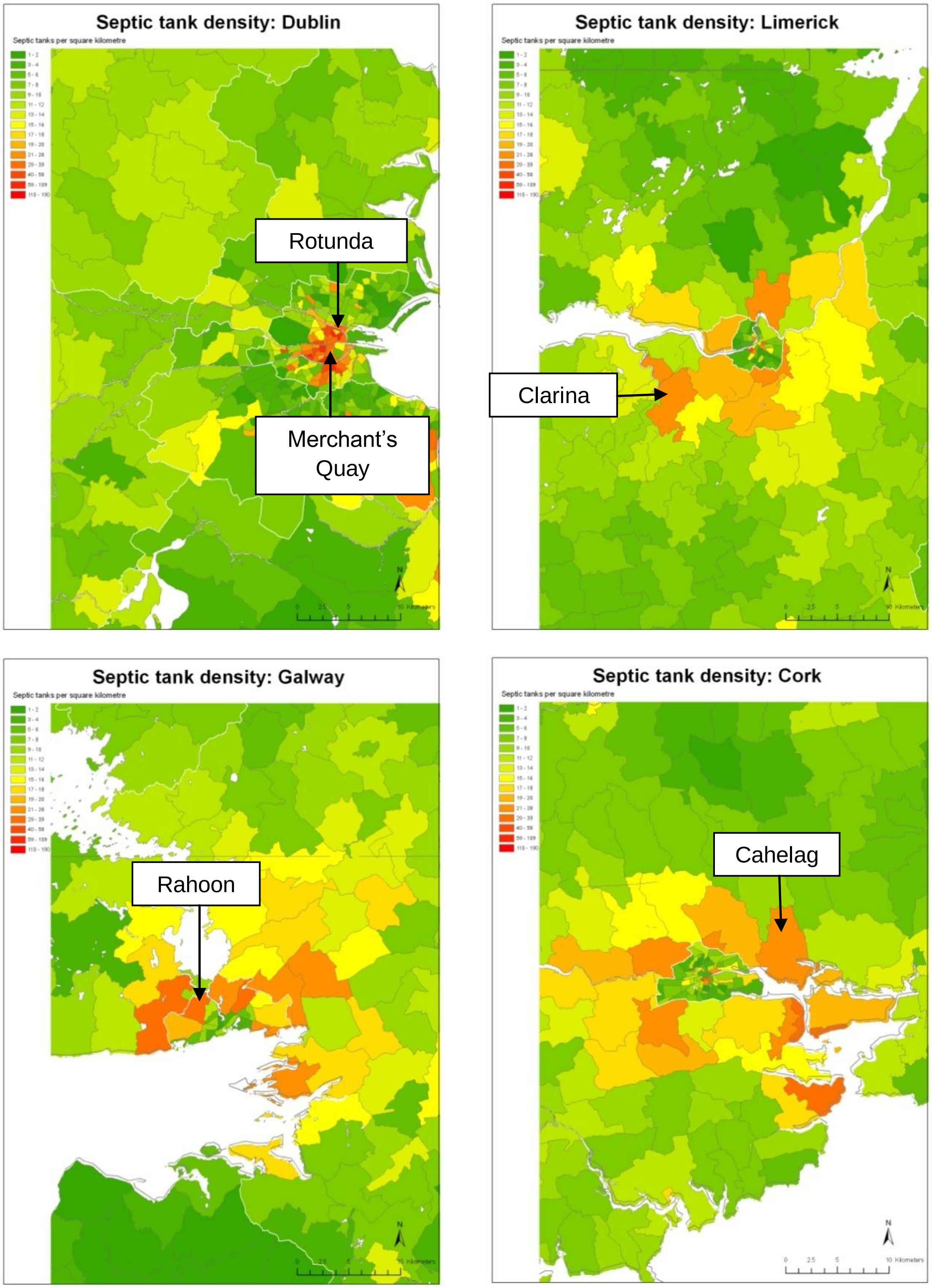


Figure 4.4 Urban septic tank densities for Dublin, Limerick, Galway and Cork.

4.5.2 Modelled precipitation impact on high risk areas

Modelled precipitation percentage increases for 2041-2060 (Figure 4.5) indicate that DJF precipitation is set to increase over the whole of the Island of Ireland to varying degrees for the period 1961-1990 to 2041-2060. Increases in the order of 15 to 20% are indicated generally, while in the west, south-west and south-east smaller areas of increases over 20% are seen. Extracts illustrating the data used in the mapping are shown in Appendix II. Given that North Atlantic storm tracks and winter continental systems prevail, this is a rational expectation. UKCIP09 outputs at the 50% probability level (Figure 4.5) tend to support these results, where increases in the region of 20% can be seen in Northern Ireland and 20-30% in south-west Wales.

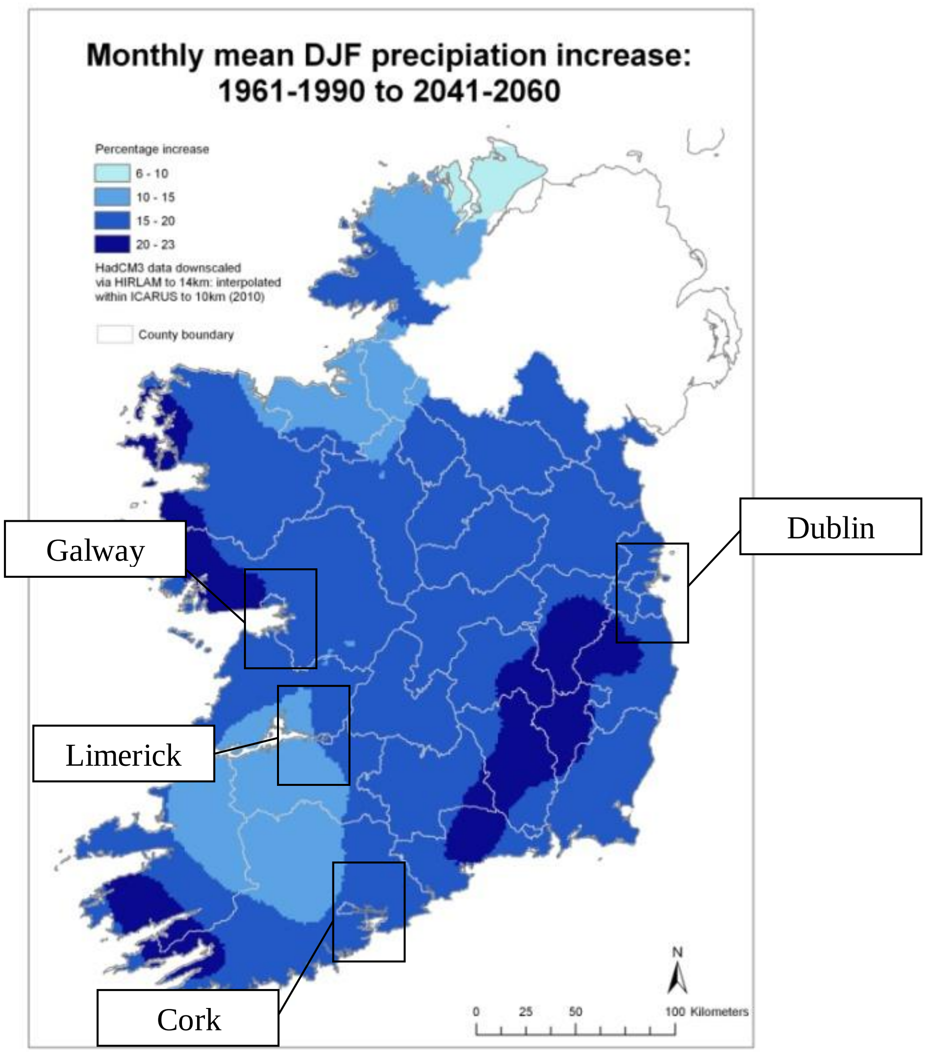


Figure 4.5 Projected precipitation increase for the period 2041-2060 over the 1961-1990 baseline.

However, due to margins of error inherent in modelling the increases cannot be viewed as a climatological forecast. They must be seen as a significant yet general indicator of projected increases in precipitation nationwide. It is reasonable to suggest therefore that all septic tanks will be impacted in the future by increased winter precipitation, thereby making adaptation the key to maintaining groundwater quality, meeting WFD objectives and retaining land for construction purposes.

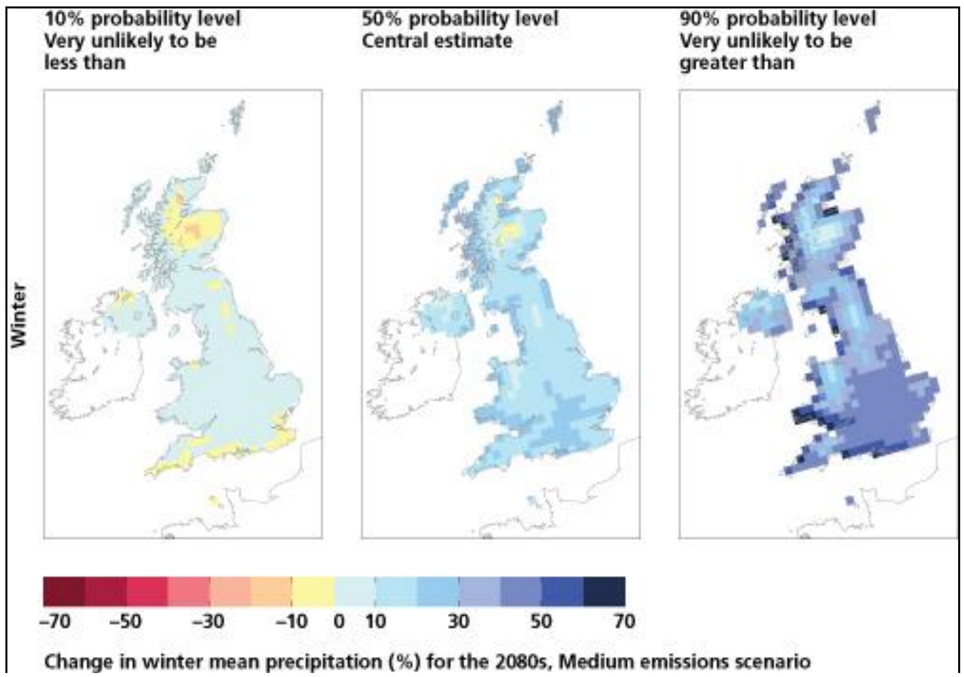


Figure 4.6 UKCIP09 winter scenarios for 2080 (UKCIP09).

The principal areas identified as presenting the highest risk in the context of STD: Cork, Galway, Limerick and Dublin, will experience increases in DJF precipitation of between 10% and 20% (refer back to Figure 4.5). In addition, they are identified by the WFD as being areas at risk of not achieving groundwater ‘good status’ by 2015 (Figure 4.7). Dublin is classified as ‘At risk’, while Cork, Galway and Limerick fall mainly into the ‘Probably at risk’ category. WFD methodology was based principally on chemical and quantitative status of water bodies, but it is important to observe that the areas of higher risk also correlate with the areas of highest septic tank density. The link between septic tank density and WFD risk assessment is circumstantial at this juncture, but nonetheless could act as a starting point for further investigation in this field.

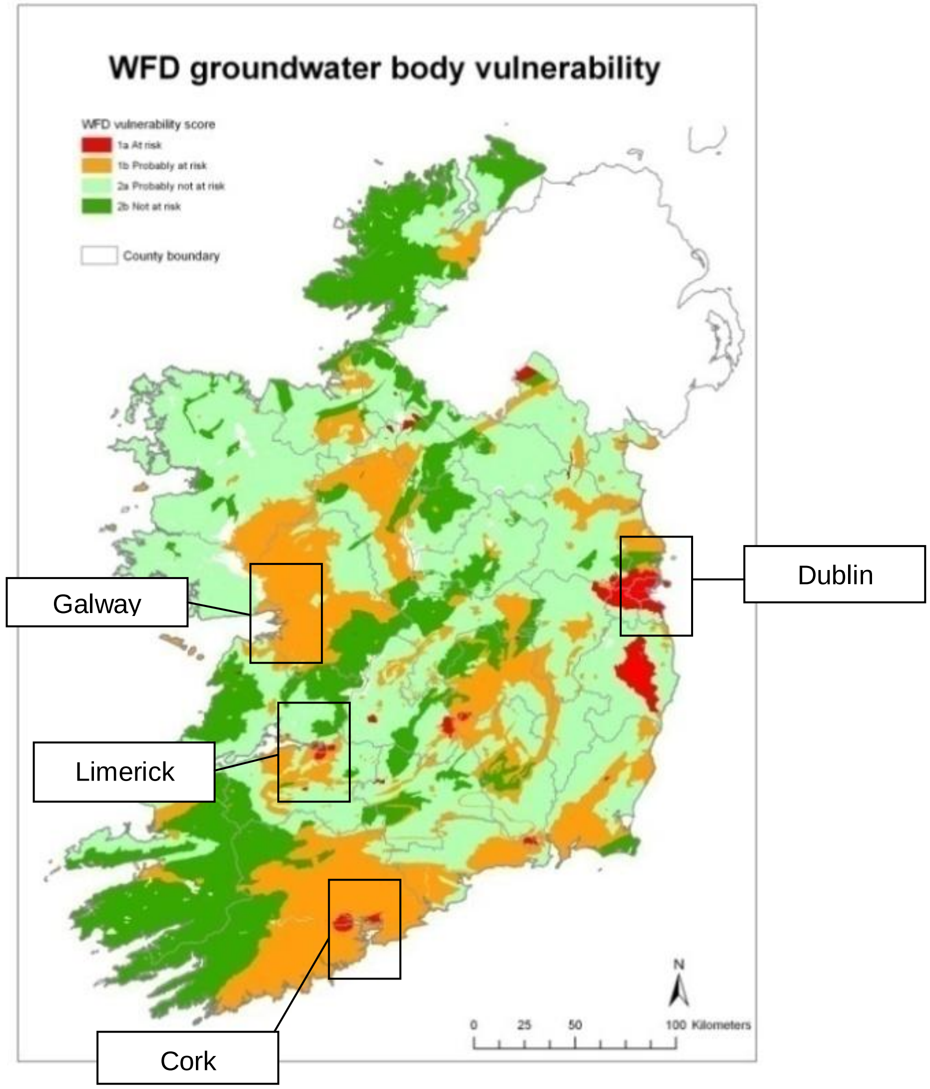


Figure 4.7 Water Framework Directive national groundwater vulnerability assessment.

While the results of this section point to high population zones as being the principal areas at risk, it is important to note that many other areas of groundwater vulnerability exist. Although septic tank density at ED level is a good indicator of potential vulnerability, numerous other factors need to be taken into account at local level. Section 4.8 will demonstrate this further. Another reason for the necessity of local scale investigation is that oversimplification of models may result in important omissions; a model result might show an area as a whole does not present a risk, yet individual sites might prove to be sources of contamination (Kaplan, 1987).

4.6 Results: Groundwater Vulnerability Index

A groundwater vulnerability index was created by assigning the three key groundwater vulnerability indicators a nominal vulnerability threshold. The indicators are septic tank density, modelled precipitation increase and WFD risk score. These were then summed by Local Authority area to create a vulnerability index. From the index, vulnerability to contamination was inferred and mapped.

Vulnerability thresholds proposed are presented in Table 4.1. The vulnerability threshold for septic tank density is $16/km^2$ as per the recommendations indicated previously (Yates, 1985). The vulnerability threshold for precipitation in the context of rising winter water tables was set at an increase ≥20% over the baseline rainfall of 1961-90. The figure of 20% can be considered appropriate as evidenced by use in other studies. For example, Wilby (2007) suggested a 20% sensitivity allowance for daily rainfall and peak UK river flow volumes to account for climate change, while Fitzgerald (2007) suggested that a safety factor of 20% on rainfall depth be incorporated in the face of scenario uncertainty. The threshold for WFD risk scores is set at the highest marker: 1a, significant risk of not achieving good status.

Table 4.1 Vulnerability Thresholds and Rating.

Vulnerability Threshold	Vulnerability Rating
Septic tank density	
STD $>16/km^2$	1
STD $\leq 16/km^2$	0
Precipitation	
Percentage increase ≥20%	1
Percentage increase <20%	0
Water Framework Directive	
EO score 1a:	1
EO score 1b, 2a or 2b	0

Utilising the WFD groundwater vulnerability assessment framework of ‘one out, all out’, the highest vulnerability rating calculated within a Local Authority’s area will be taken to be the overall score for that Local Authority. Any mitigation and adaptation strategies will thus be aimed at developing policy for each authority's worst-case scenario for a no-regrets outcome. A weighting system such as that used in DRASTIC (US EPA, 1987) to determine variable threat levels is not appropriate in this instance. The Irish data variables necessary for use within the DRASTIC framework are not all available at the requisite scale. The vulnerability index can be seen in Table 4.2 below.

Table 4.2 Local Authority Vulnerability Index derived from Vulnerability Ratings.

Local Authority	STD	Precipitation Increase	WFD Score	Vulnerability Index
Carlow	0	1	0	1
Cavan	0	0	0	0
Clare	1	0	1	2
Cork	1	1	1	3
Cork City	1	0	1	2
Donegal	1	0	0	1
Dublin City	1	0	1	2
Dublin South	1	0	1	2
Dun Laoghaire Rathd'n	1	0	1	2
Fingal	0	0	1	1
Galway	1	1	0	2
Galway City	1	1	0	2
Kerry	1	1	0	2
Kildare	0	1	1	2
Kilkenny	1	1	1	3
Laois	1	1	1	3
Leitrim	0	0	1	1
Limerick	1	0	1	2
Limerick City	1	0	1	2
Longford	0	0	0	0
Louth	1	0	0	1
Mayo	1	1	0	2
Meath	0	0	1	1
Monaghan	1	0	1	2
Offaly	0	0	0	0
Roscommon	1	0	1	2
Sligo	1	0	0	1
Tipperary North	1	0	1	2
Tipperary South	1	1	1	3
Waterford	0	1	0	1
Waterford City	1	0	1	2
Westmeath	1	0	0	1
Wexford	1	0	1	2
Wicklow	1	1	1	3

It is worth reiterating at this point that if a septic tank system is installed in accordance with the 2009 EPA Code of Practice (climate-induced water table rise notwithstanding), its potential threat to groundwater should be contained. A potentially greater threat is from legacy septic tanks installed under previous legislation and those installed in zones of low permeability subsoil.

Table 4.3: Vulnerability to Contamination inferred from Vulnerability Index.

Vulnerability Index	Vulnerability to Contamination
3	High
2	Moderate
1	Low
0	Very Low

As can be seen in Figure 4.8, the greatest vulnerability lies in a band stretching from Cork in the south west to Wicklow in the east. Under this band of vulnerability lie several productive aquifers, proximate to which is the Curragh aquifer in County Kildare mentioned previously as being high permeability, high vulnerability. Aquifers under this band are already closely monitored but should be considered as worthy for additional attention. It can be seen that the overall vulnerability of septic tanks in a Local Authority context appears more evenly distributed than an assessment based solely on STD or projected increases in precipitation would indicate. Nevertheless, it is apparent where the high risk areas lie and also where the regions most likely to support new rural construction projects are located.

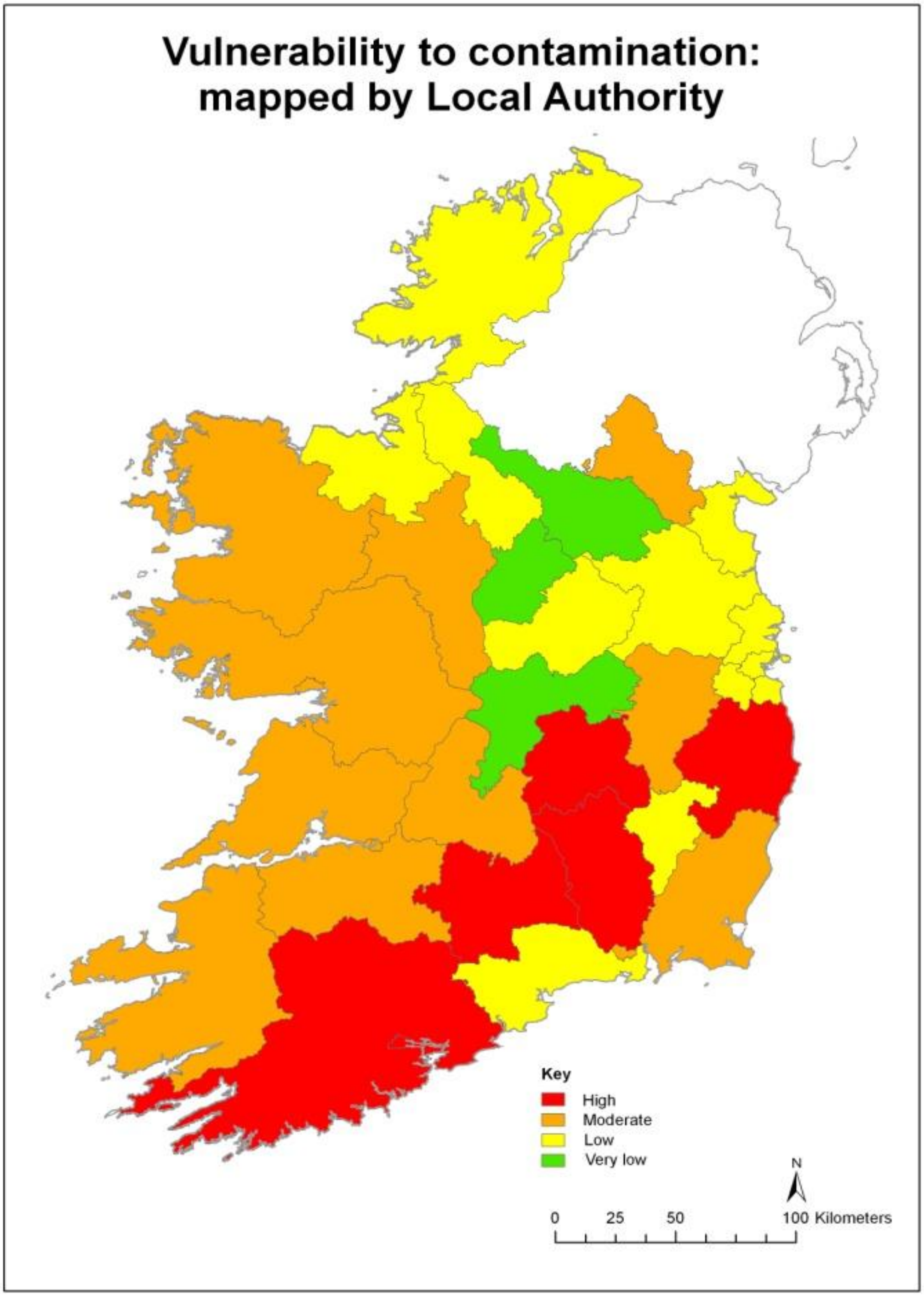


Figure 4.8 Map of Vulnerability to Contamination using the index from Table 4.3.

4.6.1.1 Limitations of the Index

A significant factor to consider at local scales is groundwater level. Even should STD be low, if the water table is high the purification zone could be in direct contact with groundwater. For example, reference to the Septic Tank Density map (Figure 4.3) reveals a STD of 12/km^2 for Athenry. Despite being below the density threshold set to indicate potential contamination, the depth to water table is only 0.85m in the winter of 2008/9 (Table 4.3). It is reasonable to suggest that the adjacent groundwater body would have a similar overall level and means that in the period indicated any septic tanks in the vicinity were probably discharging partially treated effluent direct to groundwater. Table 4.4 lists the EPA monitoring sites that have recorded depths to water table of less than four metres during the DJF period 2008/9, a period selected because all records overlap.

Table 4.3 Sites where DJF 2008/9 mean depth to water table is <4m.

Site	County	DJF 2008/9 (m)
Tully	Kildare	0.51
Kiltrough	Meath	0.65
Athenry	Galway	0.85
FBH6 - Flesk River study	Kerry	1.53
Killala	Mayo	1.55
Old Lung Bridge	Roscommon	1.84
Oldtown	Kilkenny	1.93
BNM Allen	Kildare	2.09
San Antone House	Wexford	2.10
Slieveroe	Kilkenny	2.14
Laffansbridge	Tipperary N.	2.26
Morgans	Limerick	2.37
Pollardstown	Kildare	2.45
Ballycastle	Mayo	2.53
Mayglass	Wexford	2.54
FBH1 - Flesk River study	Kerry	2.89
Ballyragget	Kilkenny	3.03
Duffy's Crossroad	Kildare	3.48
Muchgrange Fence	Louth	3.81
Cloonmagunnann	Roscommon	3.83
Bog of the Ring	Dublin	3.94

Accurate gauging of the water table depth is another factor that has to be considered. Errors could be present in the dip (distance) from the reference point (generally the top of the measuring equipment casing) to the water table. The height of the casing is approximately 0.5m to 1m. Therefore in some cases between 0.5m and 1m should be subtracted from the dip to give the true water level below ground. This means that more areas may fall into the immediate contamination zone whereby partially treated effluent is being discharged directly to groundwater. Although surveys to measure the actual groundwater level from the surface are being carried out to address this issue, they are not yet complete.

It is worth noting that the 21 groundwater level monitoring stations listed in Table 4.4 represent 33% of the 64 monitoring stations in Ireland. This is an indication of the vulnerability of the aquifers they are monitoring, thus vindicating their locations in the monitoring network. This high percentage emphasises the fact that an extension to the network is urgently required to provide effective monitoring.

While the usefulness of groundwater level measurements as an indicator of vulnerability is apparent, the low number of monitoring sites and their current distribution bias towards vulnerable aquifers renders comparisons unrepresentative at the national scale (Figure 4.9). Groundwater data is therefore not included as a factor in this research. However, it is reasonable to contend that the limited network of monitoring sites means that as yet undetected sites of high vulnerability may exist due to high water tables, representing a significant latent threat that would be compounded by increased precipitation as a result of climate change. Identification of such zones would further reduce the development capacity of available land in a construction context.

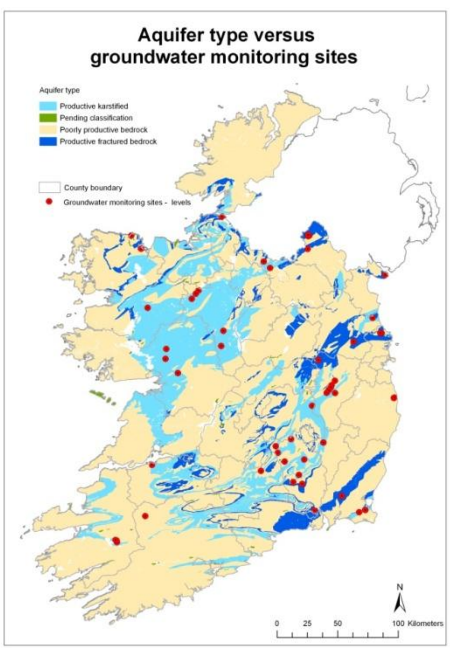


Figure 4.9 Groundwater level monitoring station locations.

4.7 Results: Exemplar study area. Athenry, Co. Galway.

4.7.1 Introduction to study area

The town of Athenry, population 3,205 (CSO, 2006) lies approximately 25km east of Galway City (Figure 4.10). It has been selected as the exemplar study area due its location above a karstified aquifer and its apparent low septic tank density. The results of this study will show that a low STD at ED level does not necessarily indicate low risk *per se*, whether at $16/km^2$ or even $8/km^2$. Septic tank density at local level, the water table height and changed precipitation regimes all contribute to risk at more refined scales. The impact on construction will then be inferred.

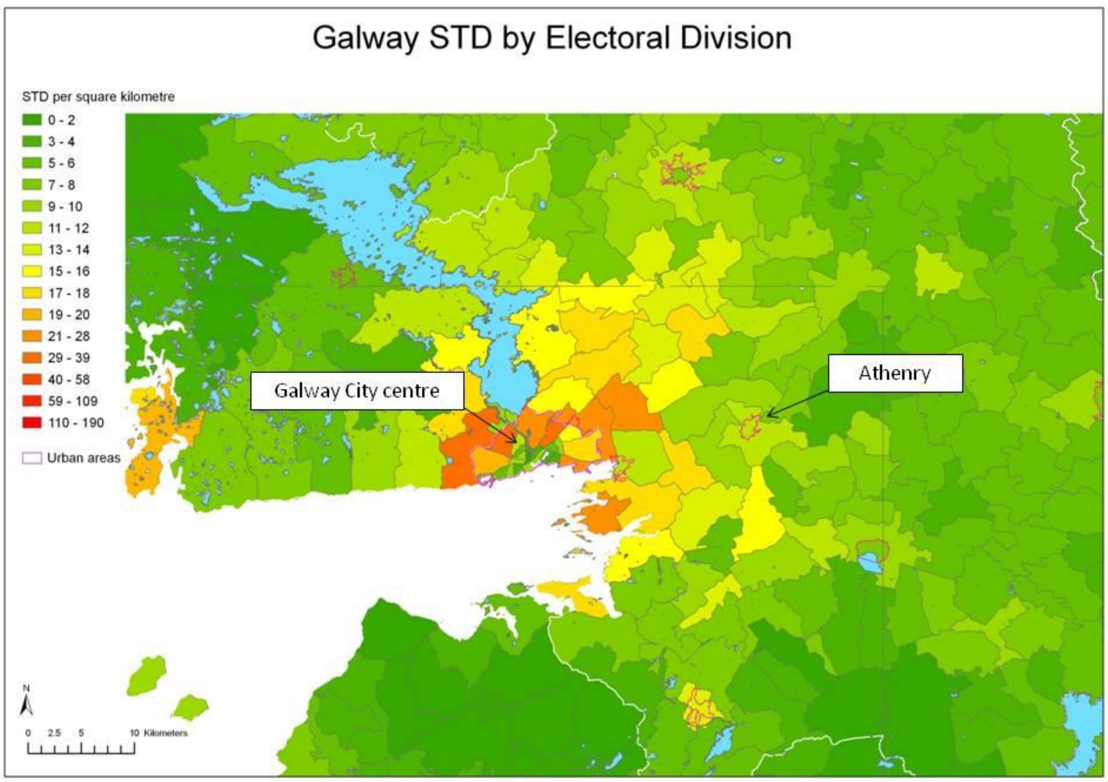


Figure 4.10 Athenry's location relative to Galway City. Note the low septic tank density at ED level.

Figure 4.10 illustrates a septic tank density of $11\text{-}12/km^2$ in the ED of Athenry. This is below the nominal level of $16/km^2$ that indicates a potential threat to groundwater. However, this is an oversimplification of the situation that exists at more refined scales.

Figure 4.11 illustrates the distribution of onsite systems surrounding Athenry, where a groundwater level monitoring station and local wells are also shown. As can be seen, there is a significant clustering of systems that results in higher densities locally than ED level density analysis would suggest.

Although septic tank density is an important component of groundwater vulnerability, depth to water table is another. Even if STD is low, if the depth to groundwater is low a substantial barrier to contamination does not exist. Unfortunately, this is the case in Athenry. In winter 2008/9 the mean depth to water table at the monitoring station in Figure 4.11 was 0.85m, well inside the minimum depth of 1.5m recommended in the EPA Code of Practice (Keegan & Clinton, 2009). As highlighted earlier in section 4.7 this means that septic tanks in the vicinity were probably discharging partially treated effluent direct to groundwater in this period.

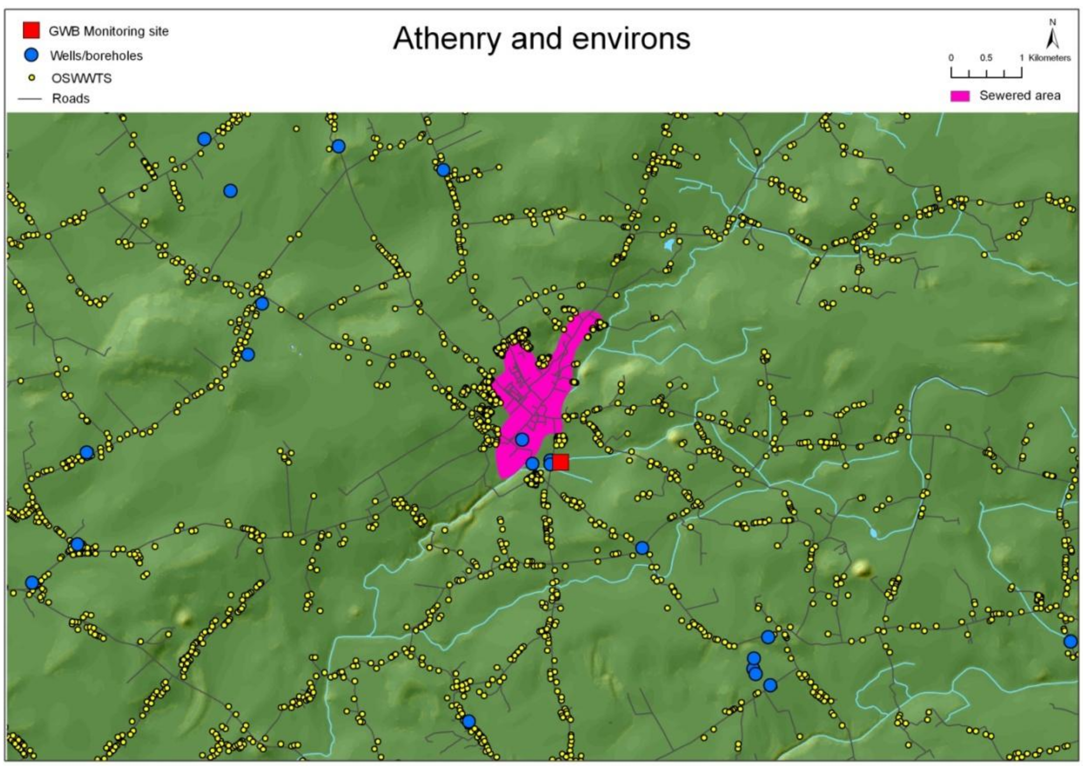


Figure 4.11 The environs of Athenry showing onsite wastewater treatment sites, wells and groundwater monitoring station.

4.7.2 Localised septic tank cluster distribution, well location and aquifer type

Figure 4.12 illustrates the distribution of onsite wastewater treatment systems (OSWWTS) around Athenry, most of which can be assumed to be septic tanks. It is apparent that the systems mirror the road network and ribbon development is evident. Two principal locations are identified for brief discussion; the townlands of Boyhill and Newtown. They have been selected due to their proximity to the groundwater level monitoring station and the presence of wells in each townland. Although it can be seen that there are four wells within *c*.1km of Athenry town, these are not discussed. They represent the principal supply for Athenry and it is therefore assumed that they will benefit from some kind of treatment before piping to households. Wells further afield are less likely to benefit from such treatment.

Boyhill is approximately 2km from the groundwater level monitoring station and Newtown approximately 4km. They have STDs of $18/km^2$ and $13/km^2$ respectively. Each townland also features a well. Boyhill's is designated as a group water scheme while Newtown's is designated 'domestic use only'. The key aspect in these examples is the STD and high water table. The high water table is assumed based on the high water table levels found locally in Athenry. In this case it can be argued that due to the local STD and high water table the water drawn by the wells in Boyhill and Newtown will be extremely vulnerable to partially treated effluent being introduced directly to groundwater by local septic tank clusters. The implication for consumers of such water is that they will be exposed to significant health risks.

There are other areas of note in Figure 4.12. For example, the townland of Castle Lambert features a STD in the order of $29/km^2$ and contains two wells supplying group water schemes. Similarly, the townland of Palmerstown has a STD of $39/km^2$ and features a well supplying a group water scheme. Values of STD such as these put these locations firmly into the high risk of contamination category. Without the local scale analysis described herein, such areas of high vulnerability may be difficult to identify.

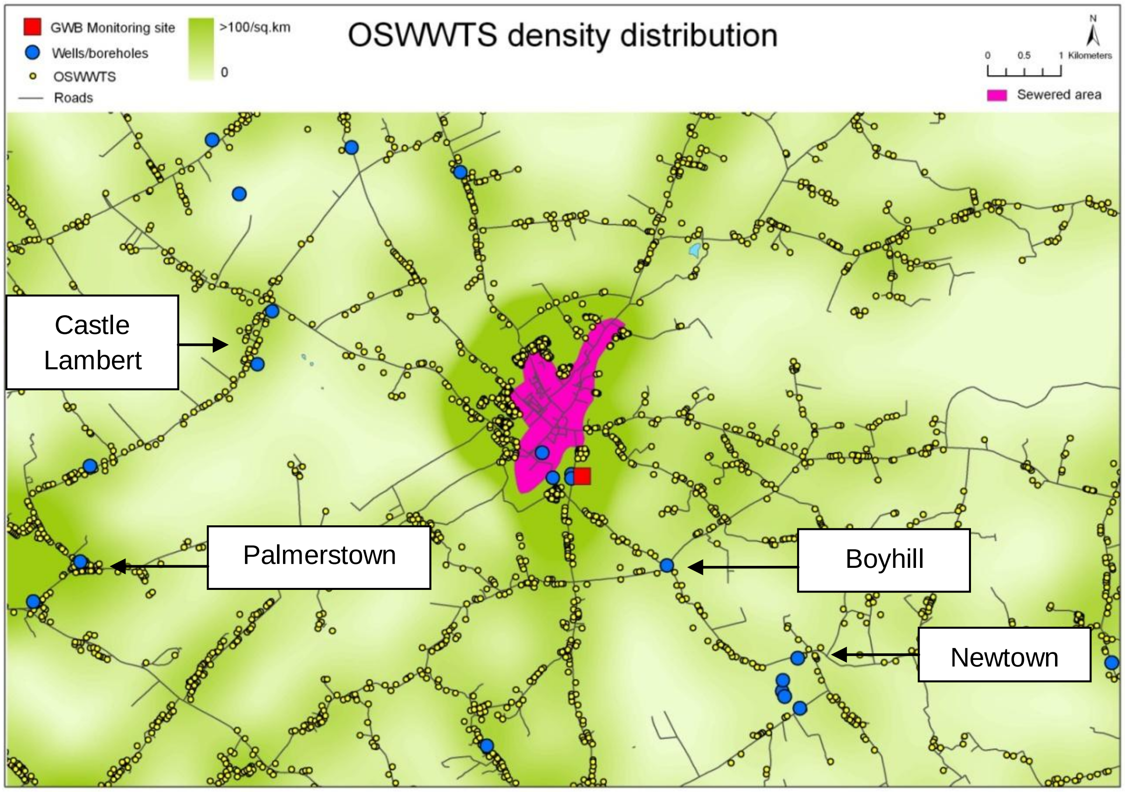


Figure 4.12 Localised septic tank cluster distribution, well location and aquifer type.

In the context of the groundwater bodies lying beneath these wells the distances involved are small. Figure 4.13 overleaf shows that all the wells in the environs of Athenry are located above just one aquifer. More importantly perhaps, the aquifer is categorised as ‘regionally important - conduit flow’ meaning that fissure permeability dominates. As such, lateral and vertical groundwater flow is relatively fast and rapid mixing can occur. In these circumstances pollutants are transported quickly and contamination is spread over a wide area.

Moreover, surface waters in some areas can receive a significant proportion of their volume from groundwater discharge. A groundwater contribution of between 50-100% is not atypical and means that groundwater discharge has a big influence on surface water quality (Craig & Daly, 2010). Thus, surface water quality may also be compromised as a result of groundwater contamination.

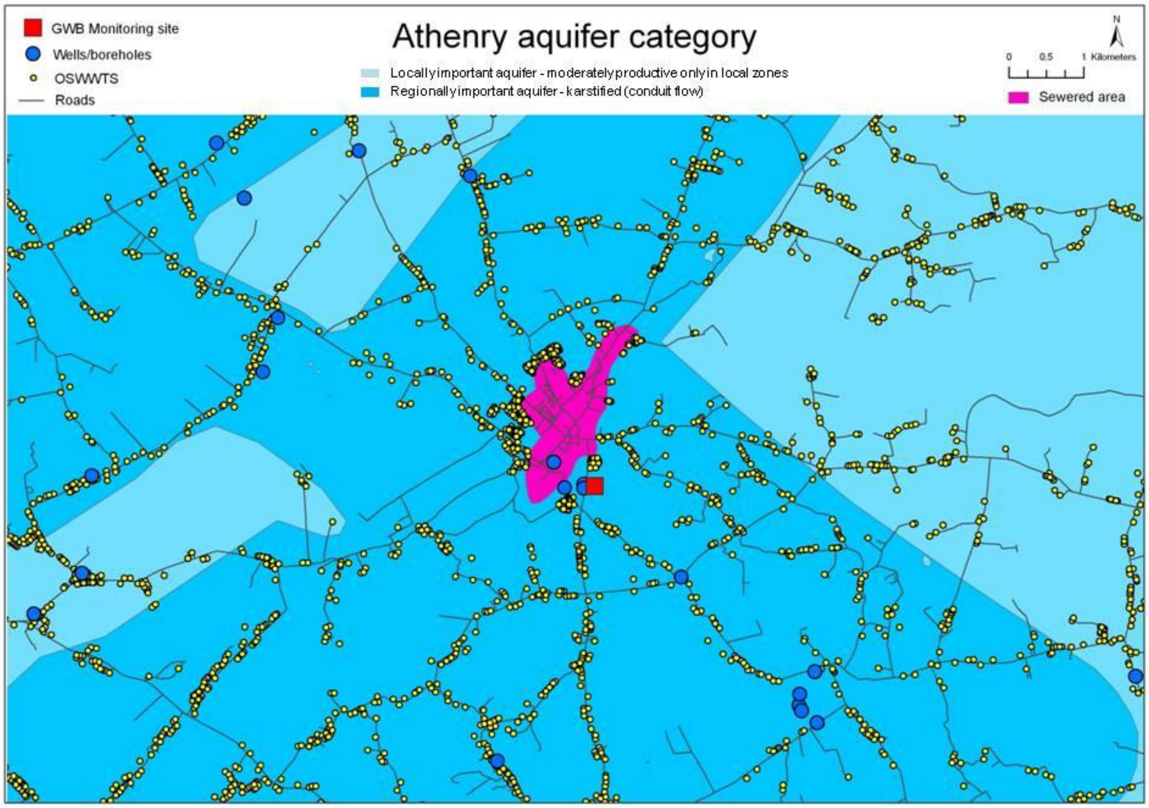


Figure 4.13 Aquifer category.

The existing situation in Athenry is likely to become exacerbated by changed precipitation regimes as a result of climate change. As indicated in section 4.6.2 the western parts of the island of Ireland are likely to experience increases in winter rainfall of up to 20%. This could have severe ramifications for areas such as Athenry whose water tables are naturally high and located in karstic environments. Precipitation will percolate rapidly and reach the water tables relatively quickly. As a result, water tables will rise and the risk of intrusion into septic tanks' purification layers increases. Contamination in such cases is likely to be widespread. As a corollary to the findings presented here the WFD groundwater body chemical status map (Figure 4.14) shows Athenry as located in one of eight areas classified as 'poor status'.

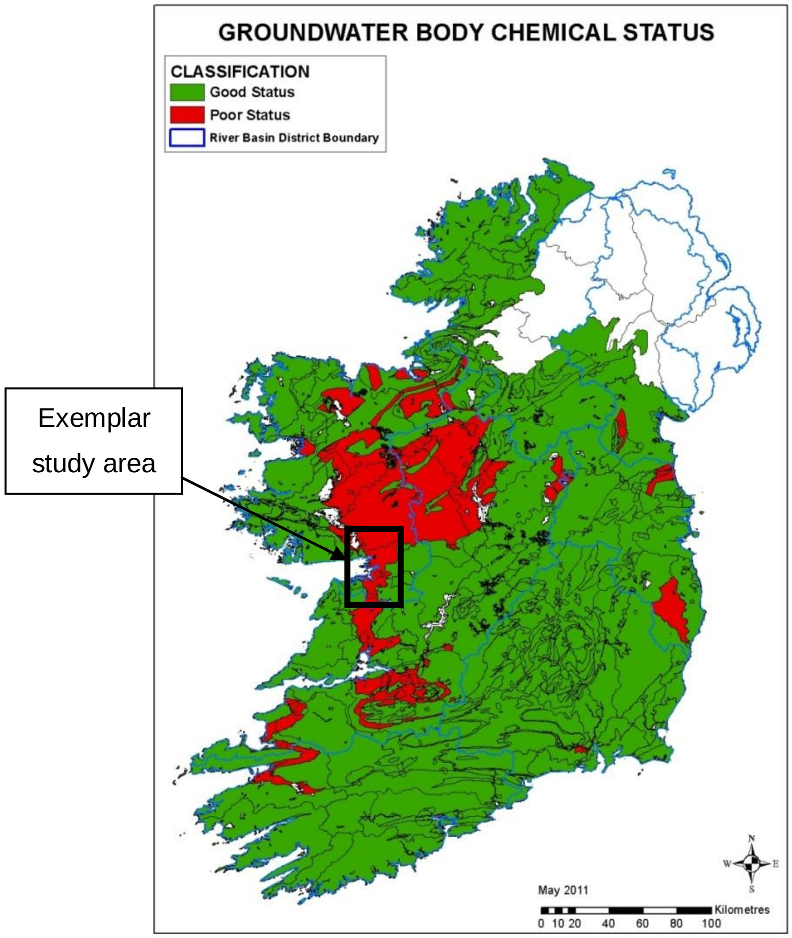


Figure 4.14 WFD Groundwater chemical status, May 2011 (Source: EPA, 2012).

The principal implication for construction in areas such as Athenry is that it will be more difficult to obtain planning permission for new-builds. Supporting this conclusion, the Sustainable Rural Housing Guidelines state that new development should be sited where wastewater treatment and disposal can be provided, avoiding sites ‘prone to extremely high water tables […] or where groundwater is particularly vulnerable to contamination’ (DEHLG, 2005: 36). This is reinforced by Circular Letter PSSP 1/10, which states that the consideration of wider planning issues such as onsite wastewater treatment concentrations should result in a ‘precautionary approach’ being adopted by planning authorities (DEHLG, 2010: 4). An Bord Pleanála is already supporting the refusal of permissions in vulnerable areas of Galway such as Kinvara where, for example, ‘the proposed development would […] subject the water table to potentially life-threatening contamination' (Carolan, 2010: 1).

4.8 Summary, recommendations and conclusion

4.8.1 Summary

The maps illustrating septic tank density, precipitation increase and vulnerability to contamination highlight the threats to groundwater quality. Although resolution of the maps ranges from local to ED to a relatively coarse county scale and the Groundwater Vulnerability Index is a preliminary indicator, a reasonable identification of vulnerable areas can be made for the purposes of assessing and instigating appropriate adaptive actions.

A policy measure that is likely to have an impact on construction is the tightening of planning regulations. It is already recommended that a precautionary approach be adopted by planning authorities (Circular Letter PSSP 1/10), and the density maps and groundwater data lend support to this protective strategy. Nonetheless, the spatial situation is more complex than the maps would suggest. For example, local authorities sharing the same aquifer but with different degrees of exposure to groundwater contamination may not necessarily decide on complementary strategies with which to address the problem. Divergent strategies may be required to address their particular circumstances, which could hinder integrated mitigation and adaptation measures. Open and frank dialogue must therefore be maintained not only between construction actors and local authorities, but also between the local authorities themselves.

The issue of onsite wastewater treatments systems in the context of climate change and construction has already impacted the legislative arena. The European Court of Justice ruled on 30 October 2009 that, under the terms of Articles 4 and 8 of Council Directive 75/442/EEC of 15 July 1975, Ireland had failed to fulfil its obligations with regard to disposal of domestic wastewater through septic tanks and onsite wastewater treatment systems. Despite the Minister for the Environment, Heritage and Local Government's assertion that he intends 'bringing proposals to Government to address these matters later on this year' (Dáil Questions, 8 July 2010), the European Commission observed on 24 November 2010 that a year after the ruling no legal measures had been adopted. Eventually the requisite legislation was published in the form of the Water Services (Amendment) Act 2012 although its practical application is not yet complete.

In the context of further work in the area of septic tanks, climate change and construction, it is important to note that vulnerability arises not only from climate-related impacts but also from underlying socio-economic changes (Lorenzoni *et al*, 2000). Nevertheless, the quality of Ireland's water resources is considered 'a key national asset' (DEHLG, 2010: 1) and should therefore remain one the government's core foci in its continuing assessment of vulnerabilities due to climate change.

4.8.2 Recommendations

The construction industry may be an autonomous sector but the inter-relationship between the industry and local authorities is important. Increases in areas vulnerable to groundwater contamination will place a premium on land suitable for development and the pressure on planning departments will increase as developers seek permission for new-builds. Thus, planners will have a fundamental role in future construction activities. It is therefore essential that building control in local authorities is exercised and that regulations are enforced, and that the construction industry recognises the necessity and legitimacy of such actions. A mutual understanding of the issues, and close coordination between the industry and local authority departments, is required if groundwater is to be protected adequately.

Irish rural planning has been seen as one of the most benign regimes in Europe. Moreover, the planning process has focused to a large extent on town planning and maintained a 'laissez-faire approach' in rural areas (Keaveney *et al*., 2004: 5). Evidence for this can be seen in the significant ribbon development mapped in the exemplar study area of Athenry. Such issues were highlighted in the Final Report of the Mahon Tribunal and have resulted in a shifting of focus onto making planning more transparent and open (Hogan, 2012). This shift needs to be cemented in order for planning practices to be monitored and planning decisions to be effective in mitigating for potential groundwater contamination.

Past planning practices and construction geographies have contributed to a situation whereby groundwater in vulnerable areas is threatened by domestic wastewater from rural housing. Increased winter precipitation as a result of climate change will potentially exacerbate this situation. As planning regulations become stricter to meet this threat the onus for groundwater protection will be transferred onto planning departments, who have 'a key role in making decisions on the suitability of sites for development' (Keegan & Clinton, 2009: 53). Planning departments must therefore be seen to be supported by bodies such as An Bord Pleanála as pressures due to developer demand increase.

In summary, recommendations as a result of this research are:

- Dwellings should be connected to mains sewerage where practicable.
- Planning practice must follow planning policy in terms of one-off housing.
- Open dialogue between construction actors and local authorities must be maintained when assessing site suitability.
- Onsite wastewater treatment system density must be taken into account when assessing sites for suitability.
- Local analysis is the key to identifying local vulnerabilities; increased research at local scales nationwide is required.
- Mechanisms for the enforcement of the Water Services (Amendment) Act 2012 should be initiated.
- The groundwater monitoring network for quality and levels should be extended to cover aquifers anticipated to become vulnerable as a result of climate change.

4.8.3 Conclusion

At first sight, the issue of domestic wastewater management in a climate change context appears to have little relevance to the construction industry. However, this research has shown that although removed from the direct consequences of climate change the construction industry will be impacted by two themes: new construction geographies; and new opportunities resulting from implementation of the Water Framework Directive.

New settlement geographies will become evident as a result of more restrictive planning guidelines. Concerns over the impact on groundwater from septic tanks means that planning guidelines are likely to apply much stricter conditions to one-off housing. A precautionary approach is already being adopted. Additionally, the sustainability of rural settlements may suffer as populations increase and migrate due to lack of housing prospects. This runs somewhat contrary to the aims of the Government’s latest housing policy, part of which is to ‘advance the implementation of actions for the development of rural communities’ (DECLG, 2012a: 27). It would appear however that there will be a contraction of construction geographies in rural environs and a consequent shift to concentration in peri-urban zones. The new focus is defined in part by the increasing vulnerability of groundwater to septic tank effluent, which is in turn driven by changed precipitation regimes.

The EU Water Framework Directive target of good status by 2015 will act as a catalyst for construction activity. Currently 46% of 529 urban wastewater treatment plants fail to meet national and EU standards, while eleven large urban areas do not have the requisite secondary treatment in place (EPA, 2012b). In two areas, Bray and Ringaskiddy, this measure is more than ten years overdue, while Arklow still lacks even a primary sewerage system. Areas where seasonality is prevalent is also a concern. For instance, tourist influxes during summer in Clifden, Co. Galway, overload the existing treatment system, causing potential pollution issues. Moreover, as onsite treatment becomes unviable in vulnerable areas due to increased winter precipitation, more pressure will be put on wastewater treatment plants generally in terms of capacity. The clear implication is that further investment in the construction of treatment plants is required if wastewater infrastructure is to be completed in time to fulfil WFD aims. Issues with respect to septic tanks indicate further urgency in this regard.

The upgrade or replacement of below-standard septic tanks could mean a substantial amount of work for construction companies. An existing example of this adaptation measure can be found in the Programme for Government 2007-2012 where the upgrade or replacement of septic tanks over 15 years old was proposed (Department of the Taoiseach, 2007). Adopting such measures and investing in infrastructure to meet EU targets for water quality will provide yet more opportunity for the construction industry, although due to the limited retrospective scope of regulatory enforcement it is difficult to estimate a figure. As an indicator of water quality's importance in England and Wales however, capital expenditure on sewerage services is set to exceed £12 billion (€15 billion) between 2010 and 2015 (Hall *et al.*, 2012). Unless Ireland meets the standards laid down in WFD 2000/60/EC by according Irish water quality similar precedence, the Irish government will face financial penalties post-2015.

This research has demonstrated for the first time the potential shift in geographies of construction due to wastewater treatment and climate change concerns. It also brings a new decision support tool to the fore for use by planners and bodies such as water quality monitoring agencies. This research has also demonstrated for the first time opportunities that may lie ahead for the construction industry in this area as a result of climate change. Until now, the focus had been on increasingly restrictive planning and a contraction of the industry in the rural environment.

CHAPTER 5
THE BUILDING REGULATIONS

5 INTRODUCTION

The evaluation of wind-driven rain and domestic wastewater management in a climate change context has illustrated the potential impacts and outlined vulnerabilities and opportunities. Possible mitigation and adaptation measures have also been examined at both the national and regional scale. Without a legislative framework, however, the recommendations remain purely advisory. A review of the Building Regulations 1997-2012 is therefore required to investigate the regulations relevant to wind-driven rain and wastewater management, and for which modifications can be proposed to address the issues raised. As a matter of course, a comprehensive evaluation of the Regulations will also identify other aspects that may be relevant to the construction industry in the context of climate change. These aspects will also be investigated and modifications recommended where appropriate.

The purpose of the Building Regulations is to provide for 'the health, safety and welfare of people in and around buildings' (DECLG, 2012d: 1). The Regulations are performance based, and as such set out the statutory minimum building standards and performance requirements that must be achieved. They comprise twelve separate Parts, categorised A to M (Table 5.1). There is no Part I. A Technical Guidance Document (TGD) accompanies each of the Parts. TGDs set out how the legal requirements of each individual Part can be achieved in practice. If followed, they are considered *prima facie* evidence of compliance with the Regulations. Observance of the Building Regulations is governed by the Building Control Regulations 1997-2009. These Regulations are crucial to the proper implementation of the Building Regulations and will therefore also be assessed as part of this study.

Table 5.1 The Building Regulations, Parts A to M.

Part	Competence
A	Structure
B	Fire Safety
C	Site Preparation and Resistance to Moisture
D	Materials and Workmanship
E	Sound
F	Ventilation
G	Hygiene
H	Drainage and Waste Water Disposal
J	Heat Producing Appliances
K	Stairways, Ladders, Ramps and Guards
L	Conservation of Fuel and Energy
M	Access and Use

The Building Regulations are expressed in general statements of intent or broad functional requirements rather than specific methods of construction. For example, Part L, Conservation of Fuel and Energy, states that:

> 'A building shall be designed and constructed so as to ensure that the energy performance of the building is such as to limit the amount of energy required for the operation of the building and the amount of carbon dioxide (CO_2) emissions associated with this energy use insofar as is reasonably practicable.'
>
> (DECLG, 2011a: 4.)

Further parts of the Regulations indicate how this may be achieved, but it is the TGDs that set out how owners, builders, developers and designers can achieve compliance with the Building Regulations in practice. Although TGDs cover the core practicalities regarding the twelve parts of the regulations, they also refer to other documents for more detailed information on some parts of the guidance.

The Building Regulations and TGDs are maintained by the Department of the Environment, Community and Local Government (DECLG). They are reviewed periodically in response to developments and issues within the construction industry, and are re-published as required to take into account the latest research and information. For example, a revised TGD A (Structure) was published in 2012; the revised TGD L (Dwellings) was published in late 2011; there is an upcoming public consultation on TGD E (Sound); TGD B (Fire Safety) is currently under review; the snow map of Ireland has been revised as part of an amendment to IS EN 1991-1-3 'General Actions, Snow Loads', based on the latest information; and TGD G (Hygiene) has been reprinted to include updated guidance on aspects such as insulating pipe work for water tanks. The Building Regulations Advisory Body (BRAB) advises the Minister on such matters and recommends either endorsement of revisions or further review.

Another regulatory aspect for consideration is that represented by the Structural Eurocodes. The Structural Eurocodes are a suite of ten harmonised mandated standards divided into 58 parts. They are voluntary codes, designed to provide a common framework for the structural design of buildings and civil engineering works and a means of demonstrating compliance with National Regulations. They are also intended to eliminate technical obstacles to internal trade within the EU. Localised conditions are acknowledged in the form of Nationally Determined Parameters (NDPs). NDPs are left open for national choice and are contained in National Annexes in which supplementary information may also be given. All Irish Standards conflicting with Eurocodes and National Annexes were withdrawn on 31 March 2010.

5.1.1 Policy Context

To evaluate the Building Regulations 1997-2012 in the context of climate change, two policy contexts must be considered: housing policy, which states the objectives pertaining to construction; and climate policy, which states the objectives pertaining to climate change.

The 'High Level Objective' of current housing policy is to give all households 'access to good quality housing' (DECLG, 2012a: 13). In a construction context, better quality housing will depend not only on materials and workmanship but also on developing building standards that specify greater resilience to a potentially harsher environment. As Sanders and Phillipson observed, 'It is important that a mechanism for incorporating uncertain information on future climates is developed to allow Standards to remain relevant' (Sanders & Phillipson, 2003: 220).

While the Government's housing policy is focused on build quality, its climate policy is focused on emissions and the use of renewable energy. This policy complements the EU's climate and energy legislation that aims to achieve the 20-20-20 targets agreed upon by members in 2007. The *National Climate Change Strategy 2007-2012* provided the national policy framework for ensuring that Ireland met its greenhouse gas emissions reduction target in this regard. The emissions narrative is continued in the National and Economic Social Council's Interim Report to the DECLG, which stated that the Government's 'Overall Aim' should be the adoption of 'a national policy position on transition to a low-carbon future' by the end of 2013 (NESC, 2012: 29). It is within these two policy contexts, good quality housing and a trajectory towards a low-carbon future, that the Building Regulations 1997-2012 will be evaluated.

5.1.2 Why modify the Building Regulations for climate change?

Buildings constructed under the current Building Regulations may not have the required resilience for future climate regimes. The Regulations may therefore require modification. As Smith points out, 'Creating volume housing that is genuinely future-proof will require a radical shift in design standards compared with current building regulations' (Smith, 2010: 37). In a construction industry context however, the European Commission concluded that autonomous implementation of such climate-related modifications, whereby the industry would assume responsibility for taking the appropriate actions, was not a viable option due to the probability of sub-optimal measures (CEC, 2009). Moreover, in an industry where contracts are awarded typically on the basis of lowest cost (Sorrell, 2003), financial constraints and investor profit-maximisation represent significant barriers to climate change adaptation (Sisson *et al.*, 2007). Indeed, Morton (2010) noted that clients associated environmental considerations with increased cost and would only bear them if obligated to do so by regulations. It can be seen therefore that modifying the Building Regulations is important for ensuring that construction professionals design for climate change. Not only are Building Regulations one of the most obvious mechanisms for adapting the built environment to climate change (Lowe, 2003), but they are also a cost-effective way to improve performance (Stern, 2007). That said, unless the Regulations are enforced it is somewhat immaterial whether or not they are modified. The failure to enforce existing regulations has already resulted in significant wind and storm damage in many cases (Lowe, 2003). For this reason, the Building Control Regulations will also be assessed.

Despite the compelling argument for regulatory review, political realities represent a considerable barrier. Political horizons, at around 5 years, are considerably shorter than climate change horizons. Indeed, the introduction of climate legislation in the form of the Climate Change Response Bill 2010 had already been postponed 'due to the political situation' (Comhar, 2010: 2). Although the Bill's primary purpose was with regard to meeting European emissions targets, it still contained important sectoral policy aims. In addition to emissions considerations, plans were requested from Ministers at sector level for the purpose of 'enabling the State to adapt to the effects of climate change' (Climate Change Response Bill 2010: 7). It is reasonable to assume that the construction sector would have been the subject, in some form, of such a sectoral plan. Although the Bill was withdrawn by the present Government, a new commitment to the introduction of climate legislation by the end of 2013 was announced in January 2012 (DECLG, 2012a). The fact that such legislative discourse is taking place in a climate change context reinforces the argument for amending the Building Regulations from a similar perspective.

The argument for modifying the Regulations may be compelling but it can be difficult to reach consensus. In the context of higher wind speeds for example, the Irish Building Standards office consulted the British Standards Institute committee regarding amendment of the Eurocode National Annex. In aiming to re-assess design wind load, the Irish Standards office referred to BRE's Digest 499, which suggested that design wind speeds could be increased by 10% with only minor increases in construction costs (Saunders, 2006). Amending the Annex was deemed unnecessary however by the British Standards committee, which gave the reason that peak wind speeds had not increased over time despite the increased frequency of such winds (Neary, 2010). This was despite recommendations having already been made for adaptation in the UK that included using roof fixings that would withstand 'at least 5% higher wind loads in the south and 10% higher in the north' (Graves & Phillipson, 2000: 47). Although consensus is hard to reach, and the risk of over-adaptation is a concern, it has been argued that the extra cost associated with designing to higher standards would be relatively modest compared with the cost of retrofitting adaptation measures (Gething, 2010). This lends weight to the argument for modifying the Building Regulations in a climate change context, and places the onus on the relevant authorities to reach agreement. This lends further exigency to a specific assessment of the Building Regulations in the context of climate change.

5.1.3 The Irish Building Regulations and climate change

Reviews of the Building Regulations in the context of climate change have not been conducted in Ireland. The UK however have been researching and publishing in this area for over a decade. For example, the UK's Building Research Establishment review in 2000 concluded that seven building regulations would be 'most affected' by climate change and that six would be 'affected' (Graves & Phillipson, 2000: 42). It also found that 112 British Standards could be 'affected'.

Further to this and other studies, in 2010 the British Standards Institute (BSI) commenced scoping the impact of climate change on its entire range of standards and regulations, although it will take 'some time' for the analysis to be completed and published (Gething, 2010). Similar research is also being carried out in Scotland, where the Building Standards Division (BSD) is currently evaluating regulations concerning the air-tightness of buildings, the effects of wind-driven rain on external building fabric, and upgrading options available to older structures to improve energy efficiency (BSD, 2012).

Indeed, the BSD is taking a prominent climate change stance regarding regulatory reviews, in that ‘the ability of buildings to adapt to changes in climate are now considered during any review of the Building Regulations’ (BSD, 2012: 13). Moreover, the BSD has undertaken to review the Regulations every three years in an attempt to increase the built environment’s resilience to climate change (BSD, 2012: 20).

The Irish Government has not published a climate change-led review of the Building Regulations to date. Given that three decades of climate research indicate potentially severe impacts in the mid- to latter parts of the 21st Century, it can be argued that climate change is an important aspect to incorporate into a review of the Regulations. Even though Irish Building Regulations are reviewed continually, only historical climate data is used to inform them. They are not re-visited for at least two years to allow for meaningful evaluation following implementation, adding an even greater time lag in the climate change context. Moreover, reviews do not appear to have climate change as one of the stated objectives, as evidenced in recent Regulatory Impact Assessments that will be discussed briefly in the following section. This adds urgency to the publication of a contemporary evaluation of the Irish Building Regulations with respect to climate change, which this research aims to fulfil.

5.1.4 Regulatory Impact Assessments and their relevance to climate change

The role of a Regulatory Impact Assessment (RIA) is to assess whether the regulation is likely to achieve its objectives. However, in contrast to the UK’s regulatory focus on climate change, it is apparent that climate change assessment is not a stated objective with respect to Irish regulatory review.

For example, the key objectives of the RIA for the Amendment to Part A, Structure (2010), were:

- to reference the Structural Eurocodes through Building Regulations and guidance;
- to maintain levels of structural safety to protect people in and around buildings;
- to further the achievement of sustainable development.

(DEHLG, 2010: 4)

A consideration of potential climate change impacts with respect to the regulation is not listed. Although the main driver for this review of Part A of the Building Regulations arose from the implementation of the Structural Eurocodes in March 2010, the opportunity nevertheless existed within this framework for a simultaneous assessment in the context of climate change. The opportunity was taken to include the objective 'to further the achievement of sustainable development', a construction strategy highlighted in the literature review as being considered the most important development in the industry to date. Yet the opportunity was not taken to address climate change, which is arguably one of the most important aspects that will impact structures in the future. Indeed, climate change will have a significant impact on the second objective, 'to maintain levels of structural safety to protect people in and around buildings'.

The omission of an overt reference to climate change is a trend observed in recent RIAs. For example, adaptation to climate change was not listed as an objective in the RIAs for Part L (Conservation of Fuel and Energy, 2010) or Part H (Drainage and Waste Water Disposal, 2009). This perhaps reflects the current climate policy of focusing on emissions reductions. That said, while some Parts of the Regulations are indeed relevant to emissions, the absence of climate change references with respect to Parts such as Structure is noteworthy.

5.2 Methodology

The methodology employed herein is analogous to that published in Garvin *et al* (1998), albeit in an Irish context. Each of the twelve Parts of the Building Regulations will be described separately. Temporally, the analysis will assess regulatory evolution where pertinent and any subsequent amendments. This is to ascertain whether climate change considerations have been incorporated in response to emerging climate change research over the last two decades or so. In addition, each TGD, standard and code relevant to the other areas of study in this research, wind-driven rain and wastewater management, will also be assessed. It is not feasible to analyse every code and standard that comprise full guidance for the Regulations within this study, as the numbers run into hundreds. TGD A (2012) alone calls on 67 principal Irish Standards, which in turn draw on other codes and standards.

For clarity, climate change impacts that are likely to necessitate the amendment of a Regulation, TGD, code or standard will be discussed during each Regulation's assessment. The results of each assessment, from which recommended actions for modification may be made, will be discursive. Although modifications are proposed where necessary, specific values and parameters are not advocated. Recommendation of quantitative amendments in this context requires proficiency in advanced scientific procedures and engineering, particularly where codes and standards are concerned. Such competency lies outside the framework of this research but within the provenance of the Government departments for which this research is designed. As such, proposals will be couched in general terms aimed at highlighting specific areas upon which regulators should focus. Again in the interests of clarity, modifications where suggested will be noted at the end of each Part’s assessment.

After the Building Regulations have been evaluated, the Building Control Regulations will be discussed. Special attention will be focused upon current measures for Building Regulation enforcement, given that, as noted previously, the enforcement of current legislation is important in attaining an acceptable degree of resilience. Once the Building Control Regulations and Building Regulations have been examined, a synopsis of the proposed actions for modifying each Part will be made in the Summary section, 5.5.1, and conclusions drawn.

5.3 Results: The Building Regulations 1997-2012

5.3.1 Part A: Structure

The purpose of Part A, Structure, is to ensure that buildings are constructed safely and soundly with respect to the health and welfare of occupants. Part A considers all forces that may be exerted upon the structure, including subterranean events. The regulation is divided into three sections: loading; ground movement; and disproportionate collapse. Loading is the section directly relevant to climate change. In its original form (1997), it stated that:

> '[…] regard shall be had to the imposed loads and wind loads to which it is likely to be subjected in the ordinary course of its use for the purpose for which it is intended'.
>
> (DELG, 1997: 12)

In 2012 it was amended to read:

> '[…] regard shall be had to the variable actions to which it is likely to be subjected in the ordinary course of its use for the purpose for which it is intended.'
>
> (DECLG, 2012: 3)

The amendment (2012) replaced the phrase 'imposed loads and wind loads' with, 'variable actions'. The reason given for this amendment was to ensure consistency with the Eurocodes. The point to note however in the context of this research is that the amendment was not a response to climate change. This is supported by examination of the RIA for Part A in section 5.1.3, where it was illustrated that climate change considerations were not an objective.

Despite the lack of reference to climate change in the Part A Regulation, TGD A (2012) may provide a *de facto* response to climate change issues. In this context, the following sentence is significant:

> 'The selection of relevant critical situations for design should be made reflecting the conditions that can reasonably be foreseen during future use.'
>
> (DECLG, 2011e: 6)

The key phrase is 'conditions that can reasonably be foreseen'. Given the substantial evidence for climate change it can be argued that climate change can 'reasonably be foreseen', with the consequence that building design should reflect this. However, the term 'reasonably' is not defined within the Regulations and it is thus open to interpretation. Building designers are therefore left responsible for selecting the climate reference periods, which may or may not include climate change considerations. This nonetheless fulfils the intent of the Regulation, which states that buildings should be constructed to withstand the variable actions to which they are likely to be subjected. As such, although compliance with the Regulations can be considered to have been met, it is not with specific reference to climate change or the potential impacts. Critically, buildings designed under such legislation may not therefore be adequately equipped to manage anticipated variations in future climate.

An example of a practical application of the phrase 'conditions that can reasonably be foreseen' would be the use of double-leaf construction in more inland parts of Ireland due to anticipated increases in winter wind-driven rain, as discussed in Chapter 3. Historically, double-leaf was used only in the more exposed regions of Ireland where it was always assumed that the outer leaf would not remain watertight, necessitating an inner leaf to maintain the integrity of the building. With projected increases in wind-driven rain, the use of double-leaf construction would appear an appropriate mitigation strategy for inland locations in the future. While this may incur higher capital costs, less expensive mitigation strategies can be incorporated easily. The use of stainless steel cavity wall ties for example has been specified for all houses 'regardless of their location' in the UK's Approved Document A (NBS, 2010: 2). The aforementioned notwithstanding, TGD A does not specify particular structural systems or designs for individual examples; the appropriate competency involved needs to be assessed on a case by case basis.

A consequence of not adapting to conditions that can reasonably be foreseen is the possible elevation of exposure classification for a given location. As highlighted in Chapter 3, the co-occurrence of higher winter precipitation and wind speeds is projected to lead to increases in wind-driven rain. This could lead, for example, to concrete being exposed to a higher level of exposure than originally planned for, resulting in an increase in building fabric deterioration. For instance, concrete structures in the west of Ireland designed for exposure classification XC4, 'cyclic wet and dry', could eventually be exposed to classification XC2, 'wet, rarely dry' (IS EN 206-1:2000: 15). As well as possible increases in rates of material degradation, such an upwards movement in exposure class could result in higher rates of reinforcement corrosion due to increased mean temperature and carbonation from atmospheric CO_2. Freeze-thaw cycles may exacerbate the situation which, if concrete structures begin to fail *en masse*, could ultimately lead to substantial disruption and cost to society (Stewart *et al.*, 2011).

Further repercussions may result due to conditions of increased winter precipitation and higher summer temperatures of longer duration. Such circumstances could lead to the drying out of shrinkable clays during summer, resulting in subsidence, and the swelling of clays during winter, resulting in heave. Although clays in Ireland do not generally have issues with shrinkage and swelling, with less than 1% of the total till coverage exhibiting such characteristics, localised sites and pockets of lacustrine clays represent a higher risk (Meehan, 2012). Such clays may expand and shrink significantly with changing moisture content, although foundations in these zones tend to be deeper to account for this. That said, the minimum width of strip foundation has not been reviewed since 1997. It would be relatively straightforward to indicate specifically that climate change should be considered in such areas, as evidenced in the England and Wales Approved Document A. This states that 'recommendations on minimum foundation depths [are] included to counter the impact of predicted climate changes'

(NBS, 2010: 1). Taking the aforementioned into account, modifications are proposed to IS EN 1997-1:2005 Eurocode 7: Geotechnical Design. Currently, section 2.4.2, Actions (4), states that 'swelling and shrinkage caused by vegetation, climate or moisture changes' should be considered for inclusion as actions (NSAI, 2005: 25). It would appear prudent to include 'climate change' as a potential consideration with respect to swelling and shrinkage in this context, and include it as a factor to be considered in the design of construction projects in vulnerable areas.

Recommended action:

- Include 'climate change' as a factor with respect to IS EN 1997-1:2005 Section 2.4.2, Actions (4).

5.3.1.1 Standards modification exemplar in the context of wind-driven rain

The standard I.C.P. 2:2002 Slating and Tiling is of particular relevance for the Irish climate, especially in the west. This standard is referenced in the National Annex to IS EN 1991-1-4, Wind Actions, and contains the driving rain map shown in Figure 5.1 overleaf.

The map is illustrated exactly as it appears in the Standard. As can be seen, the standard of reproduction is low and the detail is blurred. In addition, the map generated is based on driving rain data from the Meteorological Service Climatological Note No. 3 (1973). Given contemporary climate projections, it can be argued that the map is not suitable for the purpose for which was intended, particularly in the context of roofs where any increases in phenomena such as WDR could have a significant impact on moisture ingress. Although an updated Distribution of Driving Rain in Ireland map was published in 2010, as discussed in Chapter 3, it too did not include climate change data in its calculation. As such, it can be recommended that the standard I.C.P. 2:2002 requires modification in the form of an updated driving rain map containing values as shown in the new wind-driven rain maps illustrated in Chapter 3.

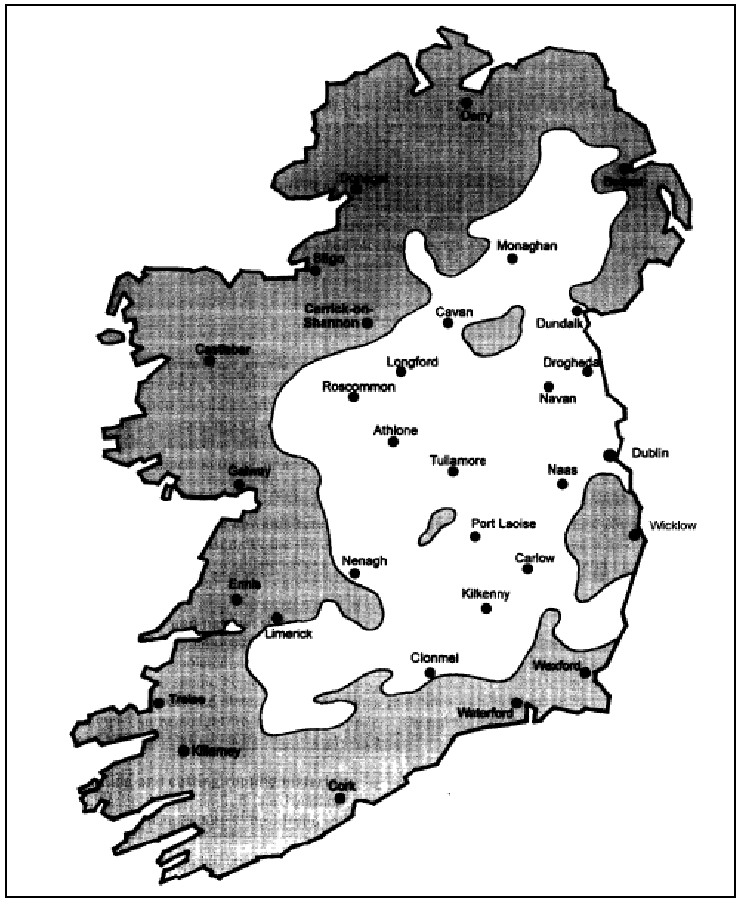


Figure 5.1 Driving rain map contained in Irish Standard I.C.P. 2:2002. Normal exposure (un-shaded area): <5m2/sec/year. Severe exposure (shaded area): ≥5m2/sec/year.

Recommended action:

- Update driving rain map in Irish Standard I.C.P. 2:2002 with maps illustrated in Chapter 3.

5.3.1.2 Exemplar of potential sub-optimal resilience due to historical climate data application

An independent study was carried out for the DEHLG in 2010 to produce draft National Annexes for each part of IS EN 1996 Eurocode 6: Design of Masonry Structures (McCullough, 2010). The National Annex values resulting from this study were incorporated into the Nationally Determined Parameters for Eurocode 6. Since IS EN 1991-1-4, Wind Actions, had not been published at that juncture, the study used

BS6399-2: Part 2: 1997 in its wind calculations. The 10-minute-mean wind speed map contained in this standard is illustrated in Figure 5.2.

Figure 5.2 10-minute-mean wind speed with a 1:50 year risk of exceedance (m/s). (Source: Kingspan, 2012).

However, the wind speed map in BS6399-2 differs from that published in TGD A (2012) in Figure 5.3 by approximately 2 m/s for a given location. Had the independent study used the current wind values, as contained in TGD A (2012), higher values for use in the National Annex to Eurocode 6 would have been the result. Buildings constructed in Ireland under Eurocode 6 therefore, which used the lower wind speed figures in its National Annex, may not be as resilient to climate change as buildings designed under codes specifying the higher wind speed values. Moreover, higher wind speeds mean a likely increase in the severity of WDR, with the result that vertical surfaces become wetter for longer. Masonry blocks fail quicker when wet (McCullough, 2010) and during winter are often saturated when in exposed sites, making them more susceptible to freeze/thaw damage. It can be seen therefore that by not using the latest climate data in standards development, potential issues for durability in the future may arise.

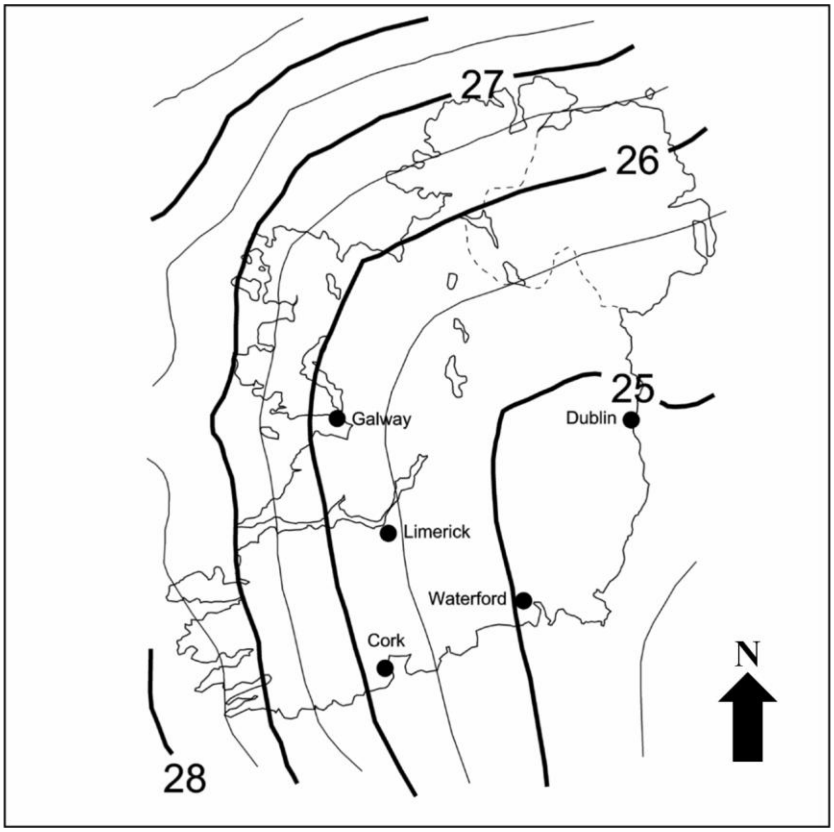


Figure 5.3 10-minute-mean wind speed with a 1:50 year risk of exceedance (m/s) (TGD A, 2012: 13).

Such changes require incorporation into building design calculations and should also be reflected in modifications to the Building Regulations and associated documents. For example, the classifications under ‘total load of load-bearing walling’ in TGD A (DECLG, 2012e: 28) could be adjusted upwards in the light of increased wind loading from higher wind speed values. Given that buildings are designed for a lifespan of at least 60 years, climate change must be factored in if buildings are to remain resilient to future climate regimes, particularly with regard to wind. As has been illustrated through the recent evolution of TGD A it is relatively straightforward to update documents to reflect such projected changes. The key issue is what data to employ in such alterations, which is an area that lies outside the aims of this research.

Recommended actions:

- Employ higher wind values in the order of 10%, as recommended in BRE 499, for design wind load calculations.
- Update wall loading classification requirements in the light of higher design wind loads.
- Revise the National Annex to IS EN 1996 Eurocode 6 using the latest wind data.

5.3.2 Part B: Fire Safety

The purpose of Part B, Fire Safety, is to ensure that a building is designed and constructed so that there are adequate means of escape in case of fire. No amendments have been made since their inception in 1991. The part applicable to this study is contained in clause B4, which states that:

> 'The external walls and roof of a building shall be so designed and constructed that they afford adequate resistance to the spread of fire to and from neighbouring buildings.'
>
> (DELG, 1997: 13)

Relevant guidance on compliance is given in TGD B and research already exists on the spread of fire externally due to wind actions. Although increases in wind speeds could result in the faster spread of fire, it is not possible to quantify the effect that climate change may have on this phenomenon. Moreover, climate change will not affect the intent of this Regulation nor compliance with it, and as such no recommendation for modification is made.

5.3.3 Part C: Site Preparation and Resistance to Moisture

The element of Part C, Site Preparation and Resistance to Moisture, which is relevant to this study is contained in clause C4. It states that:

> 'The floors, walls and roof of a building shall be so designed and constructed as to prevent the passage of moisture to the inside of the building or damage to the fabric of the building.'
>
> (DELG, 1997: 14)

In terms of precipitation, increases due to climate change will impact site works particularly in relation to site drainage. In addition, projected rainfall regimes mean that up-slope subsoil drainage for houses built on inclines may have to manage increased run-off. In the context of modifications to the Regulations however, the intent specified therein is clear. It is the TGD therefore that warrants attention in this case. Of particular interest is water table level rise in winter due to projected increases in winter precipitation. Currently, TGD C specifies that the safeguarding of the building by drainage or other means should be employed where the water table level rises to within 250 mm of the lowest floor of the building (DELG, 1997: 5). In this context, TGD C calls upon BS 8102: 1990 'Code of practice for protection of structures against water from the ground'. With changes in precipitation regimes evident in climate models however, it would be prudent to increase this figure. It has already been shown in Chapter 4 that water table levels are approaching the surface in several regions in Ireland, and with climate change the number of zones that will start to become affected by very high groundwater levels will increase. An increase in minimum water table distance to the lowest floor in the house will therefore mitigate for rises in water table level in the future.

Recommended action:

- Increase the minimum water table distance from the lowest floor in a building with respect to BS 8102: 1990 'Code of practice for protection of structures against water from the ground'. Increasing the distance by a safety factor of 20% to reflect the projected increase in DJF precipitation may be considered, although a safety factor of 2 to ensure a no-regrets solution would appear prudent given model uncertainty. 500 mm would therefore be the recommendation, although factors such as subsoil and bedrock geology may require further examination.

5.3.4 Part D: Materials and Workmanship

The purpose of Part D, Materials and Workmanship, is to ensure that work is carried out to the appropriate standard using the appropriate materials. The element that is relevant to climate change is the definition in clause D3, which states that:

> '[Materials should be used] which are fit for the use for which they are intended and for the conditions in which they are to be used.'
>
> (DEHLG, 2000: 2)

Of importance in the context of this study is the phrase 'for the conditions in which they are to be used'. While contemporary conditions are provided for in TGD D, changes in long-term climate are not. The most recent standard referenced in TGD D dates from 1994. Given that even now climate change is not factored into Building Regulations, it can reasonably be assumed that no climate change considerations are contained therein. It is the manufacturers of construction materials however onto which the onus needs to be placed. Clauses D3 (a), (b) and (c) of the Regulations state that materials must 'bear a CE Marking in accordance with the provisions of the Construction Products Directive' or comply with an appropriate standard (DEHLG, 2000: 3). It is therefore the development and certification of materials that requires attention in the context of climate change and Part D of the Regulations. Such modifications lie outside the remit of this study, although a reference to climate change data as a requirement for CE or equivalent certification would instigate research and development in this area. Higher product specifications would also help to fulfil the objective of 'good quality housing' as espoused in current housing policy (DECLG, 2012a: 13).

Recommended action:

- A demonstration of climate change data inclusion should be part of CE certification.

5.3.5 Part E: Sound

The purpose of Part E, Sound, is to ensure that buildings are constructed so that they have reasonable resistance to the transmission of airborne sound and impact sound. Climate change will not affect the intent of this Regulation, and as such no recommendation for modification is made.

5.3.6 Part F: Ventilation

The purpose of Part F, Ventilation, is to ensure a supply of fresh outside air and the removal of stale indoor air to or from spaces in a building. The objective is to limit the moisture content of the air within a building so that it does not contribute to condensation and mould growth, and limit the concentration of harmful pollutants in the air within the building. There has been no change to the Regulation since 1991, which is stated currently as:

> 'Adequate means of ventilation shall be provided for people in buildings. Adequate provision shall be made to prevent excessive condensation in a roof or in a roof void above an insulated ceiling.'
>
> (DELG, 1997: 17)

The aim of ventilation is to provide adequate air movement while limiting energy use and avoiding occupant discomfort. For this reason TGD F and TGD L (Conservation of Fuel and Energy) are inextricably linked. Air tightness is common to both documents. TGD F provides guidance on ventilation for buildings with an air permeability of at least $5m^3/(h.m^2)$ (5 cubic metres per hour per square metre of the building envelope) at 50 Pa pressure or greater, while TGD L specifies that air tightness of building envelopes should have an upper level of performance of $7m^3/(h.m^2)$.

The probable impact of climate change on ventilation is that during more extreme events air permeability will change due to pressure differentials caused by turbulence around buildings. This will result in a potential greater loss of energy but can be considered unavoidable. One alternative would be to recommend installation of energy efficient

Mechanical Ventilation Systems. Capital cost issues aside, good mechanical ventilation with a heat recovery system should be able to recover more heat energy from the air extracted than the equivalent electrical energy used by the fans. This would fulfil the aim of TGD L, that of limiting the use of fossil fuel energy and related carbon dioxide emissions arising from the operation of buildings. Thus, climate change would appear to warrant consideration of an increase in use of mechanical ventilation systems in building design. Among the relevant codes that would require evaluation by a practising engineer is IS EN 13141-4:2004 'Ventilation for buildings. Performance testing of components/products for residential ventilation. Fans used in residential ventilation systems'.

Buildings using the traditional method of openings in the eaves 10mm wide to limit condensation in roof spaces are vulnerable to precipitation being driven into the roof space due to increases in winter wind-driven rain. However, the relative humidity of outside air is a more significant factor in the management of attic condensation and moisture ingress. As no significant trend in relative humidity is evident from climate models, eaves ventilation can be considered sufficient at this juncture, although as buildings become more airtight it is important that adequate ventilation is maintained to minimise risks such as mould growth and condensation. That said, calculations pertaining to openings, overhangs and recesses should be cognisant of projected increases in wind-driven rain and take into account potential increases in moisture ingress. TGD F calls upon BS 5250: 2011 'Code of practice for control of condensation in buildings' in this regard, which may require revision should climatic conditions change.

Perhaps the most important impact that climate change will have on ventilation is the drive towards energy efficiency and zero carbon homes. As building standards become more stringent, overheating as a result of increased airtightness could become more of an issue. Ventilation must be sufficient to prevent condensation and mould growth, yet conservation of fuel and energy requires that buildings become ever-more airtight. The challenge in these cases is to ensure that overheating issues are addressed without compromising highly insulated and energy efficient stock. This however is a measure that will require addressing in the TGDs, codes and standards, and as such no recommendations for modifications to the Building Regulations are necessary.

Recommended action:

- The intent of the Regulation is still valid in the context of climate change. No modifications are advocated, although the issue of airtightness versus ventilation requires careful consideration within codes and standards.

5.3.7 Part G: Hygiene

The purpose of Part G, Hygiene, is to ensure that dwellings are equipped with the appropriate number of sinks, baths and showers, and have a provision for hot and cold water. Climate change does not impact this Part of the Regulations so modifications are not considered necessary.

5.3.8 Part H: Drainage and Wastewater Disposal

The purpose of Part H, Drainage and Wastewater Disposal, is to ensure the adequate disposal of wastewater and surface water from buildings. There was no change to this Regulation between 1991 and 1997, although it was amended in 2010 to mention specifically the environment with regard to the design, siting and construction of wastewater treatment systems. There are two aspects of this Regulation that are relevant to this study. Firstly, clause H1(1):

> 'A building shall be provided with such a drainage system as may be necessary for the hygienic and adequate disposal of foul wastewater from the building.'
>
> (DEHLG, 2010: 3)

Secondly, clause H1(2):

> 'A building shall be provided with such a drainage system as may be necessary for the adequate disposal of surface water from the building.'
>
> (DEHLG, 2010: 3)

The Regulations, codes and standards pertaining to clause H1(1) 'adequate disposal of foul wastewater' will be analysed initially. Subsequently, clause H1(2) 'adequate disposal of surface water' will be examined.

5.3.8.1 Adequate disposal of foul wastewater

With respect to the adequate disposal of foul wastewater under changed climatic conditions, the intent declared in the Building Regulations, clause H1(1), remains valid. As such it requires no modification. However, the values used within TGD H to demonstrate compliance may need revision. In this context, clause H2(1)(b) is relevant:

> 'H2 (1) A wastewater treatment system shall be so
> designed, sited and constructed that:—
> […]
> (b) it does not cause a risk to public health or the environment.
>
> (DECLG, 2010: 3)

To comply with this clause in the context of dwellings, the Regulations call upon the *Code of Practice for Wastewater Treatment Systems for Single Houses* (EPA, 2009). Currently, the Code specifies that there should be a 1.2 m minimum depth of unsaturated subsoil to the water table (EPA, 2009: 14). As has been illustrated in Chapter 4 however, there are several areas in Ireland where water table heights within this range have been recorded, and where septic tanks are located. As has also been discussed, climate projections indicate that increases in winter precipitation may lead to rising winter water tables. The result in the context of domestic wastewater treatment is that unless the minimum depth to water table is increased, the risk to the environment is likely to increase. Should winter water tables rise as anticipated, an increasing number of groundwater aquifers will become prone to contamination from wastewater treatment effluent. This has implications not only for the environment in general but also for health, where for example County Roscommon extracts 75% of its drinking water directly from groundwater.

Recommended action:

- Investigate increasing the minimum depth to water table from its current value of 1.2 m in the *Code of Practice for Wastewater Treatment Systems for Single Houses* (EPA, 2009). Based on earlier work in Chapter 4, the counties of Meath, Galway and Kildare would require particular study.

5.3.8.2 Adequate disposal of surface water

As with clause H1(1) above, the intent declared in the Building Regulations contained in clause H1(2) remains valid. As such, in the context of adequate disposal of surface water under changed climatic conditions it requires no modification. However, the values used within TGD H to demonstrate compliance with this Regulation may need revision. Two key aspects require investigation: rainfall intensity; and gutter size.

Currently, a rainfall intensity of 75 mm/hr for roof drainage design is specified (TGD H, 2010: 7), and 50 mm/hr for calculating pipe gradient and size for surface water drainage (TGD H, 2010: 24). However, given climate change projections that indicate winter precipitation increases in the order of 15% (McGrath *et al*., 2008), it may be prudent to increase design rainfall intensities accordingly. Gutter sizes may also need revision. As well as having to drain an increase in direct precipitation receipt from roofs, increased amounts of rain running off walls into gutters as a result of increased WDR means that the current specifications contained in TGD H may require modification. TGD H, informed by IS EN 12056-3:2000 'Roof drainage, layout and calculation', states currently that 50% of the area of the wall should be added to the effective area of the roof to mitigate for WDR run-off (TGD H, 2010: 21). In the light of climate estimates for WDR this figure may need revising upwards, particularly in the western areas of Ireland where increases in WDR based on work carried out in Chapter 3 are projected. Figure 5.4 illustrates a building constructed under current regulations, where roof drainage met build standards yet is not adequate to manage run-off quantity. Discolouration of the building façade from spill-over can be seen, indicating deterioration of the building fabric. Climate change will exacerbate such situations.

Figure 5.4 Building façade discoloured by excess surface water not managed by drainage provisions.

Some Local Authorities are already accounting for projected increases in precipitation as a result of climate change. For example, County Louth's County Development Plan (CDP) 2009-2015 specifies that guttering and pipe-work should be calculated on the basis of 'up to 30% increase in precipitation' (County Louth, 2009: 181). Previous research has also proposed drainage modifications to mitigate for climate change. A strategy mooted by Saunders (2006) was to decrease downpipe spacing and to increase gutter capacity by a factor of 10%. Such a strategy and capacity increase, subject to critical evaluation in the light of current climate projections, could be translated nationally.

Recommended actions:

- Evaluate design rainfall intensities in the context of IS EN 12056-3:2000 'Roof drainage, layout and calculation'.
- Examine the implementation of measures such as those advocated by Louth CDP and Saunders (2006).

5.3.9 Part J: Heat Producing Appliances

The purpose of Part J, Heat Producing Appliances, is to provide for adequate air supply, the safe discharge of combustion products and the appropriate location of oil storage tanks. Climate change will not affect the intent of this Regulation, and as such no recommendation for modification is made.

5.3.10 Part K: Stairways, Ladders, Ramps and Guards

The purpose of Part K, Stairways, Ladders, Ramps and Guards, is to provide for safe passage and protection for users of a building. Climate change will not affect the intent of this Regulation, and as such no recommendation for modification is made.

5.3.11 Part L: Conservation of Fuel and Energy

The purpose of Part L, Conservation of Fuel and Energy, is to make buildings as energy efficient as is reasonably possible. Since its introduction in 1991, Part L has been revised in 2002, 2007, 2008 and 2011. While climate change is not mentioned specifically, it can be seen that amendments are driven by national emissions targets resulting from national climate policy. To demonstrate the emissions narrative, clauses L1 (1991) and L1 (2011) are evaluated briefly. L1 (1991) stated that:

> 'A building shall be so designed and constructed as to secure, insofar as is reasonably practicable, the conservation of fuel and energy.'
>
> (DOE, 1991: 14)

The same clause, L1, stated in 2011 that:

> 'A building shall be designed and constructed so as to ensure that the energy performance of the building is such as to limit the amount of energy required for the operation of the building and the amount of carbon dioxide (CO_2) emissions associated with this energy use insofar as is reasonably practicable.'
>
> (DECLG, 2011: 4)

This text carries the intent of the original clause (1991) but its reference to CO_2 emissions is overt. It can therefore be considered to be addressing contemporary climate change issues, albeit through emissions rather than physical climate change impact concerns. It is worth noting that the withdrawn Climate Change Response Bill 2010 placed clause (5)(6)(a), ‘achieving reductions in emissions aimed at furthering transition to a low carbon, climate resilient and environmentally sustainable economy’, over clause (5)(6)(b), ‘enabling the State to adapt to the effects of climate change’ (Climate Change Response Bill 2010: 7). In this hierarchical context, it would appear that climate change is subservient to emissions considerations. That said, if projections prove accurate, the amended Part L will prove instrumental in the achievement of Ireland’s emissions target of a 20% reduction from 2005 levels by 2020 (Figure 5.5).

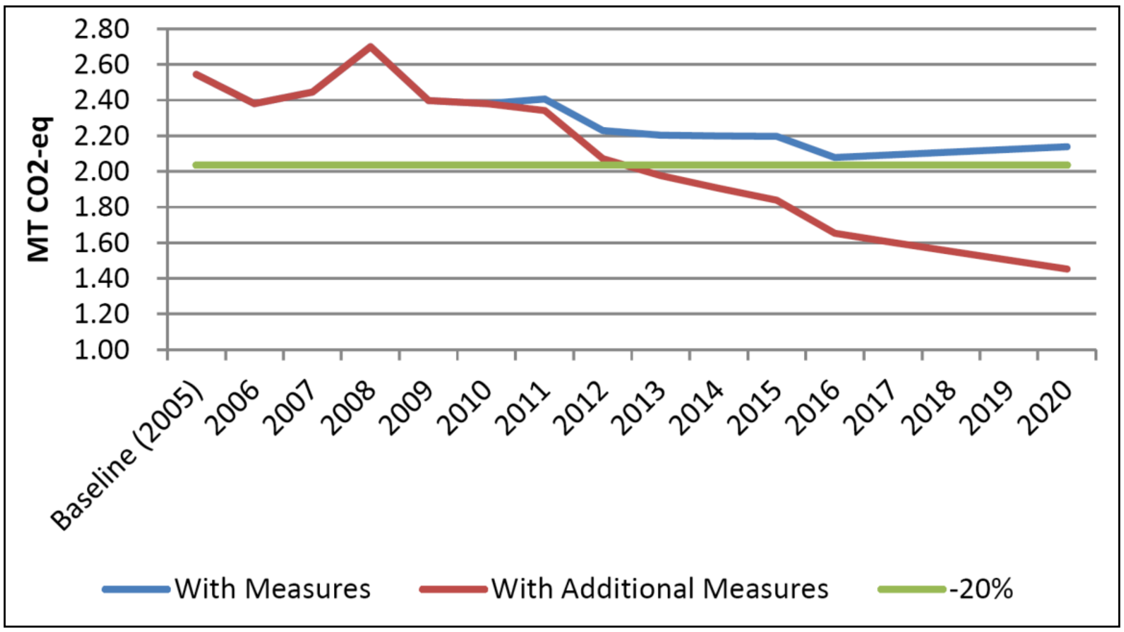


Figure 5.5 Emissions from residential buildings, 2005–2020 (Mt CO_2 eq). Red line indicates projections resulting from adoption of revised Part L, 2011 (NESC, 2012: 76).

A particular aspect associated with Part L that merits further investigation is the Acceptable Construction Details (ACDs). ACDs are designed to assist in the achievement of performance standards in TGD L by focusing on airtightness and thermal bridging (heat transfer *via* a conductive or non-insulating material). ACDs are reviewed ‘in the light of experience’ (DEHLG, 2008: 1), although current ACDs have not been revised since 2008, when the proportion of average overall heat loss due to thermal bridging was approximately 10 to 15% (DEHLG, 2008: 3). Even today, thermal inefficiency is attributed a primary role in Ireland's very high level of emitted CO_2 from buildings, emissions which are 47% greater than the average dwelling in the UK and 104% above the EU-27 level in 2005 (NESC, 2012: 73). Such thermal inefficiencies and consequent emissions are only likely to increase, as WDR increases the wetted period of vertical surfaces and thus the U-value. Thermal bridging also increases the risk of condensation due to the lower localised internal surface temperatures, causing an acceleration of impacts detrimental to the building fabric. Table 5.2 illustrates the impact on thermal conductivity when common building materials are wetted. Another factor to consider in the context of this research is air leakage, where the leakage of warm moist air through the structure can lead to interstitial condensation causing further fabric deterioration. Higher wind speeds as a result of climate change may increase air leakage and amplify this impact.

Table 5.2 Thermal conductivity comparison between dry and wetted surfaces (LEARN, 2004).

	Conductivity W/mK *Dry*	**Conductivity W/mK** *Wet*
Light concrete	0.7 - 0.9	1.2 - 1.4
Pumice powder concrete	0.35 - 0.5	0.5 - 0.95
Brick	0.6 - 0.7	0.9 - 1.2
Cement dashing	0.9	1.5
Hardwood	0.17	0.23
Softwood	0.14	0.17

A reduction in thermal performance of the building envelope and a consequent increase in the energy needed to heat it will impact negatively on the aim of achieving carbon neutral dwellings. That said, U-value recommendations have been reducing steadily since 1997, which should mean that energy losses are proportionally smaller in buildings constructed since 1997. For example, TGD L (1997) specified average elemental U-values for roofs and walls as 0.35 W/m^2K and 0.55 W/m^2K respectively; in 2008 the limits were reduced to 0.25 W/m^2K and 0.37 W/m^2K (TGD L 2008: 16); and in 2011 the limits were specified as 0.16 W/m^2K and 0.21 W/m^2K (TGD L 2011: 17). It can be seen therefore that developments in Part L have benefited from several reviews recently, albeit due primarily to emissions-related targets.

In the context of modifications to Part L of the Building Regulations, there seems little room for further recommendations beyond those planned. A third amendment to Part L is due to come into force in 2016 that will lead to the construction of ‘nearly zero buildings’. It is hoped that such improvements will lead to increased emissions mitigation in the period up to 2020 (NESC, 2012: 95). In a wider context, TGD L draws reference from 33 Irish Standards, 24 publications, 3 British Standards and 3 ISO Test Methods to mitigate for loss of thermal performance, and they themselves are reviewed periodically. Little more can be advised therefore, other than to advocate explicit use of the latest climate change data when carrying out reviews of the numerous standards and codes that inform Part L.

Recommended action:

- Review Acceptable Construction Details (2008) to align with TGD L (2011) so that guidance is sufficient to ensure compliance with current U-value aims.

5.3.12 Part M: Access and Use

The purpose of Part M, Access and Use, is to ensure adequate provision for people to access and use a building, its facilities and its environs. Climate change will not affect the intent of this Regulation, and as such no recommendation for modification is made.

5.4 Results: Building Control Regulations

Analysis of the Building Control Regulations indicates that their intent is appropriate for the enforcement of the Building Regulations. However, there are notable deficiencies in the resources made available to enforce them. The result is that the Building Control system is open to abuse, with sub-standard construction the primary potential consequence. Evidence is emerging, both physical and anecdotal, to support this hypothesis.

Under the 1990 Building Control Act the role of enforcement of the Building Regulations became the responsibility of the 37 local Building Control Authorities. Few Authorities however had the resources to inspect buildings on a continual basis. Indeed, during the peak of construction in 2007, so many buildings were under construction that 'it would have been impossible for building control or fire officers to inspect them all' (McDonald, 2011: 1). Still, official targets for inspection were low. The minimum target inspection level agreed with the City and County Managers Association (CCMA) was 12-15% of buildings under construction. Even so, 4 out of the 37 Building Control Authorities failed to meet the minimum target inspection level, and significant non-compliance issues were noted in most Authorities (O'Connor, 2012). As a result, up to 85% of buildings may not have had any building control inspection whatsoever during their construction.

The primary responsibility for compliance with the Building Regulations in Ireland rests with the designers, builders and building owners (DECLG, 2010). Certification of compliance rests with suitably qualified and registered professionals such as building engineers and building surveyors. However, the aforementioned parties generally rely on information from the architects, who in turn rely on information from the builder. Each of the latter parties generally has a vested interest in successful certification, and in an industry where cost is a principal driver the temptation is to circumvent proper construction practice. This has led to a situation in the home construction industry where the level of assurance in respect of compliance with the Building Regulations ‘is not considered reasonable or adequate’ (NCA, 2008: 3).

The lack of an independent inspection regime has already resulted in cases of sub-standard construction. For example, Priory Hall in North Dublin, built at the height of the building bubble in 2007, was found to have severe fire safety deficiencies. This led to the evacuation of all residents in 2010. The problem has yet to be rectified and residents are still in temporary accommodation. A more recent example is that of The Laurels, an apartment complex built in 2007 in South Dublin. Again regarding fire safety issues, residents were evacuated in July 2012.

Building Control in Ireland contrasts starkly with other countries. There is a 100% inspection level for new homes in Northern Ireland and the same is true in much of Europe and the USA, where 100% inspection levels are required by law (NCA, 2008: 1). The number of inspection stages is also higher. For example, the English city of Derby specifies that Building Control must be informed at each of the following stages, with the possibility of inspection during any phase:

- Commencement;
- Excavations for foundations;
- Concreting foundations;
- Material laid on site;
- Damp proof course laid;
- Upper floor joist construction;
- Drain ready for inspection test;
- Drain backfilled and ready for test;
- Roof construction;
- Electrical wiring;
- Occupation of the building;
- Final completion of building work.

(NCA, 2008: 21-22)

In Ireland, the Building Control (Amendment) Regulations (2012) are due to be signed into law shortly. However, responsibility for compliance will continue to rest with the building owner and/or developer. It can be seen therefore that even if the Building Regulations are modified to account for climate change, unless the Building Control

Regulations are enforced the modifications may not have the desired effect in practice. Indeed, raising performance standards as a response to climate change without addressing non-compliance with existing standards may 'run the risk of undermining the legitimacy of regulation generally' (Lowe, 2003: 196). Unless resources are directed towards enforcement of the Building Control Regulations, buildings may not offer the resilience necessary under future climate scenarios, no matter how extensively the Building Regulations are modified.

5.5 The Building Regulations: summary, recommendations and conclusion

5.5.1 Summary

5.5.1.1 The Building Regulations 1997-2012

The Building Regulations 1997-2012 have been examined in the context of climate change. Amendments since their inception in 1991 have also been examined to evaluate whether climate change considerations have been incorporated as a response to climate change research over the last two decades. Results indicate that no amendments have been incorporated as adaptive measures in response to climate change. In terms of mitigation for future climate, Part L was amended in response to national climate policy.

The contemporary situation in Ireland mirrors that which existed recently in the UK. Vivian *et al* (2005) observed that although climate change was beginning to be taken into account in the development of UK building standards, overt references to climate change were still lacking. They also noted that without concise guidance it was difficult for construction professionals to know when additional considerations should be applied. This appears to be the case in Ireland currently. The construction industry is reluctant to depart from guidance contained in the TGDs (DEHLG, 2002), regardless of current climate change discourse. This reluctance is nevertheless understandable. While the EU Public Procurement Directive does not exclude the use of other methods, equivalence will still need to be demonstrated by the tenderer. As such, adhering to TGDs represents the least-resistance path to satisfying the intent of the Building Regulations. For this reason, the TGDs and relevant codes and standards must be updated so that climate change considerations are factored in automatically by designers and builders.

It is apparent that it is difficult to incorporate specific climate change parameters into TGDs and Regulations. Even though codes and standards are maintained and revised continually, it takes 2 to 3 years to review and publish a new TGD, in which time climate science has often evolved and revised projections published. Complicating matters further, TGDs are standards-based documents, which places the emphasis on using modelled climate data in the formulation of standards rather than the Building Regulations and TGDs themselves. The key challenge thus becomes to encourage reviewers of the standards to utilise future climate projections in their revisions. Pivotal to this is accessibility to the latest climate change data. This is addressed, in intent at least, in the DECLG's Statement of Strategy 2011-2014, which specifies 'timely responses to requests for climate data' from 'high quality climate research programmes' (DECLG, 2012a: 32).

A strategy to provide such timely data was one of the outputs of the World Climate Conference WCC-3 (2009). An international framework to guide the development of a new concept, Climate Services, was designed to link science-based climate prediction with climate risk management throughout the world for adaptation purposes (WMO, 2009). To date it has been implemented in organisations such as the Climate Service Centre in Hamburg, whose aim is to refine the knowledge derived from German climate research 'in a practice-orientated way' and convey the findings to 'decision-makers in politics, administration, economy and the broad public' (CSC, 2012). The UK Met Office too offers Climate Services, whereby 'climate information [is] prepared, interpreted and delivered to meet society's needs' (Met Office, 2012: 1). Such a service is lacking in Ireland currently, although successful implementation of the DECLG's Statement of Strategy 2011-2014 would address this issue.

A militating factor against including climate projections in regulatory revisions is that the projections can change with the introduction of new models. Indeed the very scenarios themselves are changing, with SRES scenarios being replaced by Representative Concentration Pathways (RCPs) (Moss *et al*., 2010). It could be argued that a continual revision of standards to keep pace with advances in climate science is not simply practicable. It has also been observed that consensus is difficult to reach. An example cited was the British Standards committee's contrary view to the Irish Standards office, that increases of 10% in design wind loads were not necessary. As a counter to this however, Camilleri *et al*. (2001) and Gething (2010) argued that regulatory revision should incorporate a no-regrets policy, as no-regrets assumes resilience whether the climate changes or not. No-regrets measures taken in the design stage of construction were also considered much less expensive than retrofitting or refurbishment, which is a significant benefit in a field influenced to a considerable extent by economic considerations.

5.5.1.2 The Building Control Regulations 1997-2009

The Building Control Regulations were analysed in the context of climate change. It was found that current enforcement regulations and targets were inadequate, not only in the context of controlling construction under modified Building Regulations but also in the context of monitoring the implementation of current Regulations. It was also shown that levels of Building Control were substantially lower than those found in other European countries. The result is that the implementation of modifications to the Building Regulations would be virtually impossible to monitor above the 12-15% target agreed with the CMMA.

Without 100% enforcement such as that exhibited by other European countries, construction professionals, under ever-increasing fiscal pressure, may be tempted to make economies that only become apparent when buildings fail. If this proves to be the case, which anecdotal and emerging evidence indicates that it will be in many instances, buildings will remain vulnerable to future climatic shifts no matter what modifications are recommended for the Building Regulations.

5.5.2 Recommendations

A synopsis of recommended actions with respect to TGDs, codes and standards in the context of each relevant Part of the Building Regulations is shown in Table 5.3. An additional recommendation applicable to all Parts is that the following clause be incorporated into all TGDs: 'The selection of relevant critical situations for design should be made reflecting the conditions that can reasonably be foreseen during future use'.

Table 5.3 Synopsis of recommended actions.

	Action	Climate actor
Part A	Include 'climate change' as an action in IS EN 1997-1:2005 Section 2.4.2, Actions (4).	Precipitation and temperature
	Employ higher wind values in the order of 10% in design wind calculations.	Wind
	Update wall loading classification requirements in the light of higher design wind loads.	Wind
	Revise the National Annex to IS EN 1996 Eurocode 6 using the latest wind data.	Wind
	Update driving rain map in Irish Standard I.C.P. 2:2002.	Wind and precipitation
Part C	Increase minimum recommended water table distance to ground floor with respect to BS 8102: 1990.	Precipitation
Part D	Climate change data to be utilised in CE certification.	Wind, precipitation and temperature
Part F	Continual review of values with respect to airtightness versus ventilation.	Wind and relative humidity
Part H	Investigate increasing the minimum depth to water table in the *Code of Practice for Wastewater Treatment Systems for Single Houses* (EPA, 2009).	Precipitation
Part L	Review Acceptable Construction Details (2008) to align with TGD L (2011) to ensure compliance with current U-value aims.	Wind, precipitation and temperature

In addition to the recommendations in Table 5.3, an appropriate policy and operational framework is required that complements current climate policy, which is largely emissions-driven. The following recommendations are made in this context:

- Prioritise the introduction of legislation to succeed the Climate Change Response Bill (2010);
- Revise Building Control policy to meet the standards of other EU members;
- Utilise the most recent climate projections to inform regulatory policy with regard to the Building Regulations and Building Control Regulations.

5.5.3 Conclusions

Amending the Building Regulations to mitigate for and adapt to a changing climate regime is a rational strategy. The practicalities however have been seen to be complex. Initially, two policy contexts have to be considered, while subsequent analysis revealed that not only do the Building Regulations require modification but also the Technical Guidance Documents, codes, standards and Building Control Regulations. That said, the most recent TGDs incorporated a clause that appeared to encourage the use of projected climate information: ‘conditions that can reasonably be foreseen during future use’. Nevertheless, the clause is ambiguous, and as such is not a reliable instrument. Compounding the situation are questions over which data to use and whether it will be readily available. In addition, the feasibility of performing a comprehensive review within a timeline that maintains the Building Regulations’ relevance to each other and contemporary climatic conditions is a significant factor.

However, action still needs to be taken. While the Building Regulations may not be able to be revised in their entirety simultaneously, they can increase resilience incrementally against some of the extreme events that characterise various aspects of climate change. It is also generally more cost-effective to incorporate climate mitigation and adaptation measures at the design and build phase, which is a persuasive argument for adopting no-regrets construction-related policies. In terms of cost, legislation will ensure that no party is disadvantaged; all will have the same opportunities because they will all be bearing the same climate change-related construction costs.

Regulatory revision will ensure adaptation measures are incorporated into new construction projects, while retrofitting should be considered as a strategy to adapt current building stock. Retrofitting could also be viewed as a mitigation strategy, off-setting the potential economic effects of climate impacts by increasing insurability. In terms of construction activity, there should be significant opportunities for the industry as structures are designed and built and retrofitted to higher specifications to meet the projected climate extremes. In addition, the Renovation, Maintenance and Improvements sub-sector (RMI) should gain impetus.

Analysis of the Building Control Regulations has shown that without a proper enforcement regime it is not possible to ascertain whether proper construction standards have been adhered to. While the Building Regulations may be comprehensive, unless best practice is enforced the finished product may still not offer the resilience required. It is therefore incumbent on the Government to reinforce the Building Control Regulations in line with the standards applied in other European countries, where 100% inspection rates are generally implemented. Only through measures such as this will modifications to the Building Regulations have the desired effect.

In a spatial context, based on analysis in earlier chapters, it can be seen that regional variations are quite distinct. Regional modifications of the Regulations may therefore seem an appropriate strategy. For example, severe wind-driven rain is an issue in the west that with climate change will progress steadily eastwards. Parts A, C and D in particular of the Regulations will require careful adherence and enforcement in such areas, so it could be appropriate to modify regulations to reflect this. More zones of vulnerability in terms of septic tanks locations will also become apparent. Part H and the EPA Code of Practice will become particularly important instruments in these cases. Given the above it would appear that there is a case for regulations to be tailored regionally, but this is problematic. For example, wind-driven rain is site-specific and local factors have a large influence. As highlighted in Chapter 3, a site in an exposed area may receive less WDR than a location in a less exposed zone. This could lead to over-adaptation in the former case and under- in the latter. It can be seen therefore that it is not practicable to advocate the regionalisation of the building regulations, despite the apparent benefits of doing so.

It is relatively straightforward to modify the Building Regulations. They are performance based and couched in terms of general statements of intent or broad functional requirements, so the incorporation of an explicit phrase such as 'climate change must be mitigated for' would be relatively straightforward. The complexity lies in compliance, where the codes and standards that inform the TGDs would need extensive investigation by practising engineers using the latest climate data. Despite such complexities, organisations such as Scotland's Building Standards Division are advocating considering climate change in all Building Regulations reviews. This is the stance that the Irish regulatory authorities need to adopt if Ireland's construction industry is to deliver stock that is appropriate for projected climate regimes. Only when the Building Regulations have been revised to account for climate change, and the Building Control Regulations revised to enforce legislation sufficiently, will there be the requisite resilience in the built environment.

CHAPTER 6
DISCUSSION AND FINAL CONCLUSIONS

6 DISCUSSION: MAJOR FINDINGS OF THE STUDY

6.1 Introduction

This research into the impact of climate change on the construction industry in Ireland resulted in some unexpected avenues of investigation. Wind-driven rain was perhaps an obvious phenomenon that would merit evaluation, as were the Building Regulations, but domestic wastewater treatment arguably was not. This led to a tripartite thesis structure in which diverse yet connected areas were assessed.

In a spatial context, it was shown that climate change impacts can be expected nationwide. Varying degrees of severity are projected, but by mid-century it is anticipated that all regions will be subjected to a different climatology than they experience currently. In a construction context, climate change will have impacts beyond material considerations. Such impacts will affect not just how we will build in the future but also where. Naturally, each of the three areas investigated also produced findings peculiar to their own context. In the interests of clarity these will be discussed separately, although common themes will be highlighted.

6.1.1 Wind-driven rain

The principal finding is that during the course of this century higher wind speeds and rainfall intensities are projected by the model used in this research to advance inland, creating WDR conditions experienced previously only in exposed coastal locations. This finding is important because it gives a spatial context to the development of mitigation and adaptation strategies designed to protect buildings from the effects of WDR.

6.1.1.1 Airfield and Spell Index mapping

The mapped outputs of observed and projected precipitation and wind support the principal finding. The eastwards progression of increasing severity indicated in the mapping results will bring more locations into higher exposure zones, meaning that more buildings will come under increasing levels of physical and chemical attack. The result is that structures designed initially for a certain level of exposure may be under-designed for future climatic environments. This will lead to a higher failure rate of components such as roofs and outer leafs, and result in increased penetration through door frames, windows and gaps in masonry.

Values for WDR do not increase significantly between 2021-2040 and 2041-2060. However, the levels of driving rain expected in this period means that adaptation is still necessary, and emerging results from contemporary models such as WRF indicate sustained levels of severity post-2060. For these reasons it is imperative not to lose the adaptation narrative despite the modelling limitations outlined here.

An area of large uncertainty lies in the calculation of the Spell Index. The model failed to capture the temporal variation in precipitation sufficiently to identify the number of spells that may reasonably be expected in future, based on 1961-1990 observed spell frequencies. However, the assumption of a worst-case scenario with regard to wind when calculating the observed index resulted in an in-built margin of safety. This should not lead to complacency though. For example, based on evidence of climate change in the Holocene, Maslin (2001: 125) hypothesised that a dramatic change in climate may occur ‘over just a decade or two’. Given that climate science is at the stage where it is not a question of whether the climate is changing but of when, by how much and at what rate, the case for mitigation and adaptation grows stronger despite the limitations of model skills.

6.1.1.2 Exemplar study: County Mayo

The built environment in County Mayo will be one of the first to display the effects of increased wind-driven rain as a result of climate change. It is therefore reasonable to suggest that Count Mayo acts as a focus for built environment climate change research in Ireland. Evaluation of buildings in this context would give an insight into how the built environment constructed under current regulations is reacting to climate change. Observations made could be included into best construction practice, and the Building Regulations amended to reflect changes necessary. Modifications based upon assessment in this context, with a suitable margin of safety incorporated, may suffice to inform adaptation until such time as more refined model outputs are available. An alternative would be to construct a purpose-built research area comparable with the BRE's Innovation Park in Watford, or evaluate solutions developed in countries such as Scotland and Norway where more severe conditions are experienced.

6.1.1.3 Limitations and further work

In comparison to the site-specific wind roses illustrated in EN ISO 15927-3:2009, the Index calculated in this research can be considered as coarse resolution. This is due to the limited synoptic station network in Ireland, of which there are only 13 that have the long term records of coincident wind and rain necessary for the calculation of a baseline index. In future however, wind-driven rain calculations may be able to source data from the network of several hundred weather stations in Ireland, leading to a higher Index resolution. This assertion is based on consensus gaining momentum in the current literature that wind projections are too uncertain to be used for climate projections, and that calculations instead may be based on precipitation only. This would negate the need to source data purely from synoptic stations. Indeed, as long ago as 2004 it was noted that 'the current wind climate change scenarios [UKCIP02] are tentative on wind changes and therefore are not an adequate basis for making long-term decisions' (DTI, 2004: 8). Contemporary views in Scotland bear this out. 'Changes to wind are less certain than rainfall and therefore new approaches to assessing wind-driven rain should be based upon changes to precipitation only' (BSD, 2012: 9). Given that stronger than average winds are usually associated with prolonged rainfall (BSI, 1992), it could be argued that this is a reasonable position to take.

Should this come to pass, it will be interesting to observe when modelling for WDR whether the wind angle contained in EN ISO 15927-3:2009 will be given the default value '1', as in this study, or whether another method for calculating wind-driven rain will be developed to account for the inherent uncertainty. Either way, the current discourse appears to validate the approach adopted in this research for modelling WDR, whereby a worst-case scenario was adopted that would result in no-regrets mitigation and adaptation measures. That said, it must be noted that advances in CFD, combined with ever-increasing computer power, are making CFD an increasingly viable option. For example, work by Kubilay *et al* (2013) utilised CFD successfully to model WDR on a tower in the Netherlands. Nonetheless, CFD results such as these still require validation by semi-empirical investigations, which produce results such as those contained in this research.

Notwithstanding the limitations outlined above, this research on wind-driven rain could nonetheless form the basis of further study in this area. In addition to utilising the wide network of weather stations, site-specific driving rain maps could be created by incorporating geographical factors that could be translated into increments for use with the Map Indexes. This would result in a finer scale Map Index that could be used as a more accurate decision support tool that better informs planners and policymakers.

6.1.2 Domestic wastewater management

The principal finding is that projected increases in winter rainfall will lead to more zones of vulnerability being created in the context of groundwater contamination. This finding is important because the result will be a contraction in spatial opportunity for future construction in some rural areas. A consequence may be a shift in construction geographies to more urban regions, and limited opportunity in local areas for the accommodation of a growing population.

6.1.2.1 Septic tank density mapping

The results of the national septic tank density map support the principal finding. Regions were identified where septic tank densities were greater than $16/km^2$. In such areas, more construction and consequent installation of more septic tanks could lead to a greater threat to groundwater quality. There is therefore less likelihood of getting planning permission in these areas.

At the outset of this research it was anticipated that the density mapping would illustrate high rural septic tank densities, but this was not the case. High densities were observed instead in cities and in peri-urban zones, where accelerated construction had taken place in the late 1990s and 2000s. This has led to the current situation whereby domestic wastewater treatment is the responsibility of the householder rather than the Local Authority in these areas. However, while STDs may be higher around urban centres indicating high risk, a low STD at ED level in rural zones does not necessarily indicate low risk. Mapping at a more refined scale in the Athenry exemplar study revealed significant clustering of systems. This resulted in higher septic tank densities locally than ED-level density analysis would suggest. The situation in areas such as these is likely to be exacerbated by projected increases in precipitation which could lead to a higher risk of contamination. Such risks increase the likelihood that construction will be prohibited or at the very least restricted in these areas, leading to reduced opportunity for the industry in future.

An issue that will also become apparent as the climate changes is pressures from peri-urban septic tank locations. As illustrated in the national septic tank density map, densities are greatest overall in the peri-urban areas of towns and cities. Unless eventually connected to mains sewerage however, these high density areas could pose significant problems with respect to hydraulic loading. Although these settlements tend to be connected to treated mains water for domestic use, the discharge of large volumes of effluent into an increasingly stressed environmental system is nonetheless undesirable. WFD groundwater status is already classified as moderate to severe in cities located within the study areas. As water stress during summer is projected to increase across Ireland due to lower rainfall and higher temperatures as a result of climate change, particularly in the south-east, water sources require increased protection to maximise the available resources. A heightened risk of contamination of such resources must therefore be avoided. Construction of additional wastewater treatment plants appears the appropriate solution in this instance, investment in which is required if wastewater infrastructure is to be completed in time to fulfil WFD water quality aims. Moreover, unless wastewater treatment plants are also constructed in rural zones, the sustainability of rural settlements will suffer as populations increase and migrate due to lack of housing prospects.

An example of extreme planning restrictions that could result in such migration can be found in County Leitrim. Septic tanks were deemed a threat to surface water quality rather than groundwater in this case, but nonetheless unsuitable for use in one-off rural housing construction. The result was a blanket ban on development outside sewered areas. As expected, this drastic action generated intense discussion. A three-year EPA funded project into solutions for the treatment of domestic wastewater in low permeability subsoils was the outcome. Although the ban was withdrawn after much debate, this case serves to emphasise the critical role of wastewater treatment in Ireland, and why climate change is so important to consider in the context of septic tanks and rural housing construction.

6.1.2.2 The Groundwater Vulnerability Index

The development of the Groundwater Vulnerability Index drew on three factors: septic tank density; projected precipitation increase; and WFD score. The results of the Index support the principal finding, in that an increase in septic tank density and/or precipitation would result in greater vulnerability to groundwater contamination. While regions classed as 'Moderate' outnumber those classed as 'High' by 2:1, an increase in either of the aforementioned factors could raise the threat level in 'Moderate' zones to 'High'. In such instances, more zones of vulnerability would be created, leading to an increased threat to human health and the environment.

Although the aim of the Index was to give a broad view of vulnerability nationally, and act as a primary indicator of where developers may get the best return on investment in terms of investigating new sites for construction projects, anomalies are apparent. Counties Cavan and Longford for example are classed as 'Very Low' vulnerability, yet feature aspects that would appear to indicate high vulnerability to septic tank effluent. In the case of Cavan, while it does indeed have a high proportion of low permeability subsoils that would ordinarily compromise effective septic tank operation, it also has a septic tank inspection regime that monitors septic tank operation within the county. In the European Court of Justice's judgement against Ireland regarding the implementation of wastewater legislation, County Cavan was excepted from the ruling for this reason. Cavan also introduced a bylaw in 2004 which stated that any property within 100 m of mains sewerage must be connected to the mains. In the context of the Vulnerability Index, it could be argued that its WFD score of 'Probably not at risk' is a result of its bylaw and septic tank inspection programme. Contributing further to its 'Very Low' Index ranking, Cavan features a low STD and is located centrally, away from the most intense projected precipitation increases.

In the case of County Longford, high water table and flooding are historically an issue. However, the septic tank density is relatively low, it is not projected to receive a large increase in precipitation and its WFD score is 'Probably not at risk', leading to a 'Very Low' ranking in the Index. This nonetheless illustrates the precarious nature of the relationship between septic tanks and groundwater. Should the model projection used in this research underestimate the quantity of precipitation increase, and the water table in Longford rises to within a metre or so of ground level due to a greater quantity of precipitation than projected, septic tanks would be discharging partially treated effluent direct to groundwater. This would immediately reclassify the area as ‘High’ vulnerability, although by this stage the value in doing so would be nil.

The Longford example brings to the fore the issue of the existing groundwater monitoring network. There are only 64 stations in Ireland that monitor water table level, mainly concentrated around vulnerable aquifers. Due to this limited distribution they were not employed as a factor in risk evaluation at the national scale in this study. Crucially though, this means that potentially high risk areas, which could include sites in County Longford, may exist but remain undetected due to the limitations of the groundwater monitoring network.

6.1.2.3 Limitations and further work

Although the precipitation projections used in this part of the study represent the most comprehensive outputs available for Ireland currently, and are based on a 10 km grid rather than synoptic stations as is the case with wind-driven rain, the use of a single model is nonetheless a limiting factor. An ENSEMBLES approach, as advocated in the current literature (e.g. McGrath *et al.*, 2008; Fealy, 2010; Foley, 2010) would provide a lower risk approach to precipitation projections. Use of ENSEMBLES data would be part of the focus of further work in this area. Another significant limitation identified was the groundwater monitoring network. 64 stations monitoring groundwater in Ireland, even though located generally proximate to vulnerable aquifers, would appear too few to provide a reliable overview of water table levels. Such a network is also insufficient to provide an indication of the types of response that can be expected from water tables to the quantity of rainfall that is projected for the periods in this study. Although local knowledge is invaluable for identifying current areas of concern, identifying potential zones of vulnerability 50 years hence requires a wider data gathering network.

6.1.3 The Building Regulations

The principal finding is that despite projections of increased winter wind speed and rain intensity and higher mean winter and summer temperatures, the Building Regulations are fit for purpose and require little modification. It is the Building Control Regulations, Technical Guidance Documents and Codes and Standards that require review. This finding is important because it places the onus of revision on practising engineers rather than policymakers, although policy would require drafting to create the milieu for regulatory revision to take place. The fact that Part L has already been extensively modified however with the aim of fulfilling Ireland's 20-20-20 objectives demonstrates the feasibility of creating such an environment.

6.1.3.1 Wind-driven rain and domestic wastewater treatment

Recommendations made in the context of wind-driven rain and wastewater treatment support the principal finding. Through analysis of the two areas it was shown that the intent of the Building Regulations remained valid under changed climate conditions, but that to effect change required modification to the TGDs and the Codes and Standards that inform them. A quantitative estimation would be necessary before modifications could be made, in which case the driving rain and septic tank density maps would assist such an assessment. Despite the use of spatial context in such evaluation, a further important finding was that it is not viable to regionalise the Building Regulations. Local factors such as topography and the existing built environment generate issues at the local scale which could not be accounted for in regional regulations.

Amending regulatory instruments is critical in any attempt to adapt the built environment to climate change. Without suitable regulation and enforcement, sub-optimal construction could be the result. As an economic entity the construction industry tends to focus understandably on issues of cost even when critical issues such as climate change are being considered. As an example, in its 2011 pre-budget submission the Construction Industry Federation (CIF) commented that proposals such as 'higher standards of Building Regulation requirements' that resulted in higher construction costs 'must be deferred until the economic climate is fit to absorb such costs' (CIF, 2010: 5). While this outlook may be commendable in representing the vested interests of the industry, it does not serve the interests of end-users, who will have to inhabit buildings that are not resilient to future climates. Moral and ethical arguments lie outside the competence of this research but the issue of short-term cost concerns over long-term durability is nonetheless worthy of mention.

Although one of the principal foci of this study is the Building Regulations, it is apparent that the Building Control Regulations also require revision. An end to the virtual self-certification of developments is a prerequisite to more robust construction, particularly in a climate change context, which means that the agreed inspection targets of 12-15% of new builds should be rescinded and inspection rates brought into line with established European standards. To ensure the likelihood of robust construction in the future, Local Authorities need to sign off building work thereby providing an independent assurance that work meets the required standard. This is critical in a climate change context where impacts due to adverse conditions are projected to get worse, putting buildings under increased physical and chemical stress.

Although regulatory recommendations have been made they cannot mitigate for climate shocks such as major floods and severe winds. They can, however, incrementally increase resilience against some of the extreme events that characterise various aspects of climate change. In addition, contrary to the CIF's argument against raising standards, it could be argued that amending the regulations will have few negative economic implications. Legislation will ensure that no party is disadvantaged; all will have the same opportunities because they will be bearing the same resilience-associated costs.

6.1.3.2 Limitations and further work

All parts of the Building Regulations 1997-2012 were evaluated in the context of climate change. The TGDs, Codes and Standards relevant to wind-driven rain and domestic wastewater treatment were also evaluated. However, due to the extensive nature of the supporting documents it was not possible to evaluate all codes and standards that apply to construction. This will be addressed in further work, which will aim to identify additional critical areas for review.

6.2 Synopsis of principal findings related to similar studies

The principal findings in this research have been discussed previously at the end of each study area's chapter. A brief synopsis will be given however to give context to points raised in the Final Conclusions.

Wind-driven rain

The most recent similar study in this area is Met Éireann's Distribution of Driving Rain in Ireland (Met Éireann, 2010). However, it was generated using annually averaged data, which typically leads to the underestimation of driving rain indices. Driving rain calculated in this research uses the hourly product method specified by ISO 15927-3:2009, which gives results typically 26% higher, and sometimes 50%, than those obtained by the 'annual product' method. The maps produced in this research are, to the author's knowledge, the first to incorporate and map such hourly values, as well as a climate change component. This research therefore adds to Met Éireann's work by heightening temporal resolution and employing modelled climate outputs to test future time periods.

Domestic wastewater treatment

Septic tanks are a peculiarly Irish issue. To illustrate, a question on the Irish census form requires the input of housing sewerage type, which the England and Wales census does not. This means that Ireland is somewhat uniquely positioned to map its septic tanks, in contrast to the UK. In other European countries, for instance Germany, rural housing has to be connected to either mains sewerage or a decentralised wastewater treatment network. Septic tanks are not permitted for domestic use. As such, the maps produced in this research are therefore unique to the Irish context and the work here can only be compared with previous Irish work. In this regard, maps produced for the River Basin Districts (RBDs) are comparable, such as those produced for Shannon RBD. However, such maps did not have climate change data applied and only served to illustrate unsewered sites. This research adds to the previous work by calculating septic tank density nationally at Electoral Division resolution, analysing an exemplar area at finer resolution, and layering data in GIS to highlight areas at greater risk. This study also provides additional analysis and interpretation in the context of impacts on the construction industry.

The Building Regulations 1997-2012

In contrast to the two previous study areas, the Building Regulations are reviewed continually by a large body of personnel within the Department of the Environment, Community and Local Government (DECLG). Regular revisions are also considered by the Building Regulations Advisory Body (BRAB), which comprises 25 persons. As highlighted in the research chapter however, only historical climate data is used in such regulatory review. This research contributes to knowledge by analysing the Building Regulations in the context of climate change. The study adds a further contribution by evaluating the Technical Guidance Documents, Building Control Regulations and Codes and Standards relevant to the areas under study in the context of the construction industry.

6.3 Final conclusions

For robust mitigation and adaptation in the context of construction and climate change, a no-regrets approach is advocated. A sector in which the final product is designed to last at least 60 years does not support a modelling narrative in which model skill, scenarios and outputs are developing constantly. Moreover, due to the nature of a product that is designed for long-term durability, it will be many years before we know whether mal-adaptation has taken place. In a construction context, the cost of over-adaptation is minimal compared to the cost of under-adaptation.

The over-riding contemporary concern within the industry is survival, not climate change. This inertia will have to be overcome before mitigation and adaptation strategies can be effective. This lends weight to the recommendations in this research being enshrined in legislation and incorporated into policy.

Through analysis of wind-driven rain, domestic wastewater treatment and the Building Regulations this research has identified for the first time in Ireland inter-linked spatial and temporal issues that may have a significant impact on the construction industry in the context of climate change. Increases in zones of wind-driven rain and areas increasingly vulnerable to groundwater contamination will place a premium on land suitable for development, creating a higher demand for space that is likely to exacerbate impacts created by climatic changes. Tighter planning and Building Regulations will also place more pressure on the industry. Moreover, the development capacity of Ireland in terms of unit area is likely to fall, particularly in rural areas, the consequence of which will be higher land prices and a shift toward urban development. However, opportunities also exist. The retrofitting of buildings in the context of wind-driven rain and remedial actions with respect to septic tanks offer significant revenue streams. The inclusion of no-regrets adaptation measures at the planning and design stage too can be considered an opportunity to make a step-change in construction practice. If planners and policymakers are cognisant of the issues surrounding projections of more severe wind-driven rain and a greater threat to groundwater from septic tanks, and make the necessary regulatory modifications, the result should be a built environment in Ireland that is as climate-proof as is reasonably practicable.

APPENDIX I

Sample numerical values and calculations used to derive the modelled Airfield Annual Index (I_A) and the Annual Map Index (m_A) for the period 2021-2040.

Year	***vr*8/9**	***v* m/s (coincident with *r*)**	***r* mm**
2021	4855.1	5.4	2103.5
2022	4307.3	5.2	1898.2
2023	4596.6	5.2	2067.0
2024	5332.7	5.5	2282.1
2025	3704.4	5.1	1646.9
2026	3647.4	5.1	1630.1
2027	5657.7	5.8	2325.7
2028	4010.0	5.2	1780.3
2029	3692.5	4.9	1740.0
2030	4130.9	5.1	1871.1
2031	5024.5	5.5	2128.5
2032	3681.7	5.0	1699.2
2033	4717.4	5.5	2014.1
2034	3722.2	5.0	1688.4
2035	3522.4	5.2	1546.5
2036	3621.0	5.1	1628.8
2037	4865.2	5.4	2118.7
2038	3986.8	5.0	1826.1
2039	4039.7	5.3	1753.9
2040	3928.3	5.2	1713.2
		5.2	**37462.2**
	Sum *vr*8/9		
	85044.0		
No of years of data (N)	***vr*8/9/N**		
20	4252.2		
Multiply by Lacy's constant	0.222		
Airfield Annual Index I_A (l/m2/y)	**944.0**		
IA/200	4.720		
log10	0.674		
(19.93)+6	19.432		
Annual Map Index m_A	**20**		

APPENDIX II

Sample of the coordinates and numerical values used to derive the mapped precipitation increase for the period 2041-2060 over the 1961-1990 baseline, where:

Precip_winter_6190: Average winter precipitation receipt for 1961-1990.
Precip_4160: Average winter precipitation receipt for 2041-2060.
Pct_Inc_6190-4160: Percentage increase in average precipitation receipt during the periods 1961-1990 and 2041-2060.

Easting	Northing	Precip_winter_6190	Precip_4160	Pct_Inc_6190-4160
25000	95000	125.19	146.24	17
25000	105000	124.46	145.07	17
35000	65000	124.58	145.08	16
35000	75000	127.76	150.96	18
35000	95000	126.65	150.20	19
35000	105000	124.33	146.68	18
35000	115000	122.73	143.87	17
45000	35000	118.51	136.60	15
45000	45000	121.78	140.98	16
45000	55000	126.00	147.67	17
45000	65000	132.07	157.56	19
45000	75000	134.81	162.32	20
45000	85000	134.27	161.91	21
45000	95000	132.28	158.35	20
45000	105000	126.92	151.23	19
45000	115000	130.23	154.44	19
45000	265000	119.55	139.68	17
55000	35000	119.29	137.98	16
55000	45000	124.68	146.38	17
55000	55000	131.81	157.63	20
55000	65000	140.66	170.82	21
55000	75000	144.57	177.02	22
55000	85000	144.30	174.74	21
55000	95000	138.51	166.05	20
55000	105000	131.93	156.29	18
55000	115000	165.31	197.39	19
55000	245000	118.69	138.65	17

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BSD	Building Standards Division.
BSI	British Standards Institute.
CEC	Commission of the European Communities.
CIF	Construction Industry Federation.
CSC	Climate Service Centre.
CSES	Centre for Strategy and Evaluation Services.
CSO	Central Statistics Office.
CTMA	Concrete Tile Manufacturers Association.
DECLG	Department of the Environment, Community and Local Government.
DEHLG	Department of the Environment, Heritage and Local Government.
DELG	Department of the Environment and Local Government.
DKM	DKM Economic Consultants.
DOE	Department of the Environment.
DTI	Department of Trade and Industry.
EC	European Commission.
EOLAS	The Irish Science and Technology Agency.
EPA	Environmental Protection Agency.
EU	European Union.
FIEC	*Fédération de l'Industrie Européenne de la Construction* (European Construction Industry Federation).
IAE	Irish Academy of Engineers.
IAH	International Association of Hydrogeologists.
IIRS	Institute for Industrial Research and Standards.
LEARN	Low Energy Architecture Research Unit.
NBS	National Building Specification.
NESC	National Economic and Social Council.
NSAI	National Standards Authority of Ireland.

RAE	Royal Academy of Engineers.
RTE	Radio Telefis Éireann.
SCSI	Society of Chartered Surveyors Ireland.
SI	Statutory Instrument.
TGD	Technical Guidance Document.
UKCIP	United Kingdom Climate Impacts Programme.
UNDP	United Nations Development Programme.
UNEP	United Nations Environment Programme.
UNFCCC	United Nations Framework Convention on Climate Change.
US EPA	United States Environmental Protection Agency.
WMO	World Meteorological Organisation.
WRF	Weather Research and Forecasting (model).

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