# Appendix 5C

# Climate Change Report



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# POSSIBLE IMPLICATIONS OF CLIMATE CHANGE FOR CONSIDERATION IN THE DESIGN OF A WASTE WATER TREATMENT PLANT IN CORK LOWER HARBOUR, COUNTY CORK.

PERFORMED BY ODOUR MONITORING IRELAND ON BEHALF OF MOTT MCDONALD PETTIT CONSULTING ENGINEERING, CORK.

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# 1. Climate in Ireland

Climate is constantly changing. The signal that indicates that the changes are occurring can be evaluated over a range of temporal and spatial scales. We can consider climate to be an integration of complex weather conditions averaged over a significant area of the earth (typically in the region of 100 km2 or more), expressed in terms of both the *mean* of weather expressed by properties such as temperature, radiation, atmospheric pressure, wind, humidity, rainfall and cloudiness (amongst others) and the *distribution*, or range of variation, of these properties, usually calculated over a period of 30 years. As the frequency and magnitude of seemingly unremarkable events change, such as rainstorms, the mean and distribution that characterise a particular climate will start to change. Thus climate, as we define it, is influenced by events occurring over periods of hours, through to global processes taking centuries.

Over the millennia natural processes have driven changes in climate, and these mechanisms continue to cause change. "Climate change" as a term in common usage over much of the world is now taken to mean *anthropogenically* driven change in climate.
Evidence for an anthropogenic influence on climate change is now stronger than ever before, with the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report assertion that 'It is very likely that anthropogenic greenhouse gas increases caused most of the observed increase in globally averaged temperatures since the mid-20th century' (IPCC, 2007a). Global average temperature has increased by 0.74°C over the past 100 years with the rate of warming almost doubling over the last 50 years. Precipitation patterns have also changed with an increase in the number of heavy precipitation events being observed globally. Sweeney *et al* (2003) summed up the evidence of our changing climate with the following key points.



* Global average temperature has increased by 0.6°C ±0.2°C since 1860 with accelerated warming apparent in the latter decades of the 20th century. A further increase of 1.5-6.0°C from 1990 to 2100 is projected, depending on how emissions of greenhouse gases increase over the period.

* The last century was the warmest of the last millennium in the Northern Hemisphere, with the 1990s being the warmest decade and 1998 being the warmest year. Warming has been more pronounced at night than during the day.

* Reductions in the extent of snow cover of 10% have occurred in the past 40 years concurrent with a widespread retreat of mountain glaciers outside the Polar Regions. Sea-ice thickness in the Arctic has declined by about 40% during late summer/early autumn, though no comparable reduction has taken place in winter. These trends are considered likely to continue. In the Antarctic, no similar trends have been observed. One of the most serious impacts on global sea level could occur from a catastrophic failure of grounded ice in West Antarctica. This is, however, considered unlikely over the coming century.

* Global sea level has risen by 0.1-0.2m over the past century, an order of magnitude larger than the average rate over the past three millennia. A rise of approximately 0.5m is considered likely during the period 1990-2100.

* Precipitation has increased over the landmasses of the temperate regions by 0.5-1.0% per decade. Frequencies of more intense rainfall events appear to be increasing also in the Northern Hemisphere. In contrast, decreases in rainfall over the tropics have been observed, though this trend has weakened in recent years. More frequent warm phase El Niño events are occurring in the Pacific Basin. Precipitation increases are projected, particularly for winter, for northern middle and high latitudes and for Antarctica.

* No significant trends in the tropical cyclone climatology have been detected.
As a mid latitude country, these global trends have implications for the future course of Irish climate, and for a range of impacts which it is judicious to anticipate (Sweeney et al 2003).

A recent report published by the EPA (McElwain and Sweeney, 2007) summarised the indicators of climate change in Ireland and summarised the changes in climate over recent years.

- Ireland's mean annual temperature has increased by 0.7°C between 1890 and 2004.
- The average rate of increase is 0.06°C per decade. However, as Ireland experiences considerable climate variability, the trend is not linear. The highest decadal rate of increase has occurred since 1980, with a warming rate of 0.42°C per decade.
- The warmest year on record was 1945, although 6 of the 10 warmest years have occurred since 1990.
- An alteration of the temperature distribution has occurred, with a differential warming rate between maximum and minimum temperatures. Minimum temperatures are increasing more than maximum temperatures in spring, summer and autumn, while maximum temperatures are increasing more than minimum temperatures in winter.
- There has been a reduction in the number of frost days and a shortening of the frost season length.
- The annual precipitation has increased on the north and west coasts, with decreases or small increases in the south and east.
- The wetter conditions on the west and north coastal regions appear due to increases in rainfall intensity and persistence.
- There is an increase in precipitation events over 10 mm on the west coast with decreases on the east coast, there is an increase in the amount of rain per rain day on the west coast, and a greater increase in number of events greater than the 90th percentile also on the west coast.

The increases in intensity and frequency of extreme precipitation events provide a cause for concern as they may have a greater impact upon the environment, society and the economy. The precipitation series however require further analysis as there is large spatial and temporal variability associated with extreme precipitation events.



## 2. Expected Climate Change in Ireland.

Current research on climate change in Ireland and Britain is in broad agreement. The climate scenarios suggest that, by the middle of the present century, mean winter temperatures will have increased by approximately 1.5°C (*see Figure 2.1*), bringing the mild conditions currently associated with the far south-west coast to almost all parts of the island. Commensurate changes in secondary parameters such as frost frequency and growing season can be expected. Summer temperature increases of approximately 2°C are suggested, with the greatest increases away from south and west coasts. Precipitation changes (*see Figure 2.2*) will perhaps have the greatest impact. Studies indicate increases during the winter months, predominantly in the northwest, of over 10%. Of greater importance, however, are projected decreases of approximately 25% in amounts of summer receipts. Geographically, these are most significant in the southeast where decreases of summer rainfall amounts in excess of 40% are anticipated over the next five decades. Coupled with increased evaporation amounts, such changes would significantly impact on a number of key sectors. Blenkinsop and Fowler (2007) predicted an increase in short summer drought frequency in all areas of the British Isles except Scotland and Northern Ireland suggesting that in future, engineers may have to plan for more intense short-term droughts, but may experience fewer long term events. The current trend of increase in frequency of extreme precipitation events is expected to continue. McGrath et al., (2005) found that the frequency of very intense cyclones/storms with core pressures less than 950 hPa is set to show a 15% increase in the future simulations with even stronger increases in winter and spring seasons.

It is expected that the main features of climate change to be experienced in the Cork Harbour region will be higher mean temperatures, milder winters, lower precipitation in summer, and an increase in storm frequency.

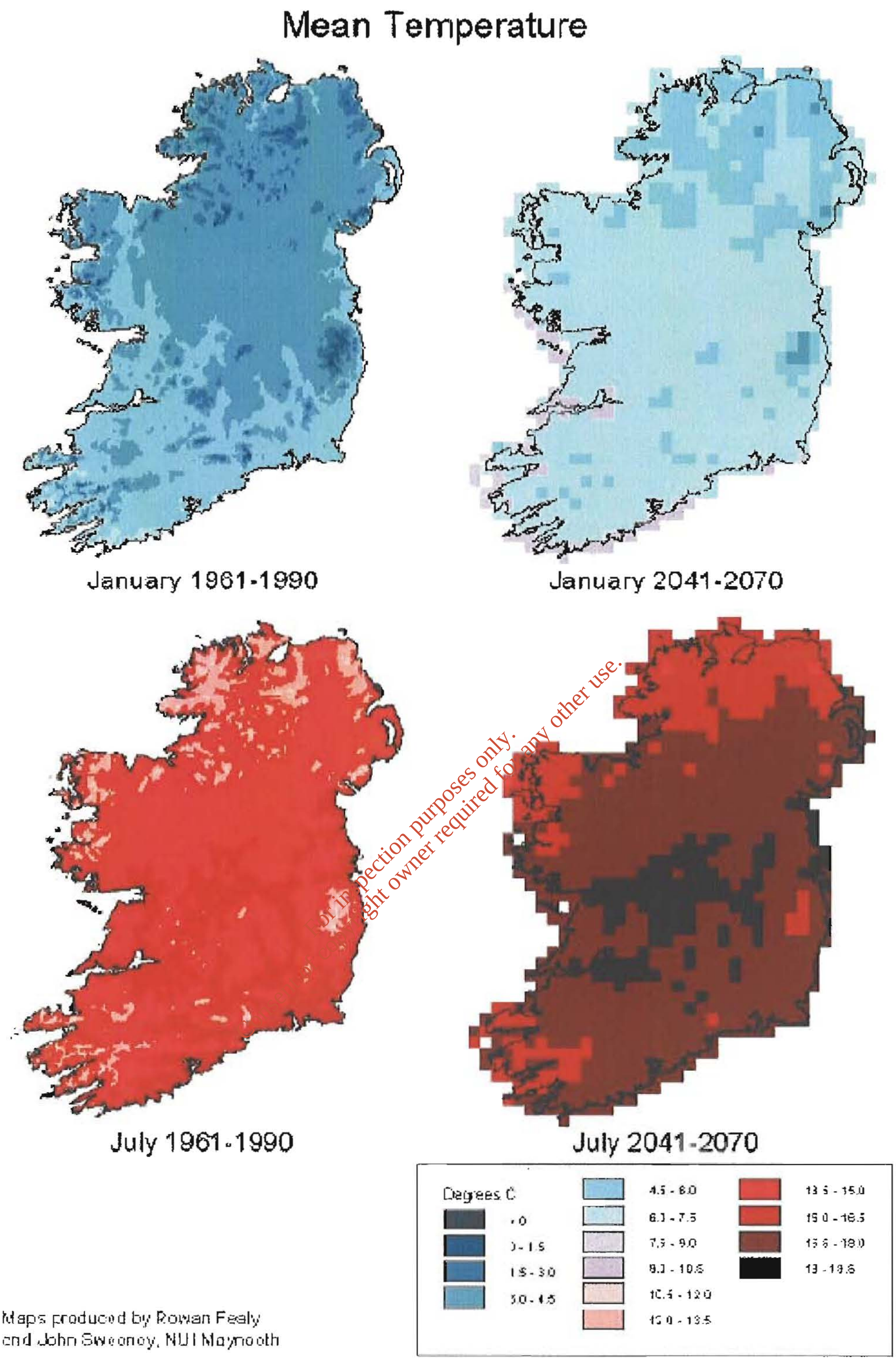




**Figure 2.1.** Downscaled mean temperature scenarios for the period 2061-2090 at a resolution of 10 km2. This approximates to the period around 2075. (Sweeney and Fealy, 2003)

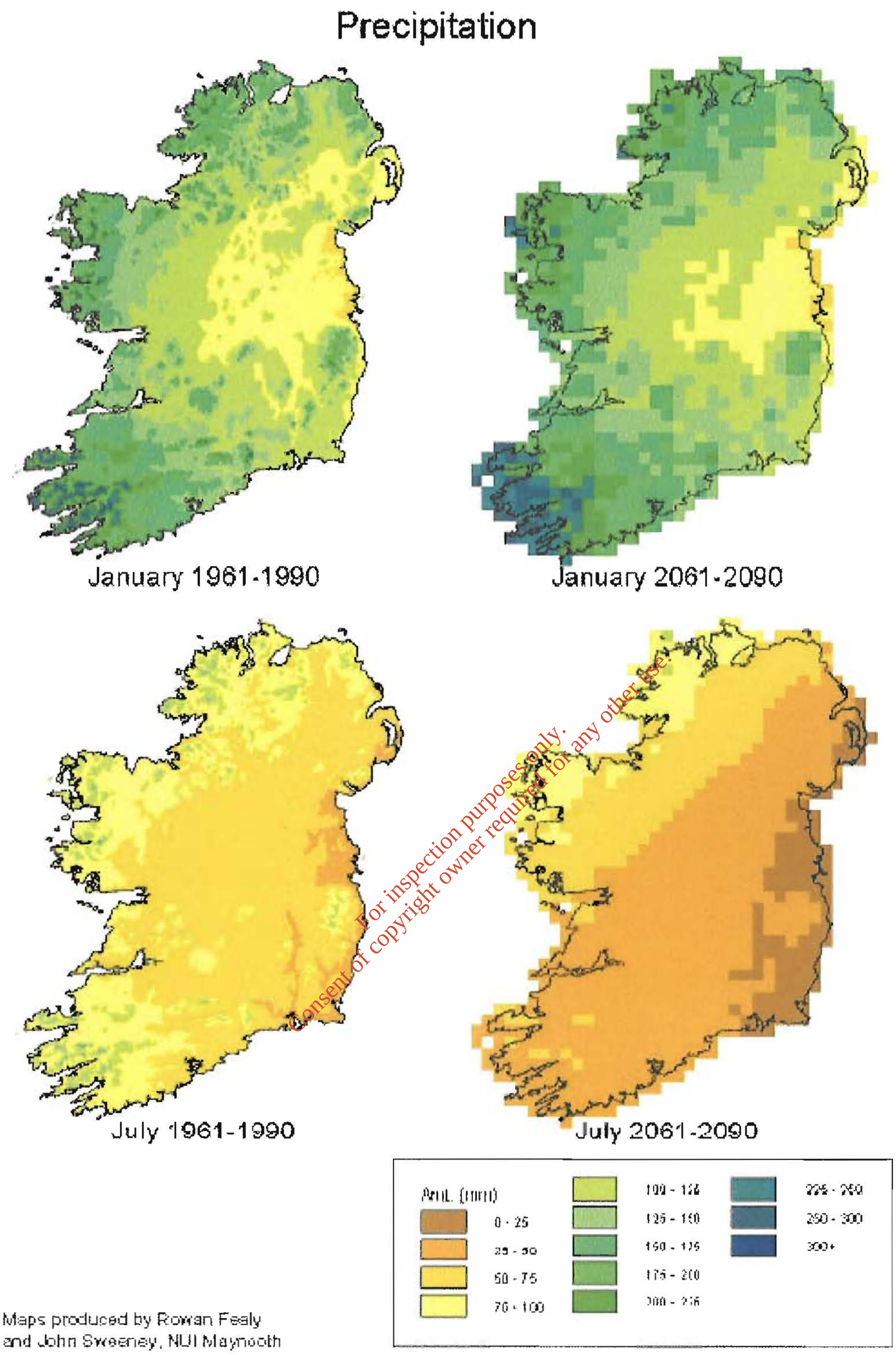


**Figure 2.2.** Downscaled precipitation scenarios for Ireland for the period 2061-2090 at a resolution of 10 km2. This approximates to the period around 2075. (Sweeney and Fealy, 2003)

## 3. The impact of climate change on hydrology.

Future changes in Irish climate are likely to have significant impacts on its hydrology. These may influence the annual and seasonal availability of water resources, with particular impacts being felt in terms of water resource management, water quality management and approaches to coping with flood/drought/storm hazards.

Ireland is relatively well endowed with water resources, however regional shortages can occur at times, especially in the east and southeast of the country, areas, which also experience the greatest population density. The rapid expansion associated with recent economic conditions of cities such as Cork and Dublin, is putting and increasing strain on the water supply infrastructure. Low flows are becoming more frequent in some areas and it is likely that future climate change will exacerbate these effects. At the same time, increases in winter precipitation particularly over the western part of the island are likely to increase the magnitude and frequency of flood events and increase the duration of seasonal flooding. Most of Ireland's present water supply comes from surface water, approximately 25% coming from groundwater. Characteristics such as soil permeability, geology and topography determine an area's response to precipitation.

Shorthouse and Arnell (1999) found that precipitation is strongly correlated with the North Atlantic Oscillation index (NAO). Increased rainfall caused by strengthened westerlies (positive NAO) has been observed for northern and western Europe, while at the same time southern Europe has experienced drying. An increase in winter storminess has also been observed by a number of authors for Ireland (Houghton and Cinneide, 1976; Sweeney, 1985; Sweeney and O'Hare, 1992; Kiely, 1999. Kiely (1999) associated the change that occurred in the North Atlantic Oscillation around 1975 with an increased westerly air-flow circulation in the northeast Atlantic which is correlated with wetter climate in Ireland. Future changes in climate are likely to have major impacts on regional and local runoff patterns. This may influence the annual and seasonal availability of water resources with significant implications for water resource use, water quality management and strategies, as well as flood/drought hazard indices in Ireland. Charlton *et al* (2006) performed a study assessing the impacts of climate change on water supply and flood hazard in Ireland. Further catchment-based research which includes analysis of climate change impacts on the hydrology of the River Blackwater is due to be published in 2007, however comprehensive data is currently unavailable. Murphy and Charlton (2006) performed an analysis of climate change impact on catchment hydrology and water resources for selected catchments, with detailed analyses of the Boyne and Suir catchments. Each of these two catchments showed a progressively increasing stream flow in January, February and March by the 2020's, 2050's and 2080s where February stream flow had increased by 25%. In contrast summer stream flows decreased markedly. The Boyne catchment showed a 50% decrease in stream flow in August in the 2080s, whereas the Suir showed the greatest decrease of around 35% in the Month of October by 2080 (Murphy and Charlton, 2006). Overall it is expected that all areas will see a significant decrease in annual runoff, which may result on long-term deficits in soil moisture, aquifers, lakes and reservoirs.
Murphy and Charlton, 2006 also analysed the impact of climate change on the magnitude of flood events. Their work gave a consistent indication that the magnitude of future flood events particularly those of a high return period (50 years) would increase significantly in the majority of catchments with little regional variation. This work may be understated as the use of ensemble GCMs and scenarios, while useful for analysis of day-to-day conditions, are less useful in capturing meteorological extremes.

These figures can be used as an indication of the potential issues facing Cork Harbour and surrounding areas in future years from a water supply perspective.

## 4. The impact of climate change on sea level and storm surge frequency and severity.

Global sea level rise is a major threat to the coastal environment and it is expected to accelerate with global warming (Church et al., 2001). Since 1993, sea level has been rising rapidly (Cabanes et al 2001) a fact that coincides with the warmest decade recorded (Hulme et al 2002). The increase in global temperatures is likely to have a huge impact on glaciers and glacier melts water during the course of the present century resulting in significant contributions to sea level rise (Fealy and Sweeney, 2005).

Sea Surface Temperature (SST) has also been showing a warming trend: Since the mid-1980s a warming trend is detectable in all seasons. In most time series this period of warming is unprecedented; 25 of the 30 time series display temperatures in this period that exceed all measurements since 1861 when the earliest of these records began. It is estimated that since 1990 there has been around a 50% chance that any given winter or summer has had a temperature in the warmest 10% of all measurements since at least 1880. In the same period, the probability of colder temperatures has decreased by around 10%. It is expected that this will lead to thermal expansion, which will continue long after 2100. Although inundation by increases in mean sea level over the 21st century and beyond will be a problem for unprotected low-lying areas, the most devastating impacts are likely to be associated with changes in extreme sea levels resulting from the passage of storms. (IPCC, 2007b).

There has been little research performed on sea level rise around the Irish coast. Projections for sea level changes around the UK have been developed using regional climate change models. In addition to the regional rise in mean sea level, changes in wind and wave climate also affect the vulnerability of various coastlines to global change. Storm surges and set-up associated with waves contribute to the sea level in coastal waters and especially at the coast. Wave heights in the northeast Atlantic have increased since the 1960s (Bacon & Carter 1993; Woolf *et al.* 2002.). It is not clear whether climate change will affect the global distribution of waves.



The severity of the impact of sea-level rise at any location will depend on whether the land is locally lifting or subsiding, and on changes in wind and wave factors. The relative importance of the various forcing mechanisms varies from site to site. In order to assess the impact of global climate change on a particular coastal environment therefore, it is important to identify and estimate the contribution of regional climatic changes.

The IPCC estimates a global sea level rise of between 0.1 and 0.9 metres in the period 1990-2100 from the full range of emissions scenarios (IPCC 2001). Their calculated sea level change is due mainly to thermal expansion of ocean water, melting of glaciers and ice caps, with little change in ice sheet volume. The consequences of sea level rise are severe and long lasting with serious implications for coastal communities, loss of land and coastal erosion (McElwain and Sweeney, 2006). The century scale rise in average sea level may threaten some low-lying unprotected coastal areas, yet it is the extremes of sea level – storm surges and large waves- that will cause most damage. The modelling of future changes in extreme sea levels is therefore of high importance, although the uncertainties in modelling such changes remain very large. A surge is generated when meteorological variables, such as barometric pressure and wind, depart substantially from average conditions. This can produce negative or positive surge conditions. The effects of a storm surge as it moves onshore are dependant on a number of factors. These include strength and direction of an onshore wind, local topographical features, occurrence with a spring or neap tide, and location of the tidal bulge. The elevation of a storm surge can also be greatly enhanced if it becomes coupled with wind waves. The duration of the surge event also contributes to its damage potential. At present, a storm surge of 2.6m has a return period of 100 years, but Orford (1988) expects this to decrease to a return period of 1-2 years by 2100. Hulme *et al* (2002) found that the largest increases in surge heights would occur off the southeast coast of the UK. They estimated that there would be an increase of 0.3 m in height of storm surges of a 50-year return period using a medium emissions scenario. The UK CIP project also found for a high emissions scenario, that by 2100, a storm with a current 50-year return period would occur more than once a year. It is important to note however, that the uncertainties associated with modelling storm surges are very large however as these are the most potentially damaging effects of climate change, these predictions should not be discounted on account of uncertainty. An increase in the incidence of extreme events has already been noted and it is expected that this trend will continue.

Fealy (2003) identified harbours that may be susceptible to inundation over the next 100 years, including the Carrigaline region of Cork Harbour. A 5-10% probability of inundation was identified in some areas of Carrigaline with a sea level rise of 0.48 m (*see Figure 4.1*). This increased to a 10-20% probability with a sea level rise of 0.88 m (*see Figure 4.2*). A 2.6 metre storm surge coupled with a sea level rise of 0.48 m showed all areas of Carrigaline at risk of inundation (*see Figure 4.3*).

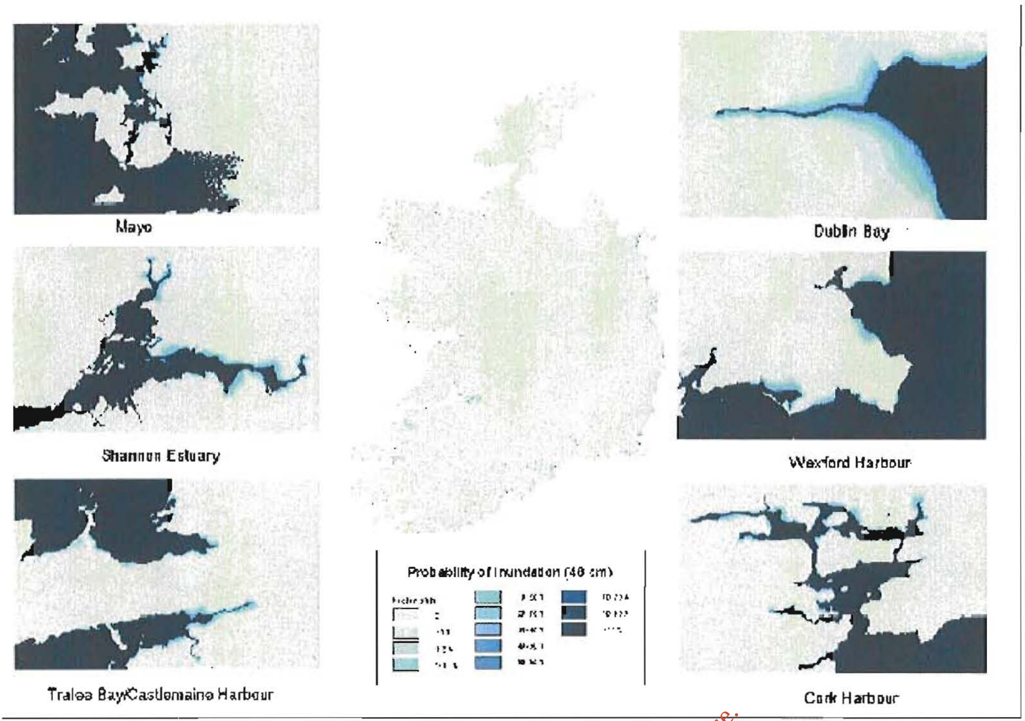


**Figure 4.1.** Possibility of inundation with a sea level rise of 0.48m (Fealy, 2003)



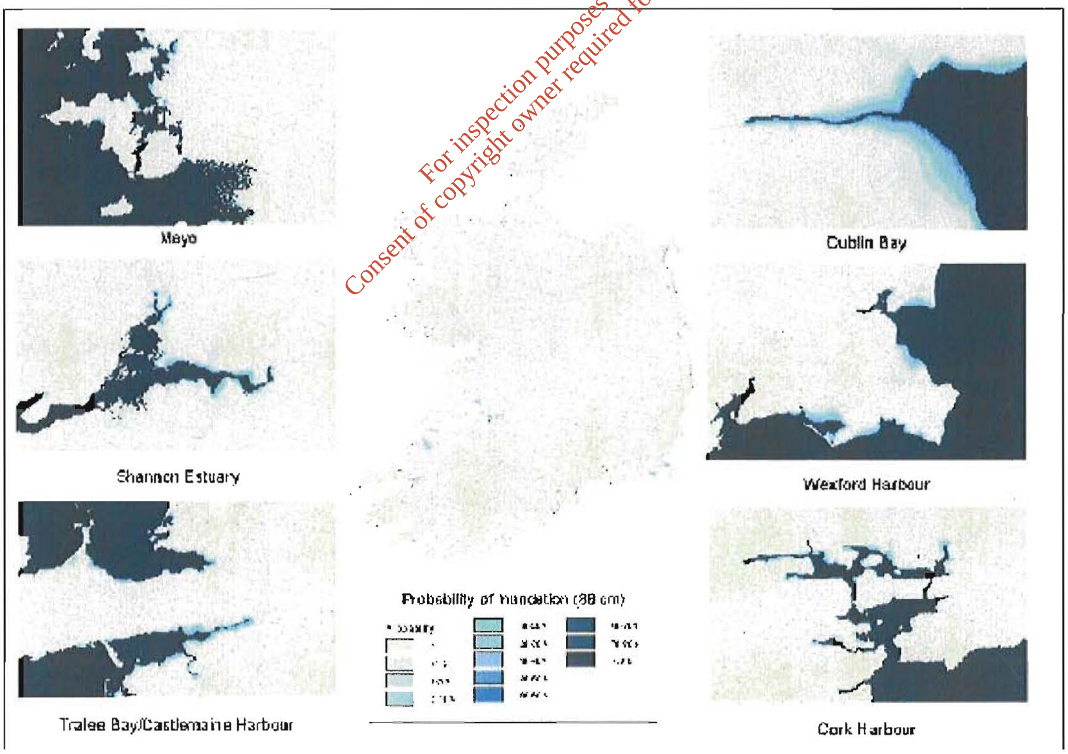


**Figure 4.2.** Possibility of inundation with a sea level rise of 0.88m (Fealy, 2003)

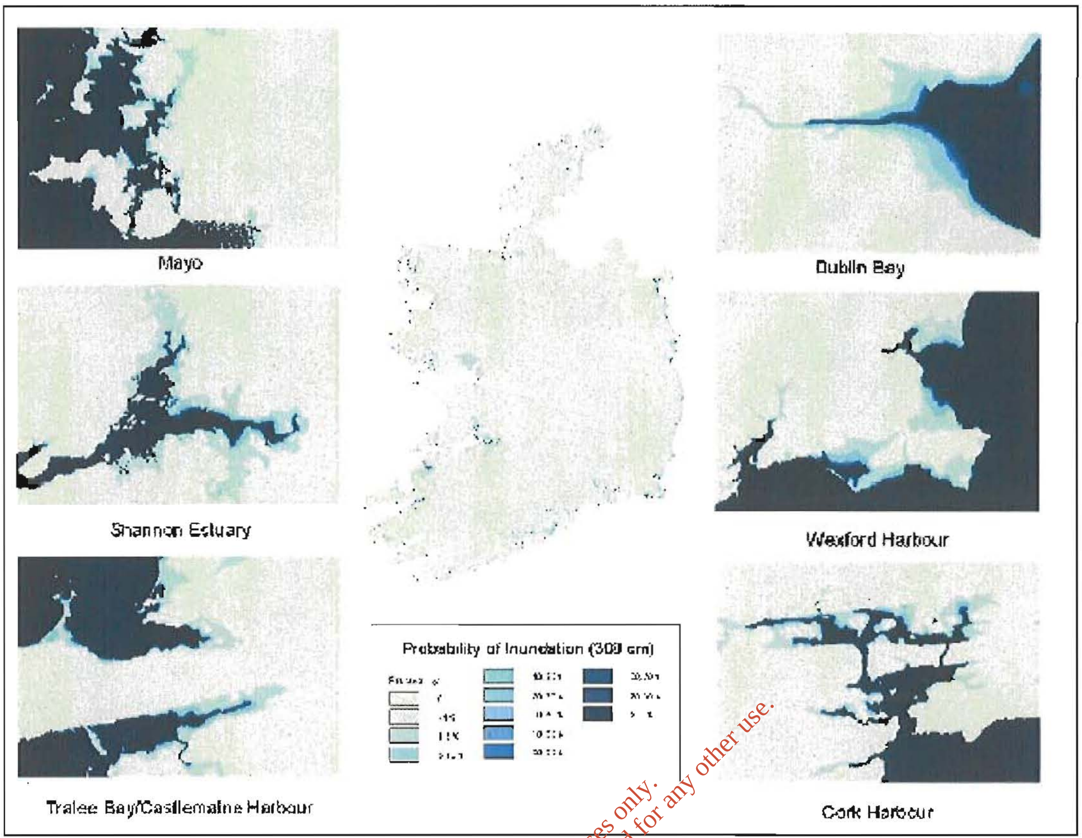


**Figure 4.3.** Storm surge coupled with a sea level rise of 0.48 m. (Fealy, 2003)

## 5. Summary

This report has outlined the main factors to be considered in the engineering design of a WWTP in Cork Harbour. To summarise:

- There will be a significant decrease in summer precipitation, which will lead to decreases in runoff, river stream flow and water availability. This could possibly lead to long-term depletions of groundwater storage and deficits in soil moisture, aquifers and lakes and reservoirs.
- Mean sea level is expected to increase by up to 0.9m, but significantly, storm surges, which currently have a return period of 50 years, could occur more than once yearly by 2100 resulting in many areas of Cork Harbour being at risk from inundation.
- The frequency of extreme precipitation events is expected to increase.

The impact of climate change on coastal societies depends both on the physical characteristics of the coasts and on whether the local economy relies strongly on sectors vulnerable to sea-level rise and extreme weather/wave conditions. Thus, in addition to physical processes, socio-economic factors need to be considered in deciding the management of vulnerable coastal areas. Therefore the following points should be considered in the planning of any coastal development.

- Coastal erosion
- Susceptibility to storm surges
- Effects of summer water shortages
- Effects of high amounts of precipitation and flood water during cyclonic events.
- Impact of sea level rise on the local population (displacement), tourism and businesses.



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