# 9. Appendix II - Background Information on odours pertaining to Cork Harbour Drainage scheme odour impact assessment.

## 9.1. Legislation pertaining to odours in Ireland

The Public Health Act of 1878 introduced legislation to control nuisance in Ireland, but its execution only became viable after the implementation of the Planning and Development Act (1963) (Scannell, 1995). Any industry producing a nuisance was controlled under these regulations and subsequent pressure from environmental lobby groups together with the development of scientific measurement techniques made it practical to quantify and control the release of gaseous environmental pollutants from these enterprises.

Odour impact from a WWTP on the surrounding vicinity may be considered a nuisance. Section 107 of the Public Health Act 1878 states that "sanitary authorities are bound to inspect their district for nuisances. Upon the receipt of any information respecting the existence of a statutory nuisance, the sanitary authority is obliged, if satisfied of the existence of the nuisance, to serve an abatement notice on the person by whose act or default the nuisance arises or continues or, if such a person cannot be found, on the owner or occupier of the premises on which the nuisance arises" (Scannell, 1995).

In order to control the possible pollution effects of large developments, relevant legislation was enacted under the Environmental Protection Agency (EPA) Act of 1992. Private and public sector developers of certain types and sizes of projects are required under section 72(4) of the EPA Act (1992) to submit a copy of an Environmental Impact Statement. If the project is of a class listed in Part II of the first schedule to the 1989 EIA regulations but does not exceed the threshold or criteria specified, the planning authority must require an Environmental Impact Statement (EIS) if it considers the project is likely to have a significant impact on the environment. One of those impacts relates to odour and is defined as environmental pollution in section 4(2) of the EPA Act (1992), as to cause a nuisance through noise or odour and/or adversely affect the countryside or place of special interest (Scannell, 1995).

Waste licensing and Integrated Pollution Control Licensing (IPC) (now IPPC) for specified facility types was implemented in 1996 by the EPA and the related guidance note was termed BATNEEC (Best Available Technology Not Entailing Excessive Cost) (i.e. now BAT which complement the BATNEEC Notes) (EPA, 1996). It set out specific conditions for these specific industries (i.e. Intensive Agricultural Production, Landfills, Waste transfer stations, etc) to be implemented in order to comply with the environmental requirements of the EPA. Minimisation of odour emissions and complaints is one of the requirements of the BATNEEC Guidance Note for industries likely to cause odour emissions. For example, a typical IPC license/Waste license condition states "that there shall be no emission to the atmosphere of environmental significance and that all operations on site shall be carried out in a manner such that air emissions and/or odours do not result in significant impairment and/or interference with amenities beyond the site boundary and at odour sensitive locations in the area" (EPA, 1996).

Local authorities and the EPA have responsibility for ensuring enterprises meet their planning and environmental requirements. Where these facilities are found to be causing odour nuisance, local government enforces Section 29 of the 1987 Air Pollution Act and serves the offenders with an abatement notice. If the facility is licensed as an IPC or Waste enterprise, the EPA can enforce the conditions of the license and either serves the facility with non-compliances for odour detected beyond the site boundary or prosecute the facility and seek a high court injunction to close the facility. Verification for the presence of odour nuisance usually encompasses the licensing officer visiting the facility and detecting the odour beyond the boundary.

In December 2005, the Department of Environment published Statutory Instrument (SI) 787 for the regulation of odours and noise from WWTP's. The main conclusions to be drawn from this SI 787 of 2005 include:

*"A sanitary authority shall ensure that in formulating and approving plans for a waste water treatment plant to be provided by the authority or on its behalf the plant is so designed and constructed as to ensure that it avoids causing nuisance through odours or noise",*

*"A sanitary authority shall ensure that any waste water treatment plant under the sanitary authority's control is so operated and maintained as to ensure that it avoids causing nuisance through odours or noise".*

It would also appear that SI 787 provides jurisdiction to the EPA to regulate WWTP for such nuisances and enforce the EPA Act 1992 *"For the purpose of Article 3(b) of these Regulations, the Agency shall be required to ensure compliance of waste water treatment plants with the requirements of the said Article 3(b), and the provisions of section 63 of the Environmental Protection Agency Act 1992 (No. 7 of 1992) shall apply accordingly".*

As part of SI 787 of 2005 *"the planning authority where granting permission for a development in accordance with section 34 of the Act of 2000 consisting of the provision of a waste water treatment plant attach such conditions to the permission as may be, in the opinion of the authority and having regard to the function of the Agency under Article 4 of these Regulations, necessary to ensure that the plant is so operated and maintained as to ensure that it avoids causing nuisance through odours or noise".*

Additionally, in considering a appeal to planning, Board Pleanala *"shall include such conditions as may be necessary in its opinion to ensure that the plant is so operated and maintained as to avoid causing nuisance through odours or noise".*

Although it is not unusual for statutory instruments not to include numerical values for the control of odour nuisance, it is apparent that there should not be odour nuisance from WWTP's in Ireland and so should be designed and operated to eliminate odour nuisance (Sheridan, 2002). In these times of regulation, guidance documents such as those for IPPC and Waste licensed facilities should be developed for WWTP design engineers and operators in order to allow them to implement Best Available Techniques (BAT). In the UK, such a guidance document was published to provide guidance for existing and new WWTP for odour assessment and control.

## 9.2. Characterisation of odour.

The sense of smell plays an important role in human comfort. The sensation of smell is individual and unique to each human and varies with the physical condition of the person, the odour emission conditions and the individual's odourous education or memory. The smell reaction is the result of a stimulus created by the olfactory bulb located in the upper nasal passage. When the nasal passage comes in contact with the odourous molecules, signals are sent via the nerve fibres where the odour impressions are created and compared with stored memories referring to individual perceptions and social values. Since the smell is individual some people will be hypersensitive and some will be less sensitive (ansomia). Therefore, the sense of smell is the most useful detection technique available as it specialises in synthesising complex gas mixtures rather than analysing the chemical compound (Sheridan, 2000).

### 9.3. Odour qualities

An odour sensation and complaint consists of a number of inter-linked factors. These include:

- Odour threshold/concentration,
- Odour intensity,
- Hedonic tone,
- Quality/Characteristics
- Component characteristics

The odour threshold concentration dictates the concentration of the odour in $Ou_E$ $m^{-3}$. The odour intensity dictates the strength of the odour. The Hedonic quality allows for the determination of pleasantness/unpleasantness. Odour quality/characteristics allow for the comparison of the odour to a known smell (i.e. turnip, like dead fish, flowers). Individual chemical component identity determines the individual chemical components that constitute the odour (i.e. ammonia, hydrogen sulphide, methyl mercaptan, carbon disulphide, etc.). Once odour qualities are determined, the overall odour impact can be assessed. This odour impact assessment can then be used to determine if an odour minimisation strategy is to be implemented and if so, which technology. Additionally, by suitably characterising the odour through complaint logs, the most likely source of the odour can be determined. This allows for the implementation of immediate odour mitigation techniques to prevent such emission in the future.

### 9.4. Perception of emitted odours.

Complaints are the primary indicators that odours are a problem in the vicinity of any facility. Perceptions of odours vary from person to person, with several conditions governing a person's perception of odour:

- **Control:** A person is better able to cope with an odour if they feel it can be controlled.
- **Understanding:** A person can better tolerate an odour impact if they understand its source.
- **Context:** A person reacts to the context of an odour as they do to the odour itself (i.e. WWTP odour source due to sewage).
- **Exposure:** When a person is constantly exposed to an odour:
    - They may lose their ability to detect that odour. For example, a plant operator who works in the facility may grow immune to the odour *or*
    - There tolerance to the odour grows smaller and they complain more frequently.

From these criteria, we can predict that odour complaints are more likely to occur when:

- A new facility locates in areas where people are unfamiliar with facilities;
- When a new process establishes within the facility (i.e. anaerobic digestion processes);
- Or when an urban population encroaches on an existing facility.

The ability to characterise odours being emitted from the facility will help to develop a better understanding of the impact of the odour on the surrounding vicinity. It will also help to implement and develop better techniques to minimise/abate odours using existing technologies and engineering design. The correct recording of odour complaints data is very important to resolving any odour impact.

## 9.5. Characteristics of Waste water odours

Odours from wastewater treatment plants/pumping stations arise mainly from the uncontrolled anaerobic biodegradation of sewage to produce unstable intermediates. Other odours come directly from industrial waste water (solvents, volatile organic compounds, petroleum derivatives) or indirectly from warm, highly degradable sulphurous effluents (Burgess et al. 2001). Typically domestic sewage sludge contains 3-6 mg $l^{-1}$ organic sulphur, mainly arising from proteinaceous material, approximately 4 mg $l^{-1}$ from sulphonates contained in household detergents and 30-60 mg $l^{-1}$ inorganic sulphur (as sulphonates) (Burgess et al. 2001). Odours are generated by a number of different waste water components, the most significant being the sulphur containing compounds (thiols, mercaptans, hydrogen sulphide), volatile fatty acids (butyric acid, valeric acid), amines (methylamine, Dimethylamine), phenols (4-methylphenol), chlorinated hydrocarbons (trichloroethylene, tetrachloride), etc. (Dawson et al. 1997). Most of these compounds have very low odour threshold concentrations as illustrated in *Table 9.2.* Different concentrations and mixtures of these compounds can intensify or reduce odour threshold concentration, determined as synergism and antagonism respectively. Hobbs et al., (2002) performed studies on various odours commonly found in pig odour. From his study he concluded that 4-methyl phenol had a negative effective on perceived odour concentration when mixed with other odourant.

**Table 9.1.** Odour detection thresholds of wastewater odour precursors.

| Chemical component | Threshold Conc. (mg $m^{-3}$) | Odour character |
|---|---|---|
| Ammonia | 0.03-37.8 | Pungent, sharp, irritating |
| Methylamine | 0.0012-6.1 | Fishy, Putrid Fishy |
| Trimethylamine | 0.00026-2.1 | Fishy, Pungent fishy |
| Dimethylamine | 0.34 ppmv | Putrid fishy |
| Ethylamine | 0.27 ppmv | Ammonia like |
| Triethylamine | 0.48 ppmv | Fishy |
| Pyridine | 0.66 ppmv | Sour, putrid fishy |
| Indole | 0.0006-0.0071 | Faecal, nauseating |
| Skatole | 0.00035-0.00078 | Faecal, nauseating |
| Hydrogen Sulphide | 0.0005-0.002 | Rotten eggs |
| Methyl mercaptan | 0.0000003-0.038 | Rotten cabbage |
| Ethyl mercaptan | 0.000043-0.00033 | Decaying cabbage/flesh |
| Propyl mercaptan | 0.0001 ppmv | Intense rotten vegetables, Unpleasant |
| Allyl mercaptan | 0.0001 ppmv | Garlic, coffee |
| Benzyl mercaptan | 0.0003 ppmv | Skunk, unpleasant |
| Thiocresol | 0.449 ppmv | Skunk |
| Dimethyl disulphide | 0.000026 ppmv | Rotten vegetables |
| Carbon disulphide | 0.0077-0.0096 ppmv | Rubber, intense sulphide |
| Acetic acid | 0.024 to 0.120 | Vinegar |
| Butyric acid | 0.0004-42 | Rancid |
| Valeric acid | 0.0008-0.12 | Sweaty, rancid |
| Propionic acid | 0.028 ppmv | Rancid, pungent |
| Hexanoic acid | 0.018 to 0.096 | sharp, sour, rancid odour, goat-like odour |
| Formaldehyde | 0.05 to 1.0 ppm | Pungent, medicinal |
| Acetone | 0.067 ppmv | Pungent, fruity, sweet |
| Butanone | 0.128 | Sweet, solventy |
| Acetophenone | 0.05 to 0.10 ppmv | Sweet pungent odour of orange blossom or jasmine |
| Limonene | 0.063 | Intense orange/lemons |
| Alpha Pinene | 0.006 ppmv | Intense pine, fresh |
| THN Tetrahydronaphthalene | - | Meat |

O'Neill & Phillips et al. (1992) and Suffet at al., 2004.

Although only indicators of odour emission from various processes within the WWTP, knowing which compound precursors that are responsible for odour is useful in designing control techniques for the minimisation and abatement of these gases. Technologies such as carbon filtration rely on the binding efficiency of the carbon (Van der Waals forces and molecular sieving) and knowing the gas constituents will help isolate the best carbon to perform the task. For example, Hydrogen sulphide because of its molecular size will not bind efficiently to activated carbon. By impregnating the carbon with potassium/sodium hydroxide chemisorption can be used to efficiently bind and hold on to the Hydrogen sulphide. Another reason for knowing Volatile Organic Compounds (VOC's) concentration present in air stream is to propose the best technology. Chemical scrubbers are good for low VOC's steady stream processes while high VOC concentration non-steady stream processes will not be as affectively treated with chemical scrubbers although many stages of treatment can be provided to buffer out the cyclic loading (but at greater operating expense).

## 9.6. Odourous compound formation in wastewater treatment plants/pumping stations

The formation of odourous components at WWTP's is usually limited to inlet works, primary settlement tanks and to the areas of sludge handling/pumping/processing, particularly during the handling of primary/anaerobic treated sludge. The formation of odours from pumping stations is usually limited to the displacement of odours from the inlet flow chamber, wet wells and any primary treatment that may occur at the pumping station (i.e. grit removal and screenings).

In WWTP's, under anaerobic conditions, the untreated primary sludge will readily decay, producing odourous components in the process. The possibility for anaerobic conversion of surplus activated sludge depends on the sludge-loading rate (k) in the activated sludge works. At a lower sludge-loading rate, the surplus activated sludge tends to be more stabilised, thus giving less cause for odour impact. In general the following values may be adhered to:

- $k < 0.05$; extreme sludge stabilisation, no anaerobic bacterial decay to be expected;
- $0.05 < k < 0.1$; moderate sludge stabilisation, some decay possible;
- $k > 0.1$ partial sludge stabilisation, anaerobic bacterial decay is most likely to occur.

The production of odourous components depends on the reduction-oxidation potential (redox-potential) and on the Biological Oxygen Demand (BOD) of the wastewater. The redox-potential is the condition under which decay can take place, while BOD is the parameter most commonly used to define the pollution strength of a wastewater.

Anaerobic bacterial decay will only take place if the redox-potential of the wastewater is low enough. Frequently this condition arises in rising mains, where anaerobic conditions occur. In gravitational sewers a slight draft provides enough oxygen to limit this, as oxygen is highly toxic to anaerobic bacteria. In certain cases, the dosing of bleach and Ferric will act as an oxidant and electron donator/acceptor and limit such conditions. It is important to use sophisticated monitoring equipment to measure dissolved oxygen and pH of the liquor to maintain ideal conditions for aerobic processes to dominate. The monitoring of sulphite levels in the inlet sewer can be used to estimate hydrogen sulphide generation levels within the WWTP.

Sludge handling processes can be more complicated depending on dewatering equipment design and processed sludge storage facilities. For example, it is reported that using high-speed centrifuges facilitate higher odour and $H_2S$ emission than low speed centrifuge due to the shearing of proteins and carbohydrates within the sludge. This allows for the oxidation and reduction of methanthione and other proteins which readily breakdown to methyl mercaptan, dimethyl sulphide and $H_2S$ (Sheridan, 2004). By dosing Ferric/Ferrous (2:1 blend) at the head of the plant odours associated with digestor gas and sludge handling can be reduced. The benefits of such dosing must be analysed since greater sludge volumes (i.e. especially primary sludge) will be produced.

### 9.7. Odour emissions formation at Wastewater treatment plants

The rate of release of odourous compounds into the atmosphere at WWTP's and pumping stations is influenced by:

- Liquid flow rate into the pumping station and WWTP,
- Trade effluent discharges containing high concentrations of sulphonates,
- Overloading of the WWTP;
- Long residence time of sewage in sewer;
- Temperature of mixed liquor (increased temperature causes increased anaerobic conditions and volatilisation);
- Positive displacement of odours through covers / from buildings especially in Pumping stations.
- The concentration of odourous compounds in the liquid phase exposed to air;
- Processes that generate surface turbulence (aeration basin, surface aerators, weirs overflows, return activate sludge channel feed, pumping of RAS/WAS/SAS, sludge thickening techniques etc.);
- Total air/surface waste water interface area;
- Maintenance of aerobic conditions within WWTP's (i.e. sludge handling, processing and storage).

Raw wastewater and sludge's have high concentrations of odourous compounds. Processes that create surface turbulence and high rates of interface renewal, such as open channel flow, weir overflows, biofilter flow distribution systems, surface aeration systems have much higher rates of volatilisation of odourous compounds than quiescent processes such as sedimentation as these processes allow for the change in the partial pressure at the surface interface and the mass transfer of the odourous compounds to the gaseous phase.

The main sources of odour emissions from WWTP's in Ireland are wastewater screening, grit separators, Grit and rag removal, inlet/outlet flow channels, (i.e. Inlet works), biotower flow distributions, primary treatment processes, flow splitter chambers (i.e. badly designed weirs that facilitate high volatilisation) and sludge handling processes (turbulent liquid removal at bottom of Gravity belt thickeners, high speed centrifuges, pumped streams, etc). With the exception of aerobically stabilised sludge's, sludge residues are the primary sources of odour emissions and should be considered high-risk sources. Other high-risk sources include, inlet works, primary settlement, pumped liquor streams and anaerobic digestion processes.

### 9.8. Odour management plan - Standard Practice

The Odour Management Plan (OMP) is a core document that is intended to detail operational and control measures appropriate to management and control of odour at the site. The format of the OMP should provide sufficient detail to allow operators and maintenance staff to clearly understand the operational procedures for both normal and abnormal conditions.

An Odour Management Plan (OMP) should be prepared for all processes. The OMP should also include sufficient feedback data to allow site management (and local authority inspectors) to audit site operations. An example of some of the issues to be considered is summarised as follows. More detailed guidance is provided with this document.

- A summary of the site and WWTP, odour sources and the location of receptors,
- Details of the site management responsibilities and procedures for reporting faults, Identifying maintenance needs, replenishing consumables, complaints procedure,

- Odour critical plant operation and management procedures (e.g. correct use of plant, process, materials; checks on plant performance, maintenance and inspection (*see Section 9.9 to 9.11*),
- Operative training,
- Housekeeping,
- Maintenance and inspection of plant (both routine and emergency response),
- Spillage management procedures,
- Record keeping – format, responsibility for completion and location of records,
- Emergency breakdown and incident response planning including responsibilities and mechanisms for liaison with the local authority.
- Public relations.

The Odour Management Plan is a living document and should be regularly reviewed and upgraded. It should form the basis of a document Environmental and Odour Management system for the operating site. The Odour Management System documentation should define the roles of the Plant Operator and staff and sets out templates in relation to the operating of the facility and reporting procedures to be employed. Requirements for the Odour management plan should be implemented thought out the site with a branched management system implemented in order to share responsibility around the site. The head manager should ensure all works are performed in accordance with the OMP. The OMP will be integrated in the overall Environmental Management System/Performance management system.

The contractor will develop and implement a detailed odour management plan for the actual as built plant and put into operation before commencement of treatment of waste water at Cork Harbour Main Drainage Scheme.

### 9.8.1. General rules for reduction of odour emissions for wastewater treatment plants operation by design – Standard Practice

The following minimum design features for the control of odours will be achieved throughout the design. These include:

- Avoid turbulence at the inlet works, weirs and when handling sludge's and return liquors.
- Sewage discharged from a rising main is more likely to be anaerobic (i.e. odourous), particularly during hot weather. Inlet covering will be performed and chemical dosing may be necessary.
- Minimise the retention of sewage under anaerobic conditions, especially in anoxic, balancing and storm tanks to prevent the formation of odourous compounds.
- Avoid accumulation of floating debris and persistent sediments in channels and holding tanks by design.
- Maintain minimal sludge delay in handling and treatment stages by design. Avoid exposure of untreated sludge to the atmosphere.
- Enclosed units should be sealed and vented to odour abatement systems. Provide storage provisions on site for odour prevention medium and chemicals.
- Ensure clear and concise odour management plans are produced for plant operation and abatement systems (i.e. complaints recording system operation and OCU maintenance procedures) (Sheridan, 2002).
- Prevent the displacement of highly odorous air through gaps or hatches in the covers over the sludge thickening and holding tanks and ensure that all air is vented through an odour abatement system. Badly sealed or broken hatches will act as significant points of odour emission. Even small openings, such as the openings around cable-duct and piping entry points, have been observed as significant sources of odour emission from raw-sludge storage tanks.
- In a covered storage tank, negative ventilation will be applied to all contained and covered processes.

- A minimum of two stages of treatment (if biological is first stage) will be provided on all odour control technologies.

### 9.8.2. Odour abatement management system/procedures – Standard Practice

Odour abatement/minimisation systems are installed with the aim of mitigating odours from the particular process(s). In some circumstances odour abatement system can become significant sources of odour especially if sufficient treatment is not being achieved. For example, insufficient treatment could be associated with system failure, poisoning of media, exhaustion of media, insufficient gas removal volume, broken covers, open hatches etc. There is a tendency in many facility environments that when an odour control system is installed it requires very little system checking especially if SCADA controlled. A simple management system incorporated into site operations can significantly reduce the risk of odour control plant failure and also provide a valuable picture for operations and maintenances schedules.

The overall odour control plant management system will vary for various technologies. For the proposed Cork Harbour Main Drainage Scheme WWTP, the following odour control/minimisation plant could be installed to control odours emanating from specific processes within the plant. These include:

- Chemical scrubbers,
- Activated carbon polishing,
- Dry chemical scrubbing (three stage),
- Biofilters
- Thermal oxidisers
- Fixed impermeable covers,
- Extraction ductwork located throughout WWTP,
- Chemical addition/dosing to waste water and sludge processing,
- Dissolved oxygen probes/pH probes located in aeration tanks and flow channels,

For each of the odour control technologies, an operational verification procedure should be performed from actually visiting each piece of equipment. For sensitive mechanical odour control plant, such as chemical scrubbers, biotrickling filters and biofilters, a daily check should be performed. Small changes in operational parameters could lead to significant emission of odours.

For odour control/minimisation plant such as pressure release values, odour control ductwork, fixed impermeable covers etc., which are less susceptible to breakdown (i.e. since there are little mechanical moving parts), a weekly check should be performed.

All system checks should be document controlled and available for viewing by odour complaints verification personnel, chief maintenance personnel and plant manager. Response/Action plans should be established for system repair where by a repair team trained in the operation and maintenances (O&M) of this specific plant are available to perform dedicated repair. O&M manuals should always be available and a spares inventory should be maintained for essential spares.

Any recording of system performance should be compared to design specification and performance as outlines within a P&ID flow diagrams developed for the built site.

*Table 9.3* illustrates a typical odour control plant daily/weekly checking procedure for odour abatement plants such as chemical scrubber, dry chemical scrubbers and flares. Certain parameters such as subjective and objective assessment checks (airflow rate, static/differential pressures etc) should be performed daily while other parameters such as odour threshold concentration should be performed quarterly which is in keeping with EPA recommendations for similar facilities. *Table 9.4* illustrates a typical odour minimisation plant system checking procedure for impermeable covers, odour control ductwork, pressure release valves etc.

**Table 9.3.** Odour control unit (OCU) checking procedure and recording.

| **Odour Abatement Plant process data sheet** | | | |
|---|---|---|---|
| **OCU name** | | **Location (NE coordinate)** | |
| **OCU P&ID ref. No.** | | **Time of check (24 hr)** | |
| **Date of check:** | | **Commissioning date:** | |
| **QA/QC by:** | | **Next service date:** | |
| **Supplier and contact details:** | | | |
| **Emergency contact No.** | | | |
| **OCU description** | | | |
| **Notes:** | | | |
| **Process description**<br>**SENSOR CALIBRATION DATES** | | | |
| **Chemical/BTF/Wet Cyclone** | **Liquid flow sensor** | | |
| **Chemical/BTF/Flare/Cyclone/CHP** | **Differential/static pressure** | | |
| **Chemical/BTF/Flare/Cyclone/CHP** | **Temperature** | | |
| **Flare/Cyclone/CHP** | **Particle concentration** | | |
| **Chemical/BTF/Flare/CHP** | **$H_2S$ sensor** | | |
| **Flare/CHP** | **Oxygen sensor** | | |
| **Flare/CHP** | **CO sensor** | | |
| **Flare/CHP** | **$NO_2$ sensor** | | |
| **Flare/CHP** | **$SO_2$** | | |
| **Notes:** | | | |
| **Subjective process verification** | | | |
| **Is the fan running and sounding OK (Y/N comments)?** | | | |
| **Is liquid recirculating within the recirculating line of the scrubber/cyclone (Y/N comments)?** | | | |
| **Is dump liquor flowing freely from overflow sump (Y/N comments)?** | | | |
| **Is liquid distributed equally over packing media (Y/N comments)?** | | | |
| **Is recirculating liquor clear or cloudy (Y/N comments)** | | | |
| **Are all liquid distribution nozzles/gate clear (Y/N comments)** | | | |
| **Notes:** | | | |

**Table 9.3 continued.** Odour control unit (OCU) checking procedure and recording.

| Objective process verification | | | | | |
|---|---|---|---|---|---|
| **Parameter** | **Average** | **Min** | **Max** | **Design value as per P&ID** | **Action** |
| Air flow rate (m3/hr) | | | | | |
| Temperature ($^0$C) | | | | | |
| Inlet ductwork Static pressure (mm WG) | | | | | |
| Differential pressure across system components (mm WG) | | | | | |
| $H_2S$ inlet conc. (ppm/v) | | | | | |
| Inlet dust load (mgN/m3) | | | | | |
| Gas consumption rate (m$^3$/hr, m$^3$/day) | | | | | |
| Odour character: (Descriptor) | | | | | |
| Notes: | | | | | |
| **Treated airflow** | **Average** | **Min** | **Max** | **Design value as per P&ID** | **Action** |
| Airflow rate (Nm$^3$/hr) | | | | | |
| Temperature ($^0$C) | | | | | |
| Outlet static pressure (mm WG) | | | | | |
| Outlet odour conc. (Ou$_E$/m$^3$) | | | | | |
| $H_2S$ outlet conc. (ppm/v) | | | | | |
| Outlet odour emission rate (Ou$_E$/s) | | | | | |
| Outlet odour character: Descriptor | | | | | |
| **Irrigation recirculation** | **Average** | **Min** | **Max** | **Design value as per P&ID** | **Action** |
| Recirculation flow (m$^3$/hr) | | | | | |
| Temperature ($^0$C) | | | | | |
| Conductivity ($\mu$s) | | | | | |
| PH (0 to 14) | | | | | |
| Redox (mv) | | | | | |
| Stability on Redox/pH historically | | | | | |
| **Irrigation drainage** | **Average** | **Min** | **Max** | **Design value as per P&ID** | **Action** |
| Dump volume (m$^3$/hr) | | | | | |
| Conductivity ($\mu$s) | | | | | |
| Batch dumping frequency (weeks) | | | | | |

**Table 9.4** illustrates a typical odour minimisation plant system weekly checking procedure for odour control ductwork, etc.

<table>
<tr><th colspan="4">Odour Abatement Plant process data sheet</th></tr>
<tr><td>Equipment name</td><td></td><td>Location (NE coordinate)</td><td></td></tr>
<tr><td>Equipment P&ID ref. No.</td><td></td><td>Time of check (24 hr)</td><td></td></tr>
<tr><td>Date of check:</td><td></td><td>Commissioning date:</td><td></td></tr>
<tr><td>QA/QC by:</td><td></td><td>Next service date:</td><td></td></tr>
<tr><td>Supplier and contact details:</td><td colspan="3"></td></tr>
<tr><td>Emergency contact No.</td><td colspan="3"></td></tr>
<tr><td>Equipment description</td><td colspan="3"></td></tr>
<tr><td>Notes:</td><td colspan="3"></td></tr>
<tr><td colspan="4">Process description</td></tr>
<tr><td>Item description</td><td>Parameter</td><td colspan="2">Compliant/Actions</td></tr>
<tr><td rowspan="4">Ductwork</td><td>Static pressure P&ID location No 1</td><td colspan="2"></td></tr>
<tr><td>Static pressure P&ID No location 2</td><td colspan="2"></td></tr>
<tr><td>Static pressure P&ID No location 3</td><td colspan="2"></td></tr>
<tr><td>Static pressure P&ID No location 4</td><td colspan="2"></td></tr>
<tr><td rowspan="4">Volume control dampers (VCD)</td><td>P&ID No. 1 Damper setting/head loss</td><td colspan="2"></td></tr>
<tr><td>P&ID No. 2 Damper setting/ head loss</td><td colspan="2"></td></tr>
<tr><td>P&ID No. 3 Damper setting/ head loss</td><td colspan="2"></td></tr>
<tr><td>P&ID No. 4 Damper setting/ head loss</td><td colspan="2"></td></tr>
<tr><td>Are all moisture drip points free flowing and unblocked?</td><td colspan="3"></td></tr>
<tr><td>Notes:</td><td colspan="3"></td></tr>
</table>

**Table 9.5** illustrates a typical odour minimisation plant system weekly checking procedure for fixed/flexible impermeable covers, etc.

<table>
<tr><th colspan="4">Odour Abatement Plant process data sheet</th></tr>
<tr><td>Equipment name</td><td></td><td>Location (NE coordinate)</td><td></td></tr>
<tr><td>Equipment P&ID ref. No.</td><td></td><td>Time of check (24 hr)</td><td></td></tr>
<tr><td>Date of check:</td><td></td><td>Commissioning date:</td><td></td></tr>
<tr><td>QA/QC by:</td><td></td><td>Next service date:</td><td></td></tr>
<tr><td>Supplier and contact details:</td><td colspan="3"></td></tr>
<tr><td>Emergency contact No.</td><td colspan="3"></td></tr>
<tr><td>Equipment description</td><td colspan="3"></td></tr>
<tr><td>Notes:</td><td colspan="3"></td></tr>
<tr><th colspan="4">Process description</th></tr>
<tr><td>Item description</td><td colspan="2">Parameter</td><td>Compliant/Actions</td></tr>
<tr><td rowspan="4">Static pressure under covers and volume flow on fresh air intake vents</td><td colspan="2">Static pressure/volume flows P&ID location No 1</td><td></td></tr>
<tr><td colspan="2">Static pressure/volume flows P&ID location No 2</td><td></td></tr>
<tr><td colspan="2">Static pressure/volume flows P&ID location No 3</td><td></td></tr>
<tr><td colspan="2">Static pressure/volume flows P&ID location No 4</td><td></td></tr>
<tr><td rowspan="4">Hatches</td><td colspan="2">P&ID No. 1 Hatch opened/closed</td><td></td></tr>
<tr><td colspan="2">P&ID No. 2 Hatch opened/closed</td><td></td></tr>
<tr><td colspan="2">P&ID No. 3 Hatch opened/closed</td><td></td></tr>
<tr><td colspan="2">P&ID No. 4 Hatch opened/closed</td><td></td></tr>
<tr><td>Are all flexible sealants in position?</td><td colspan="3"></td></tr>
<tr><td>Notes:</td><td colspan="3"></td></tr>
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The implementation of such quality checking procedures will provide both system confidence and preventative maintenance thereby reducing any risk associated with odour control/minimisation equipment.

The frequency and planning of sampling depend on the type of process. When the parameters are expected to develop gradual trends like dry chemical scrubbers rather than sudden changes like chemical scrubbers, the frequency of checking can be low (monthly, biweekly). If the system is more susceptible to cyclic loads, weekly or even daily monitoring may be required, depending on the history and the consequences that may arise from not realising an issue. More importantly seasonal changes in odour loads on plant and equipment can affect the overall performance of the system and combined with the behaviour of people on the receptor side during changing weather conditions (i.e. warm summer days could result in higher odour loads due to higher metabolic activity of bacteria coupled with people enjoying outdoor activities, etc.) For some processes, continuous monitoring may be useful, especially when the consequences of failure are significant. Risk assessment of plant failure is important to define key operational and maintenance parameters for the odour control unit (OCU). On the basis of this risk assessment measures can be defined to reduce the probability of high consequence events or to mitigate their impact.

The public will remember unscheduled emission episodes with great tenacity. It is therefore important to not fully rely on the environmental performance of odour mitigation under normal operational conditions but also consider them under unscheduled emission events. It is therefore crucial to consider and manage risks of odour emissions during:

- Odour Control Unit (OCU) commissioning,
- Start-up and shutdown of odour abatement units with consideration for duty standby on particularly odour processes (i.e. this has been implemented into the design),
- Management of highly odorous materials
- OCU servicing, and unscheduled shutdown,

In assessing these risks, it must be taken into account that response to odours is almost immediate. In order to manage these odour detection and complaint risks, a number of actions may be considered:

- Plan high-risk activities in periods where receptor sensitivity to annoyance is low like during wet weather when they are indoors, or during colder winter months, or during early morning/late evenings during periods of low atmospheric turbulence, etc.
- Consider providing standby capacity, etc.

If all else fails, inform potentially affected residents of the probability of temporarily increased odours and explain potential benefits due to these increases (i.e. maintenance of OCU, etc.)

### 9.9. Olfactometry

Olfactometry using the human sense of smell is the most valid means of measuring odour (Dravniek et al, 1986) and at present is the most commonly used method to measure the concentration of odour in air (Hobbs et al, 1996). Olfactometry is carried out using an instrument called an olfactometer. Three different types of dynamic dilution olfactometers exist:

- Yes/No Olfactometer
- Forced Choice Olfactometer
- Triangular Forced Choice Olfactometer.

In the dynamic dilution olfactometer, the odour is first diluted and is then presented to a panel of screened panellists of no less than four (CEN, 2003). Panellists are previously screened to ensure that they have a normal sense of smell (Casey et al., 2003). According to the CEN standard this screening must be performed using a certified reference gas *n*-butanol. This screening is applied to eliminate anosmia (low sensitivity) and super-noses (high sensitivity). The odour analysis has to be undertaken in a low odour environment such as an air-conditioned odour free laboratory. Analysis should be performed preferably within 6 to 8 hours of sampling.

### 9.10. What is an odour unit?

The odour concentration of a gaseous sample of odourant is determined by presenting a panel of selected screened human panellists with a sample of odourous air and varying the concentration by diluting with odourless gas, in order to determine the dilution factor at the 50% detection threshold. The $Z_{50}$ value (threshold concentration) is expressed in odour units ($Ou_E$ $m^{-3}$).

| |
|---|
| SIMPLY, ONE ODOUR UNIT IS THE CONCENTRATION OF AN ODOURANT, WHICH INDUCES AN ODOUR SENSATION TO 50% OF A SCREEN PANEL |

Although odour concentration is a dimensionless number, by analogy, it is expressed as a concentration in odour units per cubic metre ($Ou_E$ $m^{-3}$), a term which simplifies the calculation of odour emission rate. The European odour unit is that amount of odourant(s) that, when evaporated into one cubic metre of neutral gas (nitrogen), at standard conditions elicits a physiological response from a panel (detection threshold) equivalent to that elicited by one European Reference Odour Mass (EROM) evaporated in one cubic meter of neutral gas at standard conditions. One EROM is that mass of a substance (n-butanol) that will elicit the $Z_{50}$ physiological response assessed by an odour panel in accordance with this standard. *n*-Butanol is one such reference standard and is equivalent to 123ug of n-butanol evaporated in one cubic meter of neutral gas at standard conditions (CEN, 2003).

Typically domestic sewage sludge contains 3-6 mg $L^{-1}$ organic sulphur, mainly arising from proteinaceous material, approximately 4 mg $L^{-1}$ from sulphonates contained in household detergents and 30-60 mg $L^{-1}$ inorganic sulphur (as sulphonates) (Burgess et al. 2001).

### 9.11. General overview of proposed drainage scheme design

A description of the general specimen design of the drainage scheme is contained else where in the EIS.

### 9.12. Containment and ventilation/extraction of odours – Standard Practice

The containment and ventilation/extraction of odour from WWTP's should consider the following as a minimum:

#### 9.12.1. Covers

Covers should consider the following design notes before been installed.

- Covers should be sealed as far as possible. Inspection /access hatches should be sufficiently durable so that they continue to be effectively sealed for the design life of a piece of plant. Considerable care and attention to detailed design is required to provide adequate sealing of covers, particularly if passive ventilation to odour treatment is to be effective
- For tank surfaces the recently developed floating covers can be considered. These are produced from sections of hard foam material or fitted using soft foam that hardens in situ. Such covers can accommodate moving equipment, and can be replaced on a regular basis. Such covers do not require extraction and treatment.
- Overflow and discharge pipes should be designed and constructed to prevent a route for air under covers being discharged to the atmosphere.
- Design should withstand wind loadings, static loads due to snow or ice accumulation
- Equipment should be located in a small area to which suitable platform access is provided. Facilities to allow access of personnel onto covers should not be provided, and warning notices posted.

- Materials for covers and supports, and any equipment below the cover should be resistant to corrosion. Reinforced thermoplastic-based covers should have been considered at a minimum as very aggressive atmospheres may develop below the covers.
- Where possible, design should be such that equipment needed below covers can be easily and quickly removed to minimise time when covers need to be opened.
- To prevent the displacement of highly odorous air through gaps or hatches in the cover and ensure that all air is vented through odour treatment. Badly sealed or broken hatches will act as significant points of odour emission. Even small openings, such as the openings around cable-duct entry points, have been observed as significant sources of odour emission from tanks.
- Air displaced during filling will take the route of least resistance and may not pass through odour treatment systems, unless ventilated to maintain a negative pressure. Therefore, if any passive based odour treatment technology is to be used the cover must be 100% effectively sealed. The application of negative ventilation will also prevent significant odour emissions during cover opening.

### 9.12.2. Ventilation

Ventilation should consider the following design notes before been installed.

- All buildings containing sewage or sludge processes will need some form of ventilation. It should be assumed that this ventilation air will require odour treatment.
- The effective local encapsulation and extraction of process equipment, with the aim to reduce emissions to the atmosphere of the containment building, improves the indoor air quality. The odour concentration in the general indoor air can be improved using this approach to the point where odour treatment of the general air is not required. Treating a more limited flow from the local extraction system is a favoured and more economical option.
- Odour releasing units (such as screens Grit removal and rags removal) within a building should be locally enclosed, and a proportion of the required ventilation air drawn from the body of the building towards the odorous unit to ensure odours do not escape into the body of the building.
- Ventilation of a building should maintain a slight negative pressure. This negative ventilation will depend on the effectiveness of sealing of processes. Typically 6 to 10 AC/Hr are required with good sealing around odourous processes. This is required to provide a safe working environment in accordance with published occupational exposure limits, and to prevent an odour problem. By enclosing processes the emissions of aerosols and odours area minimised into the main body of the building where it could affect working conditions
- It may be advantageous to have two streams of ventilation air: one of low-volume and high-odour, drawn from the odour producing unit which can be pre-treated prior to mixing with the other stream of remaining ventilation air (high volume and low or no, odour), with possible provision of 'polishing' to reduce odours to a minimum.
- In buildings, ventilation systems and zoning of areas are designed to avoid development of potentially hazardous (explosive or toxic) atmospheres. There are no firm guidelines and rates vary widely across the Europe. Typical rates are 3 – 6 air changes per hour for a screening building, 10 air changes per hour for a sludge building.
- Design of the ventilation and odour control system may need to take in to account the handling of potentially hazardous gases, and the zone requirements of the area in which it is installed. This will avoid risks associated with hazardous gases and to provide equipment suitable for the zone requirement.
- In a covered process tank, ventilation is required only to contain and collect odours and should be kept to a minimum, whilst maintaining a slight negative pressure. Ventilation rates in this case are typically three to four air changes per hour of the volume of the headspace of the tank, and should be no less than the maximum filling rate. Smaller pump sumps which are subjected to turbulent liquid flows and instantaneously pump flows should consider at least 10 to 12 AC/Hr and should be no less than the maximum filling rate. Do not over-design the air-extraction rate. Odour removal processes tend to work more effectively at lower flow-rates

- The sitting of emergency vents, and initiation of emergency ventilation should be carefully considered, particularly if triggered by the presence of excessive concentrations of hydrogen sulphide. If likely to be a frequent occurrence, upstream treatment of the sewage/sludge or odour treatment on the emergency vent may be required.

## 9.13. Odour Scrubbing Systems

The following technologies may be considered as best available techniques not exceeding excessive cost for odour abatement during any upgrade or amendments to the WWTW design:

- Biotrickling filtration with carbon polishing system;
- Two stage biofiltration system;
- Two stage Chemical scrubbing system.

All the above odour abatement system have been shown to obtain >90% efficiency if proper engineering design parameters and operational parameters are implemented. It is recommended to locate the exhaust of any odour abatement systems higher (at least 3 to 5 metres) than the surrounding buildings in order to enhance dispersion and reduce building wake effects. Engineering and operational design are outside the scope of this document. Due to site complexity four separate odour abatement systems should be incorporated to treat odourous air from the negatively ventilated processes. The volumetric airflow required to be treated from all process will depend on the final design of the WWTP/Pumping stations and implemented odour abatement strategy. Biological abatement techniques are most cost effective. Ventilation rates for odour control should consider the guidance provided within this document and be refined when the final design has been agreed. The odour impact associated with the final design should be reassessed if overall odour emissions from the final designed WWTP and Pumping stations are higher that those contained in *Section 4.2* of this document

## 9.14. General rules for reduction of odour emissions for wastewater treatment works operation by design.

- Avoid turbulence at the inlet works, weirs and when handling sludge's and return liquors.
- Sewage discharged from a rising main is more likely to be anaerobic (i.e. odourous), particularly during hot weather. Inlet covering and chemical dosing may be necessary.
- Minimise the retention of sewage under anaerobic conditions, especially in anoxic zones and balancing tanks to prevent the formation of odourous compounds.
- Avoid accumulation of floating debris and persistent sediments in channels and holding tanks by design.
- Maintain minimal sludge delay in handling and treatment stages by design. Avoid exposure of untreated sludge to the atmosphere.
- Enclosed units should be sealed and vented to odour abatement systems. Provide storage provisions on site for odour prevention medium and chemicals.
- Ensure clear and concise odour management plans are produced for plant operation and abatement systems (i.e. system operation and maintenance manuals) (Sheridan, 2002).

## 9.15. Precise odour abatement strategies reduces complaints and cost

Prevent the displacement of highly odorous air through gaps or hatches in the cover and ensure that all air is vented through the odour abatement system. Badly sealed or broken hatches will act as significant points of odour emission. Even small openings, such as the openings around cable-duct and piping entry points, have been observed as significant sources of odour emission from raw-sludge storage tanks.

In a covered storage tank, ventilation is required only to contain and collect odours and should be kept to a minimum by maintaining a slight negative pressure. Ventilation rates in this case are typically half to one air change per hour of the volume of the empty tank, and should be no less than the maximum filling rate. If the tank is normally operated full, the ventilation rate could be reduced to 1 air change per hour for the air space, or the maximum filling rate. Odour abatement equipment tends to work more efficiently at lower flow-rates (i.e. biofilters and biotrickling filters).

Design odour abatement systems together, so that an odour abatement system (perhaps providing two stages of treatment) can treat extracted air from more than one facility. When an odour abatement system is provided, the outlet stack should be sited away from the boundary and any potential complainants and at an elevated height in order to reduce building wake effects and increase dispersion. Optimise the exit velocity of the outlet of the odour abatement system to increase dispersion effects. (Sheridan, 2002).

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# Appendix 5C

# Climate Change Report

Mott MacDonald

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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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| **ATTENTION:** | Ms. Orla Freyne |
| **PREPARED BY:** | Dr. John Casey |
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**Project:** Possible implications of climate change for consideration in the design of a wastewater treatment plant in Cork Harbour.

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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.

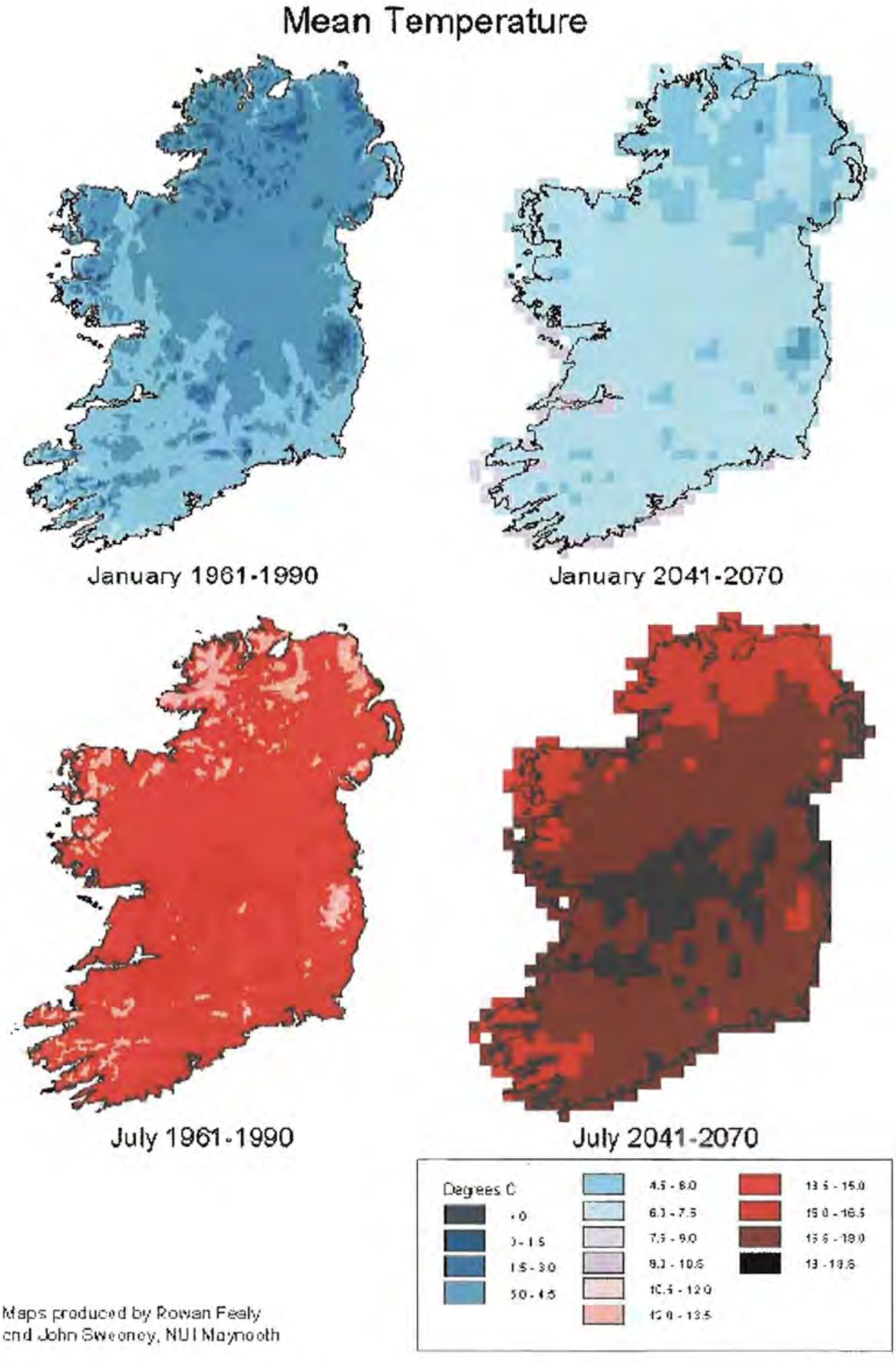


**Figure 2.1.** Downscaled mean temperature scenarios for the period 2061-2090 at a resolution of 10 km2. This approximates to the period around 2075. (Sweeney and Fealy, 2003)

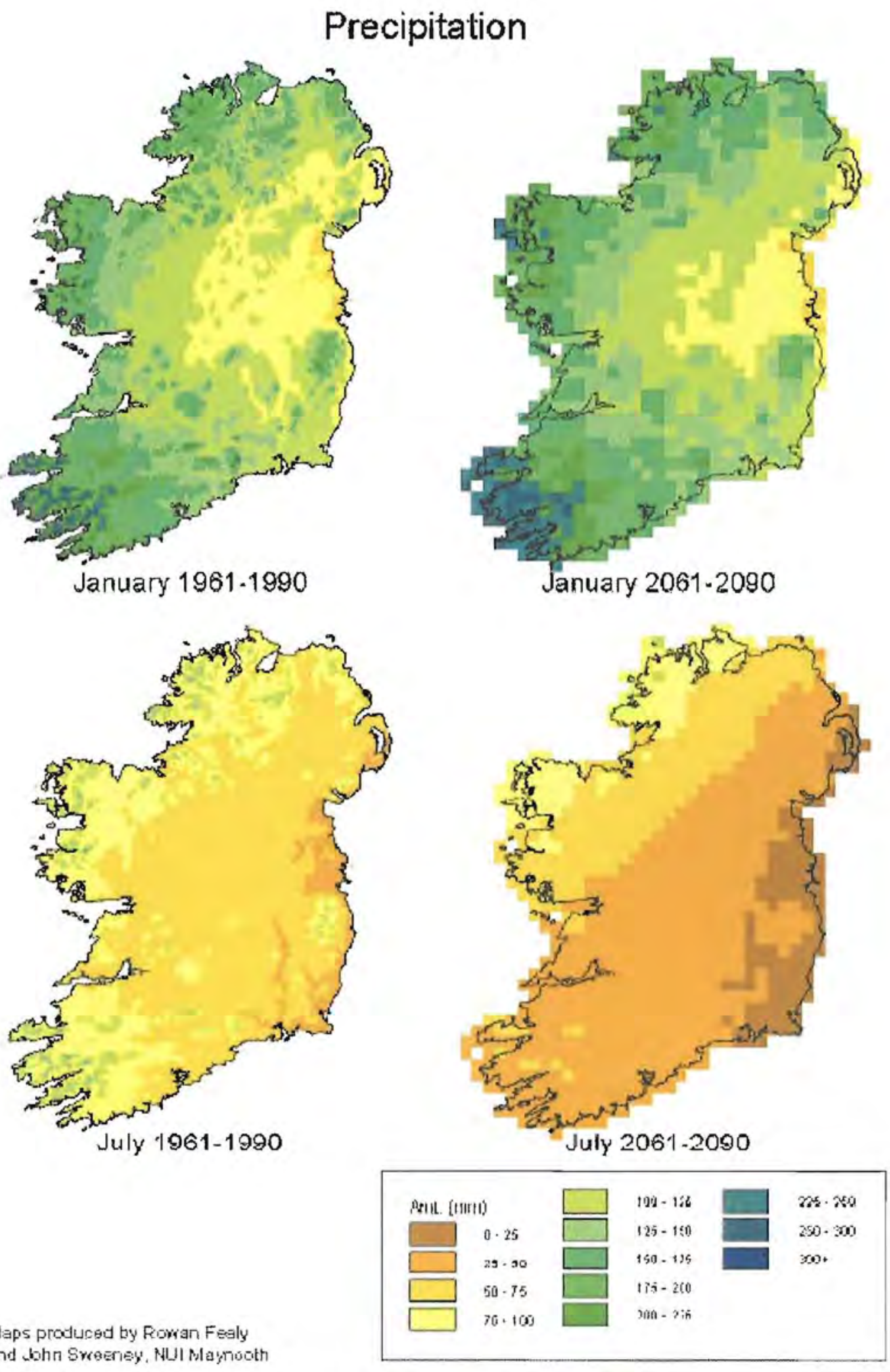


**Figure 2.2.** Downscaled precipitation scenarios for Ireland for the period 2061-2090 at a resolution of 10 km2. This approximates to the period around 2075. (Sweeney and Fealy, 2003)

## 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*).

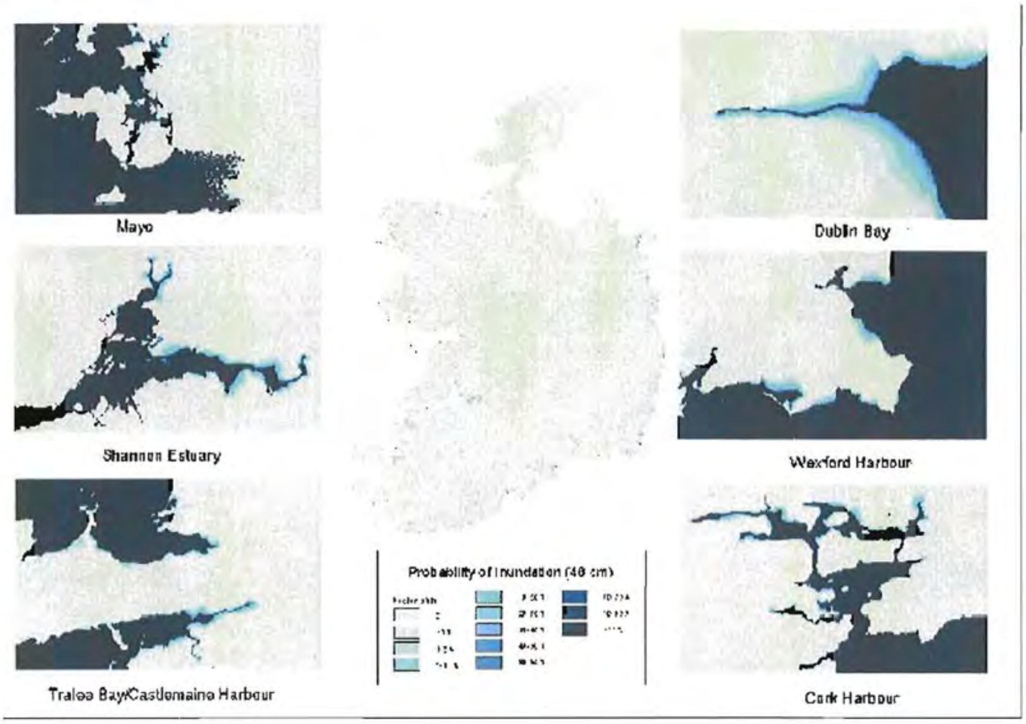


**Figure 4.1.** Possibility of inundation with a sea level rise of 0.48m (Fealy, 2003)

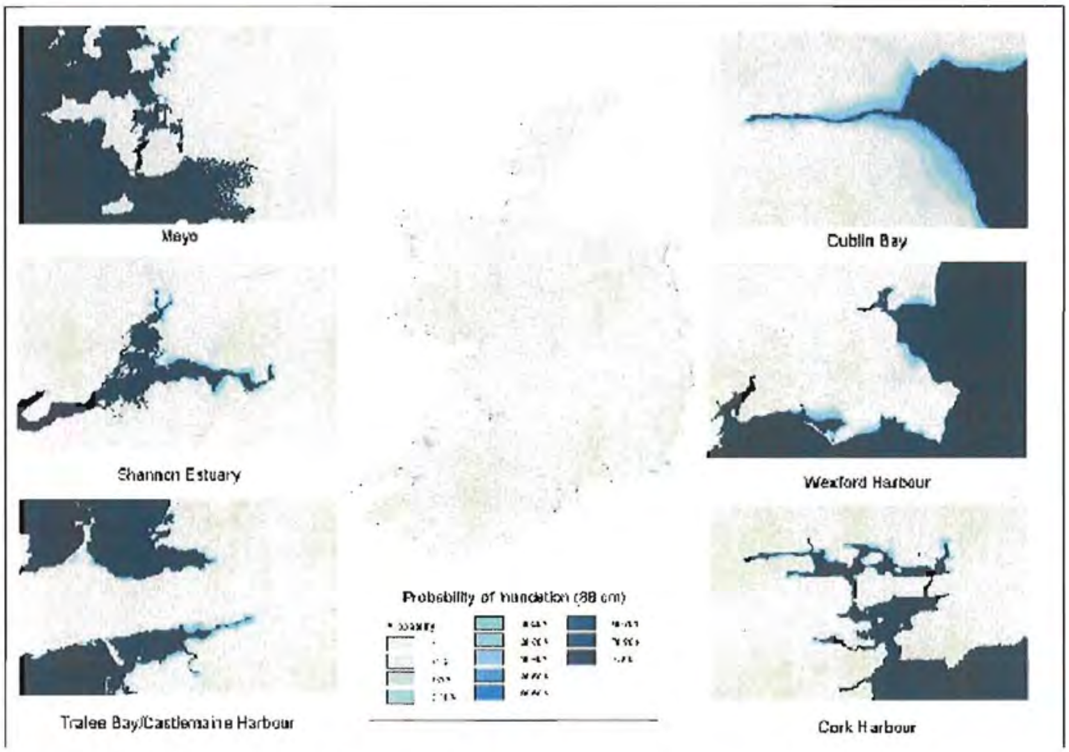


**Figure 4.2.** Possibility of inundation with a sea level rise of 0.88m (Fealy, 2003)

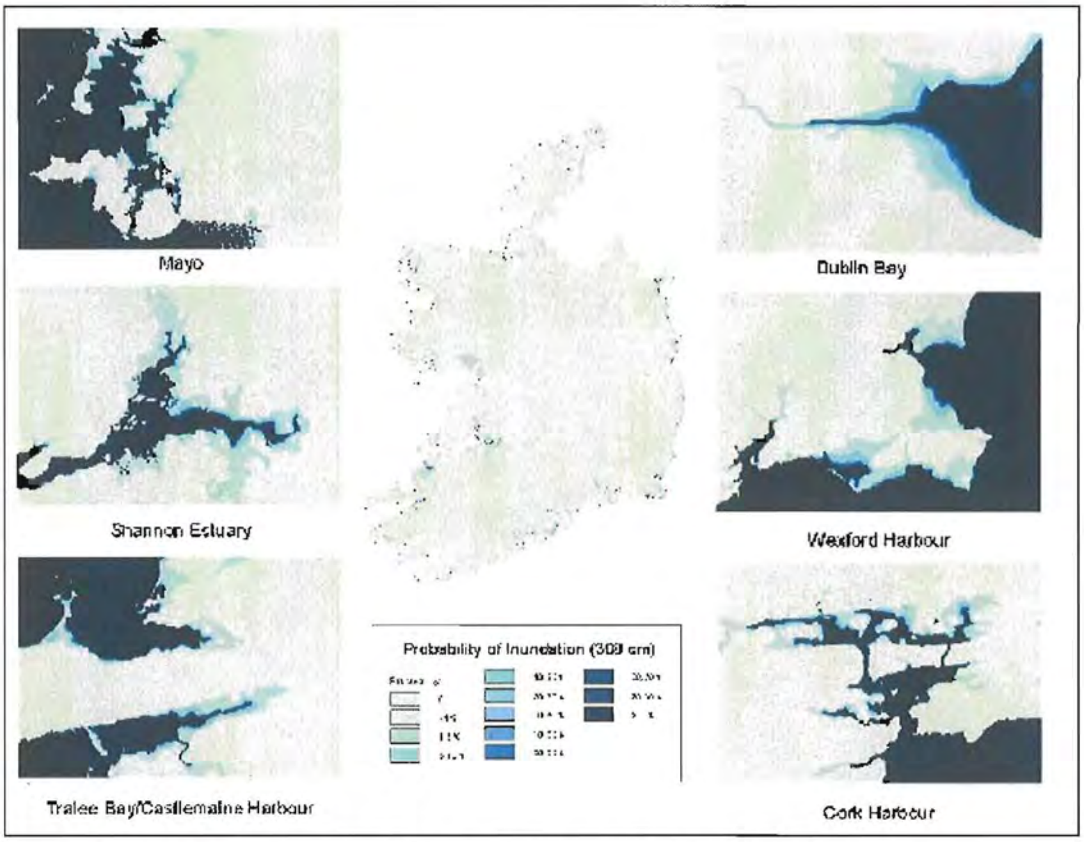


**Figure 4.3.** Storm surge coupled with a sea level rise of 0.48 m. (Fealy, 2003)

## 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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