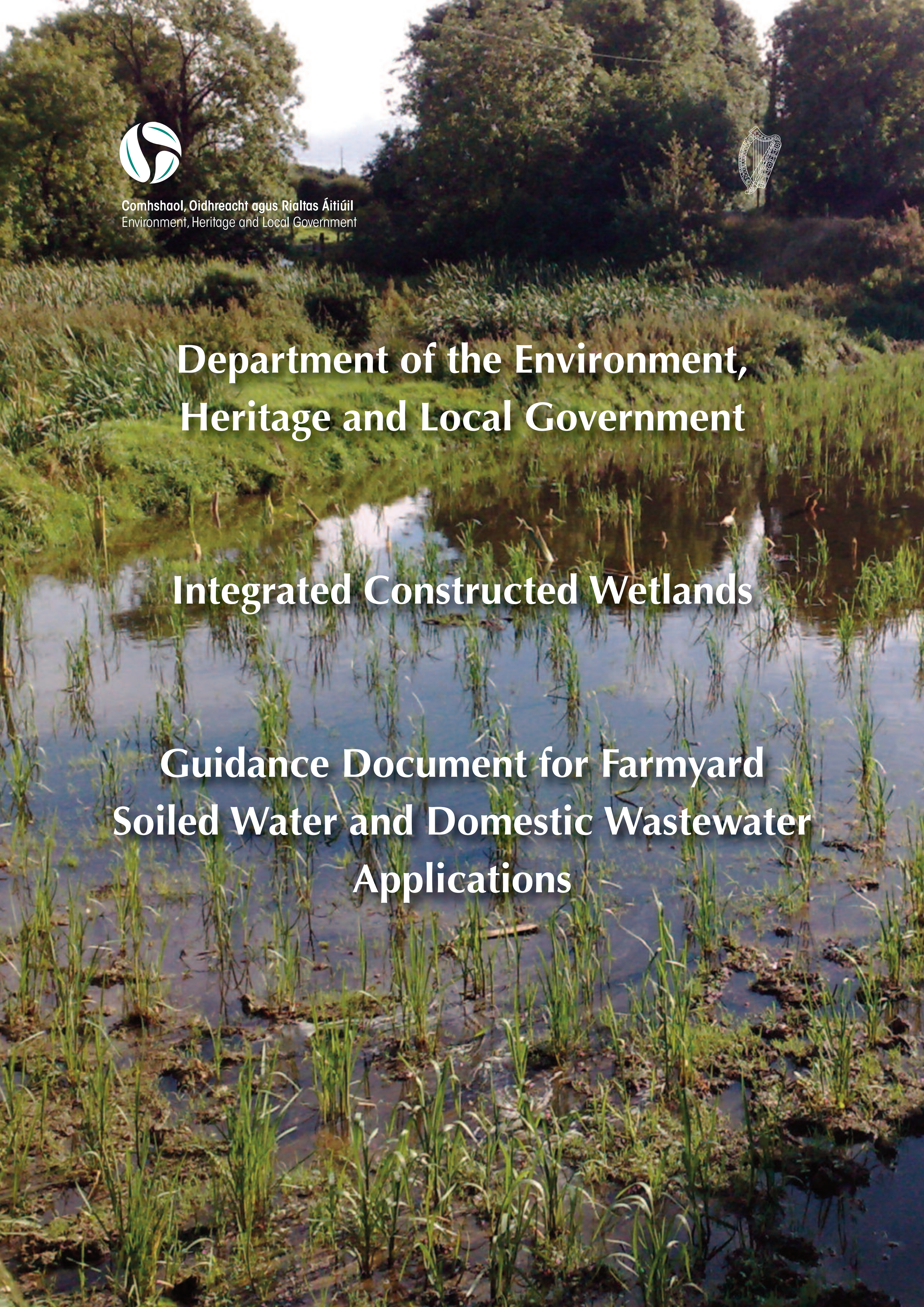

Comhshaol, Oidhreacht agus Rialtas Áitiúil
Environment, Heritage and Local Government

Department of the Environment, Heritage and Local Government

Integrated Constructed Wetlands

Guidance Document for Farmyard Soiled Water and Domestic Wastewater Applications

Foreword

Our high quality water resources are a valuable national asset and represent an essential foundation of our way of life. In addition to supplies of potable water and wastewater services for households, industries such as agriculture, manufacturing, tourism and fisheries also depend upon having abundant supplies of consistently good quality water.

Measures to protect and improve water quality such as the continuing investment in wastewater treatment facilities under the Water Services Investment Programme and the Nitrates Action Programme are contributing much to address the challenge of nutrient enrichment of our waters. We have made significant investments over recent years in infrastructure to protect and enhance water quality, but further work is required in order to achieve our targets under the Water Framework Directive (WFD) by 2015.

As announced in this Department's Statement of Strategy and in the Water Services Investment Programme 2010-2012, it is envisaged that integrated constructed wetlands (ICWs) will play an increasingly important role in Ireland's drive to reach our WFD targets by providing environmentally sustainable and cost-effective wastewater treatment facilities, particularly in smaller rural locations.

Ireland has pioneered the development of the ICW concept over the past two decades for use in the treatment of polluted wastewater through natural biological processes. ICWs integrate the sustainable management of land, water and biological resources consistent with the ecosystem approach, to promote conservation and to enhance biodiversity. In addition they have the potential to deliver on a substantial range of other ecosystem services, including flood attenuation, amenity and recreation.

Conventional wastewater treatment systems will continue to be appropriate in large urban areas, however ICWs sustainably use local natural materials in their construction, require a minimum of maintenance and have low energy requirements during use. Thus they are an extremely cost-effective way of treating wastewater from small communities.

This guidance document provides a practical framework for good practice in the design, site selection, construction and maintenance of ICWs. The particular focus of this volume is on ICWs designed for the treatment of point sources of farmyard soiled water and for domestic waste water. Later volumes are planned to deal specifically with

ICWs designed for applications such as the treatment of landfill leachate and diffuse agricultural pollution. It is aimed at practitioners in the field of wastewater treatment, planners, policy makers and other interested parties in both the public and private sectors.

The publication of this guidance would not have been possible without the commitment and dedication of many organizations and individuals (duly acknowledged elsewhere) whose knowledge and expertise was essential in bringing the project to fruition. I would like to express my appreciation and thanks to all concerned.

Mr. John Gormley T.D.,
Minister for the Enviornment,
Heritage and Local Government.
November 2010

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Figures and Tables

Acknowledgements

The Department of the Environment Heritage and Local Government wishes to acknowledge and thank the many individuals who contributed to and assisted with the preparation of this Guidance Document, in particular the representatives of the organisations listed hereunder who participated on the Steering Group and Scientific & Technical Advisory Group.

Department of Agriculture, Fisheries & Food (Environment and Engineering Services Division, Forestry Division)
Environmental Protection Agency
Central Fisheries Board
Eastern Regional Fisheries Board
Office of Public Works
County & City Managers' Association
Department of Environment, Heritage & Local Government (Planning Section, Water Quality Section, National Parks & Wildlife Service)
Éamon de Buitléar

The Department also acknowledges the contribution of the Design Manual for Constructed Farm Wetlands for Scotland & Northern Ireland and the earlier work carried out by the ad-hoc ICW team which was further developed to produce this Guidance Document.

Background: Integrated Constructed Wetland (ICW) concept

National and EU legislation requires enhanced management of water and water-vectored pollutants. The 'Integrated Constructed Wetland' (ICW) concept provides an alternative strategy to conventional practice. The concept has been applied for the past 14 years delivering a successful model of social, economic and environmental coherence (the three pillars of sustainable development). The ICW concept strives to deliver this as comprehensively as possible for a wide range of sources of polluted waters.

By adopting and implementing a strategy that integrates the management of land, water and biological resources, whilst promoting conservation and sustainable use in an equitable way, the ICW concept addresses the objectives of the EU Water Framework Directive (WFD) and has further advantages. The ICW concept has the potential to deliver on a substantial range of other ecosystem services, most notably carbon sequestration, (subject to further processing of detritus on removal), flood risk management, amenity and recreation, education and landscape aesthetic.
The intention of the ICW concept is to optimise water management and integrate the benefits from its associated wetland infrastructure to deliver a wide range of environmental returns, such as the protection and enhancement of biodiversity, the delivery of good ecological status, the protection of fisheries and improved landscape aesthetics. The ICW concept is predicated on the sciences underpinning restoration ecology and natural resource management. In addition, the broad principles of the UNEP/CBD's 'Ecosystem Approach' and the Ramsar-1971 Convention's 'wise use of wetlands' are applied.

The concept can provide a practical and cost-effective solution for both the management of water resources and the delivery of good ecological status for water and its dependent habitats. While the ICW approach has the potential, with further research and development, to address livestock wastewater, road/urban runoff, landfill leachate and industrial wastewater, this Guidance Document focuses on dealing with domestic wastewater and farmyard soiled water.

Chapter 1: Introduction

This Guidance Document is prepared for the application of the 'Integrated Constructed Wetland' (ICW) concept in the management of point sources of farmyard soiled water and domestic wastewater. Although primarily focusing on the treatment of domestic wastewater and farmyard soiled water, the fundamental principles are generic and, with further research and development, applicable to the management of polluted waters from other sources e.g. landfill leachate, animal wastewater/ slurries, mining waste, sludges and urban/road runoff[1,2,3]. Further guidance on specific issues on management of polluted waters from these sources may issue to be added to this Guidance Document.

The purpose of this Guidance Document is to provide comprehensive guidance for the assessment, design and construction of ICW systems. This document parallels a similar manual for Scotland and Northern Ireland[4] and existing guidelines for Finland[5]. The steps are outlined, ranging from assessing the appropriateness of an ICW in the first instance, to its design, installation and the monitoring process. This involves several decisions at each stage of the assessment and development process. The experience and results, upon which this document is based, indicate that an effective, robust and sustainable ICW can be established in a range of suitable locations. There will, however, be variations in design and construction reflecting the site's location and its specific characteristics.

1.1 Social, economic and environmental coherence in managing water-vectored pollutants

Across the world, social, economic and environmental coherence is sought in the management of wastewater and water-vectored pollution[6,7]. This coherence is increasingly required in addressing problems of pollution to both surface and ground water from various point and diffuse sources[8]. Achieving such coherence requires that the interlinked bio-geochemical dynamics of atmosphere, water and soils are addressed. There is now an awareness of the capacities of certain types of wetlands to achieve effective water management[9]. These include a range of environmental services such as the reduction of flooding, provision and safeguarding of water resources and the improvement of water quality[10]. More specifically, constructed wetlands are increasingly considered effective for the management of water quality issues relating to wastewater[11,12,13].

A common goal with regard to the management of polluted waters is the need for 'closed-loop' systems; making full use of the residual values of water-vectored constituents in a way that does not impact negatively on the environment and that is both socially and economically acceptable. These goals include the retrieval of energy[14], or its sequestration as organic or chemical carbon[15], the recycling of nutrients[16] and the reuse of water[17] especially in drought-stressed conditions/regions. These goals are sympathetic to the universally accepted principles of the 'Ecosystem Approach', which promote a strategy for the integrated management of land, water and living resources, promoting nature conservation and sustainable use in an equitable way[18]. The principles enshrined in the Ecosystem Approach are increasingly seen as the framework for action with regard to sustainable water and natural resource management[19,20].

Using the fact that polluted waters have constituents that are an appropriate substrate for further biological activity[21], wetlands can provide social, economic and environmental opportunities for integrated land and water management. One such approach has been under development since the mid-1990s in Ireland. Rather than being solely based upon environmental engineering, the concepts of restoration ecology[22] were applied, mimicking the structure of shallow emergent vegetated wetlands[23]. This approach was termed the 'Integrated Constructed Wetland' (ICW) concept[1]. This ICW concept combines various approaches to water, land and living resource management by integrating three objectives:

- water quantity and quality management, including flood-hazard management;
- landscape-fit towards improving site aesthetics;
- enhancement of biodiversity.

The integration of these objectives is made with the expectation of achieving synergies that might not otherwise be achieved if traditional land management strategies had been adopted. The fundamental objective is the sustainable and holistic management of polluted waters and associated land and water resources. The ICW concept continues to be developed by applying the principles of 'adaptive management'[2].

Whilst initially developed for the farming community of the Annestown stream catchment (c. 25km^2) in south County Waterford, the ICW concept has potential for application for the management of diverse point and diffuse polluted waters[24]. The appropriate application of the ICW principles has relevance in contributing towards achieving good chemical and ecological status for inland, transitional and coastal waters as required under the EU Water Framework Directive.

Three factors are considered to be key when determining the successful application of constructed wetlands to the holistic management of wastewater, namely:

- the ammonium-N concentration of the influent, and its effective removal through nitrification and de-nitrification;
- phosphorus capture and retention, (which is generally considered to be the most wetland area-dependent parameter[25,26]); and
- whether local soil materials are capable of providing effective protection to groundwaters.

This Document provides guidance for developers and regulators appropriate to the influent and site-specific needs and is based on:

1. The 'Ecosystem Approach' (as promoted by the Convention on Biological Diversity and the Ramsar (1971) Convention on Wetlands, www.cbd.int).
2. The principles of 'restoration ecology'[22].
3. Watershed analytical techniques[27].

The guidance contained in this document is based upon experience gained from the design, construction and operation of about 60 ICW systems built over the past 14 years. Two fundamental requirements are that ICW systems adequately treat wastewaters and that any discharges from an ICW are beneficial or neutral in their impact on the natural resources and ecologies of the location in which they are placed.

It is clear from the experience gained that ICWs can be:-

- economically viable, (taking account of capital costs, running costs and labour costs),
- environmentally sustainable, providing capacities for water, carbon and nutrient re-use, and
- an important addition to the landscape with significant amenity and biodiversity values.

While they are not a substitute for natural wetlands, they have a role in restoring values lost through drainage and associated land management.

1.2 Restoring emergent-vegetated wetlands and their environmental services

Natural wetlands are transitional zones between terrestrial and aquatic ecosystems. Wetlands have been vulnerable to drainage, in-filling and conversion to agricultural and forestry lands. Most of Ireland, and indeed Europe, has been intensively drained with consequential loss of the important bio-geo-chemical processes that are associated with land-water interfaces[28]. These processes and their supporting structures provide critical environmental services for sustaining human well-being[29,30]. These services are most evident in shallow emergent vegetated wetland ecosystems that were once very common throughout the country.

Natural wetlands may form wherever water slows or settles on its passage to the sea. The saturation of soil catalyses a cascade of fundamental bio-geo-chemical changes in soil structure and processes. Suites of microbial, plant and animal communities that have evolved to live in water and water-saturated soils exploit these changes and establish their own dynamic equilibrium by facilitating the retention of water and the defence of their habitats[29,30]. The dynamic equilibrium found in many ecosystems is maintained by various bio-geochemical feedback mechanisms, which in the case of shallow, emergent vegetated wetlands are:

1. The consequence of the soil becoming waterlogged and anaerobic[29,30,31,32,33].
2. The low water-pressure-head (Typically 100mm – 200mm head).
3. The establishment of durable biofilms that resist water infiltration[34,35,36,37]
4. The production and persistence of phenolic and poly-phenolic compounds that impede water infiltration, resist organic matter decay further facilitating water retention[38]
5. The production of methane that inhibits the loss of water through capillary-pore structures[39,40]

Thus, once established, wetlands have an innate capacity to sustain themselves provided there is an adequate supply of water. Indeed the suites of microorganisms, plants and animals that have evolved to such wetland conditions interact to facilitate their continued occupancy.

Within an ICW, this can be achieved by having a sequential, shallow multi-celled system that receives influent and associated water that is continuous or intermittent in supply, sufficient to replace what may be lost through evapotranspiration, surface flow discharge and infiltration to ground.

Of the diverse range of wetland types that are recognised by the 1971 International Ramsar Convention for the conservation of wetlands (there are 42, grouped into three categories), it is those classified as *palustrine, emergent wetlands*[41] that come closest to describing ICW structure and function, and that are used for this document.
These shallow, emergent-vegetated, surface-flow wetlands have robust and sustainable capacities to improve water quality[26,28,29].

Organic matter, suspended solids, faecal micro-organisms, nitrogen and phosphorus loadings, heavy metals, endocrine altering substances amongst other water-vectored constituents have been shown to be intercepted, attenuated or metabolised from the wetland through-flow[32,33,42,43,44]. The mechanisms for their reduction are biological, physical and chemical and largely depend upon the rate of the three-dimensional hydraulic through-flow, which is fundamentally dependent upon the area and configuration of the wetland[3,4,23,32,43,45].

1.3 Integrated Constructed Wetlands

An 'Integrated Constructed Wetland' (ICW) is a series of shallow, interconnected, emergent-vegetated, surface-flow wetland compartments that receive/intercept water-flows from a variety of sources. ICWs can deal with domestic wastewater (primary, secondary or tertiary) and farmyard soiled water and have the potential, subject to further research and development, to address wastewater from food processing, water-vectored animal waste, organic and animal sludges, landfill leachate, road/urban runoff and intercepted diffuse water-vectored pollution. The schematic diagram in Figure 1.1 and photograph in Figure 1.2 are examples of a typical ICW system.

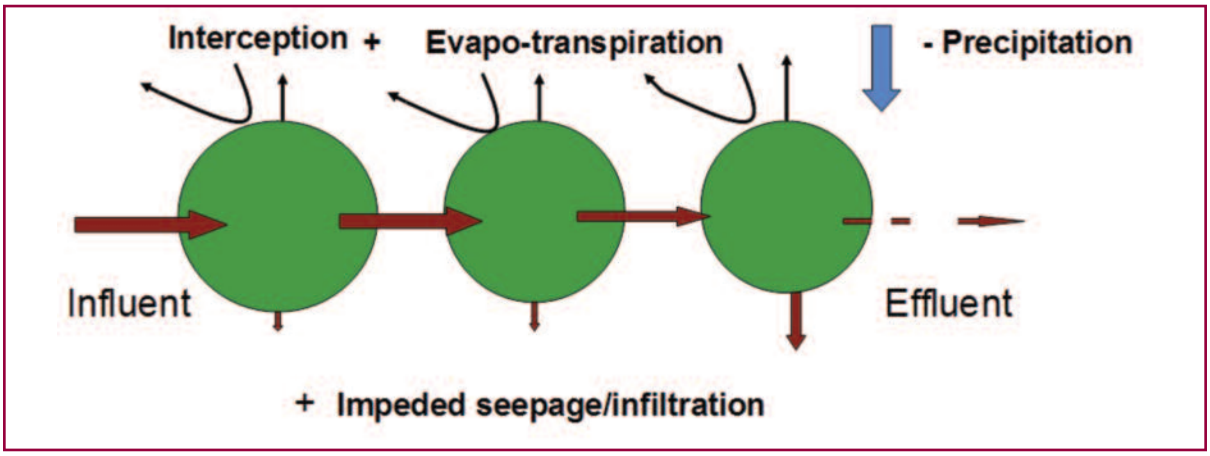

Figure 1.1 Schematic diagram of an Integrated Constructed Wetland

Figure 1.2 Example of a typical ICW system

ICW systems are distinguished from traditional 'treatment wetlands' by the integration of water flow and quality management with that of landscape-fit and biodiversity enhancement. The generally larger land areas used in ICW designs, compared with those used in other constructed wetland designs, deliver enhanced treatment with emphasis on phosphorus removal, and provides for greater system robustness and sustainability. The concept advocates wherever possible the use of on-site soils and topography, locally occurring plant species, and curvilinear embankments that harmonise with the local landscape.

The multi-cellular configuration of ICW systems operates as a series of containment structures that provide a number of sequential defensive intercepts with enhanced control of the contaminant gradient through the whole system. Each cell functions as an individual wetland ecosystem with its own distinct features, influents and effluents. Thus each cell has the capacity to impact differently on the adjacent environment. This effect is proportionate with the cells receiving the most contaminated influent being the most hydrated and 'lined' with organic matter and having the least potential to lose water through infiltration to the ground whilst the most distant wetland cells receive the least contaminated water and may be the least hydrated[46] .

The volume of influent polluted water can be greatly increased from rainfall falling on paved and covered areas. The volume of precipitation is generally difficult to forecast in Ireland and changes in rainfall patterns predicted by climate change are likely to increase volumes of run-off entering collection systems.

During intense rainfall events conventional wastewater treatment systems may not be able to deal with all polluted waters, which could lead to pollution of surface waters and ground water[47,48,49]. Furthermore, sludges that require further management are produced. When ICW systems are appropriately sized, designed and built they can treat all intercepted effluents including short-term increases in volumes.

Advantages:

1. An effective multiple-bunded intercepting infrastructure for treatment of polluted water within a defined area
2. Use of local materials with minimum 'external costs'.
3. Low maintenance requirements.
4. Ease of commissioning/decommissioning.
5. Sustainable over a long lifetime (50 years or more).
6. A robust and segmented system designed for long life and ease of management, with each segment having its own integrity, nutrient and biological status.
7. Increased biodiversity.

8. An inbuilt bio-monitoring capability that is in keeping with the principles underlying the EU Water Framework Directive and the needs of regulation.
9. Recycling of captured nutrients in a de-watered/compost form after a period of time (c. 10 to 20 years)
10. Carbon sequestration and low energy demands (subject to guidance on methodology by EPA).
11. Potential to recycle treated water and sequestered organic matter.
12. Landscape fit and enhanced scenery.
13. Creation of an aesthetically enhanced area with potential recreational capacity.

Disadvantages

1. Requires dedicated land
2. Requires competent skills for design, site analysis and characterisation, and construction.
3. Requires regulatory authorisation by planning permission and discharge licensing.
4. Construction and establishment of vegetation may be weather dependent.
5. Creation of a potential water hazard if deep areas are included.
6. May pose a threat to surface and ground waters If inadequately designed, constructed, or managed,
7. Will require ongoing informed management, monitoring and licensing.

Evaluation of alternative methodologies of dealing with domestic waste water suggest that there may be considerable advantages with ICW systems for villages and small towns due to savings in capital and operational costs[50,51].

The design and installation of ICW systems require a multidisciplinary approach to bring an understanding of wetland function.

CHAPTER 2: Site Assessment-General Overview

2.1 Introduction

In keeping with the Ramsar (1971) and UNEP/CBD ‘Ecosystem Approach’ the decision to use an ICW will be made on a joined-up evaluation of scientific, technological, environmental, economic, logistical criteria, and the specific needs of the client. A systematic and logical approach should be followed towards assessing a potential site and the wastewater as to suitability for an ICW. An early assessment of a site’s overall suitability and the properties/nature of the influent are required in order that time and expense are not wasted.

Chapters, 2 & 3 provide detailed guidance on how to assess a site’s suitability by collecting sufficient information in order to:

1. Determine if the ICW can be safely developed on the site.
2. Demonstrate that the construction and placement of an ICW will not create a negative impact on the environment, particularly waters downstream or down-gradient.
3. Provide adequate site data for an appropriate design.
4. Provide baseline information to regulators to enable planning/discharge conditions to be set.
5. Provide information to prospective contractors, in order to obtain a realistic construction price and limit the risk of encountering difficult ground conditions during construction.

This approach termed ‘Site Assessment’ comprises various tasks, including a desk study, visual assessment, and site tests.

2.2 Key issues for assessment

In addition to the environmental function of an ICW, it is an essential requirement of the ICW concept to explicitly address the social, economic and ecological considerations of the site, whereby the needs of all stakeholders in the management of the land and water resources that are linked to a site need to be given appropriate consideration. Particular regard must be given to all water quality discharges, achieving an appropriate landscape-fit and enhancing biological diversity.

As the ICW concept is based on integration into the immediate and adjacent environment, site characterisation must investigate how this requirement can be achieved and optimised. This requirement is detailed below (See Table 2.1 below). The assessment should be rigorous and comprehensive and ensure that any high-risk elements are thoroughly assessed.

KEY ISSUES	IMPLICATION for SITE CHARACTERISATION
Not relying solely on hard engineering measures which may isolate the system from the environment	Ensuring that sufficient information is gathered to demonstrate that any significant risk can be controlled by natural protection afforded by the ICW, enhanced only where necessary by hard engineering measures.
Facilitation of natural treatment processes	Ensuring that the nature and properties of the influent are known, that adequate land space is available and that the system can operate with low or zero energy requirements.
Obtaining a good landscape fit	Ensuring that the topography and the existing landscape is adequately surveyed and assessed.
Enhancing biodiversity	Understanding local ecological conditions and complementing them with an appropriate range of wetland plant species and establishment patterns towards encouraging a diverse range of habitats.

Table 2.1 Key Issues and site characterisation

2.3 Selecting the location of an ICW

As biodiversity protection and enhancement is central to the ICW concept the first step in site selection is to ensure that development of an ICW would not directly damage a site of high biodiversity value.

A desk study will determine whether the site is within a proposed or candidate Special Area of Conservation (SAC), Special Protection Area (SPA) or Natural Heritage Area (NHA) designated for nature conservation under the Habitats Directive (92/43/EEC), Birds Directive (79/409/EEC) or Wildlife Act, 1976 (as amended 2000, 2009) respectively. Information on these sites is available at www.npws.ie/en/MapsData, and further data may be requested from NPWS using the data requests form available at www.npws.ie/en/DataPolicy. If the proposed ICW site is within an SAC or SPA, an Appropriate Assessment in accordance with Article 6 of the Habitats Directive must be conducted in order to ascertain whether the ICW could have a significant negative impact on the integrity of the designated site. Guidance on Appropriate Assessment is available from the EU website (http://ec.europa.eu/environment nature/natura2000/management/docs/art6/natura_2000_assess_en.pdf) and the Department's website (www.environ.ie). The Appropriate Assessment process may result in the approval, modification or rejection of the ICW proposal by the appropriate regulatory authority.

The assessment must also determine whether the ICW discharges, either via surface or ground, to any SAC, SPA or NHA. If it does so, an Appropriate Assessment will be required to determine whether the effect is positive, negative or neutral.

ICWs should not be located such that they will have significant negative impacts on any of the habitats or species for which a nature conservation site is designated, on the site's overall integrity or on any other protected species.

Not all sites of high biodiversity value are in protected areas and therefore a field visit will be required to describe the site's habitat according to the Heritage Council's guide to habitats in Ireland[52], and to document the dominant plant species. Appropriate ecological expertise will be required for such a survey. The presence of protected plant species and use of the site by protected wild animals must also be assessed. The use of site assessment protocols such as those widely used in EIA assessments can assist this process. In general, when considering the location of ICWs sites, those with low current biodiversity value should be selected, unless that would significantly decrease the overall environmental benefits to be derived from the ICW. In particular, an ICW should not be located within a natural wetland, unless it can be clearly demonstrated through careful analysis that the environmental benefits gained by its construction significantly outweigh the negative impacts on the wetland.

A complementary approach, to the avoidance of areas of high biodiversity value, is to focus the selection of ICW sites on those areas which currently have low nature conservation values at a farm and local level, such as reclaimed/drained/

improved/degraded areas. On most farms these will form a much higher proportion of the farm than those with higher nature conservation values. ICW location on former wetlands, which have been drained and have lost most of their characteristic species, or on artificial wetlands such as farm ponds, as long as these do not hold **protected, Red List or rare** species, is allowed. The same applies to widespread wet rushy pasture on surface water gleys such as occurs in many drumlin areas. Wetlands should not be drained to allow ICW systems to be constructed.

2.4 Risk Based Approach

The general environment is by its nature variable and subject to exogenous disturbances. When considering changes to land and water management a precautionary approach is required whereby potential risks are identified and rated and then appropriately minimised or mitigated. Potential risks are therefore an important consideration in the overall approach to site assessment and design. Risk based assessment provides a framework for evaluating and managing pressures and impacts on identified 'receptors'.

The generally recommended tool for environmental risk assessment is the ***'Hazard-Pathway-Receptor".***

Risk can be defined as the likelihood (or expected frequency) of a specific adverse consequence. Applied to ICW systems, it expresses the likelihood of impacts arising from the construction or operation of, in this instance, an ICW and its water-vectored pollutants, i.e. the potential Hazard.

A *Hazard* presents a risk when it is likely to significantly and negatively affect the status of a valued resource such as surface or groundwaters or natural and built heritage i.e. the *Receptor*. An impact can only occur if a significant linkage or pathway is established between the *Hazard* and the *Receptor*. For the hazards under consideration, key factors to minimise or mitigate the risk are velocity (addressed by having an appropriate wetland configuration) and associated residence time (addressed by having adequate functional wetland area) and sub-soil quality to deliver the required impermeability.

Absolute protection from hazards and impacts is not possible and only a degree of protection can be provided. Surface water and groundwater protection are often the primary reason for the installation of an ICW system in the first instance. The adsorption of potential pollutants from discharges-to-ground into subsoil clays of sufficient depth is generally regarded as the main process of attenuation[53,54].

An additional suite of well-documented processes and structures also exist[29,30,32,33,34,35,36,37,39,40] to provide more sustainable protection than that from adsorption and soil structure alone. High impedances to infiltration are delivered by the biofilms, organic matter and humic substances that develop rapidly within wetlands once established. This impedance is further augmented by biological feedback mechanisms that secure water retention. Wetland soils provide an effective processing medium, especially for the denitrification of nitrate-N and ammonium-N due to of the presence of available carbon for heterotrophs[34,36,55,56,57],. See schematic diagram (Fig. 2.1) below. It is therefore essential that the factors determining the establishment of a functional wetland soil are addressed including the significant attenuating processes within both the wetland detritus and underlying soils. Notwithstanding the beneficial attenuating mechanisms within and beneath ICWs, these mechanisms may be bypassed if the ICW is not located, designed and maintained in accordance with this Guidance Document.

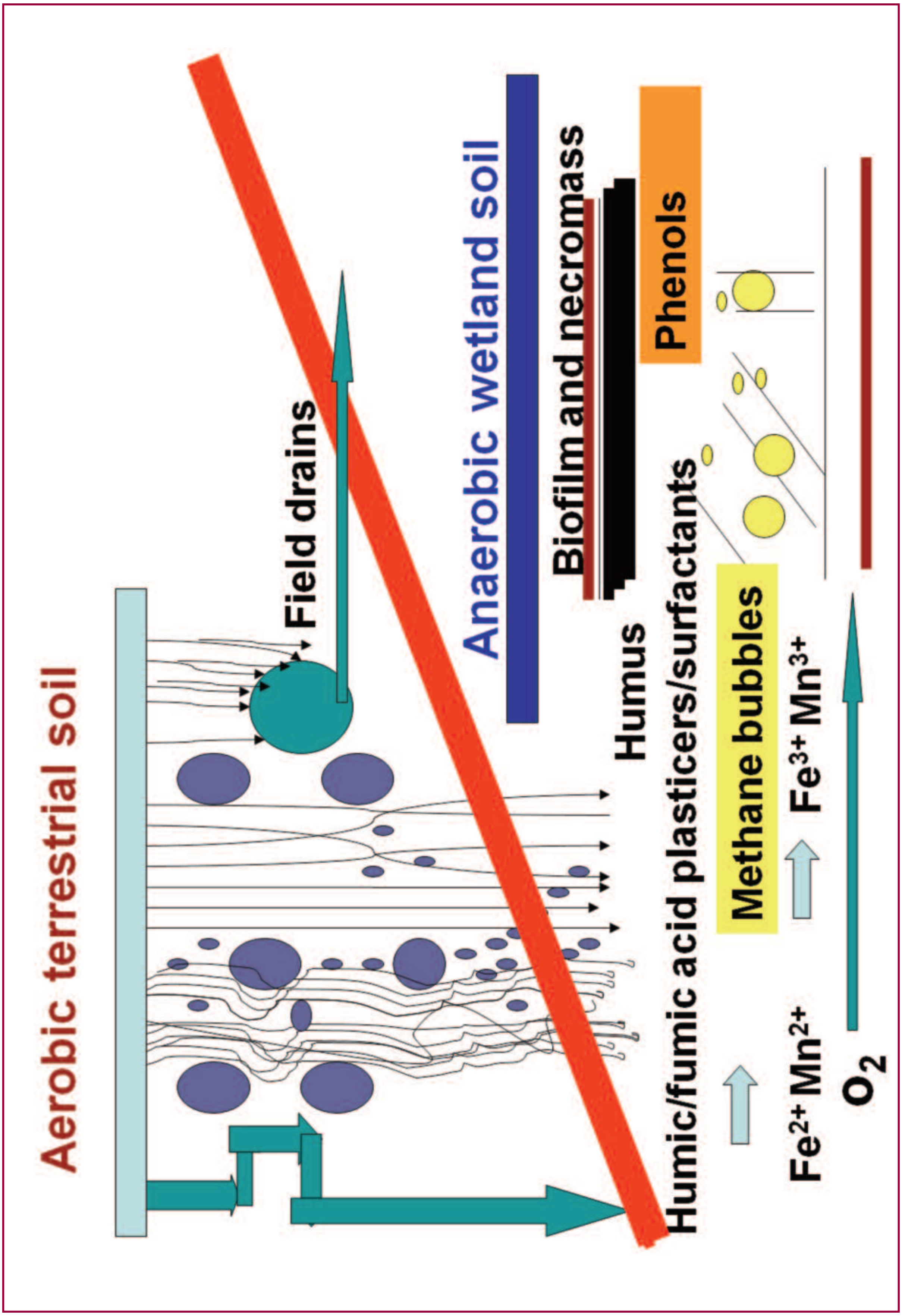

Figure 2.1 Schematic representation of the differences between terrestrial soils and wetland soils showing drainage and impedance to water infiltration to ground

2.5 Key Environmental Receptors

The key environmental receptors in the context of an ICW (Scholz and Lee, 2005) are shown below in Table 2.2.

RECEPTOR	ISSUES
Surface Water	Generally the wetland will discharge to a surface water feature (receptor) and a discharge licence will be required. The assimilative capacity of the receiving water will need to be assessed. Discharge water quality is primarily determined by wetland area thus sizing is critical.
Groundwater	There will be limited infiltration to the aquifer (receptor), which will need to be assessed in keeping with groundwater protection criteria. Nearby water supply sources need protection and the potential for conduits examined.
Soil/subsoil	The existing topsoil and subsoil will be exposed to fundamentally different environmental regimes (changing from an oxygenated to a waterlogged anaerobic state). The topsoil will be used as the rooting medium for plants in the wetland. The newly developing wetland soil will accumulate nutrients (predominantly phosphorous and nitrogen). The subsoil has a role in containing and attenuating residual infiltrating pollutants, principally ammonium-N, that may pass through the wetland soil horizon (Pathogens and P are removed primarily by detritus in the upper soil layer. Denitrifying bacteria are found in both upper and lower layers.
Landscape	An appropriate landscape fit is a key objective for all ICW systems and therefore needs to be comprehensively addressed
Flora and Fauna	There is considerable capacity for ICW systems to enhance biodiversity. Nevertheless, care will need to be taken to ensure that any protected area such as SACs or NHAs are not negatively impacted upon.
Air	Minor odours may be associated with the wetland, and their potential impact needs to be assessed,
Human	The potential impact on the enterprise, users, and neighbouring owners and properties needs to be assessed.
Archaeology	Site considerations need to include all aspects of former site use and archaeological artefacts

Table 2.2 Key environmental issues.

2.6 Hazard Characterisation

1. General

The principal contaminants, which constitute the Hazard, are dependent on the water-vectored pollutants. The influent water volume may be increased by rainfall and the volume of polluted water that enters an ICW system is related to the rainfall pattern, duration and intensity.

Precipitation influenced inflow is an hydraulic driver affecting ICW function, including maintenance and vitality. Precipitation can be of varying intensity often with extended wet or dry periods. The ICW concept is designed to cope with the widest possible range in precipitation. The key design components are therefore the provision of adequate size and infrastructural robustness to deal with the range of flow conditions whilst maintaining the level of treatment.

2. Typical Characteristics of ICW Influent Composition

The composition of influents to ICW systems can be very variable (See that for farmyards, Table 2.3 below[45,58], and for wastewater Table 2.4 below[51]).

Parameter	Farm ICW Influent (mean concentrations)	Standard Deviation	Number of samples
COD mg/l O_2	1908	6119	463
BOD_5 mg/l O_2	816	3941	386
Ammonium mg/l N	64	127	609
Nitrate mg/l N	2.6	6.2	151
Molybdate Reactive Phosphate mg/l P	10	8.3	618

Table 2.3 Influent composition of farmyard soiled water ICW systems monitored in the Annestown/Dunhill catchment

Parameter	Farm ICW Influent (mean concentrations)	Standard Deviation	Number of samples
COD mg/l O_2	1178.68	642.0	101
BOD_5 mg/l O_2	853.86	552.4	99
Ammonium mg/l N	33.99	10.47	108
Nitrate mg/l N	6.38	5.72	98
Molybdate Reactive Phosphate mg/l P	4.28	2.28	102

Table 2.4 Influent composition of wastewater ICW systems monitored in Glaslough, Co. Monaghan

Additional volumes of influent derived from intercepted runoff (e.g. roads, urban, farmyards) can be calculated from rainfall figures and the interception area, (e.g. for an interception area of 5,000 m^2 which experiences rainfall of 1,000 mm per annum, the calculated theoretical volume of soiled water will be a maximum of 5,000 m^3 per annum, an average of approximately 13m^3 per day). The influent peak volume will however be highly variable. For example, during a storm-event, where 100mm of rain falls over a 2-day period the volume of soiled water for such a site area will be about 250 m^3 per day (although evaporation and soakage at interception will reduce this volume).

Precipitation-generated volumes may be many orders of magnitude greater than that originating solely from direct sources.

The impact of precipitation relative to defined point sources can be illustrated as follows: Typically dairy washwater is about one third of the annual volume of water from intercepted precipitation on open dairy farmyard areas (typical washwater volume generated per cow is 50 litres per day). During individual extreme events, (e.g. 50 mm rainfall over a 24 hr period), washwater can be as little as 2% of the volume of water generated from precipitation on open farmyard areas[2].

This large variation in the flow to the wetland must be accommodated in the design by relating the necessary wetland area and the hydraulic residence time to the total precipitation-interception area (i.e. farmyard and its curtilage). A more detailed description of the influent is described[23,45]. The limiting factor with regard to influent composition and ICW functional vitality is ammonium -N concentration[2]. Sustained concentrations exceeding 100 mg/l and flux concentrations exceeding 250 mg/l negatively impact upon the emergent vegetation with consequential die-off. Thus, exceeding these concentrations will incur loss of vegetation. Consequently significant abuse of an ICW through exceeding its influent concentration limits will be apparent to any assessor/regulator.

3. Phosphorus Accumulation

Within the various segments of the ICW, there will be accumulation of sediment and necromass, particularly in the upper (proximal) segments. It is in this detritus matrix that the phosphorus is captured and accumulates over time. The concentration of P in this sediment can be of the order of 3kg per tonne dry weight[46]. (The multi-segmented ICW design facilitates P retention as each segment has its own P-dynamics.)

Estimates of the P build-up in the first ICW segment would suggest that it can be removed at intervals commensurate with the need to remove detritus (typically at approximately 10-20 year intervals and used as a farm fertiliser, in accordance with farm nutrient management plans, by land-spreading). Removal is preceded by circumventing through-flow, dewatering and in-situ composting. This composted sediment poses minimal risk to the environment while it remains in the ICW. However, once removed it needs to be managed in ways that avoid risk to waters. The storage requirements specified for farmyard manure in the European Communities (Good Agricultural Practice for Protection of Waters) Regulations, S.I. No. 101 of 2009 should be applied to the removed ICW detritus/sediment. Alternatively the material removed may be used as fuel with the ash derivative recycled, for example, as a fertiliser. It is important to note that the extracted material has capacity for a range of uses, otherwise the material may be considered a waste and a potential environmental hazard. Guidance for detritus/sediment (and associated nutrients) re-use will have to comply with the regulatory regime in force at the time of removal.

4. Typical Characteristics of Discharges from Integrated Constructed Wetlands

The typical characteristics of the discharges from farmyard soiled water ICW systems to surface waters and to groundwater are outlined in Table 2.5 below. These are based on 6 years of data from farmyard ICW systems in Co. Waterford. A review of discharge data (5 years) is also available[45]. Table 2.6 below gives recent data from a combined wastewater system built c. 2007 showing higher levels of attenuation and contaminant removal[51].

Parameter	ICW Discharge (mean concentrations)	Standard Deviation	Number of samples
COD mg/l O_2	65	65	514
BOD_5 mg/l O_2	15	18	408
TSS mg/l	21	41	424
Ammonium mg/l N	0.8	2.3	646
Nitrate mg/l N	1.6	2.3	577
Molybdate Reactive Phosphate mg/l P	1	1.5	658
E Coli CFU/100mls	401	1363	68

Table 2.5 Effluent composition from farmyard soiled water ICW systems monitored in the Annestown/Dunhill catchment (All data until August 2007)

Parameter	ICW Discharge (mean concentrations)	Standard Deviation	Number of samples
COD mg/l O_2	37.23	26.66	104
BOD_5 mg/l O_2	4.88	5.15	99
TSS mg/l	8.88	17.97	100
Ammonium mg/l N	0.34	0.48	108
Nitrate mg/l N	0.30	0.25	101
Molybdate Reactive Phosphate mg/l P	0.025	0.035	100
E Coli CFU/100mls	2	2	5

Table 2.6 Effluent composition of wastewater ICW systems monitored in Glaslough, Co. Monaghan

(Note – Glaslough ICW system has an average daily load of 1,400 p.e. at present on a system designed for 1,750 p.e. with a total segment area of 32,500 m^2)

Figure 2.2 Wastewater ICW system, Glaslough, Co. Monaghan

It is important to note that the volumes discharging from the wetland are periodically and volumetrically variable and there can be periods, particularly during summer months, when little or no discharge occurs to surface water. Water levels may fall below the outfall level in any wetland cell creating freeboard which further delays water through-flow on resumption of wet weather.

Exfiltration from an ICW will not be uniformly distributed, as the proximal wetland segments may have significantly lower infiltration rates due to the sealing effect of accumulating organic matter mentioned above. This effect will be less in the distal segments.

Parameter	Groundwater Depth at 3 m below ICW (Mean Concentrations)	Standard Deviation
Ammonium mg/l N	4	4
Nitrate mg/l N	0.2	1.5
E Coli CFU/ 100ml	25	27
Molybdate Reactive Phosphate mg/l P	<0.01	0.04

Table 2.7 Typical characteristics of Groundwater below Farmyard Soiled Water ICW systems (Carroll et al 2005)

2.7 Site suitability (General Requirements)

There are a number of pre-requisites that must be addressed before embarking on the assessment of a site's suitability for an ICW. These are as follows:

1. Restrictions on Construction of an ICW

It is essential that the construction of a wetland does not itself become a source of pollution or lead to the loss of significant intrinsic value at the site. These are of two distinctly different types; those dealing with water resources per se. and those dealing with significant values of archaeology and nature conservation.

A proposed ICW should not be considered for

1. Sites within 60m up-gradient of any well or spring used for potable water.
2. Sites within the inner protection zone of a public groundwater supply source, where the vulnerability rating is classified as extreme.
3. Sites within 300m up-gradient of a public supply (>10m3/day or >50 persons) borehole, where an inner protection zone has not been identified.
4. Sites within 25m of a dwelling.
5. Land beneath the projected crown area of mature trees.
6. Sites where the possibility of collapse cannot be ruled out (e.g. where swallow holes and similar karst features are known to be near the surface).
7. Sites within 15m of an exposed karst feature.
8. Sites where construction of the ICW may negatively impact a site of natural heritage value without carrying out an appropriate assessment as required by the Habitats Regulations.
9. Sites where construction of the ICW may negatively impact a site of cultural heritage value.

10. Sites where adequate land area is not available.
11. Sites in close proximity to a watercourse (no less than 10m from the initial and second ponds and no less than 5 m for subsequent ponds,).
12. Sites that cannot be adequately protected from flood damage.
13. Where neither surface water discharge nor exfiltration is possible in situations where an adequate receiving water is not available.

2. Surface Water Protection Requirements

If it is proposed to discharge from the ICW to a watercourse, then the ICW should be of sufficient size or the receiving watercourse should have adequate assimilative capacity to cope with the discharge (See Section 3.3 below).

3. Groundwater Protection Requirements

A desk study of existing information will help establish the soil types and hydrogeological setting in terms of aquifer classification and groundwater vulnerability. The site assessment works will confirm or modify this information. There are a number of basic requirements which will provide adequate protection for groundwater. These are summarised in groundwater protection responses and further details are provided in Chapter 3 and in Appendix A.

The five corner-stone processes that control the establishment, development and maintenance of wetland conditions have been shown in practice to provide adequate safeguards for the protection of associated ground and surface water receptors.

Apart from having a practical (for construction) thickness of subsoil, it is not necessary to impose further groundwater protection measures except in sensitive situations described below.

1. To facilitate the initial establishment of hydric wetland soils and to provide adequate protection to groundwater resources, a 500mm thickness of subsoil with a maximum permeability of $1x10^{-8}$ m/s is required underlain by a further 500mm of sub-soil.

2. Where a regionally important aquifer is present and the groundwater vulnerability rating is high or extreme the upper 750mm should be enhanced to achieve a permeability of $1x\ 10^{-8}$ m/s underlain by a further 250mm of sub-soil.

3. Where highly permeable sand and gravel or fractured bedrock is encountered and are in hydraulic contact with the water table the ICW should only be constructed if 750mm of low permeability material can be provided over the

sand and gravel or fractured bedrock, with the upper 500mm enhanced to achieve a permeability of 1 x 10^{-8} m/s.

4. Where there is a risk of catastrophic hydraulic leakage, for example in some areas of karst geology or areas liable to collapse or subsidence (mined areas), an increased depth of subsoil to 1,500 mm is required or alternatively, declining the site as being inappropriate for an ICW.

5. All geomembrane-lined ICW ponds shall be underlain by at least 150 mm of subsoil, the upper 50 mm of which may be a protective fine sand layer depending on the requirements of the lining contractor. The geomembrane shall be overlain by subsoil with a minimum thickness of 200 mm of low to moderate permeability and plastered with remoulded subsoil.

4. The Competency of the Assessor

The person undertaking the assessment must have appropriate competency to:

1. Collect and interpret the recorded and field information;
2. Make a visual assessment of the site and be capable of identifying situations where a specialist may be needed;
3. Assess the likely impact on existing or potential aquatic receptors and site values;
4. Assemble the necessary information from disparate sources towards designing an appropriately sized wetland, including understanding of both terrestrial and wetland soil ecology and their bio-geochemical processes.

CHAPTER 3: Undertaking the Site Assessment

3.1 Introduction

The purpose of site assessment is to determine the suitability of a particular site for the construction of an ICW. This chapter details an approach for completing the site assessment.

A site assessment is essential to enable a decision on whether an ICW is appropriate and to provide the basis for the ICW design. The data collected should be used to achieve the most appropriate design for an ICW on the site considering all available social, economic and environmental needs.

A site assessment form (Appendix C) will aide the collation of site data and act as a checklist to assist with the decision-making process. This form, when completed, will provide a record of the site assessment and design process. The text below follows the layout of this 'Site Assessment Form', and completion of the Form will benefit from being used in combination with the text below.

Since an ICW will interact with the wider environment and can enhance the surrounding landscape, the visual aspects of construction are important and the use of visual records (such as photographs or video) to support the design process is strongly advised.

3.2 Approach to Site Assessment

The following key steps must be undertaken:

A. Desk study and collation of supporting information

B. Visual Assessment
   - B.1. Characterisation of the waste water – e.g. farmyard inventory, population equivalent (PE), and volumetric ranges.
   - B.2. Evaluation of 'receptor' sensitivity and location.

C Site Tests
   - C.1 Trial hole
   - C.2 Soil characteristics and particle size analysis

D. Decision process, and preparation of recommendations.

3.3 Desk Study and Collation of Supporting Information

1. Preliminary Consultation

A preliminary consultation with the client is necessary in order to:

1. Establish the current waste water management practice(s).
2. Establish in general terms, the volume and composition of the waste water to the potential ICW.
3. Establish the client's rationale for the management of the waste water under consideration.
4. Provide the client with an understanding of an ICW system's function and how it can contribute to sustainable use of natural resources.

A good understanding between designer and client of these issues is necessary with information exchanged on budget costs for the project and other logistical items. The decision to consider building an ICW may originate with the client but may involve the adviser/designer in the decision and procurement process.

The client may have particular reasons for considering the use of an ICW and these should be noted as they may highlight potential receptors and habitats at risk.

The current management regime for any water-vectored pollutants should be established. Improvement of the existing or future waste water management other than by the use of an ICW may be a preferable option and this needs to be discussed with the client or adviser.

The nature of water-vectored effluent material and the area of intercepted precipitation (including the likely ICW area) will need to be established.

The approximate size of the required wetland (See Chapter 5.4 below) needs to be discussed and recorded in order to give the client an indication of the overall land area required for the wetland. The rationale for the area required needs to be explained and agreed in order to ensure full compliance with the design needs.

The name, address, and contact details of the client should be confirmed and some general items in the form can be filled out at this time.

2. Collation of Relevant Environmental Data and Desk Study

General

The purpose of this activity is to:

i. Obtain information relevant to the site
ii. Identify targets at risk
iii. Establish if there are site restrictions
iv. Shortlist options if more than one location is being considered.

A desk study involves the assessment of available relevant data pertaining to the site and adjoining area to determine whether the site has any restrictions on the development of an ICW. The following information will need to be collated and documented.

Topography

Base maps can be purchased from the *Ordnance Survey of Ireland,* or from regional map shops. A set of maps suitable for planning applications, termed a planning pack is the most suitable way to buy the maps and these can be used later for the preparation of any planning application.

The relevant 'Discovery Series' 1:50,000 scale map will establish the regional topographical context, showing slopes and contours, surface water features and other relevant topographical features. The grid reference for the site should be determined (computed from the Discovery Map).

The best available base map information is at scales of 1:2,500 and 1:10,000. These maps provide useful information on the immediate topography and may identify potential sites of natural or cultural heritage. (Refer to www.npws.ie for further information on such sites)

Climate

Basic data on the annual rainfall in the area should be determined. Other information of relevance may include evaporation, evapotranspiration, and wind direction data. The main sources of this data are the Meteorological Service (www.met.ie) and other commercial websites.

Surface Water

Identify potential candidate receiving watercourses for the ICW from O.S. maps. Information on surface water flows and quality may be obtained from the EPA (www.epa.ie), OPW (www.opw.ie), or Local Authority for larger water courses in the vicinity of the site. If this information is not available, receiving water flows (above the proposed discharge point) must be estimated by either:

1. Empirical formulae
2. Appropriate computer-package model
3. Direct flow measurement.

The method of estimating the receiving water flow should be noted in the Comment column in Appendix C2.3. If necessary, expert advice should be sought. Approximate catchment areas for surface water features may be estimated from discovery series maps.

Surface discharge volume from the ICW can be calculated using the following general formula:

DISCHARGE (m^3 per annum) = (A + B+C) – (D + E),

Where;

1. A = specific initial effluent volume for treatment
2. B = Intercepting (e.g. paved and roofed) area (m^2) X annual rainfall (m)
3. C = ICW area (m^2) X annual rainfall (m)
4. D = ICW area (m^2) X annual evaporation and vegetation transpiration and interception(m)
5. E = ICW area (m^2) X annual infiltration rate (m).

The baseline chemical analysis data for the receiving waters should be determined; a minimum of 3 sets of sample results should be obtained. Results may be available from the EPA or local authority. If direct monitoring is required, samples should be gathered at regular intervals over at least a three-month period (to include a period of prolonged dry weather, typically between the 1st July and the 30th September) at a point immediately upstream of the proposed discharge location. Analysis should be provided for the following parameters: 5-day Biochemical Oxygen Demand (BOD), molybdate reactive phosphate (MRP), suspended solids (SS), ammonium-N, nitrate-N and nitrite-N. Where a water quality Q (ecological status) rating is available, it should be noted along with any other water quality data. Water Framework Directive river body status should be given where available.

The general formula to describe the mixing of a discharge with river water is:

$$C_{ds} = \frac{(Q_u \times C_u) + (Q_d \times C_d)}{(Q_u + Q_d)}$$

Where:

Qu	=	the river flow upstream of the discharge
Cu	=	the concentration of pollutant in the river upstream of the discharge
Qd	=	the flow of the discharge
Cd	=	concentration of pollutant in the discharge
Cds	=	the concentration of pollutant in the river downstream of the discharge

Details of the effect of the ICW discharge on receiving water quality should be calculated for the following parameters: BOD, MRP, Ammonium-N and Nitrate-N, and any other relevant parameter, based on the characteristics of the effluent. Use of average flows should suffice for most situations, as the ICW discharge flow is directly influenced by and proportional to rainfall. The above calculations will indicate if adequate assimilative capacity for the discharge is available in the proposed surface receiving watercourse.

Compliance with the European Communities Environmental Objectives (Surface Waters) Regulations 2009 (S.I. No. 272 of 2009) and with the European communities Environmental Objectives (Groundwater) Regualtions (S.I. No. 9 of 2010) will be required.

Groundwater

The existing sources of water used by the client should be established, i.e. whether mains, private, or group water scheme.

The relevant geological and hydrogeological information for the site should be compiled.

The Geological Survey of Ireland (GSI) and the Environmental Protection Agency (EPA) are the principal sources of this information (websites at www.gsi.ie and www.epa.ie). These websites list available groundwater protection schemes. The GSI produces maps of Groundwater Resources (Aquifers) and Vulnerability to Contamination (Groundwater Vulnerability). These are combined to produce a map of Groundwater Protection Zones. In general this information is available from the website, but the relevant contact details, if further information is required, are: The Groundwater Section, Geological Survey of Ireland, Beggars Bush, Dublin 4, and the Environmental Protection Agency, Johnstown Castle, Wexford.

In addition, a national aquifer map is available on the GSI website, and it is possible to zoom in to the area in question and print the relevant excerpt if required.

Note: If a Groundwater Vulnerability Map has not been produced by the GSI for a particular area, then the extremely vulnerable areas may be obtained from the relevant River Basin Districts (RBD) project. General soil and subsoil maps are available from Teagasc (www.teagasc.ie). The shallow rock areas delineated on Teagasc subsoil maps are indicated at the 1m contour. Soil (topsoil) maps are also available from Teagasc. Existing data, available from the GSI, includes the location of outcropping bedrock and karst features and existing depth to bedrock data from their well databases. From this, areas of shallow subsoils (rock within 1m of surface) can be delineated. This can then be used in the desk study. Where information from the GSI well and karst databases are used in a desk study, the townland in which the feature is located (or more specific location if available) should be highlighted on a map

The data, when compiled should be compared to the groundwater protection response matrix in Appendix A to establish the preliminary groundwater protection response for the proposed development.

The investigation and any licensing requirements in relation to groundwater will depend on the type of ICW proposed.

In the case of an ICW where a discharge to surface water is possible, the amount of water going to ground is relatively low if a maximum infiltration rate of 1×10^{-8} m/s or better is achieved. (see sections 2.7 above). Mineral-N contained in the ICW infiltrate is considered to be the key potential pollutant of groundwater. An ICW with all shallow cells (100-300mm), and a surface water discharge, will have a variable low total-N loading discharging to ground due to both flow and denitrification. The approach outlined in Appendix B will assist in the initial assessment.

In the absence of a suitable surface receiving water for an ICW designed and constructed in accordance with this Guidance Document, a final discharge to groundwater may be considered in appropriate circumstances.

Where the final discharge is less than $5m^3$/day on average, a detailed geotechnical/hydrogeological assessment/investigation is not required.

Where the final discharge exceeds 5m^3/day on average, a detailed geotechnical/hydrogeological assessment/investigation is essential and should be carried out prior to site selection.

Guidance on such assessment/investigation is being developed by the Environmental Protection Agency and is expected to be published by mid-2011. An ICW designed on the basis of a final discharge to groundwater should not be proposed without carrying out such assessment/investigation. The Environmental Protection Agency should be consulted pending publication of such guidance.

Natural & Cultural Heritage

Particular attention must be given to areas of natural and cultural heritage and where such locations are being considered for an ICW, discussions should firstly take place with the appropriate state agencies. The relevant local authority will have a list of designated NHAs, candidate SPAs and SACs and an inventory of protected structures/archaeological sites. These locations are also available, and regularly updated, on the National Parks & Wildlife Service website, www.npws.ie. The client may also be a good source. If more detail is required Government bodies such as the *Department of Environment, Heritage and Local Government (DEHLG)* and the *Office of Public Works (OPW)*, can be contacted to discuss particular areas.

Drainage

The drainage patterns of the area being examined are critical, and field drainage maps for the particular area should be sought from the landowner or their advisor/agent. General information on the density of drainage in the area can be determined from the topographical maps. Heavy soil types should alert the assessor to the possibility of hidden drains. Reference to older, (prior to 1950), 6 inch or 25 inch maps will indicate previously wet areas which may now be drained.

Wet and heavy soils, where drainage is most likely to be found, should be singled out for special scrutiny to remove drainage infrastructure. Experience over the past 14 years has shown that undetected land drains are the principal cause of ICW systems having inadequate hydraulic retention.

Public Utilities

The first point of confirmation for public utilities should be the client. The local authority should be consulted with regard to the possible location of public water supplies and water mains in the area. Locations of gas lines, electricity cables, and communications networks need to be confirmed in consultation with all the relevant utilities. The local office for each utility should be contacted. Contact details can be found in the telephone directory for the area.

Desk Study Assessment

All the information collected through the desk study should be examined.

This overall information may highlight the inappropriateness of a potential site on the basis of the location being of significant archaeological, natural heritage or historical value or identify potential constraints. To avoid accidental damage, a trial hole assessment should not be undertaken in areas which are, or adjoining, significant sites (e.g. SACs, NHA's) without appropriate prior permission from the statutory authority.

In summary, the outcome of the desk study will be as follows:-

- A review of the topographical maps will have identified, in particular, steep slopes.
- Once the aquifer and vulnerability classes are established, reference to the groundwater protection matrix will allow determination of the appropriate response and the requirements necessary for that response. The on-site assessment will later confirm or modify such responses.
- The geological information collated will have indicated the potential of encountering karst or high resource value aquifers.
- The subsoils information will have highlighted the likelihood of encountering gravels or potentially suitable material.
- The soil map information may indicate the presence of low permeability material (e.g. boulder clays and gleys).
- The prevailing climatic data, the available dilution, and any constraints relating to land drainage, utilities, and planning will have been established.

By this stage it may be possible to eliminate sites that present insurmountable constraints.

3.4 Visual Site Assessment

The purpose of the visual site assessment is to:

1. Verify desk study findings.
2. Make an on-site assessment of the hazard.
3. Evaluate the sensitivity of the identified receptors, in particular watercourses and groundwater features.
4. Focus possible location/choice for an ICW.

1. On-Site Hazard Evaluation

The site work should begin with a visual assessment of the source of waste waters to be managed. The time of visit is important, in that the principal challenges may not be apparent on a dry day, but may be more apparent on a wet day.

It is useful to make a sketch of the proposed source, or use a map already obtained from the client to orientate the evaluation.

The various component sources of waste waters, require examination including the contributing interception area and computed run-off. The ability of each of these components to generate waste water needs to be evaluated and the expected annual volume of total waste water approximated for each component. The existing arrangements with regard to run-off should be established and examined noting all drains that may be intercepted by the ICW.

Photographs should be taken of the site, to record the general layout and structures, and various features of interest.

The purpose of this exercise is to establish a thorough picture of the client's site management profile, and to assist in completion of the design and planning application. It is important that the client is present during this process to discuss all water management activities that may impinge on the ICW and occur through the year.

2. Visual Assessment of Receptors

Topography and Landscape Fit

A topographical survey should be commissioned to survey the candidate site and the proposed ICW area and the scope of this survey should be decided at this stage.

The survey information will be used principally in the design process, to make optimum use of topography and minimise earthworks costs. The topographical survey will also allow the production of cross-sections through the proposed ICW area, which will assist in construction planning and costing.

The survey should include all relevant components of the waste water identified above and should allow computation of any contributing area.

The potential receiving waters and topographical setting of the proposed wetland system should be examined to assess the landscape fit and the possible discharge options. Again, photographic recording is strongly advised.

The landscape position reflects the location of the site in the landscape, e.g. crest of hill, valley, slope of hill.

Ideally the site should be down slope of the source of waste water and any associated interception area to allow gravity flow. A minimum 1m drop is required from the waste water source to the base of the first proposed ICW segment/cell, to allow for build up of sediment[59]. The slope of the chosen site should be estimated. Steep slopes should be avoided and preference given to sites that are mostly level. (This will have safety, cost, land-take and functional advantages.)

It is expected that some sites, that may be the most suitable for the construction of an ICW, are sites that are marginal for agricultural purposes, on the basis that they are wet. However as outlined in Section 2.3 above, such wet areas may contain or be part of areas with current high natural values and in such cases the ICW should be located elsewhere so that the ICW's contribution to biodiversity enhancement is optimised and any negative effects minimised. Prior to selecting such a site a biodiversity impact/benefit assessment should be carried out using the Heritage Council's "A Guide to Habitats in Ireland"[52]. Wet sites should also be examined to ensure that no protected species are to be found therein. In this regard, the methodology published by the National Parks and Wildlife Service should be used (www.npws.ie).

In most cases ground conditions on these sites will be conducive to constructing and sealing ponds and this will be apparent to the trained eye but this may not always be the case and an assessment and description of the sub-soils must be made.

Wet sites have inherent advantages for ease of construction and the establishment of vegetation. They are also those most likely to remain hydrated and may provide opportunities for additional aquatic features that could enhance the economic and social values of the overall exercise. Additionally, such sites may be preferable on the basis of land cost. However wet sites tend to have additional water inflow from up-slope and ground water sources, and may have intensive drainage infrastructure that needs to be thoroughly addressed (sections 5.3 and 6.3.2).

A general overview of land use, density of dwellings, surface water ponding, water bodies, drainage, vegetation, and condition of the ground should be made, and the relative distances of potential receptors from the ICW established. Special emphasis should be placed on understanding the site's drainage, including the location of existing land drainage infrastructure, as this may impact on the ICW and the overall drainage performance of the site.

Surface Water

The position and type of surface water features should be noted as this will give an indication of the relative permeability of the ground.

Based on the desk study, a watercourse should be identified for the discharge from the wetland.

A characterisation of the nominated receiving water should be made, including measurement of channel depth and width, evidence of flow (such as tide marks, debris etc) and estimation of assimilative capacity. Photographs should be taken.

Any information on water quality should be examined and water samples taken if no information is available.

Other surface water features such as ponds, lakes, beaches, natural wetlands, streams, drainage ditches, etc. should be identified.

Groundwater

Existing wells/boreholes within 300m of the proposed site should be identified and their distance and direction in terms of groundwater flow determined. Groundwater levels may be determined as part of the trial hole programme. Baseline groundwater quality data should be collected at this time where available. Swallow holes, or collapsed features such as "dolines" should be noted. Sites on karst geology must receive special attention with regard to their capacity to establish and maintain a wetland infrastructure.

Road cuttings and any open excavations in the vicinity of the site should be examined, to provide information on the subsoil profile. Similarly, the shape and nature of banks in watercourses can provide useful insights to the ground conditions.

Utilities

Information gathered during the desk study can be verified at this stage

Cultural and Natural Heritage

Using the information from the desk study, a visual assessment of the site should be undertaken. If the desk study had identified any protected sites nearby, then the assessment may require archaeological input. Photographs should be taken for reference.

Assessment of a site should identify any potential areas of archaeological interest or areas for nature conservation such as Special Protection Areas (SPAs), Special Areas of Conservation (SACs), Natural Heritage Areas (NHAs) and areas of local interest particularly existing wetlands with intact emergent vegetation. Ideally the site should have no or low value for archaeological and nature conservation, such as improved pasture, croplands and areas that have been heavily modified or drained and should not be the habitat for any protected, Red List or rare species.

The general vegetation should be described and photographed. Trees that may potentially be close to the wetland should be mapped. A vegetation assessment may support the identification of suitable ground conditions for an ICW. Existing wetland emergent vegetation may provide sources of emergent plants that might be used in its establishment.

Human

Location of dwellings or other places of assembly such as nearby schools, churches, hospitals, etc. which are not marked on the available maps, should be established and their distance from the ICW site determined. Overhead wires, poles and any other utilities should be marked on drawings.

The prevailing wind direction across the proposed ICW site should be identified, and the sensitivity of any receptors downwind identified. Impact from any localised heavy rainfall events should be particularly noted.

Drainage Systems

All sites must be examined for the presence of drains. Sites that may once have been wet will require special attention, because of the greater possibility that existing drainage infrastructure may be in place. Land-drains have proved to be the single most important factor affecting the hydraulic integrity of ICW systems as they may be a conduit for water loss short-circuiting the wetland system. Conversely, these sites, because they are generally wet and marshy, are often ideal for wetland construction and/or regeneration. This should be evaluated as part of the site assessment.

Interpreting the Results of the Visual Assessment

The relevant set back distances should be referenced and adjustments made as necessary. Sites that cannot satisfy these requirements may be identified at this time.

The nature of the *hazard* should be fully understood at this stage and this will need to be linked to the topographical survey.

Ideally the proposed receiving water should be fully assessed and samples taken for baseline analysis. If EPA or local authority water quality data is available it should be used.

A reasonable understanding of the geological and hydrogeological setting will be established, and will be verified as part of the trial hole, soil analysis and percolation test.

Any possible constraints imposed by the presence of Natural or Cultural Heritage features will be understood, and the potential of encountering drainage systems will have been evaluated.

At this stage the choice of site for the ICW should be clearly apparent.

3.5 Trial Holes and Trenches

1. General

The trial-hole and in some instances trial trenches, are probably the most critical element of the site characterisation, as their assessment will form the basis of whether or not an ICW can be constructed on the site. The purposes of the trial hole are to determine:

1. The soil and subsoil characteristics
2. The depth to the water table
3. The depth to and nature of bedrock (if encountered)
4. The location and extent of any field drains

If the trial hole and trench tests can be arranged to coincide with the visual assessment of the proposed site it can save time and expense.

2. Conducting and Logging the Trial Holes and Trenches

The trial-holes should be dug to at least 2 m, but up to 3 m, if possible, below the proposed base level of the ICW. It is critical to allow for slope. They should be spaced to give a representative sample of the site's soil and subsoil conditions. Full Health & Safety (H&S) requirements must be satisfied in the excavation and examination of the Trial Holes. A minimum of 3 holes should be dug throughout the proposed ICW area. Further trial holes may be required on sites where the ground conditions are considered to be variable, or where the proposed ICW is particularly large. Suggested minimum number of trial holes is as follows:

Area of KW	At least 3
< 0.5 ha	At least 3
> 0.5 ha < 1.0 ha	At least 4
> 1.0 ha < 1.5 ha	At least 5
> 1.5 ha < 2.0 ha	At least 6
> 2.0 ha	At least 7

The trial-hole should be kept as small as practicable. Topsoil depth and its description should be recorded. The subsoil characteristics of key interest are:

1. texture,
2. structure,
3. compactness,
4. colour,
5. layering,
6. depth to bedrock and
7. depth to water table.

An accurate description of the subsoils is required to enable design and re-use to be considered. The sub-soils should be recorded in a professional manner with reference to the BS 5930 Standard description method (Ref Appendix D for summary method). Groundwater conditions should be described, and if necessary the holes should be left open for 48 hours (and securely protected), or fitted with a standpipe to enable groundwater levels to be established.

An assessment of the suitability of subsoils for construction of embankments should be made together with an initial assessment of their suitability as an ICW base sealing layer. Confirmation soil-testing will be required and this should comprise particle size distribution (PSD) tests as outlined below.

Trenching across the slope (sometimes around the perimeter of the site) is the best way of assuring the land-drainage status of the site. Trenches where deemed necessary should be sufficiently deep and clear-cut to allow for detection of possible field drains and groundwater flows.

3. Interpreting the findings from trial holes and trenches

Table 3.1 sets out the subsoil characteristics, which determine suitability for the construction of an ICW.

FACTORS	SIGNIFICANCE
Texture	Cohesive materials comprising clay or silt are the least permeable. Sands and gravels (granular material) will present difficulties with construction due to their high permeability
Colour	Colour is a good indicator of the state of aeration of the soil/subsoil. Free draining unsaturated soils/subsoils are in the oxidised state at all times and exhibit brown, reddish brown and yellowish brown colours. Saturated soils/subsoils are in a reduced state and exhibit dull grey or mottled.
Depth to rock	Subsoil must have sufficient depth for ease of construction and for added protection for ground water
Depth to water table	Unlikely to be a problem in low permeability subsoils, but can be significant in highly permeable subsoils (Darcy's law must be applied)
Assessment of permeability	Sites underlain by natural low permeability material may not require enhancement to satisfy the requirements

Table 3.1 Soil/Subsoil Characteristics

The uniformity of the characteristics (outlined in Table 3.1) between trial holes must be considered.

4. Particle Size Distribution Test

A particle size distribution test (PSDT) is an indicator of the hydraulic permeability of the subsoil. For the required permeability of 1×10^{-8}m/s, the clay content should be 13% or greater.

In circumstances where the clay content is 13% or more but there is evidence from the 'Visual Assessment' and/or 'Trial Hole' tests that the permeability of the subsoil is greater than 1×10^{-8} m/s (for example, the area is free draining or the BS5930 description of the subsoil is silt), it may be advisable to assume that the 1×10^{-8} m/s requirement is not automatically met in these circumstances, and that enhancement at the construction stage may be required to achieve this level.

Where clay content is less than 13% but more than 10% the sub-soil can be enhanced to achieve a permeability of 1 x 10^{-8} m/s.

Because of the relatively large area of ground covered by ICW systems, a minimum of 3 PSDTs will be required at the proposed formation level. This level (depth) should be recorded in Appendix B3.3 under “Other information”. Similar to the trial hole scenario, the number of PSDTs should be increased with the size of the proposed ICW.

Area of ICW	No. of PSDTs
Minimum	At least 3
> 0.5 ha < 1.0 ha	4
> 1.0 ha < 1.5 ha	5
> 1.5 ha < 2.0 ha	6
> 2.0 ha	7

The most appropriate soil horizon for use as a liner material should be identified. Representative samples shall be taken from this horizon for laboratory testing at an approved laboratory to determine clay content to BS1377. Before commencement of this tests all particles greater than 20 mm in diameter should be removed.

5. Decision Process and Preparation of Recommendations

Table 3.2 summarises the information collected from the desk study and site assessment phases. The information is used to decide whether an ICW can be constructed on the site. A detailed outline of the general decision-making process for constructed farm wetlands including two useful decision trees has been published[4]. A decision tree from this document is presented in Appendix G.

Recommendations should be outlined in relation to any site-specific requirements necessary for the ICW design.

Information Collected	Key Issues	Implications
Topography	Slopes, land profile	Design, overall layout, landscape fit
Surface water	Receptor sensitivity Receiving water assimilative capacity, possible flood levels	Set back distances, discharge licence Possible flood levels
Hydrogeological setting	Receptor sensitivity	Design of ICW base, set back distances, monitoring
Cultural heritage	Distances from sensitive sites	Statutory and planning
Natural heritage	Site value distances from sensitive sites	Statutory and planning
Climate	Rainfall, receptors downwind	Design sizing of ICW, orientation and layout of ICW
Human	Possible odours	Set back distances and design features
Housing	Proximity	Set back distance
Farm inventory, survey	Hazard assessment	Design sizing of ICW
Depth to rock	Pathway assessment	Design, base details, site suitability
Subsoil type (BS 5930)	Pathway assessment	Design, construction and site suitability
PSDT results (BS 1377)	Required fines and clay content	Design, construction and site suitability
Depth to water table	Pathway assessment	Design, construction and site suitability

Table 3.2 ICW Decision Issues

Chapter 4: The Regulatory Process

4.1 Introduction

The construction of an ICW must conform, like any other development, to the statutory and regulatory requirements contained in the relevant national legislation and regulations. In general ICW systems intercepting point sources of polluted water require full planning permission and discharge licensing. The purpose of this section is to outline to the designer/applicant the relevant governing legislation and the procedures and documentation required at each stage of the Planning Stages.

4.2 Relevant Legislation

The construction of ICW systems is regulated by the following European and National primary and secondary legislation:

- Local Government (Water Pollution) Act of 1977 and Local Government (Water Pollution Amendment) Act of 1990, and subsequent Regulations.
- Local Government (Planning & Development) Act of 2000 and subsequent Regulations.
- EPA Act 1992 and 2007
- EU Water Framework Directive and subsequent Regulations.
- European Communities Waste Water Discharge (Authorisation) Regulations, 2007, S.I. No. 684 of 2007
- European Communities Environmental Objectives (Surface Waters) Regulations 2009, S.I. No. 272 of 2009
- European Communities (Good Agricultural Practice for Protection of Waters) Regulations, 2009, S.I. No. 101 of 2009.
- European Communities Environmental Objectives (Groundwater) Regulations 2010, S.I. No. 9 of 2010
- European Union (Natural Habitats) Regulations, S.I. No. 94 of 1997

4.3 Planning Pre-Consultation

Pre-application consultation with the relevant planning authority is always advised in advance of lodging a planning application. It will assist in establishing whether or not the development is acceptable in principle and will then help highlight relevant development plan requirements, identify procedural and technical requirements, including any fees or charges and minimise the need for the planning authority to seek additional information.

Once the applicant has some idea of the approximate details of the ICW planning proposal, with approximate sizing, location, and site characteristics (Ref Appendix C), s/he should enter into discussion with the local planning authority to ascertain their specific requirements in regard to the lodging of a planning application to ensure that the proposal will be consistent with these requirements. As outlined in Section 3.3 above there may be issues in relation to site status, arising from its location, for example within or adjacent to a Special Area of Conservation (SAC), Special Protection Area (SPA), or Natural Heritage Area (NHA) or in the vicinity of a National Monument. If this is the case, further investigation may be required, or even consideration of an alternative site.

All planning authorities now have websites, on which information relating to the preparation and lodgement of a planning application can be easily accessed. This allows each applicant to determine what is required in the preparation of a planning application in advance of pre-planning consultation and will also ensure a more productive consultation. In the case of an ICW application, which will involve a discharge licence at the final stage, there is scope here for discussion of the likely discharge licence conditions, on the basis of typical expected effluent characteristics from an ICW (see 2.6 above), and ideally the inclusion of some form of bio-monitoring in the final pond (See 5.5 below).

4.4 Information required when making a planning application

When lodging a planning application, an applicant will be required to submit specific information that is statutorily required to validate a planning application. These statutory requirements include specifications as to the number of copies of various documents to be submitted and requirements in relation to advertising and site notices. All these requirements are set out in the Planning and Development Regulations 2001-2007 and are normally available directly from the planning office of each local authority, or can be downloaded from the DEHLG website. Within the period of two weeks before submission of the planning application, a notice must be placed in an approved newspaper, and a site notice erected on the land in a 'conspicuous' position.

4.5 Planning Timescale

A planning authority must make a decision on a planning application within 8 weeks from the date the application is lodged unless further information is requested. If further information is sought from the applicant it must be requested within the 8 week period and the planning authority then has 4 weeks from the day of receipt of the further information to make a decision on the application. If the application requires an Environmental Impact Assessment (EIA) the timescales will be longer. The following table gives a general guide to the timescale involved in most cases.

Start	Notice published in paper and site notice erected
Within 2 weeks of notice	Lodge application
5 weeks from date of lodgement	Application is validated by the planning authority. Submissions or objections must be lodged.
Between 5 and 8 weeks later	Planning authority must issue notice of their decision on the application. Alternatively, they may request further information.
4 weeks after issue of notice of decision.	If no appeal is made, the planning authority will issue grant of permission, or outline permission, except where they have already made a decision to refuse permission.

Table 4.1 Optimum Planning Timescale

An appeal can be made to An Bord Pleanala against the decision of the planning authority by the applicant or by a third party but it must be made within 4 weeks beginning on the date of the decision of the planning authority and this will add significantly to the timescale above. It should be noted, however, that a third party can only appeal if they have already made an objection at the planning application stage. **An Bord Pleanála** has an objective to decide appeals within 18 weeks of receipt. This is not always possible and in such event all parties will be informed of the reasons why the decision is delayed.

In conclusion therefore, it generally takes a minimum of 12 weeks for a final grant of permission to issue, and, subject to further information being requested, or appeals being lodged, the decision on an application may take up to a total of between 30 and 40 weeks. These timescales must be considered by the applicant when planning the likely construction period and possibly going to tender for the construction work.

4.6 Discharge Licence Requirements

The construction of an ICW may require a discharge authorisation in addition to planning permission, depending on the promoter/developer of the ICW, either by:

(i) A **discharge licence to surface water** issued by the local authority under the Water Pollution Acts 1977 & 1990. Under the Local Government (Water Pollution) Regulations, 1978, S.I. No. 108 of 1978, a discharge to groundwater of domestic sewage not exceeding 5 m3/day is exempt from licensing by local authorities. Therefore all other discharges to groundwater require a discharge licence to groundwater issued by the local authority under the Water Pollution Acts 1977 & 1990.

(ii) An **Integrated Pollution Prevention and Control (IPPC) licence** issued by the Environmental Protection Agency if the ICW is associated with an activity listed in the First Schedule of the Environmental Protection Agency Acts 1992 to 2007, e.g. slaughter plant, dairy plant;

(iii) A **waste licence** issued by the Environmental Protection Agency if the ICW is associated with an activity listed in the Third or Fourth Schedules of the Waste Management Acts 1996 to 2008, e.g. landfill;

(iv) A **waste water discharge licence** (for agglomerations >500 population equivalent) or a **waste water discharge certificate of authorisation** (for agglomerations <500 population equivalent) issued by the Environmental Protection Agency if the ICW is associated with a local authority waste water treatment system.

The discharge authorisation must be applied for separately from the planning permission, with separate fee structures. This must be completed before commencement of construction to avoid any possible conflict with the planning permission.

An application for a discharge licence should be made to the relevant local authority on a standard application form obtained from that local authority. An application for an IPPC licence, waste licence or waste water discharge licence should be made to the Environmental Protection Agency on a standard application form that can be obtained from www.epa.ie/downloads/forms/lic/

In general, the following information should be provided in support of an application for a discharge authorisation. The required level of detail will vary based on the risk posed by the ICW.

– Source, quantity and quality of waste water entering ICW;
– ICW design and layout, including permeability of base and sides of ICW ponds;
– Details of the site assessment (as outlined in Chapter 3);
– Hydrogeological conditions of the site, including subsoil type and permeability, depth to bedrock, depth to water table, aquifer characterisation and

vulnerability rating, details of any wells in the area, and where relevant, background groundwater quality and proposed groundwater monitoring regime (see Section 7.4 Groundwater Monitoring).

- Quantity and quality of waste water to be discharged to receiving waters (primary discharge to surface water and predicted losses to groundwater) from ICW;
- Details of the proposed receiving water, including flow (dry weather, 95%ile and median flows), existing quality upstream and downstream of the discharge point(s), Water Framework Directive status and risk category, assimilative capacity, proposed monitoring regime, presence of any areas for the abstraction of water intended for human consumption, etc.
- Details of any sensitive receptors in the vicinity of the discharge(s), identification of impacts and mitigations measures as appropriate.

A discharge authorisation shall set standards for the quality of effluent discharge to surface water from the ICW and frequency of required maintenance, monitoring and reporting. The standards for quality of effluent discharge shall be determined on a case-by-case basis and shall be subject to the assimilative capacity of the receiving waters. The European Communities Environmental Objectives (Surface Waters) Regulations 2009, S.I. No. 272 of 2009, established stricter ambient standards than those which previously applied. The Environmental Protection Agency is currently preparing guidance on assimilative capacity calculations for receiving waters and this will be made available to the public.

Appendix E gives guidance on minimum licencing requirements for ICW systems.

Chapter 5: Designing an Integrated Constructed Wetland (ICW)

5.1 Introduction

The ICW concept and the context in which systems may be deployed have been outlined above (Chapter 1). Their design recognises the multi-faceted requirements of the site, the potential influent/s and the potential of multiple land use for the overall development including the use of in-situ accumulated materials. The most important factor in designing an ICW is to recognise that it is not a proprietary design but a conscious and deliberate attempt to implement a holistic approach to natural resource management within the context of achieving sustainable development. It is fundamentally an ecological concept and is not suited to a formulaic design, with each site having its own special ecological characteristics and requirements. (See Fig 5.1 below).

Fig 5.1 Aerial View of ICW showing curvilinear fit of segments/ponds to landscape contours

This chapter gives guidance on the designing of ICW systems for the treatment of polluted water streams including any unavoidable surface water run-off to the ICW. The content and strength of influent for which the ICW concept was initially developed (farmyard soiled water) is given in table 2.3 above. The nature of this influent is that it is highly variable in strength and flow and clearly demonstrated that ICW systems could have a wide range of application covering many water-vectored effluent types. The steps below guide the assessor (client and regulator) through the 'Design Process'. The ultimate aim is to ensure that any potential polluted water source is anticipated and dealt with, that the ICW will be robustly built and long lasting, and that the completed ICW will enhance the surrounding landscape, contribute to biodiversity and provide a range of ecosystem services, including products that might be used locally.

5.2 The ICW Process

Both anaerobic and aerobic microbial digestion are the primary processes that treat the inflowing pollutants. Emergent plant species, their litter and allochthonous organic material provide one of the main surface structures upon which microbial populations are supported, primarily forming bio-films while also facilitating the occurrence of pelagic microbial suspensions. The wetland vegetation also provides the hydraulic resistance to surface flows, increases aerobic biofilm reactive surface area and supports the precipitation of particulate matter. Necromass from both micro-organisms and vegetation contribute to the sealing integrity of the wetland and help provide carbon based energy sources for anaerobic digestion, denitrification, methanogensis and other supporting functions. Such functions also extend to the underlying soil and associated structures. In addition the wetland environment provides opportunities for a diversity of other (non-emergent) plants and animals, the interaction of which contributes to the overall biological function of the constructed wetland4[,23,60,61,62].

5.3 Preparation for the Design

A critical element in approaching the design of an ICW is an understanding of:

1. The functionality of shallow, surface-flow, emergent-vegetated wetland ecologies
2. Familiarity with the available information on the site, in particular the results of the 'Site Assessment' (Chapter 3 above, and Appendix C) and site layout.
3. Understanding of the nature and impact of an ICW on the landscape.

It is essential that the designer be fully familiar with the proposed site, through actually visiting the site and by speaking with the landowner/client. This ensures the client's wishes and requirements will be taken on board, and that the designer can consider the incorporation of existing landscape features into the proposed design, in particular, the visual aspect of the ICW design will require dialogue with the client.

The designer must be able to visualise the finished product, and its impact on the surrounding environment (here experience and demonstration are considered essential). The optimal use of the land contours is critical, particularly in achieving optimal length to width ratios for the various segments of ICW systems. It is advisable to follow the natural contours of the landscape as far as possible to ensure minimal cut and fill during construction and to maintain low length to width ratios.

An understanding of a site's needs/layout and drainage points is of particular importance. In some cases there will be a number of entry points to the initial segment/cell of the ICW. It is recommended that all existing and potential sources of pollution be captured, anticipating any management changes and accidental occurrences. Springs and land drains on the proposed ICW site must be identified and managed, preferably by being diverted away from the wetland, though their entry into any additional monitoring ponds to the system (Section 5.5 below) can be useful in maintaining necessary water levels or in the reuse of treated water. Failure to divert extraneous water can cause stability problems with the ICW base, leakage to groundwater and a reduced hydraulic residence time.

The design for an ICW will include a minimum of 3 to 4 emergent-vegetated and shallow wetland segments/cells of similar size, although, dependent on location and topography this number may be extended. The first segment requires particular attention especially if it is to receive runoff from different point sources (as in the case of the farmyard sources of soiled water) or liable to receive influents of varying levels of contamination.

5.4 ICW Area Requirements

Critically, in order to achieve the necessary hydraulic retention, the most essential elements in ICW design are sizing, positioning and configuration. In general, the larger an ICW relative to its inflow the greater its capacity to treat that influent. The area requirements for ICW systems are primarily focused upon the capacity of the system to capture and retain soluble phosphorus (molybdate reactive phosphorus, MRP). Unlike carbon and nitrogen, phosphorus does not commonly have an atmospheric phase and is generally the limiting factor in determining the efficacy of an ICW because of its tendency to be biologically recycled.

The present overall sizing formula for an ICW system has been developed from the observed performance of more than 20 ICW systems treating farmyard soiled water and domestic waste water over the past 14 years. Particular attention has been paid to understanding and addressing the robustness and sustainability of ICW systems with regard to total phosphorus and MRP removal from through-flow. As ICW systems are primarily surface-flow systems, hydraulic retention time is determined by wetland surface area. As ICW systems are 'open systems', hydraulic retention is also greatly influenced by intercepted precipitation events. These will be of varying amplitudes that may be more than 50 times the average polluted water stream volume as in the case of farmyard soiled water and combined wastewater/stormwater sources. Performance data have shown that in the case of both sources a minimum of 1.3 times the interception area is required to achieve MRP concentrations in the last ICW cell of 1.0 mg/l for farmyard effluent in the South County Waterford area[1].

As a precautionary and ecosystem based approach prevails, it is recommended that the functioning (water surface) area of a farmyard soiled water ICW requires an area calculated on the basis of twice the associated interception area. For domestic wastewater treatment an area of 20-40m^2 per person equivalent (p.e.) is required. A further land area allowance of about 25 percent of this calculated wetland area must be made to encompass the ancillary embankment areas of the overall site.

For farmyard soiled water treatment, the area occupied by an ICW is typically 1-2% of any individual farm area. These indicative area requirements for the ICW based upon the interception area and influent volume is generally a minimum area requirement.

Larger areas may be used especially where lower levels of phosphorus discharge are required. Further additional ponds may be added for water retention or monitoring purposes (Ref. Section 5.5 below).

Farmyard Soiled Water ICW
Area Required (m^2) = (2 x Interception Area*) x 1.25**

Domestic Wastewater ICW
Area Required (m^2) = (Population Equivalent x 20 to 40*) x 1.25****

* *Interception Area = Full farmyard, inclusive of roof areas, and any other areas requiring run-off capture*

** *Supporting infrastructure = Area taken up by embankments and associated access.*

*** *20 m2/p.e. for wastewater free of storm water increasing to 40 m2/p.e. when storm water is also included*

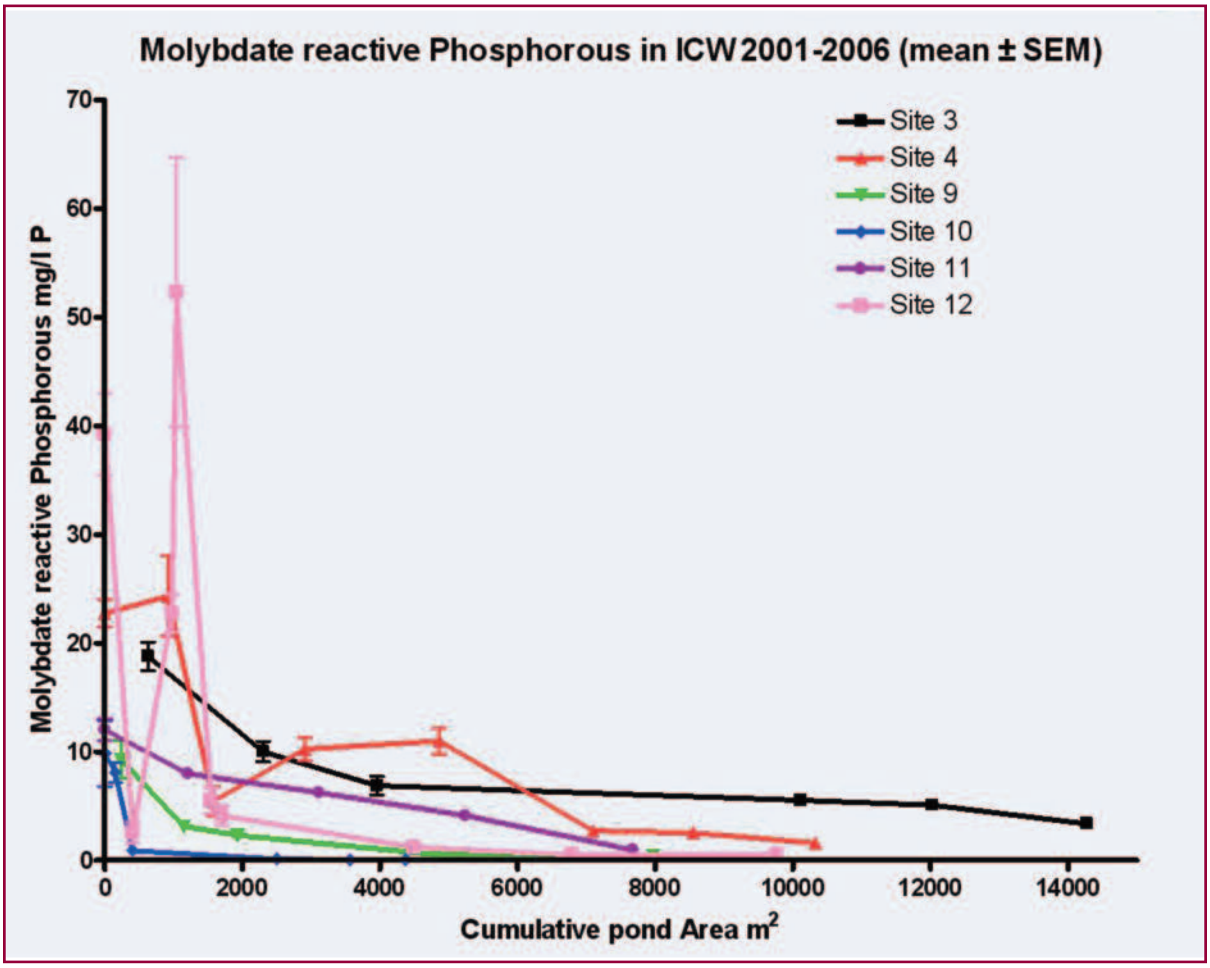

Fig 5.2 Indicative relationship between P reduction and ICW area

5.5 Configuration/Layout of ICW

1. Basic Configuration

Configuration and residence time interact by ensuring that the waste water is dispersed and flows with minimum velocity and preferential flow throughout each segment/cell of the ICW system. An ovoid shape and optimal aspect (length to width ratio) of less than 4:1 is ideal. This in turn is augmented by having an appropriate number of wetland segments/cells. Additionally, the greater the emergent vegetation density the slower the rate of flow of the influent through the system (i.e. hydraulic impedance). The segment/cell shape should ensure that as much area of the ponds/lagoons are utilised by having a level base and optimal water depth. Curvilinear shapes that ideally follow the land contours, are encouraged and will facilitate good distribution. While a length to width ratio of less than 4:1 is considered the ideal this may not always be possible, especially on sloping ground and a compensatory increase in area is advised.

It is recommended that a minimum of 4 segments/cells of similar size be constructed for any individual ICW system with a maximum surface area of any one pond in the order of 25% of the overall wetland area[4,23,45]. Ideally the first segment/cell in the ICW system should receive special attention as it will be the first to be dewatered and its detritus removed (after a period of 10 to 20 years), thus reinforcing the requirement of its area to be 20% to 25% of the overall required ICW area. An additional parallel first segment/cell may be placed to receive uninterrupted influent while maintaining optimal treatment; otherwise dewatering and detritus removal will have to take place during appropriate (dry) weather conditions.

Particular hardy species of emergent wetland plants such as species in the genera Typha, Glyceria, Carex and Scirpus are recommended for this first segment/cell as the strength of influent may at times be such as to damage the growth potential of other plant genera. This potential toxic tendency in the first segment/cell is balanced by the fact that during high flux flow periods (i.e. high rainfall periods) the concentration of the influent is diluted and plant vigour can be re-established.

The corollary of this is, that during dry periods, the influent concentration is greater and requires shallower conditions to facilitate nitrification and avoids the negative synergy between water depth and ammonium-N concentration.

Each segment/cell of the sequential multi-celled ICW arrangement functions as an individual wetland ecosystem. It has its own distinct features, influents and effluents. Thus each segment/cell has the capacity to impact differently on the adjacent environment. This is proportionate - the segments/cells receiving the most contaminated influent are the most hydrated and lose least water through infiltration to the ground whilst the distal wetland cells receive the least contaminated water and are the least hydrated and have a higher risk of soil infiltration albeit only on an occasional basis.

2. Landscape Fit/Layout

As previously stated, the landscape-fit of an ICW is one of its explicit objectives. It recognises the potential value of utilising the natural contours and features of the existing landscape. This in turn leads to economic savings in construction costs because of the reduction in cut and fill volumes.

Land forming the ICW structure requires a level of sensitivity to ensure that the final structure fits into the landscape. Whilst subsequent vegetation development may help achieve this there is a basic need for the overall structure to look "natural" and have a degree of sympathy with the surrounding countryside. This is generally achieved through best fit of the topographical layout of the ICW within the natural topography of the site. The forming of the structure to fit the landscape usually has the added advantage of reducing the ICW maintenance, enhancing its amenity value and improving its functional longevity. A typical ICW layout is illustrated in Fig. 5.1 above. The profiles and infrastructural details required to support habitat development are best addressed at this stage. The incorporation of existing vegetation, particularly trees, should be given consideration where appropriate, an exception being where deep or wide rooted trees might potentially damage the sub-soil liner or embankments.

The development of the transitional habitat or "ecotone" between the terrestrial embankment and the aquatic wetland zones can be achieved when constructing the embankments, after the broad shape of the various wetland segments is achieved. These may include some shallow and deep areas and be positioned in either south or north facing positions or both. Wide, very shallow and low elevated edges to the embankments are ideal. An ICW is a very dynamic ecosystem and such habitat infrastructure may be of a transient structure unless managed and maintained.

Experience has shown that preferential placement of ICW systems on wet sites (not designated as SACs or NHAs or a habitat for protected species) has inherent advantages for ease of construction and the establishment of additional aquatic features that can enhance the economic and social aspects of the exercise. Furthermore, such sites tend to be both preferable to the land owner and more water retentive thus facilitating water reuse.

Fig 5.3 ICW showing landscape-fit; in this example the ICW configuration reflects the meandering of the adjacent water body

3. Additional Ponds and Receiving Areas

The floral and faunal composition of receiving waters is probably the best indicator of water quality. Having a receiving water body at the outlet of an ICW will thus reflect the ICW's performance over a number of weeks, months or even years. This is highly desirable for assessing performance and is of particular value to regulatory authorities[60,61,62].

The provision of an additional area (to that required for most ICW systems) in order to treat water to even higher limits of quality can be applied to areas where there is this need (e.g. where there is low assimilative capacity in receiving waters). The additional area will be especially effective in diminishing surface flow, where the water table is below the base of the ICW, as this will increase water-loss through evapotranspiration, interception and infiltration to ground. A sufficiently large additional seasonal or monitoring pond may greatly reduce, or entirely remove, any surface water discharge from an ICW. (Water balance is achieved through surface water flow, precipitation/ infiltration and evapotranspiration/interception). An additional area of bunded wet woodland of alder or other appropriate tree species will be particularly effective for diminishing or altogether removing all surface water discharge. The construction of these additional wetland and ponded areas at the end of the ICW system, while not mandatory, is strongly encouraged, so as to realise other potential values for the site including:

a) Fishing and water based amenities where adequate water is available
b) Enhanced biodiversity and vertebrate wildlife
c) Further reduction in the mass flow of nutrients, thus having the potential to protect nutrient sensitive water bodies
d) Increased capacity to store water for longer periods before discharge to surface water thus aiding flood control.
e) Reuse of water and as a source during periods of drought.

The construction of open-water ponds require that their water depth is greater than 1 m, thus a shallower safety shelf (c. 300-400 mm) should circumscribe all areas of deeper open water. This shelf may be planted with emergent vegetation or left to vegetate naturally. If stocked with trout or other salmonids a central depth greater than 2 m is required. This pond also presents opportunities for aquatic and submerged plant communities and can be of significant amenity value.

It is important that in designing the side slopes and transition area of any final bio-monitoring pond, that they have gently sloping sides and that buffer vegetation areas are provided so as to ensure adequate safety for visitors to the site. Where space is at a premium, the transitional area may be reduced or omitted, but in general its inclusion promotes greater plant and animal diversity, and improves the safety aspects of the site.

5.6 ICW Consolidation and Vertical Layout

Fig 5.4 below contains recommended vertical layouts including a recommended maximum water depth of 300 mm. The overall berm height of each cell should be 1 m, to allow for build-up of sediment and leaf necromass, and adequate water depth and freeboard. The base and sides of each treatment pond or segment of the ICW require a permeability value of 1×10^{-8} m/s or lower (Ref 2.7 above). The achievement of this level of permeability is based on combining the 'Site Characterisation' results with an appropriate method of construction, as outlined in Chapter 6 below.

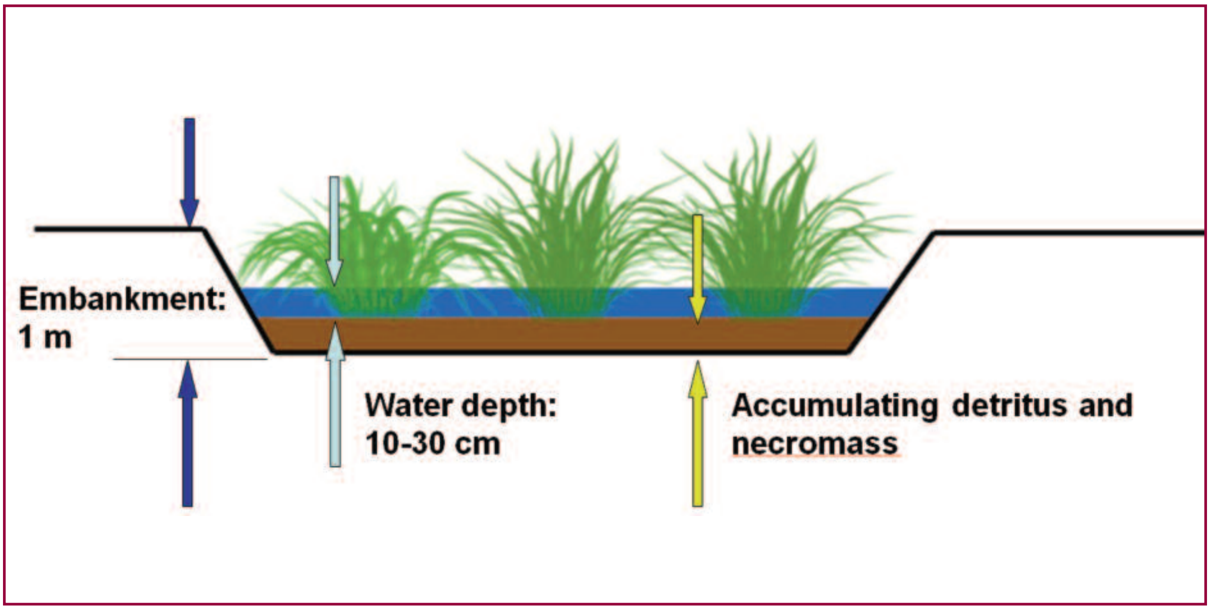

Fig. 5.4 Cross sectional view of wetland cell showing embankment and water depth

As referred to in Section 5.4 above, the embankment area around an ICW increases the area requirement by approximately an additional 25%. This additional area is required for access, safety, maintenance and monitoring requirements, and the needs of biodiversity. A total minimum embankment width of 9 m from the beginning of the land-water transitional (ecotone) area from one side of the embankment to that of the other will result. Where space is at a premium the ecotone area may be reduced. In general, such areas have high conservation value and provide greater overall sustainability besides enhancing safety of the system.

The conveyance of the through-flow from pond to pond through the system is achieved typically by the use of 150 mm diameter PVC/HDPE pipes. These pipes include an elbow fitted to each outlet point to control water depth to accommodate detritus build up over time. During low flow periods evaporation rates also tend to be high, often resulting in little or no output from the ICW to the receptor surface waters for what may occasionally be several months. The development of "freeboard" capacity during such dry periods further enhances hydraulic retention when increased flows re-occur. Discharge during periods of high precipitation will generally occur when greater assimilative capacity is available in the receiving waters. This synchronicity of flows from ICW systems with the natural weather systems reduces further the likelihood of a pollution event.

The inlet pipe to the first segment/cell should enter at a very minimum of 500mm (ideally >1 m) above the initial design water level, (there need be no minimal head difference for subsequent cells). The inlet and outlet points should be designed to allow for safe access for sampling and monitoring purposes. An area (c. 1m^2), composed of coarse stones/rocks at the beginning of each segment/cell, underneath the influent discharge pipe, may support some enhanced hydraulic distribution and aeration. It will also provide a hard standing area for access and monitoring.

5.7 Health and Safety (H and S) Considerations and Final Design Drawings

A typical preliminary H and S Plan are given in Appendix F attached. This plan reflects the generally safe nature of the final ICW layout, with particular concern for access by the general public and by monitoring personnel. Where access is possible, it may be advisable to include signage near deeper areas of the system. Fencing may be necessary, in particular at the initial receiving area, where the risk from faecal contamination is relatively high. Because of the generally shallow depth, gentle embankment slopes, vegetation density, and the overall landscape-fit, there is minimum risk of drowning. The inclusion of specific safe access to outlet points for monitoring personnel mentioned above is a particular feature to enhance health and safety. Specific attention must be given to deeper ponds by the placement of warning signs and life buoys as appropriate.

All final design drawings should include the necessary H and S requirements and:

a) be clearly laid out to show location and layout details to a contractor at a minimum scale of 1:500

b) indicate any specific site features which are to be avoided, or alternatively included

c) include detailed cross sections at minimum scales of 1:100

5.8 Wetland Vegetation

1. General

Vegetation plays a variety of essential roles in the performance of ICW systems by providing:

i) Hydraulic resistance and increased residence time
ii) Large surface-area skeletal structure to support microbial bio-films
iii) Oxygen transport to the soil substrate to aid the breakdown of organic pollutants
iv) Necromass/detritus that facilitates the long-term storage of phosphorus, and ensures the source of carbon for anaerobic metabolism, including the denitrification of ammonium-N and nitrate-N
v) Long-term storage of sequestered carbon through necromass accumulation (typically 30-60 tonnes per hectare per year)
vi) Reinforcement of the wetland soil structure through reducing infiltration and providing enhanced integrity to the wetland base structure
vii) Increased landscape-fit opportunities due to plant varieties
viii) Reducing the level of noxious smells from initial wastewater
ix) Intercepting precipitation thus reducing the overall hydraulic loading and through-flow

The primary vegetation types used in ICW systems are emergent plant species (helophytes). These species have evolved to enable them to root in soils with no available or limited soil oxygen supply, growing vertically through the water column with most of their leaves/stems in the air. They have specially adapted tissues that facilitate oxygen storage and its transportation from the leaves through the stem to the roots. They may have year-round growth and photosynthesis or be seasonally deciduous.

2. Recommended species for use in ICW Systems

While more than a hundred native species can be used, in general about 12 species have most commonly been used from the following genera:- *Carex, Typha, Sparganium, Glyceria, Eleocharis, Iris, Schoenoplectus, bolboschoenus, Cladium*. Soil and water characteristics influence the type and performance of plant species for each wetland segment/cell of an ICW. These emergent plant species (helophytes) have a structure and capacity to tolerate permanent water depths in excess of 200mm that may have ammonium-N concentrations that may occasionally exceed 100mg/l.

Specific species selection depends upon; water depth, turbidity, pH, ammonium-N concentration, soil type and ionic strength for each wetland segment/cell.

Ammonium-N concentration is a dominant factor in the establishment and vigour of emergent vegetation. Stress from ammonium-N varies with some species having very low tolerance and others appearing to survive periodic concentrations greater than 280 mg/l1. The species mix for an ICW system should be selected to optimise the overall performance of the system including its aesthetics and biodiversity.

Table 5.1 lists the species recommended for use in large scale ICW systems.

These species should be appropriate to the majority of ICW systems. Should the species listed below be judged insufficient, then other native emergent species may be considered, provided it is clearly documented why the use of this species is necessary and the species is native to the general region or locality of the ICW system. Use should be in accordance with the information available from the National Biodiversity Datacentre (www.biodiversityireland.ie).

The use of non-native species may be considered in circumstances where the non-native species does not have the potential to invade natural ecosystems. The use of non-native species must comply with any Regulations, notices or advice on non-native and/or invasive alien species issued by the Minister for the Environment, Heritage and Local Government under the Wildlife Act, 1976, as amended (2000, 2009). Under no circumstances should noxious alien (invasive) species be used (see www.invasivespeciesireland.com).

Botanical name	Common name	Notes
Iris pseudacorus	Yellow Flag	Where cell water depth is less than 20cm
Glyceria maxima	Reed Sweet-grass	Capable of withstanding high pollution at shallow depth
Phalaris arundinacea	Reed Canary-grass	Within secondary cells and adjacent embankments
Typha angustifolia	Narrow leaved bulrush	For use in regions where the species already occurs and where water depth may fluctuate
Typha latifolia	Bulrush	For use in shallow water
Bolboschoenus maritimus	Sea Club-rush	For effluents with high conductivity
Schoenoplectus lacustris	Common Club-rush	Generally for use in areas of water depth > 20cm
Schoenoplectus tabernaemontani	Grey Club-rush	For effluents with high conductivity
Eleocharis palustris	Common Spike-rush	For areas where short vegetation is required
Cladium mariscus	Saw Sedge	For use in areas where there is hard water
Carex riparia	Great Pond-sedge	Widespread use
Carex rostrata	Bottle Sedge	Shallow water
Phalaris arundinacea	Reed Canary-grass	For use in final ponds
Sparganium emersum	Unbranched Bur-reed	For use in final ponds
Equisetum fluviatile	Water Horsetail	For use in final ponds
Persicaria amphibia	Amphibious Bistort	For use in final ponds
Potentilla palustris	Marsh Cinquefoil	For use in final ponds
Oenanthe crocata	Hemlock Water-dropwort	For use in final ponds
Apium nodiflorum	Fool's Water-cress	For use in final ponds
Veronica scutellata	Marsh Speedwell	For use in final ponds
Alisma plantago-aquatica	Water-plantain	For use in final ponds

Table 5.1 Plant species to be used in ICW systems

The common reed, Phragmites australis, (frequently the only species used in other types of constructed wetland systems) may be used for limited purposes as it may be invasive and eventually dominate the whole ICW system thus decreasing biodiversity[2]. In addition, its deep roots tend to open up pathways through the wetland base and may make certain sites more vulnerable to drying out especially during prolonged dry periods. As shallow surface water wetland habitats have a greatly reduced distribution due to a long history of drainage, it may not be obvious as to what species are most suited to the range of social, economic and environmental potential of ICW structures. The final segments/cells of an ICW system also may provide opportunities to explore ecological restoration especially for obligate aquatic and immersed species.

3. The provenance of plants

Plants used must have a native provenance in order to avoid erosion of native genetic variation and, in so far as practicable, should have a regional or local provenance. If an ICW is proposed for within or upstream of an SAC, SPA or NHA, local provenance must be used and the methods by which these plants are to be obtained (or propagated) must be detailed in any Appropriate Assessment required (See Section 2.3). Where non-native species are used, every effort should be made to source plants propagated in Ireland in order to avoid the introduction of associated non-native species, particularly invertebrates and submerged and floating aquaticmacrophytes. Subsequent species enrichment, by additional planting, may be possible, or indeed sometimes necessary. Planting density and establishment are dealt with in Chapter 6 below.

5.9 The Competency of the designer

The person undertaking the design must have appropriate competency to collect and interpret all the relevant and disparate information necessary to affect the ICW objectives. A wide understanding of wetland ecosystem structure, function and process in relation to the nature of the polluted water, site conditions and hydraulic challenges are essential. This includes identifying situations where a specialist advice may need to be taken.

5.10 Summary of ICW Design Recommendations

Key Design Criteria	Guidance	Comment
ICW area relative to intercepted area	Minimum 2:1 ratio and 20-40m²/PE. (section 5.4)	Effective wetland cell area does not include bank area
Number of wetland cells	Minimum of 4 cells and less than 6 recommended (section 5.3)	There may be additional cells, such as monitoring ponds or for water recycling.
Additional Ponds	Not mandatory but desirable (section 5.5)	Facilitate monitoring, provide additional site values, and reduce direct water discharges
Length/width ratio for cells (aspect)	2:1 or less optimal recommended, 4:1 maximum. Otherwise additional area needed (section 5.5)	Long narrow channels should be avoided, as this increases velocity and can lead to lower phosphorus retention and to scouring/flushing during high flows
Relative size of individual cells	Cells should be of similar size with the first cell ideally 20% to 25% of overall ICW area to facilitate P capture (section 5.4)	All cells should be of relatively similar size to allow water to flow at as slow a velocity as possible to facilitate P capture and retention
Depth	100 to 300 mm (sections 5.4 and 5.6)	Shallow water levels are necessary to facilitate emergent plant growth and nitrification/ denitrification processes and for safety
Plant Selection	Variety of species, and planting density (section 5.8)	Role of plants is species specific and multifunctional
Soil depth below wetland cells	0.5 metres minimum with less than 1 x 10^{-8} m/s infiltration rate. (Refer to section 2.7 for additional for sensitive situations)	This will allow wetland to develop.
Distance to surface watercourse	10 metres minimum recommended	
Minimum distance to downgradient potable groundwater source	60m	

Table 5.2 Summary of ICW Design Recommendations

Chapter 6: Construction

6.1 Introduction

All aspects covered in the previous chapters on the Concept, Design, and Site Assessment of ICW systems, must coalesce during construction. The explicit drawing together of its three fundamental components; water management (flow and quality), landscape-fit and biodiversity, are achieved during this phase. Any specific planning conditions must also be taken on board. The competence of the contractor and those charged with supervising the construction are essential. In time it is expected that a larger number of competent designers, site assessors, contractors and construction supervisors, with recognised standards and portfolios of reference projects will become available.

This chapter broadly sets out the process to be followed by the developer in order to ensure that all elements of the ICW design are taken on board during this 'Construction Phase'.

6.2 Pre-construction

1. Appointment of Contractor

Once planning approval and a discharge licence has been obtained, and the client is free to move ahead with construction, the first stage is the appointment of a competent contractor. This stage should ideally involve the original designer of the ICW. There are a number of basic items required of an appointed contractor:

1. A track record in the construction of ICW or similar systems; if not, the contractor should be asked to demonstrate ability in the use of heavy machinery and earth moving towards achieving the ICW construct.
2. Possess basic technical ability in the interpretation of technical drawings and building to specification and most particularly levels.
3. Possess a H&S Statement and be asked to produce a Safety Plan for construction of the particular ICW.
4. The appointed contractor should be able to demonstrate sensitivity to landscape and ground conditions through previous works.

2. Initial Consultation and Site Visit

Once the contractor is agreed, a number of preliminary actions need to precede the construction of an ICW. Foremost of these is the consultation between land-owner/client, designer and contractor. This consultation should include:

1. Any specific directions from the local planning authority
2. Understanding of the construction work to be undertaken, through examination of the design drawings and agreement as to how it is to be done.
3. Agreed pricing and payment arrangements.
4. Joint pre-construction visit by all key players to the site to confirm the work to be done and how it will be done, and who does what. In particular all safety issues should be resolved; including site access issues and any specific H &S issues identified in the 'Site Characterisation' such as overhead wires, poor quality farm bridges etc.

When works are ready to commence a 'Commencement Notice' must be submitted to the planning authority. Before commencement of construction, the contractor must also understand that agreement and commitment to the following points are particularly important:

1. Building to the design with pre-agreed tolerances for what is to be achieved including the levels of the wetland floor and embankments, sealing of the wetland, configuration of embankments and preparation of the planting medium.
2. Disclosure of the position of any springs, land drains or other features/artefacts that may have been missed during site assessment should they become apparent during construction.
3. Closure/diversion of all land drains and springs within and contiguous to the entire wetland area of the ICW structure.
4. Agreed planting programme, specifying:- plant species, size/physiological status, planting density, whether bare rooted or container grown, and the planting method.

6.3 Construction

There are five basic tasks in the construction of ICW systems:

1. Site safety during and after construction
2. Effective use of the site's soils and topography during construction
3. The land forming of the structure to meet the design configuration and that it fits appropriately with adjacent topography.
4. The building of the bunded structure with a robust integrity that can withstand weather extremes, re-entry by heavy machinery, particularly in the first segments/cells (for removal of accumulated detritus/sediments) and maintenance of vehicular traffic along embankments.

5. The embankment/bank profiles to support habitat diversity.

1. Site Preparation

Effective use of the site's soils and topography during construction is essential to minimising costs and obtaining best use for the ICW. The topsoil on the site will usually have important, valuable properties that are conducive to vegetation establishment and enhancing ground water quality. The topsoil for each segment of the ICW should be stripped and stored for re-use during the final stages of construction. This should include topsoil under the footprint of the embankments.

Sites may be variable in their permeability and depth of subsoil; consequently subsoil or soil parent material may need to be distributed to achieve adequate coefficients of uniformity. These items should be clear from site characterisation and design documents. In particular the required soil depths are determined from the site characterisation and recommendations of Section 2.7 above.

The use of topography in minimising cut and fill should be reflected in the construction approach. This is emphasized in the design and the final fitting of the ICW into the landscape.

2. Management of Existing Drainage Systems

It is essential to minimise ground and surface water flows from surrounding drainage and overland sources, typically those from land drainage structures and sloping-ground, entering the ICW. These structures are not always revealed at the site assessment stage, and may only be discovered during construction. **It is absolutely essential to prevent any loss of water contained within the ICW through any form of land drainage that may have existed on the site prior to construction.**

Generally the interception and diversion of drainage and surface water is best achieved through the construction of an intercepting drain up-slope of the ICW. This water can ideally be re-directed to an outlet drain, or be allowed to enter any monitoring or additional segment/cell of the ICW. Prevention of water loss from within the ICW through existing drains is achieved through their total removal or destruction within the outer footprint of the entire ICW.

3. Construction of the wetland base

There are two basic water-retaining elements in any ICW, the wetland base and the embankments. To achieve the necessary water retention, several methods may be deployed, depending on site topography, soil type, and quantity, and machinery available.

The construction of the wetland base is required to achieve sufficient integrity to prevent both leaks and excessive seepage and maintain hydric conditions for the formation of the wetland soil. A permeability of 1×10^{-8} m/s is necessary to both establish the wetland soil and protect ground water (see Section 2.7 above). Methods of achieving this level of permeability depend upon a site's subsoil analysis results. This may be achieved, following removal of topsoil, by various means including:

1. Levelling of ICW base area on sites where subsoils already have the required impedance.
2. Compaction of the subsoil, in layers of approximately of 150-200 mm, using vibrating rollers on the more permeable soils to achieve 500mm depth of sub-soil liner.
3. Machine tracking with water on intermediate subsoils and again with the redistributed topsoil. This puddling technique is the method found to be the most effective. It has additional advantages in that it will demonstrate the water retention capacity of the wetland cell and provides optimal conditions for the establishment of vegetation.
4. Where subsoils are unsuitable, as indicated in the 'Trial Hole Analysis', imported material consisting of boulder clay or other high-clay content soil material may be substituted. This in turn should be compacted in layers of approximately 150-200 mm or puddle as in 3. above. An alternative is to use a geo-membrane or bentonite liner which may be as cost effective as importing suitable material.

The accumulation of organic matter from the influent will further decrease the rate of exfiltration as a result of the organic nature of the detritus. The essential component in achieving the necessary impedance to infiltration is that the structure remains adequately hydrated and the supporting soil free from conduits. If allowed to dry out and to be colonised by terrestrial vegetation, hydraulic conductivity may increase.

The construction machinery necessary to carry out the work will depend on site conditions and the scale of the undertaking, and may range from wheeled multi-tasked excavators to large tracked backhoe excavators and bulldozers.

Topsoil, because of its organic content, gathered at the site during the preliminary stage of construction is ideally suited to achieving impedance to infiltration and should be conserved for redistribution in preparation for final sealing and planting/seeding. The use of puddling where topsoil and/or subsoil is mixed with water to make self-levelling slurry is a proven method for achieving the required level of impedance where there may be some doubt with regard to infiltration. In some instances the extra topsoil may need to be used to enhance sealing. The use of water in the preparation of the wetland surface and for planting should be ideally available at this phase as it may facilitate a range of construction needs, such as the final levelling and the provision of optimal conditions for planting/seeding of the emergent plant species. A lysimeter placed 200-400mm under a wetland cell will allow for qualitative and quantitative assessment of infiltrating water. Lysimeters must be fixed in place so that any collected water is accessible and reflects the adjacent soil conditions.

4. Construction of Embankments

Embankment construction needs to be to standards that will support vehicular traffic such as tractors, have slopes that minimise soil creep and be resistant to weather erosion. A layered and tracked building method in layers of approximately 200 mm is recommended and has proven both effective and efficient.

The slope of the embankment should never be less than 1:1 - for biodiversity enhancement 2:1 or even wider ratios have special merit. The top profile of the embankment should be adequately compacted, level and wide enough to allow a tractor and mower to travel on safely. Corner and junction areas are required to be sufficiently wide to allow for easy turning of vehicles. This is supported by the curvilinear layout generally indicated in the ICW design.

Embankment construction should also be made up from the on-site materials and ideally exclude topsoil that can be used for puddling. The aim is to have low permeability in the embankments to allow for any future increasing water level in any of the wetland segments. The same construction principles apply as with the construction of the wetland base.

5. Water Retention Test

Notwithstanding that water absorption by soil, evaporation and rainfall may make the task of confirming that an ICW will retain water difficult, testing for this is probably the best indicator of compliance for client, designer, contractor and regulator. Puddled soils, subsoils and topsoil, in association with a free water surface will allow any conduits to be identified including missed drains and excessively porous patches. In addition the flatness of the soil's top surface can be checked.

This may be undertaken by filling the individual ICW segments/cells with water until a satisfactory degree of water-loss is confirmed. Where an appropriate water source is not available it may be necessary to conduct this test in wet weather.

6. Landscape Fit

Land forming of the ICW structure requires a level of sensitivity by the designer and contractor to ensure that the final structure fits into the landscape. The ICW design layout will have indicated basic shape and configuration, however the contractor will in many instances be influential in interpreting and implementing the designer's plan and the quality of what is finally achieved on site. Good communication between designer and contractor is essential.

7. Establishment of Vegetation

Various methods for establishing vegetation are effective. Success depends upon conditions and management of the wetland during the establishment period.

Figure 6.1 Spring planting and establishment by autumn of bare-rooted greater pond sedge (*Carex riparia*)

The use of bare-rooted planting stock (Fig 6.1 above) usually requires a period of settling-in. They should ideally be planted in spring or summer, when the settling-in period is approximately 2 weeks to 1 month. They are normally planted at 1 to 2 plants per square metre and with the wetland initially operating at minimum depth of approximately 100 mm. Planting accompanied by water should be undertaken as soon as possible after construction.

Pot-grown plants are the quickest to establish and minimise time-loss before operation. They are generally used for small ICW systems. The physiological status of pot-grown plants is important and if immature seedlings or plants have too little vegetative emergence above water they may fail. Juvenile plants are more vulnerable to pollution than physiologically older plants. An integral mixture of plant species gives added robustness to the overall system and allows for a measure of self-design through inter-species competition.

Direct seeding of appropriate species will require minimal water depth and turbidity to allow seeds to germinate and seedlings to develop to a physiologically mature state so that they may withstand the influents in each wetland segment. They also require that competition from residual vegetation and the seed bank in the topsoil be minimised. Setting seeds during the winter period ensures better germination in the following spring/summer. Seeds should ideally be collected from local sources.

The establishment of vegetation on the embankments may be left to natural regeneration or be seeded with grass/clover or native meadow mixtures. The planting of small tree and shrub species will usually enhance the overall landscape fit and biodiversity. Tree species that have the capacity to grow to large stature should not be grown on embankments lest they might endanger the integrity of the embankment should they become up-rooted.

6.4 Fencing

Appropriate fences should be erected to the required standards to control, where needed, the access of people and livestock and where (or when) required under any planning conditions. The shallow depth of the ICW and the surround of any deeper water such as the monitoring pond, provides a degree of built-in safety. Permanent stock-proof electric fencing has, in the main, been adequate for farm ICW systems but more closed or robust physical fencing may be necessary in certain situations especially near habitation. Generally though, people should have easy access to the wetland and visits and intimacy with it should be encouraged.

6.5 Construction of Final Bio-monitoring Pond(s) (Ref Section 5.5 above)

The construction of optional bio-monitoring pond(s), which may be an addition to the basic required ICW area, will depend upon its location, form and size. This is influenced by topography/landscape position, overall size of the treatment structure, site availability, the availability of water (whether from the preceding segments or from adjacent water sources) and anticipated amenity use. This pond may, or may not, have additional clean influent water from groundwater or surface water, such as existing springs, streams, or land drains. Achieving appropriate landscape fit, safety and biodiversity are essential. The sealing of this pond is primarily for the purposes of retaining water and its aquatic habitats. The provision of such ponds should be encouraged and not seen as a incidental accompaniment.

The landscape fit will require special attention to the adjoining land and may have generally lower embankment heights. Safety marginal areas around the inside edges of the pond with a minimum width of 2-3m should be shallow with a finished depth of less than 0.5m. The central depth should be greater than 2m if trout are to be introduced. The final outcome will, on the basis of experience to date, reflect the capabilities of the machine operator and their interaction with the designer. Discharge to the adjacent watercourse may be through an adjustable pipe, open channel, conduit/sluice, or some form of diffusion zone in situations where little or no discharge is required. The use of an adjustable pipe elbow allows the water to be monitored and managed more easily.

Chapter 7: Operation, Maintenance, and Monitoring

7.1 Maintaining Surface Flow

A fundamental requirement of the ICW concept and its design is that it be as self-managing and as self-maintaining as possible. The initial management requirements must be achieved within the physical, chemical and biological dynamics of wetland ecosystem function. The key operational necessity to achieve this is that water depths (100-300 mm) for the various ICW segments/cells should be maintained at these depths. If left unmanaged the accumulation of sediments and decaying organic matter combined with changing vegetation structure will eventually cause channelling-type flow to develop thus reducing retention time and plant contact. To minimise such channelling, surface flow must be maintained through the incremental raising of the water level in the various wetland segments. This is achieved through raising (and under special conditions where excessively deep, lowering) pipe invert levels, as appropriate.

As water depth and contaminant concentration, especially that of ammonium-N, can impact synergistically on emergent plants, the overall impact of increasing the water depth on the vegetation must be anticipated and carried out in small incremental steps. It is undesirable to suddenly reduce a wetland cell's water level through the release of water from one segment to the next as water, especially from the more polluted upper segments, may contain excessive ammonium, which could negatively impact on more sensitive vegetation. If there is a need to reduce levels, lowering the pipe/sluice when there is freeboard, or by small incremental amounts over longer periods, is appropriate.

7.2 Maintaining Access

Access to the wetland segments is generally maintained by having trackways along the top of the embankments. Their maintenance can be achieved through mowing once or twice per year or in some situations by grazing stock.

Maintenance should remove any trees that may grow to large stature on the embankments. Trees of small size or larger trees at appropriate locations may be tolerated and even encouraged, as long as the stability of the banks and their integrity are not compromised.

Fences should be maintained with particular attention to preventing livestock from gaining access to the overall ICW site (though there are situations where, through design, livestock can be managed on the site, e.g. where embankments are sufficiently wide and shallow and resistant to erosion). Any fences restricting personnel access should be maintained to the level required.

7.3 Removal of Accumulated Sediments/Detritus

Sediments, detritus and necromass will accumulate in all segments of an ICW. This will be greatest in the first segment where there is also the greatest phosphorus accumulation. Accumulated detritus should be removed when the depth of water of water is less than 200mm from the top of the surrounding embankment for that segment. This material will need to be periodically removed and managed in accordance with the European Communities (Good Agricultural Practice for Protection of Waters) Regulations, 2009, S.I. No. 101 of 2009. The nutrient (in particular phosphorus) content of the accumulated material needs to be quantified, so that it may be appropriately used when removed. There are various options for the treatment and use of this material. The simplest is land spreading on farmland after dewatering and in-situ composting. Alternatively the dewatered material may be compressed and dried for combustion or pyrolytic treatment. Land spreading should be planned to meet the requirements of GAP Regulations and be in accordance with farm nutrient management plans. The typical phosphorus content of wetland detritus in the initial wetland cell is of the order of 3 kg per tonne dry weight.

The initial removal of sediments is anticipated to be 10 to 20 years after the establishment of an ICW. The organic material that lies close (approximately 100 mm) to the wetland's floor should be retained, in order to maintain the integrity of its sealing properties. Where possible the vegetation should be removed initially and separately for use in the re-establishment of the segment. This operation will ideally be carried out during a drier summer period. The segment can be initially dried out by diverting the influent directly to the second segment and by wind-rowing before final removal for storage or direct land application. While the phosphorus content of the detritus may exceed farm needs/limits the dewatered material has high and rising economic value and can be traded.

7.4 Monitoring

Monitoring of surface and groundwater discharges may be required to comply with discharge licence requirements and to determine if the ICW is functioning as designed. The emphasis on ecosystem function of ICW systems facilitates a range of monitoring opportunities that are generally not practicable in other treatment wetland systems. Any one of these monitoring approaches listed below, or a combination of approaches, may be utilised. This wider range of monitoring parameters may be used to better understand the performance of the ICW, and the wider values for the site, while the use of indicator species (plant and animal) may be both less costly and more informative. This biological monitoring will be especially effective in establishing compliance with good farming practice and detecting abuses.

1. Surface Water Monitoring

Where the primary discharge from the ICW is to surface water, the licence (IPPC/Waste or Waste Water Discharge Licence) will specify the monitoring requirements for the discharge. Typical parameters required by the licence to be monitored in the ICW discharge may include:

- Flow (continuous monitoring using on-line flow meter with recorder);
- pH;
- Temperature;
- Biochemical Oxygen Demand;
- Chemical Oxygen Demand;
- Suspended Solids;
- Ammonium (as N);
- Nitrate (as N);
- Total Phosphorus (as P) and
- Ortho-phosphate (as P).

The licensee may be required to install a composite sampler and continuous flow monitoring. This, however, will be dependent on the scale of the ICW, the discharge volume and quality, and the receiving water scale and quality. All samples should be collected on a 24-hour flow proportional composite basis.

1) **Chemical composition** of the final surface discharge (and at discharges from individual segments within the system) with specific attention to BOD, ammonium-N, nitrate-N, and phosphorus
2) **Vegetation composition,** vigour and growth, with a recognition that some species are more tolerant to contaminated water than others[63].
3) **Invertebrate monitoring** of all or final segments of the system will provide reliable continuous insight of ICW performance and its biological value as an ecosystem[60,61,62]
4) **Turbidity** in 'still-open-water bodies' as is found in the final segment of an ICW can provide indirect indication of eutrophic status and consequently of its performance[23].
5) **Volumetric discharge** may cease during dry periods. This is a common characteristic of many ICW systems as their functional cleansing area is relatively large. Evapotranspiration during dry periods (an evapotranspiration

rate of 1 mm/day will remove 10 m^3/ha/day) and seepage into the ground (a permeability of $1x10^{-8}$ m/s will absorb 8.64 m^3/ha/day) together create freeboard that at the discharge point may prevent any discharge for long periods even in the wetter parts of the country. Monitoring discharge volumes will provide a broader understanding of the environmental and ecological performance and capacity of ICW function.

6) **Bio-monitoring** – Various fish species can be introduced to the final pond/s to give an indication of the quality of the final effluent. Inland Fisheries Ireland should be consulted as to the appropriate species, stocking rates etc. In general the presence of salmonids such as salmon or trout indicates a high level of water quality. Such surface water monitoring will only be possible where adequate depth and hydrology prevail e.g. where the monitoring pond is at or below the local water table or where there is an additional supply of water during dry periods.

Faecal indicator organisms - Levels of faecal indicator organisms may require recording, though research results to date indicate that ICW systems have the capacity to reduce their presence greatly, even in the initial cells. Very low or undetectable levels of e-coli can be expected in the ICW surface water effluent.

As noted previously, the ICW concept allows for a final stage monitoring pond (with or without fish) prior to discharge. Such ponds provide additional insight into the ongoing performance of an ICW over many seasons and much longer, even indefinitely. While such a monitoring pond may provide additional water quality management services it should not be included in the design calculation of the wetland's functional area requirement. Nevertheless, evapotranspiration, interception and exfiltration to the soil from a monitoring pond may increase the freeboard and decrease surface discharge during dry weather periods. The addition of such additional wetland/ponded areas can greatly enhance the amenity and biodiversity values of the overall site thus making the exercise of building an ICW one with multiple benefits.

2. Ambient Monitoring of Receiving Waters

Where the primary discharge from the ICW is to surface water, the licence (IPPC/Waste or Waste Water Discharge Licence) will generally specify a requirement for ambient monitoring of the receiving waters upstream and downstream of the ICW discharge. The ambient monitoring programme should be appropriate to the scale of the activity and the site specific characteristics. The suitability of ambient monitoring locations should be agreed with the EPA. Typical parameters to be monitored in the receiving waters may include:-

- pH;
- Conductivity;
- Dissolved Oxygen;
- Biochemical Oxygen Demand;
- Chemical Oxygen Demand;
- Suspended Solids;
- Ammonium (as N);
- Nitrate (as N);
- Nitrite (as N);
- Total Phosphorus (as P);
- Molybdate Reactive Phosphorus (as P);
- Faecal Coliforms; and
- Biological Quality (Q Rating) or Small Streams Risk Score (SSRS) Assessment. (This assessment must be undertaken by a qualified person)

3. Groundwater Monitoring

Any requirement for specific groundwater monitoring will depend on a risk-based evaluation of the likely impacts on a) the groundwater beneath and down-gradient of the ICW, b) down-gradient wells or c) nearby surface water receptors. Therefore, groundwater monitoring requirements will be site specific.

Where groundwater monitoring is considered to be necessary, sampling of groundwater up-gradient of the ICW is recommended. The design of the monitoring network down-gradient of the ICW should be focussed on the underground pathways likely to transmit pollutants and on the receptor at risk.

The recommended list of parameters is given in the table below:

Chemical Analysis Suite	Parameters Analysed
Basic Monitoring Suite	Field Analysis: pH; Dissolved Oxygen; Temperature; Conductivity Laboratory Analysis: pH; Conductivity; Colour; Nitrate; Ammonium; Nitrite; Total Phosphorus; Molybdate Reactive Phosphorus; Total Organic Carbon; Turbidity; Alkalinity; Total Hardness; Iron; Manganese; Sodium; Potassium; Chloride; Calcium; Sulphate; Magnesium; Total Coliforms & Faecal Coliforms (E-Coli).

The frequency of sampling will depend on the assessment of the risk posed by the ICW. However, quarterly sampling is recommended as the minimum frequency. This can be amended following evaluation of the initial test results.

Groundwater can be monitored in a number of ways. The sampling of existing and new wells adjacent to or within the ICW and its curtilage.

1. Sampling of adjacent groundwater hydraulically connected to the wetland.
2. The use of piezometers and lysimeters to measure ground water quality and quantitative flow within or adjacent to the ICW.
3. The use of adjacent watercourses, upstream and downstream of the wetland, to establish overall impact of the associated ICW system's hydrosphere.
4. Monitoring of ground water prior to commissioning an ICW will provide insight into any impact that an ICW may have on groundwater when it is operating. Consideration should be given to the impact of saturating the topsoil used in the wetlands construction that will increase ammonium concentration in the pore-water of the wetland soil even before the reception of polluted water.

Any or all of the above approaches require attention to delivering results that regulators can have confidence in. This is best achieved by describing the methodologies used, by demonstration, and by presenting results/analyses.

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APPENDIX A

Groundwater Response Matrix for Integrated Constructed Wetlands (ICW systems)

An explanation of the role of groundwater protection responses in a groundwater protection scheme is given in Groundwater Protection Schemes (DoELG/EPA/GSI, 1999).

The role of the groundwater response matrix is to provide an initial evaluation of the general suitability of a site, in this case for an ICW, from a hydrogeological perspective, as part of the desk study. It can also be used to indicate the measures that may be required to meet the required specification.

The geological and hydrogeological data that place a site within a response category is general to an area, and not specific to a site. It is therefore incumbent on the developer to demonstrate that the site conditions of a specific site are determined, before a decision is taken on the suitability or otherwise of a site. Examples of uncertainty on available data can include depth to rock values (and hence vulnerability ratings) and the presence of sand/gravel.

A risk assessment approach is taken in the development of this response matrix. The appropriate response to the risk of groundwater contamination from an ICW in the different hydrogeological settings in Ireland (see Table 1) is given by the assigned response category (R) appropriate to each protection zone – see Table 2.

Table 1: Matrix of Groundwater Protection Zones

Vulnerability Rating	Source Protection Area		RESOURCE PROTECTION AREA Aquifer Category						
	Inner (SI)	Outer (SO)	Regionally Important Aquifer			Locally Important Aquifer		Poor Aquifer	
			Rk*	Rf	Rg	Lg	Ll/Lm	Pl	Pu
Extreme	SI/E	SO/E	Rk/E	Rf/E	Rg/E	Lg/E	Ll/E	Pl/E	Pu/E
High	SI/H	SO/H	Rk/H	Rf/H	Rg/H	Lg/H	Ll/H	Pl/H	Pu/H
Moderate	SI/M	So/m	Rk/M	Rf/M	Rg/M	Lg/M	Ll/M	Pl/M	Pu/M
Low	SI/L	SO/L	Rk/L	Rf/L	Rg/L	Lg/L	Ll/L	Pl/L	Pu/L

↓ → directions of decreasing risk to groundwater

Table 2: Response Matrix for ICWs

Vulnerability Rating	Source Protection Area		RESOURCE PROTECTION AREA Aquifer Category						
	Inner (SI)	Outer (SO)	Regionally Important Aquifer			Locally Important Aquifer		Poor Aquifer	
			Rk*	Rf	Rg	Lg	Ll/Lm	Pl	Pu
Extreme	R4	$R3^{4}$	$R3^{3}$	R32	R4	R4	$R3^{1}$	$R3^{1}$	$R3^{1}$
High	$R2^{4}$	$R2^{3}$	$R2^{2}$	$R2^{1}$	$R2^{1}$	$R2^{1}$	R1	R1	R1
Moderate	$R2^{4}$	$R2^{3}$	$R2^{2}$	R1	R1	R1	R1	R1	R1
Low	$R2^{3}$	$R2^{3}$	$R2^{2}$	R1	R1	R1	R1	R1	R1

*A small proportion of the country (~0.6%) is underlain by locally important karstic aquifers (Lk); in these areas, the groundwater protection responses for the Rk groundwater protection zone shall apply.

R1 Acceptable, subject to meeting the following requirements:

1. The ICW shall be underlain by at least 1000 mm of cohesive subsoil.
2. An upper portion of the subsoil, which will vary in thickness as set out below depending on the risk posed by the ICW, shall have a permeability of less than 1x10-8 m/s. Where this is present in situ, (i.e. the subsoil is classed as CLAY (using BS5930) or, in certain situations, SILT/CLAY, and has a clay content of >13% (where the particle size distribution is adjusted by excluding materials larger than 20 mm), and is free from preferential flowpaths, the surface of the excavated portion of the pond will require plastering with remoulded subsoil. Where the subsoil is considered to have a permeability of greater than 1x10-8 m/s (i.e. is classed as SILT or, in certain situations, SILT/CLAY, and the clay content is <13% but >10%,) the subsoil must be enhanced by compaction or puddling to achieve the required permeability standard. Where the subsoil is classed as SAND, GRAVEL or SILT (in circumstances where the clay content is <10%), suitable subsoil or other material must be provided for the liner.
3. The upper 500 mm shall have a permeability of less than 1 x 10-8 m/s
4. Where the subsoil is sand/gravel, the upper 750 mm of the liner shall be installed with a permeability of less than 1x10-8 m/s.
5. The ICW shall be at least 60m away from any well or spring used for potable water.

R2[1] Acceptable, subject to normal good practice, meeting requirements 1, 2 , 4 and 5 above, but with the following additional requirement

6. The minimum thickness of subsoil with a permeability of less than 1x10-8 m/s shall be 750 mm.

R2[2] Acceptable, subject to normal good practice, meeting design requirements 1, 2, 4, 5 and 6 above, and the following additional requirements:

7. The ICW shall be at least 15 m away from karst features that indicate enhanced zones of high bedrock permeability (e.g. swallow holes and dolines (collapse features)).
8. The site assessment shall pay particular attention to the possibility of instability in these karst areas.

R2[3] Acceptable, subject to normal good practice, meeting requirements 1, 2, 4, 5, 6, 7 (in karst areas) and 8 (in karst areas).

R2[4] Acceptable, subject to normal good practice, meeting requirements 1, 2, 4, 5, 6, 7 (in karst areas) and 8 (in karst areas), and the following additional requirement:

9. Where microbial pathogens and/or high nitrate concentrations are known to be present in the water supply source, more detailed site investigation and/or restrictive design requirements may be necessary.

R3[1] Not generally acceptable, unless requirements 1, 2, 3, 4 and 5 can be met (Note 1).

R3[2] Not generally acceptable, unless requirements 1, 2, 4, 5 and 6 can be met (Note 1).

R3[3] Not generally acceptable, unless requirements 1, 2, 4, 5, 6, 7 and 8 can be met (Note 1).

R3[4] Not generally acceptable, unless requirements 1, 2, 4, 5, 6, 7 (in karst areas), 8 (in karst areas), and 9 can be met (Note 1).

R4 Not acceptable

Note 1: Establishing the required minimum subsoil thickness beneath the ponds will be difficult to achieve.

APPENDIX B

Assessment methodology for ammonium sensitive waters

The main potential pollutant of concern for groundwater is ammonium-N; high ammonium concentrations are generally found beneath ponds in circumstances where anaerobic conditions exist – 4 mg/l as N is given in Table 2.7. This is considerable higher than the surface water Environmental Quality Standard (EQS) for good status waters of 0.065 mg/l N. This is also the proposed groundwater threshold value (TV).

Careful evaluation and prediction of the likely impact of ammonium-N beneath ICWs is required as part of the site evaluation. The following factors should be considered:

- Area of ponds; the larger the area, the greater the nitrogen load entering groundwater.
- Stream flows and surface water ammonium-N concentrations; the dilution capacity of the stream depends on both factors.
- Status of nearby stream; where the stream is classed as 'high status', the surface water EQS for total ammonium is 0.04 mg/l N (mean); where the stream is 'good status' the surface water EQS is 0.065 mg/l N (mean).
- Permeability of base of ponds; this dictates the nitrogen loading entering groundwater, assuming that the ammonium concentration in groundwater is 4 mg/l N.
- Presence of a well down-gradient of ponds; the drinking water limit for ammonium-N is 0.3 mg/l.
- Aerobic/anaerobic conditions in the groundwater beneath the ponds and between the ponds and down-gradient receptors; where aerobic conditions are likely to be present, the ammonium will be oxidised and therefore the nitrogen will pose a significantly reduced risk to receptors. In circumstances where the ICW ponds are located in low-lying areas close to a stream, anaerobic conditions will often be present beneath the ponds and between the ponds and the stream. However, in circumstances where there is an unsaturated zone beneath the ponds, aerobic conditions are likely to be present.

High ammonium-N concentrations will not pose a significant threat to receptors in most circumstances as properly installed ICWs are likely to have permeabilities less than 1×10^{-8} m/s, thus reducing the pollutant loading. In addition, sensitive receptors may not be present down-gradient of an ICW.

During the site assessment phase, a quick appraisal of the site conditions, taking account of the factors mentioned above, can be undertaken.

The following equation can be used to estimate the minimum average stream flow required to maintain the ammonium concentrations below the EQS for ammonium-N:

$\mathbf{Q_{u/s} = ((Q_{gw}/86.4)(C_{gw} - C_{d/s}))/(C_{d/s} - C_{u/s})}$ where:

$Q_{u/s}$	=	the flow rate in the river upstream of the discharge (l/s)
$C_{u/s}$	=	the concentration of ammonium-N in the river upstream of the discharge (mg/l)
Q_{gw}	=	the rate of the groundwater discharge (m^3/d)
C_{gw}	=	the concentration of ammonium-N in the groundwater discharge (mg/l)
$C_{d/s}$	=	the concentration of ammonium-N in the river downstream of the discharge (mg/l)
86.4	=	conversion factor to l/s.

Worked Example:

- Pond area = 3 ha.
- Permeability of base of ponds = 1×10^{-8} m/s. Therefore groundwater input from beneath ponds = 30 m^3/d.
- Average ammonium concentration in groundwater = 4 mg/l N.
- Existing average ammonium concentration in stream = 0.03 mg/l N (if no ammonium data exist or cannot be estimated from nearby streams, assume this concentration for the purpose of the calculation).
- Assume that good status must be maintained in the stream and so the relevant EQS is 0.065 mg/l N.

$$\mathbf{Qu/s = ((Q_{gw}/86.4)(C_{gw} - C_{d/s}))/(C_{d/s} - C_{u/s})}$$

$$\mathbf{Qu/s = ((30/86.4)(4 – 0.065))/(0.065-0.03)}$$

$$\mathbf{Q_{u/s} = 40\ l/s}$$

This is a worst-case scenario in that, in many instances, the subsoil permeability will be less than 1×10^{-8} m/s. For example, if the permeability is 1×10^{-9} m/s, the $Q_{u/s}$ would be 4 l/s. This also illustrates that if there is a ‘small’ and/or sensitive stream nearby, a possible solution is to ensure that the permeability is low.

Where the nearby stream is relatively small and the stream flows are not known, it is possible to undertake a rapid calculation of the approximate average flow in the stream, assuming that the stream is not in a catchment underlain by a karstified limestone aquifer (where bypassing via underground conduits can occur), using the following equation:

Q l/s	=	A x R x 0.5 x 0.032 where:
A	=	catchment area (km^2)
R	=	average annual rainfall (mm)
0.5	=	factor converting rainfall to effective rainfall
0.032	=	conversion factor to l/s

The use of these equations provides a screening approach to enable an initial assessment of whether ammonium-N in groundwater beneath the ponds might be an issue. Rather than considering the resulting answer as pass/fail, it should be used as a guide as to whether a more detailed assessment is needed.

APPENDIX C

SITE ASSESSMENT FORM

To avoid any accidental damage, a trial hole assessment or percolation test should not be undertaken in areas, which are at or adjacent to significant sites (e.g. NHAs, SACs, SPAs, and/or Archaeological etc.), without prior advice from The Department of Environment, Heritage and Local Government, or the relevant Local Authority.

1.0 GENERAL DETAILS					
APPLICANT NAME:					
ADDRESS					
SITE LOCATION AND TOWNLAND:					
TELEPHONE NO:		**FAX NO:**		**E-MAIL:**	
Remarks following Preliminary Consultation					
Estimated Preliminary ICW Area Other Remarks					

2.0 DESK STUDY

2.1 TOPOGRAPHICAL DETAILS

GRID REFERENCE					
MAPS					
1:50000		1:10,000		1:2500	

Preliminary Assessment of Topography

2.2 CLIMATE

Rainfall mm	Evaporation	Wind Direction

2.3 SURFACE WATER

Surface Water Features	1	Comment
Name:		
Catchment Area (Ha)		
Mean Flow Estimate		
Available Dilution		
Water Quality "Q"		
Water Quality: Other		

2.4 GROUNDWATER

Source of Water (Tick as Appropriate)	Mains	Private		Group
Aquifer Category and Description				
Is there a Groundwater Protection Scheme ?)				
Vulnerability Class (Tick as Appropriate)	Extreme	High	Moderate	Low
Topsoil Type				
Subsoil Type and Thickness"				
Groundwater Response (Refer to Appendix A)				
Incidence of Karst, describe (Show location on Map)				
Public Supply Boreholes (Show location on Map, and indicate distance from proposed ICW Site)				
Domestic Boreholes (Show location on Map, and indicate distance from proposed ICW Site)				

2.5 CULTURAL SIGNIFICANCE

Presence of Significant Sites (archaeological, natural):	

2.6 DRAINAGE

Land Drainage - Maps	
- Local Knowledge (Including Soil Types)	

2.7 UTILITIES

UTILITIES	Knowledge	Safety	Needs Further investigation
Power Lines – above ground – below ground			
Gas mains:			
Sewerage:			
Water Mains:"			

2.8 OVERALL DESK STUDY ASSESSMENT

Comments arising from Desk Study Assessment
(Integrate the information above in order to comment on: the potential suitability of the site, potential targets at risk, and/or any potential site restrictions)

3.0 VISUAL ASSESSMENT

3.1.1 ON-SITE HAZARD ASSESSMENT

Type of water-vectored pollution	Ammonium-N concentration	Volume

3.2 VISUAL ASSESSMENT OF RECEPTORS

3.2.1 Topography / Landscape Position

General Comments:			
Ground Slope	Steep (>1:5)	Shallow (1:5 -1:20)	Flat (<1:20)
Difference in Level between source of influent and Proposed base of ICW 1st Pond			

3.2.2 Surface Water	
General Description of Proposed Receiving Water	
Channel Width	
Channel Depth	
Water Depth	
Evidence of Higher Water Levels	
Estimate of Flow	
Other Surface Water Features	

3.2.3 Groundwater	
Give Descriptions of the Following:	
Rock Outcrops	
Karst Features	
Springs	
Wells	
Subsoil Cuttings/Exposures	

3.2.4 Utilities	
Description of other utilities not identified in Desk Study **Verification of Desk Study Findings**	

3.2.5 Heritage	
Description of Flora **Description of Cultural Heritage**	

3.2.6 Human	
Existing Land Use	
Distance in m. to Nearest House (where relevant)	
Distance in m. to Nearest School (where relevant)	
Distance in m. to Nearest Gathering Place (e.g. Church, Community Centre - where relevant)	
Site Boundaries: (distance in m. to nearest)	
Road: (distance in m.)	
Evidence of Prevailing Climatic Conditions (particularly wind)	

3.2.7 Drainage Systems	
Drainage Systems:	

3.2.8 Interpreting Results of Visual Assessment
(Integrate the information above in order to comment on: • *The potential suitability of the site for an ICW,* • *Potential targets at risk,* • *The location of the proposed ICW system within the site).*

3.3 TRIAL HOLE							
The Trial Hole should be excavated to a minimum depth of 2m below the base of the proposed wetland.							
Trial Hole No		**Depth of Trial Hole (m):**		**Date and Time of Excavation:**		**Date and Time of Examination**	
Depth from Ground Surface to Bedrock (m) (if present):							
Depth from Ground Surface to Water Table (m) (if present):							
Depth and Description of Topsoil							

	Soil/Subsoil Texture & Classification (Include Plasticity/ Dilatancy Results)	**Density/ Compactness**	**Colour**	**Preferential Flowpaths**
0.2m				
0.4m				
0.6m				
0.8m				
1.0m				
1.2m				
1.4m				
1.6m				
1.8m				
2.0m				
2.2m				
2.4m				
2.6m				
2.8m				
3.0m				
3.2m				
3.4m				
3.6m				
3.8m				
4.0m				
Depth of Water Ingress:			**Rock Type (if present):**	

3.4 PARTICLE SIZE DISTRIBUTION TESTS (BS 1377)		
PSDT Test Number	% Clay Content	Trial Hole No. and Depth of Test Location
1		
2		
3		
4		
5		
EVALUATION of Trial Hole and PSDT Results: (Include discussion here of significance of results)		
Sketch of site showing • measurement to Trial Hole and PSDT locations, • wells and direction of groundwater flow (if known), • adjacent houses, watercourses, significant sites and other relevant features. • North point should always be included. [A copy of the site layout drawing should be used if available]		

4.0 CONCLUSION OF SITE CHARACTERISATION	
(Integrate the information from the desk study and on-site assessment (i.e. visual assessment, trial hole and percolation tests) above and conclude whether it is feasible to construct An ICW)	
Is a Permeability of 1×10^{-8}m/s achievable?	
How? What specific works are required?	
Is the assimilative capacity available for surface water discharge?	
Are there any specific features to avoid?	
Are there any specific features to include?	
How? What specific works are required?	
Other:	

5.0 Site Assessor Details

Signed: Address: Qualifications/Experience: Date of Report: Phone: Fax: Email:

APPENDIX D

SOIL ANALYSIS GUIDE
(After BS 5930)

Particle Sizes as defined in BS5930:1999

Boulder	>200 mm	Larger than a soccer ball
Cobble	60-200 mm	Smaller than a soccer ball, but larger than a tennis ball
Gravel	2-60 mm	Smaller than a tennis ball, but larger than match heads
Sand	0.06-2 mm	Smaller than a match head, but larger than flour
Silt	0.002-0.06 mm	Smaller than flour (not visible to the naked eye)
Clay	<0.002 mm	Not visible to the naked eye.

A: Examine Boulders & Cobbles

Test adapted from the British Standards Institution BS 5930:1999 Code of Practice for Site Investigations (1999).

- Using a hammer, trowel, or pick, clean off a portion of the trial pit wall.
- Examine whether the quantity of boulders/cobbles is dominant over finer material. This will usually be easily done by eye. If unsure, separate boulders/cobbles from finer material in two sample bags and compare weights by hand.

B & C: Preparation of Sample and Apparent Cohesion Test

Test taken from the British Standards Institution BS 5930:1999 Code of Practice for Site Investigations (1999).

- Collect a hand-sized representative sample from the cleaned-off portion of the trial pit wall.
- Remove particles larger than 2 mm, as far as possible.
- Crush clumps of subsoil and break down the structure of the sample.
- Slowly add water (preferably as a fine spray), mixing and moulding the sample until it is the consistency of putty; it should be pliable but not sticky and shouldn't leave a film of material on your hands. Can the sample be made pliable at the appropriate moisture content?
- If it can, squeeze the sample in your fist - does it stick together?

D: Thread Test

Test adapted from a combination of the American Society of Testing and Materials Designation Standard practice for description and identification of soils (visual-manual procedure) (1984), and the British Standards Institution BS 5930:1999 Code of Practice for Site Investigations (1999).

- Ensure the sample is of the consistency of putty. This is very important! Add extra water or sample to moisten or dry the sample.
- Check that no particles greater than 1 or 2 mm occur in the prepared sample.
- Gently roll a thread 3mm in diameter across the width of the palm of your hand. Remove excess material.
- If a thread can be rolled, break it and try to re-roll without adding additional water.
- Repeat until the thread can no longer be rolled without breaking.
- Record the total number of threads that were rolled and re-rolled.
- Repeat the test at least twice per sample. Water can be added between each test repetition, to return the sample to the consistency of putty.

E: Ribbon Test

Test adapted from the United States Department of Agriculture Soil Conservation Service Soil Survey Agricultural Handbook 18. (1993).

- Ensure the sample is of the consistency of putty. This is very important! Add extra water or sample to moisten or dry the sample.
- Check that no particles greater than 1 or 2 mm occur.
- Form your moist sample into a large roll in your hand, approximately the width of your thumb.
- Hold your hand and arm parallel with the ground. Using your thumb, press the sample over your index finger to form a uniform ribbon about thumb-width and 0.5cm thick. Let this ribbon hang over your index finger and continue to extrude

the ribbon between thumb and index finger until it breaks. Be careful not to press your thumb through the ribbon.

- Measure the total length of the formed ribbon when it breaks (i.e. from tip of thumb to end of ribbon).
- Repeat this test at least 3 times per sample to obtain an average ribbon value. Water can be added between each repetition, to return the sample to the consistency of putty.

F: Dilatancy Test

Test taken from British Standards Institution BS 5930:1999 Code of Practice for Site Investigations (1999).

- Wet the sample such that it is slightly more wet (and softer) than for a thread test, but not so wet that free water is visible at the surface.
- Spread the sample in the palm of one hand, such that no free water is visible at the surface.
- Using the other hand, jar the sample 5 times by slapping the heel of your hand or the ball of your thumb. Take note of whether water rises to the surface or not, and how quickly it does so.
- Squeeze the sample, again noting if the water disappears or not, and how quickly.
- Dilatant samples will show clear and rapid emergence of a sheen of water at the surface during shaking, and clear and rapid disappearance from the surface during squeezing. Non dilatant samples will show no discernible sheen.
- Decide whether your sample has dilatancy. Beginners often find it quite difficult to determine the presence of a sheen, unless it is very obvious. It will become easier once samples with clear dilatancy are observed.

BS5930:1999 Criteria for describing density/compactness (fine subsoils)

Term	Field Test
Uncompact	Easily moulded or crushed in fingers
Compact	2-60 mmCan be moulded or crushed by strong finger pressure
Very soft	Finger easily pushed up to 25mm
Soft	Finger pushed up to 10mm
Firm	Thumb makes impression easily
Stiff	Can be indented slightly by thumb
Very stiff	Can be indented by thumb nail
Hard	Can be scratched by thumb nail

BS5930:1999 Criteria for describing discontinuities

Term	Mean spacing (mm)
Very widely	>2000
Widely	2000-600
Medium	600-200
Closely	200-60
Very closely	60-20
Extremely closely	<20
Fissured	Breaks into blocks along unpolished discontinuities
Sheared	Breaks into blocks along polished discontinuities

Appendix E

Minimum Licence Controls for ICW Systems

- The quantity and quality of waste water entering the ICW system. The licence should specify the maximum load input to the ICW, e.g. population equivalent for municipal waste water ICWs, sources of soiled water for farmyard ICWs, etc.

- The nature, composition, rate, volume and period during which a discharge may or may not be made should be specified based on the effect of the discharge on the receiving water and the design, construction and location of the discharge outlet.

- **Emission Limit Values**
  Emission limit values on the final effluent discharge to surface water from the ICW shall be determined on a case-by-case basis and shall be subject to the assimilative capacity of the receiving waters. The European Communities Environmental Objectives (Surface Waters) Regulations 2009, S.I. No. 272 of 2009, have established stricter ambient standards that those which previously applied. The Environmental Protection Agency is currently preparing guidance on assimilative capacity for receiving waters, based on achieving compliance with these regulations. This guidance will be made available to the public.

- **Monitoring Requirements**
  Typical parameters to be monitored in the waste water entering the ICW and in the discharge from the final pond of ICW (amendments may be justified depending on the quantity and quality of waste water entering the ICW system):

Parameter
Flow
pH
Biochemical Oxygen Demand
Chemical Oxygen Demand
Suspended Solids
Nitrates (as N)
Ammonium (as N)
Total Phosphorus
Molybdate Reactive Phosphorus

APPENDIX F

PRELIMINARY HEALTH AND SAFETY PLAN FOR INTEGRATED CONSTRUCTED WETLANDS

This Preliminary Health and Safety Plan has been prepared in accordance with current H&S Regulations

1. GENERAL DESCRIPTION OF PROJECT.

1.1 Client
Insert farmer/client name here

1.2 Project Supervisor (Design Stage)
This must be a recognised appropriately qualified person

1.3 Project Description
The works consist of the following elements:

Complete as appropriate

as detailed on the Contract Drawings and/or as described in the Specification and/or the Bill of Quantities.

1.4 Timescale for Completion of Construction.
The timescale for construction is -- weeks.

Intended Contract
Commencement Date *

Intended Contract
Completion Date *

***Note:** The intended commencement and completion dates advised above are provisional, pending confirmation by the Project Supervisor (Construction Stage) that they are practicable.

1.5 Site Location

The primary site is located at ………………… as outlined on the site location map.

1.6 Drawings/Specifications

The following drawings accompany this preliminary Health and Safety plan. These should be read in conjunction with this plan.

Insert drawing numbers here

The following specifications accompany this Health and Safety plan. Insert title of any specification e.g. Guidance Document for Design and Construction of ICW systems

2. PARTICULAR RISKS.

The following is the non-exhaustive list of particular risks to the health and safety of persons as set out in Schedule 2 of SI 138 of 1995, together with the opinion of the Project Supervisor for Design Stage on what elements of the works may fall within each risk category. It should be noted that many of the risks on the project may arise out of working methods which are at the discretion of the Contractor and as such cannot be determined by the Project Supervisor for Design Stage.

2.1 Works which puts persons at work at risk of burial under earthfalls, engulfment in swampland or falling from a height, where the risk is particularly aggravated by the nature of the work or processes used or by the environment at the place of work or site.

2.1.1 Burial Under Earthfalls,

It is unlikely that deep excavations will be required for ICW systems, but include if envisaged

2.1.2 Engulfment in Swampland,

It is envisaged that this would be unlikely, but include if envisaged as a possible hazard

2.1.3 Falling from a Height,
It is envisaged that this would be unlikely, but include if envisaged as a possible hazard

2.2 Work which puts persons at risk from chemical or biological substances constituting a particular danger to the safety and health of such persons or involving a legal requirements for health monitoring.

2.2.1 Materials to be used in works e.g.: asbestos, toxic paints, solvents, adhesives, mould oil, sealants, insulation materials, toxic dust, etc.

Very unlikely – Insert NO

2.3 Work with ionising radiation requiring the designation of controlled or supervised areas as defined in Article 20 of Directive 80/36/Euratom such as: radioactive lightning conductors, radioactive smoke detectors, other disused radioactive materials or plant, radioactive installations.

None Envisaged.

2.4 Work near high voltage power lines.

2.4.1 Overhead electric wires.
Describe any wires identified in site assessment

2.4.2 External / Underground electric wires.
Describe any wires identified in site assessment

2.5 Work exposing persons at work to the risk of drowning
It is highly likely that there may be work close to a watercourse. If so this must be identified

2.6 Work on wells, underground earth work and tunnels
It is envisaged that this would be unlikely, but include if envisaged as a possible hazard

2.7 Work carried out by divers at work having a system of air supply.
None Envisaged

2.8 Work carried out in a caisson with a compressed air atmosphere.

None Envisaged

2.9 Work involving the use of explosives

It is envisaged that this would be unlikely, but include if envisaged as a possible hazard

2.10 Work involving the assembly or dismantling of heavy prefabricated components for example: heavy steel structural frame elements, heavy precast concrete frame elements or heavy prefabricated plant items.

None Envisaged

3. OTHER WORK ACTIVITIES.

Include anything here not dealt with by above questions.

4. EXISTING ENVIRONMENT AND RESTRICTIONS

4.1 Site Possession

All working hours are to be agreed in consultation with the Works Supervisor.

4.2 Restrictions on Access

Particular care is required to protect members of the public and motorists during work operations. Warning signs and/or Protective barriers and cones lights etc, must be provided to secure excavations etc. The Contractor shall order, arrange, and carry out his works in accordance with this restriction. This limitation shall be reflected in the Contractor's tender programme and in any later works programmes submitted in accordance with the Contract. The Contractor shall fully provide in his tender for any costs which may arise as a result of this restriction.

4.3 Restrictions on Working Hours

Include as desired, or as deemed by planning permission.

4.4 Surrounding Land Use

In general this will be Agricultural

4.5 Continuing Liaison

In the event of unforeseen eventualities arising during the project affecting the contract period or other resources not addressed in this plan the following procedure shall be utilised:- It shall be the responsibility of the contractor to notify the Project Supervisors for the design and construction stages (who may be one and the same person) of the changes.

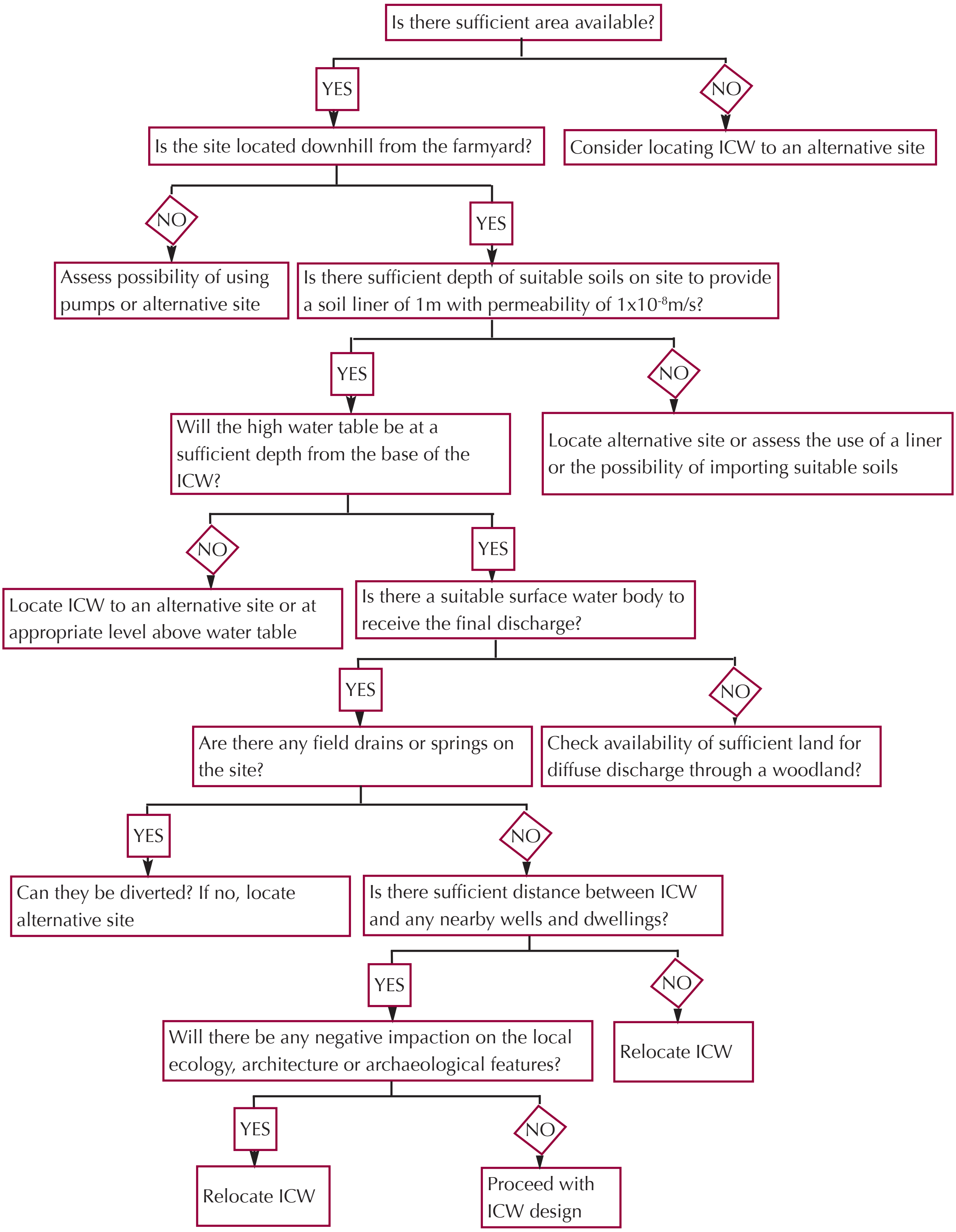
The information contained in this preliminary Health and Safety Plan has been prepared prior to the commencement of the work on site. It does not take account of any matters or information which may come to light after that time.

Signed: ....

for and on behalf of the Project Supervisor (Design Stage)

Date: ....

APPENDIX G



Is there sufficient area available?
YES
NO
Is the site located downhill from the farmyard?
Consider locating ICW to an alternative site
NO
YES
Assess possibility of using pumps or alternative site
Is there sufficient depth of suitable soils on site to provide a soil liner of 1m with permeability of $1x10^{-8}$m/s?
YES
NO
Will the high water table be at a sufficient depth from the base of the ICW?
Locate alternative site or assess the use of a liner or the possibility of importing suitable soils
NO
YES
Locate ICW to an alternative site or at appropriate level above water table
Is there a suitable surface water body to receive the final discharge?
YES
NO
Are there any field drains or springs on the site?
Check availability of sufficient land for diffuse discharge through a woodland?
YES
NO
Can they be diverted? If no, locate alternative site
Is there sufficient distance between ICW and any nearby wells and dwellings?
YES
NO
Will there be any negative impaction on the local ecology, architecture or archaeological features?
Relocate ICW
YES
NO
Relocate ICW
Proceed with ICW design

Glossary

Adsorption: the binding of molecules or particles to a surface

Adaptive Management: A systematic process for continually improving management policies and practices by learning from the outcomes of previously employed policies and practices.

Anaerobic: occurring in the absence of molecular oxygen, for example, anaerobic respiration.

Anoxic: without molecular oxygen

Attenuation: the control of the flow of water to a water course or drainage system

Biodiversity: a term used to describe all of nature's variety

Biofilm: an aggregate of microorganisms in which cells adhere to each other and/or to a surface

Bio-geochemical: term used to describe the the cycle whereby molecules move through water, land and air.

Biomass: the mass of living microbes, plants, or animals present per unit area at any given time.

Decomposition: the breakdown of litter or of dead plant or animal material into smaller molecules or particles.

Denitrification: conversion of nitrate to nitrogen gas.

Detritus: partly decomposed plant or animal litter with its associated microorganisms.

Discharge: the volume of water flow per unit time; can refer water leaving a wetland including that to surface or ground.

Ecosystem: An ecological community together with its environment functioning as a unit

Emergent plant: a plant which grows in water but which pierces the surface so that it is partially in air

Eutrophic: nutrient rich.

Evapotranspiration: the combination of evaporation from water surfaces and transpiration from vegetation.

Exogenous: an action or object coming from the outside of a system

Flux: the flow or movement of material from one compartment to another in an ecosystem.

Groundwater: means all water which is below the surface of the ground in the saturation zone and in direct contact with the ground or subsoil.

Habitat: an ecological or environmental area that is inhabited by any particular species of animal, plant or other type of organism

Heterotroph: an organism that uses organic carbon for growth by consuming other organisms

Humic substances: the end product of decayed matter usually containing quantities of trace minerals.

Hydric soil: soil that is saturated or flooded long enough during the growing season to develop anaerobic conditions in the upper part.

Hydrology: Study of the distribution and movement of water.

Hydrophyte: a plant growing in soils that are saturated or flooded long enough during the growing season that the soils become anoxic.

Landfill leachate: liquid that drains from a solid waste landfill

Landscape: gross features of the land surface, including slope, aspect, topography, land use, etc.

Litter: dead plant or animal material.

Macrophytes: aquatic plants or hydrophytes large enough to see without a microscope, includes some algae, mosses, liverworts, ferns and angiosperms.

Micro-organism: A microorganism or microbe is an organism that is so small that it is invisible to the naked eye.

Mitigation: avoiding, minimizing, rectifying or compensating for wetland losses.

Necromass: the mass of litter or dead plant and animal material per unit area at a given time.

Nitrification: conversion of organic nitrogen and ammonium to nitrate.

Nitrogen fixation: conversion of nitrogen gas to ammonium.

Nutrient cycling: the movement of nutrients among various components of an ecosystem.

Organic soils: soils composed predominantly of decomposing plant litter.

Oxidation: a chemical reaction in which the oxidation state of a chemical is increased because of the loss of electrons.

Pathway: conduits and interconnected interstitial (pore) soil spaces along which water moves.

Phosphorus capture: the extraction of phosphorus from influent water for use in growth of vegetation

Photosynthesis: conversion of carbon dioxide and water into sugars and oxygen by plants using energy form the sun.

Redox: the potential difference, usually expressed in milli-volts, between a platinum electrode and a reference electrode in a solution. It is a measurement of reducing conditions or electron pressure (availability) in a solution.

Reduction: a chemical reaction in which the oxidation state of a chemical is lowered by the addition of electrons.

Restoration ecology: any activity that initiates or accelerates the recovery of an ecosystem with respect to its health, integrity and sustainability

Saturated soils: soils in which all pore spaces are full of water and are thus anaerobic, but which may or not have standing water on the surface.

Subsoil: the term used to describe soils underlying the topsoil layer

Substrate: the surface or medium on which an organism grows or is attached

Terrestrial: land based

Transitional: the zone marking the interface between land and water

Treatment wetlands: wetlands constructed to remove nutrients from the effluent of wastewater plants or from polluted agricultural or urban run-off.

Vector: agent of transport, water transported chemicals, microorganisms, suspended solids; requires a pathway.

Water quality: the physical, chemical and biological properties of water. Water quality is usually judged from a human-use perspective and given regulatory status.

Water table: the upper surface of a zone of saturation.

Wetland: an ecosystem that is constantly or recurrently shallowly flooded or whose soil is constantly or recurrently saturated at or near the surface. Common diagnostic features of wetlands are hydric soils hydrophytic vegetation.