Overview of Measures to Control Pollution of Water Resources

DELIVERABLE 1

Dr. William L Magette

Revised DRAFT

Contents

1. Introduction.......................................................................................................................2
  1.1 Background...............................................................................................................2
  1.2 A Simple Recipe for Controlling Pressures on Water Resources.............................3
  1.3 Impediments to Controlling Pressures on Water Resources.....................................3
  1.4 Point Versus Diffuse Pressures on Water Quality....................................................4
2 Characterisation Criteria for Pollution Control Measures ..............................................7
3 An Overarching Context for Selection of Control Measures........................................10
4 Point Source Control Measures .....................................................................................11
  4.2 Urban Runoff ..........................................................................................................14
  4.3 Agricultural Point Sources......................................................................................15
5 Diffuse Source Control Measures ................................................................................17
  5.1 Agricultural diffuse sources ....................................................................................18
    5.1.1 Site controls ....................................................................................................18
    5.1.2 Perimeter controls ...........................................................................................20
    5.1.3 Exclusion techniques ......................................................................................21
    5.1.4 Forestry Diffuse Sources.................................................................................21
  5.2 Urban Diffuse Sources (Including construction activity)........................................22
6 Financial approaches (Supplementary measures – fiscal) .............................................23
7 Political approaches, including Education (Supplementary measures – legislative and educational)..........................................................24
8 Ranking of Measures......................................................................................................26
9 Summary.........................................................................................................................27
10 Bibliography ..................................................................................................................28
1. INTRODUCTION

1.1 Background

The management of water resources in catchments as envisioned in the Water Framework Directive (WFD) (European Parliament, Council, 2000) requires a diverse, yet highly integrated, approach that involves the implementation of techniques that address pressures on those resources. Because time and financial resources are always limited, the real challenge for catchment managers is to choose those techniques that offer the greatest return on investment, i.e., achieve the greatest impact (in preventing or minimising pressures) for a given input of time, energy and money. Pressures on water resources are anthropogenic activities that affect water quantity and quality.

This document primarily addresses pressures that affect water quality, on the assumption that, in general, catchment water quantity pressures must (in Ireland) be addressed at a higher level of authority than is represented by River Basin Districts (RBD). The WFD mentions, in Article 1, that water supply and flood and drought mitigation are some of the purposes of the Directive. Both of these require management of water quantity as well as quality. However, RBD activities to date have concentrated on the water quality objectives. In fact both are intimately linked, e.g. critical quality conditions occurring during low flows in rivers, yet major amounts of pollutants are transported during floods. Ultimately such linkage must be taken into account in measures, but this avenue has not yet been developed in depth.

Herein, activities that affect water quality are synonymous with those that cause water pollution, which is taken to be the introduction of inorganic and / or organic contaminants to water that negatively affect the suitability of the resource for one or more specific purposes. In truth, there is an intimate connection between water quality and water quantity and both aspects of resource protection must be addressed simultaneously in a co-ordinated fashion. The complexity of the interactions demands the use of integrative catchment modelling (Mohamoud, 2008) in order to forecast the effects of change, as well as appropriate long-term monitoring strategies to confirm the desired changes have occurred.

The main contaminants contributing to water quality degradation are inorganic chemicals (mainly species of nitrogen and phosphorus), inorganic particles (eroded soil, metals from road surfaces), organic compounds (e.g., pesticides, oils and greases from roadways), and organic matter (faeces, bacteria, detritus). The sources, or origins, of these contaminants can be well-defined point sources (e.g., discharges from easily identifiable locations, such as discharge pipes) and ill-defined diffuse sources (e.g., the landscape, including agricultural fields, forestry plantations and construction sites).

The WFD divides measures into two categories, (i) Basic measures, i.e. already required by existing legislation and (ii) Supplementary measures, see WFD Annex IV. Although this report categorises measures according to their physical attributes, where appropriate, they are linked to the appropriate WFD category.
1.2 A Simple Recipe for Controlling Pressures on Water Resources

As regards the control of anthropogenic pollution pressures, assuring a favourable return on investment requires not only selecting the appropriate techniques, but also applying these in strategic locations. (The same is true for controlling pressures on water quantity.)

This recipe for success has three fundamental ingredients:

- knowledge of the reasons for pressures on water quality (and/or quantity);
- knowledge of the locations of these pressures; and
- knowledge of the performance of measures that can address pressures.

Implicit in this strategy is the concept of tailoring actions to particular problems, and then targeting these in some priority order to those locations in a catchment that require the most attention, i.e. are causing the biggest problems. In general, a control strategy based using site-specific, targeted measures is superior to a so-called “one-size-fits-all” strategy, in which a uniform approach is taken to address a particular problem regardless of site-specific conditions (e.g., Sharpley et al., 1993; Sharpley, 1995). When the above three ingredients are available, decisions about what to do to address water pollution pressures or threats to quantity, and where to take action, are straightforward. If, in addition, the cost of each particular strategy is known, it is a simple matter to select appropriate measures within any given budget.

1.3 Impediments to Controlling Pressures on Water Resources

The recipe above presumes that implementation / adoption of selected measures is not an issue. However, this presumption is tenuous as regards measures for controlling diffuse pressures because controlling these sources of water pollution impinges on private property rights. Although under civil law, individuals can be prevented from causing a nuisance (including pollution of water resources), the nature of diffuse water pollution precludes, except in catastrophic events, establishing a causal link between activities at a specific location in a catchment and water quality. Consequently, measures that control diffuse pollution are either voluntarily adopted by some (but usually not all polluters), or the measures are imposed on all polluters by law or regulation. A long-running debate over whether voluntary or regulatory approaches are more effective in controlling diffuse pollution has ardent supporters on both sides of the argument, particularly in regards to diffuse agricultural pollution (Braden and Lovejoy, 1990). (In general, controls on diffuse pollution consist primarily of incentivised voluntary measures supplemented by a mix of regulatory measures.) Nevertheless, whether voluntary, regulatory or a mixture of measures is utilised, human behaviour becomes as important a consideration in developing a successful and effective control programme as the technical merits of the measures themselves.

The characterisation studies (EPA and RBDs, 2005) that have already been completed in the various river basins have identified the pressures, and to some extent, the locations of those pressures, on water resources. It remains to devise appropriate strategies for addressing these pressures. Unfortunately, the recipe for accomplishing this, so simply described above, is really not so simply or easily achieved.

Catchments are complex and dynamic environmental systems. Nevertheless, they obey an inescapable important law of nature: whatever enters a catchment must eventually leave the catchment, unless it is stored in the catchment. This fundamental law pertains equally to
water itself and to materials that may ultimately become water pollutants. The storage capacity of a catchment for any physical material, such as phosphorus or water itself, is finite. In the case of water \textit{quantity} management, the challenge is to assure that an adequate quantity of water (with acceptable quality) is available to meet demands. This requires that water inputs, storage and demand be integrated with water quality management.

In the case of water \textit{quality} management, catchment management activities must collectively endeavour to keep the total catchment system, as well as each of its component sub-parts, in balance such that inputs do not overwhelm the “assimilative capacity” of the natural system and create \textit{unwanted} outputs, \textit{i.e.} pollutants. In the USA, this strategy has been based on firstly, determining the assimilative capacity of a catchment, and secondly, implementing strategies that assure it is not exceeded by human activity. Assimilative capacity is expressed as a Total Maximum Daily Load, or TMDL, for a given pollutant, and “is a calculation of the maximum amount of a pollutant that a water-body can receive and still safely meet water quality standards” (USEPA, 2008). “Assimilative capacity” is the key to “sustainable use” of the planet (Cairns, 1999).

Techniques for managing water \textit{quantity} are well advanced as a result of many decades of research and practice in this field. In the main, quantity management measures will not be addressed in this document.

\subsection*{1.4 Point Versus Diffuse Pressures on Water Quality}

Anthropogenic pressures on water quality are as complex and dynamic as catchments, although for convenience these pressures are grouped into just two categories: point and diffuse. Examples of these two types of pollution pressures are given in Table 1, compiled from “Characterisation Studies” report. The measures required to address these two types of pressures are vastly different.

\begin{table}[h]
\centering
\begin{tabular}{|c|c|c|c|c|}
\hline
\textbf{Point Sources} & \textbf{Diffuse Sources} \\
\hline
\textbf{Surface Water} & \textbf{Groundwater} & \textbf{Surface Water} & \textbf{Groundwater} \\
\hline
Urban Waste Water Treatment Plants & Contaminated land & Agriculture & Agriculture \\
\hline
Storm Overflows & Waste Disposal Sites & Non-sewered Population & Non-sewered Population \\
\hline
Sludge Treatment Plants & Oil Industry Infrastructure & Urban Land Uses & Urban Land Uses \\
\hline
Integrated Pollution Prevention and Control Industries & Discharges from Mines & Transport & Transport \\
\hline
Non-IPPC Industries & Discharges from “Soakaways” & Peat Exploitation and Forestry & Peat Exploitation and Forestry \\
\hline
\end{tabular}
\caption{Examples of Significant Point and Diffuse Pollution Sources and Type of Resource Affected (EPA and RBDs, 2005).}
\end{table}

Historically, point sources have been viewed as those from which emissions to the environment can be pinpointed physically, such as the discharges from municipal and industrial wastewater treatment facilities. The emissions from such sources are relatively easy to quantify, and are relatively consistent over time. In addition, the operational processes by which to alter the emissions from point sources are “mature”, and both their
cost and performance are predictable. The application of point source control techniques produces immediate effect, \textit{i.e.} emissions are measurably diminished (although it may take considerable time afterwards for an ecosystem to exhibit improvement as a result of the controls implemented). Not surprisingly, in Europe and elsewhere, strategies to address water quality problems have focused almost entirely on point sources until relatively recently, and (at least in the US) improvements in water quality have largely been attributed to point source control measures (OMB, 2006). (Nevertheless, in the 30 years that have passed since enactment in the USA of the Federal Water Pollution Control Act Amendments of 1977, the goal of making all waters in the US “fishable and swimmable” has yet to be achieved.)

In contrast to point sources, diffuse sources of environmental emissions are characterised by the fact that no unique, physical discharge point can be identified. Diffuse sources seem to emanate from everywhere and thus include all activities that are distributed across the landscape of catchments. Because agriculture is typically the largest and most intensive user of land in (rural) catchments, this sector often receives the most attention for diffuse emissions to water. As seen in Table 1, other diffuse sources of emissions include urban land use, forestry, construction, and, in un-sewered areas, rural housing.

The transport of contaminants from diffuse sources to water resources is intimately linked to hydrologic processes, which in turn are influenced by topography, geology, soil characteristics, vegetation and anthropogenic activity (Table 2). For these reasons, unlike the emissions from point sources, those from diffuse sources are difficult to predict and cannot, in general, be collected and remediated. Consequently, measures to address diffuse sources of environmental emissions must be aimed at a myriad of locations that may be scattered about the landscape, and must focus on preventing / minimising the emissions and / or disrupting the transport of the emitted substances to water resources.

Thus, compared to point source control measures, the performance of diffuse source control measures is highly variable and difficult to predict except in broad terms. Such is the influence of site-specific conditions on the performance of these measures that data are often difficult to transfer across large distances. This is because in contrast to point source control techniques, the influence of fundamental parameters (Table 2) that control the performance of diffuse source control techniques has, in general, not been adequately described with process-oriented relationships. A case in point is vegetated buffers, \textit{i.e.}, specially maintained vegetated areas contiguous to surface waters that attempt to separate land use activities (especially agricultural activities) from the receiving water. Despite research on these measures that dates back approximately 30 years (\textit{e.g.}, Barfield, Tollner and Hayes, 1979; Magette, et al., 1989; Muñoz-Carpena, Parsons and Gilliam, 1999; and Dosskey, Helmers and Eisenhauer, 2008), a process-based description of buffer effectiveness on a site-specific basis remains elusive.

This conundrum is not limited to the agricultural sector. Despite the perception that forestry best management practices are effective in producing desirable trends in water quality, there is also considerable scepticism in their site-specific impacts due to a lack of scientifically defensible assessments (Ice, \textit{et al.}, 2004).

Another distinguishing characteristic between control techniques for diffuse emissions and point source techniques is the need to involve a large number of people in the implementation of the former. Because techniques addressing diffuse emissions must
generally be applied at source, potentially every landowner (and site manager) in a catchment has a role to play in controlling these emissions. Engendering a desire or creating the motivation for such participation by a diverse group of individuals is but one obstacle that must be overcome when implementing diffuse emission controls.

As shown in Figure 1, which focuses on farmers as a specific type of landowner, it is not enough for individuals to be motivated to do something about diffuse emissions to the environment; they must also know what to do, how to do it and be able to do it. Technically viable and practical strategies must be available for farmers to use, these must be communicated to farmers, and the farmers must have the knowledge, skills and the economic ability to implement them (not to mention the motivation). It should be noted that although Figure 1 was developed to highlight the essential requirements in the control of diffuse agricultural pollution, many of these same elements must be addressed in the control of other diffuse sources, and point sources as well, but with different target audiences.

In short, an effective strategy to control diffuse emissions to water is dependent on having participants that are ready, willing and able to take up the challenge. A strategy to control diffuse source emissions must, therefore, address at least all four groups of requirements outlined in the left-most column of boxes in Figure 1. Willingness can be genuine, as in voluntary participation, or it can be forced, as in a mandatory (i.e., regulatory) programme.

Table 2: Factors influencing anthropogenic emissions from rural landscapes to water (Magette, et al., 2008).

<table>
<thead>
<tr>
<th>Examples of Uncontrollable Factors Affecting Losses of Pollutants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weather</td>
</tr>
<tr>
<td>Type and history of geologic materials</td>
</tr>
<tr>
<td>Topography</td>
</tr>
<tr>
<td>Depth to groundwater</td>
</tr>
<tr>
<td>Soil type</td>
</tr>
<tr>
<td>Drainage density</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Examples of Somewhat Controllable Factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil physical characteristics (e.g. drainage, cultivation)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Examples of Controllable Factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil chemical characteristics (pH, nutrient levels, etc.)</td>
</tr>
<tr>
<td>Vegetation</td>
</tr>
<tr>
<td>Type of anthropogenic activity</td>
</tr>
<tr>
<td>‘Pollutant’ characteristics (chemical formulations, etc.)</td>
</tr>
</tbody>
</table>

The issue of effective participation in pollution control programmes immediately brings the need to address behavioural change as a consideration in any emissions control strategy that addresses diffuse sources, and sometimes for point source control strategies as well. Doing
something differently than before, e.g. improving the control of environmental emissions, is the essence of behavioural change. Any strategy to control pressures on water resources must, therefore, recognise the influence of human psychology.

Human behaviour is, of course, complex, and understanding why persons behave in a particular way is the focus of an entire scientific discipline. According to (Bennett, 1976) an individual’s behaviour, as well as the person’s capacity for changing behaviour, can be defined by four characteristics: knowledge, attitudes, skills and aspirations. These four characteristics encompass the influence of education (both formal and informal), cultural and environmental influences, abilities (physical, mental, or capacity), and emotional disposition towards the future on the behaviour of an individual. Thus, persons who know (from education or experience) about eco-system functions, that aspire to living in a clean environment, that believe individual actions are important, and that have the financial ability to adopt water-conserving technologies, can be expected to behave differently than a person who has little or no appreciation for the importance of ecosystems or the impact that individual actions have on ecosystems. Bennett (1976) maintains that the adoption of any new “practice” is impossible without a KASA change. Others (e.g., Miller, 1991) have characterised the influences on human behaviour in slightly different ways but most encompass at least three dimensions: cognition, affect and conation.

In summary, the effectiveness (i.e., performance) of emission control strategies for diffuse sources, as well as for water quantity management, is dependent on both technical and social factors. The design of point source emission control measures is straightforward from an engineering perspective, and the effectiveness of these is quite predictable. As point sources are highly regulated, adoption of control strategies is without question. In contrast, the effectiveness of diffuse source control measures is very difficult to estimate on a site-specific basis. Further, voluntary approaches to implementing these measures very much depend on inducing individual persons (i.e., landowners) to change their existing behaviour. (The same can be said of voluntary methods to conserve water.)

2 CHARACTERISATION CRITERIA FOR POLLUTION CONTROL MEASURES

Water quality pressures on water resources in most catchments are comprised of both point and diffuse sources of pollutants, although one of these may dominate. As suggested previously, the available measures to address these two types of sources are distinctly different. Point source control techniques are, fundamentally, “end-of-pipe” techniques that remove contaminants entrained in some flow (e.g., wastewater, stormwater runoff) before the water is released into the environment, i.e. to receiving waters. (Of course, the removed pollutants must then be managed effectively.) In contrast, diffuse source control measures are either on-site preventative measures that aim to prevent or minimise the loss of pollutants, or (near) edge-of-site (i.e., perimeter) controls that endeavour to interrupt the transport of pollutants from a source (or sources) to receiving waters.
Figure 1. A simplified logic model defining the minimum requirements for protection of water (and air) from diffuse agricultural emission sources.
Techniques by which to control emissions of pollutants to water may be characterised in a variety of ways. Table 3 outlines six criteria, described below.

**Table 3. Criteria for characterising water pollution control measures.**

<table>
<thead>
<tr>
<th>Require transporting flows to be collected and manipulated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of pollutant addressed</td>
</tr>
<tr>
<td>Effectiveness</td>
</tr>
<tr>
<td>Implementation / adoption</td>
</tr>
<tr>
<td>Financing</td>
</tr>
<tr>
<td>Structural or non-structural</td>
</tr>
</tbody>
</table>

Water is the common transport mechanism for pollutants from both point and diffuse sources. The first criterion by which catchment management measures might be characterised is thus whether or not a measure requires that the flows transporting pollutants to receiving waters be collected and manipulated. Generally, applying this criterion is the same as deciding whether pressures arise from a point or diffuse source, but not always. For example, in an urban landscape, significant diffuse sources exist (road surfaces, car parks, playgrounds etc.); however, stormwater runoff is almost always collected, and can therefore be manipulated (in contrast to runoff from diffuse agricultural sources) to remove pollutants.

Of course, the feasibility of collecting and manipulating flows containing pollutants does not preclude the use of on-site and perimeter controls in addition to, or instead of, end-of-pipe control techniques. In the urban environment site controls on relatively dispersed areas are often used in parallel with techniques that collect and manipulate stormwater runoff.

The second criterion for characterising control measures is the pollutant or pollutants that can be addressed by the measures. Most water quality problems can be attributed to just four pollutants: sediment, oxygen demanding organic materials, nutrients, and pathogens. Many more pollutants cause pressures in specific situations: heavy metals, salts, synthetic chemicals, etc. The abilities of a measure to control all pollutants are not, in general, uniform.

The third characterisation criterion is effectiveness. Depending on the source of a pollutant, the control of one contaminant often results in some control over the others, particularly when using end-of-pipe techniques. As just noted, control methods are not equally effective against all pollutants; even worse, methods that control some diffuse pollutants may actually exacerbate the losses of others. The effectiveness of most diffuse source control measures is still only loosely defined, and significant impacts on water quality are possible only when there is widespread adoption of the measures. This is in contrast to point source control techniques (end-of-pipe measures), for which design and operation procedures are well developed, resulting in predictable effectiveness. In the USA, after nearly 35 years since implementing a
national diffuse pollution control strategy, a technique by which to assess the cost effectiveness of measures has yet to be developed (OMB, 2006).

The fourth characterisation criterion for control measures concerns the ways in which they are implemented. At one level, this criterion describes the mandatory adoption of measures (by law or regulation) or voluntary adoption. As previously noted, the regulatory versus voluntary approach to pollution control has been a widely debated topic in recent years, particularly in the context of diffuse pollution control (Braden and Lovejoy, 1990). Most diffuse source pollution strategies remain voluntary, whereas most point source control strategies are obligatory and closely regulated. At another level, the ways in which measures are adopted also refers to who must adopt the strategies, i.e., will adoption be by a well-defined entity such as a local authority or a category of industrial producers, or will adoption be by a diverse audience of individuals such as landowners.

Control measures for protecting water resources also can be characterised by the way in which they are financed, i.e. whether by private or public investment. Voluntary diffuse source control strategies are typically financed by private investment although public funds are often used to facilitate adoption (either by grant aid, tax incentives, or some other scheme). Point source controls by industry are privately financed and are part of the cost of doing business. Point source controls that are implemented by sectors of government (e.g., local authorities) are publicly financed.

Lastly, control measures for protecting water resources may be characterised as being structural, managerial or political. Structural measures include physical devices that are constructed to eliminate or minimise pollutant losses to the environment (e.g., waste storage facilities, storm water detention basins, etc.). Managerial measures typically include strategies that involve only a change in practice (e.g., agricultural nutrient management planning). Political approaches may include anything from byelaws to tax incentives and can be applied at a local or national level and target general or specific groups.

3 AN OVERARCHING CONTEXT FOR SELECTION OF CONTROL MEASURES

Knowing what control measures to apply in a particular situation must be determined within the overall context of catchment water quality goals. Managers need an objective measure that defines to what extent controls must be implemented, as well as where specifically. Said differently, allowable loadings of pollutants to water must be known, or estimated, so that appropriate controls capable of assuring that such loadings are not exceeded can be selected and implemented. As noted above, this approach assumes that the performance of the various control techniques can also be quantified.

In the early 1970’s when attention became more intently focused, world wide, on water resources protection, “waste load allocation” was the generic process for determining allowable loadings of pollutants, of which oxygen demanding materials (i.e., organic matter) were of foremost interest. The Streeter-Phelps model (Streeter and Phelps, 1925) relating dissolved oxygen in the water column to the discharge of oxygen demanding material was the tool of choice for this task.
Although still a valid model for describing this relationship, the Streeter-Phelps model has now been subsumed into, or replaced by, much more sophisticated landscape-water quality models, a review of which is beyond the scope of this report. Nevertheless, these models play a vital role in the current approaches to determining allowable loadings of contaminants to water. In the USA, this approach is founded on firstly having water quality standards and then calculating the Total Maximum Daily Load (TMDL), \emph{i.e.}, the maximum amount of a pollutant that a water body can receive and still meet water quality standards, and an allocation of that amount to the pollutant’s sources (USEPA, 2007; Borisova \textit{et al.}, 2008). A similar approach is used in Australia and New Zealand.

Once estimates of the extent to which pollutants must be controlled has been established, it is possible to make judicious decisions about what measures can / should be implemented to achieve this objective. Without some objective and transparent estimate of the types of and extents to which pollutants must be controlled, there is little hope of developing a successful control strategy.

The primary focus of the Water Framework Directive is to achieve ‘good’ ecological status for all waters by 2015. Ecological status is divided into five classes (high, good, moderate, poor and bad) and is derived from measurements of biological, hydro-morphological and physio-chemical elements. The measurement of the biological elements includes aquatic flora (plants), benthic invertebrates (small animals that live on the bottom of rivers, lakes and coastal water bodies) and fish. The Directive also sets environmental objectives, which take account of the full range of pressures upon the aquatic environment (pollution, abstraction, flow regulation/transfer and habitat impact).

4 POINT SOURCE CONTROL MEASURES

Treated wastewater, from either domestic / municipal sources or industrial sources is considered to be such a threat to the environment that these pollutant sources are highly regulated at EU and national levels. Due to the fact that “significant” point sources of pollutants to water are highly regulated, there is little need for catchment managers to concern themselves with stipulating wastewater treatment requirements for these sources. The topic is only mentioned in brief below.


As noted previously, the classic definition of point sources of environmental emissions includes municipal and industrial wastewater treatment facilities. However, the generic description of a point source as one that has a readily identifiable discharge location can also include the urban landscape if surface runoff is collected in storm sewers and discharged via one or more outlets (Table 1). For example, the concept of “sustainable urban drainage systems (SUDS)” is predicated on first minimising and then collecting what would otherwise have been a diffuse source of environmental emissions (\emph{i.e.}, urban runoff) and manipulating this runoff in a way to render it less environmentally damaging, in either quantity or quality (or both).
Recently, in the US, un-sewered villages and towns of a certain population size have come to be considered as point sources in the landscape. This is due to the cumulative effect that, for example, hundreds or thousands of individual onsite domestic wastewater treatment systems (i.e., septic tanks) can have on the environment in a relatively confined geographic space. In Ireland, un-sewered areas are considered to be diffuse sources of pollution (Table 1).

In developed countries, secondary level wastewater treatment is considered to be the minimum degree of treatment that should be afforded to both industrial and domestic wastewaters. Decisions about municipal wastewater treatment (i.e., requirements, construction and funding priorities) are typically made by central governments although in some places, special wastewater treatment authorities that transcend geopolitical boundaries have been established to construct and operate facilities, including specifying pre-treatment requirements and charges for any discharges into the systems (Metropolitan Council of Governments, 2007). Industrial discharges to water also are controlled by central governments, typically through a licensing procedure that specifies a particular effluent quality. In the EU, the implementation by dischargers of best available techniques (BAT) is required under the Integrated Pollution Prevention and Control (IPPC) Directive.

Situations arise in catchments that require advanced wastewater treatment strategies to be implemented, such as for the removal of phosphorus or nitrogen. In Ireland, it would be difficult to envisage special wastewater treatment requirements beyond those afforded by secondary level processes without the endorsement of national government.

This is not to say that catchment managers cannot influence the performance of wastewater treatment facilities, or more specifically municipal facilities. As facilities are designed to accommodate a design average flow, treatment performance deteriorates at consistent flows that are significantly greater than the design average. Such a situation arises when population growth exceeds expectations during the design lifetime of a treatment facility. Two measures are routinely used to address overloading of treatment facilities prior to enlarging them:

- water conservation
- sewer network improvements.

Currently in Ireland, national government has an ongoing awareness effort (WaterWise) that encourages citizens (and businesses) to conserve water. Although the subtext of this campaign suggests people should conserve water because it is a precious resource in short supply, the effect of water conservation is also to reduce wastewater flow volumes in sewered areas. Water conservation thus can have very positive impacts on wastewater treatment efficiencies in municipal treatment facilities, if enough individuals and businesses adopt it. Unfortunately, the desire to “do the right thing” as regards environmental protection (including water conservation) is a relatively weak motivator for individuals. Thus, the most dramatic changes in water usage have been in cases where users are charged for the amount of water they use (and in some cases also for the wastewater they discharge). Water use charges require that water metering be in place, unless some notional consumption value is assumed as the basis for billing. Notional billing is less effective at
promoting water conservation than water charges based on metered consumption because users have limited ability, within the broad bands on which billing is based, to affect their water charges by changing their water use habits. Thus another measure that is effective at improving wastewater treatment in sewered areas is:

- water metering. (Supplementary Measure – demand management)

Similar to water metering, the encouragement of water conserving devices (*e.g.*, low-flush toilets), or alternatively discouraging the use of devices that use copious amounts of water (*e.g.*, high flush toilets, in-sink macerators) will have a positive effect on water conservation. Thus, another measure that can be used to enhance the treatment performance of overloaded wastewater facilities in sewered areas is:

- mandated use of water conserving devices. (Supplementary measure – efficiency and reuse)

Water re-use has been examined widely and has been implemented in many locations, particularly where water quantity issues exists. Some of the Nordic countries have made advances in

- reusing grey water for toilet flushing. (Supplementary measure – efficiency and reuse)

Both water metering and mandatory use of water conserving devices may require special bye-laws or other enabling legislation.

In Ireland, both North and South, the notion that users of water must pay according to the amount they use is highly contentious with the result that only the commercial sector is being required to install water meters and pay for this resource.

In Europe, combined sewers to convey both stormwater runoff and wastewater are common. The hydraulic load of stormwater thus places added pressure on overloaded wastewater treatment facilities. Upgrading a sewer network to convey stormwater separately from wastewater is thus one way to gain added wastewater treatment capacity and / or enhance treatment performance without making physical changes to the treatment facility. However, even when separate sewer networks exist, infiltration into deteriorating wastewater sewers also places an added hydraulic loading on wastewater treatment facilities. Thus, providing separate sewer networks may be only part of what is required to reduce the hydraulic loading on wastewater treatment facilities. Rehabilitation of foul sewers to minimise infiltration may also be required. Both of these options are major infrastructure improvements that may require implementation assistance from national government. Nevertheless, these measures can be introduced to improve the performance of wastewater treatment facilities:

- provision of separate storm sewers; (Supplementary measure – construction)

- rehabilitation of foul sewers to minimise infiltration. (Supplementary measure - rehabilitation)
4.2 Urban Runoff

As noted previously, urban runoff is considered a point source when it is collected in either separate or combined sewers, the later of which is typical in older European cities. For green field sites, the provision of sustainable urban drainage systems (SUDS) is easy to incorporate into the site design, and design advice is available (e.g., CIRIA, 2000; CIRIA, 2007a; CIRIA, 2007b). A variety of techniques comprise a SUDS design (e.g., porous surfaces, soakaways, infiltration trenches, filter drains, filter strips, swales, detention basins and purpose built ponds and wetlands), and collectively these measures attempt mimic natural systems for draining surface water. CIRIA (2007a, 2007b) lists 15 different water management techniques, as well as strategies for erosion control. SUDS minimise the volume and / or peak rate of stormwater runoff, as well as control the quality of runoff to reduce the impact of flow on watercourses. Even in brown field sites, some techniques used to create SUDS can be implemented, particularly when new building takes place. The Scottish Environmental Protection Agency (SEPA, 2003) evaluated the use of the CIRIA (2000) design document by practitioners in Scotland and Northern Ireland and found it to be a useful tool in the construction industry. However, the analysis also revealed that there was some reluctance to implement SUDS designs by the private sector due to fears that it would incur liability for maintenance costs into the future.

In the United States, practices that are widely accepted for their ability to control the volume, rate and quality of urban runoff are called best management practices (BMPs). BMPs would be considered as part of a SUDS design and can be divided into two broad (and self-explanatory) categories: structural and non-structural. For obvious reasons structural practices tend to be more expensive than non-structural control measures, not only due to their construction costs but also for ongoing maintenance costs. Structural measures have a design lifetime of 5 to 50 years.

Table 4 (TRB, 2006) summarises the more widely used BMPs in urban settings in the US, particularly for road construction, and most of these are also applicable in Europe (CIRIA, 2007a, 2007b). Infiltration practices ameliorate stormwater volumes and peak rates of runoff, and also influence runoff quality through the interaction of the chemical, physical, and biological processes between soils and water to filter out sediments and constituents from stormwater. Bioretention areas use the interaction of plants to enhance the treatment process. A consideration with all infiltration practices is their potential impact on groundwater quality.

<table>
<thead>
<tr>
<th>Section</th>
<th>Treatment Mechanism</th>
<th>Common Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Structural Controls</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Infiltration Practices/Bioretention</td>
<td>adsorption, biodegradation, precipitation</td>
<td>adequate soil media critical</td>
</tr>
<tr>
<td>Detention and Retention/Wetland Practices</td>
<td>particulate settling and biological filtering (wetlands)</td>
<td>adequate hydrology and soils required for retention/wetlands</td>
</tr>
<tr>
<td>Filtration Practices/Sand Filters</td>
<td>straining, adsorption, chemical transformation, microbial decomposition</td>
<td>effective suspended solids removal</td>
</tr>
</tbody>
</table>

Table 4. Urban best management practices for stormwater control (TRB, 2006).
Detention / retention facilities, including constructed wetlands provide storage and controlled release of stormwater, thus mitigating peak rates and sometimes runoff volumes. Some treatment of the stormwater occurs, especially in constructed wetlands, which integrate bioremediation through the use of plants.

Non-structural BMPs (Table 4) for source control include practices adopted at construction sites (source controls) to prevent the loss of pollutants, particularly sediment, from the site. The simplest and most widely used of these include:

- vegetative soil stabilisation
- non-vegetative soil stabilisation
- silt fences
- sediment traps / vehicle wheel washes.

All of these are Supplementary measures – emission controls

### 4.3 Agricultural Point Sources

The agricultural sector is typically considered to be a diffuse source of water pollutants, but within this sector farmyards are considered to be point sources due to the finite nature of their areal coverage. The European Communities (Good Agricultural Practice for Protection of Waters) Regulations 2005 (S.I. 788 of 2005), which implements the Nitrates Directive (Directive 91/676/EEC) in Ireland, addresses the control of farmyard pollution explicitly. Discharges of pollutants should not occur from these sources. Nevertheless, on farms where animals are produced, farmyards are a significant potential source of water pollutants due to the volumes of animal manures stored on site. In addition, areas on which animals exercise become soiled with faeces and urine, which then can be transported off site and into receiving waters when rainfall on the farmyard becomes runoff. This “dirty water” must be first minimised and then contained for controlled application to farmland. Another significant potential source of pollution from farmyards in Ireland is silage effluent, the discharge of high BOD, low pH liquid from ensiled grass. This noxious liquid must also be collected and stored for subsequent application to farmland or for use as a feed supplement for animals.

Most farmyards are paved with concrete. Drains, both open and covered, move potentially polluting materials from one place to another and it is essential that drains as well as the pavement itself is sound and do not leak pollutants to ground water.
Similarly, the provision of adequate manure, silage effluent and dirty water storage facilities is fundamental to the prevention of pollutant losses to the environment, not only from farmyards, but also from fields on which the manure will be ultimately utilised. Well constructed and maintained storage facilities will not leak their contents to ground or surface waters, and will provide an adequate storage period so that manure, slurry, silage effluent, dirty water, etc. can be applied at opportune times to farm land. “Opportune” times mean periods when (a) there is minimal chance of runoff from fields, (b) the mechanical properties of soils are such that they will physically support machinery, and (c) plants are actively growing and will absorb nutrients from the applied materials. In Ireland, a minimum of 16 weeks of storage duration is necessary due to climatic constraints; however, longer periods are required in many areas. Resolution of the Nitrates Directive implementation in Ireland will result in the requirement for longer storage periods in some areas by placing stricter limits on allowable manure spreading times. In summary, the following measures are essential to protecting water resources from discharges from farmyards (Basic measures – Nitrates directive storage):

- structurally sound pavement and liquid conveyances
- adequate manure storage facilities.

As with wastewater treatment facilities, the management of water around farmyards to minimise the quantity that must be handled as a waste is a straightforward way to maximise the effectiveness of existing storage facilities. The three most common and practical measures for accomplishing this are: (Supplementary measures – construction)

- minimising the extent of soiled areas (by restricting animal access)
- installing roofs over soiled areas and providing adequate guttering and rainwater drains
- diverting clean water away from dirty farmyard areas through the use of intercepting drains.

In some parts of the world, constructed wetlands have become popular as measures by which to reduce the environmental impact of contaminated runoff from farmyards. These facilities are growing in popularity in Ireland as well (Dunne, Reddy and Carton, 2005). As for urban runoff, constructed wetlands attenuate peak runoff rates and allow particulate matter time to settle and be removed from the flow. Some treatment (BOD reduction and nutrient removal) is accomplished in constructed wetlands. Although there is debate about whether wetlands serve only as temporary traps for phosphorus, these facilities can provide protection to water resources for some period of time. Thus, another measure that is feasible for application to farmyards is: (Supplementary measure – wetlands)

- constructed wetlands.

In many part of Europe, anaerobic digestion is employed on farms as a means to stabilise manure, reduce the volumes to be managed, and recover energy from these wastes. While technically feasible in Ireland (Mahony, 2002), this practice is not popular in Ireland due to the fact that government support for green sources of energy (at least at farm scale) is virtually non-existent. Where anaerobic digestion is popular
in Europe significant grants are made by central or regional governments to defray construction costs, and generous prices are paid for the energy produced. This support makes these facilities economically viable. The necessity of “green energy” premia in making anaerobic digestion economically viable is reflected in the fact that for intensive pig and poultry production, anaerobic digestion is considered a “conditional” best available technique for purposes of the IPPC Directive (EIPPCB, 2003) that should be reserved for special circumstances (Magette, et al., 2001).

Changes in energy, and, indeed, environmental, policies towards sustainable practices would immediately favour the implementation of anaerobic digestion on farms. Thus, another measure that is feasible for application to farmyards is:

- anaerobic digestion of wastes. (Supplementary measure: emission control)

5 DIFFUSE SOURCE CONTROL MEASURES

As noted previously, diffuse source control measures attempt to prevent or minimise the creation of pollutants at site and / or interrupt the transport of pollutants from sites to receiving waters. Typically, diffuse source pollutant controls address contaminants likely to be transported by surface runoff; however, some measures protect ground water resources as well.

A variety of diffuse sources exist in the landscape: agriculture, forestry (silviculture), construction. In Ireland, there appears to be relatively little or no attention devoted to preventing the loss of pollutants from construction sites, although attempts to clean road surfaces near construction sites is widespread.

In Ireland, agriculture is the dominant land use activity, and thus most catchments contain a significant proportion of agricultural activities. Here and elsewhere considerable attention has been devoted to the control of diffuse agricultural pollution. Here, most of this effort has been focused on controlling the losses of nutrients (nitrogen and phosphorus) due to the fact that soil erosion is not a particularly widespread problem, being generally limited to western counties where severe topography and overgrazing coincide. Approximately 90% of Ireland’s agricultural land base is devoted to grassland production, such that arable crop production is limited to discrete areas on well draining soils. The Rural Environment Protection Scheme (REPS) requires specific environmental practices to be implemented by farmers wishing to avail of this voluntary scheme (for which they receive financial incentives from government). The European Communities (Good Agricultural Practice for Protection of Waters) Regulations 2005 (S.I. 788 of 2005 and S.I. 378 of 2006), which implements the Nitrates Directive (Directive 91/676/EEC) in Ireland, requires all farmers to adopt a variety of “good agricultural practices”, similar in character to many of those included in the REPS programme.

In some catchments, forestry activities comprise a significant area. Coillte, the semi-state organisation that manages state-owned forests has adopted a comprehensive code of practice that includes various measures to minimise the environmental impacts of forestry operations. In addition forestry operations are subject to S.I. 788 of 2005 and S. I. 378 of 2006.
5.1 Agricultural diffuse sources
Water pollutants that typically are contributed by diffuse agricultural sources include eroded soil, nutrients, and agro-chemicals; in addition, where animal manures are applied to soil, oxygen demanding material and pathogenic organisms can be transported to receiving waters.

Broadly speaking, good agronomic practice is also good environmental practice. However, improved production, rather than environmental protection, has been the impetus driving the development, adoption and implementation of most agricultural practices. Thus best management practices (BMPs) for environmental protection are not necessarily synonymous with best agronomic practice, particularly where BMPs do not improve crop yields or profits.

The control of diffuse agricultural sources of pollution can be summarised by three approaches: site controls, perimeter controls and exclusion techniques. Site controls and exclusion techniques are addressed explicitly in S.I. 788 of 2005 and S. I. 378 of 2006. As noted previously site controls are designed to prevent (or minimise) the loss of contaminants from the production site, i.e., farm fields. Perimeter controls are designed to impede the transport of pollutants from source areas to receiving waters. Source controls are preferred to perimeter controls, however due to the influence of uncontrollable factors outlined in Table 1, source controls will not totally prevent the loss of contaminants. For the same reason, perimeter controls have a limited effectiveness in preventing the transport of pollutants to receiving waters. Exclusion techniques endeavour to increase the separation distance between sources of pollutants and potential receiving waters.

5.1.1 Site controls
Site controls to address diffuse agricultural pollutants are closely allied to good agronomic production practices and good animal husbandry. A universally applicable site control is:

- nutrient management planning (NMP). (Supplementary measure – codes of good practice)

NMP is a prescriptive approach to using nutrients on farms, and to be implemented properly, should be applied to field-sized areas. The fundamental objective of NMP is to apply plant growth nutrients in accord with plant requirements, taking into account the source of nutrients (whether inorganic commercial fertilisers, animal manure or other organic source) and the nutrient supplying capacity of the soil. When integrated with the appropriate timing of nutrient applications, NMP increases the potential for added nutrients to be utilised by plants, rather than lost to the environment. NMP is applicable to both grassland production and arable cropping. Since enactment of S.I. 788 of 2005 and S. I. 378 of 2006, nutrient management planning is a required activity for virtually every farm in Ireland.

Many producers view animal manure to be an inferior product (compared to commercial fertiliser) as a source of nutrients for crop production (including grassland) and more a bother than a benefit. This is due to the variability in the...
characteristics (particularly the nutrient content) of the manure, which in turn is largely due to poor management of water by farmers at the farmyard where manure is generated and stored, but also to natural biochemical processes that occur during manure storage. For these reasons, since the end of WWII when commercial inorganic fertilisers became economically affordable, animal manure has come to be viewed by many farmers as a waste to be disposed of rather than a resource to be carefully managed. A number of measures have been identified to improve the availability of nutrients from land applied manure to plants. These measures consist of application techniques that improve uniformity of placement and decrease nutrient losses, as well as adding materials to manure to conserve the nutrients therein and/or make them less likely to be lost to the environment. These site controls include:

(Supplementary measures – codes of good practice)

- precision placement of manure by injection into the soil or in discrete locations on the soil surface (trailing shoe or banding);
- use of calibrated manure application equipment;
- use of precision application equipment;
- acidification of manure to retain nitrogen;
- amendment of manure with P sorbing materials rich in Ca, Al or Fe.

Another widely applicable site control is: (Supplementary measure – codes of good practice)

- integrated pest management (IPM).

IPM integrates non-chemical pest control procedures (e.g., crop rotations) with chemical and biological means, with the net effect of reducing the use of chemical pesticides. In addition, the application and choice of pesticide is precisely controlled to target specific pests using the least persistent formulations possible. Another aspect of pesticide management is monitoring weather and pest infestations so that pesticides are used only when weather conditions dictate, and/or when pest infestations exceed an economically damaging level.

In arable production systems where soil erosion is likely, a variety of site controls are utilised to prevent losses of soil (and any associated chemicals). These include:

(Supplementary measure – codes of good practice)

- conservation tillage
- cover crops
- contour tillage
- strip cropping
- terracing.

Conservation tillage is also known as minimum tillage, because the objective is to leave at least 30% of the soil surface covered by crop residues after planting operations have been concluded. Such a system is best suited to producing grain crops. The residue shields the soil from the erosive forces of raindrop impact and the subsequent transport of detached soil particles in runoff. Cover crops attempt to provide the same protection to soil in the intervening period after one crop has been
harvested and before the next crop is planted. Cover crops are also called green manures because these plants take up residual inorganic nitrogen from the soil, and then return it in organic form when the crops are ploughed under prior to sowing the next crop. Contour tillage describes tillage systems in which all operations are conducted parallel to the contour elevations of the landscape. By creating obstacles (in the form of small ridges in the prepared soil) to down-slope flow of runoff, conservation tillage increases infiltration and reduces the transport of soil and sediment-bound chemicals. Strip cropping involves the production of two different types of crops, simultaneously in alternating strips, which are planted on the contour. Usually row crops are alternated with close growing grain crops (or grass) such that any soil and attached chemicals lost from the row crops are intercepted and retained in the strips of close-growing plants. Terracing involves significant earthmoving operations to reconfigure the landscape and decrease the overall slope and or slope length. Terraces, while expensive, significantly reduce soil erosion and sediment bound chemical transport in steeply sloped areas that are susceptible to this problem. On the negative side, both contouring and terracing, but especially terracing, increase the potential for pollutant transport to groundwater due to their effect on infiltration.

5.1.2 Perimeter controls
Without doubt,

- vegetative filter strips (VFS) (Supplementary measure – emission control)

have become one of the most widely used perimeter controls to disrupt the movement of eroded soil and nutrients from diffuse agricultural sources. A variety of vegetation types have been used (ranging from closely growing grasses to trees), each with particular benefits. As implied by their name, VFS attempt to “filter” pollutants from surface runoff and shallow subsurface flow (and even shallow, unconfined groundwater), by physical and / or biochemical means. Grassed filters are particularly effective in removing (at least temporarily) eroded sediment and sediment-bound chemicals from surface overland flow. Deeply rooted water tolerant plants have shown some ability to remove dissolved nitrogen from shallow groundwater. In the case of woody plants, the uptake of nutrients from soil water or groundwater effectively binds the nutrients in non-reactive biomass for a considerable period of time. With grasses and other small perennials, the binding of nutrients is more short-lived. In addition, entrapment of sediment in grassed buffer strips cannot continue indefinitely, thus management is an important requirement for VFS.

VFS located at the interface between the land and receiving waters, particularly when woody and multi-species vegetation is used, are typically called

- riparian buffers. (Supplementary measure – emission control)

Similar to both VFS and exclusion techniques is

- set-aside. (Supplementary measure – emission control)

“Set-aside” has become a common practice by which to control production output in both the EU and the USA. Effectively, this practice takes specified areas out of crop
production and leaves the land idle. While some vegetation should be maintained on the idled land, harvesting of the vegetation is typically not allowed. Usually, set aside areas are situated on the least productive soils. When strategically located between production areas and surface waters, set aside areas can function both as an exclusion technique and a perimeter control.

An unfortunate drawback to the use of VFS is their potential for releasing previously entrapped pollutants back into surface overland flow, such that on occasion, the outflow quality of runoff is inferior to that of runoff entering the VFS. In addition, VFS are not particularly effective in removing dissolved contaminants from runoff (Bundy et al., 2001). In an effort to enhance the capture of dissolved P by VFS,

- application of phosphorus sorbing materials (Supplementary measure – emission control)

has been investigated as an amendment to these areas (Penn and Bryant, 2006). Such materials have a propensity to sorb P due to their chemical nature, and include aluminium sulphate (alum), fly-ash from incinerators, and gypsum. The usefulness of these materials in decreasing dissolved P in runoff appears to be temporary, but the technique can be used with other management practices in an integrated approach.

### 5.1.3 Exclusion techniques

In addition to set-aside areas,

- exclusion zones (or buffers) (Supplementary measure – emission control)

are utilised to increase the physical distance (i.e., to create a buffer) between potential sources of pollutants and receiving waters. In the simplest sense, exclusion zones are a “cordon sanitaire” in which specific activity (e.g., application of animal manure, use of chemicals) is prohibited. Such exclusion zones are thus a non-structural approach that can be applied both to surface water protection (drains, etc.) and groundwater (wells). Riparian buffers are exclusion zone specific to watercourses and not only insulate a watercourse from pollution sources but also provide habitat. A structural approach to exclusion is:

- streamside fencing (Supplementary measure – emission control)

Streamside fencing is particularly applicable to areas in which livestock are produced, as the fencing prevents direct access to a watercourse by the animals except at specific, controlled pointed. Fencing significantly reduces the amount of direct deposition of faecal matter into streams, and also significantly reducing streambank erosion due to animal activity.

### 5.1.4 Forestry Diffuse Sources

Forested land use presents an interesting dichotomy to catchment water quality managers. Natural forested areas have long been regarded as a low-impact diffuse source and in fact have been a benchmark for what is considered to be “background”
losses of contaminants to water. When forests are actively managed for biomass production (i.e., timber or fuel) they can become a significant source of water pollution. This is often because managed forests tend to be located on soils that are of insufficient quality for other uses; such soils would be predisposed to erosion by water. In catchments with significant topographic relief, forests also tend to dominate in upland parts of the catchments in which first order streams might be particularly susceptible to contamination. Indeed, due to the location of water resources in forested areas, the quality of these waterways is generally high and therefore any contribution of pollutants is usually significant.

A number of measures have been developed to minimise negative impacts on water quality of commercial forestry. In Ireland, forests managed by the state subscribe to a code of practice that encompasses the implementation of a variety of controls designed to achieve sustainable forest management (Forest Service, 2000a). Comprehensive guidance on specific environmental topics (Forest Service, 2000b; 2000c) has been adopted to ensure the appropriate implementation of such measures as: (Supplementary measures – codes of good practice)

- restrictions on planting to non-sensitive habitats
- actively managed buffer zones with widths as a function of soil slope
- careful attention to ground preparation activities, particularly the provision of artificial drainage and sediment traps
- careful application of fertiliser, both in terms of rate and placement, manually or by ground-based machine as a first choice instead of aerial application
- careful use of other chemicals, fuel oils, etc. to prevent off-site impacts
- specific requirements for the locations and construction of harvesting roads, bridges, culverts and fords
- specific requirements for all harvesting operations.

However, in the Pacific Northwest of the USA (which has a climate somewhat similar to Ireland), Ice, et al. (2004) found that the perception that forestry best management practices are effective in producing desirable trends in water quality was rarely supported by scientifically defensible assessments. This highlights the difficulty for water research managers when trying to select from a “menu” of practices those that can deliver the greatest benefits for a particular cost.

### 5.2 Urban Diffuse Sources (Including construction activity)

As with diffuse agricultural sources, the urban landscape has the potential to contribute contaminants to water resources from vast, diffuse areas. The fundamental difference between diffuse agricultural and diffuse urban pollution is that the latter tends to be collected and conveyed in a designed sewer network. There are also differences in the types of contaminants generated in the urban and agricultural environments.

Aside from the types of measures that can be employed to treat urban runoff (outlined above under Urban Point Sources), a number of strategies can be employed as site controls in the urban environment that are completely analogous to those used in the
agricultural sector. These include such measures as: (Supplementary measures – emission control)

- integrated pest management
- nutrient management planning, and
- ordinances regarding defecation by pets on publicly managed areas.

Construction activity in the urban environment poses a particular threat to water resources, chiefly due to the considerable disturbance of soil that is a fundamental part of such activity. Eroded soil is a considerable contaminant in its own right, causing turbidity problems, reducing the transport capacity of drainage systems, and covering aquatic habitat. However, chemicals attached to eroded soil particles create another set of problems ranging from eutrophication in the case of nutrients and toxicity in the case of heavy metals.

In the USA and elsewhere, a number of “stormwater management” requirements are applied to construction sites to minimise the loss and transport of soil from the site. These include:

- minimising the extent of land disturbance at any point in time;
- keeping stockpiles of soil under vegetative cover at all times;
- strategic placement of sediment traps (including wet ponds and silt fences);
- rapid stabilisation of soil using biodegradable material (e.g., coir), crushed gravel or other suitable material;
- provision of wheel washes or other facilities at site exits to minimise vehicular transfer of soil to roadways.

6 FINANCIAL APPROACHES (SUPPLEMENTARY MEASURES – FISCAL)

Following on from the identification of KASA (knowledge, attitudes, skills, and aspirations) as a determinant in effecting individual behavioural changes in favour of water quality protection, measures that create directly observable personal financial impacts have been recognised as effective motivators to encourage a desired behavioural change. Broadly speaking, economic measures can be categorised as being incentives or disincentives, depending on whether a measure encourages a desired behavioural change or discourages the continuation of a less than desirable practice.

When large infrastructure practices have been required, yet available funding for such practices has been limited, some central governments have instituted a

- revolving loan fund

to facilitate funding of expensive projects. A pool of money is created from which successful applicants may draw at very favourable interest rates for specific time periods. Repayments back to the pool, with interest, grow the size of the fund and make money available for other projects.
Another popular funding mechanism, particularly to facilitate pollution control within the agricultural sector, is

- cost-sharing.

With this mechanism, central government shares the cost of a particular measure, such as the construction of manure storage facilities, with an individual applicant. The justification for such programmes is that some facilities cannot be justified for economic grounds and thus would not be implemented without putting an individual under economic jeopardy. The resulting protection of water resources is viewed as a public service worthy of public expenditure.

Taxes are often favoured as a way to “internalise” the costs of pollution-causing activity. Taxes on inputs, for example, nitrogen or phosphorus fertilisers, make their use more expensive; therefore according to economic theory, farmers would use only amounts necessary to produce acceptable yields. Unfortunately, flat taxes impact low income farmers disproportionately. On the other hand, due to the “relatively” low cost of some inputs, studies have found that huge taxes (as a percentage) would be required to change usage of the inputs.

Closely related to taxes are

- tax incentives

which are designed to make it financially easier for a particular measure to be implemented. Thus, for example, tax may be foregone for some period when an advanced piece of technology is purchased. Tax incentives can be extended to income tax breaks for individuals behaving in a particular way.

Similar to taxes are

- user fees

which are designed to recover the costs of supplying a particular service. Water and/or sewerage charges, as well as the more recent waste collection charges, are examples of user fees. User fees have also been applied to cover the operation and maintenance of SUDS.

7 POLITICAL APPROACHES, INCLUDING EDUCATION (SUPPLEMENTARY MEASURES – LEGISLATIVE AND EDUCATIONAL)

When public attitudes are galvanised on the need for particular changes in laws and/or regulations, implementation of political measures is reasonably straightforward. Unfortunately, all stakeholders are rarely in agreement when it comes to environmental management. The continuing debate over global warming is a case in
point. Nevertheless, political measures can be a very effective way in which to make significant changes in practices in a relatively short time.

Complete bans on the use of certain substances in the workplace or as food additives are often used to prohibit the use of materials known to cause health problems. However, this technique has also been applied to environmental contaminants, such as PCBs. In the eastern USA,

- restrictions on the composition of washing powders and other cleaning agents

was used to exclude phosphorus from intensively urbanised areas served by sewerage systems. Such a ban had the immediate effect of reducing the quantity of phosphorus in a catchment. However, total elimination is rarely achievable unless the ban applies to a large enough geographical area so as to discourage illicit importation of product. The environmental benefits of a ban will be most noticeable when a majority of the population in a catchment is served by a centralised sewerage system.

Several local authorities in Ireland have made use of

- bye-laws

to require special managerial actions (such as the adoption of nutrient management planning by farmers) based on water quality requirements. Such local regulations enable local solutions to local problems.

Again referring to the KASA model for behavioural change,

- education and awareness

campaigns are a fundamental part of most diffuse source pollution control strategies around the world. This is largely due to the fact that agricultural diffuse pollution is so significant and that individual farmers must be enticed to change production practices in order to produce measurable reductions in pollution. With such individuals in the absence of financial benefits, cultural norms and even familial customs must be overcome in order to effect changes in behaviour. In some instances, training in new technology must also be provided. Even for the population at large, education and awareness are essential components of any strategy requiring widespread public support.

In concert with education and awareness programmes,

- demonstration farms and catchments

have been widely used in the USA and elsewhere to both focus remedial efforts and provide a real-world educational setting for farmers and other stakeholders. Here in Ireland, the recently started “mini-catchment” projects co-ordinated by Teagasc will monitor the relationship between agricultural best management practices and water quality, thereby generating information that can be used to help convince landowners to adopt specific practices. In addition,
specialist delivery teams

have been used effectively in designated sub-catchments to provide one-on-one assistance to farmers. One-on-one education has been shown to be more effective than group education when comprehensive changes in agricultural practice have been required.

A variety of mandatory requirements have been utilised to combat diffuse agricultural (and urban) pollution. In the Chesapeake Bay catchment of the eastern USA

- mandatory nutrient management training

was required of essentially all farmers in the highly urbanised state of Maryland. The law mandated that only recognised and appropriately trained individuals could actually write nutrient management plans, but farmers could be considered as qualified if they successfully passed a nutrient management certification course. This is not unlike the requirement in Ireland’s REPS programme that farmers attend a certain number of course hours on environmentally friendly farming. It is a step further than the requirements under S.I. 766 of 2006 and S. I. 268 of 2005.

Similarly, in The Netherlands,

- mandatory nutrient accounting

by farmers, with financial penalties of increasing severity for nutrient imbalances was instituted as means to balance nutrient utilisation with crop uptake. A recent decision by the EU has, however, made this scheme redundant.

8 RANKING OF MEASURES

For the reasons noted above, a variety of factors impede a simple ranking of measures that should be selected to address pressures on water resources. Whereas the effectiveness of point source controls in preventing or minimising emissions of contaminants is predictable, the capital costs and running costs are significantly greater than their counterparts for addressing diffuse emissions. Yet, while diffuse control strategies may be less expensive than point source control strategies, these costs are difficult to translate from one area to another due to the effect that site specific constraints may have on their implementation, and the fact that the actual operations involved in construction are not well identified. And, of course, the effectiveness of diffuse source controls varies widely both temporally and spatially.

A comprehensive database that identifies the various parameters associated with particular measures (such as those in Table 3 above) would assist managers in making choices among measures. In the USA, a concerted attempt was begun in 1999 by the Environmental Protection Agency in conjunction with the American Society of Civil Engineers to assemble such a database for urban storm water control best management practices (Strecker and Quigley, 1999). This effort materialised into a stand-alone international database supported by industry, non-governmental

O’Tuama and Meehan (2008) attempted to discover how River Basin District Managers in Ireland viewed a selected number of characteristics associated with measures relative to each other (Table 5).

**Table 5. Relative Comparisons of Possible Selection Criteria for Measures to Address Pressures on Water (O’Tuama and Meehan, 2008)**

<table>
<thead>
<tr>
<th>Criteria 1</th>
<th>Criteria 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost</td>
<td>% Pollution Eliminated</td>
</tr>
<tr>
<td>Cost</td>
<td>Applicability</td>
</tr>
<tr>
<td>Cost</td>
<td>Ease of Implementation</td>
</tr>
<tr>
<td>Cost</td>
<td>Effectiveness</td>
</tr>
<tr>
<td>% Pollution Eliminated</td>
<td>Applicability</td>
</tr>
<tr>
<td>% Pollution Eliminated</td>
<td>Ease of Implementation</td>
</tr>
<tr>
<td>% Pollution Eliminated</td>
<td>Effectiveness</td>
</tr>
<tr>
<td>Applicability</td>
<td>Ease of Implementation</td>
</tr>
<tr>
<td>Applicability</td>
<td>Effectiveness</td>
</tr>
<tr>
<td>Ease of Implementation</td>
<td>Effectiveness</td>
</tr>
</tbody>
</table>

Managers were asked to compare one selection criterion against another (Table 5) as being less important, equally important, or more important. Even though most managers responded to the postal survey, the sample size was small and the variety of answers was too broad to allow definitive statements except on one point: cost of a measure was rarely listed as the most important factor affecting selection of a measure. The diversity of opinions on what are the most important selection criteria also underlined the utility of a decision support system to assist managers in making the complex decisions about what to do where to address pressures on water in their districts.

**9 SUMMARY**

While this is no shortage of measures that are available to address a variety of water resource pressures, there is a very real shortage of data that is pertinent to Irish conditions on the cost and performance of most of these measures, with the exception of those for controlling point sources of pollution. Due to the crucial role that site specific conditions play in the performance and, indeed, the cost of diffuse pollution control measures, a sophisticated analysis the would go beyond the scope of the
WINCOMS project would be required. Such in-depth analyses, including economic modelling, have been performed in some member states.

Nevertheless, some broad indicators of what should be done to address water resource pressures in Ireland are evident from the scientific literature. Most of this literature is, however, based on studies in the US, where catchment scale water resources management has been underway for 15 or more years.

- An educational / technology transfer element, dedicated to implementing measures in a particular river basin, is a fundamental requirement of any programme. Programme implementation should be the only responsibility of personnel involved in the education / technology transfer measure, and their activities should be guided by the need to effect KASA changes.

- As most point source measures must be approved and financed at a higher level of authority than the River Basin Districts, the RBDs should focus their efforts on addressing diffuse pressures. While measures currently required by existing legislation / regulations are the obvious techniques to select (such as REPS or Nitrate Directive requirements), RBDs should not limit themselves to these. Inventive financing arrangements, such as revolving loans, should be investigated to help manage the economic demands that some measures may require for implementation. Likewise, RBDs should explore the establishment of special management authority areas to facilitate the implementation of measures.

- A targeted approach to implementing measures in a catchment will produce superior results to a “blanket” application of a “one-size-fits-all” strategy. Techniques exist that are tuned to Irish conditions that can assist managers in identifying areas in catchments that should be given high priority.

- Practical approaches to controlling sediment and other contaminant losses on construction sites are available for immediate application in the construction industry. As these are not widely used in Ireland at present, their adoption is likely to be resisted. Any reluctance can be minimised by using well thought-out demonstration sites to help raise awareness of these measures within the construction sector.

- In the agricultural, forestry and construction sectors, measures that offer benefits for production as well as protection of water resources are easiest to implement due to acceptance by relevant stakeholders. Unfortunately, information with which to demonstrate production benefits is not always available.

10 BIBLIOGRAPHY


International Stormwater Best Management Practices Database. 2007. International Stormwater BMP Database, developed by Wright Water Engineers, Inc. and
Geosyntec Consultants for the Water Environment Research Foundation (WERF), the American Society of Civil Engineers (ASCE)/Environmental and Water Resources Institute (EWRI), the American Public Works Association (APWA), the Federal Highway Administration (FHWA), and U.S. Environmental Protection Agency (EPA). http://www.bmpdatabase.org/ accessed March 2008.


