

**Urban Wastewater
Management**

An Introductory Guide

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An FWR Guide

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Author: David Woods

**Cover photograph: Activated sludge process at Prague WwTW
© Dr Tim Evans, Tim Evans Environment**

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1.0 Preface

The purpose of this Guide is to provide an introduction to urban wastewater management for those with limited technical background. It gives information to support readers interested in effective river basin management.

The background to current urban wastewater practice is rooted in the 19thC when waterborne diseases such as cholera were endemic in the unsanitary conditions that were common in the towns. The provision of sewerage and sewage treatment, together with clean water supplies, formed the basis of dramatic improvements to public health.

Although disrupted by two world wars, the focus in the 20thC was on pollution abatement, the move to cleaner rivers and the restoration of aquatic flora and fauna.

The 21stC offers no less challenge to urban wastewater management than has gone before. The EC Water Framework Directive now requires that river water quality be restored to as near its natural state as is practicable and those responsible must publish plans and actions to achieve this in a given time-frame.

The techniques and technologies outlined in the Guide have evolved to meet these changing challenges over the last 200 years.

2.0 Introduction

Urban wastewater management is a key man-made component of the water cycle, illustrated in Figure 1. Water is taken from lakes, rivers and underground strata for use by man and is treated before discharge to a watercourse.

Urban wastewater is more usually called *sewage* and commonly comprises the waste waters from domestic, commercial, agricultural, industrial and other human activities. It is conveyed for treatment to a wastewater treatment plant, more usually called a *sewage works*, via a network of drains and sewers called the *sewerage system*. The terms *sewage* and *sewerage* will be used throughout this Guide.

Consideration of EU or UK law governing sewerage, sewage, and sewage treatment is outside the scope of this Guide. Details can be found in 'Water and the Water Environment: a summary of UK legislation and agreements', a Review of Current Knowledge (ROCK) FR/R0008 available from the Foundation for Water Research. A listing of relevant ROCKs is given at the end of this Guide.

Figure 1: The Water Cycle

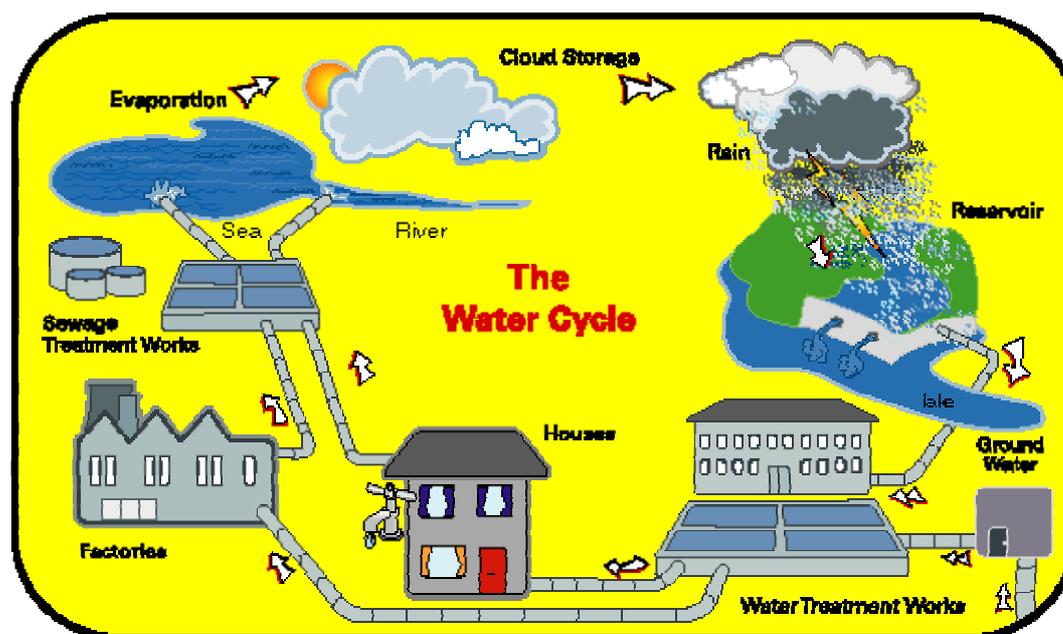


Diagram © Drinking Water Inspectorate

3.0 The Nature of Sewage

3.1 Composition

Sewage is a complex mixture of substances present in solution, as colloidal suspension or as coarse suspended matter. The mixture is mainly water with the concentrations of the other components being measured in parts per million (milligrams per litre).

Domestic sewage comprises all the waterborne waste draining from domestic properties. It contains organic matter from sanitary activities, food preparation, dishwashing and laundry as well as detergents and other chemicals used about the home. In some cases it also comprises drainage from roofs and other surfaces. If it was allowed to enter a watercourse untreated it would cause gross pollution.

Commercial sewage is more commonly known as *trade effluent* and contains the wastewaters from a host of commercial activities such as food processing, engineering, chemical and other manufacturing processes, vehicle washing and hardstand drainage as well as any domestic sewage from the trade premises. The extent of its polluting nature depends on the nature of the commercial activity. *Trade effluent* may be highly polluting for two reasons. It may contain substances toxic to flora and fauna, or it may contain high levels of biodegradable waste organic matter. In some instances mixtures of the two principal types of pollutant may be present. Both may have adverse effects on sewage treatment processes.

Agricultural sewage is highly polluting and is not normally permitted to enter the sewerage system. Processes such as dung clearing and silage clamping produce effluents that are many times more polluting than domestic sewage: such agricultural waste waters are frequently recycled to land as fertilizer.

Water companies, who own and operate the sewerage networks and the sewage treatment works, impose limits to what can be discharged to sewer by commerce, industry and agriculture. This is covered in more detail under *trade effluent control* below.

Sewage flowing through a sewerage system is often a complex mixture of components from the above sources. If discharged untreated, the impact on a receiving watercourse (river or stream) would be devastating.

3.2 Polluting Effects of Sewage

Some of the more common pollutants present in sewage, together with their impact on river quality, are given in Table 1.

Table 1: Common pollutants found in sewage and their impact on river quality

	Pollutant	Source	Impact
Suspended Solids	Suspended organic matter	Kitchen waste, food processing, faeces	Oxygen demand (see below)
BOD	Biodegradable matter in suspension, true or colloidal solution	As above	Oxygen demand (see below)
Ammonia	Urea, proteins and other compounds that degrade to yield ammonia	Urine, animal waste, coal carbonisation plants	Toxic to fish, oxygen demand
Heavy Metals	Chromium (VI), copper, nickel, zinc, etc	Metal plating	Toxic to flora and fauna

It is interesting to review the impact of untreated sewage on a hypothetical stream or small river. The following would be seen over many tens of miles of river downstream of the discharge of untreated sewage.

Initially the floating components, such as paper, wood, sanitary products (condoms, sanitary towels, etc.) and such, would become entangled in any river plant life and in overhanging branches, bushes, etc., providing an unsightly hazard for fish and animal life.

Grit and sand from roads, roofs and hardstands would be deposited where the river flowed less briskly, carpeting the bottom and interfering with benthic (bottom dwelling) organisms.

In regions of slow flow, suspended organic matter would collect on the river bed. This material is highly biodegradable. Micro-organisms feeding on it would soon use up any dissolved oxygen thereby creating *anaerobic conditions* in the deposited organic matter. Micro-organisms that thrive under such conditions (the absence of air) would continue the degradation process giving rise to the evolution of 'marsh gas', a mixture of methane and carbon dioxide.

The ongoing flow would still contain biodegradable material that had not settled out. Aerobic micro-organisms present in the water need oxygen to degrade this material.

Organic matter would be oxidised to carbon dioxide and water and ammonia would be oxidised first to nitrite then to nitrate. Nitrates are not toxic to fish.

The resulting demand for the dissolved oxygen in the river would result in 'oxygen sag', or even complete oxygen depletion, with devastating impact on flora and fauna. That stretch of the river would become 'dead'. Eventually this biodegradation process would be completed and dissolved oxygen levels would return to normal.

However, the river water would be rich in nutrients, compounds containing nitrogen and phosphorus, and there would be an explosion in plant life growth. This could result in choking of the river flow and flooding to adjacent low lying areas.

Eventually, the river would return to a level of water quality that approached that before the discharge of untreated sewage.

This whole process is called *self purification*.

It should be noted that the presence of trade effluents containing heavy metals such as copper, nickel, chromium (VI) and other toxic substances such as phenols in the sewage discharge, would depress biological activity and hinder these natural recovery processes.

Later the reader will note that the physical and biological processes described above are essentially the same as those used at the *sewage treatment works*, albeit intensified and compressed into a smaller area.

3.3 Trade Effluent Control

Trade effluents arise as the result of industrial and commercial activities and the nature and volume of any such discharge to sewer is subject to legally enforceable controls imposed by the water company owning the sewer and, in the case of certain toxic substances, by other regulatory bodies.

These controls are necessary to protect the sewage treatment works processes, to avoid contamination of usable treatment bi-products and to protect the watercourse receiving the treated effluent.

Examples of the range of trade effluents and their constituents can be seen in Table 2.

Table 2: Some Trade Effluents and their Constituents

Industry	Trade Effluent
Brewing	Suspended solids, high BOD, low nitrogen
Metal finishing	Heavy metals
Earthenware manufacture	Suspended solids, glaze materials
Fibreglass insulation	Phenols, resins

The controls imposed on trade effluent discharges to sewer depend on the particular industrial or commercial process giving rise to the trade effluent, the nature of the sewerage system into which it discharges and the available treatment at the receiving sewage treatment works. They will also depend on the use for any by-products of sewage treatment, for example, the agricultural use of sewage sludge described below. The discharge of certain hazardous substances, such as petrol, is totally prohibited.

Provided the sewerage system has no vulnerable downstream storm sewage overflows, and the sewage treatment works has adequate treatment capacity, discharges of biodegradable organic wastes, such as arise from the food and brewing industries, etc., can be successfully treated in admixture with domestic sewage. The latter provides nitrogen and phosphorus nutrients that are essential to the biological treatment process and may not be found in high carbohydrate trade effluents.

A trader wishing to discharge to the sewer must apply to the sewerage company seeking consent to discharge. The consent will usually include restrictions on trade effluent flow and composition and indicate means by which the company recoup the cost of carriage in the sewer and treatment at the sewage works through trade effluent charges. Alternatively, the sewerage company may enter into an agreement with the trader in which the latter may be asked to provide a contribution to cover the cost of any additional sewer or treatment capacity needed to accommodate the trade effluent.

3.4 Measurement of Pollution Levels

Urban sewage is a complex mixture of substances that have differing impact on the aquatic environment. Rather than attempt to analyse each individual pollutant, surrogate measures have been developed that relate directly to environmental impact and to the processes used in sewage treatment.

The principal parameters measured are:-

1. Total and suspended solids
2. Biological oxygen demand
3. Chemical oxygen demand
4. Ammonia
5. Nitrate in the final treated effluent
6. Total nitrogen and total phosphorus – when these must be controlled in the final effluent
7. Other substances may be measured if necessary, for example, heavy metals, phenols, etc.

To monitor performance samples are taken at the various stages of the treatment process: the incoming crude sewage; the settled sewage after primary sedimentation; the settled effluent after biological treatment. The latter is normally the final effluent to the receiving watercourse.

Crude sewage samples are normally analysed for 1, 2, 3, and 4.

Settled sewage samples are normally analysed for 1, 2, 3 and 4.

Final effluent is normally analysed for 1, 2, 5 and if necessary 6 and/or 7.

The *total solids* present in a sewage sample is a measure of the soluble and insoluble inorganic and organic materials present and the *suspended solids* gives a measure of the solids that may settle out at the sedimentation stages of treatment.

The *biochemical oxygen demand (BOD)* is the most important oxygen demand parameter. It mimics the biological oxidation processes that take place in nature and at the biological stage of sewage treatment. The *BOD* of a sample is associated with the suspended, colloidal and dissolved biodegradable matter present.

The *chemical oxygen demand (COD)* provides a measure of the total chemically oxidizable matter in the sample.

Free and saline ammonia is the most readily available form of nitrogen to biological processes. It principally arises through the hydrolysis of urea present in urine, but is also a decomposition product of other nitrogen bearing materials. Ammonia is toxic to fish and is oxidised to *nitrate* at the biological treatment stage.

Nitrite may be present in the effluent from biological treatment when nitrogen compounds have only partially been oxidised and provides a measure of the effectiveness of the process.

Nitrate is the final product of the biological oxidation of nitrogen bearing compounds. It is present in well nitrified final effluents from biological treatment.

In regions where the *eutrophication* (nutrient enrichment) of rivers, estuaries and coastal waters is a problem *total nitrogen and/ or total phosphate* must be measured in the final effluent and if necessary additional treatment processes are employed to reduce their concentrations.

The presence of both nitrogen and phosphorus in the sewage is essential for effective treatment. BOD to nitrogen ratios of 15:1 to 30:1 and BOD to phosphorus of 80:1 to 120:1 are necessary depending on the process employed.

3.5 Discharge Consents

The Water Resources Act 1991 regulates discharges to *controlled waters*. Discharges of sewage effluent, trade effluent or other polluting matter to controlled waters may only be made with the consent of the regulator, the Environment Agency (EA), in England and Wales, the Scottish Environmental Protection Agency (SEPA) north of the border and in Northern Ireland by the Northern Ireland Environment Agency (NIEA).

In England and Wales The Environmental Permitting Regulations 2010 SI 2010 No.675 (as amended) replace those parts of the Water Resources Act 1991 that relate to the regulations of discharges to controlled waters. Under the Regulations, water discharge activities relate to discharges to surface waters that are controlled waters but not to groundwater. In Scotland, The Water Environment and Water Services (Scotland) Act 2003 (WEWS Act) requires any activity likely to cause pollution to be authorised. The Water Environment (Controlled Activities) (Scotland) Regulations 2005 (CAR) were introduced under WEWS to control, amongst other activities, discharges to the environment including:

- Sewage and trade effluent;
- Surface water discharges from urban areas;
- Abandoned mine discharges.

In the case of Northern Ireland, under the Water (Northern Ireland) Order 1999, the Department of Environment must give permission before any trade or sewage waste, or any other potential pollution (including site drainage) from commercial, industrial or domestic premises is discharged into waterways or underground strata. The discharge consents include conditions outlining the quality and quantity of waste discharges. The conditions are drawn up to ensure that the waste can be absorbed by the receiving waterway without damaging the aquatic environment or breaching national or European Commission (EC) standards.

Therefore, to discharge effluent to a receiving watercourse a Permit is required from the EA in England and Wales, an Authorisation from SEPA in Scotland and in Northern Ireland a Consent. All set prescribed and legally binding limits of flow and composition on the discharger. Within this document the term ‘a *consent to discharge*’ will be used to refer to a Permit, Authorisation or Consent depending on the relevant location in the UK.

The flow and quality limits imposed are designed to protect the receiving watercourse and to ensure that its quality status is maintained. The *EU Water Framework Directive* is now driving improvements to river water quality and in turn will have an impact on the setting of consents to discharge. A review of this Directive is given in ‘The EC Water Framework Directive: An Introductory Guide’ downloadable from the FWR website.

The present Guide is concerned with *discharges from sewerage systems and sewage treatment works*.

4.0 Sewerage Systems

4.1 Storm Flows

Sewerage systems are designed to carry a maximum flow determined by factors such as population served, trade effluent carried, surface water received, etc. It would be prohibitively expensive to construct sewers that could carry all the sewage that can possibly be generated during a major rainstorm. Sewers are commonly protected from surcharge by placing storm sewage overflows at strategic points on the sewerage system. *Consent to discharge* is needed for such an overflow and the design must enable the *consent conditions* to be met. Often a sewerage system will require one or more sewage pumping stations to lift sewage from low lying areas into the main sewer. Such pumping stations will have overflows to protect the pumps and these overflows will also have to have *consent to discharge*.

The *sewage treatment works* itself will need to be protected against excessive flows in times of storm. Commonly the works are designed to give full treatment to three times the *dry weather flow* (3X DWF) and preliminary treatment to six times the *dry weather flow* (6X DWF). These figures may change depending on the size and sensitivity of the receiving water.

To avoid excessive pollution of the receiving watercourse, particularly during the first flush of excessive flow, storm tanks are commonly provided at the sewage works to give retention and settlement of the storm sewage from the 3X DWF and in some cases the 6X DWF overflows. These storm tanks may retain all the excess flow from a short storm for transfer to full treatment when sewage flows permit. For longer or more intense storms, where the capacity of the storm tanks is exceeded, the storm tanks remove highly polluting settleable matter before discharge to the watercourse that is itself in spate and therefore less sensitive to pollution. Such discharges are also the subject of *consent to discharge*.

Note that DWF is usually defined as the average daily flow received at the works over a period of one week preceded by seven days when the rainfall did not exceed 0.25mm on any one day. The determination of the DWF is a key factor in sewage works design.

4.2 Separate and Combined Sewers

Sewerage systems may be *combined* or *separate*, see Figure 2 below:

4.2.1 Separate Sewerage Systems

In *separate sewerage systems* the foul and surface waters are conveyed in separate pipe-work systems. In this system surface drainage from roofs, roads and other clean areas is collected and transported to the receiving watercourse via a surface water sewer.

Where circumstances demand, the surface water may pass through an oil-interceptor or a reed bed (see later under biological treatment) before passing to the watercourse.

The foul sewer carries the sewage from kitchens, bathrooms, toilets, etc., to the sewage works for treatment before the effluent passes to the receiving watercourse.

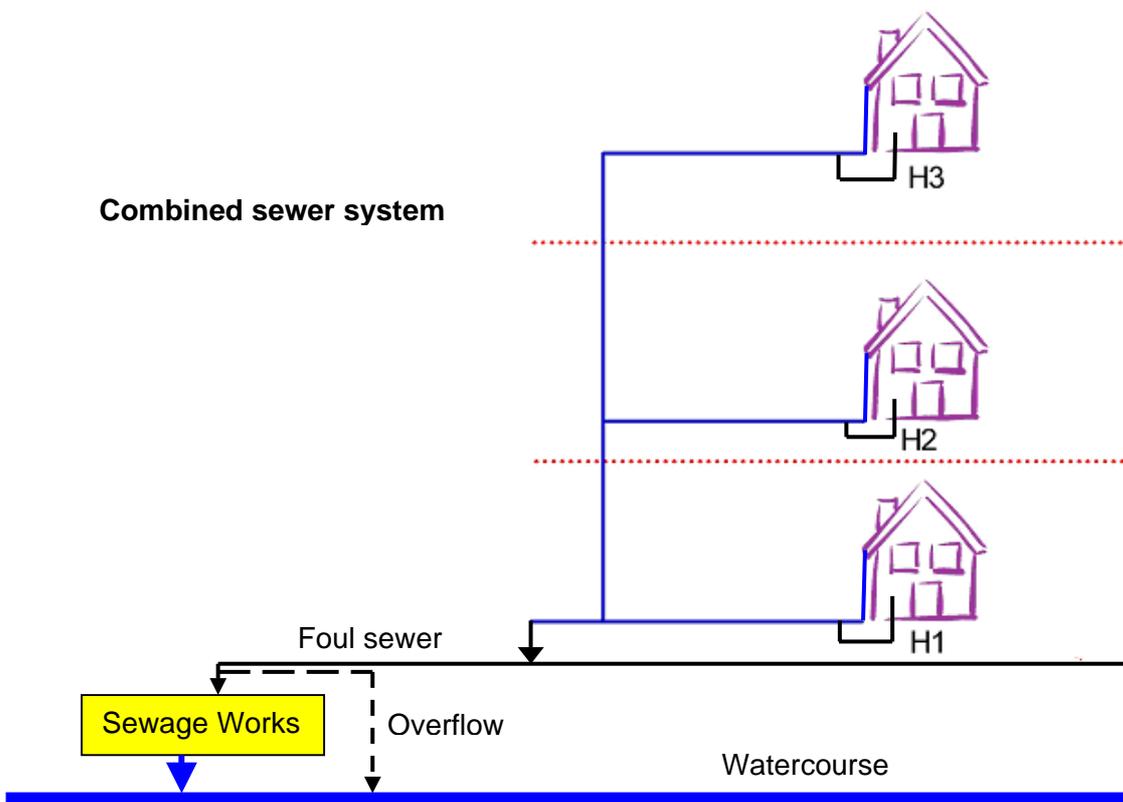
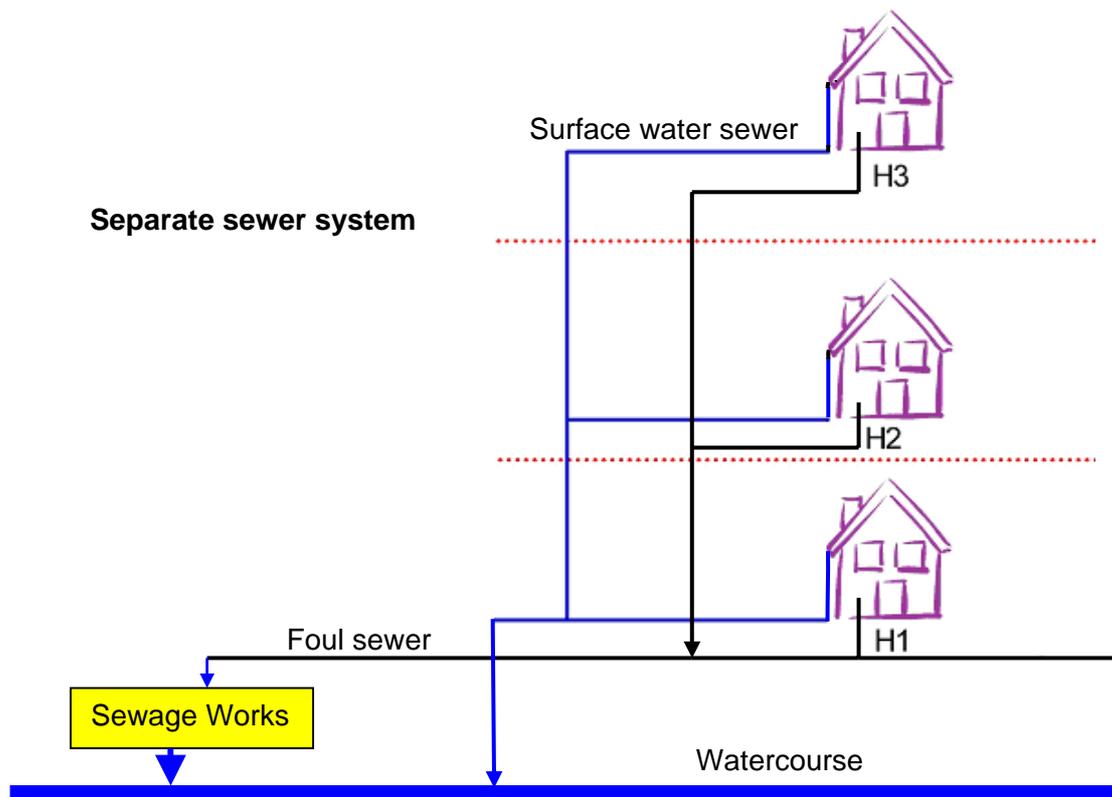
4.2.2 Combined Sewerage Systems

Combined sewerage systems carry both foul sewage and surface water and because of the latter they show the widest flow variation, particularly in wet weather. In this system both the surface water drainage and the foul sewage enter the same sewer for transportation to the sewage works. After treatment, the effluent passes to the receiving watercourse.

In a combined system, there can be wide flow variations in times of storm and the combined sewer will have an overflow up-sewer from the works to protect it in times of exceptionally high flows.

In reality it is quite likely that, in long established urban areas, there will be a mixture of combined and separate sewers.

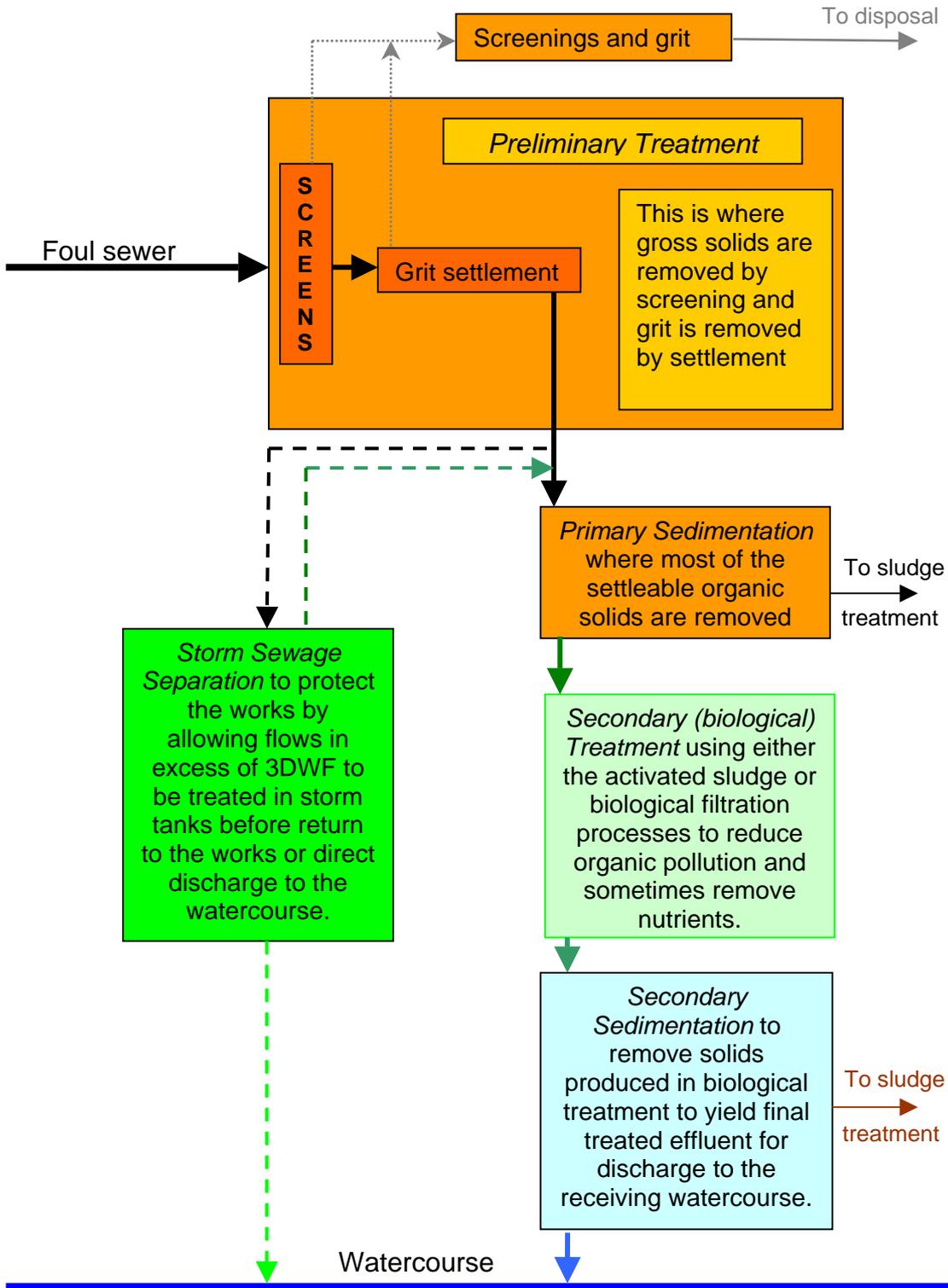
Figure 2: Separate and combined sewer systems



5.0 Sewage Treatment Plant

The sewerage system delivers sewage for treatment to the sewage works: a typical works flow-sheet is given in Figure 3 and would comprise five stages:

Figure 3: Typical sewage treatment plant flow sheet



The black line follows the basic sewage treatment system used to meet most effluent quality requirements. The line changes from black to green to blue to indicate the progressive improvement to quality through the flow sheet. The black line to the left shows the storm sewage overflow to the storm tank. This is set commonly at three times the dry weather flow to the works. The green return line from the storm tank indicates the return of sewage from the storm tank for full treatment once the storm has passed. The other green line shows the settled sewage from the storm tank passing to the watercourse under prolonged storm conditions.

The lines leading to the right indicate the by-products of the processes: grey for screenings and grit, black for primary sludge and brown for secondary sludge.

An aerial photograph of a typical, sewage works layout is given in Figure 4.

Figure 4: A typical layout for a sewage treatment plant



Severn Trent Water's Burton Joyce WwTW
©Chris Knapton Science Photo Library

When high quality treated effluents are required to meet the needs of the receiving watercourse, modifications may be needed to the above flow sheet or additional processes may be required. These process needs will be considered later.

6.0 Unit Processes in Sewage Treatment

The basic unit processes involved in sewage treatment are: -

- Storm Sewage Separation (6X DWF)
- Screening
- Grit Removal

- Storm Sewage Separation (3X DWF) and Treatment
- Flow measurement
- Primary Sedimentation
- Biological Treatment (may include nutrient removal)
- Activated Sludge Process
- Biological Filtration
- Secondary Sedimentation
- Sludge Treatment, Utilisation and Disposal
- Tertiary Treatment (often further solids removal but may include nutrient removal)

Both primary and secondary sedimentation processes, and in some cases tertiary treatment processes, result in the production of sludges. These are suspensions of sewage or biological solids that require treatment before disposal. There are several processes available and these will be outlined under 6.11 Sludge Treatment, Utilisation and Disposal, below.

6.1 Storm Sewage Separation (6X DWF)

Sewage treatment processes are not designed to cater for extreme events so storm sewage separation is essential.

The 6X DWF may be located on the trunk sewer to the works or at the sewage works. It takes the form of a weir that allows forward flow to up to 6X the design dry weather flow to the sewage works; flows above usually go direct to the watercourse. Since the 6X overflow is only overtopped in times of heavy rain when the sewage is diluted by rainwater and the watercourse is in spate, the impact on the watercourse is usually minimal.

When highly sensitive watercourses are involved the excess flow may be retained in storm tanks and returned to the sewer when the sewage flow has subsided.

Sewage flows up to 6X DWF are normally treated to remove screenings and grit.

6.2 Screening

At the sewage works the first treatment process involves screening the sewage to remove non-biodegradable solids such as sanitary ware, plastics, wood, etc. Bar screens are commonly used and a mechanical rake removes the screenings periodically to prevent blinding of the screen. Screens are provided in pairs, one duty and one standby with both to be used under unusual conditions of heavy screenings load.

Figure 5: A bar screen used to remove the screening



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The screenings are commonly disposed of by incineration or disposal to a controlled landfill site.

6.3 Grit Removal

The screened sewage is passed through a tank that provides sufficient retention time to allow grit and other heavy solids (detritus) to settle out but insufficient time for organic matter to be deposited. A typical grit removal tank is shown in Figure 6.

Figure 6: A Detritor chamber with scraper (during cleaning)



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Settled grit is scraped towards a collection point where it is removed typically by raking up an inclined plane or pumped out using a screw pump. The grit is usually disposed to landfill.

6.4 Storm Sewage Separation (3X DWF) and Treatment

Flows over 3X DWF are spilled over a weir and flow into storm tanks. Here suspended solids settle out. In the event of a prolonged storm the settled storm sewage overflows from the storm tank to the receiving watercourse. The discharge is very much diluted by rainwater and has had screening, grit removal and settlement treatment so its effect on a watercourse in spate will be minimised.

Figure 7: Storm tanks and outlet channel



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Storm tanks may be circular or rectangular. They are fitted with scrapers to move the settled solids, the sludge, to hoppers from which it is pumped to the sludge treatment facility. The retained storm sewage is pumped back to the main sewage flow to treatment once the storm is over and sewage flows have fallen.

6.5 Flow Measurement

The flow to treatment is usually measured downstream of screening and grit removal and any works return flows such as storm sewage from the storm tanks. This measurement is important since, combined with analysis for suspended solids, BOD and ammonia it allows calculation of the pollution load passing forward to treatment.

The BOD of crude sewage may range from 600 mg/l for a strong sewage to 350 mg/l for an average sewage and 210 mg/l for a weak sewage.

Sewage flow measurement is normally by use of a flume or restriction in the channel carrying the sewage that results in a difference in liquid level between upstream and downstream of the flume. The difference in liquid level together with the flume characteristics, allow the flow in the channel to be calculated.

Figure 8: A flow measurement channel



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6.6 Primary Sedimentation

The measured crude sewage flow is then subjected to sedimentation in either circular or rectangular primary sedimentation tanks. The aim is to reduce the suspended organic solids level and its associated BOD.

The volume of tankage provided is designed to optimize suspended solids capture.

In circular tanks the sewage flows radially outwards to leave the tank via a peripheral weir. Suspended solids fall to the bottom of the tank where a scraper sweeps them into a hopper at the base of the tank from which they are periodically removed as a sludge containing 2-4 % dry solids. The primary sedimentation process may remove some 60-70% of the suspended solids and 35-50% of associated BOD present in the crude sewage feed.

Figure 9: A circular primary sedimentation tank



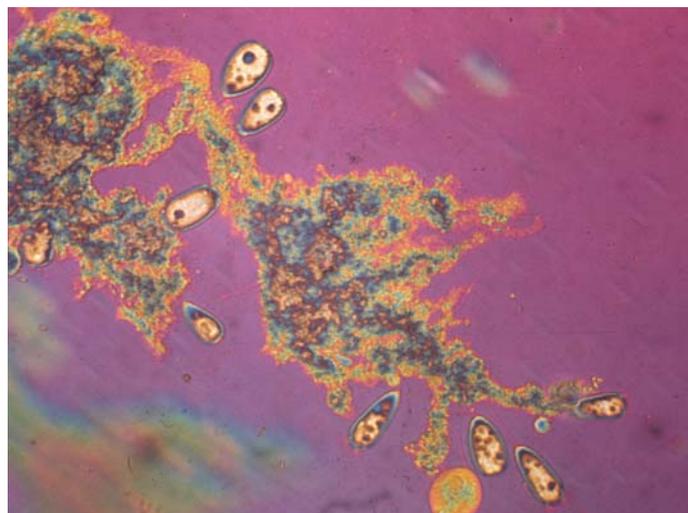
Primary settlement at Prague WWTW © Dr. Tim Evans., Tim Evans Environment

Figure 9 shows the weir over which the ‘settled sewage’ exits a circular primary sedimentation tank. The scraper that sweeps the sludge solids into the central hopper is suspended from the bridge that is driven round the tank by an electric motor.

6.7 Biological Treatment

Settled sewage from primary sedimentation is then treated biologically to oxidise organic matter to carbon dioxide and water and ammonia to nitrate. There are two basic biological processes: the activated sludge process and biological filtration. Both utilise bacteria and protozoa species in the presence of air (aerobic conditions) to facilitate oxidation. The former does this in open suspension whilst the latter utilises a support medium.

Figure 10: Bacteria and protozoa species are at the heart of biological treatment



Photograph © Dr Gordon Jones, FWR

6.8 The Activated Sludge Process

In the activated sludge process a suspension of activated sludge is created and sustained in an *aeration tank* to which a steady stream of air bubbles is applied either by the *diffused air* or the *surface aeration* process. The size of the *aeration tank* and hence the detention time of the contents is a function of the extent of purification needed to meet the final effluent *consent* conditions.

Bacteria utilise the polluting organic matter as food and aggregate in sludge *flocs*. These *activated sludge flocs* provide a home to free-swimming and attached protozoan species that graze on the bacteria. Carbonaceous material is oxidised to carbon dioxide and water and nitrogenous material is oxidised first to nitrite then to nitrate.

The mixture of incoming settled sewage and *returned activated sludge* (see below) is called the *mixed liquor*. The *mixed liquor* suspended solids level is carefully controlled to optimise treatment and a proportion of the *returned activated sludge* is bled off as *surplus activated sludge*. Since pollution load is removed by active bacterial growth on the sludge floc particles there will usually be excess *activated sludge* production.

The incoming settled sewage feed displaces the aeration tank contents which pass to secondary sedimentation tanks. The effluent from these tanks is commonly sufficiently treated to allow direct discharge to the watercourse within consent conditions.

The activated sludge from the bottom of the secondary sedimentation tanks is returned to the aeration tank to facilitate treatment of the settled sewage flow. A proportion of this *returned activated sludge* is bled off to the works inlet so as to maintain a chosen level of *mixed liquor* solids; the *mixed liquor* is the mixture of settled sewage and activated sludge in the aeration tank.

Key control parameters for the activated sludge process are the *mixed liquor* and *returned activated sludge* suspended solids, the dissolved oxygen level in the *mixed liquor* and the BOD of the settled sewage feed from the primary sedimentation tanks.

There are two basic ways of introducing air into the *aeration tank*: by *diffused air* and by *surface aeration*. The *diffused air process* is shown in Figure 11.

Figure 11: A *diffused air activated sludge aeration tank* in operation and empty to show the *diffuser dome system* used to admit bubbles of compressed air into an *aeration tank*.



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In the *surface aeration process* air bubbles are entrained in the *mixed liquor* by violent agitation of the tank contents using a *surface aerator*. These are frequently fitted with a draw tube to provide complete mixing of the tank contents.

Figure 12: A *surface aerator*



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The dissolved oxygen level in the *aeration tank* is controlled using an in situ oxygen meter linked to the air supply controls. In the UK *surface aerators* are fixed in concrete *aeration tanks*.

6.9 The Biological Filtration Process

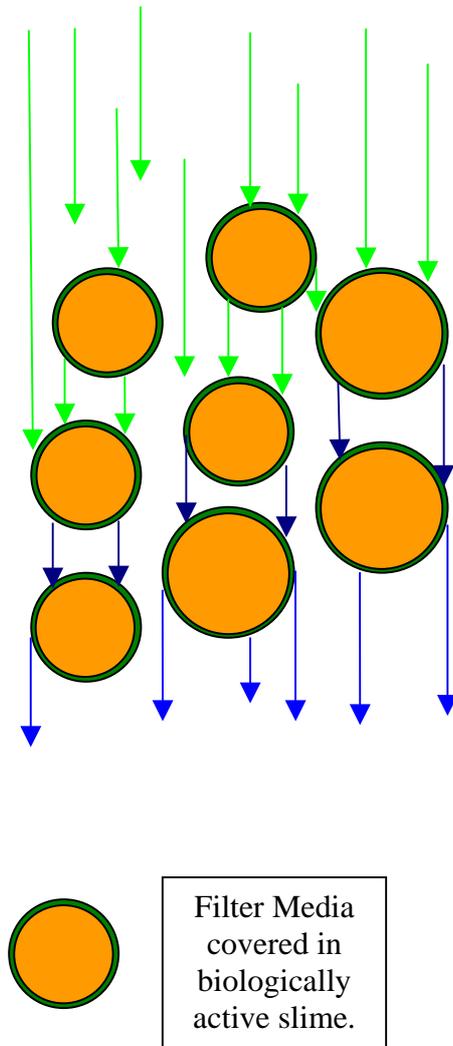
The name of this process is misleading since whilst it is a biological process, it is not filtration. *Biological filters* may be rectangular or circular. A typical circular *biological filter* is shown in Figure 13. The *biological filtration process* is described in Figure 14.

Figure 13: A biological filter



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Figure 14: The biological filtration process



In this secondary process settled sewage leaving primary sedimentation is distributed over the surface of filter medium and allowed to percolate through the media bed. The media is commonly crushed rock of size 40-50 mm.

Biologically active slime grows on the surface of the media and a flow of air is induced upwards through the body of the filter. The slime contains a range of organisms including bacteria, protozoa, worms and fly larva.

As the settled sewage percolates through the media bed it comes into contact with the biologically active slime. The organisms utilize the carbonaceous and nitrogenous organic matter as food drawing oxygen to support the process from the air flowing through the bed. The thickness of the slime is controlled by grazing organisms that utilize it as food. The rate at which the settled sewage is applied is critical since an over-supply of foodstuff could result in rapid growth of the biological slime causing filter blockage and 'ponding' of the filter surface.

The effluent from biological treatment passes to the secondary sedimentation stage.

The effluent that discharges over the weir of the secondary settlement tank (often called a humus tank in biological filtration plants) is usually of sufficient quality to go directly to the receiving watercourse. Unlike the sludge from secondary treatment in

the activated sludge process, all the humus sludge is usually returned to the head of the works for co-settlement with crude sewage solids.

The process described above is that of single filtration. The pollution load that can be treated by biological filtration can be increased by use of recirculation or alternating double filtration modifications.

If the pollution load to a biological filter is progressively increased, the biological film thickness on the support media will thicken. Eventually the film will become so thick that water cannot percolate through the body of the filter and will collect at the surface of the filter. This is called 'ponding' and the filter must be rested before satisfactory treatment can be resumed.

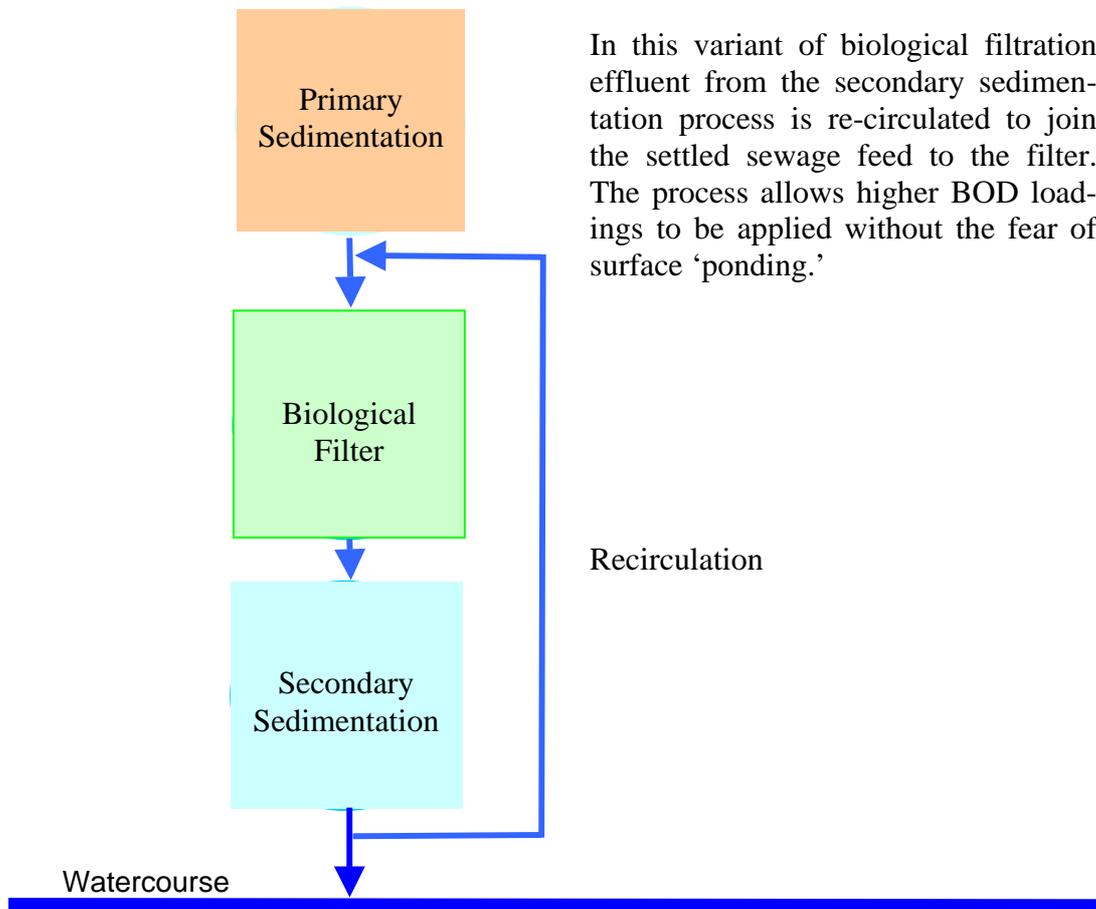
Figure 15: Sedimentation tanks used for the removal of solids following biological treatment. See below for explanation of the process.



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Biological filters may treat high pollution loads provided this film growth can be controlled to avoid *ponding*. Two techniques are employed: recirculation and alternating double filtration. These are described in figure 16 below.

Figure 16: Single filtration with recirculation.



Alternating double filtration is another variant of biological filtration designed to increase treatment capacity. In its simplest form, the settled sewage flow is applied to one of two biological filters. After secondary sedimentation, the effluent from the first filter is fed to the second filter for further treatment. Periodically, the roles of the two filters are reversed.

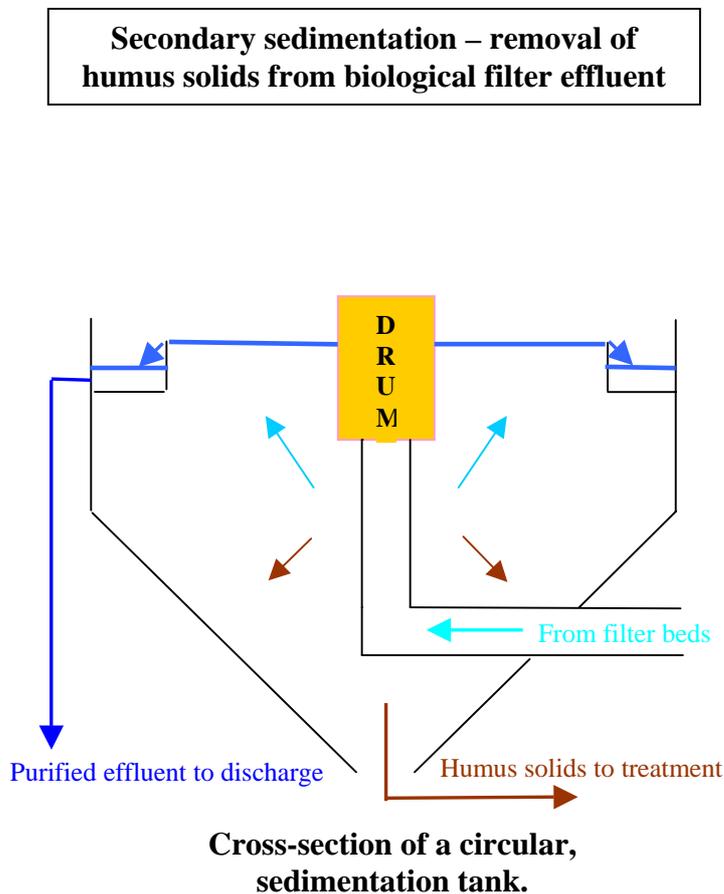
Both single recirculation and alternating double filtration modes have the effect of reducing biological film growth on the filter media thus enabling greater BOD loads to be treated compared to single filtration with recirculation.

Of the two biological treatment processes, activated sludge and biological filtration, the biological filtration process is the least flexible, whilst the activated sludge process can be adapted for nutrient removal.

Both processes require solids removed in a sedimentation stage before the treated effluent is discharged to the watercourse.

6.10 Secondary sedimentation

Figure 17: Schematic of a circular secondary sedimentation tank on a biological filtration plant



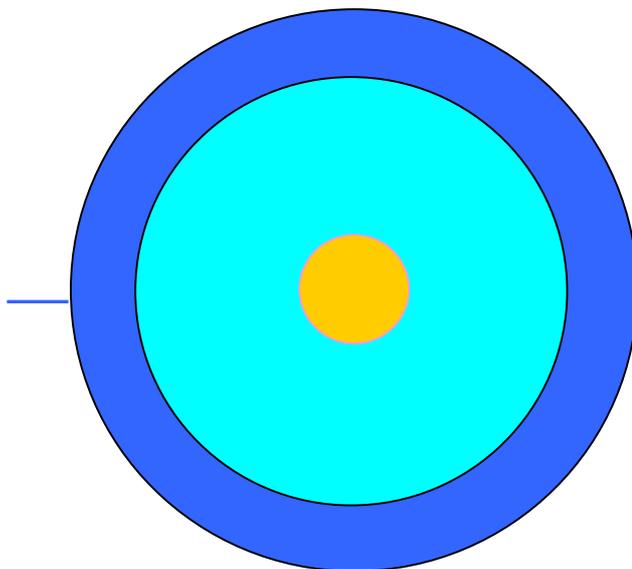
The discharge from the filter bed comprises purified effluent and biological solids called 'humus sludge'.

The secondary sedimentation process separates these two components.

The percolating filter effluent enters via a pipe that delivers it to the central baffle, the drum. The baffle forces the flow downwards and outwards.

The humus solids (brown) settle into a collecting hopper at the base and are removed from the bottom of the sedimentation tank by hydrostatic forces. Humus sludge is usually mixed with primary sludge before treatment.

The purified effluent exits the settlement tank over a weir that runs all round the top of the circular tank and leaves the tank via an effluent channel.



Plan of a circular secondary sedimentation tank

Figure 18: Final effluent from sewage treatment being discharged to the watercourse.



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6.11 Sludge Treatment, Utilization and Disposal

Sewage sludge is a major bi-product of sewage treatment and requires appropriate treatment to reduce the organic content further and to make it suitable for utilisation or disposal.

There is a range of treatment options depending on the nature of the sludge, the location of the sewage works and its final destination. Ideally, since sewage sludge is a valuable source of bio-solids and nutrients such as nitrogen, application to agriculture is the best option. However, such applications are only permitted under carefully controlled conditions and not all sludges may be suitable. Also final disposal will be influenced by the location of the works in relation to available agricultural land.

Sludge treatment centres are often set up at the larger sewage works to which sludges from smaller works are imported. It is important to transport cost savings that sludges are consolidated at the works where they are generated. A sludge of 4% dry solids occupies only half the volume of a sludge of 2% dry solids. Such consolidation can be achieved by careful operation of the sedimentation processes.

6.11.1 Anaerobic Sludge Digestion

In this process fresh sludge is incrementally fed to a large mass of actively digesting sludge in the absence of air and maintained at around 35 degrees centigrade. The retention period of the sludge increments is some 15-30 days depending on the process design.

In the digestion process anaerobic bacteria that live in the absence of air, but are able to utilise oxygen present in nitrates, etc., convert much of the sludge organic matter first to carboxylic acids then to sludge gas that is roughly 70% methane and 30% carbon dioxide. The process greatly reduces the fatty solids and the pathogen content of the sludge.

Figure 19: Egg-shaped anaerobic sludge digesters



Egg shaped anaerobic digesters at Thames Water's Reading WwTW
© Dr. Tim Evans, Tim Evans Environment

The sludge gas produced is valuable for use in combined heat and power systems that provide heat to maintain the process temperature within the digestion plant and part of the sewage works power needs. At very large sewage works sludge gas may provide all the works power needs and there may be the opportunity to export power to the local electricity grid.

The egg-shaped digesters shown in Figure 19 are unusual, as digesters are usually cylindrical concrete tanks and are often part buried to provide heat insulation. In recent years resin lined steel tanks have been used at medium sized works as a cheaper, but effective, alternative to concrete.

Digestion tanks are fitted with means of agitation of the sludge to facilitate gas release and to prevent settlement of the heavier solids to the tank floor. This can be achieved mechanically using paddles or by recirculating the sludge gas into the tank through 'sparge pipes' located to induce maximum mixing of the tank contents.

Digestion tanks are of two types: fixed roof and floating roof. The fixed roof digester is connected to a gas holder for gas storage whilst the floating roof digester allows gas storage above the active biomass in the digester itself.

Provided that agricultural land is near to hand and trade effluent control has avoided serious contamination by heavy metals liquid digested sludge may economically and safely be applied to agricultural land to great benefit to the farmer. This is done under strict control with regular sampling of the land and chemical analysis to monitor soil quality.

Liquid digested sludge is often applied to land using a soil injection process that delivers the sludge indirectly from the tanker without the need to run the tanker over the land. This is achieved using tractor drawn sludge-injection equipment linked to the tanker by an umbilical cord in the form of lightweight, flexible hose.

6.11.2 Sludge Incineration

At large sewage works where sludge may be contaminated or the works is remote from agricultural land sludge incineration may be the most economical solution.

The sludge is first thickened using either centrifuges or filter presses to remove water. Once ignited sewage sludges burn sufficiently well not to need auxilliary fuel.

Sludge incineration itself produces ash that is frequently contaminated with heavy metals and must be safely disposed.

The incineration process is heavily regulated to ensure that environment standards are maintained.

6.11.3 Sludge Dewatering and Disposal

In this process the sludge is thickened to a cake usually using filter presses or rotary vacuum filters and the cake is then disposed to regulated landfill. This process was much favoured in industrial areas where sludges were heavily contaminated. Undigested sludges can be successfully dewatered and disposed in this way.

There are other sludge treatment and disposal options. The above is not an exclusive list of sludge treatment and disposal options but covers most of UK practice.

6.12 Tertiary Treatment Options

Biological treatment, particularly the flexible *activated sludge process*, can be designed and operated to give high quality effluents low in solids, BOD and with ammonia fully oxidized to nitrate. When even higher effluent standards are required this can be achieved by further reducing the suspended solids level and with it the associated BOD.

At larger sewage works *rapid gravity sand filters* have been used. The feed from the final sedimentation tanks is discharged to the surface of a coarse sand filter that traps the suspended solids. Periodically the filter is backwashed to maintain the filtration rate and the washings are returned to the head of the works.

At small works *reed beds* are now commonly employed. Reed beds are shallow basins into which the final tank effluent is fed. The basin has an established reed population that actively encourages further oxidation of residual carbonaceous and nitrogenous matter in the vicinity of the roots. There is also solids entrapment in the bed. Very high quality effluents can be achieved, the reed bed acting as a treatment buffer to the small works whose treatment capacity might otherwise be compromised at times of high sewage flows.

An older system for solids removal involves passing the effluent from the final sedimentation tanks onto grass plots that trap solids, and associated BOD, as the effluent passes through. The plots are used in rotation to avoid overload.

All the above processes are referred to as *effluent polishing*.

6.12.1 Nutrient Removal

The presence of excess nutrients, principally nitrogen and phosphorus, may result in the watercourse becoming *eutrophic*. Such waters encourage the growth of algal blooms that block the sunlight and produce a high oxygen demand when decaying. When this is the case nutrient reduction may be necessary at the larger sewage works in the catchment.

The *activated sludge process* is the most flexible since it can be adapted to remove nitrogen, through the use of *anoxic zones* in the *aeration tank* that reduce nitrate to elemental nitrogen that is lost to the atmosphere. In an *anoxic zone* the mixture of incoming settled sewage and *returned activated sludge* does not receive aeration. Bacteria present utilize nitrate as a source of oxygen for the degradation of pollution. The nitrogen released by this process is lost to atmosphere and the nitrogen present in the final treated effluent is reduced accordingly.

The process can also be adapted to the reduction of phosphorous levels in the final effluent – a description of this adaptation is outside the scope of this Guide.

Alternatively, nitrogen and phosphorous may be removed in additional dedicated treatment process units – again a description of these processes is outside the scope of this Guide.

7.0 Reflections

Sewage treatment was pioneered in the UK in the 19thC when the Industrial Revolution accelerated the move to urbanization of the population. Frequent outbreaks of waterborne disease occurred because of the poor sanitary conditions. A Royal Commission on Sewage Disposal, 1901-15, was set up to investigate the sewage disposal problem and to develop safe solutions. *Biological filtration* became a common treatment system for urban sewage until the early 20th C when the *activated sludge process* was developed. The Royal Commission suggested a 20 ppm BOD, 30 ppm suspended solids standard would be appropriate for an effluent diluted 8 times when discharged to a river with an upstream BOD of 2mg/l. This was considered the norm for many years before higher river quality standards were dictated and stricter effluent *consent conditions* were applied at many works.

An FWR Guide to the ‘Evolution of River Basin Management’ traces its development over the last 160 years and is downloadable free from the Foundation’s website.

8.0 Glossary of Terms

The descriptions given in this glossary are not definitive but are sufficient to allow the non-specialist to follow the text in this Guide.

Activated sludge is a suspension of flocculated sewage solids, bacteria and micro-organisms maintained in suspension and aerated in an activated sewage plant that oxidises sewage pollutants principally to carbon dioxide, nitrates and water.

Ammonia is a compound of nitrogen and hydrogen present in sewage principally as a result of the degradation of urea, a component of urine.

Anoxic zones are zones in an activated sludge plant that are not aerated which promotes the activity of facultative bacteria that utilise nitrates as a source of oxygen the nitrogen being expelled as nitrogen gas thus providing a method of reducing the total nitrogen level in the treated effluent.

Aerobic conditions is the situation where an actively respiring biomass, as would be found in an activated sludge plant, has a sufficient supply of oxygen to allow the ready biological oxidation of biodegradable pollutants present in the sewage feed.

Anaerobic conditions occur in the absence of oxygen as is the situation in the sludge digestion process where anaerobic bacteria reduce organic matter in the sludge first to carboxylic acids then to methane and carbon dioxide [sludge gas].

Biological filtration a biological oxidation process where the bacteria and other micro-organisms are found in a biologically active slime that builds upon a support media such as stone around which air freely circulates: it is not a filtration process but a form of biological reactor.

Biochemical oxygen demand [BOD] is the prime test for organic pollution and is assessed by measuring the oxygen uptake, in milligrams per litre, of a known volume of the sample under test, diluted with distilled water to which nutrients have been added, when incubated for five days at a temperature of twenty degrees centigrade.

Chemical oxygen demand [COD] measures the oxygen consumed, in milligrams per litre, when a known volume of pollutant is oxidised by dichromate under vigorous conditions and is a surrogate for measurement of the total carbon present.

Consent to discharge is a permit issued by a regulatory body to allow discharge of trade effluent, storm sewage or treated effluent to a public sewer or a watercourse and stipulates the conditions under which the permit is issued.

Controlled waters in the Water Resources Act 1991 has the meaning given in section 104 of that Act namely: relevant territorial waters, coastal waters, inland freshwaters and ground waters,

Crude sewage is the untreated sewage as it arrives at a sewage works.

Diffused air is a system by which compressed air is introduced into the mixed liquor in an activated sludge plant through diffuser domes located on the tank floor.

Dry weather flow provides a basis for sewage works design and is defined for mainly domestic sewage as the average daily flow to the works, in megalitres per day, during seven consecutive days without rain preceded by seven days when the rainfall did not exceed 0.25 mm on any one day.

Eutrophication is the process by which a body of water becomes enriched with nutrients, commonly nitrogen and phosphorus, which leads to a proliferation of algal and plant life.

Filter press is a mechanical device for the dewatering of chemically conditioned sewage sludges by squeezing, over several hours, between grooved metal plates fitted with filter cloths that allow water to drain away to produce a filter cake that continues to dry when stacked.

Final effluent is the fully treated discharge from the sewage treatment works to the receiving watercourse within the parameters laid down in the *consent to discharge*.

Grit is particles of mineral matter from roofs, road surfaces and yards, etc., that enter the public sewer with surface run-off after rain.

Humus sludge is a suspension of largely organic matter that collects at the base of secondary sedimentation tanks following the biological filtration of settled sewage.

Mixed liquor is the suspension of activated sludge under treatment by the activated sludge process.

Nitrates are biological nutrients produced during aerobic biological treatment processes as the final stage of the oxidation of ammonia.

Nutrient removal is the process of removal of nitrogen and phosphorus bearing compounds to minimise or prevent the eutrophication of receiving waters.

Phosphates are biological nutrients found in sewage.

Preliminary treatment is the term for the screening and grit removal processes at a sewage treatment works.

Primary sedimentation is the process of settling out mainly organic solids from crude sewage following screening and grit removal.

Returned activated sludge is the activated sludge returned to the activated sludge process from final sedimentation. It combines with the settled sewage feed to make the mixed liquor.

Reed beds are shallow ponds planted with reeds that have the capacity to provide further purification of an effluent after conventional sewage treatment and are of particular use to provide buffer capacity at small sewage treatment works when flows vary widely.

Rotary vacuum filter comprises a filter cloth covered mesh drum pivoted along its axis to rotate whilst dipping into a sludge bath such that when the air pressure in the drum is reduced the pressure differential sucks the liquid from the sludge leaving a sludge cake on the filter cloth that is mechanically scraped off.

Secondary sedimentation is the process of removal of sludge solids after the biological treatment of settled sewage that produces returned activated sludge in the case of activated sludge process and humus sludge in the case of biological filtration.

Screenings are the materials removed during the screening of crude sewage and comprise gross solids such as paper, wood, sanitary wear, etc., that have been conveyed by the sewage flow.

Sedimentation is the process of removal of settleable solids from a sewage flow by slowing the flow as it passes through a tank: see primary and secondary sedimentation above.

Self purification is the natural processes both physical and biological whereby a watercourse may recover water quality following the upstream discharge of sewage.

Settled sewage is sewage following the removal of settleable solids by primary sedimentation.

Sewage is the liquid that flows in a sewerage system and is a complex mixture of inorganic and organic substances in coarse suspension, as colloidal suspension and true solution derived from domestic, industrial, commercial, agricultural and surface water discharges to the sewer.

Sewerage systems comprise the network of pumps, pipes and overflows that convey sewage to sewage works for treatment.

Sludge digestion is an anaerobic treatment process carried out at 35°C during which bacteria that live in the absence of air reduce organic matter firstly to carboxylic then to a gaseous mixture of methane [70%] and carbon dioxide [30%] the resulting digested sludge being substantially fat and pathogenic bacteria free and therefore suitable for application to farmland.

Sludge incineration is the disposal of sewage sludges, after dewatering, by burning under environmentally controlled conditions and requires minimal external energy input since sludge cake is autothermic. However the resulting ash may be rich in heavy metals.

Storm sewage is that which discharges over the 6X and 3X DWF overflows in the sewerage system and at sewage works at times of heavy or prolonged rainfall.

Storm sewage overflows are designed to protect sewers and sewage works from excessive flows that may cause damage to plant or processes, see storm sewage above.

Storm tanks are provided to catch and retain the first, most polluting, flush of storm sewage discharged over a 3X and sometimes a 6X DWF storm sewage overflow they are designed so that the storm sewage can be returned to the sewage works for treatment once the sewage flow subsides, or, in the case of prolonged storms to provide treatment by sedimentation before the dilute settled sewage discharges to the watercourse.

Surface aeration is a variant of the activated sludge process where the mixing and aeration is provided by paddles inserted into the mixed liquor and rotated rapidly to agitate the surface and entrain air. Such systems are frequently provided with draw tubes located below the paddles to improve the mixing and aeration process.

9.0 Other FWR Guides and Reviews of Current Knowledge (ROCKs)

Guides

- FR/G0001 The EC Water Framework Directive – An Introductory Guide
- FR/G0002 A Householder’s Guide to Water Supply and Sewerage
- FR/G0003 The Evolution of River Basin Management in England and Wales
- FR/G0004 Drinking Water Standards and Guidelines (revised April 2007)
- FR/G0005 Standards for Recreational Water Quality
- FR/G0006 Urban Rainwater Harvesting and Water Reuse – a review of potential benefits and UK practice
- FR/G0007 Householder's Guide to Private Water Supplies

ROCKs

- FR/R0001 Sewage Sludge Disposal
- FR/R0002 Eutrophication of Freshwaters
- FR/R0003 Endocrine Disrupters in the Environment
- FR/R0004 *Legionella* in the Environment
- FR/R0005 *Cryptosporidium* in Water Supplies
- FR/R0006 *Giardia* in Water Supplies
- FR/R0007 Causes of Copper Corrosion in Plumbing Systems
- FR/R0008 Water and the Water Environment: a summary of UK legislation and agreements.
- FR/R0009 Cyanobacterial Toxins in the Water Environment
- FR/R0010 Household Chemicals and the Water Environment
- FR/R0011 Urban Drainage and the Water Environment: a Sustainable Future
- FR/R0012 World Water: Resources, Usage and the Role of Man-Made Reservoirs
- FR/R0013 Desalination for Water Supply