6 WATER SUPPLY, TREATMENT AND FLOOD ALLEVIATION

Chapter summary

The chapter presents some of the basic information in regard to incorporating water supply, treatment and flood alleviation within a restoration design.

In general the larger the site, the greater the potential for water supply and flood alleviation. Details are presented of water treatment systems including wetland systems and settlement lagoons which may treat water before use within or discharge from the site.

Issues related to these topics fall primarily under the remit of the Environment Agency and are associated with the available groundwater and surface water supply and storage capacity. Although a number of the case study areas have the potential to be incorporated into flood risk management schemes these are likely only to be important on a local scale. However, where multiple, adjacent units cover large areas potential exists to provide significant benefits downstream. Such may be the case with the group of units including Scorton and Kiplin Hall which encompass several kilometres of the Swale Valley. The case is similar in terms of water resources where quarries generally have only a local impact. However, to date each unit has been considered in isolation and a more strategic approach would be required to realise a relatively high level of risk to the landowner/quarry operator is perceived in relation to the creation of flood alleviation schemes in terms of liabilities and future maintenance requirements.

6.1 Flood alleviation

If the restored surface level of the quarry void is below the original floodplain then it could potentially provide additional flood storage capacity. The amount of flood storage created depends on a number of factors:

1) Existing water level in the quarry
2) Volume of the quarry void at the time of the flood
3) Shape of the quarry
4) Position on the floodplain
5) Elevation above the flood water level
6) Location within the catchment.
7) Antecedent groundwater level
8) Nature of the storm hydrograph

Floodplain and river terrace sand and gravel deposits are often considered to have high value by mineral operators due to a low proportion of fine silt and clay. These deposits are often liable to inundation or may be connected to the river system with relative ease. Quarry restoration on a river floodplain will impact on the functional nature of the floodplain and influence flood risk and effects should inundation occur. Modification of the landform during restoration may also lead to changes in rainfall run-off and an associated risk of local surface water flooding.

Due to the unpredictability of the impact of changes to the river bank, maintenance of the status quo may be seen as the preferred option. General advice often given by the Environment Agency is for no extraction within 20 m of river banks (to maintain bank and channel stability and to reduce the risk of pollution).

During restoration it is essential that features are not formed that may impede floodplain flowpaths, reduce the available floodplain storage volume or retain flood waters behind embankments. Flood conveyance (flow) is the ability of the floodplain to transfer water and is dependent on a number of factors, including hydraulic roughness, flow area, gradient and wetted perimeter as outlined in the Manning equation. Increasing the irregularity of the floodplain surface may reduce the ability of the floodplain to convey flow and thereby increase flood risk locally and reduce it downstream.

Finished restoration levels including any landfill material should not exceed the original floodplain elevation. Quarry restoration provides the opportunity to increase the existing floodplain storage depending on normal restoration water levels, landform, proximity to channel and relationship to flowpaths, river catchment size and nature of the flood hydrograph. Restored wetlands can double as washlands for flood alleviation (*Clayton et al, 2000*).

Sediment movement during a flood event can be significant resulting in deposition and infilling of the restoration with generally fine grained alluvium. Erosion of sediment from the restoration is also an important consideration both for the site and downstream parties. The soil composition and potential contaminant content therefore requires assessment.

The River Lavant is cited (*Symonds Group, 2006*) as an example where use of restored gravel pits has been made to manage flood risk. Following the flooding of Chichester during 1994 a flood defence scheme was implemented which made use of elements of new channel, existing watercourse and two gravel pits to restrict culverted flows through the city. A series of control structures, flood warning procedures and the maintenance of winter pit levels ensure there is an appropriate volume of additional storage space to maintain a proportion of the flood flows.

A distinction is made between flood risk management (ie active measures on demand) and more passive effects on flood risk. A recent study (*Symonds Group, 2006*) assessed the influence of aggregate quarrying in river floodplains on flood risk and biodiversity, to identify ways in which beneficial effects can be optimised. The net effect of quarry excavations, spoil tips, overburden mounds and aggregate stockpiles on flood storage capacity and floodplain conveyance were examined. The residual long-term effects following the different types of restoration were assessed together with the impact on biodiversity. The main findings of the *Symonds Group Report* (*2006*) were that the impact of quarrying and flooding was generally localised. In order to obtain the greatest benefit from the available flood storage capacity it would be necessary for a site to operate at the peak of the flood hydrograph, potentially reducing the highest water levels. Additional flood storage capacity at other points on the hydrograph would be unlikely to have a significant impact.

6.1.1 Discussion of flood alleviation schemes

Incorporation of flood alleviation and summer baseflow support schemes as part of quarry restoration are often discussed but have not become standard practice in quarry restoration. Wildlife benefits would be considerable, but large areas are required before effects on downstream flooding are significant. Reasons for reticence include the unpredictability of river interaction with a site. Liabilities are associated with long-term maintenance and impacts on surrounding land and downstream siltation. A considerable capital investment may also be required if engineered inlets/outfalls are to be used. Potentially the Environment Agency could contribute to the works/management; however local priorities, budgets, etc will not necessarily coincide with the proposed restoration period unless incorporated in a regional strategy.

Specific flood alleviation schemes must generally be relied upon to operate at the ‘push of a button’ or at specific level/time on a flood hydrograph. Therefore considerable investment in modelling etc may be required which is only likely to be justified for a project of significant size. Areas with potential for flood alleviation schemes do exist, such as the corridor along the River Swale, south of Catterick.

6.2 Water treatment

Restoration may involve the treatment of water to be discharged from the site or to add value to the site afteruse such as treatment of water supply or sewage treatment for the local population generating potential income. In addition aquaculture and agricultural practices may require water treatment prior to discharge. Water entering the site may also require treatment before distribution within the site, for example road or agricultural run-off before contact with nutrient-sensitive habitats.

Various technologies are available from basic settlement lagoons, wetlands, hydrocarbon traps, flocculants and filter systems to complex automated treatment units for potable supply. Dissolved contaminants tend to be more difficult to treat, potentially requiring manipulation of water redox conditions and pH.

Active treatment requires on-going inputs of electricity, chemicals and supervision and primarily passive treatment systems have the most potential for incorporation within quarry restoration. A passive water treatment system may be considered to utilise naturally available energy sources such as topographical gradient, microbial metabolic energy, photosynthesis and chemical energy and requires regular but infrequent maintenance to operate successfully for its design life. Several of the available treatment systems are discussed by *Younger* (*2000*) in relation to the treatment of mine drainage. These include:

i) aerobic, surface-flow wetlands (reedbeds);
ii) anaerobic, compost wetlands with significant surface flow;
iii) mixed compost–limestone systems, with predominantly sub-surface flow (reducing and alkalinity-producing systems (RAPS);
iv) sub-surface reactive barriers to treat acidic, metalliferous groundwaters;
v) closed system limestone dissolution systems for zinc removal from alkaline waters and
vi) roughing filters for aerobic treatment of ferruginous mine waters where there is no room for a surface wetland.

The treatment of water for potable purposes may comprise pre-treatment (with or without chemicals), mixing, coagulation, flocculation, settlement, filtration and sterilisation, depending on the quality of the starting water. In many cases groundwater is likely to be of a higher quality than surface water. Water-based quarry restoration may provide the opportunity for abstraction of significant quantities of groundwater. However, the groundwater will likely be derived from a shallow aquifer, susceptible to contamination from the surface. Agricultural practices in particular may lead to elevated concentrations of agri-chemicals. Potable water treatment is discussed extensively in the literature and is not specific to water based quarry restoration although several of the secondary and tertiary treatment processes may be readily applicable within water based quarry restoration and are discussed below.

6.2.1 Natural treatment systems

There is potential for natural treatment systems to be incorporated within a range of end uses at a site.

Reedbeds and other wetland species such as willow can be used to treat wastewater effluent from industrial processes, sewage treatment works and farm and road run-off. The principles of treatment are to provide suitable residence times, surface areas and redox conditions to allow microbial action to occur. The resultant breakdown products of contaminants/nutrients can then be consumed during plant growth. Contaminants are also filtered out or stored within sediment. Settlement ponds are therefore often incorporated within a system design.

Other treatment systems can involve vertical water flow and floating macrophyte basins (eg duckweed or water hyacinth). It is noted that willows also have potential to remove metals from contaminated water for reedbeds. Surface area requirements are generally 5 m^2 per population equivalent (PE) for secondary sewage treatment (ie after settlement), for tertiary treatment (polishing) 1 m^2 per PE is usual.

All biological wastewater treatment systems rely on natural processes and organisms. In a 'natural treatment system' processes proceed at 'natural' rates thus limiting the energy input to liquid transport, partial aeration and plant harvest, when applicable.

Industrial applications include a treatment system developed for a major chemical products facility at Billingham in which seven 0.7 Ha bunded reedbeds were created to treat up to 3,000 m^3/d of industrial effluent containing substances including methanol, acetone and phenol (*Hawke and José, 1996*).

Slimbridge natural water treatment system (based on *Hawke and José, 1996*)

At Slimbridge in Gloucestershire artificial feeding, fertiliser run-off and bird faeces from the wildfowl collection lead to increased nutrient levels and BOD in the 2,200 m^3/d of water discharged to the adjacent stream. Therefore a 1.5 Ha natural treatment system was devised to enhance the wildlife interest and improve water quality with good results. Average effluent concentrations were reduced by 67% for BOD, 90% for Total Suspended Solids, 15% for Ammonia, 42% for Nitrate, 70% for Total Phosphate, 80% for Zinc and 79% for Lead (*Hawke and José, 1996*). These reductions were anticipated to improve as the system matured. The system design incorporated the following features:

A twin pump system was needed to provide the required head and flow rates as the site was virtually flat-lying. The site had a clay base so that no additional lining was required. A total retention time of 83.5 hours was estimated with a system capacity for 967 population equivalent and an optimum water depth of 15 cm. Approximately 30% of the system is open water with the remainder planted with 40% reeds, 10% reed mace, 10% bulrush, 10% yellow flag iris and others.

The untreated water is pumped to a stilling pond where the water levels are controlled by a float cut-off switch to the pump. A 35-hour retention time facilitates sedimentation and some bacterial breakdown. An estimated 25 years will pass before de-silting is required.

Sluice pipes direct water via horizontal flow through up to three parallel reed/wetland beds, some 50 to 80 m in length, which may be isolated and drained in rotation as required for maintenance and to allow oxidation of organic litter. The vegetation acts to breakdown the pollutants.

Water from the reedbeds is directed to a small lagoon containing floating rafts of vegetation with the roots suspended within the water. From this lagoon water cascades across limestone to precipitate phosphate and oxygenate the water as it enters the subsequent deep pond. The deep pond acts as a store for the precipitated phosphate. Effluent water passes through two small polishing reed/bulrush beds before discharging through outlet pipes half filled with limestone to precipitate any remaining phosphate.

A major purpose of the reeds/willow is to provide large surface areas within the root zones suitable for the microbial populations. Natural systems primarily rely on surface flow of water through the wetland. However, constructed wetlands are generally more efficient and rely on the flow of water through a generally 60 mm thick granular substrate in which reeds are planted at a density of ~4 per m^2.

6.2.2 Constructed wetlands

Constructed wetlands are engineered systems designed to use the processes that occur in natural wetlands, but do so within a more controlled environment. Some systems are designed to treat wastewater, while others have multiple uses, such as using treated wastewater effluent as a water source for the creation and restoration of wetland habitat for wildlife use and environmental enhancement.

Constructed wetlands treatment systems generally fall into one of two general categories: sub-surface flow systems and free water surface systems.

Sub-surface flow systems are designed to create sub-surface flow through a permeable support medium. Such systems have also been referred to as root-zone systems and vegetated submerged bed systems. The media used are typically soil, sand, gravel or crushed rock. These greatly affect the hydraulics of the system having an open structure, a high density of plant roots and better potential for microbial nutrient removal. Sub-surface flow systems provide limited opportunity for wildlife benefits other than water quality improvement. They are more common in the UK where there is a shortage of land and they occupy smaller areas than surface systems.

Free water surface systems, on the other hand, are designed to simulate natural wetlands, with the water flowing over the support medium at shallow depths. Because the water flows over the surface there is less opportunity for nutrient removal processes to work. They tend, therefore, to be quite large and they are often used for the tertiary treatment of wastewater. However, they provide more opportunity to create wetland habitats. Both types of wetlands treatment systems typically are constructed in basins or channels with a natural or constructed sub-surface barrier to limit seepage.

The native common reed (*Phragmites australis*) is often used in constructed wetlands. It is fast growing and can be harvested and used in thatching and screen construction. Willow (*Salix* spp) species are grown too. They have a high capacity for nutrient uptake and coppiced poles can be used as biofuel. If constructed wetlands are utilised as part of farmland management the harvested materials can provide income, as well as an amenity and habitat. As an integrated element of water treatment they can prove cost effective, environmentally friendly and are more pleasing to the eye than traditional waste treatment plants.

6.2.3 Constructed reedbed treatment systems

Wetlands have been used for wastewater treatment, consciously or by default, for hundreds, if not thousands, of years. By the middle of 2000, there were over 530 water company systems, with over 200 installed by Severn Trent Water alone (*Grant and Griggs, 2001*). The number of installations by private individuals and independent installers is unknown.

The two basic types of reedbed system and some of their derivatives are:

- *Vertical flow systems (VFS)*
  Secondary treatment systems
  Sludge treatment reedbeds

- *Horizontal flow systems (HFS)*
  Sub-surface flow systems (SFS)
  Free water surface (FWS)
  Tertiary (polishing)

These are often combined with other systems to provide a final water treatment solution. Other treatment systems that may make use of reeds and other plants include:

- Pond and lagoon systems
- Aquaculture treatment systems
- Land treatment
- Sewage farms
- Grass plots
- Floating macrophyte basins (eg duckweed or in the tropics water hyacinth-based systems)
- Storm wastewater overflow treatment (at wastewater treatment works)
- Storm water treatment systems (highway run-off)

In the vertical flow reedbed the wastewater passes down through layers of free-draining sand and gravel. There are usually two or more beds that are used alternately; allowing a regime of rest and loading so that the surface, which becomes clogged in use, is able to recover its permeability by natural biological processes. Whilst high levels of treatment can be achieved in a single stage, many systems use two or more vertical stages in series as well as in combination with secondary settlement tanks and horizontal flow, as it is considered that vertical systems are more tolerant of blockage.

The horizontal flow bed for secondary treatment of settled wastewater is known as a sub-surface flow system (SFS) as the wastewater passes through the planting media and root zone rather than over the 'soil' surface as in the free water surface system (FWS). In a SFS horizontal flow reedbed the media (soil, sand and gravel) are saturated with the water level maintained just below the surface (typically 25-50 mm), but usually with the capability to flood the surface for weed control. Horizontal flow reedbeds can be used to provide tertiary treatment, or final polishing, of secondary treated effluent.

Advantages	Disadvantages
▪ Simple construction ▪ Minimal fall required, typically <200 mm ▪ Tolerant of hydraulic overload (eg roof water) ▪ Requires little maintenance once established, typically weeding and annual reed cutting ▪ Weed control possible by surface flooding ▪ Low cost ▪ Can provide storm water treatment ▪ Robust ▪ Good buffering of peak flows ▪ Can provide de-nitrification of nitrified effluent ▪ Proven performance	▪ Minimal nitrification ▪ Solids in the wastewater can cause premature blockage ▪ Minimal long-term phosphorus removal

Table 6.1: Advantages and disadvantages of horizontal flow reedbeds for tertiary treatment (ie following secondary treatment) (*Grant and Griggs, 2001*)

The visual aspect of reedbeds and the green image has been responsible for much interest and growth in awareness of wastewater and its associated treatment problems. Whilst this is unlikely to be significant in vertical flow beds, ponds and horizontal flow reedbeds could be expected to benefit from the enormous area of root hairs that provide hospitable conditions for microbes. FWS wetlands depend on emergent plants to provide surfaces for microbial growth.

Natural wastewater treatment systems provide the ideal conditions for pathogen die-off (time, filtration and predation) and so effluents tends to be low in pathogens, sometimes meeting EU bathing water standards in terms of measured bacteriological parameters.

It is often assumed that the plants in a reedbed system consume the nutrients in the wastewater. However even systems designed specially to do this using fast-growing, regularly harvested, floating plants in a warm climate would still need a theoretical area of 30-50 m^2/person to remove most of the nitrogen and phosphorus from domestic wastewater. Thus, in the UK climate, within a typical reedbed system most nutrient removal is the result of micro-organisms, sedimentation, and chemical and physical binding in sand, gravel and soil. In ponds and horizontal flow beds in particular, the mass of fine root hairs act as an effective filter trapping small suspended particles by physical entrapment and electrostatic attraction. The high level of microbial activity around the roots may then help breakdown these particles provided the loading is not too high.

The sizing of the bed area per population equivalent (PE) is crucial in order to avoid blockage. Early UK systems tended to use areas around 0.8 m^2/PE for the first stage and 0.25 – 0.5 m^2 for a second stage. Typically, sand filters use areas of 3 – 5 m^2/PE. Horizontal flow systems for secondary treatment systems give an area of 5 m^2/PE. For tertiary horizontal flow reedbeds, sizing tends to be between 0.5 – 1 m^2/PE (*Grant and Griggs, 2001*).

6.3 Run-off management and SUDs

A sustainable approach to drainage is increasingly undertaken as part of the Environment Agency's initiative to increase the management and partial treatment of surface water at source wherever possible.

With an increase in flooding predicted to be one of the likely effects of climate change the disposal of water at source reduces pressure on large scale systems by retaining water and providing partial treatment before it is released to watercourses.

Regulatory processes which incorporate SUDS techniques include Land Drainage Consents, Discharge Consents, planning applications, Flood Risk Assessments and development proposals.

Where a final landform has the potential to increase natural run-off the use of flood attenuation ponds or other sustainable drainage system may be required (*Martin et al, 2000*). The principle of the SUDS approach to water management is to regulate flows and ensure as much surface water as possible infiltrates into the ground within the area of a development. The objective is achieved by adopting 'soft' engineering methods, which utilise the natural characteristics of the area in which they are installed. Aside from prevention of run-off there are four general methods of control:

a) Filter strips and swales
Filter strips and swales are vegetated surface features that drain water evenly off impermeable areas. Swales are long shallow channels whilst filter strips are gently sloping areas of ground.

b) Filter drains and permeable surfaces
Filter drains and permeable surfaces are devices that have a volume of permeable material below ground to store surface water. Run-off flows to this storage area via a permeable surface. This can include grass, gravel or various types of porous paving.

c) Infiltration devices
Infiltration devices drain water directly into the ground. They may be used at source or the run-off can be conveyed in a pipe or swale to the infiltration area. They include soakaways,

infiltration trenches and infiltration basins as well as swales, filter drains and ponds. Infiltration devices can be integrated into and form part of the landscaped areas.

d) Basins and ponds

Basins are areas for storage of surface run-off that are free from water under dry weather flow conditions including floodplains and detention basins. Ponds contain water in dry weather, and are designed to hold more when it rains and include balancing and attenuation ponds and flood storage reservoirs. The structures can be mixed, including both a permanently wet area for wildlife or treatment of the run-off and an area that is usually dry to cater for flood attenuation. For further details see (http://www.ciria.org/suds/index.html).

6.4 Silt settlement lagoons

The standard means of reducing the silt content of site drainage water prior to discharge off-site is to pass it through settlement lagoons of appropriate dimensions. A scoping calculation for lagoon dimensions may be made using a standard method, which is detailed within *NCB* (*1982*).

It is recommended that sedimentation pond design is based upon overflow rate such that:

$$\frac{Q\ \mathrm{m^3/s}\ \text{(the outfall from the pond)}}{A\ \mathrm{m^2}\ \text{(the pond surface area)}} = 1 \times 10^{-5}\ \mathrm{m/s}^{*}$$

* This is analogous to the settling rate which, from Stokes Law, would settle a shale particle of 4 µm.

Further details on surface water management are presented in *Geoffrey Walton* (*2004*).

6.5 Water supply

The demand for water resources is set to rise with increasing population, and industrial and agricultural requirements. Climate change is predicted to reduce summer rainfall and soil moisture content in many parts of the UK. The topic of water resources is large and not within the remit of this study, however the following points may be considered in relation to the potential for water based quarry restoration to provide a water supply fit for purpose.

Purpose of supply:

Domestic	Potable supply (average 5 l per capita per day requirement) Grey water ~195 l per capita day
Industrial –	Cooling, (heat pumps), often recirculated Consumed in process
Irrigation	Seasonal variations in demand dependent on crop type (see *Section 3.4.2*)

Distance from site to source of demand
  Infrastructure required including pipes and power supply
  Pumping capacity and regime
  Storage capacity

Water quality requirements
  Starting water quality
  Level of treatment required
  Chemical composition – specific requirements for different usage
  Potential for fouling of system (sediment, bio-fouling, iron precipitation)
  Variation in water quality of supply
  Maximum permitted variation in discharged water quality (eg temperature drop/rise)

Flow requirements

Volume of supply required
Variation in volume of demand
Variation in available water resource including climatic factors
Security of supply (vulnerable to what risks)
Discharge requirements

6.6 Watercourse management/supplement

An often held perception of the effects of quarry discharges upon watercourses is that they are detrimental in terms of impact upon ecology and reduction in stream flow.

Quarry voids may intercept large quantities of groundwater, however the majority of this is ultimately conveyed to watercourses. The common view that mineral extraction causes a reduction in the total volume of water entering watercourses is therefore perhaps a misconception. More significant changes to watercourses, rather than overall flow reductions, are variations in the temporal flow and spatial distribution of water caused by temporary water storage within quarries and discharge at specific points along a watercourse. The actual net change, from the pre-existing condition, of water in storage and discharged is unclear due to several interrelating factors, such as, the increase in evaporation from waterbodies and increased humidity within quarry voids.

A study undertaken in the Mendips (*Somerset County Council, 2005*) investigated the impacts of quarry discharges on local water courses within the Mendips based upon detailed analysis of streamflow, discharge and ecological data.

The study concluded that the impacts of quarry discharge upon ecology of receiving watercourses within the project area were small. The area had been subject to quarry discharges for such a long period of time that it was difficult to determine baseline natural conditions. However, no substantial evidence of negative effects was observed and, by causing some seasonal streams to flow all year, the development of permanent aquatic communities was favoured. The ecology of the area has undoubtedly been altered as a result, but benefits to fauna are evident and local residents view favourably the perennial steam flows. The long-term impact of quarry closure is a serious consideration. When pumps are turned off and quarries allowed to flood it may take many tens of years before some hard rock quarries fill to the point where they once more discharge to the adjacent watercourse.

A main finding of the study was that the proven ability of quarry water management schemes to regulate stream flows could possibly be developed further. Flow regimes within watercourses could be regulated to optimise the requirements of the various stakeholders. In an era of increasingly unpredictable climatic change, it would be advantageous to have the means of regulating flow in watercourses. The ability to lessen the probability and effects of flooding and to augment water levels in drought periods would be of great benefit, both to certain types of ecological environments and to protect human interests. However, the resolution of potentially contradictory ideals of stream flow characteristics of different stakeholders, together with statutory requirements, will require careful consideration.

From the Mendips study it appeared that quarry water management schemes within individual quarries have been developed in isolation with little consideration of catchment-wide objectives.

Also numerous influences other than quarry discharge determine the characteristics of watercourses within the project area. Such influences include discharge from sewage treatment works, agricultural run-off, road run-off and possibly the relict effects of historical landfilling etc. A need therefore exists to examine integrated water management within a catchment, and this may potentially require the integration of Mineral Planning with the Environment Agency River Basin Management Scheme. The pooling and analysis of environmental data is also considered a key part of this.