National Groundwater and Contaminated Land Centre

A Guide to Monitoring Water Levels and Flows at Wetland Sites

Asiantaeth yr Amgylchedd Cymru
Environment Agency Wales

English Nature

The Wildlife Trusts

RSPB

Environment Agency

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Scope

This booklet has been produced to promote good practice in the hydrological monitoring of wetland sites. It is targeted towards conservation organisations such as English Nature, the Wildlife Trusts and RSPB, and aims to promote the setting up of arrangements for sharing data between such organisations and the Environment Agency.

This document has been produced by

ENVIRONMENT AGENCY

The **Environment Agency** is responsible for controlling pollution of air, land and water throughout England and Wales. It also has responsibility for managing water resources, flood defences and freshwater fisheries.

And supported by

ENGLISH NATURE

English Nature is the government agency that champions wildlife and natural features throughout England.

The wildlife TRUSTS

The Wildlife Trusts are a unique national partnership of 46 independent charities, the Urban Wildlife Partnership and Wildlife Watch, the junior branch. Collectively the Trusts manage more than 2,200 areas of wetland habitat, covering more than 11,400ha. The Wildlife Trusts have a central Water Policy Team to promote best practice in wetland management and offer advice to landowners in the wider countryside through a network of Otters and Rivers Project Officers.

RSPB

The Royal Society for the Protection of Birds is the charity that takes action for wild birds and the environment. It is Europe's largest voluntary wildlife conservation body.

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1. Introduction

This booklet has been published to assist with the monitoring of water levels and flows at wetlands, although for the purpose of this document we have not included estuaries in our considerations. It suggests a number of methods to collect accurate and meaningful measurements of groundwater (underground water) levels and surface water levels and flows. It also outlines how surface water and groundwater may interact at wetlands, and how information on water levels and flows can be used to gain a better understanding of wetland processes.

There are numerous types of wetland, providing varied and diverse habitats. Many factors determine which wetland species thrive and compete successfully with other species, including hydrochemistry, meteorology, ecology and management practices. However, hydrology and water quantity are considered to be the main factors driving wetland ecosystems. A knowledge and understanding of water processes, therefore, is crucial in developing an effective wetland management.

Although this document concentrates on monitoring water levels and flows, it must be stressed that these are only two elements of many. Without an understanding of all the factors influencing a wetland, it is doubtful if the meaning of water level and flow measurements will be fully understood.

A fundamental part of understanding water processes is having information on the levels and flows of groundwater and surface water in different parts of the wetland or surrounding area. This will help in working out where the water forming the wetland comes from, where it is going and the cause of any change in the wetland's water supply.

As part of its duties, the Environment Agency maintains a wide system of groundwater and surface water monitoring throughout England and Wales. Many wetland management organisations also undertake their own water level and flow monitoring using monitoring boreholes and surface water gauges. However, more detailed information could be obtained if the design of monitoring facilities or arrangements were improved. The aim is to establish a routine exchange of data between the Agency, Wildlife Trusts, the RSPB, English Nature and other organisations to build up a database of water level information. This can then be used by all interested organisations.

By promoting an awareness of best practice, and sharing information, the results of water level and flow monitoring can be used to manage water resources effectively, thus protecting our valuable wetland habitats.

2. The role of the Environment Agency and statutory nature conservation bodies

English Nature, the Countryside Council for Wales, Scottish Natural Heritage and the Northern Ireland Environment Service are responsible for overseeing the management and general protection of the United Kingdom's biodiversity, including wetland sites. The responsibility for protecting the water resources that help create and sustain wetlands resides with the Agency.

Wetlands are protected by national and international treaties and conventions. The legislation can be divided into two types, that covering protected wetland species and that including the wetland habitat itself. The main articles of legislation are summarised in Section 9 of this booklet.

Advice on water level and flow monitoring can be obtained from the Water Resources Section at your local Agency office, details of which can be found at the end of this booklet. The Agency may also be able to provide useful information on water levels and flows near your site.

We encourage voluntary bodies and other organisations to contact us so that arrangements can be made to share information and resources, benefiting both parties.

Some arrangements for sharing detailed information have already been made between the Agency and other organisations, but more are needed. One example is the Hydrological Monitoring of Wetlands project that has established a monitoring programme for 48 Sites of Special Scientific Interest (SSSIs) in East Anglia.

Before carrying out any operation that could possibly *affect* a designated wetland, whether on the wetland site or not, the relevant nature conservation body must be contacted for permission. Thus, for example, excavations to establish underlying geology in the vicinity of a wetland may require permission. Consent may also be required from the Agency to install certain types of surface water measurement instruments, such as weir plates. Therefore, you should contact the Agency before carrying out any work in the vicinity of a wetland site that could possibly pollute or disturb the flow of water. We will tell you whether permission is required and, if it is, how to apply. Authorisation may also be required from the Internal Drainage Board. Your local Agency office will be able to provide contact details.

3. What is a wetland?

Many plants and animals depend on wetland habitats. A great many plant species cannot survive unless the water table is within 10cm of ground level. Wading birds must have wet soils in the spring and summer to find food to rear their offspring. Maintaining the appropriate water levels and flows in a wetland is vital to the conservation of much of Britain's flora and fauna. Further information on the water level requirements of selected flora and fauna can be found in the references given in Section 9.

There are many definitions of what constitutes a wetland. One is that:

"Wetlands are areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six metres."
(The Convention on Wetlands, Ramsar, Iran, 1971)

This is a very broad definition. Another one was offered in a publication by Wheeler *et al* in 1995 (see reference in Section 9):

"Wetland is land that has (or had until modified) a water level predominantly at, near, or up to 1.5m above the ground surface for sufficient time during the year to allow hydrological processes to be a major influence on the soils and biota. These processes may be expressed in certain features, such as characteristic soils and vegetation."

These definitions suggest that water in different types of wetland such as marsh, river or lake, can interact with one another. Water level and flow monitoring can help piece together how this interaction is occurring.

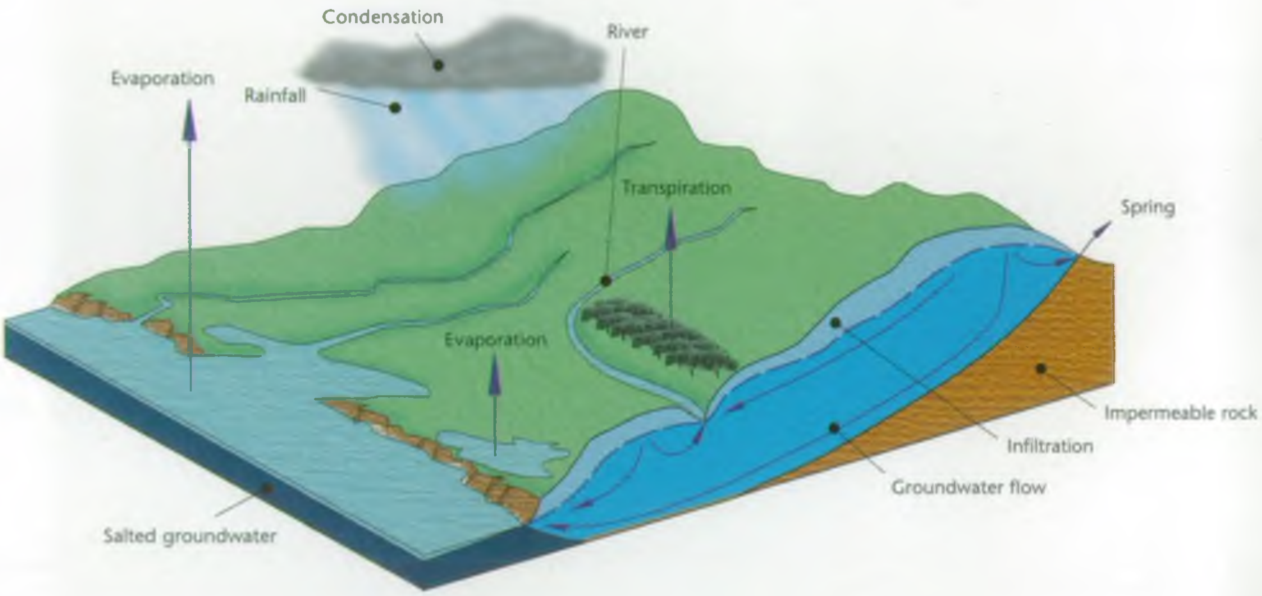
4. The hydrological cycle

The hydrological cycle is a term used to describe the way water circulates in the natural environment. There are four main parts of the circulatory system:

- precipitation (including snow as well as rainfall);
- effective precipitation (precipitation that recharges the aquifer);
- surface water (rivers, lakes and the oceans);
- groundwater (water moving or stored below ground).

The sun provides energy to power the system, evaporating water from lakes and oceans, or releasing it to the atmosphere from vegetation by transpiration. The water vaporises to form clouds and condenses to rain or snow. Some of the precipitation collects on the ground to form ponds or lakes, or runs over the surface as streams and rivers to enter the oceans. Another portion of precipitation, the effective precipitation, percolates through the soil into permeable rocks (aquifers) and becomes groundwater. Groundwater flows through the spaces between grains of rock particles, or through cracks in the rock, and comes to the ground as a seepage at springs, rivers and in the ocean *(Figure 1)*.

Figure 1 *The hydrological cycle* *With permission of the UK Groundwater Forum*



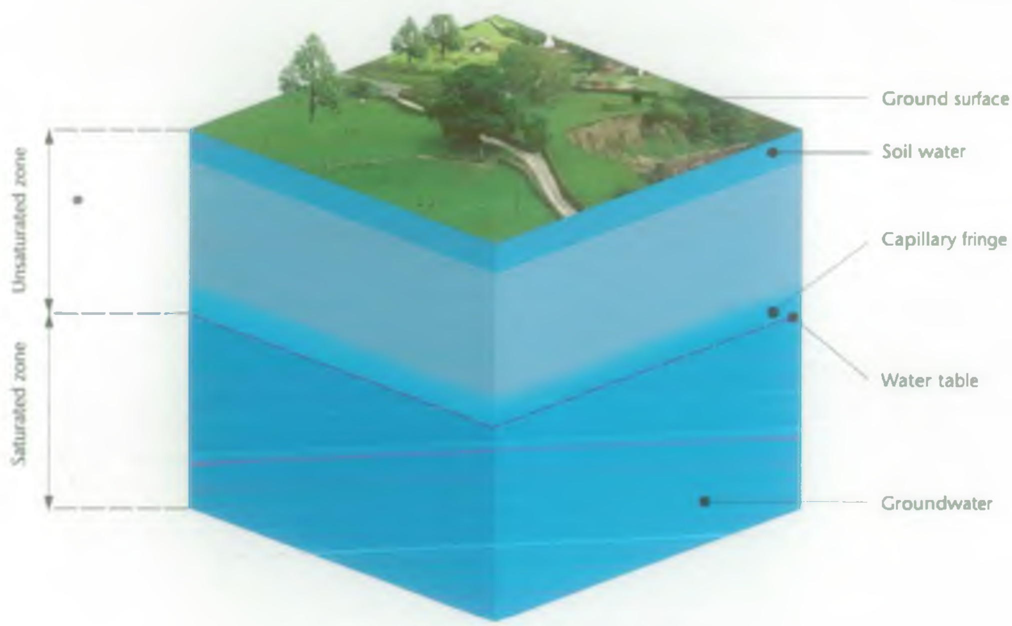
Springs occur where the groundwater surface (the water table) intersects the ground surface and groundwater flows out of the aquifer to become part of the surface water system. This may be in valleys or along coastlines. Rivers often rely on groundwater seepages for flow in the drier summer months.

The depth to the water table will depend on how much effective precipitation replenishes groundwater compared with how much water leaves via springs or other means. The water table will generally rise during the winter and fall in summer because of seasonal variations in precipitation and evapotranspiration.

The soils or rocks beneath the water table are saturated, while those above the water table are unsaturated. Although unsaturated, shallow soils will still usually hold some water as soil moisture, which adheres to soil or rock particles. This moisture can be used by vegetation and returned to the atmosphere by evapotranspiration. Precipitation percolating down through the ground will adhere to soil or rock particles until the soil reaches saturation (the field capacity). When a soil has reached its field capacity, any further infiltration will drain to the water table, becoming effective and recharging the aquifer. A soil that is drier than its field capacity has a soil moisture deficit. Note that recharge can occur even when there is a soil moisture deficit.

Immediately above the water table, water is drawn up into pore spaces by capillary forces into a thin zone called the capillary fringe *(Figure 2)*. The thickness of this zone will depend on the rock/soil type: the finer the rock particles, the thicker the capillary fringe.

Figure 2 *Profile of subsurface water* *With permission of the UK Groundwater Forum*

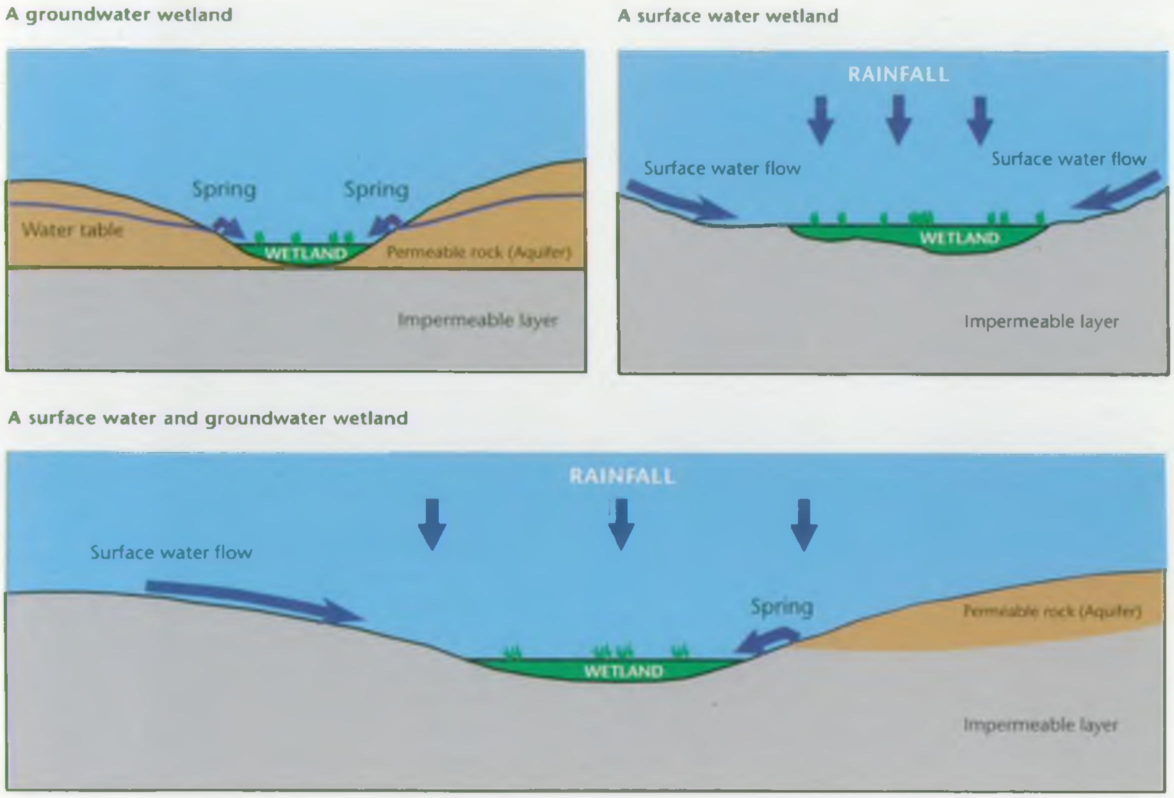


5. Types of wetland

Many wetlands are formed on waterlogged ground, where infiltrating water is blocked by a shallow layer of low permeability soil, such as clay, or where the water table is so high that it meets the ground surface, creating seepages. Any wetland habitats formed in these ways will be susceptible to fluctuations in the water table.

However, not all types of wetlands are dependent upon groundwater. Some will derive all their water from rainfall and surface run-off, while many will depend upon both groundwater and surface water; a few different types of wetland are illustrated in *Figure 3*.

Figure 3 *General types of wetland*



The interaction between the surface water and groundwater can strongly influence ecological processes. The drying of wetlands may be a natural process, as the ground level rises through the accumulation of organic matter and other types of flora and fauna succeed the wetland species (seral progression). In other cases, climatic or artificial factors may influence the wetland water supply and hence the ecology. The understanding of water processes at an individual wetland therefore provides an essential management tool.

6. Monitoring groundwater levels and flows

Monitoring borehole, Tubewell, Monitoring well, Dip-well or Piezometer?

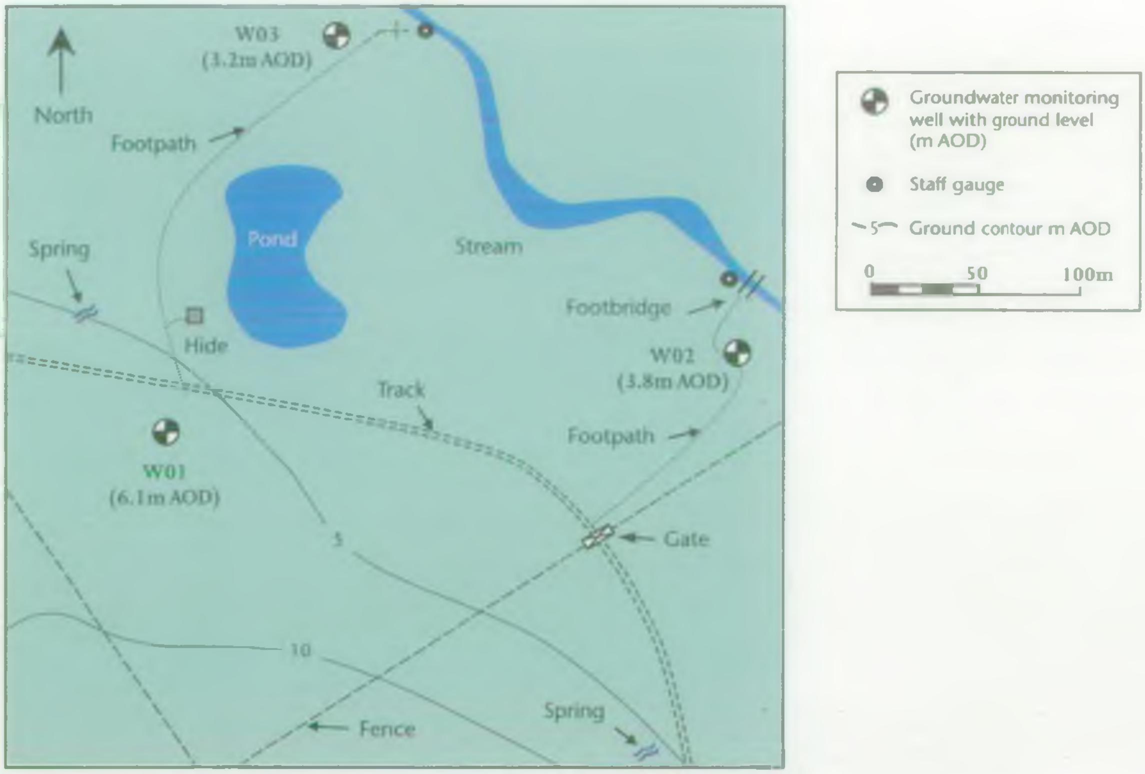
Groundwater levels can be measured using any hole that is dug below the water table. However, holes that collapse, become damaged, or are inadequately designed will provide little useful information. Groundwater monitoring holes are known by a number of terms, including monitoring boreholes, monitoring wells, dip-wells and boreholes. The term **monitoring borehole** is used in this booklet. Monitoring boreholes connect groundwater with the atmosphere, and the level of the groundwater in the borehole is the level at which water pressure is equal to atmospheric pressure. The term dip-well is generally used for monitoring points constructed below the expected lower level of variation of the water table. A piezometer is a more specialised type of monitoring borehole, used to record water pressure – and, by inference, level, in a specific geological layer. Further details are given later in this section.

Planning

Before setting out a groundwater monitoring scheme we recommend contacting your local Agency office to discuss your proposed scheme. Some background planning is essential. A good place to start is preparing a scale plan of the wetland and surrounding area. The Ordnance Survey publishes maps at scales of 1:50,000, 1:25,000 and 1:10,000 over the whole of Great Britain, and at 1:2,500 and 1:1,250 in certain areas.

The 1:50,000 and 1:25,000 scales are unlikely to provide sufficient detail, but a photocopy of one of the larger scale maps (with the permission of the Ordnance Survey) could form a base plan that can be annotated with relevant features such as springs or water issues, ponds, access tracks, and the like (*Figure 4*).

Figure 4 *Base plan*



The geology influences the occurrence of springs and other wetland features. Geological maps are often held by local libraries or can be purchased from the British Geological Survey. These maps come in "solid" and "drift" versions. Basically the "solid" geology is the older, underlying rocks while the "drift" is the more recent, superficial deposits laid down since the last Ice Age. The "drift" maps will probably be the most useful, as wetland sites are generally shallow surface features. Geological details, such as the boundaries between different rock types, or types of "drift" deposit, can be drawn onto the Ordnance Survey base plan. A cross-section constructed using the geological map information could be useful when deciding how deep the monitoring boreholes need to be and the best method of installing them.

At the planning stage, it is important to establish if there are any buried service cables or pipes beneath the site. This can be undertaken by contacting the local water, telecommunications, gas and electricity suppliers, giving details of the site location and, if possible, a grid reference.

Digging pits or making auger holes (described later) will establish the local geology in more detail and will provide an indication of the depth to the water table. If drilling or digging works are intended for these environmentally sensitive sites, it should be borne in mind that drilling on an SSSI is a notifiable operation and requires consent from the relevant nature conservation body (see Section 2). Furthermore, obtaining access and permission to drill on wetlands can take a long time, with potential restrictions being bird breeding, shooting seasons, and the like.

Deciding the number and location of monitoring boreholes

Deciding how many monitoring boreholes to install will depend on the objectives of the study, the size of the area, the resources available, the uniformity of the drift geology and other practical aspects. At least three monitoring points, arranged in a triangle, are needed to give the direction of groundwater flow; many more may be needed for a detailed study. However, there may be existing monitoring points nearby that could be used to supplement your own monitoring, hence reducing the number you need to install at the site. The Agency has a network of monitoring boreholes (see Section 2) and in addition to this the Environmental Health Department of the local council holds a list of domestic water wells.

Deciding where to locate monitoring points will be dependent on site-specific conditions. It is nearly always preferable to place monitoring boreholes on firm, dry ground. Although this may not be possible on many wetland sites, it makes installation easier and reduces the risk of surface water leaking into the monitoring borehole, thereby giving misleading groundwater level readings. The ease and the legality of access must also be considered, bearing in mind that materials to build the monitoring borehole will need to be transported and someone will need to make regular visits to take groundwater level readings.

Designing a monitoring borehole

The exact design of a monitoring borehole will depend on site-specific conditions and the reason for any particular study of groundwater levels. For instance, cheap and not particularly robust materials could be used if a study were to last only a few weeks, such as to investigate daily fluctuations in water level during the growing season. For longer studies, much more sturdy monitoring facilities will be required that can remain serviceable for perhaps many years.

The guidelines given below should therefore be amended to suit site-specific conditions. Remember that data quality will be sacrificed if short cuts are taken.

Depth and construction of monitoring boreholes

The minimum depth of the monitoring boreholes (and hence the amount of material needed to build them) will be dependent on the depth to the water table, which will vary from season to season. The background information, such as the elevation of springs or water levels in nearby wells, should provide a fair indication of what to expect. As a rule of thumb, the higher the ground, the deeper the groundwater table. Therefore if three monitoring points are installed, for example, two of the three could be on lower ground to minimise the depth and cost of installation.

The bottom of a monitoring borehole must always lie below the water table. The seasonal variation in the water table should be allowed for when planning the depth of the monitoring borehole (methods of excavation are described in the following section). Plastic tubing is placed in the drilled hole to prevent the sides collapsing (see following section). The parts of the tubing that lie below the water table are slotted to allow groundwater to flow freely into and out of the borehole as the water table rises or falls (the response zone). The slotted section of tube is often wrapped in a fine mesh, known as a geomembrane wrap or sock, to reduce the entry of silt or fine sand. The open end of the tube should be sealed with an end-cap for the same reason. It is a good idea to have a section of plain (non-slotted) tubing, about 25-50cm long, below the slotted section to act as a sump or sediment trap (these dimensions are only a guide – longer sediment traps may be required in very silty material). Any sediment accumulating in the borehole will settle in the sump and not clog the response zone. However, the sediment will still need to be cleared periodically, once the sump is full.

The slots in the tubing should not extend to the ground surface, otherwise rainwater could leak into the tube and give misleading readings. The section just below ground should be lined with plain (non-slotted) tubing. The gap between the side of the borehole and the plain section of tubing should be sealed with concrete or bentonite, which is a type of clay that swells when mixed with water to form a watertight seal. The gap between the slotted tube and the side of the borehole should be filled with clean gravel (a filter pack). The filter pack should be designed to prevent the surrounding soil being drawn into the tube, but not be so fine as to prevent the ingress of water to the tube. Guidelines on the design of filter packs can be found in *'The Control of Groundwater for Temporary Works'*: see the references in Section 9. A layer of fine sand should then be placed on top of the gravel to stop the concrete or bentonite from leaking downwards into the filter pack and the slotted tube. The construction of a typical monitoring borehole is shown in *Figure 5*.

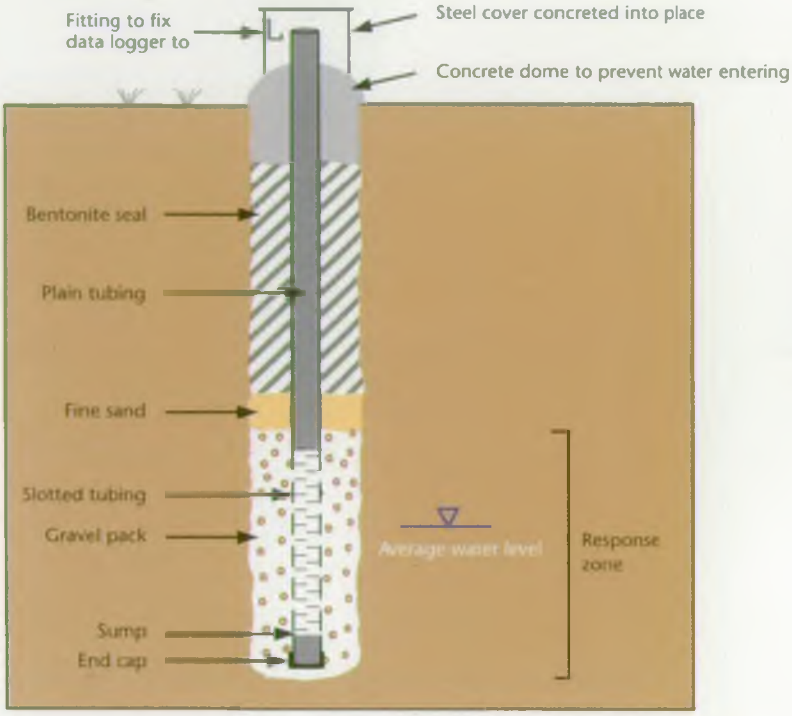
Types of plastic well tube

Specialist plastic well tubing is commercially available in plain or pre-slotted lengths (normally three metres) that are usually threaded at each end so that sections can be screwed together. The tubing is commonly available in internal diameters of 19mm, 50mm and 100mm. The smaller diameter tubing is useful in certain circumstances but tends to clog easily, can become obstructed, is difficult to clean out (described later) and is not suitable for collecting samples of water if required for chemical analysis. For all practical purposes an internal diameter of about 50mm, or larger, is recommended. Advice on purchasing plastic tubing and other specialist monitoring borehole materials can be obtained from the British Drilling Association; contact details are given in Section 9.

Well tubes could also be made using plastic tubing available from DIY stores. In this case, the slots will need to be cut using a hacksaw or small circular saw. If using "home-made" tubes, make sure they are robust and not liable to buckle or crack, and that they are not going to degrade and present a chemical hazard. As a guide, tubes made from uPVC or HDPE are usually appropriate.

Plastic land drainage or irrigation pipes could also serve as well tubes. They are pre-slotted, but usually come in fairly large diameters of about 150mm. This may make it difficult to drill a wide enough hole if manual methods are used (described later).

Figure 5 Monitoring borehole



Joining lengths of well tube

If threaded tubing is not available, then joining lengths of tubing can be problematic. If the tubes are manufactured with a male and female connection at each end, they can be kept together using adhesive or a grub-screw. Since the connections bulge on the side of the tube, care must be taken to ensure a gravel pack can still pass the joints to reach the deeper parts of the borehole. Adhesive may be picked up in the chemical analysis of any water samples taken from a monitoring borehole constructed in this manner, giving misleading results.

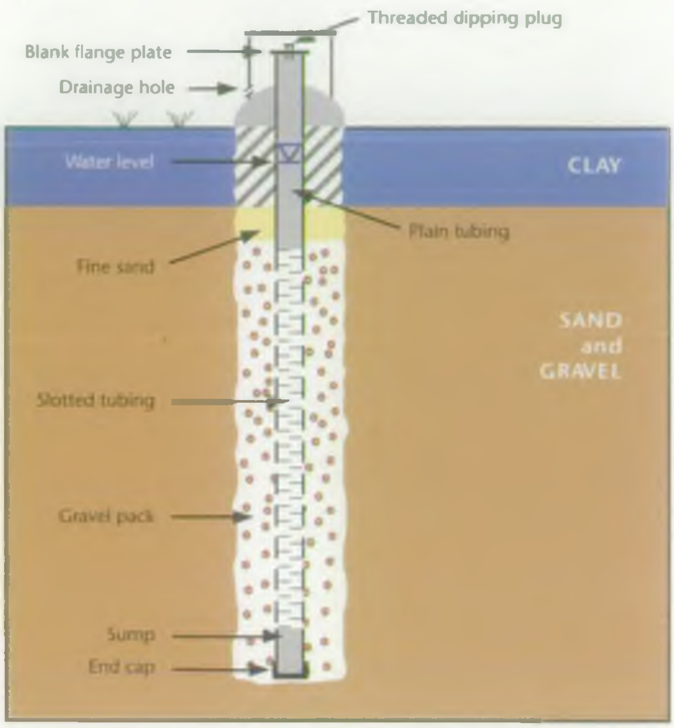
Completing a monitoring borehole

Finally, the top of the borehole should be covered with a cap to stop foreign objects falling in. Ideally, the tubing protruding above ground should be provided with a fitting to allow for the installation of a data logger protected securely by a steel cylinder, concreted into place and sealed with a lockable lid (*Figure 5*).

Installing a data logger

Data loggers can be mounted to the inside of the steel liner. In the Agency's Anglian Region, this was undertaken by welding a metal frame to the inside of the security cover into which the loggers fits. Further information on data loggers is given later. If the borehole is overflowing, drainage holes should be drilled into the side of the protective casing to allow the water to drain away and prevent the security cover from becoming flooded (*Figure 6*). Monitoring overflowing or artesian groundwater is described in the next section.

Figure 6 Monitoring borehole for confined conditions



Special cases

Confined and artesian conditions

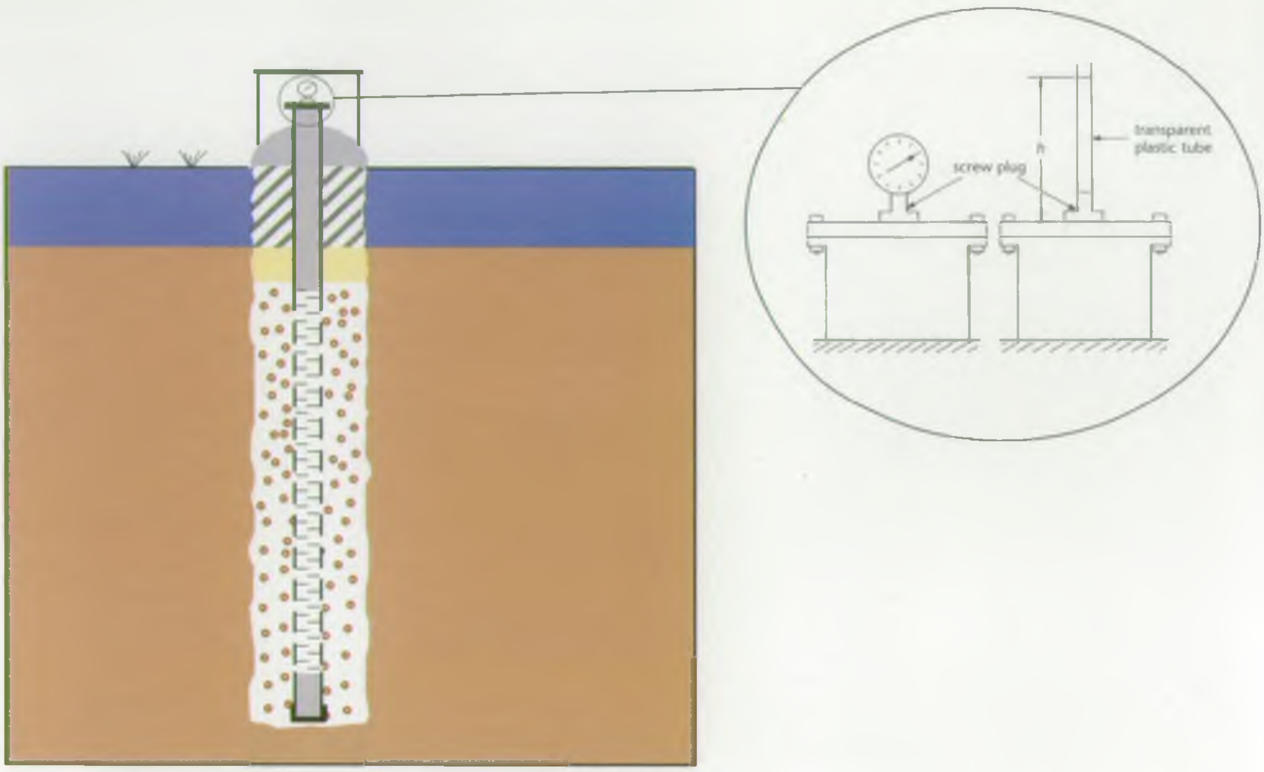
In some cases, groundwater in a permeable material such as sand or gravel, will be under pressure due to an impermeable layer above it, such as clay. If a monitoring borehole is drilled and lined with non-slotted tubing through the clay, the water in the sand or gravel will rise up the well. The water level recorded in this situation is equal to the water pressure in the material penetrated by the slotted lower section of the borehole. This is known as a confined condition (*Figure 6*). If the water rises above the ground surface, this is known as an artesian condition. In these instances, the response zone should be placed in the permeable layer.

If groundwater overflows the top of a monitoring borehole (artesian groundwater), the monitoring borehole should be constructed to prevent groundwater from persistently flowing from it and being lost from the aquifer but still allow future groundwater level measurements to be undertaken (see *Figure 6*). This will require the non-slotted top section of the monitoring borehole to protrude above ground level. The tube should be fitted with a blank flange, complete with a threaded dipping plug (*Figure 7*). To obtain a water level reading, the plug is removed and replaced with a transparent tube or a pressure gauge. It is not always appropriate to use a transparent tube, since depending on the groundwater head, the tube may need to be very long, which may be unmanageable. For example, a three-metre length of tubing would be very difficult to hold vertically while the head is measured; for these conditions use a pressure gauge.

If a tube is used, the groundwater will rise up inside the tube until it reaches what is known as its "rest water level". The tube should be held vertically and the vertical distance between a fixed point on the flange (establishing a reference point is described later in this section) and the water surface measured; this is the groundwater level. It is important to ensure that the transparent tube forms a good seal with the flange on the top of the monitoring borehole.

Alternatively, a pressure gauge can be used to obtain an artesian groundwater level reading, since groundwater under 1 bar of pressure at ground level will rise to approximately 10m above ground

Figure 7 Monitoring set-up for artesian conditions



level. Each pressure gauge will need calibration for an accurate reading. Once the plug has been removed the pressure gauge can be screwed into the threaded dipping pipe and a reading obtained.

Piezometers and nested piezometers

Where it is important to measure the groundwater level, or pressure, at a specific depth in an aquifer, or within a specific geological layer, a **piezometer** can be installed. A piezometer is a monitoring borehole whose response zone (slotted section) represents only a small proportion of the total depth of the aquifer. Piezometers are often installed where an aquifer contains horizontal layers of low permeability material, such as clay; in this situation, the groundwater pressure above the clay layer may be very different from that below it.

A further refinement of the piezometer is the **nested piezometer** (*Figure 8*). Two or more tubes are installed in the same borehole, with the response zone of each tube set within a specific permeable layer. Water leakage between the permeable layers must be prevented by sealing the gap between the tubes and the sides of the borehole with bentonite.

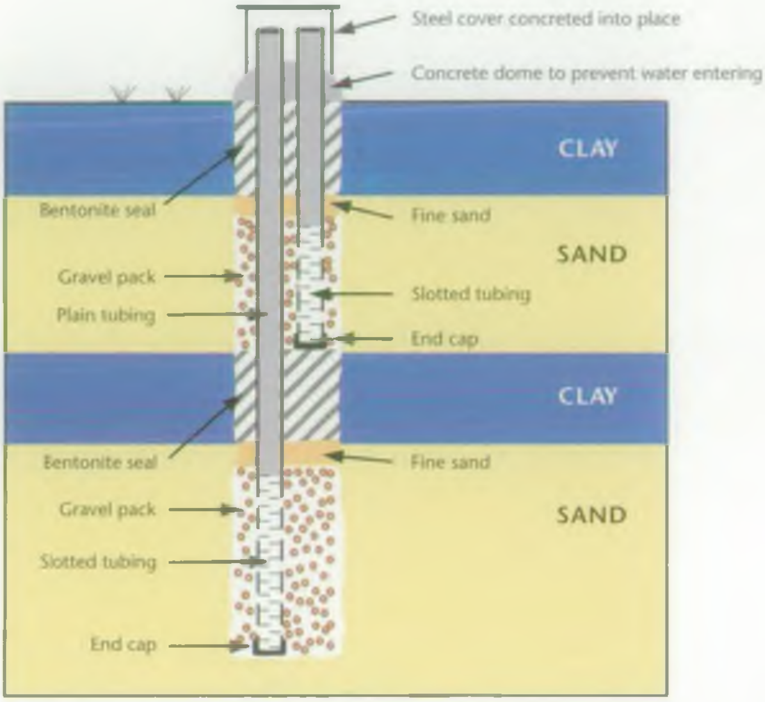
If piezometers are nested, small diameter tubing is normally required. However, this may not be appropriate if water sampling is required in addition to, or instead of, water level monitoring. If water sampling is required, it is often more appropriate to install two separate piezometers, but close to each other, say three to four metres apart, and use larger diameter tubing.

Methods of installing a monitoring borehole

Drilling

Monitoring boreholes can be sunk in a number of ways and the technique adopted in any situation will be governed by the geology and site conditions. It is stressed that ***operating any type of drilling machinery is potentially dangerous. It should only be carried out by appropriately trained and experienced persons. If drilled boreholes are required, the Agency recommends that drilling works are undertaken by specialist contractors. Your local Agency office should be able to supply you with details and guidance on contacting your nearest specialist contractor. Information on drilling can also be obtained from the British Drilling Association (see contact information at the end of this booklet).***

Figure 8 Nested piezometer



Additionally, before any excavations are undertaken, a search for any buried cables or pipes should be made on-site by an appropriately trained person using a cable-locating device.

Specialist borehole drillers commonly use "cable-tool percussion" techniques (also known as "shell and auger") to drill through relatively soft or granular soils. This involves repeatedly raising an open-ended tube on a cable attached to a winch and letting it fall to make a hole. Steel casing is then pushed to the bottom of the hole to keep it open and the process repeated. Plastic tubing is then placed inside the steel casing and the casing withdrawn. Harder rocks require methods such as rotary drilling, but this technique is very expensive and tends to be used for deep boreholes. Since most small wetland monitoring projects tend to be more concerned with the shallow groundwater information, rotary drilling would not generally be a technique used.

The potential damage to the wetland ecology caused by the drilling equipment should always be considered when selecting a drilling technique for a wetland site. In particular, full consideration must be given to the logistics of accessing the site with drilling equipment, and the effects of such access on the wetland environment. Further, full consideration must be given to the geology of the site (as mentioned in the Planning Section). For example, drilling through a perched aquifer (a saturated lens above the water table) may drain the wetland and destroy the site.

Mechanical excavators

Installing a monitoring borehole into a hole dug using a mechanical excavator invariably disturbs the surrounding ground and makes it very difficult to place a gravel pack or concrete/bentonite seal. This technique can perhaps be used in gravel where a filter pack is not so important, but it is difficult to achieve a good quality monitoring borehole installation and this method is generally not recommended.

Hand augers

A shallow borehole can be drilled using relatively cheap methods. In many cases, the groundwater at wetlands is rarely more than about three metres below ground (although this could vary markedly between summer and winter).

Boring by hand auger is a common method of drilling shallow boreholes. It works best in soft soils that are relatively stable, such as clayey sands, silt or peat. It is of limited use in soils that are not self-supporting (such as sands or gravels) as the hole collapses as soon as the auger is withdrawn, especially below the water table. Coarse gravels or cobbles can also be very difficult physically to auger through.

One way of preventing hole collapse is to auger a short section of hole, remove the handle from the auger, place a slightly oversized steel tube over the auger and then drive it to the base of the hole. For practical reasons, short sections of steel tube should be used, connected with threaded joints. This process is repeated until the required depth is reached. Plastic tubing can then be inserted and the steel tube slowly withdrawn as the gravel pack, sand, bentonite and cement is poured in. This is a laborious technique and problems are often encountered withdrawing the steel tube.

Motor driven augers

Portable motor-driven augers are available that can reduce the time and physical effort of drilling compared with a hand auger. Shallow boreholes can also be sunk using an agricultural post-hole auger mounted on a tractor.

Installation materials

When installing the plastic tube, care must be taken to keep it vertical so that the gravel pack can be placed evenly in the gap between the tube and the side of the borehole (the annulus). The gravel pack should also be "tamped down" using a length of thin rod as it is being placed. If the gravel pack is placed too "loose" it will settle over time, which could result in the ground slumping at the top of the borehole.

Bentonite is available in pellet or powder form. Pellets are the easiest to use, and should be briefly wetted in a bucket before placing in the borehole. Natural soil moisture will then cause them to swell and form a seal after a short time.

It is worthwhile making a cement 'dome' around the plain tube protruding from the ground. This will discourage water from ponding around the top of the monitoring borehole.

Cleaning a monitoring borehole

The inside of the monitoring borehole should be cleaned after installation to remove sediment introduced into the borehole during drilling. This can be done by bailing out dirty water using a cylinder on the end of a rope. A more effective method is a simple inertia pump (basically a one-way valve) fitted to the end of a length of stiff plastic tube. The tube and valve are lowered down the monitoring borehole and rapidly lifted up and down a few centimetres. A pulse of water is lifted to the surface. This method induces a surge and backwash of water in the base of the monitoring borehole that encourages sediment to be washed out of the gravel pack. These inertia pumps are relatively cheap. The monitoring borehole will need to be cleaned periodically to prevent excess sediment building up in the bottom and clogging the response zone.

Monitoring well survey

Groundwater level records are of little value unless they are all measured relative to a fixed point, or *datum*. A datum could be a fixed point within or near the wetland, such as the top of a concrete gate post. The level of the ground surface next to each monitoring borehole can then be determined relative to the datum. The depth of the groundwater surface below ground at each monitoring borehole can then easily be converted to a level below the datum.

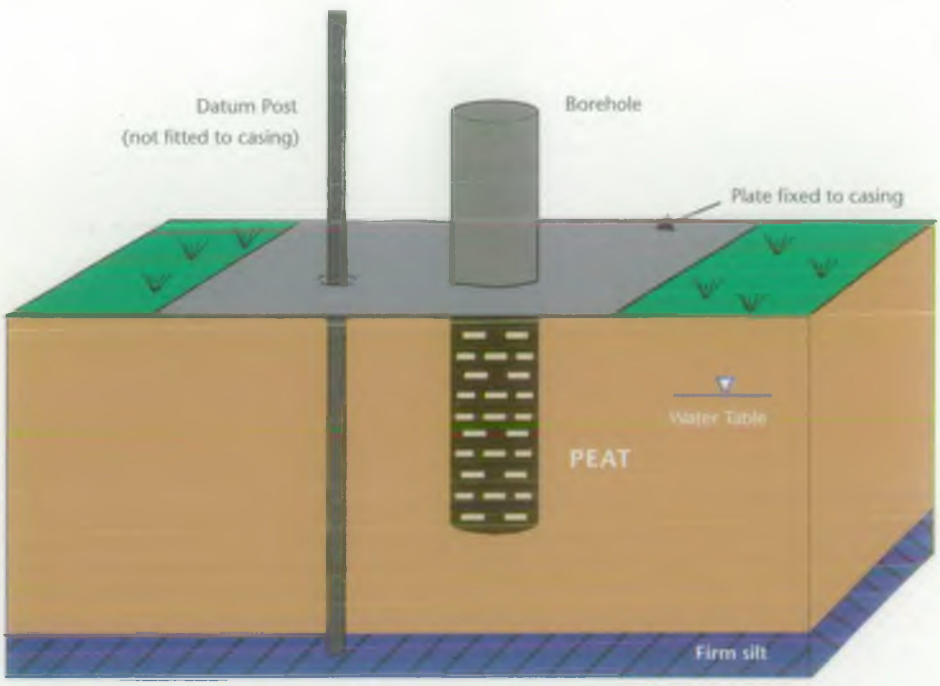
The most accurate way of obtaining level measurements is by using a surveyor's level. This is essentially a telescope on an adjustable base and tripod that allows the line of sight through the telescope to be kept horizontal. Ground levels are measured along this horizontal line using a measuring staff. With practice, an accuracy of a few millimetres can be achieved.

It is worth remembering that the level of very absorbent ground, such as peat, can vary significantly depending on its wetness. Therefore, any boreholes sunk in this sort of ground should have a nearby datum post that is founded in firm ground so that the height of ground at the monitoring point can be regularly corrected (*Figure 9*).

Ideally, the elevation of the site datum should be related to the national datum used by the Ordnance Survey, the Ordnance Datum. This is used on all contour maps published by the Ordnance Survey, although benchmark heights on the maps should be checked for the latest survey results. Heights are therefore expressed as metres above (or below) Ordnance Datum. The Ordnance Survey has accurately surveyed the height of benchmarks throughout the country. Benchmark symbols ( ) are engraved or drawn on permanent structures, such as on houses or bridges and the like. The location and height of these benchmarks are shown on 1:2,500 scale maps.

The level of a site datum or monitoring borehole can be estimated from contour maps to an accuracy of about half the contour interval. On 1:10,000 scale maps this interval is five metres, so an estimate of the height at any point can be made to ±2.5m. This may be adequate in very large sites in hilly areas, but a greater degree of precision will be required in most cases.

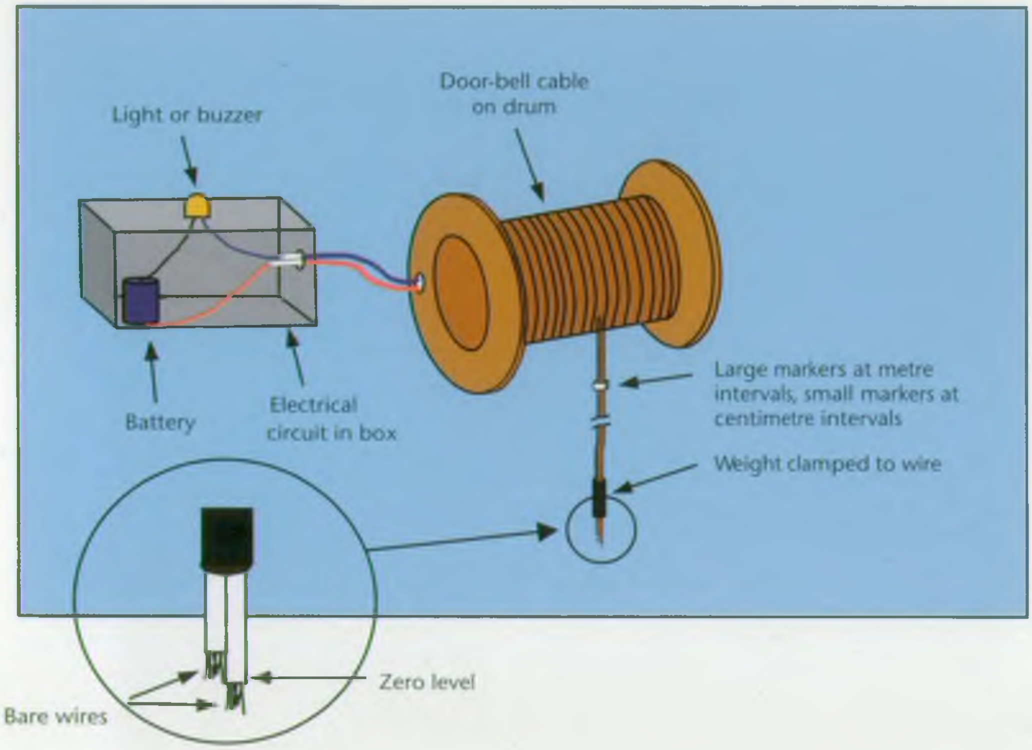
***Figure 9** Setting a borehole datum post*



Measuring groundwater levels

The depth to groundwater in the monitoring borehole must be measured accurately, to within about 1cm. This is usually done using an electric contact dip-meter, which basically consists of a length of twin core wire with a pair of electrodes on the end. When the electrodes touch the water an electric circuit is completed that activates a buzzer or a light. The twin core cable is marked in metres and centimetres, like a tape measure. The depth to water can be measured relative to a fixed point of reference, such as the top of the monitoring borehole tube or steel cover. The reference point should be clearly marked on the borehole to allow future monitoring to be undertaken from the same point. Dip-meters should be checked every 12 months against a steel tape. The dipper tape should be accurate to 1cm in 10m; if it fails to meet this criterion it should not be used. A detailed description of using a dip-meter is given in the Agency's '*Directorate of Water Management Hydrometric Manual*' (see Section 9). Commercially available dip-meters are relatively expensive, but if it is not possible to use a commercial dipper, accurate readings can be obtained using a home-made instrument constructed with a length of door-bell cable and a simple electrical circuit (*Figure 10*).

Figure 10 *Home-made dip-meter*



In cases where the groundwater level is very shallow, it may be possible to obtain accurate readings simply by lowering a tape measure into the tube and watching for "ripples" as it touches the water surface. The tape must be weighted so it hangs straight and allowance must be made for the length of the weight when taking the depth reading. Other types of dip-meter can be improvised, but the electrical contact type is usually the most accurate and can be used in all types of monitoring borehole. If sampling, wash the dipper with de-ionized water before dipping.

Automatic water level recorders can take measurements at very frequent intervals and record the information digitally on commercially available ***data-loggers***. These instruments provide a way of taking regular measurements without frequent visits. Several weeks' worth of readings can be stored by the instrument before it needs to be "downloaded". This could be useful in remote sites, or when very frequent measurements are needed to measure daily changes in the water table caused by transpiration, tidal effects, groundwater/surface water abstraction or land drainage. These devices periodically require maintenance and calibration and a robust borehole cover to fix them to (see Monitoring well survey, page 14). There are also simple mechanical devices that record the maximum and minimum groundwater levels over any given period.

The frequency of groundwater level measurements will depend on the exact purpose of the groundwater monitoring scheme at an individual site and the resources available. Generally, the continuity and regularity of monitoring are more important than the frequency. A record of groundwater level measurement taken regularly every week over a long period is usually preferable to readings taken every day for a month and then not at all for a further month.

Recording groundwater level readings

Ideally, an accurate topographical survey of a wetland should be undertaken to allow a correlation between the hydrological and the ecological information to be made. If this is not possible, then at least the elevation of the monitoring points should be accurately established. The groundwater level readings should be recorded in a way that makes them easy to understand and interpret. This can be done using a record sheet for each monitoring borehole that allows all relevant information to be recorded systematically (*Figure 11*).

In this example, the ground level at the borehole was determined by survey to be 3.8m Above Ordnance Datum (AOD). The point used to take the measurement against, the top of the steel cover, was 0.9m above ground. The measuring point was therefore 4.7m AOD. The groundwater level readings were first recorded as metres below the measuring point. The height of the measuring point was then subtracted to give the depth of the groundwater surface below ground. Finally, the depth below ground was converted to metres AOD so that the groundwater levels in all the wells on the site could be directly compared with one another. The "comment" box on the record form was used to make relevant observations. In this instance, the monitoring borehole was known to have been drilled to 2.8m below ground. Sediment accumulating at the bottom of a borehole can block the response zone, so the base of the borehole was measured to see how much had built up. It was found that the bottom of the borehole was probably blocked with sediment to 2.2m below ground, so the borehole was cleaned on the next visit.

Readily available computer spreadsheet packages provide a good way of keeping a central record of groundwater level readings. In some circumstances, it may also be possible to record the data in a computer format that is compatible with the system used by the Agency, which could be useful in any "information sharing" agreement. We can discuss whether this is appropriate on a case-by-case basis.

***Figure 11** Monitoring borehole measurement record sheet*

Groundwater level record form

Well	W02
Measuring point	Top of steel casing
Height of measuring point above ground level (m)	0.9
Ground level (m AOD)	3.8
Measuring point level (m AOD)	4.7

Site name	Madeup Downs
Depth of well (metres below ground)	2.8
Well location (Grid reference)	SD 1235 3215

	Groundwater level			
Date	Metres below measuring point	Metres below ground	Metres AOD	Comments
1/8/00	1.85	0.95	2.85	Bottom of well = 2.7m below ground
8/8/00	1.15	0.25	3.55	Heavy rain last two days
15/8/00	1.90	1.0	2.80	Base of well 2.2m below ground. Clean well next visit
22/8/00	1.70	0.80	3.00	Cleaned well. Bottom 2.8m below ground
29/8/00	1.90	1.00	2.80	

7. Monitoring surface water levels and flows

Planning

The background planning for surface water monitoring is very similar to setting up a groundwater level monitoring programme. You should contact your local Agency office to discuss your proposed monitoring scheme. Compiling a base plan and background information (including details of underground service cables and pipes in the vicinity of the proposed works) will help develop the basis of a surface water-monitoring scheme. The number of monitoring points and their location will obviously depend on the specific site. When planning the access to the monitoring points, ***particular attention must be paid to the potential hazards of working near water, especially as the person taking the measurements may be operating alone.***

Before any excavations are undertaken, a search for any buried cables or pipes should be made on-site by an appropriately trained person using a cable-locating device.

Surface water level gauges

The simplest method of accurately measuring surface water levels is by using a graduated staff gauge, securely mounted to a post. Various types of automatic surface water level gauges are available that can give very frequent measurements over extended periods. These require more effort to install, but can be very useful in flowing channels where the water level can change rapidly. If a gauge is installed in moving water, you must ensure that the structure to which the gauge is mounted does not produce eddies around the gauge that will produce erroneous readings. For example, the gauge could be located in a part of the channel that has a relatively low flow.

A common problem when installing surface water gauges at wetland sites is finding a means of securing them firmly, so that the water level readings are consistently taken to a fixed datum. In shallow standing water that lies over a soft base, such as peat, it may be possible to drive a steel rod down into firmer ground. It is often prudent to check the level of surface water gauges against the main site datum regularly and adjust them accordingly. This is easier if a secondary datum point is installed nearby, surveyed to the main site datum and located where it can be easily secured. The *'Directorate of Water Management Hydrometric Manual'* identifies that the gauge should start at zero and be levelled back to a fixed, secure benchmark, although it may not be necessary to relate a single surface water gauge to Ordnance Datum. However, if there is a group of gauges and monitoring boreholes on the site, the gauges should be levelled to a common datum. It is generally recommended that Ordnance Datum should be used and the metre marks on the gauge should indicate m AOD.

Surface water level measurements can be recorded on a record form similar to those used for groundwater levels, with surface water gauge readings converted to a common datum. If groundwater level monitoring is also being carried out on the site, then the same site datum should be used for the surface water level measurements. This allows groundwater and surface water levels to be directly compared.

Flow measurements

The rate of flow in surface water channels is a very useful supplement to surface water level measurements. However, it should be noted that in many groundwater-dependent wetlands, the rate of surface water flow is so small that measuring it can be difficult and some measuring devices (such as weirs) may even serve to block the flow. Bearing this in mind, flow can either be calculated from measurements of water velocity and the cross-sectional channel area, or by installing a weir. Most aspects of stream-flow measurement are covered in British Standard ISO 748: 1997 *'Measurement of Liquid Flow in Open Channels'* and the *'Directorate of Water Management Hydrometric Manual'*.

The velocity/cross-sectional area method, although not that accurate, is relatively simple to perform and can be carried out without constructing any permanent apparatus. In its simplest form, the cross-sectional wetted area of a channel can be calculated using measurements taken with a staff rod. The surface velocity can be found by measuring the time taken for a float to travel over a set distance. The float must sit low in the water so that air resistance is minimised (an orange is a good substitute for a purpose-built float). However, the flow near the bottom of a channel will be slower than at the surface due to the effects of friction against the channel bed. Therefore, as this method measures the surface velocity it will overestimate the flow.

At some sites it is possible to correlate the surface velocity with the average velocity in the vertical. This can be undertaken using the velocity distribution method, which is detailed in BS ISO 748: 1997 *'Measurement of Liquid Flow in Open Channels'*. The normal procedure is to apply an estimation factor of between 0.8 and 0.95, depending on the channel shape, water depth and type of float. The higher values are generally taken if the bed is smooth. An example flow calculation is shown below.

Example – float gauging

A float is placed in the centre of a channel and the time taken for it to travel 10 metres is measured three times to gain an average.

Results

Float travel time:	1st = 14 seconds
	2nd = 12 seconds
	3rd = 13 seconds
	Average = 13 seconds

Therefore, the velocity = distance/time = 10/13 = **0.77m/s**

Average channel width = 5 metres
Average water depth = 1.2 metres
Therefore, cross-sectional area = width x depth = 5 x 1.2 = **6m²**

Flow = velocity x cross-sectional area x estimation factor
= 0.77 x 6 x 0.95* = **4.39m³/s**

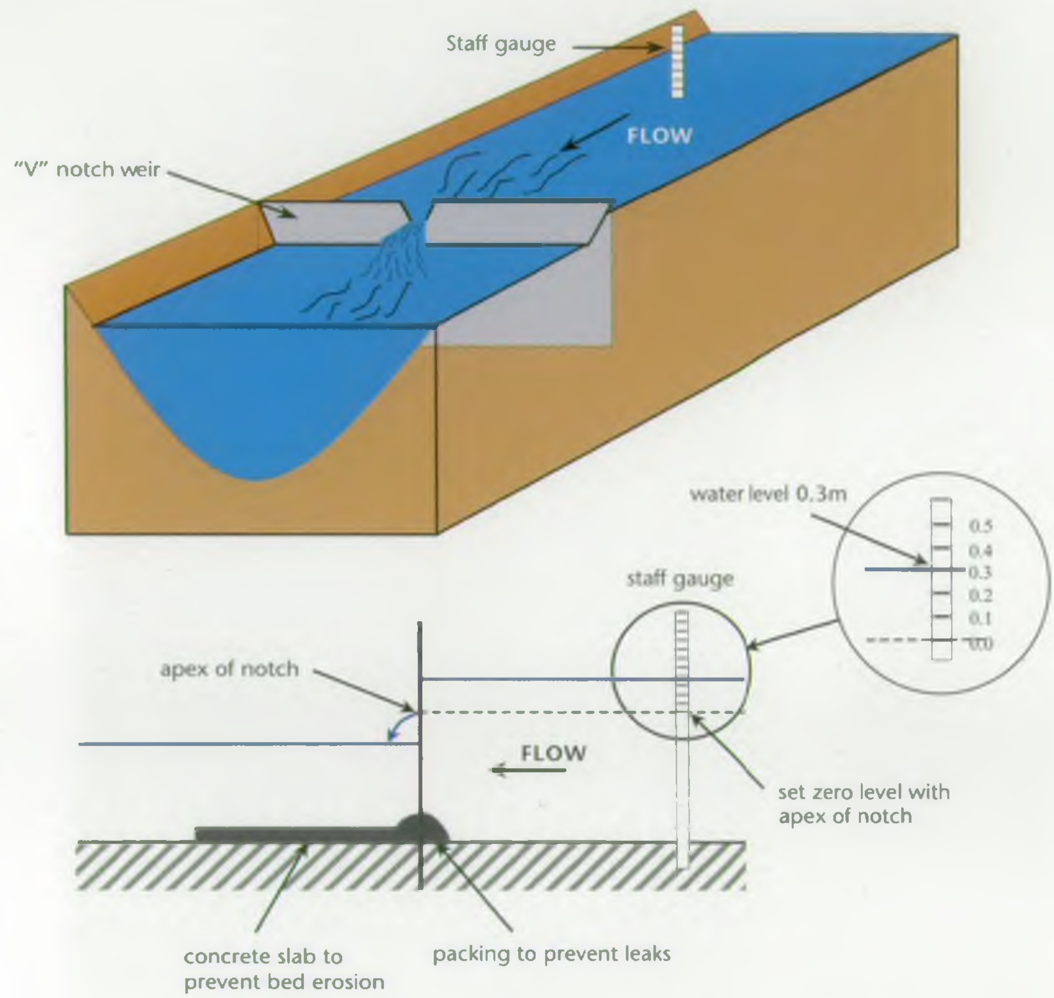
* The channel depth has a smooth bed and so an estimation factor of 0.95 is used

There are a number of portable current meter gauges that can accurately measure the velocity at various points across a channel and at different depths. These commonly comprise an impeller and revolution counter that relate flow velocity to revolutions per second. These systems are relatively costly and taking the measurements is time-consuming.

If you decide to use a portable current meter, the *'Directorate of Water Management Hydrometric Manual'* details a number of characteristics sought for a good current meter gauging site. The main factor is that upstream of the measuring section there should be a long, straight, uniform, well-defined channel. If this distance is expressed as a multiple of river width then it would be 10 x the river width downstream of the nearest upstream bend. ***For rivers less than 50m wide, a straight approach of 4 x the channel width is acceptable***. Flow should be confined to a single channel, the section should be at right angles to the river and direction of flow and not be located near artificial or natural obstructions, such as control/release structures. The section should be free from weed growth, have a relatively smooth channel bed and well-defined, stable banks. Since flow varies with depth in a river channel and current meters only measure point velocity, the current meter must be located to obtain an average velocity. Therefore the current meter should be located at 0.4 of the depth from the river bed – how this procedure is determined is detailed in the *'Directorate of Water Management Hydrometric Manual'*.

Flow measurement weirs are plates set across the channels. Common types have rectangular or "V" notches cut into them. The water backs-up behind the plate until it spills over the notch. The flow can be calculated from the height of water above the notch, measured using a staff gauge upstream of the weir (*Figure 12*).

***Figure 12** "V" notch weir*

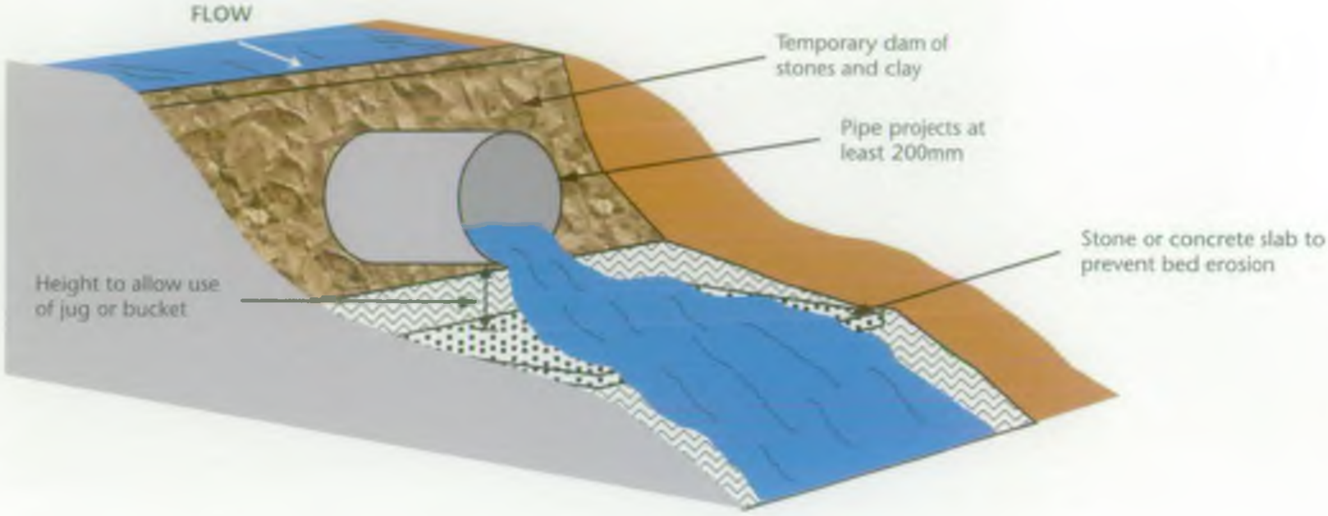


Compared with float gauging, a correctly constructed "V" notch weir is a more effective method of flow measurement. However, installation is not easy and requires considerable effort. Poor workmanship will quickly become apparent by leaks and the eventual washing out of the weir. A detailed description of the correct dimensions for a weir and the methods of calculating flow are contained in the British Standards publication referenced in Section 9 of this booklet.

It is stressed that before installing a weir, the Agency or Internal Drainage Board must be consulted regarding the impacts that the weir may have on water flow and the water environment. A Land Drainage Consent will be needed.

Spring flows are most easily measured by constructing a "catch-pit" at their point of outflow, with a tube that allows water to flow out of the pit. The rate of water flowing from the tube can be measured using a bucket and stop-watch (*Figure 13*). The bucket used for this method should be calibrated. Therefore, if the bucket is thought to be capable of holding 10 litres, calibrate it by measuring 10 litres of water into it using a measuring jug and mark on the side of the bucket with a line.

Figure 13 Measuring spring flow using a catch-pit



A more detailed description and practical advice on all of these methods for measuring flow can be found in *'Hydrology in Practice'* and *'Field Hydrogeology'* (see Section 9).

Springs and their outflows can support a range of highly specialised fauna and can exist as populations comprising few individuals. Before building catch-pits to measure spring flow, an ecological assessment should be undertaken to minimise risk to these specialised and vulnerable species.

8. Using water level data

Accurate water level information can be of great benefit to wetland management. The information can be used to determine and predict long-term water level trends. It can also provide an insight into how the water regime works and therefore aid management of the water system. For example, the effects that wetland management practices, such as scrub clearance, have on the water table can be identified.

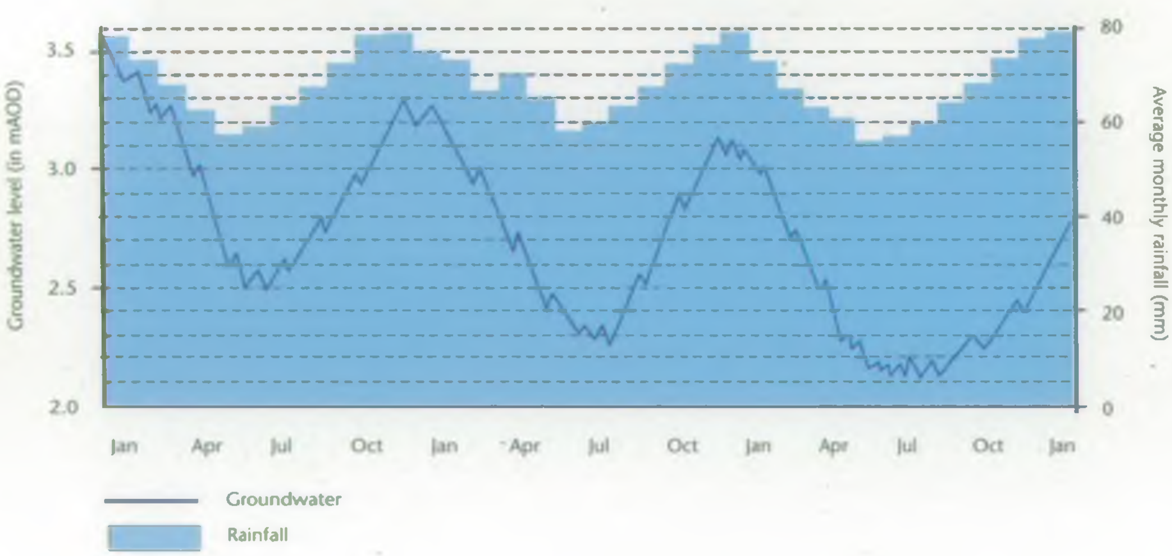
The value of the water level measurements will be enhanced if rainfall and (ideally) evapotranspiration data are also available. Evapotranspiration can have a surprisingly large effect on water levels. There may be a discernible daily rise and fall of water level, in response to water being removed by plants, during daylight hours in the growing season. Therefore the factors influencing the amount of evapotranspiration, such as the type of vegetation and the time of year, may also influence water levels to some degree. The Meteorological Office can provide information on rainfall and evapotranspiration obtained from measuring stations around the country, but you will be charged for it. A discussion of your specific requirements is available free of charge and a quotation for the cost of their services can be provided on a site-by-site basis.

The first steps in interpreting water level information are making hydrographs, which are graphs that show groundwater or surface water levels over time, and drawing groundwater contours, which show a map of the groundwater level at a specific time. This information can be used to improve your understanding of the hydraulic regime of the wetland, that is, the nature of groundwater and surface water levels and flow, and the interaction between them.

Hydrographs

Water level information (groundwater or surface water) can be displayed on a graph that allows the variations in water levels over time to be seen easily (*Figure 14*). This example shows groundwater levels, but a similar graph can be created for surface water measurements.

Figure 14 *Example hydrograph*



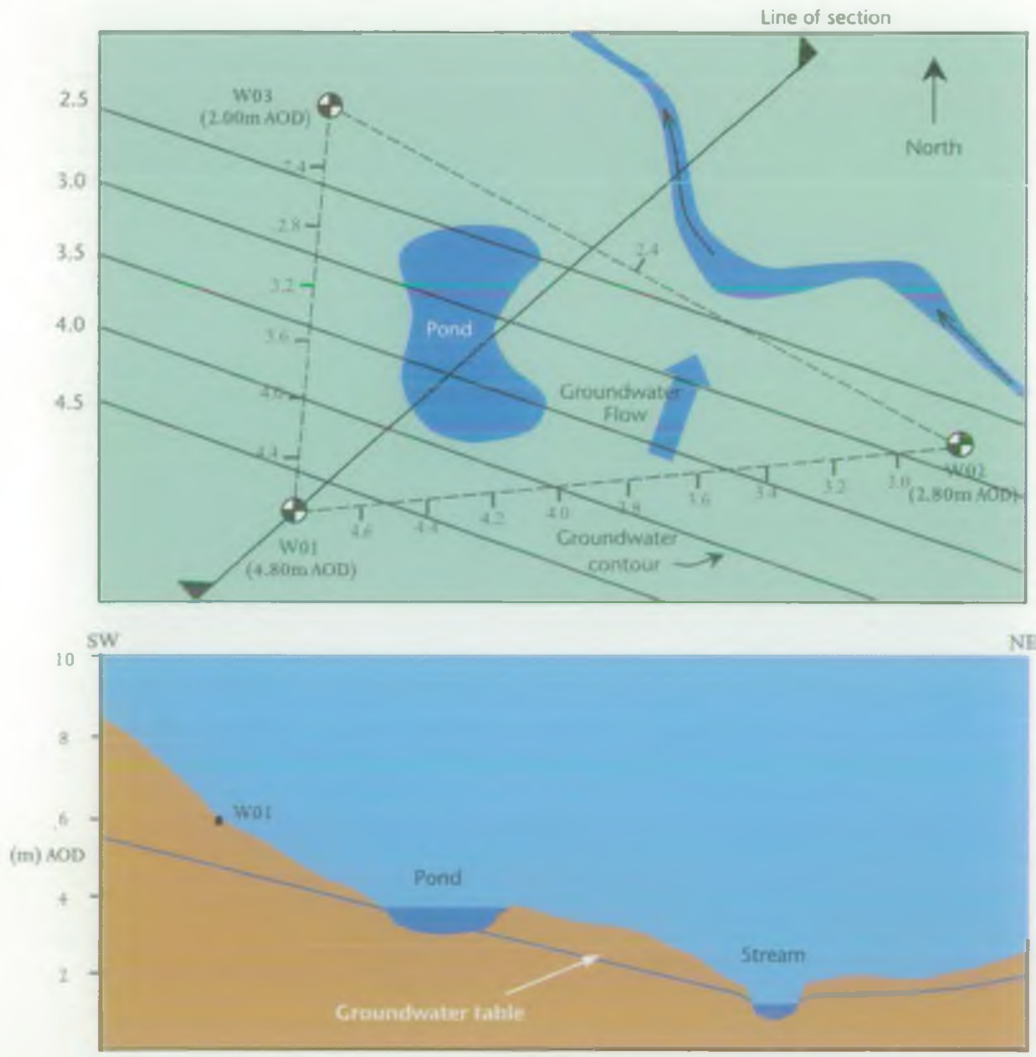
In the example hydrograph, groundwater levels and rainfall have been plotted on the same graph. In this example, groundwater levels and rainfall follow a seasonal variation; high in winter and lower in summer (note that most, but not all, aquifers in the British Isles follow this pattern.) The highest and lowest levels reached by groundwater in successive years are gradually declining. Therefore, the water table is slowly falling. If the ecology or the site critically relies on groundwater to maintain wetland habitats, this could lead to progressively larger amounts of drying out in the summer months. This could detrimentally affect wetland ecology. However, it can be seen that the amount of rainfall remains fairly constant. Therefore, the decline in the groundwater level does not appear to be related to rainfall over the monitoring period.

In this hypothetical example, it is possible that factors other than rainfall are affecting the groundwater level, such as an increase in the evaporative demand of the wetland, poor site management, local pumping of groundwater for irrigation or public supply, or increasing surface water run-off by clearing ditches. Ditches may even intercept the groundwater table, thus reducing groundwater flow to the wetland. Groundwater levels often take a long time, perhaps many years, to respond to influencing factors. Therefore a long record is needed to identify any historic groundwater level changes.

Groundwater contours

A map of groundwater contours shows the level of the groundwater surface, just as the contours on an Ordnance Survey map show the height of the ground AOD. If the groundwater contours are shown as metres AOD, they can be directly compared with the ground surface shown on an ordinary ground contour map. Therefore the depth to groundwater at any point on the site can be easily estimated. Groundwater contours also show which way the water table is inclined and therefore which way groundwater is flowing. This can indicate the relationship with surface water, and determine from where the wetland water supply is derived (*Figure 15*)

Figure 15 *Groundwater contours and cross-section*



Groundwater contours are easily drawn using a technique that requires a minimum of three monitoring boreholes arranged roughly in a triangle (if more wells are present, they should all be included).

The groundwater levels (in metres above a common datum) are written on a scale plan next to their corresponding monitoring borehole. Next, lines are drawn on the plan between each monitoring borehole to make a triangle, or series of triangles. Each line is then divided into a number of short, equal lengths in proportion to the difference in groundwater level at the end of each line. The points of equal groundwater level on each of the lines are then joined to form contour lines. Choose a contour interval that is appropriate to the overall difference in groundwater levels. The direction of groundwater flow is perpendicular to the contour lines (*Figure 15*).

A cross-section can also be drawn that shows the ground surface, the groundwater table and relevant water features. In the example groundwater contour plan and cross-section (*Figure 15*), a summer condition is shown when groundwater maintains the water supply to a pond and delivers base flow to a stream. A long-term decline in the water table in the summer months would remove the water supply to these habitats.

The groundwater contour plan and cross-section therefore reveal the relationship between groundwater and surface water. Identifying trends from groundwater hydrographs can give prior warning of possible wetland drying out and allow appropriate management strategies to be put in place before the event occurs. They can also indicate the effects of wetland management practices on the water table.

The hydraulic regime – an example from Redgrave and Lopham Fen (Suffolk)

The groundwater contours and cross-sections should give a fair indication of the groundwater and surface water processes working at a site. Further details can then be added to gain a clearer picture of the links between groundwater and surface water, and the ecology of a wetland. The section through Redgrave and Lopham Fen (*Figure 16*) shows details of the geology, the natural direction of groundwater movement and how different types of fen are related to the groundwater conditions and the geology.

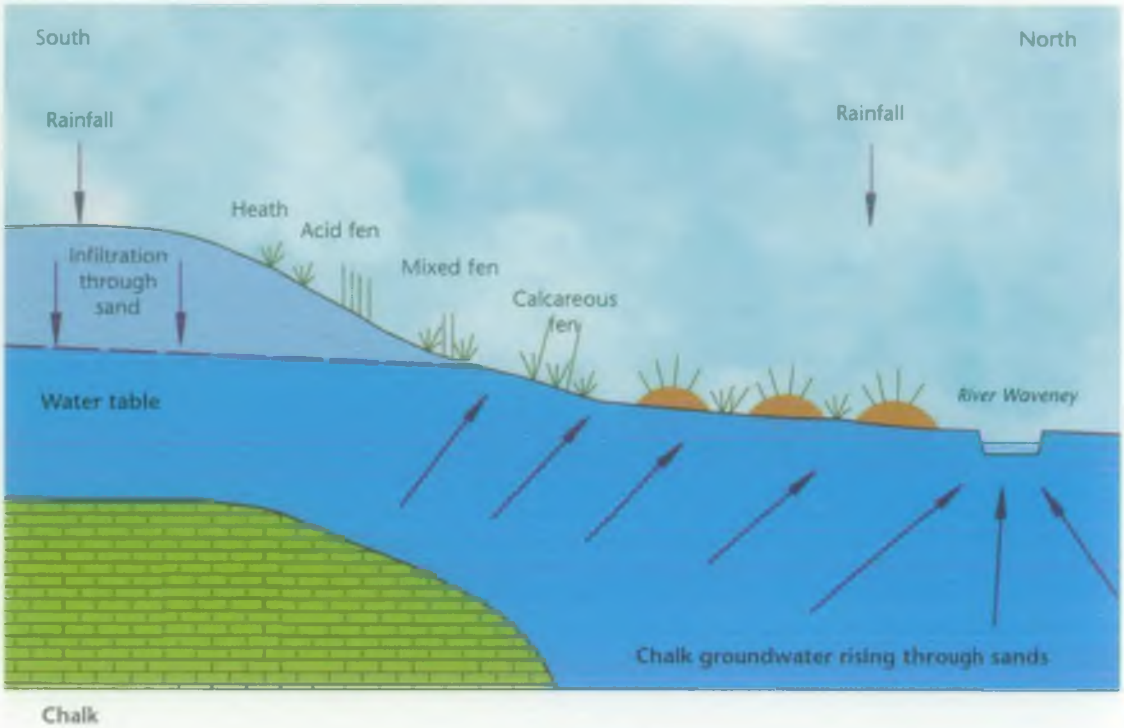
In the case of Redgrave and Lopham Fen, groundwater rose into the fen from the underlying chalk. Groundwater issued from springs and seepages and kept the peat subsoil supplied with a lime-rich, nutrient-poor water. An acid wet heath was also maintained at the higher margins of the fen by rainfall, which was more acidic than the groundwater.

In the late 1950s, two boreholes were drilled nearby to provide public water supply. As a consequence of pumping, the upward movement of chalk groundwater was replaced by a downward movement of more acidic rainwater. The fen began to dry out and the flora and fauna changed. In particular, the number of species preferring calcareous conditions declined and species of trees and shrubs preferring drier ground invaded the site. Soil litter accumulated, raising the ground level and exacerbating the drying process and seral progression.

Steps have been taken to encourage recovery of the ecology. The boreholes affecting the wetland were relocated away from the fen in 1999 and a 30cm layer of soil litter was removed to help halt the serai progression. The restored flow of water will be managed using a sluice, scrub clearance undertaken to reduce water loss by evapotranspiration and the reintroduction of traditional fen management practices.

The recovery of Redgrave and Lopham Fen was aided in no small part by a detailed knowledge of the water regime gained from reliable water-level measurements. However, the scheme could not have been achieved without the co-operation of the Agency, Essex and Suffolk Water, English Nature and the Suffolk Wildlife Trust.

Figure 16 Section through Redgrave and Lopham Fen *With permission of the UK Groundwater Forum*



This example shows how the concern for the survival of an important wetland can be put into action and produce a favourable outcome using co-operation and good scientific data. By collecting adequate information and sharing resources, the success at this site could be repeated at wetlands under threat throughout the country.

9. References, key contacts and legislation

References

Acreman, M. (ed), in association with the British Hydrological Society, 2000,
The Hydrology of the UK, chapter 9,
Rutledge,
ISBN 0-415-18760-5

Brassington, R., 1998,
Field Hydrogeology, 2nd Edition,
John Wiley and Sons,
ISBN 0-471-97347-5

Brooks, S. and Stoneman, R., 1997,
Conserving Bogs: The Management Handbook,
HMSO, London,
ISBN 0-11-495836-X

BS 3680: Part 4A
Thin Plate Weirs. Methods of Measurement of Liquid Flow in Open Channels, 1981,
British Standards Institution

BS ISO 748:
Measurement of Liquid Flow in Open Channels, 1997,
British Standards Institution

CIRIA 113:
Control of Groundwater for Temporary Works, 1988,
Construction Industry Research and Information Association

English Nature, 1997,
Water Level Requirements of Wetland Plants and Animals,
English Nature Freshwater Series No 5

English Nature and the Environment Agency, 1999,
Water Abstraction and Sites of Special Scientific Interest in England

Environment Agency, 1997,
W6/i/529/1 *Current Meter Gauging Methods Small Streams and Rapidly Changing Stage*,
R & D Project Record

Environment Agency, 1998,
Directorate of Water Management Hydrometric Manual Volume 34, chapters 1-12

Gilman, K., 1994,
Hydrology and Wetland Conservation,
John Wiley and Sons

Price, M., 1996,
Introducing Groundwater 2nd Edition,
Stanley Thornes (Publishers Ltd),
ISBN 0-7487-4371-5

Shaw, E.M., 1988,
Hydrology in Practice 3rd Edition,
Stanley Thomas (Publishers Ltd),
ISBN 0-7487-4448-7

UK Groundwater Forum, compiled by R.A.Downing, 1998,
Groundwater: Our Hidden Asset,
National Environment Research Council
ISBN 0-85-272304-0

Wheeler, B.D., Shaw, S.C., Bradley, P., Power, S.J.,Wise, S., Clark, C. & Routh, C.J.S., 1995,
Wetland Resource Evaluation & the NRA's Role in its Conservation: Resource Assessment
Environmental Consultancy, University of Sheffield,
NRA R&D Note 377

Key contacts

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The Wildlife Trusts,
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Legislation

Legislation that protects wetland species includes:

- the Wildlife and Countryside Act, 1981 (as amended);
- the Ramsar Convention of Wetlands of International Importance, especially as Waterfowl Habitat (1971);
- EC Directive 79/409/EEC on the Conservation of Wild Birds (1979), which established Special Protection Areas (SPAs) and emphasised the need for wider measures to protect bird species and habitats;
- The Bonn Convention (1979) on Migratory Species of Wild Animals;

Legislation that protects wetland habitats includes:

- the Berne Convention (1979), the Council of Europe Convention on the Conservation of European Wildlife and Natural Habitats;
- EC Habitats & Species Directive (1992) (92/43/EEC), which established Special Areas of Conservation (SACs) to protect habitats and (non-bird) species.

The Conservation (Natural Habitats &c.) Regulations 1994 implement the European Conservation of Wild Birds 1979 Directive and the European Habitats & Species 1992 Directive into UK law.

10. Glossary

Aquifer – a permeable body of geological material (rock or sand for example) containing significant amounts of groundwater.

Artesian condition – the condition where the true level of groundwater is above the ground surface but is prevented from rising to its true level by an overlying low permeability layer such as clay.

Auger – a device used to drill shallow holes into soft ground such as clay or silt, which basically comprises a steel rod with wide helical threads that is rotated into the ground.

Bentonite – a naturally occurring clay that swells when mixed with water. Refined bentonite is used in the drilling industry to make a watertight seal. Sodium is often added in the refining process to enhance the swelling properties.

Biota – living organisms.

Capillary fringe – a layer of soil that is saturated with water drawn-up from the water table by capillary action.

Confined conditions – the condition where groundwater is prevented from rising to its true level by an overlying low permeability layer such as clay.

Evapotranspiration – a combination of evaporation from open surface water, evaporation from the soil surface and transpiration from plants.

Field capacity – the maximum amount of water that a soil can hold until being drained by gravity.

Filter pack – clean, rounded "pea gravel" placed around the response zone of a monitoring borehole to minimise the ingress of silt or fine sand.

Groundwater – water occurring below ground, occupying openings, cavities and spaces in rocks.

HDPE – High Density Polyethylene. A type of plastic commonly used to make well tubes.

Perched aquifer – a groundwater lens perched above the water table, formed where significant quantities of infiltrating water accumulate in low permeability material above the water table.

Precipitation – rainfall, snow or hail.

Response zone – the length of plastic tubing in a monitoring borehole that has slots cut into it to allow the entry of groundwater.

Seepages – a zone where the water table is in contact with the ground surface, forming wet ground rather than a defined channel.

Serai progression – the sequence of changes in the types of flora and fauna occurring in response to a change in the environment.

Soil moisture deficit – a soil that has not reached its field capacity, capable of soaking up more water before it begins to drain.

Spring – a point or a line where the water table is in contact with the ground surface. Groundwater will then flow on the surface, perhaps forming a defined channel.

Surface water – water standing on or flowing over the ground surface (rivers, lakes, streams and the like).

uPVC – ultra Polyvinyl Chloride. A type of plastic commonly used to make well tubes.

11. Acknowledgements

The authors would like to thank all project board members and all external consultees who contributed to the production of this booklet. The Agency's project team included John Davys (National Groundwater and Contaminated Land Centre), Sarah Evers (Project Manager), Steve Fletcher (Project Executive), Caroline Scott (Midlands Region), Mark Whiteman (Anglian Region), and Vicky Williams (Midlands Region). The external project board included Rob Cunningham (The Wildlife Trusts), Chris Newbold (English Nature) and Paul José (RSPB). Further external consultees included Matt Self (RSPB), Clive Dork (English Nature), Julian Small (Yorkshire Wildlife Trust), John Jackson (Norfolk Wildlife Trust), Kevin Gillman (Independent Consultant), Rick Ireland (Severn Trent Water), David Gowing (Cranfield University), Kevin Hiscock (University of East Anglia) and Mike Hardman.

Addendum

Figures 7, 10, 12 and 13 are based on diagrams in *Field Hydrogeology* by Rick Brassington (see reference list). Permission to reproduce them is gratefully acknowledged.

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