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# Guidelines for monitoring of wetland functioning

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## 1 Introduction

During the last century, the number and size of wetlands in Europe has dramatically decreased. It is estimated that only one third of wetlands existing at the beginning of the 20 century remains (SCHULTLINK & VLIET 1997). Peat harvesting, drainage of forests and agricultural lands, lowering of lakes, streams and groundwater tables have led to dramatic decrease in wetland area and associated flora and fauna (e.g. DUGAN 1990; WHEELER 1995; DIERSSEN 1998; PFADENHAUER & GROOTJANS 1999). Many of the remaining wetlands are highly degraded due to drainage and eutrophication (SUCCOW 1988; VERHOEVEN et al. 1993; HEATHWAITE 1995). National and international authorities have concluded that the remaining wetlands are important and need protection, and several conventions and directives have been adopted.

The Ramsar Convention is an international treaty concerning cooperation in conserving wetlands of international importance (RAMSAR BUREAU 1990). The Bern Convention on European Wildlife and Natural Habitats aims at conserving flora and fauna and their natural habitats (Schultlink & Vliet, 1997). The EU Habitat Directive (92/43/EEC) and the Bird Directive (79/409/EEC) give further support for wetland conservation. As undisturbed natural wetlands, species rich seminatural wetlands and wetlands with a more or less intact hydrology have become very rare, there is an increasing interest in the restoration of degraded wetlands (WHEELER et al. 1995; PFADENHAUER & KLÖTZLI 1996; PFADENHAUER & GROOTJANS 1999; TREPEL 2000). In recent years, there has been an increasing use of wetlands as nutrient traps (e.g. JANSSON et al. 1994; LEONARDSON et al. 1994; VYMAZAL et al. 1998; TREPEL 2000). Many of the problems concerning eutrophication of aquatic systems are attributed to intensification of agriculture, involving increased fertilisation and straightening of streams and lowering of groundwater tables. As one solution to this problem, the construction, reconstruction or restoration of wetlands has been initiated (e.g. FLEISCHER et al. 1994; HOFFMANN 1998; TREPEL 2000). Also in this area, EU directives have influenced and accelerated the ongoing activities, as e.g. the Surface Water Directive (75/440/EEC), the Bathing Water Directive (76/160/EEC), the Groundwater Directive (80/68/EEC), the Drinking Water Directive (80/778/EEC), the Urban Wastewater Directive (91/271)EEC), the Nitrate Directive (91/676/EEC), the Environmental Impact Assessment Directive, the proposed Ecological Quality of Water Directive, (COM(93)680 final), the proposed Integrated Pollution Prevention and Control Directive (COM(93) 423 final), (85/37/EEC) and the proposed Water Framework Directive.

Apart from biological and water cleaning services, wetlands have other functions beneficial to society, as e.g. flood control, irrigation, drinking water reservoirs and recreation. To successfully protect and manage wetlands, long-term strategies are needed. Today, several guidelines exist for management, design, evaluation, protection, conservation, delineation, and restoration of newly constructed, restored and existing wetlands. Many of these approaches are sectoral, meaning, means that they consider either biological parameters or abiotic features as hydrology or nutrient dynamics. Interdisciplinary approaches are rare inspite of the differentiated functions of wetlands, including habitat and regulation functions as well as services for the human society. Therefore information from different disciplines is urgently needed for both wetland management and the evaluation of the success of restoration and wetland construction projects. To our knowledge international or national strategies for monitoring and experimenting on wetland functions are scarce or non-existing. We have not found any published general guidelines concerning an interdisciplinary approach to process oriented wetland monitoring.

The objective of these guidelines is to integrate the knowledge of monitoring and experimenting on wetland processes gained in the project "Wetland Ecology and Technology" (WET). The aim of the project has been to promote and support mobility of young researchers between home institutes and hosting institutes of the seven partner institutions involved. The wetland research carried out by the partners in six European member states (SE, DK, DE, NL, IT, PT) combines a wide range of wetland disciplines reflecting different environmental problems in the countries, different research tradition and scientific backgrounds. These guidelines will therefore cover a wide range of wetland research approaches, but do not, however, claim to be a complete collection of monitoring and experimenting aspects. Here, we are primarily focusing on freshwater wetlands. A general overview is firstly given on monitoring and experimenting in wetlands followed by case studies from WET partners.

## 2 Targets for wetland protection, restoration and construction

The need for protection and restoration of wetlands has been recognised for a long time in environmental policy and nature conservation. Previously the focus has mostly been on wetlands as habitats for wildlife. During the last decade the importance of wetlands as sinks and/or sources for nutrients and greenhouse gases has become increasingly evident (MITSCH 1994). Today, four main targets for wetland protection, restoration and construction can be identified:

- Improving water quality (trapping and transformation of nutrients and pollutants)
- Restore or protect wetlands as habitats for plants and animals
- Water management (flood control, water supply)
- Recreation

In some, but not in all cases the different targets can coincide, e.g. in wetlands constructed for nutrient retention which can also increase biodiversity of agricultural landscapes (KIEHL & WEISNER 1997). On the other hand, different targets may often be conflicting (e.g. if a pristine wetland should be used to clean polluted water). In general, targets for the use of a wetland have to be well defined for effective management. The definition of targets is indispensable if the efficiency of projects on wetland protection, restoration or construction are to be controlled.

The objectives of wetland use and protection differ between the countries involved in the project. In Denmark wetlands are constructed and reconstructed both to abate nitrate pollution of the sea and coastal regions, and at the same time to enhance natural values (HOFFMANN et al. 1998). In Sweden, the objectives are similar (LEONARDSON et al. 1994; JANSSON et al. 1994; FLEISCHER et al. 1994; GUSTAFSSON et al. 1998), Germany and the Netherlands follow similar objectives, but with a stronger emphasis on nature conservation and habitat protection. Both in Germany and the Netherlands there are many projects on the restoration of wetlands which have been degraded by drainage and intensive land-use in the past (GROOTJANS & VAN DIGGELEN 1995; PFADENHAUER & KLÖTZLI 1996; PFADENHAUER & GROOTJANS 1999; ROTH et al. 1999; WILD et al. *in press* a,b). In

Italy, the use of (re-)constructed wetlands for nutrient retention is increasing (see e.g. 4.4). In Portugal, the main focus is on protection of natural or seminatural wetland communities (LILLEBOE et al. 1999).

Wetlands are defined as ecosystems which are temporarily or permanently influenced by water (MITSCH & GOSSELINK 1993; KADLEC & KNIGHT 1996). The Ramsar Convention states "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 meters" (RAMSAR BUREAU 1990). Hence, the water may be present as groundwater close to the surface or as flooding water down to a water depth of 2 m (some authors 6 m). A multiple classification system for wetlands exists with the different disciplines of vegetation science, geology, and hydrology using different terms. Traditional terms for wetland types, often used in common language and literature, are given by MITSCH (1994). Most of these classifications refer to natural wetlands, and the denomination give indications of hydraulic regimes, soil type, water characteristics, vegetation, location in landscape etc. Several other types of wetland classification e.g. in geomorphological groups, water sources or hydrodynamics have also been developed (GOPAL 1990; MITSCH 1994).

With respect to wetland management, it can be useful to distinguish between constructed, reconstructed/restored and natural or seminatural wetlands. Such an operational division also allows differentiation of the above defined targets. Sometimes, it is appropriate to make a further classification, used e.g. by KADLEC and KNIGHT (1996), depending on how the main water flows in a wetland; surface flow (SF) wetlands and subsurface flow (SSF) wetlands. In reality, there are also wetlands that are intermediates between these extremes and wetlands where water is stagnant. It is useful however to use this distinction for wetlands with a potential for nutrient retention. In SF wetlands the major part of the water moves above the soil/sediment surface, whereas in SSF wetlands, water moves in the soil as interflow or shallow groundwater. When choosing methods for monitoring of hydrological parameters and nutrient turnover processes in a wetland, strategies will differ considerably for these two types, as will be discussed later in this paper.

## 3 Monitoring strategies

### 3.1 General Aspects

Today, the interest of wetlands generally concerns three disciplines; hydrogeology, nutrient (substance) dynamics and biological values. Which of these fields should be monitored, depends on the objective of wetland use and/or protection. They are all interrelated; nutrient dynamics for example can not be monitored without monitoring hydrology. Furthermore, the biota of a wetland is highly affected by water and nutrient dynamics

#### Catchment characterisation

The location of the wetland in the landscape has to be considered as it strongly influences its function. Knowledge about interrelationships between the wetland and the surrounding landscape is important for the success of wetland construction/reconstruction and restoration projects as well as for the protection of natural, presently undisturbed wetlands. Catchments and subcatchments relevant to the wetland have to be distinguished. In this sense, natural borders and water sheds are more important for the monitoring than administrative boundaries (c.f. EU Water Framework Directive; GUSTAFSON et al. 1998). In general, it is necessary to know the origin of the inflowing water, flow paths in the landscape and the fate of the water leaving the wetland. For both the set-up of a monitoring programme and the evaluation of the results, information about the catchment geology, geomorphology, vegetation and land-use is needed.

**Scales**

When planning a monitoring program, the appropriate selection of the scales to be studied (e.g. catchment, subcatchment, wetland, sites within a wetland) depends on the objectives of the study. The objectives also influence where the sampling plots shall be located in the wetland (e.g. along transects, as nested plots, in a regular or random design). For surface-flow wetlands, all water inlets and outlets have to be included in a monitoring program in order to set up a water and mass balance. For subsurface-flow wetlands recharge and discharge areas have to be distinguished. These guidelines generally deal with a scale of the size of a given wetland and scales within the wetland.

**Starting point**

Monitoring of constructed/reconstructed/restored wetlands should start well before the work commences. The assessment of the starting situation is necessary in order to evaluate the success of the realised measures at a later date. To monitor nutrient abatement, it is in most cases necessary to screen the hydrological and water nutrient conditions in an area before selecting a wetland site. Such studies can address the following questions - are there significant amounts of the substances in the water and does the future wetland have the potential to transform or retain them? Does the substance cause downstream damage? Can the wetland decrease this damage for a reasonable amount of money? Does hydrology allow for a sufficient water retention time? Do hydrological conditions favour water saturation of the soil? If the objective is to protect or enhance the values of wetland biota, it is very important to define and to document the reference state. When measures to restore habitats are being taken, selection of a reference wetland can facilitate the interpretation of biological development.

**Intensity and duration**

Intensity and duration of monitoring have to be adapted to the objectives of the wetland use, and to the amount of money available. Intensity can change during the monitoring period. In general it is beneficial to start on a high intensity level and reduce the monitoring program when the main patterns of water flow and processes are known. Since many parameters undergo heavy fluctuations within and between years, it is important that monitoring programs proceed during longer periods (at least several years) to identify trends in wetland performance.

### Monitoring and modelling

To optimise the monitoring and reduce costs, monitoring procedures can be combined with modelling of selected parameters. Such strategies can broaden knowledge, extend the information level and help to generalise the assessment of wetland performance. The modelling aspects are dealt with in other parts of the WET guidelines (TREPEL et al. 2000).

### Coordination

Wetland monitoring programs have to be coordinated by regional or local authorities in cooperation with experts from the different investigation fields. If a monitoring program is carried out in different areas (wetlands, regions, countries) the selection of parameters and the sampling methods have to be coordinated in order to ensure the comparability of the data (HELLAWALL 1991, MARENCIC 1997). Furthermore, among different working groups working in the same area, effective coordination can bring many advantages, e.g. data exchange. Both the integration and adaptation of existing monitoring programs and the development of new techniques for integrated monitoring can help to reduce costs and to improve data quality and information content (BROWN & ROWELL 1997; BRICKER & RUGGIERO 1998; KNETSCH & MATTERN 1998; SCHAEFER 1998).

## 3.2 Hydrogeology

Many aspects – if not all – related to the understanding of wetland functioning are connected to the understanding of hydrogeological parameters. Basic information about wetlands will always include hydrogeological data. Hydrogeological considerations should always be made before any monitoring is initiated.

General information about the geology in the catchment area should first be gathered. Land use information (e.g. arable land, paved areas, forest etc.) is also important. Location of the wetland in the catchment, and possible function(s) should be considered.

A waterbalance (or other hydrological information) for the wetland is often needed. To calculate such a balance basic geology, topography, soil conditions, together with information about water level, flow pattern, hydraulic heads, hydraulic conductivity etc. must be gathered. Thus, to describe and understand the hydrological processes taking place in a specific wetland, one will needs to go through several of the topics listed below:

### 3.2.1 Soil characterisation

Soil characterisation is often required for several reasons (e.g. hydrology, vegetation analyses). From a hydrological viewpoint the description of the soil profile and the identification of the different soil layers or horizons is important when you wish to locate water-bearing layers (and also for the interpretation of the groundwater flow pattern. Furthermore the soil profile provides information about the soil layers which are important for the measurement of hydraulic conductivity and hydraulic heads (hydraulic potentials). In surface-flow wetlands the characterisation of soils and sediments is necessary to permeability of the bottom, and if permeable, which means water exchange can take place with groundwater storage.

Soil characterisation should include information on soil type, texture, and organic content (Box 1 and 2). Classification system used and the definition of the texture classes must always be included (e.g. SOIL SURVEY STAFF 1975; TODD 1980; MCRAE 1988; BRIDGES 1990). Other characteristics such as colour, smell, redox state, content of nodules or concretions, degree of sorting, should also be added.

Some soil properties can also be used as indicators for hydrological conditions (see 3.5).

Box 1: Example of texture classes used in description of mineral soils.

| | Texture class | Dominating grain size |
|---|---|---|
| Stony and gravel soils: | Stones | >20 mm |
| | Coarse gravel | 6 - 20 mm |
| | Fine gravel | 2 - 6 mm |
| Sandy soils: | coarse sand | 0,5 - 2,0 mm |
| | Medium sand | 0,125 - 0,500 mm |
| | Fine sand | 0,063 - 0,125 mm |
| Silty soils: | Silt | 0,002 - 0,063 mm |
| Clay soils: | Clay | <0,002 mm |

Box 2: Characterisation of peat soils

*Peat (soil must contain at least 12-18% carbon)*

*Type:*

| | |
|---|---|
| Fibrist: >2/3 | fibre content (i.e. fibre>0.15 mm); |
| Hemist: 1/3-2/3 | fibre content |
| Saprist: <1/3 | fibre content |

### 3.2.2 Subsurface flow wetlands

#### Groundwater flow pattern

Groundwater discharged from the upland flows through the wetland and often ends up in the stream as shown in figure 1. In the upland there is a more or less strict vertical movement of water (infiltration of precipitation surplus) down to the groundwater reservoir, whereas in the wetland the groundwater flows more or less horizontally (or upwards) to the stream (figure 2). The underlying groundwater may have passed the redoxcline, i.e. the depth at which oxygen has disappeared, which indicates that nitrate, if present, may be denitrified. The underlying groundwater may also be old (e.g. > 50 – several hundred years) and thus not contaminated with such elements as e.g. nitrate or pesticides. The recently formed groundwater - lying in the upper part of the reservoir - and close to the discharge areas, i.e. low-lying areas such as riparian wetlands, floodplains and the like, takes the direct path towards the surface recipients (streams, lakes and fjords). In agricultural areas the recently formed groundwater and water trapped in ditches and drains often has a high content of elements, i.e. it is contaminated with nitrate, other nutrients and pesticides. But as the water takes the more direct path to the recipients it may eventually flow through wetlands, where it is exposed to different biogeochemical processes (plant remidiation, plant uptake, denitrification, adsorption etc.) that may reduce the contamination of the nearby surface recipients.

The groundwater flow pattern is controlled by the difference in hydraulic heads between the upland and the wetland and the differences in hydraulic heads along the flow lines in the wetland. The hydraulic conductivity of the soil layers has, however in most cases, a decisive influence on both the groundwater flow pattern and the velocity by which groundwater runs through the wetland. Soil layers or soil horizons with small grain size (clay, silt), dense and compact soil layers, cemented soil layers (hard plan), or highly humified peat may act as impermeable barriers for water - they have an extremely low hydraulic conductivity - where as other layers may act as water-bearing layers – they have a high hydraulic conductivity.

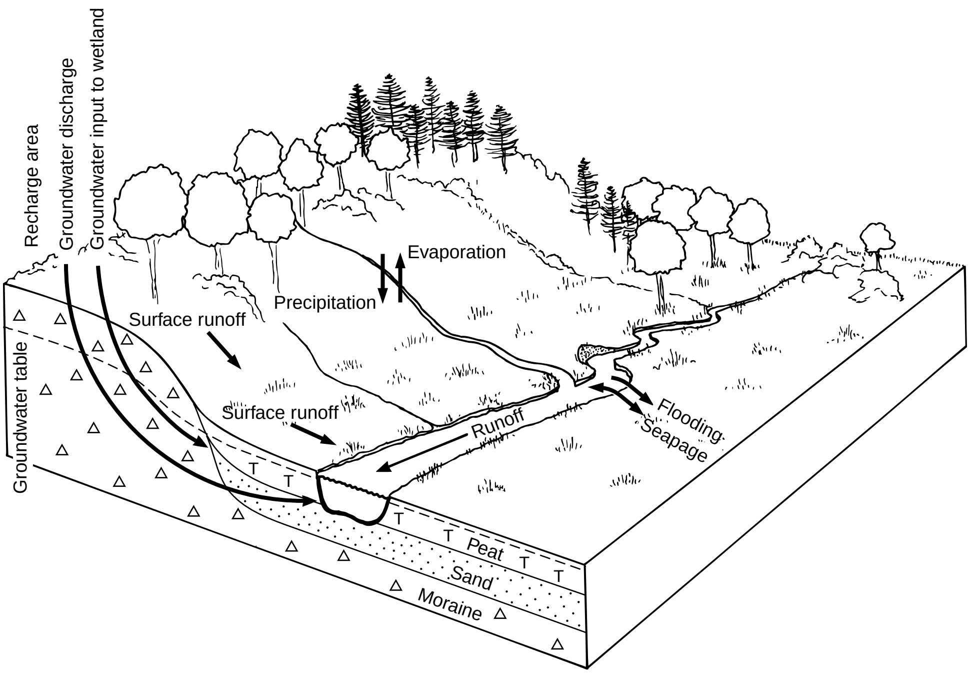



**Fig. 1:** Hydrological processes in a riparian wetland.

### 3.2.3 Measuring the groundwater table – installation of piezometers

When the soil profile has been characterised the necessary information is provided for installation of piezometers (i.e. a tube mounted with a screen of varying length) to measure the groundwater table or the piezometric/hydraulic heads at different depths. Piezometers are also used for taking water samples for chemical analysis.

Measuring the free groundwater table is performed by installation of a piezometer with a screen at full length, i.e. from bottom of the tube to just below the ground surface (a few centimetres from the ground surface). Given that the groundwater table in wetlands is often fluctuating (e.g. during the year, after precipitation) measurements should be carried out weekly - or every two weeks - in order to characterise temporal variability. (Automatic data acquisition systems allow continuous measurements, giving a much higher resolution and may further record sudden incidents.)

To elaborate the groundwater flow pattern and groundwater flow rates in a groundwater fed wetland it is important to gain knowledge about the hydraulic heads at different places in the wetland, e.g. along a transect from the hillside to the stream. The hydraulic head may also vary between different soil horizons or soil layers, and thus installation of piezometers in piezometer nests, i.e. with screens of limited length (e.g. 10 cm) located at different depths is necessary in order to get an exact and detailed description of the groundwater flow pattern (figure 2). This is required if localisation of specific biogeochemical processes - e.g. denitrification - is needed, or if the fate of an element along the flow path – e.g. nitrate or phosphate – needs elucidation (retention, transformation, or leaching of the element in question).

**Hydraulic head – groundwater movement – topographical survey.**

The groundwater flow is calculated by use of Darcy's Law:

$$v = K \frac{\Psi_1 - \Psi_2}{l}$$

where v = velocity, K = hydraulic conductivity, Ψ= hydraulic head, and l = length between measuring points.

This partly empirical expression says that the flow rate through porous media is proportional to the head loss and inversely proportional to the length of the flow path.

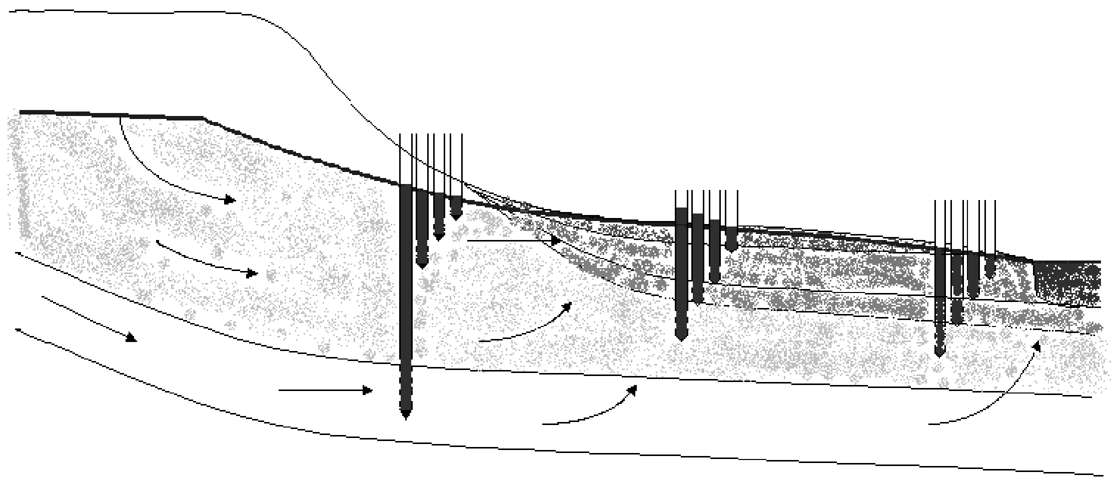


**Fig. 2:** Cross section of a river valley showing installed piezometer nests along a transect from hill slope to riverbank. Note that in the middle nest there is pressure water (artesian water) in the deepest piezometers. Water level is measured in the piezometers (top of piezometer to water table) and converted to hydraulic heads, by levelling top of piezometers to a common reference system, e.g. elevation above sea level.

The measured water levels in the piezometers (figure 2) have to be converted to hydraulic heads before the calculation can be carried out. This implies that the top of the piezometers must be levelled in order to convert the measured water levels to hydraulic heads. Levelling can be achieved in connection with the topographical survey, which is an important and necessary auxiliary parameter not only for hydrological considerations, but also for pedological and botanical investigations.

**Hydraulic conductivity**

As shown in Table 1 hydraulic conductivity varies greatly with soil type, texture and in organic soils, the degree of humification. From this it can be implicitly deduced, that hydraulic conductivity in the water-bearing layers is of decisive importance for the transport of water and nutrients and for retention of nutrients.

As mentioned above the hydraulic conductivity (and bulk density) in peat soils are related to the peat's degree of humification. The latter can be expressed in terms of the content of fibres longer than 0.15 mm (BOELTER 1969). The greater the fibre content, the higher the hydraulic conductivity and the lower the density, and vice versa. The bulk density of peat depends on the type of peat and varies from approx. 0.02–0.26 g dry weight $cm^{-3}$ (BOELTER 1969; CLYMO 1983). Danish studies indicate that the bulk density of lowland bog peat ranges from 0.11–0.46 g dry weight $cm^{-3}$ (HOFFMANN et al. 1993), while VEDBY (1984) states that the bulk density of mineral-free peat and mineral-containing peat lies in the range 0.07–0.3 g dry weight $cm^{-3}$ and 0.2–0.7 g dry weight $cm^{-3}$, respectively. The typical hydraulic conductivity of different soil types is shown in Table 1.

In some instances, when the interpretation of the soil profile is simple (not complicated), e.g. sandy soil layers (horizons) with uniform grain size, it is possible to find values of hydraulic conductivity in the literature (many hydrology text books have tables with hydraulic conductivity, e.g. TODD 1980).

**Tab. 1:** Hydraulic conductivities measured in different soil horizons and soil types (HOFFMANN et al. 1993)

| Material | Saturated hydraulic Conductivity (cm $s^{-1}$) |
|---|---|
| Weak humified peat | $1 \cdot 10^{-2}$ |
| Moderate humified peat | $5 \cdot 10^{-3}$ |
| Highly humified peat | $1 \cdot 10^{-3}$ |
| Compacted peat | $5 \cdot 10^{-5}$ |
| Coarse grained sand | $1 \cdot 10^{-1}$ |
| Medium grained sand | $1 \cdot 10^{-2}$ |
| Fine grained sand | $1 \cdot 10^{-3}$ |
| Sand with gyttja | $1 \cdot 10^{-4}$ |
| Silt | $1 \cdot 10^{-7} – 1 \cdot 10^{-4}$ |
| Gyttja | $1 \cdot 10^{-9}$ |
| Clay | $1 \cdot 10^{-9} – 1 \cdot 10^{-7}$ |

Hydraulic conductivity can be determined using slug tests (BOUWER & RICE 1976; BUTLER 1998). The method can be carried out in different variants: “auger hole method”, “piezometer method” or “slug test”, which are in principal the same. It is simple to carry out the method in practice, but at the same time it demands some experience to guarantee accurate results; the theory behind is partly empirical and somewhat complicated. In the field the procedure is as follows:

*Installation of tube*

An auger hole is drilled down to the groundwater table and a tube or piezometer is positioned in the hole. After this a worm auger is positioned inside the tube (same dimension as inside diameter of tube) and used for drilling. With the worm auger the hole is deepened little by little. Every time the hole has been excavated the tube is pushed downwards. When the desired depth for measuring hydraulic conductivity has been reached a small cavity is excavated just beneath the tube. Alternatively, the tube is withdrawn a few centimetres. It is important to know the exact dimension of the cavity. For a tube with a diameter of 4 cm the length should be 8-10 cm. The tube is emptied for water several times and it is important to ensure that the cavity maintains its original dimension (i.e. the cavity must not collapse or fall in, because the calculation afterwards will not be correct). At small time steps or continuums the rise in the water level is measured in a tube (piezometer) under which a small cavity has been excavated (with known dimensions, see figure 3). The tube is momentarily emptied for water and measuring begins. NOTE, it is also possible to fill the tube with water and measure how quick the water level decreases to the starting point (equilibrium).

Measuring has to be performed three times in order to evaluate the reliability. If the measurements differ from each other it is often due to changes in the dimensions of the cavity, i.e. the cavity has fallen in or collapsed (e.g. sandy soil horizons). Eventually there is still soil debris in the tube.

In many instances it is possible to get a reasonable estimate of hydraulic conductivity simply by using already installed piezometers. The screen is acting as a modified cavity. By use of this type of measurement it is often possible to get a reasonably accurate estimate of hydraulic conductivity – especially horizontal hydraulic conductivity, whereas vertical hydraulic conductivity is more uncertain (anisotropic soils). In river valleys with horizontal groundwater flow this modified method may be quite satisfactory. Below and in figure 3 the different factors to measure and calculate are presented.

Figure 3 shows, which distances are to be measured:

1. Diameter of piezometer tubes - 2r – as piezometer radius is needed later in the calculation.
2. Distance - E – from top of piezometer to water table.
3. Distance from top of piezometer to beginning of screen (should be measured before installing).
4. If an impermeable soil layer is found then the distance between top of piezometer and the impermeable layer must be known. This should be noted during the soil profile description.
5. Length of screen – must be measured before installing. The figure also shows $d_1$ and $d_2$, which is the position of the water table during the measurement at time, $t_1$ and at time, $t_2$.

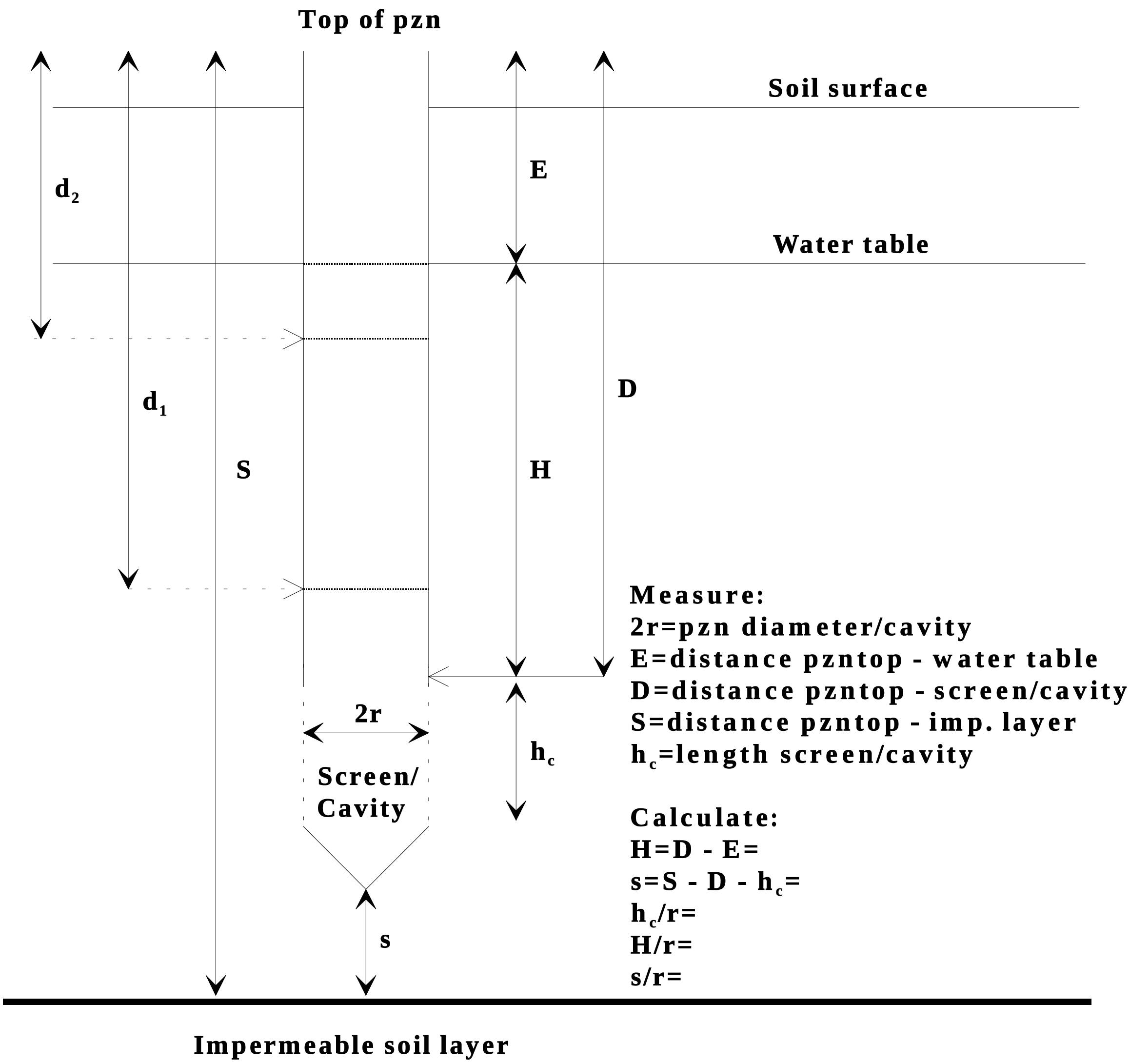



**Fig. 3:** Schematic illustration of set-up to measuring of hydraulic conductivity in the field. pzn = piezometer.

*Calculation of hydraulic conductivity*

Hydraulic conductivity, K, can be calculated by use of several, partly empirical formulas. An often used method is the piezometer method by LUTHIN and KIRKHAM (1949). It is written as follows:

$$K = \frac{\pi r^2 \left[ \ln\left(H - d_1\right) / \left(H - d_2\right) \right]}{C\left(t_2 - t_1\right)}$$

Where H is the distance from the water table to the cavity (or the screen) as shown on figure 3.2:3, and $d_1$ and $d_2$ is the distance from top of the piezometer to the water table during the measuring, at time, $t_1$ and time, $t_2$. C is called 'shape factor', which is related to:

**1**. Ratio between length and radius of the cavity (or screen) i.e. **hc/r**;

**2**. Ratio between distance from water table to cavity (or screen) and radius of cavity (or screen) i.e. **H/r**;

**3**. Ratio between distance from top of piezometer to an impermeable soil layer or an infinite permeable layer under the cavity (or screen) and radius of the cavity (or screen) i.e. **s/r**.

The Shape factor, C, has been determined by YOUNGS (1968) and can be found in tables. Consult tables 2, 3 and 4.

**Tab. 2:** Values of the shape factor C (Expressed as the ratio C/r) for cylindrical cavities.

| h/r | H/r | C/r values with impermeable layer at depth s/r = | | | | | | | C/r values with infinite permeable layer at depth s/a = | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 4 | 8.0 | 4.0 | 2.0 | 1.0 | 0.5 | 0 | 4 | 8.0 | 4.0 | 2.0 | 1.0 | 0.5 | 0 |
| 0 | 20 | 5.6 | 5.5 | 5.3 | 5.0 | 4.4 | 3.6 | 0 | 5.6 | 5.6 | 5.8 | 6.3 | 7.4 | 10.2 | 4 |
| | 16 | 5.6 | 5.5 | 5.3 | 5.0 | 4.4 | 3.6 | 0 | 5.6 | 5.6 | 5.8 | 6.4 | 7.5 | 10.3 | 4 |
| | 12 | 5.6 | 5.5 | 5.4 | 5.1 | 4.5 | 3.7 | 0 | 5.6 | 5.7 | 5.9 | 6.5 | 7.6 | 10.4 | 4 |
| | 8 | 5.7 | 5.6 | 5.5 | 5.2 | 4.6 | 3.8 | 0 | 5.7 | 5.7 | 5.9 | 6.6 | 7.7 | 10.5 | 4 |
| | 4 | 5.7 | 5.7 | 5.6 | 5.4 | 4.8 | 3.9 | 0 | 5.8 | 5.8 | 6.0 | 6.7 | 7.9 | 10.7 | 4 |
| 0.5 | 20 | 8.7 | 8.6 | 8.3 | 7.7 | 7.0 | 6.2 | 4.8 | 8.7 | 8.9 | 9.4 | 10.3 | 12.2 | 15.2 | 4 |
| | 16 | 8.8 | 8.7 | 8.4 | 7.8 | 7.0 | 6.2 | 4.8 | 8.8 | 9.0 | 9.4 | 10.3 | 12.2 | 15.2 | 4 |
| | 12 | 8.9 | 8.8 | 8.5 | 8.0 | 7.1 | 6.3 | 4.8 | 8.9 | 9.1 | 9.5 | 10.4 | 12.2 | 15.3 | 4 |
| | 8 | 9.0 | 9.0 | 8.7 | 8.2 | 7.2 | 6.4 | 4.9 | 9.0 | 9.3 | 9.6 | 10.5 | 12.3 | 15.3 | 4 |
| | 4 | 9.5 | 9.4 | 9.0 | 8.6 | 7.5 | 6.5 | 5.0 | 9.5 | 9.6 | 9.8 | 10.6 | 12.4 | 15.4 | 4 |
| 1.0 | 20 | 10.6 | 10.4 | 10.0 | 9.3 | 8.4 | 7.6 | 6.3 | 10.6 | 11.0 | 11.6 | 12.8 | 14.9 | 19.0 | 4 |
| | 16 | 10.7 | 10.5 | 10.1 | 9.4 | 8.5 | 7.7 | 6.4 | 10.7 | 11.0 | 11.6 | 12.8 | 14.9 | 19.0 | 4 |
| | 12 | 10.8 | 10.6 | 10.2 | 9.5 | 8.6 | 7.8 | 6.5 | 10.8 | 11.1 | 11.7 | 12.8 | 14.9 | 19.0 | 4 |
| | 8 | 11.0 | 10.9 | 10.5 | 9.8 | 8.9 | 8.0 | 6.7 | 11.0 | 11.2 | 11.8 | 12.9 | 14.9 | 19.0 | 4 |
| | 4 | 11.5 | 11.4 | 11.2 | 10.5 | 9.7 | 8.8 | 7.3 | 11.5 | 11.6 | 12.1 | 13.1 | 15.0 | 19.0 | 4 |
| 2.0 | 20 | 13.8 | 13.5 | 12.8 | 11.9 | 10.9 | 10.1 | 9.1 | 13.8 | 14.1 | 15.0 | 16.5 | 19.0 | 23.0 | 4 |
| | 16 | 13.9 | 13.6 | 13.0 | 12.1 | 11.0 | 10.2 | 9.2 | 13.9 | 14.3 | 15.1 | 16.6 | 19.1 | 23.1 | 4 |
| | 12 | 14.0 | 13.7 | 13.2 | 12.3 | 11.2 | 10.4 | 9.4 | 14.0 | 14.4 | 15.2 | 16.7 | 19.2 | 23.2 | 4 |
| | 8 | 14.3 | 14.1 | 13.6 | 12.7 | 11.5 | 10.7 | 9.6 | 14.3 | 14.8 | 15.5 | 17.0 | 19.4 | 23.3 | 4 |
| | 4 | 15.0 | 14.9 | 14.5 | 13.7 | 12.6 | 11.7 | 10.5 | 15.0 | 15.4 | 16.0 | 17.6 | 20.1 | 23.8 | 4 |
| 4.0 | 20 | 18.6 | 18.0 | 17.3 | 16.3 | 15.3 | 14.6 | 13.6 | 18.6 | 19.8 | 20.8 | 22.7 | 25.5 | 29.9 | 4 |
| | 16 | 19.0 | 18.4 | 17.6 | 16.6 | 15.6 | 14.8 | 13.8 | 19.0 | 20.2 | 20.9 | 22.8 | 25.6 | 29.9 | 4 |
| | 12 | 19.4 | 18.8 | 18.0 | 17.1 | 16.0 | 15.1 | 14.1 | 19.4 | 20.3 | 21.2 | 23.0 | 25.8 | 30.0 | 4 |
| | 8 | 19.8 | 19.4 | 18.7 | 17.6 | 16.4 | 15.5 | 14.5 | 19.8 | 20.6 | 21.4 | 23.3 | 26.0 | 30.2 | 4 |
| | 4 | 21.0 | 20.5 | 20.0 | 19.1 | 17.8 | 17.0 | 15.8 | 21.0 | 21.5 | 22.2 | 24.1 | 26.8 | 31.5 | 4 |
| 8.0 | 20 | 26.9 | 26.3 | 25.5 | 24.0 | 23.0 | 22.2 | 21.4 | 26.9 | 29.6 | 30.6 | 32.9 | 36.1 | 40.6 | 4 |
| | 16 | 27.4 | 26.6 | 25.8 | 24.4 | 23.4 | 22.7 | 21.9 | 27.4 | 29.8 | 30.8 | 33.1 | 36.2 | 40.7 | 4 |
| | 12 | 28.3 | 27.2 | 26.4 | 25.1 | 24.1 | 23.4 | 22.6 | 28.3 | 30.0 | 31.0 | 33.3 | 36.4 | 40.8 | 4 |
| | 8 | 29.1 | 28.2 | 27.4 | 26.1 | 25.1 | 24.4 | 23.4 | 29.1 | 30.3 | 31.2 | 33.8 | 36.9 | 41.0 | 4 |
| | 4 | 30.8 | 30.2 | 29.6 | 28.0 | 26.9 | 25.7 | 24.5 | 30.8 | 31.5 | 32.8 | 35.0 | 38.4 | 43.0 | 4 |

**Tab. 3:** Values of the shape factor C (expressed as the ratio C/r) for a hemispherical cavity

| H/r | C/r values with impermeable layer at depth s/r = | | | | | | | C/r values with infinite permeable layer at depth s/r = | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 4 | 8.0 | 4.0 | 2.0 | 1.0 | 0.5 | 0 | 4 | 8.0 | 4.0 | 2.0 | 1.0 | 0.5 | 0 |
| 20 | 8.9 | 8.8 | 8.6 | 8.1 | 7.5 | 7.0 | 5.9 | 8.9 | 9.4 | 9.8 | 10.7 | 11.2 | 14.2 | 4 |
| 16 | 9.0 | 8.9 | 8.7 | 8.2 | 7.6 | 7.1 | 6.0 | 9.0 | 9.5 | 9.9 | 10.7 | 11.2 | 14.3 | 4 |
| 12 | 9.1 | 9.0 | 8.8 | 8.3 | 7.7 | 7.2 | 6.1 | 9.1 | 9.6 | 10.0 | 10.8 | 11.3 | 14.3 | 4 |
| 8 | 9.2 | 9.1 | 8.9 | 8.5 | 7.9 | 7.4 | 6.3 | 9.2 | 9.8 | 10.1 | 10.8 | 11.3 | 14.3 | 4 |
| 4 | 9.5 | 9.5 | 9.5 | 9.2 | 8.5 | 7.9 | 6.8 | 9.5 | 10.2 | 10.4 | 11.1 | 12.4 | 14.4 | 4 |

**Tab. 4:** Values of the shape factor C (expressed as the ratio C/r) when a plug of soil remains at the bottom of the tube. (The cavity has no vertical extension, but in stead a small amount of soil remains in the piezometer/tube; that is why h/r is negative). Average values are given over the range H/r = 4 to H/r = 20.

| h/r | C/r values with impermeable layer at depth s/r = | | | | | | | C/r values with infinite permeable layer at depth s/r = | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 4 | 8.0 | 4.0 | 2.0 | 1.0 | 0.5 | 0 | 4 | 8.0 | 4.0 | 2.0 | 1.0 | 0.5 | 0 |
| -0.5 | 2.5 | 2.5 | 2.5 | 2.4 | 2.2 | 2.0 | 0 | 2.5 | 2.6 | 2.7 | 2.9 | 3.1 | 3.6 | 6.3 |
| -1.0 | 1.9 | 1.9 | 1.9 | 1.8 | 1.7 | 1.6 | 0 | 1.9 | 1.9 | 2.0 | 2.1 | 2.2 | 2.3 | 3.1 |
| -2.0 | 1.1 | 1.1 | 1.1 | 1.1 | 1.0 | 1.0 | 0 | 1.1 | 1.1 | 1.1 | 1.1 | 1.2 | 1.3 | 1.6 |

*The slug test*

**Another** calculation method to estimate hydraulic conductivity is the “the slug test” by BOUWER and RICE (1976). The formula is written:

$$K=\frac{r_c^{\,2}\ln(R_e/r_w)}{2h_c}\frac{1}{t}\ln\frac{y_0}{y_t}$$

See figure 4, where $r_c$ = radius of piezometer, $r_w$ = radius of cavity, $R_e$ is an empirical parameter (by some also called the effective radius). $R_e$, is determined according to one of the two equations below.

As K, $r_c$, $r_w$, $R_c$, and $h_c$ are constants it follows that (1/t) ln $y_0/y_t$ must also be a constant. We can benefit from this by plotting field data (continuos values of water level and time) as ln $y_t$ against time, t. The expression (1/t) ln $y_0/y_t$ is obtained from the straight line, which is the best fit to the measured field data. The slope of the straight line is $-1/t_0$.

$R_e$ is determined according to one of the two following expressions: (please refer to figure 4; remark that the distances are measured from the water table, which is different from figure 3)

1. If S > H+$h_c$ (this is D on figure 4), i.e. s>0 (see figure 4)

$$\ln(R_e/r_w)=\left(\frac{1.1}{\ln(D/r_w)}+\frac{A+B\ln[(S-D)/r_w]}{h_c/r_w}\right)^{-1}$$

or 2. If S=H+$h_c$ (this is D on figure 4), i.e. s=0 (see figure 4)

$$\ln(R_e/r_w)=\left(\frac{1.1}{\ln(D/r_w)}+\frac{C}{h_c/r_w}\right)^{-1}$$

The coefficients A + B and C can be read from a graph (see figure 5) and these are related to $h_c/r_w$.

*Comments to expression 1 (mentioned above):*

a) Valid if: $S>H+h_c$

b) Valid if the distance to an impermeable layer (also called floor) is infinite.

c) If S is much greater than D (i.e. $H + h_c$), so the term ln $[(S-D)/r_w]$ is greater than 6, but still a value of 6 should be used for the term ln $[(S-D)/r_w]$

Expression 2, comments:

a) Valid if $S=H+h_c$ (this is D on figure 3.2:4), i.e. s=0 (see figure 4)

b) Should be used when measuring of hydraulic conductivity takes place in an already installed piezometer with a screen (i.e. the piezometer has a bottom)

Box 3 shows an example, where the hydraulic conductivity is calculated according to BOUWER and RICE (1976). Following measurement of the water table, calculation of hydraulic heads, hydraulic conductivities etc. it is possible to calculate the flow of groundwater through a given wetland by use of the Darcy equation. Box 4 shows such an example.

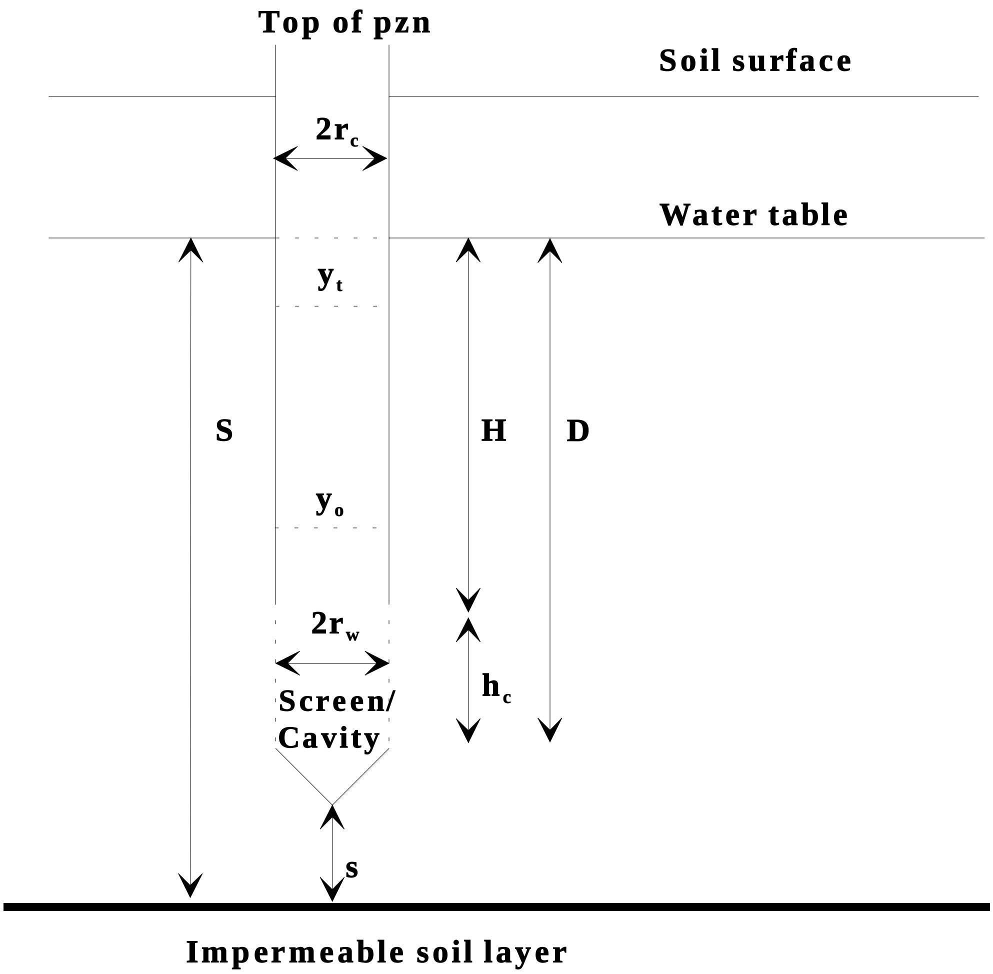



**Fig. 4:** Schematic illustration of the parameters, which are constituents of the Bouwer and Rice (1976) slug test method to calculate hydraulic conductivity.

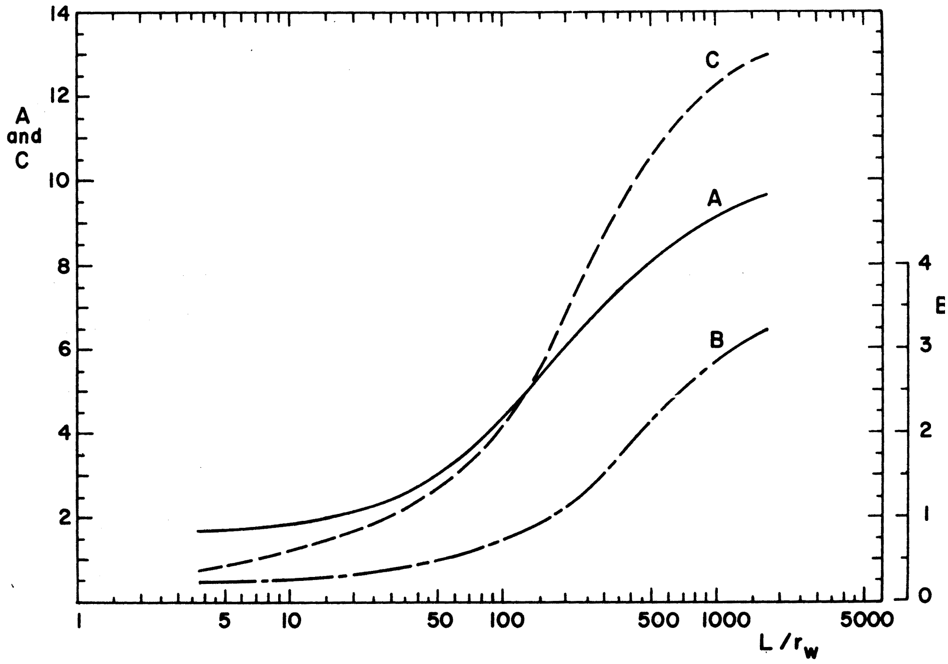


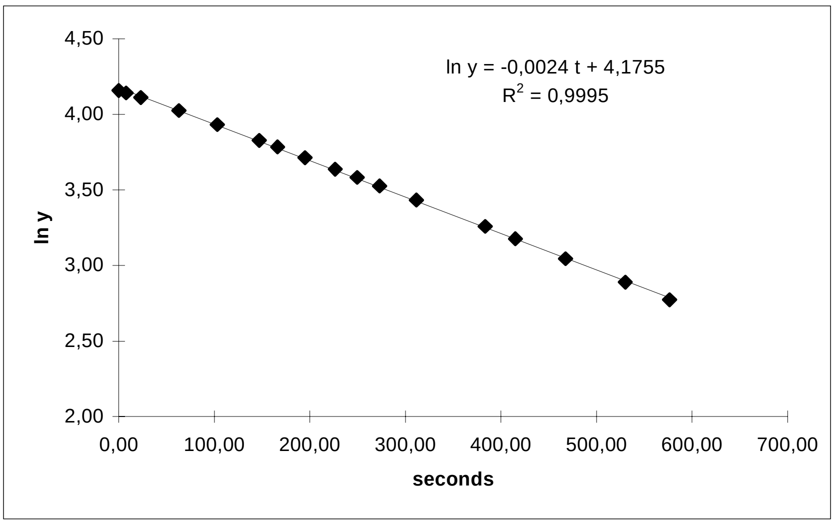

**Fig. 5:** Graphs from which the coefficients A, B, C, can be read in connection with the calculation of hydraulic conductivity by use of the Bouwer and Rice (1976) slug test method. $L/r_w$ is the same as $h_c/r_w$ , i.e. length of cavity divided by radius of cavity.

## Box 3: Example: Calculation of hydraulic conductivity, after BOUWER and RICE (1976)

The table shows measurements taken in the field: Length of piezometers, distance to water table, piezometer radius, screen length and screen radius. Piezometer is momentarily emptied for water and at small time steps the water level (the rise) was measured until the groundwater table is back in equilibrium.

| Station: 1 piezometer no.: 1 | | | water table Start=234 cm D=300-234 cm D=66 cm | | PZN length=300 cm Screen length: $h_c$=20 cm | | | | PZN radius: $r_c$=2.05 cm Screen radius: $r_w$=2.45 cm |
|---|---|---|---|---|---|---|---|---|---|
| | | | s=0 S=D | | | | | | $h_c$ / $r_w$ = 20/2.45=8.16 |
| | First measure | | | second measure | | | Mean | | |
| $y_t$ | | | | | | | $y_t$ | | ln ($y_{t2}$ – 234) |
| cm | min | sec | sec | min | sec | sec | cm | sec | |
| | | | | | | | | | |
| 298 | | 0 | 0 | | 0 | 0 | 298 | **0** | 4.15888 |
| 297 | 0 | 8 | 8 | 0 | 7 | 7 | 297 | **8** | 4.14313 |
| 295 | 0 | 23 | 23 | 0 | 23 | 23 | 295 | **23** | 4.11087 |
| 290 | 1 | 3 | 63 | 1 | 3 | 63 | 290 | **63** | 4.02535 |
| 285 | 1 | 42 | 102 | 1 | 44 | 104 | 285 | **103** | 3.93183 |
| 280 | 2 | 25 | 145 | 2 | 29 | 149 | 280 | **147** | 3.82864 |
| 278 | 2 | 44 | 164 | 2 | 48 | 168 | 278 | **166** | 3.78419 |
| 275 | 3 | 13 | 193 | 3 | 17 | 197 | 275 | **195** | 3.71357 |
| 272 | 3 | 44 | 224 | 3 | 49 | 229 | 272 | **227** | 3.63759 |
| 270 | 4 | 7 | 247 | 4 | 12 | 252 | 270 | **250** | 3.58352 |
| 268 | 4 | 30 | 270 | 4 | 36 | 276 | 268 | **273** | 3.52636 |
| 265 | 5 | 8 | 308 | 5 | 15 | 315 | 265 | **312** | 3.43399 |
| 260 | 6 | 20 | 380 | 6 | 27 | 387 | 260 | **384** | 3.25810 |
| 258 | 6 | 51 | 411 | 6 | 59 | 419 | 258 | **415** | 3.17805 |
| 255 | 7 | 42 | 462 | 7 | 53 | 473 | 255 | **468** | 3.04452 |
| 252 | 8 | 45 | 525 | 8 | 55 | 535 | 252 | **530** | 2.89037 |
| 250 | 9 | 31 | 571 | 9 | 42 | 582 | 250 | **577** | 2.77259 |

The figure shows continuous measurements of water level and time after the piezometer momentarily has been emptied for water.



*Calculations*

The straight line, which fits best to the field measurements of water level, y, and time, t, is:

$\ln y = -0.0024\,t + 4.1755$

At time, t=0 we have:

$\ln y_0 = 4.1755$ $\Rightarrow$ $\mathbf{y_0 = 65.07}$

At time, t=300 we have:

$\ln y_t = -0.0024 \times 300 + 4.1755 = 3.4525$ $\Rightarrow$ $\mathbf{y_t = 31.579}$

The coefficient, C, is found on figure 4, as the ratio between length and radius of the screen :

$\mathbf{h_c / r_w} = 20/2.45 = \mathbf{8.16}$ $\Rightarrow$ **C = 1.1**

Now the expression: $\ln(R_e/r_w) = \left(\frac{1.1}{\ln(D/r_w)} + \frac{C}{h_c/r_w}\right)^{-1}$ can be calculated,

as all values at the right side are known: D=66; $r_w$=2.45; C=1.1 and $h_c/r_w$=8.16

$$\ln(R_e/r_w) = \frac{1.1}{\ln(66/2.45)} + \frac{1.1}{20/2.45} = 2.1334$$

and now we are able to calculate the hydraulic conductivity, K, by inserting of the value for $\ln(R_e/r_w)$ in the BOUWER and RICE's (1976) formula: $K = \frac{r_c^2 \ln(R_e/r_w)}{2h_c}\frac{1}{t}\ln\frac{y_0}{y_t}$

$$K = \frac{(2.05)^2 \times 2.1334}{2 \times 20}\frac{1}{300}\ln\frac{65.07}{31579} = 0.000547 \text{ cm s}^{-1} \text{ or } 0.47 \text{ m d}^{-1}$$

**Box 4: Example: Calculation of groundwater flow through a wetland:**

*Site description*

Little Meadows is part of The Big Meadows restoration/rewetting project. Length of the river valley is approx. 2 km. The hill slope has a height of approx. 1 m. The distance between hill slope and the stream is 22 m.

*Soil profile*

A gridnet was laid out with three transects at intervals of 500 m. Profile descriptions were made at the hill slope (0 m) in the middle of the meadow (10 m) and near the stream (20 m). The profiles turned out to be reasonably homogenous with the following dominating soil layers:

| | |
|---|---|
| 0-100 cm | weakly humified peat (fibrist) |
| 100-200 cm | peaty fine grained sand |
| 200-300 cm | medium grained sand with pebbles and fragments of organic material |
| > 300 cm | clay |

*Piezometer positions (piezometer nests)*

Due to reasonable homogenous soil conditions only one transect with three stations (piezometer nests) were installed in the centre of the river valley. The stations were placed on the hill slope (0 m), in the middle (10 m) and close to the stream (20 m). The piezometers were positioned at three depths: each representing a soil layer. The lengths of the screens were 50 cm (25-75 cm; 125-175 cm and 225-275 cm). Top of piezometers and soil surface levelled with levelling instrument.

*Hydraulic conductivity*

Piezometers were used to estimate hydraulic conductivity according to Bouwer and Rice.

K:

| | | |
|---|---|---|
| 0-100 cm | $5 \times 10^{-3}$ cm $s^{-1}$ or | 43.2 m $day^{-1}$ |
| 100-200 cm | $1 \times 10^{-3}$ cm $s^{-1}$ or | 8.64 m $day^{-1}$ |
| 200-300 cm | $5 \times 10^{-3}$ cm $s^{-1}$ or | 43.2 m $day^{-1}$ |

*Groundwater flow through*

Measurements of water level in piezometers 10.10.1999. These were converted to hydraulic potentials. Groundwater table was approx. 0.2 meter below soil surface.

| Piezometer | Ψ Station 1 (slope) | Ψ Station 2 (middle) | Ψ Station 3 (stream) |
|---|---|---|---|
| PZN 2 (125-175) | 10.00 m | 9.75 m | 9.50 m |
| PZN 3 (225-275) | 10.00 m | 9.75 m | 9.50 m |

The flux of water, v (m $day^{-1}$) through the three soil layers between station 1 & 2 (v_1-2), and between station 2 & 3 (v_2-3) is calculated by using Darcy's equation . Distance, l, between stations is 10 m.

| | K m $day^{-1}$ | $\Psi_1 - \Psi_2$ m | $\Psi_2 - \Psi_3$ m | $v = K \frac{\psi_1 - \psi_2}{l}$ v_1-2 | v_2-3 |
|---|---|---|---|---|---|
| PZN 1 (25-75) | 43.2 | 0.25 | 0.25 | 1.080 | 1.080 |
| PZN 2 (125-175) | 8.64 | 0.25 | 0.25 | 0.216 | 0.216 |
| PZN 3 (225-275) | 43.2 | 0.25 | 0.25 | 1.080 | 1.080 |

The amount of water, V, flowing through a sectional area (cross section), a, with dimension 1 m × soil layer's vertical size is calculated for each of the soil layers. For soil layer 1 the position of the groundwater table is taken into account (layer 1: 0-100 cm; groundwater table 0.2 m below ground).

| Soil layer | Sectional, a m × m | $V_{1-2} = a \times$ v_1-2 $m^3$ | $V_{2-3} = a \times$ v_2-3 $m^3$ |
|---|---|---|---|
| Layer 1 | 1 × 0.8 | 1.080 × 0.8 | 1.080 × 0.8 |
| Layer 2 | 1 × 1 | 0.216 × 1 | 0.216 × 1 |
| Layer 3 | 1 × 1 | 1.080 × 1 | 1.080 × 1 |
| Total Σ | 2.80 | 2.160 | 2.160 |

Thus on the 10. October 1999 the flow of groundwater was 2.16 $m^3$ $day^{-1}$ per running meter to the stream. Assuming homogenous groundwater flow to the stream the whole river valley discharges: $2.16 \times 2000 = 4320$ $m^3$ groundwater $day^{-1}$ .

### 3.2.4 Surface-flow wetlands

In monitoring programmes, a water balance is a prerequisite for mass balances of nutrients and other substances (see 3.3.1). Calculating water balances (Box 5) is often easier for wetlands fed by surface water than for subsurface-flow wetlands, as it is possible to install flow meters or weirs at the inlet(s) and outlet(s).

> Box 5: Water balance of a surface-flow wetland
>
> Inlet + precipitation = outlet + seepage + evapotranspiration + change in surface water storage.

Setting up a water balance for a surface flow wetland does not necessarily imply that all parameters have to be measured. Inflow of water may be as diffuse groundwater seepage leaving only the outflow of water to be measured. Evapotranspiration may be of importance from a qualitative point of view, but in most cases it is sufficient to use figures for potential evapotranspiration – simply because there is always enough water, meaning that actual evapotranspiration and potential evapotranspiration are very close (if not identical) to each other. In addition to information about annual fluctuations, it is also important to measure the water level in wetland, because it indicates any changes in the surface water storage, which may be an important parameter in the water balance.

The flow path through the wetland can be followed by use of tracers, e.g. bromide or chloride.

**Catchment area**

Dividing the catchment area into subcatchments in a river system and making synchronous flow measurements in the river at the boundaries between the subcatchments is a very efficient tool to point out where in the catchment water is discharged to the stream. Figure 6 shows an example from the River Gjern catchment area.

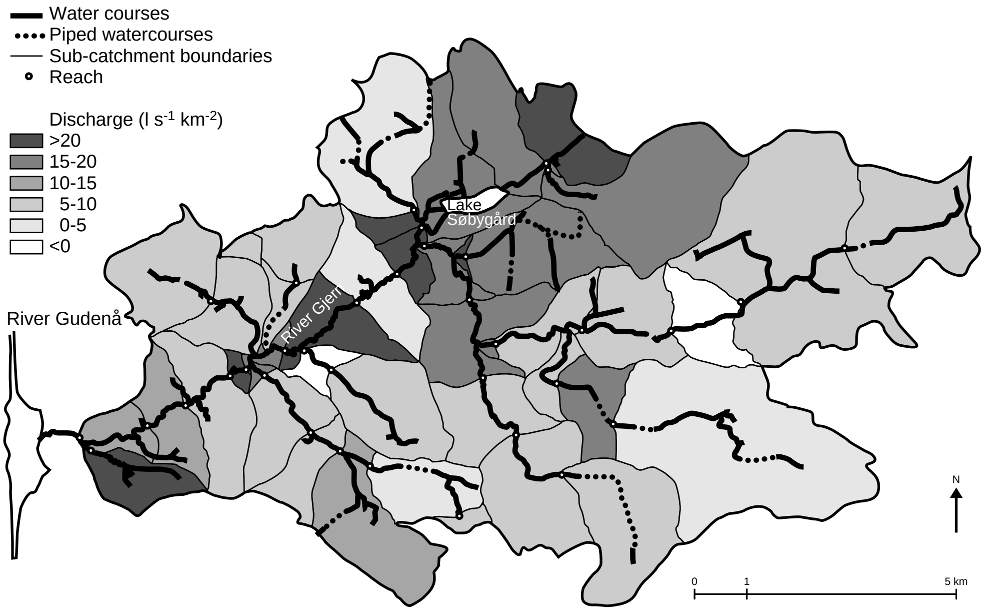



**Fig. 6:** Synchronous flow measurements at 35 monitoring stations in the River Gjern system and the resulting discharge from the subcatchments gives invaluable information about where in the catchment the riparian wetlands have high or low through-flow of water (From KRONVANG et al. 1997).

## 3.3 Nutrient dynamics

### 3.3.1 Substance mass balances

When a proper water balance is calculated, it is generally no problem to connect concentrations of the substance of interest and perform a mass balance. Most of the problems are connected to variability in time and space and the sampling methodology. Principally, you multiply the water inflow by concentration in inflow and the water outflow by outflow concentration, and calculate the difference. The difference between import and export represents the amount of the substance that is removed, trapped or retained in the wetland.

$$\sum(Q_{in} * C_{in}) - \sum(Q_{out} * C_{out})$$

Where:

- $Q_{in}$ are the different water inflows (including groundwater inflow and precipitation)
- $C_{in}$ are the different water inflow concentrations
- $Q_{out}$ are the different water outflows inflows (including infiltration to groundwater flow and evapotranspiration)
- $C_{out}$ are different water outflow concentration

The mass balance can be calculated in the same way for any substance. In subsurface flow wetlands, water is collected in groundwater tubes. (see section hydrology). For surface flow wetlands water is sampled in the inlet and outlet, as well as in precipitation and groundwater in- or outflow (if significant). If the surface flow wetland lies on impermeable soil e.g. clay or strongly decomposed and compressed peat, groundwater inflow or outflow is probably insignificant and can be neglected. Sandy soils, however, are more permeable and water contribution from and to groundwater should be monitored (see 3.2). As the wetland matures, organic deposits in the bottom may decrease the permeability and hence water exchange through the bottom.

For surface flow wetlands with few inflows and often one outflow, the general problem is to adjust a sampling program to the variability of water flow rates and substance concentration in time. Events with heavy rains connected to intense field runoff, cause high peaks in water flow. Sometimes, a major part of the annual transport occurs after such rains. Moreover, re-suspension caused by high flow rates can lead to a considerable export of suspended solids under such conditions. If the sampling program fails to include such events, the reliability of the data will decrease dramatically. Nowadays water samplers exist which adjust the amount of sample to the flow rate (continuous flow-proportional sampler) and which integrate the flow and concentrations during the sampling period.

For subsurface flow wetlands, spatial variability in hydrology and soil distribution often generates sampling problems. The considerations connected to field sampling are described in the hydrogeology chapter (3.2). To correct for mixing of groundwater, tracers (e.g. bromide or chloride) can be used. In this case substance removal is calculated by correcting it for dilution from groundwater. Examples for the calculations of mass balances in subsurface-flow wetlands can be found in HOFFMANN (1998) and BLICHER-MATHIESEN (1998).

Today, interests concerning wetland removal and transformation generally apply to the following compounds:

**Nitrogen**

The most common objective for the reconstruction and construction of wetlands today is to take advantage of the abilities to remove and transform of nitrogen. Nitrogen can appear in several forms in a wetland. Total nitrogen (Tot-N) represents the sum of all fractions i.e. particulate nitrogen, nitrate, nitrite, ammonium and dissolved organic nitrogen. Tot-N removal represents the overall efficiency of nitrogen removal of the wetland including sedimentation of particulate nitrogen. However, measuring different nitrogen fractions can tell you a lot more about the processes occurring in the wetland. In diffuse nitrogen pollution from agriculture, nitrogen often exists in the form of nitrate. This is a preferable form since it is readily denitrified under anaerobic conditions where a utilisable carbon source is present. It can also be retained in a wetland by uptake from plants. A nitrate balance, then, can indicate if denitrification is an important nitrogen sink in the wetland (which is most often the case). Ammonium can be significant if the inflow is polluted from wastewater, or agricultural animal production. Ammonium can be bound to clay particles and settle at the bottom of surface-flow wetlands or it can be taken up by plants and thereby retained in the wetland. It can also be produced from mineralization of organic matter. Nitrite is a poisonous nitrogen compound, but because it is readily reduced or oxidised, it is generally not found in high concentrations in wetlands. In some cases, when high concentrations can be suspected, it can be interesting to distinguish between nitrate and nitrite, but, nitrate and nitrite are often lumped together in the analysis method (WOOD et al. 1967). The difference between total nitrogen and the inorganic forms ($NO_3$ , $NO_2$ , $NH_4$) consists of particles and dissolved organic nitrogen (humic and fulvic acids, amino acids etc; KADLEC & KNIGHT 1996). The particles can be living or dead organic matter (algae and plant material). In surface flow wetlands, removal of particulate nitrogen by sedimentation can be a significant removal of N. In subsurface flow wetlands, the particle transport is negligible, but the sampled water has to be filtered due to particle contamination from the piezometer tubes. In peat wetlands, dissolved organic nitrogen can be an important export product (STEPANAUSKAS et al. 1999). A complete nitrogen survey could also include gaseous nitrogen forms as nitric or nitrous oxide, but in the usual case, when resources and money are limited, only measurements of total nitrogen, nitrate (+nitrite) and ammonium are made.

**Phosphorous**

A phosphorous budget usually includes a total phosphorous and a phosphate budget. The main transport of phosphorous is particle bound, and in subsurface flow wetlands, such transport is negligible. In surface flow wetlands, sedimentation of mineral particles with adsorbed phosphate make up the major part of the P removal. Phosphate dynamics of a wetland includes adsorption/desorption, and plant uptake. The phosphorous sorption is pH and redox sensitive and, hence, very critical for retention performance of the wetland (KADLEC & KNIGHT 1996; HOFFMANN 1998).

**Metals**

Some wetlands are used for the retention of toxic heavy metals (lead, zink, copper). Mass balances of these can be made as described above. Moreover, metals involved in redox dependent microbial and chemical processes (iron, manganese, aluminium) are often measured to give more insight into the processes in the wetland. There are some sampling considerations e.g. in maintaining reduced forms of iron and manganese (HEANEY & DAVIDSON 1977).

**Pesticides, antibiotics and hormones**

These compounds are often found in runoff water from agricultural activities. The fluctuating redox conditions in wetlands are thought to promote the breakdown of such compounds. The public concern for these problems have resulted in sampling programs for drinking wells and streams and lakes in Sweden, Denmark and Germany.

**Suspended solids**

A balance of suspended solids is made by measuring the concentration of particles in inflow and outflow water. In subsurface water this transport is of course negligible. This is commonly measured in the unit g/l, but since many pollutants are transported, adsorbed to, or assimilated in particles it is also closely connected to the substance balances. It is also possible to measure the amount of nitrogen and phosphorous, as well as any other substance, in the particles.

**Other substances**

Wetlands can be used to trap and transform many other substances (e.g. from mine drainage water), but the general principal remains the same, i.e. a budget based on nutrient concentrations and water flow in and out of the wetland.

### 3.3.2 Process estimates

Often, a mass balance is sufficient to evaluate wetland performance, and in many monitoring projects the available amount of money limits further investigations. However, there are both simple and sophisticated methods to learn more about the retention processes in different wetland systems. As for the mass balance approach, spatial variability of the substrate generates problems. A large number of replicates are often needed to estimate a process accurately and to perform statistical analysis. Sampling techniques and sample treatment can be adjusted to reduce variability, e.g. identification of sub-areas, topo-sequences or catenas (GROFFMAN et al. 1993). However, even in obviously homogenic areas, rates of processes can be highly variable (PARKIN 1987). It is also important to identify areas in the wetland where processes are significant, shown e.g. by BLICHER-MATHIESEN and HOFFMANN (1999). A compilation of methods for estimating nutrient turnover, most of them used in the WET project, are presented below.

**Denitrification and other nitrogen transformations**

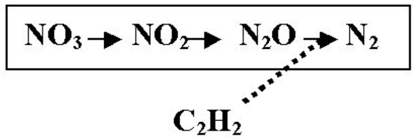
Since nitrogen removal is the main objective for the majority of wetlands today, processes in the nitrogen cycle will be given most attention in this compilation. The nitrate not accounted for in the mass balance of nitrogen described above is often considered to be lost via denitrification, which is the microbial process where nitrate is transformed to nitrogen gas (Box 6; TIEDJE 1988). However, there are alternative routes for nitrate in a wetland. Plant or microbial uptake, e.g., could account for some of the loss. In that case, it might only be a temporal removal, and the nitrogen will be recycled again in another form during decomposition of organic matter. The aerobic nitrification process (ammonium transformed to nitrate) produces nitrate, and if input of ammonium is high in a wetland with oxidised environments, this production of new nitrate will cause an underestimation of denitrification in the nitrate balance. Dissimilatory nitrate reduction to ammonium is another anaerobic process where nitrate is microbially transformed to ammonium (TIEDJE 1988). This alternative dissimilatory route will conserve nitrogen in the system, and also contributes to confusing process estimates from mass balance measurements. To date, however, it has not been shown to be a significant process in wetlands. If one is interested in knowing the actual denitrification in a wetland, some methods are available which can be used in field experiments, lab experiments and experiments combining field and lab activities. Brief descriptions of some methods used in WET can be found below.

*Acetylene inhibition method*

This method estimates denitrification of external nitrate. Acetylene blocks the last enzymatic reaction in the chain $NO_3$, $NO_2$, $N_2O$, $N_2$, causing an accumulation of $N_2O$ (Box 6). Contrary to $N_2$ this gas only exists in trace amounts (300 ppb) in the atmosphere, and small increases are easily detected on a GC. The most used application of this method is the soil core sampling. Intact soil cores are incubated at in situ temperature and moisture conditions and subjected to an acetylene concentration of 10%. Acetylene can be applied in overlaying water or injected in the soil and there are several different experimental set-ups described in the literature (TIEDJE et al. 1989, DAVIDSSON & LEONARDSON 1998). One drawback of this method is that acetylene also inhibits nitrification. This means that if there is a close coupling between nitrification and denitrification, mediated by diffusion of nitrate from aerobic to anaerobic microsites in a natural system, the incubation cannot mimic this, resulting in an underestimation of denitrification. In wetlands used for nitrate removal this is not a problem, as external nitrate is the dominating form. But, because of this drawback it is recommended to employ short incubations (3-5 hours). The acetylene inhibition method combined with soil core sampling (Box 7) is the most used technique to measure denitrification in the field. However, temporal and spatial variation demands frequent sampling with many replicates, especially if annual denitrifications rates are to be estimated. In a study of a peat soil DAVIDSSON and LEONARDSON (1998) took 4 samples over one year, each one containing 3 sampling days. During one sampling day, 20 soil cores (2.6 cm inner diameter) were treated with acetylene, and 20 samples served as controls.

Box 6:

**Denitrification and the acetylene inhibition technique**




**Denitrification** is the microbial transformation of nitrate via nitrite and nirous oxide to nitrogen gas. It is performed by heterotrophic facultative anaerobic bacteria. The process requires a carbon source, oxygen free environment and presence of nitrate. When oxygen is depleted, the aerobic respiration switches to nitrate respirtaion where the nitrogen atom in nitrate is used as electrone acceptor. This process is favoured in wetlands recieving nitrate rich water. In wetlands, large pools of organic matter is usually present, and the water logged soil results in decreased oxygen availability. These conditions results in the use of wetlands for nitrate removal.

**Acetylen ($C_2H_2$)** blocks the reduction step from nitrous oxide to nitrogen gas, causing an accumulation of this compound. This can be used for estimating denitrification, since nitrous oxide measurements can be made very sensitively, using a gas chromatograph

*$^{15}$N labeled nitrogen*

$^{15}$N-labeled nitrogen can be used to trace an applied nitrogen source through the nitrogen cycle (KNOWLES & BLACKBURN 1993). The use of $^{15}$N methods for estimations of processes in the nitrogen cycle is generally restricted to lab experiments. $^{15}$N labelled compounds are expensive and field scale applications are, with some exceptions, not conducted. In properly designed laboratory experiments, several processes can be measured simultaneously (denitrification, nitrification, uptake, release, mineralization). $^{15}$N is applied in a desirable form, e.g. nitrate, and after an incubation period, different pools of nitrogen can be examined for the $^{15}$N labelled atom. Such experiments can e.g. give information about weather denitrification, uptake or dissimilatory nitrate reduction to ammonium is the main sink for nitrate, or if the coupled nitrification/denitrification is important for nitrogen removal (MYROLD 1990).

*$Ar/N_2$ method*

This method has successfully been used in field experiments of subsurface water flow. It requires a detailed water balance and temperature, pH, conductivity, dissolved oxygen, carbon dioxide and nitrous oxide information. By measuring the increases in dissolved dinitrogen and comparing this to dissolved argon, denitrification can be estimated. The idea is that argon is inert and the concentration is only affected by solubility, whereas the dinitrogen is produced by denitrification. The method is simple to apply, but relies on a laborious water balance, and demands sophisticated laboratory equipment (BLICHER-MATHIESEN & HOFFMANN 1999).

**Carbon balance**

Denitrification is a desirable process in wetlands used for treating nitrate rich water. Since this process consumes organic carbon, a carbon balance can help to evaluate the long-term performance of the wetland. The carbon balance should include primary production in the wetland, as well as import and export of organic carbon, e.g. allochtonous organic material and dissolved organic carbon. It should also include estimates of decomposition, denitrification and the corresponding amount of organic carbon. Stoichiometrically, organic matter oxidation using nitrate can be described by the simplified formula based on the Redfield C/N/P molar ratio of 106/16/1: $(CH_2O)_{106}(NH_3)_{16}(H_3PO_4) + 84.8NO_3 \rightarrow 106CO_2 + 16NH_3 + H_3PO_4 + 148.4H_2O$. In this reaction, 1 mole of C in organic matter plus 0.8 mole of $NO_3$, produces 1 mole of $CO_2$ and 0.15 mole of $NH_4$ (DAVIDSSON & STÅHL *in press*).

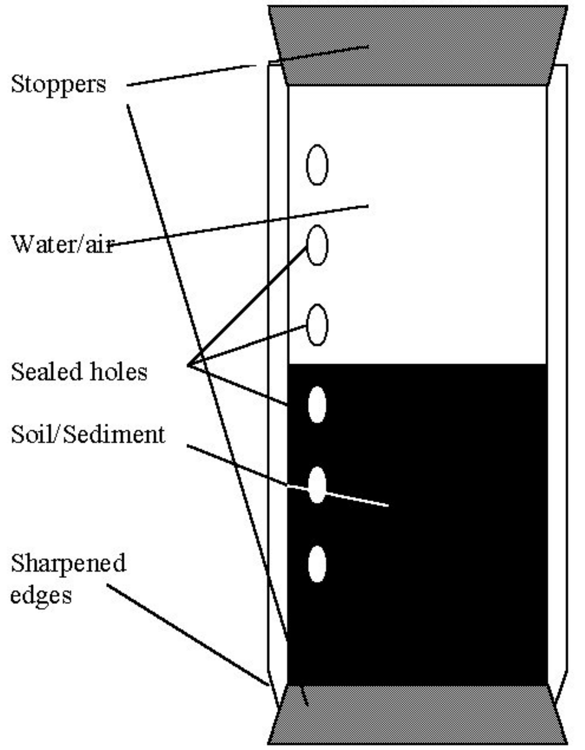
**Plant uptake and Sedimentation**

In addition to investigations of microbial nitrogen transformations, estimations of plant uptake will give useful information about internal nitrogen cycling. Often, the main concerns are connected to problems of harvesting methods and scale/variability of vegetation. After harvest, the plants can be analysed for the substance of interest. The sedimentation rate of suspended solids can be analysed by traps where sedimentated material is collected (ASPER 1987). However, this is only relevant to surface flow wetlands, where sediment export can occur. Furthermore, this information provides little extra than that gained from the mass balance of suspended solids do. Measurements on sedimentation are therefore seldom taken. For long term removal of the nutrients taken up by plants, the wetland vegetation has to be harvested, and the same applies to the sediments.

### 3.3.3 Field and laboratory experiments on nutrient dynamics

In addition to knowledge of the actual rates of the processes in wetlands, information of process limiting factors, sustainability of the processes, or potential process rates can be valuable. Such knowledge can be necessary for predicting long-term performance of the wetland, and can also give indications of how to establish good management practice. It may be wise to conduct some screening experiments before construction or restoration, to assess potential and limitations of processes.

Box 7




**Soil/sediment core sampling**

Plastic tubes are carefully pressed into the soil or sediment. Sharpened edges facilitate the penetration. A stopper is placed in the upper end before the soil core is pulled up.

A stopper is then placed at the bottom. The exchange of nutrients between soil and overlaying water can be monitored over time. Gas exchange can be monitored by analysing the overlaying water and/or gas phase. Experiments can be made by adding nutrients, inhibitors, etc. to the soil core. This can be made by injections through drilled holes in the plastic tubes, which can be sealed with silicone.

### Limiting nutrient for denitrification

If knowledge is required as to whether denitrification is limited by the amount of readily available carbon in a wetland, or if the wetland can transform even more nitrate than is imported, amendment experiments can provide this information. Series of additions of organic carbon, nitrate and combined additions are made parallel to the estimations of actual denitrification, using e.g. the acetylene inhibition technique. The response of the additions is then compared to the actual denitrification rates. If nitrate additions show the highest rates, it implies that the wetland soil/sediment can transform more nitrate than is presently imported. If organic carbon additions give higher response, the wetlands carbon source is insufficient for ambient nitrate concentrations (DAVIDSSON & LEONARDSON 1996).

### Potential denitrification rates

This estimate can be used to confirm measurements made on a mass balance scale. The experiments are simple, fast, and made in laboratory. Principally, all limiting variables for denitrification are reduced, and the denitrification rate will only be dependent on the amount of denitrification bacteria in the soil (i.e. the amount of denitrification enzymes). Small soil samples are treated with water, nitrate, carbon, chloramphenicol, and acetylene and are made anaerobic. The production of nitrous oxide will then be linear and reflect the denitrification rate. Often one or several of the additions are excluded, providing information about limiting nutrient (TIEDJE et al. 1989).

**Quality and endurance of the C-source for denitrification**

The amount, production rate and quality of the organic carbon source in a wetland is crucial for the sustainability of denitrification. By performing long-term experiments, optimising temperature and nitrate concentration and monitoring nitrate disappearance over time, the future performance of the wetland can be predicted.

**Phosphorous sorption-desorption capacity of wetland soil**

Phosphorous removal or release in a wetland depends on redox conditions, pH and binding sites in the soil material. Experiments with soil and P enriched water can give indications on future phosphorous performance in a wetland. Water phosphate content is measured before and after being thoroughly mixed/shaken with wetland soil. This procedure can be carried out with water containing different concentrations of oxygen.

### 3.3.4 Parameters related to nutrient turnover processes

Further to measuring specific elements, other parameters, often used in standard monitoring programs can provide additional information. Oxygen concentration and redox potential affects denitrification, the balance between denitrification and dissimilative nitrate reduction to ammonium and phosphorous sorption. Low redox potential indicates nitrate depletion and probably high denitrification potential. Temperature influences microbial processes, and may explain seasonal differences in removal efficiency. pH, conductivity, smell of sulphide and bubble formation can, if interpreted correctly, provide additional information about processes and water flow paths.

### 3.3.5 Conclusion

A mass balance provides the overall answer to the question: How good is a wetland in transforming/removing this substance? This approach is often the fastest and simplest way to evaluate the wetlands function. If more information is required, investigations on specific process rates, as well as experiments on regulating factors give important and sometimes crucial information on the wetland's current performance and that in the future. The acetylene inhibition method is usually the most suitable method to measure denitrification in the field. Ideally, it is possible to combine mass balances, process rate measurements and addition/treatment experiments to answer questions arising during the monitoring. This is, however, the exception, while the simple mass balance approach is the rule. It is finally a matter of economy, and a simple mass balance study can in many cases produce the desired information.

## 3.4 Biological Parameters

When monitoring a wetland, the selection of biological parameters to be studied has to be adjusted to the questions addressed. Biodiversity, species composition and rarity of plants and animals are parameters which are often used to evaluate the ecological quality of an ecosystem and its value for nature conservation (e.g. KEDDY 1991; HEYWOOD & WATSON 1995). Biological parameters can also be used as indicators for the present state of an ecosystem and for the monitoring of changing environmental conditions (e.g. HUNSAKER & CARPENTER 1990; ELLENBERG et al. 1991a; PHILIPPI et al. 1998). In studies on nutrient retention, it is important to have some data on vegetation parameters (e.g. biomass production) which may be necessary for the evaluation of the results (3.4.3.). Examples for biological parameters and methods used for the characterisation of wetlands in respect to different questions can be found below.

### 3.4.1 Assessment of biodiversity

If your intention is to assess the wetland's biodiversity it would in general be necessary to determine all different species present in the wetland. In practice it is not possible to study all organism groups. It is thus necessary to select relevant groups, such as target species for nature conservation (e.g. rare plants or animals), species/groups which play a key role for the ecosystem (e.g. plants as primary producers), or indicator species. Depending on the species or species group appropriate methods have to be chosen.

The biodiversity of an ecosystem can be studied at different scales and by using many different parameters (see e.g. HAILA & KOUKI 1994; HEYWOOD & WATSON 1995; ROSENZWEIG 1995; KIEHL & WEISNER 1997; DIERSSEN & KIEHL 2000). The following aspects of biodiversity may be relevant for wetland studies.

#### Diversity of biotopes/habitat types

Per definition, wetlands are ecosystems "between" terrestrial and aquatic systems. Therefore, the spatial variability of the water level (e.g. wetness gradients, mosaics of wet and dry spots, presence of surface water) and its temporal change (water level even or fluctuating) are the main factors influencing wetland habitat diversity and hence diversity of the flora and fauna. The spatial distribution of open water bodies as habitats for aquatic organisms can easily be obtained by field mappings in combination with aerial photographs or remote-sensing techniques (BUDD 1991). Topographical surveys in combination with groundwater level at different elevations can provide an overview of the spatial pattern of the wetness in all types of wetlands (see chapter hydrology). The presence and the range of gradients and different microhabitats have a positive effect on the diversity of the flora and fauna (e.g. POLLOCK et al. 1998).

For the evaluation of the habitat quality, data on the temporal variability of the water level is also important. Some wetlands e.g. river valleys, flood plains and certain types of ponds are only temporarily wet and thus suitable for wetland species. On one hand, many wetland species need more or less constant water levels. On the other hand, certain species - many of them rare and endangered - are specialised to live in temporary outdrying stream banks and pond bottoms (HEJNY & HUSÁK 1978). These examples show that information on wetland hydrology (see chapter 3.2) is needed in order to characterise habitat diversity.

Habitat diversity depends, however, not only on topography and hydrology but also on the trophic status, land use and/or on disturbance events. Vegetation maps (see 3.4.2) can be used for the evaluation of habitat diversity as vegetation composition and distribution reflect these environmental factors. The differences between vegetation types can show the spatially different environmental conditions for plant growth (range of habitats for different plant species) but also the presence of different habitats for animal species. Additionally, information on vegetation structure (e.g. vegetation height, spatial distribution of high and low vegetation, presence of different layers) is useful for the evaluation of habitat diversity.

**Species richness**

Species richness, i.e. the number of species in a certain area, is the most common parameter for the assessment of biodiversity. Although it simply means to count the number of species, difficulties occur in practice due to taxonomic and methodological problems. Many species groups (e.g. insects) are difficult to identify. Others are only temporarily present (e.g. migratory birds). For species which are permanently present and more or less easy to determine like plants, species lists for the whole wetland can give an overview over the flora. But if the question is to compare different wetlands or sites within a wetland in more detail, the results are greatly influenced by the study design, e.g. the number, size and location of the sampling plots (ROSENZWEIG 1995; GASTON 1996; KIEHL & WEISNER 1997). In comparative studies it has to be clearly defined what is a species and how subspecies or hybrids between species will be counted (this may be a problem in studies of plant diversity). Data will be biased if different taxonomic levels are directly compared.

In a monitoring programme, the selection of species groups for an assessment of species richness will depend on the question. The sampling method used within a monitoring program should always be the same during the whole period of the monitoring. In respect to the method, the results have to be comparable to the results from other areas which may serve as reference areas. Commonly used indicator species groups for wetland fauna are birds, fish, and aquatic macroinvertebrates (e.g. LEIBOWITZ & BROWN 1990; BRETTHAUER 1991; PAINTER & FRIDAY 1995).

For monitoring plant species richness, the decision about the size of the sampling plots is very important because the number of species is related to the sampling area (this relation exists of course also for animals). In general, it would be best to investigate plant species richness by species-area curves (see ROSENZWEIG 1995). In a monitoring program, however, there may be not enough time to investigate species richness at different scales. If plant species richness shall for example be monitored on permanent plots (see below) the size of the plots which shall directly be compared must always be the same in order to ensure the comparability of the data.

**Evenness**

Species richness is a measure for the number of species independent of the proportion of each species in an ecological community. For ecosystem processes (e.g. water and nutrient dynamics of a wetland) and species interactions, however, it makes quite a difference if all species are present in the same quantity, or if one or a few species dominate and others are only present with single small individuals. The presentation of species richness values without any information on the relative proportions of the species can be misleading if biodiversity of wetlands is to be evaluated, especially given that dominance of a few species is a common phenomenon in wetlands. Evenness or equitability values describe the relative proportions of species within a plant or animal community and hence the level of dominance. For the calculation of evenness values, data on species abundance, frequency and/or cover are necessary. The most commonly used evenness index presented by PIELOU (1966) is calculated when the Shannon diversity index H' is divided by log n (n: number of species). Other authors modified this evenness index or presented new indices for different purposes (ROUTLEDGE 1983; SMITH & WILSON 1996).

**Diversity indices**

In many biodiversity studies diversity indices are calculated (e.g. Shannon index, Simpson diversity index). The disadvantage of these indices is that species richness and relative-proportion (evenness) effects can not be separated from each other. Species richness is still the most useful measure of diversity which means that the calculation of complex diversity indices is not necessary in most cases (GASTON 1996). Evenness values may be calculated additionally if the wetlands under comparison differ in species dominance.

For the evaluation of wetland biodiversity, we recommend to present species richness and evenness as separate values rather than in a joint index in order to show which effects are a result of species richness and which are due to evenness. A comparison of different wetland types showed that plant species richness and evenness were correlated in natural and seminatural wetlands but not in constructed wetlands (KIEHL & WEISNER 1997).

### 3.4.2 Vegetation as an indicator for environmental change

Vegetation studies are included in many monitoring programmes as plant species can be used as indicators for environmental conditions (e.g. ELLENBERG et al. 1991 a & b; GOLDSMITH 1991). Plants as primary producers have a great effect on ecosystem function in wetlands, e.g. on hydrology and on nutrient and carbon dynamics (e.g. GOPAL 1990; VYMAZAL et al. 1998). Some wetland types, e.g. mires and bogs are built up by the accumulation of plant biomass due to the inhibition of decomposition under waterlogged condition. Furthermore, plant species composition and vegetation structure influence the habitat conditions for other organism groups (e.g. animals or fungi). Therefore, the detection of the spatial distribution and the temporal change of plant communities can provide important information on the effects of environmental factors relevant for the wetland. A description of different methods for vegetation monitoring can be found below. Special problems of vegetation sampling in aquatic systems (e.g. water plants) are discussed by GOLTERMAN et al. (1988).

**Permanent plots**

Permanent plots are marked quadrates for vegetation monitoring in regular intervals (e.g. yearly). GOLDSMITH (1991) and HERBEN (1998) summarise and discuss principal considerations of permanent plot studies. Nevertheless, some important points will be mentioned below. In general, permanent plots have to be well marked and their location in the field has to be documented precisely in order to find them after many years and to describe the location to a new person collecting data. Plot size should not be too large in order to allow the detection of all plant species without disturbance of the plot. For statistical analyses of the data it is more useful to have a higher number of smaller plots than few larger plots. For destructive methods (e.g. biomass sampling), additional plots are needed or the plots have to be split into one part for non-destructive sampling and another part for destructive sampling. The selection of the plot location depends on the questions (e.g. description of gradients, comparison of different vegetation types or management methods, etc.).

Advantages and disadvantages of different sampling designs (random, systematic, stratified) are discussed by KNAPP (1984b), ØKLAND (1990) and GOLDSMITH (1991). Replicate plots will always needed in order to know if an observation is due to a certain environmental factor or only a random effect. For the detection of trends and/or fluctuations in the data several statistical methods can be used (e.g. JONGMAN et al. 1987 HUISMAN et al. 1993).

Plant species composition and species richness on permanent plots can be estimated using different field methods (KNAPP 1984a MOORE & CHAPMAN 1986; ØKLAND 1990; GOLDSMITH 1991). Some common methods which can be used in monitoring programs are listed below. Additional information on vegetation structure can be obtained when the height of the different vegetation layers and/or shoot length of the plant species is measured.

*Presence/absence data*

Presence/absence data are species lists of the vegetation in a certain area, for example for a whole wetland, for different zones within a wetland or for a permanent plot. Presence/absence data are easy to collect but they do not give any quantitative information about the observed species. Therefore, changes of species abundance and hence population dynamics can not be monitored. Presence/absence data can, however, show at least changes in species richness, for example an increase during the colonisation process in newly constructed wetlands or a decrease due to an unfavourable management.

*Cover-abundance scale:*

Percentage cover of all species on the permanent plot can be estimated by eye and classified according to the BRAUN-BLANQUET method (1964). For species with low cover the abundance is also detected. For a precise monitoring of vegetation changes on permanent plots the decimal scale of LONDO (1976) is of great use than the Braun-Blanquet scale as it allows for the detection of small changes. If this method is used in a monitoring program it is important that the person who collects the data has some experience with the method and that the data are collected always by the same person (at least there should be very few personnel change) because the estimation of percentage cover is to some extent subjective. This method is commonly used in Central Europe and in the British National Vegetation Classification (see GOLDSMITH 1991) because it is less time consuming and therefore less expensive than the other methods described below. For most purposes it is accurate enough for the description of the general pattern and the magnitude of vegetation changes. If slight changes are to be detected and if different workers collect the data the point frequency method or frequency analyses is preferred (see below).

*Point-frequency method*

The point frequency method is a more accurate method for the estimation of vegetation cover (KNAPP 1984b; GOLDSMITH 1991) than the visual estimation with a cover-abundance scale. It is, however, much more time consuming. It has to be judged from case to case which method is preferable.

*Frequency*

Frequency analyses are non-absolute measures of vegetation analysis (GOLDSMITH 1991; ØKLAND 1990). Frequency is defined as the proportion (e.g. percentage) of quadrates in which the species is present in relation to the total number of quadrates. The quadrates are mostly arranged in grids. Depending on the spatial resolution and the required accuracy, a 1 $m^2$ frame can be divided for example in 16 25x25 cm quadrates or in 100 10x10 cm quadrates. This means that coordinates make it also possible to detect changes in the spatial pattern of each species (which can be useful if e.g. small scale spreading shall be studied). The information from the data is, however, not the same as the information from a cover estimation, because even very small individuals of species which may be negligible in their effect on aboveground biomass and community dynamics, can easily reach a frequency of 100 % whereas the estimation of percentage cover would give low values. The advantage of this method is that it is easy to apply and that it gives the same results independent to the recorder. Furthermore it does not require much experience apart from knowledge of the species.

**Mappings**

Repeated vegetation mapping can illustrate changes in the spatial distribution of plant communities in a study area. Before vegetation maps can be produced, vegetation analyses have to be carried out in order to classify plant communities which can be mapped. General considerations on vegetation mapping as well as descriptions of different methods can be found in KÜCHLER & ZONNEVELD (1988). For mapping of single species (e.g. endangered species), good topographical maps and/or aerial photographs are needed in order to allow a precise detection of the local occurrence of plant individuals or groups of individuals. A classification of plant densities (number of plants per area), age and/or developmental states (e.g. proportions of seedlings, juveniles, adults, flowering individuals) should consider future potential changes in the population as far as possible. In repeated mapping, the same classes must always be used if the data is to compared later.

**Monitoring of plant populations**

Monitoring of plant population dynamics will normally be carried out for a selected species e.g. for rare species as target species in nature conservation (HUTCHINGS 1991). For precise analysis of population dynamics and for the interpretation of the results, it is not sufficient to estimate the cover or frequency of a species. Information on the age, size and/or developmental states of the individuals within a plant population is needed for the evaluation of population viability (e.g. OOSTERMEIJER et al. 1994; FRANKEL et al. 1995). Repeated population mapping and long-term observations of marked individual plants can illustrate positive or negative trends in population development.

### 3.4.3 Biological parameters relevant for studies on nutrient retention

To interpret and evaluate results of nutrient retention in wetlands some additional biological parameters are needed. Denitrifying bacteria need carbon from organic matter in the soil (see 3.3.2). Therefore the carbon content of the soil can limit denitrification. In wetlands, soil-organic matter is influenced by plant productivity since the decomposition of dead plant material is slowed down or prevented under wet, anoxic conditions (peat formation). Estimates of the production of aboveground and below-ground plant biomass can give an idea of long-term sustainability of the current processes (nutrient retention etc.). The nutrient content of plant material (e.g. N, P, K) should be measured if information on nutrient cycling and nutrient output (e.g. during harvest of plant material) is required.

*Aboveground-plant biomass / standing crop*

In wetland monitoring programs, data on plant production can be used for different purposes. In restoration projects which aim to reduce nutrient availability for plants, a decrease in plant production is a measure of the success of a particular management strategy. In denitrification studies, it is important to know if carbon from the soil or sediment which is used by bacteria is sufficiently replaced by carbon fixation. Detailed measures of net aboveground primary production by repeated samplings during the year (DYKYJOVÁ & KVET 1978), will not be possible in most monitoring programs. The measurement of peak-standing crop (dry weight of the aboveground plant biomass at the time of maximal vegetation development) allows at least a rough estimation of plant production in order to compare different sites or different years. Data have to be interpreted carefully, however, as peak-standing crop is greatly influenced by weather conditions (e.g. DE LEEUW et al. 1990). Descriptions of methods can be found in MOORE & CHAPMAN (1986).

*Belowground-plant biomass*

In wetlands, below-ground plant production contributes considerably to the organic matter content of soils and sediments. Dead roots and rhizomes can for example serve as carbon sources for denitrifying bacteria which are more accessible than litter from aboveground plant parts. Although data on belowground plant biomass and litter are very useful for denitrification studies and studies on peat accumulation (in combination with data on decomposition), they are rarely collected because sampling in wetlands is very difficult and time consuming (see ONDOEK & KVET 1978). A comparison of different methods for the measurement of below-ground biomass can be found in CALDWELL & ROSS (1989) and NEILL (1992).

## 3.5 Indicators

Direct data acquisition in monitoring programmes may be reduced if good indicators for environmental conditions, wetland processes and the dynamics of flora and fauna are available. During the last decade numerous indicator systems have been developed for different purposes and scales in environmental management (e.g. HUNSAKER & CARPENTER 1990; ELLENBERG et al. 1991a; MURPHY et al. 1994 ADAMUS 1996; SPENCER et al. 1998; WICHERT & RAPPORT 1998). Most of them are used for the general assessment of environmental quality. The problem with many highly aggregated indicators is that they can not directly be applied to other systems than those for which they were developed. The use of certain plant or animal species as biodindicators depends on the aims of a monitoring project. Below, some examples of well tested indicators are presented which may be of practical use in wetland monitoring programmes in order to reduce sampling costs.

Wetland soils reflect the hydrological conditions. If no money is available for detailed hydrological studies (see 3.2), at least basic information on the range and the fluctuation of groundwater levels can be obtained from **indicators based on soil properties** (e.g. GALUSKY et al. 1998; THOMPSON & BELL 1998). In mineral soils, the depth of the fully reduced zone (no oxidisation features, except around living plant roots) indicates the lowest level of the groundwater. The range of the partly oxidised soil layer with iron oxide concretions is an indicator for water level fluctuations. In peat soils, the humification of the peat can for example be used as indicator for former or present artificial drainage of the wetland. Some experience, however is needed to distinguish between peat types and different humification classes.

**Vegetation** is often used **as an indicator for environmental conditions** (see 3.4.2). In wetlands, indicator values of ELLENBERG et al. (1991b) can be used e.g. for a rough assessment of moisture conditions, nutrient availability and soil acidity. Although these indicator values have been developed for central Europe several studies have shown their reliability and applicability in northern and western Europe (MOUNTFORD & CHAPMAN 1993; DIEKMANN 1995; SCHAFFERS & SYKORA 2000). Plant species as indicators for water type and origin see VAN WIRDUM (1991), GOSLEE et al. (1997), and AMOROS et al. (2000).

The **abundance of rare species or target species** can serve as an indicator for the success of wetland protection or restoration projects. It depends of the aim of the monitoring programme which indicator species or species groups are to be considered. Methods for the assessment of biological parameters can be found in chapter 3.4.

The **saprobic system** is a common standardised method for the assessment of water quality in aquatic systems which can also be applied in surface-flow wetlands (FJERDINGSTAD 1964; SLÁDACEK 1973). Saprobic indices based on aquatic indicator organisms summarise the effects of organic pollution and/or and eutrophication. This means that the effects of different factors (e.g. nutrients, pollutants) can not be separated from each other. In studies on nutrient dynamics more detailed data acquisition will be necessary (see 3.3).

## 4 Case studies

### 4.1 Skjern River, Denmark

The Skjern River was regulated in the 1960s, i.e. straightened, diked and pumping stations were built. The river valley was drained and 4000 hectares of meadow and marshlands were converted to arable land. In 1998 the Danish Parliament passed a Public Works Act for the restoration of the lower reaches of the Skjern River system. About 2200 hectares of nature are to be restored. The civil works started in 1999 and will proceed until 2002. These works include the removal of old dikes and pumping stations, excavation of a new river course (re-establishment of the old meandering reaches, re-establishment of the old delta at Ringkøbing Fjord), filling of old drainage canals and recreation of the natural wetland in the Skjern River valley. Total costs for restoration project appear from the Table 5 below.

**Tab. 5:** Total costs for the Skjern river restoration project.

| Investment | EURO |
|---|---:|
| Land acquisition/compensation | 12.300.000 |
| Design | 1.900.000 |
| Outdoor facilities | 15.000.000 |
| Information (incl. nature centre) | 2.000.000 |
| Monitoring of Ringkøbing Fjord | 1.000.000 |
| Environmental monitoring | 1.200.000 |
| Sundry | 540.000 |
| **Total** | **34.000.000** |

The total cost of the project is expected to be in the order of 34 million EURO

**Objectives:**

- to recreate a natural wetland habitat of international importance
- to develop the leisure and tourist potential of the Skjern River valley
- to improve the aquatic environment of Ringkøbing Fjord

*Measures*

Restoration of the natural meandering will allow the river to break its banks and flood the meadows: it will improve the spawning conditions for the fish in the river - such as e.g. the Atlantic Salmon. Furthermore a reduction in ochre pollution is expected.

Restoring the natural environment of the river and its valley will create optimal conditions for valuable flora and fauna, in particular the indigenous fish of the river. Raising groundwater levels will stop the soil processes that lead to leaching of ochre (elevation of the groundwater table in the whole project area will “bury” pyrite under reduced conditions).

When the river runs high, it will be allowed to flood the neighbouring meadows, where its content of nutrients, mostly from agriculture and fish farming, will be deposited and taken up by meadow vegetation. The nutrients would otherwise have ended up in Ringkøbing Fjord,

The restoration project will create a patchwork of ponds, meadows, reedbeds and meandering watercourses - an open river valley landscape with associated marshlands. The countryside will be kept open by grazing animals, hayfields and reedbeds. This large area of undisturbed wetlands will provide suitable habitat for numerous species of birds and animals that have declined - the bittern, otter, black tern and corncrake, for example. The project will create a wetland area with good spawning grounds and nurseries for fish such as the local wild stock of Atlantic Salmon, which has been close to extinction.

*Monitoring programme*

A comprehensive monitoring programme has been set up to follow all aspects of the restoration of the Skjern River. It includes the following subprograms:

1. **Hydraulics and flooding risks**. This includes form and shape of the river and its tributaries as well as moisture conditions in the riparian areas (water level and water level fluctuations). This subprogram is further intended to acquire basic data needed in subprograms 2, 3 and 7. Among others the following actions will be carried out: Topographical survey and levelling of the whole river system. Annual levelling of the river bottom. Registration of bank erosion (3 times per year in the whole system). Continuous recording of water level and flooding (8 stations). Hydraulics and Manning numbers. Total costs: 70.000 EURO.
2. **Water and nutrient transport.** Objective: To follow the water quality and to calculate the importance of the project with respect to retention and turnover of nutrients, i.e. nitrogen, phosphorous and iron. The following parameters will be sampled and analysed along the river at 7 stations: Suspended solids, loss on ignition, total phosphorous, soluble phosphorous, total nitrogen, nitrate+nitrite, total iron, soluble iron, sulphate and also pH and temperature. Further, this subprogram will support and provide data for subprojects 1, 5 and 7. Total costs: 165.000 EURO.
3. **Retention of nutrients in lake Hestholm** (shallow lake, which is part of the restoration). Objective: To calculate the retention of solids and nutrients in the new established lake. Total costs: 13.000 EURO.
4. **Physical habitats in the river.** Objective: To assess the importance of re-establishment of physical varying stream stretches (meandering). The subprogram will also provide data to subprograms 6, 8 and 10. Total costs: 47.000 EURO.
5. **Deposition and cycling of nutrients in the riparian areas.** Objective: To estimate the "self-purification" which originates from deposition of sediment and nutrients in the riparian areas. The subprogram is closely connected to 2 and 3. Total costs: 40.000 EURO.
6. **Stream vegetation.** Objective: To follow the development in stream vegetation after the restoration – especially to follow the rare species *Luronium natans* and *Oenanthe fluviatilis*. Total costs: 47.000 EURO.
7. **Riparian and terrestrial vegetation.** Objective: To follow changes in riparian and terrestrial vegetation as a consequence of the restoration. Total costs: 72.000 EURO.
8. **Stream invertebrates and riparian insects.** Objective: To study the invertebrate fauna before and after the restoration. Total costs: 54.000 EURO.
9. **Birds and otter.** Objective: to survey the change in number and species of birds. To survey the change in number of otters. Total costs: 76.000 EURO.
10. **Fish.** Total costs: 387.000 EURO
11. **Groundwater monitoring.** Objective: Monitoring of groundwater quality. Total costs: 13.000 EURO.
12. **Annual report, co-ordination, elaboration of monitoring programmes, Skjern river homepage on the Internet.** Total costs: at present unknown.
13. **GIS-data acquisition, drawing of maps, calculations.** Total costs: 17.000 EURO.

14. **Acquisition of basic data (climate data, photo, etc.).** Total costs: at present unknown.

15. **Final report (All activities).** Total costs: at present unknown.

## 4.2 Pohnsdorfer Stauung, Germany

The "Pohnsdorfer Stauung" is a base rich terrestrialization fen of about 120 ha situated in the eastern lake and moraine landscape of Schleswig-Holstein (northern Germany). It is divided in two polder ("Westpolder" and "Eastpolder") separated by the ditched river "Neuwührener Au". In the "Westpolder" occur highly humified alder and segde peat, the "Eastpolder" consists of weakly humified segde and brown moss peat with a small area of *Sphagnum* peat. The "Pohnsdorfer Stauung" has been drained by a pumping station and used for agriculture since the early 1950s. Only small parts remained as alder forests and reed swamps. Despite intensive efforts, agricultural use was not profitable, therefore the area was sold to the private foundation "Schrobach-Stiftung" in 1988. Since then measures for re-establishing higher water levels have started.

### Objectives

The aim of rewetting is both to increase habitat quality for wetland species and to stop mineralization of the peat to prevent nutrient export from the fen. Main conservation objectives have been focused on water birds and amphibians, therefore extensive areas of shallow water adjacent to reed beds and tall-sedge fields have been created.

*Measures*

Since 1989 the moraine parts of the area are under extensive land-use (cattle grazing and haying). In 1992, the first ditches were sealed in the "Eastpolder", in 1993 the insertion level of the pumping station was increased by 80 cm, and in 1996, a dam was constructed in the main ditch of the "Westpolder". These measures have resulted in an increase of the overall water level and in both polders shallow lakes developed.

*Research*

The effects of the measures have been documented by several reports. Research work included both biological and hydrological aspects:

- vegetation mapping of the complete area (1994 and 1999), permanent plots (every 1 to 2 years since 1994)
- ornithological mapping of breeding and resting birds (1994 and 1999)
- survey of amphibians (1998)
- engineer report on topography and water levels (1991)
- geohydrological studies with several drillings (1996)
- quantification of P-pools in the soils (1996)
- WASMOD modelling of scenarios with different water levels and land-uses (1998-99)
- hydrochemical research since 1999: water samples (analyse for $NO_3$, $NH_4$ $N_{tot}$, $PO_4$, $P_{tot}$, DOC, TOC, K) fortnightly (surface water (5), Piezometer nests (3)), automatic measurement

of waterlevels with loggers at 5 points, quantification of the amount of water at the inlet and outlet of the "Westpolder".

The aim is to quantify the sink and source function of the flooded fens (P-release, denitrification) and to observe the concentration of nutrients in the soil water under changing water levels.

*Financial support*

Research work has been financed by the foundation "Schrobach-Stiftung" (most biological surveys, engineer report 1991), by LAWA (WASMOD-modelling) and by the regional environmental agency (LANU-SH) (hydrochemical research). No finance plan for a continuous monitoring program exists at present.

**Tab. 6:** Monitoring cost for the Pohnsdorfer Stauung

| **Investment costs** | EURO |
|---|---|
| engineer report (elevation) | 10000 |
| 5 automatic waterlevel logger | 5000 |
| batteries | 350 |
| piezometer tubes | 200 |
| **Total** | **15550** |
| | |
| **Operation costs** | |
| water samples 25days/year | 5000 |
| analysis laboratory | 10000 |
| evaluation | 11000 |
| **Total** | **26000** |
| | |
| **Biological research** | |
| Amphibian mapping (40 h) | 1800 |
| Breeding bird mapping (50 h) | 2250 |
| Vegetation mapping (50 h) | 2250 |
| Permanent vegetation plots (20 h) | 900 |
| **Total** | **7200** |

*First results*

Soon after being rewetted, the Pohnsdorfer Stauung has attracted a variety of waterbirds. Breeding birds include bittern, crane and garganey and resting species are dominated by different species of waterfowl and waders. An important population of treefrogs inhabits the area. The first nutrient analyses show a high variability in the concentrations with high concentrations of ammonia, phosphate and DOC in the surfacewater at some time of the year.

### 4.3 River Rååån, Sweden - nutrient removal wetlands

The river Rååån is located in southern Sweden and flows out in the Öresund near the city of Helsingborg. The catchment is 193 $km^2$, has no lakes with a land use of intensive agriculture (73% fields). Drainage has influenced the landscape, the wetlands have disappeared and small streams now run in culverts. As a consequence, River Rååån today shows among the highest concentrations of nitrate in Sweden (around 10 mg $NO_3$-N $l^{-1}$). In the last ten years, measures have been taken to restore and reconstruct some of the wetlands in this drainage basin, in order to promote nutrient removal and increase biodiversity. Many of the wetlands have been constructed through local initiatives, by projects financed from private funds, projects often including some kind of monitoring program. The aim of the monitoring program described below is to evaluate and quantify nutrient removal performance of two wetlands in River Rååån. In this program, two ponds with an easily described hydrology have been selected. This means the they have only one inflow and one outflow, and that they are underlain by impermeable soil, preventing groundwater inflow and outflow. The monitoring program includes water chemistry analysis and water flow measurements of the inflow and outflows of the selected ponds.

**Pond 1. Fastmårup.**

This pond was constructed in 1992 and was increased in area 1993. It lies parallel to the stream, and water is supplied from an inlet and regulated by a threshold. The free water surface is 4400 $m^2$ and the volume 2900 $m^3$, The drainage area of the stream is 11 500 ha and it is estimated that 50% of the water runs through the pond.

Water samples are taken monthly at the inflow and outflow. Water flow is measured at every sampling occasion, using a water flow transmitter (Rototron RRI 25 PV-50). Flow is calculated using the mid section method, which is based on several water speed measurements along the cross section of the stream. For small water flows, the floatation method, based on cross section area and water flow velocity, is used.

**Pond 2. Ormastorp S.**

This pond was constructed in 1993, by a combination of excavations and construction of a dam. The surface area is 4500 $m^2$ and the volume is 6700 $m^3$. The drainage area is 240 ha.

Water flow is measured every week, using a V notch weir and a water flow transmitter (Rototron RRI 25 PV-50). Small water flows are estimated by measuring the time necessary to fill a container with a known volume. Weakly flow estimates have been calculated by using data from a national water data station. Here, an automated water sampler is installed, which consists of a peristaltic pump that continuously collects water (0.9 ml/min). Accumulated water is sampled every week.

For both ponds the following substances are analysed: Full sampling program: total nitrogen (Tot N), total phosphorous (Tot P). Reduced program (6 measurements a year): nitrate, ammonium, phosphate.

**Tab. 7:** Costs for monitoring of the Ormatorp S wetland

| **Investment costs** | EURO |
|---|---|
| 2 automatic water samplers | 1200 |
| 4 batteries | 2400 |
| Flow meter | 600 |
| Pegel | 180 |
| Weir * | 1800 |
| Data logger * | 700 |
| **Total** | **6900** |
| | |
| **Operation costs** | |
| 104 analyses of P and N | 2250 |
| Tubes for pump | 50 |
| Batteries | 120 |
| Purchase of water data | 180 |
| 200 hours labour sampling, evaluation | 13250 |
| **Total** | **15850** |

*planned for 2000

### General considerations

There are large fluctuations in the nutrient removal performance of the wetlands due to variations in climate and hydrology. It is therefore of great importance to collect a long term series of measurements, and have them evenly distributed over the year, to be able to interpret the results correctly.

In addition to the above described program, there have been occasional investigations concerning vegetation development and sediments in these wetlands.

## 4.4 Castelnovo Bariano Italy

The experimental wetland of Castelnovo Bariano (Rovigo, Italy) is a constructed free water surface wetland built in the riparian area of the Po river, at about 100 km from its mouth into the sea. It consists of two wetlands, each consisting of three modules in series, with a mean depth between 0.5 and 1 m. The area of the ponds totals six hectares. Water from the Po river is supplied by means of a pump system. The input flow is mantained in the range 2000 m3/d with a nominal detention time greater than 3 days.

Two levees, the height of which are 15 and 12 m above sea level, protects both wetlands from Po flood. A system of grids enables the feeding of each wetland module separately and this also permits their maintenance (periodic cleaning, etc.). One set of ponds has a U-shaped bottom while the other set has different depths in order to create a vegetated area with reed stands (30-50 cm depth) and an area without emergent vegetation (50-100 cm) crossed by a small channel (150 cm).

### Objectives

The pilot project was founded by Regione Veneto, and its main purpose is to purify river water by nutrient removal in the wetland. It serves as a demonstration wetland where experimenting and educational activities are important aspects. The experimenting part is carried out by the University of Padova and it is mainly focused on estimating pollutant removal.

*Monitoring program*

To fulfil the objectives the following activities are running:

- **Water chemistry** is measured at the inlet and at the outlet of the treatment system in monthly tests. Tests last 15 days and water samples are obtained by mixing 8 aliquotes gathered every 6 hours. The measured parameters are:
    - water level, dissolved oxygen (continuosly with an automatic probe)
    - flow rate for inflow and outflow (continuously)
    - Biological oxygen demand (BOD5), ammonium ($N\text{-}NH_4$), nitrate+nitrite ($N\text{-}NO_x$), total dissolved inorganic nitrogen (TDIN), dissolved organic nitrogen (DON), total dissolved nitrogen (TDN), Particulate nitrogen (PN), total nitrogen (TN), phosphate ($P\text{-}PO_4$), dissolved organic phosphorous (DOP), total dissolved phosphorous (TDP), particulate phosphorous (PP), total phosphorous (TP), and suspended solids (SS)
- **Sediment deposition** is measured twice a year in 20 spots in the wetland.
- **Soil metal content** is measured once a year and checked against the content measured before wetland flooding.
- Three **tracer measures** have been carried out to assess residence time and to calibrate a 1-dimensional model for water circulation.
- **Plant biomass production** is measured once a year.
- **Water table level** is measured every 15 days
- **Mosquito monitoring** is carried out during summer using three mosquito traps which are collected weekly.

Acquired data will be used to set up a mass balance for the measured elements, and for modelling the wetland performance. A rough estimate for costs of the monitoring is Euro 750 per survey. The price of the equipment used in the monitoring program (basically automatic sampler and a probe for water level fluctuation) is approximatly 7500 Euro.

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