PART THREE: MANAGEMENT

9.A. PHYTOREMEDIATION OF SOILS

A variety of technical soil remediation methods exists, however, most of them are very expensive, technically complex and exert undesirable side effects on the environment.

Phytoremediation is a cost-effective and environmentally friendly technology that uses plants to extract, degrade or immobilize contaminants from soil, water and sediments.

While phytoremediation has broad applicability, this chapter will present an overview of the current state-of-the-art of the application of phytoremediation and emphasize its applications to toxic heavy metals.

INTRODUCTION

When describing soil as a habitat for biological life, the upper 30-cm layer of the earth's crust generally is considered. It is in this zone that most biological processes take place. Soil from this zone also is responsible for dust resuspension, involuntary pollutant ingestion by children and grazing animals (Thornton, 1982) and contamination of surface runoff. It is also known as the arable layer, where most agricultural activities are performed. Agricultural soil is regularly mixed in the course of plant bed preparation, which results in a rather uniform distribution of pollutants within this layer.

Phytoremediation of soil is a variety of cost-effective (Tab. 9.1) remediation methods using plants, which are effective to a depth that is delimited by their rooting zone. With a few significant exceptions, this is not deeper than 50 cm in the case of herbaceous plants (Kucharski et al., 1998; Raskin & Ensley, 2000). In some cases, deep-rooting trees are being used to extract organic solvents from deep aquifers (Negri et al., 1996).

METHODS OF PHYTOREMEDIATION

Phytoextraction

How does it work?

The method is based on the ability of some plants to take up contaminants from soils by their roots and transport them to aerial parts, e.g., leaves. Such plants are known for their ability to accumulate and tolerate significant amounts of contaminants. Contaminants are removed from the environment by harvesting and carefully disposing the plants.

Fig. 9.1
Phytoextraction of lead in the vicinity of a former zinc smelter (photo: E. Wysokinska)

Where?

The technology is applicable to moderately contaminated land.

What plants?

Basic requirements for plant species used are as follows: production of high biomass, good accumulation properties in above-ground parts, and tolerance to the local climate. The most commonly used species for metal phytoextraction are those of the Brassicaceae family, e.g., Indian mustard.

TABLE 9.1
Relative costs of phytoextraction

STEP OF PROCESS	% of total cost
Field preparation	<1
Fertilizers and plant protection	<1
Chemicals for plant protection	<1
Plant care	<1
Irrigation	<1
Seeds and planting	7
Sampling and monitoring	7
Amendments	67
Contaminated crop disposal	<1
Scientific supervision	15
Total	100

How to apply?

The efficiency of this technology depends on biomass production and contaminant concentration. These factors in turn are dependent upon complex interactions among plant physiology, soil chemistry, hydrogeology and climate. The effectiveness of phytoextraction is often enhanced through the use of soil and plant amendments. The role of soil amendments is to facilitate the uptake of metals from soils to plants. Usually various chelators are used for that purpose (EDTA, DTPA, HEDTA) followed by organic (citric or acetic) acids.

Phytostabilization

How does it work?

This method converts soil contaminants into inert, immobile elements using metal tolerating plants. The mechanism may include absorption, adsorption, accumulation, precipitation or physical stabilization of contaminants in the root zone. Plants with well-developed root systems prevent contaminant migration via wind and runoff through the soil profile. Plant root biochemical activities can change soil pH as well as convert metals from a soluble to insoluble form.

Where?

Phytostabilization may be applicable to large areas of contaminated soil, sludge and sediments that are not amenable to alternative forms of treatment; and for remediation of heavily polluted sites.

What plants?

The best are carefully selected indigenous species of grass and shrubs, which develop a dense and strong root system. Good results were achieved using, e.g., Deschampsia caespitosa, in the case of heavily metal-polluted soils.

How to apply?

Phytostabilization of heavily polluted sites may be achieved using a combination of chemical and biological methods.

- the upper layer of soil is treated first with chemicals (e.g., lime, commercial fertilizers as needed) to adjust soil pH, fertilize, and to transform metal compounds into non-soluble forms;
- the next step is to develop a robust plant cover to reinforce the soil surface, to maintain the desired soil chemical conditions and to minimize soil transport processes (e.g., erosion and wind transport) (Vangronsveld et al., 1995, Kucharski & Nowosielska, 2002).

Rhizofiltration

This method is applicable to surface water, wastewater and (extracted) ground water contaminated with low concentrations of contaminants. For this purpose, aquatic plants or terrestrial plants (grown hydroponically) are used. The mechanism of rhizofiltration is based on adsorption or precipitation of contaminants onto plant root surfaces or bioaccumulation in plant tissues. Contaminants are then removed by physically removing and disposing of the plants (US EPA, 1997).

Rhizodegradation

This method uses plants to degrade organic contaminants in soil by microbial activity in the rhizosphere (root zone). In this application, it is often the microbial community associated with the rhizosphere that is responsible for the chemical degradation. Plant roots can affect this process by increasing soil aeration and changing soil moisture content. Rhizodegradation is also known as plant assisted biodegradation (US EPA, 1997).

Phytodegradation

This method uses plants to degrade organic contaminants within plant tissues by metabolic processes. It may be applicable in situations where poor soil conditions or the concentrations of soil contaminants preclude the actions of natural biodegradation (US EPA, 1997).

Phytovolatilization

This method uses plants to volatilize or transpire contaminants. Contaminants are transported from water or soil through plants to the atmosphere (US EPA, 1997). This approach is applicable in situations where reduced risks associated with atmospheric volatilization justify the transfer from one environmental compartment to another.

Land farming

This method is a relatively simple, cost effective method of soil clean up that is achieved through routine agricultural practices performed on contaminated land. The functional process in this case is natural attenuation, i.e., oxidation of pollutants, microbial decomposition in the root zone and pollutant destruction by UV radiation.

This approach is implemented with or without the use of plants and uses standard agricultural operations such as plowing, harrowing, seedbed preparation and harvesting. The procedure is repeated, exposing new layers of pollutant-contaminated soil to aeration and solar radiation. Crops grown in such situations are not to be consumed. This method is used for cleaning large areas of land that are contaminated with biodegradable organic compounds such as oil, gasoline and other organic chemicals. The approach can be applied either *in situ* or *ex situ* using prepared beds. The advantages of this technology are simplicity and cost effectiveness. (Reisinger et al., 1996).

PRACTICAL IMPLEMENTATION OF PHYTOREMEDIATION

Phytoremediation appears to be a „natural technology" - simple and uncomplicated. However, phytoremediation is relatively new and continues to evolve. There are some important factors that should be observed carefully in order to achieve the expected results and to avoid disappointments:

- plant species used for phytoremediation will be **different** depending on the purpose;
- it is desirable to use an **indigenous species**, one that is locally adapted and resistant to the substances polluting the soil;
- optimally, the selected plant should **not require special care**, should be **tolerant** to naturally variable weather conditions and should grow well on the type of soil to be remediated;
- for **optimal performance**, regular watering and fertilizing may be necessary; and
- the use of **exotic plant species**, even those shown to be very effective elsewhere, is potentially problematic. Cultivation procedures will need to be developed specifically for the plant/environment (Kucharski et al.,1998). This developmental process can be time consuming and expensive.

Treatability study

Full-scale phytoremediation projects are generally preceded by **preliminary experiments**, known as „treatability studies", performed under a controlled environment in laboratories, growth chambers or greenhouses. The experiments are carried out in pots containing the contaminated soil to be cleaned-up or stabilized. These studies seek to:

- **identify the plant species** that will grow well on the target soil, tolerate the contamination and perform appropriately in terms of treatment;
- calculate the optimal **cultivation conditions** (e.g., fertilizing and irrigation); and
- calculate the **amount of soil amendments** to be added in order to mobilize contaminants (in the case of phytoextraction) or to immobilize contaminants (in the case of phytostabilization).

When the distribution of contaminants in the target area is suspected to be non-homogenous, a **strip test** for verification of phytoextraction efficiency in natural conditions is recommended (Sas-Nowosielska et al., 2001).

These measures are suggested to optimize the potential for successful phytoremediation by considering critical points in the decision-making process (Box 9.1).

IMPLEMENTATION OF PHYTOEXTRACTION AND PHYTOSTABILIZATION

Considering the practical aim of this manual, only phytostabilization and phytoextraction are currently ready for widespread, full-scale application.

Phytoextraction

Phytoextraction will be most applicable in **large areas that are slightly above regulatory limits**. Once it has been shown to be practical by treatability tests, a number of field-scale factors need to be considered including:

- site characterization;
- seedbed preparation;

- planting;
- biomass production;
- amendment application;
- harvesting; and
- crop disposal.

The success of a phytoremediation process depends on the amount of biomass produced per unit time that allows for rapid removal of pollutants (phytoextraction), or to thoroughly cover the contaminated spot (phytostabilization) - Fig. 9.2. Therefore, those areas that support rapid plant growth over the longest growing period would be the best locations for successful phytoremediation.

Fig. 9.2
Sunflowers - a good species for phytoextraction
(photo: N. Slabon)

An important component of phytoextraction is environmentally **responsible crop disposal**. Successful phytoextraction will result in highly contaminated biomass, which may be considered as hazardous waste. In a large-scale deployment, the amount of material requiring disposal may be quite large, e.g., tens of tons per hectare. Disposal may include a combination of:

- volume reduction (e.g., composting);
- incineration;
- disposal at a hazardous waste dumping site; and
- potential recycling.

Another important consideration is the time required to reach regulatory criteria in the clean up. Phytoextraction may take **multiple crops** to remove sufficient quantities of the contaminant. Time will need to be balanced against cost and environmental impacts when evaluating the feasibility of phytoextraction.

Phytostabilization

In practice, phytostabilization is the **most commonly applied** form of phytoremediation.

Field deployment of phytostabilization includes the following steps:

- site characterization;
- seedbed preparation;
- amendment application;
- planting; and
- plant cover production.

Theoretical knowledge of phytoextraction is very well developed. Experiments have been conducted on various scales and many interfering factors have been identified, however, implementation on a large scale has been limited (Fig. 9.3).

The other methods of phytoremediation are less well developed and may be considered experimental. To date, they have not been shown to be cost-effective and their commercial application is a matter for the future (Kucharski et al.,1998).

SUMMARY

There are significant differences between the demands of phytostabilization and phytoextraction in terms of the applied plant species.

Phytostabilizing plant species need to create a dense root mat, which would isolate the contaminated soil zone from deeper layers of soil, keep the absorbed pollutants bound in the root mat and prevent wind erosion of contaminated soil (Fig. 9.4).

Fig. 9.3
Crop damage due to excess zinc
(photo: R. Kucharski)

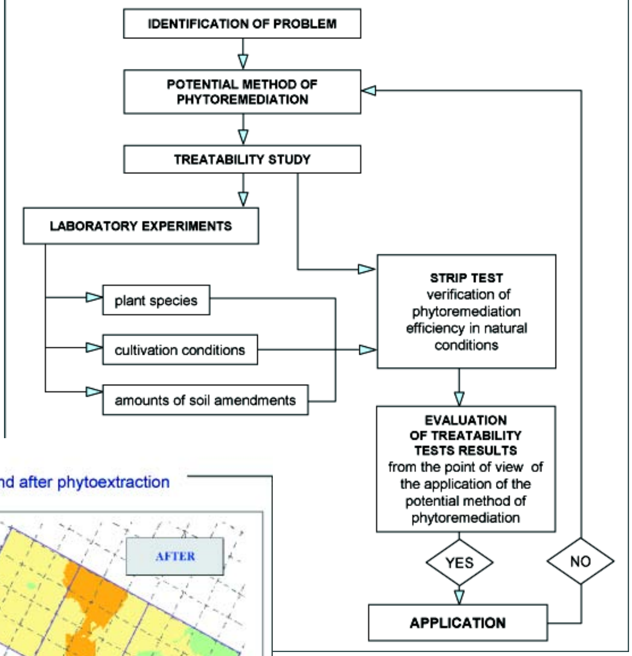
Phytoextracting plant species, on the contrary, should transfer the pollutants from roots to shoots to allow contaminant removal with the harvested crop. Large above ground biomass and widespread root systems are required for these purposes.

Fig. 9.4
Root system development (Deschampsia sp.)
(photo: N. Slabon)

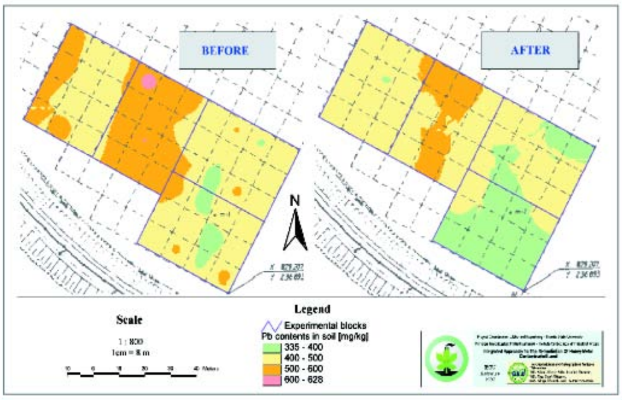
Some plant species have a natural ability to take up and concentrate high levels of toxic heavy metals. In the case of nickel, more than 300 plant species are known to „hyperaccumulate” this metal. Unfortunately, these plants are generally small and not suited to mechanical harvesting procedures. To date, these plants have been of experimental interest only. The most commonly used plants for metal phytoextraction are those from the *Brassicaceae* family, (e.g., Indian mustard and its cultivars), sunflowers and other crop plants such as corn and sorghum.

Phytoremediation is a promising and environmentally acceptable technology for remediation of contaminated land and water. As with all technologies, the success of phytoremediation will depend on its suitability to the specific application. Careful characterization of the target site and comparative evaluation of the available technologies will help to ensure success (Box 9.2).

BOX 9.1
Implementation scheme for identification of soil phytoremediation method



BOX 9.2
Lead concentration in soil before and after phytoextraction



MAKE SURE TO CHECK THESE RESOURCES:

Guidelines: chapters 5.B, 5.I-5.Q

9.B. HOW TO MANAGE WATER CYCLES IN WATERSHED

WATER FUNCTIONS IN THE ENVIRONMENT

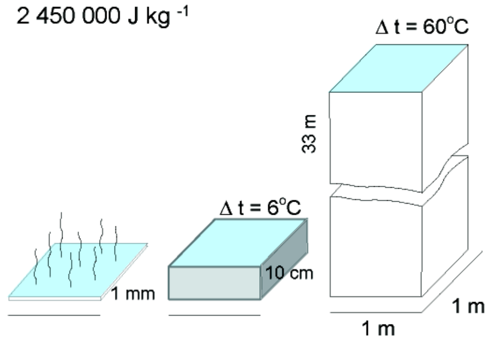
Water is a fundamental component of all living organisms. It not only forms their internal medium enabling the chemical reactions regulating life but also secures the maintenance of definite cell shapes and the whole body - conditions for their proficient functioning.

Being a good solvent for many compounds, water leaches them when percolating through soils and non-soil materials (e.g., rocks), and then transfers them together with subsurface runoff to rivers or lakes. Insoluble materials can be transferred in the form of a suspension. No wonder that water being displaced in the landscape significantly influences the spread of various substances in the environment.

The ability of water to absorb large amounts of heat determines its significant role in temperature regulation of not only man's body, but also the environment surrounding him. Thus, for instance, evaporation of 1 litre of water, i.e., a 1 mm thick film of one square metre, absorbs as much energy as is necessary to heat a 33 m high air column by 60°C (Box 9.3).

BOX 9.3
Role of water
in temperature regulation

Latent heat of water evaporation:
2 450 000 J kg $^{-1}$



HEAT AND WATER BALANCES

The balance between all fluxes of incoming and reflected radiation, as well as energy emitted by the active surface, defines the amount of energy intercepted by the landscape. The temporary state of this balance is called the net radiation (Rn) and it determines the amount of energy used for the internal workings of ecosystems. The full equation for heat balance is:

$$Rn+G+LE+S+A+F+M+...=0$$

where:

Rn - net radiation, G - soil heat, LE - latent heat, S - sensible heat, A - heat of advection, F - heat of biogeochemical processes, and M - heat stored by plant cover. All fluxes are expressed in W m $^{-2}$.

The last two fluxes are very small in comparison with the others and so are omitted in calculations.

Similarly, the water balance equation at a field scale and short period (one or a few days) is:

$$P+E+H_S+H_G+D+\Delta R_S+\Delta R_G+\Delta R_I=0$$

where:

P - precipitation (positive), E - evapotranspiration (negative) or condensation (positive), H_S - surface runoff (if surface inflow is higher than surface outflow, H_S is positive, otherwise it is negative), H_g - subsurface inflow or outflow (including lateral flow), D - percolation to ground water (negative) or capillary upward flow (positive), ΔR_S - change of surface water retention, ΔR_G - change of soil water retention, and ΔR_I - change of plant cover water retention (change of interception).

Lengthening a time scale to a month or longer period one can neglect the change of plant cover retention, ΔR_I. To increase the space scale to a catchment, the water balance equation can be expressed as:

$$P+E+H_S+H_G+\Delta R_S+\Delta R_G=0$$

Increasing the time scale to a decade or more (if neither wetland formation nor desertification are observed) one can neglect the change of water retention and rewrite the equation as:

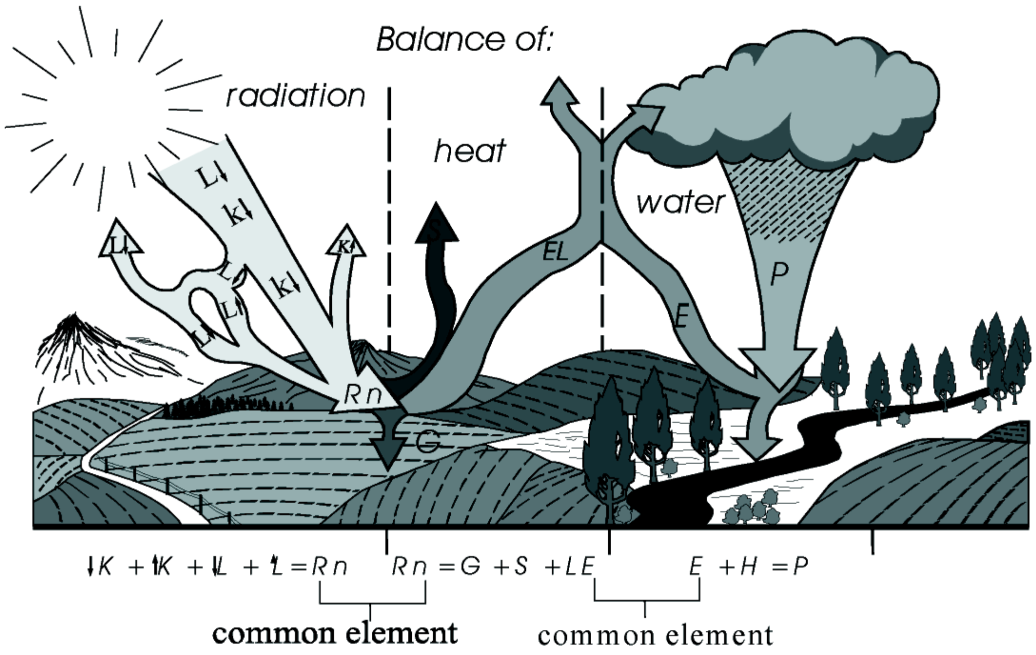
$$P+E+H=0$$

Finally, for the earth's surface the water balance equation becomes:

$$P+E=0$$

BOX 9.4

Balance of radiation (left part), heat balance (central part) and water balance (right part)



For the heat balance equation, as well as for the water balance equation, the fluxes entering a system are denoted as positive while outgoing ones are marked as negative.

These two balances are strongly coupled by the flux of latent heat in the heat balance and flux of water vapour in the water balance (Box 9.4).

FACTORS DETERMINING WATER BALANCE STRUCTURE

The structure of catchment water balance depends mainly on:

- an amount of **energy** available for evapotranspiration;
- variability and time distribution of **precipitation**; a parameter that is discrete in time and space;
- **physiographical** characteristics of a catchment (slope, denivelation, soil cover);
- density and type of **plant cover** and its development stage; and
- **land use**.

HOW PLANT COVER INFLUENCES CATCHMENT PROCESSES

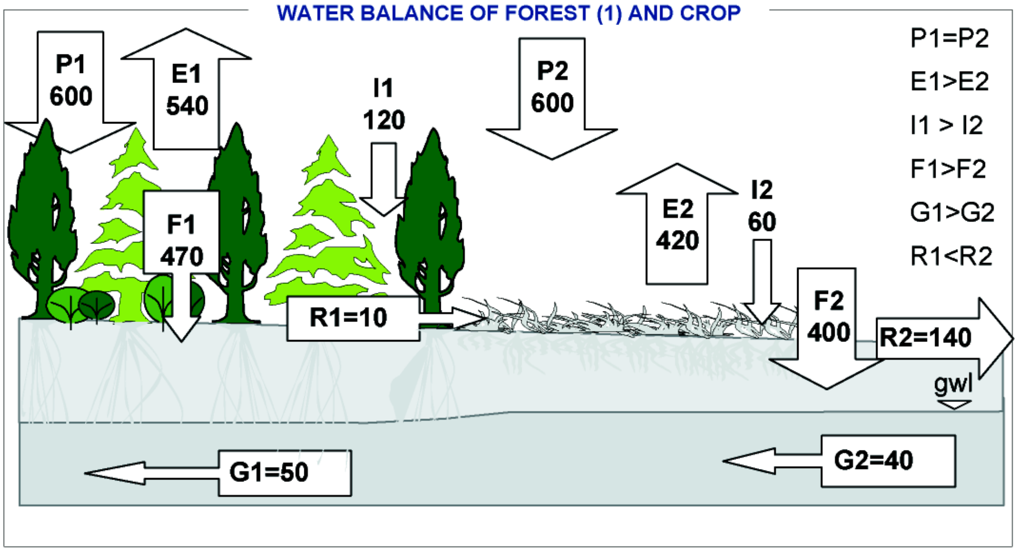
Generalizing, it can be proved that plant cover within a catchment causes (Box 9.5):

- increased evapotranspiration;
- reduced surface runoffs, both due to increased infiltration to soil and evaporation;
- a slowing and increasing time extension of subsurface runoff from soils characterized by higher contents of humus (in underflows situated in ground covered by forest water flows all year round while ditches, situated among fields under cultivation, are dry in summer, even in a year of average precipitation); and
- modification of microclimatic conditions, as in the case of fields protected against wind by forests or shelterbelts where evapotranspiration is lower than in open spaces (Box 9.6).

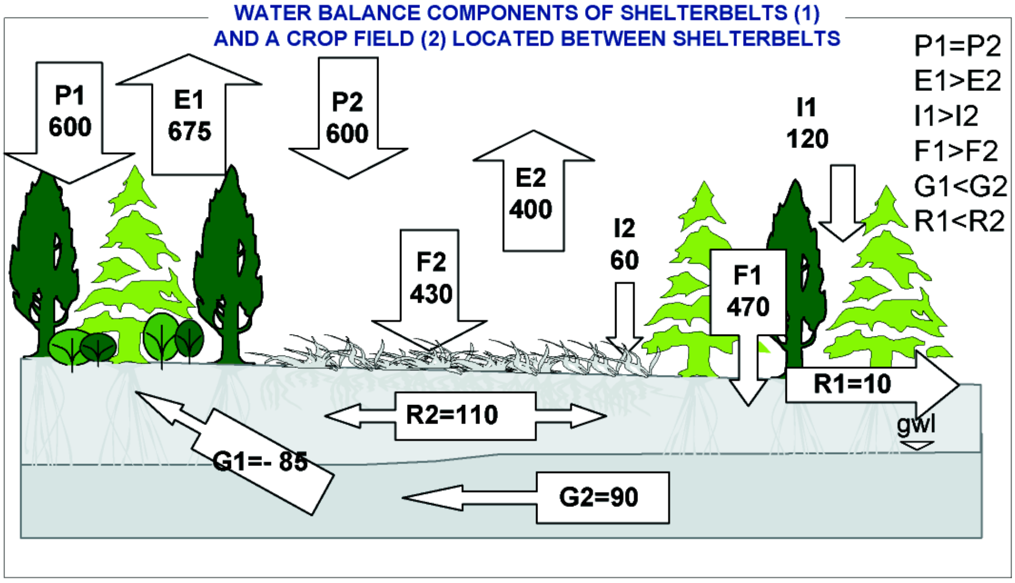
BOX 9.5

Water balance structure of shelterbelts (left part of the upper picture), crop field (right part of the upper picture) and crop field located between shelterbelts (bottom picture)

WATER BALANCE OF FOREST (1) AND CROP



WATER BALANCE COMPONENTS OF SHELTERBELTS (1) AND A CROP FIELD (2) LOCATED BETWEEN SHELTERBELTS



P - precipitation

F - infiltration

E - evapotranspiration

R - surface runoff

I - interception

G - subsurface flow

$$P=I+F+R=E+G+R$$

$$E=F+I-G$$

PRINCIPLES OF WATER DEFICIT CONTROL IN AGRICULTURAL CATCHMENTS

Water shortage is observed in many regions of the world where low precipitation and high evapotranspiration occur. Water deficits may often happen during the summer season, mainly because of the prevalence of light soils, low precipitation and very high atmospheric water demands. Table 9.2 shows an example of water shortage in the Wielkopolska region of Poland.

Proper water management in a landscape can improve these unfavourable conditions. It can be attained mainly through:

- **increasing small water retention** aided by artificial reservoirs storing excess thaw waters;
- **increasing soil retention**; and
- forming **plant cover structure**.

Increase of small water retention

An increase of small water retention can be obtained mainly through:

- the exploitation of existing **small field water reservoirs**;
- reconstruction of **destroyed post-glacial ponds**;
- **interceptions of draining waters** at the time of their greatest runoff in **local depressions**; and
- introducing **swelling equipment** (gates) in the network of drainage ditches.

Small field reservoirs not only store water in their basins, but also increase **retention in the soil** surrounding the reservoir (Box 9.7). Increases of soil retention near small field reservoirs can be even higher than retention increases in the reservoir itself. Small water reservoirs contribute to the **rise of ground waters** in neighbouring areas, **increase the humidity** of soils and, subsequently, **decrease soil drifting**.

The exploitation of small field reservoirs in the spring season can increase water availability of rural catchments by an amount equivalent to 20 mm of precipitation.

INCREASE OF SOIL WATER RETENTION

The best way for improving soil water retention is by **increasing the content of organic matter in the soil**. Soil organic matter plays an essential part in improving water conditions in agricultural landscapes. Organic matter increases soil retention because it retains more water than non-organic matter. Specifically this means an improvement of soil structure by increasing the average size pores, which determine the amount of water accessible for plants.

In some cases, a 1% increase of organic matter increases water supply in a 30 cm ploughed layer by 10 mm or by 100 m^3 ha^{-1}.

TABLE 9.2

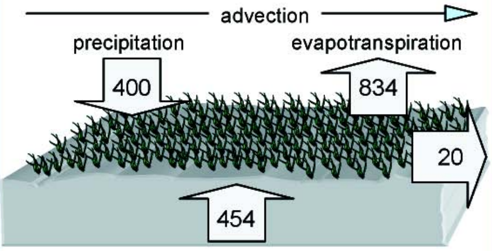
Water shortage in Turew landscape (Poland) during the summer (April - September)

CLASS NUMBER	SOIL TEXTURE	UNIFORM WATERSHED				MOSAIC WATERSHED			
		normal	dry	v. dry	ex. dry	normal	dry	v. dry	ex. dry
1	Pl, pl.ps, pl:ps, ps.pl,	425	359	286	246	10	-56	-129	-169
2	ps, ps:pl, ps:gl	445	379	306	266	30	-36	-109	-149
3	ps.gl, pgl.gl, pgl:gl	485	419	346	306	70	4	-69	-109
4	pgm.gl, pgm:gl	525	459	386	346	110	44	-29	-69

One dot between symbols (pl.ps) means thickness of upper layer equals 30 cm, and bottom layer 70 cm
Two dots means inversely - upper layer thickness equals 70 cm but bottom layer 30 cm
pl, ps, - sand, pgl - loamy sand, pgm - sandy loam, gl - loam

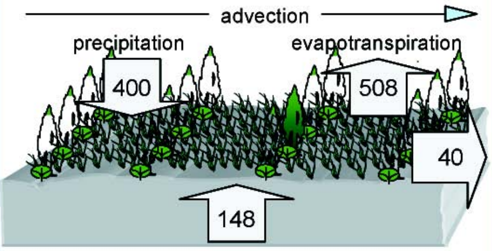
BOX 9.6
Impact of shelterbelts on alfalfa field water balance under advection

WATER BALANCE OF A ALFALFA FIELD
WITHOUT SHELTERBELTS



$$P + ETR + H + R = 0$$
$$400 - 834 - 40 + 454 = 0$$

WATER BALANCE OF A ALFALFA FIELD
WITH SHELTERBELTS



$$P + ETR + H + R = 0$$
$$400 - 508 - 40 + 148 = 0$$

An increase of water retention by 100 mm^3 ha^{-1} has significant economic meaning because the increase is not a single event but refers to each rain event, which can be accumulated in the soil. Thus, during a year, the amount of retention should increase several times.

If retention in a ploughed layer is repeated only three times during a year, the increase of soil water supply during a summer season will reach about 30 mm. This makes an essential saving, even without taking into account the improvement of soil moisture - thermal conditions favourable for vegetative growth and activity of microorganisms and soil fauna.

The proper structure of plant cover within agricultural landscapes exerts a strong positive effect on water cycling. The structure of plant cover, especially shelterbelts, plays a particular part in improving water conditions. They exert a favourable influence on the microclimate by **reducing wind speed by 35-40%**, increasing **relative air humidity, decreasing potential evaporation, increasing snow depth, and reducing the melting rate of snow** in spring. When taken altogether, these increase the percolation rate by 300 m^3 ha^{-1} in areas covered with shelterbelts compared to open areas (Box 9.7).

BASIC GUIDELINES FOR WATER MANAGEMENT IN A LANDSCAPE

Improvement of water cycling in the landscape requires:

- developing landscape complexity by introduction of shelterbelts, meadow strips and restoration of midfield ponds;
- increasing organic matter content in the soil;
- keeping as much water as possible in the landscape for as long as possible, taking care that it is properly allocated; and
- ensuring that as much water as possible moves from the soil into the atmosphere via plant transpiration, but not as evaporation from the soil to the atmosphere.

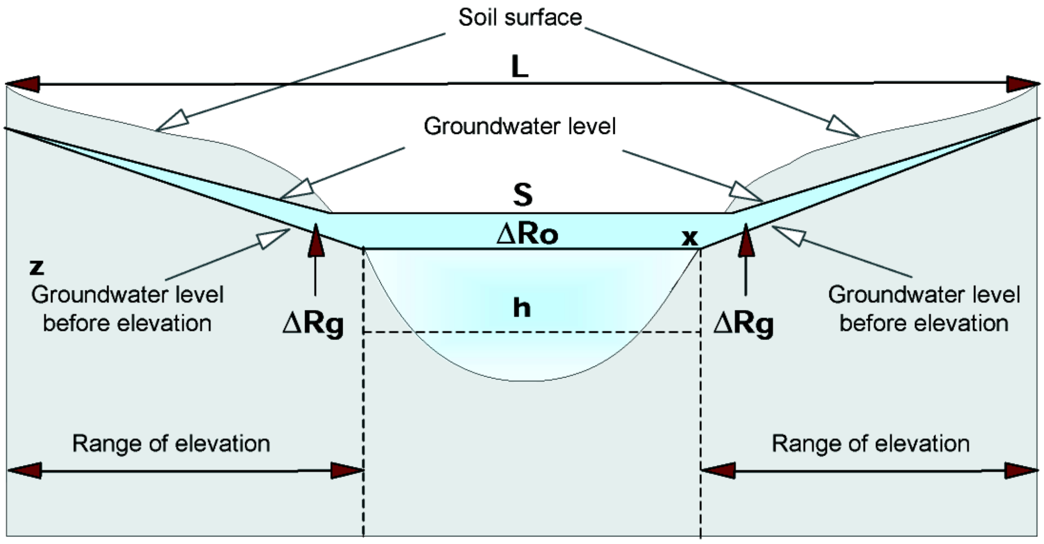
HOW TO DO IT

For this purpose:

- **unsystematic and partial draining** should be used more widely and every opportunity for retaining draining runoffs in a catchment area should be utilized;
- supplementary **to drainage retention, agromelioration measures** for improving the physical-water properties of soils and increasing their retention capacities and, consequently, decreasing water deficits for plants during the summer, should be widely applied;
- the scope of necessary agromelioration must take into account **negative interactions of farm work mechanization** for soil structure by condensing surface soil layers; and
- **proper landscape management** of catchments by optimizing arable land structure and adjustment of agricultural output to the natural resources of the environment, as well as introduction of shelterbelt networks, are fundamental conditions for increasing the effectiveness of water resource exploitation.

BOX 9.7

Water retention in midfield ponds and in soil surrounding a pond

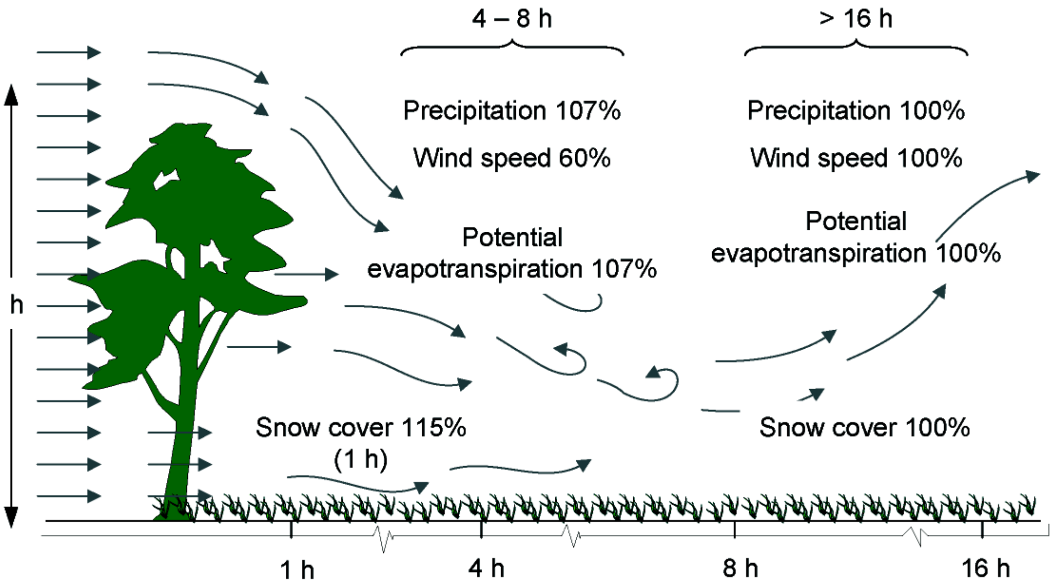


h – average depth of water in a pond, ΔRo - water retention in a pond, L – range of water retention increase in soil, S – pond diameter

(Kedziora, 1995)

BOX 9.8

Impact of shelterbelt on microclimat of adjoining fields



Distance from the shelter measured as a multiple of a trees height (h)

MAKE SURE TO CHECK THESE RESOURCES:

Guidelines: chapters 4.C, 4.E 4.J

9.C. CONTROL OF DIFFUSE POLLUTANT INPUTS TO WATER BODIES

ENVIRONMENTAL EFFECTS OF UNSUSTAINABLE AGRICULTURE

To increase production farmers simplify plant cover structure, both within cultivated fields (selection of genetically uniform cultivars and weed elimination) and within agricultural landscapes (elimination of hedges, stretches of meadows and wetlands, small mid-field ponds). Animal communities in cultivated fields are also impoverished (Ryszkowski, 1985; Karg & Ryszkowski, 1996). Farmers interfere with matter cycling in agroecosystems directly by inputs of fertilizers, pesticides, etc., or indirectly by changing water cycling and decreasing holding capacities of soils for chemical compounds. In addition, agricultural activity often leads to decreased humus contents. Increased use of power equipment enables not only deeper soil ploughing, but also land surface leveling, modification of water drainage systems, etc., which leads to changes in the geomorphological characteristics of the terrain. These effects of farming activity result in the development of a less complex network of interactions among agroecosystem components. Relationships between agroecosystem components are altered so that there is fewer tie-ups of local matter cycles. Thus, increased leaching, wind erosion, volatilization and escape of various chemical components and materials from agroecosystems have been observed (Ryszkowski, 1992, 1994).

How to reconcile agriculture activities and environmental protection

Many environmentally significant effects of agriculture intensification are connected with the impoverishment or simplification of agroecosystem structure. However, a farmer in order to obtain high yields must eliminate weeds, control herbivores and pathogens, insure that nutrients are easily accessible only for cultivated plants during their growth, increase mechanization efficiency, amongst other things. Therefore, agricultural activity aimed at higher and higher yields leads inevitably to the simplification of agroecosystem structure, which in turn causes further environmental hazards.

Fig. 9.5
Diversified agricultural landscape
(photo: I. Wagner Lotkowska)

Such an ecological analysis leads to a conclusion of major significance for the sustainable development of rural areas. Applying intensive means of production, farmers cannot prevent the threats to arable fields, as noted above, and these increase the risks of diffuse pollution to ground and surface waters, evolution of greenhouse gases (N_2O, CO_2) and water or wind erosion. It must be clearly said that although farmers can moderate the intensity of these processes through proper selection of crops and tillage technologies, they are not able to eliminate them entirely.

A higher control efficiency of environmental threats evoked by agriculture could be achieved by structuring agricultural landscapes with **various non-productive components** like, e.g.:

- hedges;
- shelterbelts;
- stretches of meadows;
- riparian vegetation strips; and
- small ponds.

Therefore, any activity to maintain or increase **landscape diversity** is important not only for aesthetics and recreational reasons, but even more so for environment protection and for the protection of living resources in the countryside.

EFFECTIVENESS OF VEGETATION BUFFER ZONES FOR CONTROLLING DIFFUSE POLLUTION

Recent developments in agroecology and, especially in studies on agroecosystems and rural landscape functions like solar energy flows, matter cycling, and maintenance of biodiversity, help to tackle the problems of environmental threats. Studies on impacts of plant cover patterns on agricultural landscape functions are especially relevant in this respect.

There is an increasing amount of evidence that **permanent vegetation strips can control the dispersion of chemical compounds leached out of cultivated fields** (see recent published proceedings of conference on buffer zones edited by Haycock et al., 1997). To describe the effectiveness of buffer zones for controlling diffuse pollution, the results of studies carried out by the Research Centre for Agricultural and Forest Environment in Poznan, Poland will be presented.

Reduction of chemical compounds in ground waters

Nitrate concentrations in ground water from beneath meadows and shelterbelts studied in the Wielkopolska region (Poland) were significantly lower than those in ground water under adjoining fields. In some areas the reduction in the mean nitrate concentrations in ground water under the biogeochemical barrier (shelterbelt) was 34 fold (from 37.6 mg L^{-1} to 1.1 mg L^{-1}; Bartoszewicz & Ryszkowski, 1996). But usually the decrease in nitrate concentrations under the biogeochemical barrier was lower, in the range of 10-20 fold. In ground water under some cultivated fields very high concentrations of nitrates, reaching 50 mg NO^-_3-N per litre, were detected, while in the stream draining this watershed the average concentration of NO^-_3-N over many years did not exceed 1.5 mg NO^-_3-N per litre (Table 9.3). The stream is separated from fields by stretches of meadows, hedges, and shelterbelts. Thus, the strong controlling effect of these biogeochemical barriers can be observed (Bartoszewicz, 1994; Ryszkowski et al, 1997). The decrease of phosphate concentrations in ground water under the fields and biogeochemical barriers was less striking; usually the concentration decrease was 10-50 percent.

Concentrations of many chemical compounds migrating from the ground in outflows from neighbouring cultivated fields are seriously reduced when the water passes under such biogeochemical barriers as shelterbelts, mid-field forests and riparian vegetation strips (Box 9.9).

Prevention of compound export from landscapes to waters.

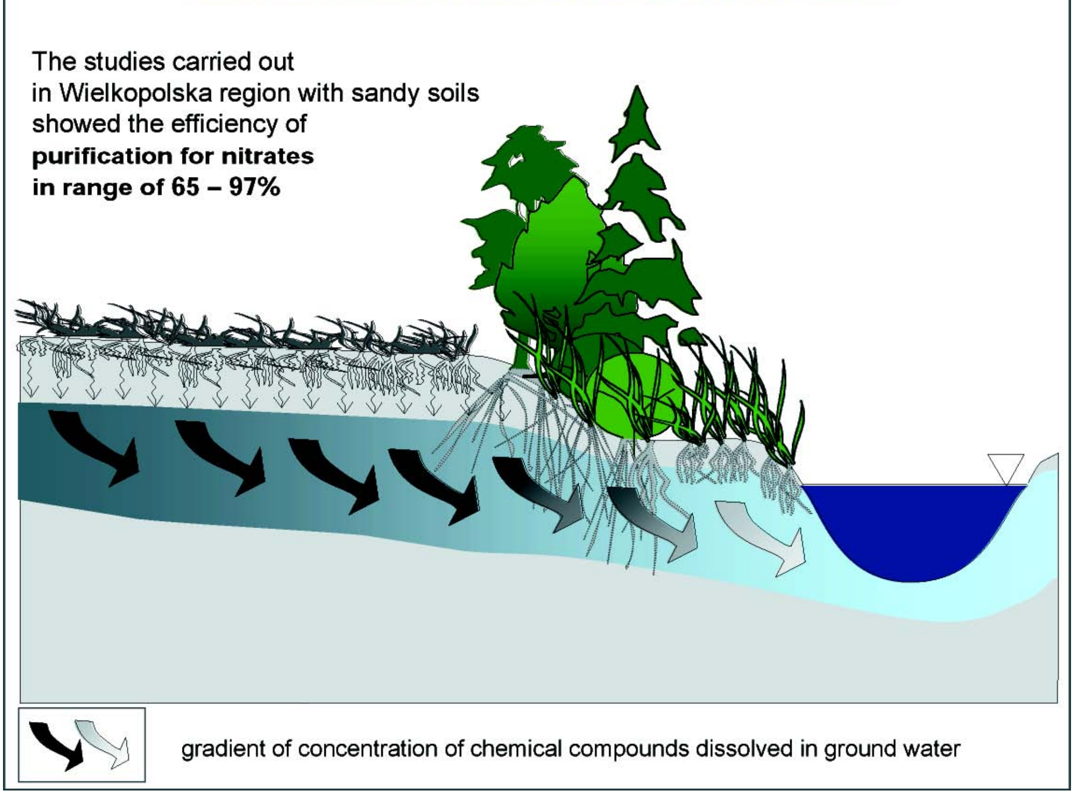
The great influence of plant cover structure on the output of elements from watersheds was shown by Bartoszewicz (1994) and Bartoszewicz & Ryszkowski (1996). The studies were carried out in two

TABLE 9.3

Mean concentrations of NO_3-N (mg dm^{-3}) in ground water under cultivated fields, shelterbelts, small forests and meadows in the Turew agricultural landscape, Poland

Period of sampling	Culitivated field (a)	Shelterbelt or forest	Meadow (b)	Reduction (a-b):a (percent)	Reference
1982-1986	22,2	1,0	-	95	*Bartoszewicz & Ryszkowski, 1996*
1982-1986	37,6	1,1	-	97	*Bartoszewicz & Ryszkowski, 1996*
1972-1973	12,6	0,3	-	98	*Margowski & Bartoszewicz, 1976*
1984-1986	33,1	8,1	-	75	*Ryszkowski et al., 1997*
1994	52,4	2,7	-	94	*Ryszkowski et al., 1997*
1995	13,1	4,9	-	63	*Ryszkowski et al., 1996*
1986-1989	48,3	-	6,5	87	*Bartoszewicz, 1990*
1987-1989	15,9	-	0,7	95	*Bartoszewicz, 1990*
1987-1991	13,1	-	2,8	79	*Szpakowska & Zyczynska-Baloniak, 1994*
1993	18,7	-	1,4	92	*Ryszkowski et al., 1996*
1993	22,1	-	2,0	91	*Ryszkowski et al., 1996*
1994	19,1	-	1,2	94	*Ryszkowski et al., 1996*
1994	13,4	-	2,4	82	*Ryszkowski et al., 1996*
1995	18,3	-	0,6	97	*Ryszkowski et al., 1996*

BOX 9.9
Function of shelterbelts in purification of groundwater pollution



small watersheds. The first one, called a uniform watershed, was 99% composed of cultivated fields and 1% small forests. In the second one, called a mosaic watershed, cultivated fields made up 70% of the area, meadows 14% and riparian forest 16%. The mean annual water output from the mosaic watershed during a 3 year period was 70.2 mm^2 and in the uniform one, 102.0 mm^2. The mean annual precipitation for both watersheds was the same; 514 mm^2 (Table 9.4).

From an uniform arable watershed, 20.4 kg of inorganic nitrogen leached from 1 ha annually, 20% of which was in the form of ammonium ions.

When the migration of mineral components from a mosaic watershed was analysed, a low leaching rate of nitrogen constituents and different ratio of nitrate to ammonia ions were observed. The annual leaching rates of N from 1 ha of this watershed amounted to about 2 kg (ten times less than in the uniform watershed), and both ionic forms of N were represented in almost identical proportions. Even more striking were the differences between the uniform arable watershed and the mosaic one with respect to seasonal variations in the migration of nitrogen. The majority of both nitrogen ion forms (86%) had leached from the mosaic watershed during winter, while during the summer period, the leaching of both nitrogen forms (particularly nitrate) was negligible.

Enhancement of resistance to degradation

Naturally compatible structures that assist in controlling matter cycles in agricultural landscapes are of great importance for **enhancing a countryside's resistance to degradation**.

Various plant cover structures like hedges, shelterbelts, stretches of meadows and riparian vegetation strips are of special interest. Application of these structures has several benefits, of which the most important are:

- they can be easily planted;
- they are not expensive and could provide

TABLE 9.4

Annual mean water output (mm) and nutrient loss (g m^{-2} $year^{-1}$)
from two small watersheds in Poland, from November 1988 – October 1991

SEASON		**UNIFORM WATERSHED**			**MOSAIC WATERSHED**		
	Precipitation (mm)	Water output (mm)	NO_3-N	NH_4-N	Water output (mm)	NO_3-N	NH_4-N
Winter season Nov.-April	220,7	60,8	12,3	3,0	56,8	0,90	0,95
Summer season May-Oct.	292,9	41,2	4,0	1,1	13,4	0,05	0,25
Whole year	513,6	102,0	16,3	4,1	70,2	0,95	1,20

(Bartoszewicz, 1994)

economic benefits (e.g., timber, herbs, honey etc.);

- they can fulfil some societal needs (hunting, photography, mushroom and berry picking, etc.); and
- they are very important from the point of view of ecological engineering, because biogeochemical barriers exert controlling effects on non-point pollution.

Mid-field water reservoirs

Mid-field water reservoirs also intercept che-mical substances, immobilizing them in bottom deposits where they are subjected to transformation by biogeochemical processes.

The role of small mid-field ponds, lately neglected and often treated as wastelands, is particularly significant for more efficient use of fertilizers. They may serve as a tool for modification of matter cycling because the chemical compounds leached from fields co-uld be returned to arable fields with sediment. Such forms of field fertilization were applied in the past on a fairly wide scale, as was described by General Dezydery Chlapowski in his book on agriculture published in 1843.

MAKE SURE TO CHECK THESE RESOURCES:

Guidelines: chapters 4.E, 5.B-5.G