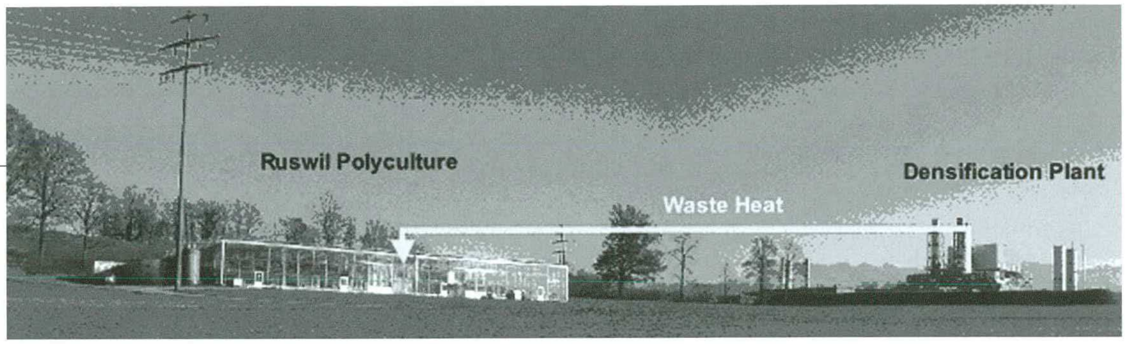


Figure 5.34
Natural gas densification plant and Polyculture Greenhouse in Ruswil

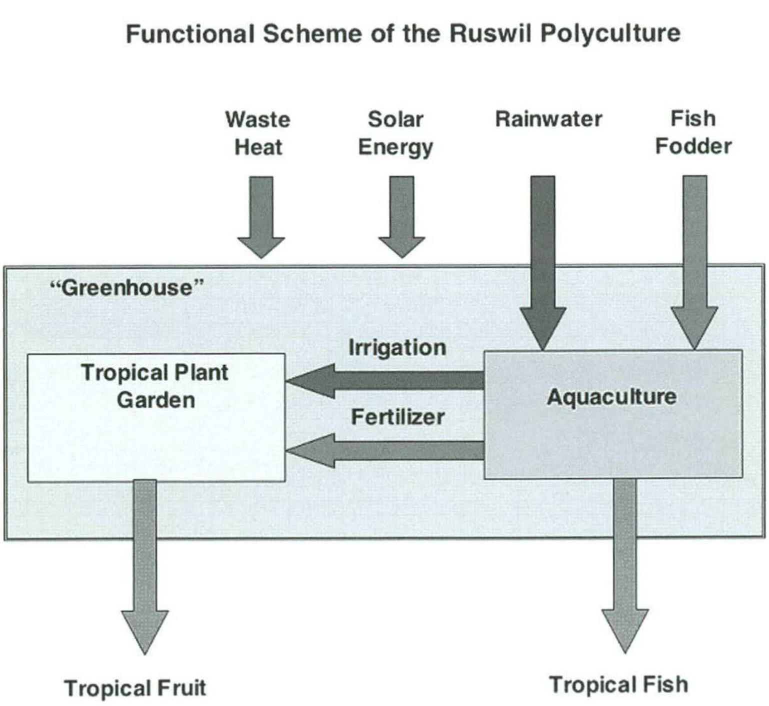
Figure 5.35
Functional Production Scheme of Ruswil Polyculture

5.6.2 Waste heat turns into tropical products – The Tropical Greenhouse Project Ruswil

J. Heeb

Introduction

Waste heat (or process heat) is a well known, but to little used energy resource. In Ruswil, in the center part of Switzerland, a natural gas densification plant is being operated as a part of the European gas-pipeline network. The plant generates more than 100 GWh (1 GWh = 1000 kWh) waste heat per year. Options to use this energy to heat villages failed due to cost reasons. Today 40 GWh of the waste heat are turned into ecologically sound electricity and up to 30 GWh will be used for the production of tropical fruit and fish as a contribution to substitute energy consuming imports.



Current situation

The energy legislation of the Canton of Lucerne (Switzerland) requires the utilization of industrial generated waste heat. The "Tropical Greenhouse Project Ruswil" was launched to evaluate options to use waste heat for agricultural production. Today a 1500 m^2 greenhouse is under operation as pilot project (figure 5.34). The pilot proves to be ecologically sound and economically viable. Within the next years the greenhouse area will be expanded to ca. 20 000 – 30 000 m^2.

System Design

The principles of ecological engineering (e.g. considering waste as a resource, multy-functionality, ecosystem based design, system integration, etc.) as well as the Asian polyculture systems provided the basis and guidelines for the development of the "Ruswil Polyculture" (figure 5.35).

In the Ruswil polyculture the production of tropical fish (Tilapia) and tropical fruits (Bananas, Guava, Carambola (starfruit), Mango, etc.) are combined and linked in terms of water and nutrientflows. The wastewater from the fish is being used for irrigation and fertilization of the entire tropical fruit garden. Or in other words: the tropical fruit garden can be considered as a "natural wastewater treatment system" of the tropical fish production. Small aquaculture ponds are being used for stabilization and nitrification of the fish's wastewater as well as for a first step production of aquaculture based vegetables and flowers. The fish fodder is not produced in the greenhouse, but bought on the market. It compensates for the export of nutrients out of the greenhouse due to selling the products. The "system-drivers" of the Ruswil systems are the waste heat, the solar energy (light), rain water and fish fodder.

Results and comments

Five years of operation of the project show that the utilization of waste heat as a resource for tropical fish and fruit production in Switzerland is feasible. Depending on the production concept a yearly yield of 60 – 80 tons of tropical fruit and 15 – 20 tons of fish can be reached. According to an evaluation carried out by costumers, the quality of the fruit and fish is higher compared to imported products. The system can be operated organically, no chemical pesticides had to be used. Due to the installed drip irrigation system the water consumption of the greenhouse is very low. Not more than 400 liters of irrigation water are being used per m^2 and year. Live cycle assessment (LCA) based comparisons show that the indoor production of the tropical products based on waste heat show an up to 10 times higher ecological performance as products imported on a flight transport basis. The energy consumption of the system is very high (ca. 6-8 GWh per 10 000 m^2 and year). Therefore it has to be clearly pointed out that the operation of the system is only ecologically sound and economically recommendable as long as waste energy is available. A major concern of production problems in winter due to a lack of light did not prove to be relevant. In order to run the system economically viable a minimum production area of 10 000 m^2 is recommended. The Ruswil polyculture has developed into a leading tourist attraction. It provides a good platform to communicate the principles of ecological engineering to a broader audience.

Conclusion

Tropical indoor polyculture systems are a promising and ecological and economical sound option to use waste energy wherever this resource is available in larger quantities (and there the waste energy cannot be used for direct heating of houses). Organic production of high quality products is technically and economically feasible (see: www.tropenhaus-ruswil.ch).

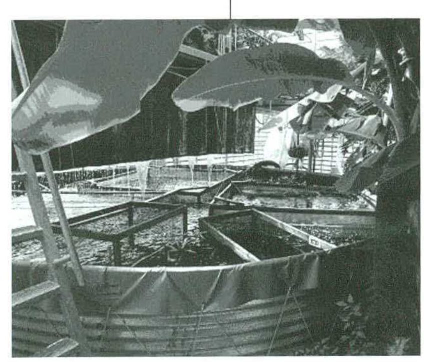
5.6.3 Typha Ponds for Rain- and Wastewater Retention and Utilization

J. Heeb

Introduction

In most of the cities and villages wastewater and storm water are still mixed and drained into the sewer system. Due to a decrease of the natural rainwater infiltration capacity caused by surface sealing construction of houses and infrastructure the increasing amount of storm water is leading to overloaded sewer systems whenever heavy rain event occur. As a result large amounts of the mixed waste- and storm water are directly discharged into rivers and lakes leading to negative ecological impacts. New concepts for a more sustainable water management in cities and villages are needed to avoid this problem. Typha (cattail) ponds represent a promising option to increase the retention capacity of settlements. At the same time new valuable natural habitats can be created and raw material for ecologically sound building materials can be produced.

Figure 5.36
Ruswil impressions: Jungle garden, fishponds, and proud papaya harvesters)



Current situation

In Switzerland cities and village are obligated to provide enough retention capacities in order to avoid overloaded sewer systems and to hold back mixed waste- and storm water. As a result technical and cost intensive retention basins (made out of concrete) are constructed in many places. The village of Geuensee (Switzerland) was facing the same problem. The "traditional technical option" providing 300 m^3 of retention capacity would have caused investment costs close to € 500 000. Do to an initiative of the mayor of this village alternatives to technical retention basins were evaluated. Finally a Typha pond project was implemented. The system provides 2 500 m^3 of retention capacity. The cost of the system did not even exceed € 40 000.

Figure 5.37
Typha retention pond Geuensee

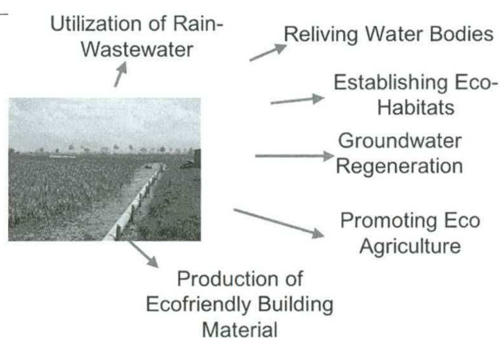


Figure 5.38
Multifunctionality of the Typha retention pond Geuensee

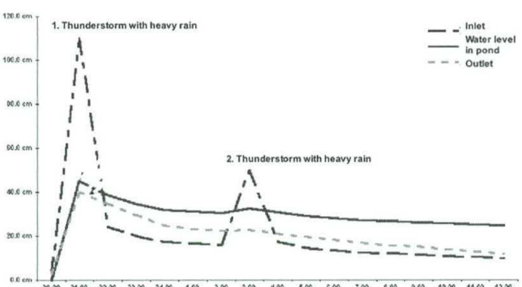


Figure 5.39
Water dynamics in the Typha retention pond during 2 heavy rain events in summer 2003

Figure 5.40
Harvesting and using Typha seeds as a additive for clay plaster production

System design

In Geuensee a Typha retention pond system with a surface are of 3 500 m^2 and a retention capacity of 2 500 m^3 was constructed on agricultural land. No liner was used. The water level is being regulated by a simple wooden weir (figure 5.37) and varies in between 20 cm (normal low water level) and 80 cm (high water level during heavy rain events). Depending on the drainage management the system can hold back the mixed wastewater and rainwater for more than 2 days. In the system the water gets party purified and the pond works as a efficient sedimentation field for sand and sludge. The system's design represents typical principles of ecological engineering such as being ecosystem based, multifunctional and renewable energy based (figure 5.38).

Results and comments

The Geuensee project has been operated now for 2 years. The Typha pond proves to work efficiently as a retention basin. At the same time a diverse natural habitat has being developed and raw material for ecologically sound building material production could be generated. Investigations will be carried out concerning accumulation of critical substances such as heavy metals. Monitoring will be started in 2005.

Conclusion

The Geuensee Typha pond presents a ecologically and economically interesting alternative to technical retention systemes. The technology provides a new income option to agriculture since farmers can offer retention services to villages and towns and produce raw material for building material production (see www.iees.ch).

5.6.4 A complete recycling (ecosan) system at student dormitories in Norway

P.D. Jenssen

The concept

The Agricultural University of Norway is pioneering environmentally safe solutions to organic waste and wastewater treatment. In 1997 a first generation recycling system based on ecological engineering principles was built serving 48 students. The system reduces water consumption by 30%, it nearly eliminates pollution, and it produces a valuable plant fertilizer and soil amendment product from the waste material (figure 5.41).

The concept is based on:

- Separate treatment of toilet wastewater (blackwater) and water from kitchen and shower (greywater).
- Modern and reliable vacuum toilet technology with high comfort.
- Liquid composting of toilet waste and organic household waste for sanitation, stabilization, removal of odours and production of high quality liquid fertilizer. Liquid composting can be substituted for or combined with biogas production.
- Simple and reliable filtration of greywater for producing a water quality suitable for irrigation groundwater recharges or simply discharges to a nearby stream.
- A patented machine for fertilizer distribution that hydraulically "shoots" the liquid bio-fertilizer into the ground, resulting in higher yields and less pollution from run-off.
- Water-saving devices for showers, characterized by high comfort.

Wastewater composition

The composition of nitrogen (N) Phosphorus (P) and Potassium (K) in domestic wastewater and organic household waste is close to an optimum ratio for plant growth.
Hence, this waste material constitutes a near ideal plant fertilizer. The majority of the plant nutrients in wastewater - 90% of the nitrogen and up to 85 the phosphorus (when phosphate free detergents are used as in Norway) - are found in toilet waste (table 5.7). In addition toilet waste contains the majority of other pollutants such as organic matter and pathogenic organisms.

Table 5.7 Wastewater composition, Norwegian figures

Component	kg per person and year	% in toilet waste (blackwater)
Nitrogen	4.5	90
Phosphorus*	0.7	85
Potassium	1	79**
Organic matter***	35	40-75

** using phosphate free detergents*
*** From Vinnerås (2002)*
**** as chemical oxygen demand (COD)*

The toilet concept

Conventional toilets use from 6 - 20 litres per flush and this account for up to 20 - 40 % of the water consumption in sewered cities (Gardner 1997). By the use of modern vacuum toilet technology the amount of water per flush is reduced to about 1 litre. First of all this makes it possible to save water, but it also reduces the blackwater volume to an amount that can be handled separately. The vacuum toilet technology has been developed through maritime use and is known for reliability and modern design. The price is comparable to that of ordinary water closets. The vacuum generator requires little electricity. The latest development in vacuum technology is vacu-

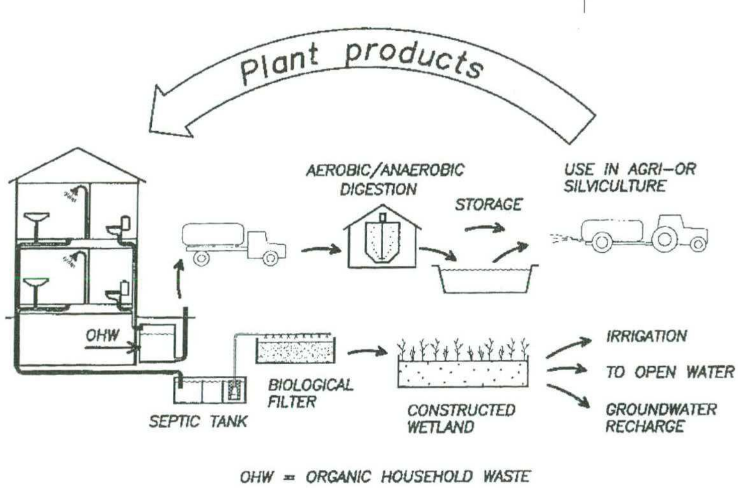


Figure 5.41 The complete recycling system at the student dormitories based on separate treatment loops for blackwater and greywater

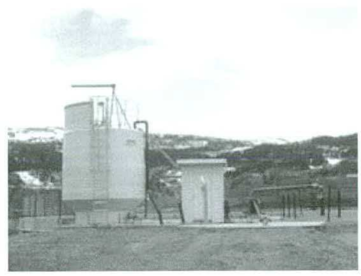




Figure 5.42
a) wall mounted vacuum toilet,
b) the liquid composting reactor,
c) direct ground injection (DGI).

um on demand (VOD) where vacuum is generated only when needed. Such systems, which also are available in solar powered versions, have an energy consumption of 4KWh/person and year. The blackwater is collected in tanks, usually one separate tank for each building. 3-5 people will produce 5 - 10 m^3 blackwater per year. The 48 students produce 10m^3 of blackwater per month. The blackwater is collected monthly and trucked to the treatment facility.

Converting Blackwater into Fertilizer

In order to sanitize (kill pathogenic micro organisms - bacteria, virus and parasites) and to remove odours the blackwater must be treated. This is done by a liquid composting reactor (figure 5.42b) (Skjelhaugen 1999). In the liquid composting reactor the blackwater is mixed with milled organic household waste (other organic waste material is also possible to use i.e. animal manure or food processing waste). The household waste is added in order to increase the concentration of organic matter and speed up the composting process. The biomass is composted at a temperature of 55-60° C and the end-product is an odourless fertilizer slurry. The liquid composting efficiently reduces the pathogenic organisms and the composted material meets the standards of the European Union sludge regulations with respect to bacterial content. The liquid composting unit runs with a net energy surplus in terms of heath, but this is not yet utilized. Biogas production alone or combined with liquid composting or thermal hydrolysis is being considered both from an energy perspective and to meet future requirements with regard to health and hygiene. Hydrogen production using algae is also an interesting option combined with anaerobic digestion.

Direct Ground Injection – DGI Concept

The slurry from the liquid composting can be applied directly as liquid fertilizer using *Direct Ground Injection* technology. The DGI hydraulically "shoots" the liquid fertilizer into the ground (figure 5.42c), leading to a more efficient fertilizer use and thus avoiding over-use and run-off to rivers, aquifers, etc. Almost all of the nitrogen/ammonia is utilized and not evaporated as happens with traditional spreading through the air. Tests have shown comparable yields for the same amount of bio-fertilizer using the DGI method, making it possible to decrease the use of chemical fertilizer.

Table 5.8 Average performance of the Kaja greywater treatment system over six years of operation (concentrations in mg/l).

Parameter	Effluent septic tank	Effluent wetland	Removal%	Total removal%*
BOD	87	5,6	94	97
Total phosphorus	0,97	0,05	95	99
Total nitrogen	8,7	2,6	70	97

**assuming 90% of N, 80% of P and 50% of BOD in blackwater*

Greywater treatment

The daily greywater production is 115 liter/student. Primary treatment is in a 10 m^3 three compartment septic tank, followed by an aerobic biofilter and constructed wetland both filled with light weight aggregate The total area of the system is 100 m^2, the depth of the wetland 1 m and the retention time is 7 days. The treatment results are shown in table 5.8.

Total phosphorus is effluent concentration 1/10th of the discharge consent for large advanced treatment systems in Norway and total nitrogen is below the WHO drinking water requirement of 10 mg/l. The high P-removal is due to the P-sorbing capability of the light weight expanded day aggregate (LWA). The Faecal Coliform (FC) counts in the outlet are generally below 100 TCB/100 ml and 8 out of 22 samples have shown 0 FC/100ml. The effluent values are very stable and no decreasing trend has been observed for any parameter over the first 6 years of operation.

Experiences, maintenance and economy

The vacuum system has worked reliably with no major problems. Most of the students are satisfied, but some complain that the vacuum system is a little noisier. The service interval on the vacuum generating system is 2 years. The students are encouraged to use a biological toilet cleaner that helps prevent urine stone deposits in the toilet valve and piping system. The major cost is collection of the toilet waste once a month. Dual flush vacuum toilets that use about 0,5 litres on the average are now available. This would increase the emptying interval to once every two months. Such toilets, if they where installed, would reduce the main operating cost of the system by 50%.

The greywater treatment system has had no maintenance need the first 5 years. The sludge accumulation in the septic tank has not yet reached levels where emptying is necessary.

Because of a dual piping system the in-house plumbing is more expensive. There is no need, however, for a secondary sewer collection system. This system is economically competitive especially in areas where no sewage network exists or where there is high costs connected to building or upgrading an existing sewer.

Conclusions

- Recycles 80 -90% of the nitrogen and phosphorus in the wastewater. Reduces nutrients and organic matter (BOD) >95%, hence; near zero emission.
- Reduces the need for pipelines - the most expensive part in a traditional sewage network.
- Replaces expensive chemical fertilizer.
- Makes it possible to recycle nutrients locally, decreasing the need for transport of fertilizer.
- Makes energy production from waste resources possible.
- Greywater treatment facilities can easily be adapted to the terrain.
- Facilitates development of real estate in areas with no existing sewage network.
- Saves 30% of the domestic water consumption. Adding more water saving devices makes it possible to save up to 50% or more.
- It is possible to use the separated greywater for irrigation or groundwater recharge after filtration, thus saving even more water.

5.6.5 *Decentralized urban greywater treatment at Klosterenga Oslo*

P.D. Jenssen.

Introduction

Today it is possible to foresee completely decentralized wastewater treatment systems in urban areas where the blackwater fractions (urine and faecal matter) are reclaimed for fertilizer and potentially energy production (Jenssen et al 2003). The water from kitchen sinks and showers (greywater) is treated locally in compact low maintenance systems that constitute attractive landscape elements (Jenssen and Vråle 2003). These systems can coexist with decentralized water supply.

Greywater composition and treatment needs

Greywater contains little nutrients (nitrogen and phosphorus), because 90% of the nitrogen and 70-80% of the phosphorus in the blackwater. Greywater may contain more than 50% of the organic matter and, surprisingly, a relatively high content of bacteria and even virus (Ottoson 2003). If greywater is discharged to smaller streams in urban areas or used for irrigation or groundwater recharge advanced treatment that reduces organic matter and the hygienic parameters is needed.

System design

At Klosterenga, in the capital of Norway, Oslo, the greywater is treated in an advanced nature based greywater treatment system in the courtyard of the building. The system consists of a septic tank, pumping to a vertical down-flow single pass aerobic biofilter followed by a subsurface horizontal-flow porous media filter.

Results and comments

The Klosterenga system was built in 2000 and has consistently produced an effluent quality averaging to:

- COD 19 mg/l
- Total nitrogen 2,5 mg/l
- Total phosphorus 0,03 mg/l
- Faecal coliforms 0

For nitrogen the effluent has consistently been below the WHO drinking water requirement of 10 mg/l and for bacteria no faecal coliforms have been detected.
The space required for this experimental system is about 1 m^2/person, and part of the treatment area is also used as a playground (Fig. 2).
Additional aeration, in the summer season, is provided by a flow-form system (Wilkes 1980). This is not necessary for the treatment performance but adds aesthetic value. It is estimated, that saturating the wetland media with phosphorus will take more than 40 years at Klosterenga. This

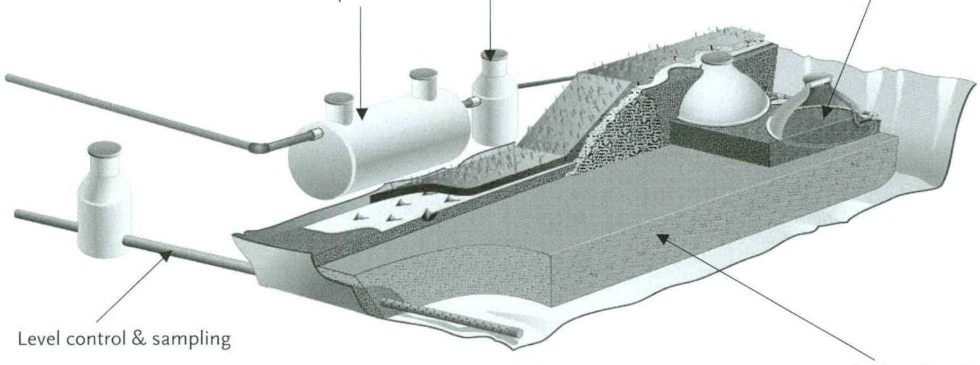


Figure 5.43
The latest generation of constructed wetlands for cold climate with integrated aerobic biofilter in Norway.

is due to a new light weight expanded clay aggregate (LWA), FiltraliteP^{TM}, which has very high phosphorus sorption and bacteria reduction capabilities. Preliminary investigations indicate that systems with FiltraliteP have potential for excellent virus reduction.

With such high qualities of the effluent water, as shown above, the need for a secondary sewer collection system is reduced because local streams or water bodies can be used for receiving treated water even in urban areas.

Conclusion

A combined vertical flow biofilter followed by a horizontal flow wetland filter for advanced greywater treatment is developed. The total area requirement is $1m^2$/ person and the effluent meets European swimming water standards with respect to indicator bacteria and WHO drinking water standards with respect to nitrogen. The low area requirement of the system and the high effluent quality facilitates use in urban settings, discharge to small streams, open waterways or irrigation or groundwater recharge.

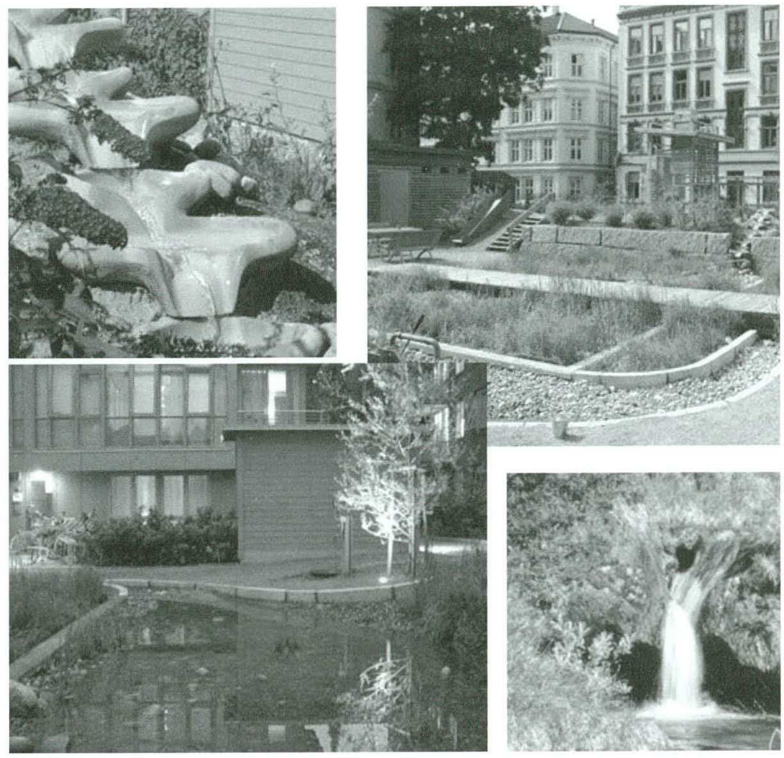


Figure 5.44
The Klosterenga greywater treatment system. Upper right; the wetland in the foreground the biofilter is underneath the playground behind the stonewall. Upper left; Flowforms. Lower left the effluent is exposed in a shallow pond. Discharge to a local stream is possible; the stream was reopened.

5.6.6 Experience with ecological engineering in India

B.B. Jana

Preface

Application of ecological engineering is of great significance in the developing countries because of its low cost, eco-friendly nature, ease of operation due to diverse habitats and variety of tropical biological agents well known for their immense biofilter potentials.

Control of eutrophication has become a global challenge in the present day of environmental degradation. Wetlands in India are not only the means of water conservation, but they are the source of livelihood for million of people for various economy driven activities. On the other hand, a large number of water bodies have been turned into eutrophic and hence become unsuitable for aquaculture activities.

Management of eutrophic water bodies in tropical countries for economy driven activities is of immense importance for economic development in the country (Figure 5.45). This approach is most pertinent in the developing countries because of rapid pace of industrialization at the cost of the environment which results in an unsustainable development.

This is often done by reclamation of water bodies and using the natural food web manipulation through ecosystem approach.

Figure 5.45
Societal benefits of ecological engineering

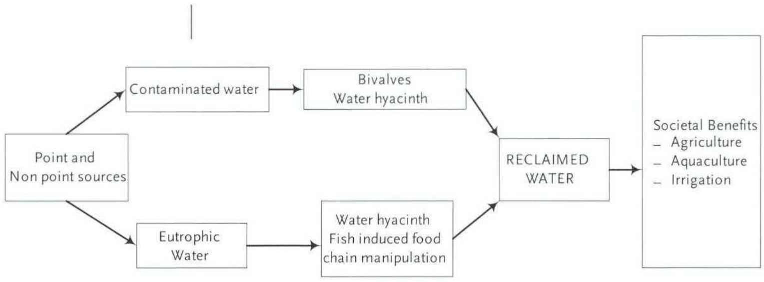


Figure 5.46
Eichhornia

Figure 5.47
Floating macrophytes

The International Centre of Ecological Engineering, Kalyani University has been working quite for long time on the reclamation of eutrophic and contaminated aquatic habitats with a view to use them for economic activities. The researches in the centre have been carried out or are in progress in the following areas: Professor B.B. Jana and his school in the International centre of ecological engineering, University of Kalyani, West Bengal, India have been working on reclamation and rehabilitation of polluted and eutrophic water bodies using various biological agents. Some of the research activities are summarized here under.

I. Macrophytic reclamation of eutrophic waters

It is demonstrated that nutrient removal capacity of water hyacinth (Eichhornia) (Saha and Jana, 2002 a and b) under simulated eutrophic conditions was significantly higher in the mixed enrichment with N and P than either with N or P separately. Further, density dependent removal of P and N was more pronounced at low nutrient levels than at high nutrient level. Preference for N over P occurred when space and nutrients remained unlimited.

Lemna, another floating macrophyte, removed nutrients mainly from water phase, whereas, emergent macrophyte, *Scirpus* utilised P exclusively from the sediment. Plant recovery of both N and P was high in emergent macrophyte than in the floating macrophyte. While comparing the nutrient removal capacity of floating and submerged macrophytes, it was observed that *Hydrilla* was more efficient than *Trapa*. The latter

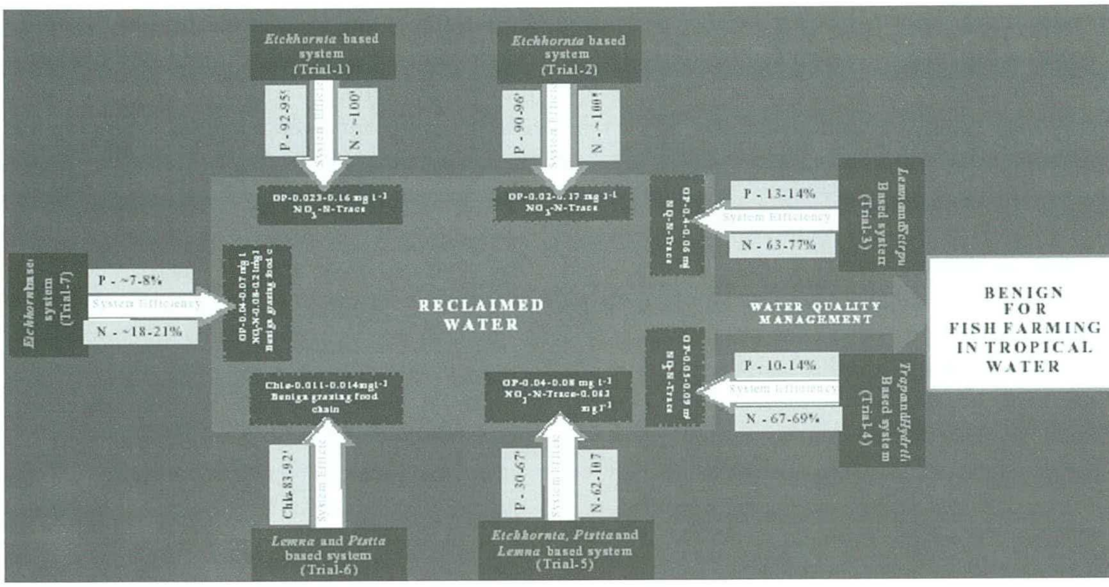


Figure 5.48
Beneficial effects of macrophytic reclamation and possible reuse of reclaimed waters for fish farming

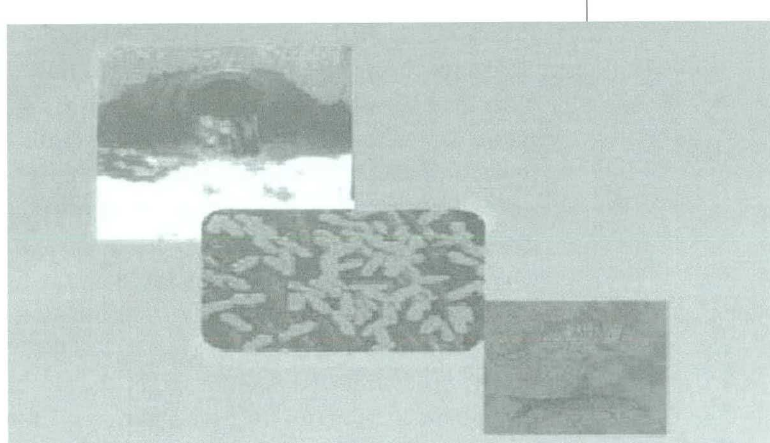
removed nutrients from water phase, whereas, the former removed both from water as well as from sediment. Plant recovery of both N and P was high in submerged macrophyte than floating one.

Introduction of macrophyte resulted in decline of denitrifying bacteria but increase in heterotrophic bacterial populations. The floating macrophytes (*Lemna* and *Pistia*) were also responsible for controlling algal bloom (*Microcystis*) through shading effects; the effect was more pronounced in case of *Lemna* compared to *Pistia*. As a consequence, species diversity of phytoplankton was significantly altered due to the presence of both macrophytes; the diversity index was higher in *Pistia* than in *Lemna*.
Introduction of fish caused nutrient mobilization from the sediment to the water phase by the bioturbation activities of fish. Periodic harvest of macrophytes and introduction of fish during the mid phase of the experiment has a profound role in the reclamation process of eutrophic system by macrophytes.

II. Food chain management for controlling algal bloom

Our studies (Dutta-Saha and Jana 1998) amply proved that herbivorous fishes such as silver carp, bighead and tilapia were highly efficient in controlling permanent *Microcystis* bloom in an eutrophic lake. Limnocorral experiments conducted in the lake showed that introduction of these fishes resulted in sharp decline (60 - 93%) of initial *Microcystis* population within 3-7 days of fish introduction. Both gross and net clearance of *Microcystis* was maximum in silver carp followed by bighead and tilapia. Short term high retention of *Microcystis* by tilapia indicated that the clearance effects did not last long due to high rate of defaecation of undigested *Microcystis*. Nearly 6 - 180% nutrient enrichment of the limnocorrals was attributable to the defaecation of test fishes suggesting their ichthyoeutrphication potentials, which were in the order: tilapia >bighead > silver carp. It is concluded that silver carp is more suitable for cleaning *Microcystis* in the lake because of its minimal ichthyoeutrophication effects. On the basis of experimental findings it may be recom-

Figure 5.49
From eutrophic water, waterbloom alga to fish



mended that *Microcystis* blooms in the tropics can be profitably utilized for enhancement of fish production by culturing silver carp of above six months age group. Catla and bighead of above two months age group can also be used.

c. Use of freshwater bivalves in the reclamation of contaminated water bodies

The results of reclamation studies of heavy metal contaminated water bodies (Das and Jana, 2003 a and 2003 b) showed that the freshwater mussel, *Lamellidens marginalis* is the most suitable candidate for removal of cadmium from cadmium intoxicated environments. It is observed that both bivalves (*Lamellidens marginalis*) and gastropods (*Pila globosa, Lymnaea stagnalis*) are able to accumulate cadmium in considerable amounts in their different tissues, and the rate of accumulation is both dose and time dependent. Small animals are more sensitive to cadmium accumulation than large ones.

The cadmium uptake also adversely affected the filtration and oxygen uptake. As a result, weight of the animal was reduced. Enzymatic assay (alkaline and acid phosphatase, GOT and GPT) of gills and liver revealed a strong inhibition by the cadmium level of the environment. However, animals can be brought back to their normal state after exposing them to suitable depuration treatment for metal elimination from their body. It is demonstrated that presence of *Eichhornia* in the system induced the depuration of cadmium at a much faster rate compared to a chelating agent EDTA. Thus, the same animal can be used several times provided they are brought back to their normal state by depuration and cadmium can be removed from the system by harvesting the macrophytes.

Eichhornia, being an efficient heavy metal and other toxic substance absorbers induced fish cadmium depuration because of high rates of cadmium accumulation from ambient water by the macrophyte, resulting in a clear-cut concentration gradient between fish and water. This, in turn, enhanced cadmium depuration possibly by the mechanism of leaching of metal-rich residuals from permeable body surface. A metal chelator, in the uncontaminated water increased the rate of depuration of cadmium from gill and viscera of cadmium-contaminated carp. It indicates that leaching from the more permeable body surface might be a significant route for the elimination of cadmium in fish.

Though cadmium depuration was faster in rate in liver than in muscle, the latter recovered earlier than the former because liver accumulated more cadmium than muscle.

An interaction between tissue and treatment was clearly evident from this study. As a result, depuration by liver did not differ between clean water and Eichhornia treatments.

The results further showed that, there was substantial decline of tissue cadmium and subsequent distribution to other compartments of the ecosystem, as there was concomitant rise of cadmium in water and sediment apart from Eichhornia tissue.

Eichhornia can be profitably used as biofilter for reducing cadmium load of fishes before being sent to market. This can be achieved by employing a treatment tank containing clean water and Eichhornia in which marketable live fishes are to be kept for few weeks prior to marketing. Further, researches are in progress for examining different aspects of depuration and to make fish safe for human consumption.

III. Sediment raking as a tool for increasing productivity

It is known that bottom mud of eutrophic waters acts as sink in phosphorus, whereas it acts as a source of P to the overlying water in oligotrophic system. Sedimentation, adsorption, chemical transformation and phosphorus uptake are some of the mechanisms for phosphorus dynamics in natural waters. Bottom raking in presence of fish caused 280% increase in orthophosphate level in surface and bottom water. In bottom water net effect of raking was 13-161% greater than effect of fish as bioturbation agent (Chakraborty et al., 2004). The results of study implied that sediment raking can be used as a tool not only to improve ecosystem health but also to increase the fish production.

d. Wastewater fed aquaculture as a reclamation strategy

Wastewater fed aquaculture is a unique system where enormous amounts of wastes of diverse origin are utilized and converted into fish biomass. The wastewater reclamation using the principles of ecological engineering and operating through integrated actions, like 'living machines', and fish biomass as the final output is of great significance in tropical developing countries because of use of energy saving biological sewage treatment system mitigating the energy intensive mechanical system. Such a low cost, environmentally sustainable treatment system has a definite edge over traditional high cost energy intensive mechanical wastewater treatment plant in developing countries (figure 5.50).

There are more than 130 sewage fed fish farms in Calcutta which the largest wastewater fed aquaculture system in the world. The extent of pond fertilization by sewage depends upon the sewage characteristics, climatic conditions, physical feature of the pond and the species of fish culture (Jana, 1998). Basically the culture system has been evolved based on local experiences.

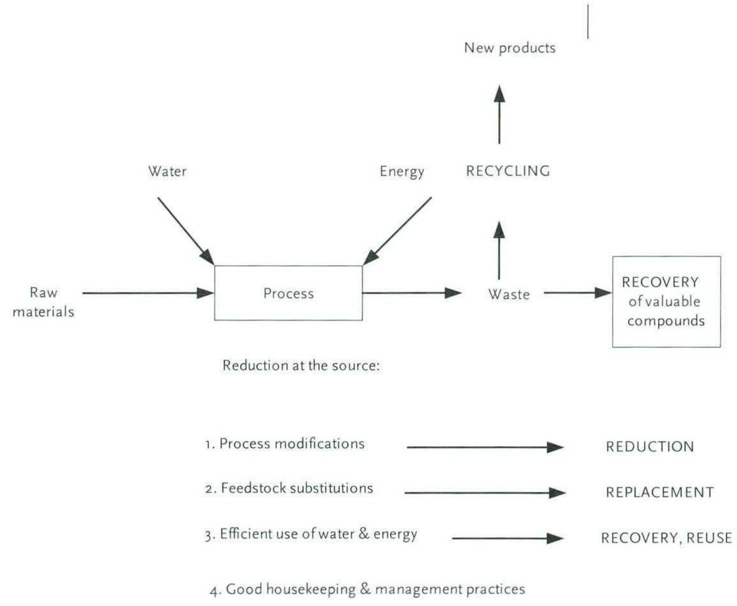
A study was carried out in Klayani sewage fed fish farm (Jana and Ganguly, 2002) for a period of two years. The farm receives about 17 mld of domestic sewage from about 82,000 inhabitants of the Kalyani township in West Bengal. Of the total of 17 mld sewage, 11 mld is treated through conventional systems before being discharged into the river Ganga. Only about 6 mld is treated through biological system using a 3-step biological treatment system consisting of 2 anaerobic ponds in the first step, 2 facultative ponds in the second step and 4 stocking ponds in the third step.
The facultative pond or the waste stabilization system has been proved to be most dynamic in reclamation process registering 22-69% of total reclamation due to its enhanced microbial activities and development of intense algal bloom which triggered further reclamation of effluents by providing aerobic condition.

The next subsystem of fish growing ponds was primarily responsible for converting organic wastes into fish biomass through the grazing-detritus-food-chain mechanism using the well known ecological principle of recycling through microbial biogeochemical nutrient cycle and grazing and detrital food webs. The reclamation of the wastewater has been studied using certain biogeochemical cycling bacteria as indices. To conclude, it may be stated that there was a scope for further reclamation of the existing final effluent by increasing the distance of the effluent for 200 m, implying the scope for construction of 1-2 more stocking fish ponds for aquaculture. This would ensure much more environmental protection of the sewage effluents considering the stringent measures which may be imposed in future.

However, permissible limit of water quality has been achieved with the existing practices. Further, studies are necessary to test the hypothesis and to examine the efficacy of the biological treatment system. The mechanism and quantification of microbial reclamation process through organic matter decomposition in wastewater aquaculture system have also to be elucidated.

Other research activities in the International centre of ecological engineering include: Hydroponics, organoponics, artificial island using *Pistia, Eichhornia, Nymphoides,* culture of duck weed (fish food) and Azolla (biofertilizer), propagation of aquatic crops- *Trapa, Euryale, Ipomea, Marsilea,* irrigation of used water in kitchen garden, compost of water hyacinth, use of bivalves-heavy metal biofiltering, algal bloom control by fish, use of larvicidal fish in mosquito control, intergrated management for water conservation, artificial island of macrophytes, urine separation and its use, vermicomposting, etc. Experiments are being carried out to demonstrate the ecosystem stability using various organisms of different trophic levels.

Figure 5.50
Process chain reductions and waste as a valuable resource



5.6.7 Increasing the natural values of treated wastewater

R. Kampf, T.C. Claassen, H.P. van Dokkum, E.M.Foekema and J. Graansma

Introduction

The island of Texel, The Netherlands, is facing many problems and opportunities in water management. It is quite different from the mainland, it has very high natural values, and it is a well-known tourist resort and is still an agricultural stronghold. The island is enclosed by the North Sea and the Wadden Sea. Apart from a drinking water line from the mainland, there is no external fresh water supply. Basically it forms its own watershed, it is a small version of the water system on the main land and thus interesting for testing new policy and plans. Until recently many measures in the water system on the island were taken without taking 'all' aspects into consideration. The agriculture requires lower groundwater tables, leading to intrusion of brackish water and diminishing of the fresh phreatic water lens below the surface of the island. Contrary, nature conservation prefers higher groundwater levels and restoration of saline ground water at several natural areas. The high dikes, a safeguard against seawater, also form a huge barrier for migrating fish. The De Cocksdorp siphon fish ladder has been an important step towards a more sustainable water system with more opportunities for fish to migrate from the sea to the island water system (Wintermans, 1998).

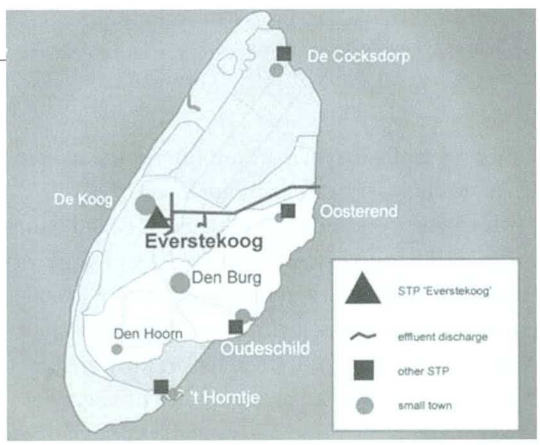


Figure 5.51
STP Everstekoog and other STP's on the island of Texel

Integrated water management learned that the way the water system on the island of Texel is managed is not wise. The idea appeared that 'all water problems' should be tackled jointly with an integrated approach of 'all the aspects of water affairs'. Therefore the project Water for Texel Master Plan (Projectgroep Masterplan, 2000) has been started, in which all parties on the island who have interest in water management are taking their share. It directly appeared that such a plan makes sense and is worth the effort. The Water for Texel Master Plan aims on gaining knowledge on the very complex Texel water system (surface water, groundwater, treated wastewater (effluents)), on the enhancement of the natural values of the surface waters on Texel by separating the different flows and qualities, combining the various interests on Texel (figure 5.51). In the meantime the water-related organisations (agriculture, nature, recreation) have accepted the Master Plan, and agreed with a whole array of measures. The total estimated costs of the Master Plan are about € 25 million, the implementation started in September 2001. Several pilot projects, focusing on improvement of diverse natural habitats have been initiated (Projectgroep Masterplan, 2001).

During dry periods the treated wastewater is considered to be a valuable source of water on the island, but even after treatment in a low-loaded activated sludge plant the quality is not good enough. Although the water is very clear, from a biological point of view it is still 'dead water'. Without additional treatment or dilution it is not suitable for fish. The main sewage treatment plant on Texel, STP Everstekoog is located in the centre of the island (figure 5.51). The effluent from Everstekoog flowed to the north in the direction of a brackish area, with high natural values, before being pumped into the Wadden Sea. It was pointed out that it is much more favourable to use the effluent in an area with high agricultural values south of the Everstekoog treatment plant. For this purpose a diversion channel has been constructed.

To improve the effluent quality a full scale constructed wetland was added to the STP in 1994. To monitor the efficiency a joint 4-year research project has been started in 1995 (Schreijer, Kampf, et al., 1996; Kampf, Toet, et al., 1996).

The Everstekoog constructed wetland

The STP Everstekoog is an oxidation ditch with a load of 45,000 P.E. (Population Equivalents) in summer and only 10,000 P.E. in winter (Figure 5.53). Dry weather flow in summer is 3000-4000 m^3/day; the maximum flow is 10,000 m^3/day. Phosphorus removal takes place simultaneously by dosing ironchloride to the aeration basin. The full flow of the STP is treated in the surface-flow constructed wetland since 1994. The system consists of a presettling basin, nine parallel ditches with a length of 150 m and a discharge ditch. The first part of each ditch is only 0.2 m deep and has vegetation of reed (*Phragmites australis*) or cattail (*Typha latifolia*). The deeper (0.5 m) part has been planted with submerged aquatic plants. One ditch is a control without macrophytes (figure 5.52).

Total water surface is 13,000 m^2, total volume is 7,140 m^3. The mean total hydraulic retention time (HRT) in the constructed wetland was just over 2 days at dry weather flow in summer. In the first research period (1995-1996) all ditches received the same flow, in 1997/1998 different flow regimes through the ditches resulted in HRT´s of 1.6 up to 11.3 days (resulting in retention times in separate ditches of 0.3, 1, 3 and 10 days).
The investment costs of the constructed wetland alone were less than € 250,000, excluding the extensive instrumentation for the research project. This leads to capital cost of € 25,000 annually. Maintenance and supervision costs are also about € 25,000 per year. At a flow of 1,200,000 m^3/year the specific cost is about per € 0.05 per m^3 at an HRT of 2 days and € 0.10 at a HRT of 4 days. To put this in perspective the costs for transport of the wastewater to the STP are estimated at € 0.10 per m^3 and for the treatment of the wastewater in the oxidation ditch, including sludge treatment, € 0.50 per m^3. For monitoring and research purposes an extensive instrumentation was fitted in the wetland: pressure sensors for flow measurements, oxygen probes with thermometers, redox sensors and a weather station (Kampf, Schreijer, et al., 1999; Schreijer, Kampf, et al., 2000, Toet, S, 2003).

Figure 5.52
Everstekoog: Areal view of the Everstekoog constructed wetland, on the background the STP (photo: Simon Smit, Texel)

The quality of the effluent of the STP Everstekoog was typical for a well functioning oxidation ditch (very low loaded activated sludge plant). Results of 1997 - 1998 are summarised in Table 5.9. The effluent has become clear water, but still with an odour. Despite the removal of particles in the settling tank, the effluent still contained fine activated sludge particles, with a variety of bacteria.

Table 5.9 Effluent quality of STP Everstekoog (1997-1998)

Parameter	Mean concentration	Standard deviation N >=22
NO3-N (mg/l)	2.6	2.5
NH4-N (mg/l)	1.1	1.6
Total N (mg/l)	6.2	4.3
Total P (mg/l)	1.1	0.7
COD (mg O_2/l)	32	6
E. coli (number per ml)	590	730

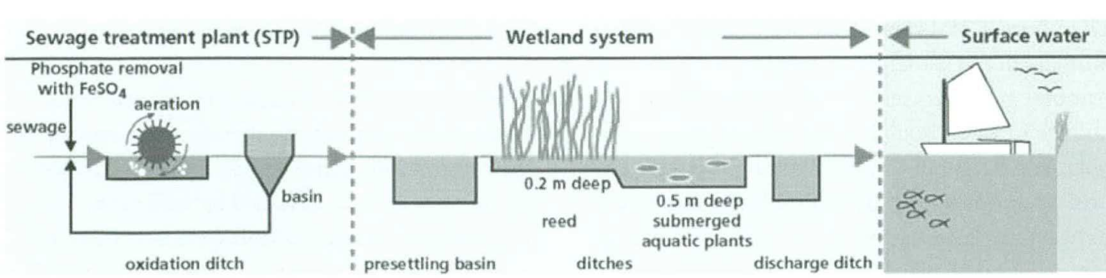


Figure 5.53
Everstekoog: Scheme of the sewage treatment plant and the constructed wetland

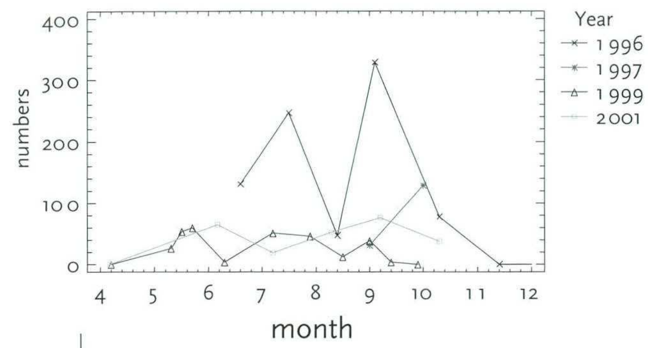


Figure 5.54
Daphnia in the presettling basin of the Everstekoog constructed wetland in four different years

The hydraulic retention time had a profound effect on nitrogen removal (mostly due to denitrification) in the constructed wetland. Ammonia levels in the effluent of the constructed wetland varied, but were mostly well under 1 mg/l, nitrate concentrations went down to < 0.5 mg/l at the longer hydraulic retention times, even in winter.

The load of N and P with the STP effluent to the Everstekoog constructed wetland is around 5,000 kg N/ha/year and 700 kg P/ha/year. Nitrogen removal was calculated as 1,250 kg N/ha/year. This means that a surface area of at least 5,000/1,250 = 4 ha (instead of 1.3 ha) is needed for a complete nitrogen removal in the system (HRT of 8 to 10 days). Phosphate removal in the Everstekoog constructed wetland was rather low, leading to the conclusion that when low P-concentrations in the effluent are preferred biological or chemical removal in the activated sludge plant is more attractive.

To our opinion the 'classic' water quality parameters do not describe the changes in the water in the constructed wetland aptly. Already in the presettling basin of the constructed wetland the water started to 'live', started to resemble eutrophic, but clear surface water. Regularly the water turned red through high numbers of zooplankton, mainly *Daphnia magna* (figure 5.54).

The number of different species of plants and animals in the wetland has grown each year. Another good parameter to demonstrate the change in water quality is the diurnal oxygen pattern. The oxygen level in the effluent of the oxidation ditch was low, in the presettling basin it was only 2-3 mg/l. In the part of the ditches with submerged aquatic plants the daily oxygen pattern started to resemble the pattern of normal surface water. During daytime, the submerged aquatic plants and algae produced such an amount of oxygen that the level rose well above the saturation value (up to 20 – 30 mg/l). The high oxygen levels in the afternoon helped oxygen to penetrate deeper into the sediment. At the end of the day, the oxygen levels dropped sharply. This 'solar energy process' for production of 'free' oxygen-supply was also stable during longer periods, and functioned even under ice in wintertime.

The effluent of the constructed wetland was even more turbid then the effluent of the STP, but it was a different kind of suspended solids. Instead of activated sludge flocs, the water contained algae, *Daphnia* and other small wildlife. An interesting observation was that the presettling basin and the ditches with a short retention time did not contain any fish, despite the high numbers of *Daphnia*. The reason is probably that the high concentrations of free nitrogen at high loads during certain periods of the day, when nitrification in the STP is less than average, are toxic for fish. Only after a hydraulic retention time of over 2 days in the ditches the water was suitable for fish such as Stickleback. On Texel both Three-spined Stickleback (*Gastrosteus acculeatus*) and Nine-spined Stickleback (*Pungitius pungitius*) occur, it is the main food of Spoonbills (*Platalea leucordia*), breeding in good numbers on the island. In ditches with more then 3 days HRT the number of Stickleback could be high, up to 25 per m^2.

Constructed wetlands can be rich in wildlife (Kadlec and Knight, 1995 and Knight, 1996). Although the Everstekoog constructed wetland is situated in the agricultural part of the island natural values are attractive. The numerous fish attracts high numbers of birds. Especially Spoonbills (*Platalea leucorodia*) come to feed on small fish. In 1997 40 birds of 11 species bred in the constructed wetland (Kampf, Schreijer, et al., 1999; Kampf, Eenkhoorn, et al., 2002).

The high numbers of *Daphnia* in the constructed wetland effected also the disinfection capacity of the system. For disinfection to a level of 10 E.coli per ml, a HRT of 2 days will be sufficient. Possibly, due to wildlife in the system, the E.coli numbers were rarely below 1 per ml. For E.coli values of less then 10 per ml throughout the year, the HRT must be at least 4 days. To minimise the influence of storm water flows it is important to buffer as much water in the system as possible. For a surface flow system this can be done by means of an appropriate design of the weirs.

A surface flow constructed wetland, like the Everstekoog system, is a simple and attractive system. It is also cheap as long as land costs are not too high. It looks like a Dutch polder landscape; the maintenance of the system resembles the maintenance of ditches and canals the waterboard is accustomed to already for centuries.

Spin-off: The Kwekelbaarsjes system – A food-chain based constructed wetland

The massive development of *Daphnia* and other zooplankton in the presettling basin of the Everstekoog constructed wetland in summertime, as depicted in Figure 5.54, had puzzled us first, but also led to some innovative ideas. The first question that arose was: how can all these *Daphnia* (only *Daphnia magna*) survive? The numbers of algae in this basin (<10 mg/l chlorophyll-a) were very low, not enough to maintain this population. Most aquaculture systems have an algae module involved, see for instance Borowitzka & Borowitzka, 1988; Proulx & La 1985; Staudenmann, Schönborn, et al., 1996. This led to the hypothesis that the zooplankton lived mainly on bacteria, the so called 'pin-point flocs' in the effluent. To test this hypothesis experiments were conducted using 80 l microcosms. One set was kept in the dark to prevent algae growth, another set in light to stimulate algae growth. It could be shown that the occurrence of *Daphnia* in the pond was determined by the availability of activated sludge flocs and loose bacteria, thus proofing that *Daphnia* indeed consumed activated sludge flocs.

The observation was being stated with microscopic determination of the guts contents. Also on a practical scale in the Everstekoog constructed wetland the consumption of sludge particles contributed in a sizeable reduction of suspended solids in effluent from STP's (Groot, 1998; Hoogstrate, 2001; Rosenkranz, 2001). The effect of *Daphnia* in a pond with well-treated wastewater can also be described by the filtration capacity. McMahon & Rigler and Lampert give values of up to 4 ml/*Daphnia* per hour (McMahon & Rigler, 1965; Lampert, 1987). This means that a population of 100 individuals per litre will filtrate 400 ml/l/h. This means that 'every drop of water' in the presettling basin will pass the body of a *Daphnia* 10 times per day. Thus during the 1.3 days hydraulic retention time in the presettling basin the treated wastewater will be filtrated 13 times by *Daphnia* on an average, when 100 *Daphnia* per litre are available.

It was concluded that growing *Daphnia* in a surface flow constructed wetland could be an interesting process. In principle it is possible to lower the amount of sludge discharged to the surface water, but it could also be a contribution to disinfection of the effluent of a STP by consumption of pathogen bacteria, as could also be derived from the results with the Everstekoog constructed wetland (Schreijer, Kampf, et al., 2000).

One of the problems on the island is that for defence against the sea, high dikes have been built. This makes the island much more difficult to reach for fish migrating from the sea to the island waters. It is hardly a problem to migrate back to the sea. The fish is easily pumped or flushed out with superfluous water. The new and higher dikes resulted thus in lower number of fish on the island. Together with other changes in landscape and land use, this has resulted in a worsening of the food supply for fish eating birds on the island. Not only the number of Three-spined stickleback had decreased, but most of the fish remained smaller indicating a part of the population does not migrate anymore (non-migrating Stickleback stay much smaller than the ones that grow up at open sea (Wintermans, 1998). Three-spined Stickleback (*Gasterosteus acculeatus*) grow up at sea and migrate back to inland waters to spawn, like salmon. To enhance fish migration a fish trap to siphon fish from the sea across the high dike has been constructed near De Cocksdorp, on the northern tip of the island, in 1995. Improved effluent could well play a role for the increasing the attractiveness of the lure flow, needed to attract fish to the siphon.

One of the most striking birds of Texel, the Eurasian Spoonbill, feeds mainly on Sticklebacks. It is a contrasting situation, the number of

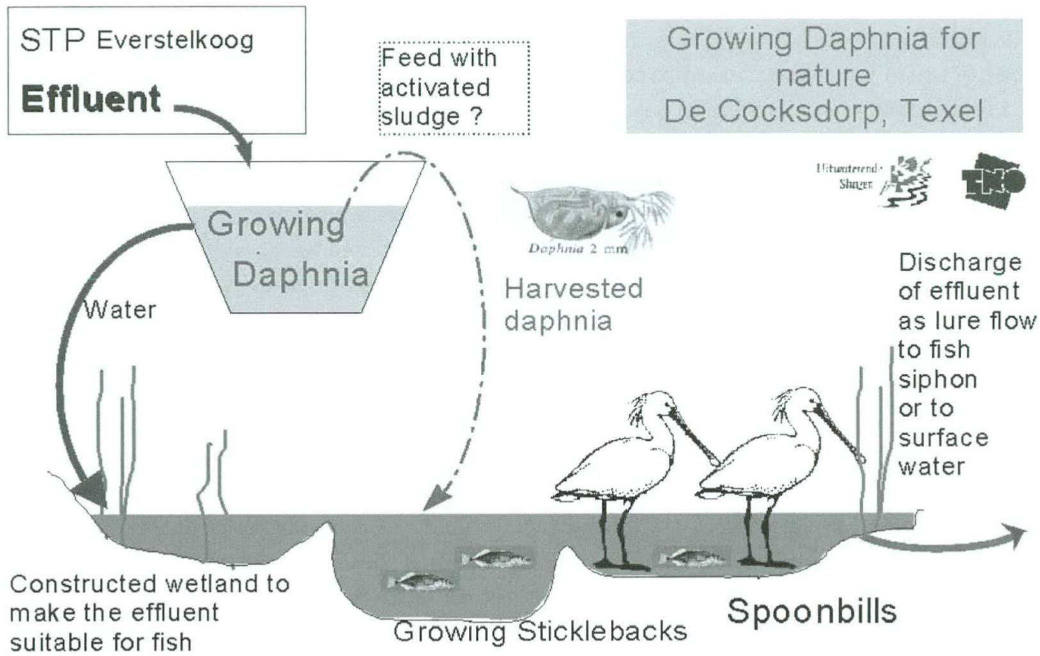


Figure 5.55
Sketch of the 'kwekelbaarsjes system' to grow biomass on the 'energy available' in treated wastewater

Spoonbills in The Netherlands have increased the last years, from around 250 around 1980 to 1543 in 2002, with 220 pairs on Texel alone (Van Dijk, 2003; Overdijk, pers. comm., 2003). The Spoonbill is a highly valued species on Texel, as being a big white bird. A favourite bird of many people, inhabitants of the island as well as of tourists. It can be considered a an indicator for the success of nature conservation and for water quality measures on the island (Kampf, Eenkhoorn, et al., 2002).

All these aspects are brought together in the development of a step-wise food-chained water system, in a Dutch catchword (difficult to translate): the 'kwekelbaarsjes system', described in Figure 5.55 (Kampf, Schreijer, et al, 1998 and Kampf, website).
Basically, the system comprises a step-wise 'food-chain type' system to increase the ecological value of effluents from oxidation ditches. In the *Daphnia*-basin the sludge particles are used to culture *Daphnia*. The effluent flows through the constructed wetland to make the water suitable for fish. The harvested *Daphnia* can be transported to a deeper part of the 'kwekelbaarsjes system' to be consumed as food for fish, such as Sticklebacks. This part is too deep for Spoonbills to forage. The last, shallow part of this specially constructed wetland could be constructed as foraging area for Spoonbills. The governing board of the Waterboard accepted this idea and gave permission for further development of the process. Interesting in this decision was that the Waterboard choose for a more or less uncertain and innovative ecological engineering process.

One of the uncertainties in the 'kwekelbaarsjes system' is the 'Growing *Daphnia*-module' in Figure 5.56. Despite the amount of knowledge about *Daphnia* available we could not find systematic knowledge about the process of growing *Daphnia* on treated wastewater. In the laboratory we focused on the possibility of production of *Daphnia* with activated sludge as the main food source. We have continued the research project with experiments aimed at the cultivation of *Daphnia* on effluent at a pilot scale. Also harvesting of *Daphnia*, based on the work of Proulx (Proulx & La, 1985), has been taken into account. The experimental work was carried out on the Everstekoog STP in four 25 m^3 ponds and four 2 m^3 mesocosms (figure 5.56). In 2002 we focused on process stability of the system and on ecotoxicological aspects (Foekema & Kampf, 2002). Results of the literature study and biological tests (Blankendaal, Foekema, et al., 2003) with efflu-

ents of nine STP's (including Everstekoog and De Cocksdorp) showed little to some eco-toxicological effects on the growth of *Daphnia* in pure effluents. Contrary, more effects on the growth of algae have been found, as was expected based on earlier experiments (Groot, 1998, Kampf, Jak, et al., 1999). Special attention should be paid to avoiding overloading of STP's with a 'food-chained constructed wetland' if this leads to lower removal efficiencies and thus increasing the risk of negative effects of the effluents, due to compounds with toxic effects
The research confirmed that the 'kwekelbaarsjes system' can lead and stimulate innovative co-operation between engineering and nature (ecological engineering).

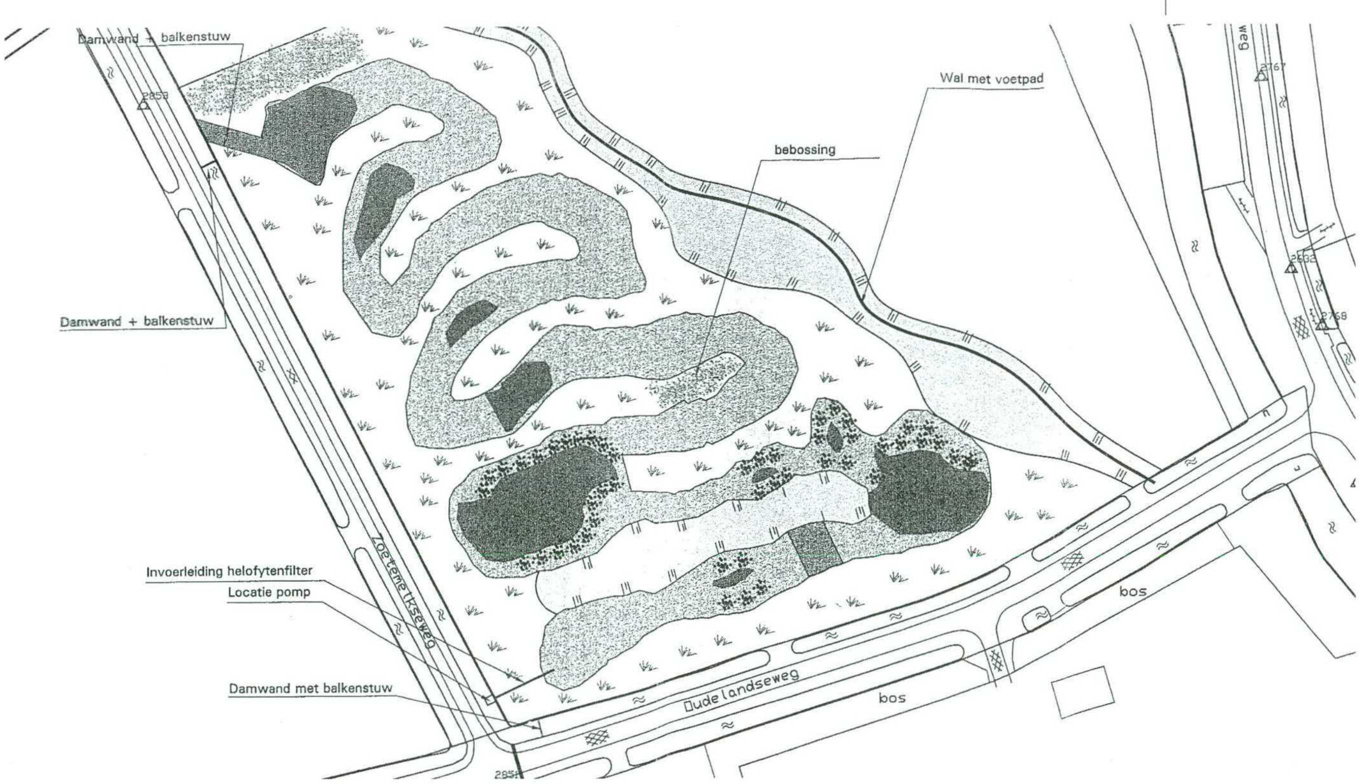
Prospects of food-chain based water systems

Demonstration of the values of the surfaceflow constructed wetland on Texel lead to a slow, but steady increase of interest in the Netherlands for this type of upgrading effluents. The first large scale constructed wetland of this type was developed at the STP Land van Cuijk, where an intensive monitoring programme is being carried out, (Eijer-de Jong, Willers, et al., 2002).

Figure 5.56
Test facilities on Texel. On the foreground the four 2 m^3 mescosms, behind the four 25 m^3 ponds. At the background the Everstekoog constructed wetland.

Friesland Water Authority is planning a similar project on the island of Ameland, an island comparable to Texel. The idea that could be worked out is not to discharge the effluent anymore into the Wadden Sea, but to keep it on the island itself. This is encouraged in Dutch governmental policy. Plans are in a developing phase to bring the water into the dunes to replenish the groundwater, after a pre-treatment in ponds. The water can be infiltrated in some dune valleys, 'shaped according to ecological engineering principles'. It will support a groundwater stream for several farmers who are located downstream in the polder and will strengthen the 'fresh water lenses in the dunes, making it possible to restore some wetlands in

Figure 5.57
A 'natural' constructed wetland Sint Maartensdijk



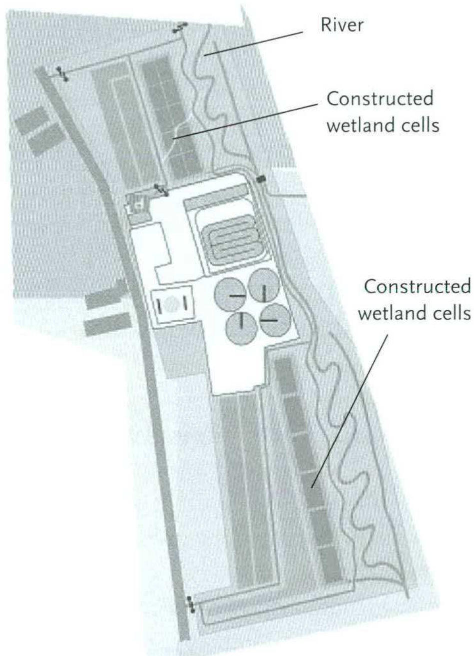


Figure 5.58 Waterpark Groote Beerze (NN, 2001)

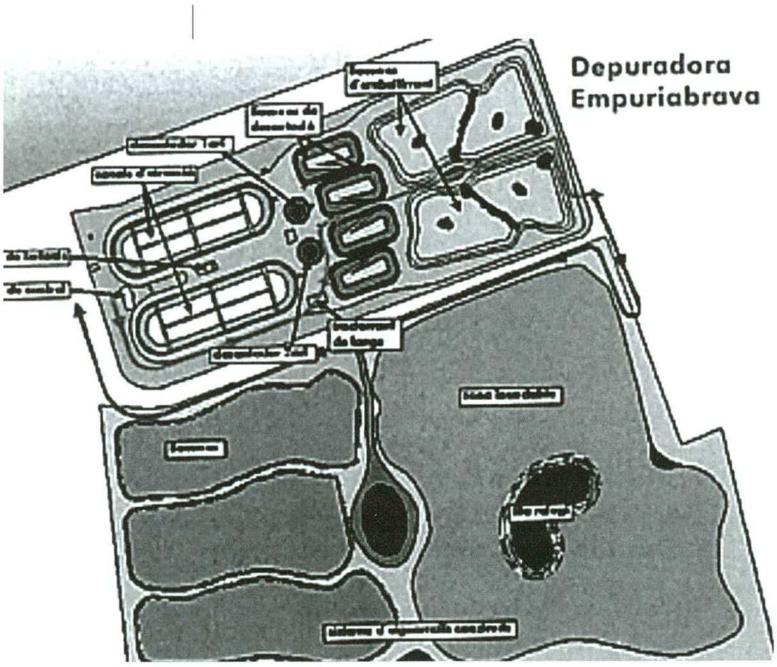


Figure 5.59 The Empuriabrava STP in Spain

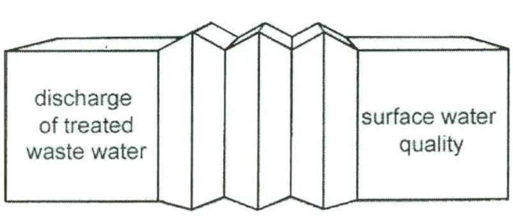


Figure 5.60 The 'Water harmonica' as a buffer between the sewage treatment plant and surface water, based on (Claassen, 1996)

the dune valleys in the nearby nature reserve. If, for reasons of nature protection, dune infiltration is not possible, the polished effluent will be brought to selected polderditches. Another possible project is an idea for the STP Group on the mainland of Friesland. After an Everstekoog-type surfaceflow wetland, including some *Daphnia* ponds, a series of ponds could function as a fish spawning area (especially for Pike) for the surrounding canals, which are lacking natural values. This project is supporting the policy of closing the urban watercycle. The recently built constructed wetland Sint Maartensdijk, a combination of a root-zone constructed wetland for polishing of effluent and a nature and recreation area (Ton, M., 2000), Figure 5.57 demonstrates how this can be outlined in practice.

These principles of ecological engineering are further applied in the Waterpark Groote Beerze, a combination of a constructed wetland and its surroundings. The extension of the STP Hapert (Waterboard De Dommel) is combined with a river restoration project. The effluent is polished by passage through root-zone reed-beds, open-ponds and wetland forest before it is discharged into the river Dommel (Figure 5.58 (NN, 2001). Good examples abroad are the Ekeby constructed wetland in Sweden, the famous Arcata Marsh in northern California (USA) and the 7 ha Empuriabrava constructed wetland for polishing and reuse for nature and agriculture in the Costa Brava in Spain, depicted in Figure 5.59 (Sala, L., Mujeriego, R., 2000 and Sala, L., 2003, pers. comm.).

The results in a wider perspective: the 'water harmonica'

Basically, a constructed wetland, including foodchain based water systems, like the 'kwekelbaarsjes system' is a medium between 'conventional' engineering (sanitary or process engineering) in a sewage treatment plant, conventional polder and ditch management and waterway management in canals and lakes. For constructed wetlands it already has been tackled on a theoretical way by Theo Claassen of Friesland Water Authority (Claassen, 1996). The basic idea is depicted in Figure 5.60.

This model uses a 'buffer' between the sewage treatment plant and the surface water, on which the effluent of the STP is discharged. In this buffer or linkage part the different fields of engineering and ecology meet each other to improve the quality of the STP effluent into natural 'living' surface water. The examples, described in the paragraph above (not only the Everstekoog constructed wetland and the 'kwekelbaarsjes system', but also the other examples) fit very well within the 'water harmonica concept'. It seems to be an useful way of describing the use of ecological engineering principles in water management. Multifunctional constructed wetlands seem to be good tools in water management focused on improving water quality, natural values, buffering water, recreation and using nutrient for agricultural production, which may all go hand in hand.

Also in the Netherlands a lot of work has been done recently on separation of water flows, like separate discharge of rain water, but also a further separation of wastes, preventing discharge in sewer systems is emerging actually (Mels, Mes, et al., 2002). However, in many cases it is not (yet) possible to separate wastes at the source. In those cases it is obvious to choose for a clever solution, bearing in mind that wastewater was often 'the best water we had'. Before using, it was rather expensive: drinking water and rainwater that has been 'mis-used' to discharge relative small volumes of wastes (about 700 l faeces, urine and kitchen wastes are diluted into a total stream of 30,000 l wastewater per person annually). As is demonstrated in the Everstekoog research project it is possible to convert wastewater, after treatment in a well functioning wastewater treatment plant, followed by a constructed wetland, into usable and valuable surface water. Even the nutrients and sludge particles in the effluent can be used beneficial, as demonstrated in the research carried out for 'kwekelbaarsjes system'. This opens the door for natural constructed wetlands with recreational, natural and possibly even agricultural functions to convert treated wastewater in usable and biological healthy surface waters.

5.6.8 Phytoremediation. A green technology

Mrs G.. Blom-Zandstra

An extensive use of certain synthetic organic chemicals in the past decades led to many long-term contamination problems. In particular, the widespread use of pesticides in agriculture and the large scale production and often improper disposal of other chemicals or heavy metals resulted in numerous instances of contaminated soils, surface and ground water. A number of methods are currently used for decontamination of polluted environments, the majority of which is based on *ex situ* chemical inactivation or thermal degradation of pollutants. The cost of removal and transportation of large quantities of contaminated materials, however, makes these methods impractical and unfeasible compared to *in situ* decontamination techniques. There are two prominent *in situ* techniques, bioremediation and phytoremediation, which utilise the biological capability of selected microbes or plants to degrade, remove, or biofix hazardous chemicals in the environment. plants and microbes can contribute to bioremediation phytoremediation in different ways, as overviewed in Figure 5.61.

The effectiveness of biological remediations has been well demonstrated for a variety of contaminants, such as oil spills, explosives, nuclear wastes, leachates from landfill and sewage works, industrial effluents, heavy metals and other toxic chemicals such as pesticides. The techniques offer low-cost, low maintenance, environment-friendly renewable resources for *in situ* cleanup of polluted environments. The use of natural agents for benefit of the environment also makes these technologies more amenable to public acceptance than some of the currently used methods such as incineration.

The term 'bioremediation' is often associated with the use of micro organisms and microbial processes. Indeed, bacteria are the most studied class among micro organisms with respect to pollutant degrading processes, and numerous isolates have been reported for their degrading capabilities against a specific compound or a class of chemicals (Harvey et al. 2002; Mejare & Bulow, 2001; Nichols et al., 1997). However, less realised is the fact that similar metabolic pathways that break down a vast array of naturally-occurring and synthetic chemicals are also present in many higher plants (Sandermann 1992; Pflugmacher et al., 2000). Indeed, plants have been regarded as 'green livers' to reflect their detoxification capabil-

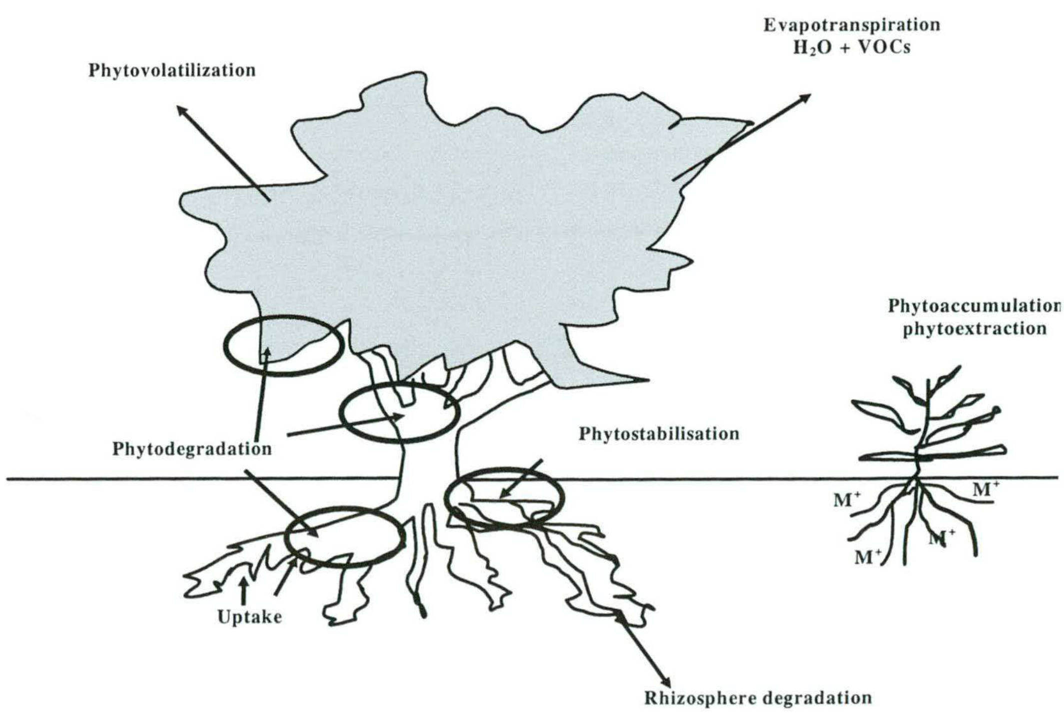


Figure 5.61
Overview of different forms of bioremediation and phytoremediation. (VOC's = volatile organic compounds).

ities (Pflugmacher & Sandermann, 1998) Despite this, plant based remediation is still considered a nascent technology that has not found commercial applications at a scale that is equivalent to the use of bioremediating microbes. In a practical situation, the choice between using microbes or plants, alone or in combination, under natural environments or in bioreactors or constructed wetlands, is largely determined by cost and time constraints, level of contamination and chemical nature of contaminants. However, the use of either microbes or plants alone in a remediation effort may have certain limitations, and a combined action may be needed for problem situations. The remediating capability of a biological system may be affected by a number of environmental and other factors; such as:

1 The ability of remediating microbes or plants to grow in a heavily-contaminated environment may be severely restricted.
2 The hydrophobic nature of many organic pollutants may pose a major obstacle to their uptake by plants. For example, root uptake and translocation of highly hydrophobic compounds may be severely limited in most plant species.
3 The decontamination rates achieved by biological remediations are generally much slower than those achieved by physical and chemical means. This may be more evident in the case of plants, the growth of which is further dependent on environmental factors, soil condition, availability of nutrients and water etc.

Under natural conditions, however, these limitations may be overcome by the synergy that exists between plants and micro organisms in the soil.

Synergy between Plants and Microbes

Plants play an important role in activating microbes. They provide microbes an important source of minerals, and root exudates that contain carbohydrates, enzymes and surfactants etc and may also affect soil characteristics, like pH, water flux, and availability of oxygen. In particular, the presence of secondary metabolites and enzymes in exudates seems to play an important role in enhancing microbial activity.

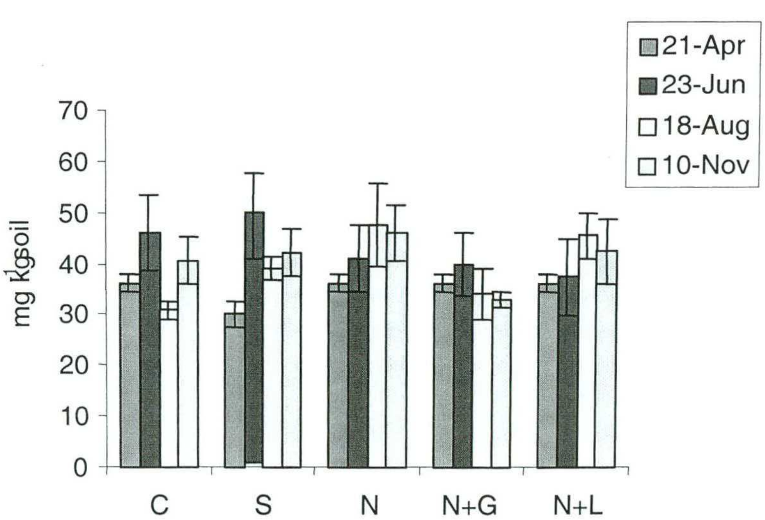
In cold regions of USA, where other cleanup technologies may not be feasible, the total petroleum hydrocarbon concentration of a diesel-contaminated soil has been shown to decrease significantly more in the presence of rhizosphere and nutrients compared to a non-vegetated or non-fertilized control soil (Reynolds et al., 1997). Similarly, the degradation of several chlorinated pesticides has been reported to be higher in a rhizosphere soil than a non-vegetated soil, with a similar increase observed in non-vegetated soils that were added with materials released from plant roots (Yoshitomi & Shann, 2001).

It is well known that microbial numbers are much greater in the rhizosphere than in a non-vegetated soil (Reynolds et al., 1997). From studies with synthetic artificially-contaminated soils it is known that Quillaya saponins enhance biological degradation of polychlorinated biphenyls (PCBs) in soils (Fava and Di Gioia, 1998). The aerobic biodegradation of PCBs is even better performed by soya lecithin as it enhanced the bioavailability of PCBs to the microcosms and provided a good source of carbon for bioremediating microbes (Fava and Di Gioia, 2000). Similar results have been obtained with natural soils. For a soil contaminated with heavy metals, Kozdroj and Van Elsas (2000) showed a significant effect of root exudates on the development of bacterial populations. The stimulation of bacterial populations depended upon the conditions that prevailed their habitat; for example, in heavy metal contamination flooding played a crucial role in stimulation of bacterial activity. It was shown that the exudates reduced the bacterial diversity towards domination of the fast growing bacteria, and this was more evident when the contamination level was higher. A similar trend has been shown for soils contaminated with organic contaminants. Yoshitomi & Shann (2001) showed that some members of the soil microbial community were able to utilise the root exudates from *Zea mays* L., and this increased mineralisation of ^{14}C-pyrene. The late season accumulation of three flavones (morusin, morusinol, and kuwanon C) in fine roots of mulberry (Morus sp.) have been shown to support the growth of a PCB-degrading bacterium *Burkholderia* sp. LB400 (Leigh *et al.*, 2002). It has been suggested that the dead mulberry roots can serve as a source of substrate for PCB-degrading bacteria.

It is crucial for the microbe-plant synergy to work that a population of micro organisms present in soil contains species that are capable of transforming soil-bound and recalcitrant compounds. An adaptation and selection within the microcosmical habitats may occur and a population may change considerably with time in response to the type and degree of a contamination. For example, composition of microbial population was shown to be changed in a soil contaminated with dibenzothiophene (DBT) with time towards those micro organisms that were specialised in degrading the particular contaminant (Duarte *et al.*, 2001). A progressive change over time following treatment with DBT- containing petroleum has been shown, and PCR-DGGE analyses has also showed a selection of *Rhodococcus erythropolis,* with specific capacity to desulphurize DBT.

The rate of remediation by rhizosperic interactions may be further enhanced by increasing the activity of indigenous microbial species by providing appropriate growth conditions. The process may be further accelerated by manipulating the composition of microflora in the rhizosphere through selective introduction of microbes with broad-ranging bioremediation properties. The bacterial species that are known to be most useful in bioremediation belong to the genera *Flavobacterium, Arthrobacter, Azotobacter,* *Pseudomonas* and *Burkholderia,* which may also be suitable for introduction to the rhizosphere.

Figure 5.62 Degradation of PAH with time in naturally contaminated soil from Maarn, located in the middle of the Netherlands. C = untreated, S = sterilized with g-rays, N = fertilized with nitrogen, G = planted with grass (Holcus), L = planted with lupin.



Mycorrhiza is a root-fungus symbiosis with a high potential for phytoremediation (Meharg and Cairney, 2000) due to a high fungal biomass being formed in soil based on a carbon derived directly from the symbiotic host plant. Though much of research on the use of mycorrhiza has so far been focused on phyto-extraction of metal ions from contaminated soils (Leyval et al., 1997), attention is now being diverted to mycorrhizal involvement in degradation of organic pollutants. Symbiosis with mycorrhiza has advantages upon the interaction between plants and bacteria as:

- mycorrhiza hypha grow from the rhizosphere into the soil resulting in an effective uptake of water, nutrients and contaminants.
- mycorrhiza hypha can grow into micropores reaching contaminants that cannot be reached by plant roots.
- mycorrhiza have the potency to bind heavy metals so detoxifying the rhizospere in favour of plant growth.

Critical success factors

The interaction between plants and microbes and success in degrading contaminants may substantially differ between plant species and soil types. Some plant species are much more successful in affecting the degradation process than others.

Despite our understanding of certain aspects, information on specific plant characteristics is still scarce, and factors responsible for successful interaction between plants and microbes specialised in contaminant degradation are generally not well understood. Schnoor *et al.* (1995) presented a survey with examples of plant species and enzymatic processes specifically successful in degrading some contaminants. Apparently, exudation of (secondary) metabolites plays an important role in activation or transformation of specific bacterial habitats. Also plants that have a greater capacity to leak secondary metabolites with a potential role as surfactant may have high potential in bioremediation (Fava & Goia, 1998, 2000). The nature of compounds in exudates, the quantity in which they enrich the rhizosphere with substrate for microbes and the timing of exudation may be crucial for the success of overall remediation process. The availability of nitrogen may also be an important factor. It has been indicated (Smit *et al.*, 2000) that fertilisation can improve the interaction between plants and microbes.

Limitations

The great potential for biodegradation of contaminants by microbes or plants is often hampered by the lack of bioavailability of a contaminant in soil. In fact the bioavailability of a chemical is the major determinant of success of the whole remediation process. For example, a soil contaminated with PAH, located in the middle of the Netherlands (Maarn) appeared to be suitable for growing different plant species, but this did not lead to any significant removal or degradation of PAH (figure 5.62).

The quick PAH availability test, developed at Wageningen University (Cuypers *et al*, 2000), showed that the PAH contamination was in bound form; a stable end situation with the advantage that the contamination posed no risk to the environment but at the same time a disadvantage that no further degradation could be achieved. Based on these results, the Dutch government decided to give this area a go-ahead for a park with a playground for children.
Many organic compounds are only partially degraded by micro organisms under aerobic conditions. For example, degradation of kerosene oil in contaminated soil is enhanced by up to 5 fold by bioventing (figure 5.63).

Under these conditions, production of much more CO_2 has been recorded compared to that in control, indicating the involvement of microbial activity in kerosene degradation. This was further supported by DGGR- analyses (figure 5.64) showing an increased amount of DNA in the contaminated soil compared to that in control soil samples.
Plant root growth will only survive contamination until a certain critical toxic concentration of the polluting compound has been reached. As shown in

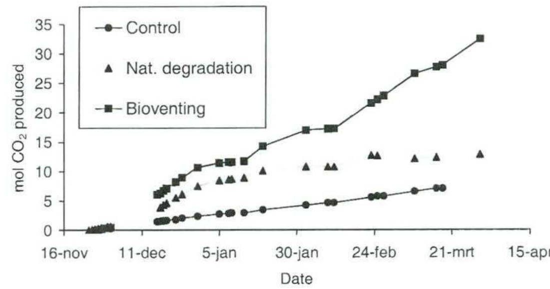


Figure 5.63
Production of CO_2 with time of a soil contaminated with kerosene with (I) and without bioventing in comparison with an uncontaminated soil.

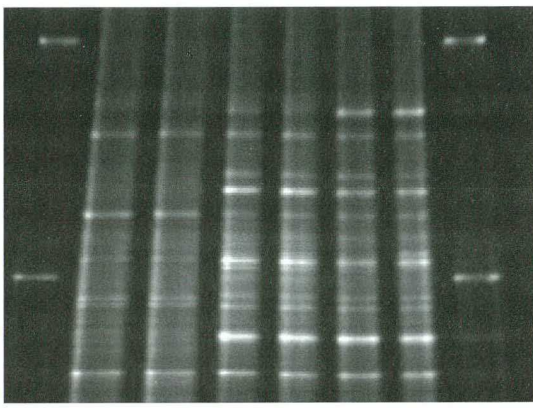


Figure 5.64
DGGE-gel with DNA bands of soil contaminated with kerosene with (+K) or without (-K) bioventing compared with the uncontaminated soil (C).

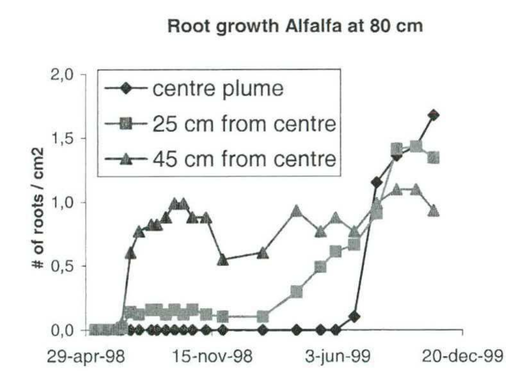


Figure 5.65
Root growth of alfafa in soil contaminated with kerosene in a spiking experiment at different distances from the centre of the plume at different dates from the beginning of the experiment.

Figure 5.65, root growth of alfalfa plants only occurs in the plume of a kerosene contamination, where the contaminant is below its critical toxic concentration. Root growth of alfalfa in first instance only occurs at a distance of 45 and 25 cm from the centre of the plume. Rooting in the centre only occurs a year after planting. Only then, complete biodegradation of the kerosene can occur. Contaminated soils often contain many different components. Apart from organic contaminants, often heavy metals are also present. In such situations, root exudates not only provide a carbon source for microbes but also form chelates with many metals, and thus detoxify the soil for both microbial activity and root growth. In this context, mycorrhiza may also play an important role. Hildebrandt *et al.* (1999) showed how *Zea mays* can be protected against the toxicity of heavy metals after inoculation of the plant with the arbuscular mycorrhiza fungus *Glomus intraradices*, isolated from the zinc violet. This is an opportunity to adapt plants suitable for bioremediation of organic contaminants to survive additional metal toxicity.

Whilst phytoremediation has a great potential for application in a variety of situations, its limitations must also be kept in view to provide a focus for further innovations. The success in improving the rate and range of phytoremediation would certainly need an integrated approach. This may involve strategies to increase root mass, and the use of bioremediating microbes in the rhizosphere and genetic engineering. The integration of biotechnology to improve phytoremediation should, however, also take into account the constraints on biotechnology itself, especially due to the public disapproval of GM technology. However, whilst it imposes a constraint on mainly crop and animal production areas, it should provide an opportunity for phytoremediation using non-food plants to demonstrate biotechnology in a more acceptable way, i.e. for the direct benefit of the environment.

5.6.9 *Traffic control and traffic noise reduction*

B. Ursem

Traffic in the Netherlands and, indeed, throughout the urban areas of Europe has now become so dense that it must be controlled in order to avoid major traffic jams. Traffic has also become an environmental issue. Noise is one of the most obvious pollution. These aspects are attracting serious attention in the establishment of new road infrastructural projects in densely populated areas.

Low noise asphalt or other forms of surface are common noise reduction treatments. Grained rubber from old tyres can be mixed with asphalt and provides an enormous noise reduction, but creates an open surface, becoming especially dangerous when water sticks to the rubber, and freezes during the winter. Speed reduction is also naturally a well-known way to reduce traffic noise in urban areas. Remote speed control, as can be seen on the motorways around Rotterdam in the Netherlands, provides noise reduction, as well reduction in air pollution.
A completely new approach can be achieved with the use of a mixture of asphalt and plant fibres. Fibres with a high percentage of silicon can be very useful and do not burn off during in the heat of asphalting.

Plants are also being used in other ways to increase the effective use of motorways. For example: botanical polymers, together with monochromatic light, are in use in a traffic control system on road surfaces. Botanical polymers appear as dotted lines on road surfaces. If the light is switched off, these dotted lines are invisible. If switched on, the dotted lines mark bright and clear the lanes. The road surface can be divided in a three or four lane system, when the density of traffic increases. This can be seen on the motorways around the city of Utrecht in Central Holland. Plant fibres are also used in the biocomposites used to make motorway crash barriers. Most crash barriers are made of metal or fibre glass. The use of bio-composites is still in development, and is part of a proposed research program at the Delft University of Technology (partners Faculty of Aerospace Engineering, Botanical Garden TU Delft).

Traffic is the most important source of environmental noise in Europe. (Table 5.10). Some measures, for example, erecting noise barriers, only reduces the impact of the noise.

In the Netherlands, two noise-reduction action plans were implemented. The objectives of the national environmental plan (Dutch NMP/NMP2): were (comparing 1985):

- No increase in noise level by the year 2000;
- No increase of noise level and no serious disruption by noise by the year 2010.

The second action plan covers a structure-outline of Traffic and Transport (Dutch SVV II; comparing to 1986):

- The number of houses within the 55 dB(A) zone of a road is 5 % less by 1995.

Table 5.10 Noise nuisance per source (The percentage of the Dutch population that suffers between 1990 till 2002).

	1990 %	1995 %	1998 %	1999 %	2000 %	2001 %	2002 %
Traffic and/or industry	50	44	42	41	43	42	43
From where: air traffic	25	21	19	18	19	18	19
railway traffic	5	5	5	6	7	6	7
road traffic	34	30	28	28	29	30	32
industry	5	4	4	4	4	3	4
neighbours	27	24	20	20	20	21	20

Source: CBS (2003) Mind: the noise nuisance of people of 18 years and more

Table 5.11 Useful plants from naturally dry areas

Useful plants from naturally dry areas				
Scientific name	English name	soiltype: sand	clay	peat
Achillea millefolium	Yarrow	X	X	X
Anthemis tinctoria	Yellow chamomile	X	X	-
Anthylli svulneraria	Kidney vetch	X	X	-
Berteroa incana	Hoary Alison	X	-	X
Campanula glomerata	Clustered bellflower	-	X	-
Campanula rotundifolia	Harebell	X	X	X
Centaurea scabiosa	Greater knapweed	-	X	-
Cerastium arvense	Field mouse-ear	X	-	-
Chamaenerion angustifolium	Rosebay willowherb	X	X	X
Chrysanthemum leucanthemum	Ox-eye daisy	X	X	X
Daucus carota W	ild carrot	-	X	-
Dianthus deltoides	Maiden pink	X	X	-
Dianthus armeria	Deptford pink	X	-	-
Dipsacus fullonum	Teasel	X	X	-
Galium verum	Lady's Bedstraw	X	-	-
Geranium pratense	Meadow cranesbill	?	X	-
Glechoma hederacea	Ground ivy	X	X	X
Hieracium pilosella	Yellow hawkweed	X	-	-
Hieracium aurantiacum	Orange hawkweed	X	-	-
Hypericum maculatum	Imperforate St John's wort	X	X	-
Hypericum perforatum	Perforate St John's wort	X	-	-
Jasione montana	Sheepsbit scabious	X	-	-
Lathyrus pratensis	Meadow vetchling	X	X	X
Linaria vulgaris	Common toadflax	X	X	X
Malva alcea	Musk mallow	-	X	-
Malva moschata	Musk mallow	-	X	-
Melandrium album	White campion	X	X	X
Melandrium rubrum	Red campion	X	X	X
Melilotus officinalis	Ribbed melilot	X	X	X
Melilotus altissima	Tall melilot	X	X	-
Melilotus albus	White melilot	X	-	X
Oenothera biennis	Common evening primrose	X	-	-
Oenothera erythrosepala	Large-flowered evening primrose	X	-	-
Ononis spinosa	Spiny rest-harrow	X	X	-
Ononis repens	Rest-harrow	X	X	-
Onopordum acanthium	Cotton thistle	X	X	X
Origanum vulgare	Marjoram	-	X	-
Pastinaca sativa	Wild parsnip	-	X	-
Pimpinella saxifraga	Burnet saxifrage	X	-	-
Plantago media	Hoary plantain	-	X	-
Potentilla reptans	Creeping cinquefoil	X	X	X
Potentillaargentea	Hoary cinquefoil	X	-	-
Potentilla tabernaemontani	Spring cinquefoil	X	X	-
Prunella vulgaris	Self-heal	X	X	X
Reseda luteola	Weld	-	X	-
Sanguisorba minor	Salad burnet	-	X	-
Saponaria officinalis	Soapwort	X	X	-
Satureja vulgaris	Savory	X	-	-
Satureja Acinos	Basil thyme	X	-	-
Scabiosa columbaria	Small scabious	X	X	X
Sedum Album	White stonecrop	X	X	-
Sedum sexangulare	Tasteless stonecrop	X	X	-
Senecio erucifolius	Hoary ragwort	X	X	-
Silene dichotoma	Forked catchfly	X	-	-
Stachys officinalis	Betony	-	X	-
Tanacetum vulgare	Tansy	X	X	-
Tragopogon porrifolius	Salsify	-	X	-
Tragopogon pratensis	Goatsbeard	-	X	-
Verbascum blattaria	Moth mullein	X	-	-
Verbascum nigrum	Dark mullein	X	X	-
Verbascum densiflorum	Great mullein	X	-	-

- The number of houses within the 55 dB(A) zone of a road is 50 % less by 2010.

In order to get a good prospective in noise figures (source RIVM, Bilthoven 2003):
- a silent area values a maximum of 40 dB(A);
- an area of background sound and the noise of a quiet street values a maximum of 50 dB(A);
- a motorised highway at a distance of 10 meters from the highway values a maximum of 70 dB(A).

The Government aims to limit vehicle noise emission, from, for example, tyres, brakes, engines and aerodynamics. Even an increase in tax on several items, such as on transport with a high noise impact, on the infrastructure, and finally on the vehicles and fuel (source F.B.J. Elbers, München 1997).

Noise barriers are the most frequently used noise reduction measure along roads.
The noise barriers along motorways, highways and other roads were, in most places, very effective in blocking the noise of the traffic, but can be ugly. On the ring roads around big cities, curved transparent noise barriers are often seen. These provide some light for houses just behind the barriers. Older noise barriers are usually made of concrete, steel or epoxy. Nearly all of them are covered with graffiti, and unsightly. Allowing plants to grow over such barriers is therefore a much more attractive idea.

When should a noise barrier be used?
A cluster of houses in the countryside, a terrace of houses, a small village or a concentration of farmhouses can need a localised noise protection (either from the railway or roads). Where many motorways, highways and roads pass through urban areas, more concentrated protection is necessary.
Important parameters for creating a noise barrier include the level of noise at the front of a house, the efficiency of the noise barrier and the cost per house. Other aspects of importance include visual nuisance, barrier effect, etc. These aspects are difficult or impossible to estimate in mathematical terms. The acoustic capacity at the front of a set of houses can be calculated by the formula:

$$\sum_{i-1}^{n}\left(L_i - L_g\right)$$

where:
L_i the acoustic burden at the front of house i
L_g the applied preferable ultimate value
n the number of houses where noise exceeds the preferable ultimate value

The acoustic effect diminishes drastically when a noise barrier used, and its effectiveness increases with increased height. The acoustic effect corresponds with the same diminishing number of decibels per house, as given by the formula:

$$\Delta dB_{houses} = \sum_{i-1}^{n\,ref}\left(L_{i\,ref} - L_g\right) - \sum_{i-1}^{n\,ref+\bar{n}}\left(L_{i\,ref+a} - L_g\right)$$

where:
$L_{i\,ref}$ represents the acoustic burden at the front of house i, on the traffic side of the reference blind. In other words, the situation without a noise barrier.
$L_{i\,ref+a}$ represents the acoustic burden at the front of house i on the other side of the noise barrier.
a is the height of the noise barrier (accuracy figure of 0,5 meter).
L_g is the relevant preference ultimate value.
$n\,ref$ represents the number of houses where the preference ultimate value is exceeded without the noise barrier.
$n\,ref+a$ represents the same as $_{n\,ref,}$ but with noise barrier.

Associated problems can be the cost, for example the measure of the outcome of a MER study (Dutch Environment Effect Report) or the needed length of the proposed noise barrier. Indication: the total length of the proposed noise barrier is 4 times the average distance of the houses to the proposed noise barrier.

'Green' noise barriers
Noise barriers can be grouped into simple barriers based on a green approach and more technically complex ones. The latter are more in use in densely urban areas. A very effective example, the PV-noise barrier, can be seen along the A9 motorway near Ouderkerk aan de Amstel. Photovoltaic solar cells are placed on top of a glass-steel construction. 2160 solar cell panels produce 205 kWp

and 176,000 kWh per year, which is equivalent to the use of 52 households annually. As a side effect, it reduces carbon dioxide emission by about 107 tons per year, because of the non-conventional production of electricity. A similar, but less advanced solar cell noise barrier can be seen along the A27 motorway, north-east of Utrecht. The more green approach combines noise barriers with living plants. The first plants used for this purpose were fast-growing trees which respond well to trimming and pruning. Willow twigs were planted and woven together as they grew attaching enlaced mat to the noise barrier.

The noise reduction by the combined plants and barrier was much higher than before. A good example can be seen along the A2 motorway between Abcoude and Vinkeveen. However, willow does not always grow at the same rate and density of branching. After some years, the lower parts become barren of leaves, and the noise blocking effect diminished drastically. Other species have been tried, for example field maple (*Acer campestre*), false acacia (*Robinia pseudoacacia*), hornbeam (*Carpinus betulus*) and other known prunable trees. Good examples of the latter examples can be seen along A 1 motorway north of Hilversum and Bussum.

Because of their effectiveness and visual impact, integrated noise barriers have become popular throughout the Netherlands. In some cases, the growth of plants completely covers the barrier. As with the willow; the lower part of the barrier eventually became barren of leaves, exposing the old construction. This was overcome by adding other plants and small bushes in planting boxes filled with soil. These boxes were set at a slight angle in order to catch enough rain. An example of such a barrier can be seen along the A27 motorway between Bilthoven and Hilversum. It was found that after six to ten years, these boxes were empty.

The only plants that could survive were bramble (*Rubus fruticosus*), rasberry (*Rubus idaeus*), elder (*Sambucus nigra*) and some drought-resistant plants which occur normally on formerly logged areas (rosebay willowherb (*Epilobium angustifolium*), foxglove (*Digitalis purpurea*), common evening primrose (*Oenothera biennis*), perforated St. John's wort (*Hypericum perforatum*), etc.).

Because of its variable success, a more ecological approach in plant selection was used and therefore plants suitable for arid areas were used in boxes for new integrated noise barriers. Sedum species, such as white stonecrop (*Sedum album*) and biting stonecrop (*Sedum acre*), turned out to be most successful. An example of a *Sedum*-integrated noise barrier can be seen along the A10, west of Amsterdam. However, *Sedum*-integrated noise barriers appear less effective in killing traffic noise than those with the other bushes.

An entirely new approach is the recent use of TEXOLITE® in noise barriers. These TEXOLITE® noise barriers absorb noise to a level of at least 16 dB(A). All other artificial noise barriers isolate and reflect, instead. The TEXOLITE® noise barrier can be covered with bushes or, without the use of wall bars, be overgrown with vines or lianas (for example ivy or *Hedera helix*).
An almost fully environmental approach was created in 1999, and appeared on the market as the MW- Noisekiller (= **M**osterd De **W**inter Noisekiller). The MW-Noisekiller can have a maximum height of 6 meters and is 60 centimetres wide. Soil substrate is hold in place by synthetic wire netting. Plants can easily grow on the substrate and within five years the noise barrier is overgrown. Because many plants are kept in containers, planting can be carried out throughout the year, except during frost. This green noise barrier absorbs noise to a level of approximately 15 dB(A).

In all these attempts to create environmentally friendly approaches to noise reduction, lack of knowledge of plant ecology is still a big problem. In most places, there is very well developed and prosperous plant growth in the first 5 to 8 years. After this, gaps start to appear where plants have either died, or grown too big. In a few cases, a single plant type dominates all the other originally planted species.
In order to avoid the domination of a single species or a total lack of growth, a more environmental approach is necessary.
Most species from naturally dry areas can grow easily in these noise barrier boxes or in the MW-Noisekiller (Table 5.11).

All of these species are perennial or spreading biannual plants which are adapted to a dry environment and indigenous to the flora of Europe. Annuals are not listed, because they increase necessary maintenance. Some additional annual plants could be used, such as *Matricaria recutita* (scented mayweed), *Papaver argemone* (prickly poppy), *Papaver dubium* (long-headed poppy), *Papaver rhoeas* (common poppy), *Silene armeria* (sweet William catchfly) and *Trifolium arvense* (haresfoot clover).

In more urban areas, where noise barriers are placed without soil substrates, the growth of vines and lianas are a preferable solution in order to hide the construction. As soon as the noise barrier is overgrown, the rough surface created by the leaves will contribute to an acoustic reflection and reduce noise effects. Indigenous suitable vines and lianas include *Clematis vitalba* (traveller's joy) on clay soils and *Hedera helix* (ivy), *Humulus lupulus* (hop) and *Lonicera periclymenum* (honeysuckle) on all mentioned soil types. In cities or very densely built areas, lianas or vines could be considered. Possibly *Akebia quinata* (common akebia), *Aristolochia macrophylla* (Dutchman's pipe), *Campsis radicans* (trumpet vine), *Celastrus*- and *Clematis* species, *Hydrangea petiolaris* (climbing hydrangea), *Parthenocissus* species, *Passiflora caerulea* (blue passion flower), Periploca gaeca (silk vine), *Polygonum aubertii* (Russian vine), *Rosa* species, *Wisteria floribunda* (Japanese wisteria) and *Wisteria sinensis* (Chinese wisteria).
By means of all these different plants, we can conclude that noise barriers will become much more attractive than those in use right now in most places in Europe.

The building of noise barriers will remain a necessity in order to reduce noise disturbance along motorways and major road systems in the open air in urban areas.

5.6.10 Buffer plantings improve air quality along highways

F. Tonneijck

Introduction

Various components in ambient air can adversely affect humans, plants and animals. More than two thirds of Europe's population lives in urban and suburban areas. Air pollution in urbanized areas continues to be an important environmental problem with respect to human health. Increasing road traffic is primarily responsible that air quality in and around cities does not comply with current guidelines. Traffic is a prominent source for the emission of nitrogen oxides (NO_x), Volatile Organic Compounds (VOCs) and dust particles such as particulate matter with an aerodynamic size of 10 µm or less (PM10). PM10 contains many toxic chemicals such as heavy metals and organic compounds. It has been shown that living near a major road adversely affects human health and that long-term exposure to particulate matter air pollution from vehicles is associated with increased mortality from respiratory and cardiovascular disease and from lung cancer (Hoek et al., 2002). Ozone (O_3) is formed from Nitrogen dioxide (NO_2) and VOC's under the influence of sunlight. O_3 is considered to be the most indicative compound for the severity and the adverse effects of summer-type smog episodes and concentrations close to the highways are less than at a greater distance. Reduction of the concentrations of NO_2 and VOCs will eventually result in a reduced potential for the photochemical production of O_3.

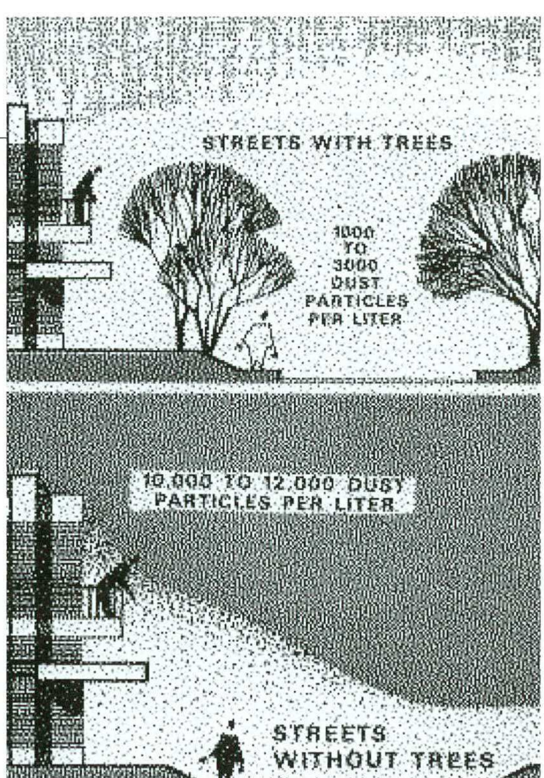


Figure 5.66
The number of particles in the air with and without trees (from Robinette, 1972)

There are many reports that air pollutants such as sulphur dioxide (SO_2), nitrogen oxides (NO_x), ozone (O_3), volatile organic compounds (VOCs) and dust particles have caused dramatic effects on the performance of plants and vegetation. Although indirect effects via the soil also can occur, plants only respond to air pollution if the pollutant has been taken up by the leaves or has been deposited on the leaf surfaces. Accumulation of air pollutants by aerial plant parts has often been reported. Vegetation is considered to be an important sink for ambient air pollution. This phenomenon was basic to the idea that plants can be used to improve air quality by reducing the amount of pollutants from the surrounding air both indoors and outdoors.

Plants might have a positive effect on the air pollution situation near highways (Tonneijck and Blom-Zandstra, 2002). In this chapter we focus on the effects of plants on the distribution of NO_x and PM10. These components are causing the main environmental problems in the vicinity of highways with heavy traffic. Evidence is presented that vegetation remove vehicle emissions effectively and the mechanisms by which leaves and vegetation affect air pollutant concentrations are described. Some related studies on the capacity of plants to remove atmospheric pollution are also described shortly (see figure 5.66).

Evidence of filtering capacity by roadside vegetation

NO_x

Nasrullah et al. (1994) studied the effect of roadside buffer plantings on controlling air pollution by determining the distribution of NO_2 in open fields and planted areas near roads of various structures. As could be expected, NO_2 concentration was found to decrease with increasing distance from the road. Plantings with 15-20 meter tall trees at the level of the road significantly reduced the NO_2 concentration up to a distance of 150 meter compared to the open field situation (Figure 5.67). The effectivity of the tree plantings tended to be greater as the height of the trees increased and was two times greater during calm weather than on windy days, thereby indicating the importance of local weather conditions. The proportional reduction in NO_2 concentration by the tree plantings was circa 13, 17, 7, 13, 12 and 11% at a distance of 5, 10, 30, 70, 110 and 150 meter from the road and was circa 12% on average compared to the unplanted areas.

PM10

One adult tree can accumulate up to 18 kilograms of dust per year (McPherson, 1990). Conifers are generally more effective than broad-leaved deciduous trees in removing fine dust particles from the air with pine trees being more effective than cypress. Since fine dust particles contain many heavy metals, concentrations of these chemicals in vegetation as well as in soil are indicative for the distribution of PM10 near highways. Windbreaks with various tree species have proven to be effective at trapping and accumulating heavy metals such as copper, lead and zinc.

As an example, Figure 5.68 shows the effect of different types of barriers on the deposition of lead along highways. The concentration of lead decreases with increasing distance from the road under all circumstances. The proportional decrease in lead concentration in response to increasing distance is much greater in the presence of hedgerows and trees than in open terrain with no barrier and even is greater than in the presence of a noise reduction wall of 4 meter height. Lead concentration in vegetation at a distance of 25 meter is circa 45% of that in plants close to the highway. The lead concentration at 25 meters amounts to 20% in the presence of a 5 meter tall hedgerow and to 5% in the presence of a deciduous forest.

VOCs

Vegetations play an important role in removing VOCs from the atmosphere. VOCs include a great variety of components such as the polycyclic aromatic hydrocarbons (PAHs). PAHs are common byproducts of fossil fuel combustion and several of these compounds have carcinogenic and mutagenic properties. In ambient air, PAHs as well as other VOCs can occur in the gas phase or be adsorbed onto dust particles. Generally, plant uptake of VOCs is similar to the uptake of NO_x and PM10 and depends on the nature of each VOC. However, specific information on the effectivity of buffer plantings to reduce the atmospheric concentrations of VOCs along highways is very scarce. Calculations by Wagrowski & Hites (1997) for an extensive area (urban, sub-urban and rural) have shown that existing vegetation can take up 4% of the PAHs which are present in the ambient air.

Foliar uptake of air pollution

The general process by which pollutants are removed from the atmosphere, is called deposition. This deposition can occur by precipitation as wet deposition and by dry deposition of gases and particles. Dry deposition of gases and particles to leaf surfaces is governed by the nature and concentration of the air pollutant, turbulent transport

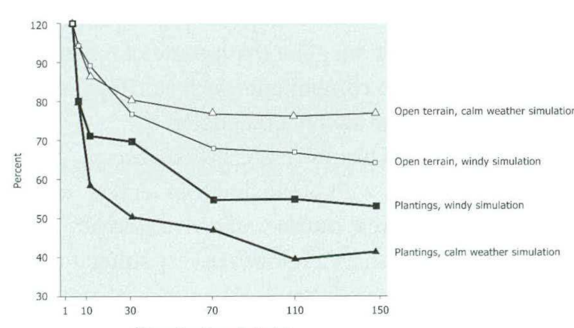


Figure 5.67
NO_2 concentration (expressed as percentage of the concentration measured at 1 meter from the edge of the road) at various distances from the edge of the road for situations with and without tree plantings (Nasrullah et al., 1994). ■ With trees on windy days; ▲ with trees on calm days; □ open field on windy days; △ open field on calm days.

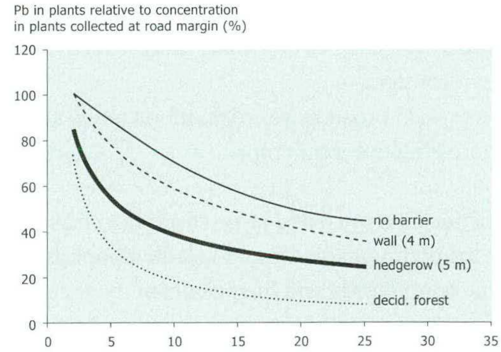


Figure 5.68
Effects of different barriers (no barrier, noise reduction wall, hedgerow and close deciduous forest) on relative lead concentrations in plant samples collected along roadsides in Baden-Württemberg, Germany (after data from Schweikle, 1999)

processes and leaf characteristics (Hanson and Lindberg, 1991). For ground-level emission sources such as traffic on highways, highest dry deposition occurs in the direct vicinity of the source where the air pollutant concentrations are highest and decreases downwind.

Plants are capable to take up a wide array of air pollutants and the rate of uptake depends on leaf properties, structure of the vegetation, nature of the component and environmental conditions. Pollutants react with the external surfaces of the leaves and are exchanged with the leaf interior following diffusion through stomata. The outer aerial surfaces of leaves are covered by a cuticle. The cuticular layer acts as a barrier to water and gas permeation and it forces most of the evaporating water and gas molecules to pass through the open stomata. Stomata also are common features of plant leaves and are minute pores in the leaf surfaces through which gases are exchanged between the leaf interior and the atmosphere.

The functioning of stomata depends on many factors such as those related to plant species and environmental conditions. The opening of stomata is greater during the day than during the night and is also greater under humid conditions compared to dry conditions. The main route of foliar uptake for gaseous components such as NO_x and O_3 is through these stomata (Lendzian & Kerstiens, 1991). This process is called absorption. Plant species with broad and thin leaves have a relatively great number of active stomata per unit leaf area and therefore are very suited to absorb gaseous air pollutants. A large leaf area per unit area of soil such as is present in trees also is beneficial for removal of gases from the air. The capacity of plants to absorb NO_x is as follows (Hanson & Lindberg, 1991):

1. Plant species with broad and thin leaves are equally effective as crops but more effective than conifers;
2. Trees with broad leaves (deciduous trees) are more effective than crops.

Plant cuticles represent a large sorption compartment for both nonvolatile and volatile lipophilic organic compounds and the permeability of cuticles for these chemicals is determined mainly by the solubility of the chemical in the cuticle. The cuticle hereby acts as a buffer taking up components from the atmosphere and gradually exchanging these compounds with the leaf interior. In contrast to stomatal uptake, cuticular uptake continues during the night when stomata are generally closed and during the winter when plants are hardly active. Variations among cuticles from different species are large and plants that contain many leaves with thick and fatty cuticles, are very well capable of adsorbing organic chemicals. Among those plants are conifer species and crops such as cale.

PM10 has been identified as the major component of urban air pollution associated with human health effects in Europe and North America. The particles present in the atmosphere vary in size from a few nanometers to 10 μm in diameter. These particles contain various heavy metals (Pb, Zn, Cu, Mn, Cr) and organic chemicals. The capture of particles by solid objects such as leaves occurs by a variety of impaction processes. Particles in an airstream are most readily impacted onto moist, rough (including hairs), or electrically charged leaf surfaces (Pye, 1987). They can also be resuspended following impaction and the retention is increased if the surface is sticky. Once impacted it requires strong forces to dislodge the majority of particles from a leaf surface. All plants are capable of capturing PM10. Generally, conifers are more effective in removing fine particles and less effective in absorbing gases from the atmosphere than deciduous trees.

Vegetation characteristics and effects on air pollutant concentrations

Traffic emits a variety of atmospheric pollutants and the uptake of each depends on the nature of the component and the plant species. Vegetations which are supposed to be effective biofilters of vehicle emissions, must therefore consist of different plant species. The greater the leaf area the better is the capacity of plants to remove air pollution and trees constitute essential elements in these vegetations next to shrubs and short vegetation. Other biological aspects such as growth rate of the species and the presence of leaves or needles throughout the year are also important factors to consider when planting a vegetation that is an effective biofilter.

Vegetation structure is thought to be crucial to scavenge gaseous and particulate air pollutants. Plantings must be somewhat transmissive at the side of the highway to let the emissions pass through the canopy in order to filter out particles and gases. A value of 40-50% for this so-called hedge porosity is considered to be optimal. Trees and buffer plantings represent physical structures in the landscape and these structures influence microclimate in terms of wind speed and air turbulence. For aerodynamically rough vegetation such as hedgerows, isolated trees, shelter belts, woodlands and even for continuous forest cover, deposition rates for air pollutants can be 2 to 16 times greater than onto short vegetation.

Inhomogeneities in the landscape as is the case near forest margins result in an increased deposition of gaseous pollutants and fine dust. Within this context, the use of trees to create sharp edges near highways is a good way to proceed. Plant height is also important since a tree can reduce the wind velocity and hence the pollutant concentration up to a distance of 30 to 50 times its height. The deposition of relatively large particles increases with a decrease in wind speed. Air turbulence is affected by the surface roughness of the leaf canopy; the greater the surface roughness the greater is the turbulence and hence the rate of deposition of air pollutants.

Some examples of related studies

NASA and Indoor Air Pollution (http://www.wolvertonenvironmental.com/air.htm)

In the early 1970's, NASA identified more than 100 VOCs that were emitted by synthetic materials inside their spacecrafts. NASA realized that indoor air pollution in isolated structures could present health-related problems and should be addressed. Later reports showed that more than 900 VOCs could be found in air of public buildings.

As part of its research into 'closed ecological life support systems', NASA began to study the cleansing powers of nature through the synergistic reactions taking place between plants and their root microbes. In 1984 NASA first published studies demonstrating that interior plants could remove VOCs from sealed test chambers. Consequently, NASA had constructed a tightly sealed building termed the 'Biohome', a one-person habitat that was made up of various synthetic materials. Upon entering the original construction, one experienced severe burning of the eyes and respiratory discomfort, both classic symptoms of 'sick building syndrome'.

Interior foliage plants and a small prototype fan-assisted plant filter were placed throughout the living quarters to evaluate their ability to remove VOCs that were present in the indoor air. Results showed that most of the VOCs had been removed. The ultimate test was the fact that one no longer experienced the symptoms of 'sick building syndrome.

Trees in the West-Midlands, UK (see brochure by Stewart et al.)

A number of epidemiological studies have shown that a rise in PM10 concentrations of 10 $\mu g\ m^{-3}$ (as a 24 hour average) is associated with an increase in mortality of 1%. The reduction in PM10 concentrations which would result from future tree planting would therefore be beneficial to human health.

For the West Midlands urban area (900 km^2) in the UK, an attempt was made to quantify the benefit of future tree planting. Using health statistics and predictions of the effects of tree planting on urban air quality, the effect of various tree-planting schemes on the deposition of PM10 and the resulting effects on human health was estimated. Calculations showed that doubling the number of trees in the West Midlands could reduce excess deaths due to particles in the air by up to 140 per year.

American forests: CITYgreen (www.americanforests.org)

The burning of fossil fuels has introduced a steady flow of deadly pollutants into our atmosphere, yet very few urban areas can meet national clean air standards. However, we are surrounded by efficient air cleaning machines viz. trees. Based on research in 50 US cities, a methodology has been developed to assess the air pollution removal capacity of urban forests with respect to NO_2, SO_2, O_3, carbon monoxide (CO), and PM10. The software programme CITYgreen estimates the amount of pollution being deposited within a given study site and reports on an annual basis the amount of each pollutant that has been removed, as well as the dollar savings. See for an example the data in Table 5.12. Even more important than providing accurate and detailed information on the extent and value of tree cover, is that now the tools and systems for communities themselves are available to routinely monitor and plan for healthy tree cover.

Table 5.12 Trees and air quality around the country*

City	Pounds of pollutants removed annually by trees	Annual value of trees with respect to air pollution
Washington, DC	878,000	$2.1 million
Atlanta, GA	19,000,000	$47 million
Portland, OR	2,000,000	$4.8 million
Denver, CO	1,000,000	$2.6 million

* Data obtained from www.americanforests.org/graytogreen/air/

Air filtration in Chicago

In Chicago (11% tree cover) in 1991 trees removed 15 tonnes of CO, 84 tonnes of SO_2, 89 tonnes of NO_2, 191 tonnes of Ozone, 212 tonnes of PM_{10}. Removal rate 9.7 kg/ha/year for Chicago.

Urban plantings

Small plantings near houses (Schaeffer et al., 2004) show energy savings for reduced heating or cooling, catch of PM_{10}, Ozonereduction, uptake of NO_2, SO_2, CO, CO_2, reduced run-off, scenic value, wildlife, improved waterquality, noise abatement, savings in healthcare and increase in property values. One green ash tree (Fraxinus pennsylvanica) of 30 years old can save according to McPherson (1994) 201 Kwh for cooling, 8,3 Mbtu for heating, catch 0,9 kg PM_{10}, 0,297 kg Ozone, 0,3 kg NO_2, 0,8 kg SO_2, 0,07 kg CO, 164 kg CO_2. Schaeffer et al. (2004) give different tables about air pollution reduction and other benefits to the environment for different vegetation types, for different yard types, different tree species and plants on balconies.

Summary

In summary, ecological engineering, contrary to environmental technology (see table 5.1), comprises the following:

A 'begin-of-pipe' approach: problems are handled at the source, in accordance with the principle 'first prevent, then mitigate and only then compensate'.

Use of power from the sun and other natural resources.

A consistent insertion into natural systems and the requirement of multifunctionality, create a clear limitation of adverse environmental effect and reduces the risks for vulnerable processes and systems.

A preference for decentralized solutions: those involved have better access to planning and development procedures.

Use of cyclic systems to guide waste flows to other processes (1-3 (20 or 100) times reuse; downcycling, cascades).

Insertion in a sociocultural context, in which ecological requirements as design criteria are assigned the same importance as economic and technical aspects.

Less displacement of problems in time or space.

6 The concept of nature and the significance of biological diversity

H.D. van Bohemen

6.1 The concept of 'Nature'

Introduction

The concept of 'nature' is experienced and defined by many people differently. This also applies to the concept of biodiversity. For one person nature is something that corresponds to health, for the other something virginal, or 'green' or not made by man.

There often also appears to be a large discrepancy between nature and cultivation. This section addresses the meaning, the development and the current position of the concept 'nature'.

In particular, if we as human beings intervene in nature, it is important to clarify the objective, but it is also essential to realize that the set objectives sometimes are not/ cannot be achieved. The target typology system in the nature policy of the Netherlands has been established to be able to link quality requirements to habitat creation, conservation or management measures. But nature is not aware of target types and chooses its own paths, processes, patterns and structures that are just as valuable for nature. And nature is in continual development, with periods of blossoming alternating with periods of death. Some phases in the natural process of succession occur quickly, others more slowly, we take this into account especially if we wish to use control measures such as mowing, grazing, felling and peat cutting to retain a certain picture of nature.

Background to the concept of 'nature'

The meaning of the concept of 'nature' is strongly determined by time and place. In our western civilization, a large discrepancy between nature and cultivation can often be recognized. If we are able to consider the relationship between man and nature, roughly four phases can be distinguished (Moser, 2000).

1. Nature as an enemy.
2. Nature as a distant partner. Man accepts the good side of nature; in the European Jewish/Christian tradition: man as the crowning glory of creation.
3. Nature as an object. The demystification of nature with a more materialistic vision as the result. Arising from anthropocentrism.
4. Nature as a messenger. In the near future we can arrive at the insight that we are ourselves a fully-fledged component of creation.

The concept of nature can mean the essential characteristics of something or the invisible powers, or the instinctive and behavioural characteristics of man and animals, the conditions that prevailed on earth before the arrival of man, but also 'natural' areas for human recreation.

Habermas distinguishes three fundamentally different positions taken by man with respect to reality: an objective, a normative and an inward focus; objective: reality as a collection of things and events; normative: reality where norms apply which we accept as right; inward: the world of the individual reality formed by subjective judgement, wishes, needs and feelings. For the outcome of human activities, research (literature) shows that it is important to take account of all of these three positions.

> For a forest dweller, a forest is a natural system with an economic value; ecologists see a forest as a living community in which plants and animals interact with each other and the environmental conditions, for the people who use the forest for recreation it can be an object of beauty, but also a symbol of the country in which

they live. The abstract concept of nature as an objective scientific construction gains its significance through the manner in which humans attach values to it in a subjective manner. The concept of nature cannot be divorced from the culture in which we live (Toogood, M. 2001).

This can be illustrated by the position of nature preservation, nature conservation and management and nature development in the Netherlands. There are continual discussions about the significance of three types of landscape: the new nature landscapes, the old cultivated landscapes and the modern urban landscapes, which are founded on various nature concepts. The natural landscapes evoke associations with wild, original nature, the cultivated landscapes with pastoral nature and the urban landscapes with functional nature (Keulartz, 2001).
These interpretations rest in turn on certain ecological theories, moral or ethical principles and aesthetic viewpoints (see table 6.1).

The three manners of approach indicate people's needs and desires. History shows us that the different approaches have led to major conflicts with respect to how to deal with our surroundings. The current manner of thinking based on the (self-) interest of sectors, groups and individuals, results in negotiations, instead of an open dialogue aimed at forming a consensus. Gaining the freedom to obtain a more balanced approach between, and integration of, the various points of view is essential for policy and management that offers space for the continued existence of plants and animals.

Nature in the Dutch government policy

Within the context of preparing the document '*Natuur voor mensen, mensen voor natuur* - Nature for people, people for nature' and in part based on criticism of the concepts in the Nature Policy Plan of 1990, a socio-scientific study was carried out into the images the Dutch population had of nature. These images form a frame of reference in which to better incorporate the nature policy (Buijs, 2000). Moreover, it appears that there is a close relationship between people's images and experience of nature. The nature images are classified into five types, varying from the image of nature as wilderness, through autonomous, decorative, comprehensive to functional.
The *image of nature as a wilderness* assumes the ideal image of nature as a wilderness.
The *autonomous image of nature*, which is very close to the previous image, emphasizes uninfluenced nature.
The *decorative image of nature* considers the recreation function to be decisive.
The *comprehensive image of nature* considers everything that grows as being nature.
The *functional image of nature* concerns the use that man can make of nature.
The research of Buijs (2000) shows that for the human population of the Netherlands there are major differences in the way 'nature' is considered. Moreover, these images of nature show a relationship with the preferences that people have for landscapes. Rugged nature landscapes are valued by people who prefer an image of nature as a wilderness.

Furthermore, the researchers expect there to be a certain degree of convergence of images of nature among the Dutch population, in particular as a result of the many groups of volunteers that are not just involved in 'nature consumption', but also in 'nature production'.

Table 6.1 The concept of 'Nature'

	Ecological theory	Ethical perspective	Aesthetic viewpoint
Wild nature	System ecology	Ecocentric	Objectivist
Pastoral nature	Community ecology	Partnership	Subjectivist
Functional nature	Production ecology	Anthropocentric	Formalistic

Nature in relation to ecological engineering

When using the concept of nature in this book, in the strict sense this concerns the spontaneous developing plants and animals.
When addressing vegetation, the concept of nature concerns the mass of individual plants at a certain location in a self-chosen order in time and space, against the background of the possibility of human influence or use in the form of felling, mowing or grazing. Here the concept of nature in the strict sense changes into the concept of nature in the comprehensive sense, whereby human action plays a role. When management occurs strictly for the conservation and development of the species, this is ecological engineering in the strict sense.
If man also benefits, or in general, if nature provides functions, goods or services to man, then this is ecological engineering in the comprehensive sense. 'Ecological engineering' is understood to be 'the design of sustainable ecosystems for the benefit of humans and nature' (Mitsch, 1993). For an overview of the developments and the practical applications of ecological engineering, you are referred to the section concerning ecological engineering.

Moser (2000) sums up the most important characteristics of ecological engineering in relation to the concept of nature as follows:

1. The main orientation is long term and ecocentric or holistic.
2. Diversity is endless and continues to increase although strongly limited by human action.
3. Interactions between the components are extremely diverse with many of them not yet being described scientifically.
4. Evolution, self-organization and sustainability are 'silent' laws of nature.
5. Non-invasiveness is an essential principle in the ecosphere.
6. Embeddedness is also an essential principle.
7. Sufficiency and effectiveness are supplementary principles.

The degree of naturalness

The concept of 'nature' is open to a wide range of interpretations (Moser, 2000) and descriptions, from functions that nature provides to man (Timmermans, et al, 1999) to accurately described definitions of constituents of nature for practical applications such as typologizing growth of woody plants (Koster, 2001).
Numerous classifications can be found in the literature for the degree of naturalness of ecosystems in the sense of the degree of undisturbedness, this is to say ecosystems that have developed without the influence of man or that have adjusted to relatively limited recurring human interventions at set times, for instance annual mowing (Van der Maarel, 1972).

The degree of undisturbedness can be characterized using a scale of ten. Van Leeuwen talks about the degree of dynamics added to the ecosystem by man:
Class 1: completely undisturbed;
Class 2: includes fields;
Class 3: includes cultivated grassland;
Class 4: includes wet grassland;
Class 5: includes hedges, old dykes and young coniferous forest;
Class 6: includes heathland, wooded banks, old coniferous forest and young deciduous forest;
Class 7: includes marshes and scrubland in the dunes;
Class 8: includes salt marshes, moors and old deciduous forest;
Class 9: includes mud flats and virgin forest.

This classification is comparable to that of (Westhoff, 1946):
Cultivated landscapes, semi-natural landscapes, more or less natural landscapes and natural landscapes.

Another classification concerns the influence of man on nature, the degree of hemerobie. Hemerobie is 'the total of all intended and unintended effects exerted by man on an ecosystem' (Jalas, 1955; Sukopp, 1972).

The '*Handboek Natuurdoeltypen in Nederland* - Handbook National Typology of Target Situations in the Netherlands for Nature' (Bal et al., 1995) distinguishes four management strategies.

Table 6.2 Several characteristics of types of landscapes according to Bal et al., 1995

	main group 1 more or less natural	main group 2 guided natural	main group 3 semi-natural	main group 4 multifunctional
spatial scale	landscape > 1,000 hectare	landscape > 500 hectare	ecotope/mosaic up to app. 100 hectare	ecotope normally a few hectare
management strategy	no human inter-vention,only initial measures and external management	simulating and stimulating certain natural processes	fixation at the level of ecotopes of a pattern of succession phases	linking with additional functions
development time	long	long	rather short	short
predictability	limited	rather limited	rather large	large

These are in the order of human influence or the decrease in naturalness:

1 Allowing large-scale processes that (physically and biologically) shape landscapes to occur undisturbed for the benefit of natural differentiation at landscape level (totally natural and more or less natural).
2 Influencing large-scale processes that (physically and biologically) shape landscapes to increase differentiation at the landscape level (guided natural).
3 Promoting specific succession phases by means of medium- and small-scale ecotope-oriented management (semi-natural).
4 Linking with other usage functions of the area (multifunctional).

Table 6.2 shows four characteristics of the main groups (Bal et al., 1995):

1 the spatial scale of the main group
2 the strategy to follow
3 the development time
4 the degree of predictability of the mix of species and the type of landscape that will arise using the given strategy.

When using the nature target typology approach, the intention is to link concepts of 'diversity' and 'naturalness' together or to link the combination of target types to the corresponding natural processes. With our current knowledge, the species-specific requirements of the target species appear to link to abiotic preconditions and ecological processes as well as to surface area size indications, despite the fact that the presence of species in a certain area can be partly attributed to chance factors.

The use of the concept of nature in relation to planning, design, construction, use and management of road infrastructure deals with two aspects. On the one hand the recognition of the intrinsic value of plants and animals in their self-chosen order in time and space, in other words the spontaneous character of vegetation and living communities). On the other hand the services that plants, animals, vegetation and living communities provide (such as the purification of polluted air and water and in the aesthetics of nature) can contribute to people's feeling of welfare.
Although contradictory to the principles formulated above, in a number of situations accelerating the process of creating rich herbal growth in roadside verges can be useful. On the one hand if use is made of the erosion resistance of vegetation by using compost hydroseeding, where seeds of plant species native to the location are added to the compost. On the other hand in situations where, in view of the distance to the source, the chance of (re)colonization is extremely low, seeding can be useful. A manner that is more in keeping with the principle of spontaneity is 'making available' a number of seed sources in the neighbourhood where (re)colonization is desired.

Biodiversity

Outside of the circle of biologists and ecologists, it is also becoming clearer and clearer how great the significance is of biodiversity. Political forums both on the local and world scale are taking into consideration the conservation, management and sustainable use of biodiversity.
One of the most important documents discussed at the UNCED conference 1992 was the 'Convention on the conservation of biological diversity in accordance with human development'. The term biological diversity or biodiversity refers to the total variation of animals, plants and micro-organisms, ecosystems and ecological processes. In this convention, biodiversity is defined as 'the variation among living organisms from all sources, including terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes the diversity within species, the diversity between species and ecosystem diversity (UNEP, 1992).
In principle we can distinguish three levels of biodiversity: genetic diversity, species diversity and ecosystem diversity:

- genetic diversity is the variation of information in the genes;
- species diversity is the variation of living organisms on earth;
- ecosystem diversity is the variation of biotopes, biotic communities, ecological processes and food webs.

The genetic codes contain the information for the forming, development and functioning of organisms. The variation is expressed in the large number of species. Moreover, there is a large variation within each population of species and there can be differences between populations of a species. In addition to species, the diversity of ecological functions and processes at the ecosystem level is essential. These aspects are related to each other, whether in the form of competition or in the form of cooperation.

Biodiversity is seen more and more as one of the significant factors of the living world of our global as well as local environment. Tilman (1996) found a relation between biodiversity and production and stability of ecosystems. According to him: a 50% reduction in the number of species will give in certain areas a reduction of productivity of ca. 10-20%.
Biodiversity means from a qualitative viewpoint the richness of species, genetic diversity, resilience, vitality. Functionally it means the function and services of ecosystems (food production, clean air, clean water, renewable material – economical services -), prevention of erosion, climatic regulation, pollination – ecological services -) and the 'supply' of beauty, identity, recreational possibilities – social and cultural services -). Also a classification of function in production, regulation and information is in use.

According to Hawskworth and Kaling-Arroya (1995) there exist ca. 14 million species on earth; 12-13% has been officially described.

In the Netherlands more than 42,000 exist (table 6.3). Table 6.4 shows the botanical diversity in the Netherlands.

Table 6.3 The biological diversity in the Netherlands and the world

Group	The Netherlands	The world
Virus	?	?
Bacteria*	>1,000	4,670
Macrofungi	3,500	64,000
Microfungi* 1000-en		
Protists without algae	1,144	33,000
Algae	3,800	28,000
Mosses	507	22,960
Higher plants	1,450	250,400
Invertebrates without arthropods	3,384	153,450
Arthropods without insects	3,147	149,600
Insects	17,455	977,000
Higher vertebrates (amphibians, reptiles, birds, mammals)	457	49,316
Total	ca. 42,000	ca. 1,800,000

(* no exact data, figure is rough estimate)

Table 6.4 Botanical diversity in the Netherlands

Spermatophyta (plants with seeds)	
Angiospermae	ca. 1400 species
Gymnospermae	2 species
Pteridophyta	
Club-mosses	7 species
Horse-tails	8 species
Trueferns	ca. 35 species
Bryophyta (mosses)	
Liverworts	ca. 125 species
Common mosses	ca. 380 species
Algae	
Chlorophyta (Green algae)	
Charophyceae	ca. 20 species
Desmidiaceae	ca. 450 species
Remaining	ca. 1150 species
Euglenophyta	ca. 250 species
Dinophyta	ca. 300 species
Cryptophyta	ca. 25 species
Haptophyta (Prymnesiophyta)	ca. 100 species
Chrysophyta	
Phaeophyceae (Brown algae)	ca. 73 species
Bacillariophyceae (Diatoms)	ca. 1300 species
Xanthophyca	ca. 120 species
Chrysophyceae	ca. 350 species
Rhodophyta (Red Algae)	ca. 78 species
Macrofungi c	a. 3500 species
Microfungi	very many, total number unknown
Lichens	ca. 633 species

(From: E.J. Nieuwkerken and A.J. van Loon, 1995, Biodiversiteit in Nederland, National Natural History Museum, Leiden)

During the last centuries the quality and the quantity of biodiversity have been decreased due to all kinds of human activities: building of villages, towns, infrastructure, intensifying agriculture, reallotments, draining, habitat destruction and habitat fragmentation (table 6.5). The rate of change has increased due to greater human influence. A number of native species disappeared or has been pushed back and species native to other parts of the world have reached our country.

Man as a biological entity is subject to the same ecological laws as all other life forms and is therefore dependent on the effective operation of natural systems. Human activities must contribute to maintaining the stability and diversity of nature and here ecological boundaries can provide direction and advice. To make the conservation and development of biodiversity in the widest sense possible in the long term, it is important to look at natural systems in a different manner to the way in which many people and groups in our society do at the moment. Initially this means gaining insight into the habitat of plants, the recognition that plants and where they grow form part of a coherent ecosystem, instead of dismissing them with an anthropocentric judgement described in terms of a 'useful crop' or 'weed'. As appears to be the case for new agrarian nature conservation, the financial valuation is to a large degree normative for a number of those involved. The same applies for the ecosystem level, for entire wetlands and rain forests, where countless numbers of species are threatened with extinction.

An ecosystem is understood to mean a habitat patch, determined by physical factors, and the species, which to a greater or lesser degree have relationships with each other, that it contains. Eco-

Table 6.5 Changes of terrestrial species groups during the last decennia (Van Strien, 1991)

species group	**% of the species**	**% of the species**	**% of the species**	**% of the species**	**% of the species**
	appeared	increased	stable	decreased	become extinct
Fungi	7	11	39	28	15
Higher plants	1	22	43	30	4
Ants	0	0	66	34	0
Diurnal butterflies	0	15	10	59	15
Mammals	15	27	29	24	4

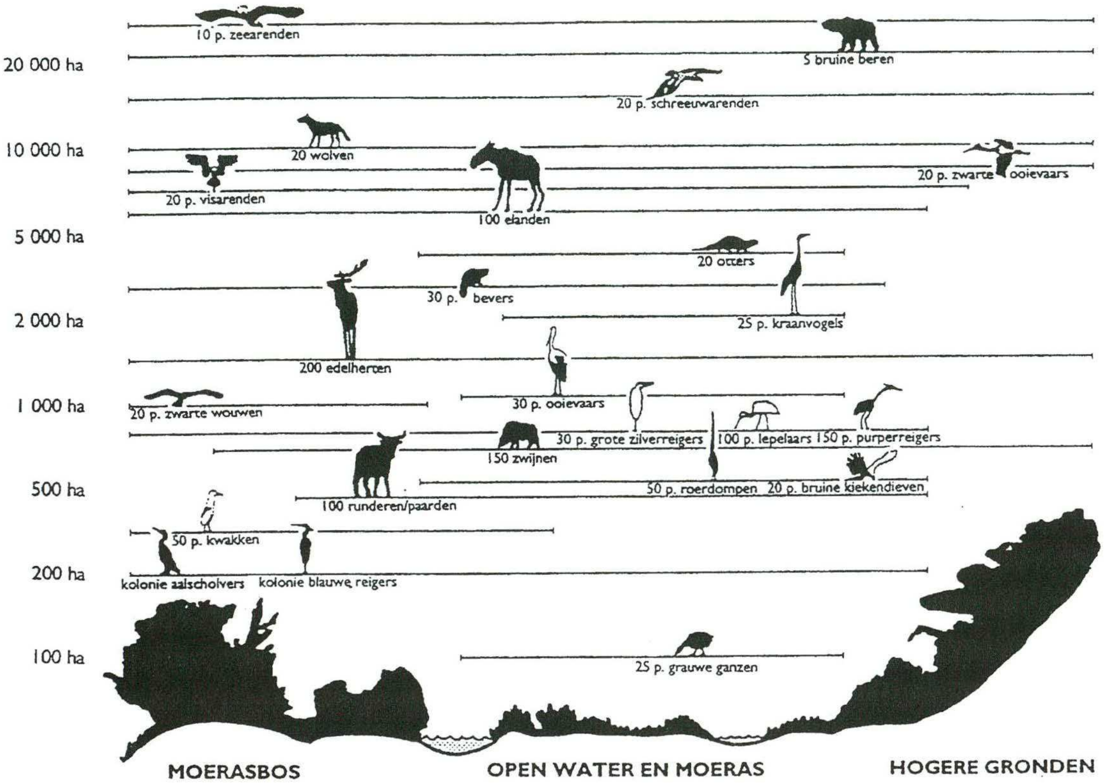


Figure 6.1
Survival of animal species in relation to the level of scale of the landscape (moerasbos: wet woodland; open water en moeras: open water and wetland; hogere gronden: higher ground) (Source: Helmer, W., G.. Litjens, W. Overmars, Rivierenpark Geldersche Poort, Stroming B.V. 1992)

systems are characterized by components (organisms, populations, species, habitat patches, etc.), processes (photosynthesis, decomposition, succession, cycles of materials) and properties (resilience, adaptability, competition, cooperation, etc.). The energy required to maintain and develop ecosystems originates from the sun.

Although an ecosystem is an abstraction, the use of the term, because to a certain degree it can be demarcated and can be classified, can make a substantial contribution to the conservation of plants and animals. To accomplish this, a multifaceted conservation strategy is required, based on the multilayer structure and complex composition of ecosystems.
There is still too little realization of the fact that in the end many species of plants and animals can only survive in nature areas that have not been fragmented (figure 6.1). Fragmentation of habitat patches increases the edge/surface area ratio. Areas in the centre usually accommodate different species than the species that are dependent on the environmental conditions that occur in the edge zone.
Furthermore, large areas often fulfil a source function for areas where there is a high chance of

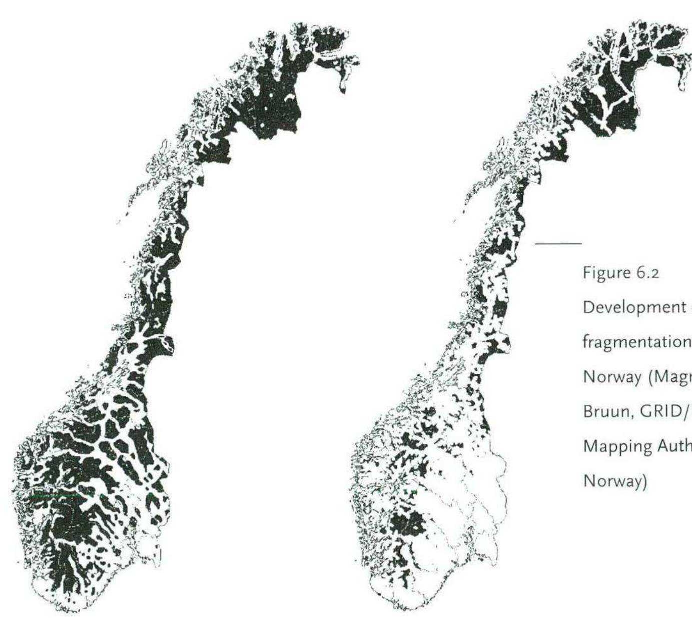
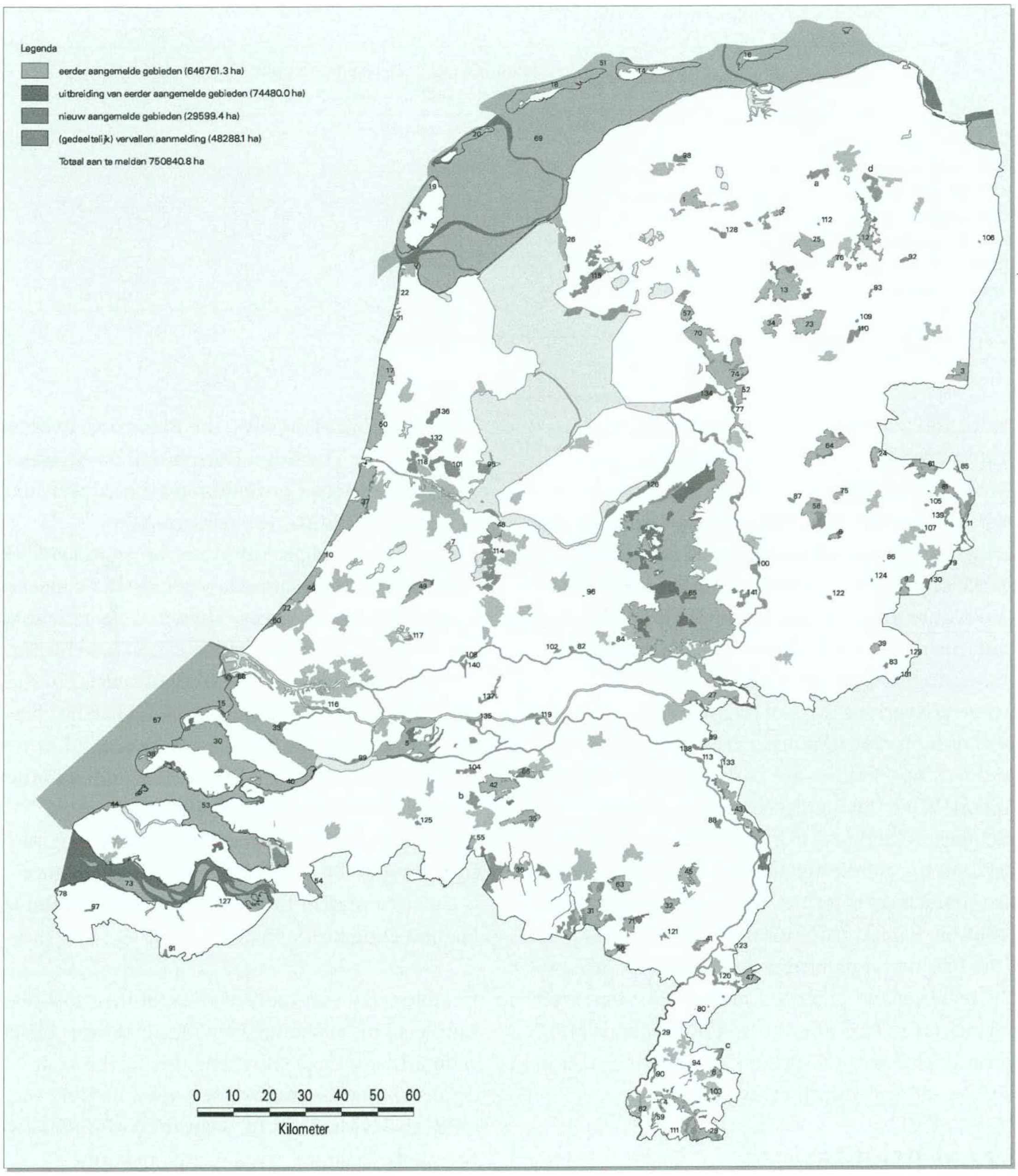


Figure 6.2
Development of fragmentation in Norway (Magnue Bruun, GRID/Nat. Mapping Authority, Norway)

Figure 6.3
Conservation zones
Bird Directive



Opdrachtgever:

Ministerie van Landbouw Natuurbeheer en Visserij, Directie Natuurbeheer

Productie en Cartografie:

Alterra, Centrum Geo-informatie
mei 2003

Voor nadere informatie zie Gebiedendocument.
Voor een toelichting op de selectie zie het Lijstdocument.

Figure 6.4
Announced areas
Habitat Directive

Table 6.6 Legal instruments concerning nature conservation in the Netherlands

	species protection	exemption per species needed	exemption per area needed	compensation obligatory
Nature Conservation law	-	-	+	-
Flora and Fauna law	+	+	-	-
Habitat Degree	+	+	+	+
Bird Degree	+	+	+	+
Bern Convention	+		-	-
Bonn Convention	+		-	-
Ramsar Agreement	-		-	-

N.B. For Areas of the Ecological Main Infrastructure compensation is obligatory.

extinction and that can be populated from the source areas.

Agriculture, urbanization and infrastructure all contribute to the defragmentation and disturbance of previously (relatively) extensive, unbroken nature areas. Even a country such as Norway with relatively few inhabitants is becoming increasingly fragmented (figure 6.2).
There are various ways of combating the effects of fragmentation, disturbance and contamination, and new possibilities are currently under investigation. When taking decisions concerning changes in land use, it is important to take into account the conditions that the organisms, which are characteristic for the area concerned, require from the habitat patterns and processes.
One manner of determining the significance of the patterns and processes at the ecosystem level for man is to examine the functions, goods and services that natural systems can provide. This will be addressed further in chapter 7.

Legal orientation: Global, European, Dutch nature conservation law

During the last decades new legislation have been developed about conservation of species and concrete habitat patches.
For the Dutch government the Convention on Biological Diversity, stressing the need for conservation and sustainable use of ecosystems, is an important basis for conservation policy objectives. Further the Netherlands contributes to the implementation of international agreements: European Unions Habitat Directive, the Ramsar Convention on Wetlands, The Bonn Convention on Migratory Species, the Bern Convention on the Conservation of European Nature, the African-Asian Agreement on Migratory Water birds and CITES.
The nature conservation law consists of conservation of species and areas. There has been a rapid development in nature conservation law during the last years. The conservation of species of the Habitat Directive and the Bird Directive has been implemented in the new Dutch Flora- and Fauna Act. The conservation of areas is included in the Dutch Nature Conservation Act.
Figure 6.3 shows the special conservation zones according to the E.U. Bird directive and Figure 6.4 gives a map of the announced areas of the EU Habitat Directive.

In table 6.6 a summary is given of the most relevant legal instruments concerning nature conservation. In concrete situations the most recent details should be studied (see: www.natuur loket.nl; www.minlnv.nl; www.minvrom.nl, www.europe.en.int, www.rechtspraak.nl
See also: Anonymus, 2003. Wie is er bang voor de Korenwolf?

The amoeben method

Ten Brink (1990) designed the 'amoeben method' to visualize scientific data. This method provides administrators a picture of the state of the water environments, based on ('attractive') parameters that clearly show the difference between existing values when compared to a reference. It provides an indication for the description of the ecological quality (amoebe: *algemene methode voor de ecologische beschrijving - general method for ecological description) or AMOEBA, the Abstract Method for Overall Examination of Biological Ambience (figure 6.5)*.
The amoebe metaphor as a conscious simplification can have disadvantages as the 'amoebe' does not align with the actual processes of the ecosystem involved (De Jong, 2002).

The amoeba representation of nature has been influential as it simplifies reality, to be easily understood. But at the same time due to the simplification it concerns a limited number of species which can be manipulated easily without taken into account the complexity of ecosystems.

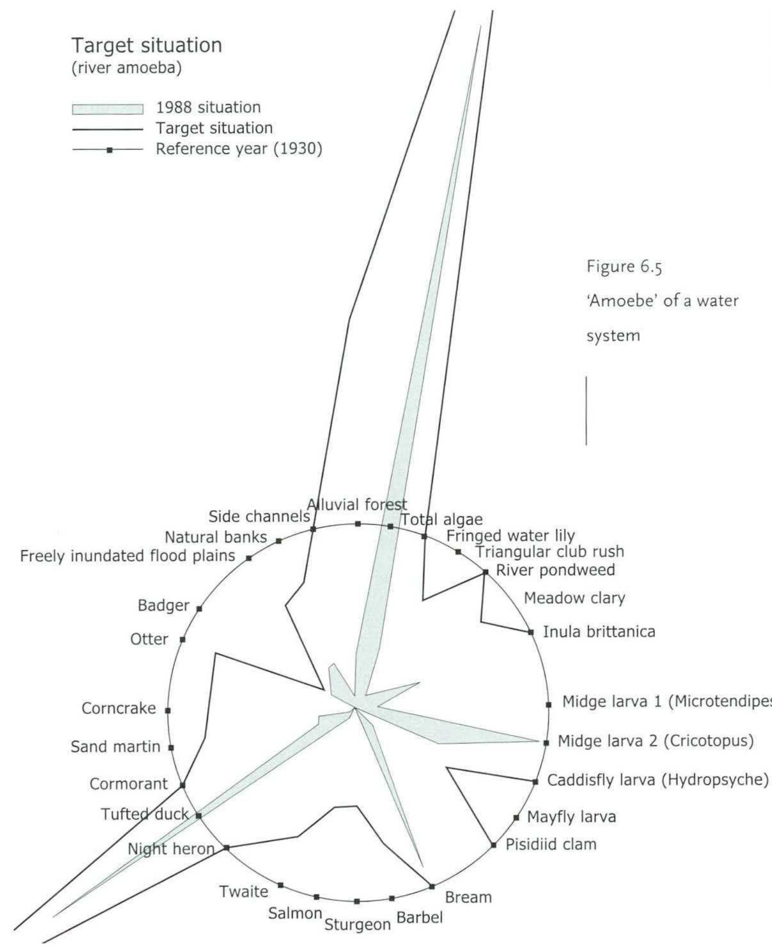


Figure 6.5
'Amoebe' of a water system

7 Overview of goods and services that can be supplied by natural systems

H.D. van Bohemen

Integration of human-dominated systems with natural ecosystems can lead to increased efficiency with a higher degree of sustainability.

An ecosystem can be described as 'any unit that includes all of the organisms in a given area interacting with each other and with the physical environment so that a flow of energy leads to a clearly defined trophic structure, biotic diversity and material cycles in an ecological system or ecosystem' (Odum, 1971). This definition can include humans with different intensities of influences. A gradient of influence can be found from ecosystems hardly influenced by man up to fully human-dominated systems.
Within ecosystems, ecosystem functions can be identified, such as the regulation of the atmosphere, the regulation of the hydrological cycle, gross primary and secondary production, and habitat for plants and animals.
In addition to the description of ecosystems as a functioning entity, it is also possible to make use of ecosystem services. Ecosystem services are the conditions and processes through which natural ecosystems and the species within them sustain and fulfil human life (Daily, 1996). They maintain biodiversity and the production of ecosystem goods, such as timber, natural fibres, and the biomass of fuels. Regulation of CO_2/O_2 balance, water for human use, waste treatment, hunting, recreation possibilities are also examples of services. In this definition, goods refer to matter, service is a form of action and ecosystem functions is reserved for the properties of ecosystem as functioning entity.

Many classifications of the functions that nature can have have been published in the literature (Daily et al., 1997, Daily et al., 2000 and De Groot et al., 2002). In Daily (1996) an overview is given of the services of various systems: marine, freshwater, forest and grassland systems, with the accent on the characteristics of the systems that enable life on earth. The term ecosystem services is understood to mean the conditions and processes that make it possible for natural systems and the species associated with them to enable sustainable human existence (Daily, 1996) (services = conditions and processes that can supply goods).

Man depends on nature for the supply of air to breath, water and other resources that make his existence possible. Ecosystem services maintain biodiversity and enable the production of ecosystem goods, such as wood, fuel, natural fibre and medication. In addition to the production of goods, the ecosystem services are actually the life-enabling functions (production, consumption, decomposition and recycling). Ecosystem services are based on ecosystem functions. Daily (1996) gives a general overview of the services:

- freshwater supply;
- purification of air and water;
- reduction of the effect of floods and drought;
- detoxification and decomposition of waste;
- soil development and soil protection;
- pollination;
- biological control of diseases and infestations;
- production of raw materials (fibres, wood and nutrients);
- distribution of seeds;
- recycling of nutrients;
- protection of habitats;
- maintaining biodiversity;
- protection against damaging UV radiation;
- stabilization/regulation of the climate;
- moderation of the extremes in weather with respect to temperature and wind-speed;
- atmospheric regulation (uptake of CO_2 and the release of O_2),
- opportunity to experience beauty;
- influencing the human spirit.

As an example, the services that soils can supply:

1 The soil protects seeds and provides support for germination and growth.
2 The soil supplies nutrients and water.
3 Soil life plays a major role in the decomposition of dead organic matter and waste.
4 Material cycles occur in the soil.
5 The soil processes are essential for the cycles on a world scale (C, N and S cycles).

But the pollination of plants by animals is also an essential service that contributes to the continued existence of flowering plants. This also applies to the natural combating of diseases and infestations and for the spread of seeds.

Table 7.1 Primary Goods and Services Provided by Ecosystems

Ecosystems	Goods	Services
Agro ecosystems	– Food crops – Fiber crops – Crop genetic resources	– Maintain limited watershed functions (infiltration, flow control, partial soil protection) – Provide habitat for birds, pollinators, soil organisms important to agriculture – Build soil organic matter – Sequester atmospheric carbon – Provide employment
Forest ecosystems	– Timber – Fuelwood – Drinking and irrigation water – Fodder – Nontimber products (vines, bamboos,leaves, etc.) – Food (honey, mushrooms, fruit and other edible plants; game) – Genetic resources	– Remove air pollutants, emit oxygen – Cycle nutrients – Maintain array of watershed functions (infiltration, purification, flow control, soil stabilization) – Maintain biodiversity – Sequester atmospheric carbon – Moderate weather extremes and impacts – Generate soil – Provide employment – Provide human and wildlife habitat – Contribute aesthetic beauty and provide recreation
Freshwater systems	– Drinking and irrigation water – Fish – Hydroelectricity – Genetic resources	– Buffer water flow (control timing and volume) – Dilute and carry away waste – Cycle nutrients – Maintain biodiversity – Provide aquatic habitat – Provide transportation corridor – Provide employment – Contribute aesthetic beauty and provide recreation
Grassland ecosystems	– Livestock (food, game, hide, fiber) – Drinking and irrigation water – Genetic resources	– Maintain array of watershed functions (infiltration, purification, flow control, soil stabilization) – Cycle nutrients – Remove air pollutants, emit oxygen – Maintain biodiversity – Generate soil – Sequester atmospheric carbon – Provide human and wildlife habitat – Provide employment – Contribute aesthetic beauty and provide recreation
Coastal ecosystems	– Fish and shellfish – Fishmeal (animal feed) – Seaweeds (for food and industrial use) – Salt – Genetic resources	– Moderate storm impacts (mangroves; barrier islands) – Provide wildlife (marine and terrestrial) habitat – Maintain biodiversity – Dilute and treat wastes – Provide harbors and transportation routes – Provide human and wildlife habitat – Provide employment – Contribute aesthetic beauty and provide recreation

A list (see table 7.1) of goods and services per ecosystem is given in 'People and Ecosystems: The Fraying Web of Life'. This list makes a distinction between agricultural, forest, freshwater, grassland and coastal ecosystems (Anonymus, 2000).

A threat to the ecosystem services is the fact that when disturbance due to human activity occurs, many of these services are not directly translated into costs. Nor are the owners of land compensated if they maintain the systems instead of exchanging them for, in the short term, more profitable land use. The chapter concerning the relationship between ecosystems and economy addresses in more detail the significance of assigning value to ecosystem services.

Table 7.2 Survey of small animals and plants in the soil

Survey of small flora and fauna in the soil (1 m²; 30 cm deep) (from: Dunger, 1974)

Group	Average number of individuals	Average weight in gr.
Microflora		
Bacteria	1 bill	50
Aktinomyceta	100.000 mill	50
Fungi	1000 mill	100
Soil algae	1 mill	1
Microfauna		
Flagellates	0,5 Bill	} 10
Rhizopodes	0,1 Bill	
Ciliates	1 Mill	
Mesofauna		
Rotatoria	25.000	0,01
Nematodes	1 Mill	1
Acarina (mites)	100.000	1
Collemboles (springtails)	50.000	0,6
Macrofauna		
Enchytraeids (worms)	10.000	2
Gastropodes (snails)	50	1
Aranae (spiders)	50	0,2
Isopodes	50	0,5
Diplopodes	150	4
Chilopodes	50	0,4
Myriopodes	100	0,05
Coleoptera larva	100	1,5
Diptera larva	100	1
Other insects	150	1
Megafauna		
Lumbriciden (earthworms)	80	40
Verbebrate (e.g. moles)	0,001	0,1

'*Biodiversiteit in de gebouwde omgeving*'- biodiversity in the built environment (Timmermans and De Molenaar, 1999) assumes the classification of the functions of urban green into three types: sociopsychological functions, regulation functions and economic functions.

The *sociopsychological (or welfare) function* is subdivided into

- general informative functions:
  - orientation function: recognition in time and space;
  - educational function: knowledge and information.
- functions for physical welfare (recreational functions)
  - passive recreational function;
  - active recreational function (study of nature, fishing, walking, bicycling).
- mental well-being (mental health)
  - socio-educational functions;
  - aesthetic function;
  - ethical function;
  - emotional function.

The regulation function for human health or the perception of health:

- climate control function (sun, wind, rain);
- limitation of nuisance (protection function: visual, sound, air pollution);
- water buffer function;
- water purification function.

The economic function (prosperity)
This group of functions will be addresses in more detail in chapter 13.

This overview is comparable to Daily's overviews (1997), but although mention is made of the significance of providing habitats for birds, pollinators and soil organisms, nothing much is said about the independent ecological significance, therefore separate from human use, of natural areas.

Each of the services mentioned can be substantiated (see Daily, et al., 2000). An example is 'soil fertility'. Soil life plays an important role in allowing matter to circulate in ecosystems. The numbers of species involved, as well as the numbers per species are large. Soil can contain: bacteria, fungi, algae, flagellants, rhizopods, ciliates, rotifiers, eels, worms, springtails, snails, centipedes, and the larva of beetles and flies. (for quantities per m^2 of soil, see table 7.2 taken from Tiere im Bodem).

There are in the soil complex biogeochemical cyclic processes at various levels of scale, in which plants and animals play an essential role in the decomposition of organic matter.

There are still scientific questions:

- Are the natural processes involved as efficient as they appear to be or is it possible that technology can allow energy and materials to be used more efficiently.
- What is the actual human load-bearing capacity of the earth. What part can we 'siphon off' before the load-bearing capacity is affected irreparably.

Furthermore, natural systems are subject to change, with considerable changes occurring in the short and sometimes long term to processes, functions and species (Ayres, 1989, 1993).
An example of change in the long term concerns the development of life on earth.

- Phase 1: Fermentation-based forms of life that increased the concentration of CO_2 in the atmosphere.
- Phase 2: The waste product from phase 1 became the raw material for photosynthetic processes, with O_2 being released.
- Phase 3: The waste from phase 2 becomes essential for the life forms that developed subsequently.

An example that is applicable in the relatively short term situation:
It is possible to classify plant species as 'r strategists' and 'K strategists' (MacArthur and Wilson, 1967). r strategists are pioneer species with a short life expectancy, can colonize an area quickly; their characteristics are: maximum mobility and reproductive power, producing lots of seed, and displaying fast growth and little competitive strength. K strategists have a long life expectancy, they are less mobile, develop efficient use of energy and raw material and invest in structure and less in reproduction.

Grime developed a system that classified plants as competitive, stress tolerant and ruderal (Grime, 1986).

General principles can be derived, based on functions and services, that can be accentuated differently in the various sectors of our society.
Within industry, 'industrial ecology' offers opportunities to realize greater sustainability. This focuses on making material cycles closed, on checking whether there are natural substances that can be used (biomimicy) and on full integration with natural processes as well as using waste from one industry as raw material for another.
In a built up area, the following conditions are concerned when material is used:

- In the design and construction phase, renewable raw materials must be used wherever possible.
- In the usage phase, it must be possible to replace components without the need to make much effort.
- In the disposal phase, components must be able to be dismantled or to fall to pieces without appreciable environmental effects and must be reusable.

In general the following should apply:

- Activities occur in the context of natural systems or systems that are derived from natural systems.
- In principle, use will be made of renewable or reusable materials (material circulation in closed cycles).
- The focus is on conservation and development of natural systems and functions.

Sustainability only applies to regenerative systems. Continual replacement occurs in a cyclic process, in which sunlight functions as the external energy source.

When the function of roadside verges is examined, it can be seen that they provide, in addition to civil engineering and traffic functions, sociopsychological and ecological functions.
These are the:

- *Orientation function.* Vegetation is often used to make the hierarchy of roads visible, such as low bushy vegetation in side streets, lines of trees on central reservations and grassy vegetation along the edges of through routes. Normally a single species is used to achieve visual unity.
- Verges of through roads allows for normally low intensity of management, while verges in a city district are often managed more intensively (lawn management).

- *Aesthetic function.* Verges are specially designed to be attractive, in particular at the entrance to a borough, to project an image of environmentally friendly management.
- *Symbolic function.* The administration concerned sometimes wants to underline its 'green image'.
- *Ecological function.* Verges can represent important ecological value due to the special design and management.
- *Economic function.* Planting mostly costs more than it yields. A design that takes final felling into account can produce a higher yield as a result of cost reductions, because, for instance, the road does not need to be blocked off when the trees are felled.
- Increasingly other economic functions also arise: a location for solar collectors, windmills or biomass production. Harmonization with the biodiversity function is important.

Recently De Groot et al. (2002) developed a standardized framework of ecosystem functions, ecosystem goods and ecosystem services of natural and semi-natural ecosystems. Table 7.3 provides an overview of ecosystem functions, the ecological structures and processes underlying these functions and examples of specific goods and services derived from these functions; only goods and services are included which can be used on a sustainable basis.

In chapter 13 the relation with economical aspects will be dealt with.

Table 7.3 Functions, goods and services of natural and semi-natural ecosystems*

	Functions	Ecosystems processes & components	Goods and services (examples)
	Regulated functions	***Maintenance of essential ecological processes and life support systems***	
1	Gas regulation	Role of ecosystems in biogeochemical cycles (e.g. CO_2/O_2 balance, ozone layer, etc.)	1.1 UVb-protection by O_3 (preventing disease) 1.2 Maintenance of (good) air quality 1.3 Influence on climate (see also function 2)
2	Climate regulation	Influence of land cover and boil. mediated processes (e.g. DMS-production) on climate	Maintenance of a favourable climate (temp., precipitation, etc.) for, for example, human habitation, health, cultivation.
3	Disturbance prevention	Influence of ecosystem structure on dampening env. disturbances	3.1 Storm protection (e.g. by coral reefs) 3.2 Flood prevention (e.g. by wetlands and forests)
4	Water regulation	Role of land cover in regulating runoff & river discharge	4.1 Drainage and natural irrigation 4.2 Medium for transport
5	Water supply	Filtering, retention and storage of fresh water (e.g. in aquifers)	Provision of water for consumptive use (e.g. drinking, irrigation and industrial use)
6	Soil retention	Role of vegetation root matrix and soil biota in soil retention	6.1 Maintenance of arable land 6.2 Prevention of damage from erosion/siltation
7	Soil formation	Weathering of rock, accumulation of organic matter	7.1 Maintenance of productivity on arable land 7.2 Maintenance of natural productive soils
8	Nutrient regulation	Role of biota in storage and recycling of nutrients (e.g. N, P &S)	Maintenance of healthy soils and productive ecosystems
9	Waste treatment	Role of vegetation & biota in removal or breakdown of xenic nutrients and compounds	9.1 Pollution control/detoxification 9.2 Filtering of dust particles 9.3 Abatement of noise pollution
10	Pollination	Role of biota in movement of floral gametes	10.1 Pollination of wild plant species 10.2 Pollination of crops
11	Biological control	Population control through trophic-dynamic relations	11.1 Control of pests and diseases 11.2 Reduction of herbivory (crop damage)

Continuation table 7.3 Functions, goods and services of natural and semi-natural ecosystems

	Functions	Ecosystems processes & components	Goods and services (examples)
	Habitat functions	***Providing habitat (suitable living space) for wild plant and animal species***	
12	Refugium function	Suitable living space for wild plants and animals	Maintenance of biological & genetic diversity (and thus the basis for most other functions)
13	Nursery function	Suitable reproduction habitat	Maintenance or commercially harvested species
	Production functions	***Provision of natural resources***	
14	Food	Conversion of solar energy into edible plants and animals	14.1 Hunting, gathering of fish, game, fruits, etc. 14.2 Small-scale subsistence farming & aquaculture
15	Raw materials	Conversion of solar energy into biomass for human construction and other uses	15.1 Building &Manufacturing (e.g. lumber, skins) 15.2 Fuel and energy (e.g. fuel wood, organic matter) 15.3 Fodder and fertilizer (e.g. krill, leaves, litter)
16	Genetic resources	Genetic material and evolution in wild plants and animals	16.1 Improve crop resistance to pathogens & pests 16.2 Other applications (e.g. health care)
17	Medicinal resources	Variety in (bio)chemical substances in, and other medicinal uses of natural biota	17.1 Drugs and pharmaceuticals 17.2 Chemical models & tools 17.3 Test – and essay organisms
18	Ornamental resources	Variety of biota in natural ecosystems with (potential) ornamental use	Resources for fashion, handicraft, jewellery, pets, worship, decoration & souvenirs (e.g. furs, feathers, ivory, orchids, butterflies, aquarium fish, shells, etc.)
	Information functions	***Providing opportunities for cognitive development***	
19	Aesthetic information	Attractive landscape features	Enjoyment of scenery (scenic roads, housing, etc.)
20	Recreation	Variety in landscapes with (potential) recreational uses	Travel to natural ecosystems for eco-tourism, outdoor sports, etc.
21	Cultural & artistic information	Variety in natural features with cultural and artistic value	Use of nature as motive in books, film, painting, folklore, national symbol, architect, advertising, etc.
22	Spiritual and historic information	Variety in natural features with spiritual; and historic value	Use of nature for religious or historic purposes (i.e. heritage value of natural ecosystems and features)
23	Science & education	Variety in nature with scientific and educational values	Use of natural systems for school excursions, etc. Use of nature for scientific research

* Adapted from Costanza et al., (1997), De Groot (1992), De Groot et al., (2000)

8 Constructing materials, policy and practice

8.1 Construction raw materials: policy and supply practices in Northwestern Europe

H.S. Pietersen in cooperation with M.J. van der Meulen and T.P.F. Koopmans

Introduction

Building, construction and several industrial processes require large amounts of natural or crushed aggregates, limestone and clay. In the past, communities exploited local resources, which is clearly reflected in historical architecture and crafts products. Nowadays, raw materials are traded internationally and shipped over fairly large distances.

In accordance with the trend of internationalization, and because of a relatively big dependency on imports, the Dutch Ministry of Transport, Public Works and Water Management has commissioned an inventory of the provision of sand, gravel, crushed rock, limestone, silica sand, clay and fill material in northwestern Europe. The results of the study will be used to benchmark the Dutch provision and governing policy. The studied materials are the principal minerals worked in the Netherlands. The study area consists of the Netherlands, and the main countries it imports from or exports to: Belgium, Germany (North Rhine-Westphalia and Lower Saxony), UK (England, Wales and Scotland), Norway and Denmark (Figure 8.1).

Data

All data used in this study can be obtained from the internet; (www.international.bouwgrondstoffen.info).

Introduction to the study area

The Netherlands

In 2000, the Netherlands produced about 88 Mt of (fine) filling sand (36 Mt of which marine dredged), 21 Mt of (coarse) sand, 6.6 Mt of gravel, 4.0 Mt of clay and 1.5 Mt of limestone for industrial use. About 15 Mt of aggregates were exported, 34 Mt were imported (Figure 8.2).

Dutch mineral planning policy aims at a sustainable exploitation of surface mineral resources to meet the demand for construction and building materials, at an economical use, and maximum use of renewable and secondary materials (recyclable industrial by-products and waste materials; Anonymous, 2001a). The national government provides mineral planning guidance and is the permission authority for the state waters. The provinces address mineral planning in regional plans and are the permission authority for the land area.

In the past decades, land extraction has met with a growing societal resistance. As a consequence, provincial administrations have become increasingly reluctant to grant extraction permits. This especially applies to large-scale coarse sand and gravel extractions which, for geological reasons, are operational or considered in the southeastern half of the country, while a large part of the demand is generated elsewhere.

In order to sustain the aggregates supply, assignments ('taakstellingen'), i.e. amounts of quarry products for which permits are to be granted, have been negotiated between national and provincial rulers. For concreting and masonry sand, the assignments up till 2008 add up to

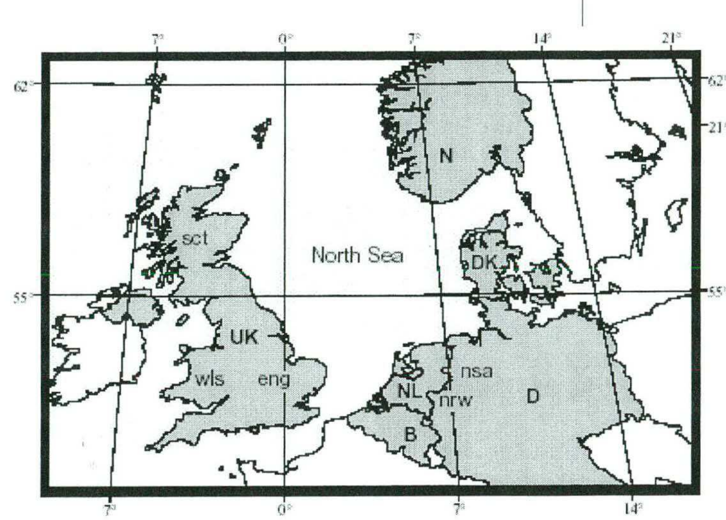


Figure 8.1
The study area: the Netherlands (NL), Belgium (B),Germany (D), North Rhine-Westphalia (nrw), Lower Saxony (nsa), Denmark (DK), the United Kingdom (UK), England (eng), Wales (wls), Scotland (sct) and Norway (N).

about 75% of the expected national demand. The production of gravel, which only occurs in the south-easternmost part of the country, has been allowed to become reduced to a level of regional self-supply.

The policy to stimulate the utilization of secondary materials, by means of product quality control on the one hand, and the taxation and banning of landfilling with recyclable materials on the other, has been quite successful. Their use rose from ~7 Mt/a in the early 1980s to 33 Mt in 2000; their

Table 8.1 Definitions of resources and commodities

Material	Description
Aggregates	Sand, gravel, crushed rock and secondary materials, used in construction and the building materials industry for its granularity (as opposed to, e.g., silica sand, which is used for its chemical properties).
Asphalt waste	Bitumen-coated material derived from pavements (secondary material).
Blast furnace slag	Slag from the production of iron from iron ore (secondary material).
Clay	Fine grained cohesive material used for construction (dike building, the covering of land fills, etc.), and fireclay used in the building materials industry (for the production of bricks, pipes, tiles, etc.). Clay for fine ceramic applications, such as china clay and ball clay, is excluded.
Coal bottom ash	Coarse ash from the burning chamber of coal-fired power stations (secondary material).
Coal fly ash	Ash precipitated from the off-gases of coal-fired power stations (secondary material).
Colliery spoil	Waste rock from the mining and processing of coal (secondary material).
Construction and demolition waste	Any material arising from the processes of construction and demolition (secondary material).
Crushed rock	Any sedimentary rock (limestone, sandstone, etc.) or crystalline rock (granite, porphyry, etc.) used for aggregates production.
Fill material	Any aggregate or clay for fill uses.
Gravel	Coarse natural aggregate used for concreting, drainage media, etc.
Limestone for industrial use	Carbonate rock (limestone, dolomite and chalk) for non-aggregate uses, i.e. for cement clinker production, as a flux in the metal and glass industries, in the chemical industry, in animal fodder, etc.
MSWI bottom ash	Coarse ash derived from the burning chamber in municipal solid waste incinerators (secondary material).
MSWI fly ash	Ash precipitated from the off-gases in municipal solid waste incinerators (secondary material).
Primary materials	Natural (quarried) materials.
Sand	Concreting sand, masonry sand and (usually coarse) sands for other purposes which require specific granular compositions. The term excludes sand used as fill material and for non-aggregate purposes (i.e. silica sand).
Secondary materials	Earthy and stony waste materials and industrial by-products, used as alternatives to the primary materials considered in this section.
Silica sand	Sand used as a quartz resource, used for the production of, e.g., glass, water glass, zeolites, carborundum, ceramics, and in foundries.
Steel slag	Slag from the production of steel from iron and scrap iron / steel (secondary material).

share in the total provision rose from 6 to 15%. The use of renewable materials, especially timber, is stimulated by demonstration and research projects carried out or commissioned by the government, in cooperation with the timber and building industries. The current share of timber-framed and timber-built houses is about 8%/a. The government has also issued guidelines for sustainable building.
At present, the national government is considering a lesser role in mineral planning. The regulatory system of provincial assignments for concreting and masonry sand will most probably be abandoned; as a result of this, the home production may fall back in the foreseeable future.

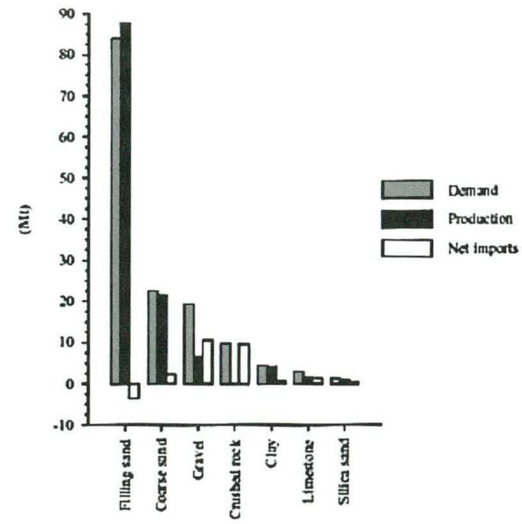


Figure 8.2
The provision of aggregates, clay, limestone and silica sand in the Netherlands in 2000 (data from Koopmans et al., 2003; Van der Meulen et al.).

Germany (North Rhine-Westphalia and Lower Saxony)

In 2000, North Rhine-Westphalia produced about 81 Mt of sand and gravel, 43 Mt of crushed rock, 22 Mt of limestone for industrial use, 7.1 Mt of clay and 3.3 Mt of silica sand (Figure 8.3). Lower Saxony produced 48 Mt of sand and gravel, 12 Mt of crushed rock, 5.5 Mt of limestone for industrial use, 1.5 Mt of silica sand, 2.6 Mt of clay and 1.5 Mt of silica sand (Figure 8.4). Germany exported about 19 Mt of sand, gravel and crushed rock to Belgium and the Netherlands, mainly from North Rhine-Westphalia, and in the case of the Netherlands primarily by shipping down the Rhine. About 20 Mt of aggregates were imported, the larger part from France and Norway.

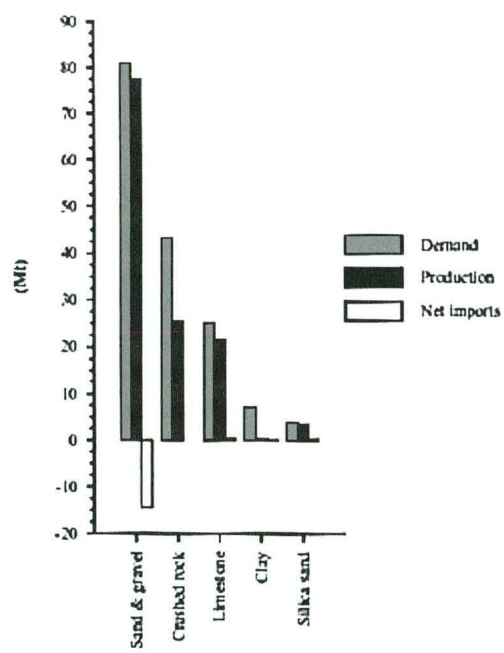


Figure 8.3
The provision of aggregates, limestone for industrial use, clay and silica sand in North Rhine-Westphalia in 2000 (data from Knoll & Kramer, 2003). Sand and gravel are not monitored individually; data for fill material are not available. Inconsistencies — demand should approximately equal the sum of production and net imports — are due to limitations of the data sets used.

Germany used about 75 Mt of secondary materials for building and construction, which is about 10% of the total materials use (disregarding fill material, for which no data are available). The use of renewable raw materials for building and construction is limited to timber; ~12% of the houses built yearly are timber-built or timber-framed.
The German federal government is responsible for planning guidance for silica sand, some types of clay and various non-building minerals not considered in this study. It also provides policies for sustainability, environmental protection, waste management and recycling (Anonymous, 2001b). In accordance with these policies, the federal government and the building industry have reached an agreement aimed at increasing the recycling ratio for building materials.
Mineral planning guidance for building and con-

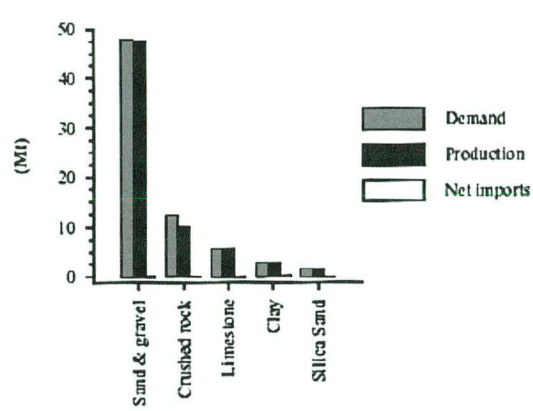


Figure 8.4
The provision of aggregates, limestone, clay and silica sand in Lower Saxony in 2000 (data from Knoll & Kramer, 2003). Sand and gravel are not monitored individually; data for fill material are not available

struction raw materials is the responsibility of state governments. Shared topics are the economical use of natural resources, promotion of the use of secondary materials and renewable materials, minimization of transport, a decrease of wet extraction and a reduction of extraction in areas of nature interest.

The Lower Saxon government has defined areas which are either reserved or to be considered for future extraction (Anonymous, 1994). The North Rhine-Westphalian government has formulated intentions for mineral extraction, without defining spatial specifications (Anonymous, 1995). Permitted reserves are to last for 25 years at all times.

German extraction permission authorities are regional governmental tiers. In Lower Saxony and North Rhine-Westphalia, these are the so called 'Landkreis' and 'Regierungsbezirk' authorities, respectively, which operate within the policy framework provided by the state governments.

Norway

In 2001, Norway produced about 52 Mt of aggregates (crushed rock, sand and gravel) for use in building and construction (Figure 8.5). About 10 Mt of crushed rock were exported, mainly to Germany, Denmark and the UK. The variety of available rock types enables the production of a wide range of crushed rock qualities. This includes crushed quartzite which is used as a quartz resource (as silica sand in the other countries). About 1.3 Mt of this material was produced, almost entirely for exports. Norway produced over 6.3 Mt of limestone for industrial use, 2.0 Mt of

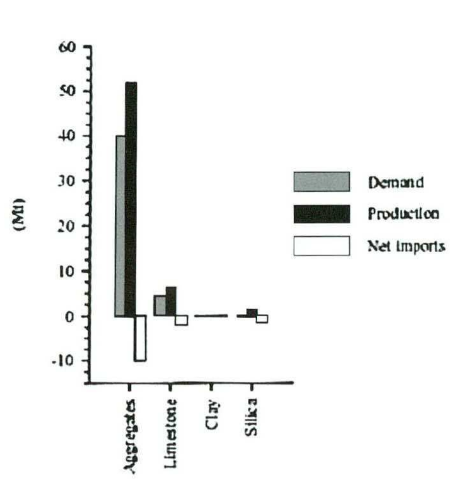


Figure 8.5
The provision of aggregates, limestone, clay and silica (crushed quartzite) in Norway in 2001 (data from Broekmans & Neeb, 2003). Aggregates are not monitored individually; data for fill material are not available.

which were exported. Clay is produced in limited amounts (44 kt in 2000) for home production of structural ceramic products.

These products (rather than the raw material) are also imported, mainly from Denmark.

The only secondary material for which data are available is construction and demolition waste. Production in 2001 amounted to about 1.5 Mt. recycling is estimated at 11%, which is low compared to the other studied countries. The use of renewable raw materials for building and construction is limited to timber. Over 4.5 million m^3/a are used in construction; about 62% of all houses built in 2001 are timber framed or timber-built: this is the highest share in the study area. A downward trend is predicted because of an increasing share of high-rise building.

Raw materials policy in Norway is characterized by general national planning guidelines and regulations, implemented by local authorities (counties and municipalities) which have a large degree of autonomy (Dagestad, 1999). Economical considerations and employment generated by the mineral extraction industry play an important role in planning decisions.

Both national and local authorities support production for exports of aggregates, and consider the development of coastal superquarries for this sole purpose.

Due to the combination of large building and construction materials resources and a low population density, waste recycling is hardly an issue. Policy aims to increase the utilization of secondary materials in building and construction.

In conjunction with this goal, guidelines for bound applications are under development. The use of renewable raw materials, i.e. timber, is driven by tradition and local availability, and not enforced by government policy.

Belgium

In 2000, Belgium produced about 38 Mt of crushed rock and gravel, 10 Mt of sand (3 Mt of which marine dredged), 10 Mt of limestone, 5.8 Mt of clay, 4.0 Mt of silica sand and 3.6 Mt of fill material (mainly fine sand; Figure 8.6). Belgium is a net exporter of crushed rock and gravel (7.9 Mt in 2000, mainly to the Netherlands and France) and a net importer of sand (about 15 Mt, from the Netherlands, Germany and the UK).

Belgium uses various secondary materials, such as construction and demolition waste, asphalt waste, industrial slag and ashes. The total production in 2000 was about 11 Mt; the overall recycling percentage was about 75%. The share of secondary materials in the total provision was about 9%.
The use of renewable raw materials for building and construction is limited to timber. The percentage of timber-built and timber-framed houses built yearly is estimated between 8 and 12%.
Belgian policy on raw materials and mineral planning is the responsibility of the regional governments. The federal government only provides policy on related environmental issues. In the Flemish region, provinces and municipal administrations are extraction permission authorities for large and small exploitations, respectively. In the Walloon region, extractions of any size are permitted by the municipalities. Sea bed extraction permits are issued by the federal government. In the whole of Belgium, the building and construction raw materials provision is essentially left to the market. In the Flemish Region, the so called gravel decree ('grind decreet'; Anonymous, 1993) provides for the gradual reduction of gravel extraction, and an extraction stop in 2006. The Flemish government is currently redesigning its mineral planning policy. A new decree aims at a sustainable exploitation of mineral reserves (Anonymous, 2002a). It introduces a mineral planning horizon of 25 years, stimulates the utilization of secondary materials, and addresses the environmental hygiene of minerals and restoration and aftercare of extraction sites. The Walloon regional government is also reconsidering its mineral planning policy, and aims to increase the export levels of quarry products for economical reasons (Anonymous, 2002b). Views on sustainability, especially concerning the utilization of secondary materials, are similar to those in Flanders.

Denmark

In 2000, Denmark produced about 58 Mt of aggregates (mainly sand and gravel; 12 Mt of which marine dredged), 5.7 Mt of limestone, 1.7 Mt of clay and 0.8 Mt of silica sand(Figure 8.7). On average, it is a self-supporting country, about 3 Mt of (mainly) aggregates are imported and 2 Mt exported. The most important import category is crushed rock from Norway.
About 3.8 Mt of construction and demolition waste, asphalt waste and power plant residues have been used as secondary materials in 2000, which is about 5% in the total provision. Recycling percentages, as far as they are known, are high: about 90% for construction, demolition and asphalt waste, and 80% for power plant residues. The use of renewable raw materials for building and construction is limited to timber. Almost 10% of the houses built yearly are timber-built or timber-framed.
Danish mineral planning guidance is the responsibility of the national government (Anonymous, 1996a, 1997, 2000a).
Important policy topics are the economical and sustainable use of natural resources, environmental and geographical aspects (water supply, archaeological and geological interests, landscape protection, agriculture, forestry, etc.), which have to be taken into account in planning decisions (Anonymous, 1999). Within these boundary conditions, the raw materials provision is largely left

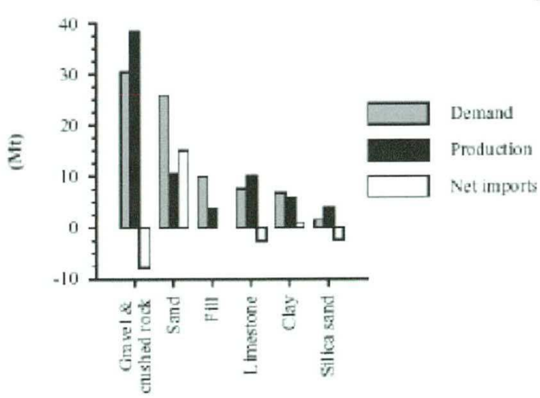


Figure 8.6
The provision of aggregates, limestone, clay and silica sand in Belgium in 2000 (data from Desmyter et al., 2003).

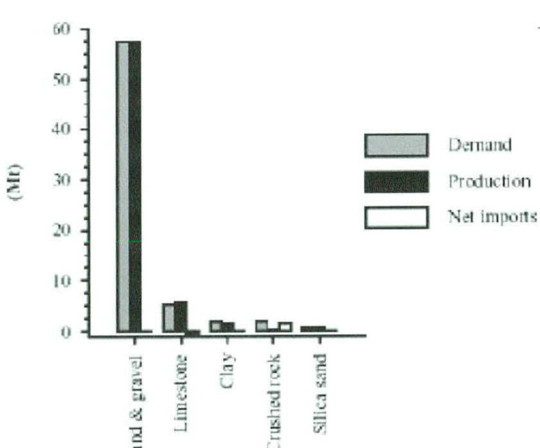


Figure 8.7
The provision of aggregates, limestone, clay and silica sand in Denmark in 2000 (data from Nielsen et al.2003). Sand and gravel are not monitored individually, data for fill material are not available.

to the market. Extraction permits have to be obtained from counties, which have their own mineral planning policies.
Policy goals for secondary materials are to achieve 90 % recycling of construction and demolition waste, screening and separate collection of environmentally damaging waste fractions and to increase environmental planning in the building process (Anonymous, 1998, 2000a). There are no quantitative goals for the use of renewable materials, but it is supported by the general policy goal on sustainability.

England/Wales and Scotland

In 2000, England and Wales produced about 77 Mt of sand and gravel (23 Mt of which marine dredged), 62 Mt of crushed rock, 54 Mt of fill material, 10 Mt of clay and 3.7 Mt of silica sand (Figure 8.8). An unknown but substantial amount of limestone was produced (the total production in Great Britain was about 28 Mt). Over 7 Mt of marine dredged sand and gravel were exported, mainly to the Netherlands (4 Mt), Belgium (2,5 Mt) and France (1 Mt).

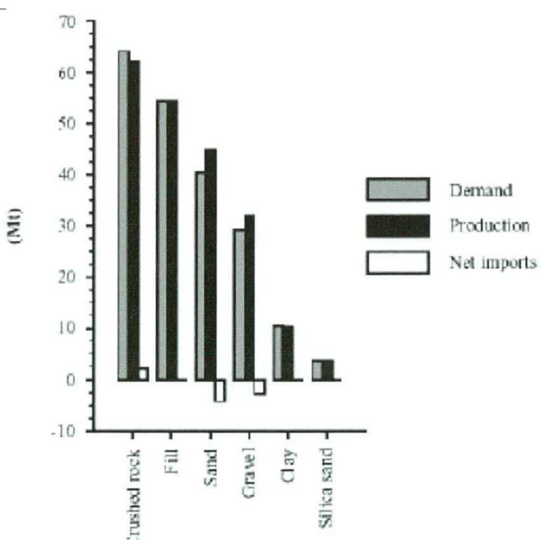


Figure 8.8
The provision of aggregates, clay and silica sand in England and Wales in 2000 (data from Harrison et al.,2003). Limestone data are only available for the whole of Great Britain.

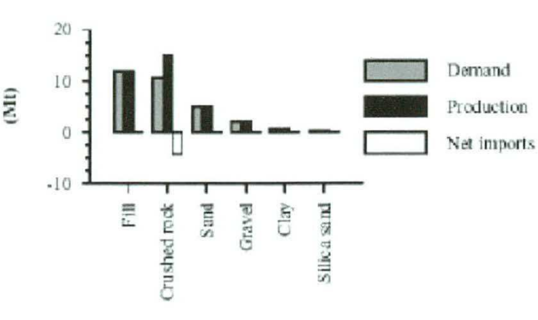


Figure 8.9
The provision of aggregates, clay and silica sand in Scotland in 2000 (data from Harrison et al., 2003). Limestone data are only available for the whole of Great Britain.

Scotland produced about 15 Mt of crushed rock, 12 Mt of fill material, 7.0 Mt of sand and gravel, 0.5 Mt of clay, 0.5 Mt of silica sand, and an unknown quantity of limestone (Figure 8.9). 4.6 Mt of crushed rock were exported, mainly to England (2.2 Mt), Germany (1 Mt) and the Netherlands (1 Mt).

The production of secondary materials, such as construction, demolition and asphalt waste, slag, ashes and colliery spoil, was about 139 Mt in England and Wales, and 9 Mt in Scotland. 47 Mt (33%) of this amount were re-used in England and 4 Mt (41%) in Scotland.

The use of renewable materials for building and construction is limited to timber. The number of houses built yearly that are timber-built or timber-framed is estimated at about 10% for England/Wales and about 50% for Scotland.
The British national government provides planning guidance for mineral extraction (Anonymous, 1996b). State authorities develop views on regional planning guidance, development plans and planning applications. The English and Welsh policies aim at an adequate supply of building materials and a maximization of the use of secondary materials (Anonymous, 2000b, 2000c, 2000d, 2000e, 2001c, 2001d). Within the framework provided by these views, the economic planning regions develop mineral planning guidance policies. These are implemented by the authorities responsible for minerals and waste planning, and the issuing of extraction permits: the county councils, unitary authorities and national parks. Sea bed extraction permits are issued by the Crown Estate, which manages Crown-owned land and marine domains (almost the entire British sector of the North Sea).

The Scottish Executive aims to combine economic growth with care for the environment (Anonymous, 2001e). Regarding the aggregates provision, this translates to an adequate supply for building and construction, taking into account landscape, amenity, nature, agriculture, cultural heritage and water interests. The national planning policy is implemented by local planning authorities, which deal with mineral planning in the broader scope of local development plans. The Scottish Executive supports aggregates produc-

tion for exports from coastal super quarries, but wants to limit the number of such exploitations for environmental reasons.
Scottish planning guidance for secondary materials is limited to the recommendation that planning policies should provide for reworking of mineral waste deposits, and the recycling of construction and demolition waste.
In 2002, an aggregate levy of £1.60 (~€2.35) has been introduced in the whole of the UK, in order to address the environmental costs associated with quarrying (noise, dust, visual intrusion, loss of amenity, and damage to biodiversity).
Neither the English/Welsh, nor the Scottish policy aims at the substitution of non-renewable raw materials by renewables.

Relevant EU legislation and policy

Some aspects of the extraction, processing and application of the materials considered are governed by EU legislation and policies on the environment and sustainable development adopted by the studied countries. The extraction of minerals and related planning and/or permitting policies are subjected to EU-defined environmental impact assessments (Anonymous, 1985, 2001f). The utilization of secondary materials is promoted as a part of EU strategies on waste management (Anonymous, 1997b) and sustainable use of natural resources (Anonymous, 2002d). Policy lines specifically addressing sustainable development of the EU non energy extractive industry have been proposed in 2000 (Anonymous, 2000f; see also Anonymous, 2003).

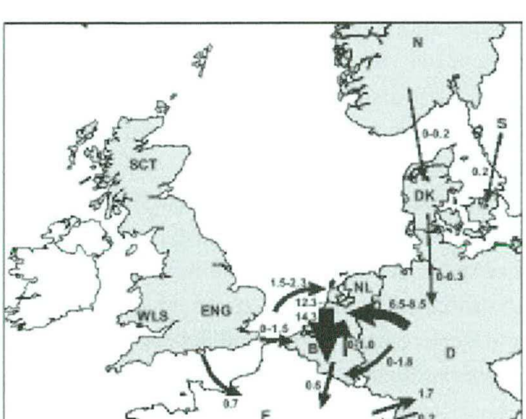
Trans-boundary trade

General

In 2000, about 65 Mt of aggregates were traded between the countries in the study area, which is about 13% of the total production of 508 Mt (disregarding fill material). The trade volumes for the other materials are 3 – 6 Mt (4%) out of 79Mt of limestone for industrial use, 1 Mt (2%) out of 46 Mt of clay and 2 – 3 Mt (9%) out of 27 Mt of silica sand.
The consistency of the aggregates data is sufficient for mapping imports and exports (Figures 8.10 – 8.13). Ranges shown are introduced by differences in the data sets of the exporting and importing countries, either quantitatively, or arising from differences in definitions (e.g. sand vs. gravel). The origins of imports of non-aggregate materials and the destinations of exports are poorly known.

Sand and gravel

The most significant trade in sand occurs between Germany and the Netherlands, and between the Netherlands and Belgium (Figure 8.10). The sand imported by the Netherlands from Germany is generally coarser than the sand exported from the Netherlands to Belgium. The most significant trade in gravel occurs between the Netherlands and Germany, and between the Netherlands and Belgium (Figure 8.11).
Exports from the UK shown in Figures 8.10 and 8.11 are the sand and gravel fractions in marine-dredged sand-gravel mixtures, which are classified in the importing countries.



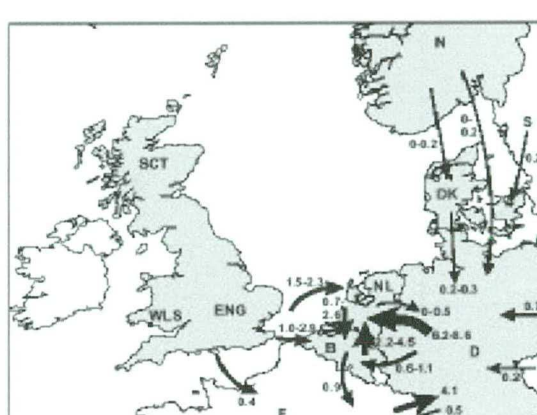


Figure 8.10
The trade in sand (filling sand excluded) in the study area in 2000; figures in Mt

Figure 8.11
The trade in gravel in the study area in 2000; figures in Mt

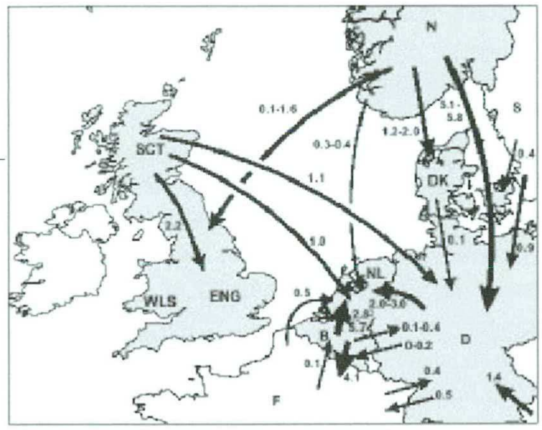


Figure 8.12
The trade in crushed rock in the study area in 2000; figures in Mt

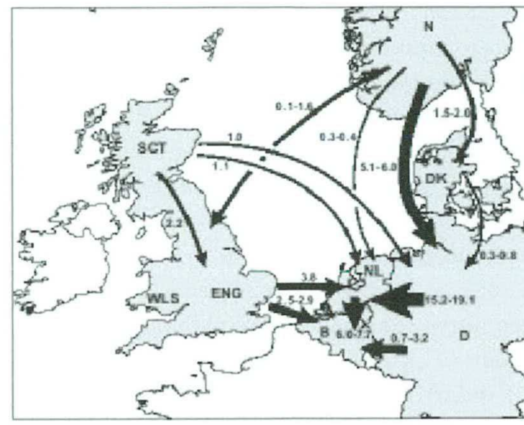


Figure 8.13
The net trade in aggregates in the study area in 2000; The arrows indicate the direction of net supply, the absolute difference between exports and imports (given in Mt)

Crushed rock
Crushed rock is transported over larger distances than sand and gravel. Figure 8.12 clearly identifies three major exporting states: Scotland, Norway and Belgium. The larger part of their export volumes are imported by the Netherlands and Germany.

Net trade in aggregates
Figure 8.13 shows the net trade in aggregates in the study area. Scotland, Norway and Germany are the main exporting states; the Netherlands and Belgium are net importing states.

Sustainable extraction

General
All the studied countries aim, to a varying extent, to minimize the environmental impact of mineral extraction.

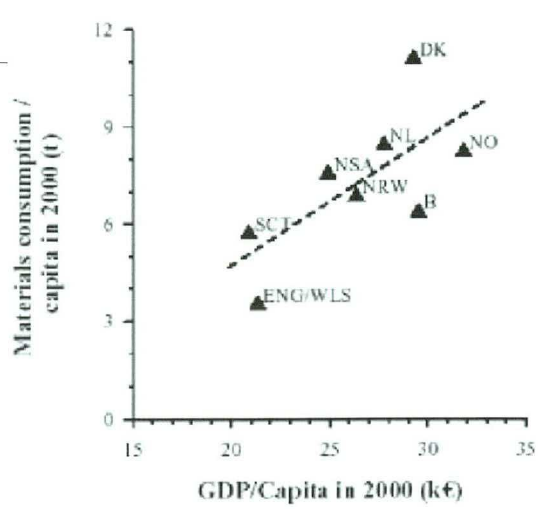


Figure 8.14
The relationship between gross domestic product (GDP) per capita and aggregates consumption per capita.

Strategies to achieve this include the stimulation of an economical materials use and recycling. Some countries have added substitution of primary materials by renewables.

Economical use of raw materials
The average consumption of aggregates in the study area was about 6 t / capita in 2000. Differences between states seem to be largely explained by their macro-economical situation: Figure 8.14 shows a fairly good correlation between the gross domestic product and materials use per capita. There is no clear-cut explanation for the observed consumption pattern arising from differences in policy.

In some individual cases, consumption levels can be attributed to a specific environmental factor. The western and northern parts of the Netherlands, for instance, have a largely muddy or peaty subsurface. Building in these areas tends to result in compaction of the underlying soil, and building requires above-average amounts of fill material.
When fill is disregarded, the Netherlands ranks among the countries with the lowest materials use (Figure 8.15).
High demands for aggregates brought about by unique geological or geographical factors still have to be accommodated financially. Accordingly, the existence of such factors does not interfere with the general dependency on prosperity (Figure 8.14).

Secondary materials

Various earthy and stony secondary materials are used as alternatives for the commodities considered in this study.

Coarse and medium grained secondary aggregates, such as stony construction and demolition waste, slag and bottom ashes are mainly used as foundation or fill materials, substituting gravel and crushed rock. Fine grained industrial and energy production by-products are used in the building materials industry, e.g. as a pozzolanic or hydraulic component in cement, substituting primary materials such as limestone and clay (Hendriks & Pietersen, 2000).

Figure 8.16 displays the utilization of some secondary materials in two ways: the total consumption in 2000 (upper panel) and recycling percentages (lower panel). As recycling and waste management are often discussed in the context of scarce space, Fig. 8.17 shows the relationship between the recycling percentages, the share of secondary materials in the total provision, and population density.

The highest recycling percentages occur in the Netherlands, Denmark and Belgium. The Netherlands and England/Wales have relatively high shares of secondary materials in the total provision of minerals considered in this study. For Norway both values are low. Denmark has a high recycling percentage; however, given the high overall aggregates consumption (Figures 8.14, 8.15), the share of secondary materials in the total provision is low.

Altogether, there is some correlation between the utilization of secondary materials and population density (Figure 8.17).

This suggests that recycling and waste management is indeed more of an issue if space is considered an asset. Denmark, having a relatively high recycling percentage at a low population density, and England/Wales vice versa, are the clearest exceptions to this.

Renewable materials

The use of renewable building materials is supported in most of the studied countries. However, in contrast to secondary materials, none of the studied countries have set quantitative targets.

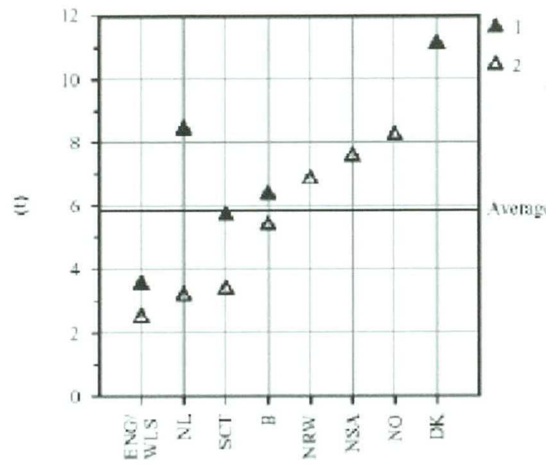


Figure 8.15
Aggregates consumption per capita including (1) and excluding fill material (2). Fill material consumption is not monitored by Germany and Norway, and is not included separately in the Danish data.

Figure 8.18 shows the share of timber-built and timber-framed houses, which is the only quantitative result on renewable materials use obtained in this study.

Although using renewable and recycled materials are equally consistent with the concept of sustain-

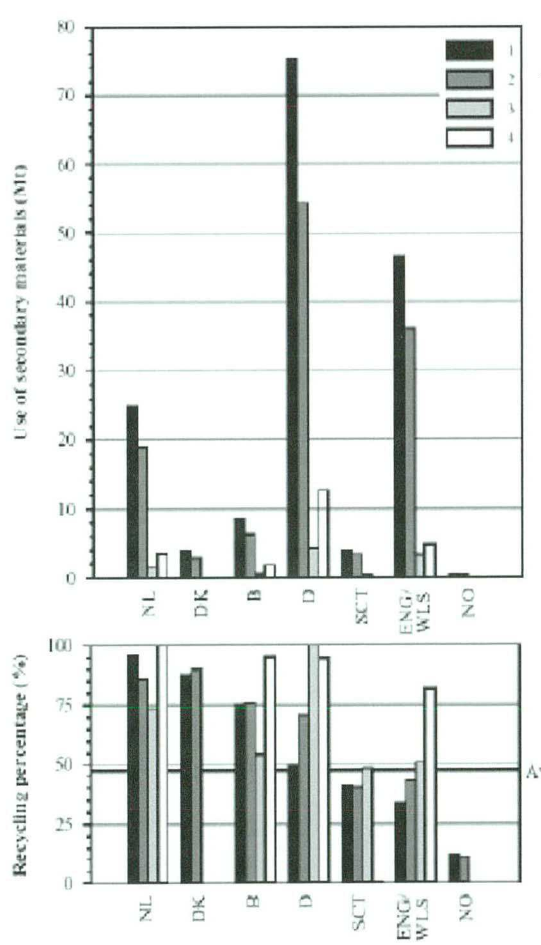


Figure 8.16
The use of secondary materials in the study area(see text for explanation): 1) all secondary materials, 2) construction and demolition waste and asphalt waste, 3) ashes (coal, and MSWI fly and bottom ashes), 4) slag (blast furnace slag, steel slag, phosphorous slag). The reader is referred to the regional reports for data on specific secondary materials. Data for individual German states are not available.

ability, the share of timber-framed houses and the recycling percentage of secondary materials are not at all correlated. On the contrary, Norway and Scotland, having below average recycling percentages, make the highest use of timber in building.

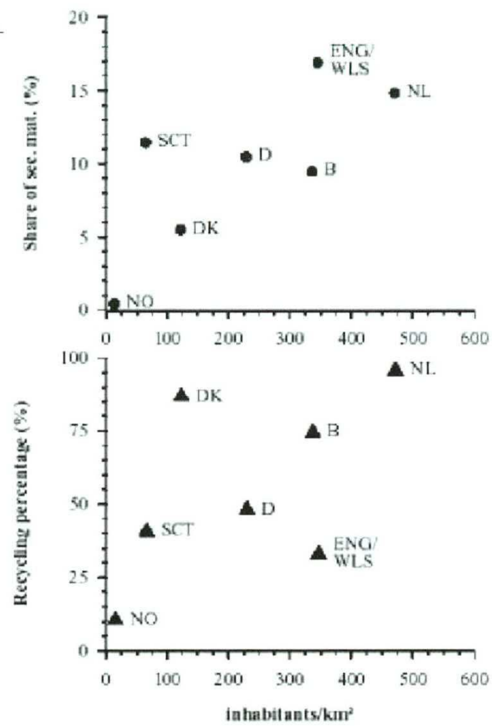


Figure 8.17
The use of secondary materials in the study area vs. population density. The shares of secondary materials in the total German provision is an overestimate, because fill material lis disregarded (for lack of data).

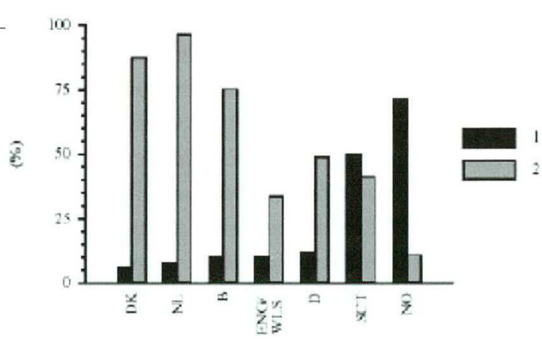


Figure 8.18
The share of newly built timber-framed and timber built houses in the study area (1) and recycling percentages for secondary materials (2, as in Figure 8.16 and 8.17, lower panels).

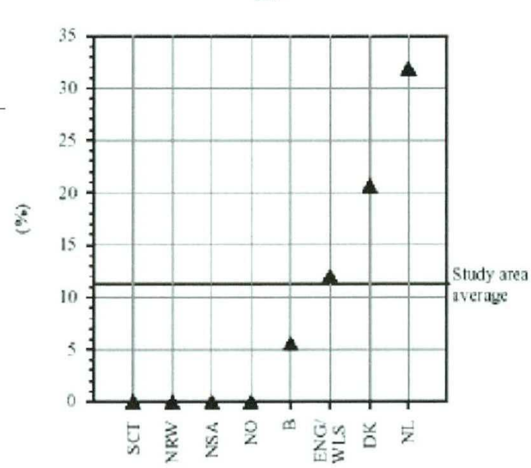


Figure 8.19
The share area of sea-won aggregates in the total aggregates provision in 2000.

The Netherlands, Belgium and Denmark, having the highest recycling percentages, have the lowest shares of timber-use.
This is consistent with the observation that the use of timber is driven by tradition and local availability rather than policy.
The Dutch building materials provision policy treats shell valves as a renewable resource. The annual permitted volumes in the primary extraction areas are limited to the estimated average yearly growth increments of the exploitable shell stocks (Beukema & Cadée, 1999).

Sea bed extraction
In the past two decades, the Dutch government has actively stimulated a shift from land-won to sea-won filling sand, in order to decrease the impacts of land extraction. The main reason for this has been the societal resistance against on land extraction. As yet, it is not clear whether or not the shift is desirable from an ecological point of view. In the other countries, sea bed extraction is mainly undertaken because of the availability of aggregate resources. Figure 8.19 shows that the highest share of sea-won aggregates in the total provision occurs in the Netherlands.

International comparisons

General
Each of the studied countries has a policy for the exploitation of the surface mineral resources considered in this study: aggregates, limestone, clay and silica sand. Shared topics mainly relate to sustainability (e.g. minimization of extraction, economical materials use, recycling, environmental impact assessments), most probably because this is a well-established EU policy theme. However, sustainability indicators, such as the aggregates consumption per capita, the recycling percentage of secondary materials and the share of secondary materials in the total provision, reveal large differences. Policy results in sustainability objectives and trends; the absolute level of indicators is usually related to other factors, such as the building tradition, population density, economical considerations, etc. In fact, mineral planning policies primarily provide guidelines for permission authorities, and hence mainly affect materials supplies.
There are no effective policy instruments regulating the use of primary materials once extracted.

The stimulation of secondary materials use has been successful in most of the study area. Part of the success can probably be attributed to the fact that recycling is a shared objective of mineral planning and waste management policies. Especially taxation and banning of landfilling with recyclable materials has proven to be effective. The study area as a whole is virtually self-supporting for the materials considered. It hosts sufficient resources, and the North Sea and the rivers Rhine, Meuse, Scheldt and Elbe provide bulk transport infrastructure.

Regional

There are pronounced differences in the extent to which countries are willing or able to extract the studied materials.
Scotland, the Walloon Region and Norway favor production for exports of aggregates. A significant share of the aggregates extracted in North Rhine-Westphalia and from the British sector of the North Sea is exported, which is possible under the current permission policies, but not explicitly favored. The importing countries either face resistance against extraction, such as the Netherlands, or have limited reserves, such as the Netherlands and Belgium. Denmark and Lower Saxony are more or less self-supporting, in accordance with their possibilities and policies.

The Netherlands and North Rhine-Westphalia

The intended effects of the Dutch restrictive permission policy are an ever more economical materials use, the stimulation of alternative (secondary or renewable) materials, and a shift towards sea-bed extraction. There have been measurable positive results: recycling percentages, and the shares of secondary and sea-won materials in the total provision rank among the highest in the study area, the aggregates use (when disregarding fill material) among the lowest.
However, the policy has also brought about substantial imports. In policy, this is considered a side-effect, of which the consequences are not measured according to the same standards as the domestic effects.
The German states have formulated a goal of minimizing transportation of building materials. North Rhine-Westphalia is currently accommodating the larger part of the Dutch underproduction of sand. This is not entirely consistent with the transportation objective, but it can apparently not be prevented under the current non-restrictive permission policy.
The trade relationship and production differences between North Rhine-Westphalia and the Netherlands have recently been criticized in Germany, e.g. by the joint North Rhine-Westphalian environmental organizations (Gerhard, 2002).
The fact that some aspects of the relationship seem unintentional may call for some policy harmonization.

Future trends, recommendations

Societal resistance against mineral extraction has been an issue in three consecutive European conferences on Mineral Planning (Van der Moolen *et al.*, 1998; Fuchs *et al.*, 1999; Anonymous, 2002c). Research and policies of most of the studied countries are in some way directed towards sustainable extraction. In this context, production restrictions are often considered a solution to resistance on local up to regional scales.
If this would be pursued by North Rhine-Westphalia, the Netherlands and Belgium may face scarcity of aggregates.
To some unknown extent, the associated price effects will allow for higher levels of recycling, or the exploitation of geologically poorer resources. However, there are limitations to what can be achieved on a national level under conditions of scarcity. Therefore, the Dutch and Belgian building and construction sectors will probably be forced to consider aggregates imports from more remote countries.
Also, Dutch permission authorities will probably be asked to reconsider restrictive policies.
Altogether, regionalization of the aggregates production within the study area, aimed at sustainability, could have the adverse effect of increasing transports of aggregates towards or within the study area. The Commission of the European Communities puts sustainable development of the quarrying industry in an international perspective (Anonymous 2000f).
It recommends the best use of locally available resources as a basic principle, and full impact assessments, comparing local and more remote sites, as a standard in permitting procedures.

8.2 Renewable materials in the building industry and the civil and hydraulic engineering sector

A. van den Burg

Introduction

Renewable materials are materials that become available within a short period of time through natural growth or cultivation. A material being renewable does not automatically mean that it will perform better environmentally. For this, it is important that the environmental effects of materials and products are considered in connection with the use of materials in a building during its entire life (from cradle to grave). The use of renewable materials in the building industry prevents the exhaustion of "finite" raw materials supplies that are becoming increasingly rare, such as sand, gravel, clay, metallic ore, petroleum, etc. If they are cultivated sustainably and soundly, renewable materials are generally favourable with respect to emissions, waste, nuisance, degradation and energy use. These materials are biodegradable or can be converted for energy production (energy from biomass) in the ultimate waste phase.

The use of renewable materials in the theme of eco-engineering in construction can be divided into two fields:

- The Commercial and Industrial Building Sector (B & U Sector).
- The Road and Hydraulic Engineering Sector.

The best-known renewable material is timber. Various other renewable materials are flax, shells, straw, jute, coconut, etc.
In the B & U sector there are many possibilities for the use of renewable materials combined with woodframe construction (WFC). In other European countries (Scandinavia, Germany, Austria, United Kingdom) woodframe construction is a more familiar construction technique than in the Netherlands, which is why the use of renewable materials is greater there. To encourage the use in the Netherlands, system innovation of the building practice is desirable. This will only be possible when a transition occurs from the current large-scale use of pre-cast concrete to other building systems. This combination can prove to be a good one through the saving of the finite raw materials for the production of concrete. Lighter foundations are sufficient for these dry and light constructions, making a considerable saving possible on surface minerals that are becoming increasingly rare, e.g. sand and gravel. In this system, the construction of walls and floors in other materials than concrete results in a direct saving of concrete. Furthermore, WFC elements are easy to construct industrially, which is in keeping with the concept of Industrial, Flexible and Dismantable construction (IFD).

Renewable building products have a number of specific qualities that match new developments in the field of home comfort and indoors living environment. Specific qualities of building products based on renewable materials are:

- Materials that are pleasant to work with with regard to weight, allergies and skin irritations.
- Health aspects: they do not contribute to emissions and radon radiation; they have the power to absorb harmful substances.
- Favourable effect on the indoors environment, because of the capacity of (organic) materials to permanently absorb or release substantial amounts of water (moisture-regulating) and the possibility to build in a vapour-open way.
- Favourable acoustic and heat insulating properties.
- Natural look and feel of the materials.

Promising construction-product-market combinations with renewable materials

Building with care for the environment and the health of the inhabitants in mind is enjoying increasing attention of the government, consumers and parties involved in construction. Besides energy, water and waste, materials are one of the main themes in the concrete development of sustainable building.
For a sustainable society, a careful use of primary "finite" materials is important. The use of an increasing quantity of renewable materials plays an important part and not only with regard to the availability of materials, but also with regard to the reduction of CO_2 emission. That the care for health is also a part of sustainable building is not so well known.

Building with products based on renewable materials is a global development. Not only in the building industry, but also in the automotive industry there are opportunities for these materials. Countries as South Africa and Russia are working intensively on R&D programmes that can make a positive contribution to both sustainable and healthy building. Renewable products currently enjoy only a modest but growing share of the market for building products. Products from Dutch agriculture, e.g. flax, hemp and straw, are suitable for use in building products. The building industry offers many opportunities. Here building means: new houses, existing houses, renovation and self-building.
The Ministry of Agriculture, Nature and Food Quality (LNV), the Ministry of Housing, Regional Development and the Environment (VROM) and the Ministry of Transport, Public Works and Water Management (V en W) have carried out research in which the possibilities of renewable materials used in building products are investigated. On the one hand, the research is meant to supply knowledge regarding the use of these materials in the building industry and, on the other hand, to produce a number of existing practical examples which could encourage a larger-scale use. Providing interesting uses of renewable materials (if necessary in combination with other materials) with the accompanying practical processing conditions for consumers and builders (project developers, architects and contractors) is a prerequisite for increasing the market demand of renewable materials.

Ten practical examples of available building products

A. Flaxboard
Flax is an agricultural product that is cultivated in the Netherlands, Germany and Belgium. Flaxboards are made from flax shives, which is a by-product from the production of linen. Flaxboard is often used as core material or for the internal parts of doors, inner walls, prefab roof-boxes and furniture. The boards can be used for renovation and in new constructions.

B. Cellulose insulation material for existing buildings
Cellulose is an insulation material produced from recycled paper. In the building industry it can be used for both thermal and acoustic insulation.

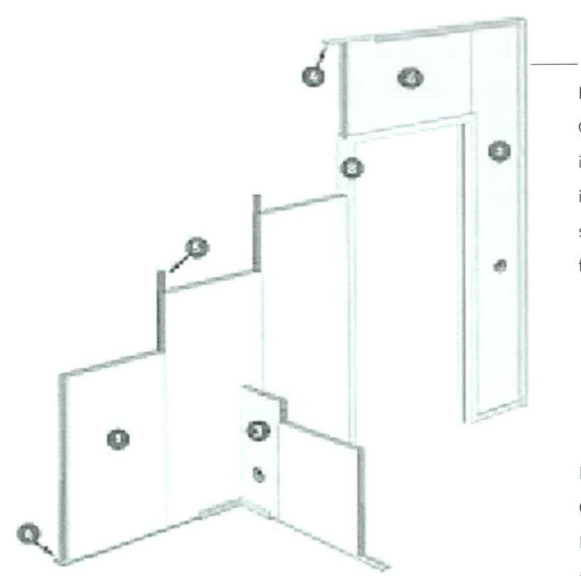


Figure 8.20
Quick and Easy instruction for installing prefab wall systems based on flaxboard (Faay)

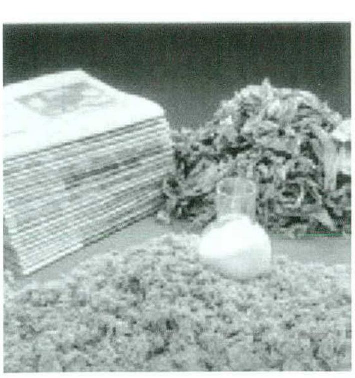


Figure 8.21
Cellulose insulation
Photo: Linex roof element with cellulose

Legend
1. isofloc
2. Celit wood fibre board
3. pro clima building paper
4. damp proofing
5. plaster (fibre) board
6. floor
7. ventilation
8. construction board
9. roofing
10. installation space
11. diengage profile
12. wall

Cellulose is available in loose form and as compressed boards. Cellulose has excellent heat-insulating and good sound-damping properties. Moreover, it can be attached seamlessly to existing building components. It is a recycled product from renewable origin. In the ultimate waste phase, energy recovery is possible.
These insulation products are fire resistant and anti-fungal because both the loose material and the boards have been treated with boron products.

In the Netherlands, prefab roof elements with a cellulose insulation filling (see photo, Linex roof element) are also available.

Loose cellulose can be blown by professional companies. Cellulose boards are also available to do-it-your-selfers (DIYers).

C. Flax and hemp wool insulation material used in prefab roofboxes

Fibres made of flax and hemp bark are excellent renewable materials for the production of (thermal) insulation blankets. Insulation materials made of flax or hemp wool can be used for thermal and acoustic insulation in prefab roofboxes in the same way as systems based on mineral wool (glass wool and rock wool). In addition to this, these insulation materials can also be used for the insulation of slanting roofs, roof elements, floors and (grid) ceilings, (WFC) exterior walls, partition walls and cladding units.
The insulation blankets are made anti-fungal and fire-retardant using ammonium phosphate and/or boron salts, sometimes in combination with water glass. Fire- resistance class B2 according to DIN 4102 and fungus-resistance according to DIN IEC 68 are guaranteed.
Compound construction elements, such as insulated roof elements (rafter roof or prefab roofbox), exterior walls and inner leave, are also available.

A prefab roofbox element consists of:
1) batten, 2) counterbatten, 3) fibre cement board 3,5 mm, 4) purlins, 5) flax insulation, 6) damp-resistant film, 7) chipboard 12 mm:
When using flax and hemp insulation materials in WFC, several advantages can be combined (e.g. light, renewable, re-usable, energy recovery in the final waste phase). Architects and principals who opt for WFC are an important target group for these insulation products. Blankets made of flax and hemp insulation materials are suitable for the professional building market, but also for the DIYer.

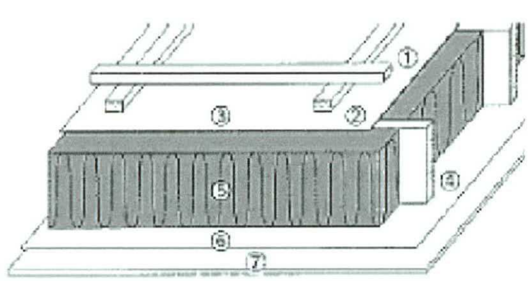


Figure 8.22
Prefab roofbox element (Heraklith)

Figure 8.23
Sheets and rolles made of flax and hemp insulation material

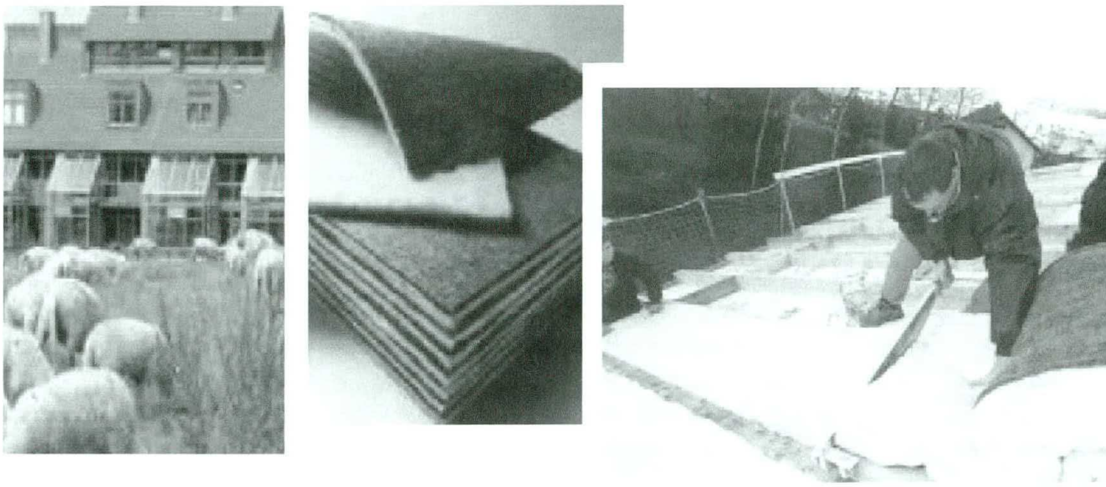


Figure 8.24
Sheep's wool as insulation material; from product to application

D. Sheep's wool in upper floors and in wall and roof insulation.
Sheep's wool becomes available when sheering sheep. The use of sheep's wool for fabrics (warm winter clothing), blankets, textiles and carpets is best known traditionally. However, wool is also extremely suitable as insulation material for various building applications. Sheep's wool insulation is used in exterior walls, roofs, partition walls, acoustic (grid) ceilings and false ceilings.

The insulation products consist of two layers of felt: a (dark-coloured) supporting fleece with a densely-needled structure and a large tensile strength, and a (light-coloured) fleece with an open structure for optimal thermal insulating qualities, 0.3% sulcofuron is used to protect the wool insulation product against damage done by insects. Low-density fleeces can be made extra fire-resistant with borates. High-density fleeces are already fire-resistant themselves.
The product is used in exterior walls, roofs, partition walls, acoustic (grid) ceilings and false ceilings. For vertical use, trusses and laths are required to which it can be attached (tacking), because the material itself lacks sufficient stiffness. Combining the product with WFC or using it in cladding units are the most obvious applications. Sheep's wool can also be used as an insulator for pipes and wiring, usually with an aluminium outer layer.

E. Coconut for the (sound) insulation of floors
Coconut palms grow in practically all tropical areas. Not only coconut oil and copra, but also coconut fibres can be extracted from coconut husks. Traditionally, these fibres are used in mats and carpets. Due to their good resistance against natural decomposition, there are a many uses for coconut fibres.
For sound insulation, coconut fibres are traditionally applied in strips. A well-known application are the so-called "spijkerregels", which consist of a wooden or chipboard strip with a layer of coconut. These "spijkerregels" are often used in double-framed walls. Furthermore, coconut mats are regularly used as support for plastering. Coconut fibre is extremely suitable for the damping of low-frequency vibrations in particular. Due to this property, the fibre is used in low-noise spaces (studios) and in spaces with high noise levels (catering industry), often in combination with latex. The combination with latex enables the large elasticity of the fibre to be utilized completely.

Pressed board and needled mats (non-wovens) of different densities are available, even bound with latex.

Coconut felt is inherently fire-resistant (fire-resistance class B2). If desired, coconut fibres can be made extra fire-resistant with borates.

Coconut fibre can be used as insulation material to support heavier subfloors, such as concrete hollow-core slab floors. Coconut felt can be combined with hair felt for acoustic separation in for example WFC-constructions, in order to meet the sound-insulation requirement of 0 dB. In apartments with hard flooring, coconut products can be used as a finishing floor to realize the +10dB requirement. Its potential is therefore large in houses where noise levels are an important factor, such as in apartments, near airports or along motorways.

F. Cork for the insulation of (flat) roofs

Cork is chiefly known as corks in wine bottles, which is in fact the major market for cork. In addition to this, cork is suitable for applications in carpeting, shoes and insulation materials, for example. Cork is extracted from the bark of the cork oak (Quercus suber L.) in Mediterranean countries (Portugal 51%, Spain 26%, Italy 7%, Morocco 6%, Algeria 4%). Expanded cork sheeting is suitable as an insulation product for cavity walls, floors and roofs. Cork has the interesting advantage of having good resistance against pressure load. This makes it extremely suitable for applications in flat roofs that can be walked on.

Using steam, cork is expanded to sheeting in an autoclave. During expansion, the natural resin (suberin) in the cork deliquesces. No artificial additives are used in cork sheeting.
The most important technical qualities of cork are its good insulating properties, its water repellence, its fire-resistance, its limited compressibility and its resistance to biodegradation. Due to these properties, cork is extremely suitable for numerous insulation applications in the building industry.

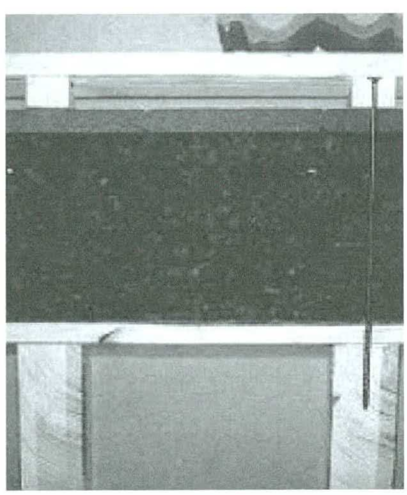


Figure 8.25
Cork used as insulation under a roof

Expanded cork sheeting can easily be applied in today's building practice, in both the professional and the DIY market.

Cork being moisture-proof and rot-resistant makes it an extremely suitable material for insulation applications in cases where there is the risk of (incidental) seepage of water or leakage, such as in flat roofs and exterior walls. However, despite the fact that cork will not rot quickly, any unforeseen leakages must always be repaired.

G. Closed thatched screw roof

Everyone knows the thatched roof of that cosy pancake restaurant or that splendid listed (farm) building. Not so well known is that modern houses can also have thatched roofs. These are the so-called closed thatched screw roofs where the thatch has been attached to a base plate. These roofs meet the requirements of the Building Decree and are less flammable than traditional thatched roofs. A beautiful thatched roof will of course always cost more than a tiled rood, but it is certainly worth having!

With good quality thatch, an aesthetically fine thatched roofing can be realized. Due to modern building and comfort requirements, a modern thatched roof is closed. Such a roof is also called a screw roof. The thatch is attached on site to a base plate (underlayment, OSB or another plate material of at least 18 mm thick) with screws and galvanized steel wire. The build-up from the outside is a 28 cm layer of thatch on a wooden plate carried by rafters or purlins. If desired, additional insulation can be applied on the inside of the roof between the rafters or the purlins.

Thatch is unsuitable as roof covering for flat of slightly slanting roofs: the higher pitched the roof, the longer the life of the thatched roof. The closed screw roof consists of plate material of at least 18 cm thick (OSB, underlayment), thatch, galvanized steel wire and screws. It is of the utmost importance that the underconstruction is built draft- and damp-proof. The roof can even be prefabricated. The thatch is applied on site by a thatcher.

Straw and reed are the oldest roofing materials of the "low countries". Reed is a perennial grass that grows in the water or on marshy soil and, depending on the place, grows up to 1-4 metres high. At the end of July or the beginning of August, the stem has almost reached its maximum height. Not all reed is suitable for thatch. Thatch reed grows mainly in freshwater peat pools, although in the Netherlands reed grown on raised soil has been used as roofing material for many years now. Thatch is fine (aesthetical reasons), hard but also tough (brittle reed snaps), straight and 1.6 – 2 metres long. Thatch has a fresh, yellowy colour, strong, thick stalks and a white base. Dutch thatch is mainly cut in Overijssel, Friesland and Noord- and Zuid-Holland. For 1992, the exploited reed-land is estimated at 4,500 hectares. Approximately half of the thatch is grown in the Netherlands, the other half is imported from Austria, Hungary, Romania and Turkey.

Unlike most roofing materials used for slanting roofs, reed is a renewable material. The amount of fossil fuel required for a thatched roof is very small and, apart from reed, there is hardly any waste either. Reed cultivation does use pesticides; however, the bulk of the reed comes from nature reserves, which actually benefit from reed cutting. The life of a thatched roof is shorter than that of a tile roof and it requires more maintenance. However, contrary to roof tiles, thatch does contribute substantially to the insulating value of the roof. In the summer a thatched roof heats up slower (summer cool), which means that it takes longer before cooling is needed. Using reed as a roofing material dovetails with the measure S471 in the national Sustainable Building package "When possible, use renewable materials".

According to the Dutch Federation of Thatchers, a closed thatched screw roof has, under normal conditions and with a 45 degrees pitch, a minimum life of 25 years, but often lasts 35 years. Furthermore, to guarantee the quality of a thatched roof, the Federation of Thatchers also carries out inspections on completion.

Availability

The closed thatched screw roof is supplied by thatchers who are members of the Federation of Thatchers in Nijkerk. Affiliate companies may all call themselves certified thatchers. A certificate is only presented after a theoretical and practical examination in combination with three years' practical experience. There are approximately 250 thatching companies scattered all over the country, most of which are members of the Federation of Thatchers. More information can be found at www.riet.com.

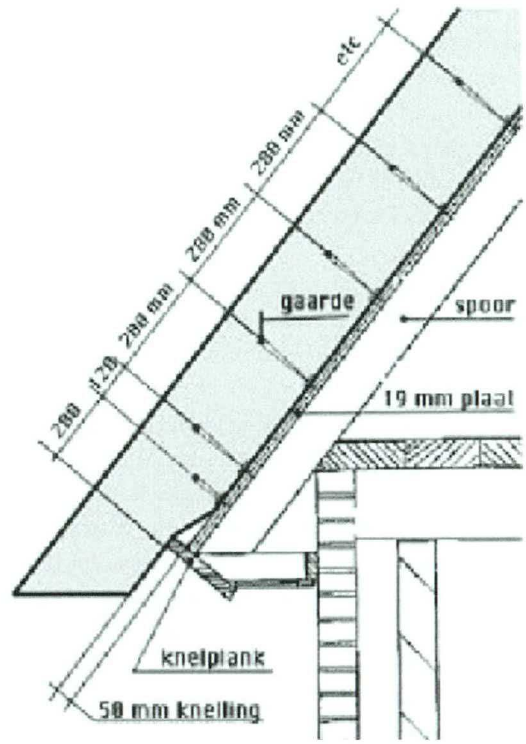


Figure 8.26
Sketch of screw roof - thatched

Legend
Gaarde – steel wire
Spoor - rafter
Knelplank – barge board
Knelling – tilting fillet
Plaat – purlin

Figure 8.27
Applying a thatched srew roof

H. Bricklaying with shell-lime mortar

Bricks can be laid with shell-lime mortar or so-called shell-lime bastard mortar. Such mortar lasts long and allows bricks to simply be re-used after a building has been demolished. Shell-lime mortar is made from clean shells - produced yearly by the sea - sand and water.

Shell lime is made from shells that are burned with coke and then slaked with water. Masonry mortar can be made by adding water, sand and, if desired, cement.
Shells are formed by shellfish, which, during their life, bind lime from seawater. Shells are a renewable material; the shell banks, which are sometimes 40 metres long, continue to grow. All kinds of shells can serve as raw material for the production of shell lime, also those from foreign waters. Shells from the food industry (e.g. mussel shells) can also be used as raw material. Shells mixed with clay, however, are unsuitable (they are used for cycle and walking paths, for example).

Shells are sucked up with a vessel that is equipped especially for this task: a trailing suction hopper dredge. A pump sucks the shells upwards through a suction pipe into a chute. Most of the sand disappears through the gauze of this chute. Lumps of peat and boulders are separated from the shells by means of a 5-metre-long vibrating sieve.

The quality of shell-lime bastard mortar is good. Thousands of monuments and modern buildings show that these types of mortar are durable and sufficiently strong. As shell-lime bastard mortar hardens slower than cement mortar, the full compressive strength is achieved later. A special characteristic of shell-lime mortar is the relative good elasticity, which allows setting to be absorbed to a certain degree without the outside wall cracking straight away. According to the manufacturer, the use of shell-lime (bastard) mortar also reduces the chances of efflorescence and frost damage.

Using shell-lime mortar in brickwork is a variable measure in the National Sustainable Building Packages (S073). Its use also conforms to sustainable building measure S471 "When possible, use renewable materials". Using shell-lime mortar in brickwork in the civil and hydraulic engineering sector has important advantages for the environment: it is a renewable material, the brickwork has a long life and the mortar a low energy content (during hardening, CO_2 is bound as well). An important additional advantage is that the bricks can be re-used whole. By using shell-lime (bastard) mortar for bricklaying, brick walls are in fact dismantable. If well organized, re-using brick can be of great advantage to the environment.

Shell lime is a renewable raw material and has a low energy requirement for its production. A major indirect effect on the environment is that shell-lime mortar can be chipped off, so that bricks can be re-used whole. In the Netherlands there is an ever-growing mountain of masonry granulate from buildings built with cement mortar; this material is used in a relatively low-value way. In the Netherlands, there is a supply of "sec-

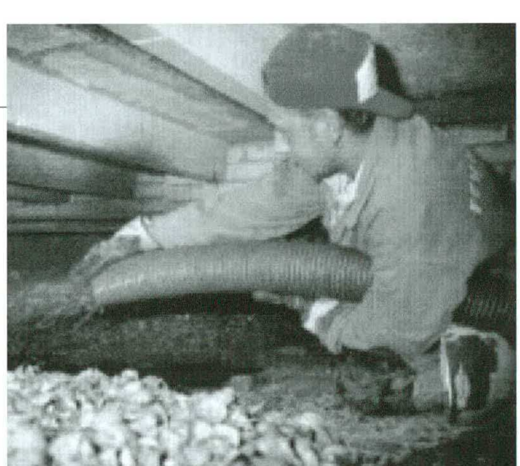


Figure 8.28
Applying the insulating shells

ond-hand" masonry bricks that can be re-used for brickwork. This way, the energy and clay requirements for baking new bricks are avoided.

Availability
The Dutch shell-lime industry once was a large and important industry: scattered over the whole of the Netherlands there were over 130 kilns where shells were burned to make masonry mortar. Now there is only one operational shell-lime kiln in Harlingen. This factory produces 'zakgoed' used in the restoration sector for masonry mortar and plasterwork (mortar is a mix of water, sand and a binding agent, in this case shell lime) but also ready-made, KOMO-tested, so-called shell-lime bastard mortar (1 part cement, 3 parts shell lime and 7 parts sand) in silos. The 1:3:7 shell-lime bastard mortar (1 part Portland cement, 3 parts shell lime and 7 parts sand) costs approximately 95 Euros per ton.

I. Shells as bottom sealing
Shells can make an important contribution to a healthy and pleasant indoor climate in buildings, especially when moisture under the floor is a problem. A dry and warm floor is the basis of a healthy house. In damp areas, shells can be an important and sustainable means to realize such floors. In 1989 an old method was rediscovered to keep out the damp and nasty smells from the soil under houses. Shells washed clean with freshwater were applied under ground floors. A nice incidental circumstance is that a thick layer on the floor of the crawl space is also good floor insulation.

Product
Shells are the calciferous cases of (dead) shellfish. Experience has shown that hard shells washed clean in freshwater act as a good bottom sealing. Shells are a renewable material; the shell banks occasionally measure up to 40 meters and continue to grow. Hard shells washed clean with freshwater can be used as an insulating bottom sealing under the floors of houses and public buildings.

Shells are sucked up with a vessel designed specially for this task: a trailing suction hopper dredge. A pump sucks the shells upwards through a suction pipe into a chute. The only processing the shells undergo is to be washed with freshwater to rinse off the salt. Salt is undesirable as it is hygroscopic. After transport by lorry, the shells are blown under the floor. When the building is demolished the shells can either remain in situ or be re-used again.

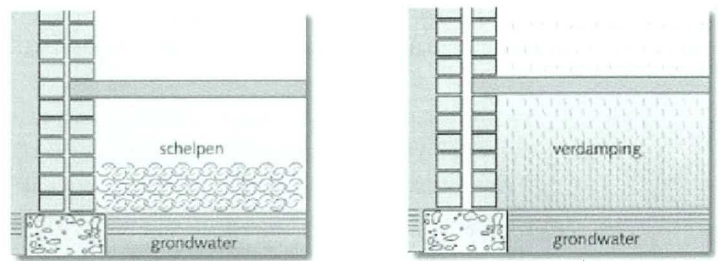


Figure 8.29
Crawl space with shells (on the left)

Crawl space without shells (on the right)

Use
Hard shells washed clean with freshwater can be used as bottom sealing under the floors of houses and public buildings. A good thick layer of shells (at least 25 cm thick) under the floor has four functions:

- damp-proofing
- it keeps out smells
- thermal insulation
- lightweight filler

Insulating shells can be used under both wooden and concrete ground floors in houses and public and commercial buildings. After the crawl space has been cleaned, the shells are blown under the floor through a big hose. These shells function as bottom sealing and they prevent damp and smells. As a layer of shells on the ground prevents cold radiation they also have a heat-insulating effect, as a result of which heat loss through the floor is reduced.

Shells neutralize smells, because the calcium binds with the mercaptan-forming humic acids. The natural radioactivity of the shells is 50 times smaller than the standard below which building materials can be used unlimitedly. This way, the shells do not contribute (or only to a very limited degree) to radon emissions (if any) into the house. Shells have an unlimited life, they are not deformable, they are heat accumulating, electrostatically neutral, diffusing (air diffusion is possible), preserving (through the high level of calcium in combination with timber) and smell-neutralizing. A dry crawl space acts as an excellent repellent against damp-loving vermin, such as wood lice, but also prevents the growth of fungi.

In 1996, a life-cycle analysis (LCA) was carried out for shells as bottom sealing. This LCA showed that not the shell as a natural product as such, but the transport of shells makes the largest contribution to the total environmental impact of shells as a bottom sealing. It is recommended to transport them by ship and in clean lorries as much as possible. Apart from that, the environmental impact of the winning, washing, transport and application of the shells over a period of 50 years pales into insignificance when compared to the environmental advantage achieved by heat insulation of the ground floor.

A thick layer (at least 25 cm thick) of clean, washed, hard (whole) shells does not only prevent smells and damp, it is also a relatively light filler (600 kg/m^3) and a thermal insulation material. The thermal conductivity (lambda) of dry shells is measured as 0.106W/mK. With the prevailing conditions in crawl spaces, the moisture content of the shells is approximately 2%, making the effective lambda value 0.125W/mK. In these circumstances, a 25 cm layer of shells creates an insulating layer with a thermal resistance of 2 m^2K/W, well over the requirement of 1.3 m^2K/W mentioned in the Energy Premium Regulation. This insulation value is too low for newly built houses, where a thicker layer of shells (32 cm) must be applied to meet the minimum requirement of $R>2.5m^2K/W$. Sustainable building projects have been realized using a 65 cm layer of shells.

Figure 8.30
House built of straw bales

The moisture-resistance factor (μ) of stationary air is 1. A 98 mm layer of shells has a μ of 1.3. With a 164 mm layer, the value of μ is 1.38. It is to be expected that the moisture-resistance factor is even higher with a layer of shells of 250 mm or more.

Clean, washed insulating shells with a product certificate that guarantees the quality cost approximately € 36 per m^3; a layer of 25 cm then costs € 9 per m^2. A subsidy of € 4.50 per m^2 is granted for the shells when a minimum layer of 25 cm is applied.

J. Exterior walls made of straw bales

Walls of buildings can be built of straw bales. In the United States, this building method is now making steady headway. In the Netherlands, a number of appealing projects have also been realized.

Products

Straw consists of the dried stalks of grains or leguminous plants. A distinction is made between straw from winter wheat and summer wheat, rye, barley, oats and leguminous plants. The wheat is usually harvested with a combine harvester. The straw remains on the land only for relatively short periods of time. It dries in the sun, is turned over a few times and compressed into bales.

Zeeland and Groningen are the most important straw-producing provinces. The majority of the straw is used as litter in stables; when the price of straw is low, the farmers are inclined to plough the straw back under. Straw dealers have united in the HISFA, the Dutch Association of Straw Dealers.

The small traditional bale of straw is bound with two pieces of string and can easily be lifted by one person. The weight and size of a straw bale is somewhat variable, depending on the moisture content of the straw and the adjustment of the straw press. A straw bale measuring 50x37.5x105 cm weighs 13.5 kg; bales measuring 1 m^3 then weigh approximately 70 kg. Straw bales are cheap; depending on the season, the price of a bale lies around € 2.30 to € 3.20.

Use

A wall built of straw bales must, if it is to meet modern requirements, be finished off. Often, a coat of plaster is applied, but a finishing using panelling is of course also a possibility. One cannot use straw bales to build supporting inner or exterior walls. Straw bales combine well with woodframe constructions. As straw bales are relatively thick and because the material lends itself for building one's own house, most opportunities lie outside the Randstad on larger lots. In built-up areas and on small plots, the thicker walls will soon be considered a problem.

Walls built of straw bales are vulnerable from a building physics point of view. During and after building, the bales of straw may not become wet, for example through leakage. This is why a wooden or steel frame with a roof is built first, followed by the walls of straw bales. These walls must be finished in a damp-open way, so that no condensation will occur in the wall. The thick wall has a good thermal and acoustic insulating value. Under normal, dry circumstances, the biological resistance of siliceous straw is good. It is important, mainly with regard to fire safety, that straw bales are incorporated into modular walls or are plastered over.

Straw is a renewable building material that is available in abundance and can be used in the building industry to replace concrete and limestone in walls. Little energy is needed for the production of a bale of straw; it is mainly for pressing straw into a bale. Once the straw has been applied in a wall, it contributes to the thermal and acoustic insulation of the wall. Waste from straw is innocuous. The only drawback from an environmental point of view is the use of pesticides in grain cultivation. There is no damage to the landscape, on the contrary: large-scale use of straw in the building industry encourages the farmers to cultivate grains. Provided it is applied professionally, its life is the same as that of any other wall. Bales of straw from a modular wall may even be re-used; plastered straw-bale walls can easily be processed without creating a mountain of waste.

The use of timber in the civil and hydraulic engineering sector

Introduction

The Directorate-General for Public Works and Water Management (Rijkswaterstaat) is responsible for the construction and maintenance of a large number of civil works. Besides the use of concrete and steel, a great deal of timber is used also. The Road and Hydraulic Engineering Institute (DWW) and the Civil Engineering Division (BD) of Rijkswaterstaat work together with research institutes and the industry on innovative projects where timber is used. This paragraph gives an overview of the timber applications that can already be used and of projects that are in the research or monitoring phase. Finally, an outline is given of the future of the use of timber in the civil and hydraulic engineering sector.

In 1995, the DWW and the BD together started up the innovation programme Timber in the Civil and Hydraulic Engineering Sector. The reason for this was the use of an increasing number of materials, such as aluminium, concrete and steel, that in the extraction, production and waste phases cause a high environmental impact. Timber is not only renewable, it also requires little energy for production and processing, and is therefore ecologically sound. A pragmatic rather than a scientific approach has been chosen in which the client is given an active role from the start.

Concrete cases with timber in the civil and hydraulic engineering sector

A. Timber gantries

The first product to be developed was a timber gantry. The aim of this project was to test the

Figure 8.31
Photo of the gantries at Alkmaar

technical possibilities of building with timber and to show this to a large group of users. The government architect, by order of the DWW, made a large number of different designs. Next, a client was found and the technical design was worked out. For the realization of this project, experts from the Civil Engineering Division of Rijkswaterstaat, the Centrum Hout (Timber Information Centre), the Delft University of Technology and research institutes, such as TNO Building and Construction Research and SHR (Stichting Hout Research [SHR Timber Research]) as well as from timber producing and processing companies were involved. The result is that on the exits of the Zonzeel traffic junction (national highway 16/national highway 59) three timber gantries have now been erected. And also that in the spring of 2003, four timber gantries were erected before the Kooijplein junction in Alkmaar. There is also an option for fifty-three timber gantries along national highway 73 in Limburg.
The first timber gantries might have been approximately 1.5 times more expensive than steel ones, after scale-up the price of a timber gantry is approximately the same as a steel one.

Figure 8.32
Collision test on timber crash barrier

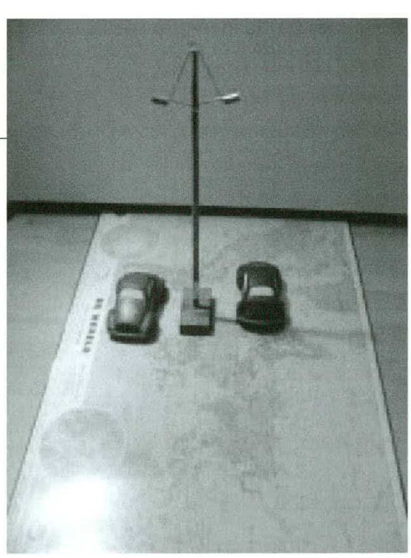


Figure 8.33
One of the timber lamppost designs

B. Timber crash barrier

After the gantry pilot project, the idea has arisen to develop a timber crash barrier. In countries such as France and Finland, timber crash barriers are used often. In Until recently, crash barriers in Canada were also largely built of timber. Regrettably, steel is increasingly being used for the new roads.

For this project, the DWW, the Centrum Hout and the Delft University of Technology set up a collaboration. The first designs were made in 1999. To test the timber crash barrier, a series of experiments were carried out. First, a number of laboratory tests at Delft University of Technology (interaction of the timber post with the ground, and bending tests of the attachment of the lower rail). Subsequently, a number of "Full Scale" tests were carried out with a car and a coach at the test course of the National Transport Inspectorate in Lelystad. On September 4th, the final tests carried out by Delft University of Technology and TNO Building and Construction Research were successfully wound up, allowing the timber crash barrier to be built in a pilot test along a national highway.

C. Timber lampposts

A final design for timber lampposts was finished in August 2003. They were designed by the Bouwdienst Zoetermeer and Bureau Boorsma by order of the DWW. MIII architects from Rijswijk are styling the design. Crash tests are to be carried out in 2003 and a number of lampposts are to be erected in a pilot project in the vicinity of the N44 at Wassenaar.