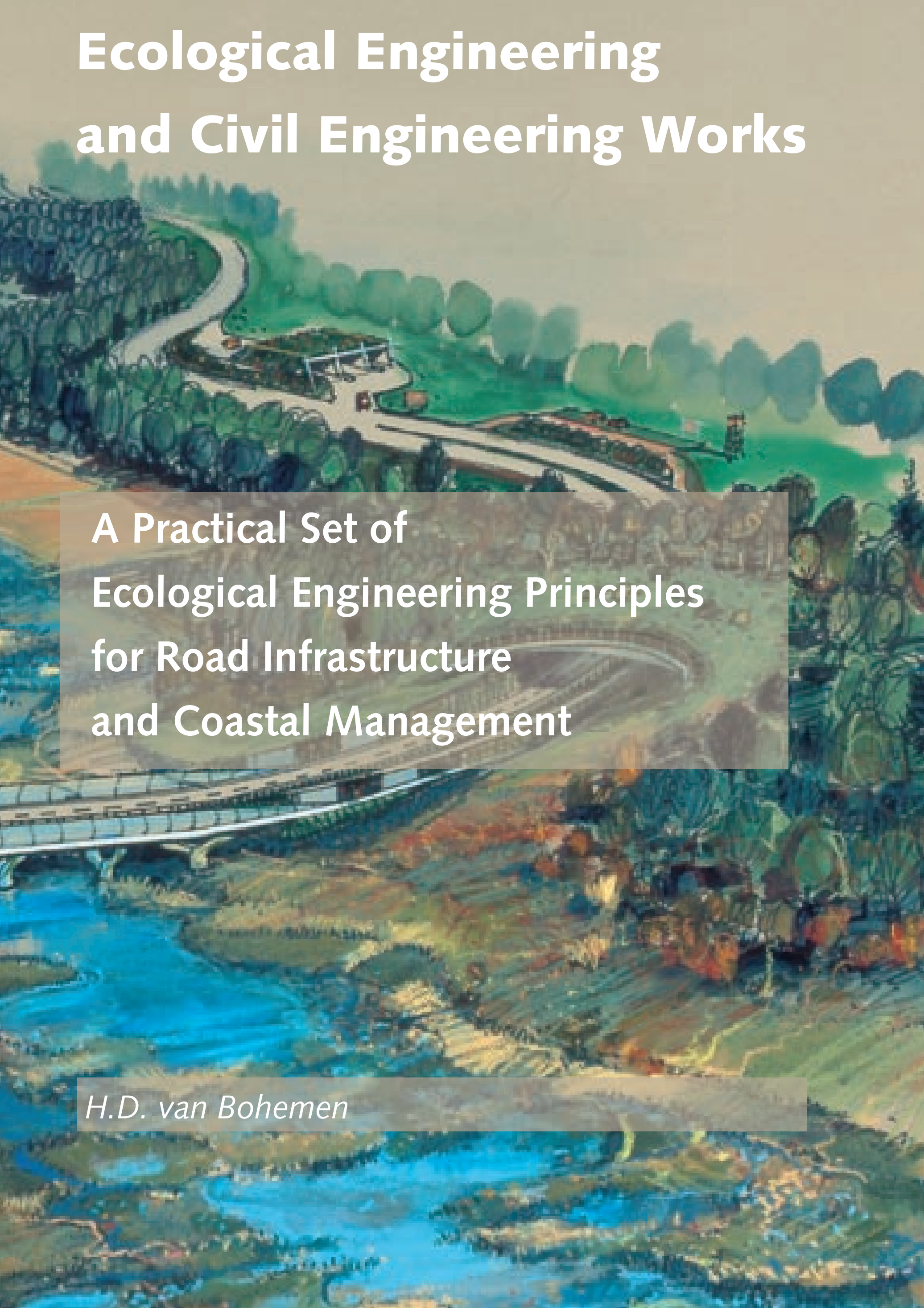
Ecological Engineering and Civil Engineering Works

A Practical Set of Ecological Engineering Principles for Road Infrastructure and Coastal Management



H.D. van Bohemen

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Preface

This thesis is the result of years of active service in the field of research and consultancy with regard to agricultural, civil engineering and nature issues. My supervisor, Prof. dr.ir. Ch.F. Hendriks, encouraged me to formulate in thesis format the knowledge and insights I have gathered over the years with regard to ecological engineering. Thanks to the consent of the management of the Road and Hydraulic Engineering Institute I have been able to do this, first in the capacity of part-time staff member at the Delft Interfaculty Research Center "De Ecologische Stad" (The Ecological City) of Delft University of Technology, and later on in the capacity of part-time staff member at the Material Science and Sustainable Building of the Faculty of Civil Engineering and Geosciences of the Delft University of Technology.

The many years I have been involved with the integration of human activities into an ecological framework has been essential for my choice of the subject. On the one hand, these activities involved work regarding the relationship between agriculture and nature in my capacity as a member of staff and later on as a member and deputy secretary-general of the Natuurwetenschappelijke Commissie (Natural Sciences Committee) of the Dutch Natuurbeschermingsraad (Nature Conservation Council). On the other hand, the activities involved research and consultancy with regard to the relationship between nature and ecology and civil engineering works in the capacity of subdivision manager of nature and landscape consultancy, and later on head of the environmental research department, and currently in the capacity of research coordinator of 'onderzoek milieumaatregelen infrastructuur' (research environmental measures infrastructure) at the Road and Hydraulic Engineering Institute of the Directorate-General of Public Works and Water Management of the Ministry of Transport, Public Works and Water Management.

The Delft University of Technology have also been instrumental to appoint me as part-time staff member at the Delft Interfaculty Research Centre for the Sustainable Constructed Environment, especially the research programme "The Ecological City", and later as part-time researcher/lecturer at the Faculty of Civil Engineering and Geosciences of the Delft University of Technology.

In many cases, provisions and solutions to issues are solved in a monodisciplinary way. Experience has shown that multifunctional solutions are often possible, e.g. by linking functions or through the multifunctional use of space for more efficiency with regard to the individual activities. Nature, both in The Netherlands and globally, is deteriorating rapidly, despite many initiatives employed to delay this deterioration or enhance biodiversity.

It appears that there are yet more possibilities to solve conflicts between nature and culture. By adopting a more ecological point of view and acting on the basis of ecological design, it is possible to provide an important contribution to the reduction of man's impact on our proper human environment as well as that of plants and animals. This is evidenced by the study results and case studies presented in this thesis.

The possibility has emerged of applying ecological knowledge and insights when designing, realising, managing and maintaining road infrastructure and coastal management. In this respect, the main characteristics to be achieved are as follows:

- Enhance integrality (greater coherence) between functions.
- Improve ecological quality.

- Increase aesthetic quality.
- Improve societal appreciation.

The learning experiences presented below as well as the principles of ecological engineering that will be presented are, in my opinion based on the results of this research, essential for achieving better sustainability than is currently the case.

- Nature and the environment should be placed in a more social-ecological context, especially in connection with an economy that takes ecological patterns and processes into account.
- A transdisciplinary approach to nature and environmental issues is essential for more sustainable solutions to issues regarding the relationship between man and nature.
- ‘Real sustainability’ may be achieved through an ecosystematic approach in which ecological functions of ecosystems are valued equal to ecological goods and ecological services which ecosystems provides to man.
- Experiencing nature, or ‘the sense of wonder’, to name the title of a book by Rachel Carson, is essential for sustainable attention to the preservation and development of natural values as a raison d’être for human society.

A very personal incentive has been my many years of work with colleagues. In 1991, a large share of the knowledge existing at that time was summarised in ‘Nature engineering and civil engineering works’, contributors to which were P. Aanen, W. Alberts, G.J. Bekker, H.D. van Bohemen, P.J.M. Melman, J. van der Sluijs, G. Veenbaas, H.J. Verkaar and C.F. van de Watering. I was offered the opportunity to become the co-editor of this publication together with D.A.G. Buizer and A. Littel.

This thesis forms a synthesis of original performed applied research, as well as outsourced studies about the relation of (construction, management and maintenance of) civil engineering works and environment, nature and landscape. A special focus has been given on integrating knowledge concerning the understanding, use and control of patterns and processes of ecosystems into the construction, use and management and maintenance phases of civil engineering works. Special attention is paid to roads, waterways, road verges, slopes, banks and bridges and viaducts related to the main motorway infrastructure as well as in the field of layout and maintenance of coastal fore dunes.
Results have been included in this thesis from other studies in the same field carried out under the responsibility, but in close cooperation with the Road and Hydraulic Engineering Institute, of the Regional Directorates of the Directorate-General of Public Works and Water Management, in order to be able to present a more integral approach concerning the construction, management and maintenance of motorways, as well as management of coastal fore dunes in the Netherlands.

This thesis highlights the most important aspects referred to above concerning motorways and nature, environment and landscape. For aspects about environmental impact assessments (EIA) and motorways, reference is made to the thesis by dr. E.J.J.M. Arts, productgroup leader Tracé/EIA at the Road and Hydraulic Engineering Institute and as far as the subject compensation is concerned, to the soon to be published thesis written by *drs*. R. Cuperus, productgroup leader Nature and Landscape at the Road and Hydraulic Engineering Institute. For the fields of noise and roads and airquality and roads, reference is made to both existing literature

and to upcoming publications within the scope of the ongoing ‘Noise Innovation Programme’ contracted to the Road and Hydraulic Engineering Institute and the recently launched ‘Airquality Innovation Programme’ of which the Road and Hydraulic Institute will also become responsible.
Also reference can be made to some reports of the OECD Road and Transport Scientific Expert Group about Environmental Impact Assessments of Roads (1994) and the Roadside Noise Abatement Study (1995) of which I have been one of the participants.

A number of the following chapters have been written with colleagues at the Road and Hydraulic Engineering Institute: Mrs G. Veenbaas, G.J. Bekker, W. Janssen van der Laak and P.J. Keizer. Others as well have provided important contributions, both in small and large quantities, and delivered comments and suggestions: E.J.J.M. Arts, M.C. van den Berg, K. Canters, R. Cuperus, J.W. de Jager, Mrs. M. Löffler, N.M.M. Koeleman, J. Koolen, Mrs. A.G. Piepers, A.W.J. van Schaik, Th. Verstrael, J.G. de Vries and J. van Westen.

Many others have also contributed, directly or indirectly, to the facilitation of this thesis in various other ways: Prof. dr. V. Westhoff, who has inspired me from a very early stage and provided me with all of his reprints of articles, Prof. dr. M.F. Mörzer Bruijns, who has shared his knowledge with me, Prof. dr. J.J. Barkman, who has assisted me in my doctoral research into the diversity of the vegetation of pine groves in the province of Drenthe, Prof. dr. P. Zonderwijk, with whom I published in 1970 in the series of scientific communications of the Royal Dutch Society for Natural History (KNNV), a publication about the development and organisation of nature conservation in the Netherlands, and last but not least all the members of the Natural Sciences Committee (Natuurwetenschappelijke Commissie, de zgn. N.W.C.) of what formerly was known as the Nature Conservation Council (Natuurbeschermingsraad).

I would also like to acknowledge ir. L.A. Bosch, ir. P. Aanen, and Prof. dr. Ch.F. Hendriks, who have afforded me the freedom to compile this thesis.

Secretaries, too, have provided indispensable contributions. They are Claudia Blok, Beppie Bronkhorst, Sylvia van Halderen and Margot Mekkes as well as the help of Tom Dingjan, Rob Leurink and John de Koning for drawings and technical assistance.
I feel greatly indebted for all of them. My objective has been to present the knowledge in a more holistic way that may create added value for a future approach of problems.

Last but not least, I am greatly indebted to my parents, who in bygone days offered me the opportunity to engage in formal and non-formal educational activities that have broadened my Dutch and global perspective (through study trips, visits to conventions and active participation in the International Youth Federation for Environmental Studies and Conservation, working together with many friends like Th. Vethaak, F. v.d. Vegte and D. Withington as well as in the Royal Netherlands Society for Natural History (K.N.N.V.), and to my wife Janny, who has allowed me to spend a large portion of my spare time ‘upstairs’ in my study.

Hein van Bohemen
Delft

Contents

1. General Introduction

A. Aim of the Study

Regardless of the fact that Dutch ecosystems are highly antropogenic in nature, they nevertheless contain relatively rich and varied ecological values. Civil engineering can have a negative influence on these values such as motorway infrastructure in a traditional design and coastal defence in a full technical approach.

During the last decades, the Road and Hydraulic Engineering Institute of the Directorate-General of Public Works and Water Management of the Ministry of Transport, Public Works and Water Management has carried out a broad range of studies on how to prevent, minimise, mitigate and/or compensate the negative impact of motorways during the whole lifecycle.
This thesis offers, in the form of a collection of published and new papers, a retrospective view with the aim to synthesise and evaluate the accumulated - and sometimes scattered - published knowledge with the goal to form a strong, coherent foundation for further work in the field of ecological engineering and civil engineering works.

The most important research question to be answered in this thesis is: which principles of ecological engineering have been implicitly or explicitly applied for the past decades, and which principles should be advised to reach a more sustainable stage in the planning, design, realisation and maintenance and management of civil engineering works in particularly towards motorways and coastal management?
The main question can be broken down into a number of subquestions that will be answered in this thesis:

a. To what extent have ecological, landscape-ecological and ecosystem theories played a role in the relationship between motorways and nature and in the relationship between coastal management and nature for the past decades?

b. Which principles of ecological engineering have or have not been applied. Which principles have given positive or negative results?

c. Is it possible, on the basis of the answers to above questions, to formulate a set of generally valid principles of ecological engineering? On the basis of the results of the investigation, it should be possible to compile a set of principles of ecological engineering that can be applied to civil engineering, with an emphasis on road infrastructure and coastal management.

B. Approach

Research Design
A number of sub-areas (integrating motorways into the landscape, the effects of roads and traffic on air, water and soil, road-verge management, fauna provisions and sandy-coastal management) have been chosen and the most relevant abiotic and biotic processes and the human influence have been described.

For each sub-area, research questions have been formulated that have been answered to a greater or lesser extent on the basis of the results of this investigation.
With the help of case studies into the design, construction, maintenance and management of motorway infrastructure and coastal management, it has been possible to evaluate which principles have been applied, and on which basis. The results have been compared with the insights obtained from literature; the differences and similarities have been evaluated and knowledge gaps have been identified.

On the basis of the results that have been recorded in the following chapters for each sub-area, a generally valid set of principles of ecological engineering for civil engineering and earthmoving has been developed and will be presented as a synthesis

The study will also touch upon the significance of a more holistic approach towards problem-solving in the mentioned before sub-areas.

Research Methodology
Different methods have been applied for the studies that were performed and presented. On the one hand, statistical studies have been performed; on the other hand, conclusions have been drawn from case studies. In the relevant chapters it is has been clearly indicated which method was used.
During the research into the spread of pollutants to air, water and soil, a large number of measurements were usually carried out on the basis of statistically sound sampling (random sampling). Also, use has been made of forecasting models that simulate certain conditions.

During the presented research into vegetation, use has been made of selective sampling tests that were extended at a later stage with a system of random samples in order to monitor the changes in the course of time in a statistically sound way. Use has also been made of carefully selected test areas in order to investigate the effects of maintenance measures.

The research into the integration of roads entails case-study research, since separate situations have been scrutinised and defined on the basis of a comparison of differences and similarities. What is involved here, is identifying the 'how' and 'why' of certain designs and development processes rather than looking for statistically demonstrable relationships between certain variables.
When opting for case studies, one should bear in mind that the results of analyses of one or more case studies may not necessarily be generally applicable or valid. Reliability and validity are pivotal topics in case-study research. Case-study research, especially after the publication of Yin (1989), has received support in the areas of explorative, descriptive, illustrative and explanatory research. Yin (1989) offers the following definition of case-study research: 'an empirical enquiry that investigates a contemporary phenomenon within its real-life context when the boundaries between the phenomenon and context are not clearly evident and in which multiple sources of evidence are used'.

In a study into the use and effectiveness of environmental impact studies, Arts (1999) goes into extensive detail with regard to the benefits and drawbacks of case studies. Van Bueren et al. (1999) report on the value of case-study research and offer a number of recommendations.

Whenever an analysis based on a case study or a large number of case studies is involved, the criteria for the selection of the case study/ studies will be indicated. Great pains have been taken to make sure that the cases are not connected in space or time, so that presuppositions can be falsified.

C. Outline of the Thesis

The thesis consists of a general introduction (the current first chapter) in which the problem, means and methods used are summarised. An overview is also given of the development and place of ecological engineering with regard to civil engineering (see section d).
The core of the thesis consists of three parts:

A Road Infrastructure and Ecological Engineering

In this part, the main research results with regard to environmental aspects and road infrastructure are summarised in a number of chapters (2, 3, 4, 5 and 6) and the way ecological engineering knowledge has been applied will be examined.

B Coastal Dynamics and Ecological Engineering

In this part, a number of published articles (Chapter 8 and 9) have been included that are preceded by a preface (Chapter 7). This part is concluded with an analysis of the implications for nature of the investigation into a more dynamic form of coastal management as a form of ecological engineering (Chapter 10).

C Conclusions and Recommendations

This part takes a retrospective look at the research presented and provides a summary of the main conclusions that have been drawn from the performed research (Chapter 11 and 12). In conclusion a set of principles of ecological engineering is presented (Chapter 13), which are based on this thesis as generalization of the conclusions of chapter 11 and 12 and current ecological research.

Finally, there follows references, a Dutch summary, an English summary, a curriculum vitae and a list of scientific publications accompanied by published reports, studies and articles that provide an insight into 40 years of my work with regard to the relationship between nature and culture.

D. Introduction of Ecological Engineering in Relation to Civil Engineering

Many concepts have been developed from ecology and landscape ecology that provide an insight into the composition and functioning of landscapes and ecosystems: these include general concepts (H.T. Odum, 1983; E.P Odum, 1963, 1971; Forman 1995; Tjallingii, 1996; Farina, 2001) as well as concepts with regard to sub-areas such as fragmentation and roads (Saunders and Hobbs, 1991; Forman et al., 2003), meta-populations (Opdam, 1991; Harrison, 1994) and the significance of corridors and connectivity: (Saunders and Hobbs, 1991; Noss, 1991; Forman, 1995).
In this thesis, landscapes are considered as mosaics that can be described on the basis of the habitat-corridor-matrix model developed by Forman (1995).

In 1963, the American H.T. Odum was the first to define the concept of ecological engineering as being: ‘environmental manipulation by man using small amounts of supplementary energy to control systems in which the main energy drives are coming from natural resources’. In 1983, Odum added the following emphasis: ‘the engineering of new ecosystems designs is a field that uses systems that are mainly self-organising’.

In the western world, Europe and the US, the emphasis lay on creating artificial swamp areas (constructed wetlands) for the purification of waste water, and the maintenance and restoration of nature reserves. The restoration of lakes by means of biomanipulation may also serve as an example of ecological engineering.

The first experiments in Western Europe and the United States date back to the sixties. Nowadays, there are now thousands of plant based systems to treat wastewater.

In the eastern world, like China, the emphasis lay on the development and management of production processes in combination with the management of the natural environment for the benefit of both. The knowledge obtained from ecological engineering has, moreover, been applied for a long time in different cultures. The Chinese fish-rice aquacultures have been known to exist for 2,000-3,000 years. In Europe as well, recycling techniques such as the use of compost have been used by especially agriculture.

From a nature conservation and nature development point of view, a great deal of knowledge has been obtained in the field of nature engineering from research into the functioning and management of nature reserves (Londo, 1997). The following scheme (Figure 1) indicates the position of nature engineering as well as ecological engineering as meant in this thesis.

As a result of man's far-reaching influence on the landscape, various forces have come into play that try to call a halt to or reduce the deterioration of nature.

As a result of serious fragmentation of the Dutch landscape and ecosystems by roads and other infrastructure, the intensification of agricultural use, the pollution of air, water and soil and the destruction of habitat locations and ecosystems, the discipline of 'nature engineering' as envisaged by Londo (1997) has been developed. However, we also see a broadening taking place, especially with regard to the co-ordination and linking of functions in the field of energy generation, food production, waste management and re-use, as well as in the field of civil engineering. Here, the objective is to use or improve functions of natural systems for the benefit of food production, the purification of waste water, the protection of land against floods whereby the proper natural values of systems remains as much intact as possible, as well as the application of technical knowledge (e.g., mitigating measures in the form of constructed fauna tunnels) in such a way that natural

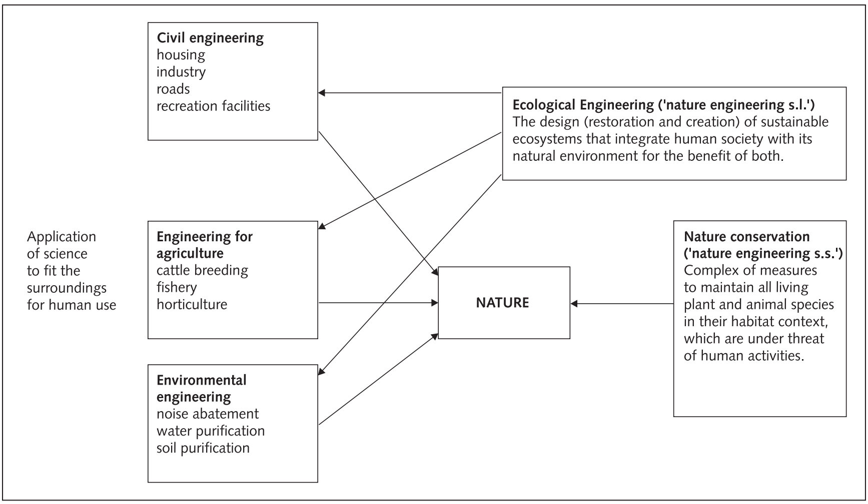

Figure 1. Various man-made techniques in relation to nature (after Londo, 1997; modified by Van Bohemen, 2002)

processes can continue as undisturbed as possible in the case of human interventions such as road building. The maintenance and promotion of the restoration of ecological functions in the form of compensating measures can also be considered an aspect of ecological engineering.

Environmental functions, according to De Groot (1992), are 'the capacity of natural processes and components to provide goods and services that satisfy human needs (directly or indirectly). Human needs may be divided in two main categories: physiological needs (need for O_2, water, food, health) and the psychological needs (opportunities for cognitive and spiritual development, recreation, safe future for both present and future generations)'. Daily (1997) distinguished ecosystem services, the conditions and processes through which natural ecosystems, and the species that make them up, sustain and fulfill human life, and eco-system goods (forage, timber, fuels).

In order to make a distinction between the significance of components, patterns and processes of ecosystems independent from man, and those in which man's dependence on ecosystems is expressed, the following categorisation may be useful:

- Ecosystem functions: functions that enable the life and survival of organisms and ecosystems for their own sake.
- Ecosystem goods: agricultural products, organic substances that can be used as construction material (wood, reed, reed-mace) and organic substances used for the generation of energy.
- Ecosystem services, for example water and major element cycles, supplying plant nutrition, decomposition, pollination, natural pest control, opportunities for recreation.

Mitsch (1991) provided a summary of synonyms for ecological engineering: synthetic ecology, restoration ecology, bioengineering, sustainable agro-ecology, habitat reconstruction, ecosystem rehabilitation, biomanipulation, river restoration, wetland restoration, reclamation ecology, ecosystem restoration, nature engineering. Ecological engineering uses (or is based on) ecology, both theoretical and applied. The emphasis is especially on the application of knowledge concerning the ecosystem theory (Odum 1963: Jørgensen & Müller, 2000). This means that a holistic approach is sought. In Figure 2 the wide spectrum of ecological engineering and ecosystem restoration is given in relation to the intensity of human input.

Ecological design and nature engineering in the broad sense contribute to partnerships between man and other life forms. Todd (1993) developed the concept of 'living machines': man-constructed living systems that can be used to produce fuels, to decompose and convert waste substances, to produce food and to integrate buildings into the natural world. The principles of ecological wastewater purification using constructed wetlands have for instance been derived from the ecology of water systems, while accommodating all levels of the food chain: bacteria, algae, higher plants, molluscs and fishes. Each of these plays its own specific role in the system (Todd & Josephson, 1996).

This applied field of science combines ecology and civil engineering because some situations require high-level technology for the sustainable operation of such systems. Ecological engineering centres on the restoration, design and construction of water and terrestrial systems, the restoration and management of nature reserves, and the ecologically sound harvesting of existing or to be reconstructed ecosystems (e.g. agro forestry). Bradshaw (1987) indicates the significance of ecological engineering as a test of many ecological theories: ‘the restoration of a degraded system is the acid test for understanding such a system.’

A distinction can be made between ecological engineering in a more narrow sense (nature-engineering measures for the benefit of the maintenance and development of species and systems) (natuurtechniek s.s.) and ecological engineering in the broader sense (in which the definition of Mitsch and Jørgensen (1989): ‘the design of ecosystems for the benefit of humans as well as the natural environment’ applies (natuurtechniek s.l.). Here the term ecological engineering is proposed for both approaches, as it makes manifest the (in)direct relations (or interconnectedness) between human actions and nature on a particular place in the course of time and can (re)connects us with natural processes in order to minimize negative environmental impacts and to protect biodiversity. Important elements in this connection are (Mitsch and Jørgensen, 1989; modified):

1. Based on ecological knowledge to understand short- and longterm processes and reactions of human influences.
2. Applicable, in principle, to all types of ecosystems in relation to human influence.
3. Civil-technical and design aspects usually make up important parts.
4. Economics should not be opposite of ecology. All ecosystem services should be

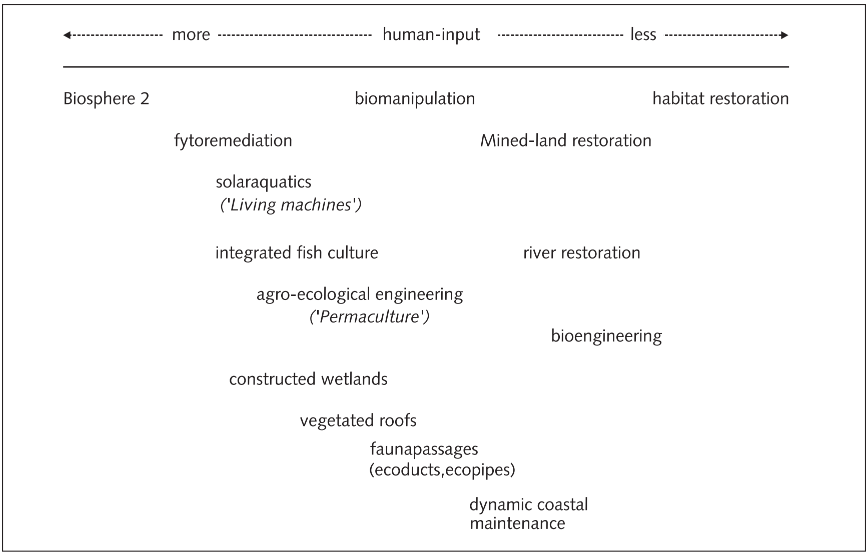

Figure 2. The spectrum of ecological engineering and ecosystem restoration (after Mitsch, 1991)

taken into account in economic evaluation, like cost-benefit analysis.

5. There is an ethics focused on the conservation and sustainable use of ecosystem services. The recognition of the value of ecosystems for human use (wastewater purification, dynamic coastal management, production of renewable raw materials, the possibilities to reduce adverse effects of human action on nature by the adoption of mitigating measures) creates a better awareness of the need to preserve ecological values, despite their long-known importance as habitats for plants and animals in such systems.

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A. Road Infrastructure and Ecological Engineering

In the next five chapters effects of design, construction and use of road infrastructure on the abiotic as well as the biotic environment will be described on the basis of original research carried out by or on behalf of the Road and Hydraulic Engineering Institute.

The possible mitigation measures to reduce the negative effects will be dealt with together with a survey of their usefulness seen from the viewpoint of the set goals.

We will further look how ecological engineering can play a greater role in the future in reducing environmental effects of roads and their use as well as optimizing the integration of road infrastructure in the landscape.

First the influence of road infrastructure and traffic on soil, water and air quality will be described, ecological research in roadside verges and the effects of fragmentation of nature by motorways and traffic and defragmentation activities will be shown.

In the form of an essay the history of integration of motorways in the Dutch landscape will be described, the development and use of design criteria and a contribution towards forming of a theory of integrating roads in the landscape will be given.

Finally in 'Infrastructure, ecology and art' a review of some case studies will give a different look about the possible options of incorporating road infrastructure in the landscape.

2. The Influence of Road Infrastructure and Traffic on Soil, Water, and Air Quality

H. D. Van Bohemen
W. H. Janssen van de Laak

Abstract
Polluting substances are spread as a consequence of the construction and use of roads. This chapter provides a summary of the substances with which traffic pollutes the environment on a local, regional and global level. The mechanisms of dispersion of pollutants to soil and groundwater are described. Based on environmental quality requirements established in rules and regulations in the Netherlands, the paper discusses mitigating measures necessary to limit the distribution of pollutants along highways. Most of the data come from original research carried out by or by order of the Road and Hydraulic Engineering Institute. For comparison, other data from the Netherlands have been included. It is shown that source-oriented measures (volume and technical) will have more effect on environmental quality than measures with regard to treating runoff. The use of porous asphalt instead of nonporous asphalt on highways in the Netherlands has environmental benefits. The chapter also pays attention to combined use of the roadside verges for treatment of runoff using ecological engineering techniques in the form of natural processes in helophyte filter systems in combination with enhancement of ecological values along highways.

Introduction
The combustion processes of vehicles and the wearing of vehicles, road surface degradation, wearing of signposts and crash barriers, and application of road maintenance chemicals (deicing salts) disseminate pollutants into the environment; some are spread diffusely while others are deposited in the immediate vicinity of the road. A distinction is made between air pollutants that originate in vehicle engines due to insufficient combustion, which results in the incomplete conversion of fuel into water and carbon dioxide (CO_2). These substances include nitrogen oxides, hydrocarbons, carbon monoxide, and fine particulate material. In addition there are substances that lead to contamination of soil and water closer to the road. These are heavy metals (such as Pb, Zn, Cu, Cd, Cr, Pt), mineral oil, and polynuclear aromatic hydrocarbons (PAHs). Herbicides, dead leaves, and other organic material (faeces, dead animals), waste, and all sorts of materials that fall from trucks (e.g., sand, gravel, soil, salt, chemicals, agricultural products) or after car accidents can also pollute the environment. The quantity of pollutants is determined by traffic intensity. Contamination data from other countries are hard or impossible to compare. The degree of lead application in petrol and the use of crash barriers can differ from country to country and from region to region. Water that runs off highways and off roads in residential areas can also differ in content. The runoff in residential areas contains more nutrients, and that from highways contains more PAHs (McElroy and others 1989). The next section discusses in more detail the quality of the runoff from highways and the factors that affect it.

The manner of spreading of pollutants depends on the quantity of rainwater and the distribution of rainwater over time, as well as the road surface material applied, i.e., DAB (closed asphalt concrete) or ZOAB (porous asphalt). In the case of ZOAB, some of the contaminants are retained in the pores. Heavy metals are present in or attached to particles and largely remain in the road surface (RIZA 1996).

Contamination with Gaseous Compounds, Heavy Metals, and PAHs Along Highways

Air Pollution Caused by Road traffic
Vehicle fuel is a mixture of hydrocarbons to which some compounds (dopes) have been added in order to improve combustion properties. In connection with the difference in emission, three fuel types are distinguished: petrol, LPG, and diesel. Incomplete combustion means that the exhaust fumes contain not only fully combusted products but also some air-polluting substances, even after passage through a three-way catalyst. The main air pollutants are NO_2, SO_2, CO, PAHs, benzene, and fine particulate material.

On 19 July 2001, a new administrative measure concerning air quality came into effect in the Netherlands. This measure is based on European Union directives, which gives a list of limit values for air pollutants and must be met by 2010. In order to achieve these limit values, plan thresholds for the years up to 2010 have been established in order to reach the limit value of 2010.

Fine particulate material and NO_2 are the substances exceeding the limit values along roads with high traffic intensity. NO_2 emission from traffic is a relatively important source of the total national NO_2 emissions. For fine particulate material, such transgression is structural, since the limit values are exceeded, in any case, by the background concentrations. For that reason an extensive survey into such particulate material is currently in progress. For NO_2 the general administrative measures for the years between 2001 and 2010 have a descending series of values, from 58 $\mu g/m^3$ on 1 January 2001 to 42 $\mu g/m^3$ in 2009.

A general administrative measure has ordered municipalities to survey the bottlenecks between air pollutants due to road traffic and the limit values and to draw up plans within three years specifying how the limit values can be satisfied in 2010.

Pollutants that contribute to long-distance air pollution will not be further considered in this chapter. They form part of the background pollution. Their impact can be local, but in most cases is regional or global.

Climatic conditions are essential in interpreting pollution from roads and traffic. Furthermore, the form of the pollutant is important. Fine material will remain in the air for long time and larger particulate material settle due to gravity.

Emissions of Heavy Metals and PAHs Due to Road Traffic and Presence of a Road

The main processes by which vehicles disseminate pollutants into the environment are combustion processes, the wear of cars (engine, tires, brakes) leaking of oil and coolants, and corrosion. Lead and PAHs are released in combustion processes, zinc is derived from tire dust (zinc is a catalyst used in the manufacture of tires), and copper is derived from the corrosion of radiators and brakes; the other heavy metals have mixed origins (Oostergo, 1997). Table 1 shows the emissions by road traffic in tons per year in the Netherlands based on a car fleet of six million vehicles.

In a survey of a water extraction area near Arnhem, a very extensive study was made of pollution components originating from road traffic. The result was as expected, i.e., some heavy metals, mineral oil, and PAHs were found. Although other substances were also found, these could not be traced to road traffic

Table 1. Calculated indication of emission of heavy metals and PAH by car traffic per emission source (tons/year) (Oostergo, 1997).

Contamination	Exhaust	Oil leaks	Tires	Brakes	Radiator	Total
Arsenic	0.17	0.015	0.013	0.004		0.199
Cadmium	1.2	0.002	0.73			1.932
Chromium	1.7	0.014	2.6	0.518		4.832
Copper	0.25	0.061	3.65	9.072	50.910	63.943
Lead	240	1.96		0.022	0.072	242.054
Nickel	1.7	0.007	2.48	0.285	0.192	4.664
Zinc	2.3	1.49	175	0.117	0.168	179.075
PAH-10	187	2.32	1	0.004		190.324

(KIWA, 1998). The nongaseous pollutants are strongly bound to dust particles or aerosols. Depending on the size of the particles to which the dust substances are bound, they will be distributed closer to or further from the road. Some of the substances settle on the road surface, and some are blown into the immediate vicinity of the road. Figure 1 shows the distribution of pollutants.

Substances can also remain in the air for a long time before being deposited. During rain, substances will be brought to the ground, while in dry periods the substances will stay and be transported in the air.

Distribution of Pollutants

Pollutants can be distributed and deposited in the environment in various ways (Figure 1): via the atmosphere, in the form of wet or dry spray and deposition, and in the form of road runoff. At the beginning of the 1990: the Road and Hydraulic Engineering Institute (Boland, 1995) studied distribution by wind and runoff of heavy metals and PAHs on both DAB and ZOAB roads with different traffic intensities. At the locations concerned, pollutant mass flows into the immediate environment of the road due to traffic were studied.
Table 2 shows the outcomes of the mass-flow surveys for the locations studied. Climatic conditions play an important role in the way of spray and deposition; in wet periods road runoff will be important and under dry conditions spray will dominate.

Atmospheric deposition.
Atmospheric deposition occurs when pollutants are spread by the air and settle on or in the soil. This flow of pollutants is also regarded as diffuse soil pollution and has mainly impacts on the atmospheric environment before they settle (long-distance atmospheric spray). Sources of atmospheric deposition include industry, traffic, refineries, power plants and waste-processing companies. The substances may remain in the air for a longer period of time and move over larger distances before they settle. That is the reason why approximately 60%-90% of atmospheric pollution, depending on the type of pollutant, originates abroad. Lijzen and Ekelenkamp (1995), based on data from 1990, provide a summary of soil pollution by heavy metals from atmospheric settlement in tons per year (Table 3).

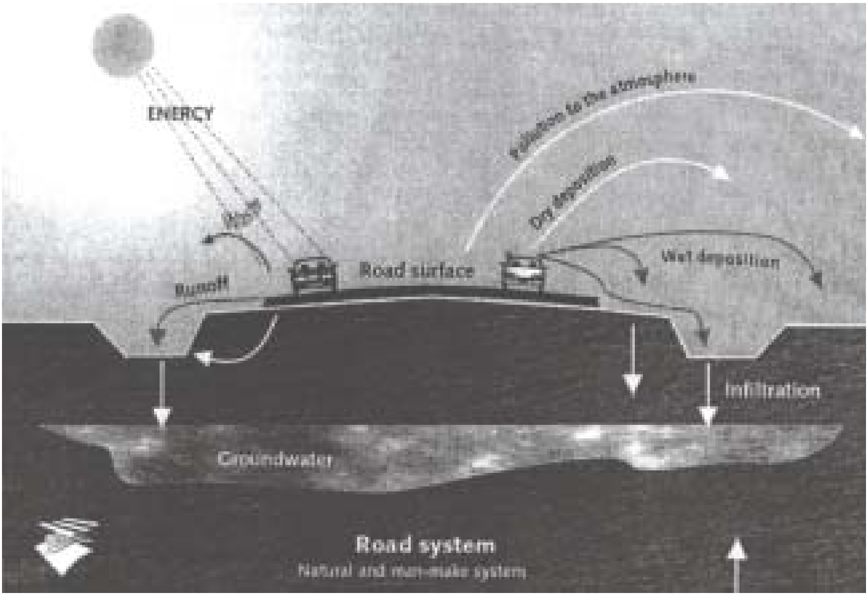

Figure 1. The emission and immision patterns of pollutions from road and traffic (Source: DWW/Delft).

Spray by wind along highways as a source of pollution.
There is spray by the wind if substances whirled up by traffic or wind are transported by the air and land elsewhere; spray can be dry or wet. In the case of dry spray, the particles spread in a dry condition; in the case of wet spray, they spread due to splashing and the vaporizing of rainwater. In both cases, a large part lands on or in the immediate vicinity of the roadside (Boland 1995). Figure 2 shows the average spray of PAH-10 (the ten main PAHs) by spray at various locations as a function of distance from the road. The deposits by spray at locations with ZOAB are much smaller than in the case of roads with DAB.

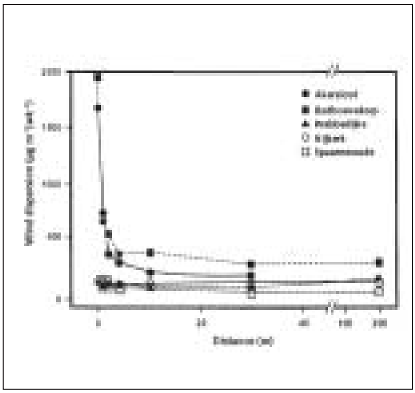

Figure 2. Average deposition of sum-PAH-10 by wind dispersion at various research locations as a function of the distance from the road (Boland, 1995).

Runoff as a source of pollution.
Water that runs off a road surface can convey

Table 2. Mass flows of PAH and heavy metals by spray and runoff (Boland, 1995; Wijers et al., 1994) (data Zeist 1999 from Erisman et al., 1999)

	DAB						ZOAB					
Location	Akersloot		Badhoevedorp		Krabbendijke		Nijkerk		Spaarnwoude		Zeist	
Period	Jul 88/feb 90		Oct 90/Feb 91		Oct 91/Mar 92		Nov 92/Mar 93		Nov 93/Mar 94		Jun 99/Nov 99	
Intensity	47,000 cars/day		74,000 cars/day		21,000 cars/day		39,000 cars/day		78,000 cars/day		90,000 cars/day	
	spray	runoff	spray	runoff	spray	runoff	spray	runoff	spray	runoff	spray	runoff
PAH												
NAF	28	2	38	6	23	9	15	1	1	1	0	3
FEN	692	16	675	54	253	130	588	4	124	10	3	13
ANT	55	0	60	10	17	13	17	0	17	2	0	2
FLU	1091	34	121	224	412	168	747	8	189	19	5	7
BaA	209	11	89	60	58	91	58	2	20	4	0	9
CHR	201	16	340	98	100	125	151	3	50	6	2	9
BKF	86	9	69	20	24	152	44	2	58	8	1	2
BaP	153	22	108	6	24	165	43	3	27	1	1	4
BPE	229	11	233	100	110	110	74	5	39	11	1	5
INP	541	11	164	180	59	159	96	4	42	8	2	1
Sum	3285	132	3027	758	1080	1122	1831	32	567	76	11	54
Heavy metals												
Chromium	2.2	0.2	2.8	1.0	1.4	1.3		0.2	0.2	0.2	0.3	0.5
Zinc	44.0	12.0	43.0	46.0	39.0	30.0		3.1	1.3	3.5	5.7	4.5
Lead	25.0	2.4	33.0	12.0	26.0	8.8		0.9	0.7	0.2	0.9	3.3
Cadmium	0.5	0	0.3	0.4	0.1	0.4		0	0	0	0	0.1
Nickel	1.3	0.2	1.6	1.5	0.6	1.8		0.4	0	0	0.2	0.5
Copper	7.4	2.1	10.0	6.7	8.3	7.5		1.2	0.6	0.7	1.3	1.7

* Measured at various locations and expressed in mgr/week/m road length/roadhalf for heavy metals and µg/2 weeks/m road length/roadhalf for PAH.

Table 3. Soil pollution by heavy metals from atmospheric settlement (tons/yr) (Lijzen and Ekelenkamp, 1995)

	Cadmium	Chromium	Copper	Nickel	Lead	Zinc	Arsenic
Atmospheric settlement	3.5	12.9	16.0	24.1	150	410	13.2

some of the pollutants in a dissolved or suspended form to the roadside. Most metals and almost all PAHs are bonded to the silt that is flushed off roads. The quantity of rainwater that runs off varies between 20% and 80%. The runoff depends on the degree of evaporation, spray and pool formation, type of road (inclinations), and especially the type of road surface used (DAB, ZOAB). When running off, the rainwater dissolves particles and soluble substances; approximately 6%-9% of the total dissolved substances originate from the rainwater itself. Table 4 provides a summary of the quality of the runoff from the various types of roads, and the quality of rainwater.

It is expected that the composition of the road runoff during runoff is not constant. High concentrations of dangerous substances in runoff are formed especially in the first flush after a dry period (Fritzer 1992), because then buffered pollutants run off the road surface more quickly. Generally speaking, it is expected that the effects of the first flush are much stronger in hilly areas than in flat areas. Currently, however, Dutch specialists have different ideas about the degree to which first flush plays a role. It is expected that during comparable showers of rain, the first-flush effects on ZOAB roads are less pronounced than on DAB roads.

This is because the open structure of ZOAB leads to considerable delays in runoff. In dry periods it is expected that the road surface becomes increasingly polluted. The scientific theories, however, point in another direction. The line of thought behind this is that although the road surface is polluted, at the same time it is depolluted by traffic, which “rides off” the pollution. Each time, a type of ceiling is reached, above which further pollution will not take place. RIZA (1996) obtained a picture indicative of the pollution effect by measuring the road water quality after a 7-week dry period. In the case of DAB roads, for some substances there was slightly more pronounced pollution than for ZOAB. After a long period of dry weather, however, the pollution was no more pronounced. The results are given in Table 5. Ongoing surveys along the A12 near Bunnik will provide more insight into the first-flush effect.

Without diversions, rainwater runs off onto the roadside. Direct runoff to surface water was looked into in a study in the western part of the Netherlands involving six provincial roads (Tauw and Omegan 2000). From this study it appears that the average quantity of runoff that reaches the ditch generally ranges between nil and 0.5%. In the summer period - or at least in the period that has relatively high grass vegetation - the quantity of runoff that reaches the ditch is nil. In the winter period, runoff into the ditches is 0.2%-0.5%. During heavy rain showers, the runoff can be higher for a brief period. Since highways generally have broader verges than provincial roads, it may be assumed that in the case of highways the direct runoff from the road to the surface water is nil.

In special situations it is necessary to collect and drain rainwater, especially from the viewpoint of traffic safety (for instance, near junctions), for hydraulic reasons, or in drinking water winning areas. In many cases such collection occurs via a drainage system discharging into the roadside ditches, but other solutions are also possible.

The main aspect of this manner of collection is that apart from evaporation and wind spray, an important part of the runoff enters the surface water via a point discharge.
Furthermore, we have to realize that the results of analyzing measurements depend strongly on the measurement method used (Erisman and others 1999).

Several factors can influence the distribution of pollutants. In the context of roads, there can be the influence of the road surface, the effect of rainwater and traffic intensity, the effect of noise screens, and the effects of plantings. Some of the effects will be described below.

Influence of road surface on distribution.
On DAB, the water flows off the surface and onto one or both sides of the road (depending on the cant) while directly carrying pollutants to the roadside. In the case of ZOAB, rain drains into the pores (the top 1-4 cm) and via these pores runs off to the roadsides. Some of the pollutants remain within the pores in the road surface, especially on the hard shoulders (RIZA, 1996 and Berbee et al., 1999). The road

Table 4. Quality of runoff for highways (national roads), motorways (provincial), and muncipal roads (Anonymus, 1998, 2000, 1995; KIWA, 1998; CIW, 2002)

	Highway		Motorway		Muncipal road		
Contamination	DAB	ZOAB	N-S-Holland DAB	La Cabine DAB	Lelystad DAB	Breda DAB	Rainwater
Suspended solids (mg/liter)	153 - 354	2 - 70	49 (5-300)		90	150	
NO_x N (mg/liter)	0.5 - 0.9	1 - 2		1 - 26	0.91		
N-Kj (mg/liter)	1 - 2	1 - 2			2.7		
COD (mg/liter)	143 - 149	16 - 18			78		
BOD (mg/liter)	6	1			5	8.7	
Cadmium (µg/liter)	1 - 5	0.1 - 1	0.7 (0.1-6.5)	<0.4 - 0.52	1.6		0.2
Chromium (µg/liter)	3 - 26	0.4 - 3	12 (1-47)	<2 - 14.8	16		0.5
Copper (µg/liter)	11 - 163	14 - 107	37 (2-160)	22.8 - 140	49,8		2.0
Nickel (µg/liter)	4 - 15	1 - 9	5 (1-21)	<10			0.6
Lead (µg/liter)	51 - 195	2 - 34	18 (5-110)	<10 - 100	342,5*	10	4.6
Zinc (µg/liter)	225 - 530	18 - 133	152 (22-700)	111 - 313	247,5	135	15
Oi1 (mg/liter)	3 - 8	<0.1 - 0.2	0.5 (0.025-2.7)	0.55 - 1.2	4.1	0.58	<0.1
PAH (VROM) (µg/liter)	3.7 - 4.3	<0.2 - 0.2	0.9 (0.0-5.3)	0.43 - 1		2.5	0.4

** measured in 1980 when Pb-containing petrol was still in use.*

Table 5. Composition of runoff from highways after a long dry period (RIZA,1996)

	DAB		ZOAB	
Substance	Normal	After 7 weeks of dry weather	Normal	After 7 reeks of dry weather
Suspended solids (mg/liter)	153 - 354	181	2 - 70	53
N-kj (mg/liter)	2 - 3	6.5	0.3 - 0.5	4
COD (mg/liter)	146 - 149	200	16 - 18	89
Oil (mg/liter)	3 - 8	2.7	<0.1 - 0.2	0.8
Copper (mg/liter)	91 - 163	129	14 - 107	53
Lead (mg/liter)	51 - 106	86	2 - 22	18
Zinc (mg/liter)	225 - 493	590	18 - 133	49

top of the traffic lanes remains open by the water-pumping effect of car tires. There is, therefore, a buffering effect in the road surface. The quantity of rain that runs off is also limited due to the open structure, which leads to rapid evaporation of the rainwater. It is, however, necessary to keep the structure open, and therefore, in particular, the hard shoulders should be periodically cleaned. In addition, the quantity of rainwater that usually runs off to the verges appears to be much smaller than in the case of DAB. Due to evaporation, in the case of ZOAB, an average of approximately 20% of the rainfall will run off, whereas for DAB this is approximately 80%. In the case of ZOAB there is also less wind spray, which makes the ratio between the mass flows from spray and runoff differ for ZOAB as compared to DAB. Figure 3 presents this ratio for ZOAB and DAB.

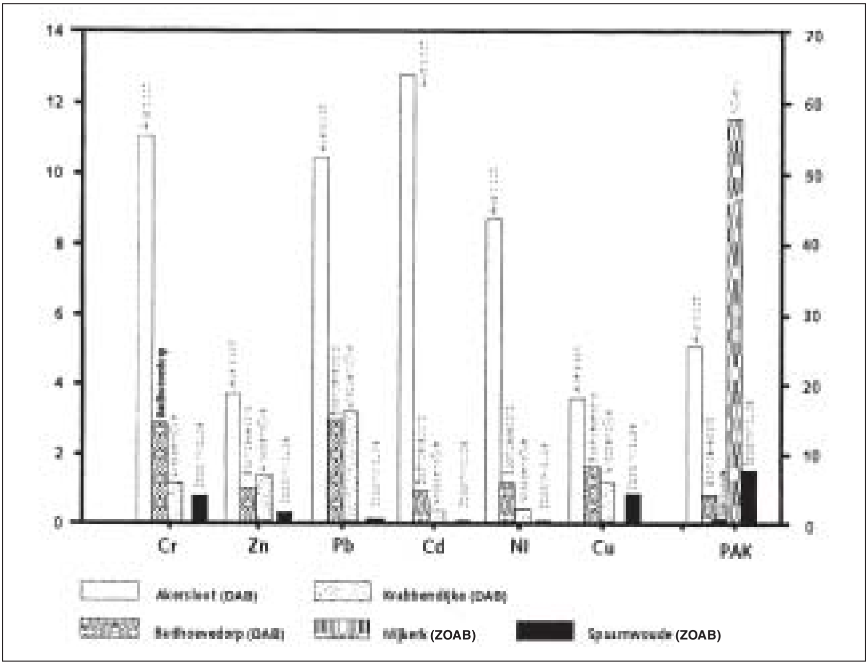

Figure 3. The ratio between mass fluxes of wind dispersion and runoff for heavy metals and PAH-10 at the various research locations (Boland, 1995; Wijers et al., 1994).

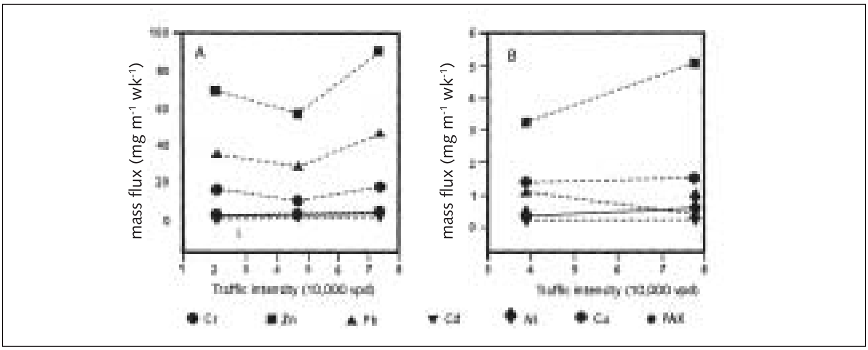

Figure 4. The total mass fluxes of the various substances as function of traffic intensity (Wijers et al., 1994).

Effects of rainwater and traffic intensity.
From correlation analyses, it appears that there is no statistical correlation between the deposition of substances and the amount of rainfall. The largest part of the runoff mass flows correlate with the quantity of rain, but this does not apply to spray. Dry spray appears to make up an important part of the deposition. A doubling of traffic intensity appears to lead to a much smaller increase in the deposition. Figure 4 shows the results of studies into the relationship between deposition and traffic intensity.

Effect of noise screens.
From surveys made of the distribution of pollutants around the noise screen near Nieuwegein, it appears that the screen has a markedly concentrating effect on the deposition of pollutants (Erisman and others 1999).

Effect of plantings.
As stated, 70%-90% of pollutants are distributed by spray. The planting of trees and scrubs (wind hedges) limits the spreading of contaminants by spray. The contaminant or pollutant is not removed, but leads to extra pollution of the zone between the road and the plantings. There also is the impression that there is more pollution directly behind the planting and less at a greater distance. Further surveys by the Province of Utrecht done in cooperation with the Ministry of Transport along two provincial roads will be carried out to get more detailed information about these processes.

Emissions from Road ''Furniture" and Road Surfaces
In addition to settlement from road traffic, zinc, which originates from road ''furniture" (e.g., crash barriers and, to a lesser degree, road signs and road portals), is an important source of pollution. In situations with crash barriers, there is a strong increase of zinc concentrations in the runoff. The degree of pollution depends especially on the corrosion speed, about which there are various estimates (28-50 g/m^2/yr) . Calculations for 1996 indicate that the emission can be estimated at 63-82 kg zinc per year per kilometer of highway (Recent measurements show a decrease in corrosion speed (Korenromp and Hollander, 1999)).

The material that makes up the road surface can also erode and end up in the environment. Under normal circumstances, road surface wear is up to 0.04 mm of asphalt per year, due to vehicles driving over the road surface, which leads to tracks that start to fray. Lijzen and Franken (1994) have made calculations of the emission of heavy metals expressed in kilograms per hectare of road surface per year. Table 6 gives the emissions of road surface asphalt in kg/ha road surface per year. Leaching of chemicals due to weathering of roads can occur, especially when road construction contains secondary material.

Means and Materials of Winter Maintenance

Other possible sources of pollution are the means and materials (deicing salt) of winter maintenance. Compared to other sources, this contamination by heavy metals is very limited, however. Lijzen and Franken (1994) calculated the emission of heavy metals expressed in kilogram per hectare of road surface per year. Table 7 gives some figures of heavy metal emissions due to means and material of winter maintenance.
De-icing salt contains highly soluble NaCl, and chloride is very mobile. Soil and groundwater can become brackish in winters with a lot of snow and ice. Furthermore, plants adopted to brackish situations can become established. In case of ZOAB, deicing salt is a bigger problem.

Because of the open pores, ZOAB requires more salt in periods of black ice during wintertime. In the relatively mild maritime climate in the Netherlands these disadvantages are more or less accepted.

Road Accidents, Litter, Leaks, and Herbicides and Pesticides

Chemicals can spread into the environment due to car accidents. Although highly unpredictable in nature, the effects can be serious, depending on the chemical compounds involved. Solid litter may or may not break down, and leaks from vehicle lubrication and hydraulic systems can also cause pollution. In the Netherlands the policy is to use weedkillers or other chemicals along highways for maintenance purposes only in exceptional situations.

Quantity of Pollutants in Verges and in Verge Ditch Bottoms

Depending on the pollutant and the properties of the soil, the pollutants will bond to the soil (accumulate) or percolate into the soil and end up in the groundwater. If the soil becomes saturated with pollutants, they may percolate into to deeper parts of the soil and, in the long to very long term, into the groundwater.
In various studies (DWW, 1990) the quantities of pollutants in the soil and in the groundwater along highways have been determined. From the results it is apparent that the contamination is especially present close to the road and to a depth of approximately 40 cm. At a distance of approximately 10 m from the road, the quality of the soil is comparable to the background quality of the soil. In the top layer of the soil, in the case of older roads with DAB (20-25 years) the concentration of single substances (Pb, Zn, PAH) usually exceeds the target value, and in some cases even the intervention values.
Along highways with ZOAB, the concentration will be less and an exceed of the target values shall be reached in a much longer time due to accumulation of pollutants within the porous asphalt.

In groundwater only Cr was found to exceed the target value. Furthermore, target values were found to be exceeded of only in very specific situations, with a soil having a low pH, as found in North Brabant (low pH increases the mobility of ions in the soil). Tables 8 (A2) and 9 (A27) illustrate data of spreading of pollutants at various depths and various distances from the DAB roads. The A2 is older than the A27 and the A27 shows a relatively low accumulation.

Investigation of polluted sediments in ditches along highways gives the following results. The Rijkswaterstaat Directorate for South Holland has carried out extensive surveys (RWS, 1991) about the quality of polluted sediments of roadside ditches. Distributed over the province, a total of 56 of roadside ditch bottoms were sampled. The results of the analyses were compared to the then-applicable standardization systems and led to the following conclusions. According to an estimate, approximately 100,000 m^3 of sediments from roadside ditches in South Holland will need to be disposed of.
This quantity is divided into four quality classes, ranging from clean (class 1) to seriously polluted (class 4) .

There is now a new classification system. The result is 30% in class 1 , 55% in class 2, 12% in class 3 and 3% in class 4. Class 4 is contaminated or polluted to such a degree that it must be dumped under controlled conditions. The substances that determine class 4 are contaminated with PAHs; in addition, oil, lead, copper, and zinc are found to an increased degree in some of the samples.

Table 6. Emissions of some heavy metals and PAH from road surface asphalt (Franken, 1994)*

	Cadmium	Chromium	Copper	Nickel	Lead	Zinc	PAH-10
Asphalt	0.000	0.082	0.004	0.039	0.004	0.014	0.217

*Values are kg/ha road surface/yr.

Table 7. Emissions of heavy metals from material of winter maintenance (Lijzen and Franken, 1994)*

	Cadmium	Chromium	Copper	Nickel	Lead	Zinc	Arsenic
Deicing salt	<0.004	<0.16	0.36	<1.12	<0.20	0.52	0.048

*Values are in kg/ha road surface/yr.

The quality of the bottom of roadside ditches depends on the manner of road drainage and on the distance from the road. Roadside ditches into which a road drainage pipe opens contain sediment of a worse quality than roadside ditches where this is not the case.
In the case of roadside ditches that do not have a drainage pipe and are located more than 15 m from the road, there is hardly any pollution, and the sediment is practically always of class 1. In ditches situated within 15 m of a road, sediment of class 2 and, to a lesser degree, class 3 is found. No correlation was found with other environmental factors, such as traffic intensity, type of soil, or dredging frequency.

Accumulation and Mass Balances

Accumulation.
At the beginning of 1990, the A58 south of Breda was opened for traffic and provided a good opportunity to study the dispersion and accumulation of pollutants from the opening of a highway. The zero situation concerning the pollution status of the soil in the roadside and the groundwater was established just before the road was opened, and then measurements were made at 6 months and 1, 2, 4, 7, and 10 years after the opening of the highway. From the measurements taken in the autumn of 1999 (10 years after the road was opened), it appears that the percentages of heavy metals, oils, and PAHs vertically as well horizontally, do not substantially deviate from the percentages during the zero measurement. It therefore appears that hardly any accumulation has occurred; the amounts fluctuate around the target values (Marinussen, 1999). This is a road surfaced with ZOAB.
The NUON drinking water company had a study done (De Jonge and others, 1999) of the effects of infiltration of collected runoff from a provincial road in two low spots (pools) on the quality of the soil and on the groundwater within the water extraction area. This study showed that in deeper groundwater usually no pollutants can be demonstrated to exist. The risk for effects on unprocessed potable water extraction quality appears to be slight in the situation studied. However, it was found that in the two infiltration pools studied, the target values and, incidentally, the intervention values for certain substances were exceeded. In the runoff and in the pool bottom, this sometimes applies to Pb and Zn. In the splash water, slight exceedences of the target values were found. Higher concentrations of Pb may also be due to higher pollution levels in the past.
In the case of the verge soil, the residence time and the traveling time through the bottom appeared to be considerable. Since the half-life of many organic compounds is on the order of days or months and that of PAHs is on the order of a year, it may be expected that such

Table 8. Environmental quality of verges at various depths and distances from A2 road (Utrecht-Amsterdam) (DWW, 1990)

Distance to road surface (m)	Depth boring (cm-mv)[a]	Cadmium (mg/kg)	Chromium (mg/kg)	Copper (mg/kg)	Nickel (mg/kg)	Lead (mg/kg)	Zinc (mg/kg)	Arsenic (mg/kg)	PAH-10 (mg/kg)
0.6	0 - 5	2.0 *	25	111 *	24	600 **	590 *	5.0	5.7 *
	25 - 35	1.6 *	64	24	10	120 *	170 *	2.9	3.5 *
	95 - 105	<0.1	6	3	6	<10	13	1.8	0.2
2.0	0 - 5	1.8 *	30	91 *	25	600 **	495 *	5.5	6.7 *
	25 - 35	0.6	32	24	20	80	120	9.0	14 *
	95 - 105	0.5	34	21	22	125 *	110	9.0	17 *
4.0	0 - 5	1.2 *	30	46 *	19	280 *	235 *	8.0	11 *
	25 - 35	0.7	32	24	19	135 *	130	8.0	36 *
	95 - 105	0.4	52	28	34	55	100	14	3.9 *
10.0	0 - 5	1.0 *	42	70 *	32	260 *	195 *	11	2.6 *
	25 - 35	0.3	67	41 *	44 *	120 *	155 *	18	2.2 *
	95 - 105	0.3	53	28	39 *	25	87	14	0.2
200	0 - 5	0.9 *	66	105 *	34	85	200 *	20	1.6 *

[a]cm-mv: cm below ground level. * indicates > target value; ** indicates > intervention value.

Table 9. Environmental quality of verges at various depths and distances from A27 road (Utrecht-Hilversum) (DWW, 1990)

Distance to road surface (m)	Depth boring (cm-mv)[a]	Cadmium (mg/kg)	Chromium (mg/kg)	Copper (mg/kg)	Nickel (mg/kg)	Lead (mg/kg)	Zinc (mg/kg)	Arsenic (mg/kg)	PAH-10 (mg/kg)
0.6	0 - 5	0.5	9	35	6	170 *	75	3.6	1.0
	25 - 35	0.1	4	4	3	15	20	2.1	0.1
	95 - 105	<0.1	3	<1	<1	<10	6	0.6	<0.1
2.0	0 - 5	0.4	8	26	3	210 *	52	2.5	0.9
	25 - 35	0.1	6	8	1	40	18	2.3	0.1
	95 - 105	<0.1	4	2	<1	<10	6	1	0.1
4.0	0 - 5	0.3	8	18	1	140 *	41	2.6	0.4
	25 - 35	0.1	7	12	<1	50	19	2.6	0.2
	95 - 105	<0.1	3	<1	<1	< 10	2	0.5	<0.1
10.0	0 - 5	0.2	8	21	3	120 *	34	4.0	0.3
	25 - 35	0.3	10	28	<1	15	59	7.0	0.3
	95 - 105	0.2	2	<1	4	75	3	3.2	0.1
200	0 - 5	0.2	5	10	1	50	13	2.7	0.1

[a]cm-mv: cm below ground level. * indicates > target value.

substances will largely disappear. In the situation studied, the computed quantity of runoff was 0.2% of the total quantity of groundwater extracted each year, which would mean a very slight contribution if there were no adsorption or degradation. The risk in this case is therefore limited by adsorption, degradation, and dilution. The conclusion was that the water extraction was not at risk at all. From this research it becomes apparent that even in the case of a concentrated collection of runoff and infiltration at a local point in the soil, accumulation of pollutants is a very slow process.

Mass balances on national and local scales. Mass balances provide an understanding of the scope of environmental problems caused by various substances. By making visible all known emissions and immersions in the various environmental compartments, a picture is created of the distribution route and the possible gaps in our knowledge thereof. The scale on which the mass balances are drawn is important. An emission on a national scale, which, compared to other sources, is not that big, can have important effects on a local scale. In order to evaluate a mass balance on the national scale, the emission of road traffic must be compared to the emission of other polluting activities. Table 10 indicates the main sources of heavy metals and PAHs in tons per year in the Netherlands in 1999. The emission is given for the three compartments - air, water, and bottom. (For the detailed emissions by traffic arranged by specific parts of the vehicle, see Table 1.)

In order to make statements about the contributions of the mass flows along motorways to the total emissions of car traffic, based on the results of studies made at five locations, the total deposition pollutants of highways was calculated in tons per year. The results are listed in Table 11. This table also includes the calculated emission by car traffic and the deposition along highways as a percentage of the emission by car traffic. From the table, it can be seen that only a small percentage of the total emission by car traffic is due to deposition from highways on the verges (15% for chromium and only 0.2% for PAH). Erisman and others (1999) stated that: “From computations of the mass balance it appears that only less than l% of the emission of heavy metals in the runoff and the deposition winds up in the first 50 metres of the road, the rest is spread over a much larger area. It must be taken into account that a large part of the emission by car traffic is spread diffusely and contributes to the background deposition of heavy metals and PAHs. Measures to reduce the deposition along highways would therefore contribute very little to reducing emissions on a national scale.”

The mass balance given is a moment in time. Due to the increase in road length, the adaptation of the type of asphalt, and the increase in traffic, the pollution level can increase or decrease due to adaptations in the engine and car parts. Changes in the applied technology also lead to a decrease of certain substances (for instance Pb and Cu) and an increase of other substances (Al, Sb, Ni, Ti). The emission of Pb was reduced by reducing the number of cars that use leaded petrol. In radiators, more Al is used than Cu; Sb, Ni, and Ti are used in brake linings rather than asbestos. PAHs are on the decrease due to the introduction of three-way catalysts. The catalysts, however, do lead to contamination with Pt.

An example of a mass balance on the local scale is a roadside. Such a mass balance describes the flows of substances between the various local compartments: soil, groundwater, and surface water. Table 12 shows the results of a model calculation in qualitative form.

Table 10. Total emissions (tons/yr) of important social activities in the Netherlands in 1999 (CBS, 1999)

	Chromium	Zinc	Lead	Cadmium	Nickel	Copper	PAH-10
Industry							
Air	2.38	63.5	27.5	0.86	2.03	4.01	196
Water	31.3	62.6	13.8	0.35	32.5	35.7	0.15
Bottom soil	58.7				26.1		
Oi1 refineries							
Air	1.28	0.001	0.16	0.003	37.5	0.40	0.08
Water	0.014	0.176	0.003	0.001	0.335	0.24	0.001
Agriculture							
Air	0.015	0.035	0.014	0.001	0.389	0.011	75.8
Water	0.003	4.31	34.4			0.007	0.585
Bottom soil	65	2240	30.6	5	86	780	3.84
Waste incineration							
Air	0.192	0.167	0.196	0.053	0.451	0.111	0.168
Water	1.5	3.79	0.54	0.05	1.31	0.527	0.016
Bottom soil	1.16	2.32	0.435	0.092	0.774	0.310	
Traffic							
Air	1.37	22.3	4.76	0.03	10	29.4	255
Water	0.521	140	7.37	0.024	0.555	25.8	10.4
Bottom soil	0.611	150	2.11	0.031	0.72	4.37	3.75
Consumers							
Air	0.015	4.76	2.50	0.058	0.278	10.5	118
Water	3.11	212	73.6	0.779	7.79	136	0.509
Bottom soil	0.013	3.51	26.3	0.003	0.033	26.4	3.64

Description of Some Available Models for Estimation of Mass Balances

The behavior of contaminants in the soil is a complex process. In order to make an indicative description of the dispersion between the various soil layers, groundwater, and surface water, it is possible to use some models. Below are described three examples of models which are in use.

One-dimensional box model.
The methodology used for the results computed in the given local mass balance computation (see above) is a 1-dimensional box model. It has been described and compiled in the modeling environment STEM developed by Resources Analysis (Delft, the Netherlands). It has four compartments: a top layer with a high percentage of organic substances, a sand layer, a layer saturated with shallow groundwater, and a compartment with surface water.

The model simulates a square meter of roadside. This receives a quantity of rain that is constant over time and within it is a background percentage of contaminant.
The deposition from the road by wind dispersion and runoff also is constant. The model is intended as a theoretical experiment and not as a predictive model. The results should be interpreted in that line.

Most contaminants end up in the ground- and surfacewater and top layer. The high contents in the surface water may be overestimated due to the structure of the model (DWW, 1995).

Table 11. Calculated total deposition (spray + runoff of highways (tons/yr). The calculated emission by the car traffic (Oostergo, 1993) and the deposition alongside highways as a percentage of the emission by the car traffic have also been included.

	DAB (mean + SD)[a]	ZOAB (mean + SD)[b]	Total (mean + SD)	Emission	%
Chromium	0.625 ± 0.154	0.016 ± 0.007	0.641 ± 0.0161	4.31	14.9
Zinc	15.045 ± 3.506	0.238 ± 0.076	15.283 ± 3.582	178.95	8.5
Lead	7.537 ± 1.864	0.033 ± 0.031	7.570 ± 1.895	242.03	3.1
Cadmium	0.119 ± 0.025	0.001 ± 0.000	0.120 ± 0.026	1.93	6.2
Nickel	0.489 ± 0.175	0.032 ± 0.016	0.522 ± 0.191	4.38	11.9
Copper	2.953 ± 0.827	0.075 ± 0.005	3.028 ± 0.832	54.87	54.5
PAH-10	0.333 ± 0.090	0.037 ± 0.091	0.0370 ± 0.181	190.32	0.2

[a] Basis is 2028 km DAB highway; calculation: x mg/m/week * 2028 * 2 (roadsides) * 52 (week) * 10^{-9}.
[b] Basis is 572 km ZOAB highway; calculation: x mg/m/week * 572 * 2 (roadsides) * 52 (week) * 10^{-9}

Table 12. Results of mass balance model calculation of a roadside (qualitative indications)[a] (DWW, 1995)

	Zinc	Lead	Copper	Naftalene	Fluoranthene
Top layer	00	0000	00	000	0000
Sand layer	0	0	0	00	00
Groundwater	000	0	000	000	000
Surfacewater	0000	0000	000	00	0

[a] 0: small accumulation; 00: moderate accumulation; 000: considerable accumulation; 0000: very considerable

ECOSAT.
ECOSAT is a computer program developed by Landbouw Universiteit (Agricultural University) in Wageningen, in which a 1-dimensional model is used to compute the accumulation and distribution of contaminants in the soil. For the model computations, the following aspects and others must be established as a basis: (1) the quantity of infiltrating rainwater derived from the road surface, (2) the concentrations of the pollutants/contaminants in the runoff, and (3) the behavior of the pollutants in the soil. The soil properties, that must be entered in the model are very important.

CSOIL.
The CSOIL model is frequently used in practice to compute both potential and acute exposure, and thereby to estimate the risk of damage to the environment and to human health. The model was developed by the Dutch Institute for Human Health and the Environment (RIVM) and is extensively described by Van de Berg and Roels (1991).
The model was developed as a policy instrument for deriving intervention values. All things considered, it is less suitable for the full computation of any exposure of man in a single standard situation and thus also the estimation of the risk involved. In this connection, it is only well suited for estimating the exposure via intake, since it consistently overestimates the intake of soil containing pollutant substances, so that its statements concerning the exposure risk are relatively safe.

Table 13. Target and intervention values for soil and groundwater (Anonymous, 1991/92 and 2000)

	Soil (mg/kg dry substance)		Soil water (µg/liter dissolved)		
			Target value		
	Target value	Intervention value	Shallow	Deep	Intervention value
Arsenic	29	55	10	7.2	60
Cadmium	0.8	12	0.4	0.06	6
Chromium	100	380	1	2.5	30
Copper	36	190	15	1.3	75
Mercury	0.3	10	0.05	0.01	0.3
Lead	85	530	15	1.7	75
Molybdenum	0.5	200	5	3.6	300
Nickel	35	210	15	2.1	75
Zinc	140	720	65	24	800
PAH-10	1	40	-	-	-
Mineral oil	50	5000	50	50	600

Environmental Quality Standards for Soil, Water, and Air

In the Dutch National Environmental Plan-3 (NMP-3) (Ministry of VROM 1997), dispersion means the contamination of soil, water, and air and the immediate living environment by substances. The contaminants that are released by traffic are also covered in this topic. For environmentally dangerous substances, environmental quality standards have been developed based on risk computations made by RIVM and on the most recent scientific research. The environmental quality norms are published in the memorandum "Integral Standardization for substances." In this context these are target values and MTR values (MTR = maximum allowable risks). The MTR values for surface water have been established. For soil and groundwater, the MTR values have already been scientifically founded, but not yet been established on a policy level.
In NMP-3, the following policy objectives have been stated for the environmental quality targets: (1) In the very short term (if possible before 2000) , the MTR value of all substances may no longer be exceeded due to emissions; and (2) in the longer term (if possible before 2010), the target value for all substances may no longer be exceeded due to emissions.
There are two laws in the Netherlands formulating requirements to the water and soil quality; the Waste Water Act and the Act on Soil Protection. The objective of these two laws is to realize the quality of water and soil at the level in which ecosystems can be regarded as sustainable. By general administrative measures, norms have been established with target, limit, and intervention values.
For air quality, environmental requirements have been formulated in the Act on Environmental Management. Within the scope of the European Union framework directive on air quality, the EU has formulated new norms for some substances in order to protect public health. On 19 July 2001, these binding limit values were implemented in Dutch national laws and regulations. Limit values of pollutants stemming from road traffic can be found in Table 13.

Mitigating Measures

Mitigating measures can be taken in order to limit the adverse effects of runoff and spray. In this context, there is a distinction between measures taken at the source and more effect-oriented measures taken at the road itself. Measures at the source are the only way to realize lasting solutions. This will require initiatives at the level of the European Union and be time-consuming. Therefore attention is now focused on handling emissions in the vicinity of the roads. The treatment depends on the type of pollutants, dispersal route, and availability and characteristics of the available land.

Source-oriented Measures

As stated, only part of the total emission of road traffic winds up in the roadside via runoff; another part is spray. Therefore, the adoption of effect-oriented measures at a local level results only in a limited contribution to the reduction objectives established in the various policy documents. Source-oriented measures (volume and technical) will thus have more effect on environmental quality than measures that treat runoff. Volume measures are focused on the reduction of the annual number of kilometers driven, and technical measures are focused on reducing the emission of dangerous substances by application of other materials and techniques or by changing the composition of fuel.

Such measures are adopted within the scope of the European Union. Good examples are the reduction of the lead content of petrol; alternative materials for brake linings to prevent Cu pollution and for tire rubber to prevent Zn pollution. Alternative materials (e.g., wood) for crash barriers and lampposts can also reduce pollution.

Measures for Combating Emissions Via Spray

On roads with closed asphalt, spray is a much more important contamination route than runoff. For instance, on highways with closed asphalt concrete (DAB), 57%-83% of the pollution is caused by dry and wet wind spray. From recent studies along provincial roads, the prominent role of wind spray has become apparent. Of the total emission by traffic, approximately 90% is distributed by wind spray and approximately 10% by runoff (Tauw and Omegan 2000).
Generally speaking, it is very difficult to control pollution by wind dispersion. On highways the laying of ZOAB is very effective in combating pollution of soil and surface water with metals by means of spray. The state policy is to stimulate the use of ZOAB on highways to reduce noise nuisance, and this will at the same time reduce the spreading of pollutants. On smaller provincial and municipal roads, it is usually much more difficult to reduce the influence of spray; so the highest possible goal for these roads is to limit its influence.
The application of ZOAB is less suitable for this type of road. Alternatives may be the planting of trees and bushes and possibly also noise screens in order to restrict the pollution to the immediate vicinity of the road. Safety aspects may limit some of these measures, e.g., an obstacle-free zone where no planting can take place.

Measures for Combating Emissions Via Runoff

In the handling of runoff it is important to keep an eye on the various ways that runoff is released. In the case of roads without drainage pipes, runoff usually infiltrates into the soil. In this context the pollution becomes concentrated in the few meters alongside the road. For hydrological or safety reasons it may be necessary to provide roads with drainage pipes. The collected water often is discharged into a dry or wet ditch situated nearby or is allowed to infiltrate into the soil (for instance, infiltration pools in so-called cloverleaf junctions).

Table 14 shows measures that can be taken to counteract emissions taking place via the runoff. The measures that have been included in the table have been developed by a subworking group of the Dutch Commission for Integrated Water Management (CIW 2002) . These are measures for each type of road or road section in relation to the vulnerability of the area. There is a subdivision into basic facilities and numbered measure packages for specific situations. In this context, clearly controlled infiltration is the most important measure. The important aspect of controlled infiltration is not only specifically created in infiltration facilities but also infiltration into the top layer of the verge can be considered as such. “Controlled” means provided with an effective management plan, and this management plan must include a monitoring program. The situations and measures studied indicate that the installation of drainage pipes and discharge systems must be avoided as much as possible in view of the high costs involved (Grontmij 1999).

The efficiency for the removal of heavy metals of settling basins for treatment of runoff is disappointingly low: around 40% for runoff of DAB and less than <20% for runoff of ZOAB. The very low efficiency in the case of ZOAB can be explained by the already low concentrations of suspended solids in runoff from ZOAB. It is recognized that Table 14 shows the general solution.
For each location the most suitable solution must be selected, with the provincial authorities, as the parties executing the provincial environmental decree, playing an important role.

In road building, the establishment and management of verge ditches can be focused on stimulating ecological functions. In addition to their water-draining functions, verge ditches - if also designed based on ecological principles - can also enhance natural values.
In situations where highways have been built on a large volume sand cunette, seeping water may enter the roadside ditch (Iwaco, 1996). Along the A2, for instance (Iwaco, 1996), at many places species-rich water and waterside vegetation were observed with seeping water indicators such as water horsetail (*Equisetum fluviatile*) and unbranched bur-reed (*Sparganium emersum*) and clearwater indicators such as charophytes or stoneworts (*Chara sp.*) and blunt-fruited water-starwort (*Callitriche obtusangula*). Although at these spots no physical indications of seeping water were demonstrated to exist, inflow of water via the cunette remains a possibility.

In view of the importance of the vegetation concerned, disconnection of the runoff via a separate drainage system with a helophyte filter at these spots can prevent polluted water from winding up directly in the roadside ditch. A helophyte filter also supplies additional nature values (De Graaf and others, 1997). The following section deals with the significance of helophyte filters for the purification of polluted runoff using natural processes.

Ecological Engineering

In addition to the maintenance and development of nature values, the design and realization of roads can also use specific ecosystem services in the form of ecological engineering. Plants and animals can be deployed to enhance environmental quality. Ecological engineering means the design of sustainable ecosystems, which involves the integration of human and natural systems for their mutual benefit (Mitch and Jørgensen 1989). An example is the purification of polluted runoff using natural processes in helophyte filters. The switch from nonporous to well-maintained porous asphalt also has a considerable positive effect on the quality of runoff from highways (Berbee and others 1999). Helophyte filters can be of use in the long run if combined with the enhancement of ecological values along highways, especially where nonporous asphalt is used.

Application of Helophyte Filters

Constructed wetlands have been created to treat domestic wastewater and industrial wastewater and to purify wastewater from recreational sites. These are constructed environments, but in some situations natural wetlands are used for the purification of wastewater, where the purification process proceeds without the intervention of mechanical facilities, except for any influent pump and aids for water level management (Vansina, 1992).

Helophyte filter systems make use of natural processes which reduce the extra input of nutrients in the form of a self-purification process of water, plant and soil, without artificial energy supplies. The plants that play a role in the absorption of substances also provide substrates for microorganisms, slugs, snails, and insect larvae. Helophyte filter systems are used in many countries throughout the world. There is a relatively large variation in removal efficiency (Duel and During 1990, Strecker and others 1992). More and more studies are being done into the possibilities for purifying runoff from residential areas and from roads/motorways (Yousef and others, 1994; Oleson and others, 1996; Shutes and others, 1997).

A literature study ordered by the Ministry of Transport and carried out by the University of Utrecht (De Graaf and others, 1997) on the purifying effect of helophyte filters (Kadlec and Knight, 1995) demonstrated that they can have an added value in the removal of microcontaminants (heavy metals and PAHs) in runoff as compared to only settlement or infiltration in the soil. They can also play a role in the removal of nutrients. The important factors are the binding of nitrogen and phosphorus in the above-ground and under-ground biomasses (Duel and Te Boekhorst, 1990), the accumulation of dead organic material, denitrification, adsorption of soil particles, formation of fairly insoluble compounds, and the settlement of suspended materials. The facilities near roads are especially relevant for purifying water from discharge points of road drainage pipes or point discharges of water from tunnels. Especially in those situations, higher concentrations in verge ditch bottoms can be found.

In principle, three basic types of constructed purification wetlands that use plants/water plants can be distinguished based on the manner in which wastewater flows through: waterflow above the surface, through root zone filter, and via an infiltration field. Based on a computation for a vertically percolated reed infiltration field as an example of a peripheral facility for the processing of runoff, an understanding has been gained concerning the effluent quality to be expected, the increase of pollutants in the soil, the possible dimensions, and the required number of square meters of infiltration field per surface area of road surface. Also reviewed were such aspects as dry periods in summer and the effects of high

Table 14. Recommended measures for each type of road or road section in relation to vulnerability (situation of new roads or reconstructions) (from CIW, 2002)

Type of road	Measurements in non/hardly vulnerable areas
Motorways (roads with hard shoulder)	Basis: - ZOAB - periodically clean the hard shoulder (twice a year) - do not collect runoff - controlled infiltration[a] of runoff into the verge - if collection necessary: 1) controlled infiltration[a] 2) if 1) not possible, discharge via a retention ditch/ dry ditch into the roadside ditch - if DAB is necessary same measures except for cleaning the hard shoulder
Through-going motorways outside the built-up area (gov./prov) and urban motorways	Basis: - do not collect runoff - controlled infiltration of runoff into verges[a] supplementary, if collection is necessary: 1) controlled infiltration[a] 2) if 1) not possible, discharge via retention ditch/dry ditch into roadside ditch
Other streets inside built-up area	Basis: - disconnection policy/keep water within urban area - local evaluation whether infiltration[a] discharge into surface water or drainage to purification is sensible
Country roads	none
Service areas (e.g., near gasoline stations)	Basis: 1) evaluation of risks of calamities 2) if l) low risk, collect runoff, apply silt-collection pit, discharge into surface water or controlled infiltration[a] 3) if high risk, apply oil spills via a oil separator
Viaduct, bridges for car traffic	Basis: 1) collection[b] 2) controlled infiltration[a] 3) if 2) not feasible, discharge via retention ditch/dry ditch into the roadside ditch
Large traffic tunnels, aquaducts, lowered positions	Basis: 1) controlled moving away of sand and silt from sand collection and silt basement, respectively 2) pump remaining water away and controlled infiltration[a] 3) if 2) not feasible, discharge into surface water 4) controlled infiltration or discharge of tunnel wash water into RWZI

a Controlled infiltration means infiltration into the soil with in it sufficient adsorption capacity for pollutants, sufficient infiltration capacity and the application of a soil-control program. Controlled infiltration can occur in the verge, in a central or decentralized infiltration facility or via passage through the soil. It means in practise made-to-measure.

Supplementary measures for areas with increased vulnerability[a]
1) controlled infiltration[a] 2) if 1) not feasible, infiltration outside the protected area[a] 3) if 2) not feasible, discharge into the surface water outside protected area[c]
l) if possible ZOAB 2) if DAB used, collection and controlled infiltration[a] 3) take outside vulnerable area followed by controlled infiltration[a] 4) if 3) not feasible, discharge outside protected area into surface water[c]
1) controlled infiltration[a] 2) bringing outside area followed by controlled infiltration[a] 3) if not 2) feasible then outside protected area into surface water[c]
traffic-limiting measures
1) take outside area and controlled infiltration[a] 2) if 1) not feasible, take outside protected area, discharge into surface water[c]
l) take outside area and controlled infiltration[a] 2) if 1) not feasible, take outside protected area, discharge into surface water[c]
1) take outside area and controlled infiltration[a] 2) if l) not feasible, take outside protected areas and discharge into surface water[c]

b The intention for bridges is infiltrate a considerable part (approximately 80%) of the rainwater and for the rest to be allowed to overflow into the surface water.

c If infiltration outside a protected area is not feasible, discharge into the surface water outside the protected area whether or not after passage through the soil.

chloride contents due to winter maintenance of roads.

The biological availability of heavy metals and PAHs is a condition for the possibilities for purification by constructed wetlands. In water/ soil systems, usually Hg, Cd, Zn are mobile; Ni, Cu and Cr are moderately mobile; and Pb is usually not available. Metals are more mobile at a low pH and in an oxygen-rich environment; the absorption efficiency increases at higher concentrations. In the case of PAHs, the binding to the organic fraction plays a large role and the availability is hardly affected by the pH. The important factors in this context are the settlement of the particles to which PAHs have been bound and the manner of removal by microbial degradation. Oxygen availability also is important. Heavy metals can be removed by sedimentation, by binding to the soil, and by plant uptake, with the latter occurring especially in the growing season.

From the literature study it appears that constructed wetlands with waterflow above the surface rarely lead to improvement as compared to settlement installations. Infiltration fields can have an added value as compared to sand filters. The rhizosphere of plants has an advantageous effect on the removal of heavy metals; in addition, the rhizosphere has a favorable effect on the degradation of PAHs by microorganisms. In the case of infiltration fields, harvesting (mowing) of materials removes part of the heavy metals from the system. Helophyte filter systems also make up marsh systems by themselves, which can be part of the ecological structure, or function as buffer zones in the case of lands that are in agricultural use. They can even be combined with ditches in agricultural land with a high nutrient load. As far as plant material is concerned, reed *(Phragmites australis)* is preferred to bulrush *(Thypha sp.)*, despite its lower absorption efficiency for heavy metals. Reed also has a better resistance to water fluctuations and high chloride contents.

Arrangement of Helophyte Systems Near Highways

In order to be able to implement a helophyte filter system at the right time, at the right place and with an optimal layout, the following steps should be taken into account. First, water and matter-balance studies should be carried out in order to establish the hydraulic properties and pollution load for establishing the desired set-up of the system. The important date are the quantity of polluted water to be drained and processed, the soil material to be applied, the amount of intake flow, residence time of the water, regulation of the water level, pollution load, rainwater, evaporation, and information on groundwater movements.

After data collection, a cost-benefit analyses should take place. Costs involve the space occupied, building, and management, and the profits involve removal of waste substances, production of any renewable raw materials which may be used, as well as development of natural values. A provision for pretreatment is important for a long service life and efficient operation of a helophyte filter system. The pretreatment consists of separation grids, sieves, and settlement basins for collecting sand, small stones, oil, silt, etc. Such facilities help prevent the helophyte system from becoming silted up and can serve as buffers during extreme conditions.

The Directorate-General of Public Works and Watermanagement, have different helophyte filter systems in use for treatment of grey water from some local office buildings, an experimental site along the A2 near Hilversum with a constructed wetland and some special designed roadside ditches for cleaning of point discharges and some helophyte-filter systems in cloverleaves of the in november 2003 opened new motorway A5 as well as eco-ditches, ditches which have been widened for buffering rainwater with ecologically friendly, gradually sloping down banks to increase ecological quality.

The helophyte filter system can be summarized as follows: The substrate of the helophyte filters depends on the objective of the system to be used. Depth is a minimum of 0.5-1 m for sufficient root growth. (Hall and others, 1994). Water inflow should not be more than 60 mm/ day, and flow rate should be 0.3-0.5 m/sec at the supply point. If the flow rate exceeds 0.7 m/sec, plants can be injured. Surface area should be 0.5%-5% of the total drainage area, depending on the presence of prepurification facilities. Various species of plants can be used. Reeds, rushes, and bulrushes are often used because they are very resistant to degradation due to their richness in relatively undependable cellulose; in winter the stems remain upright and in spring they continue their growth so they can be easily harvested (Verbeken and van der Werf, 1997).

Significance of Microbes and Plantings in Collection and Degradation of Pollutants (Phytoremediation)

Phytoremediation is a relatively new method for handling various types of soil contamination. Phytoremediation is made up of two different processes: (1) the stimulation of the degradation of organic compounds (PAHs and oil) by micro-organisms; and (2) the extraction of heavy metals from land soil and polluted sediments using plants. Although phytoremediation as a possible technique has been known for some time, it has rarely been applied in actual practice. The application of phytoremediation on land soils is especially possible in situations where the time period necessary for the process does not pose any problems. For this purpose, roadsides in principal seem to provide an effective possibility, but some objections can be recognized. Most pollution is found in the first metres of the roadside, which is the very part that is mowed several times a year or on average every five years is stripped of its top layer. Furthermore there is the question how phytoremediation relates to current ecological roadside management.

Recommended Measures

On the National Scale
Measures to be taken on the national scale must be source-oriented, since effect-oriented measures on a local scale in order to prevent the spreading of pollutants will be less effective because only a small part of the deposition takes place in the immediate environment of the road. Reducing the number of kilometers driven would be an option - although such a measure is outside the competence of the government - as would the application of other materials and a change in the composition of the fuel used. Examples of material applications are zinc in tires, and copper and chromium in brake linings. The use of other materials in road "furniture" (crash barriers and road portals) would reduce pollution (e.g., using wooden crash barriers instead of galvanized).

On the Regional and Local Scale
The application of ZOAB on highways is an effective way of reducing the spread of pollutants. Further, the planting of bushes and trees along verges in relation to the prevailing wind and exposure could possibly reduce the immisions elsewhere. Particulate material usually will be bound, noise screens limit the

spreading of emitted substances. Especially where road drainage pipes drain in ditches, effect-oriented measures are relevant. Under special circumstances the use of infiltration as well as helophyte filter systems near point discharges can be useful.

Recommendations on Analysis Methods and Model Development
In the selection of a research method or the use of models, it is important to take the comparability of the collected data into account. It is important to include the following aspects: seasonal effects, traffic intensity, spreading conditions (exposure to prevailing wind), slope, presence of noise screens, cleaning schedules for ZOAB, as well as data on background concentrations of pollutants. Further aspects of interest are the age of the road surface and the soil type found on site.

Conclusions

Pollutants and Dispersal Routes
A road and its use leads to emissions of polluting substances via the air, runoff, and by dry or wet spray into the environment. The pollutants, in addition to specific air-polluting substances, are heavy metals (especially Zn, Cu, and to a lesser degree Pb), PAHs, and mineral oils. Runoff pollutes verges immediately next to the hard shoulder, whereas wind spray displaces pollutants over larger distances. Depending on the type of road and the type of road surface, approximately 30%-90% of total emissions are spread by means of spray and 10%-70% are spread by runoff. There is a big difference between DAB and ZOAB road surfaces. Along DAB roads, wind spray is the main manner of spreading. Along ZOAB roads the relative significance of spray is strongly reduced. Mass flows along ZOAB roads are 1-2 orders of magnitude lower than along DAB roads.

There is no clear relationship or correlation between the total mass flows and traffic intensity. Deposition due to runoff usually has a significant correlation with the quantity of rain.

Quality of Runoff
The type of road surface strongly determines the degree of pollution of the runoff. The total emission of DAB roads exceeds that of ZOAB roads because the spreading of pollutants in the case of ZOAB by wind spray is considerably lower than that near DAB roads. In the case of ZOAB roads there is less spray and a part of the pollution remains in the pores.

Pollution of Soil and Water
Often, the pollutants appear to be restricted to the top 30-40 cm of roadside soil and decrease with distance from the road. At 10 m from a road, is at background levels. Percolation through to groundwater depends on the amount of pollution, the degree of adsorption to soil particles, the height of the groundwater level, and the degree of degradation.
Exceeding the target values in soil will not occur until many years after the road has been opened. In the groundwater, limited exceeding (chromium) of target values were observed.
The bottom of roadside ditches can become polluted by point discharges.

The Future

The Commission for Integrated Water Management in the Netherlands has drawn up a policy document on how to deal with the problems of contamination or pollution by traffic, especially focused on runoff. One of the main recommendations included in the report is that the most effective way to control pollutants is to do so at the source. Although in the National Environmental Management Plan (NMP) (Ministry of VROM 2001) and the National Traffic Transport Plan (NVVP)

(Ministry of Transport 2001)* already policy has been initiated in order to comply with more strict European requirements that are to lead to reduction of the emission of air pollutants and micro pollutants from vehicles, once again explicit reference is made to the importance of this policy line. The important factors in this context are not only air pollutants, but also, e.g., the use of zinc in tires and the use of copper and chromium in brake linings. The reduction of use of these materials can only be realized at the EU level and usually requires much time.

The National Traffic Transport Plan (Ministry of Transport 2001)* also includes that the state will reduce diffuse soil pollution due to infrastructure. Especially in ecologically vulnerable areas and groundwater protection areas, effect-oriented measures will be used for the controlled reduction of diffuse pollution. These effect-oriented measures to collect and reduce the concentration of pollutants, such as infiltration facilities and helophyte filter systems, are in addition to the source-oriented policy.

The spreading of pollutants by spray, however, remains an important way in which pollution ends up in the soil and water. The above-mentioned facilities make only a small contribution towards reducing such pollution. It is therefore important to gain the necessary understanding of how this form of pollution can be reduced by effect-oriented measures. In this context, it is important to gain insight into the effect of sound-insulation measures and the installation of plantings.

* The NVVP has been rejected by Dutch parlement; a new Mobility Plan is in preparation and will be published in 2004 or 2005.

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3. Ecological Research in Roadside Verges in The Netherlands: An Overview

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P.-J. Keizer

Abstract
This chapter reviews the development and current situation of and the prospects for the ecological value of road verges, with an accent on motorway verges, in the Netherlands. It is based on applied ecological research carried out in recent decades. It presents both a general overview of the flora, vegetation and fauna present on Dutch motorway verges, in relation to the results of the applied research carried out by or on behalf of the Road and Hydraulic Engineering Institute (DWW) of the Directorate-General of Public Works and Water Management of the Dutch Ministry of Transport, Public Works and Water Management, in combination with research done elsewhere.
The studies show the ecological importance of motorway verges as well as the management practices to maintain and to increase the ecological values. On grassy roadsides mowing with the removal of the grass cuttings is still the best option. It shows also that in many locations opportunities still exist for 'new' nature along motorways.

Based on the gained knowledge it is now possible to include ecological aspects in all phases of 'road life': routing, design, construction, management and actual maintenance. A research agenda for the coming years is included as well.

The chapter concludes with ecological engineering principles to be applied in planning, design, construction and management and actual maintenance of roads and motorways in order to further the successful implementation and optimization of ecological values on road and motorway verges.

1. Introduction

This chapter reviews the ecological values of motorway verges in the Netherlands in comparison with those in other West European countries. The changes in human attention and attitude to road verges over the last 100 years are explained and a description is provided of applied research carried out by or on behalf of the Road and Hydraulic Engineering Institute (DWW). The DWW is a research and advisory institute of the Directorate-General of Public Works and Water Management (Rijkswaterstaat) of the Dutch Ministry of Transport, Public Works and Water Management. The Rijkswaterstaat is responsible for the design, construction and maintenance of motorways in the Netherlands.

The Netherlands covers an area of 41,526 km^2; only land: 33,883 km^2. On this area there are 116,093 km of metalled roads. Outside the built-up areas (villages and towns) there are about 57,450 km of metalled roads, which is an average of roughly 1.69 km/km^2. Including built-up areas this figure is approximately 3.4 km/km^2 (CBS, 1998). Of the metalled roads outside built-up areas, the national government is responsible for 3159 km (5.5% of the total road length) of which 2291 km of motorways, the provinces for 6640 km (11.6%), the local governments for 41,284 km (71%) and the water boards for 6368 km (11%) (CBS, 1998).

Almost all roads in the Netherlands are provided with verges. Verges alongside the country's motorways cover ca. 14,390 ha

(Van der Horst, 2001) of which ca. 12,600 ha is grassland vegetation, ca. 1,760 ha planted woodland and 4,505 km watercourses. In a densely populated country like the Netherlands, road verges form a significant constituent of the landscape where (semi-) spontaneous development of vegetation can occur (Westhoff & Zonderwijk, 1960; Way, 1969, 1977; Zonderwijk, 1978, 1979, 1991; Sýkora, 1998, Sýkora et al., 1993, Keizer et al., 1998, Wonink et al., 1995). In our intensively used agricultural landscape monotonous species-poor grasslands dominate. The more or less natural and semi-natural grassland are less than 3,000 ha or 0.5% of the total grassland in the Netherlands. Roadside verges with a diverse species-rich grassland play an important role in maintaining biodiversity. In all these roadside verges a large variety of vegetation types can be observed. Most of them need some maintenance, being part of an artificial and intensively used landscape.
This offers a good opportunity for applied ecological research on optimization of vegetation management (in terms of biodiversity versus expenses) and on their function as habitat and corridor for several groups of fauna. Based on the results of such research, this chapter presents some principles on ecological engineering that may be used to optimise the ecological values of road and motorway verges in combination with their technical functions.

The ecological function of roadside verges (beside the technical and traffic related functions) is fully acknowledged by the national government, as expressed in the Second Transport and Transportation Plan (Anonymus, 1990) and probably also in the Mobility Plan (2003, currently under development by the Ministry of Transport, Public Works and Water Management) in order to fulfil this objective. "Rijkswaterstaat" has developed close co-operation with the Wageningen University and several biological research agencies.

2. Definition and functions of 'road and motorway verge'

The term 'road verge' refers to the space between the edge of a road surface and the edge of the adjacent area with a different land use or different native vegetation. In this chapter, road verges are those sections of a road and motorway that are situated between the traffic lanes and/or between the outer traffic lane and the adjacent property border as far as they were created or are managed by the road manager. Thus, road verges include here watercourses (ditches), areas of water (ponds, small lakes), and the vegetation growing near service stations and road junctions.

Road verges have four functions:
- road engineering (technical);
- traffic;
- visual-landscape or aesthetic;
- ecological and landscape ecological.

In the days that ecology was not considered, mainly road engineering and traffic functions determined the design, construction and maintenance of road verges. Verges and slopes contribute to the sturdiness of the roadbed and the road itself, and they accommodate cables, pipes and road signs, while also playing a role in the collection and drainage of runoff. They also help to increase traffic safety as they act as refuges for broken-down vehicles or for vehicles that have been involved in an accident.

The visual-landscape or aesthetic functions of roadside vegetation can be subdivided as follows (Schone and Coeterier, 1997):
- The road is fully blended into the landscape ('inpassen').
- Connecting the road to the landscape (to

orient road users) ('aanpassen').
- Providing a contrast between the road and its surroundings in order to emphasize the road's own character as compared to that of the landscape: the road dominates the landscape ('veranderen').

In an ecological sense, a road verge can have the following functions (Forman, 1995 and 1998; Forman *et al.*, 2003; Logeman & Schoorl, 1988) (Figure 1):
- habitat patch (temporary or permanent living and residence space for plant and animal species and communities).
- connection or migration route (corridor) for species (connection element between fragmented areas; species movement alongside or "through" a habitat patch).
- stepping-stone (species can bridge an unsuitable habitat in steps).
- isolator/a barrier (from/against undesirable effects from the surrounding area; there can also be a filter effect).
- distribution core or source (species find a favourable habitat patch from where the population can expand and spread out over a larger area).
- sink (a "reception" area for species in areas where they cannot survive independently);
- regulator (species which can predate pests in agricultural fields from the road verge habitat).
- refuge (for endangered plant and animal species; plants and animals can also withdraw to it on a temporary basis).

For the ecological significance of road verges the relations with the hinterland are very important, as are the width of the verge, the degree of 'connectedness' of various habitat patches of verges, and the quality of environmental variables like soil, water and air of the verge and its surroundings. Each of these aspects plays a role at various scales: the verge as such, the verge in the landscape and the network of verges in combination with other ecologically valuable networks at various levels of scale.

The economic effect of road verges on the income of their owner is practically zero, or, in fact, negative. In the past, the grass cuttings and the wood from the roadside vegetation had some economic value. Given an optimal

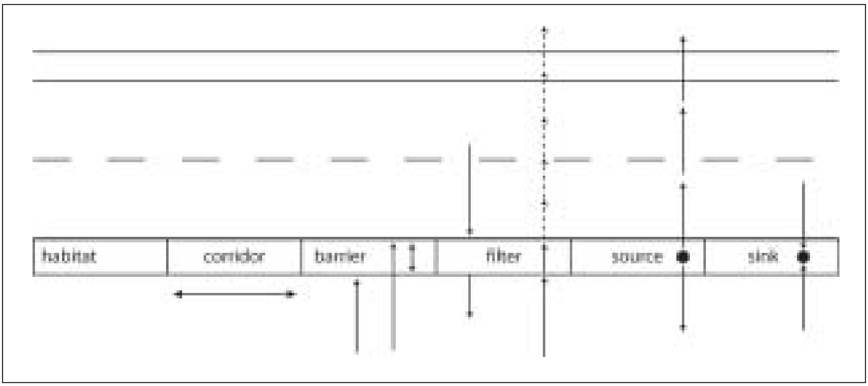

Figure 1. Ecological functions of roadside verges (after Forman et al., 2003).

design, the function of the road verge as a sink for pollutants could result in cost savings, since in many cases (except for groundwater- and drinking water protection areas) no costly sewage measures are necessary (Van Bohemen & Janssen van der Laak, 2003).
In order to maintain the functions, grassy road verges are mown with varying intensities. There are several reasons for this. First, the verge has a function for the traffic as a place to erect traffic signs, light poles, etc. The road user must have a clear view of them. Likewise, bends in the road must be visible. Not mowing means that trees and shrubs would develop spontaneously, concealing the above-mentioned structures; therefore an intense mowing programme of three or more turns per year is applied here.

The remaining open areas of road verges where cars are caught in case of accidents need less frequent mowing; they only must be accessible. Here mowing once or twice a year (with removal of the cut grass) is sufficient.

3. Problem definition

Research on ecology of roadside verges is often carried-out by organisations other than universities e.g. road-managing institutions. Nevertheless research often takes place in co-operation between road managers and universities and is done by students or by biological advisory and research offices. Consequently many results are not published in easily accessible journals. This chapter will give an overview of past and present developments of ecological research of roadsides, using among other things student reports, internal reports of the Road and Hydraulic Engineering Institute (DWW) and other road ecology institutions and governmental reports.
More specifically, this chapter deals with the following research questions.

1. Which views on nature management exist(ed) from 1945 to the present time in nature reserves and in roadsides?
2. What is the ecological significance of road verges based on the data on flora, vegetation and fauna? Which changes have been observed and what can be concluded from these changes?
3. What is the effect of various mowing regimes on the flora, vegetation and fauna of road verges?
4. What is the connection between various levels of nutrient availability and the composition of plant communities on road verges?
5. How can we apply the results of the above four questions on the design, construction and management of roadside verges?
6. Again based on questions 1-4, is it also possible to derive principles that have a more general significance in the field of nature engineering and is broadening towards ecological engineering possible?
7. Which control mechanisms allow for the cost-effective application of the principles derived in order to optimise the ecological quality of road verges?

These questions have been treated in studies carried out in-house by DWW or outsourced by this organization. Results of other research are included as well. The collected information has been used to formulate general principles for design, construction and management of road verges.

Management (of roadside verges) is defined here as the complete procedure from biological research leading to installation of management plans with description of measures, the actual application of these measures in the verges and the evaluation of the resulting communities of flora and fauna. The different plans are: landscape plan, construction plan, management plan, including time and financial planning as well as the measures to be taken. The set of measures should therefore lead to **maintenance** of the biological (and other) qualities for a chosen state in the succession series. In some studies sometimes the word maintenance is used for management.

4. History and scope of road verge vegetation management in the Netherlands

4.1 Pre-1960's

Until the early years of the twentieth century, road verges were not really designed or managed for any special purpose other than for technical and traffic reasons: they were simply the transition between the road and the adjacent land. Local farmers used them for hay production or for grazing (Burny, 1999). Trees were almost always present: they provided wood, leaves (fodder), fruits and some shelter from strong winds and sunshine.
At the beginning of the twentieth century, the appearance of new roads received increasing attention as an important aspect of road building. As early as 1916 a regular advisory body was established within the State Forestry Service, with the aim to advise the Ministry of Transport on road plantations and their design (*Landinrichtingsdienst*, 1991). This partnership lasted until 1997. The recommendations were focussed on landscaping, viz. on integrating the road into the existing landscape and constructing guiding structures for road users by means of rows of planted trees and forest patches. Overdijking (1935, 1943) and the report *Wegbeplanting* (1939) suggested that under certain circumstances roads could also be designed without rows of trees, arguing that in some landscapes verges without or with only a few trees with local flora and vegetation can be of scenic value. In the designs of new roads, the perspective of the road user (car driver) was the central viewpoint, but the impact of the road on the existing landscape received little attention. The possible biological value of the road verge vegetation and maintenance issues were not considered before the 1970's. For example, even in the survey on 200 years of waterways and of road construction and management (Bosch & Van der Ham, 1998) there is no mention of road verge maintenance, although the biological importance of river and canal banks was stressed.

As stated above, theories on road and road verge design mainly were developed from the point of view of the road user. The Dutch nature conservationist J.P. Thijsse (1945) developed ideas on road verge design. He suggested very open tree rows or no road plantations alongside high-speed roads, and denser road plantations alongside low-speed 'roads', such as cycle tracks and footpaths. Even in 1926 J.P. Thijsse said in a speech (Gorter, 1986): "There is a need of engineers who, before the construction of a road or railway, should travel to the area where it is to be built and assess the landscapes one by one and where it is scenic should say "there it should not go along".

It is very probable that these suggestions never reached the road engineers who made the actual designs and built the roads, because there was no regular communication structure linking biologists and landscape architects within the Ministry of Transport. In this period, biologists had no specific interest in road verge ecology. This is understandable, because the general biodiversity in the Netherlands was much higher than it is today and road verges did not add much to biodiversity at the landscape level.

Between the 1930's and 1960's, the motorway network started to develop (Figure 2). From the

Figure 2. Development of the motorway network in the Netherlands (H+N+S, 1996)

1960's and 1970's onwards the strongly increasing intensification of agricultural methods caused a great loss of wild flowers and 'weeds' in the agricultural fields. At the same time the awareness grew that on road verges some of the wild grassland flora could survive if the maintenance was made somewhat similar to that of grassland in nature reserves (see below).

4.2 The 1960's (lawn maintenance)

Until the 1970's, road verges were managed like lawns. They were mown (often by flail mower) five to eight times in a year and the clippings were left behind. Chemical weed killers were used to remove all plants except the grass. The main reasons to mow verges were to increase safety and to create a tidy appearance. However, there were also economic reasons.

At the time, it was thought that the quantity of herbs on road verges should be restricted, since 'weeds' could pose a risk to agriculture, and too intensive herb growth would threaten traffic safety. As a side effect, the grass experienced no further competition from other plants (herbs) and at many spots the grass grew so much better that mowing had to be done increasingly often (Anonymous, 1975; Westhoff & Zonderwijk, 1960).

4.3 The 1970's: the turning point

During the early 1970's, there was an increasing awareness of nature conservation and environmental care. In 1970, the Council of Europe launched 'N70' – the European year of nature conservation. This stimulated new instruments or the renewed application of existing methods in nature conservation and nature management. It also influenced other organizations involved with the management of public green areas.

In the framework of road maintenance the new idea was to create road verges covered with wild flowers. This idea, which resulted in important ecological restoration, was published by Zonderwijk (1973, 1978, 1979). Probably more important was the fact that Zonderwijk organized an energetic communication campaign on ecological road verge maintenance with road authorities and engineers at all levels in road construction and maintenance organizations. He promoted ‘colourful road verges’, that is, verges with species-rich, semi-natural grassland vegetation. This should develop spontaneously under the application of this so-called ecological roadside management, without sowing or planting. The aim was to have verges that accommodate wild flowers reminiscent of the traditional hayfields, with locally rare species (including such fauna as butterflies, bees, hoverflies and beetles). Basically, this maintenance consisted of introducing the old-fashioned, low-intensity farming system of hay production. Frequent mowing encourages grassland plants to tiller more energetically, so that the seeds of other plants are not given an opportunity to sprout. Flowering herbs give verges a more lively appearance and provide pollen and nectar for insects, which in their turn are important for pollinating plants. In areas with seed production companies, it may sometimes be necessary to carry out certain control measures. Zonderwijk claimed that an ecologically based maintenance strategy could be realised at lower costs than the traditional lawn mowing regimes. This contributed considerably to the acceptance of the new idea.

Unfortunately, farmers showed gradually a decreasing interest in purchasing road verge cuttings, which led to higher costs for processing of the cut grass.

In subsequent years, the relevance of this kind of road verge maintenance became widely known. Several organizations published guidelines on optimal ecological road verge maintenance and issued reports on road verge vegetation and erosion prevention (Anonymus, 1975, 1980, 1990; Heemsbergen *et al.*, 1991). These organizations played an important role in disseminating the theory, knowledge and practical experience of ecologically based road verge maintenance.

4.4 The 1970’s, 1980’s and 1990’s

Mowing with lower intensity (e.g. mowing once or twice a year) was on the increase, and removing the cuttings impoverished the soil. This was especially effective on broad road verges, which suffer less from margin effects such as input of nutrients. The chemical control of grassy road verges decreased with the final objective that State road and waterway managers would stop using chemical control agents altogether.
Design, construction and maintenance of road verges became focused on nature engineering. This means that favourable abiotic environmental conditions for plants and vegetation are created. Together with the design, construction and maintenance, the continuity in management and variation in soil and gradient situations will create the development of a wide variety of vegetation types.

Much knowledge about plants and animals on road verges was recorded in this period in books, symposium reports and manuals, e.g. Bouwman *et al.* (1988), Heemsbergen *et al.* (1991), Aanen *et al.* (1991), Van den Berg & Van den Hengel (1994), and Schippers and Van der Weijden (1996). The latter publication focuses on the development of natural verges alongside country roads, cycle tracks and footpaths, and presents twelve road verge target types in the form of ecograms. Full attention is paid to the factors that are essential in the creation of verges such as soil type, hydrological and nutrient status of the soil as well as to the later maintenance aspects.
Many phytosociological data can be found in the survey on plant communities in the road verges of the Netherlands (Sýkora *et al.*, 1993).

An advisory body on roadside management was installed in Wageningen, the Consultancy Group Vegetation Management (Adviesgroep Vegetatiebeheer). This group performed studies on the ecology of flora and fauna in linear landscape elements. An important element was the regular feedback from actual practice. From 1990 onwards the national government introduced a new method in nature management, viz. control by result. The areas with nature management were tested against so-called target types; using this method the management can be evaluated more effectively. This method was also adopted in roadside management.

5. Development of theories about nature protection, nature conservation, nature management, and nature development in relation to road verge management

Until ca. 1950, the common practice in nature conservation was to merely protect nature areas (including semi-natural landscapes, see below) from damage caused by building roads and houses, agricultural re-allotment schemes, etc. Westhoff (1939, 1956, 1965; Westhoff *et al.*, 1942 and 1946; Meltzer and Westhoff, 1942) induced the awareness that some measures are necessary in nature reserves in order to maintain the biodiversity of several plant communities. For seminatural grasslands the continuation of low-intensity farming in the 'old-fashioned' way proved to be the key factor for maintaining valuable plant communities and rare species. In these grasslands the structure of the vegetation is artificial, but the species composition and the distribution of the species are completely natural; they deserve the same care and protection as completely natural systems, although they require a different type of management (Westhoff, 1956; Van Leeuwen, 1968).

The studies by Van Leeuwen (1965, 1966, 1973 and 1981), Londo (1971, 1977, 1997) and Westhoff (1988) made an important contribution to understanding the importance of nature-engineering techniques for the successful creation of habitats for plants and animals. Important knowledge was gained about the relationship between soil types, hydrological conditions and vegetation, and the significance of gradients leading to highly diverse systems.

The idea of the need for corridors in order to conserve genetic diversity (and thus the long-term survival of populations) was developed from the island biogeography theory (MacArthur & Wilson, 1964) and applied to populations in isolated land habitats. The concept of metapopulations, populations and subpopulations was developed in the early 1970's (Den Boer, 1971, 1990; Opdam, 1987, 1990; Opdam *et al.*, 1993). The process of the regular extinction of subpopulations (due to stochastic fluctuations) made clear that the landscape must be sufficiently penetrable to organisms in order to (re)colonise suitable habitat patches. It was further suggested, and subsequently proven, that road verges could serve as a migration route for carabid beetles (Vermeulen, 1995).

Road verges also can serve as dispersion routes for plants (Nip-van der Voort *et al.*, 1979). The dispersal capacity of the individual species is most interesting, and could be studied in roadsides of roads in the newly built polders in the former IJsselmeer. Recently, spectacular expansions of some plant species alongside road verges and railroads (e.g. *Senecio inaequidens*, *Cochlearia danica*) have shown that these verges can facilitate the spreading of some plants. However, many other plant species seem to disperse slowly and only when the suitable habitat is present (Bakker, 1989;

Van Dorp, 1996). In addition to the expansion and settlement of native plants there are also exotic species (adventives and neophytes) that find a habitat alongside motorways. Robbrecht (1983) refers to 'motorway neophytes'. Examples of this category are: *Senecio inaequidens*, *Oenothera biennis*, *Matricaria discoidea* and others.

Senecio inaequidens
Ernst (1998) describes the invasion, dispersal and ecology of the South African neophyte Senecio inaequidens in the Netherlands: introduced in Europe with wool transport and rapidly spreading over the continent. It was concluded that the dispersal alongside railways (Koster, 1991) and motorways (Kehren, 1995) is an important factor. It now also successfully invades other habitats with open structure, such as riverbanks, forest clearings and coastal see dunes. Ernst (1998) provides evidence of the causes: adaptation to winter temperatures in Western Europe, prolongation of the flowering period, modern traffic and climatic changes.

Three processes are important in the evaluation of the importance of road verges for the distribution of plants (Van Dorp, 1996; Van Groenendaal en Kalkhoven, 1990):

- The phenology of the species concerned: the maturation of diaspores.
- The number and the distribution in the landscape of the sources from which seed can be spread.
- Distribution mechanism.

According to Verkaar (1990), in a suitable habitat the estimated time required to travel 500 m under the effect of wind dispersion is one year for birch (*Betula species*.), 150 years for Goat's-beard (*Tragopogon pratensis*) and 500 years for Meadow Vetchling (*Lathyrus pratensis*). In this context, no attention was paid to extreme conditions (incidental human or animal influences that can have an important effect on the dispersion). Furthermore, the probability of germination and settlement may vary according to local soil and vegetation properties. Consequently, many plant species need a long time-span for a successful colonisation of new areas. This emphasises the necessity of a long continuity of a management system that produces and maintains suitable habitats.

Poschlod *et al.* (1996) stated that many plant species in the cultivated landscape of northwestern Europe have limited distribution and settlement opportunities. Fragmentation and isolation hamper dispersal for many species from semi-natural habitats. Also the seed bank appears to play a limited role in (re) colonisation of suitable habitats, some 'weeds', ruderal and pioneer species excepted. This can be seen after soil perturbations in road verges due to digging (say for laying cables), when species like Common Poppy (*Papaver rhoeas)* and Rape (*Brassica napus)* flourish.

Zoochory probably plays a subordinate role in roadsides, because grazing animals (the most important vectors) are absent. On the other hand, strong air movements, in a direction parallel to the road may significantly enhance the movement of seeds, even of species that normally are not anemochorous. This is an interesting unexplored field for further studies.

The use of de-icing salt periodically causes salty circumstances in a narrow zone next to the road surface. This has, together with regular soil removal in this zone, created a suitable environment for some halophytes, because some ecological conditions are comparable to coastal salt marsh. Thus, not only Early Danish Scurvy grass (*Cochlearia danica*) but also such species as Reflected Saltmarsh Grass

(*Puccinellia distans* subsp. *distans*), Lesser sea spurrey (*Spergula salina*) and Buck's horn Plantain (*Plantago coronopus*) are increasingly found in the interior of the Netherlands, but only near roads.

The strong influence of man on landscape structures puts restrictions on the dispersal possibilities of many plant species. Expansion of towns and villages, roads, modern agriculture hampers seed spread and reduces suitable places for establishment of plants. Also traditionally acting ways of seed transport like on animals or machines (e.g. important for *Rhinanthus angustifolius* (Bakker, 1989)) have decreased considerably. After realising the limited dispersal possibilities of many plants some researchers carry out experiments on intentional spreading of plants by laying out hay of desired vegetation types or sewing seeds of desired species. It is still under discussion weather this method is scientifically sound and ethically correct, and then which conditions should be fulfilled.

6. Flora and vegetation in roadside verges in the 1980's and 1990's

6.1 Introduction

This paragraph provides an overview of the Dutch applied research on road verge flora and vegetation. Much of it was carried out, paid and/or conducted by the Road and Hydraulic Engineering Institute (DWW). It forms part of the development of the ecology of long narrow landscape elements into a separate field of science (Forman, 1998; Forman et al., 2003; Sýkora, 1998). Studies will be reviewed on the classification of roadside vegetation, on the quality of roadside vegetation and how to measure it, on vegetation maintenance and what it costs, and some remarks about vegetation of dikes and concerning fungi in roadside vegetation are made. Finally some concluding remarks are given about the maintenance and development of botanical quality of roadside verges.

6.2 Research from a botanical viewpoint

- *System of road verge vegetation types*

An important phase in the studies of road verge ecology was the application of the Braun-Blanquet approach (Schaminée *et al.*, 1995) on roadside vegetation in the Netherlands (Sýkora *et al.*, 1993) and in Flanders (Zwaenepoel, 1993). Sýkora *et al.* (1993) made over 2500 vegetation relevés on road verges. 712 plant species were found, that is about half of the total number of all indigenous species in the Netherlands. The majority of the plants were characteristic of mown, unfertilized hayfields (*Arrhenatherion*), but also pioneer species of ruderal vegetation types were common. Sýkora *et al.* (1993) distinguished 69 road verge plant communities in the Netherlands.
Zwaenepoel (1993, 1998) studied 904 relevés with 717 species in Flanders, but with a low incidence of rare species. Zwaenepoel distinguished 37 vegetation types, which were more broadly defined than the Sýkora types. He characterized the types according to hitherto rarely used properties, for example richness of flowering plant species and therefore attractiveness to the road user.
Rare species were underrepresented in the road verge relevés of Sýkora (1993), indicating that road verges may be rich in species but contribute relatively little to the survival of rare and endangered species. For that purpose nature reserves are much more important than road verges. This was found although some selection for species-rich vegetation and rare plants was performed.

The results of the above-mentioned studies were only partially incorporated into the system

‘Vegetation of the Netherlands’ (Schaminée *et al.*, 1995-1999). Compared to other grassland vegetation types (e.g. those from nature reserves and from historical data), road verge vegetation types are often fragmentarily developed (Sýkora *et al.*, 1993). Many of the road verge relevés have therefore been combined into ‘trunk plant’ communities, i.e. communities that are dominated by few species and which cannot be assigned to vegetation types on the level of association or alliance. However, some communities that are restricted to the roadside environment are unattractive places or forbidden areas, leading to an underrepresentation in the total set of vegetation relevés.

Some vegetation types prefer, or are even restricted to road verges, such as the *Thero-Airion*, in shaded places like under rows of planted trees the *Melampyro-Holcetea mollis*, some types of ruderal vegetation and some scrubs dominated by bramble (*Rubus* spp.).

- *Botanical quality of road verges in the Dutch agricultural landscape*

In 1997 a study was made on the botanical quality of road verges in the Dutch agricultural landscape (De Bonte *et al.*, 1997). In this study, the research questions were:

1. Which plant species have their focus on road verges in parts of the Netherlands?
2. Which vegetation types are found on road verges in the Netherlands, and what is their botanical value?

These questions were answered using desk research and the files of the University Wageningen. At a national scale, 796 species of higher plants were found on road verges. Of these, 159 species preferred road verges in at least one of the six geomorhological regions covered by the study. Especially areas with Pleistocene sandy soils appeared to have many characteristic species.
In Figure 3 the relationship between vegetation types on sandy soils according to maintenance regimes are given (De Bonte *et al.*, 1997).

- *Richness of plant species on road verges and in the hinterland*

De Bonte *et al.* (1997) also studied the botanical quality of road verges related to that in the hinterland. The Motorway A12 was selected for the study because it makes a representative west-east cross-section through the Netherlands. The observations were restricted to grasslands and dry heath in four different landscape types: peatland meadows, river clay, low sandy soil, higher (and drier) sandy soil.

For comparison of roadside with adjacent land 257 vegetation relevés were made alongside the A12 motorway – 88 in the road verges according to a random protocol to avoid selection, and 169 in the hinterland at distances of 125 and 250 m from the verge relevé. The average number of species per 10 m² relevé on the verges was 32.7 and in the hinterland 11.5. The total number of species found on the verge (245) was also higher than the total found in the hinterland (220), although the number of relevés in the hinterland was almost twice the number of roadside relevés. Although they accommodated hardly any rare species, verges contained usually more species. They therefore contribute strongly to the general biodiversity in the agricultural landscape (De Bonte *et al.*, 1997).

The plants that were found more in the roadside relevés belong to the following ecological groups: ruderals, species of moderately fertilised meadows and weeds of arable fields. Interestingly, in the roadside were more weeds than in the adjacent arable fields. Approximately half the species (i.e. 142) were

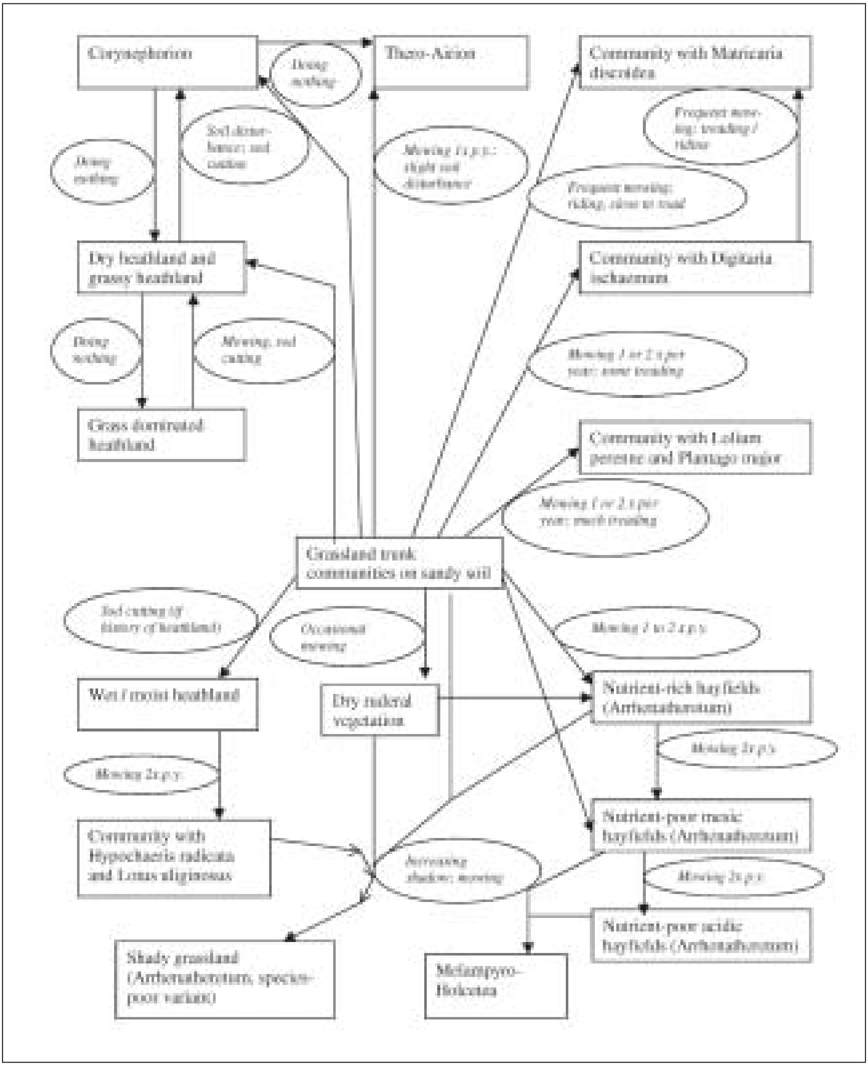

Figure 3. The relationship between vegetation types on sandy soils according to maintenance regimes (after De Bonte et al., 1997)

found both on the verge and in the hinterland. For some species, their presence was limited to a certain landscape type (Table 1).
Ninety-seven species were found only on the road verges. Examples of species which were found more or exclusively on road verges: *Arabidopsis thaliana, Bellis perennis, Centaurea jacea, Cochlearia danica, Daucus carota, Erophila verna, Leucanthemum vulgare, Pastinaca sativa, Raphanus raphanistrum* and *Silene latifolia ssp. alba*. During the survey, 70 species were found only in the hinterland.

- *The Top-10 of roadside verge plant species and the botanical 'hotspots' in roadside verges*

The 'Top-10' of plant species of the Dutch roadside verges are according to Keizer (2002): Cochlearia danica, Achillea millefolium, Allium vineale, Arrhenatherum elatius, Leontodon autumnalis, Heracleaum sphondylium, Pastinaca sativa, Valerianella locusta, Verbascum nigrum and Anthriscus sylvestris. On the basis of the observations made for the investigations of verge flora-measuring net (Tromp and Reitsma, 2001) a global survey of so-called 'Hot Spots' for the flora in roadside verges has been made, defined as locations where species with grid square frequency (UFK) 6 or lower are present. Figure 4 and Table 2 provide a picture based on preliminary data for the years 2000-2001 with completion for the year 2002 and 2003. The hot spots identified so far are scattered all over the country. In view of the limited amount of data, it may be expected that the number of spots with rare plant species as well as species of the Red list will increase after studying roadside more intensively.

- *Effects of mowing regimes on the flora and vegetation of road verges*

The 1970's saw the implementation of low-intensity verge management, comprising mowing once or twice a year with removal of grass cuttings. This was based on extensive studies in nature reserves. Here the low intensity mowing regime led to vegetation types with low production, where low competitive species can survive. Generally, such

Peat meadow area (hm 5-52)	**Gelderse Vallei (hm 85-110)**	**Veluwe (hm 110-135)**	**River area (135-189)**
Bromus sterilis	*Humulus lupulus*	*Anchusa arvensis*	*Anagallis arvensis*
Papaver rhoeas	*Juncus bufonius*	*Calluna vulgaris*	*Chenopodium ficifolium*
Senecio inaequidens		*Carex pilulifera*	*Chenopodium polyspermen*
Deschampsia cespitosa		*Danthonia decumbens*	
		Deschampsia flexuosa	
		Erica tetralix	
		Festuca ovina subsp. *tenuifolia*	
		Galium saxatile	
		Molinia caerulea	
		Pinus sylvestris	

Table 1. Plant species found in only one landscape type in a limited study area during the 1997 survey along the A12 between hm 5-52; 85-110; 110-135 and 135-189 (De Bonte et al., 1997)

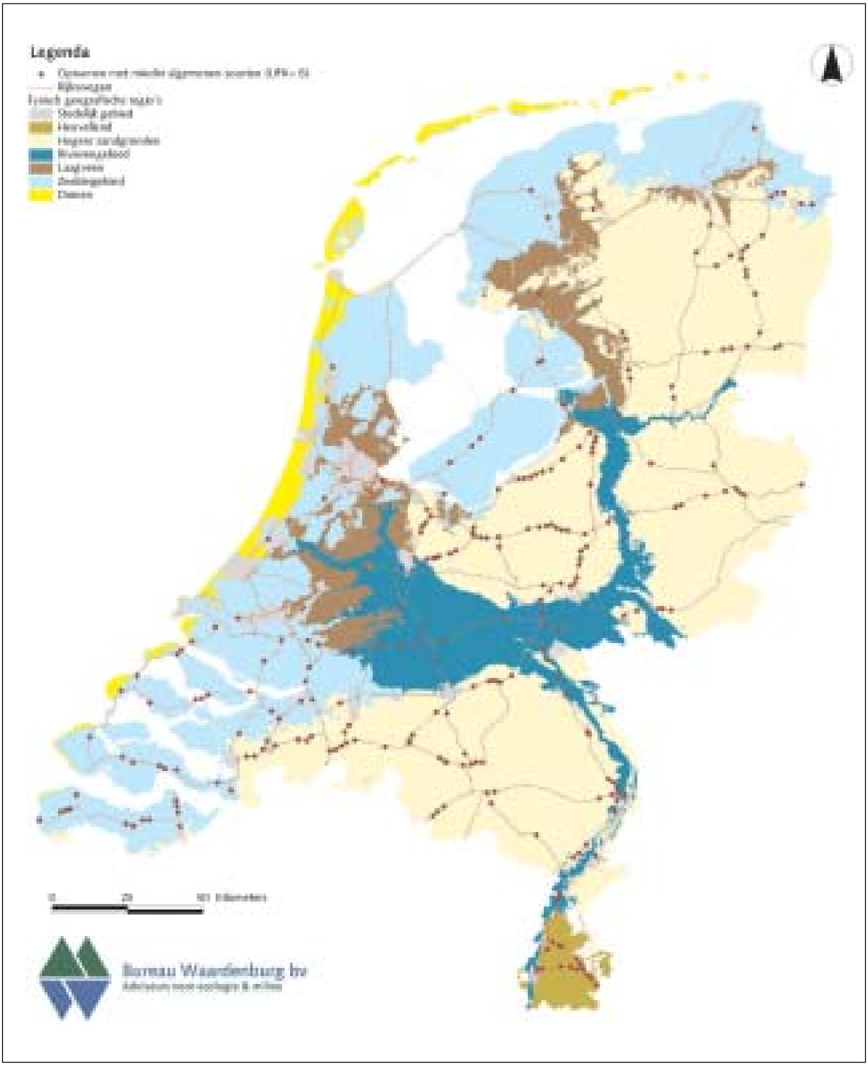

Figure 4. Botanical hotspots along Dutch motorways (Tromp and Reitsma, 2001; completed with data of 2002 and 2003)

Linaria repens	3	Phleum arenarium	5	Oenothera biennis	6
Luzula luzuloides	3	Potamogeton polygonifolius	5	Phleum pratense s. serotinum	6
Ophrys apifera	3	Rumex cripsus x obtusifolius	5	Picris hieracioides	6
Draba muralis	4	Sagina apetala	5	Pimpinella major	6
Eranthis hyemalis	4	Scrophularia umbrosa	5	Pimpinella saxifraga	6
Hieracium caespitosum	4	Senecio inaequidens	5	Plantago coronopus	6
Lamiastrum galeobdolon	4	Solidago canadensis	5	Populus nigra	6
Mahonia aquifolium	4	Symphoricarpos albus	5	Populus x canescens	6
Rorippa austriaca	4	Vicia lathyroides	5	Quercus petraea	6
Rorippa nasturtium-aquaticum	4	Aphanes arvensis	5	Ranunculus lingua	6
Taxus baccata	4	Orobanche minor	5	Rapistrum rugosum	6
Tilia cordata	4	Anthemis cotula	5	Rosa rubiginosa	6
Vulpia bromoides	4	Armeria maritima	5	Sambucus racemosa	6
Eleocharis quinqueflora	4	Linum catharticum	5	Samolus valerandi	6
Agrostis castellana	5	Sherardia arvensis	5	Sanguisorba officinalis	6
Armoracia rusticana	5	Hypericum elodes	5	Scirpus sylvaticus	6
Berteroa incana	5	Dactylorhiza incarnata	5	Sonchus palustris	6
Carex oederi s. oederi	5	Agrostis vinealis	6	Spergularia media s. angustata	6
Centaurium pulchellum	5	Alisma lanceolatum	6	Vaccinium vitis-idaea	6
Clematis vitalba	5	Asparagus officinalis s. officinalis	6	Verbascum nigrum	6
Cynodon dactylon	5	Carex flacca	6	Vicia tetrasperma s. tetrasperma	6
Equisetum x litorale	5	Centaurium erythraea	6	Vulpia myuros	6
Euphorbia cyparissias	5	Cichorium intybus	6	Dipsacus fullonum	6
Geranium pyrenaicum	5	Cochlearia danica	6	Lathyrus tuberosus	6
Glyceria notata	5	Diplotaxis muralis	6	Chara globularis	6
Hieracium sabaudum	5	Elytrigia atherica	6	Agrimonia eupatoria	6
Juncus ambiguus	5	Eryngium campestre	6	Anthoxanthum aristatum	6
Lamium maculatum	5	Festuca cinerea	6	Filago minima	6
Lepidium campestre	5	Galium verum	6	Fragaria vesca	6
Medicago arabica	5	Heracleum mantegazzianum	6	Knautia arvensis	6
Mycelis muralis	5	Hippuris vulgaris	6	Rhinanthus minor	6
Myosotis laxa s. cespitosa	5	Impatiens parviflora	6	Euphrasia stricta	6
Myosotis ramosissima	5	Isolepis setacea	6	Anthemis arvensis	6
Oenothera erythrosepala	5	Juncus subnodulosus	6	Galeopsis segetum	6
Oenothera parviflora	5	Lythrum portula	6	Genista pilosa	6
Ononis repens s. repens	5	Mentha x rotundifolia	6		

Table 2a. List of plant species with UFK =/< 6 in 2000-2003 based on ad random selection (Tromp and Reitsma, 2001)

Anthemis cotula	EB-13	Genista pilosa	KW-15	Centaurea cyanus	GE-12
Eleocharis quinqueflora	BE-10	Hypericum elodes	KW-7	Hordeum secalinum	GE-12
Aphanes arvensis	BE-10	Dactylorhiza incarnata	KW-7	Nardus stricta	GE-12
Orobanche minor	BE-10	Agrimonia eupatoria	GE-12	Trisetum flavescens	GE-12
Armeria maritima	KW-11	Anthoxanthum aristatum	GE-12	Cynosurus cristatus	GE-12
Linum catharticum	KW-11	Filago minima	GE-12	Euphrasia stricta	GE-16
Sherardia arvensis	KW-15	Fragaria vesca	GE-12	Genista anglica	GE-16
Anthemis arvensis	KW-15	Knautia arvensis	GE-12		
Galeopsis segetum	KW-15	Rhinanthus minor	GE-12		

Table 2b. Red List species in 2000-2003 based on ad random selection (Tromp and Reitsma, 2001)

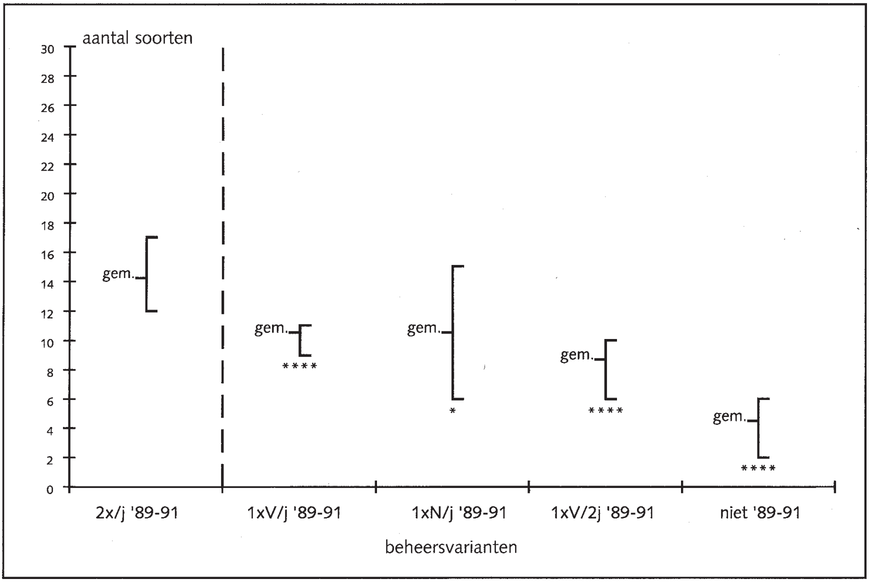

Figure 5. The effects of different mowing regimes on the plant species in the test sections on sandy soils near Voorthuizen (A10) (Van Schaik and Van den Hengel, 1994).

Legend:

2x/j:	two times/year mowing and removal of cuttings
1xV/j:	one time/year mowing in spring and removal of cuttings
1xN/j:	one time/year mowing in autumn and removal of cuttings
1xV/2j:	Every two year mowing in spring and removal of cuttings
Niet:	No mowing

*: significant lower number of species with regard to two times a year mowing.

vegetation types are species-rich. To answer the question whether such management could lead to the same result on road verges DWW launched a study on the effects of various maintenance regimes on the frequency of plant species on road verges. Biomass production and nutrient content of the soil were included in the study. Two roadside verges were selected, one on dry sandy soil (Voorthuizen, Motorway A12, with *Galio-Koelerion* and *Thero-Airion* grassland) and one on alluvial clay (Tiel, Motorway A15, with *Arrhenatherion* grassland). Some parts of the verges studied were shaded by trees and bushes, while others were not. The selected locations are representative of most of the verges of motorways in the Netherlands. Figures 5 and 6 show the results of the number of species in relationship to the various

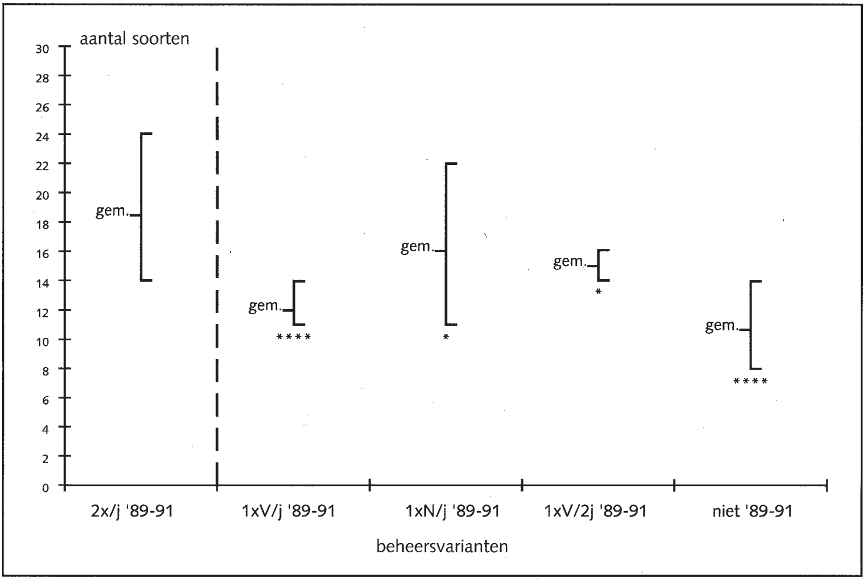

Figure 6. The effect of different mowing regimes on the plant species in the test sections on clay soils near Tiel (A15) (Van Schaik and Van den Hengel, 1994).

Legend:
2x/j: two times/year mowing and removal of cuttings
1xV/j: one time/year mowing in spring and removal of cuttings
1xN/j: one time/year mowing in autumn and removal of cuttings
1xV/2j: Every two year mowing in spring and removal of cuttings
Niet: No mowing
*: significant lower number of species with regard to two times a year mowing.

maintenance regimes (Van Schaik and Van den Hengel, 1994).
In spite of some methodological deficiencies such as lack of independent replicates, which hamper statistical analysis, the study clearly shows that mowing twice a year with removal of the cuttings produces the highest species diversity of vascular plants. Under that treatment the vegetation barely changed during the studied period (1992 - 2003). A lower mowing frequency reduces the botanical diversity.
On sandy soil, mowing once a year (in the autumn) with removal of the cuttings produced results comparable to mowing twice a year. In plots without maintenance on clay soil a dense vegetation of Common Nettle (*Urtica dioica*) with some scattered Reed Canary-grass (*Phalaris arundinacea*) and Cow Parsley

(*Anthriscus sylvestris*) developed, and on sandy soil a dense layer of partially dead Red fescue (*Festuca rubra*) with some False Oat grass (*Arrhenatherum elatius*) with starting invasion of some trees. Shady plots were distinctly poorer in species than fully exposed plots. This illustrates clearly that under trees species-rich grasslands cannot develop, probably due to light competition.

Contrary to other maintenance experiments (Bakker, 1989; Oomes & Mooi, 1981; Willems, 1983) focused on mowing and removal twice a year, in this experiment the number of species under this management did not increase. A possible explanation is that at the start of the experiment the maximum number of species was already present at both locations, since the mowing twice a year with removal of hay had already started at least five years before the start of the study. An additional explanation is probably the presence of a limited number of seeds in the soil and lack of good seed sources nearby.

In England Parr and Way (1988) found that mowing road verges twice a year led to an increase of species richness, as long as the hay was removed. Since no decrease in the soil nutrient content was found, this increase was attributed to the removal of the hay. Raking leads to open spots that provide opportunities to new species: light can reach the soil, which facilitates seeds germination (Bakker, 1987). Berendse *et al.* (1992), however, found a decrease of species after the same treatment in species-rich moist grassland. A possible explanation is that there was a very restricted seed bank and that good seed sources were absent. This study also showed a decrease of species numbers under shady conditions. Research on the relation between biomass-production and plant species richness (Vermeer and Berendse, 1983; Melman and Verkaar, 1991; Oomes, 1990; Oomes *et al.*, 1996) showed a positive correlation between nutrient availability and biomass production and a negative correlation of both with species diversity. Vegetation with an above ground production of 10-12 ton dry biomass/ha/year coincides with species poor grassland vegetation. A production of about 5 ton/ha/year shows an optimum of the number of plant species. Bakker (1987) found that mowing with removal of hay decreases the soil Nitrogen content by 4,1-5,7 % and the Phosphate content by 3,2 %. To decrease the nutrient contents substantially with this method is therefore a long lasting process.

Oomes (1988) observed that the predicted reduction of biomass production as a consequence of removal of hay in grassland is evident only in the first few years after the start of this treatment. Subsequently, it fluctuates according to climatic variations over the years (Boer, G., 2000). Oomes and Van der Werf (2003) wrote that removal of nutrients over a long period of times sometimes creates extremely low availability of phosphorus (P) and potassium (K) in the soil, and a decrease of the plant species diversity and concluded that if this is the case addition of P and K can be necessary.

Schaffers (2000) performed a detailed study of the effects of maintenance measures applied to various verge vegetation types in relation to soil properties. He found that after mowing the nutrients potassium (K), nitrogen (N) and phosphorus (P) rapidly leach from the cuttings into the soil. Removal of the grass within two weeks is necessary to counteract the effects of atmospheric deposition.
After the mowing, the cuttings have to dry for some time in order to facilitate their processing. Schaffers (1995, 2000) drew the following conclusions from his study:

- Highly productive communities (incl. false oat communities): the supply of nitrogen from the environment can always be counterbalanced by promptly removing the cuttings, which also reduces the phosphorus (P) and potassium (K) levels.
- Low-productive communities: mowing and removal of the cuttings cannot compensate the atmospheric N-input. Maintenance must be aimed at keeping the potassium (K) and phosphorus (P) levels as low as possible. Removal within 1-2 weeks is then necessary.
- Semi-shaded rough-herb communities (incl. Ground-elder (Aegopodium podagraria) association): nutrient poorness-focused maintenance for preservation is not strictly necessary. In order to prevent too much ruderalisation, it is desirable to promptly remove the cuttings.
- Moist tall herb communities: prompt removal of the cuttings reduces the disposable quantity only of potassium (K); there is hardly any reduction of the other nutrients.

A general problem with the prompt removal of the cuttings is that the seeds are removed along with the mown plants. During drying, seeds still present in the cuttings can mature. The evaluation of the right time for mowing and removing the cuttings must be based on the composition of the vegetation (many or few annual and biennial plants as compared to perennials), maturation or not while still on the mown plant, and the degree of drying of the cuttings

The following can be concluded concerning the choice between the removal of cuttings (nutrient reduction) and the time of the fall of the seeds. Grassy vegetation requires maintenance that is similar to traditional haymaking; the seed setting should play a role in the selection of the mowing dates. For fertile soils, the favourable mowing periods are around 15th June and around 15th September, and for nutrition-poor soils around the end of August only. When determining the exact mowing date it is important to take the weather into account, because wet weather generally is unfavourable for seed ripening on the cut plants.

Case-study: Mowing maintenance alongside the A58 motorway

Based on the knowledge pointed out above, the management of the verges alongside the A58 motorway in the province of Zealand is performed with ecological objectives (Meijer & Smits, 1990), i.e. maximum species diversity. For the grassland vegetation, the following mowing regimes were installed in strips parallel to the traffic lanes.

- Mowing and removal of cuttings twice a year (spring - between 15 May – 15 June - and autumn – between 1 September – 1 Oktober -) for botanical aspects.
- Mowing and removal of cuttings once a year (spring) so that strips remain unchanged in winter, allowing fauna (insects and small mammals) to hibernate.
- Mowing and removal of cuttings once a year (autumn) especially for rare or relatively rare flora (some locations).
- Mowing and removal of cuttings once every three years (autumn); especially intended for rougher edge vegetation alongside dense, woody vegetation types in order to provide a habitat for fauna.

In 1988, before the start of the new management regime vegetation recordings were made. In each of the years 1993 through 1996, vegetation recordings were made at fixed locations in order to gain a better understanding of the development of the flora and vegetation types over the years (Veer *et al.*, 1998).

The recordings with mowing twice a year showed little floristic changes compared to 1988: a relatively species-rich *Arrhenatheretum* remained in these verges with high densities of False Oat-grass (*Arrhenatherum elatius*), Red Clover (*Trifolium pratense*), Wild Carrot (*Daucus carota)* and Wild Parsnip (*Pastinaca sativa*).
With mowing once a year not much changed either, but the species density dropped somewhat. Mowing once every three years led to rough growth with increase of species as Couch Grass (*Elymus repens*), Creeping thistle (*Cirsium arvense*), Cow Parsley (*Anthriscus sylvestris*), Stinging Nettle (*Urtica dioica*) and woody plants.

The study shows that mowing twice a year leads to the highest number of plant species with the highest number of 'flowering' herbs, followed by mowing once a year in spring (differences small and often insignificant). Both lead to similar nature values (according to Clausman & van Wijngaarden, 1984). Mowing once every three years in autumn leads to higher, rougher and more species-poor vegetation with lower value than mowing twice a year. Possibly the differences between mowing once and twice a year will become more evident after a longer time span.

Case study: Mowing times and rare plant species in road verges

In choosing the mowing regime and the optimal mowing time, it is also important to take into account the presence of relatively rare species and plant species that are characteristic of the phytogeographical district (Zonderwijk, 1991). Based on a selection of more or less rare plant species growing on road verges listed by Zonderwijk (1991), the distribution in time of mowing regimes is globally indicated in Table 3. It shows that it is difficult to give general advices. Local conditions, including the weather, must also be weighed when taking the decision concerning the exact date for the mowing and removal of the grass cuttings.

- *Effectiveness of road verge management*

It is important for road managers to know whether the money spent on vegetation management actually results in the desired vegetation. Therefore, in most of the regional districts of the national road authority the vegetation is evaluated every five to seven years. Brief reports on the subject are published, usually accompanied by advice concerning the improvement of maintenance measures. In 2001, an evaluation of the ecological management in roadsides was carried-out (Kalwij *et al.*, 2001). It was possible to use data from the period of 1986-1988 made for the publication by Sýkora *et al.* (1993). 545 plots along highways from the period 1986-1988 were resurveyed, spread all over the country. In the revisited plots, a total of 409 species of vascular plants were found in 1986/1988; in 2001, 410 species were found. Of these species, 333 were found in both periods; in 2001, 76 species had disappeared and 77 new ones had appeared.

A comparison of the absolute distribution over the grid square frequency ('UFK') classes shows that the number of common species had increased. The plant species have been divided over grid square frequency classes (UFK's) based on a grid of squares of 5x5 km over all of the Netherlands, of which there are in total 1677. This number of squares has been divided over nine frequency classes ranging from: UFK 0 (= extinct plant species in the Netherlands), UFK 1 (= 1-3 grid squares, extremely rare) to

Tuberous pea	*Lathyrus tuberosus*	Where the vegetation is developing strongly, mow no later than the middle of May; otherwise do not mow before the end of September.
Field scabious	*Knautia arvensis*	Flowers from June to well into September; mow from the end of September. Early mowing means before the middle of May.
Hawkweed oxtongue	*Picris hieracioides*	Early mowing in May; second mowing not before the end of September.
Chicory	*Cichorium intybus*	Early mowing in May or June, or from the middle of September.
Nodding thistle	*Carduus nutans*	Not before the middle of September; if necessary, before the middle of May.
Common gorse	*Ulex europaes*	Do not mow; if mowing, mow around the bush, as in the case of broom.
Harebell	*Campanula rotundifolia*	Mow once a year; from the second half of September.
Hawkweed	*Hieracium umbellatum*	Mow at the end of September; if necessary, before the middle of June.
Fritillary	*Fritillaria meleagris*	Mowing from the middle of July
Common broomrape	*Orobanche minor*	Mowing from the middle of September; if necessary, before the middle of May.
Goat's-beard	*Tragopogon pratensis*	Does not support early mowing; mow in July when the seed has been blown away.
Greater yellow-rattle	*Rhinanthus angustifolius*	Mow after seed maturation (middle of August).
Rough hawk's beard	*Crepis biennis*	Do not mow early; mow from August.
Black mullein	*Verbascum nigrum*	No later than the middle of May; preferably after the middle of September.
Common star of Bethlehem	*Ornithogalum umbellatum*	Mow in summer /after flowering/seedforming

Table 3. Mowing times of vegetation with more or less rare plant species in road verges (after Zonderwijk, 1991)

UFK 8 (= 711-1210 grid squares, very common) and UFK 9 (= 1211-1677 grid squares, extremely common).

The fairly common and the very common species had increased by one and two class units, respectively. The species not found in 2001 were mainly very rare to uncommon species, and the number of endangered species for the Netherlands as a whole decreased by 40% in the second period. This indicates a decrease of the floristic value of the motorway verges. The number of ruderalised plots increased by 94%.

In the Netherlands, there is continuous nitrogen deposition and due to this external eutrophication ruderalisation of the vegetation occurs, i.e. tall, rapidly growing broad-leaved perennial herbs start to dominate in the vegetation. Due to this ruderalisation, a reduction of the percentage of vegetation types of nutrition-low soils with usually less common species could be observed.

These developments could have been caused by (Kalwij *et al.*, 2001; Sýkora *et al.*, 2002):

- too late removal of the cuttings (nutrients end up in the soil);
- insufficiently careful removal of the cuttings;
- no longer maintenance of road verge sections at further distances from the road;
- deposition of ditch mud;
- lack of maintenance (leading to ruderalisation and secondary succession to woody vegetation);
- careless maintenance (incorrect mowing time, frequency or method used);
- disturbance by pedestrian or wheeled traffic and digging (e.g. for the installation of cables);
- rotary cultivation;
- absence of checks on the work and penalties on activities carried out poorly by green contractors.

Assuming that the observations are representative of all motorway verges, the maintenance carried out did not lead to an improvement of the national floristic composition. On the other hand, the plots were originally selected to make a survey of roadside vegetation, and not with the aim to make repeated comparisons. This could mean that stands richer in species than average have been selected, with as a consequence a larger chance to find impoverishment.

In spite of the above-mentioned negative developments, road verges – if correctly created and managed – still provide important habitats for plant species that elsewhere are decreasing.

- *Road verge flora monitoring network*

In 1999, DWW resolved to set up a flora and vegetation monitoring network focussed on motorway verges as part of the subproject General Species of Flora Measuring Network Netherlands (which in turn is part of the National Ecological Monitoring Network) (Van der Peijl *et al.*, 1999). The objective is a standardised set-up and execution of the monitoring of motorway verge vegetation in order to evaluate the effects of maintenance measures and to contribute to the national measurement objectives. Such monitoring will provide a global understanding of any changes in motorway verge vegetation. In total 1600 relevés of 3 x 3 m^2 will be established during four years in the verges of the motorways. Subsequently, they will be monitored once in every four years. After a pilot study in 1999 (De Goede, 2000) in 2000, a start was made with the first round 400 relevés (Tromp and Reitsma, 2001). So far, no statement can be made concerning the effects of the maintenance until the entire monitoring network has been completed and the first repetition carried out. Nevertheless, based on part of the first rounds – which were carried out in various places in the Netherlands – an understanding has been gained of the distribution of certain species alongside motorways, for example, the Creeping Thistle (*Cirsium arverse*), Common Ragwort (*Senecio jacobaea*), Heather (*Calluna vulgaris*), Sheep's Sorrel (*Rumex acetosella*), Wild Parsnip (*Pastinaca sativa*) and Wild Carrot (*Daucus carota*). See for these species the figures 7 with preliminary distribution maps (Tromp and Reitsma, 2001).

- *Maintenance costs and ecological values of motorway verges*

Managers and decision makers must have a clear insight in the costs and benefits of the ecological roadside management as applied today. Therefore a study was carried-out which compares the costs of several different maintenance regimes (De Jong *et al.*, 2001). The study was limited to grasslands, tree meadows and ditches, and showed that the change from traditional frequent flailing maintenance to ecological maintenance (mowing twice a year and removal of the cuttings) had led to a marked increase in ecological values and to varying effects on the maintenance costs.

The largest increase in ecological values was found in grasslands. Ditches appear to have the highest ecological potential if given a new, nature-friendly design. The ecological values (actual and potential) of the tree meadows are low compared to the other two studied vegetation types.

The maintenance costs of moderately nutrient poor grasslands and tree meadows decreased as a result of the transition to ecological maintenance. In the moderately nutrient-rich and very nutrient-rich grasslands, a cost increase was noted, except for a cost reduction between 1975-1985. In the case of ditches, maintenance becomes less expensive after a new-design investment.

In the cost item 'processing cut grass' considerable savings can be made if new and cheaper or money generating sales and/or processing methods are found. Contamination leads to limitations on the use of grass as fodder or compost (Meijer *et al.*, 1993). The chemical quality of roadside grass improved markedly, partly because lead is no longer added to petrol. TNO, ENECO and the Province of Gelderland are carrying out further studies into less expensive processing methods for road verge cuttings, since the costs of such represent one-third of the total costs of verge maintenance. One of the possible uses of cut grass may be using the material as organic soil improver, but there are strict legal requirements.

- *Vegetation management on dikes*

Dikes have in common with roadsides a technical function that can be combined with an ecological function. Both are long narrow landscape elements with (sometimes) unfertilised and mown grassland vegetation. At the request of the Road and Hydraulic Engineering Institute (DWW), Sprangers (1996 and 1999) for sea dikes and Liebrand (1993 and 1999) and Van der Zee (1992) for river dikes studied how a maximal biodiversity can be combined with optimal technical function as protection against flooding. In the case of dikes especially an effective resistance against erosion by wave attack is most important.

The mowing maintenance results are similar to that of road verges. Ecologically speaking, mowing twice a year with removal of the hay

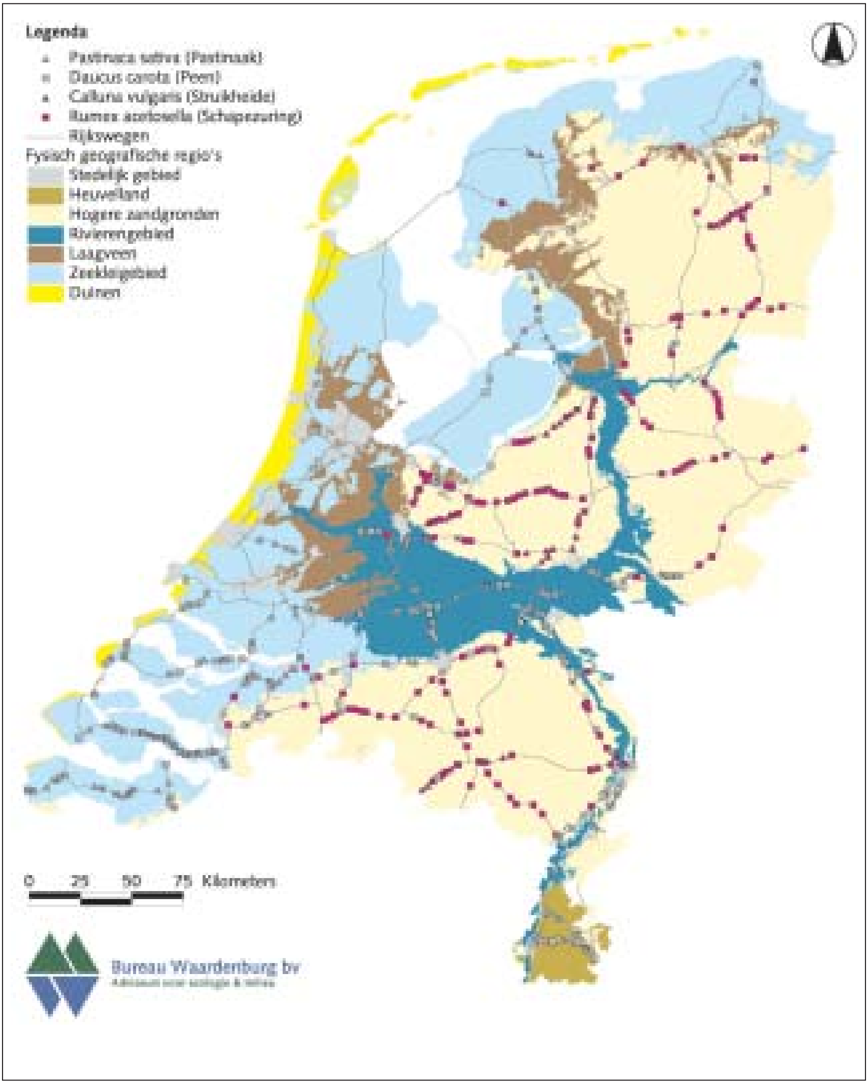

Figure 7. Distribution along motorways of Calluna vulgaris, Rumex acetosella, Daucus carota and Pastinaca sativa (2000-2001 supplemented by data from 2002 and 2003) (Tromp and Reitsma, 2001)

in June and without removal in September, mowing once in June with removal, mowing once in September with removal, mowing in June with removal and grazing in September are fairly effective maintenance methods of dike vegetation. However, in practice the grasslands on dikes are often rented to local farmers who make an intense use of it, leading to higher chance of erosion and a less strong turf than would be optimal for the strength of the dike.

Liebrand (1999) showed that after reconstruction of a dike, restoration of a species-rich *Arrhenatheretum* vegetation which is characteristic for the river area in the Netherlands is possible. Three methods have been tested successfully. The best option is to save a strip with rare species during reconstruction of a dike, from where the species can spread over the reconstructed parts. Secondly, sods of the 'original' vegetation can be taken away and stored, which are placed back after the reconstruction. Thirdly, hay from a place with the desired vegetation can be spread on the surface of the reconstructed area. Seeds from this hay fall and germinate to a sufficient degree to create a vegetation more or less like the desired one. Success is however also dependent of the 'right' soil composition, similar abiotic conditions (slope, exposition, etc.) before the reconstruction and ecological management after establishment of the plants. This approach is not yet applied on road verges, but seen from an ecological point of view it could be useful in some situations. See also Wells et al., (1981) and Schippers and Gardenier (1998).

- *Vegetation types, fungal communities and maintenance practice*

Keizer (1993) studied the relationship between vegetation types, fungal communities and management practice along road verges with planted trees. A special feature of this habitat is that the trees take up nutrients from the soil and these nutrients are not returned to the soil because the majority of the leaves are blown away. In some places, this very open nutrient cycle causes severe impoverishment of the topsoil. Vegetation management comprising mowing once a year with removal of the grass cuttings also contributes to a nutrient output from the system: nutrients stored in the cuttings are taken out of the system, and leaves are not trapped by the road verge vegetation. This maintenance is therefore essential to maintain this special situation.

The result is a vegetation typical of nutrient-poor soil conditions (especially for nitrogen and phosphorus). Under such conditions there usually is a rich flora of ectomycorrhizal fungi. Many of these species are restricted to the roadside environment and do not occur in forests with the same tree species. Fungal communities from unfertilised grassland vegetation are often rather well developed too. Continuation of the management is essential to maintain the characteristic fungal communities. Interestingly, the same pattern can be found on road verges on sandy soils and on clay soils: large numbers of ectomycorrhizal fungi on nutrient-poor sites, but with almost completely different fungal species composition on both soil types.

- *Research from a ecohydrological viewpoint*

The local hydrological situation and the quality of groundwater and surface water near road verges are important conditions for flora and fauna. Specific ecohydrological relations for each physical-geographical region in the Netherlands have been distinguished and described (Everts *et al.*, 1982; Van Wirdum, 1991; Westhoff *et al.*, 1970, 1971 and 1973; Zonneveld, 1987). Road constructions may influence local hydrological systems, for example in the case of roads on sand bodies in peatland areas, but in many cases these effects are of little significance.

The technical function of road makes an efficient draining system necessary. Therefore often a road ditch is part of the road construction. These ditches can have significant ecological values for resident and migrating water-bound organisms. In this context it is essential to regard the road verge and the road verge ditch as interconnected ecosystems. Often, a relative good water quality is present because one side of the ditch is outside the influence of agriculture (fertilizers, chemical pesticides). In addition, most of the water from the road-body is filtered in the sand that was used for its construction. In cases where the road is in the immediate vicinity of drinking water extraction areas extra water cleaning measures may be necessary (Van Bohemen & Janssen van der Laak, 2003).

In recent years, views have changed concerning the design and maintenance of road verge ditches. The traditional water draining function is nowadays often combined with an ecological and even water retaining function. Wherever possible, ditches can be reconstructed with low slopes that consist of a marshland zone, thus enabling to develop a marshland ecosystem. A survey by Van Strien and Van den Hengel (2000) has shown that about 50% of motorway verges qualify for a nature friendly design and maintenance. DWW produced an attractive brochure, which presents various types of bank reconstructions and ditch management systems, including costs, to inform roadside managers and non-specialists on ecological ditch management (Van Strien and Van den Hengel., 2000; Figure 8). (See also: Melman, 1992; Melman et al., 1986; Zonderwijk, 1976, 1986; and Zonderwijk and Zon, 1976; lit.ref. on p. 243, 245)

- *Ecological roadside management under pressure*

In many places, the ecological quality of road verge vegetation is under pressure because traffic has become much more intensive, more roadside infrastructure (portals, cables, etc.) is being built and more noise-barriers are constructed. More frequent disturbance and pollution are important external sources of pressure. Also repeated reconstruction projects do not allow road verges to reach a mature and stable stage. Moreover, in spite of all the information on the ecological value of road verges, and the essential role of proper maintenance non-recognition of the ecological importance by those who should be concerned show by contrast an absence of knowledge and understanding. They easily designate road verges and other green elements as superfluous corners and residual spaces, which soon can obtain a non-ecological function. In case of shortage of budgets, money saving programs often find in ecological roadside management and maintenance an easy object to cut budgets, although in case of reduced mowing frequency or non-removal of cut grass the vegetation quality will rapidly decrease.

- *Concluding remarks*

Roadside vegetation can be relatively species-rich. Roadside verges can considerably contribute to the biodiversity in an intensively used landscape. However, the communities are often "unsaturated" compared to related vegetation types elsewhere, e.g. in nature reserves; this is possibly due to the long, narrow shape, frequent disturbances, lack of seed sources and insufficient maintenance. Vegetation maintenance is essential to maintain the roadside grassland vegetation, comprising mowing with removal of the hay. It is not yet known which mechanism is most important for plant diversity: creation of gaps, impoverishment of the soil or seed transport by the

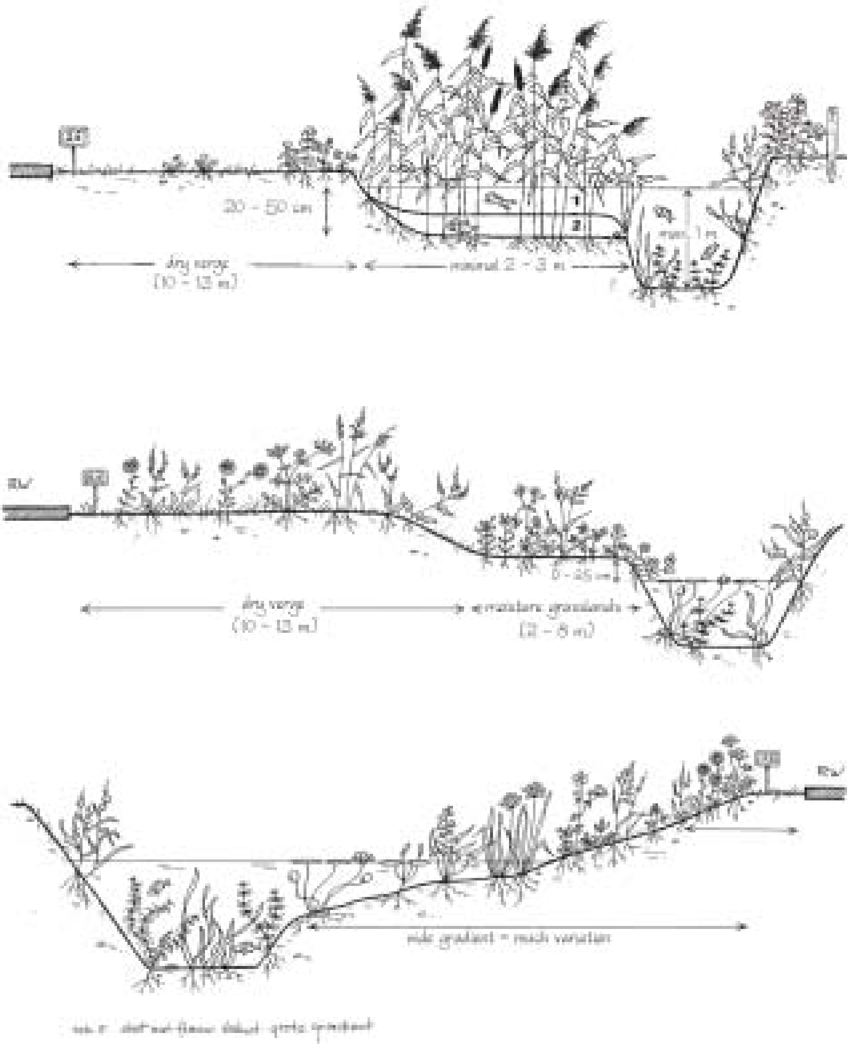

Figure 8. Different designs of motorway verge ditches (some examples from Van Stien and Van den Hengel, 2000)

machines. Recently a tendency seems to emerge where budgets for ecological roadside management and maintenance are cut. This will inevitably lead to losses of ecological quality of roadsides and therefore also of the whole landscape.

7. Fauna in roadside verges in the 1980's and 1990's

Introduction

Any vegetation harbours fauna communities. In this paragraph research on small animals will be reviewed for which roadside verges can serve as habitat. For large animals roads forms a barrier in the landscape. Information on prevention of road killings and construction of and use of fauna passages is presented in chapter 4.

- *The occurrence of reptiles on motorway verges*

Zuiderwijk (1989) found that the Viviparous Lizard (*Lacerta vivipara*) is quite often present on motorway verges, albeit that verges alongside railways are preferred to those alongside roads. Sand lizards (*Lacerta agilis*) have an even more striking preference for railway verges. The Viper (*Vipera berus*) occasionally occurs in roadsides with heathland vegetation, especially if there is a moist area in the vicinity. The Slow Worm (*Anguis fragilis*) and Smooth Snake (*Coronella austriaca*) are virtually absent from road verges but perhaps somewhat more common on railway verges. This is probably attributable to differences in relief at the micro and the macro scale. The ring-snake (*Natrix natrix*) is far from common in road verges, but can live in a motorway habitat, if well-developed marsh vegetation is part of the verge or surroundings. Zuiderwijk (1989) described an optimal ring-snake road verge as variable regarding vegetation, but a ditch must be present. The verge should be between 25 and 100 m wide, although this may include suitable hinterland. It also needs over one-year-old stacks of road verge cuttings or compost stacks for its eggs.

Generally speaking, road verges rarely form optimal habitat for reptiles, with the possible exception for Sand lizards. But if the verge borders a suitable habitat, it can be included in that habitat. Heterogeneity and alternating horizontal and vertical layers are necessary conditions for all species of reptiles (and probably also for other small animal species). The adoption of measures requires a prior understanding of the species that are found (or potentially are to be found) in the area concerned.

- *Small mammals on motorway verges*

In order to gain an understanding of the role of small (about mouse size) mammals on motorway verges in relation to the hinterland, a study was set up in the central and eastern part of the Netherlands (Van der Reest, 1992). During the period 1987-89, motorway verges and the adjacent area were studied for the presence of small mammals at more than 50 spots. The aim was to ascertain the composition of the small mammal fauna on motorway verges, the influence of environmental factors and control measures, and the spatial dynamics of species and populations.
The following small mammals were found: wood mouse (*Apodemus sylvaticus*), common vole (*Microtus arvalis*), common shrew (*Sorex cf. araneus*), field vole (*Microtus agrestis*), bank=wood=red vole (*Clethrionomys glareolus*) and white-toothed shrew (*Crocidura russula*). The subterranean vole (*Pitymys subterraneus*), pigmy shrew (*Sorex minutus*), weasel *(Mustela nivalis*), mole (*Talpa europaea*) and brown rat (*Rattus norvegicus*) were found incidentally.

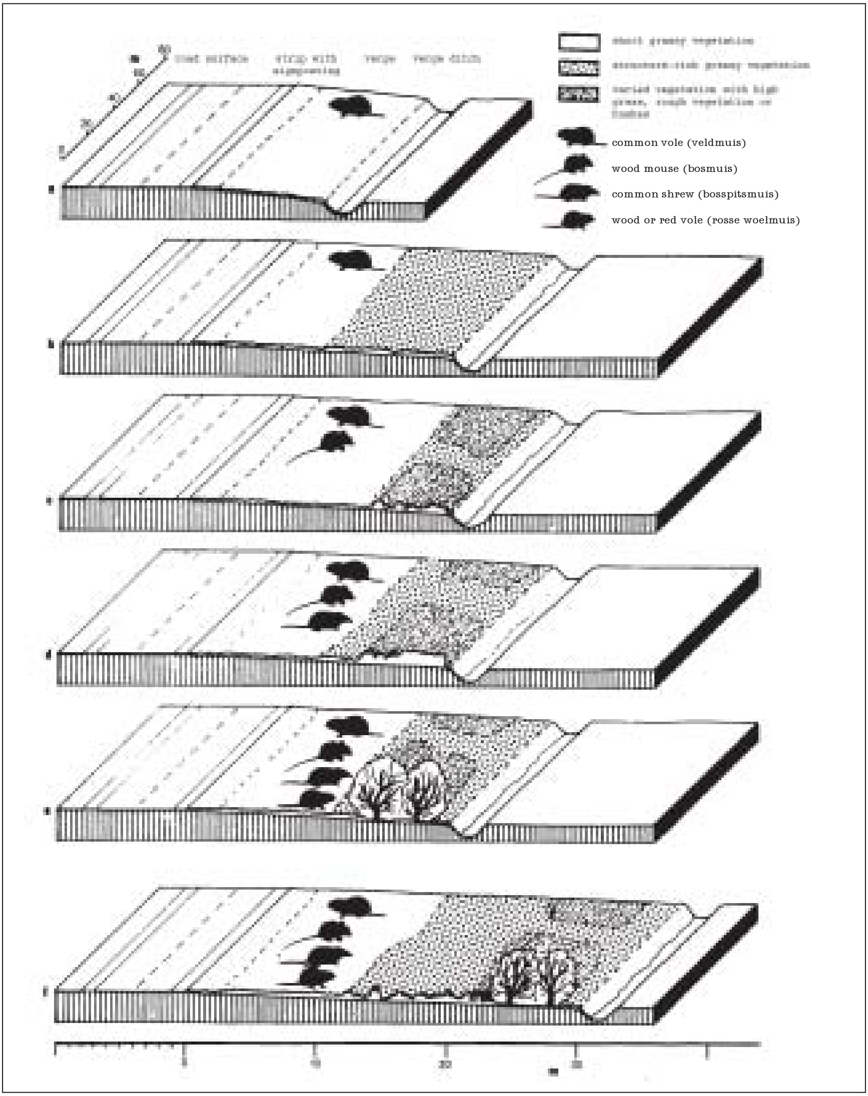

Figure 9. Six design variants (Van der Reest and Bekker, 1990)

Type a	*Narrow (< 10 m), structure poor, grassy vegetation* ● Poor small mammal fauna, mainly Microtus arvalis (Veldmuis/Common vole). ● Frequent mowing (2-3 times/year)
Type b	*Wide (> 10 m), low grassy vegetation* ● Poor small mammal fauna, mainly Microtus arvalis (Veldmuis/Common vole), sometimes massive. ● One or two times mowing per year; leaving cuttings on fixed places will increase mouse density.
Type c	*Wide (> 10 m), structure rich, grassy vegetation* ● Varied small mammal fauna; mainly Microtus arvalis (Veldmuis/Common vole), but also Apodemus sylvaticus (Bosmuis/Woodmouse) and less Microtus agrestis (Aardmuis/Field vole or Short-tailed vole). ● Varied stripwise mowing regime, with leaving cuttings on fixed places.
Type d	*Low grassy vegetation with a strip of tall vegetation (rough herbage: dry verges; reed: wet verges)* ● Varied small mammal fauna; frequent Microtus arvalis (Veldmuis/Common vole) and Sorex cf. araneus (Bosspitsmuis/Common shrew). ● In wet-dry situation: Micromys minutes (Dwergmuis/Harvestor or Dwarf mouse); in dry situation in southern part of the Netherlands: Pitymus subterraneus (Ondergrondse woelmuis/Pine vole). ● Mowing 1 – 2 times/year with removal of cutting; 1x/2-3 years on the rough strip. For Pitymus: local turn over of soil; for Micromys: maintenance of reed in ditch.
Type e	*Wide low grassy vegetation and a strip with shrubs* ● Varied small mammal fauna. Microtus arvalis and Sorex cf. araneus in grassy vegetation. Apodemus sylvaticus and Clethrionomys glareolus (Rosse woelmuis/Bank, Wood or Red vole) in shrubzone. ● Mowing grassy vegetation once/year; left cuttings locally on fixed place; regular pruning of shrub.
Type f	*Wide verge with low and intermediate high grassy vegetation via a fringe vegetation changing in planting of trees.* ● Varied small mammal fauna. Microtus arvalis and Sorex cf. araneus in grassy zone; Apodemus sylvaticus, Clethrionomys glareolus and Sorex cf araneus in plantings. Potential for: Crocidura russula (Huisspitsmuis/House of White-toothed shrew and Sorex minutus (Dwergspitsmuis/Pygmy cf. Lesser shrew). ● Varied mowing regime of grassy vegetation. Plantings need periodic pruning and pollarding. Edge and fringe vegetation once/2-5 year mowing or pruning.

Table 4. Six design and maintenance variants of roadside verges in relation to small mammal fauna (after Van der Reest and Bekker, 1990)

The common vole and wood mouse often procreate on verges. For these species, road verges function as preferred habitat patches especially if suitable habitat spots are lacking in the vicinity. Other species of mice are only temporarily present on verges. Wide verges with a richly varied vegetation structure, low-intensive management, a large biomass above ground and a thick layer of litter encourage the presence of small mammals. If there are preferred areas for the field mouse, wood mouse and bank vole present in the hinterland, the road verges usually accommodate smaller numbers of these species. Furthermore, the uniform mowing maintenance of verges causes insufficient variation in the vegetation structure for small mammals. It was also found that ditches parallel to the verges can be a barrier for poorly dispersing species.

Figure 9 and Table 4 gives examples of design suitable as habitat for small mammals.

- *Birds and road verges*

For some bird species, especially those, which reluctantly cross open areas (example: Nuthatch (Opdam *et al.*, 1993)) roads may serve as a corridor for migration through the landscape. Especially roads with rows of planted trees in the verges may serve effectively for this purpose. On the other hand, each year in the Netherlands, approximately two million birds – mostly breeding birds – are killed by traffic (Van den Tempel, 1993). Rodent-eating species, such as the barn owl, little owl and kestrel), are extremely vulnerable. For example in the period 1998-2001 58 barn owls, 46 buzzards, 9 kestrels, 2 sparrow hawks, 1 short-eared owl and 4 long-eared owls were found dead along a 30-km stretch of the Almere-Lelystad section of motorway A6. Of these, 73% were found between hectometre posts 69.4 and 72.6. There were striking differences between the numbers of victims in various subsections. In addition to the design of the road, especially the local environmental structures are important.

Apart from road killings the disturbance effects of roads and traffic can have a negative effect on bird populations. For the application of environmental impact assessments that must be made before a decision on road building projects is taken, DWW initiated a study on effects of traffic noise on birds (Reijnen, 1989, 1995; Reijnen *et al.*, 2002; Foppen *et al.*, 2002). The disturbance distance appeared to be 100 m (forests) up to 1500 m (meadows). On a motorway with 75.000 vehicles per day the effect distance in an open landscape with 75 % woodland is 81 m for woodcock and 990 m for cuckoo. In open grasslands the effect distance is 100 m for coot and 1130 m for black-tailed godwit. The density reduction of breeding birds for woodlands is from 37-99 % and 36 – 82 % in grasslands. It should be realized that occupying optimal and suboptimal habitat patches is populationsize dependent.

Barn owls and roads / traffic

For some birds traffic accidents are the most important factor of mortality. In the case of Barn owls it was estimated that the A6 motorway accounted for more than 50% of the annual mortality of this species in the province of Flevoland (Fopma, 2002). Throughout the country, traffic is responsible for over 40% of the annual Barn owl mortality (Anonymus, 1996). The positive effect of ecological road verge management on rodents thus has an unwanted drawback for some birds (Van der Reest, 1992). At the population level, these road-kills seem to have rather small effect on the breeding populations of the birds of prey. Despite a yearly loss of approximately 50 % of the population and a strong increase in traffic intensity, the number of breeding pairs of the barn owl has increased over the past 20 years

(Bijlsma, 1993). But before 1963 less than 5 % of the barn owls were killed by traffic, in 1982 30 %, in the 1990's 50 % and in areas with a dense barn owl population even 70 % (De Jong, note). The intensification of agricultural practices (use of chemicals) combined with reduction of nesting possibilities in farmhouses were the main causes of the decline of these owls. During the last years the population is recovering. Future studies should give insight in the future relationship between owl road kill and the population dynamics.

In order to reduce road killings among Barn owls, the maintenance of the motorway A6 in the Flevoland province was changed from twice a year (with removal of the hay) to once a year in spring. The result was a higher, ruderalised vegetation with high densities of Creeping Thistel (*Cirsium arvense*) and Common Nettle (*Urtica dioica*). The owls seem to avoid this vegetation, as it makes their preys less perceivable. Final conclusions, however could not be drawn, because unexpectedly the field mouse population in the arable fields exploded, which made this area much more attractive for them than the roadsides. The number of road casualties appeared to be low and made a statistical analysis inopportune (Fopma, 2002, Figure 10). Barn owls use kilometre signposts along roads as lookout posts, which are risky places. Special adopted signposts should be designed to prevent the use as lookout post. Clearly, more studies on hunting behaviour, moving of individual birds, shifts in populations, effects of traffic lights (Rodts *et al.*, 1998) and noise barriers, effects of artificial 'extra' feeding grounds, should be carried-out to get better understanding of the nature of this owl and how effectively reduce the number of traffic victims.

Birds and transparent noise barriers

A frequently overlooked detrimental effect of

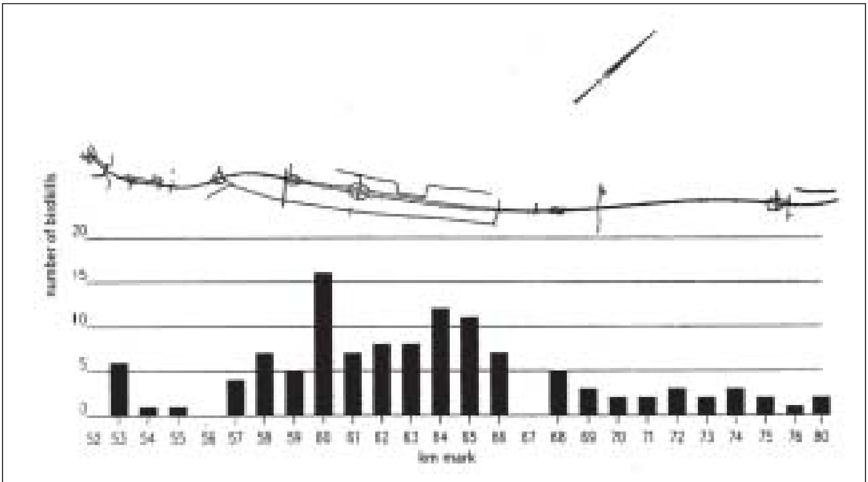

Figure 10. Barn owls as road-kills along the A6 motorway Almere-Lelystad from km 53 till km 80 (RWS/Dir. Flevoland, 1998).

roads on birds is the presence of transparent noise barriers (Notenboom, 2002a,b; Biber, 1994). Flying birds do not see these barriers in time and hit the barrier. In this, the presence of trees and shrubs reflected by the transparent barriers or seen through them is an important factor (Schmid and Sierro, 2000). Simple, effective measures are available, for example applying non-transparent markings, like black stickers 1.5 m apart representing hawks, or vertical rather than horizontal lines. They preferably should be coloured and non-reflecting, (Klem, 1990; Schmid and Sierro, 2000). Shrubs or trees near the transparent barrier should be avoided. Guidelines for 'bird-friendly' noise barriers are given by CROW (2002) and Notenboom (2002a,b).

Positive effects of roads on birds
In some circumstances special habitat conditions can be created for birds near motorways. Several small bird species breed in the hedgerows and shrubs in the roadside. However, it is questionable if they have a real positive impact on the population level of these species.

At some locations, for example in areas within cloverleaves of motorways and in noise barriers steep sandy slopes have been made for the Sand Martin (*Riparia riparia*). Some of them were used successfully by the birds. At several other locations – and especially near large motorway junctions where large sandy habitats were established during the construction of the junction – mixed colonies of black-headed gulls (*Larus ridibundus*), herring gulls (*L. argentatus*) and lesser black-backed gulls (*L. fuscus*) have settled and have prospered over the years. Often common terns (*Sterna hirundo*) join them. The lack of ground predators like foxes (*Vulpes vulpes*) and stoats (*Mustela erminea*) and the virtual absence of human beings during the breeding season may have contributed to the success of these colonies. For sake of safety of car drivers and birds fences have been constructed to prevent young birds from crossing the motorways, and this has turned out to be a very effective and cheap measure. In addition, regularly harrowing the sandy soil is needed to provide an optimal breeding habitat.

- *The significance of road verge vegetation as insect habitats*

In some studies the effects of various maintenance systems on the arthropod fauna was tested. Groups that have been investigated include Carabid beetles, Butterflies, Crickets and Grasshoppers, Bees, Spiders. The first two groups receive traditionally more attention and will be reviewed below.

Melman *et al.* (1990) found a higher insect diversity in sections that had been mown once or twice a year than in sections that were mown less frequently. This agrees with the results of the study by Grosskopf (1988), who found that a maximum mowing frequency of twice a year had the most favourable effects on the diversity of ground beetles. Other studies show that the number of ground beetles increase together with differences in height within the vegetation (Morris & Rispen, 1987).

This led to recommendations for maintenance that create more vegetation structure. It means that every year about 10 - 25 % of the vegetation is not mown, every year another part. This might give shelter and hibernation places for insects (Wallis de Vries & Knotters, 2000). This kind of vegetation maintenance is called differentiated maintenance. A problem is that in the unmown vegetation parts some ruderalisation could take place, leading to losses of the most wanted plant species, which are also important for the insect fauna (Keizer, 2000).

By initiative of DWW, The Wageningen University (Raemakers *et al.*, 2001) carried out a preliminary study on the importance of roadside plant communities for various groups of invertebrates. The study focused on the occurrence of seven groups of invertebrates in the road verge. The question was whether plant communities can function as indicators for the occurrence of invertebrates and how maintenance measures influences these communities. The seven groups of invertebrates were *Carabidae* (omnivores and polyphagous carnivores), *Apidae* (flower visitors), *Curculionidae* (herbivores), *Orthoptera* (polyphagous herbivores), *Delphacidae/Cercopidae* (herbivores), *Syrphidae* (various feeding strategies) and especially terrestrial spider ssp. (polyphage carnivores). This study showed that road verges are important for the invertebrates groups. Road verges are relatively important for ground beetles, grasshoppers and bees. According to Raemakers et al. (2003) the highest species diversity of hoverflies have been found in wet vegetation types. Bees, groundbeetles and spiders have a high species diversity in vegetation types in dry habitats. The number of species found was fairly high; also rare and endangered species were found. Rare species have been found in the studied locations especially in rare plant communities growing under dry circumstances.

To ascertain whether insects can complete their entire lifecycle on a road verge, in the winter of 2001/2002 sods with a surface area of one m^2 and a thickness of 20 cm were taken from the surface of the road verge. A number of ground beetles, grasshoppers and some spiders and bees use road verges as a hibernaculum. The study shows that grasshoppers can reproduce themselves in the road verges. Hoverflies which have been observed during summertimes did not show hibernation in the road verges.

Raemakers *et al*. (2003) have studied the correlation between invertebrates and plant communities and found a strong correlation, better than with the combination of moisture, soil- and structure variables. Plant communities were more strongly linked to environmental factors and insects seemed more or less dependent of the vegetation and not vice versa. This correlation was stronger in dry grassland communities than in moist or wet grasslands, in other words, in dry grasslands more characteristic invertebrate species were found than in wet grasslands.

For some species (e.g. the *Apidae*), the correspondence between plant and insect community was variable or even absent (Raemakers *et al.*, 2001). Raemakers *et al.* (2003) found that the studied plant communities of road verges are poorer of groundbeetles and spiders than the same vegetation types in nature conservation areas. The same applies for spiders between the median strips and the nature conservation areas.
In the median strip less invertebrates have been found than in the road verges, and less species (but not significant) in the road verges than in the conservation areas. But it can be concluded that probably isolation-effects play a role. The lower number of species can also be caused, according to Raemakers et al (2003) by a lower diversity of plant communities on a location, as well as the surface areas of the plant communities. It is recommended to reduce isolation between the road verges and areas with comparable vegetation types.

This research leads to the conclusion that maintenance meant to enhance insects should act via the vegetation. Future research by Sýkora and colleagues at the Wageningen University on the relation vegetation, invertebrates (dispersion capacities) and maintenance in roadsides will put more light on this topic.

Habitat and corridor function of road verges for carabid beetles

Vermeulen (1995) showed that a road verge connected with a source area accommodates more stenotope poor grassland-inhabiting species than an isolated site. For two studied species, the straight-line distance covered along a 12-metre-wide road verge in one year was on average approximately 26 m; most individuals did not go further than 50 m, exceptionally up to 150 m. A simulation model was developed which predicts that after ten generations these beetles will have travelled 500-1000 m, given a road verge width of 24 m. However, in narrower verges, e.g. 2 m, the corridor function will extend for approximately 10 m. A prerequisite of the model is that the habitat types of linked sites must correspond, and the animals must be prevented from ending up in unsuitable areas, which in that case would function as sinks. The narrower the connection corridor, the closer together should the habitat fragments be. Vermeulen (personal communication) recommends on a verge 10 m wide and 500 m long one could create two “stepping stones” of at least 50 m wide.

Narrow sections in the corridor usually have an adverse effect on the dispersal speed and lead to the loss of individuals. It can be assumed that corridors function best where populations/ subpopulations are viable as part of a metapopulation (Den Boer, 1990; Vermeulen, 1995).

Generalising from the studied carabids to non-flying ground-inhabiting arthropods, the following conditions are important for road verges as a dispersal corridor:

a. The soil structure and vegetation in the corridor must correspond to the habitat patches to be connected.
b. The wider the corridor, the more effective it is.
c. On fairly narrow road verges, wider habitat patches can be included in order to increase the effectiveness as corridor.

Butterflies on road verges

Stimulated by governmental protection plans (Ministerie of Agriculture, Nature and Fisheries, 1989) the DWW commissioned a study at 55 locations on the significance of road verges for butterflies. The study (Bink *et al.*, 1996) showed that motorway verges are inhabited by a fair number of butterflies (Table 5), including species that have decreased on national scale, such as the grayling (*Hipparchia semele*) and green hairstreak (*Callophrys rubi*). Sometimes, even species of international significance were found, such as the brown argus (*Lasiommata megera*).

In Dutch motorway verges 30 of the 57 native species were found. Thirteen species can complete their entire lifecycle on a road verge. Eleven other species may do so as a result of adapted road verge management (Bink *et al.*, 1996). They also showed that 62% of the visited roadside habitats could be enhanced by maintenance measures: 20% by adjusting the mowing date, 13% by a differentiated mowing regime, 22% by a combination of the two maintenance types, and 7% by selecting individual trees or bushes to be cut. At 29% of the studied verge locations, the applied maintenance appeared to be good for butterflies. Relatively rich in butterflies were road verges in semi-open landscapes with in the hinterland deciduous or mixed forest, hedges, windbreaks, shelterbelts, heathland, grasslands low in nutrients. Migrating butterflies were observed more in the road verges in open landscapes than in forested areas.

Scientific name	Dutch name	English name	I	II	III	IV	V	VI	VII	VIII
Pieris rapae	koolwitje	Small White	41	175	8.8%	M				
Pieris napi	geaderd witje	Green-veined White	38	279	12.2%	M				
Pieris brassicae	groot koolwitje	Large White	29	82	3.8%	M				
Coenonympha pamphilus	hooibeestje	Small Heath	27	122	5.7%	R				
Lycaena phlaeas	vuurvlindertje	Small Copper	23	146	6.1%	R				
Thymelicus lineola	zwartsprietdikkopje	Essex Skipper	21	275	12.8%	R				
Maniola jurtina	bruin zandoogje	Meadow Brown	21	117	5.5%	R				
Vanessa atalanta	atalanta	Red Admiral	20	32	1.2%	M				
Gonepteryx rhamni	citroenvlinder	Brimstone	17	48	2.2%	M				
Aglais urticae	kleine vos	Tortoiseshell	16	45	2.3%	M				
Polyommatus icarus	icarusblauwtje	Common blue	14	210	9.8%	R				
Inachis io	dagpauwoog	Peacock	13	26	1.2%	M				
Lasiommata megera	argusvlinder	Wall Brown	11	62	2.9%	R				
Cynthia cardui	distelvlinder	Painted lady	8	18	0.8%	M				
Araschnia levana	landkaartje	Map Butterfly	7	50	2.3%	M				
Thymelicus sylvestris	geelsprietdikkopje	Small Skipper	6	57	2.7%	R				I
Ochlodes venata	groot dikkopje	Large Skipper	5	83	3.9%	R				I
Aphantopus hyperantus	koevinkje	Ringlet	3	166	7.7%	R				
Pyronia tithonus	oranje zandoogje	Gatekeeper = Hedge Brown	3	38	1.8%	R				I
Celastrina argiolus	boomblauwtje	Holly Blue	3	9	0.4%	M				
Polygonia c-album	gehakkelde aurelia	Comma	2	2	0.1%	M				
Hipparchia semele	heivlinder	Grayling	2	2	0.1%	R	*	z	!!	I
Pararge aegeria	bont zandoogje	Speckled Wood	2	3	0.1%	pR				
Callophrys rubi	groentje	Green Hairstreak	2	21	1.0%	R				
Aricia agestis	bruin blauwtje	Brown Argus	1	26	1.2%	R	*	z	!!	
Fabriciana niobe	duinparelmoervlinder	Niobe Fritillary	1	2	0.1%	pR	*	zz	!!!	
Anthocharis cardamines	oranjetipje	Orange Tip	1	1	0.05%	pR				
Quercusia quercus	eikenpage	Purple Hairstreak	1	1	0.05%	pR				I
Maculinea alcon	gentiaanblauwtje	Alcon Blue	1	1	0.05%	G	*	z	!!	I
Limenitis camilla	kleine ijsvogelvlinder	White Admiral	1	1	0.05%	G	*	z	!!	I

Sequence of butterflies found in motorway verges arranged according to the number of locations (I) with the number of individuals (II) and the percentage of the total individuals observed (III). Also information is given about the status in the roadside verge during the research period (IV): R = resident, pR = potential resident; G = guest in the verge, M = migrant in the verge and if the species is included in the Red List (V). In column VI information is given about rarity, VII about trend and VIII gives international importance.

NB:
! means: > 50 % - < 75 % decrease (according to Bal et al., 1995)
!! means: > 75 % decrease (according to Bal et al., 1995)
z means: in < 12.5 % of the total Atlas squares (according to et al., 1995)
zz means: in 5 % of the total Atlas squares (according to et al., 1995)
resident: everywhere present
guest: sometimes present, presence is dependent on the surrounding landscape
migrant: occasionally present, not dependent on the surrounding landscape

Table 5. Butterflies and their nature value found in motorway verges (after Bink et al., 1996)

Optimal butterfly habitats in roadsides are: verges with a width larger than 10 m, a surface area larger than 0.3 hectares, grassy vegetation lower than 90 cm for the top layer and 40 cm for the middle layer. The management should therefore aim at road verges with these properties.

Based on this information the computer program 'Bermvlinder' was developed as a help for road designers and road verge managers. The program gives the user recommendations for changes the management into a maximal 'butterfly-friendly' way and produces lists of butterfly species, which may profit by the measures (Bink *et al.*, 1996; Maaskamp and Van den Hengel, 1998).

Along the Motorway A58 in the Province of Zeeland the effects of different mowing frequenties of roadside vegetation on the occurrence of butterflies have been studied in 1993-1996. Since 1991 the mowing regime is twice a year (in spring and autumn) on a strip nearest to the road, once a year (in spring) for the strip between the former strip and the ditch and once every three years (in autum) locally near woody vegetation (see for the botanical

aspects paragraph 6.2). Most numerous species: Thymelicus lineola (in Dutch: Zwart-sprietdikkopje) and Pyronia tithonus (in Dutch: Oranje Zandoogje), which have little dispersion capacity. Other species with a higher dispersion capacity were present in lower numbers. Also rare species have been observed.
In the studied situations (Bak et al., 1997; Bak et al., 1998) the highest density of butterflies has been found in the verges with the lowest mowing frequency and the lowest density in the verges which have been mown twice a year. In situations with mowing in spring it is advised to leave an uncut 1 m wide zome for three years (Meijer and Smits, 1990). Although no information before 1991 is available it is reasonable to suppose that the value for butterflies has increased, as can be deducted from the fact that on intensively management vergers less butterflies were counted.
The main factors for butterflies in roadside verges are (Bak et al., 1997):

a. presence of nectar plants
b. presence of host plants
c. structure of the vegetation
d. micro-climate
e. surrounding landscape

An important factor is the wide of the verge. In general the wide of the grassy verges along the A58 is 20 m and gives opportunities for different maintenance regimes and a high variety of habitat patches.
More information is needed about the proportion of butterflies which may be killed by strong vortex-currents which are caused by the traffic. The study of Bak et al. (1997 and 1998) gives an indication of the negative effects as a statistical analysis has been made about the influence of the distance from the road in the same maintenance types. A significant higher density ($p < 0,05$) of butterflies were present in the verges mown two times a year further away from the road than the part immediately bordering the road. Comparing mowing regimes two time a year and one time a year far from the road shows a higher density in the last regime.

Habitat and corridor functions of road verges
Based on the existing literature, including the above-mentioned studies, Van Eupen and Knaapen (2000) made a summary of the possible habitat and corridor functions of road verges. They found that for most animal species, road verges represent a marginal habitat. However, verges can be an optimal habitat for a fair number of species from the groups of grasshoppers, crickets, butterflies, bees, hoverflies, ground beetles and reptiles, as well as two mouse species and perhaps some amphibians and bats.

Apart from the detailed study of ground beetles, little study has been made in the Netherlands of the corridor function of road verges. A corridor function seems important for a small number of ground beetles, mammals, reptiles and amphibians. Perhaps some grasshoppers, crickets, bees, ground beetles, small mammals, reptiles, amphibians and butterflies may benefit from the corridor function of road verges, but roads as such probably have more adverse effects for these animals.

Clearly, for a good understanding of the role of roadsides in the environment, road verges must be evaluated against their relationship to the hinterland. The occurrence of species on a road verge can be a property of the roadside itself, but is often only due to their occurrence in the hinterland (Van der Reest, 1992; Zuiderwijk, 1989; Bink *et al.*, 1996).

In recent decades, a fairly complete picture has been obtained of the floristic and phytosociological significance of road verges in relation to the management carried out. Knowledge on faunistic values of roadsides is now rapidly growing. We now leave the beginning phase which had a predominantly inventory character. The knowledge now gained enables us to do experimental studies (Raemakers *et al.,* 2003)

The next step will be to implement these scientific based results into the all-day practice of the roadside management and maintenance in the form of more detailed management and maintenance programmes (based on the plan-do-check-act approach that is nowadays becoming in use) and a scientifically based prioritisation of the desired measures. In the case of nature development projects related to road verges we may better than before be able to make predictions based on nature-technical knowledge and experience (Londo, 1997; Westhoff, 1988).

Entomofauna and landscape-ecological aspects of green noise barriers

Due to the expected increase of noise barriers DWW undertook a study about the possibilities of "green" screens instead of constructions made of non-renewable materials (Anonymus, 1990b). Vos and Winkelman (1989) conducted a study to get an impression of the insect and spider fauna of green anti-noise constructions (screens of thin corton steel with willow stems and stacked-container constructions). A total of 274 insect and spider species were found. The number of such species is markedly influenced by the width of the road verge and the composition of the verge vegetation in relationship to its management. In the case of the stacked-container constructions, a positive relationship was found between the number of insect species and the age of the construction. In this study no effect of the traffic on the diversity was found; dust on leaves can have negative influence on the growth of caterpillars (Boer Leffef, 1971). The diversity of insects in 'green noise barriers' is high if the verge vegetation is species rich too. When planning 'green noise barriers' the surrounding landscape should determine the types to be used, and should be in accordance with the nearby landscape elements.

- *Concluding remarks*

Clearly, roadsides harbour various animal groups. It is the most important habitat for small animals (insect size). Small mammals attract birds of prey; some of which are at risk to be killed by traffic in considerable numbers. Sometimes it is possible to adjust the management to prevent these road killings. Transparent noise barriers form another danger for birds. For most other groups of larger animals roadside verges are relatively insignificant.

For small arthropods roadsides are an important habitat for some groups. The roadside can function as corridor if it is not too narrow, contains the same habitat as the source area and if 'stepping stones' of larger areas suitable habitat are present.
Optimizing the management and maintenance for both habitat and corridor function of roadsides is currently carried-out.
Ecological effects of road killings among insects are as yet completely unknown, but maybe in some cases significant.

8. Ecological aspects of road verges and road verge vegetation management in some West-European countries

Around 1970, in countries neighbouring the Netherlands a parallel development took place, paying more attention to the ecological significance of road verges. This was a result of similar developments in society like more concern for the (ecological) impoverishment of the landscape, and related losses of biodiversity, connected with among other things, the growing road network in highly man-influenced environments. It also became known that road verges can accommodate plant species that have decreased due to an increased intensity of agricultural land use. In the sections below, some of the studies from West-European countries on roadside ecology will be reviewed

United Kingdom
Interest in the ecology of road verges developed in the UK a little earlier than it did in the Netherlands (Moore, 1967; Dunball, 1974; Mabey, 1974; Way, 1969, 1977). For example, the 'Road verges: their function and management' symposium was held as early as 1969 (Way, 1969). In the symposium focus was put on various major changes in the traditional method of maintenance, the influence of mechanical and chemical methods with ecological effects, and the expected extension of the national road network. The botanical importance of road verges was stressed. For example, Cambridgeshire has a total of 1260 species of flowering plants and ferns, and 520 (41%) of these have been recorded in the road verge region. In 1962, at least 27 of the 300 rarest species were found on road verges in the UK. Each of these species occurs, on average, at only 10 localities in the British Isles, which means that road authorities bear a responsibility to save these sites (Perring, 1969). The colonisation of halophyte plants along motorways, quite extensive in the U.K., has also been studied (Scott and Davison, 1982).

Already in 1969, a three-strips maintenance system was proposed based on Moore (1967) and Perring (1967). This maintenance system comprises the regular mowing of a strip (1-1.5 m wide) bordering the road; next to this is a zone which is mown in the summer and early autumn; and then there is a strip (near planted woodland) which is mown only in the early autumn. Road verges of particular conservation interest require special attention. Besides plants, interest has also been shown in butterflies and other forms of wildlife. Linear habitats (e.g. hedgerows and road verges) were already regarded as refuges for the rapidly diminishing wildlife, and as essential for the maintenance of a degree of stability in the landscape. Although a number of weeds of agricultural importance occur on road verges, in general they do not pose a threat to agriculture (Chancellor, 1969). The use of chemical sprays to restrict the height of road verge vegetation and to eliminate noxious weeds was common in these days, although the ecological effects of such a treatment increasingly became more and more a matter of concern.

In 1968 the British Ministry of Transport published a report "Layout of Roads in Rural Areas" (Ministry of Transportation, 1968), in which guidelines were given about the width of traffic lanes, central reserve as well as the verges. Besides seeding of verges, planting of trees was stimulated. Fauna in roadside verges increasingly attracted attention. In 1979 the Countryside Commission published a Code of Practice: Grass cutting and hedgerow treatment on roadside verges. It gives some practical tips for roadside maintenance: different mowing regimes according to the location. On wide verges natural scrubs and woodland should be allowed to develop and remain intact. The code has helped to improve the maintenance along motorways (Dowdeswell, 1987).

In 1993, English Nature published *Roads and nature conservation: guidance on impacts, mitigation and enhancement* (Ramsay, 1993). This document provides comprehensive guidance on handling nature conservation philosophy in the context of the planning and design of new roads, as well as improvement of planning schemes which offers opportunities for habitat creation by application of the conservation measures. An update can be found in Byron (2000).

In 1996 the Highway Agency published the first environmental plan about roads ‘Living with Roads’ (Highways Agency, 1996), which has been followed in 1999 by ‘Towards a Balance with Nature’ (Highways Agency, 1999) in which the Highway Agency of the U.K. presents their strategy of management including the use of performance indicators. The maintenance and enhancement of biodiversity should be promoted on the areas owned by the state. Likewise is the state responsible for mitigation measures for fauna. In the Strategic Roads 2010 report the Highway Agency (2000) sets a target to manage the road network under the Biodiversity Action Plan.
In 2000 the Highways Agency published the Highways Agency Biodiversity Action Plan (HABAP)(Cresswel and Associates, 2000) which gives detailed information why and how the Highway Agency will play a role in the conservation and enhancement of biodiversity in England. The Highways Agency is responsible for 10.400 km of roads and owns approximately 30.000 ha of land between the highway boundaries, but not occupied by the road carriage, called the ‘soft estate’. In 1999/ 2000 an audit on the existing biodiversity on the soft estate was carried out which gives information about priority species and priority habitat: 42 % of the priority species and 53 % of the priority habitat are known, or are likely to occur within the soft estate.
For the daily maintenance of road verges contractors are responsible, which is guided by Route Management Strategies and Environmental Plans that enable a more holistic and route-based approach to environmental issues, including biodiversity. Further guidance is given in the Design Manual for Roads and Bridges vol. 10 (Department of Environment and Transport (Anonymus,1992) including sections on habitat creation, pollution control, translocation and ecological management techniques for grassland, scrubs, woodlands and hedgerows and information can be found in the Trunk Road Maintenance Manual (Highways Agengy, 1999).

A difference with the Dutch approach of roadside management is that in the UK planting and seeding of many plant species is a common practice. In the Netherlands only few grass species are usually seeded to prevent erosion on new-built verges, followed by natural development of vegetation (under mowing regime).

Belgium
In 1984, the regional road authority in Flanders (Belgium) issued the Road Verge Maintenance Decree, which states that road verge vegetation should not be mown before 15 June and that the grass cuttings must be removed. However, the local workers were not ready for this change, and the Decree was not immediately implemented in practice. In subsequent years, though, the application of ecological road verge maintenance gradually became more common. The publication of the survey of road verge vegetation types (Zwaenepoel, 1993) was an important contribution to the acceptance of ecological road verge management in Flanders.
The Flemish Ministry for the Environment and Infrastructure stimulates and finances the application of ecological engineering and research into habitat and corridor functions (Anonymus, 1996). The study by Claus and Janssen (1996) details the interrelationships between the environment, nature and infrastructure, as well as the significance of

ecological engineering. It also discusses the design, creation and maintenance of road verges, partly inspired by experiences gained in the Netherlands.

The report 'Fauna elements on the road verge along the E314 motorway' (Gorssen *et al.*, 2000) illustrates the great significance of road verges for invertebrate fauna. This applies especially to wide verges; on narrow verges, there is a high percentage of fauna indicating disturbed sites. The verges of the E314 are important habitats for heath and nutrient-poor grassland species: on them were found a rich spider fauna, ground beetles and grasshopper fauna. These animals are hardly found in other habitats, as confirmed by the established barrier effect of wood-covered verge sections. Dry, nutrient poor verges are very important in view of the serious deterioration of this type of habitat in the landscape elsewhere. The quality for butterflies was lower than expected. Also vertebrates (six amphibian species, two reptile species and nine small-mammal species) were found during the survey. Rodts *et al.* (1998) published a book about fauna-casualties, which give also information about the fauna in roadside verges.

In 2002 the Flemish government has decided to abolish all the use of chemical weed killers in road management. This forced the road managers to introduce new measures for weed control. In this process a close co-operation with Dutch road managers was established who had already built-up experience.

Godefroid (1998) studied the roadside vegetation, ecology and pedology in Wallonny and found that roadside verges act as refuge for relics of the former landscape, finding a strong correlation between eco- and phytogeographic characteristics of the studied region and the differentiation and the synchorology of roadside vegetation. Principal factors determining the composition and the structure of roadside vegetation are geology, nutrient richness, acidity, humidity, altitude, continentallity, climate as well as embankment slope and exposition, roadside width, traffic intensity, management and maintenance practices (abandonment, mowing, burning) and adjacent land use. Evidence has been found about the importance of biological fluxes between interconnected biotopes and that seldom rare indigenous species are found on roadside verges. The chance of finding these species is related to the frequency in the surrounding matrix. This demonstrates the importance of the conservation of habitat patches where these species are growing. This endorses the importance of the combination of linear and patchy elements in the landscape as a functional entity (Godefroid, 1998).

The Walloon region has started a pilot project in which all communities are stimulated to practice the so-called "fauchage tardif", i.e. "late mowing", with the idea to enhance wildlife in these areas. In this project generally no chemical herbicides are used, mowing once or twice a year with removal of the cut grass is applied, with no use of the flail mower (as it destroys animal life). Information for road managers is provided (Peeters & Janssens, 1999). About 100 communities support the idea and apply the "fauchage tardif".

A difference between the Belgian and Dutch attitude towards roadside ecology is that in Belgium the government generally shows less concern about adverse effects of roads in the landscape and how to counteract these. Generally, awareness of these problems and research and implementation of solutions like ecological roadside management have started later than in the Netherlands. After a period of getting used to the new approach the ecological roadside management is becoming relatively successful.

Germany
Since the 1930's, the planning, design and construction of motorways in Germany has taken into account the importance of inserting motorways into the landscape. Since approximately 1970, more attention has also been paid to the ecological aspect of roads and motorways. In the 1970's, various seminars were held on the topic of hydraulic and road engineering and the landscape, during which time for ecological aspects was reserved and initial studies took place (Trautmann and Lohmeijer, 1975). Interest in such aspects was recognized by the Federal Republic, which included in the 1980 Traffic Roads Plan the objective to take the interests of nature and landscape conservation into better account during the planning, design and the construction of new roads. In 1981, Deutsche Strassenliga issued a publication concerning the ecological effect of motorways and roads on the environment (Ellenberg *et al.*, 1981).

Since around 1980 more detailed investigations have been carried-out in Germany on road verge vegetation (Ellenberg *et al.*, 1981; Krause, 1984; Ullman *et al.*, 1988), nature conservation values of roadsides (Ullman & Heindle, 1986; Stottele & Schmidt, 1988) and the ecological and geographical differentiation of the vegetation along major roads in lower altitudes of temperate Europe (Ullman & Heindl, 1989). The composition of the road verge flora was found to be dependent on the seed bank, invading species, traffic and maintenance, but shows qualitatively and quantitatively affinities primarily with the regional floras (Stottele & Schmidt, 1988; Ullmann & Heindl, 1989).
The studies by Kopecky (1978), Stottele and Schmidt (1988), Ullmann *et al.*(1990), Hansen and Jensen (1972) describe a marked resemblance in the form of the degree of presence or absence of zoning parallel of the road and motorways in the West European Countries. In addition to plant species that are characteristic of the studied area, there are also widely spread plant species of synanthropic, meso- to euhemerobe character (cf. Jalas, 1965).

In the period 1970-1975, studies on seeding on road verges were made along motorways between Dortmund and Darmstadt (Trautmann and Lohmeyer, 1975). They found that after some time, the species composition adapted itself to the local habitat factors. It confirms that the habitat determines the composition of the vegetation and the more extreme nutrient poor or nutrient rich the more different the effect will be. Even years later, changes still occurred, usually in the form of an increase of herbaceous and ligneous species. The increase of herbs was especially remarkable under mineral-rich or lime-rich conditions. They also referred to the danger of alien plant species or foreign ecotypes of species in seed mixtures. Some neophytes are showing an aggressive spreading and can become dominant.

Mader (1979, 1981, 1986, 1987) studied the significance of road verges for the fauna and of the barrier effect of roads (Mader, 1980) and the contributions of road verges in the ecological infrastructure. Ellenberg *et al.* (1981) and Reck and Kaule (1993) provided a summary of the ecological aspects of fauna along roads and in road verges.

Schmidt (1998) reported on plant dispersal by motorcars by counting numbers of seedlings and species in the car-dispersed flora found in sludge from the front, back, wheels and under surface of a car. The plant species were compared with the local flora as well as with the road verge flora. Cars can disperse almost all plant species growing in road verges, but not all species found actually grow in roadsides as dispersion is only one aspect of establishment of a vegetation.

Wasner (1984) concluded from his investigations that the intensity of roadside management highly influences the structure of the vegetation, but also the diversity of the small (insect) fauna. Especially too early mowing (before the flowering of most of the species) decreases the number of feeders on nectar or pollen, and also the leaf- and seed users, leaf- and root miners and species which directly depend on the structure of the vegetation. He also found that mowing too short (less than 10 cm) negatively influenced soil living species. Mowing to far within the plantations influenced negatively the occurrence of insects.

A very extensive study by Stottele & Schmidt (1988) and Schmidt (1987) indicates that generally there is road-guiding vegetation along roads that is relatively uniform but with locally high diversity. However, rare or endangered species occur only occasionally. In the former western of Germany, road verges cover approximately 200,000 hectares (1988). A supra-regional comparison produced six different, widely spread road verge associations with ten locally and floristically clearly differentiated sub-associations. The ligneous vegetation along roads in addition to common trees and bushes contained many (planted) exotic and pioneer species.

Ullman *et al.,* (1988) and Ullmann & Heindl (1989) studied ecology of roadside vegetation. Like other authors, they found clear vegetation zones along the road, corresponding to the distance to the road. Common anthropophilous species dominated, with a wide ecological amplitude, intense competitive powers and the ability to penetrate any road verge community, such as *Festuca rubra, Poa pratensis, Achillea millefolium, Holcus lanatus, Taraxacum officinale, Plantago lanceolata, Agropyron repens, Cirsium arvense* and *Artemisia vulgaris* (cf. also Pfadenhauer, 1997). In Germany botanically interesting are especially the non-wood-covered parts of the road verge sections situated at some distance from the road, especially where there are various exposures and slopes. Important is grassland-like vegetation: nutrient poor or ruderalised former hay field type of vegetation (*Arrhenatheretum*). In warmer areas, also annual ruderal vegetation types are found.
Since in Germany the road verges in many areas accommodate 30-50% of the native plant species, they play an important role in the conservation of the native flora, especially on nutrient-poor, base-rich soils with plants from grasslands, acidic sandy soils with heathland, mesophilous grasslands and dry verge communities, but they show seldom rare or endangered plant species.

The following gives an overview of the most important conclusions of the study of Stottele and Schmidt (1988) shows a striking similarity with the Dutch situation:

- In order to keep the borders free from high growth, in many cases it is sufficient to mow only twice a year;
- Ditches alongside roads should not be cleared more often than once every 3-5 years;
- In woody and ruderalized *F. rubra* vegetation, mowing should be carried out once early in summer; after some years, this should gradually be changed to once every 2-3 years late in summer;
- Local ruderal vegetation can be mown every 3-5 years, heath vegetation every

10-15 years;
- Tall oat-grass (*Arrhenaterum elatius*) vegetation must be mown at least once a year. During the first years, new vegetation should be mown twice a year;
- It is sufficient to mow sunny edge vegetation, open lime-rich grasslands and dry pioneer vegetation every 2-3 years;
- It is vital to remove the cuttings.

Furthermore, the following recommendations have been made (Stottele, 1989):
- Plantations should be adapted to the species found locally.
- If a road verge is narrower than 8 m, hedge-bank-like plantations with bush are useful.
- Richly structured hedges, bushes and woodland edge shrub vegetation with wide herbaceous fringes are preferred above wood plantations with a high proportion of trees.
- In open landscapes, ones should use as little as possible trees. Exotic or habitat-foreign species, except on narrow central reservations, should not be used.
- Allow areas inside clover-leaf junctions in principle to grow as open as possible like grassy or heath vegetation.
- Humus- or nutrient-rich top soil must not be used to cover the road verge soil; only it should be used when planting of woody species.
- As little as possible should plants be sown. Encourage as much as possible the natural vegetation (spontaneous establishment of plants) in which the succession is regulated by maintenance measures.
- Design and management plans – including regular monitoring and, where such is necessary, the adaptation of the plans – are an important condition for succesful management.
- In road-guiding landscape construction activities, design and creation based on ecological targets and ecosystems adapted to the local environmental conditions are essential for the long-term conservation and development of landscape-ecological values.

Based on study Rattay-Prade (1988) recommended not to introduce nutrient-rich topsoil to new road verges, but laying out of hay from species-rich grasslands, which preferably should come from nearby to the spot to be treated, can be successful. It is desirable to markedly limit the sown quantities of plants (especially of stolon forming grasses). Furthermore, it was advised that managers who determine the mowing date should pay more attention to the rhythm of flowering and the moment of seed maturation and to the animal species that are characteristic of grassland-like vegetation. In Germany, many of the plantations alongside motorways developed into dense vegetation without a shrub and herb layer due to the lack of management (Rattay-Prade, 1988). He therefore advised to promote richly structured hedges, bush-shaped and edge plantations, in addition to widely spaced trees or spontaneous establishment and growth of woody species.

In addition to the developments in the understanding of the effects of road verge management, more and more publications on the design and creation of habitat patches alongside roads and waterways have appeared. A richly illustrated publication by Schultz-Pernice *et al.* (1991) presents many examples of ecologically successful projects realised in order to create and improve habitat patches for plants and animals in the vicinity of roads and waterways in Bavaria.

Comparing German and Dutch road ecology research and road design the following may be stated. In Germany much more extensive studies on roadside ecology have been published than in the Netherlands, leading perhaps to a better insight and understanding of roadside ecology. However, in many cases roadsides of motorways are considerably narrower than in the Netherlands. This may lead to less well-developed roadside vegetation communities. When new roads were built, in Germany more than in the Netherlands attention was paid to a design such that the surrounding landscape was as little as possible negatively influenced. This has led to motorways that better insert in the landscape and cause less visual disturbance compared to some Dutch situations, but the German design tradition has been copied in many situations in the Netherlands.

Scandinavian countries
The Swedes have developed in the 90's an active programme on the application of ecological road verge maintenance (Persson, 1995). Owing to the large stretches of road verges (more than 100.000 km) the primary focus was on areas with a high potential for species-rich vegetation. Examples of such situations are places with limestone bedrock (e.g. the islands of Gotland and Öland and the Siljan area) and those with high groundwater tables. Effective material has been published by the Swedish Road Administration such as examples for ecological designing of roads, attractive roadside flower identification brochures with advises for proper management. A study was conducted into the maintenance regimes of Swedish road verges (Persson, 1995) with the result that mowing once or twice in summer and the removal of grass cuttings increased both species number and species diversity.

Also some successful nature developing projects have been conducted, such as 'creation' of a Calluna dominated heathland vegetation in a slope near a new-built road.
A very attractive flora for identifying plants of Swedish roadside verges has been published by the Swedish Road Administration (Vägverket, 1999), useful for the road managers and also for other people interested in roadside flora.

In Norway, Gjaerevoll (1990, 1991, 1992) composed a global description of the road verges in that country. The various types were also photographically recorded.

In 1972, Hansen and Jensen published a report titled 'Vegetation on road verges in Denmark'. Only roads of average traffic density were studied; motorways were excluded, as were mown road verges. All roads studied are situated in an east-west direction, in order to make a comparison of exposure possible.
In the above-mentioned study in Denmark, 268 species have been found on road verges. The most frequent species are: *Achilea millefolium, Festuca rubra, Taraxacum spec., Dactylis glomerata, Agrostis tenuis* and *Plantago lanceolata*.

In Finland it has recently been recognized that mown road verges may be a substitute for traditional (semi-natural) hayfields. There are large areas of the latter in Fennoscandinavia (Tikka *et al.*, 2000). Although there is a difference in species composition and community structure, and in the present state road verges are not a substitute for semi-natural grasslands, grassland species may be enhanced by means of a suitable mowing regime, by abandoning the use of de-icing salt and herbicides, and by allowing vegetation to establish itself naturally on verges (Tikka *et al.*, 2000). In the study it was found that when cuttings were not removed, mowing just once each summer produced the highest species diversity and the highest number of grassland

species. This finding deviates from those of studies in the Netherlands and in Sweden, and may be due to the abiotic situation or the use of de-icing salts, which negate the effects of frequency of mowing.
The Finish study also looked at the role of road verges and railway verges as corridors for grassland plants. Based on a study of the degree of prevalence and their spatial (in)dependence, it was concluded that road verges and railway verges can play a role as dispersion route (Tikka *et al.*, 2001).

Although the Scandinavian countries differ widely by nature from the Netherlands, there is a striking similarity in attitude towards roadside management. In Scandinavian countries too, especially in Sweden, it is recognised that roadsides harbour several species that have become rare in the agricultural landscape (in Sweden for example *Lathyrus linifolius, Trifolium medium, Galium verum*, in Finland also *Campanula cervaria*). They all have ecologically based roadside mowing programmes although in details differing from the Dutch management programmes. Deputes of national road administrations in Scandinavia meet every year for exchange of new information.

9. Discussion: nature engineering and ecological engineering in roadside verges

In the preceding sections the significance of roadsides as habitat and corridor for flora and fauna has been shown and how management and maintenance can help to develop these values. Based on that knowledge it is now possible to include ecological aspects in all phases of the ‘road life cycle’: routing, design, construction, maintenance, reconstruction and demolition. Below a summary of management recommendations will be given, based on the above sections.

Nowadays knowledge on ecosystems can be applied in the development of management and maintenance plans, which should preferably include both the roadside verge and wider landscape ecological context. Several documents support this approach: the Council of Europe (2001) developed a Code of practice for the introduction of biological and landscape diversity considerations into the transport sector, the US Government (Garret and Bank, 1995) published a paper “The Ecosystem Approach and Transportation Development” and the Convention of Biological Diversity (CBD, 2002) gives “Operational guidance for Application of the Ecosystem Approach”.

There is still a difference between the ideal management (on paper) and the real practice which has been shown in the studies of Kalwij *et al.* (2001) about the effectiveness of road verge vegetation management and the results of studies concerning the fauna in roadsides as described by Raemakers et al. (2003).
It is important that ecological principles are taken into account in all steps of the roadside management; only then good results can be expected. This also applies to nature engineering projects where suitable abiotic factors are created in order to promote ecological values of the area concerned.

The gained knowledge as presented in the paragraphs 6, 7 and 8, can be fully applied in the form of ecological engineering. Now there is the challenge to effectively communicate this knowledge to local, regional and national authorities and to landscape architects, civil engineers, landscape designers, planners, policy makers, and related professions.
While applying effective roadside management (and ecological engineering projects) the following aspects should be taken into account (partly based on Van Eupen and Knaapen, 2000):

Not or not easily to influence

- Geographical position and position in a certain plant-geographical district.
- Type of the hinterland; the potential of a road verge is also determined by the surroundings (type of historical-landscape and whether or not it is a part of an ecological infrastructure).
- Exposition towards the sun.

To influence by design and construction

- Relief (both micro and macro); presence of ditches and other waterways.
- Ground- and surface water level as well as the quantity and quality of the water; presence of ditches and other waterways.
- Soil type, soil texture, humus layer, litter layer; also the presence of gradients between wet and dry, nutrient-rich and nutrient-poor, cold and warm, humus-poor and humus-rich soil conditions.
- Presence of soil foreign to the area; compost usually contains many plant nutrients, which is unfavourable for species rich communities. Undisturbed soils usually are richer in plant species (including rare and protected ones) than disturbed soils. The use of nutrient poor top soils is therefore recommended.
- The width, length and surface area of the verge; the wider the verge, the higher the potential as a habitat for diversity of plant and animal species and the larger the significance as dispersal corridor.

To influence by maintenance measures

- Maintenance time and intensity; phases; continuity, type and way of use of (heavy) machinery.
- Horizontal and vertical structural variation: species composition and diversity, variation in open and closed parts of vegetation, presence/absence of well developed gradiant type of marginal vegetation types going from grassland, fringe, mantle till woodland vegetation.
- Microclimate.
- Effects of disturbance from the road as well as from the hinterland.

In road reconstruction projects, sods of the topsoil of botanically interesting road verge sections should be stored as short as possible and replaced in the new situation. Buffer zones between the verge and an area that is in intensive agricultural use can be useful to isolate local ecologically valuable roadsides from the surroundings, although this aspect was not yet studied in detail. In addition, ecological infrastructure can increase in value if the habitat patches to be connected correspond to each other and to the connecting roadside. Spontaneous development of flora, vegetation and fauna should be furthered; therefore artificial introduction of plants or seeds is not recommended. In some situations it may be useful to promote the dispersal of species by first mowing species rich grasslands and later using the mowing machine in less diverse grasslands, or laying out hay from species-rich vegetation on species-poor new-constructed places. The hay should preferably come from nearby fields.

For woody vegetation spontaneous development or initial planting without intensive maintenance of tree species will give sufficient results. Only in special cases planting and maintenance of tree species can be desirable from an ecological viewpoint.

A planned approach

In addition, a planned approach is crucial for achieving predefined objectives. It is essential to adjust the landscape plans, design plans, construction plans, maintenance plans according to the results of regular monitoring and evaluation.

In this process it is essential to communicate the results of the ecological roadside management to the local and central managers, politicians and road users. Only than the funds will be continued which guarantee continuity in the ecological management. Although in the Netherlands there has been established a relationship between policymakers, civil engineers, ecologists and road managers and the maintenance people there are still some gaps between the parties concerned. This is partly caused by a lack of knowledge and partly due to ignorance of the ecological values, therefore insufficient recognition of road ecology. It requires more attention of local roadside managers and biologists.
In order to optimize communication between above-mentioned people about the measures to be taken the costs of all management and maintenance activities should be presented in budget terms to facilitate decisions on priorities. For the Dutch national governmental road system comprising of 3,244 km the costs of maintenance are (Anonymous, 2001):

- Grassy vegetation € 12-14.5 million/year (12.600 ha).
- Woody vegetation € 6.5 million/year (1750 ha).
- Removing waste € 7 million/year.
- Maintenance of road ditches € 7-8 million/year.
- Composing/updating landscape and management plans: € 0.7-0.9 million/year (n.b. all plans should be revised every 10 years).
- Weed control (locally on pavement and on open asphalt) € 0.9-1.4 million/year.

10. Conclusions and recommendations

General guidelines on roadside management and maintenance
Design and construction of road verges is the start, but once established, based on nature technical principles, the basis for ecological road verge maintenance in grassy vegetation is regular, low-intensive mowing and removal of the cuttings. The frequency should be adapted to the current and potential value of the vegetation in relation to the fauna actually present or which can be expected by proper management. The time of mowing should be adapted to the flowering/seed setting period of the most characteristic plant species that are present. Once the target situation has been reached, the maintenance should be continued. There are situations that have low potential ecological values, e.g. shady places, narrow verges, places with strong influence of agriculture or places which require intense maintenance for safety reasons (e.g. unobstructed view in bends). Here a large investment in ecological maintenance is perhaps not wise and a balance between cost and output must be found.

Research clearly has shown the positive effects on biodiversity of mowing with removal of the grass cuttings. Two main mechanisms are supposed that cause this biodiversity: changed competition relations (for light and soil nutrients) between plant species and the creation of gaps in the soil, which enable seeds to germinate. So far there is no insight which of the two might be the most important. In view of optimizing mowing a better insight seems highly desirable. An extra complication is that there is a considerable N-deposition, which causes an increase of soil fertility; high productivity above 8 ton dry weight/ha/year will lead to low diversity; 3-7 ton dry weight/ha/year can lead to high as well as low

diversity due to the influence of low P and K and in some situations addition of P and K may be needed in grassland vegetation.
For arthropods the situation is easier to predict; most of them need short, open vegetation because of their thermophilous nature.

Opportunities for new nature along roads
Road verges can make an important contribution to connect ecologically valuable areas providing corridors for species. If necessary, species should also be prevented from mingling. For example, in areas where the Northern vole (*Microtus oeconomus arenicola*) an endangered species in the Netherlands, is present, road verges must be laid out and managed in such a way that field mice cannot reach those areas via road verges.
The design, construction and management of road verges should be focused on the local landscape and the plant-geographical district to which the area belongs, and on the animal species that are characteristic of the area concerned.

As an example, heathlands are a characteristic element in the Pleistocene sandy area. Roadsides in this area can be constructed such that this vegetation will develop there, including some of the characteristic fauna, e.g. sand lizard. The management then must be adapted especially for this ecosystem: removal of tree-seedlings and mowing with intervals of 5 to 10 years.
Likewise other characteristic vegetation types can be promoted, such as hay fields on nutrient-poor soils, marshland vegetation on flattened banks of watercourses.

Where trees, woodlots or plantations are desired from an ecological, landscape-ecological or visual-landscape point of view, native species should be used, preferably by spontaneous development. Under moist to wet conditions, this means planting or spontaneous development of willow and ash rather than poplar hybrids. In drier areas, the use of oak and beech is recommended. In suitable situations gradual transitions from grassland to forest may be created, with shrubs and tall herbs, although they are relatively difficult to maintain.

Rows of trees can sometimes be desirable not only for guidance of motorists but they can also serve as flying routes for bats and provide suitable habitat for ectomycorrhizal fungi.

Recommendations for future research
The reviews in the previous sections show where most research has focused on. However, it also makes clear where gaps in knowledge are and where future research is needed. Below some recommendations for future road verge related research are presented.

1. *Grassland vegetation:*

- Effect of different mowing regimes. Continuation of the long term studies on the effects of different mowing regimes in permanent plots along the A1 and the A15 should take place with a reduced frequency: for instance once every 3 years instead of every year. This research should be broadened to find more accurate succession series in road verge vegetation in relation to maintenance practice and costs involved. Local workers desire this knowledge, because they experience lower budgets but wish to maintain nature values as much as possible.
- As our knowledge on various groups of organisms increases, a better adjustment of the management measures can be reached in order to enhance biodiversity. This process of expanding knowledge leading to better management systems is an ever-continuing process.

- Seed banks. In view of unclear results of different researches it is desirable to study seed banks in the soil in relation to management measures. This knowledge is important to estimate the resilience of vegetation types to strong disturbances.
- Sowing of plant species. For semi-natural situations sowing of plant species is in principle not recommended from a nature conservation point of view. There is however a need to know for which species the dispersal distance and dispersal time have become too large to reach the road verge in a reasonable time. Small scale sowing experiments in and in the neighbourhood of road verges should be considered.
- Disturbances. Continuity in vegetation management is a condition for maintaining and development of biodiversity. Due to all kinds of activities (laying of cables, placing of road furniture) discontinuity in the vegetation of road verges is often the case. Studies should take place how these interferences can be reduced.
- More attention should be paid to special 'hotspots' where rare and uncommon plant species occur, indicating special habitat conditions, such as gradients. It is important to develop an eye for such special situations and to promote them. Therefore it is from an ecological point of view essential to make an inventory of all rare plant occurrences (according to certain criteria), which should lead to extra care in the maintenance of the habitat patch in which they occur.
- Flying insects. Locally large numbers of flying insects are harmed or killed by traffic. The research question is: What does this mean for the maintaining and developing of more or less "flowerful" habitat patches near motorways.

2. Trees and shrubs; plantings and spontaneous development

Beside the more traditional planting trees (and shrubs) in rows, as tree meadows, in clumps of trees or as wood, the spontaneous establishment of trees and shrubs can have in some situations more ecological and esthetic values than a plantation. In spite of the need of more detailed information about the possibilities under different circumstances, in general spontaneous establishment of trees and shrubs should be considered more into the design and maintenance of roadside verges. There is still a need to inform more people on the ecological functions and on the ecological, landscape visual and esthetical values of stimulating spontaneous growth of trees and shrubs.

3. Processes in road ecosystems

Road and road verges can be seen as road ecosystems. So far, research has focused mainly on plants and some animal groups. This implies that the majority of the biota is not studied. More knowledge on representatives of these other groups and their interactions is needed to expand our understanding of the system, e.g. on the actual and potential role of decomposers in the decomposition of organic material. This is scientifically interesting, but can also lead to new management methods.

In this respect studies on the effects of root herbivores and fungal grazers, effects of inoculation of soil biota, introducing half-parasites on the diversity and biomass production of grassland vegetation should be promoted as new insight can be useful for consideration of the pros and contras in relation to costs of maintenance measures.

4. Biofilter function of road verges

More studies on the combination of functions should be promoted:

- Construction of hedgerows and other type of tree rows and plantations to decrease or isolate air pollution.
- Creation of constructed wetlands for purifying road run-off as well as promoting ecological values.

5. Median strip of motorways: vegetated or concrete?
The construction and the maintenance of the small road verges between the traffic lanes are becoming controversial. 10 Year of research of different methods of construction made clear that finishing with nutrient poor sandy soil is the best option from an ecological as well as maintenance point of view. A comparison should be made between the pros and contras of using this method instead of a more standard use of concrete barriers. If concrete barriers have to be installed, there is a need for better designs that also serve ecological values.

6. Biodiversity in extra parallel strips along motorways outside "the right of way"
The question is: what is the optimal width of road verges in different types of landscapes. The next question can be: is it possible to increase the biodiversity if the amount of habitat patches as stepping stone or in the form of long stretches parallel to the road are created (in the form of enhancing the existing ecological value or by forming new habitat patches).

7. From transparent noise screens to a more integral design approach
More and more noise screens, which are made of transparent material, have been and will be built. Noise screens made of transparent material can cause bird kills. A design with vertical stripes will prevent bird collisions. Although guidelines have been published about preventing bird collisions when using transparent screens there is little or no acceptance by policy makers or designers. Research is needed how to make more use of existing knowledge to reduce the amount of bird kills and how to make communication more effective.
It should be wise when this aspect can be seen in a much wider context like landscaping the surroundings of motorways with intensive use in the form of a 'noise barrier landscape'. In a 'noise barrier landscape' a combination of functions could be realized. These functions could be: noise reduction, water retention, water purification, recreation with as well promotion of ecological values.

8. Communication
It should be noted that ecological road verge management and concrete maintenance measures as such (mowing once or twice a year and removing the cuttings) on grassland-like road verges are not much discussed; there is a broad consensus regarding the appropriateness of this practice. Although there is sufficient knowledge to know what to do to our road verges, the daily practice deviates from the available insights and knowledge, leading to undesirable, suboptimal situations.
Therefore, more knowledge would be useful on communication patterns, how decision-makers digest the presented information, because it sometimes leads to irrational outcomes.

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4. The Fragmentation of Nature by Motorways and Traffic, and its Defragmentation

H.D. van Bohemen, G.J. Bekker and G.Veenbaas

Abstract

This chapter describes the effects of the construction, presence and use of motorways on nature, and the possible mitigating measures to reduce the effects. The main aim is to give a review of the research on the relationship between motorways and ecological values on various levels of scale, initiated, conducted or managed (when the study was contracted out) by the Road and Hydraulic Engineering Institute (DWW) of the Ministry of Transport, Public Works and Water Management in the Netherlands. The main part of the chapter is focused on the developed knowledge concerning fragmentation of habitat patches by motorways, and on the possibilities and effectiveness of defragmentation (mitigation) measures. We also discuss how in recent decades this subject has successfully been included in the policy-making process. It formulates some defragmentation strategies based on a synthesis of the knowledge developed and insights gained, despite the continual problem posed by lack of knowledge about certain aspects. Finally the main research questions still to be answered have been formulated.

1. Introduction

This chapter provides an overview how motorways and traffic influence ecological patterns and processes and how to reduce these impacts on the basis of the research initiated, conducted or contracted out by DWW (Road and Hydraulic Engineering Institute of the Directorate-General of Public Works and Water Management of the Ministry of Transport, Public Works and Water Management in the Netherlands).

The subject forms part of a new developing field called 'road ecology' or 'road systems ecology' (Forman et al., 2003) or 'infrastructural ecology' (Van Bohemen, 2002), as the science of ecology and landscape ecology to explore, understand and address the interactions of infrastructure/roads and traffic with their surrounding environment.
The problem definition (Section 2) comprises the questions to be dealt with in this study. It focus on the impact of roads on nature, with an accent on the fragmenting effect of motorways and the possibilities of defragmentation measures such as fauna passages. The problem definition is followed by a description (section 3 and 4) of the impacts of roads on nature and the significance of ecological infrastructures, thus presenting a common basis for the main theme of the study: the impact of the fragmenting effects of motorways on nature and the possible mitigating measures intended to reduce such effects (Sections 5, 6, 7, 8 and 9). Gaps in the knowledge are described. In spite of knowledge gaps the ecological effects of mitigating measures will be dealt with based on the available knowledge. Finally, some defragmentation strategies (Section 10) are formulated in the form of a synthesis, and conclusions are drawn and recommendations made (Section 11).

2. Problem definition

The following questions have been formulated and answered based on studies DWW initiated, conducted, or contracted out and managed in the case of studies conducted elsewhere.

1. Is there a conflict between motorways and nature values? If so, what are the aspects

of the conflict, what negative effects do roads have and what is their extent?
2. Which organisms are adversely affected due to disturbance and fragmentation by motorways, and which mitigating measures are suitable for these organisms?
3. What is the relation between the characteristics of mitigating measures and their effectiveness in reducing negative impacts?
4. What interaction can be established between the development of knowledge about fragmentation and defragmentation, and the policy for and the execution practice during the construction of motorways in the Netherlands in the last 30 years?
5. Can general principles for policy and implementation in the field of defragmentation measures be formulated based on the studies conducted?

3. The impact of roads and traffic on nature

The construction and use of roads leads to adverse effects on the environment and nature (Van der Maarel, 1972; Ellenberg et al., 1981; Mader, 1981; 1984; Aanen et al., 1991; Kaule, 1993; Van Bohemen et al., 1994; Van Bohemen, 1996, 1998 and 2001; Bekker et al., 1995; Forman, 1995, 1997, 2003). Beside the inserted literature some reports of international congresses focused on roads and nature provide an effective understanding concerning (results of) studies about the impact of roads on nature (in Europe: SETRA 1985; Canters et al., 1997; Carsignol, 1992; in North America: Evink, 1996; Evink et al., 1998; Evink et al., 1999; Evink, 2001; Australia: Saunders and Hobbs, 1991).

Ecologically speaking, roads and traffic have four main negative effects:

1. They cause loss of habitat patches
2. They form barriers and isolate habitat patches
3. They create disturbance due to noise, light and air pollution
4. They are responsible for direct mortality (fauna victims due to collision with vehicles).

In the first place, there is the loss of habitat patches: asphalt and concrete replace habitat patches forever. Table 1 shows how much space is occupied by the various types of road and railway.

Secondly, roads form physical barriers: a road can divide a habitat patch into separate areas, each of which can become too small for the survival of a population.

Thirdly, habitat patches are disturbed by roads and traffic (noise, light, pollutants), and for certain species this reduces the quality of habitats adjacent to the road. In the Netherlands, studies of the relationship between breeding birds and motorways have been conducted (Reijnen & Foppen, 1991a, 1991b; Reijnen, 1995; Foppen et al., 2002), as well as studies about the effects of light on meadow birds (De Molenaar et al., 2000) and on small mammals (De Molenaar et al., 2003).

In addition to the impact of noise on animals, changes can occur in the quality of the air, the soil, the groundwater and the surface water, and this can affect the behaviour and survival of plants and animals (Forman et al., 1997, 2003). Road construction also creates microclimatological changes that can affect the quality of the remaining habitat patches (Mader, 1981).

Fourthly, traffic is responsible for the death of many animals. For instance, 10-15% of the Dutch badger (Meles meles) population

Modality	Type	width in m	Surface area (ha/km)
Railroad	Conventional	26	2,6
	HSR upgrade	32	3,2
	HSR new	35	3,5
Motorway	2x1 traffic lanes	32	3,2
	2x2 traffic lanes	54	5,4
	2x3 traffic lanes	60	6
	2x4 traffic lanes	72	7,2

Table 1. The general amount of space taken up by different types of infrastructure at surface level (Piepers et al., 2001).

(approximately 400 individuals) is killed each year on motorways (Bekker & Canters, 1997), as are between one and two million birds (Tempel, 1993), and many frogs and toads (Vos & Chardon, 1994), along with other small animals are killed.

The density of a road network (see Figure 1), the configuration of the road network and the location and design of individual roads in the landscape, its intensity of use and the speed of the cars are important factors concerning the impact of roads on flora and fauna. Many disturbing effects from roads and traffic differ in the extent from the road. The determination of the width of the road-effect zone of the different causes in relation to topography, wind and groundwater flow provides an understanding of the problem in a specific area (Forman et al., 1997, 2003).

However, roads can have positive effects too. Roadside verges and ditches can provide a new type of habitat for species and can provide a corridor function which can be positive, but in certain situations negative. Positive corridor function if they connect separated habitat patches by facilitating e.g. the daily movement

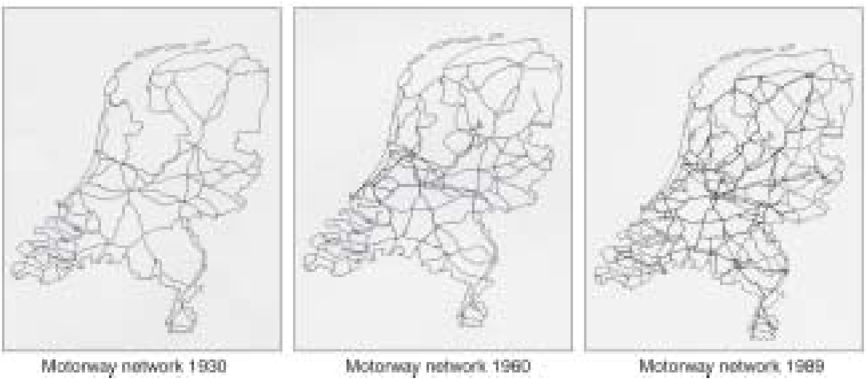

Figure 1. The development of the road density in the Netherlands (H+N+S, 1996)

or dispersion; negative corridor function when they facilitate e.g. the invasion of non-native species. Futher they can provide partial compensation for the loss of habitat for certain species (Aanen et al., 1991; Van Strien and Van den Hengel, 2000).

4. Meaning, conservation and development of ecological infrastructures

The island theory (MacArthur and Wilson, 1967) and the metapopulation theory based on it (Levins, 1970; Opdam, 1987, 1991) are tools for describing and predicting the causes and effects of fragmentation and for finding means to reduce effects. Despite the contention between advocates and opponents (Brussaard and Van der Weijden, 1980; Diamond, 1975; Den Boer, 1983 and 1990) there is consensus about the fact that persistence of many plant and animal populations vitally requires sound ecological infrastructures in order to counteract the uniformity and fragmentation of nature and the landscape (Jongman, 2002).

The concept of the ecological infrastructure by forming of ecological networks – made up of core areas, buffer zones and ecological connections at various levels of scale – has been a useful tool for conservation, repair and development of the occurrence of species and ecosystems (Ministry of Agriculture, Nature and Fisheries, 1990).
There is increasing interest in the manner in which the road- and motorwayinfrastructural elements can contribute to nature development. The idea is not only to eliminate the bottlenecks between ecological infrastructures and roads, railroads and waterways as much as possible, but also to convert these into possibilities to improve the environmental and nature quality of areas. All these activities will contribute to a more sustainable infrastructure, especially in highly populated areas like the Netherlands. Ecological road verge design and ecological based maintenance produce road verges rich in species; this applies not only to flora (including many flowering species, which have an esthetic value) but also to fauna. Road verges can also form a corridor between habitats; this has for instance been proven for ground beetles (Vermeulen, 1995). The banks of roadside ditches are important as habitats and corridors for less common animal species, such as the grass snake (Natrix natrix) and water shrew (Neomys fodiens). In addition to measures to prevent and reduce the degradation of the abiotic and the biotic environment, the effects can also be reduced by providing more space for plants and animal species in road verges and the surroundings in the form of compensation to reach no nett loss of nature values (Cuperus et al., 2001). This can be done by widening the roadside verges and including the adjacent agricultural land (e.g. with the help of agreements with the farmers for less intensive use).

With regard to the planning of ecological units and structures, it is possible to distinguish a hierarchy of ecological networks at various levels of scale which are all important for survival of species (Bennet and Wit, 2001; Van Opstal, 1999):

a. Global scale: The Global 2000 programme includes 233 'ecoregions' with core areas, corridors and restoration areas.
b. Continental level: Within the European nature policy, one of the priorities is the realisation of Natura 2000 – a coherent European ecological network of the European Union – the European Ecological Main Structure, as part of the continental strategy as well as the Pan-European Biological and Landscape Diversity Strategy for Europe, forming an European Ecological Network.

c. National level: To combat the further degradation of nature, the Netherlands introduced its Ecological Main Structure (EHS) in the Nature Policy Plan (Ministry of Agriculture, Nature and Fisheries, 1990).
d. Provincial/regional level: Provincial/ regional authorities are working on Provincial and Regional Ecological Infrastructures, respectively.
e. Municipal/local level: Some municipalities in the Netherlands have drawn up a Municipal Ecological Structure for their municipality or parts thereof, like the ecological infrastructure of Amsterdam and Apeldoorn among other cities.

Highly human influenced (cultural) landscapes (Barends eds., 1986) can be regarded as comprising of a mosaic of various landscape elements, for instance various types of forests, grasslands, fields, road verges, ditches, hedge banks, hedge belts, etc. Forman (1995) characterizes a landscape using his 'habitat-corridor-matrix' model. Habitat means the circumstances under which a species can survive. Usually, habitat means a spatial unit that is suitable as a living area for an individual or a population of a species; we use in this article the term 'habitat patch'. The matrix is shaped by the prevailing ecosystem or the land use determined by humans. The habitat patches make up tangible landscape units that differ from the surroundings and are characterized by soil, relief, vegetation and/or fauna. A corridor is a connection between habitat patches.

Within cultural landscapes there are, beside the general increase of land-use intensity, two negative processes that are important for many plants and animals: the increased density of roads and their barrier effect, as well as the reduction of the degree of connectedness of ecologically important elements.

In landscapes, various sub-units can be distinguished based on their function. For animals, these can be such areas as general place of residence, foraging area, reproduction area, rest-, sleeping- and hibernating area or refuge. The areas can be found at various places in the landscape resulting animals being compelled to move through the landscape. Movement is one of the basic properties of animals, but also plants show a form of flow (spreading of seeds, rhizomes, tubers or bulbs). Plants sometimes need animals for their spreading; also vehicles can play a role (wind, tires) (Wace, 1977; Schmidt, 1989).
The evaluation of the impact of roads in landscapes vitally requires knowledge about the existing pattern of the habitat patches in the landscape and the biology of the species concerned. In addition, it is important to include in the evaluation the sometimes long-term effects of earlier initiated processes (Scott Findlay and Bourdages, 1999). A one-time survey of the situation usually is inadequate. An important role can also be played by stochastic processes and processes (both at a microscale and at the scale of the landscape) that can only be judged over a long period. An important distinction is between animals with large or small home-ranges, animals living on a very local scale, as well as between habitat specialists and habitat generalists.

5 Fragmentation

5.1 The term fragmentation

Fragmentation can in general be described as 'the process in which there is area reduction and the bisection of biotopes and landscapes, and in which the functions of the landscape are changed for people, plants and animals' (Van den Berg (ed.), 1990). A definition more focused on organisms is: 'The dissection and reduction of the habitat area available to a given species caused by habitat loss (e.g. due to land-take), habitat isolation (e.g. due to barriers) or increasing distances between neighbouring habitat patches' (Piepers, 2001). (Figure 2).

5.2 Fragmentation as an environmental theme

Both in the Netherlands and abroad, fragmentation as an environmental theme did not come to the fore until the 1980s. In 1986, the former Research Institute for Nature Management (now Alterra) organized a symposium on the significance of small landscape elements (Opdam et al., 1986), which probably was the first symposium on this subject in the Netherlands. DWW continued along this line and at its initiative in 1987, a workshop was held on the fragmentation of the Dutch landscape by infrastructure (Van de Watering & Verkaar, 1987). In a programming study conducted by RMNO (Council for Environmental and Nature Studies) (Van den Berg (ed.), 1990), the subject was explored from historic-geographical, landscape-ecological, hydrological, social-spatial, environment-psychological and landscape-architectural angles.
Table 2 illustrates the degree of fragmentation of the land use in the Netherlands.
The table shows the results of a quantitative analysis of the spatial configuration of the land use for the Netherlands as a whole and for the Ecological Main Structure (EHS). The natural units are highly fragmented. The EHS score is slightly more favourable. A striking aspect is the small average area of deciduous forest both in the Netherlands as a whole and in the EHS.

5.3 Fragmentation in a landscape-ecological sense

For a sustainable way of conservation, restoration and development of plant and animal populations, it is important to take into account the various landscape-ecological levels of scale and the positions and functions of organisms in them (Forman, 1995; Farina, 2001). In this context the population and meta-population concept is essential.
A population is a group of individuals of the same species living, reproducing and interacting in the same area. A metapopulation comprises spatially separated subpopulations that are interconnected via dispersion flows (Opdam, 1987, 1990). In a metapopulation the local populations display its own dynamics and the distance between the local populations still allows for interaction (Hanski & Gilpin, 1991). Practical experience has shown that such a population is more stable than a local, isolated population. Habitat patches can be recolonized after extinction of the local population (Opdam, 1987).

The effects of fragmentation are highly dependent on the type of ecosystem, the species of plants and animals, and the scale of view (Opdam and Hengeveld, 1990). Also the type and degree of isolation can differ: more or less unsuitable terrain or barrier effects due to ribbon-shaped structures (roads, canals, railroads) increase the level of isolation and can decrease the stability of the metapopulation.

Fragmentation can occur as the result of natural or human processes. Natural processes are, for instance, fire, wind, floods and landslides. Natural landscapes therefore often have a mosaic pattern (Forman, 1995). Also human action has led to mosaic landscapes, which can accommodate additional species as a result of the increase in habitat variation.

The effects of fragmentation can be determined at the level of individuals, populations, living communities and ecosystems. Studies have shown that the

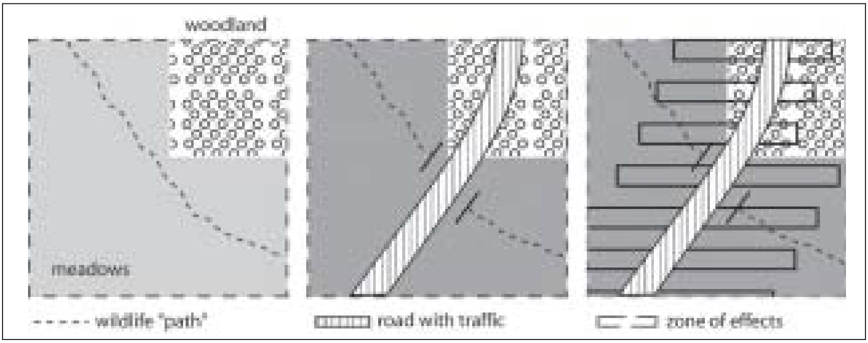

Figure 2. Habitat fragmentation by a road (Veenbaas, 1990)

	Total surface area in ha	number of units	average surface area in ha (x)	standard deviation	average distance between areas in m (y)	index* relationship (x/x__/ y/y__)
The Netherlands total						
grassland	1372725	93256	15	142	85	7.5
arable land	965968	111415	9	84	118	3.2
deciduous wood	181447	183280	1	9	136	0.3
coniferous wood	175903	45219	4	61	205	0.8
heath	13415	7098	2	20	132	0.6
without vegetation	17615	8428	2	43	489	0.2
other natural land	122471	67292	2	35	188	0.4
fresh water	342032	51745	7	832	166	1.7
National Ecological Network						
grassland	173931	35301	5		162	1.3
arable land	46891	19458	2		244	0.4
deciduous wood	119570	37332	3		145	0.9
coniferous wood	164404	15550	11		189	2.5
heath	13321	1967	7		109	2.8
without vegetation	13449	3572	4		649	0.3
other natural land	106154	22895	5		196	1.1
fresh water	27371	11664	2		274	0.3

** This index is a standard for the fragmentation in which the size of the units and the distance between them are taken into account. To make sure that one of either factor does not weigh heavier in the final result, the actual values have been related to the respective maximums, so in fact the percentage of the maximum score is used in the calculations. The ultimate index value increases as the average surface area grows and/or the distances between them decrease. A low value, therefore, means a high level of fragmentation.*

Level of fragmentation of land use in the Netherlands (calculated for the Netherlands as a whole and the National Ecological Network).

Table 2. Level of fragmentation of land use in the Netherlands (Fliervoet et al., 2001 in: Piepers et al., 2001)

number of species in a habitat patch is markedly reduced if more than 80% of the original habitat patch have been lost and the remnants become isolated (Andren, 1994). However, loss of only 40-60% of the habitat patches can markedly reduce the number of species. The actual effect depend on the species' requirements, the mobility of the species as well as the concrete pattern of habitat patches.

For some animal species the degree of interconnection of the landscape elements plays a vital role in the movement of animals in fragmented landscapes (Verkaar and Bekker, 1991; Seiler and Veenbaas, 1999). Connectivity is a species-specific property and can play a role both inside and outside the habitat patches. The interconnection of habitat patches can be improved by creating intermediate habitat patches (stepping stones) or corridors that also can fulfil a habitat function (hedges, hedge banks, banks, road verges) as well as mitigation measures near or above and under roads, railways and canals.

In addition to movements within metapopulations and the phenomenon of dispersion, also 'source-sink' relations play a role (Dias, 1996). If within a local population the number of births is greater than the number of deaths and all niches have been filled, then the surplus can start to occupy empty habitats or disappear in a "sink".
If there is a negative birth/death ratio, the population can survive if there is continual immigration from a source population. It appears that the source-sink dynamics can have a stabilizing effect on the dynamics of metapopulations (Pullian, 1988).

Due to the complexity of systems and the relationships within and between them, it is important for an intervention (e.g. the planning, construction and use of a road) not only to study the species in the immediate surroundings but also to carry out population-dynamical studies of many species over a relatively large area in order to be able to make a complete picture of the species involved or may become affected in the future.

5.4 Fragmentation by motorways

Central to this chapter is the fragmentation of nature as a result of the construction, presence and use of motorways and the spatial configuration of motorways within the landscape. According to the quoted definitions, the building of roads leads to fragmentation of habitat patches. Furthermore, their use leads to disturbance of habitat patches in the surroundings and death (road-kills) of animals trying to cross the motorway (Van Bohemen et al., 1994; Bekker et al, 1995; Forman et al., 2003).

In the last three decades, both the number of roads and the traffic intensity have markedly increased in the Netherlands, as elsewhere in the world. In 1996, the mesh size of the motorway network (computed by laying out the road network in an imaginary square raster over the land) was 32 km, that of all governmental roads and provincial roads together 7.5 km, and that of all hard-surface roads 1.2 km. Especially the mesh size of the motorway network decreased during the 25-year period, from 75 to 32 km (Figure 3) which can affect many species of large wildlife (Forman and Hersperger, 1996; Forman et al., 2003).

For purposes of the conservation and development of biotopes for plants and animals, not only the density and mesh size of the road network, but also the width of the roads and the traffic intensity are important

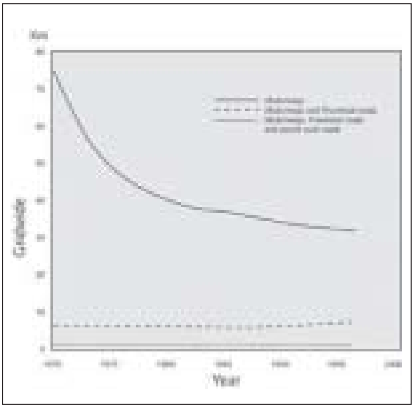

Figure 3. Grid width development for each paved road category in the period from 1970-1996 (Piepers et al., 2001)

(Mader, 1979, 1984; Mader et al., 1988; Ellenberg et al., 1981). Many roads have been widened over the course of time. In the period 1970-1996, the traffic intensity in all road categories more or less doubled which highly increases the barrier effect of roads and the width of the affected zone.

Despite the fine-mesh network in the Netherlands, widening as well as new infrastructure are considered to be still needed (Ministry of Transport, Public Works and Water Management, 1990, 2001). However, there is increasing worry about the negative effects roads and traffic have on the environment and nature (Ministry of Transport, Public Works and Water Management, 1990, 2001 and Ministry of Agriculture, Nature and Fisheries, 2001). Therefore an increasing number of mitigating measures are being taken. If mitigating measures do not reduce the damage enough (e.g. not reaching a no net loss level) compensating measures can be carried out (Cuperus et al., 1999, 2001) (see paragraph 7.3).

In recent years more and more countries have started to pay attention to the phenomenon of habitat fragmentation by roads and traffic. This is also a result of the increasing visibility of the negative effect on nature values due to the increasing number of roads and their traffic-intensity.

6. Bottlenecks between motorways and nature at various levels of scale

During the preparation of the Dutch Second Transport and Transportation Structure Plan (Ministry of Transport, Public Works and Water Management, 1990) and the Nature Policy Plan (Ministry of Agriculture, Nature and Fisheries, 1990) there was a need for a review of the knowledge about the effects of fragmentation and of the possibilities to limit the fragmentation of populations of animal species due to the existing motorways. At the request of the Ministry of Agriculture, Nature Management and Fisheries, the Ministry of Transport, Public Works and Water Management, the Ministry of Housing, Regional Development and Environment, the Centre of Environmental Science of the Leiden University conducted a study of the effects of roads and traffic on mammals and birds (Van der Fluit et al., 1990). The study revealed that the policy objective of conservation, restoration and development of natural and landscape values at certain spots can be contrary to the presence and use of the existing system of motorways. For the first time in the Netherlands, a bottleneck analysis was made in this field. The following animal species were involved in the analysis, based on a vulnerability determination in which a link was made between the importance of nature conservation and the sensitivity to fragmentation: red deer (Cervus elaphus), roe deer (Capreolus capreolus), wild boar (Sus scrofa), red squirrel (Sciurus vulgaris), otter

(Lutra lutra), badger (Meles meles), polecat (Putorius putorius), pine marten (Martes martes), stoat (Mustela erminea), weasel (Mustela nivalis) and various bird species characteristic for marshlands, meadows, forests, heathlands and small-scale landscapes. The study defined a bottleneck as a location in which a motorway is situated in an actual or a potential habitat or connection zone, in the Ecological Main Structure or at a site where many animals become traffic victims. The results are shown on the accompanying map (from Van der Fluit et al., 1990) (Figure 4).

The study report also includes a summary of types of measures that can be taken on roads to eliminate or reduce the effects at an individual, a population and a species level. All the necessary mitigation measures were included in a proposal for a national action plan. Also the total budget needed to carry out this plan has been included in the report.

In 1992 a survey and descriptive study followed of the effects of fragmentation by the existing and planned network of motorways for the areas in the Dutch Ecological Main Structure (EHS). Map overlays were used to survey the intersections of the EHS by the existing and planned motorways and to include these in a computer data base (Morel and Specken, 1992).

The conclusion of that study is that motorways lead to the highest number of current and future intersections of the EHS, viz. 245 as compared to 182 railroad and 78 national waterway intersections (a total of 505 intersections). After that study, in each province more detailed reports on the fragmentation situation were completed. Herein, the possible solutions formulated have been more focused on the bottleneck locations. For each bottleneck to be eliminated, a detailed survey is conducted on site and a design study will take place.

Provincial and municipal roads form an important part of the road system network and present their own problems. Especially an integrated approach is of importance in which the effects of motorways, provincial and local roads are taken into account. When diverting traffic to a motorway network simultaneously the elimination or limitation of through traffic on the underlying road network should be made possible.

7. Results of the research initiated, put out to contract or carried out by the Road and Hydraulic Engineering Institute (DWW)

7.1 Introduction

This section provides a summary of the research initiated and carried out by or put out to contract by the Road and Hydraulic Engineering Institute (DWW) of the Dutch Ministry of Transport, Public Works and Water Management, in which the results are placed in the context of application and – where relevant – in an international context.

The following procedure has been quite consistently followed throughout the different studies:

- First, an extensive literature study was conducted about the subject to be studied, depending on the expected quantity of available useful information.
- The research results were recorded in one or several intermediate reports.
- If the study had the quality of a doctoral thesis, the knowledge was presented in that form.
- Concrete measures have been taken or

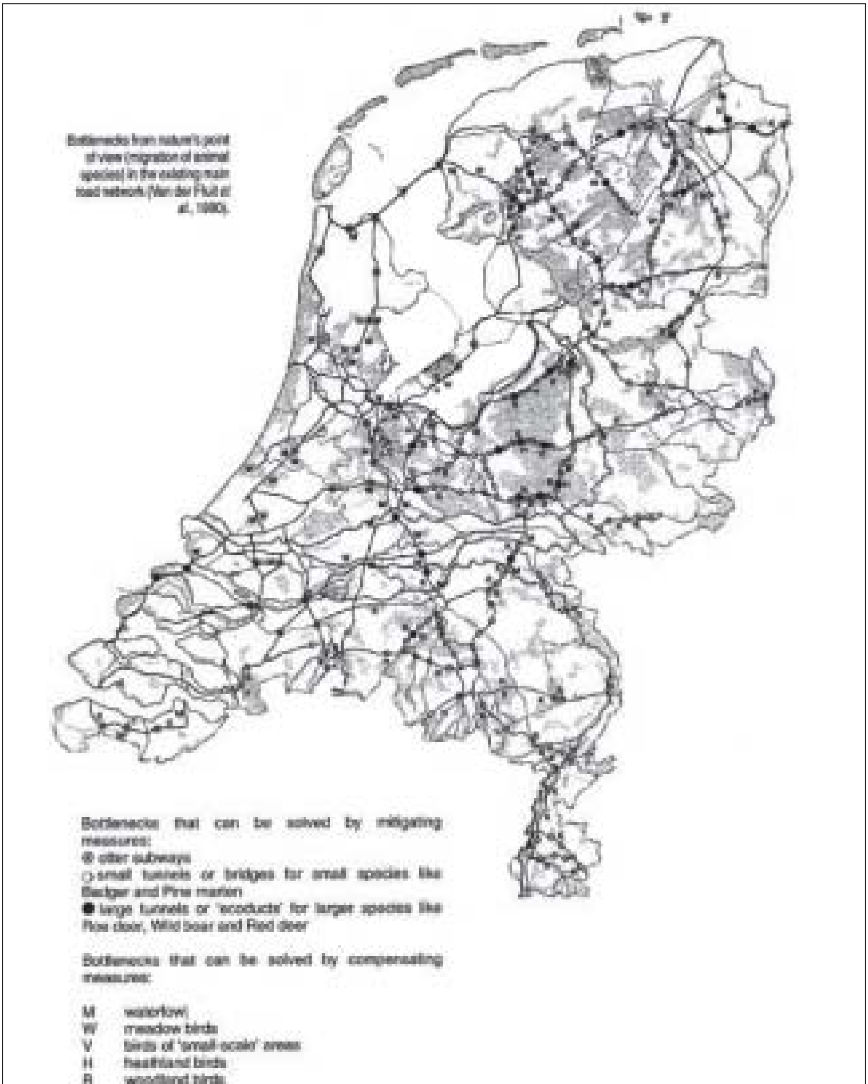

Figure 4. Bottlenecks between motorways and areas of ecological importance in the Netherlands to be solved by mitigation or compensation measures (Van der Fluit et al., 1990)

existing measures adjusted to the new knowledge.
- Regular monitoring takes place to see if the predictions about the use are correct.

Many means of communication were used (internally and externally) to distribute the results as wide as possible: in the form of the flyer-series the DWW-'pointer', in the report-series of DWW 'Defragmentation' as well as in the form of videos, interviews, lectures on symposia and workshops and at national and international congresses, and articles in Dutch and in international magazines.

First in this paragraph, the studies of the impacts of roads and traffic on animals are discussed (7.2). This is followed by a section (7.3) about the study of the relationship between mitigating measures and certain animal species, the studies of the use of fauna passages and about the effectiveness of fauna-passages at population level.

7.2. Study of the impact of roads and traffic on animals

- *Breeding birds and roads*
  Various studies conducted at the end of 1970s and the beginning of the 1980s (Van der Zande et al., 1980; Nijland et al., 1982; Verstrael et al., 1983) established that roads with traffic have negative effects on breeding birds. At the time, however, there was no systematic method to predict such effects. Therefore in 1986 a multi-year study of these effects was started by the Road and Hydraulic Engineering Institute – DWW. The objective was to use the study results as a basis for developing an impact prediction method for drawing up environmental impact reports on motorways. The study was focused on birds of forests and grasslands.

A reduced density of breeding birds along roads with car traffic appeared to be a general phenomenon: in the forest areas, in 60% of the species (in 29 of the 41 studied species) a reduced density was established along the road (Reijnen and Foppen, 1991a, 1991b; Reijnen, 1995), and in open meadow areas, such effect was established for 7 of the 12 statistically analysed species (Reijnen and Foppen, 1991a, 1991b; Reijnen et al., 1995b and 1996). The effect was also marked for the summated densities of all existing species (Reijnen, 1995; Reijnen et al., 1996).

Reijnen and Foppen (1991a) formulated the following results: On a motorway used by 75.000 cars/day the smallest effect distance (the distance up to which the effect can be established) in an open area with 75 % woodland is 81 m (woodcock – Scolopax rusticola) and the largest 990 m (cuckoo – Cuculus canorus; in open grassland: 100 m (coot – Fulica atra) and 1130 (black-tailed godwit – Limosa limosa). The density reduction in the effected zone is 37%-99% in woodland and 36%-82% in grassland. For all species combined the effect distance and density reduction are 460 m and 34 % in wooded areas and 710 m and 39% in grasslands. The density reduction is considerable, but varies depending on the species as well as the number of cars/day. For forest birds, such reduction in a zone of 250 m along the road was 20-98 % (Reijnen et al., 1995), whereas for meadow birds in a zone of 500 m along the road the reduction was 12-52% (at a traffic intensity of 50,000 motorized vehicles per 24 h).
The multi-year study conducted in young forests made it clear that fewer species have a reduced density and that the density reduction is smaller when the

general number of birds is higher (Reijnen & Foppen, 1995a; Reijnen et al., 1995a).

A detailed study (Reijnen and Foppen, 1991; Reijnen and Foppen, 1994) of the willow warbler (Phylloscopus trochilus) in the period 1988-1991 revealed that the males tended to avoid breeding areas along the road: breeding couples first settled in the breeding areas slightly further away from the road. Only later did willow warblers built a nest in the areas along the road. The majority of these were first-year males. Furthermore, the male willow warblers in the area along the road produced a total of 40% fewer young than those in the control areas. The first-year males that nested closer to the road (< 200 m) also appeared to be hardly loyal to their breeding ground: only 6% also bred there in one of the following years. Also the average dispersion distance for these males in the zone close to the road was much greater (Foppen and Reijnen, 1994). All results indicate a reduction of the quality of the breeding area alongside roads.

Reijnen et al. (1997) stated that the results show that in the Netherlands with a dense road network the population loss in the western part of the Netherlands may be 12% for the summed densities of meadow birds and 16% for the black-tailed godwit (about 3200 breeding pairs). In a recent study (Foppen et al., 2002) it has been calculated on the basis of detailed mapping of birds that around 15 % of the total land surface of the Netherlands birds are negatively influenced.

The results of the elaborate study have been translated into a prediction method for the effect distances of roads with motorized traffic in the case of birds breeding in open meadow areas and forests (Reijnen et al., 1992 and 1995). This in Dutch, English and Russian translated method is in particular valuable in environmental impact assessments. The method deals with the relationship between motorways and birds; other effects (habitat loss, habitat fragmentation) and cumulative effects should also be considered.

- *Amphibians and roads*
  In 1994, a literature study was conducted on the effects of roads on herpetofauna and the effectiveness of measures (Vos & Chardon, 1994); most of the literature which has been found came from Germany and Switzerland. It appears from this study that at the level of the individual amphibian, road-kills are the main impact of roads. The probability that a road is crossed by amphibians depends on the mobility of the species, the seasonal migration distance between the different functional parts of the habitat, and the road density. The survival probability of individuals that venture onto the road especially depends on the traffic intensity and speed, and the time-duration the animal spends on the road. Approximately 50% of crossing toads are killed by traffic at a traffic intensity of 15-40 cars per hour (Vos & Chardon, 1994).

  Model simulations applied to the Common toad (Bufo bufo) and the Common frog (Rana temporaria) show that a population will eventually become extinct if more than 40% of the full-grown animals are killed by traffic each year. This does not include natural number fluctuations and road-kills of young animals. Based on the intensity of traffic on the Dutch road network in relation to the survival probability of road-crossing toads, motorways and secondary roads comprise absolute barriers.

In the south-western part of Drenthe, a model study was conducted on the impact of roads on the occurrence of Moor frog (Rana arvalis) (Vos & Chardon, 1996; Vos, 1997). This revealed that the quality of the habitat patches is the main factor determining both the absence or presence of Moor frog and the size of the population in the pools. The presence of roads plays a role: if there are many roads in the immediate vicinity, it is more likely that no Moor frog will be present in the fen bog.

The larger the surface area of bog vegetation in a fen bog, the larger the probable occurrence of Moor frog, and the more roads within a radius of 750 m around a fen bog, the lower the probability of the occurrence of Moor frog. In Van der Sluis and Vos (1996) two areas have been studied in the provinces of North Brabant and Gelderland to find out whether network populations of amphibians in areas intersected by roads will be able to survive. By means of regression analysis the relationship was studied in areas – enclosed by motorways and roads which act as barriers – between the distribution pattern of amphibians, size of the area and number of ponds. The hypothesis was tested whether a population network will function better with an increasing size of the area. In Gelderland a significant relation has been found between the number of species per pond, the size of the subarea and the number of ponds per subarea indicating the size of the potential population network. In North-Brabant no such significant relation was found, probably due to the fact that the habitat fragmentation was already so high that the populations do not work as a network. On the basis of the study in Gelderland the presence of two species could be predicted in an area of 400 ha, three species in an area of more than 3500 ha. These data should be used with care, because not only the size of the area is important also the amount of water- and terrestrial habitats (Van der Sluis and Vos, 1996).

Bugter and Vos (1997) investigated the minimum size a network population enclosed by roads should be for the sustainable survival of the species at the regional level. Where the areas are too small, the barrier effect must be reduced by implementing mitigating measures, or compensating measures can be used to increase the quality and/or the quantity of habitat within the road network. Pattern studies conducted in some pilot areas ascertain whether amphibian species are lacking more often in relatively small areas surrounded by roads. A simulation study using the metaphor model – a meta-population model of IBN- DLO (now Alterra) – revealed that (Bugter & Vos, 1997):'… species with a large action radius, such as the Common toad (Bufo bufo), are more prone to extinction of a network population in an area that is enclosed by roads than species with a small action radius, such as the Smooth newt (Triturus vulgaris); the survival of species with relatively low mobility, such as the Smooth newt, depends on pool clusters with short distances between the pools; for the Tree frog (Hyla arborea), which is already endangered due to the relatively poor habitat quality, extra fragmentation by roads usually leads to the local network population becoming extinct; where the barrier effect of roads becomes too large to guarantee a fair exchange, mitigating measures are always necessary in order to allow for recolonization.'

- *Red squirrel and roads*
  As much more became known about the degree of road disturbance suffered by birds breeding in forests and grassland areas, and relatively little was known about the disturbing effect of roads and traffic on mammals, a study was conducted on the possible effects of road traffic disturbance on the red squirrel (Sciurus vulgaris), a relatively common species in the relevant habitat type in the Netherlands. The average density in Scotch-pine (Pinus sylvestris) woodland is one squirrel per hectare.The average number of dreys (nests) per squirrel is 4.5, in which the drey density mirrors the differences in habitat quality and changes in density as a function of time. The study was conducted by the Research Institute for Nature Management (now Alterra) (Nieuwenhuizen & Van Apeldoorn, 1995).

  The study investigated whether the red squirrel suffers from noise emanating from car traffic on roads. The hypothesis to be tested was that the drey density of squirrel in Scotch-pine forests is adversely affected by the noise load produced by car traffic. The study shows that the drey density in road and control areas are not significantly different. There could be an effect, but the large variance in drey density is mainly due to other factors. It should be noted that the study was limited to coniferous forests, and thus no statements can be made about other forest types.

- *Hedgehog and roads*
  DWW commissioned studies of road-kills among the hedgehog (Erinaceus europaeus), an animal species that is common in the Netherlands (De Vries, 1999; Huijser, 1999; Huijser and Bergers, 2000). Various studies conducted in Europe established that the number of dead hedgehogs per kilometre of road each year varies from 0.4 to 2.9, and here and there to 6. In the Netherlands, the total number of hedgehog traffic victims is estimated to be between 113,000 and 340,000 per year. Population surveys show that in the Netherlands there are approximately 250 hedgehogs/km^2. Hedgehogs have amply overlapping home ranges of 5-50 hectares (males), 2-20 ha (females) and 2-12 ha (sub-adults).

  Generally speaking, the males cover a distance of 870- 1700 m each night and the females 625-1000 m (Mulder, 1996). Roads by themselves are not an obstacle to hedgehogs, but roads with busy traffic at night do present a serious problem. It also appeared that hedgehogs usually do not roll up when confronted with a moving car; nor do they forage on the road surface, as was generally supposed. They tend to cross roads at high speed and always take the shortest possible route (Mulder, 1999).

  The main death factors are diseases, predation, winter mortality and road-kills. Approximately 30-60% of the hibernating adult hedgehogs do not show up the following year. Although road-kills amount to 5-20% of the population, by themselves they usually are not responsible for a decrease in hedgehog populations, although it is possible that they become extinct locally (Mulder, 1996).

  The locations of hedgehog road-kills are not fortuitous. A study by Huijser et al. (1999) showed that there are positive and negative relations with various road characteristics, landscape types and landscape elements. Wide roads present larger barriers than narrow ones, but usually have fewer road-kills. In forest and urban areas, more hedgehogs are killed than in agricultural landscapes. Forest edges, hedge banks or lane plantations close to the road produce more victims than such elements at a distance of more than 100 m from the road. Where such elements are perpendicular to the road, such produces more victims than elements parallel to the road.

To reduce roadkills of hedgehogs Huijser (2000) advised that the optimum habitat should be decreased along motorways, increased at a distance of about 100 m from the motorway and where landscape elements are situated perpendicular to the road and of interest for hedgehogs these places are the right ones for taking mitigating measures under or above the road.

- *Animals and road lightings*
  A literature study of the ecological effects of road lightings reveals that these effects are slight on flora and vegetation and are limited in space, but the effects on the fauna are clearly there (De Molenaar et al., 1997). Lights can result in disturbance of behaviour and biorhythm as can cause disorientation. The degree of the impact depends highly on the animal species and the type of light.

  After the literature study some field studies have been initiated and commissioned by the DWW. The study of the influence of road lights on meadow birds showed that the quality of the breeding area of the black-tailed godwit (Limosa limosa) due to road lights is adversely affected up to several hundred metres from the road; the earliest breeders appear to nest further away from the road; no adverse affect on the breeding success was established (De Molenaar et al., 2000). A second study was started on the impact of light on the movement behaviour of smaller mammals. In the experiment the repelling or attracting effect of light on mammal species were studied. The results (De Molenaar et al., 2003) show no significant repelling effect of the used light on the studied species. Polecat (Putorius putorius), Stoat (Mustela erminea) and (Red) Fox (Vulpes vulpes) were (statistically significantly) attracted to the light. This may also be the case for Muskrat (Ondatra zebethica) and the Weasel (Mustela nivalis). Hedgehog (Erinaceus europaeus), Brown hare (Lepus europaeus) and Roe deer (Capreolus capreolus) as well as Common (Brown) rat and mice as a group did not show difference in the spatial movements under dark or light conditions.

- *Discussion about the impact studies*
  During the last decades the impact of different disturbance factors on animal species have been studied, which give general insight into the impact.
  On the basis of the impact studies of roads and traffic on animal species in the Netherlands as well as abroad (Forman et al., 2003) mitigation measures to reduce the impacts are taken (see next paragraph). Still important questions remain unanswered:

  - What is really causing the reduced density of breeding birds. There is a strong evidence that traffic noise is an important causal factor, but in open grasslands visual effects can also be of importance.

- Effects of noise on non-breeding birds and on mammal species.
- Effects of light on bats.
- Effects of light on other than the studied mammal species like Red deer, Wild boar and Badger.
- What is for the different animal species the critical road density (including traffic intensity) above which a population cannot persist in relation to the spatial landscape pattern.
- Effect between species (e.g. prey-predator relations).
- Influence of accumulation of effects.

7.3 Defragmentation in practice

7.3.1 Mitigating measures

General
In order to reduce the effects of roads and traffic on the environment and nature, their planning, design and construction must pay attention to the possibilities to prevent or reduce the negative effects on nature by taking mitigation measures, measures to eliminate or reduce the adverse effects on nature values.

In the planning phase, better route-planning and more effective use of the existing infrastructure can reduce the impact of road construction and road usage on the environment. A positive contribution to the reduction of negative effects on nature can be made by formulating regional mobility plans that pay attention not only to the effectiveness of mobility-regulating measures but also to the effects on nature values.

In the design phase, it is possible to apply an integrated design approach. In such an approach, as many functions as possible are harmonized. In the construction and maintenance phase, ecological engineering measures provide possibilities to conserve, restore and develop ecological values.

Design sequence of steps to mitigate and compensate adverse effects
In 1978, the US Council on Environmental Quality indicated a desired sequence for assigning priorities to mitigating measures:

- Prevent adverse effects.
- Minimize adverse effects by reducing the intervention.
- Correct the adverse effects by restoring the affected ecosystems.
- Compensate for the effects.

For the Netherlands, this approach was worked out in the Second Structure Traffic and Transportation Plan (SVVII) (Ministry of Transport, Public Works and Water Management, 1990). In it, the keywords are avoidance, mitigation and compensation for adverse effects.

Avoidance of negative effects
The first step to counteract negative impact of roads on nature in the planning process is to abandon a proposed road project. If that is not possible an attempt must be made to route and design the road in such a way that the effect on nature is minimal and that any loss of the existing and potential nature values is avoided or prevented.

The prevention of effects is not regarded as part of the mitigation or compensation process. It is a matter of prevention if vulnerable habitat patches are not within the sphere of influence of the proposed intervention. There can also be avoidance if activities occur outside the critical period for animals. The best return on investment for nature is obtained where the adverse impact on the ecological values is prevented at as early a stage as possible.

Mitigation measures
The damage of an intervention like road construction can be restricted by restoring or improving migration corridors for species, preventing fauna victims and reducing the disturbance. Mitigation means the adoption of measures to reduce adverse effects, for instance, fauna passages over or under roads, fauna exits in canals, fencing, noise-reducing measures and measures for reducing lighting effects (Bekker, 1997, 1998; Bekker et al., 1995). The main aim of fauna passages is to conserve local animal populations, provide a corridor for animals regularly moving between resting and foraging areas or migrating between summer and winter areas, and for dispersion (settlement in other areas).
A secondary objective is that the passage of animals contribute indirectly the distribution of seeds: seeds can be carried in the fur or in the intestinal track.

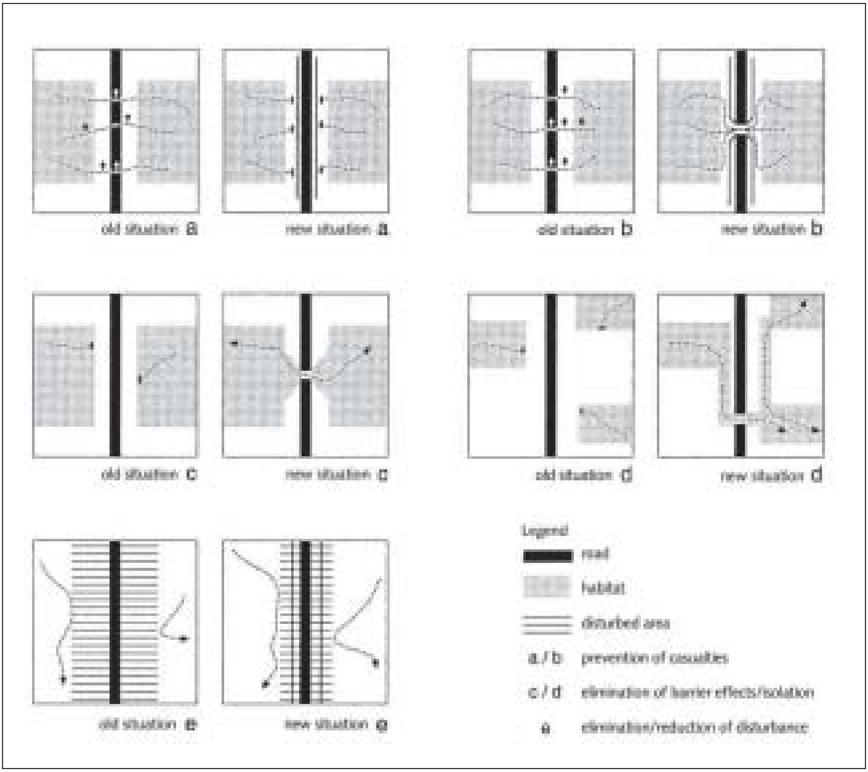

Figure 5. Principles of mitigation measures (from Oord, 1995)

Figure 5 (after Oord, 1995) provides a summary of source- and effect-oriented mitigating measures for the effects of road- and motorway construction and their use (after Piepers (ed.), 2001).
The principles of mitigation measures against accidents, barrier effects, isolation and disturbance (from Oord, 1995).

Defragmentation measure are based on one or more of the following principles (Figure 5 a-e):

1. restriction (with fencing) of the animal's ability to move between habitat patches or making it safer (fencing combined with safe passages) to reduce the number of accidents (a and b);
2. elimination of the barrier effects of a road (f.i. modified roadside verges with passageways)(c);
3. elimination of habitat isolation (f.i. corridors in roadside verges to guide animals to passageways or as a link to habitat located further away) (d);
4. elimination/reduction of disturbance by screens (e).

'With all these measures, the location has to be selected first. Source-oriented mitigation measures (reduced traffic intensity or speed, reduced noise level by using low noise road surfaces) not only have a broad scope of operation, they must be implemented over a large area (or, as the case may be, over long stretches of infrastructure).
This is different for effect-oriented measures. In this case, the measures have to be tailored to specific locations and closely related to different types of animals. This is usually fairly difficult, because the animals that the measures are designed for live along entire sections of a motorway. In practice, bottlenecks usually occur when infrastructure crosses the national or provincial ecological networks or other areas protected under government policy, but also information from provincial animal conservation plans and data on animal road accident casualties or cases of drowning in case of canals can give indications to locate mitigation measures.
The great length, the usually narrow verges and the generally short distances between the entrances that have to be kept open to farms and fields cause practical problems in implementing effect-oriented measures along roads in rural areas. This limits the possibilities for placing continuous fencing and screens.' (Piepers (ed.), 2001)

It is interesting to see that for individual species special fauna-passages are developed like cables over roads and motorways for Red squirrel and Pine marten (Bekker, 2002). The study by Bekker showed all kinds of different constructions (tight ropes, steel wires, rope ladder, adapted motorway portals in use for road signals).

Recently a new integrated form of mitigation measure has been developed: a combiduct (Brandjes and Smit, 2002). The combiduct is a combination of an open ecopassage (open U-gutter form or vegetated eco-strip on an existing viaduct) and a concrete fauna pipe underneath the open fauna-passage or under the surface of an existing viaduct, or beneath an open vegetated eco-strip on a viaduct.

Planning of fauna passages
The effectiveness of measures increases if all roads at various levels are included in the decision process of the measures to be taken. In this context, it is also important that road managers also keep in contact with the managers of ecologically valuable sites and areas.

For the sustainability of a solution it is vital that all measures be carried out based on an integrated design. The entire concept must as much as possible be harmonized with the surrounding landscape, including road verges and adjacent habitat patches, such as hedges, ditches and habitats for forest and meadow birds. Defragmentation studies usually only pay attention to the effects and measures due to the crossing or intersection of nature areas and ecological connection zones. Apart from (the successfully applied) ecological road-verge management, more attention must be paid to the ecological connections that run parallel to roads and canals. That is also a big opportunity for increased interest among farmers for what is known as agricultural nature management.

In the planning and execution of measures, it is vital to take into account any future developments, especially if quality impulses for nature development are carried out in the long term. *Veluwe 2010* (Province of Gelderland) proposes among other measures useful for animals, the reduction of spatial fragmentation and the enlargement of the habitats of the large mammals by eliminating barriers. This can be done by removing fences, reducing traffic intensity on local and regional roads and increasing the number of ecoducts over motorways and railroads in the Veluwe area (currently there are only three) by at least 15, as well as more fauna-passages under roads and railways. The ecoducts are necessary to realize the desired 'sturdy' ecological connection zones between the Veluwe and other actual and potential important areas for large mammals in the Netherlands as in other parts of Europe.
In other situations, it is planned that bridges for roe deer will be also made suitable for larger animals like red deer.

Costs of fauna-passages
The costs of mitigating measures play an important role in the decision process of the provisions to be installed. The costs given below are estimates based on rough parameters and estimated lengths and sizes of the adaptations. And there are differences between new and existing situation, which is more expensive. In principle, the following figures can be used (2003 price level):

- Ecoduct: 3,5-6,5 million euros
- Roe deer tunnel: 4000 euros per linear metre (2.75 x 2.5 m; dug-out)
- Migration tunnel: 5900 euros per linear metre (1.5 x 2.5 m; drawn or pressed)
- Badger pipe: 400-600 euros per linear metre (cross section 0.4 m; dug-out under the existing road with concrete without reinforcement)
- Amphibian tunnel: 680 euros per linear metre (1 x 0.75 m)
- Ecoculvert: 730 euros per linear metre (1 x 2 m)
- Adapting the existing bridge with a stump[1] bank: 2000-8000 euros
- Purchase of additional land: 30,000-55,000 euros per hectare
- Fencing: 20.000 - 40.000 euros per km.

For comparison

- Motorway: per km 15 – 20 million euros
- Tunnel: per km 125 – 135 million euros
- Road on piles: per km 30-35 million euros

Compensation
If after avoidance and mitigation still negative effects on nature remain, compensation is the next option to stimulate a no net loss of ecological values. It means creating, restoring or enhancing habitat patches to compensate for the remaining predicted effects. If compensation near the interference or further

[1] From a point of view of recycling and sustainable use of material this is a good option as otherwise the owner of the stumps have to pay for dumping or for destruction.

away is not possible financial compensation should be the last step in the process (Cuperus, 2003; Cuperus et al., 2001).

Towards an ecosystem approach
In the Netherlands, the adoption of mitigating measures has become standard practice for both new and existing roads. Although the barrier effect is reduced for some animals, it must be taken into account that such measures sometimes do not combat all negative ecological effects. For instance, soil, geomorphological and hydrological characteristics and location-specific gradient situations with the related plants and animals require an approach that is more focused on ecosystem functions and ecosystem processes, as well as entirely different measures. If ecological damage cannot be avoided, perhaps large landscape bridges, tunnels and roads on columns would help.

7.3.2 The use of fauna-passages

One of the ways to check whether the measures to combat fragmentation (all types of fauna passage, including the guiding provisions) are effective, is to establish whether the fauna passages are used by the species for which they were intended. Next, comparative studies can for instance be used to ascertain which type and which dimensions, which material and which maintenance produce the most usage, in order to realize an optimal passage in as far as the design and use are concerned. Beside the knowledge that fauna-passages are used by the organisms for which they have been built it is important to know whether the passages contribute to the long term existence of populations.

- *Amphibians and roads: knowledge development and application*
  The first fauna provisions were designed for amphibians. At the beginning of the 1960s, Switzerland worked on measures to preserve amphibians on the basis of the first counts of amphibian roadkills (Heusser, 1960). Circa 1975, the Netherlands saw the start of the first actions to protect migrating toads from traffic. As far as mitigating measures are concerned, already various types of tunnels, and the accompanying guiding systems (screens, chutes) are being applied. The acceptance of the provisions by amphibians varies. This depends not only on the type of the provision, but also on its location in the landscape (guidance by landscape elements). Animals should be guided in some way to the tunnel entrance and it is important that the direction of the tunnel does not deviate too much from the migration routes. The diameter of the tube must be at least 60 cm with a length of up to 20 m; for longer tubes, the diameter must be at least 1 m. For tubes longer than 50 m, the diameter should be 150 cm. Furthermore, it is vital that guiding screens should be installed and keep in repair. Their length depends on the willingness of animals to walk along a screen and the width of the migration zone. In order to prevent water from remaining in tunnels, the fall must be approximately 1% (Vos & Chardon, 1994). Furthermore, the use of a tunnel depends, besides the occurrence of species and their densities, on the tunnel material, soil substrate, the light entry, the number of and distance between the tunnels, and the characteristics of the screen (material, height, length, exits, vegetation near the screen and the positioning of the screen).

It is not yet possible to make a statement based on the study of the use of tunnels concerning the influence of tunnels on the survival of populations in the long term. Concerning the effect of tunnels on the exchange between populations at regional level no information exists. In addition to tunnels, also ecoducts, culverts with dry banks and viaducts provided with an unpaved zone can be used by amphibians; amphibians will also use concrete or wooden surfaces (Brandjes and Veenbaas, 1998).

In the adoption of measures it is important to keep all migration routes as intact as possible: biotopes should not be separated and the water quality should be protected. The appeal of the water, where mating and reproduction take place, as a factor determining the migration is probably also determined by its scope.
The temperature of the water also plays a role (possible on infrared radiation effect) as well as the microclimatological circumstances.

- *Use of fauna pipes*
  Beside tunnels for amphibians in the seventies special pipes for badgers have been built. During the last decennia studies have shown the use by badgers of these badger pipes. In order to know if and under which conditions other (small) animal species make use of these provisions 50 fauna pipes (also called: eco-pipes or fauna-tunnels) were studied in the Netherlands in autumn 2001 and spring 2002 (Brandjes et al., 2002). From the literature-study it became clear that the use of fauna pipes are influenced by: the dimensions of the pipe, the microclimate inside the pipe, the functioning of fences, the structure of the surroundings of the openings, the presence of species in the surrounding, the use of the pipe by predators.

No data could be found about: the use by reptiles, the frequency and the total number of individuals which make use and the relationship between the dimensions of the pipe and the use by species.

To know more about the presence of the species in the neighbourhood of the pipes reference pipes with ink beds have been placed; due to the large differences in use these counts have not been used in the statistical analysis.

The results of the study of Brandjes et al. (2002) shows the following:
- All pipes have been used with an average of 3,8 species/pipe/studied period (3 months).
- Amphibians did use the pipes with a diameter of 30-40 cm.
- The length of the pipe is negatively correlated with the use by marten, weasel and stoat.
- Mice probably visit mostly the pipes, but do not pass them completely.
- Use of badgers affected negatively the use by hedgehogs, but did not effected other species.
- Frequent use by domesticated cats has a significant negative effect on the use by other mammals.
- In more humid pipes more passage of amphibians were counted.

In a study by Van Eekelen and Smit (2002) it was found that differences are caused by the size of the provision as well as the location of the passage within the habitat. When a passage is larger and more humid the use of the number of species is likely to be larger. In an optimal habitat situation (nature reserve) a relatively small fauna pipe will show more frequent use than in suboptimal habitat situations.

- *The use of ecoducts*
  Studies of the use of ecoducts by animals have already produced many data to enable better design and realization. The older French types of ecoducts did not function as predicted. These provisions were small (4.5-8 m wide), not covered with vegetation and poorly situated in the landscape. The newer types which were constructed near Mulhouse in 1985 are wider and have a parabolic shape; they provide better results.
  The first two ecoducts in the Netherlands over the A50 between Arnhem and Apeldoorn, which were constructed between 1986 and 1989, are used by different animal species (Litjens, 1991; Berris, 1997). From almost the first day on the following species make use of the ecoduct of Terlet: red deer, wild boar, fox, rabbit and roe deer. Some years later badger crossings were observed too, as well as pine marten and ground beetles.

  In 1992 and 1993 a study was undertaken of the use of three types of fauna passages (13 pipes, 2 adapted culverts and 1 ecoduct) under and over the A1 near the Boerskotten estate (Nieuwenhuizen and Van Apeldoorn, 1994). The ecoduct was opened in november 1992. The measurements were made by counting tracks. This led to the following conclusions:
  - All passages were used.
  - Pipes and culverts were used by five species of mammals (hedgehog, rabbit, fox, pine marter, stoat) and the ecoduct by nine species (hedgehog, red squirrel, rabbit, hare, fox, marten, stoat, polecat, roe deer)*, not including the various species of mouse and vole.
  - Some species seem to prefer a certain type of passage. Foxes and rabbits for instance used the pipes more often than the culverts. The roe deer, hare and red squirrel only used the ecoduct. It was striking that the small species – such as mice and voles – did not use the pipes.

  The mitigation approach near Boerskotten is a good example of integration of different measures: along 6.4 km: 13 pipes, two adapted culverts and one ecoduct have been built.

  Also outside the Netherlands studies have been made of the use and effectiveness of fauna provisions. In 1991 Germany saw the start of a comparative study of the effectiveness of ecoducts for some groups of organisms. In one part of this study the effect was studied for some five ecoducts before and after the construction of a road, and in the other part a comparison of the use of eleven ecoducts in Germany, France, the Netherlands and Switzerland was made (Keller and Pfister, 1997; Pfister et al., 1997). In the first-mentioned study one of the five fauna passages had a width of 50 m (combination with the local road), two a width of 80 m (one without path, one with agricultural road), one of 29 m (agricultural road with strip of vegetation) and one of 20 m (agricultural road with strips of vegetation for cattle). In the comparative study, three fauna passages were included in Germany (10-35 m wide), four in France (8-12 m wide), two in the Netherlands (Terlet and Woeste Hoeve, 50 m wide) and

* Number of observations of animals on the ecoduct Boerskotten during the controls (222 times) of ink- and sandbeds during the period November 1992 - November 1993: rabbit 334, roedeer 300, hare 176, marten 117, fox 100, hedgehog 45, red squirrel 21, polecat 11, stoat 9 (Nieuwenhuizen and Van Apeldoorn, 1994).

two in Switzerland (200 m and 140 m wide, respectively). Some supplementary studies were conducted concerning the use by insects, spiders, small mammals and birds and special attention was paid to the badger including a telemetric study of behavior.

The preliminary results show that some forest ground beetles hardly use the passages but remain in the forest. The question is whether the passage of some individuals is not already sufficient to prevent complete genetic isolation. In this case, a real connection can only be realized by full afforestation of the ecoduct. Furthermore, it appeared important to have a corridor with the same type of vegetation on the ecoduct as the habitat patches to be connected.

The use by mammals increases as the bridge becomes wider (50-100 m). Also narrow viaducts are used, but in the study it was discovered that the entire population of red deer eschewed the passage, whereas beforehand they did roam the area. On the other hand, wild boar exhibit learning behaviour, viz. after a time they started to use narrow passages, while at first they had become disoriented.

The use by fauna of the ecoduct over the A1 has been studied (Van Eekelen and Smit, 2000) and found the use of roe deer and red deer. The wild boar do not only cross the ecoduct but if forms part of their feeding area.

- *Co-use by fauna of motorway viaducts as an underpass*

Figure 6. The wall of tree-stumps (photo: G.J. Bekker)

Under Zandheuvel viaduct (A27 near Hilversum), a row of tree stumps was installed underneath the over-dimensioned viaduct in order to investigate to what degree it would function as a faunahabitat and -corridor (Figures 6). Later a viaduct near Zeist (A28) was underneath equipted with a row of tree stumps.

Van der Linden (1997) showed that the construction of a stump wall is an effective mitigating measure to counteract the barrier effect of a motorway for some animal species. The stump wall was used as a corridor by insects, mice, voles and shrews. Also other animal species use the space under viaducts, but their numbers vary depending on the viaduct studied (in the case of Zandheuvel, also mole, red squirrel, roe deer and polecat; underneath a viaduct near Zeist: also rabbit, roe deer, polecat, fox, weasel, stoat, hedgehog and hare).
In 2000 Ottburg and Smit studied the co-use of the Zandheuvel viaduct as well as the viaduct near Zeist which both show use by small mammals and amphibians. The Zeist ecoduct could be fully designed as a fauna passage as the planned road had been cancelled. In 2000 beside the mentioned species passage of mice, rat, cat, roe deer and salamander. Hare could not be found probably due to increasing the amount of shrubs near the viaduct. For the first time fish passage has been studied which shows use of the water course underneath the viaduct by different fish species.

Van Eekelen and Smit (2000) studied the co-use of motorway viaducts in the A1 on the Veluwe by fauna as an underpass. Co-use could be shown by small mammals, reptiles and amphibians. The use can be stimulated by redesign the interior by increasing the amount of vegetation cover, guiding structures and increasing the attractiveness by construction of water pools near the entrance. In some dark situations putting special lighting for use in day time to stimulate plant growth within the viaduct could be helpful for animal use.

- *Co-use by fauna of motorway viaducts as an overpass*
  Some regional directorates intend to make some existing viaducts over motorways suitable for co-use by animals in order to contribute to the elimination of some habitat fragmentation bottlenecks along motorways. To study the effectiveness of adaptations of viaducts for fauna co-use, measurements were made of the current use of these bridges. For this, sand beds and track tubes were used to conduct track studies, and existing observations of mammals, amphibians and reptiles were collected (Dorenbosch & Krekels, 2000; Van Eekelen & Smit, 2000). Although the current use of the studied, non-adapted viaducts by animals is slight, in the study period seven species were observed on the viaducts: the hedgehog, polecat, fox, wood mouse, brown rat, rabbit and smooth newt as well as insects. A positive correlation was established between the use of the viaduct by animals and the presence of small-scale landscape elements with a well-developed structure nearby the viaducts.

  Based on the distribution study of animal species in the area, for each viaduct a forecast of its use was drawn up. The viaduct and the surrounding landscape must be adapted for co-use by animals.

  Van Eekelen and Smit (2000) found little co-use of viaducts of the A1 on the

Veluwe, but by demetal part of the road on the viaduct or by introducing vegetated strips or by placing stumps on the viaduct could increase co-use by animals.

- *Co-use by fauna of dry edges along waterways under viaducts of motorways*
In order to detect the main gaps in the knowledge of the use of fauna passages in the Netherlands, in 1996 a literature study was conducted on the use of all types of fauna passage in the Netherlands and abroad, including lower passages underneath roads not constructed as fauna passages (Smit, 1996). This study also provided a summary of the methods that were applied or are suitable for establishing the use of fauna passages, along with their advantages and disadvantages. The study shows that for most fauna passages (e.g. ecoducts, badger pipes and amphibian tunnels) by now knowledge has been accumulated about their use by the target or other species. Less is known about viaducts and bridges adapted for the co-use by animals as an underpass.

Especially about the use of wooden passageways, floating plank bridges, concrete walking strips in culverts and continued banks under viaducts there was a lack of knowledge. Therefore in 1997 an exploratory study of the use of fauna passages along waterways was conducted (Brandjes & Veenbaas, 1998; Veenbaas and Brandjes, 1999), in which also the (partly new) study methods – footprints and tracks on sand beds and on ink bed paper - were tested in practice. Practically all passages appeared to be in some use, but not all were used by the target species. Although the study was focused primarily on mammals, also amphibians appeared to frequently use these passage strips. An important factor in such use is the openness: the wider and shorter the whole underpass, the more the passageway is used. Also the width of the passage strip is important, especially for mammals: the broader the strip, the more often it is used, and also by more species. In addition to such frequent users as the brown rat and (wood)mouse, those using the passages included the hedgehog, fox, stoat, polecat, stone marten, water vole, muskrat, vole and shrew; most species use only foot planks 40 cm or broader, and the fox and stone marten only travel along continued banks.

The exploratory study was followed in 1998 and 2000 with an experimental study in order to draw up guidelines for design and lay-out. The use and the effect of cover material have been studied. This study showed that (Brandjes et al., 2001):
- In 2000, 18 animal species were detected on foot planks (17 in 1998); these animals included the hedgehog, water shrew, weasel, stoat, polecat, stone marten, newt, toad and frog.
- In the same year, 30 animal species were detected on continued banks (25 in 1998); these animals included the hedgehog, water shrew, fox, weasel, stoat, polecat, stone marten, badger, roe deer, newt, toad and frog.
- Widening the wooden passage way led to significantly more weasel tracks but significantly fewer tracks of all animals combined (this was especially due to the decrease in the number of mice tracks).
- The creation of stump walls on continued banks led to significantly more mouse tracks.
- Except for fox and stone marten, the co-use by humans appears to have a

negative impact on the use by fauna.
- As a result of the significant positive impact that the widening of wooden passageways from 70 cm to 100 cm has on their use by the weasel and of the fact that broader passages generally are used by a wider species range, it is advisable to broaden existing wooden passageways in culverts and under bridges.

Monitoring methods
To study the use of fauna-passages several methods are available. Track beds consisting of fine sand are used for studying footprints and tracks from larger to smaller mammals, up to mice, voles as well as frogs and toads, if moisture conditions are suitable (Brandjes et al., 1999).

The track method with an ink stamp plus a sheet of paper in front and behind (Figure 7) can very effectively be used on planks, continued banks in culverts and under bridges and other flat, delineated 'walking' strips as well as in fauna pipes (ink stamp and paper sheets fixed on a board).

Often it can determine larger mammals (e.g. the weasel, marten, badger) down to the species level, and sometimes also smaller animals (e.g. the wood mouse, thanks to its characteristic jumping gallop) (Brandjes et al., 1999). Amphibians can be determined down to group level (frog, toad, newt). Also birds sometimes leave prints and in some cases can be determined down to the species level (e.g. common heron).

Infrared detectors are useful for detecting whether and if so when passages are used. However, they do not provide an understanding of the species using the passage; animals scratching around near detectors produce many registrations that are irrelevant to the chosen purpose.

Figure 7. Ink 'stamp' with sheets of paper and tracks of some mammals (photo: G. Veenbaas)

An automatic video recording system, made up of an infrared light source, an infrared-sensitive black-and-white camera, a recorder and passive infrared motion detectors, is suitable for monitoring of animal passage (including species identification) as well as to get information about the behaviour of passing animals. The so-called fauna-monitor is also useful in case of trackmethodes cannot be applicated (Sips et al., 2002).

7.3.3 Study of the effectiveness of fauna passages at the population level

Use of fauna passage

♦ ♦ ♦	= tracks on > 3 passages, of which many on > 1 passage
♦ ♦	= tracks on > 3 passages, of which fairly many on > 1 passage
♦	= few tracks on > 3 passages
ooo	= many tracks on 1 or 2 passages
oo	= fairly many tracks on 1 or 2 passages
o	= few tracks on 1 or 2 passages
#	= walked, number of tracks unknown
( )	= number of studied passages

	viaduct (3)	large wildlife under pass (1)	rect. small game tunnel 1.2x0.6 (wxh) (1)	round small game tunnel, 0.8-0.85 m (3)	badger tunnel round, diam. 0.3-0.4 m (90)	dry culvert (culvert with dry ridge) (2)	bank strip under bridge, unpaved, (approx. 10)	bank strip under bridge, unpaved, w/tree-stumps (2)	bank strip under bridge, paved, (approx. 17)	gangway under bridge/in culvert (30)	floating planking in culvert (1)	dub bank under viaduct (1)	bicycle tunnel w/slab bank (3)	bicycle tunnel with basalt block strip (1)	bicycle tunnel with concrete walkway (1)	walkway over viaduct or bridge (1)
red deer (*Cervus elaphus*)	ooo															
roe deer (*Capreolus capreolus*)	♦♦♦	oo										o				
fallow deer (*Cervus dama*)	o															
Scottish Highland cattle	#															
wild boar (*Sus scrofa*)	ooo															
red fox (*Vulpes vulpes*)	♦♦	oo		oo	♦♦	o	♦						o			
badger (*Meles meles*)	oo			oo	♦♦											
beech marten (*Martes foina*)					♦♦		o		♦	♦						
marten (*Martes spec.*)	oo	o			♦♦	oo										
polecat (*Mustela putorius*)	o	oo		oo	♦♦		♦♦		♦♦	♦		oo				
stoat (*Mustela erminea*)	o	oo			♦♦		♦♦		o	♦♦						
weasel (*Mustela nivalis*)		oo		o	♦		o		o	♦				o		o
stoat/weasel (*Mustela spec.*)					♦	o						oo				
hedgehog (*Erinaceus europaeus*)	oo	oo			♦♦	oo	o			o					o	
hare (*Lepus europaeus*)	ooo	ooo			o			o	♦							
rabbit (*Oryctolagus cuniculus*)	ooo	ooo		o	♦♦	oo							oo			
rabbit/hare (*Oryctolagus /Lepus*)					♦		o		♦♦			o				
red squirrel (*Sciurus vulgaris*)	oo						o			o		o				
mole (*Talpa europaea*)							♦	o	o			oo	o			
muskrat (*Ondatra zibethicus*)							♦♦		oo							
rat (*Ondatra/Rattus*)		o														
brown rat (*Rattus norvegicus*)			o		oo		♦♦		♦♦	♦♦♦	oo				oo	
water vole (*Arvicola terrestris*)							o		♦	o					o	
wood mouse (*Apodemus sylvaticus*)							♦♦		♦	♦		ooo			o	
mice, voles		oo	o		o	oo	♦♦♦	oo	♦♦	♦♦♦		ooo	oo	oo	o	
water shrew (*Neomys fodiens*)										oo						
shrews							♦		♦			oo				
domestic cat (*Felis catus*)		oo	oo	o	♦♦		♦♦	o	♦♦♦	♦♦		o				o
dog (*Canis canis*)		oo	o		o		♦♦	oo	♦♦	o					o	o
toad					o					♦					o	
frog										o					o	
newt/salamander					o					♦						
partridge (*Perdix perdix*)		oo														
pheasant (*Phasianus colchicus*)		oo														

Table 3. The use of fauna passages (Piepers et al., 2001).

The first step in the study of the effectiveness of a fauna passage is to establish whether it is used by the intended species. The next step is research on the viability on population level. For this stage, DWW started a research project. The study has a long preparation period, since it concerns a new type of study with many complicating factors, such as other developments in an area that influence the survival of a species, and since the data about the dispersion of relevant animal species are only available to a limited degree. In the current phase of the project, it is being analysed whether and if so where suitable study locations to study the population-effect of fauna-passages are suitable for three animal species – the badger (as indicator to evaluate for badger tunnels), red deer (as an indicator to evaluate ecoducts) and crested newt (as an indicator to evaluate animal walking boards (=foot planks) under bridges and in culverts).

7.3.4 Conclusions about the use of fauna passages

Studies of the relationship between infrastructure with traffic and fauna reveals that the effects differ from species to species. Knowledge about the presence, distribution and dispersion of the species that are actually or potentially present in the area where fauna passages should be built, is essential.
Table 3 provides a summary of the studies of the use of fauna passages as a provisional picture.

7.3.5 Questions still to be answered

Besides the need for more research concerning the effects of roads (part 7.2) the following questions concerning the effects of mitigation measures need to be answered:

- The effectiveness of fauna passages at the population level;
- The quantity and optimal size of the mitigation measures to be taken in relation to the behavior of the species, to the landscape type and the real local contribution of the barriereffect.

8. Effective defragmenting activities: a review about policy making and implementation in the Netherlands

The consequences of political decisions (structure schemes, policy plans, implementation programmes, environmental impact reports) extend over many years. In order to take optimum account of nature and environmental aspects, it is important to integrate these aspects into the planning process at an early a stage as possible. For the traffic, transportation and infrastructure sector, the Second Transport and Transportation Structure Plan (Ministry of Transport, Public Works and Water Management, 1990) and the National Traffic and Transport Plan (Ministry of Transport, Public Works and Water Management, 2001; will be replaced by a new so-called Mobility Plan, which is in preparation) included policy rules for the relationship between infrastructure and ecological aspects. The important thing now is to use long term exploratory studies and strategic environmental impact reports as well as studies more oriented towards economics (e.g. such as the Method Economic Effects of Infrastructure), in order to convert the recommendations into generally acceptable norms that can be used in practice with regard to the relationship between nature and infrastructure. This would provide the chance to prevent, mitigate and compensate for adverse ecological and environmental effects and – if possible – to make use of opportunities for nature development. The sooner the contributions of ecologists and environmental scientists are included in the planning process, the easier it will be to include their view therein and to lower the total costs for a certain level of objectives to be accomplished for the environment and nature.

The following review shows how in recent decades in the Netherlands increasing attention has been paid to the fragmenting effect of roads/motorways and how in the policy process mitigating and compensating measures can be used to accomplish greater defragmentation of habitat patches (updated from Bekker and Canters, 1997; Van Bohemen and Teodorascu, 1997).

Measures, initiatives, innovations, embedding

Pre-1976

Road-kills among mammals and amphibians are the most visible negative effects of traffic on nature. Defragmenting measures were first taken for amphibians on secondary roads. Later interest was growing, due to the decrease of the badger populations in the Netherlands, of constructing badger pipes under motorways to decrease the number of casualties among badgers.

In 1974, action on motorways was initiated. The first badger tunnel was rather large with no effective fencing and much discussion about who should foot the bill. A lot of local action to draw public attention towards the animal road kills. All this was reinforced by the interest for nature: especially the European Nature Conservation Year (in 1970) was a major event.

1976-1980

Four rectangular badger tunnels (1.2 by 0.8 m) were built; holes soon appeared in the fencing; there is still discussion about who should pay for it; much local action.

1981-1986

Five more round pipes (∅ 0.3 - 0.5 m) were created and another, better badger fence was applied. Much discussion took place about the exact design, what dimensions, which supplementary measures, and what the approach should be in the immediate vicinity. Payment of fauna passages by the responsible party became accepted. This was also based on the discussion about the ‘grey’ environment, the rule ‘payment by the party that causes the damage to nature’ became generally accepted. The first measures for the badger were realized in the underlying road network. Measures also taken in the adjacent landscape (creation of hedges as guidance). First (oral) data obtained about the use by the badger and other animals. The study of broadening policy reach of the subjects fragmentation and defragmentation was begun in the period 1975-1980: study and reports by the former Research Institute for Nature Management (now Alterra) with regard to the construction of viaducts for deer over the A50 between Arnhem and Apeldoorn. In 1980 the Minister of Transport, Public Works and Water Management decided during the determination of the trajectory that near Woeste Hoeve a viaduct for deer and some underpassages for badger should be constructed. In 1981, design proposals followed, that would be further detailed by a working group in the period 1983-1987.

In 1984 – at the urging of administrative bodies and after the Ministry of Agriculture, Nature Management and Fisheries, the Association for the Conservation of Nature Monuments and the Association for the Deer in the Veluwe Area stated they were prepared to contribute to the costs; the decision was made to construct a second viaduct for deer near Terlet.

1986-1991

Approximately 40 badger tunnels realized under the A73 with effective fencing; more data about use of badger tunnels obtained; the first two ecoducts constructed in the

Netherlands (Woeste Hoeve and Terlet) are used by deer, badger as well as other animals. The first fauna tunnel created under an existing motorway (A27). Less discussion about the need for fauna passages, but more questions regarding how and where. The development was concluded with recognition of the problems within the Ministry of Transport. The policy to take measures against the fragmenting effect of motorways established in the Second Structure Transport Plan (Ministry of Transport, Public Works and Water Management, 1990) which was approved by the Parliament. It was also reinforced by the policy of the Ministry of Agriculture, Nature Conservation and Fisheries on the Ecological Main Structure (EHS) and the species policy (Nature Policy Plan, 1990).

There were more studies about impacts of roads with traffic on nature and for the Dutch situation applicable theories further underpinning the fragmentation problem. First exchange at a practical level with foreign colleagues struggling with the same problems (especially in France) took place.

1991-1996

In this period mitigating measures became standard for new motorways. The non-governmental organisation 'Das en Boom' was asked to collect data about badger road-kills. Discussion concentrates especially about the number and position of the measures. Extension of ingenious solutions: wooden passageways or concrete passageways in culverts, using of stump walls under viaducts. In 1990 and 1992, studies were conducted and published that provided an understanding of the relationships between the Ecological Main Structure and the motorways.
Based on this information the first implementation programme concerning mitigating measures for existing motorways was formulated and the first funds to be earmarked for mitigating measures were provided within the Multi-year Programme for Infrastructure and Transport. The University of Wageningen and the Research Institute for Nature Management (now Alterra) of the Ministry of Agriculture, Nature and Fisheries supported the practical realization by providing the relevant theory and knowledge with

		Motorways	Prov.roads	Municipal roads	Railways	Total
Realized badger tunnels in the Netherlands till 1998	Limburg	61	35	38	1	135
	Noord-Brabant	73	30	30	2	135
	Utrecht	58	15	30	1	104
	Gelderland	1	0	4	1	6
	Noord-Holland	1	1	0	1	3
	Overijssel	75	12	17	0	104
	Drenthe	40	7	1	0	48
	Friesland	2	9	5	0	16
	Total	291	129	125	6	551
		52%	23%	24%	1%	100%

Table 5. Realized badgertunnels till 1998 in the Netherlands (info DWW, 1998)

financial support from the Road and Hydraulic Engineering Institute (DWW).

In the meantime the Minister of Transport, Public Works and Water Management made Euro 650.000 available to place badger pipes under existing motorways in 1991 and 1992.

In this period the Directorate-General of Public Works and Water Management (RWS) drew up a defragmentation plan in broad cooperation with all regional directorates under the guidance of the RWS-wide Working Group for Mitigating and Compensating Measures established in 1992 (now the Working Group for Policy and Realization of Defragmenting Measures). Based on the project plan of DWW 'From Fragmented to Defragmented', which was supported by the head office of RWS, this led to an integrated programme in which research, public information, coordination of RWS-wide activities, and policy preparation in the field of defragmentation were all combined.

In 1994, the Ministry of Transport, Public Works and Water Management decided to earmark a budget of almost thirty million euros, to cover a period of ten years, for mitigating measures (ecoducts and ecopipes), including the installation of fencing if needed along the existing motorways. Table 5 provides an overview of the badger tunnels realized in the Netherlands till 1998.

For the imbedding in the policy process clear, quantified objectives were approved by the Ministry (EHS = Ecological Main Structure of the Netherlands):

- In 2000, to have eliminated 40% of the bottlenecks between the EHS and the motorway system.
- In 2010, to have eliminated 90% of the bottlenecks between the EHS and the motorway system.

In 1995, DWW organized the International Conference on Habitat Fragmentation and Infrastructure (Canters et al., 1997). At it, the problem was widely recognized. Also in 1985 there was an international conference in Strasbourg that had a stimulating effect. The results and recommendations of the conference of 1995 were summarized in a statement (Declaration of the Conference Habitat Fragmentation, Infrastructure and the Role of Ecological Engineering) which then played an important role in gaining even more national as well as more international recognition of the subject (Van Bohemen, 1997).

The adoption of the Infra Eco Declaration by the participants led to many tangible activities. This is interesting to report; although it cannot be verified whether or not the activities would have been performed anyway, its usefulness can be established based on the references made to the Declaration.
In the further design of defragmenting measures in the Netherlands, as well as in other European countries, an important role was played by the possibility to refer to such a declaration. It has had stimulating influence in the USA too (Van Bohemen, 1996;Forman et al., 2003).

1996-2003

Based on the Declaration, the Infra Eco Network Europe (IENE) was built up which held its first annual meeting in 1996, leading to an intensive exchange of knowledge and experience and the coordination of research. Also based on the Declaration and the start of IENE, an EU COST proposal was drawn up; this led to COST Programme 341 in which 16 countries are carrying out a joint European programme (COST= European Cooperation in the field of Scientific and Technical Research.). The Infra Eco Declaration worked as a tool to increase the interest and involvement of

Figure 8. Solved and unsolved bottlenecks between motorways and nature in the Netherlands (info DWW, 2002)

relevant parties. Countries stimulated each other to draw up state-of-the-art reports. In Trocmé et al. (2003) a European review is given about the problems and summaries the possible solutions and ways forward to reduce the effect of fragmentation by motorways.

Joint efforts realized a European manual (Luell (ed.), 2003), which includes a detailed summary of the defragmenting measures based on experiences from 16 countries.

The first ecoduct over an existing motorway is realized at the end of 1999 (over the A1 near Kootwijk). Permanent recognition in policy plans, both within the civil service and politically, as well as by non governmental organisations, as expressed in the required budget being made available is essential for future measures to be taken.

For an effectively underpinned prioritization of measures in the Netherlands, the Programme of Defragmentation Measures 1997-2002 was drawn up for existing motorways. This programme indicated the measures that should be implemented between 1997 and 2002 based on the prioritization of all fragmentation bottlenecks. Also, a package of measures was presented; these were then summarized in the implementation programme referred to above. Communication, in the form of an open planning process, is an important attention point in this context. Not only all those involved (planners, environmental specialists, designers, builders, managers) but also all those interested (neighbours, nature and environmental organizations) must be given the possibility to influence the process at as early a stage as possible.

Type of fauna passage	Number
badgertunnels	280
small-fauna tunnels	175
large-fauna tunnels	4
ecoducts	5
tunnels for amphibians	2
eco-culverts	12
modified engineering structures	170

Tabel 5.The number of fauna passages that have been built under and over motorways in the Netherlands until the end of 2003 (source: Road and Hydraulic Engineering Institute)

Based on the Second Transport and Transportation Plan (Ministry of Transport, Public Works and Water Management, 1990), which will be replaced by a new Mobility Plan, and the Nature for People, People for Nature Plan (Ministry of Agriculture, Nature and Fisheries, 2001), a Multi-year Defragmentation Programme (MPJO) 2002-2010 is being drawn up. Figure 8 shows the situation at the end of 2002 of the solved and still to be solved bottlenecks between motorways and nature in the Netherlands (source: Road and Hydraulic Engineering Institute). The MJPO will be published in May 2004.

The total fence length along the motorways in the Netherlands is about 600 km. Almost 600 fauna passages have been built varying from badger pipes, small and large fauna tunnels and overpasses to adaptations of existing constructions like bridges, viaducts and culverts (table 5).
The unsolved bottlenecks between motorway and nature (here the Ecological Main Structure (EHS) of the Netherlands) have been prioritised for taken measures in the coming years in cooperation with the provincial authorities and published in the form of a map, showing first and second priorities, in the 'Meerjaren-programma Infrastructuur 2003' (Long Term Programm for Infrastructure) (Ministry of Transport, Public Works and Water Management, 2003). Although the Netherlands

has been the first country in the world to have developed a formal national defragmentation programm, with an annual budget allocated for the mitigation of existing bottlenecks, it took almost 13 years after formally accepting the concept of mitigation and compensation in the Second Transport and Transportation Plan (Ministry of Transport, Public Works and Water Management, 1990) before the map could be published in the Long Term Plan for Infrastructure (Ministry of Transport, Public Works and Water Management, 2003). The first map, which has been prepared in 1990 in cooperation between the Ministry of Transport, Public Works and Water Management, the Ministry of Agriculture, Nature and Fisheries and the Ministry of Housing, Physical Planning and the Environment (Fluit et al., 1990) appeared in 1990 in the Nature Conservation Plan (Ministry of Agriculture, Nature and Fisheries, 1990).

In certain situation the design, construction and maintenance of fauna passages show shortcomings (holes in fences, fauna pipe and tunnel entrance blocked, water in fauna pipe or tunnel) which reduce the use of these provisions (Piepers, 2003a). In the coming years more attention will be paid towards inspection of the construction and the maintenance. The drawing up and use of a separate Fauna Management Plan describing all the provisions and the needed maintenance and inspection is an important tool for success of the measures. An information system is in preparation and will be finished by the end of 2003 (Piepers, 2003b).

Lessons learned

On the basis of experiences during the last decades the process of policy making and implementation of mitigation measures in the form of fauna passages in the Netherlands has been summarized in Figure 9.

The figure describes the results of a participatory observation in the main steps. It is based on Bekker (1997 and 1998), adapted to and detailed on the basis of experiences of the three authors. The visualization of the policy process should be read in the form of an upward going spiral. The different steps of the figure can be further explicated:

- The problem was recognized; first, by certain persons and agencies, and later by more. The lesson learnt is that recognition by the organisation which can offer solutions for a problem is essential.
- The first steps were only possible because one or two individuals dared to stick their neck out (motivation).
- It appeared to be possible to find solutions, first slowly and after very sceptical discussions, but the solutions were improved and the provisions were used by animals. The efforts were ‘translated’ into an increase in the number of badgers in the Netherlands; also the positive effects on amphibian populations were remarkable. This shows the public and politicians about the usefulness of the measures to the public and the politicians.
- Development of knowledge of the problems and of their solutions remains very important.
- Also vital are the partnerships between various research fields and implementation disciplines, making for short communication and action lines: ecologists are now participating in project groups that used to be made up only of civil engineers.
- Internationally shared recognition underlined the importance. Looking over the borders of the country learnt that other people and countries struggle with the same questions and exchange of knowledge accelerate and improve the approach.

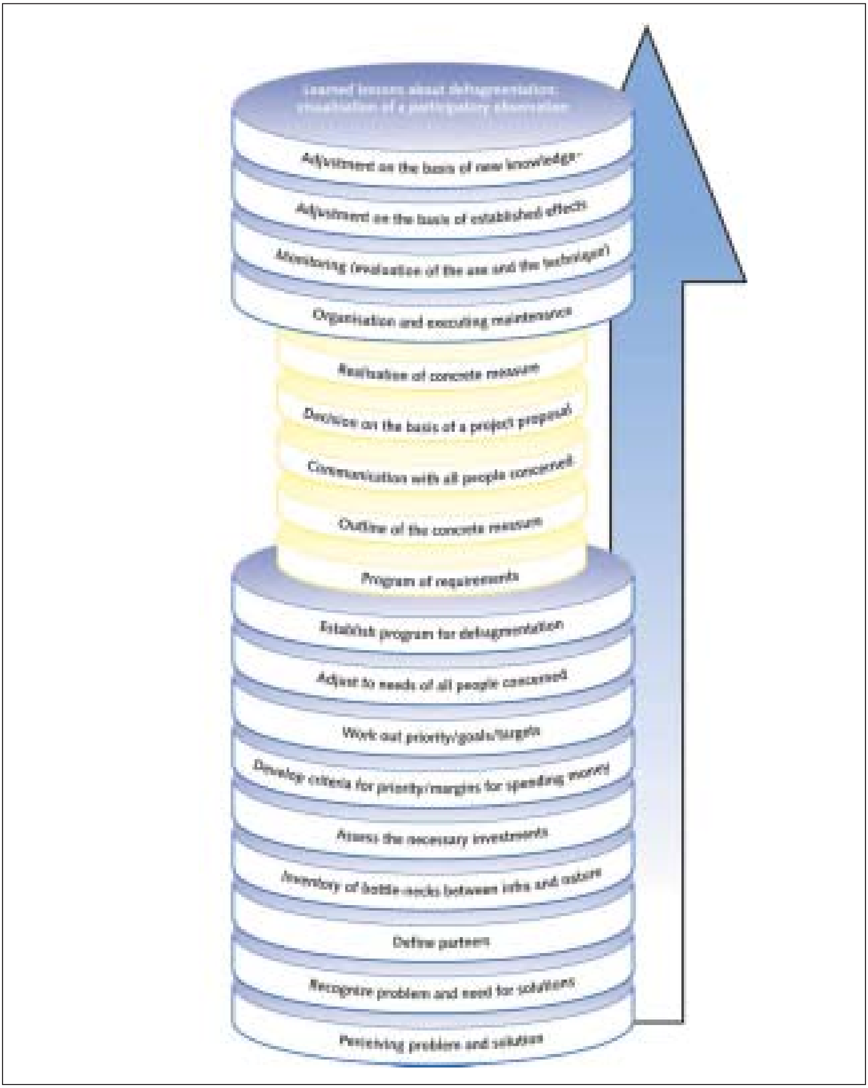

Figure 9. The lessons learned about defragmentation; visualization of a participatory observation. The narrowing part of the figure refers to a concrete mitigation measure.

- The public response and involvement of study and action groups play an important part in the formation of general support (e.g. the non-governmental organisation Das en Boom). Also other private organizations have a stimulating effect (for example the Dutch Society for Nature Protection). So non-governmental organisations play an important role.
- The attention of politicians was caught, and political will and support were obtained in order to solve the problem. At the national level, the political will was translated into policy objectives and the related budgets (Second Transport Structure Plan, Nature Conservation Plan, National Transport and Transportation Plan in preparation which will be replace by a Mobility Plan, Nature for People, People for Nature Plan).
- The efforts must be maintained. Requests should be made continually for money for future measures as well as for maintenance embedded in road management and road maintenance procedures.

As an explanation of the success it has been learned that it is very important that:
- The problem of fragmentation can be explained, that it is recognizable and that the solutions are both understandable and realizable.
- It takes time to develop the total stretch from idea to generally accepted policy and implementation themes.

Today, knowledge develops extremely rapidly. The concept of the formation and realization of nature networks is being given further shape. Also areas of larger size and other mammals than badger are being looked at: the wolf, lynx, wisent and elk, which could have their homes in the Netherlands in the future, but cannot survive in a sustainable manner due to the present fragmentation of our landscapes. If at first the badger was a guide species for defragmentation measures near for instance the A73, now the red deer is involved in the discussion about fauna provisions in areas where this species used to be found (Groot Bruinderink et al., 2001). The red deer is an important target species for future large-scale natural areas. It is also possible to make a connection with Germany. In the Netherlands, Belgium and Germany, there are large natural areas, which justifies the formation of a north-west European ecological network for large mammals.

Depending on the desired adjustments and new developments, it is possible to restart at a lower level (see figure 9) and return the process of defragmentation in whole or in part.

Conclusion of the defragmentation policy and implementation process

One of the preconditions for success is that a scientific understanding is obtained of the effects of fragmentation by roads and of defragmentation effects; social and political will is also essential for the realization of defragmentation (De Vries, 1999).

Economical and social spin-off of fauna measures
The building of provisions for fauna have given different kinds of spin-off in the field of manufacturing, research and in the social field. In the past provisions had to be specially designed and manufactured. As the number of concrete provisions are increasing, industries are more and more interested in designing and construction of prefab culverts including passage possibilities for terrestrial fauna, prefab amphibian tunnels and measures like ecoducts (new construction types and other forms).
Also in the field of combined design and

construct approaches for realizing ecoducts have been stimulated, which has been successfully taken up by the private market. As an example of a new tendering approach the ecoduct De Borkeld which has been built in Overijssel near the village of Rijssen was given out in a 'design and build' contract form. In such situations greater variety of disciplines (architects, landscape architects, ecologists, engineers, designers) are becoming involved than normally is the case in such projects and knowledge and ideas of the market will be used for more creative solutions.

9. Discussion

During the last two decades studies dealt with about effects of motorways and traffic on nature have given insight into the intensity and the extent of the effects on the studied groups of animal species.
The research on the use of implemented mitigation measures has given evidence of the usefulness of different types of fauna-passages to certain animal species.
It is interesting to see that due to the integrated approach of the Dutch Ministry of Transport, Public Works and Water Management (fully coupled activities in the sphere of research, advice, concrete measures, evaluation and a strong communication programme) has led to a spontaneous willingness for taking concrete steps and realisation of mitigation measures by all (private and governmental) organisations involved.

Although we know that the different types of fauna passages are in use by different species we are now reaching a phase to learn more about the real effectiveness of mitigation measures for the survival of species on (meta) population level. Long-term studies are essential as most of the research carried out has a time-span of less than one year till five years. That is often too short. Scott Findlay and Bourgas (1999) studied the response time of wetland biodiversity to road construction on adjacent land and found that in wetland biodiversity loss appeared decades after the intervention.
Beside there is a need for more studies during the coming years in the field of:

- The design of viaducts and ecoducts for combined human and animal use in all possible variants (walking, cycling, horse riding, car traffic).
- Adjustment between type and size of the measures and the specific functions and types of species which should use the passages.
- The most rational maintenance of the vegetation on ecoducts and other type of passages in relation to the requirements of the different species for which the passage is meant for.
- Passages with special provisions, like stump walls, lack detailed information about the optimal size and layout.
- Looking from the species angle the question arises whether the existing measures will cover all animal groups which show sensitiveness for habitat fragmentation by roads and traffic. Reptiles, certain insects and some other invertebrates groups are more susceptible to habitat fragmentation than other groups.
- More detailed knowledge is useful about the behavior of animal species using fauna-passages (daily movements, season dependent or use only for dispersion) and the future use (otter, and red deer and other mammals in areas where there are ideas or plans for re-introduction or expectation for 'spontaneous' arrival of such animals) in combination with the

minimum number of provisions per km infrastructure. Also the question is relevant what degree of impassability is acceptable or what is the degree of passibility.

Apart from the studies in relation to practical issues, more and more studies take place in the Netherlands at universities. Examples of these studies are: effect of isolation of spiders caused by roads; optimising the network of provincial and municipal roads in the light of ecology, nature and environment; habitat fragmentation and effect of roads on the spreading of plants; effect of fragmentation on the grass snake; degree of connectivity of roadsides and nature-friendly banks for different organisms. Looking at all these initiatives and activities a full integrated research plan should be useful in combination with the plans to be developed when the European COST 341 programma comes to an end.

A broader approach could be chosen in the future in the form of a more integrated ecosystem approach in order to maintain and upgrade the natural values and functions of roadsides and the surroundings and improving the permeability of roads and motorways.

Also cost-benefit analysis are becoming more and more important. The knowledge about the cost-effectiveness of mitigating measures for animal species and ecosystem functioning in relation to integration of sound-barriers, measures against the pollution of air and soil as well as development of ecological, psychological, social and art values in roadsides and surroundings will become relevant (Van Bohemen, 2002).

10. Synthesis: Defragmentation strategies.

In 1990, an evaluation study of the effects of the existing motorways on nature and the possibilities for defragmentation of nature was conducted (Van der Fluit et al., 1990). Some years later it was examined whether the defragmentation measures at the network of motorways and at that of the railroads contributed to the realization of the Dutch Ecological Main Instrastructure (EHS) (Ministry of Agriculture, Nature and Fisheries, 1999). The main conclusions were:

- The current implementation of measures intended to realize the EHS has not yet produced a coherent and sturdy system.
- Both the knowledge and the understanding of the effects of fragmentation have considerably increased.
- There is a need for a nation-wide plan, in which choices and priorities for defragmentation are detailed and underpinned.

Based on the spatially coherent larger landscape-ecological units of nature distinguished in the Netherlands, some robust connections (corridors) have been selected, known as strategic defragmentation locations. The selection is a first impulse to make possible the mutual consultation about a more coherent policy context and as well as a coherent defragmentation programme.

Despite the construction of ecoducts, badger tunnels, ecoculverts and other provisions, there is no equal treatment in the policy processes between traffic, transportation and infrastructure and the ‘ecological accessibility’ on ecosystemlevel. This applies also and especially to provincial, regional, municipal and local situations. Various approaches to reduce the effect of fragmentation can be distinguished: limitation of the need for new or widened infrastructure, optimization of the planning process in order to reduce the degree of fragmentation, and improvement of the size and quality of the mitigating works and compensating measures. All measures must be implemented in an optimized context. After the construction of a road, clear quantitative objectives must be formulated in maintenance plans and should be monitored as well.

Five strategic actions

As reported earlier, in the planning and construction/reconstruction of infrastructure, it is important to adopt the following strategy wherever such is possible: in the first place, prevent, avoid or minimize negative effects; in the second place, implement mitigating measures; and in the third place, compensate for any damage remained. This entails the following five actions:

1. At a strategic level it must first be ascertained how the demand for transport and transportation can be satisfied via means other than the construction of a road at ground level (areal planning coordination of the functions for living, work and recreation, price policy, underground construction, public transportation and the use of waterways).
2. Given the decision in favour of a road, its optimum location must be established in a search area that is as large as possible, which give possibilities to avoid and to minimize negative effects.
3. The road must then be fully integrated (including mitigation measures) into the landscape.
4. Thereafter, the physical compensation must be realized near the new road and in such a way that the surface area and the quality of habitat patches are not negatively affected.
5. Finally, financial compensation must not be made until full physical compensation of the intervention to reach no net loss has turned out to be impossible.

Viewing not only the significance of ecoducts as a passage potential for animals but also the operation of areas as ecosystems, it might become apparent that larger ecoducts (landscape bridges) are necessary or that the road will have to be created under the ground. In order to eliminate a road's barrier effect and to protect both surface water and groundwater, roads on columns might also be an answer.

The above mentioned steps 'prevention, avoidance, minimizing, mitigation and then compensation' can be adapted based on recent studies. As an example a more detailed procedure for planning and designing road infrastructure is given below, based on ecosystem functions, ecosystem goods and ecosystem services (Daily, 1997) (adapted after Guterstam et al., 2002). The following steps can be distinguished:

1. *Determine the ecosystem functions and services of the area concerned.*
   Establish the processes that allow for the ecosystem functions and services.
2. *Determine the influence of the proposed intervention on the use and loss of ecosystem functions and services and processes.*
3. *Determine the possibilities for preventing negative effects.*
4. *Ascertain the alternative possibilities with less negative effects.*
5. *If it is not possible to prevent further negative effects, ascertain the possible mitigating measures.*
6. *If despite the mitigating measures it is still not possible to obtain 'no net loss', the remaining effects must be compensated for elsewhere, preferably close to the intervention concerned.*
7. *If compensation elsewhere is not possible, establish the possibilities for financial compensation.*

8. *Determine the measurable indicators for the establishment of effects and establish the success and failure factors.*
9. *Draw up a monitoring plan.*
10. *Establish in an agreement how to deal with unpredicted negative effects that may be found in the future.*
    A further step is to include nature restoration and nature development in projects in order not only to realize 'no net loss' of nature values, but also to obtain better nature values than existed before the realization of a project in the area.

Towards a system of guidelines and norms
In the last three decades, many studies have been conducted on the relationship between infrastructure and traffic on the one hand and nature on the other hand. Many bottlenecks between road infrastructure and nature areas have been eliminated. A great deal more can be accomplished by an area-specific approach to traffic and transportation problems together with planning of the ecological infrastructure on different scales. On the one hand, it is necessary to focus the approach on the local situation; on the other hand, it would be highly desirable to have unequivocal recommendations available in the form of guidelines and norms to supplement the existing environmental quality standards and environmental quality systems. In the field of emissions and immissions of air and soil polluting substances reference values and target values have become part of the environmental policy. It would be a logical step to formulate standards for the ecological aspects of roads and motorways as well. A first start towards such an approach can be found in the National Package of Sustainable Construction for the sectors Ground, Road and Waterworks (Anonymus, 1999, revised 2002). Also in the new version, the formulation of many aspects in the ecological field remains free of commitment, despite the fact that the Ministry of Transport, Public Works and Water Management has the intention to carry out the so-called 'permanent' measures before 2003 and the 'variable' measures before 2010. 'Permanent' measures' have undisputed advantages for the environment, can be generally applied and do not or hardly lead to added costs; 'variable' measures also have undisputed environmental advantages, but they will create higher costs.

In the 'Handboek Robuuste Verbindingen' (Handbook of Robust Connections) (Alterra, 2001) a survey is given about the maximum distance between fauna passages for different species, ranging from 125 m till > 1250 m. For frogs a maximum of 500 m have been advised and for badger, red deer and otter > 1250 m.

As an example for laying down a standard for mitigation and compensation it is possible on the basis of the available knowledge about the valuable conservation areas (National Parks, Areas under the European Habitat and Bird Directive) to decide that per 10.000 ha habitat area which has been separated x ecoducts should be built, or x faunatunnels per km fragmented ecological main structure or x ha compensation area per km near motorways (Cuperus, 2003). These facts can be very useful in cost/benefit analysis in which nature is still mostly a p.m. item in the financial balance sheets.

In a study about the Veluwe the following guidelines were given (Anonymous, 1994):
- small fauna-pipes: 1/km in conservation areas; otherwise 1/5 km.
- amphibiantunnels: 1/km in areas rich of amphibians; otherwise 1/5 km.
- roedeer passage: 1/5-10 km.
- badgerpipe: for local movement: 1/250-500 m; for long range movements/

migration: 1/1-5 km.
- ecoduct for each large conservation area.
- adaptation of viaducts: where it is technically possible and ecologically desirable.

As the reaction of species on the design and location of fauna passages (pipes, tunnels and adapted culverts as well as overpasses) is different it would be wise to implement a variety of fauna provisions in a certain location and along a longer stretch of motorway the mixture of provisions should be repeated. One should take into account differences in openness, different coverage of vegetation nearby and farther away of the entrance, the size of the animals and the potentials for future use. For successful passage a wide range of fauna passages should be made available; studies are still needed to find the most cost-effective strategy for a certain stretch of motorway to be successful on a population level (Carr et al., 2002).

11. Conclusions and recommendations

Fragmentation: an internationally recognized problem

All sorts of developments, including the formation of road networks, have made the loss and fragmentation of habitat patches for plants and animals an increasing problem for the conservation of nature. Creating nature reserves will not halt the degradation of biodiversity. All sorts of conventions and EU directives (Ramsar, Bern, the Bird and the Habitat Directive) call for attention to be paid to the importance of nature. In addition, all European countries now recognize fragmentation by roads as a problem. Studies carried out during the COST action 341 learned that even in Norway and Sweden – where the human population density is relatively low – roads and traffic take their toll. In Sweden, over 60% of otter mortalities are caused by traffic; in Norway a local subpopulation of reindeer had been isolated by road construction. In Denmark and Switzerland, fragmentation by infrastructure is a limiting factor for the hare. A study conducted by the World Wildlife Fund on large carnivores showed that the development of infrastructure is limitative for the corridor development for this animal group, unless adequate measures are taken.

Fragmentation: solutions

In various countries, studies have been conducted in order to establish where the ecological main structure leads to bottlenecks with the motorway network. Ecological techniques or ecological engineering play important roles in the conservation, restoration and development of nature values in relation to the infrastructure. For a large part of the field, the studies discussed provide a scientific underpinning, but future studies must supply data for more encompassing solutions to the usually complex problem of fragmentation and defragmentation. Defragmentation programmes are drawn up.

In addition to defragmentation measures themselves, also more and more value is being attached to their optimum incorporation into the planning process. Also the design and maintenance of road verges – not only as habitats for plants and animals, but also as corridors for certain animals – play relevant roles.

Fragmentation: evaluation of mitigating measures

Most mitigating measures have a positive effect on indivual animals. In any case, the measures taken for the Dutch system of motorways have been very important for the badger at population level as well. This rare species in the Netherlands is again gradually increasing in

number despite the increasing number of road-kills. In just fifteen years, the Dutch badger population doubled as a result of the measures taken on roads, the safeguarding of setts and badger routes, and the re-colonisation by young orphaned badgers, which have been accommodated in a centre.
Also at provincial, municipal and local levels more attention is being paid to mitigating and compensating measures. The knowledge that is now available could however be used even more effectively if more coherence was created between the national, provincial and municipal networks of dry and wet infrastructures and ecological networks at various scales.

Fragmentation and defragmentation: included in the policy cycle
After the exploration of a problem area and its recognition, the complete inclusion of the policy field into the general policy cycle is necessary for it to play a permanent role in the policy processes. The problem would then receive lasting attention – which has appeared in principle to be very effective based on the study of the implementation of defragmentation in the Netherlands over the last three decades. The policy cycle comprises the following stages: policy memorandums and plans, realization programmes, management and maintenance programmes, monitoring programmes and the continual adaptation and adjustment of memoranda, plans and programmes based on new knowledge, new insights and practical experiences. In this context it must be said that maintenance of fauna passages is not always optimal and when cutting of budgets have to take place fauna passages as a topic often stay behind. Continuous attention is still needed.

Recommendations
It remains necessary to stimulate the application of the existing knowledge in order to continue a 'no net loss' policy for nature. In addition, studies remain necessary in some subfields. The following are somewhat striking recommendations based on the foregoing:

- Make widely available a summary of all possible measures related to concrete situations: an up-to-date toolbox for designers is essential.
  (See for instance: www.wildlifecrossings.info as the IENE website www.iene.info, which gives a wildlife crossing toolkit.)
- Better coordination between the design, realization and future maintenance of fauna passages.
- Implement monitoring programmes to observe the use and status of maintenance of the fauna passages in such a way that sound conclusions can be drawn (studying a large number of provisions in the same period with the same method).
- Harmonize strategic, tactical and operational plans and programmes at the international, national, regional and local scales; this is essential for a more successful application of defragmentation measures.

Especially during the design phase of eco-structures and other fauna passages, it is possible to raise the effectiveness, on the condition that the following aspects are taken into account: the surroundings, dimensions (height, width, length) and form (rectangle, convex, road on columns and other forms), material (concrete, steel, wood), set-up (number of eco-structures or ecopipes per km) and form and length of fencing in relation to the function.

A further integration of civil engineering and the application of ecological engineering can play an important role in the conservation, restoration and development of ecological values along road infrastructure. Through better coordination between the planning of land use and of infrastructure, nature conservation and nature development will produce more possibilities for conserving and developing ecological values. At an early phase of road planning, important nature areas can be avoided. If this is not possible prevention, minimizing of effects and mitigation and compensation can limit the damage to ecological values.

The combination of some large provisions with many smaller provisions is necessary for the sustainable survival of animal populations at various levels of scale. On the one hand, these are provisions specifically for the fauna and on the other hand provisions that allow for the co-use of for instance viaducts and bridges by fauna – not only in rural but also in suburban and urban areas. Bringing nature closer to man, can increase man's valuation of nature. This is certainly important now that it looks like man will increasingly be accommodated in urbanized areas.

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5. Essay: Landscape Integration of Motorways in The Netherlands: Past, Current and Future Developments

Hein van Bohemen

This essay is the result of research into the past, current and future developments concerning landscape integration of Dutch motorways. It is based on an analysis of material that I have managed to gather on concrete designs, the results derived from these designs as well as the various connected organizational processes involved in that. This chapter analyses the information discussed in the previous chapters and introduces topics for a possible follow-up. It is not merely a further study and reflection based on the previous chapters. The objective of this chapter is also to raise research questions pertaining to possible alternatives from various scientific disciplines for integrating roads into the landscape. In order to find solutions to problems in society, there seems to be a need for a more holistic approach in addition to the reductionist approach generated by, among others, Descartes. Society represents subjectivity, chaos and uncertainty, while science represents objectivity, a selfless search for truth in which high quality standards must be met. Taking into account the increasing complexity of society, the combination of a science aimed at 'dissection' with a science aiming at synthesis might significantly contribute to environmentally and ecologically sound societal developments. In particular, the focus will be on the relation between nature, landscape, motorways, art and perception and experience.

1. Preface

Roads connect locations and form barriers. Speaking in terms of landscape, they may form autonomous elements or form the basis of a landscape. Roads may possess an actual architectural beauty, their own landscape-ecological significance or may be strongly dominated by (historic) plantations.
The integration of roads into the Dutch landscape forms part of a societal and social-economic development process. There has been a shift of focus from connecting locations per sé to taking the significance of the road and its surroundings to man, plants and animals into account as much as possible. A great variety of principles, objectives and accents is present in the design of Dutch motorways. In general, the development moves from paying attention to the surroundings to planting trees along the roads for practical considerations (such as shading, shelter, road signs, constructive reinforcement, aesthetical purposes, wood returns), then attention for, and focus on, visual-landscape, functional-aesthetic and architectonic aspects whereby the attention to landscape-ecological aspects gradually increases, and finally to the use of a more integral spatial concept for the integration of motorways and, on a number of occasions, back to a view of the road as a broad transport lane encapsulated by high noise screens.

This chapter discusses in further detail the concept of landscape in relation to design and construction of motorways. It provides an illustration of the insights that have been gathered over the years with regard to the level of integration and design concepts of Dutch road infrastructure. Case studies are used to provide insight into the development of the design principles and means.
The significance of experiencing nature and landscape from the road and art along the road

have been analysed separately. Therefore, the results of this investigation have taken the shape of a discussion on a possible theoretical framework that may bring about enhanced harmonisation between the roads and its surroundings on different levels of scale and takes into account the significance of the physical environment, biodiversity and the perception of the value of biodiversity.
Finally, some dilemmas are presented as well as opportunities for taking into account in future road integration the significance of nature and landscape for maintaining and developing optimal conditions for man, plants and animals.

2. Definition of the Problem

The objective of the study discussed in this chapter is to trace the development of the relation between Dutch motorways and the landscape on the basis of literature search, analysis of cases studies, interviews with (former) employees of the 'Verkeerswegen', the former landscape design office concerning motorways within the Dutch State Forest Service (later 'Verkeerswegen' became part of Department of Rural Areas) and site visits. In this way, conclusions may be drawn and suggestions for future endeavours may be made. If certain questions cannot be answered on the basis of current expertise and experience or any insights obtained, research questions will be formulated.

The main question can be divided into the following sub-questions:

1. How are the concepts of 'landscape' and 'landscape integration' interpreted? Has the interpretation changed in the course of time?
2. In what way has the relation between motorways and the Dutch landscape been expressed in concrete designs and implementation? Which styles may be distinguished, and can a general pattern be discerned in the use of design principles?
3. Which roles have ecology, landscape ecology and nature engineering played in the design, construction and maintenance of motorways over the years?
4. What role does the perception and/or experience of nature and landscape from the road play?
5. What role does art play in the design and realisation of motorways?
6. Can general principles be formulated with regard to the landscape integration of motorways that may contribute to solving future motorways design issues?

In order to find answers to the above questions, use has been made both of generally accessible reports, as well as grey literature (as it is known), plans containing designs of, and construction data on, motorways of the former department 'Verkeerswegen' of the State Forest Service and later part of the Department of Rural Areas, as well as reports on research and/or consultancy activities by, or commissioned by, the Road and Hydraulic Engineering Institute in the field of the relationship between motorways and traffic and the landscape, environment and nature. A number of case studies have been used. Finally, interviews were held with H.M. van de Berg, J.A.H. Huisman, J.W. de Jager, M. Loenen, A.W.J. van Schaik, J.G. de Vries, J. van Westen and N. Zuurdeeg.

3. The Concepts of 'Landscape' and 'Landscape Integration'

Landscape
There are many definitions of the concept of landscape. Landscape has already been 'sung in a variety of ways' (Zonneveld, I.S., 1979; Zonneveld, J.I.S., 1987, 1971; Lemaire, 1970, 1996; Kolen en Lemaire, 1999; Schama, 1995).

Landscape means many things to many different people. The general public will think of nature, green and open spaces or a beautiful scenery. Landscape can be defined from the point of view of various disciplines as well, among others from a geological, geo-morphological, archaeological, vegetation, ecological, landscape-ecological, cultural-historical, historical-landscape, landscape planning and art-historical perspective. The geographer Von Humboldt (1847) spoke of the 'Totalcharakter einer Erdgegend' [the total character of a region].

Troll (1950) introduced the concept of landscape ecology in order to express the coherence between soil, relief, water, climate, vegetation, fauna and man within a particular landscape unit or ecotope.
J.I.S Zonneveld (1987) defines landscape in the geographical sense as the material part of that which is located on and at the surface; this material entity is separated by its appearance and content and has a history. It involves that part of the surface of the earth that is visible to the eye and experienced by the observer as a characteristic combination.
Forman (1995) defines landscape in a landscape-ecological sense as a mosaic of habitat patches and corridors situated within a matrix.

In terms of landscape, three aspects play an important role in its perceptional value for man: appearance, ecology and history. People will mainly experience the appearance of the landscape, but may also experience it through the ecology and history of the landscape, or to put it more poetically, 'in whispers from the past' (De Soet, 1974). In this connection, it becomes apparent that not only the measurable reality (objective) plays a role, but also the observer's perception and experience and frame of mind (subjective). In this connection, several different movements may be recognized within society: the naturalistic approach which has led the human environment to be dominated by geographic and ecological determinism, and, as a counter-reaction, the later culturalism (landscapes as cultural works). Rather than promoting dualism, Lemaire en Kolen (1999) suggest approaching landscape as a cross-pervasion of nature and culture.

Landscape is also defined as the location or area where landscape 'occurs'. Norberg-Schultz (1980) distinguishes between the 'natural place' and 'cultural place'. The 'natural place' concerns man's adaptation to the natural substrate. The 'cultural place' involves the social and emotional bond between people and their surroundings. According to others, there are also 'vacant' locations (Auge, 1992). This term is used, for example, by Ten Hooven (1999) and Vroom (2000) for describing the constructed bird reservation Starrevaart near the A4 motorway between Amsterdam and The Hague.

In this study, landscape is defined as a specific part of the earth's surface visible to the human eye. It consists of a dynamic system of interrelated functional-spatial and visual-spatial aspects as interpreted by man. In this sense, the landscape is the result of abiotic, biotic and anthropogeneous patterns and processes, to which man attributes significance (Teer and Hoeffnagel, 1980). At the same time, landscape is the product of nature (climate, soil, plants and animals) as well as man (through his influence on, and mental perception of, the landscape) (Lörzing, 2001).

Landscapes change continuously. As a result of human influence, most natural landscapes have become culturally determined landscapes. Gradually, or sometimes abruptly, the past becomes visual in the present-day landscape. Some historically grown landscapes start to resemble each other as a result of a homogenisation process setting in that reduces differences (Jongman, 2002). Landscape may also develop into urban landscapes or landscapes aimed at particular functions; this is increasingly noticeable in the current motorway landscapes. More and more, these motorway landscapes are considered 'passage' landscapes. They are intended for quick passage and any connection to a particular location is deemed inessential or even undesirable; they are so-called car landscapes (Ibelings, 1999). However, the ecological aspect of motorways is recognised and acknowledged. This concerns the ecological significance of the roadside vegetation and the promotion of connections through fauna provisions such as ecoducts and fauna tunnels. Others call attention to the motorway in its function of human 'abode' (Houben, 2003). Houben regards the car as 'a room with a view'. The interpretation of the surroundings as a panorama plays a significant role in this respect.

Concepts such as urbanscapes, artscapes and waterscapes are evidence of new accents in landscape design. What is involved is a dialogue with the surrounding landscape (Galofaro, 2003). The term 'earthscape' is used as well. This is a landscape that is no longer connected with the land and its natural components, but rather spans the whole planet, without any distinction between nature and the built-up area (Galofaro, 2003).

A great variety of Dutch landscapes may be distinguished. There are many landscape typologies available. A division that gained prominence around 1990 is based on geomorphological, hydrological and soil characteristics and distinguishes between nine Dutch physical-geographical regions (Anonymous, 1990; Gonggrijp, 1989): hills, higher sandy plains, river areas, fenland, sea-clay land, sand dunes, closed sea inlets, tidal areas and the North Sea, each of which can be subdivided yet further. In terms of natural management, the following entities are distinguished on the basis of the intensity of human influence: natural units, nearly natural units, man-guided natural units, semi-natural units, cultural units (crops) and multifunctional units. Also divisions are available that are based on historical-landscape and cultural-historical characteristics.
Barends *et al.* (1986) distinguishes in the Netherland between eleven main regions (Figure 1).
In the past decades, much of the diversity within and among various landscape types has disappeared; natural aspects have deteriorated as a result of the technological possibilities making the relationship between the natural environment and human activity increasingly less compulsive. However, there are many areas and sites still present along the Dutch motorways which are valuable from an landscape ecological, ecological and visual landscape point of view and currently have (potential) ecological and landscape ecological values.

Road Infrastructure and Landscape
Over time, roads have grown into finely meshed networks. Together with waterways and dykes, roads form an important basis for opening up of many of our Dutch landscapes. Natural waters and roads, canals and ditches have become intricately intertwined with our landscape. The 'Atlas Interfererende Netwerken' [Atlas of Intervening Networks] (Van Buuren, 2001) gives an overview of the historical development of road and rail infrastructure and water networks the beginning of our era. Table 1 presents the

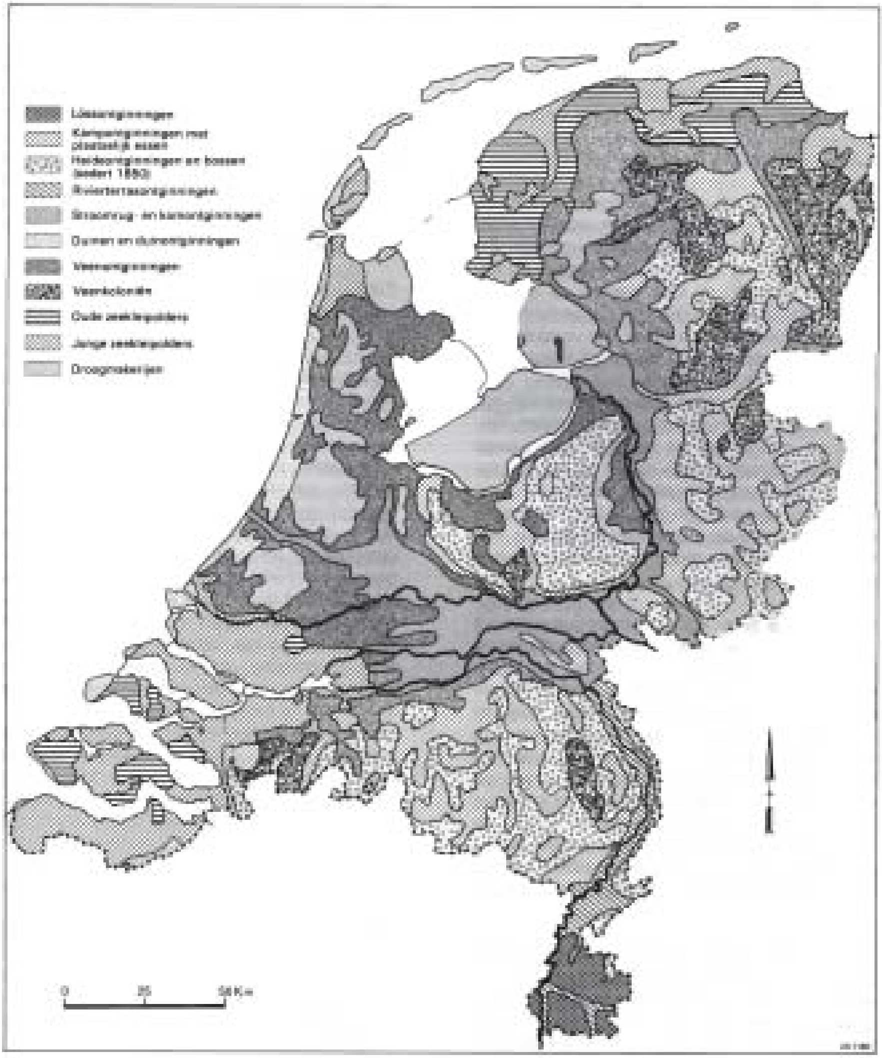


Figure 1. Cultural Landscapes in the Netherlands (Barends et al., 1986).

1940	87 km
1950	121 km
1955	207 km
1960	351 km
1965	583 km
1970	983 km
1975	1,529 km
1980	1,770 km
1985	1,907 km
1990	2,084 km
1995	2,198 km
2000	2,260 km

Table 1. Development of the Dutch motorway network from 1940 in kilometres (CBS).

development of the Dutch motorway network from 1940 until the present day in kilometres. Since the first half of the 20th century, in particular between 1950 and now, the urban network has quickly spread across the open space. After 1965, as a result of the increase of traffic, quick expansion took place of a coarsely meshed motorway network that was, as it were, superimposed on the old connection pattern (Vroom, 1988). Between 1965 and 1975 the national road network grew with almost 1000 km. In this connection social-cultural factors played an important role: growth and migration of the population, reduction of the size of families, living requirements and lifestyles. From an economical point of view, the increase in welfare and technological innovations and their applications also play an important role.
The so-called upperlying and underlying road network have different mesh widths. Apart from the occupation of space, a cross-cutting of parcelling and parcel patterns is currently taking place, which is a negative development from a historical-landscape point of view. Important relationships for man and nature are severed, and there is an increasing measure of disruption (noise, light, vibrations, visual impediments) and pollution of air, soil and water. In order to reduce the negative impact of these factors, 'softening' or mitigating measures are taken. Examples of mitigating measures are the installation of acoustic baffles and fauna passages such as fauna tunnels and ecoducts. These affect the landscape to a greater or lesser extent.

Valuation of the built environment, including the road infrastructure, is culturally determined and appears to change strongly over time. However, a number of more or less constant factors may be distinguished: spatial orientation, legibility, recognizability and the identity of objects (Vroom, 1988).

Motives and starting points for the construction of motorways will play an important role in the following discussion of the 'integration' of roads into the Dutch landscape. Primarely are the origin and objective of the vehicle movements, housing plans, land division and construction of industrial and business sites. In the planning, design and construction of roads, a following sector planning policy is often involved. Also, on a number of occasions a (sometimes unconscious) steering governing policy may be discerned; the construction of motorways causes additional, unforeseen developments. Examples are business sites that often take the shape of 'prime locations'. During recent years, prime locations have sprung up at many exits and junctions of motorways.

Integrating Motorways into the Landscape
In addition to the technical design of motorways, such as the roadbed, the foundation and surfacing of the road and road furniture, attention is being paid to the way in which the road is integrated into the landscape. Landscape integration is generally understood to mean the method of routing, the fitting and

blending of roads within the landscape. Until recently, the guiding principles pertaining to technical and landscape integration were derived from the Richtlijnen voor het Ontwerpen van Autosnelwegen [Guidelines for the Design of Motorways] (Anonymous, 1992a and 1992b). Its landscape section illustrates how (the coherence of) existing qualities may be taken into account and how new landscape qualities may be added.

Various approaches are involved in landscape integration: functional, landscape-ecological and visual-spatial approaches. The final design must solve the traffic and transport demands and the negative impacts of the use of these roads. With regard to nature and landscape, the objective is to prevent, to avoid, to reduce, to mitigate and/or compensate negative effects on vulnerable natural values and visual-landscape, archaeological and historic-landscape objects and structures. The road is made more attractive to car drivers, and occasionally extra facilities are provided in order to make the road more acceptable to people living in the neighbourhood. Design reflects the various aspects of the landscape (that are to be harmonised). The road may also be considered an element independent of the landscape, either added as a new element or subjected to the existing landscape set-up. Solutions to design issues are based on the various types of landscape that the road runs through. (Anonymous, 1992a and 1992b).

In the period from 1950 to 1980, the views of members of the department of landscape architecture of the Wageningen University played a major role in the design of motorways. Many road landcape designers had received their basic training there. The 'Wageningse School' [Wageningen school] played a dominant role (initially under the supervision of professor J.T.P Bijhouwer and later of professor M.Vroom), on the one hand, through the method of landscape analysis in which soil, groundwater and vegetation were placed in a vertical set-up, and on the other hand, the approach according to which the landscape consisted of soil, flora, fauna and man, who through his actions, exerted a strong influence on the landscape (Roncken, 2003).
In De Visser (1997), as the result of a study on man's contribution to the development of the landscape in terms of land consolidation, an overview is given of the development of, and discussions on, landscape construction and landscape management concepts. The visual relation was central to landscape management, in consideration to the changes which living material goes through in the course of time; a kind of spatial time and time art is concerned. An active policy was involved in the construction of landscapes, as well as a creative approach with regard to equipping the space with vegetation, forest strips, parks and ponds (Anonymous, 1963).

Furthermore, from approximately 1970, landscape integration put more focus on existing ecological values or the ecological potential. In this connection, the accent lay on spontaneous development, or a type of natural development in which man eventually determined the end result through design, construction and management measures by using nature engineering techniques.
After 1990, in particular, the landscape integration of motorways involved the mitigation of the negative impact of roads and traffic on nature through the construction of fauna provisions such as ecoducts and fauna tunnels. In the case of existing roads, these often take the shape of additions. In the past, there was never any question of an integral, balanced design in the construction phase. At present, fauna provisions form an integral part in the construction of motorways, although it

	Culture-oriented (man-made)	Nature-oriented (nature)
Shapes and materials foreign to the area (foreign)	Post-war professionalism (rational design)	(Neo)Romantic (idyllic design)
Shapes and materials native to the area (native)	Landscape approach (traditional design)	Nature-oriented approach (ecological design)

Table 2. Four Design Approaches (based on Lörzing)

might be argued whether these provisions are sufficient in size and number.

Instead of the tripartite division other approaches may be thought of in terms of the integration of roads into the landscape. Lörzing (2001) distinguishes between four types of influence on the landscape: 100 % influenced by human culture till 100 % natural, 100 % original till 100 % alien influence. Four design approaches are placed in a matrix (Table 2). The approach chosen for interventions in the landscape, e.g. the construction of motorways, depends on rational and emotional considerations, culturally determined norms and assumptions that may change over time. Around 1970, in particular, a more nature-oriented approach to motorways evolves in which the ecological significance of the landscape is taken into account.

Vroom (1988) mentions a number of possible objectives for the integration of motorways:

- Minimising the perception and visibility of the road of people living in the neighbourhood;
- Minimising the damage resulting from cutting through agricultural plots or business sites;
- Minimising the negative impact on ecological relationships;
- Avoiding 'obstacles' of various types and sizes that are considered valuable (cultural-historic and archaeological objects);
- Leaving intact visibly connected patterns within the landscape and lineal elements.
- Improving or enhancing the spatial structure of the landscape;
- Experiencing the landscape from the road: spatial orientation based on the question of: Where am I?;
- Taking into account regional and land use plans, avoiding obstacles that may frustrate future developments;
- Designing a barrier against expanding urbanisation, for example a ring road.

Vroom (1988) grouped these objectives into three types of approaches to road design. Integration means consciously taking the surroundings of the road into account, both in terms of routing and design (Vroom, 1988):

- Integration is *blending* ('wegwerken'): roads should be seen, heard and felt as little as possible.
- Integration is *inserting* ('invoegen'): adding onto existing and possible future landscape characteristics.
- Integration on the regional level: making the road *autonomous* on a local level ('verzelfstandigen').

Van den Toorn (1991) distinguishes between three types of integration that correspond with a particular time period:

- *The road within the landscape* in the pre-World War II period.

Integration with the objective of reducing intervention in the landscape by planting trees in order to shield, display or reinforce the road in the landscape (e.g. a section of the old national road from Utrecht to Arnhem).

- *The shape of the road* in the post-World War II period to far into the 1960s.
  The main focus was on aesthetics and safety improvement of the increasingly busy roads by means of the design. In this connection, the expected speed of cars determined the motorway design. Plantation was added mainly in order to highlight road curves (e.g. the A16 from Rotterdam to Breda and the A4 between The Hague and Amsterdam).
  The road was designed as an autonomous element. Plantation mainly had a functional purpose and the aesthetics were aimed at the road proper, in particular its functionalism. One might ask whether this may be considered a separate category – in the course of time there was a gradual development towards 'the road as a landscape'; no clear-cut point in time can be distinguished.
- *The road as a more or less isolated landscape*
  As a result of the increasing occupancy of space (Figure 2), the increasing differences between motorways and their surroundings as well as the change in social-societal significance of traffic and transport, the autonomy of the motorway received more focus (e.g. the A27 between Stichtse brug and Vianen and the A58 between Bergen op Zoom and Vlissingen). This approach was in vogue in particular from the beginning of the seventies to the eighties.

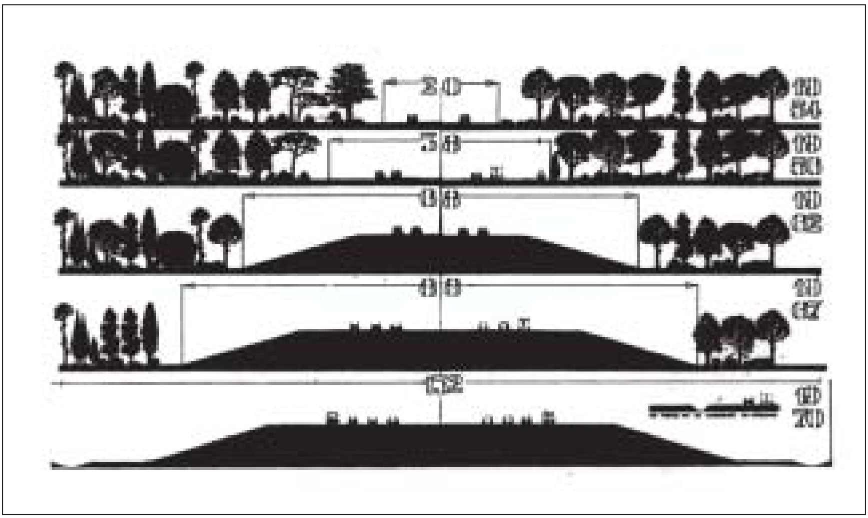


Figure 2.The expansion of the design profile of the RW 27 through Amelisweerd between 1954 and 1970. Eventually, the road through Amelisweerd was sunk into the landscape.

In their study of the way motorways are experienced by drivers and people living in the neighbourhood, Schöne and Coeterier (1997), distinguish between the following three types of relationships of the road with its environment:

- Super-ordinate ('bovengeschikt'; 'verande-ren'): the road dominates the landscape.
- Coordinate ('nevengeschikt'; 'aanpassen'): the road and environment form a whole in which they have a similar role and significance.
- Subordinate ('ondergeschikt'; 'inpassen'): the road is fully blended into the landscape.

Following developments in Germany and the United States, in the mid 1930s, landscape characteristics were taken into account in the construction of the Dutch motorway network. The emphasis lay on the aesthetics of the road. In the course of the 1970s, the idea of a more autonomous road began to take root.
In the course of the 1990s, landscape-ecological, nature and environmental engineering aspects were given additional focus, albeit somewhat hesitantly. The discussion between the Directorate-General for Public Works and Water Management and the motorway landscape design department of the State Forest Service concerning the visual-spatial and ecological significance of, e.g. the design instrument of 'tree meadows' (Anonymous, 1989) and the earlier preference for, and domination of, visual-spatial aspects in favour of the ecological approach may serve as an example.

At the end of the 20th century and the beginning of the 21st century, a discussion evolved on the necessity of gaining more control over the design of new developments within the landscape; the focus was on road architecture (Anonymous, 2000). At the same time, in a number of situations, motorways were constructed and modified seemingly lacking a broadly supported integral view; it looks they are based on a sectoral approach. In quick succession, large, locally clustered bands of infrastructure were realised that have no contact with the surroundings. There are more and more modification to the motorway system: new ramps, the addition of lighting, local expansion of the motorways, the implementation of acoustic baffles and modifications, and additions to the road furniture such as concrete barriers in the median strip, GSM masts and road portals. As a counter-reaction, there is now an increasing call for adapting motorway integration to the dynamic character of the motorway (Anonymous, 2000). The time is ripe for increased attention to the multiple use of space and its consequences for the integration of motorways.
If roads are considered ecosystems, there will be even more design requirements. Landscape integration involves the application of landscape-ecological as well as ecological expertise: along with technical, aesthetic and ecological aspects, the design will have to incorporate landscape-ecological aspects in order to integrate biological and ecological patterns and processes in the road design on the landscape level.

4. Development of the Landscape Integration of Dutch Motorways

The current section provides a more detailed overview of the development of the landscape integration of Dutch motorways, from the "planting and cutting down of trees" to "integral plans and the design of motorways" (Anonymous, 1964; Anonymous, 1991; Anonymous, 1997; Bleijs, 1971; De Jager, 1992; Harsema, 1991; Hoogerkamp and

Period	Road-building organisation and planning at the national level in the Netherlands with regard to motorway design and construction	Characteristics of the integration of motorways in the Netherlands
Roman Age	Through roads with surfacing (layers of stone and/or crushed stones); after the fall of the Roman Empire, the roads disintegrated and all expertise was lost.	
Middle Ages	Mainly construction of roads within village areas and local roads between settlements. Hessian roads were long distance routes (over the borders) Hanseatic roads were connecting former Hanseatic towns.	
1500 to 1700	Transport mainly by boat and barge. From 1600 road construction along barge-canals, such as Haarlemmertrekvaart (1631), Weespertrekvaart (1638), trekvaart tussen Haarlem en Leiden (1656). After 1650 more existing unpaved roads were paved.	
1700 to 1806	Paving of unpaved roads between Amsterdam and Haarlem from 1762 to 1767; between Den Bosch and Boxtel from 1741 to1806 (road between Boxtel and Stratum finished in 1818) and between The Hague and Haarlem from 1804 to 1807. (In 1775, Trésaquet provided guidelines for the construction of crushed-rock roads. This expertise reached the Netherlands later on under French rule).	
1806 to 1860	Road construction under Lodewijk Napoleon (King of Holland from 1806 to 1810) (Holland usurped by France from 1810 to 1813) and King William I (1814 to 1840). From England came the development of 'macadamisation' of main roads (development of road pavement of crushed-rock on a layer of flat stones). Crushed rock were used in the eastern and southern part of the Netherlands. In other parts the main roads of clincker paving. Around 1850 there is a network of paved roads between the provincial cities.	Addition of plantation along roads for shading and road marking during snowfall and inundations.
1860 to 1900	Little attention to road construction, mainly construction of railways.	

Period	Road-building organisation and planning at the national level in the Netherlands with regard to motorway design and construction	Characteristics of the integration of motorways in the Netherlands
After 1900	After 1900 with the arrival of the car, there is renewed interested in the construction of roads.	
1915	Appointment of a National Roads Commission to advice the minister of waterstaat.	
1916	Collaborations between the State Forest Service and the Directorate General for Public Works and Water Management.	Consultancy with regard to up-rooting, cutting and planting of trees and bushes, transfer of technical expertise and promotion of 'unity in outlook'.
1927	First National Roads Plan to improve the 2800 km national roads based on the Road Tax Act of 1926.	
1930-1940	The concept of a road with separate carriageways finds acceptance. Around 1936 the motorway is accepted as a new category of main connections Revisions of the National Roads Plan in 1932 and 1938. From around 1935 to the present day influence of vegetation science	Key considerations for integration are efficiency, safety, speed and beauty. Planting of indigenous plant material that is directly adapted according to the locally present abiotic conditions.
1945 to 1960	1958: Revision of the National Roads Plan.	Traffic safety and efficiency become important design criteria. Adaptation of landscape management to technology. Monumental plantings. Between 1950-1960 verge management=lawn management.
1960-1970	After 1960 the intensity of traffic increases and the road network expands. 1966 Structure scheme for motorways.	In integration a shift occurs towards a spatial, expressive approach.There is no input from ecology: verge management is still lawn management.
After 1970	More interest in nature conservation, partly influenced by the European Nature Conservation Year N70.	Introduction of ecological verge management. Development of fauna provisions.
1970 to 1979		Discussion on various design approaches (e.g. on the A6 between Almere and Lelystad). In 1971 decision to shift A27 trace near Amelisweerd to spare a greater part of an ecologically important (former river) forest.

Period	Road-building organisation and planning at the national level in the Netherlands with regard to motorway design and construction	Characteristics of the integration of motorways in the Netherlands
1972		The road section of the A1 near Rijssen is modified in order to accommodate for a juniper thicket of mycological interest
1975		Again conflict about the motorway A27 through Amelisweerd.
1977	1e Structuurschema Verkeer en Vervoer (First Structure Scheme Traffic and Transport or SVV-I).	
After 1980		The road as an autonomous element, including construction areas on the basis of nature engineering and the use of objects of art. Construction of acoustic baffles.
1982	National Roads Plan.	
1982		After a bitter dispute a deeper most west situated trace has been chosen for the motorway A27 through Amelisweerd.
1987	Decree Milieu-effectrapportage (Environmental Impact Assessment Decree) Agreement between the Directorate-General for Public Works and Water Management and the Rijksdienst voor Oudheidkundig Bodemonderzoek [State Service for Archaeological Investigations]	As a result of influence from the environmental sector, alternative road sections are considered. The attention towards archaeology led to inventory, valuation, and monitoring of archeologically significant objects, as well as management measures.
1988		Completion of the first two Dutch ecoducts.
1990	Second Structure Scheme Traffic and Transport (SVV-II).	Accessibility, traffic safety and the environment are considered of equal importance. De-fragmentation becomes a current topic. Compensation is accepted as a policy theme.
1992	Malta Treaty for the protection of the European archaeological heritage (in 1998 there is an act sanctioning its implementation; this act is to be included in the revised Monuments and Historic Buildings Act)	Integration of archeologically significant objects in spatial planning becomes a legal possibility. A manual on integration into infrastructure planning is scheduled for publication in 2004.

Period	**Road-building organisation and planning at the national level in the Netherlands with regard to motorway design and construction**	**Characteristics of the integration of motorways in the Netherlands**
1995	Manual published about mitigation measures with regard to fauna.	Overview of expertise and experiences in the field of fauna underpasses (tunnels; pipes) and overpasses (ecoducts) that reduce the fragmentation of nature by roads and waterways.
1996	Referentiebeeldenboek autosnelwegen [Reference images book for motorways].	The booklet gives an overview of the landscape-integration possibilities under various circumstances.
1997	Leidraad en checklist landschappelijke inpassing hoofdwegen [Guidelines and checklist landscape for integrating motorways into the landscape].	Overview of aspects that are to be collected and evaluated in each planning phase for the landscape integration of motorways.
1999	Nota Belvédère [Belvédère memorandum]	Promotes the consideration of cultural-historic values.
2000	Architectuurbeleid 2001-2004; Ontwerpen aan Nederland [Architectural Policy 2001-2004; Designing the Netherlands]	One of the special projects: Development of a route design for the motorway A12 between The Hague and the German border.
2000-2004	Nationaal Verkeer en Vervoer Plan (National Traffic and Transport Plan or NVVP) rejected by parliament; Nota Mobiliteit [Mobility Memorandum] - under construction.	Continuing discussion on the significance of the road and its surroundings: broad range of opinions.
	Urgengy Act ('Spoedwet' to improve the speed of motorway upgrate processes	The landscape and landscape integration may suffer from roads with limited cross sections.
	European and Dutch Nature Conservation law (among others. Vogelrichtlijn [EU Directive on the conservation of wild birds], Habitat-richtlijn [EU Directive on the protection of natural and semi-natural habitats and of wild fauna and flora], Flora and Fauna Wet [Flora and Fauna Act].	Damage prevention and mitigating/ compensatory measures find full acceptance.

Table 3. Summary of the development of the landscape integration of Dutch Motorways from the Roman Age until the present day

Zonderwijk, 1977; Overdijkink, 1941; Visser, 1992). Table 3 provides a summary of this development; more details will be given below.

Detailed History
The following section describes the various developments in more detail.

Circa 1600-1806
During this period, paved roads were beginning to be constructed outside of towns, as well as planted roads on country estates and in large Dutch land-reclamation projects. Based on scientific insights, Trésaquet (1716 to 1796) invented the use of crushed rock as a pavement for road construction.

1806 to 1860
Napoleonic roads formed a network of paved roads under those that were constructed as a result of the influence of Lodewijk Napoleon (1806 to 1810) and the French usurpation of the Netherlands (1810 to 1813). Under Napoleon, decrees were issued in the usurped regions for the paving of roads. A 1805 act required land owners of adjacent lots to plant trees along the road. This landscape integration was of a functional nature: providing shelter, shading, marking, guidance, beauty and economic yield in the shape of fruits and wood (De Jager, 1992). Because Napoleonic rule was short-lived, only the roads between Antwerp and Breda, Utrecht and Amsterdam and Breskens and Sluis may be considered truly Napoleonic. After the reign of Lodewijk Napoleon, King William I (1813 to 1840) continued constructing and/or paving the remaining "Napoleonic roads", primarily to promote trade (Zuurdeeg, 1980). In 1840, trees were planted along all existing national roads. The national road network was expanded until approximately 1860, and the main roads constructed between 1806 and 1860 were then referred to as 'old government roads' (De Jager, 1992). Around 1850 virtually all roads between the provincial capitals were paved (Van Tol, 1987). Many of these roads, including many roads of lower order, were provided with rows of planted trees.

1860 to 1900
Between 1860 and 1900, the emphasis lies on the development of railways. In 1839 the first railway between Amsterdam and Haarlem was opened. In 1860 a law made it possible to construct a national railway network. The roads received little maintenance. Some roads were even narrowed (Zuurdeeg, 1980).

Around 1900
Due to the rising popularity of the car, there was renewed attention for the development of (national) roads. The technique of planting trees along roads formed the primary focus of integration in the landscape.

1915
Formation of a National Roads Committee.

1916
In 1916, at the request of the Minister of Waterstaat (Lely, 1915) a collaboration agreement is signed between the Ministry of Agriculture on behalf of the State Forest Service and The Directorate General for Public Works and Water Management focusing, in particular, on the uprooting, cutting and planting of trees and bushes, the selection of tree species, planting methods and maintenance. 'Unity in outlook' was a pivotal consideration. This entailed a formalisation of existing consultancy practices with regard to the cutting and planting of trees and bushes as well as a continuation of (the tradition of) tree planting.

Beginning of the 1920s
This era marked the beginning of a more planned form of integration of main roads.

1927
The first National Roads Plan was published in 1927. Influenced by the Road Tax Act of 1926; its main consideration is the significance of connections for through traffic between major Dutch cities. According the Road Tax Act, the state and provinces were to draw up road plans. There were both a National Roads Plan for 'primary roads' (with a length of 3,000 km) and provincial road plans for 'secondary roads' (with a length of 4,000 km). Municipalities and water boards became responsible for 'tertiary roads'. A Road Fund was set up on the basis of the Road Tax Act for the construction, maintenance and improvement of national roads. Provinces could also apply for the Road Fund.

1929
G.A. Overdijkink, was employed by the State Forest Service as a deputy forester to advise on planting along national roads and state-owned canals. In addition to giving advice on planting, more attention was paid to the layout of the road. Overdijkink was also involved in the 'De weg in het landschap' ['The Road within the Landscape'] committee of the national heritage protection society, the Bond Heemschut [Heemschut League].

1930 to 1940
From the beginning of the 1930s, a type of landscape integration evolved in which the esthetics of roads was given the central focus in addition to efficiency and safety considerations. In Germany, during the 1930s, attention arose for the beauty of the road, along with visual aspects of traffic safety. With German motorways, the emphasis lay on striving for a harmonic relation of the road with its surroundings. Similar to the parkway approach in the United States, during the first generation of German motorways, the road was regarded as an architectural artwork that formed a single entity that fully considered the topography of the landscape. Straight stretches of road were alternated with road sections meandering through the landscape. Landscape-aesthetical qualities were promoted. National-Socialism played a key role in the construction and design of German roads. These were considered a binding element of the German empire. The principles of 19th-century German park construction were applied to roads. This was regarded as a progression from the 18th-century English Romantic gardening art. In the meantime, the first Italian motorway was constructed, running from Milan to the upper Italian lakes. The concept of motorways had been under development in Germany since 1924; 1926 and 1927 saw the completion of concrete designs for motorways (Schütz and Gruben, 1996). In 1933, Hitler commissioned the construction of a German motorway network. The most important integration principles were on the one hand 'der Wald' [the forest], a Proto-Germanic symbol. Derived from a quote by Alwin Seifert, who has had a huge influence on the design of German motorways: "Eine Strasse aber muss Bäume haben, wenn sie eine deutsche Strasse sein soll" ["a road must have trees if it is to be a German road"] and on the other hand the "natural aesthetic" that found expression in meandering roads that were connected with the concept of "wandern" [wandering]. This concept found continuation in "Autowandern" [car wandering] (Schütz en Gruben, 1996).
In the United States, the parkways formed long, small parks with large recesses between the plantations so that drivers might enjoy the beauty of the landscape while driving.
In this period there is increased attention for the integration of the road into the landscape, as well as aspects like wood production and traffic guidance. The road is considered more than just a carriageway; the plantation forms a connection between the road as a product of

civil engineering and the landscape that the road runs through.

1932
First revision of the Dutch National Roads Plan.

1933 to 1934
The concept of the motorway finds acceptance with the Dutch Minister of the Ministry of Transport, Public Works and Water Management: roads with separate carriageways, fixed bridges and few junctions with other types of roads.
In 1933, the Heemschut League appointed a permanent committee known as 'De weg in het landschap' [The Road Within the Landscape]. In 1920, there had already been a report called 'De schoonheid in het bijzonder 't natuurschoon in verband met beloop, beplanting en kunstwerken van en aan den weg' [Beauty, in particular the natural beauty of the course of, and plantation and civil-engineering works along roads] of Wegerif, an architect from the Hague. However, the 1920 Nederlandse Wegencongres [Dutch road congress] failed to take notice (Van Winden, 1991). In these days the time was now ripe for more interest for esthetics.

1935
In 1935 the 'De weg in het landschap' brochure by The Road Within the Landscape Committee of the Heemschut League, Vereniging Het Nederlandse Wegencongres [The Dutch Road Convention Association] and the ANWB [Royal Dutch Touring Club] was published. The editor was Overdijkink. The brochure contained tips concerning the relationship between plantation and the (characteristic) landscape picture. The emphasis was on 'harmonious integration of roads into the surrounding landscape, with 'vista points' and 'avoidance of unnecessary damage to the existing natural beauty'.
Overdijkink (1935): 'The idea that the road must meet certain aesthetic criteria regarding its position within the landscape was gaining more and more ground. Gradually, the idea took root that the road, in its capacity of traffic lane, did not need to conflict with the natural beauty. The function of plantation may be described as shaping the connection between the road as a technical product and the landscape that the road runs through".

1935 to the present day
Plant sociology or vegetation science was further developed. Encouraged by Van Leeuwen and Doing (1959), the general guidelines of using indigenous plants found acceptation, the emphasis being on poplars and oaks. The starting point was to only use those tree and bush species that were traditionally found in the area concerned in relation to the existing local soil and hydrological conditions. The civil engineering character of the sand foundations was to be taken into account as well as the composition of the soil and the angle and exposure of the slopes.

1938
Revision of National Roads Plan.

1941
1941 witnessed the first edition of the 'Langs onze wegen' [Along our Roads] Heemschut League booklet written by Overdijkink. It contained a plea for a correct definition of the road section from a landscape point of view, and a cross-direction profile with 'vista points' and the avoidance of 'unnecessary damage to the existing natural beauty'. The booklet described the road within and running through the landscape as well as the road as a component of that landscape. Plantation received a great deal of attention.
The aesthetic principles of integration based on the use of plants were to become guidelines during many decades. Important design

elements and aspects included: plantation, the location of roads and plantation within the landscape, direction, width and elevation. In this connection, the starting point is that the plantation was to harmonise with the landscape that was dissected by the road.

1945 to 1960

At the State Forest Service, Benthem and De Jonge broadened the views on the use of plantation for cultural-technical works. In 1947, the Sate Forest Service created the Landschaps-verzorging [Landscape Care] department.
As a result of the increase in the number and speed of cars, traffic safety and the efficiency of motorways become important design criteria. The main emphasis lay on technical traffic requirements. In the Netherlands of the 1950s, there was increasing attention to the beauty of roads. Expertise was transferred to road designers and managers through excursions and training. In 1959, the expertise was laid down in a picture book called 'De schoonheid van de weg' [The Beauty of Roads].
Increasingly, functional aesthetics came to the fore: landscape management was adapted to technology (e.g. the design of the RW 16 between Rotterdam and Breda). In those days, the style was based on monumental plantation that followed the axis of the road, a closed road picture and planting in square-shaped and triangle-shaped groups. Examples are the motorway between Amsterdam and Utrecht and the motorway between Arnhem and Nijmegen, where three monumental rows of poplars were planted around 1950 (one row on the median strip and two on each side of the road).

Until 1950, farmers collected the mown grass from the verges. Between 1950 and 1970, lawn management dominated the state-owned verges.

1960 to 1970

In the (1950s and in particular the) 1960s the approach was based on 'faith in technology' and the quest for greater road capacity through the expansion of the Dutch motorway network. This found expression, for example, in the way the A50 between Heteren and Wolfheze was routed straight through the valley of the Heelsumse Beek and a push-moraine (the construction of the A50 was begun in 1968; the motorway was opened in 1972). A spatial-design approach, as it was called, was involved here, with no influence as yet of ecological considerations (Grob and Zuurdeeg, 1999 in Van Winden, concept - 2002). It was decided to elevate the A50 through the stream valley on piles and to add broad median strips (up to 30 m) in the area in which the road runs across the Doorwerthse Heide [Doorwerth Heath] in order to emphasize the natural characteristics of the surroundings. The two carriageways are also stepped and parallel along the contour intervals.
In 1964, Huizinga (Van Winden, concept-2002) pleaded for beautiful roads that avoid monotony and disturbance. The layout, plantation and surroundings of the road determined the look of the road. The use of indigenous trees and bushes was not only important from an ecological point of view (characteristic for the region), but also from the point of view of ensuring that the personal taste of the designer did not dominate too much the picture. Flowering verges were also considered by many to be beautiful and deserving of application.

The 1960s are characterised by a major expansion of the road network capacity. The creative layout was to support the efficiency of the motorway (Van Winden, 2002). However, there are also other examples from the 1960s where wider road sections are used, for instance the section of the A1 north of

Naarden, which has gradual slope on the west side with a gradient of 1:7. This allowed an excellent view of the fortress of Naarden. Also an ad hoc approach is visible, for instance in the Noordrand motorway near Rotterdam. This is an example of planning and implementation that was 'behind the times'; few aspects of its surroundings were taken into account during the integration of the motorway. The Noordrand was constructed between 1965 and 1973.

In the course of the 1960s, the Motorway design department of the State Forest Service shifted it focus from monumental plantation to a more 'spatial-expressive approach'. The road between Hoevelaken and Zwolle which was completed in 1964 may serve as an example: the main emphasis was on the view and integration. Use was made of a road that has broad sections with carriageways that were further apart and a wider median without a crash barrier. It was found possible to take the structure of the landscape into account in connection with the property situation; large amounts of land were available because it was owned by the state through the Dienst der Domeinen [State Property Department].

1966

In 1966, the 'Structuurschema Hoofdwegen' [Motorway Structure Scheme] was published. It unfolded a plan for the next 30 years. The map of the structure scheme divided the Netherlands in a rhombic network of motorways with a total length of 3700 km untill 2000 bringing the intention of the total network to 5300 km. In 1966, Huizinga left the State Forest Service and went on to work for the Directorate General of Public Works and Water Management.

After 1970

Around 1970, and particularly after that year, there was increased attention from within society to the environment, nature and landscape conservation. This was partly due to the European Conservation Year (N70) and changing societal circumstances (e.g. the formation of new political parties). In 1974, a public and political debate (which started already in 1968 by the Action Group Oosterschelde Open) on whether or not the Oosterschelde should be closed, resulted in 1976 the governmental decision for a moveable flood barrier. The increased attention to nature and the environment found its way into the construction of motorways in the shape of increased attention to landscape integration, environmental impact assessment and ecological verge management. In 1971, after years of debate the "dune road" proposal of 1952 between The Hague and Leiden was moved from the map as well as in 1972 the "Leidse Baan" proposal along the railway between The Hague and Leiden. Around 2000 the existing road has been adapted. Other examples are the A27 at Amelisweerd, the A50 across the Veluwe and the so-called 'paddestoelentracé' [mushroom road section] within the A1 near Borkeld. Explicit attention was given to the relationship between landscape design and management (Maas, 1971).

> Up to 1950: farmers acted as "verge managers", as they harvested the mown grass.
> 1950 to 1970: verges treated as lawns (mown 10 times a year).
> After 1970: ecological verge management (mown once or twice a year; the mowed vegetation was disposed of) (influence of Zonderwijk) (Anonymous, 1972, 1975, 1980; Zonderwijk 1971, 1973, 1974, 1978).

In designing and managing grassy verge vegetation, as a result of ecological considerations, the emphasis lay more and more on the spontaneous settlement of plants.

Mowing times were harmonised with the development cycle of plants within the verge that are interesting from a geobotanical point of view.
But the main reason for the success of ecological maintenance has been money-savings due to reduction in number of mowing turns.

People also became aware of the fauna, which resulted in the modification of verge vegetation. From a design point of view, attention was paid to the significance of grassy vegetation and integration with fauna by means of, for instance, the application of low and locally rough vegetation and gradual transitions into bushes, boscages and plantations. After 1970, as a result of regional expertise with badger tunnels, a strategy was developed that aimed at the reduction of the defragmenting impact of roads on fauna through badger tunnels and later ecoducts.

1970 to 1979
In this period there was much discussion about the philosophy of design that was selected for the A6 between Almere and Lelystad. There was a shift from a design approach that entailed a monumental 40 km long road with plantation on either side of the road in the shape of six rows of oaks towards a road design that took into account the agricultural and spatial quality of the reclaimed land (Van Winden - a concept - 2002). Experts frequently debated on the design approach that was to be used. Broad median strips are characteristic of this period. State-owned land (domain) is made available for a monumental form of integration.

In the later design of the Hattemerbroek junction, too, there was discussion between members of the monumental school of design that focused on alleys of trees and members of the ecological school of design that focused on adapting the design to local circumstances.
In the eastern part of the Netherlands, under the influence of Zuurdeeg, a staff member of Motorway Landscape Design Department of the State Forest Service, some sections of the national roads are left unplanted in order to prevent the road from dominating the small-scale landscape. The varied soil pattern and relief effectively rendered it impossible to have continuous, uniform rows of trees (Anonymous, 1991). In many instances, nature was considered of less importance.

The first examples of ecological design were the badger crossing at Hernen and the creation of habitat patches for amphibians in the shape of swampy hollows and continuously flowing slopes moving from wet to dry.

1971
A debate started about the A27 motorway that would run through the Amelisweerd, a (former river) forest that is located on a natural river embankment. This marked a societal turning point. Stoffers (1970) puts it as follows: ‘In 1970 especially, the awareness that man is ruining his proper human environment has strongly pervaded all layers of society". In 1971, the Vereniging Het Nederlandse Wegencongres [Dutch Road Convention Association] organised a convention on ‘Weg en Landschap’ [Roads and the Landscape]. It focused on the function of the road from the point of view of drivers, the shape of road, the road within the landscape and the conflicts between the motorway and the landscape and possibilities for solving these conflicts (Anonymous, 1971).

The working group Amelisweerd, after a five months of action, has been successful to convince the minister of transport to decide for a better, less harmful trace of the A27 near Amelisweerd.

On November 1971, on a study day of the Dutch Institute of Land-Use Planning and Housing, Van der Maarel (1972) presented his views on 'the road and its surroundings'. His views were based on an ecosystem approach, eight functions of well-being that nature and the landscape perform, and eleven ecological characteristics (e.g. diversity of species, rarity, naturalness and inability to be replaced). He also pointed out the significance of a wide-meshed motorway system and the protection of macro-gradients and areas that are important from an ecological or cultural-historical point of view.

1972
The road section of the A1 on the Borkeld near Rijssen was modified in order to accommodate for a juniper thicket that was interesting from a botanical and mycological point of view. This became known as the 'mushroom road section' (under the influence of Barkman, a professor of plant ecology and vegetation science). This marked the first time that local ecological values became guiding principles in the integration of a Dutch motorway. Partly, this was a reaction to worries within society over the damage to the environment that began to take root around 1970. A few years later, this concern was to result in the choice for the construction of a flood surge barrier in the Oosterschelde rather than a closed dam.

1975
Again conflict about the A27 near Amelisweerd; a motorway on a dike or to dig the motorway with long slopes or with a vertical wall, as well as discussions about the real need of the motorway. Action Amelisweerd became active.

1977
The First Structure Scheme Traffic and Transport (SVV-I] published. Instead of 3,700 kilometres, 3,000 kilometres of motorway was deemed sufficient until 2000. In this state memorandum, spatial planning and the environment in particular determine the integration. It envisages a reduction of mobility, selective car use and the stimulation of public transport.

During the 1970s, roadverge management focusing on the expansion of the floristic richness gained increasing acceptance (Hoogerkamp and Zonderwijk, 1977). Roadverge managers acknowledged that the man-managed median and roadverge strips have a character of their own that is very significant from an ecological point of view, and that it can be expanded through ecological management. In addition to increasing the width, the addition of micro-relief would create interesting habitat patches for plants, small mammals, bees, humblebees, butterflies, grasshoppers, amphibians and reptiles.

1977
The Action Amelisweerd changed into an environmental association Friends of Amelisweerd.

1982
After many years of bitter dispute, a deeper, more towards the west route for the A27 through Amelisweerd was selected. The Friends of Amelisweerd after years of legal controversy about the permit to cut trees stopped their action in 1982 when all trees were cut (Grimbergen et al., 1983). One ha of forest was maintained; the additional costs involved amounted to over 20 million guilders.

The new National Roads Plan of 1982 providing for fewer roads, as opposed to 1977.

1986
The A27 through Amelisweerd was opened; it

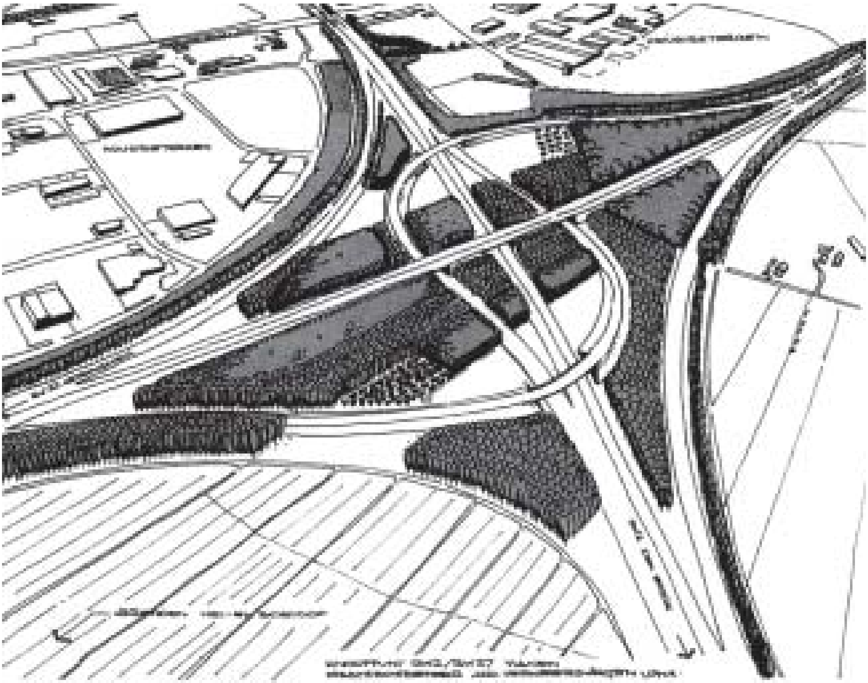


Figure 3. The layout of the Vianen junction is an example of a layout that, while being related to the surroundings, has a more autonomous monumental shape with large 'tree-meadows' with oaks, and poplars in particular, forming a 'green' portal to the Randstad (design by Nas, Elffers and Meijer).

has become a deep situated motorway with vertical walls where the motorway meets the Amelisweerd forest: 4 km motorway for 215 million guilders, the most expensive motorway in these days.

After 1980

Increasingly, the motorway was regarded as an autonomous element that included an ecological approach based on nature engineering as well as objects of art.
At Steenwijk, along the A32 on the provincial border, a low wall made up of large stones perpendicular to the motorway as a refence to the dolmens that are characteristic of this Dutch region and of archeological importance.

The autonomy of the road increased, particularly in urbanised areas. This was partly the result of the installation of acoustic baffles. At first, these were installed on an ad hoc basis, but afterwards on the basis of a specific design concept. The noise barriers along the A10 north of Amsterdam may serve as an example. However, few autonomous road sections were still present outside of the urban areas. The

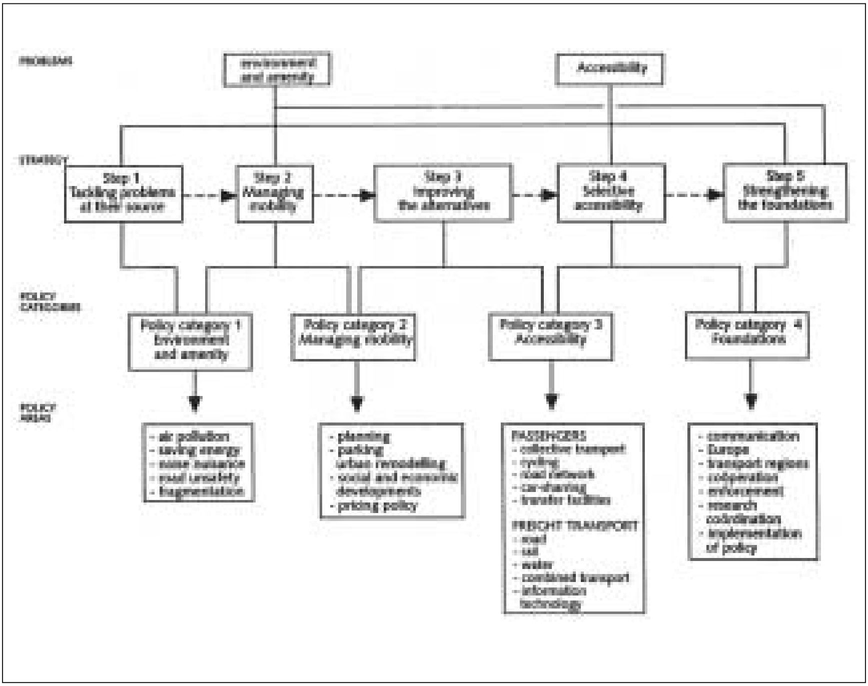


Figure 4. Issues with, and objectives of the SVV II

design by Elffers and Nas for the road between Almere and Lelystad with 6 rows of poplars was realised only on the section near Lelystad. An example of an autonomous junction in the landscape is Vianen (Figure 3).
In 1981 the Directorate General for Public Works and Water Management (Rijkswaterstaat) published the report "The Rijkswaterstaat and the care for the environment", which gave an overview of the relation between civil engineering and the environment and consequences for the policy future organisation and the need for environmental expertise within the organisation.

1987
On September 1 of 1987, the Dutch Environmental Impact Assessment (EIA) Decree came into force. It marked a point in which there was more mature focus on environmental aspects in the planning and design of, among others, motorways. Since the eia's showed that the descriptions of the effects on the landscape often considered only cultural-historic or visual-spatial aspects, the need arose for a more

holistic landscape approach. This resulted in a system made up of subsystems (which in turn consisted of a set of elements different in shape, use and origin) on various levels of scale between which there existed a more or less complex system of relationships. Gradually, a series of deliverables was developed for use during the various planning phases of road-building projects (the landscape vision, landscape sketch, landscape plan, layout plan, management and maintenance plan).

1989
The A50 between Arnhem and Apeldoorn was opened. A well considered landscape integration was selected, as well as the construction of two ecoducts. The Woeste Hoeve ecoduct was constructed between 1984 and 1988; the Terlet ecoduct between 1987 and 1988. They were intended as viaducts for deer or cerviducts for remedying the disruption of the migration routes of the red deer. This project manifested the advancing awareness of the significance of ecological routes for red deer and other terrestrial organisms (five badger tunnels also formed part of this section) and the willingness to pay for such facilities. The term cerviduct was soon changed to ecoduct, since other animal species also came to use of the provisions.

1990
The Second Structure Scheme for Traffic and Transport (SVV II) was published in 1990. It envisaged a balance between accessibility, safety and livability (quality of human life and nature). It specified various concrete objectives (Figure 4).

Evaluations, e.g. a study from 1993, testify to the difficulty of realising the SVV II approach in actual practice. Despite some successes in certain sub-areas, as a result of the quick autonomous growth of mobility, some objectives were not achieved within the planned timeframe. A certain tension remained between economic considerations and livability objectives. The 'rekeningrijden' (electronic road pricing) project that was included in the SVV II was deemed infeasible both from a societal and political point of view.

The Nature Policy Plan from 1990 also explicitly focused on the relationship between fauna and motorways. This was the first time in Dutch history that a map was published of the bottlenecks between motorways and ecologically significant areas. Defragmentation gradually became a topic of interest. Although the map was created by the Ministry of Housing, Spatial Planning and Environment, the Ministry of Agriculture, Nature and Fisheries and the Ministry of Transport, Public Works and Water Management, the time was not yet ripe for incorporating the map into the Second Structure Scheme for Traffic and Transport, even though it received serious consideration in the plan. In the Multi-year Programme for Infrastructure and Transport of 2003, for the first time, a map was published that covered the whole of the Netherlands and provided defragmentation measures as well, although in actual practise, many provisions had already been constructed by Rijkswaterstaat, for example, as a result of a resolution of parliament to accelerate realisation of badger tunnels.
The Second Structure Scheme for Traffic and Transport made it possible to repair the damage that had been done to nature by the past construction of motorways.

1990 to 2004
The design focused even more on integration. There was increased attention to landscape-ecological integration by means of mitigating measures in the shape of, among others, ecoducts, badger tunnels and the

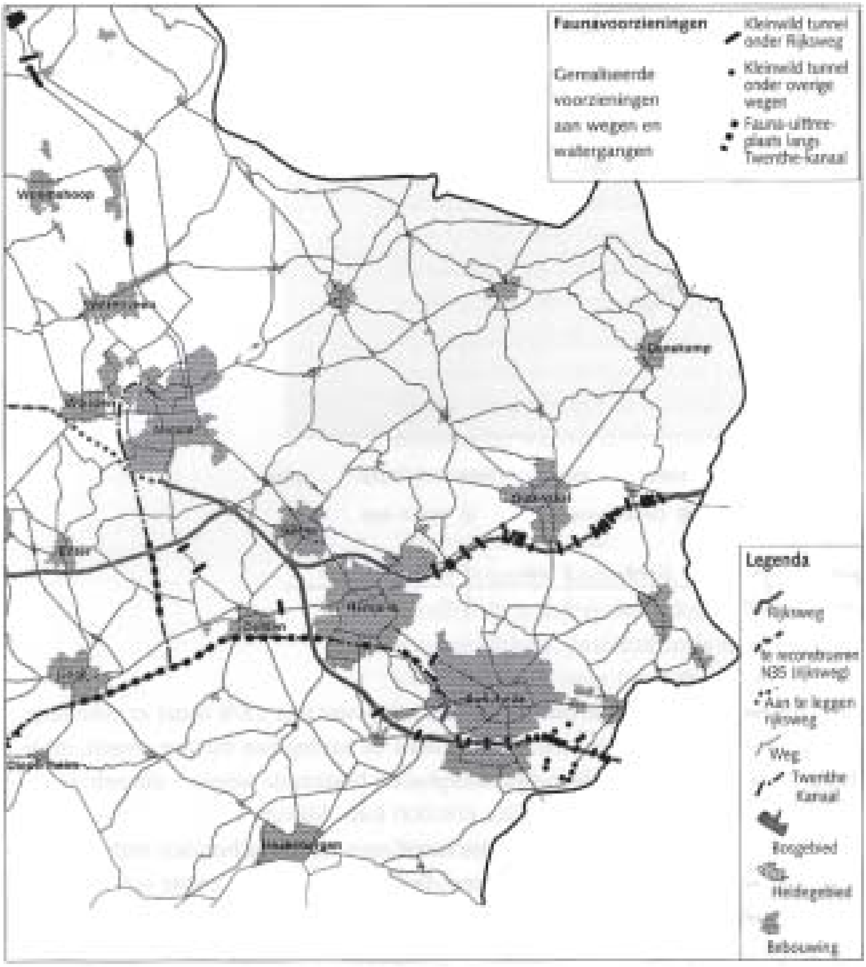


Figure 5. Overview of realized fauna provisions in the Almelo-Enschede regions (Krekels, 1996)

implementation of compensatory measures (Cuperus, 1999). Figure 5 illustrates an integral approach to the planning and implementation of fauna provisions in the Almelo-Enschede region. For the A35 in the area south-east of Enschede, measures were implemented in the form of a modified layout in accordance with the Landinrichtingswet [Land Arrangement Act].

In the then current revision of the Road Design Guidelines for Motorways (Anonymous, 1992), three considerations were focused on: economic-functional quality, ecological quality and aesthetic quality. A 'landscape' section was added. Not only was there an integral approach with regard to the design, but designers were also allowed some freedom. Terms such as 'tuning' and 'visibility' were introduced from a landscape point of view: 'The characteristics of the motorways that are (re)constructed and the ecological and visual-spatial aspects of the landscape must be harmonised and designed in such a way that the landscape is made to function as a coherent whole'.

As a result of the Malta Treaty of 1992 and the Belvédère Memorandum of 1999, more emphasis was put on the protection of archaeological and cultural-historic values. As early as 1987, an agreement was reached between The Directorate-General for Public Works and Water Management and the State Service for Archaeological Investigations on the promotion of the protection of archaeological objects during the construction of roads. In 1998, the House of Commons approved an act sanctioning the implementation of this agreement, which was to be included in a future revision of the Monuments Act of 1998. Culture history, incorporating archaeology, landscape history and historical geography, would depend on a declaration of intention between both parties. Currently a manual on the implementation of the Malta Treaty and the Belvédère in the planning and design of motorways is in the making and will be published in 2004 (Huizenga, 2003).

On January 1, 1993, on the basis of the Roads Revision Act, the responsibility for a large part of the old national roads was transferred from the Directorate-General for Public Works and Water Management to local authorities such as municipalities and provinces. In 1993, as a result of the government decree Green Space Structure Plan (Anonymous, 1993), the compensation principle came formally into force to interventions such as the construction of motorways in a number of major area categories (e.g., forests, nature conservation areas and nature development areas).
In 1994, the 'Tracéwet' [Transport Infrastructure Planning Act] was implemented (that was sharpened in 2000) as an answer to managerial issues (such as lengthy procedures) with regard to the decision-making concerning line infrastructure. Figure 6 provides an overview of the procedures of this act. The government is given more freedom to intervene in the activities of municipalities, so that the possibility arises of circumventing land-use planning. Research by Hobma (2000) shows that municipalities will mainly co-operate if they have an economical or traffic-technical interest in new motorways. Hobma's case studies show that considerations such as the damage to landscape values or the endeavours of local environmental groups are only considered when economical and traffic interests are lacking. His conclusion was that success is not determined by administrative power, but rather by an object-oriented form of planning in which the concerned municipalities are actively involved.

In 1995, partly occasioned by the international conference 'Habitat Fragmentation and

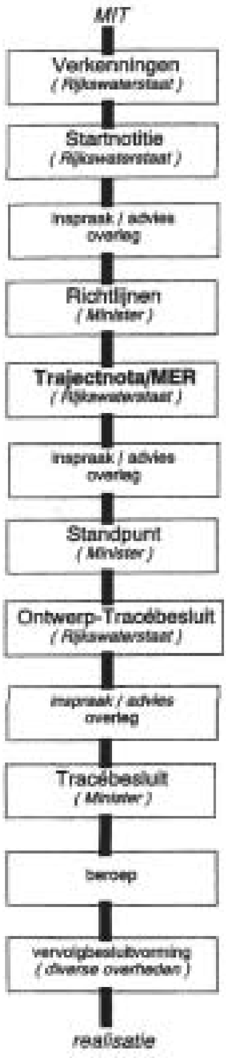


Figure 6. Procedure of the Tracéwet (Transport Infrastructure Planning Act)

Infrastructure' (Canters et al., 1997), the Handbook for fauna measures along roads and waterways was published (Oord, 1995). It provided a practical overview of expertise and experience that is available for reducing the fragmentation of nature by roads and waterways. In addition to a general ecological background to fragmentation and defragmentation, specific functional requirements are specified for each measure in order to inform designers of their freedom in adapting the design to the local situation.

In 1996, the former Motorway landscape design department published Reference Picture Book of Motorways, which was primarily meant to improve communication among those concerned with landscape design for motorways. It distinguishes between tracks (integration of road sections), junctions (layout of junctions and intersections) and layout of parking and rest areas (Anonymous, 1996).

In 1997 the Handbook and Checklist for the Landscape Integration of Motorways was published (Hermens and Van Schaik et al., 1997). It provided an overview of activities and intrinsic aspects involved in the landscape integration of motorways and was meant as a tool for drawing up programmes of requirements. It distinguishes the following planning levels: landscape vision (for the benefit of a notification of intent for an environmental impact assessment), landscape sketch (for the benefit of a planning report/ environmental impact assessment), landscape plan (for the benefit of the design of the road section decision/general plan), layout plan (for the benefit of realisation: planning development/specifications) and management plan. The planting plan forms part of the layout plan with regard to plantation.

The guidelines describe the increasingly complex process of integration: from the question of whether or not to plant rows of trees along roads to an integral design which provides for quality of road-building, culture, architecture, ecological and aesthetics qualities.

In 1997, Schöne and Coeterier published the results of an investigation into the way drivers and people living in the neighbourhood of motorways experience the landscape. It became apparent that the experiences of both groups are fundamentally different. To drivers, the road is dynamic and ephemeral; the landscape is considered scenery; the road forms a connection, it is a world in itself and provides a short-lived experience. People living in the neighbourhood, however, experience the road as static and permanent; the landscape is considered a living environment; the road is considered part of the surroundings and generally a barrier. It was found that drivers preferred as much harmony as possible between the road and the surrounding landscape. Moreover, Schöne and Coeterier (1997) noted a preference for surroundings that exude stillness and provide good visibility. There was a unanimous preference for planted 'green' noise barriers as it suggests a natural environment and a clear dislike of concrete and steel objects.

Since 1990 there has been an increasing reversal of town centres and outskirts. This has changed the ration between the number of companies, offices, showrooms and hotels within the city and those at its outskirts. More and more industrial parks are constructed, if possible on a prime location. These nestle themselves within the vicinity of highways. It may be said that highways are becoming the new axis of land occupation in the Netherlands. Motorways gain increasing autonomy within the landscape (e.g. the widening of roads and the installation of acoustic baffles). It must be said that the old national roads, as they our known, dating from the 19th century were also made autonomous by means of heavy row plantation (Visser, 1992). The determining role that motorways play in this connection may also be observed in other European countries (Neutelings, 1998). Sometimes, motorways take on the shape of corridors that form the axis of such concentration of buildings. Corridors come into being on various levels of scale: mega-corridors along international transport axes, national corridors and regional corridors. There is also an ecological type of corridor that is diametrically opposite to said corridors. In its 'Corridors in balans' [Balanced Corridors] advisory report (Anonymous, 1999), the Advisory Board of the Ministry of Housing, Spatial Planning and the Environment asks whether these unplanned corridors should be turned into planned entities. It developed six typologies for ensuring a differentiated approach to this complex and dynamic phenomenon. The four main typologies concern the interaction between the motorway and the urban environment; the other typologies focus on the relationship between the motorway and its rural surroundings. The main types of design are (Anonymous, 1999):

- The "Las Vegas" type: large, urban, dynamic, prime locations;
- The French type: high-quality, transferia;
- Ruhr-area type: a bushy strip on both sides of the traffic axis;
- Bali type: buildings are not taller than the forest.

Typologies concerning the relationship between the motorway and the rural surroundings are:

- Wide agricultural landscapes;
- Eco-viaduct landscape.

In this period, nature conservation legislation was sharpened as a result of legal harmonisation of European and Dutch nature conservation legislation (Anonymous, 2003). The protection of species as envisaged by the Flora and Fauna Act and the new Nature Conservation Act will determine the protective regime for the relevant areas. The implementation of legislation will have a major impact on the policy, implementation and management of motorways. When a significant damaging impact is expected, a habitat evaluation, as it is called, must be performed. If no damage is expected, then no deterioration of natural qualities or disruption of species should occur in the area.

Mid-term review

In the period between 1990 and 2004, both politicians and the public gradually acknowledged that motorways dissect landscapes and ecosystems and disturb hydrological relationships, that the environment is damaged by pollutants from traffic and that not only people living in the neighbourhood, but also a number of breeding-bird species suffer from the noise (Reijnen, 1995). It was also acknowledged that motorways may be considered important carriers of an autonomous architectonic beauty and can have ecological functions (Aanen et al., 1990). These aspects had already been recognised in previous decades, and solutions had been found for many problems. But this period is characterised by the acknowledgement and recognition that more integral solutions are required by many groups within society. However, the search for solutions was based on two different approaches: the motorways as an autonomous element and the road as an integral part of the landscape.
In actual practice things turned out more unmanageable. There was an increase of mobility which resulted in the deterioration of the quality of the living environment. Also, a number of targets regarding noise and air pollution (NO_x, dust particles) were not met.

Within and outside of the government there appears to be a great diversity of opinion, which is partly the result of the strong development of individualisation in the Netherlands.
For the sake of illustration, a random selection of expressions are presented that may seem random sound bites. However, they come from representatives of societal groups. These statements have been defended and, consciously or unconsciously, affected the decision-making process:

- The road as an autonomous work of art: "the beautiful grey-white and black lines flowing through the landscape".
- There are many untidy left-over areas along roads ("no man's land").
- Greenery mainly serves as decoration.
- Large mono-functional office and business parks and large-scale mass facilities spring up along the highway like unplanned snippets, as it were. Although some measure of conscious planning is involved, e.g. in the shape of prime locations, only a single interest is involved.
- *Views of the road* as an autonomy of the highway (acoustic baffles alongside the road).
- *Views from the road* have changed dramatically: in the Netherlands, parkways are virtually infeasible. However, some Dutch areas may be still be considered parkways.

In the autumn of 2002, a survey among motorists was held. It included questions about aspects of integration of motorways in the landscape (Anonymous, 2002). In general, road users are satisfied with the care for the direct surroundings of motorways. As for the surroundings, they are mainly interested in the quality of the verge. In general, motorists are satisfied with the maintenance of verges, although they are frequently frustrated by garbage or arrears of maintenance. In general, they are satisfied with the number and quality of parking and rest areas. However, an evaluation of topics of main and secondary interest showed that the quality of road is regarded most important, while the surroundings of the motorway (e.g. clean verges, beautiful scenery) are considered of lesser importance. Although motorists clearly consider the surroundings of the motorway of secondary importance, they do consider them significant. It appears that verge management, nature facilities (e.g., wildlife viaducts, verges with flowers and plants) and the integration of the motorways within the landscape are the most important aspects which make the direct surroundings of the highway more attractive.

In October 2000, the National Road and Traffic Plan was drawn up in order to replace the Second Structure Scheme Traffic and Transport. It contained assumptions such as 'it's OK to drive a car' and 'driving a car is fun'. As a result of a difference of opinion on electronic road pricing , the plan was rejected by the House of Commons. A Mobility Memorandum is in the making, and is scheduled for publication in 2004. In the National Road and Traffic Plan, the emphasis lay on mobility, although nature and environmental policy were taken into account.

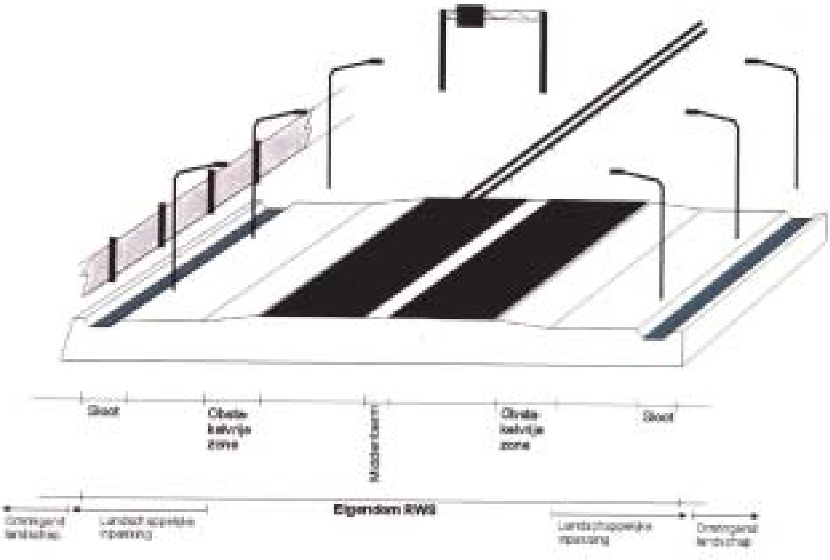
Defragmentation activities find continuation. This found expression in the drawing up of a defragmentation program that will be modified bi-annually and envisaged the implementation of concrete measures. Partly as a result of the Belvédère Memorandum and the 3rd Architectural Memorandum, Architectural policy 2001-2004 Designing the Netherlands, the attention for national roads as part of the Dutch layout is increased. The A12 from The Hague to the German border is used as a test route.

The fast development of (auto)mobility and the reaction to it in the shape of the 'Spoedwet' [Urcency Act] may have a negative impact on some aspects of landscape integration, since in some cases there is not enough space available for expanding motorways.

On the basis of a number of case studies, the following section analyses which design criteria have played a role in the layout and integration of motorways into the landscape.

5. Development and Use of Design Criteria for Landscape Integration of Motorways on the basis of a number of case studies

Originally, the layout of national roads was determined by civil-engineering requirements of road building which were aimed at solving issues regarding the composition of the soil, the groundwork, the use of road metalling materials and the location (and soil conditions) to which plantation must be added. At a later stage, traffic management came into play, and the two disciplines were to influence each other.
Since approximately (1935-)1950, aesthetic considerations have become important design aspects. The road must not only be efficient, but should also have an aesthetic value (the beauty of the road) that provides motorists with a safe and suitable road view. There should be a blending road view in which all elements are geared to one another (Huizinga, 1971). The road view strongly depends on the type of road and type of landscape. Each type has its own function and requirements with regard to the layout and is influenced by the measure of emphasis on the land and the type of landscape that the road runs through (Huizinga, 1971). The road was seen as not only forming a route between two points, but also a line or strip (the length or longitudinal section) of which all aspects (texture and colour of the paving material, road markings, crash barriers, rows of trees, plantations, forests, boscages, bushy growth, open spaces,



Legend:
sloot = ditch
obstakelvrije zone = obstaclefree zone
middenberm = median strip
omringend landschap = surrounding landscape
landschappelijke inpassing = integration in the landscape
eigendom RWS = ownership of the Directorate General of Public Works and Water Management

Figure 7. Standard cross section of a motorway (info: DWW)

buildings etc.) play a role in the integration. The layout of the cross section (Figure 7) was also considered important (width of the pavement, the number of carriageways, the width of the strips, verges and the proportions between them). Verges might continue into low or high, sloping or mounting road cross sections. They are limited by ditches, trenches or fences. The spatial design mainly focused on the horizontal surface, although the vertical aspects (roads on different levels, fly-overs, buildings) also played an important part. The extent to which curved lines and straight profile lines are used is mainly determined by traffic-safety requirements and is partly dependent on the surroundings.

The quality of the road is mainly determined by:
- the longitudal line;
- the cross section with the number of carriageways, median strip and roadside verges;

- altitude and relief;
- trees, shrubs and plantations;
- viaducts;
- acoustic baffles;
- road furniture (crash barriers, portals);
- the coherence between the aforementioned aspects.

A number of case studies have been analysed in order to present an overview of the development of landscape integration and the shifts in focus in the course of time. The emphasis of these case studies lies on the period between 1960 and 1980, when Dutch motorways and highways expanded rapidly. A number of more recent cases focus on the rapid changes to motorways and the motorway network and their expected expansion in the near future.

Case Study – the A50 Between Arnhem and Zwolle

In 1932, the A50 between Arnhem and Zwolle was incorporated in the Natural Road Programme. The road section was proposed to the west of Apeldoorn. In the 1950s, the road section was situated east of Apeldoorn. The road section was determined in 1962 and modified in 1967: a road section along the eastern side of the Veluwe, partly inside and partly outside of the wet grasslands, along open fields and fenlands. In 1977, the 30 km between Apeldoorn and Hattem were opened. Zuurdeeg (1977) describes the impact of the road section of the A50 from a design point of view, in which he shows that the original culture historical landscape pattern is preserved as much as possible.

On the basis of the landscape analysis commissioned by the Motorway landscape design department of the State Forest Service, the emphasis was on:

- the altimetry of the road axis. It should be no higher above ground level than necessary for the construction of the 'cunet' (sand body)l;
- the layout of the earthworks, e.g. verges, road sections and ditches are fitted in the spatial composition of the landscape;
- the integration of parallel roads, the cancellation of local roads, and the development of continuous roads at a certain distance from the new motorway;
- the design and placement of 'green' elements, with the objective of creating an acceptable road view and transition into the adjacent landscape; the road was given more depth and variety by means of plantations.

It was known from experience that a structural approach of motorways integrating in the landscape was possible if a landscape plan was drawn up at an early stage in the planning process. This motorway still serves as an example of the possibility of responsible integration within a varied cultural landscape. However, developments within the various landscapes must be taken into account in the future, e.g. the Apeldoorn Channel, attention to the reduction of barrier effects, taking into account urbanisation processes around Apeldoorn and management-technical requirements (Hoeffnagel et al., 2000). The construction of extra lanes (for rush hours), the possible construction of lighting, and the addition of road portals at every 600m would entail a break with the original integration objective for the A50, which was to let drivers experience the Veluwe. With new provisions, the attention of drivers will be directed entirely to the road.

Case Study – the A6 Between Almere and Lelystad

The landscape planning of the A6 in the 1970s was characterised by a major difference in opinion with regard to the selection of two different approaches:

- The 'Elffers' approach (from the latter half of the 1960s) to opt for a large monumental form: 6 rows of oak trees on either side of the road at a distance of 14 m instead of 10 m from the roadside.
- The 'Huizinga' approach. In 1996, Huizinga left the State Forest Service for the Directorate-General of Public Works and Water Management. Huizinga rejected Elffers' proposal because of the expected tunnelling effects, lack of variety and the danger of 'polderblindheid', a fixation on the horizon or a distant object that causes drivers not to take notice of signals close by (1978; report by Huizinga).

Rather than having an autonomous motorway between Almere and Lelystad, the Landscape Plan of 1979 proposed the integration of the motorway within the landscape, in which the road and surroundings must be regarded as a coherent whole. The road section was divided up into 16 subsections. Proposals were made for each subsection on the basis of local characteristics of land use and existing elements. Planting trees in rows was chosen in some sections. A compromise may be observed in the end, although the emphasis is on the relationship with the surroundings. Van Winden (2002) concludes that the discussion on the A6 heralded a turning point where 'monumentalism' was dropped in favour of 'regionalism'. He quoted Huizinga: 'small-scale, ecologically-oriented and avoidant of structure'. The cultural act does not find expression in the shape of landscape structures or elements, but rather in landscape art/objects. In a broader framework (the layout of new reclaimed land and in architecture), in those days, these different approaches played an important role. One group was in favour of monumentality and symbolism, while the other camp wanted to emphasise spatial qualities.

Case Study – the A73 Between Nijmegen and Boxmeer

In regard to the A73 section between Nijmegen and Boxmeer, the designers decided to integrate the road into the landscape as much as possible, which meant that the road was built as much as possible on ground level, that the median verge was sometimes broadened significantly and that no plantation was added to locations where the motorway passes through open spaces; in urban areas there is a more "closed" road picture.
The differences between open and closed, high and low, dry and wet were used as design means.

Case Study – The A73 between Boxmeer and Venlo

In regard to the A73 section between Boxmeer and Venlo, it was decided not to let the road dominate the view; the main emphasis was on the existing landscape (designer: Henk Volkers) (study: 1982 to 1987; implementation: 1990 to 1998; 36 km).
The motorway runs parallel to the Maas river, and this found expression in the motorway design in terms of continuity (equal layout of bridges and acoustic baffles) and the width (a continuous road on ground level with wide verges).
As a result of the decision to let the existing surroundings dominate the view, the quick, unforeseen changes in the landscape (the construction of mushroom nurseries, the expansion of residential areas, new acoustic baffles, prime locations) had a major visual impact. Moreover, the choice for an identical design for the acoustic baffles and bridges produced a dated appearance (Van Dooren, 2000). The badger fences that were originally meant to be put in the ditches, now stand in

the middle of the wide verge, where, despite their green colour, they do not blend in with the background (Van Dooren, 2000).

Case Study – The A73 Between Venlo and Maasbracht (still to be built)

As a result of the increasing influence of local and regional factors, for the A73 between Venlo and Maasbracht uniformity, and consistency of design became the central focus in the design. A road trace was selected that complemented the composition of the landscape in the north-south direction the Maas Valley, steep slopes of the 'high terrace' and occupation zones; there is room for a certain measure of autonomy of the road within the landscape. The motorway should be a strip following the contours of the Maas and the steep slopes. The road view was to provide a calm and clear picture as opposed to the varying picture of the surroundings.
An appropriate (integrated) gaining of independence can be seen. Van der Velden and Vroege (1998) put this as follows:

- The layout of the motorway matches the regional level of scale.
- The layout must take into account the local level of scale (integration of the road at the local level).
- The dimensional characteristics are adapted to the relations between the Maas and the steep slopes (appropriate dimensions).
- By selecting a continuous plantation line of 2-3 rows, the road is contrasted with the direct surroundings (independent character).

The roadside plantation should form a third dimension: the road is easy to see, the plantation matches the regional scale and distinct from the local plantation. It is, as it were, a broad planted lane following the north-south structure of the landscape. West-east connections are accentuated by single or double rows of trees. The road crosses the Swalm valley on a long viaduct; the Ruhr valley will be crossed with a tunnel.
In order to reduce the claim of space, strongly narrowed median strip was selected and concrete barriers in the median strip will be incorporated into the design.
Mitigating and compensation measures are incorporated into the nature compensation plan for an optimal reduction of the barrier effect of the road. The nature compensation plan concentrates not only on mitigating and compensatory measures, but also takes into account potential ecological values. Much negotiation was necessary on the number and size of fauna passages

A proper 'house style' was selected for the entire planning process, and a 'total concept' was used by creating an architectural platform that focused on all elements (bridges, viaducts, tunnels, verges).

The actual design in the planningprocess of this section of the A73 took place at a late stage in the process. A conscious decision was made to allow independence of the motorway.
However, visual integration took place at a late stage in the process. It should be possible to create designs at an early stage of the planning process as possible. If there had been a design study incorporating the various design alternatives for the east and west section, this would have generated probably a broader support for the final choice (Dings, 2001).

Case Study – The A32 Between Meppel and Leeuwarden

The national motorway A32 was a replacement of the existing connection between Meppel and Leeuwarden. This motorway was largely bundled together with the railway line and the old national road. The layout of this national motorway through a rural area is subordinate

to, or equally important as the surroundings. The motorway is at ground level and has little plantation, if any. In urban areas, the layout is mainly determined by environmental requirements as a result of the urban influence (many intersections, acoustic baffles and business sites).
De Vries (1992) described the creation of the landscape plan and integration of the section of the A32 motorway between Werpsterhoek and Grouw. During the analysis phase, the characteristics of the landscape were studied along with those of the planned road:

- Landscape patterns: these are primarily determined by the composition of the abiotic situation (former salt-marsh ridges, former salt-marsh plains, clay-on-peat areas and peat areas), which has resulted in differences in occupation. Individual patterns were formed by: the A32, the railway line, high-voltage line and the Prinses Margriet canal.
- Functional aspect: the A32 forms part of a supra-regional network that is connected with the local road system.
- Visual-spatial aspect: a former salt-marsh ridge with buildings and plantation dominates the open landscape.
- Ecological aspect: barrier and corridor effects and presence of habitat patches.

From a functional point of view, doubling the width of the road entailed a major increase in the autonomy of the road. From a visual-spatial point of view, the road gets more presence through tall works of civel engineering and the construction of rest areas. During the comparative assessment phase, detailed starting points were formulated for the aforementioned aspects. The most important conclusion was that the road was regarded as an autonomous, continuous element and a landscape view was realised that is recognisable and visible from the road. However, in contrast to the desire to promote openness of the landscape, plantation between the motorway and the railway was maintained to form a kind of screen.
During the design phase, the starting points were elaborated into concrete design proposals. At the east side of the road, grass verges were chosen so that the grassland areas remained fully visible. However, the vegetation between the road and the railway remained a dilemma. The height of the trees was reduced by felling the tall poplars, so that a strip of lower trees and bushes remained as protection.
These specific design ideas found expression in the planning program. For connections with the supra-regional road system, plantations were added with the aim of guiding traffic. On ground level, species which are typical of the alder forest were planted; on the road section species typical of the elm/ash forest were planted.

The rest areas along the RW32 may serve as design example. These road-related elements with proper functions require protection from the wind. At the same time, an open view to the surrounding grassland areas was to be maintained. Geometric design (the use of triangles and circles) was chosen as a contrast to the surrounding landscape. The road furniture and the use of colour were chosen to harmonise with the design of the civil engineering objects, which form a coherent whole (De Vries, 1992). Much attention was paid to details (paving, the location of picnic seats, etc.).

Case Study – the A58 Between Bergen op Zoom and Vlissingen

The A58 connects Bergen op Zoom and Vlissingen and forms an autonomous element within the landscape. Because of its flat position, the surroundings determine the road view. The motorway mainly runs through a sea-clay area that was gradually reclaimed by man. One may distinguish between the old land, the relatively old dikings and more recent areas of reclaimed land. During the construction phase of the motorway, broad verges were added to the A58 (a surface of approximately 250 hectares of grass verge) that had previously been left virtually unplanted in order to match the open landscape of Zeeland.

In the course of the 1980s, road maintenance gradually transformed from the maintenance of lawn-like vegetation to maintenance consisting of two mowing sessions per year; the cut grass was disposed of. Gradually, a road verge rich in plant species developed. In 1991 and 1992, the verges were redesigned on the basis of nature engineering principles. Natural habitats were expanded, the corridor function for plants and animals was promoted, pools were dug out and there were many gradual transitions realised.

In 2000 a new landscape plan for the A58 appeared (Anonymous, 2000). Causes both internal and external call for modifications. The chaotic view must be eliminated, being the result of the addition of prime locations and glasshouses. There were also problems regarding the maintenance of the (plantation surrounding the) rest areas and plantation that got too close to the road. Defragmentation measures were implemented, and a choice had to be made between collecting or purifying waste water.
From a botanical and fauna point of view, the verges had increased considerably as a result of design and maintenance based on nature engineering principles.

The 'left over areas' near the Vlakebruggen form a special landscape. These are located at the junction of the A58 and the channel through Zuid-Beveland. Between the railway line and the motorway, some sections have been elevated using the soil that remained after the expansion of the canal. These sections have been provided with circular, deepened patches, which look like bomb craters. They have a depth of 1.65 m in regard to the surrounding ground level and are surrounded by a small dyke that is 1.5 m high. The diameter is 30 m. This lay-out has resulted in a great diversity of environments that offer habitat patches for plants and animals.

Case Study – the A11 Between Leiden and Bodegraven
The A11 connecting Leiden with Bodegraven via Alphen was constructed in phases and replaced the road along the Oude Rijn [Old Rhine river] (the by-pass motorway to Alphen aan de Rijn was finished in 1989 and the motorway between Leiden, Alphen and Bodegraven between 1990 and 2000). It was chosen to 'bundle' the motorway with the railway line. Starting points included (Berkenbosch et al., 1992):

- The buildings along the Old Rhine river and the characteristic land-division patterns should continue to dominate the view.
- The road should be constructed as low as possible above ground level.
- No tall trees should be present near roads crossing waterways, only thickets.
- The space between the motorway and the railway line (20 to 80 m) for cables and pipes should be designed as much as possible on the basis of ecological principles as a compensation for the loss of nature values while original land parcels and ditches are kept intact and should form an ecological backbone: small-scale alternation of water, swamps, wet grasslands and boscages; the barrier effect of the road in regard to animals is reduced by means of eight fauna provisions.

The layout of the various types of land in this ecological area was carefully detailed, including the required maintenance. In this way, the best possible integration of the motorway into the landscape was achieved as well as making the motorway as 'subordinate' as possible (Berkenbosch et al., 1992).

Case Study: the A50 Between Oss and Eindhoven

The construction of the 23-km road section of the A50 between Oss and Eindhoven is an example of a '1980s' type of project based on landzoning plan procedures rather than the Tracé act (Transport Infrastructure Act) that came into force at a later stage.

In 1993, as a result of local integration requirements, negotiations with municipalities took place which results in the meandering trace.

The motorway runs through open and half-open wind-born sand landscapes, cuts through wind-born sand ridges, runs through the reclaimed moorland landscape and along Son en Breugel, Veghel, Uden and Nistelrode and crosses the Wilhelminakanaal, the Dommel and Zuid-Willemsvaart.

Although an integral, total vision was lacking, among others the following starting points were used (Roijen, Van Heeswijk, 2003):

- Where possible, the motorway must be inconspicuous ("introvert") and left unplanted in order to blend with the existing landscape.
- Apart from mitigating measures, compensatory measures must be taken in other parts of the area.
- Noise-protection systems (transparent screens, acoustic baffles and noise barriers) must be uniform and "introvert"; they should not dominate the surroundings.
- There should be no lighting or traffic signals.

Since no integral integration approach was used, the project came to be characterised by ad-hoc solutions. In fact, designers were only involved in the preliminary design phase. No quality system was available for evaluating aesthetical aspects.

With respect to the integration, as much as possible was visualised on the basis of a steady rhythm (church towers, viaducts, the ecoduct at Nistelrode, the deepened section near Son). For viaducts, a design was sought that avoided heavy bridge parts; a distinction was made between viaducts under and over the A50. The walls of the viaducts were as much straight as possible, and subways for cyclists and pedestrians were designed to make the space appear as large as possible.

The Dommel river flows under an expanded viaduct and have a broad, dry edge zone. However, the watercourse is not clearly visible from the motorway. Here, the driver could have received better visual emphasis on the Dommel through the construction of reed beds, which could also have had a water purifying function.

The following may be said about this section of the A50:

- The design was incorporated into the planning process at a very late stage. It would have been preferable to have asked for input from designers during all stages of the process. This goes for road designers, ecologists, environmental experts and architects;
- There is no integral, substantive view with regard to design on route level;
- There is no aesthetic quality control by designers at any stage of the process;
- Designers should have been allowed to pay more attention to details;
- Municipalities should have a greater say in the details of the design.

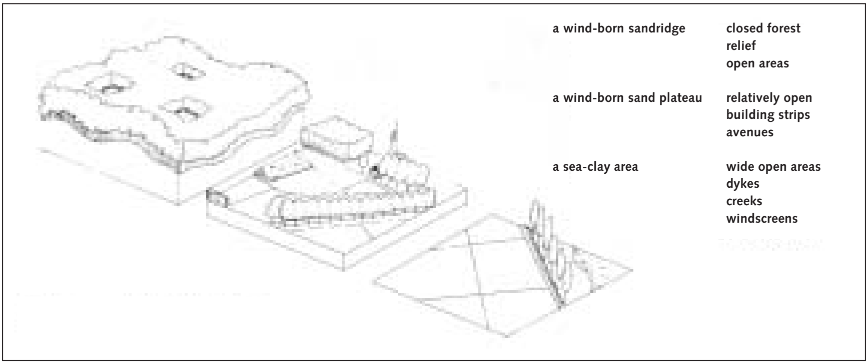


Figure 8. Landscape Types (Van der Velden, 1996)

Case Study - the A4 Zoomweg-Noord from Dinteloord to Bergen op Zoom *(still to be built)*
In 1996, a landscape plan was drawn up for the 'Ontwerp Tracé Besluit' (Draft Road Section Decision) A4 Zoomweg-Noord: Dinteloord – Bergen op Zoom (Van der Velden, 1996). The Zoomweg-Noord is to run across three clearly distinct landscape types; from south to north: a wind-born sand ridge, a wind-born sand plateau and sea-clay areas (see Figure 8).

The wind-born sand ridge is rich in relief and, as a result of the existing forested areas, quite closed. The wind-born sand plateau is relatively open and flat and has arable fields, meadows, greenhouses, villages and roads with row plantations. The reclaimed land consisting of sea clay forms wide, large open spaces with rigid dykes, straight ditches surrounding parcels of land and several winding old creeks. Remains of 16th-18th-century defence works can be found in the areas, that were constructed in order to protect the province of Zeeland on the east side. There are defence dykes, inundation areas, earth fortresses and dry moats. The most important characteristics of the landscape units have been taken into account by the designers. The road should respond to its surroundings; on the wind-born sand ridge there should be broad forest strips (Figure 9). It is proposed to reconstruct the old Fortress De Roovere (Figure 10) located on the transition to the more open wind-born sand plateau through digging part of the soil, thus promoting open water and wet grassland vegetation fed by seepage water. To mark the military history, a new bastion will be placed alongside the motorway to be built which may prove a suitable location for a work of art. On the wind-born sand plateau, two rows of trees will be planted on either side of the road that leave room for viewing the landscape. Two rest areas have been planned as a gateway between the wind-born sand plateau and the sea-clay area, where the old dyke will be restored. Each rest area will have its own theme. The eastern rest area will be based on the wind-born sand landscape, while the western rest area will form an expression of the open sea-clay area. The motorway in the sea-clay area is determined by wide, open roadside verges (Van der Velden, 1996).

A compensation plan has also been drawn up for the motorway section. There will be several fauna tunnels. A cyclist bridge is planned that

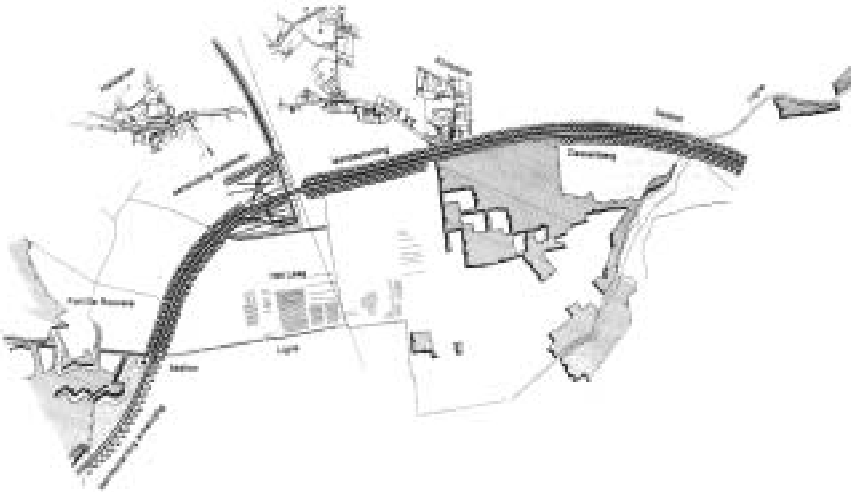


Figure 9. The proposed motorway section in the wind-born landscape (Van der Velden, 1996)

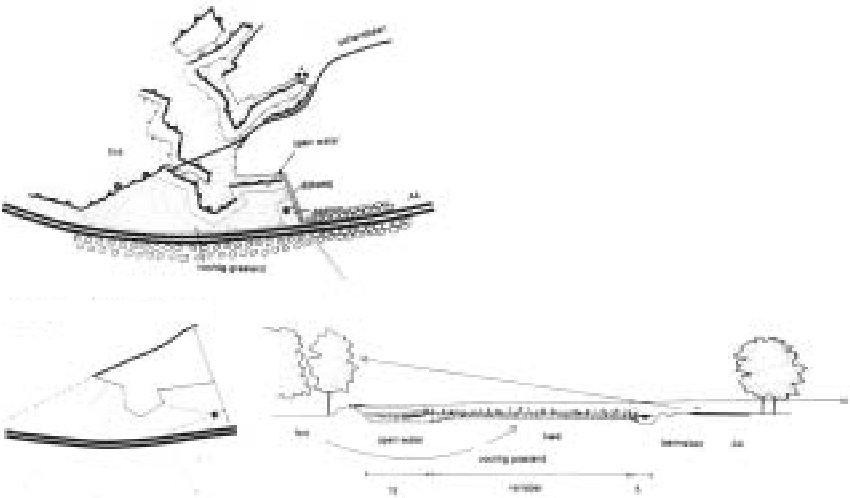


Figure 10. The design of the old fortress De Roovere (Van der Velden, 1996)

will included ‘green’ strips. Locally, broad verge ditches will be dug and wide culverts will be created for water drainage with wide terrestrial banks for fauna-passage facilities.

Case Study – Landscape Plans of Sections of the A1, A2, A27 and A28 inside the scope of the Direction of Utrecht

As a result of rapid changes in the landscapes of the province of Utrecht, a need arose for updated maintenance plans for planted areas. This was the immediate cause to revise the existing landscape plans on the basis of general starting points for the area of the entire direction (Van Schaik et al., 2002).

The motorways are not considered an autonomous element of the landscape, but as part of a larger whole. The starting points are based on ecological and landscape-visual aspects as well as an univocal road view. The main memorandum finds expression in the landscape plans for each road road section and in the following years, layout plans and modifications of roadside verge management plans will follow.

The motorways in this area of the Netherlands are generally divided into three types: ‘roads in the meadows, ‘roads in the forest’ and ‘roads in the urbanised area’.

The design vision was translated into concrete layout and design aspects for the following ‘buildings blocks’:

- Landscape (geomorphology, archeology, cultural history).
- Nature (plantation, grassy vegetation, verge ditches, defragmentation).
- Road view (landscape art, acoustic baffles, objects of art, road furniture, junctions and intersections).
- Road use (rest areas, carpool locations, social safety).
- Environmental aspects (air pollution, water drainage, lighting, wind turbines).

The main points of this design focussed on:

- Interrelated intentions, recommendations and guidelines for the benefit of landscape quality;
- Sustainability (functional quality from an ecological and economical point of view) and identity (architecture and quality of design);
- The relationship between the road and its surroundings are paramount in shaping the road (technical design, landscape integration and mitigating measures);
- Solutions for each bottleneck.

The philosophy of the Utrecht Directorate has shifted from the original design philosophy of optical guidance by means of ample road plantations towards a design philosophy in which the road is considered an autonomous spatial element where the surrounding landscape is brought right up to the road and become part of it. In this way, the surrounding landscape can be experienced as closely as possible from the road. The design can be managed functionally, efficiently and in a flexible way, so that the continuity and clarity of the road can be maintained despite of continuous changes.

Case Study – The A12 Between The Hague and the Ruhr Area

The Architecture Memorandum ‘Designing the Netherlands - Architectural Policy for 2001 to 2004 - specified that as a result of an increase of scales in infrastructure, there was a lack of recognition of the motorways and the changes in the land use near motorways. The integral design objective for the A12 is to gain more experience in regard to bridging the (continuity of the) infrastructure and its surroundings.

Since motorways, including the A12, have not been designed in one go (the A12 was routed in approximately 1930 and constructed in the period of approximately 1936 - now), a clear

coherence between the various sections of the road is lacking. The A12 will undergo drastic changes in the coming years in a number of locations (Anonymous, 2002a en 2002b).
The A12 project was divided up into three parts:

- Short-term route design of the A12;
- Long-term route design of the A12;
- Design of modular acoustic baffles.

The long-term route design involves the formulation of design strategies and tactics for defining a lasting method of dealing with infrastructure within the spatial planning.
The short-term route design provides intermediate ideas for modifications to the A12. It provides starting points for the design for controlling and inspiring designers and is restricted to the layout of the road profile.
The long-term route design envisages starting points for a more integrated spatial planning. 'Building blocks' are designed for 'route continuity', 'landscape types' (the road through the meadow, forest and the city) and 'point locations' (specific unique elements within the landscape). The main objective is to create continuity in the road view through uniformity of the road profile, its subsections and its design (in particular viaducts, acoustic baffles, portals, lighting and verges). Another objective is to promote visibility and recognisability of the surrounding or underlying landscape (e.g. the culture-historical landscape and archaeological sites) from the road.
The focus is primarily on:

a. *Route Continuity:*
   - Acoustic baffles: these must have a coherent design; a form family will be created;
   - Objects of civil engineering (viaducts): these should be as 'transparent' and 'light' as possible;
   - Defragmentation: ecotunnels, ecoducts, small modifications such as animal paths/stump walls on existing viaducts;
   - Road furniture: combination of functions;
   - Road lighting: separate lighting columns in the median verge are preferred; in vulnerable areas there should be minimum lighting.
   - Elements with regard to social safety: subways for cyclists and pedestrians.

b. *Types of Landscape:*
   The road in the meadow:
   - Plantation: linear plantation (rows of trees) must eventually disappear; some individual bushes, trees or groups must be maintained in unplanted verges; the best view possible must be retained.
   - Acoustic baffles: transparent screens.
   - Viaducts: as slender and open as possible.
   - GSM facilities: antenna masts with open frame constructions.

   The road in the forest:
   - Plantation: only well-structured (spontaneous) plantation in the verges, the slope of diggings should be free of large bushes or trees;
   - Acoustic baffles: the screens must be provided with plants as much as possible.
   - Viaducts: heavier types can be used.
   - GSM facilities: antenna masts with a closed construction.

   The road in the city:
   - Plantation: the visibility of prime locations must be maintained or emphasised; less attractive parts of the city must be masked with plantation; plantation can have a function for the collection of dustparticles; in the urban areas, there can be a gradual increase in the number of "coloured" bushes

(hawthorn, blackthorn, guelder rose, elder and rowan).
- Acoustic baffles: 'high-tech' appearance, covering them with plants is also an option.
- Civil engineering objects (Viaducts): in the city the road need not be hid; elevated roads would be possible as also multiple use of space.
- GSM facilities: closed constructions.

c. *Point locations:*
- Art: limited use of unique artwork; only for the purpose of orientation.
- Archaologically valuable elements: identification of, and reference to locations with significant archaeological significance, insofar as a level of information is visible.
- Cultural-historically valuable elements: ditto.
- Landscape art: on locations that are suitable for a large-scale elements, e.g. intersections.
- Rest areas: the layout must be harmonised with wishes of motorists as well as surrounding landscape.
- Carpool locations: must be made safe from a social point of view; visibility of surroundings.
- Junctions/intersections: for each location it must be determined whether subsequent or individual design is required.
- Wind turbines: national policy must be followed.

The transitions between these three landscape types must find emphasis in the design approach.

Summary of the approach to the A12 landscape plans:
- The selected design must leave room for flexibility and efficient maintenance.
- The plan will be based on the existing set-up.
- Continuity, uniformity and large dimensions form the basis for the plan (cf. the 'Grand design' of the 19th-century).
- An individual design through restrictions, producing a powerful and businesslike result. The layout should match functionality.
- Cultural-historic qualities; where possible, the archaeological quality of the surroundings must be made visible to motorists.
- The barrier effect of the road for nature must be eliminated where possible; the added ecological value is central in this connection.
- Bring unity to the civil engineering works through design-technical measures such as the use of colour and vegetation.

The following tentative theoretical framework has been formulated: a route is a meaningful connection between locations that are functional and recognisable, which adds value for users of that route and users of the surroundings (Van Zelm van Eldik and Heerema, 2003). The functional value, appreciation value and future value of a route made up of lines, spaces and points form the starting point for improvement of the spatial quality of the road and its surroundings. These starting points may be translated into three design objectives and nine design guidelines (Van Zelm van Eldrik and Heerema, 2003: Tuenissen et al., 2003):

- Design objective for lines:
  1. Increasing the continuity of the line;
  2. Increasing the interference at the border between lines and surfaces;
  3. Increasing the contrast between the lines.

- Design objective for surfaces:
    4. Increasing the identity of the surface and using the barrier effect of the line;
    5. Increasing the contrast between surfaces.
- Design objective for points:
    6. Reinforcing the identity of the line;
    7. Reinforcing the identify of the surface;
    8. Reinforcing of the contrast between surfaces;
    9. Reinforcing the contrast between lines.

The route design for the A12 tries to increase the spatial quality of the motorway landscape. A coherent whole should be designed for the motorways, viaducts and verges and for those parts of the surroundings that have a visual or immediate functional relationship with the motorway (Van Zelm van Eldik and Heereman, 2003).

Some remarks have to be made. Some of the dangers involved in the tripartite division of 'meadow', 'forest' and 'city' are: simplification of patterns and processes on lower levels of scale, less attention to historical-landscape patterns and the limitation of ecologically valuable organism in their natural set-up of space and time. Not just the open landscape, forest landscapes or city landscapes are concerned, but also the diversity of landscape determined by historical-landscape, landscape ecological and social/societal factors.
The motorway landscape is reduced to a road design. The motorway landscape consists of the line (the continuous median verge), sections of the actual road and the surfaces that are influenced by the road; these surfaces may vary in size according to the varying size of the sphere of influence. The two-dimensional concepts must be considered in time and space. It is proposed to use acoustic baffles along the entire route consisting of a concrete plinth, a lower part equipped with 'green' and a transparant screen. Depending on the landscape, the side that is equipped with 'green' may vary in size. Before using the transparent parts a study should take place of the possible negative effects for birds.

According to Van Zelm van Eldik and Heerema (2003), the route is shaped by 'an interplay of user value, appreciation value and future value in connection with the layered landscape (soil, networks and occupation) and taking into account economic, social, ecological and cultural interests of users of the route and surroundings'. But the 'collaborative engineering' principle, in which all designing disciplines work together from the outset must be expanded in order to prevent a situation in which decisions are made about people, who have not been consulted.

Finally it looks that a historical awareness of the past use of design principles for landscape integration seems to be lacking. Locally, the pavement of the road will be expanded soon, and this will result in the construction of concrete barriers on the median strip. Another danger of a use which is too stringent of the division of meadow, forest and city is that, e.g. in the meadow, no rows of trees may be used, although this may be acceptable from a cultural-historical point of view and may even desirable from an ecological point of view. The simplification may result in the fact that the historical-landscape variety will no longer be incorporated into the planning.

Case study A4 Midden-Delfland (Delft-Schiedam/Vlaardingen)

Plans for the building of the A4 motorway section between Delft and Schiedam/ Vlaardingen, through the rural area of the region Midden-Delfland, date from before the World War II. In 1965 a governmental decision has been made to construct the road and around 1970 a sand embankment was realised. Up till now no road has been built, due to opposition of action groups, of local government and of the parliament. In 2001 the provincial government of South-Holland took the initiative for an integral plan for construction of the motorway, as well as to increase the livability and the quality of nature of the region of Midden-Delfland. The procedure for the environmental impact assessment has been started and if extra financial support can be found the construction can be started in 2006 or 2007.

Special case studies

In addition to the above analyses of motorway sections, because of their special character and the added value that they may bring in other situations, the following location-specific case studies have been included: the Hattemerbroek junction, the Beekbergerwoud, Einderbeek, the Eco-recreoduct A15, as well as a discussion of so-called Rest areas and finally an overview of so-called Hotspots of integration of motorways in the Dutch landscape will be treated.

Case Study – the Hattemerbroek Junction

The 60 ha Hattemerbroek junction was finished in 1977 and connects the A28 with the A50. The visual-landscape and ecological aspects of the junction were created on the basis of nature engineering principles. As a result of the roads on different levels, differences in altitude came into existence that enables a great variety of vegetation. In the low, winding curves in the central parts of the junction, the water vegetation in the pools changes into edge vegetation which gradually changes into a willow-alder forest, then changing into an oak-beech forest at a higher level. The junction is situated in an open reclaimed-land area.
By making the currently overgrown plantation

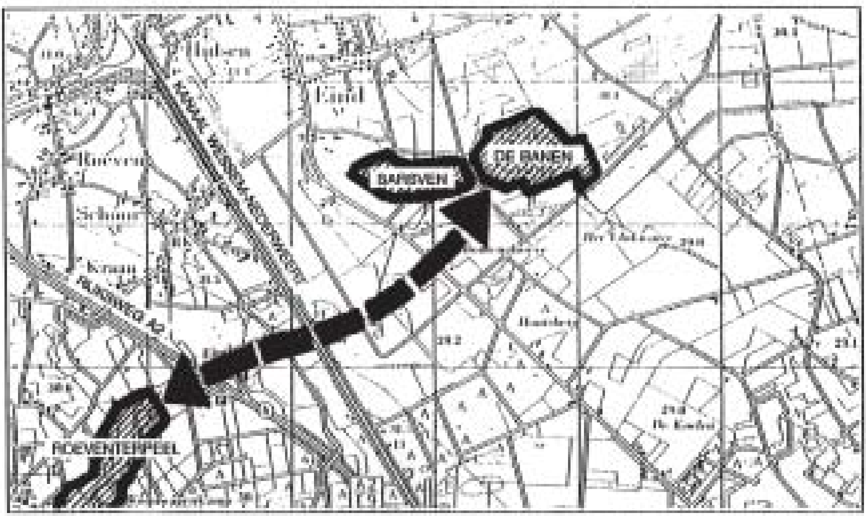


Figure 11. Corridor between Roeventerpeel, Sarsven and De Banen (Anonymous, 1996; one of the nominations RWS Sustainable Development Price)

more transparent, the obstruction to view the surrounding landscape may be eliminated.

Case Study – the Beekbergerwoud

In 1870, south-east of Apeldoorn, the remaining Dutch oldgrowth forest was felled. Later on, the A50 was designed and implemented straight through the former forest area. Two rest areas with gas stations and two viaducts were situated in the middle of the former forest area.

A study by the 'Vereniging van Natuurmonumenten' (Nature Monuments Association) showed that seepage from the Veluwe still occurs in the area, and even remains of forest plant species can be found; it is one of the few Dutch areas in which *Geum rivale* can still be found. The Nature Monuments Association has developed a plan for nature development and bought part of the land in this area. Negotiations are being made for the possible future layout and modifications of the A50 in this area.

Case Study - Einderbeek

For an area perpendicular to the A1 south of Eindhoven in the municipality of Nederweert, a plan has been developed for an ecological connection zone around the Einderbeek for the benefit of the implementation of a connection between the nature areas of Sarsven, De Banen and Roeventerpeel (Figure 11). In the middle of the proposed corridor, a rest area and gas station have been built in the past. A plan has been created that has been nominated for a sustainability award in 1995 (Anonymous, 1996). It has not been implemented to date.

Case Study – the A15 EcoRecreoBridge

There seems to be support for a plan to build a robust green zone over the A15/Betuwe goods transport railwayline south of Rotterdam.

A wide viaduct over the combined motorway/ railway best conveys the ambitions: something needs to be done here for nature, considering the enormous combinations of the infrastructure, even though counterarguments are also being formulated: this may be too expensive in relation to its function, it may not be integrated further considering the decisions already taken on residential buildings and the advanced stage of the plans for reconstructing the A15. Also, there is uncertainty of policy regarding external safety and environmental norms. Of three possibilities (a road under the landscape bridge of 200-400 m width, a road with renovating existing viaducts and a road with a 60-80 m wide 'green' viaduct), only the last option seems to offer opportunities from a policy and practical point of view. The individual designs that were the result of a workshop in 2003 will be incorporated into an integral design (Koopmanschap and Van der Linden, 2003; Anonymous, 2003).

Case study – Advertisements Along the Road

In the 1970s, on a European level, agreements were made on advertisements along motorways. These were required because of the local proliferation of billboards. All sorts of regulations have been drawn up.

It looks like there is a gradual development of the legalisation in the shape of prime locations and large-scale advertisements, e.g. on the walls of hangars at industrial sites along the highway. Near Ede, cinemas have been built that feature huge, distracting billboards. Ironically, these were built in the area of the location, where, at the beginning of the 1960s, a double row of oaks was planted till the area, in which the seepage from the Veluwe determined the ground-water level of the valley with its moist, open pastures.

Case study – Remainder Areas

As a result of the design and construction of infrastructure, remainder areas, as they are called, may come into existence. These are terrains that can no longer be used for their primary function as a result of external changes. In the New High-Speed Train Line Memorandum (Anonymous, 1994), for instance, remainder areas are described as generally point-shaped terrains that come into existince when individual infrastructure lines are incorporated into an infrastructure bundle. They may also be brought about as a result of the simple dissection of a landscape. These remainder areas have been assigned the status of 'integration zone' and must contribute to the landscape integration of the high-speed train line. Since on some occasions, these remainder areas are considered at a late stage of the implementation process, as becomes obvious from the contest and the book "A design for places left over after planning" (Atelier HSL, 2003), we will consider this phenomenon in further detail. Hageman (2003) defines a remainder area as a space that is situated along a national road. Although it is the property of the Directorate-General for Public Works and Water Management, it does not form a functional part of the road.

Remainder areas take up approximately 30% of the total surface of the national roads, approximately 2-3 ha/km of a national road (at an average national-road width of 45 m). Hageman (2003) distinguishes the following four types of remainder areas:

1. Junctions; all unprofitable areas that are enclosed by a motorway junction or the junction between a secondary road and a national road.
2. Diagonals; the piece of land that remains after a line or infrastructure has cut diagonal through a land parcel, rendering it economically useless.
3. Wedges; a piece of land that is enclosed by two lines of infrastructure, rendering it economically useless.
4. Enclosures; a piece of land that is enclosed by (two) lines of infrastructure, rendering it economically useless.

Hageman (2003) describes a method, in which, on the basis of general (physical) characteristics, a decision may be made in regard to the use of remainder areas. A mono-functional approach has been chosen for the definition of the concept of remainder area: a remainder areas is an area that does not form a functional part of the main infrastructure. From the point of view of an analytical, reductionist approach in which the emphasis is on economic profit, this is a correct assumption. However, it may lead to single-sided solutions. From a more holistically oriented solution approach it produces limitations.
An analysis of remainder areas shows that the status of remainder area depends on the presence or absence of a use.

Many "diagonals" or "remainder areas" seem to have a function or to have been assigned a function (and therefore no longer belong in the category of remainder areas):

- As part of the integration of the road into the landscape (verges, slopes, enclosures in junctions);
- As a striking point within the landscape;
- As water storage reservoir;
- As greenery provision for the purification of polluted air;
- For the benefit of purification of run-off by helophyte filters;
- As areas for ecological restoration based on nature engineering principles for the benefit of creating habitat patches.

From a landscape-ecological,spatial and social-psychological point of view, the term "remainder area" is an awkward description for terrains and areas along infrastructure and infrastructure bundles. Such terrains and areas must be indicated with the function that they actually fulfil or will be fulfilling. What is striking, is that many of the frequent studies into remainder areas do not consider in the design phase the presence of remainder areas in relation to functions that are determined from a visual-landscape and landscape-ecological view (Anonymous, 2003), although these are considered during the implementation phase (Anonymous, 2003). There can be great pressure on the remainder areas from the surroundings: use for hobby horses, dovecots, kitchen gardens and suchlike. It is important to take positive pressure of use into account. If it is to be nature, it must be adapted to the dynamic environment for optimal result, but they may also be used for alternative living or helophyte filters. The result of the (relatively late) contest on five remainder areas near the HSL gave a large number of different solutions that in a number of proposals combine the ecological potential and characteristic aspects of the landscape with technology, social-societal and cultural significance.

Case Study – Hotspots Landscape Integration and Orientation of Dutch Motorways

In order to investigate whether there are sections of motorways or objects along motorways in the Netherlands that may be considered to be of special value from the point of view of landscape integration and orientation, a survey was held among a number of people who are or have been involved in the integration of motorways, as a form of expert-judgement.

The Dutch motorways were evaluated on the basis of a number of criteria:

- The landscape type that the motorway runs through is recognizable.
- The concrete landscape is reasonable complete and intact.
- The landscape can be viewed from the motorway.

Above these:

- The presence of special objects of importance from a landscape visual, historical or archeological viewpoint.

On the map of the Netherlands (Figure 12), the indicated motorway sections and objects have provisionally been defined as ‘hotspots’ of landscape integration.

The ‘hotspots’ require special attention during modification or reconstruction. The draft report ‘Hotspots landschappelijke inpassing’ [Hotspots of Landscape Integration] will be evaluated by internal and external experts before it is published.

As part of the A12 Route project a new method using photocameras is underway for analysing the different visual-spatial charactistics of the landscape surrounding motorways, like the A12 (Anonymus, 2004).

In the near future a more detailled mapping of the ‘hotspots’ of landscapeviews of all Dutch motorways should take place, including actual and potential ecological ‘hotspots’, in the verges as well as in the surrounding of motorways. Mitigation and compensation measures should be included as well. This may lead to a more strategic landscape integration approach of motorways.

Blending, Insertion and Autonomisation of the Road Within the Landscape

Vroom (1988) distinguished between a number of design aids for the approaches of ‘blending’, ‘integration is insertion’ and ‘autonomy of the motorway’. Since this distinction covers all possibilities that are or have been applied, it is used as a ‘stepping stone’ for a summary of the examples and case studies.

Design aids for **‘***blending***’** (making the road as invisible as possible) are:

- earth walls (with and without plantation);

Figure 12. Indicative map of 'Hotspots' of Landscape Integration and Orientation of Dutch Motorways (Van Bohemen). In view of the scale of the map locally some objects damaging to the landscape may exist. In principle both sides of the motorway should be of interest; contrary to this rule some one-sided extraordinary landscape views have been indicated. No rights can be derived from this map.

- screens (with and without plantation);
- sunken roads (through the use of impenetrable membranes, open or closed U-profiles, tunnelling).

In urban areas, earth walls and plantation may be created as part of the entire landscape plan for the motorway and the surroundings. In open areas, earth walls and plantation can make the location of the road visible from a great distance. According to Vroom, a road can be made less visible in an open landscape by planting at a greater distance from the body of the road, although this really entails a kind of integration. Although sunken roads in open landscapes may result in ecological disadvantages, they can also offer several advantages: animal facilities can be created at ground level, which improves their effectiveness for a number of species.

In the blending, but inserting as well, coupling with existing infrastructure may take place: the expansion of existing roads and the parallel construction of, or bundling with watercourses and railway lines. However, it remains to be seen whether bundling does not further increase the ecological and social barrier effects. Further study is urgently required.

In the *'Integration is inserting'* approach, with regard to the road section the main directions of the existing landscape pattern as well as characteristic elements are taken into account. Examples in which main directions are determined by geomorphology and patterns of occupation are taken into account the A32 and A4 Zoomweg-North. The road is not blended, but adapted and made to co-ordinate, and the dimensions of the motorway are harmonised with those of the landscape pattern and elements (Veldkamp and De Vries, 1992).

Integration also takes into account the orientation points within the landscape, such as dykes, wind-blown sand ridges and planted lanes. In this connection, modifications are made in the technical design as well as in the landscape. An important question: how detailed can the intervention be without losing track of the big picture. After all, the 'legibility' of the landscape remains a priority. This may conflict with the objective of 'maintaining as much as possible the area-specific natural relationships and values' (Slagter, 1991). This has often resulted in tension in debate. In the 1990s, for example, the Motorway Landscape Design Department of the State Forest Service and the Directorate-General of Public Works became alienated because insufficient use was made of the new expertise obtained by the Road and Hydraulic Engineering Institute in the field of ecologisation of the design in the field of defragmenting and compensatory

Figure 13. Motorways on pillars (Nosewicz and Wildenberg, 1999)

measures. Later new insights were incorporated integrally.

With *'autonomy'* (autonomisation on the local level, insertion on the regional level), the motorway will become an autonomous element with regard to the surroundings; the road begins to contrast with the landscape (Veldkamp and De Vries, 1992). In terms of integration, according to Vroom there is a search for coherence on a higher level of scale. The routing is based on the proper characteristics and requirements of the motorway rather than the existing landscape pattern. However, well-considered contrasts may result in specific design effects. Motorways on pillars or (double) portals with plates or with open or closed U-profiles may also be considered as a type of autonomy (Nosewicz and Wildenberg, 1999) (Figure 13).

The result of the analysis of the case studies may be summarised in an overview. Table 4 provides a summary of the development of the case study described previously and design considerations with regard to the landscape integration of Dutch trunk roads.

6. Experiencing Nature and the Landscape from the Motorway

Ecological Orientation
Since the 1970s, ecology has come to play an increasingly important role in the construction and management of roads, firstly with regard to the maintenance and development of nature values in roadside verges, and secondly with regard to increase the road user's experience level of nature and landscape according to the Nature Policy Plan (1990) and the Memorandum Nature for People; People for Nature (2000). The Nature Policy Plan included a joint study by the Ministry of Housing, Spatial Planning and Environment, the Ministry of Agriculture, Nature and Fisheries and the Ministry of Transport, Public Works and Water Management which described bottlenecks between the national-road network and valuable nature areas. This was the first time that such topics were included in a policy memorandum. The overlay approach that was chosen with regard to motorway infrastructure and ecologically significant areas has proven successful and has become known as the 'Dutch approach for mitigation and compensation planning' (Forman et al., 2003). In the Landscape Memorandum (1992), the government policy on the Dutch landscape is laid down. Among the considerations is the 'supraregional infrastructure'.

People tend in general to become very attached to their local environment, while plants and animals depend on specific environmental circumstances for their growth and development. Beside the climate the hydrology and soil of a particular site or area determine the composition of the vegetation and the fauna associated with that vegetation to a great extent. Since motorways are often routed through completely different landscapes, road users may appreciate the visibility of the various landscapes and the transitions between those landscapes. Each area is defined by its local abiotic conditions and the plants and animals that thrive under those conditions. The landscape is, as it were, 'legible'. Bink (1991) calls this the aesthetic experience of the nature-lover. According Van Winden (2002), this experience is determined by an ecological vision.

The ecological approach to the design of civil-engineering works became in vogue primarily after the 1970s. In the United States McHarg developed his 'Design with Nature' (1969), an ecological method for regional planning. In the United Kingdom, Ruff provided an overview in

Design Criteria	1910	1930	1950	1970	1980	1990	2000
Planting Technique	.... ->						
Landscape Integration (The Road Within the Landscape: Aesthetic requirements)		.... ->					
Traffic oriented Objective (Traffic safety) (Efficiency) (Functional aesthetics)			.... ->				
Nature Engineering (Ecological verge design and maintenance)				.... ->			
Local autonomisation of the motorway (Use of acoustic baffles) (Further expansion of the width)					.... ->		
Landscape-ecological Integration (Wildlife viaducts) (Badger tunnels) (Ecoducts)						.... ->	
Coherence (Design of a motorway landscape for the maintenance and reinforcement of spatial quality; bringing coherence to the various aspects of spatial qualities)							.... ->
Large-scale Autonomisation Along a Longer Route (Modifications to motorway landscapes are only aimed at measures for the promotion of mobility, including required environmental measures; this may lead to a limitation of the coherence and deterioration of landscape integration)							... ->

Table 4. Overview of the Development of Design Accents (after Visser, 1992).

‘An Ecological Approach to Landscape Design’ (1982) of the principles involved: ‘working with nature; enrichment through complexity; involvement of the users; minimal energy consumption; natural landscape outside the front door’.

In the Netherlands, ecology has received emphasis in designs since the 1930s (Londo, 1977), primarily as a result of the development of vegetation science and (landscape) ecology as well as practical experience in nature reserves and in nature and ecological gardens and parks. Since the 1970s, this development has been reinforced by the ecological design of urban areas. In ‘Ecological Conditions’ (1996), Tjallingii provided an overview of a considerable part of this development. With regard to the integration of road networks within nature, three different approaches are available, as can be noted from the debate on the so-called ‘two’ and ‘three’ networks (De Lange et al., 1996; Witsen et al., 1998). Since 1970, in the planning, design and maintenance of motorways, there has been increased attention for ecological aspects, especially in regard to verge management and the realisation of fauna provisions. However, there is still no integral application on an ecosystem level in which the flow of water, air and substances is taken into account in relation to the functionality of road ecosystems or in relation to the dispersion in space and time of plants and animals in the road ecosystem to and from ecosystems close by or further away. Or, to quote Lyle: a ‘design for human ecosystems’ (1985) requires yet another development cycle.

The publication Nature Engineering and Civil Engineering Works (Aanen et al., 1990) gives an overview of the theoretical backgrounds and practical expertise with regard to the application of nature engineering principles in civil engineering, including the ‘green’ elements along motorways. Nature engineering studies have yielded important results with regard to the ecological quality of road verges, e.g. keeping the verge as nutrient poor as possible and mowing it in general twice a year. Disposing of the clippings after the mowing positively impacts the ecological quality of road-verge vegetation.

Aanen et al. (1990) contains a plea for a nature engineering approach to roadside plantings and verge ditches that may increase ecological value while reducing maintenance expenses. In 1989, the results were published of research into the use of various design aids. It was demonstrated that the ecological significance of treemeadows (trees in grasslands) was limited in comparison with verges or plantation with a herb and a shrub layer. 2004 will see the publication of concept guidelines on the significance of structural planting and its stimulation through spontaneous development (Van Schaik, 2003, in preparation).
As for the nature engineering layout of verge ditches, the publication ‘Bermsloten... Natuurlijk’ [Verge ditches... naturally] (Van Strien and Van den Hengel, 2000) offers examples of the ways in which environmentally-friendly roadside verges can be constructed and managed, such as demonstrated earlier in publications about the ecology and maintenance of watercourses of Melman, 1992, Melman et al., 1986, Zonderwijk, 1976, 1976, 1986 and Zonderwijk en Van Zon, 1976.

The increasing number of fauna provisions (such as ecoducts) form important, largely visible landmarks for the relationship between ecology and motorways. These viaducts for animals contribute to the defragmentation of the Netherlands. The different shapes of the realised ecoducts are very interesting; none are identical in size. As a result of its design, the

ecoduct near De Woeste Hoeve is strongly connected with the earth. The hyperbolic 'mouths' backing away drill through the earth, as it were (Van Winden, 2002). This does not entail a reversal of the dominance of nature over technology or vice versa (Van Winden, 2002); rather, the ecoduct is an example of a balanced marriage between nature and technology. The round shape forms the 'arch shape' of bridges, caves and vaults and therefore has a functional appearance: 'it looks sturdy' (Van Winden, 2002).
The ecoduct near Terlet has a more traditional viaduct shape. At Kootwijk, there are viaducts that are covered with soil; by integration in the embankments they manage to convey the impression that the motorway lanes has been drilled through the earth. By giving the earth precedence as a building material, the impression is created that this particular 'work of civil engineering' contributes to Dutch nature. Currently approximately 700 fauna provisions have been created above and below motorways. It is to be expected that many will follow, although not exclusively for motorways.
A generally valid evaluation framework for an optimal implementation and design from a (multi)functional as well as from a human perception point of view will be needed for motorways but for provincial and local roads too. This should enhance the experience of motorists and the people living in the neighbourhood as well as possible visitors.

The Experience of Nature and Landscape in Relation to Motorways
A number of studies carried out or commissioned by the Road and Hydraulic Engineering Institute provide insight into the aspects that play a role in the experience of road users with regard to the integration of motorways into the landscape. Coeterier (2000) distinguishes between three types of relationships between roads and their surroundings: subordinate, coordinate and super-ordinate. These match the subdivisions of blended, inserted and autonomous of Vroom (1988) and those of integration, adaptation and modification– development of an infra-landscape – (Schöne et al., 1997), aspects which can also be expressed in terms of the relationship between man and nature.
The experience of the landscape by motorists is determined by speed, busy-ness, monotony, knowledge of the landscape, landmarks, or objects within the landscape.

With reference to legislation on environmental impact assessment (1986/1987), more insight was required into the effects of human experience on interventions such as motorways. In 1986, this resulted in the publication of The Effects of Motorways on Human Experience (Boekhorst et al., 1986). It formulated criteria for people living in the neighbourhood as well as motorists. These criteria determine the appreciation by both groups of motorways within the landscape. Staats and Coeterier (1990) provide the results of a environmental-psychological study commissioned by the Road and Hydraulic Engineering Institute with regard to the development of a methodology for predicting the visual impact of the (re)construction of motorways on the landscape for the purpose of environmental impact assessment. This methodology was tested on the basis of two projects . It was found that the effect of the construction of a motorway on the properties of landscape images could be gauged for the:
- beauty of the landscape;
- coherence between landscape elements and the measure of unity;
- rural character;
- accommodation value, the extent to which it is pleasant to experience the landscape;
- suitability for cycling;

- artificiality of design;
- historical character of the landscape;
- attractiveness of the spatial structure;
- appreciation value with regard to sensual impressions.

The effect of the construction of motorways was found to be negative for all of these characteristics. Schöne et al. (1997) investigated which aspects play a role in the way road users and their passengers experience the integration of motorways into the landscape; the people living in the neighbourhood of roads were left out of the scope of this study. Oral surveys and written questionnaires among 1,470 and 232 motorists respectively, showed that motorists prefer motorways that have been fully integrated into the landscape and appreciate it highly when the landscape is visible from the road. It was found that verges play an important role in this connection. The presence of bushes at some distance from the road was also received positively, since bushes may adapt the road to the landscape. It was indicated that rest areas should provide possibilities for more rest. Furthermore, it became obvious that a distinction must be made between people who drive often and people who seldom drive. According to the majority of interviewed motorists, road designs should take the following considerations into account:

- the beauty or ugliness of the landscape;
- the soil type, the wetness;
- the irregularity of the landscape;
- the age of the landscape;
- the level of 'artificiality' of the landscape;
- the type of vegetation present in the landscape.

The interviewees indicated expressed different requirements for the layout of verges in rural and urban areas. Artwork was preferred urban areas rather than rural areas. For rural areas a more area-specific design was suitable.

The width of the median and road-side verges was very important with regard to the desired integration. Apart from the actual objects that may be experienced by the motorist, the visual possibilities depend on the relation between the driving speed and the openness of the landscape. Bell (1997) found that a 'viewing session' of one second at 100 km/h required an opening of 27m, while an opening of no more than of 9.6 m would be required at a speed of 42 km/h. Furthermore, the visual angle will depend on the speed.

With the objective of analysing policy and project studies, Stolp (2002), developed a method to learn more about the perception values of citizens of interventions into the landscape. On the basis of interviews and questionnaires among a representative sample from human population groups, the way in which civilians experience the quality of the living environment is evaluated in a measurable way when interventions are planned in or near his/her living environment. But it should be realized that the perception value is only an aspect of the psychological and social aspects of human life.

A strong example of a possibility for visualisation is an object that is interesting from the point of view of the geological development of the Netherlands: a non-implemented permanent geological outcrop near the A1 near Boerskotten. The objective was to achieve a permanently visible geological outcrop, few of which are found in the Netherlands. Apart from drillings, a great deal of knowledge on the geological and soil-scientific historical development of our country, has been obtained from artificial outcrops (quarries, road incisions, digging trenches for pipes). A solid layout and proper maintenance outcrops may contribute to science and education. Terracing and a sufficiently wide (continuous) path should guarantee both manageability and accessibility. Gonggrijp (1988) provides an overview of the possibilities with regard to disclosing objects of geological importance as well as specific layout proposals for their visualisation (Figure 14 a and b and Figure 15).

An increasing number of people live in isolation from the natural world and have no awareness of the consequences of their actions to the environment, nature and the landscape (Orr, 2002; Göpfert, 1990; Beattie and Ehrlich, 2001). According to Walmsky (1997), an improved integration of ecological processes and societal developments would require (to paraphrase):

- adaptation to the local environment, to the location and climate;
- the promotion of societal cohesion; i.e. *community-making* .
- the application of eco-technology or ecological engineering; the application of regionally proven natural materials and ecological building concepts.
- a striving for aesthetic harmony (inspired by artwork).

Moreover, it should be possible to improve the visibility of ecological (main) structures. According to Van der Rijn and Cowan (1996), the “visualisation of nature” is an essential link bringing the natural world back to the fore in the daily consciousness. In this way, developments may be steered into a more sustainable direction. Instead of concealing positive and negative effects, more sensory perceptions may bring greater knowledge and involvement. As discussed earlier, Thayer (1976, 1994, 1998) proposes a “visual ecology” which would “express the unseen” and “visualise and organise the internal functionality of a landscape”.

The development of demonstration projects which improve the visibility of technological processes by managers and users of the motorway may be important from a point of view of sustainable development. For instance, the Directorate-General for Public Works and Water Management, might first consider placing signs with information on the flora, fauna and the landscape near interesting habitat patches at rest areas. Such signs have already been placed in some locations, e.g. in several rest areas along the A58 in Zeeland. Where possible, routes may be created that can be accessed from the rest areas in order to present knowledge to a broader audience. Par excellence, rest area are locations where ecological engineering might be applied in many different ways (Bakker and Van Westen, 2002; Van Bohemen, 2002). Ecological engineering is defined as using nature in such a way that it performs useful functions for man while the value of nature is left intact as much as possible.

People living in the neighbourhood may also become involved in such locations. In the United States, the *Adopting a Highway* project is successful as a result of the involvement of the people living in the neighbourhood. This can sometimes be difficult at times, for instance when grass species dominate while a sign is saying ‘Wild flora sponsored by the local grocery” and no flowering plants can be noticed during a large portion of the year.
In 2001, the “Watch Out for Wildlife” program is initiated in Florida. The objective of the program was to educate drivers of motor vehicles and school children on the relationships between transport facilities and animals. The objective is to improve the level of knowledge of current and future road users in order to reduce the number of collisions between cars and animals.

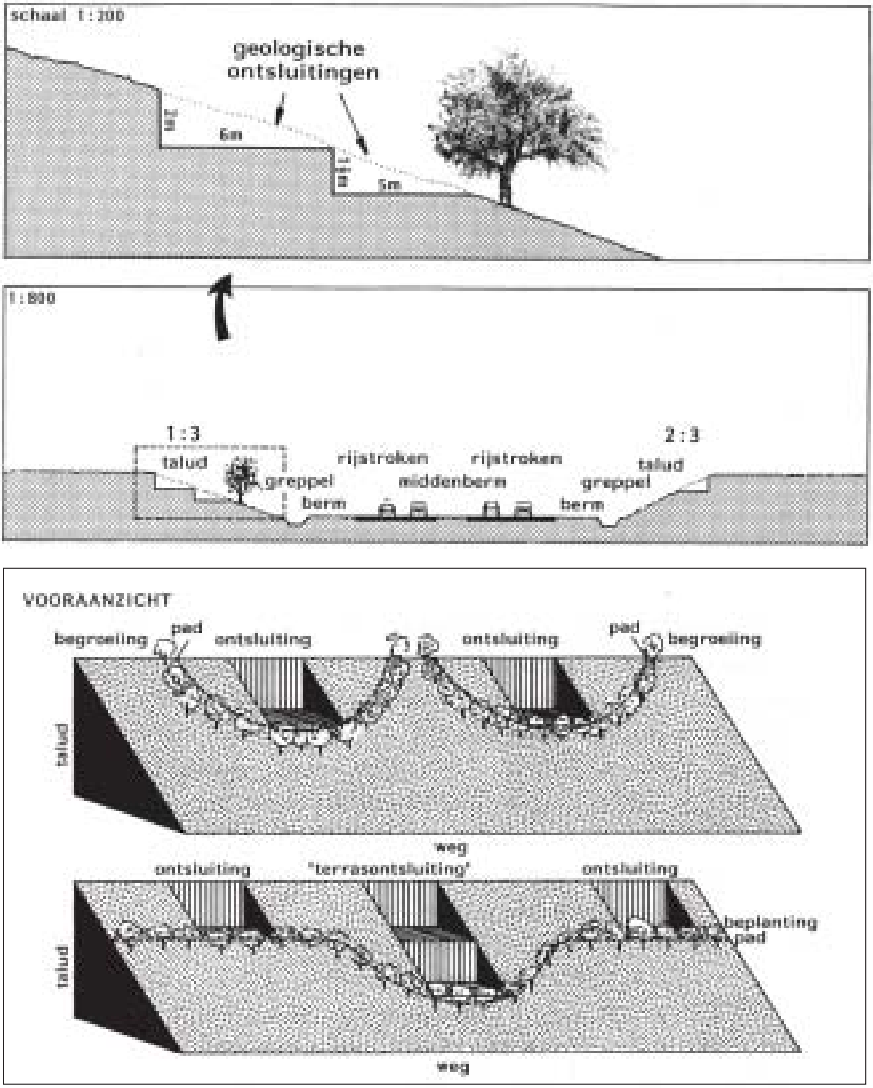


Figure 14 a and b. A Proposal for a Permanent Geological Outcrop near Boerskotten Along the A1 (Gonggrijp, 1988)

Figure 15. Interesting (eroded) soil profile near Boerskotten in 2003 (photo: Van Bohemen)

In the Netherlands, a brochure was published that contained a motorway map with the location of defragmentation measures and information on a number of animal species that play an important, visible role in the highway ecosystem. The brochure formed part of a temporary exhibition called 'De platte eend' [The Flat Duck] (Timmermans and Volkers, 2003) (Figure 16).

As a result of the changes that have taken place in society, the results of the 1990 survey about the perception of motorways are not likely to be identical to those of the 2003 survey. Due to the increased mobility, the public is beginning to lack a sound knowledge of their local environment; they seem to have become 'fundamentally uprooted'. In foreign environments, they tend to seek out familiar aspects first (very generalised e.g. they may be start looking for the local McDonalds); they will only look for adventure and entertainment in the second instance. Further study on the perception of new elements (business sites, prime locations) is required. More insight should be provided into the significance of the local spot in order to make people attracted to 'the local spot' again.
A survey by NIPO (Anonymous, 2002) showed that despite the fact that people clearly consider the surroundings of motorways of lesser importance than the quality of the road, they do consider the surroundings important. It was found that care for verges (60 % of the interviewed motorway users), nature provisions such as wildlife viaducts and verges with flowers and plants (56 %) and the integration of the road within the landscape (50 %) are the most important factors that make the direct surroundings of the motorway appealing.

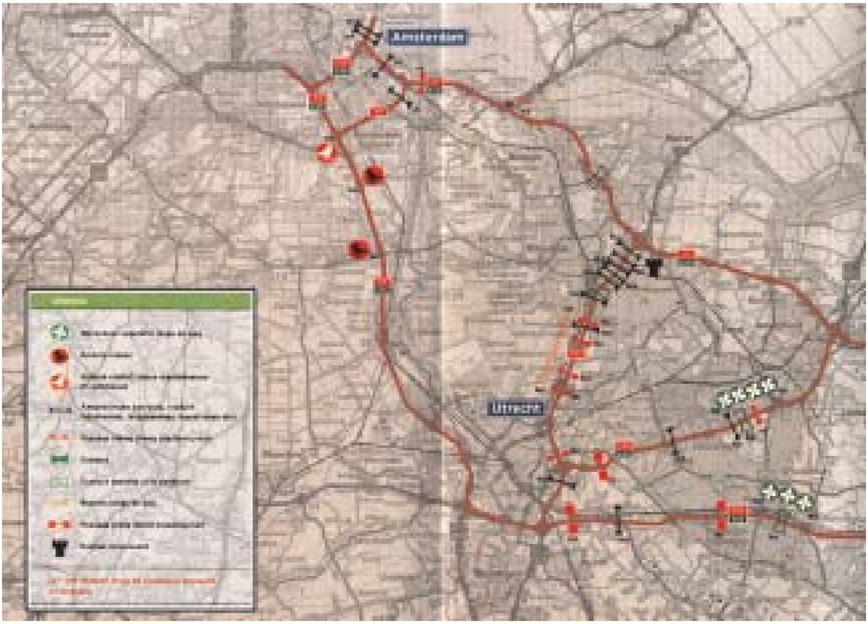


Figure 16. A Road Map with Fauna Provisions (inset: legend) (Rijkswaterstaat, 2003).

7. Art and Artwork along the Motorway

Preface
Art plays an important role in society. It has also found application in the framework of infrastructure.
The application of visual art is a result of (Daels, 1987):

- the cultural and societal need to integrate art into our immediate living and working environment;
- the need to express and understand the societal impact and social function within our living and working environment;
- the need to enhance the appreciation value of our living and working environment through spiritual and surprising form aspects; on the one hand, this may generate spontaneous reactions, e.g. graffiti art, and on the other hand this may result in collaborations between various disciplines).

The significance of art also entails the need of people to share and express their history. Objects of art and artists may play a role in promoting the public's involvement in planning and design processes. In this connection, visual art is not required per se; artists may also contribute by visualising and interpreting patterns and processes, for instance those involved in the integration of motorways, nature and the landscape (Van Bohemen, 2002). This entails:

- making the artist a partner in the design process;
- providing artwork in the form of a landmark or logo;
- expressing new functions that the area is to fulfil;
- accentuating landscapes or specific landscape details;
- installing autonomous objects of art that are not part of the context of the environment;
- promoting the integration of civil engineering and ecological engineering and placing the results within a broader societal framework.

This is expressed, for example, by putting artists in the position of cultural planning officers. Sometimes the question arises whether artists should be allowed to question the role of the road, travelling and travellers in the first place; often this is not what has been envisaged.
Beside the broadening of art in the field of objectives also finds expression in the use of various new materials (e.g. sheet iron, steel, shotcrete and plastics) and the associated new techniques.

The broadening of evaluation and appreciation has also taken place with regard to motorways. Motorways are considered contemporary landscape and cultural values (Daels, 1987). By paying attention to the beauty of landscapes, the significance and quality of these landscapes may be increased from a road user's point of view, thus enhancing the livability value. To a large extent, the landscape harbours the history of the Netherlands. Various types of landscape and settlements are found in the Netherlands, each with its individual historical-landscape, cultural-historical, aesthetic and economical-functional qualities in spite of the homogenisation which took place. Giving precedence to technical and economical values will reduce the ecological quality and livability value of the landscape.
In 1986, the results of a study were published in 'Landschapskunst/Kunstlandschap' [Landscape Art/Artistic Landscape] (Lörzing, 1986), in which the development of artistic expressions on a landscape level formed a central theme. This type of art was influenced by the advent of 'Earth Works' and 'Land Art' in the United States. A type of art is evolving in which artists intervene in the landscape. This may also result in a tension between nature and culture. Nature is regarded as a derivative of human action, and any natural development within man-made cultural landscapes is regarded as a fluke occurrence (Lörzing, 1986). It should be said that natural values may also be developed purposefully; an example is the tidal creek along the Maasvlakte (Lörzing, 1986). According to Lörzing, 'nature in the Netherlands exists by the grace of cultural landscapes'. A narrow interpretation would entail a depreciation of nature; in a broader interpretation, nature and culture may be of mutual 'use'.

According to Van Schaik et al., (2002), the "limiting conditions and starting points for landscape art along motorways", are:

- (landscape) art must be recognizable as such (and where possible enhance orientation and provide added value);
- (landscape) art must make the road recognisable and provide added value on a route level; in this sense, it may have the form of a landmark (only in locations suitable for large-scale interpretation, such as junctions and possible intersections);
- quality is more important than quantity (although objects of art must have big dimensions and striking qualities).
- on the one hand, the function of (landscape) art is to 'shock people out of

their complacency', on the other hand, (landscape) art may play an affirmative role, i.e. refer to (historical, regional/local) objects or qualities already present in that location. In this way art may contribute to a better orientation;
- the choice of (landscape) art must be based on the road user's perspective;
- (landscape) art must match the style of the Directorate-General for Public Works and Water Management rather than reflect the artist's wishes;
- the design should be maintenance-friendly;
- the artwork should not be accessible to third parties, but only to the manager.

Land Art

Art and artwork may contribute to the identity of roads. In 'Landschapskunst/Kunstlandschappen' (Landscape Art/Art Landscapes) (Lörzing, 1986) provides an overview of the relationship between art and landscape through the centuries. Lörzing discusses the influence of the development of 'Land Art' into 'landscape art'. 'Land Art' evolved in the United States in the latter half of the 1960s and quickly spread. Its development and the highpoint of 'Land Art' (1966-1973) coincide with the period in which ecology becomes a topic of public interest, partly as a result of the writings of Odum (1953) and Carson (1962). Artists discovered the possibilities of, e.g. the large-scale use of earth, ditches, earth mounds and motorways as an aesthetic potential (Boettger, 2002). It is a movement that is directly concerned with the landscape. 'Land Art' is a form of landscape art; a situational art that it applied to landscape. The first 'Earth Works' were realised in the United States, e.g. the Spiral Jetty by Robert Smithson in the Great Salt Lake of Utah (1969). Smithson encouraged other artists to become active in this field of large-scale sculpture within extensive landscapes. It is an art form that assimilates the landscape itself. The reverse may also be the case, since many perishable forms and materials are used on purpose. At first, interventions took place in which the earth was used as a material for artistic products. Later on, smaller-scale interventions took place, and an integration of nature and art developed. In some cases, artists also concern themselves with 'land reclamation', the conscious restoration of disrupted landscapes. Other central themes are the connectedness of man and nature, the inventory of plants and animals and the perception of natural processes.

'Land Art' or 'landscape art' is a method of integrating art into the landscape that refers to distant locations, to the universe, to the future, to the location proper or to the origin of the location in relation to the landscape. At the same time, it is meant to increase the appreciation value of the landscape. The art became part of the landscape, and afterward the artists went on to create their own landscapes so that they became involved in troubleshooting of landscape layout issues as co-designers.

In the Netherlands, Robert Morris created an 'Observatorium' [Observatory] (circular earth walls in an otherwise flat landscape) in the shape of an astronomical clock in Velzen (1971-1977). Later on, his work was relocated to Swifterband between Lelystad and Dronten. Turrell created a 'Celestial Vault' near Kijkduin in order to convey the experience of light and space of the sky.

A number of artists active in the Netherlands are intensely preoccupied with the relationship between art and nature, not only in the shape of (symbolic) objects per se (such as the green cathedral near Almere by Marinus Boezem), but also objects that perform a particular function, such as acoustic baffles and sound barriers along roads. Boezem's art fits into the

Figure 17. Acoustic Baffle Designed by Krijn Giezen (photo: Van Bohemen)

tradition of Land Art. Land Art was primarily a type of 'conceptual art' that manifested itself outside of museums. The autonomous creations may appear in various shapes in different locations; some may even be relocated. When an artist starts designing a sound barrier, s/he will be moving more and more into the direction of applied art.
An example is Krijn Giezen's sound barrier (Figure 17).

'Aardzee' [Earth Sea] (1982) by Pieter Slegers is located along the Vogelweg in the southern part of Flevoland and has the shape of a rest area. Along a 5-hectare surface, earth foundations sloping upwards are combined along a broad watercourse. Long ago, this area formed part of the Zuiderzee; now one may zigzag between the earth walls and view the current 'earth sea' through a hole in the wall. Richard Serra installed a long, pigmented concrete wall, the height of which refers to the water level of the former Zuiderzee before the land reclamation. As a result of the sloping inclination of an earth foundation that is dissected by the wall, first one experiences an 'underwater' sensation, then, while walking upward, the view.
The objective of Adriaan Nette's "Het Theater van de Natuur" [The Theatre of Nature] design is to stimulate individual nature appreciation . Jeroen van Westen's works involves nature art rather than land art. His main concern is the here and now of the landscape and the way it is approached and interpreted by the public (Zijlmans, 1999).
In 1970, Le Roy published 'Natuur uitschakelen; Natuur inschakelen' [Activating and

Deactivating Nature], which outlined a 'gardening' method in which nature may take its own course. This has proved to be a promising approach for achieving a particular result with as little disturbance as possible, provided management and maintenance activities are performed.

Another kind of 'Land Art' project is the construction of an ecological cathedral (Le Roy, 2002). Here, Le Roy makes use of the time factor that is involved in spatial processes, and visualises it by coupling it to complex dynamic systems and networks that are directly connected with current developments in urban, architectural and spatial planning.

1987 saw the publication of 'Kunst langs de weg' [Art Along the Motorway] (Daels, 1987). Daels considers the question of why art should be allowed to play a role in connection with hospitals, schools, factories, city squares and parks, but not motorways. According to Daels, motorways are the 'cathedrals'[1] of the 20th century, they may play a role in enhancing the informational value. At that time, the motorway A15 was considered boring, even though the road clearly provided a varied picture from a visual landscape point of view; the variety of landscape and spatial characteristics might be brought out by means of visual interventions.

Art may enhance visual stimulation, which may have a positive impact on the appreciation value and, according to Daels, speed behaviour.

[1] Cathedrals are materialisations of a higher, unknowable goal, the divine. This comparison only holds from a construction point of view, although the additional emphasis on mobility in our current society may suggest otherwise. With regard to the road, the functional dimension is seldom transcended, only in the case of (the details of) viaducts.

'Beelden in de Berm' [Images in the Verge] (Van Munster and Post, 2003) shows that 'true' (l'art pour l 'art) artworks have been realised along the roads, a very limited number of which symbolically refers to natural characteristics or phenomena . 'Horizontale; golvende blauwe buizen' [Horizontal, undulating blue pipes] by Mary Teeuwen de Jong at the entrance of the Kiltunnel refers to the fact that the tunnel runs below a waterway. 'Kikkers' (frogs) by Cor Dera along the N304 south of Apeldoorn refers to the term 'kikkerlandje' [frog country] that is used by the Dutch to describe their atlantic location. 'Acht bronzen buizen' [Eight bronze pipes] by Henck van Dijde along the N207 features signs attached to the pipes that resemble fungus on a tree; this is to emphasize our relationship with the life surrounding us.

Apart from the planting of indigenous vegetation planted near the "de overpanning" [the span] by Marijke de Boey along the A12 at the exit to Wageningen, as advised by professor Zonderwijk, there are little or no examples in which a connection is made between the ecological significance of the location and the artwork along motorways. Exceptions are the Land Art projects in the new IJsselmeer polders, near the flood barrier in the Oosterschelde on Neeltje Jans with a zebra-like pattern of sea-mussel and cockle shells which forms an art work as well as a breeding site for common terns and plovers.

Objects of art along motorways are usually associated with bridges, viaducts and acoustic baffles such as the A1 and A6 viaducts with which a concrete slab slants upwards from a pillar, or the 'remains of Roman pillars' in the verge near the junction between A15 and A4 at Pernis: the 'Dorische zuilen' [Doric columns] (1990), in which a pillar of the viaduct has been decorated to made to look like a Doric pillar.

At the Holendrecht junction along the A2 between Utrecht and Amsterdam, an object of art was installed that is especially visible to people flying overhead. The terrains between the main ramps are not treated as remainder areas, but considered part of the 'mobility area': there are three high earth walls in the shape of an apple, pear and banana in which deep grooves have been cut. It is an example of Land Art. Since the slope of the artwork is locally steeper than the natural slope of earth, the earth of which the objects of art are made up is elevated in layers on the basis of the cover or envelope method (Rebel and Meisner, 2001). The earth walls are densely covered with Salix arenaria. To the south of the objects of art, watercourses, reed areas and terrestrial vegetation in strips have been added to the terrain, which express the rural location and the local allotment pattern. They mainly serve for water-storage purposes.

Near Almere, on the junction of the A6 and A27, six, and seven-metre high, elephants of shotcrete have been installed (1999).

Near the Velperbroek junction along the A325, a 'dancing square' was installed in 1987, a blue steel 'square' that changes in shape as motorists watch it in their mirrors.

An artwork by Hans Koetsier (1986) at the Velperbroek junction combines parallel low earth embankments and gullies and plantation. Its purpose was to serve as the 'gateway to the Netherlands'. As a result of the installation of acoustic baffles, hardly any view remains from the motorway to the junction. However, a good view can still be obtained from the roundabout.

Krijn Giezen created an acoustic baffle of waste material (stones, pieces of asphalt, soil, wood and other organic material) stored inside a cage with iron bars having a mesh width of 15x15 cm. Its objective was to form a 'botanic' wall. Its sinus shape lends it a dynamic appearance while the object offers a variety of environments (light, dark dry, wet) for plants and animals (Figure 17).

On Zuid-Beveland near the Vlake tunnel, a number of 'bomb craters' (official name: 'paddenpoelen' [toad pools]) have been created in the earth that was dug out for the tunnel and the widening of the canal through Zuid-Beveland. New bridges were built for the provincial road and the railway line. In a 'remainder area' of approximately 7 acres, designer H. Volkers created a number of round basins of equal size and depth in a regular pattern, surrounded by a little dyke. Although 'autonomous' designs sometimes become the object of discussion, they can play an important role in making certain locations look more attractive and increasing their ecological value. In this way, wet and dry environmental circumstances are brought about with various levels of exposure that offer living conditions for a variety of organisms.

In the United States, a number of artists have founded an eco-art movement. Many of the artists are concerned with making natural processes transparent to the public and providing them with a sensual experience of those processes. Many of these objects of art are restorative in nature, such as the restoration of a river that was buried by waste, or the 'bringing to life' of the slag hills of Pittsburg that are still virtually unplanted after thirty years.
In the Netherlands as well, people are striving for a synthesis of art, landscape and nature. An example is the 'Look and Feel' project; new objects of art based on this theme have been realised at the Traject De Verbeelding (The Imagination Route) in Zeewolde (www.verbeelding.nl).

Use of Colour
Colours may reinforce, weaken or harmonise a particular atmosphere or character. Colours do seem to affect people's moods, and the appreciation value varies with the age and worldview of the beholder. The Kleurengids Rijkwaterstaat [Directorate-General for Public Works and Water Management Colour Guide] (Van Maanen, 2003) provides an overview of the significance and use of colours with respect to roads, watercourses and all constructions that enable the flow of traffic (viaducts, tunnels, sluices, bridges, aquaducts, junctions). The colour guide provides a large number of examples.
No connection is made with the application of natural materials or natural colour schemes. Natural colours from mineral and plant materials and the imitation of natural colour schemes are to be preferred from a sustainable development and perception point of view (Anonymous, 2002).

Aesthetics of Mobility
In the 1990s there was increasing attention to the value of aesthetics (Houben et al., 2002). Houben (1999) introduced the concept of 'mobility aesthetic' and regards 'mobility' as an activity in itself rather than an intermediary between living, working and recreation. In her opinion vehicles must be regarded as mobile 'rooms with a view'. Moreover, the road should 'tell a story'. The route should emphasize the landscape and add something to it. The concept of a story was not new. During a 1970 symposium on 'De weg naar en door de natuur' [The Road to and through Nature] (Gorter et al., 1971), the significance of the perception of various landscape had already been discussed. This concerned the negative effects of nature and positive appreciation aspects of the road through nature and the landscape. However, not only nature and the landscape were concerned, but also beauty and harmony between construction, the use of materials, expression and the location within the landscape.
From this point of view, the motorway should be seen as a design issue (Houben, 1999): the motorway as a public space within which we travel as motorists. The motorway is not just meant for transportation, but also has an aesthetical dimension. According to Houben (1999), the mobility aesthetic is an aesthetic of the condition of the movements at the time of you are mobile. The variety of landscapes and landscapes elements plays an essential role in this connection (Anonymous, 1999).

However, the concept of 'a room with a view' needs to be put into perspective. It is the same with sustainable building: if buyers are offered the choice between a luxurious bathroom or a sustainable facility, in many cases people will opt for the luxurious bathroom. The car could be a lounge, featuring a state-of-the-art stereo set, a phone, a fax machine and a sensual voice telling you where to turn left or right. It seems as though car is becoming a living room or office moving through the halls (motorways) of a building (the Netherlands).

Relationship between various functions
When placing artwork, we should not only consider the entire integration issue from a technical and economical point of view, but also from a psychological, social and ecological point of view. Apart from achieving harmony and, in some cases, a contrast with the developing landscape, it should be prevented that the relationship between nature, the environment and the surroundings is needlessly disrupted. Achieving better integration of the various aspects will require an area-specific approach in which direct and indirect actors are involved. Not just a small area along the motorway must taken into account, but the entire area if we are to prevent that large

bundles of infrastructure start developing that are unrelated to the surroundings. Hoogeind east of Breda along the A27 is an interesting example of the integration of a noise wall, water-purification (helophyte filter systems), geobotanically interesting vegetation, walking areas, gabions which forms an artistic reference to the former fortification function of Breda: in total a noise barrier landscape (see also page 258 and 259).

An example that was less successful from an ecological and visual-spatial point of view, is the noise barrier on the north side of the A12 near Leidsche Rijn. This is a strict, high dyke made up of waste material and covered with a layer of nutrient-rich soil, an area that is uninteresting from an ecological point of view. Another ecologically uninteresting noise barrier lies north to the A20 separating the Vinex suburb of Nieuw-Terbregge from the A12. Its rigidity is only interrupted by a pavilion made up of crash barriers with a lookout post embedded in an incline of black-grey asphalt, the so-called Observatory. The dyke is made up of waste material and has been converted into a park on the urban side. The pavilion was constructed in analogy to a temporary construction in the Hoeksche Waard which has been built for the purpose of having a possibility being isolated for 24 hours for meditative purposes. In itself, this is an interesting object. It suggests the relationship between standstill and speed through the use of materials that belong to the motorway. Unfortunately, the park is in no way related to the motorway, artwork or suburb.

Often functions are not interconnected. For unclear reasons, seldom design criteria are chosen that reflect functional coherence and the relationship with the environment. Sometimes criteria are chosen that have no relation at all. The time factor plays an important role here. People immediately want the final outcome of the designs, while afforestation has a long development time. Since many people live in urban environments, it is essential to offer them insight into, and experience of, the living, developing ecosystems. Not in the shape of imitations, but rather of biological elements that are designed in such a way that they are adapted to the elements of a constructed environment while ecological and landscape ecological patterns and processes are expressed. Therefore, the aesthetic design must primarily focus on the conditions of the location and the needs of road users. This does not make for free art, but rather an art that is related to the principal, (future) users (man, plants and animals) and basic ecological principles. For a better understanding of the chosen forms, it may be useful to visualize the significance of the various aspects, their coherence as well as the motivations for particular design considerations. Concealing may also be of functional value. For example, along the A2 near Hunsel (between Nederweert and Maasbracht) a 30 m high antenna has been decorated in such a way that it resembles a conifer in order to make it less noticeable.

In France, landscape architect Bernard Lassus created a number of striking designs for rest areas along the motorway (Aire d'Autoroute): a rest area near Crazannes in the Charente and one in Nîmes-Caissargues, constructed between 1989 and 1990. The special aspect of the Nîmes rest area is that it not only offers a view of the city but also invites motorists to visit the city. The space thus created offers elements from the surroundings as well as a formal garden that is perpendicular opposed to the motorway and features a neoclassical façade from the broken-down theatre of Nîmes (Bann, 1999). Many functions have been subtly combined.

Let us consider the relationship between art, civil-engineering objects (such as viaducts) and ecological values from the point of view of making a contribution to the prevention or reduction of the deterioration of the biodiversity. The following scheme (Table 5a, b, c and d) provides an overview of various levels of scale of the (negative and positive) possibilities of developing nature values in the design and implementation stage of motorways.

Use of Herbaceous Plants, Bushes and Trees
In 'Pflanzen Künstwerke' (Bartelsheim, 1999), possible relationships between art, artists and plants are described. Bartelsheim discusses in detail the possibilities in regard to the use of plants by artists who wish express a more intensive relationship with ecological concepts. This approach primarily consists of consciously trying to visualise the negative aspects (erosion, reduced biodiversity, deterioration of the climate) of the use and consumption of natural resources. The use of plants, bushes and trees plays an important role in expressing the fact that there are ways of positively influencing environmental factors such as soil, water and climate, and even of creating more complete ecosystems. In this respect, the main reason is not to vitalise the artwork, but to revitalise nature. Bartelsheim (1999) distinguishes between three levels of integration of ecology and art:

- Involving the landscape, using natural materials from the immediate surroundings, integrating artwork (natural design) into its immediate natural environment.
- Objects of art that visualise natural elements and processes and increase the beholder's awareness of ecological relationships (demonstrating natural qualities).
- Objects of art that raise ecological questions in regard to infrastructure through photography, painting, action or plays (use of multimedia techniques).

What is essential is not restoration per se, but also raising public awareness.
A project in which the threatened European grasslands were central, was the 'Future Garden' project by Harrison (Harrison, 1996). On the roof of the Exhibition Hall in Bonn, five threatened types of grassland were brought together. The cut grass was deposited in the river forelands of the Rhine near Bonn, with the objective of enriching the 'parent grasslands' in Bonn with the seed obtained from the river forelands. On the one hand, a dialogue with the public was created (social-community objective), and on the other hand the project showed the way in which art may contribute to ecological restoration.

During the International Architecture Biennial (2003) in Rotterdam, a 'mobile nature reserve', drove through the city: a city bus designed as a mobile jungle (the 'jungle bus'). The designer (Matton) and the principals saw this as an active designing act. Every city planning design creates its own biotopes for plants and animals (usually pioneers and exotic types); by choosing the right 'natural' starting points and giving shape to them, the city and nature in their mobile form become cultural expressions. Nature is separated from its natural context. However, the question remains whether people are being sent the right message from an educational point of view. Can nature exist if it has been separated from its roots? The project touches on the artificial character of many nature development projects, but also expresses a desire to bring nature closer to the people. The public receives seed that they are to sow. You can question if the selection of the plane tree species was in fact a good choice. However, it is typical of current developments;

Objects of Art	Evaluation
"Earth Sea" (walls and ponds) by Piet Slegers	Interesting from a visual point of view; the ecological quality leaves a lot to be desired.
Traffic junction at Velperbroek by Koetsier	Interesting from an ecological point of view; better quality might be achieved through modifications.
Holendrecht junction by J. Kalfsbeek	Uninteresting from an ecological point of view; better quality may be achieved through modifications.

Table 5a. Influence of Landscape Art on Nature Values at a Landscape Level

"Living house" in Bernisse by Anne Mieke Backer	Use of willows. Although these may be successfully applied in public areas, they have a limited lifespan.
Observation huts in Harderbroek by Krijn Giezen consisting of pressed bales of reeds and a roof made up of sheaves of reeds	Unfortunately, accessibility is limited; could be applied more often. However, there is the danger of fire (vandalism).

Table 5b. The Artist's Influence on the Use of Natural Materials

NAP [Normal Amsterdam Level] project by Van Gasteren	Explores the relationship between sea level and the water level of urban area like Amsterdam.
Water-level gauge glasses in Flevoland (not realised) by Frans Peeters	Explores the relationship between the water level of the IJsselmeer and the water level in agricultural areas in the polder.
Wind organ in Vlissingen and near Petten	Conveys the meaning of wind to the public.

Table 5c. Art Referring to Natural Processes

Acoustic baffle in the shape of a 'botanic wall' along the A15 near Rotterdam by Krijn Giezen	An example of multi-functional design: noise reduction, use of waste material and the growth of vegetation.

Table 5d. Art that Uses Waste Materials (re-use)

the number and burden of exotic plants continues to increase. The stimulus of sowing exotic species places an extra burden on our ecologically valuable environments. Although the plane tree is growing well in cities. 'Exoten langs de snelweg' [Exotic Species Beside the Motorway] (Van Dijk, 2003) contains a plea for the use of exotic plants. The idea was derived from the French A77, where a number of rest areas and parts of the surroundings have been planted with special trees. These particular road sections bear the name of the tree that was used along the route. This shows the influence of landscape architect and dendrologist Piotr Jeziorowski, who invented the concept of the 'autoroute de l'arbre'. He also designed a tree garden near a motorway restaurant that contained six tree rooms. Each room conveys a particular aspect of the importance of trees for man. This type of approach might be used in the Netherlands, in the vicinity of a city. However, in the case of motorways in rural areas, more attention should be paid to the original ecological and biogeographical meaning of the areas that the road runs through.

Conclusions

On the basis of the preceeding paragraphs, the following may be concluded with regard to the relationship between the motorway, art and nature.

Modest use has been made of artists and objects of art during the planning and realisation stage of motorways. It has been found that objects of art are placed locally along motorways, usually in the shape of an object of art that forms a landmark, emphasizes a particular detail or refers to particular characteristics of, or phenomena in, the surroundings.

Hardly any large-scale 'Land Art' projects occur along Dutch motorways. Objects of art with an artistic appearance that also represent a particular function seldom occur.

The verge is considered significant with regard to the experience of the road by the road user. However, this fact is seldom taken into account when it comes to using natural processes and materials or with regard to the role that art can play in this connection.

Barring some exceptions, many activities in the field of the layout of roads, rest areas, carpool locations and service locations are mono-functional in nature.

Let us take an example of how a more multifunctional design is possible.

When designing car parks, rest areas and service locations, more attention should be paid to the combination of functions as well as landscape integration. Such locations should be more easily recognisable to motorists and people living in the neighbourhood. They might feature a shop selling local products, provide information about the surrounding areas and its ecology, offer a good view of the surrounding countryside and be designed according to the local situation. Several places along French motorways may be studied where rest areas are designed in the shape of belvederes and balconies that offer a view of the countryside.

The aforementioned examples confirm the Galatowitsch's (1998) conclusions in an article on ecological design: "art and science are not at opposite ends of the spectrum, but ecological design may be fruitful in creating places to enrich human experience as well as the ecosystem functions and ecological goods and services". Art can play an intermedian role in this respect.

8. Discussion: Towards a Theoretical Framework?

Apart from specific knowledge in regard to the separate areas of civil engineering, environment, nature, landscape, psychology, sociology and economy, greater insight is needed in, on the one hand, the underlying principles for each discipline and, on the other hand, the relationship between these principles, in order to achieve more optimal and integral results in regard to the integration of motorways. In this section, an overview is given of the development of a theoretic foundation in regard to design principles in the integration and design of the motorway and its surroundings.

For the evaluation of the relevancy of the various aspects, the development of the Dutch

motorway network and the phases of the various parts of that network should be taken into account. Van Zelm van Eldik and Heerema (2003) summarised the development on the network level in five phases:
Introduction (construction of routes, based on a network vision of the various generations of national-road plans), junctioning (completion of the total network), up-scaling (adding extra links and increasing the capacity), integration (the network and individual road have been functionally, ecologically and visually integrated into the surroundings) and modifications (external developments may require modifications).

During the evaluation stage, it is also important to involve existing and expected bottlenecks in regard to accessibility, traffic safety and livabliity of the network and in its surroundings; a recent overview was published in the report "Kwaliteit functioneren hoofdwegennet 2003" (Functional Quality of the Motorway Network) (Anonymous, 2003).

When (re)designing landscape as a result of, for example, the construction or reconstruction of motorways, maintaining and developing of spatial quality (Hooimeijer et al., 2001) should be starting points (De Vries and Heerema, 2003); in the cited analysis frameworks, ecology is one of the interests and the soil and human networks have condition-creating and condition-setting significance for occupation by man. From the point of view of a broadly defined sustainable development concept, the vegetation and the associated fauna should be added between 'soil' and 'networks and occupation'. An integral, iterative planning and design framework could be created for the road and its environment. If something is changed within the surroundings, the motorway and verge design will require the same level of evaluation. In actual practice, the characteristic identity of the surroundings and the dominance of the motorway seem to be more important than a fully integrated design.

This section will evaluate to what extent 'building blocks' are available for a theory of motorway integration. A theory should be able to explain reality, provide a simplified model of reality in such a way that hypotheses based on the theory generate falsifiable statements.
In 1991, Van den Toorn (Van den Toorn, 1991) laid down the preliminaries for a theory on the integration of motorways into the landscape. The question of whether the expertise and experience with regard to landscape integration can be described and organised in an unambiguous way and placed within a broader framework will be answered below. Table 6 shows the categorisation by Van den Toorn (1991).

Can the period in which 'the shape of the road' dominates be considered an independent phase? According to Van Winden (1991), what is concerned is actually a division between 'the road within the landscape' and 'the landscape of the road', in which both involve design with great emphasis on visual-landscape aspects. However, an intermediate phase should be used as the emphasis changes throughout the development process from a limited concept of aesthetics to a broader meaning.

Vroom (1988) describes three types of integration: blending, insertion and autonomisation, which fit in the general framework of using design means for the integration of motorways and correspondend to the above-mentioned tripartition.
Similarities and differences may be further clarified through an evaluation of four aspects: objects, assumptions, methods and tools (Van den Toorn, 1991) (see Table 7):

Period	Emphasis	Character	Examples
Before Word War II	The road within the landscape	Integrating the road into the landscape	Sections of the old national road between Amsterdam and Utrecht
From World War II to the 1960s	The shape of the road	Aesthetic care comes first, partly as a result of the development of traffic science	A16 between Rotterdam and Princenhage, A4 between The Hague and Amsterdam, A1 between Hoevelaken and Deventer, The road between Aarlanderveen and Nieuwkoop
From the end of the 1960s to 1991	The road as landscape	The road surface increases; there are more possibilities of using extra land for the landscape plan	A27 between Stichtse brug and Vianen, A58 between Bergen op Zoom and Vlissingen, Everdingen junction, A12/New section Utrecht-Arnhem

Table 6. Development of Landscape Integration (Van den Toorn, 1991)

- objects: specify the scope of the design issue;
- assumptions: determine to a high degree the approach used for solving design issues;
- methods: means for solving problems;
- tools: analysis and problem-solving tools.

On the basis of a closer analysis of the available literature and case studies, an overview is given in Table 8 of the developments between 1990 and 2000. On the basis of the insights gathered from the Wegen naar de Toekomst [Roads to the Future] project and an ecosystem-theoretic approach, it will be predicted how integration may develop in the future. In the case of the 'ecological road', it may concern the restoration of the former landscape-ecological quality, the reinforcement of existing landscape-ecological qualities and the addition of landscape-ecological qualities from the point of view of an ecosystem approach.

New and Additional Significance of Existing Design Means

Figure 18 gives an overview of possible mitigation measures for nature in relation to the different construction types of motorway infrastructures, as an initiative for a more balancing approach of pros and cons.

The eight chosen examples give only a basic idea, as very many different construction types and different means of provisions to increase the permeability to maintain connectivity between habitat patches, are possible. De Boer (1993) gives an overview of pipes, open and closed U-profiles and sheet constructions, which can be situated very deep, deep, half-deep, on surface level, half-rised, rised and very much rised above the surface level; the last options can be in the form of embankments or on piles or columns. The illustrated possibilities of mitigation measures to enhance connectivity give an idea of

Emphasis	Objects	Assumptions	Methods	Tools
The road within the landscape	Plantation	The road disrupts the landscape. This may be remedied through plantation or by reinforcing the landscape; the road is made to match the existing situation	No real method; blending; as little damage as possible	Tree felling permit; Plantation plan; Use of native tree species
The shape of the road	Location line and composition of road profile	Design speed and traffic safety determine the use of plantation; radii of curves dimensioning of road sections; civil-technical and functionalistic aspects	Systemic approach to the road profile (in length and in width) designs	Aesthetic care focusing on the suitability of the road view
The road as landscape	The road as part of the regional landscape or the road landscape	Economic developments increased the significance of the road; the road is increasingly experienced as an autonomous element	More procedural method as a result of new legislation (noise nuisance, environmental impact assessments, etc.)	Integration of the different disciplines, plan formation and procedures

Table 7. Three Types of Landscape Integration (after Van den Toorn, 1991)

mitigation measures for keeping the corridor function for fauna as unimpaired as possible. Beside the given examples many more adjustment possibilities and construction types for use of flora and fauna are available (Trocmé et al., 2003; Luell et al., 2003): Emphasis can be on providing links above the infrastructure (wildlife overpasses, multifunctional overpasses) or below the infrastructure (viaducts, underpasses for large, medium-sized and small mammals, culverts with dry ledges) or reducing mortality by fencing, warning systems, lay-out and maintenance of vegetation or noise barriers, adaptation of kerbs). The choice of the provisions to be selected also depend on the topography and the (groups of) target species, habitat and/or landscape type.

It can be concluded that
- roads on surface level, without mitigation measures for nature is disadvantageous due to habitat loss, disturbance/edge effects, mortality, barrier effects and in some cases corridor function for alien/fast spreading of exotic species which can form a negative impact on the native flora and vegetation;
- roads on an embankment, in spite of strong negative visual effects, give possibilities to make different kinds of fauna passages to reduce the barrier effect, which can vary

Emphasis	Objects	Assumptions	Methods	Tools
Defragmentation of the road versus regarding the road as a technical landscape (the road as an autonomous element)	The elimination of the defragmenting action of the road versus the road as an introvert object.	Reducing the impact on nature and the environment, combating noise nuisance and promoting safety with regard to speed.	Tracé Act/ environmental impact assessment. Mitigation and compensation.	Environmental impact assessment reports; acoustic baffles; fauna passages.
The road of the future (according to WnT); electronic highway	The road as a technical, dynamic system; the road as an autonomous system; the road as a hyper-object with several points of contact at the local level.	Increase of mobility / mobility is fun. From a functional and visual point of view the road no longer forms part of the area it runs through.	Closed technical system (road signs, traffic signals, information, noise reduction).	Carpooling; Transferia; Computer-driven; Dynamic traffic management; Intelligent systems; Transferia.
The ecological road on the basis of ecosystem-theoretical starting points	The local level, the regional level, the supra-regional level and the corridor within a coherent framework: the road as ecosystem at various levels of scale.	Ecological approach on the basis of ecological engineering principles and nature engineering maintenance. Functional combination nature and technology (ecological engineering) and advantages for both man and nature; independence and coherence with the surroundings.	Road ecology or infrastructural ecology as a new field of knowledge and the development of methods. Road ecosystems as a conceptual framework.	Ecosystem goods and services; e.g. bio-filter systems with production and nature value.

Table 8. Developments Between 1990 and 2000 and a Further Outlook

from small to very large underpasses;
- roads on wide viaduct or a road on piles or columns give, in spite of negative visual effects, positive social and positive landscape-ecological effects (in most cases noise screens are needed, but they do not increase the fragmentation effects, if measures are taken to prevent birdkills. Preference should be given to 'light' structures instead of robust massive pile constructions.
- Roads in tunnels provide no negative visible, social or landscape-ecological effects; in some situations effects on the hydrology can be expected. When the tunnel elements are sunk locally or are constructed in place local negative effects can arise.

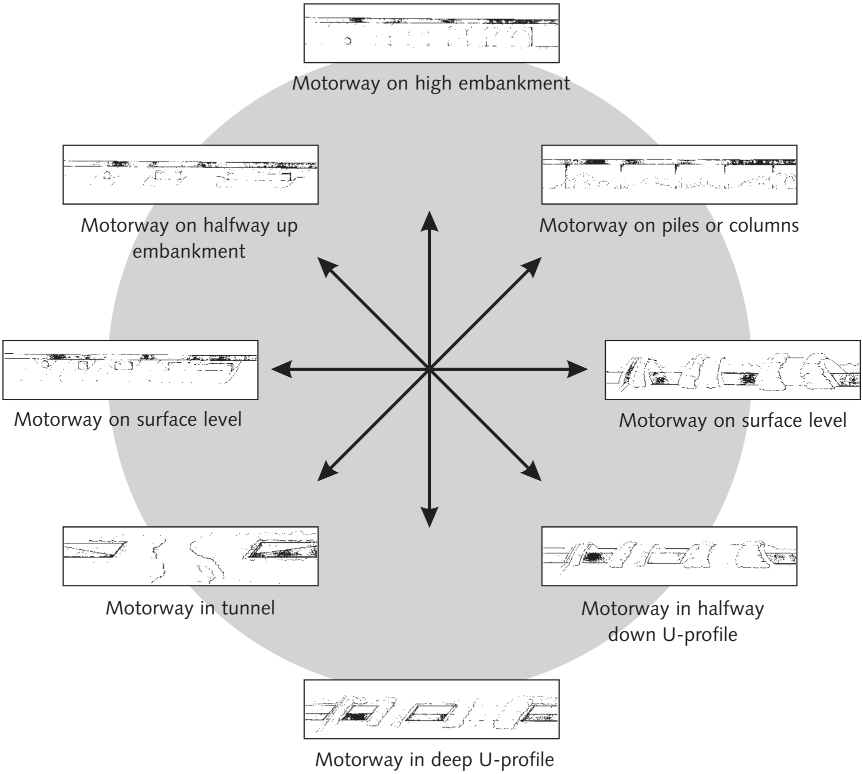


Figure 18. Different construction types of motorway infrastructure in relation to different sized mitigation measures for nature.

Explanation of figure 18:
Beside the classification of landscape design options of motorways on surface level: to camouflage the road in the landscape, to integrate the road with the surrounding landscape or to make the road independent of its surroundings, it is possible to vary the height of the infrastructure to solve part of the environmental and social effects of the road and the traffic. Beside the situation on surface level the infrastructure can be placed on a height, 'half'height embankment or can be constructed on piles (as a long viaduct) or can be brought under the ground (via a bored tunnel, with tunnel elements or cut-and-cover tunnel concept) on different levels of depth. Within the mentioned options three types of constructiontypes for the infrastructure can be distinguished: pipe, U-profile (with or without cover) or sheet. The shown mitigation measures can vary in each situation in size.

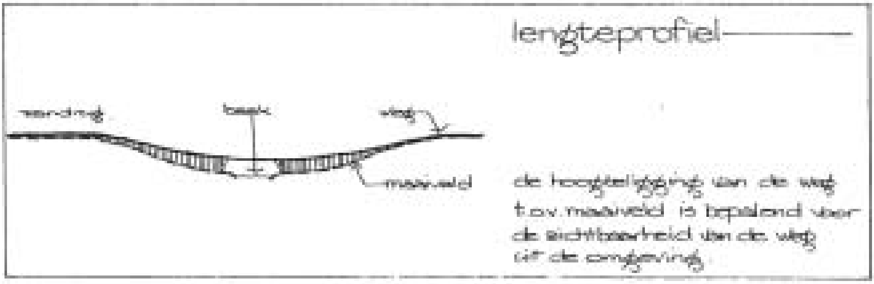
Type of terrain	Design means	Visual properties	Ecological significance	Ecological engineering significance
Water- and bankvegetation	Pools and ponds. Verge ditches. Gradient-rich zones.	Spatial effect. Reflections of light. Gradual transitions.	Swamp and water plants; fishes; reproduction biotope for amphibians and insects.	Purification of the run-off by means of helophyte filtering systems, production of useful biomass and value of biodiversity
Terrestrial herbaceous vegetation	Grassy verges in varying widths and ecological quality. Gentle and steep slopes.	Open. 'Resolving' difference in height. Increasing visual functioning.	Habitat for grassy vegetation; Entomofauna (butterflies, grass-hoppers, wild bees) and small mammals.	Combating of erosion and practical use of biomass; biodiversity
Shrub vegetation	Thickets to increase vertical diversity on grassy verges. Bushes for guiding fauna.	Soften hard infrastructure lines	Diversity of indigenous bushes: broom, Salix arenaria, willow, barberry, hawthorn, blackthorn, blackberry; entomo-fauna; birds.	Catching and purification of air pollution; biodiversity.
Hedges	Parallel hedges between roads and cycle paths. Hedges in median strips	Protect against lights. Traffic guidance.	Biodiversity	Biodiversity. Catching air pollution
Forest (closed plantation; tree layer, bush layer, herbaceous layer)	Forest as a connection with surrounding forests and as an autonomous unit.	Provide for visibility of exits. Reduce visual nuisance.	Diversity of tree and bush species: pine trees, oak trees, beech trees, hornbeam trees, ash trees, willow trees; birds, insects and mammals.	Biodiversity; ecosystem goods and services
Trees	Trees in rows. Trees in groups.	Planted avenue formation. Spatial variety, guiding and marking.	Variety of tree species; insects, birds and guiding function for bats.	Catch and purification of air pollutants, biodiversity; ecological goods and services.
Treemeadows	Trees planted in strict pattern in grassland.	Accentuation and marking, often applied in loops of inter-sections of motorways.	Uninteresting from an ecological point of view.	Catch and purification of air pollutants.

Type of terrain	Design means	Visual properties	Ecological significance	Ecological engineering significance
Plantings rich in structure	Planting trees and bushes in a 'random' set-up with many internal and external transitions. Promoting spontaneous development of bushes and trees.	Softens hard infrastructure lines. Vista points.	Variety of tree and bush species; gradient-rich structures; birds, entomofauna.	Catch and purification of air pollutants; biodiversity
Earth walls	Earth walls in various sizes and shapes to reduce noise impacts.	Visual separation in the median verge, as noise barrier, as division between road, rest areas and parking lots.	Grassy, bush and tree-like vegetation; gradient-rich situations depending on relief, exposure and steepness.	Combating noise nuisance; biodiversity
Civil engineering objects (viaducts)	Eco-'wallpaper'. Eco-lines. Eco-points. Eco-surfaces.	Softens large concrete surfaces	Point and linear habitat patches and corridor function for plants and animals.	Combinating of functions

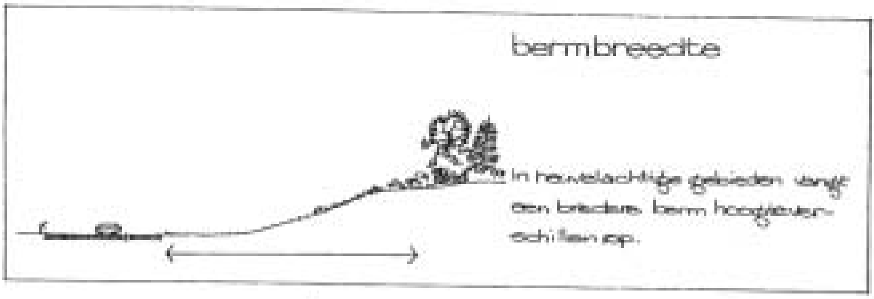
Table 9. Terrain Types, Design Means, Visual Properties and Ecological Significance Combined with the Significance from Ecological Engineering Point of View

Table 9 provides an overview of the most common types of terrain, design means and visual properties and ecological significance, with the addition of application according to the broad concept of nature engineering or ecological engineering that are to be applied in the design and drawing up of landscape and layout plans. During the implementation stage, the large scale of the motorway should be taken into account in order to prevent that a 'Garden of Eden to the square centimetre" is realized that is not longer maintainable. Other means are available as well, such as road furniture with an ecological function, overgrown or 'green' roofs of buildings in the vicinity of the road as well as Land Art and Land Art-like objects that may play a role in the reinforcing the integration of a more ecologically -oriented motorways.

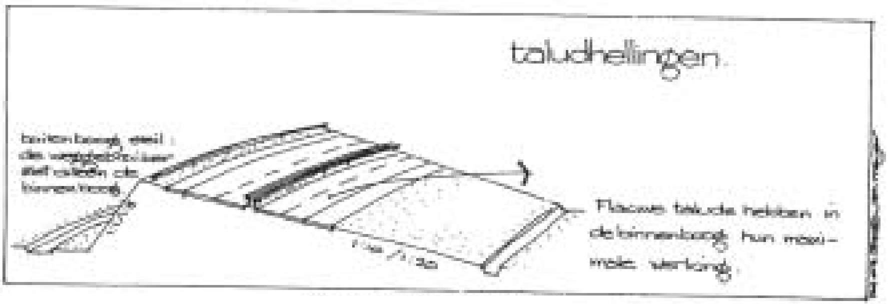
The broad use and further development of the above mentioned design means may contribute to the improvement of the quality of living conditions, including appreciation factors on a route and network level. Also the quality of motorways may be improved by using the design means throughout the planning and design process. What is involved is designing quality (De Vries and Heerema, 2003), in this case the space as a condition-creating environment for the promotion of the ecologically functioning of the motorway and its surroundings. Figure 19 illustrates this by means of a number existing design means that should be further developed into a full set of ecological engineering means (like air-purifying activity of plantation, helophyte filtering



The design mean longitudinal section



The design mean verge width



The design mean slope

Figure 19. Design Instrument Longitudinal Sections, Verge Width and Slope (from Cursus Beheer Groenvoorzieningen [Course Management of 'Green' Provisions] ; editor-in-chief J. van der Sluijs)

systems, “green” acoustic baffles with air-purifying properties).

Looking Ahead
In the next few years, combinations of grey networks, grey-green junctions and green-blue structures will become more prominent. Hover-trains in motorway verges, HSL [High Speed Line] connections, interregional connections (sometimes in bundled form): heavy bundles require ‘heavy’ measures (Heerema and De Visser, 2002): infra-polders (long, stretched, deep laying parts of land), large-scale under-tunnelling, e.g. for the development of wet ecological axis (e.g. a robust connection between Bodegraven, Driebruggen and Haastrecht; east of Gouda).

Infrastructure on piles may also be considered instead of infrastructure on ground level for the restoration of vulnerable nature areas, such as the motorway through the former Beekberger-woud and the provincial road through the Ankeveense Plassen in the province of North Holland. Traditionally in areas with less supporting strength of the (sub)soil, infra-structure was built on earth embankments, but these have a number of disadvantages for nature and landscape. This should be reconsidered in the light of expected (large-scale) measures in the field of water management (retention basins for water provision and flood prevention) and reconnecting of areas of ecological value.

Extra attention may also be needed for innovations that may be found, e.g. in the *Roads to the Future* project. The first phase of this project was primarily aimed at technical issues (such as road surfaces of the future). Later there is more attention to multi-functionality and the surroundings (such as the proposed project with regard to the rest areas of the future, which also may focus on the production and use of sustainable renewable materials), but also interest in environmental issues like studies about the self-cleaning road surfaces, as well as visions about the role of art along motorways. As a mind-experiment we may see in the future the full integration of infrastructure problems and solutions both above and below ground level of road and rail transportation on various levels of scale, including the spatial quality, and in relation to an ecosystem framework in which the infrastructure and the surroundings are seen as a coherent functioning whole.

An inspiratory booklet about motorways of the future ‘Ik woon aan de wereldweg’ [I Live Along the Global Road] (Anonymous, 2002) which has been published by the Road to the Future Project, presents many ideas and designs with regard to this search for innovations for the distant future (2030) of the physical infrastructure, albeit still in the shape of ‘the art of getting lost’.
It concerns the following issues (in random order):

- energy from the green areas;
- wood from large-scale plantation;
- bio-filters;
- bio-verges;
- electricity from road surfaces;
- wind-energy generation in the median strip;
- air and water purification installation under the road;
- acoustic baffles in or on the road;
- anti-noise protection;
- electricity supplied to the electric car from the crash barrier;
- covered roads;
- multifunctional roads;
- multi-layered roads;
- low-energy and low-emission roads;
- smart roads and vehicles;
- modular road surface;

- the car as a mobile sensor;
- dynamic road profile.

In the theoretical framework that is to be developed, other aspects will also play a role, such as the continuing internationalisation (with a greater significance of the hinterland connections), urban developments and business sites along and over the motorway and advanced dynamic traffic management with toll roads or pay-per-kilometre systems. It may be expected that motorways will also often become bundled with other more dynamic infrastructures. These systems will become increasingly complex.

More and more, the increasingly dynamic character of society will be taken into account. This concerns ideas on how to visualise the continuous change in technical landscapes (harbour sites, industrial sites, agricultural production areas) in the design as well. This concerns dynamic and continuous changes and also the way in which nature responds with spontaneous development. Often, these are systems with a high level of dynamism and great flexibility. The question is how dynamic processes may be used for the reinforcement of the individual character; this does not concern a final image, but rather change as a permanent value (Kalfsbeek et al., 2002). It is important to steer spontaneous processes through design and management in such a way that no nature reservations on roadside verges are created with all the policy implications that would imply. Still, an ecologically valuable terrain may evolve that can also provide man with ecosystem goods and services, beside the reservation of sufficient space for nature conservation and nature development areas, primarily aimed for the conservation and development of nature values. In both approaches to nature in specific situations, the intrinsic value is concerned (which can be partly reflected in the itz-value, i = international significance , t = trend: the species shows a negative trend in the Netherlands and z: the species is rare in the Netherlands), perception value (identity, diversity, legibility, interpretation) and user value (functional suitability, ecological use, effectiveness, accessibility, guiding activity), but each situation with a different emphasis. By defining existing and potential ecological qualities, as well as making them visible and negotiable, so that the levels may be determined with the involved parties (Van Leeuwen and Weernekens, 1999).

Considering the many new forms of giving meaning to the motorway, the available framework of landscape integration with the known design instruments requires new design concepts.

In Holland Avenue (Anonymous, 2002), an impression is given of the design 'terms, tools and strategies'. The terms, tools and strategies relate to the visual 'intake' of the road user and does not only regard the motorway as a means of moving from A to B, but will also become an environment in itself: a place for humans to be. The motorist's view from the road forms the basis for the so-called Rondje Randstad [A Trip Around the Randstad] case study. An overview is given of the situation of the motorway, verge and surroundings while driving from Delft, to The Hague, Amsterdam, Utrecht, Rotterdam and back to Delft. In this connection, the verge is considered no man's land or a 'non-location'. According to the study, it seems unintended and lies open and unused. However, road users consider the experience of the verge essential. One also forget that other organisms exist on this planet (such as plants and animals that form a complex combination of roadverge ecosystems that are connected to the surrounding and, based on comparative ecological studies, are extremely valuable to the Dutch landscape. The study proposes two design strategies:

- Allow the verge to disappear: build directly along the motorway;
- Add new functions to the road that are independent to the motorway or its surroundings (windmills, cemeteries, plantation or a fields of flowering poppies near exits).

For the design of the surroundings, in the framework of Holland Avenue a distinction is made between:

- open landscape vistas;
- urban vistas.

The trip around the Randstad was photographed and analysed in order to record the visual experience of motorists. In itself, this is an interesting approach, but when using the data the local ecological significance (in the sense of abiotic circumstances, plant and animal species, landscape-forming patterns and processes) is essential. This meaning cannot be gleaned from pictures, and values therefore should not be dismissed as 'unplanned'.

Since increasingly less space is available in the Netherlands and increasingly large-scale infrastructure bundles will determine the landscape, considering on and realising provisions with a combination of functions for relieving the pressure on the landscape: in this connection, this involves primarily combinations of utility functions and natural functions and ecosystem services in the shape of multiple use of space.

In the framework of bottlenecks between large-scale ecological structures (EHS) and road and railway infrastructure, so-called grey-green junctions are developed as locations where infrastructure and ecological connections are joined. For the eastern part of Venlo, a study was made into a robust combination of infrastructure and ecological structures. A distinction was made between an underground layer of infrastructure, a top layer at ground level and an eco-layer as a green roof (Groot et al., 2002). These ideas are currently also being worked out in other locations, including in the Gooi, in which an ecoduct is being designed with an office of a multinational company. The director's chamber is planned on top of the ecoduct and is to offer a view over the ecoduct as an expression of the 'green' company philosophy.

From a nature conservation and nature development point of view, it is relevant to know that complex ecosystems with a long development time (woods, high-peat and low-peat areas and heaths) require low dynamics, while 'simple' ecosystems with a short development time (eutrophic waters, beach plains, grasslands, swamps) may be realized in highly dynamic environments. However, what is more important than separation and combination issues is the evaluation of the compatibility of functions. Not just the spatial dynamism (which plays a role in the 'casco concept') is important, but also the conditional and positional factors (Vissers et al., 1995).
The conditional harmonisation of functions in a particular location is determined by:

- the properties of the location: the soil, ground and surface water and the vegetation with the associated fauna;
- the requirements of each of the various functions.

The positional harmonisation is the harmonisation between various functions on different locations that have spatial relationships (seepage, infiltration, emission and deposition of substances and animal movements) (Vissers et al., 1995).
There are many examples of combinations of

functions that have been applied to road infrastructure, e.g. in verges, ditches, side banks, rest areas and within and outside motorway junctions. Considering the turnover rate of these habitat patches along the road (usually circa 15 years), combination with ecosystems with a relatively short development cycle is useful, such as grassland vegetation, wetland-type vegetation, bushes, low-growing woodlands, thickets, boscages and waterways.

In the course of time, other functions have been added, such as small-scale and large-scale mitigating measures and extra functions such as the purifying activity of wetland vegetation for the benefit of filtering out pollutants. However, the possibilities in the form of ecological engineering are not exhausted yet. For instance, verge ditches and hinterland may be combined through helophyte-filter fields that may also yield products (bulrushes, willow and reeds), civil engineering works may be provided with 'eco-points', 'eco-wallpaper', 'eco-ledges' and 'eco-strips' (Van den Bos et al., 2000), and the roofs of (service) buildings near the road may be provided with vegetation with ecological values. 'Real' objects of art may also represent interesting ecological values by consciously taking ecological potential into account.
More additions to the aforementioned designs and ideas may be made from the point of view of sustainability – this would concern areas both in and outside the urban sphere -: layout for the benefit of sustainable energy generation, water management (retention), local food production, the promotion of biodiversity, the promotion of social cohesion, the restoration of ecosystem processes, the use of plants for the benefit of the production of fibres, deys, soaps, wood, foodstuffs, urban agriculture, bio-filters and the associated 'green jobs', employment in the field of 'green' services.

Points of special interest
Subjects that require special attention in the near future in regard to the integration of motorways:

Large-scale:
- the increase of the width of motorways and other infrastructure;
- the need for emphasis of the proper form characteristics of large linear elements and point elements (viaducts);
- the development of new types of motorways, e.g. with pay-lanes, lanes with separated regional and long-distance traffic;
- infra-polders;
- large-scale bridges over motorways;
- multi-modal junctions (transferia, rest area);
- multiple use of space;
- grey/green/blue junctions;
- experience of the road section's design and the cross section by the road users and people living in the neighbourhood.

Small-scale:
- further fragmentation (as a result of more infrastructure and increasingly small mesh width of road networks) of patterns and processes that are important from a historical-landscape and landscape-ecological point of view, including the development of new de-fragmentation measures;
- adjacent parallel strips along motorways can have a role for improving the ecological quality with compensation for the owner or user.
- locally and regionally characteristic social-economic developments.

To summarise, it may be said that solutions are required for the organising operation of local, regional and supra-regional infrastructure with individual forms, new solutions for the elimination of the barrier effects and other negative effects as well as the use of development opportunities with regard to nature and the landscape.

Education and research

Within the field of *education and research*, extra attention is required for the landscape-ecological integration of infrastructure. As a result of the strong separation between disciplines, the technical aspect gets the upper hand in the troubleshooting of traffic and transportation issues.

Extra attention should be give to the following topics:

- Transferring expertise and experience in regard to the relationship between infrastructure and the surroundings in the broad sense to a new generation and formulating proposals for research into new approaches.
- Bringing civil engineering, garden and landscape architecture and sustainable building closer together.
- Focusing on aspects of perception and experience in regard to movement and observation of objects within the landscape and of natural processes.
- Combating noise nuisance and mitigating other undesired environmental effects, design of rest areas, design of ecoducts, constructing elevated and sunk roads, transferia and carpool systems, integration of roads and watercourses, ecological building on the basis of ecological engineering principles, and a better harmonisation of sign-posting, signalling and automation systems, where possible in combination with other functions.
- A scientific foundation and further theory building in the field of landscape-ecological integration and design of road and railway infrastructure.

It is important to develop a large number of possible solutions for coupling the increasingly autonomous road systems to the autonomy of the environment. This will bring about harmonised super-systems in which there is room for both social and economical values and ecological values may continue to develop.

This requires a total spatial design and layout concept of the road and its surroundings, together with the region through which the road traverses. Apart from the primary transportation function, motorway user requires: rest, variety, legibility, recognizability, orientation, experience and safety. People living in the neighbourhood of the road demand attention for barrier effects, noise nuisance and air pollution. Plants and animals require: sustainable habitat patches, corridors and a large measure of permeability of the infrastructure.

Discussion

We must do away with the illusion that motorways are constructed to last forever. We need to make a conscious choice whether to run after the facts to a greater or lesser degree, or to offer forward-looking solutions that also take into account starting points for sustainable ecosystems that are not influenced by the spirit of the times or fashionable considerations (‘mobility is fun’, ‘the environment is out’, etc.).

The *result of the integration* of motorways is determined by:

Visions (on aesthetics, traffic safety, ecology);

Opinions (whether or not to use poplars in the Dutch landscape);

Use of language (remaining areas or a verge full of flowers);

Individual charismatic personalities;

Local circumstances and

Financial means for a large-hearted integration.

Taking into account the period of the last 100 years, one may say that from the beginning of the 20th century until World War II, plantation was central to the integration of roads. After that period, aesthetics and safety aspects came to the fore and the landscape in the broad sense was taken into consideration. Through the technical transition from straight roads to a more 'flowing' road line and the increased insight into the composition of the landscape, more integration in the existing landscape took place. The rapid increase of the intensity of traffic led to motorway expansions, the addition of road furniture (portals; telecommunication masts) and the installation of acoustic baffles at the local level, which in turn resulted in the autonomisation of the motorway. This autonomisation significantly reduced the visibility from the road of striking, area-specific elements. The route that was carefully designed in the past as well as providing a view on the characteristics of the landscape gradually disappeared. Nevertheless, in the Netherlands a number of sections of roads also may be considered from a landscape integration point of view as 'hotspots' that have great significance from a landscape, historical and visual point of view.

In the planning, design, (re)construction, management and maintenance of motorway infrastructure, politics, policy and implementation are faced with the challenge of taking into account:

- integral spatial quality;
- the road from the road user's point of view;
- the road from the point of view of people living in the neighbourhood;
- the road as ecological and landscape-ecological entity;
- the road as a work of art;
- the road as an architectural object.

The challenge is to promote a synthesis between spatial and infrastructure planning, economical and social developments, city planning, architecture, historical-landscape and cultural-historical values and ecological functionality: the question is how to move from an approach in which each discipline is applied separately to an area-oriented, transdisciplinary infrastructure planning. One of the options is to look for possibilities for combining speed, globalised, large scale, macro-economic and social-economic aspects of infrastructure with slowness, regional, small-scale, regional- and local-economic and social-psychological aspects, while taking into account the specific (landscape) ecological patterns and processes.

The general conclusion would be that it seems as if the infrastructure is increasingly becoming an example of technological dominance, a type of intervention in the landscape and adaptation of ecosystems to our existence, in which less attention is given to the ecological value, with the exception of local compensatory measures and ecological building on the basis of ecological engineering. Ecosystems are complex in nature; although we are gaining more and more insight into its functionality, much knowledge is still lacking. What we get to see is rather the 'surface' of ecosystems (Wood, 1989).

Because less and less links are made between man and nature, ecological and technological processes should be made more visible in the designs (Thayer, 1994, 1998). The assumption is that what we see and experience may say a lot about the way we deal with the environment and the degree of sustainable activities. Aesthetics play an important role in man's visualisation and sensory perception, but a responsible design approach would also include a 'healing' dimension – a correction process within the landscape based on a normative point of view – (Thayer, 1998).

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6. Infrastructure, ecology and art

Hein van Bohemen

Abstract
In keeping with the 'industrial ecology' metaphor, roads and railways should be regarded as forming an ecosystem with their surroundings, just like industrial systems (factory premises, manufacturing industries) that have had to start functioning as ecosystems in which the flow of energy, water, raw materials and waste products has been made to recycle as far as possible. In this type of system approach, the flow of material, transport, emissions and energy and the habitats of plants and animals are geographically, systematically and functionally integrated, especially when they are based on a greater degree of interweaving between man and nature than is currently the case. In short, a new way of looking at the meaning of ecology in relation to the physical infrastructure.
In the chapter, examples are given about the practical implication of linking ecological patterns and processes within the design process of civil engineering object, as well as the possible contribution of art in forming infrastructural landscapes.

1. Introduction

This chapter is a review of case studies which take a different look at the meaning of ecology in relation to the physical infrastructure, such as roads and railways.

We propose the term 'infrastructural ecology' as coordinating framework. Three case studies demonstrate how to improve adjustment of various ecological functions in the planning, designing and implementing phases of an infrastructural project within an area. Although the emphasis is largely on ecology, one should not forget that in incorporating infrastructure into the landscape, it is important to take as many as possible relevant interests into account, including the cost/benefit ratio of proposed measures.

The Netherlands, as well as many highly populated areas in the world, is becoming increasingly determined by the infrastructure - motorways, provincial roads, railways, telecommunication facilities, waterways, airports. These represent an important characteristic of much of our landscape. It is difficult to imagine our life without them now. In order to achieve as efficient as possible an incorporation of the infrastructure into our landscape, an increasing amount of attention is being paid to aspects, such as durability, liveability and sustainability. Due to the limited extent to which this is done, because emphasis is placed either on architectural design, visual landscape, noise, ecology, re-use of materials or social aspects and too little or only limited cohesion is achieved, little use is made of more adjusted, integrated solutions to problems in the field of incorporating infrastructure into the landscape.

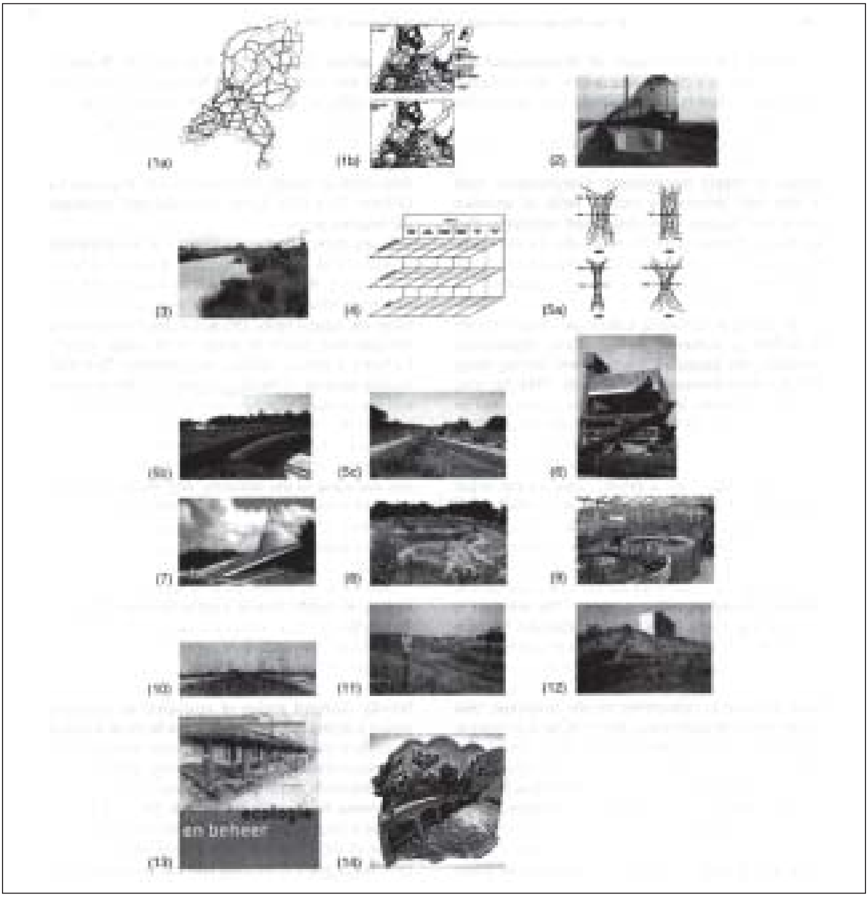
All sorts of rapid developments in the field of mobility, which often have a monofunctional character, are having increasingly greater effects, both positive and negative. Faster traffic leads to a greater spread of living, working and recreation, which in turn generates more transport requirements. The growth in the population and the growth in the economy have led to extensions in the main ports and new connections with the surrounding countries. We should not forget that although the motorway infrastructure takes up approximately 1.5% of the Dutch surface area, annoyance can stretch out to 20-25% of the surface area (Reijnen, 1995). This annoyance is made up of noise, air, ground and water pollution and considerable effects on nature (fragmentation of nature reserves, fauna victims, the effects of noise and lighting on breeding birds (Figs. 1-14).

At the same time, the roadside verges, ditches and banks of ditches alongside roads and railway infrastructure also harbour ecologically interesting plants and animals (Keizer et al., 1998). Approximately 800 of the ca. 1400 plant species which can be found in The Netherlands grow on roadside verges and approximately 1000 alongside the railways, thereby making an important contribution to the biodiversity of the whole of The Netherlands. Not only species that are generally found in The Netherlands, but also generally less common and even fairly rare species have been found. Approximately 160 plant species can be found almost exclusively in roadside verges, partly as a result of the intensive agricultural use that is made of the land. In farming, the diversity of species that used to be present has been reduced to a small number of species that can be regarded as highly productive from the point of view of biomass production. Roadside verges are clearly fulfilling a refuge function for a number of plant species.

The roadside verge forms a suitable habitat for certain groups of creatures, including butterflies, grasshoppers, beetles and dragonflies. Verges can also play a role as a corridor for certain species. In order to increase the corridor effectivity connections should be established where these are lost (Fig. 2). The brochure that was published in 1999 (Verstrael et al., 1999) contains a summary of the importance of the verges of motorways in The Netherlands.

More creative solutions could be formulated in the field of spatial effects of increased mobility, the possibilities of channelling the use of space by means of infrastructure and the possibilities of taking more into account than just the neutralization of negative infrastructure and mobility effects on the environment and ecology. More emphasis should be given to repair the damage done to the environment, nature and the landscape, as well as to developing ecological values. Attention can be given to further improvement in the quality of the habitat provided by roadside verges and canal banks. Dozens of successful ecological engineering projects involving restoration and creation of habitats for plants and animals have been carried out within traffic loops, besides and under flyovers and alongside roads.

Another way of increasing ecological value could be an extra strip parallel to the infrastructure that would have to be designed and managed as a kind of nature habitat. The 'greenway' idea could be applied on various different scales of size. One could even imagine solutions which are actually based upon the infrastructure's potential for annoyance for living, working, nature and the landscape instead of combating that annoyance (Van Bergen et al., 1999). There are also ecological possibilities in the field of multiple use of space. The multiple use of space involves intertwining (combining), stacking (making use of the space above and below surface level) and making functions more flexible (combining within time), with the aim of raising the quality of the space. In order to improve the adjustment of the various aspects with one another, the following three-way division of infrastructure can be useful: man-made physical infrastructure, natural infrastructure and social infrastructure (Flink, 1997), where the infrastructure in this approach is given a broad formulation. Essential to such an approach to reality is that attention is given simultaneously to the various ways of looking at problems and solutions, including the multitude of



Figs. 1-14. (1a) Surface area affected bij noise pollution due to traffic on motorways in The Netherlands. (1b) Detail maps of surfaces which are effected by sound pollution. (2) Continuous railway verges: the photo taken on a railway viaduct shows a green verge linking the verges on both sides of the viaduct. (3) New habitats along highways and railways by ecological engineering techniques. (4) Sustainability indicator diagram. (5a) De-fragmentation measures: different designs of ecoducts. (5b) Ecoduct. (5c) Ecoduct. (6) Dutch submission to Expo 2000. (7) A lawn on the roof of the library of the Technical University Delft. (8) Helophyte filter A1. (9) Some tanks in a solar aquatics or 'living machine" system. (10) Planned underpass motorway A2 between Amsterdam and Utrecht. (11) Noise barrier landscape. (12) Gabions filled with limestone in a noise barrier. (13) Art, ecology and management. (14) An art's impression of integrating animal and human mobility over a watercourse.
(from Van Bohemen, 2002; figure 1a and 1b from Reijnen, 1995; photograph 2 from G.A. Morel)

interactions between the various focuses of attention.

A co-ordinating framework in bringing together the three fields mentioned could be the concept of the citydome (de Boer et al., 1996). The aim of the citydome method is to make profit and loss visible by making use of the supply of environmental and natural goods in a certain area (a city). The metaphorical dome, which is put figuratively over a city, is the reference point for setting targets.

Formulating emission ceilings for various environmental loads in a certain area is a stimulus for aiming policy at supply management. Compensation both within and between the various fields of attention could thus become more visible and negotiable. Part of the production capacity could also be used economically for extending the capital/quality of nature and the environment instead of for consumption (de Boer et al., 1996).

In 'The Ever-Changing Landscape', Peters (2000) described a common feeling about impressions regarding the landscape when he was driving along the A2 from Amsterdam to Utrecht. "On the way, there are precious few places where a driver has an unrestricted view of the landscape of marshy meadows with an electricity pylon at fixed distances. It is not exactly what you would call beautiful. If you are lucky, you might see a heron." One cannot argue about taste, but we will return later to whether the same sad story applies everywhere. It is a fact that the landscape along some roads is being increasingly governed by so-called 'sight' locations (high-profile spots alongside motorways for attracting attention to businesses) and distribution sheds. The question is whether there aren't any cleverer solutions for such provisions with better results for nature and the landscape.

Involving art and aesthetics opens up new channels for man - the 'me' person - to ask that attention be given to (alterations in) the landscape, thus increasing their importance. By working as a catalyst, apart from exposing the visual value, it could also make other important factors (emotional value) 'visible' and thus increase our involvement and well-being.

The aesthetic function should be an integral factor in spatial planning (Jumelet and Beeldman, 1999). It may be possible to develop aesthetics for mobility, with the car seat or the train compartment as 'room with a view' (Houben, 1999). Roads would no longer be just for transport but possess an aesthetic dimension as well. The aesthetics of mobility are, according to Houben (1999), the aesthetics of being in a state of movement such as that in which you find yourself at those moments when you are mobile. The 'VROM- Raad' (Council of the Ministry of the Environment), in their advice contained in "Corridors in Balance" (1999), mention six types of landscape, which cover all the different scales of city and open landscape, for designing motorways. Three types are related to the landscape outside cities: the open agricultural landscape, the ecoviaduct and the Bali-type. The other three are more urban: the Ruhr area, Las Vegas and La Défense. They form a series from real open landscape till extreme urban.

In searching for other solutions, it is also important to take a look at the significance of the landscape's stratification. Reference is made to the following: the first layer which is made up of soil and water; this forms the natural basis. The second layer is that of the infrastructure which is made up of roads, canals, harbours, railways, stations and pipelines. The third layer is made up of buildings, cities, woods and areas that has not been built-up, open space. The question is whether the first layer does not contain more; soil and water and vegetation, which is made up of plants in combination with the place in which they are growing and according to the hierarchy they themselves have taken on together with the fauna with which they are associated. If we look at an area in this way, it could lead to a different way of spatial planning with more implicit and explicit attention for ecological values.

According to Peters (2000), we should also be looking at stratification in a temporal sense. Different approaches are required for old city centres that have existed for centuries and distribution sheds that either get a new function after 5 years or are demolished. Nature is also subject to temporal stratification. The broadly accepted notion of ecological development makes it seems as though nature can be created within a couple of years. Certain abiotic environmental conditions can indeed be achieved quickly with the aid of environmental techniques. However, some natural ecosystems both inside and outside The Netherlands require a long incubation time. Their development is linked to soil types and hydrological conditions that have taken years to develop and are developing still. These conditions are sometimes related to a process that has lasted from dozens to hundreds and even thousands of years. At the same time many types of nature possess a great capacity to repair themselves.

In ecological terms, patterns and processes can be found in various scales of size. The application of general ecological principles at the level of an ecosystem within the planning, designing and building of infrastructure can lead to the development of solutions to traffic and transport problems that are, ecologically speaking, more sustainable. The following are suggestions that could very well be worked out in more depth in a new discipline, 'infrastructural ecology'. Such knowledge can be made use of when introducing infrastructure and when adjustments are made to the direct surroundings of infrastructure, but also, in particular, when re-developing the entire surroundings of infrastructure that requires construction or improvement.

2. A new way of thinking

A different way of thinking can provide possibilities for achieving a greater degree of ecological sustainability in any further development and adjustments to infrastructure (networks) in relation to the (wider) surroundings. The new way will need to be inspired by the essential characteristics of living systems (Connery, 1999). It is important that the assumptions upon which much infrastructure and other construction work is carried out are made more explicit, expanded and combined with the characteristics and properties of living systems, whilst taking into account plants, people and animals in all their diversity. Taking living systems into account and remaining open to creative processes in creating infrastructure could create a system of infrastructure that is characterized by a greater degree of comprehensiveness, achieves higher aesthetic values and has a higher quality for society. Successes have been achieved in the field of ecological sustainability, both inside and outside The Netherlands, but there is no question yet of a real breakthrough. Here is a random selection.

- On the basis of Dutch Second Transport Structure Plan (Ministry of Transport, 1990) and National Traffic and Transport Plan (Ministry of Transport, concept, 2001), many mitigating measures (Fig. 5) have been carried out successfully and many mitigating measures are still in the pipeline (van Bohemen & Teodorascu, 1997). The brochure "De-Fragmentation: By Bits and Pieces", published in 2001 (Anonymous, 2001), provides a picture of the state of the art with regard to de-fragmentation around the motorways. The aim is to have solved, by 2010, 90% of the bottlenecks formulated on the basis of a confrontation of the motorways and the ecological main structure. In view of the measures taken, it seems that 40% of these bottlenecks had already been solved by 1999: the implementation plan of the Directorate-General of Public Works and Water Management is right on schedule according to the starting points. These figures do look different though when one takes a look not only at the currently chosen species, but also at the functioning of ecosystems (Van Bohemen, 1998).

- The National Package for Sustainable Construction provides many points of departure. A policy resolution in the Dutch National Traffic and Transport Plan (Ministry of Transport, concept, 2001) says that the government should apply the fixed measures for sustainable construction in their entirety prior to 2004 and that prior to 2010 this should also apply to the variable measures in constructing and maintaining civil infrastructure.

- The Dutch submission to the world exhibition in Hannover. The Netherlands stacked up in the form of a building with seven floors, from top to bottom: windmills and water, forests, flowerbeds, green-houses and sand dunes (Fig. 6). The question is whether there is any future for this form of stacking as a way of creating space; in any case it shows that nature can also be given a place in multiple space usage. It is true that for practical reasons essential items are missing, such as helophyte filters (constructed wetlands) for water purification and the positioning of the various layers is exceptionally creative, the design is more a metaphor than a real construction type. But nevertheless it shows a way of thinking of making use of limited space available in a densely populated area.

The present method of planning, designing and constructing roads is highly standardised (Roads Act, guidelines for motorways (ROA) and guidelines for non-motorways (RONA), Programm Durable Safe and generally accepted standardisation of the road infrastructure). It is aimed in particular at the transport function. In future it is possible that not only the product "road" will be subject to evaluation, equally important will be service in the sense of value to society in fact, particularly service in its broadest sense and this includes valuable landscapes, aesthetics, cultural-historical significance and the quality of life in the societies of man, plants and animals, which are being affected (both positively and negatively) by infrastructure, traffic and transport. Instead of thinking in terms of infrastructure, we should be thinking more from the point of view of the region involved. Every region requires more than the standard design of infrastructure that it is currently being given.

Not only does every region require specific attention, but also every local situation. A simple example of a lack of respect for the local situation is the way in which subterranean paths (tunnels) are sometimes designed. A lack of local knowledge, cost savings and the inability of some planners and designers to take into account "the human element" (Connery, 1999) leads to subways that are frightening for pedestrians and cyclists, that is if they are created (usually with a minimum of design) at all.

By developing a different ''way of thinking" in which the functioning of living systems is central, more account will be taken of man and nature, resulting in a quality improvement in the widest sense, as a tangible feeling of cohesion, wholeness or comprehensiveness (Connery, 1999). In The Netherlands, simple facilities in existing subterranean tunnels (such as creating rows littered with tree stumps) have already led to making tunnels that can also be used by certain fauna (amphibians, lizards, insects and weasels).

Another example of where there is room for improvement concerns the construction of noise barriers, a steady growth in The Netherlands from 10 km in 1977 to about 450 km by the end of 1999, in many shapes and sizes. They are efficient for noise reduction, but they are often an impoverishment ecologically and with regard to the appearance of the landscape, excluding the good examples of course. Glass noise barriers can lead to quite a number of victims among birds. German studies have shown that frosted 2 cm vertical stripes at 4 cm intervals can reduce the number of victims considerably.

Gearing the functions better to one another can reduce damage. Instead of putting up a noise barrier along the A27 for combating noise pollution, grass walls were chosen which reduce noise considerably.
Because the ground leading to the road gradually inclines to 1.5 m in height, birds crossing the road are given an upward lift, thus reducing the numbers of victims among birds.
An example of using noise barriers at Hoogeind (Breda), which we are going to discuss later, shows that more valuable facilities are possible when several functions are taken into account, a so called noise-wall landscape.
In the field of high-rise buildings in city areas and at the edge of roads, translating the high-rise situation into ecological preconditions can be an option (Yean, 1999). Such a new way of thinking was developed within the framework of the southern circular motorway around Amsterdam (Koedood and Timmermans 1999). A comparison was drawn with a mountainous region with zones going from high to low. In the top zone one can expect to find the kestrel. The gyr falcon might even return to the city surroundings. At the moment they brood in nesting boxes on cooling towers at power stations. Special cemented nesting stones, special roof tiles or nesting boxes could play a role for the swift. Another possibility is an artificial wall of sand and cement blocks or cement slabs for the sand martin. On flat rooftops, a 'stretch of beach' made up of sand and shells can be constructed to provide a breeding place for the common tern.

Vegetation on the rooftops of buildings and over roads can also make an important contribution to improving the ecology and water management of areas in the countryside and in the city.
Making use of the effects of vegetation can be used to achieve more gradual water drainage. Other advantages are a favourable effect on humidity, increased uptake of CO_2 and release of O_2, increase in the aesthetic design and increase in ecological value.
The ecological perspective on infrastructural systems provides a new possibility for collective research and co-operation and a feeling for more intuitive approaches to the solution of problems (Connery, 1999).

By increasing the involvement of artists as well, infrastructure (networks) can take on an even greater importance for society. This does not mean just involving art as decoration, although this can be a valuable addition to the designs, but the essence of art as a source of intuitive knowledge and the intellectual ability of imagining shapes. Artists are often highly trained in this and this knowledge and experience is often less developed in others.

An example of how artists play a guiding and innovating role can be seen, for example, in the "Mousehole" ("Muizengaatje") project in Rotterdam-Noord, which will be discussed later. An early involvement of artists in design teams can stimulate powerful creative processes, which can lead to unconventional solutions. Some artists are capable of bridging the gap between the public and nature.
In order to promote the development of more integrated approaches to the relationship between nature and the environment together with the infrastructure, traffic and transport, the Road and Hydraulic Engineering Institute of the Dutch Ministry of Transport is working together with a number of foreign partners on the development of a sort of "motorway system", not for replacing existing instruments, such as environmental impact assessment reports, but as an addition and with possibilities for application on the whole procedure of forming ideas up to and including the management and maintenance of infrastructure.

3. Thinking in terms of ecological sustainability

Sustainable development means in the long run finding a balance between systems that have been largely directly affected by man and semi-natural and (more or less) natural ecosystems, instead of weighing up interests and placing the emphasis on the predominantly (anthropocentric) interests of (in decreasing order) legislation, economy, safety, social aspects, beauty, environment and, usually in the last place, nature. The same type of hierarchy can be seen in decisions that have an effect within 1-4 years and decisions that only have an effect in the long term. What is important in sustainable development is finding the balance between technology sustainability and ecology. It is a challenge to link infrastructure's speed. comprehensiveness and quality of being large-scale to slowness, specific local habitat circumstances and small-scale size.
Technological sustainability has a technological or market-adjusted solution to every problem. Quite the contrary, ecological sustainability works together with nature, by integrating human activities with natural patterns and processes (streams, cycles). Both approaches assume the same hypothetical problem, but act upon the basis of different ideologies and beliefs. Insufficient knowledge of each other's (in)capacities leads to continuing along different paths.

Natural resources are becoming increasingly scarce, there is an increase in CO_2, environmental problems are becoming more complex and less simple to solve with the aid of conventional monodisciplinary methods. Ecological engineering, ecotechnology or nature techniques in the widest sense can provide the answer because they are aimed at designing and repairing sustainable ecosystems that can also satisfy man's needs. Emphasis should be placed upon a more holistic approach. Using the ecosystem theory can contribute here.

It is against this background that Thayer (1976) emphasized some years ago the need to make ecology more visible and he spoke of 'visual ecology', "a new sort of aesthetics that will teach people about the value of nature and the possible symbiotic relationship between culture, nature and design. This strategy:
- makes the abstractions that we put onto the land visible and discernible;
- makes complex natural processes visible and comprehensible;

- exposes systems and processes that were previously hidden);
- emphasizes our connection with nature.

In practice, this strategy encompasses making the flow of wind and water, organic decomposition processes, the incidence of light, growth and change visible, tangible and edible."

Put into concrete terms, it involves the following essential ecological principles:
- energy comes from the sun;
- diversity is the basis of the resilience of ecosystems;
- in principle, an ecosystem does not produce any waste matter;
- material is continually re-cycled through ecosystems;
- natural processes can be guided by means of conscious interventions.

Life develops on the basis of the biological foundations: production, consumption and reduction (in particular by means of competition, co-operation, partnership and the formation of networks). When we look at these principles against the background of traffic and transport, next to the currently dominant principles of separatism between modalities (car, bus, train, bicycle and pedestrian), it is especially the principles of competition, co-operation and partnership that need to be expressed more strongly in our society, or as Wang and Yan (1998) put it, it involves the following.

1. Competition, in order to make efficient use of the natural resources and econiches available.
2. Symbiosis between man and nature, between various groups of people and between every ecological unit that has been affected by man and the 'next ecosystem level in line'.
3. Self-reliance in order to perpetuate structural, functional and process stability by means of self-organisation and recycling processes.

4. Thinking in patterns, flows and networks

Landscapes are made up of mosaic-like patterns of landscape elements with various pedological, hydrological and ecological characteristics. From a landscape ecological point of view, landscape mosaics are made up of three elements: habitat patches, corridors and a matrix. The matrix forms the area in which the habitat patches and the corridors can be found.
From an ecological point of view, networks play an important role within the concept of the habitat patch, corridor and matrix approach. An ecological network is a collection of sites with habitats for certain species that are related to one another to a certain degree due to the fact that individuals from these species (can) move from one site to another (van Langevelde, 1999). Ecological networks, such as the Dutch Ecological Main Infrastructure, can contribute to the sustainable survival of biodiversity. The Ecological Main Infrastructure is made up of the following items:

(a) natural core areas where the circumstances are entirely aimed at preservation and management of ecosystems, habitat patches and populations of species;
(b) nature development areas;
(c) corridors or connections: straight landscape elements, broad zones, broad areas designed to be multifunctional and stepping stones;
(d) buffer zones that protect the network of core areas from negative influences.

The Dutch Institute for Forestry and Nature Research (currently known as Alterra) recently described the importance of green arteries throughout man-made landscape (Opdam et al., 2000). Green arteries throughout man-made landscape refers to the interweaving that is formed by giving landscape elements, if they are not necessary for the production of food, other functions (filter function for materials, water retention, opening up an area for recreation, pest regulation in cultivation, habitat for insects that play a role in pollination and reservoir for organisms that are important for natural soil processes). The concept of green arteries can be applied to a number of situations involving roadsides, alongside the more large-scale connecting zones, as a way of increasing the importance of nature outside the Ecological Main infrastructure. The concept of green arteries only works if it is carried out regionally. It is also more suited to solving all sorts of spatial problems in a more regional approach and realising collective aims. If an improved water-retaining capacity is achieved due to green arteries, the local owner of the ground could be paid for the added value from the reduced costs of the district water board. The following question could also be asked, "during road construction how can money for nature compensation be used for strengthening the green arteries?"

Solutions for fragmentation of habitats can be found by looking on various scale levels (continental, national, regional and local) at the possibilities for enlarging the ecological networks, extending the surface area of the units of the network and reducing the resistance of the in-between areas that have a different function. Bottlenecks can be detected when these networks are confronted with the networks that are essential for man. Very extensive studies in this field have been carried out for the main road and rail infrastructure in The Netherlands and in a number of European countries. With the help of mitigating measures, such as ecoducts, badger tunnels, toad tunnels, roe tunnels and raised ledges in culverts can (partially) solve the bottlenecks with regard to the mobility of some species.

The network approach provides an interesting analysis and design instrument, provides possibilities for stimulating ecological sustainability and provides points of departure for promoting innovative solutions to the intersections of ecological and physical and economic main structures (VROM, Department of the Environment, 1999; Hydraulic and Civil Engineering Institute, 1999).

5. Thinking about linking functions: ecological engineering

Apart from conserving and developing ecological values in designing and realising civil-technical objects, such as roads, use can also be made of specific ecological functions. Purifying the polluted water that drains off roads with the aid of natural processes is one possibility (Fig. 8). Nature technique, in the widest sense of the word, ecotechnology, or as it has been called, ecological engineering, has developed in particular from within the field of purifying waste water, but it is now being given an increasingly broader field of application whereby plants and animals help to improve the quality of the environment. Ecological engineering in the broadest sense of the word, can be said to amount to the following.

- A 'beginning of the pipeline' approach: problems are tackled at their source according to the principle of 'prevention, then mitigate, then compensate'.
- Use of energy from the sun and other natural resources.
- Consequent incorporation into natural systems and assuming multifunctionality leads to a clear limitation of environmental

effects and risks to processes and systems.

- A preference for decentralised solutions: those involved have more access to procedures for planning and development.
- Using recycling systems to channel the flow of 'waste' towards other processes (1-3, 20 or 100) multiple re-use; down-cycling, etc.).
- Incorporation into the social-cultural context, whereby ecological principles are put on an equal footing with social and technical basic assumptions.
- Less displacement of problems in time or space.

Ecological design and ecological engineering, in the widest sense of the word, promote partnership between man and other life forms. Todd (Lerner, 1997) developed the concept of 'living machines': living man-made systems with which we can produce our fuels, degrade and convert our waste materials, produce our food and integrate our buildings in the natural world. For example, the principles of ecological waste water purification were taken from the ecology of a pond, which has a place for all levels of the food chain: bacteria, algae, higher plants, molluscs and fish, all play a role in the system. This is the field in which ecological engineering and civil engineering meet up, because a technological tour de force is sometimes necessary in a number of situations in order to permit such systems to function permanently.

6. Art's contribution in forming infrastructural landscapes

Art can play a role in integrating civil engineering and ecological engineering into a broader framework within society. Art can play a role, in particular in relation to the greater involvement of people in planning and design processes. Not only in the form of visual art, but in particular the contribution that can be made by art and the artist in processes involving for example, the integration of roads, nature and the landscape. Art can be applied in various ways:

- involving the artist in discussions during the design process;
- placing a sculpture as a recognition point or as a (logo)type;
- emphasizing landscapes or a special scenic detail;
- placing an independent sculpture, separate from the surroundings.

Paying attention to the beauty of landscapes will increase their importance and quality for the user. The history of The Netherlands is largely visibly tied up with its landscape, whereby a series of different types of landscapes and settlements have developed, each with its own characteristic qualities (landscape historical, cultural, aesthetic, ecological and economic-functional quality).

In several countries this approach is already done. But in most cases only one aspect has been chosen instead of making use of a more integral design concept, which honours all mentioned qualities of landscapes.
Research has shown that a number of descriptive characteristics are always important for the impressions of observers, i.e. use, unity, degree of naturalness, historic character, degree of spaciousness - including openness and variety. It also seems that both car drivers and the people living in the neighbourhood have their own objections and desires that can be classified according to the hierarchic satisfaction of needs theory. A problem that is higher up the list needs solving first.
In 1997, the results were published of a study into road users' impressions of the way in which motorways are fitted into a landscape, whereby the most important things were

specifically the design aspects of the road: the route itself, the verges, the surrounding vegetation and the special objects, such as rest places, sculptures, viaducts and noise barriers. The most important conclusions from this 1997 study are: a distinction should be made between people who drive a lot and those who drive very little - they each have their own impressions of the road; almost all drivers assume that a road has been constructed in harmony with its surroundings; road design depends upon the situation: an important role in road incorporation, for example, is the width of verges and the width of the central reservation; city and country areas give rise to different reactions; orientation points are important and when roads are bundled with other infrastructure it is desirable to make the railway, the pylons or (modern) windmills visible every now and again,

7. Application of the link between patterns, processes and design

There are various examples in which nature and landscape values have been highly promoted in road projects, such as the A58 project between Bergen op Zoom and Vlissingen, where a differentiated mowing regime has been initiated for the wide verges and extra plant and animal habitats have been created by developing coppices, water gardens and ponds. Similar initiatives on a lesser or greater scale have been and are being undertaken in other parts of The Netherlands. In the Amsterdam-Utrecht corridor study, a large-scale ecological connection has been suggested by placing the motorway and railways on pillars in some places.

By way of illustration, here are three examples that have been worked out more fully, which show that even more can be achieved by coupling functions.

7.1. Landscape noise barriers at the Hoogeind junction

The noise barriers made of large earth berms at the Hoogeind junctions near Breda are a good example of linking as many (relevant) functions as possible. Hoogeind lies in the valley of a small regulated lowland stream, the Molenley, which crosses the A27 to the east of the municipality of Breda. In the area of the stream, ecologically interesting low-nutrient situations occur and there was a marshy peat (with a high elderwood content, formed from past woodland areas) in the central part of the stream's valley. Sideways seepage occurred and there was a false groundwater level on top of clay-like sediments: these are rare hydrological circumstances with a potential for ecological development.

One of the projects in this area involved the reconstruction of a number of exit roads from the A27 motorway (closure and re-design). In re-designing the southern exit road to the centre of Breda, a combination was found for constructing noise barriers, giving attention to Breda's history, water retention, planning a swampy area for the purification of polluted stream water, joint recreational use and nature development on and near to the sound barriers to be built. The stream has been allowed to meander again (it had previously been straightened), anti-acidification measures have been introduced and the perception of nature from the motorway and from the neighbourhood has been increased. A hilly landscape with noise barriers made of large earth berms has been created here where a multitude of functions has been very cleverly combined.
The stream is situated in between two noise barriers. Water levels are allowed to fluctuate up as far as the footpaths (grass paths) that are situated at the foot of the noise barriers.

Hydroseeding of the noise barriers has been used to sow indigenous grasses and other plants which prefer low nutrient levels and which are rapidly rooting. To compensate the lower level of deep seepage water and to reduce the acid environment of the stream valley, the noise barriers on the eastern side have been fitted with gabions filled with limestone which demonstrate an extremely slow rate of extraction. The pH of the water coming out of the barrier is at the moment 6.8. The gabions give the impression of an angular fortress, which is a reference to the historical importance of Breda as a fortified city. The vegetation looks extremely natural: a great deal of marsh vegetation, groundwater-dependent and warmth-seeking vegetation. Interesting animals can also be found here (reed warblers, wood mice, buzzards and partridges). The many functions described have been brought together here in a limited area, which has led to the realization of a greater usefulness, ecological value and sustainable in the long run (Okhuizen, 1999).

It is a pity that a minimum of effort went into implementing the culvert where the Molenley passes under the A27. A larger flow-through opening, with sections above the average water level, could have led to an interesting connection with areas of ecological importance that has been developed on the other side of the motorway. The question is also whether the design took into account the degree to which it can be adequately managed.

7.2. The Mousehole: integration of infrastructure, ecology and art

Another example of integrating infrastructure, ecology and art can be found under the motorway A20 in Rotterdam at the point where it intersects the Bergweg. Part (300 m) of this motorway has been placed upon piles and the Mousehole developed under one large viaduct in a neglected, unkempt, unused spot where rubbish was dumped illegally and vagrants found shelter. Regular cleansing had no effect. Placing high fencing as part of efficient management would have been a radical solution, but the municipality chose to re-design it in such a way that it partly made efficient management possible and on the other hand improved the environmental quality by combining ecological values and the visual arts (Anonymous, 1998). The desired aim is raising the value of an unused spot both for nature and for man, by means of a double strategy:

(a) create the conditions for nature development;
(b) use art to clarify the function of the public space, so that the whole becomes easier to survey and safer.

Large projects involving infrastructure (motorways, railways, viaducts and bridges) are often marred by unused spots that have no clear function. In this place, a railway, canal and motorway had been constructed over various periods of time without any co-ordinating ideas - this was often not possible in many situations and it is also a question of progressive insight and adjustment to the requirements of the time. A plan was developed with the support of artists and residents which allowed room for: suggestions for re-designing the infrastructure, (public) transport, the role of nature, water management (reservoirs) and lighting. Clarifying the various functions was central. Nature had to become the connecting factor so that unused spots would get a new importance (promoting ecological infrastructure, making water retention reservoirs visible with nature-friendly banks (natural water purification). Apart from the aspects with regard to content, a communication and participation strategy was also developed. Together with the Council for the Homeless and Rotterdam's Public Works Department, research is being done into whether the vagrants can be given a role and responsibilities in the construction and maintenance.

The Visual Arts Centre and the borough of Rotterdam Noord (a district in the north of Rotterdam) are preparing an educational programme aimed at schoolchildren about the role of water, traffic and nature in the sustainable city. Attention will also be paid to the residents, users and other persons involved to show them how people from the different professional worlds of art, infrastructure, government, nature and environment, can bring about a revolutionary result that is capable of raising quality from a spatial point of view.

The project can be a model for numerous other situations in which so-called city and infrastructural 'leftover' spots occur. The starting point is making the functions more visible. Passers-by will experience the meaning of the place and start to feel more responsible for it. What have the artists been able to contribute and in what way? The independent position of the artists is important. In their workshops they are 'disinterested parties'. By putting well-aimed questions, they are able to add an intrinsic and aesthetic quality. Thinking about this provides solutions that sometimes turn out to have a greater utility value.

This ideological development along the whole route of the A20 between Kleinpolderplein and Terbregseplein emphasizes the synthesis of the usual approaches and adds to these a number of new dimensions:

- 'legibility' of infrastructure;
- respect for unplanned social-cultural activities;
- the interweaving of nature and culture;
- the nature as purifying 'machine' and in particular a strategy for coping with unused city space (Wesenmael, 2000).

7.3. Service areas and parking places

A nation-wide network of service areas and parking places has been constructed alongside the national motorways. A service area is usually a parking place with a petrol station.
A combination of facilities is also often found at the service areas: restaurant, truck shop, assembly rooms, hotel, shop, as well as facilities, such as toilets, cash dispensers, telephone, fax, Internet, car pool areas and playground apparatus for children.
The service areas are, in principle, linked to motorways. The assumption is that there will be a petrol station every 20 km and a restaurant every 40 km and there are service areas without facilities in tourist areas.
Realization takes place according to the ''guidelines for the development of service areas".

In 1993, a study entitled "Dutch service places" was carried out with suggestions for improvement, such as designing a 'service stop' made up of compact, well-organised stops. The driver who is taking a break should be provided at the same time with a view of the surrounding landscape.

In 1995, a study trip was made into the incorporation of roads and service areas into the landscape in France, with the emphasis being on design. In the field of service areas, the level of quality of the French 'Aire de Service' and the 'Aire de Repos' is extremely high, in the words of the French landscape architect Bernard Lassus, they are intermediate places, gardens in between road and landscape'. They are situated in places that are

as attractive as possible, they are 'balconies' with a good view of the surrounding landscape and you are a 'guest' instead of a user.
There are various possibilities for realising more room for ecology in service areas. One of these possibilities is to make more use of water as a means of design. Environmental construction from an ecological engineering point of view, sometimes used locally in service areas, could be given a greater role at the stages of design and construction in order to increase the ecological value.

A gradient from cultural towards a more natural design can be realised by means of zoning. The cultural heart around the service station and a more 'natural design' as a transition towards the neighbouring landscape.
Although there is a tendency towards uniformity in the landscape of The Netherlands, many motorways pass through various types of landscapes that have their own character from a landscape historical, ecological and a visual-scenic point of view. This variation breaks through the monotony of the road. A service area should be a place where information about the local character of the landscape is made available. Specific design could attract attention towards the flora and fauna characteristic of the area concerned. In this way, such places can take on some educational meaning (Nijkamp, 1971).

What is important is being 'explicit': bringing nature closer, with the possibility of 'self-discovery' and opportunities for experience.
A simple board with the name of the trees, flowers and surrounding vegetation provides people with the possibility of getting to know something. Buying a folder can provide people with more background information.
It may even be possible to offer the chance of making a short walk that could provide a view of the variety possibly in the form of a 'nature path'. The reasons for the mowing regimens should also be made visible by means of an information board.

More insight can be given into achieving targets with a differentiated mowing regime. For the rest area maintenance residents could also become involved in such a location. 'Adopting a highway' has become a successful project in US. This is sometimes complicated if only grass species are predominant with few noticeable flowers, while an information board has been put up with the text: 'wild flowers sponsored by the local grocer and it turns out that there are no flowering plants to be seen for most of the year.

8. The potential for infrastructural annoyance

Various studies (van Bergen et al., 1999; Roads to the Future 1999-2000) look into whether, with the aid of mitigating measures, the annoyance caused by motorways could not be translated, in some other than the usual ways, into a form that could work as a productive factor. Ecological approaches can also contribute here, both alongside and in combination with either spatial solutions or solutions based on town and country planning.

Can noise, gasses, radiation, vibration and light be considered as a raw material? For the benefit of greenhouse agriculture: residue warmth and CO_2; biomass production; CO_2 and NO_x; energy generation: warmth, vibration and sound? The question is whether combined forms of agriculture are possible, such as greenhouses and offices next to the motorway, where CO_2 and NO_x act as an ingredient for plants and surplus O_2 is filtered off and supplied to offices.

Another form involves the production of coleseed. Coleseed can be used to help make agrobitumen and fuel. Such approaches can also be seen as a broad version of the notion of compensation. It is all about making human intervention 'palpable' owing to the fact that effects have to be compensated in order to be able to achieve a certain agreed degree of quality.

9. Conclusions

Sustainable development and the meaning of nature has led to a need not only to mitigate and compensate negative effects of infra-structure, traffic and transport, but also in particular to actively promote ecological value. We already have a great deal of knowledge in the field of ecological patterns and processes in relation to design, construction, management and maintenance, and mitigating and compensating the effects of infrastructure and traffic, including the cost aspect, but deepening our knowledge can lead to measures that are even more effective.
On one hand, increasing the quality of habitats and the corridor function for the fauna of roadsides and canal banks, and on the other hand, enlarging the functional importance of marsh vegetation as helophyte filter for the collection and purification of water collected from roads.

Ecological engineering, based on ecosystems theory and integration of ecosystem functions and ecosystem services in our society and ecological design, that minimise environmental impact by integrating with living processes can be of great help to conserve and regenerate nature as well as making use of nature on the basis of stewardship.
Intensifying research in the field of the relationship between infrastructure systems and ecosystems can provide forms of infrastructure that are, more integrated with the surroundings. An integral approach can lead to greater ecological quality, more profit for society, often at lower costs. The emphasis needs to be placed upon further integration of ecological engineering during the design, planning and realization of infrastructure. Particularly in the field of multiple use of space, ecological engineering offers possibilities for obtaining extra added value for plants, humans and animals.

Deepening our knowledge on combating the annoyance and severance effects of infrastructure can provide more effective measures. In order to strengthen the relationship between the major and minor road systems, research could be aimed at the effects of road density and network structures on various groups of animal species.
Research into the width of the effect zone for certain animals is also desirable. We propose using the term 'infrastructural ecology' to cover the fields of attention mentioned. The development of new ideas with a theoretical basis in the field of combining road and rail infrastructure with ecological infrastructure can provide new challenges for the implementation of problem-solving measures.

10. Looking ahead

This chapter was written in order to draw attention to the importance of combining (landscape) ecological aspects with art in the design, construction and management of infrastructure. Work is being done and new initiatives are underway at the moment in an attempt to reach a more consistent approach. Take, for example, the following.

- Interviews, discussions and exhibitions within the framework of RemakingNL: a project on cityscape.
  landscape and infrastructure (Cusveller et al., 2000).

- The Delft Interfaculty Research Centre, The Ecological City, where more than 12 people are doing doctoral research into integral solutions in the field of planning, design, construction and management of built-up areas. Subjects: sustainable city, traffic and transport, water in city areas, planning strategies, green networks, building in the nuisance zone, ecological designs of infrastructural facilities (Canters et al., 1999).

- The Dutch National Traffic and Transport Plan (Ministry of Transport, concept, 2001) promotes a more integrated and innovative approach for solving environmental problems in relation to infrastructure and traffic. Especially in the field of noise, water and air pollution reduction as well as mitigation measures innovation is stimulated (see the Programm Road to the Future).

- Within the Ministry of Transport, Public Works and Water Management, the Hydraulic Engineering Institute, work is being done on designing a route as one of the pilot projects within the framework of the new Architectural Policy Document (Anonymous, 2000). The route design is an integral landscape design for a whole route (A12) from The Hague right up to the German border. Starting points for the design are:
  - Continuity, more uniform and generous sizes form the basis of the plan.
  - The design will be geared to the function.
  - The green elements will need efficient management, whilst the added value for nature is of prime importance.
  - The culture-historic quality of the surroundings must be made visible to the road user.
  - Bringing unity into the constructions and engineering structures.
  - Giving a place a look of its own will be promoted, which should give powerful and business-like results.

These are important challenges to give (landscape) ecological aspects in road (and rail) infrastructure planning, design and building a more important place in an integrated way and within an interdisciplinary relationship.

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B Coastal Dynamics and Ecological Engineering

1. **Coastal dynamics and ecological enigineering: Introduction (chapter 7)**

2. **Layout and management of sea dunes (chapter 8)**
   H.D. van Bohemen and G. Veenbaas (reprint Nature Engineering and Civil Engineering Works) (1991) 122-139.

3. **Environmentally friendly coasts: dune breaches and tidal inlets in the foredunes. Environmental engineering and coastal management. A case study from the Netherlands (chapter 9)**
   H.D. van Bohemen (reprint Landscape and Urban Planning 34) (1996) 197-213.

4. **Ecological engineering and coastal dynamics. A synthesis. (chapter 10)**

7. Coastal Dynamics and Ecological Engineering: Introduction

The following two chapters give an overview of the development of the relationship between nature and coast from the period towards the end of the eighties to the beginning of the nineties, a period that has been of vital importance for the currently accepted and progressively developed form of coastal management, namely the dynamic maintenance of the sandy coastline as it was in 1990.

The chapters concerned are:

1. '*Layout and management of sea dunes*' by H.D. van Bohemen and G. Veenbaas (1991),which gives an overview of experiences with different types of sand replenishment (behind, within and in front of the beach ridge); the beach-ridge fortification Voorne and the one between 's-Gravenzande and Kijkduin (The Hague) are used as case studies.

2. '*Environmentally friendly coasts: dune breaches and tidal inlets in the foredunes. Environmental engineering and coastal management. A case study from The Netherlands*' by H.D. van Bohemen (1996) gives an overview of the possibilities for making 'notches' in the dune breach as well as stimulating tidal inlets or tidal-inlet-like shapes. It discusses various studies into this field that were commissioned or facilitated by the Road and Hydraulic Engineering Institute. The annex presents an overview of the then desired and planned research into the area of the ecological significance of more dynamic forms of beach-ridge management in relation to the environment.

Apart from the chapters, based on published papers, included here, the following articles may prove useful for reference:

- H.D. van Bohemen and F. van der Meulen, 1987. Verzwaring van de zeereep tussen 's-Gravenzande en Kijkduin; alternatieve mogelijkheden ter verhoging van de Natuur- en landschapswaarden. Notitie Dienst Weg- en Waterbouwkunde/Delft.
- H.D. van Bohemen, P.D. Jungerius and F. van der Meulen, 1989. Herstel, ontwikkeling en beheer van landschapsecologische processen op het strand en in de buitenduinen. in: De Levende Natuur,1989, no. 5, p.p. 88-97.
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- H.D. van Bohemen, 1993. Natuurvriendelijke oevers ook voor de zeekust?! Natuurtechniek en kustbeheer. in: OTAR 7/8, pp. 215-217, Den Haag.
- H.D. van Bohemen and A.W.J. van Schaik, 1993. Tidal creeks, report of a seminar. RWS/DWW MIO 93/Delft.

This chapter is concluded with the article 'Ecological engineering and coastal dynamics. A synthesis.'. In this contribution, a comparison is made between the research proposed in the second chapter and the research that was effectively performed. It also makes clear to what extent between 1990 and the current date environmentally-friendly coastal management based on ecological engineering has made it into policy documents. The extent to which the proposed measures have been put into practice is also investigated. The section is concluded with an overview of 'lessons learnt'.

8. Layout and Management of Sea Dunes

H.D. van Bohemen and G. Veenbaas

Summary
Dunes in the Netherlands serve as a major defence against the sea. Because of local erosion of the coastal dunes protective measures are necessary to maintain the safety of the low-lying hinterlands. It is important in retaining the sea defence function that the high natural, scientific and landscape values are taken into account. During the last few decades more and more insight has been gained into the possibilities for a habitat (re)creation approach for various civil engineering works in order to preserve and enhance natural and landscape values. This certainly applies also to coastal defence works. By means of well-considered habitat (re)creation measures sufficient scope can be created for the most natural possible design. This applies to reinforcement both in front of, in or behind the sea ridge. Instead of rigid sand walls coastal dunes are allowed to establish that have a geomorphological pattern strongly resembling the features that could be expected to develop by nature. Two examples of dune reinforcement are discussed, in the execution of which landscaping techniques have been applied to fit in the sand supplies as harmoniously as possible with the natural dune landscape. The examples relate to one project on the island of Voorne and one along the coast of Holland between 's-Gravenzande and Scheveningen. Originally, attention was focused on visual and spatial aspects; at present interconnection is increasingly sought with landscape ecological values and processes. Creating conditions for the most natural possible development by means of habitat (re)creation techniques, while observing the requirements set by the protection of the polderland, is more and more getting common practice. A brief account is given of experience gained with new methods of planting marram, a grass growing in the foredunes. As a result of ongoing wash-out (caused for instance by sea level rise) and wind erosion more interventions will be needed during the next few decades to guarantee the safety of the polderland and other functions assigned to the dunes. In the near future attention will also be paid to a more dynamic coastal management, featuring beach and foreshore nourishment to counteract the erosive forces.

1. Introduction

The over 40,000 ha of dunes in the Netherlands are part of a long, narrow strip of dunes from Calais (North of France) to the northern tip of Denmark (See Figure 1). The Dutch dunes take a special position; they are a transition between the clearly different, calcareous dunes with a more southern aspect in France and Belgium and the northern, lime-deficient dunes of the German Wadden islands and Denmark. The special character is due in particular to the presence of different types of coast, their relatively large area, the large variety of landscapes, macro- and micro-gradients, the diversity of vegetation and fauna, the relatively low degree of deterioration of the dune area. The large variety of landscape types is caused by:

- differences in climate;
- differences in geology and geomorphology;
- differences in coastal development (erosion, accretion and stable coasts);
- differences in chemical composition of the soil (e.g. lime and ferrous content);
- differences in hydrology;
- relief. In this respect especially the difference in microclimate between north-facing and south-facing slopes plays an important role.

The abiotic variety highly determines the biological diversity, of both vegetation and fauna (Doing, 1988; Westhoff, 1982).

Figure 1. Dunes in Europe. (Council of Europe, 1985)

The plant communities present in the dune area may be subdivided according to the degree of groundwater influence into a xerosere (no groundwater influence), a mesosere (groundwater influence just noticeable), a hygrosere (dry only in summer) and a hydrosere (permanent influence of water, aquatic plants) (Londo, 1971).

The diversity of organisms and ecological communities of the Dutch dunes has been partly destroyed, however, during the last few decades as a result of:

- fixation of geomorphological processes. Hardly any primary or secondary dune valleys are formed any longer, for instance, because of large-scale dune stabilization;
- the rapid succession after the fairly sudden disappearance of former differences in dune management, leading to increasing monotony of vegetation types;
- the increase in intensive forms of recreation, fragmentation by building up, industry, roads, etc., and
- the increasing effects of air pollution (acid rain) and disappearance of nutrient-poor, moist dune valleys by eutrophication and lowering of the groundwater table (e.g. by water extraction); (Westhoff & van der Maarel, 1982; van der Meulen & van der Maarel,1988).

In addition to the value of the dunes as natural areas dunes are also important for a number of utilitarian functions (house-building, drinking water supply, etc.) (Hoozemans et al., 1989). Moreover, maintaining the safety of the polderland is still the main function of the dunes.
The dunes, formed from sea sand by marine and aeolian forces, offer a natural protection in addition to the dikes against flooding by the sea. All kinds of coastal defence measures are taken in the sea ridge and elsewhere in the dune area in order to prevent breakthroughs during storms. In planning and executing such coastal defence measures more and more attention is paid to the nature engineering potentials besides the conventional civil engineering methods. Moreover, it was found that if the existing or expected future natural processes are taken into account, interesting nature developments may take place. In this respect a distinction should be made, however, between the possibilities and limitations of erosion, accretion and stable coasts (Arens et al., 1989).

2. Landscape ecological characteristics and importance of the coastal dunes

Roughly, three types of coast are to be distinguished in the Netherlands (see Figure 2).

1. The uninterrupted beach and dune coast of the provinces of North and South Holland, featuring a continuous line, running on for tens of kilometres, of sandy beach with dune areas immediately behind;
2. Wadden coast consisting of a series of elongated barrier islands separated by wide tidal in- and outlets;
3. Estuary coast, featuring long sea channels or estuaries, cutting deep into the land.

There is no clear division line between these coastal types, however. The most clear-cut transition between land and sea is the uninterrupted coast. The Wadden coast is a genuine transition zone between sea and land. The value of the dune area from the point of view of nature conservation may be derived, for instance, from the presence of rare and fairly rare plant and animal species. The Dutch dunes are found to be rich in rare and fairly rare plant species (see Figure 3).

Far more important from the conservation point of view is the high diversity of ecosystems and

Figure 2. Present coastal types of the Netherlands (Wolff, 1982)

the highly dynamic character as compared with most other natural areas. As a result there is also a large variety of stages of succession.

Plant geographically the Dutch dune area is divided, on the basis of differences in lime content of the soil, into a northern part that is relatively poor in lime (± 0.5 - 2% CaC03) (Wadden district) and a southern part that is high in lime (2 - 10% CaC03) and accommodates a larger diversity of plant species (Dune district).
In the Dune district the landscape behind the sea ridge is characterized by a complex of thick, tall and species-rich dune scrub and a mostly continuous cover of herbaceous grasslands.

Four major plant communities are to be distinguished in this area: the Sea Buckthorn-Elder scrub (Hippophaë-Sambucetum), the Sea Buckthorn-Privet scrub (Hippophaë-Ligustretum), the Buckthorn-Hawthorn scrub (Rhamno-Crataegetum) and the Privet-Birch scrub (Ligustro-Betuletum) (Sloet van Oldruitenborgh, 1976).

In the Wadden district these scrubs are of only minor importance. This area is dominated by dry and moist dune heaths and low creeping willow scrub, while the dune grasslands are more open and rich in mosses and lichens. Woods are not (yet) or hardly developed. Because of the intensive use for centuries it is partly unknown how this development will be.

For many plants and animals the beach is an extreme environment. That's why only a limited number of plant and animal species are found here. The species found include such plants as Sand couch grass, Sea rocket, Lyme grass, Sea sandwort as well as the birds Kentish Plover and Little Tern.
Next to the beach is the sea ridge, formed from sand by the sea and wind forces. Only after a fresh water reserve has accumulated in the embryonic Sand couch grass dunes Marram is capable of developing. By its rapid growth and catchment of sand, Marram may cause the embryonic dunes to close up into a dune ridge or sea ridge. This process takes place at an accretion coast. At an erosion coast a sea ridge develops that is steep at the seaward side. By the sand's shifting inward the sea ridge again takes its original form, but it has moved inland (rolling sea ridge).

Because the wind effects and sand turbulence prevail on the beach and in the sea ridge and the lime content in young substrate is relatively high also in the Wadden district, most plant species of the beach and sea ridge are found in both the Dune district and the Wadden district. This applies to Marram (Ammophila arenaria), Lyme grass (Leymus arenarius), the dune variety of Perennial sow thistle (Sonchus arvensis var. maritimus), the dune variety of Red fescue (Festuca rubra var. arenaria), Sea bindweed (Calystegia soldanella), Sea holly (Eryngium maritimum) and Sea buckthorn (Hippophaë rhamnoides).

The larger the distance from the sea, the clearer the difference between the Wadden district and the Dune district. Roughly, the Dutch dunes can be classified by vegetation, soil and hydrology into (Bakker, 1976):

- calcareous, dry dunes (sea ridge with Marram and Sea buckthorn, Privet and Hawthorn
- lime-deficient, dry dunes (dune heaths);
- moist, calcareous dune valleys;
- moist, lime-deficient dune valleys;
- dried-out dune valleys;
- wet valleys and banks of dune lakes.

The dune landscape has a characteristic soil and hydrology, vegetation and fauna. There is a large diversity of macro- and microgradients. Moreover, the dune area has important (landscape ecological) relationships with its surroundings. In summary, it may be stated that the Dutch dune area has high and locally even unique natural values.

It is true, however, that during the last few decades a number of (partly unfavourable) changes have occurred, such as a decline of natural dynamics, a reduction in the number and size of moist dune valleys, in addition to the general lowering of the groundwater table that was initiated long ago. Further, there is a fragmentation of areas and a decrease in the diversity of gradients between dry and wet dune coastal landscapes and between dunes and hinterland, which development is an

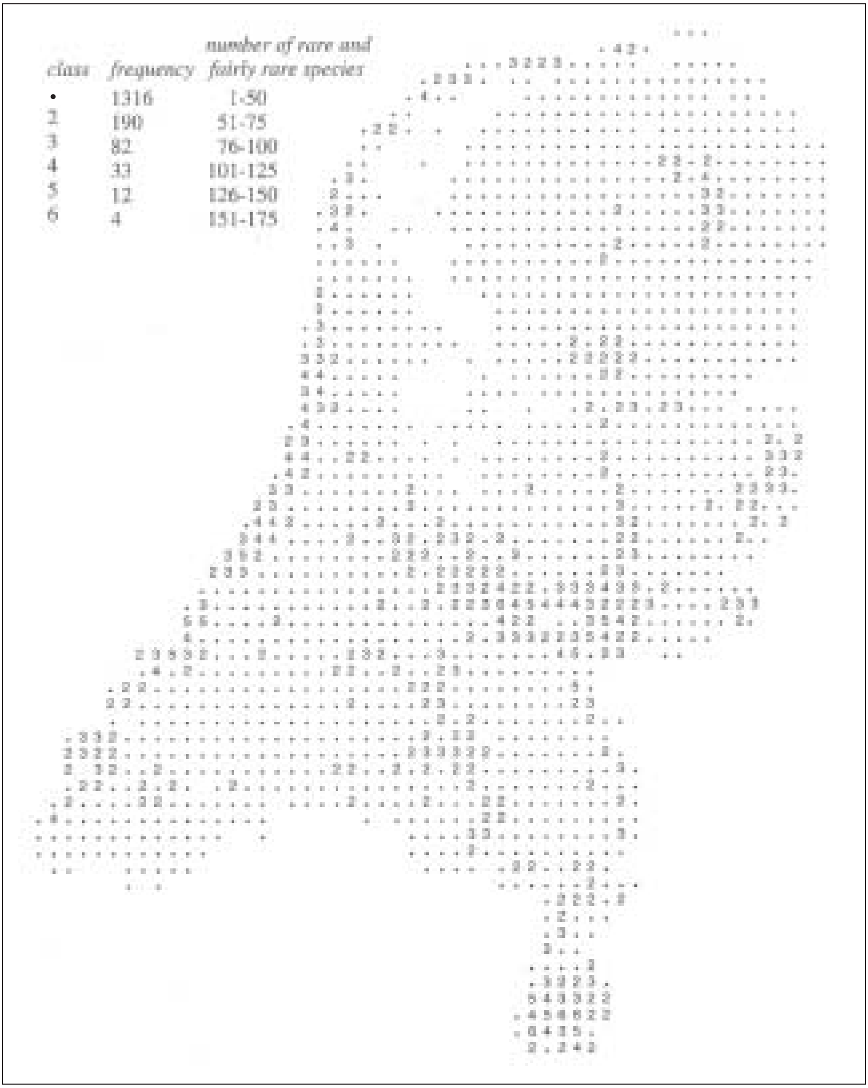

Figure 3. Distribution map of rare and fairly rare plant species (van der Meijden, 1987)

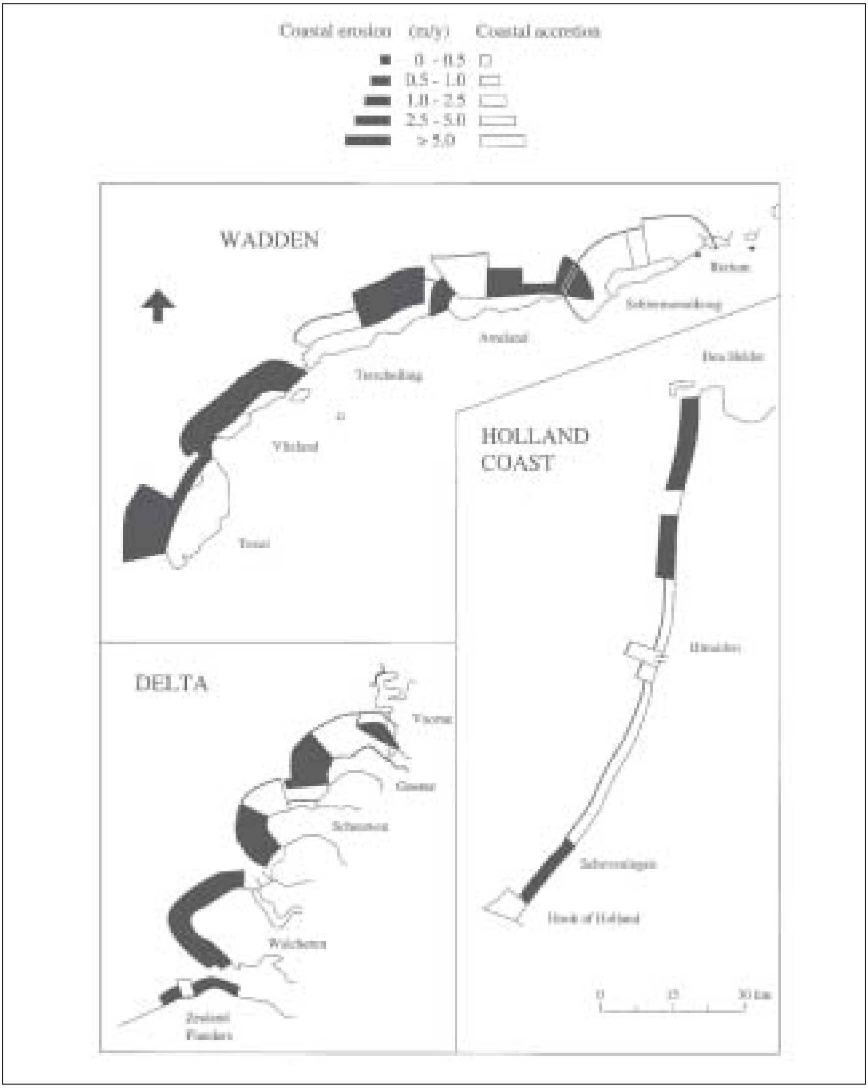

Figure 4. Mean annual shifts of coastal line (van Bohemen et al., 1989; data from RIKZ, The Hague)

impediment to the exchange of organisms between areas. In spite of the above deterioration the Dutch dune landscape still is a grand and valuable natural area (Ministry of Agriculture and Fisheries, 1989).
Measures to further conservation and development of natural values may contribute to the significance of the area. In this context attention could be focused on:

- conservation and development of hard-to-replace ecological communities (e.g. old woods, nutrient-poor grasslands and heaths)
- protection against and prevention of eutrophication of nutrient-poor, moist dune valleys;
- allowing development of young, primary dunes.

A precondition for the success of such an approach is a dynamic coastal landscape with a balanced ratio of younger and older dune environments and the accompanying gradient-rich situations.

3. Coastal defence and habitat (re)creation

3.1 Measures to consolidate sea defence dunes in the most natural possible way

A major part of the Dutch coast has been exposed to erosion for centuries (see Figure 4). Gradually a change has taken place in the way of dealing with the coastal recession. Until recently, wherever the coastal line retreated or safety was jeopardized, dikes, dams, breakwaters, pile rows, etc. were built. At present the insight and knowledge about coastal morphological processes are increasingly taken into account enabling a more dynamic coastal management. Initially this took the form of a flexible coastal management featuring a landward shift of the sea ridge to maintain a closed dune front. Subsequently, emphasis shifted to a so-called bottleneck policy, in which sand supplies are used to counteract local erosion. At the moment research and policy analyses are carried out which may result in a policy to slow down or stop erosion.
The key point is that natural processes are integrated instead of being “fought”. This implies that in the Netherlands sand is now the preferred material, whereas the conventional constructions made up of materials that do not naturally occur in the Netherlands are preferably no longer used. Hard elements have considerable side effects on adjacent coastal reaches.

The following possibilities (see Figure 5) are available for reinforcement of the sea defence dunes by means of sand:

- supply within the sea ridge;
- supply on the beach, and
- supply on the foreshore.

After a policy analysis has been carried out one of the above possibilities is generally opted for. The possibilities and their effectiveness are strongly dependent on local conditions.
In this context attention will be paid to those aspects that are related to nourishment within and behind the sea ridge. Within the next few years beach nourishment and perhaps also foreshore supply will play a more prominent role as measures to counteract coastal recession.

From an evaluation of beach nourishment carried out in 1987 (Anonymus, 1987) it appears that under the sometimes capricious natural conditions dimensioning of (periodical) beach nourishment is quite feasible.
This means that it is mostly possible to determine in advance whether the supply will meet preset requirements regarding lifetime and whether it will be effective in terms of

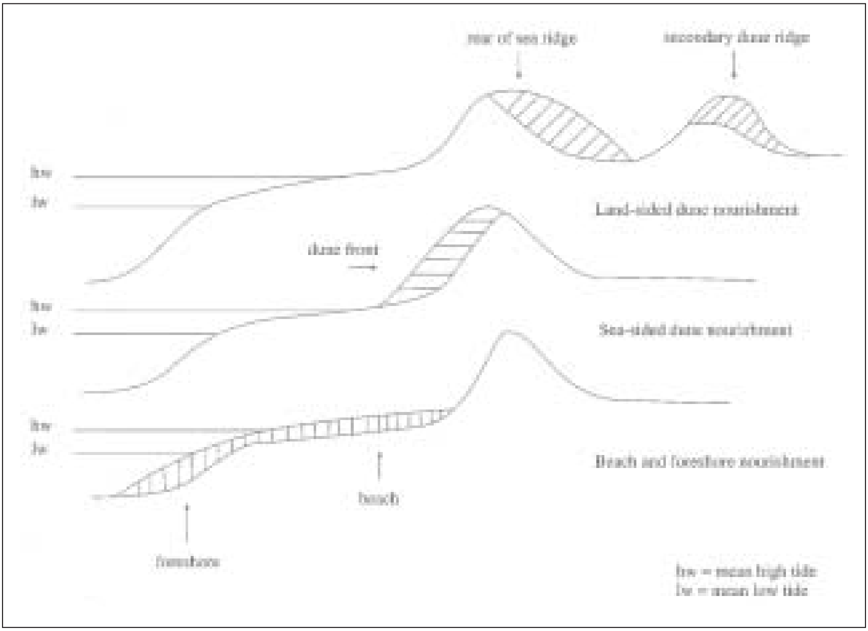

Figure 5. Location of supply in cross section (van Bohemen et al ., 1989).

coastal morphology (Anonymus, 1987). If such measures turn out to be feasible for longer stretches of coast, this will offer more scope to nature development in the coastal dune area. In assessing the effects the origin of the sand should be taken into account, however.

3.2 Methods to establish vigorous marram vegetation

In dune reinforcement it is essential to prevent the supplied sand from being blown away. Of old the placing of screens of brushings and planting of marram were the measures applied for this purpose. Recent research has shown that good results can also be obtained by sowing marram or by harrowing in rhizomes.

After sowing or harrowing, the sand surface has to be established by means of straw.
During dune reinforcement works on the island of Voorne the three methods have been studied in practice (van der Putten & van Gulik, 1988). It was found that if these three methods are applied under optimal conditions (such as good quality planting material, regular drift-over of fresh sand), little difference in marram growth is observed between the methods.
Marram sowing is less expensive than harrowing in rhizomes and marram planting is most expensive. Table 1 gives a survey of the conditions for application of the methods mentioned.
Earlier research (van der Putten & van Gulik, 1985) has shown that planting marram on sand

where marram has grown before will lead to death or slow regrowth of the marram. From laboratory research featuring selective elimination of bacteria, fungi or eelworms it appears that probably soil fungi in combination with eelworms promote the degeneration of marram and lead to the replanting problems. Continuous new drifts of (beach) sand are essential to keep marram in healthy condition. Nordic marram, by the way, is less sensitive to these organisms. Research is continued to solve the problem of the wilting marram, which may eventually lead to erosion.

3.3 Voorne dune reinforcement

Build-up and erosion of sea defence dunes.
As far as the polders are concerned the island of Voorne got its present layout during the fifteenth century. The dunes did not then form a closed front yet, so that dikes were also needed on the sea coast as a protection against the sea. Not before 1650 there were dunes both on the north-western and north-eastern side and on the south-western side of the island, as in the present situation (Pilon,1988). By the nourishment of drifting sand and measures to stabilize this sand new dune ridges formed locally. In particular during the first half of the present century a new sea ridge was created several times on the seaward side, cutting off the beach plains behind from the sea. The dune valleys thus created have a very high natural value (in particular with regard to vegetation, but also to the other biotic and abiotic features) (Adriani & van der Maarel, 1968). Though here, too, negative trends are found as a result of various interventions, changes in management and acid rain, these dune valleys are still quite valuable (Boot & van Dorp, 1986). In other places, however, erosion took and takes place, especially at the south-western coast and most prominently at the "Groene Punt" (Green Tip).

Preparation of reinforcement and execution of temporary measures.
During the second half of this century erosion became so strong locally that drastic measures were needed.
In order to meet the safety standards laid down in the Delta Act the sea ridge between the Brielse Gat dam and the Haringvliet dam needed reinforcement. The plans were carefully elaborated, partly in view of the very high natural value of the Voorne dunes.

Before work on the definitive reinforcement could be started, the situation along the south-western coast and at the so-called Green Tip had become so critical that temporary measures had to be taken beforehand: between 1973 and 1975 the sea defence line was closed along its entire length by means of a sand wall of limited height and on the south-western side a beach nourishment was carried out (Voogt & van der Putten, 1988).
In 1977 another beach supply was carried out in such a way that beach erosion could be compensated for until 1983 - the year in which the final reinforcement would start. These temporary provisions have partly determined the location of the planned definitive reinforcement. After careful consideration of the technical, financial and nature conservation aspects it was decided to opt for an outward reinforcement on the north-western side and an inward reinforcement on the south-western side. The transition from outward to inward was located at the Green Tip.

In order to blend in the reinforcement as naturally as possible into the dune landscape and into the sea ridge a "Compensatory Landscape Adaptation Plan" was drawn up by a working group set up for this purpose.
The major conditions to be met were:

- the reinforcement should nowhere be lower than the minimum profile;

	Marram sowing	Rhizomes	Marram planting
Sensitivity to drift	not suitable if during germination covered by more than 5 cm of sand or sand is blown off	less sensitive to sand drift-over	stabilizing sand by bundles of reed culms
Period of application	only between 15 Sept - 1 April	rhizomes to be processed fast. Not in freezing weather	preferably not in summer
Fertilizing	single dose 80-20-20 NPK/ha (slow release)	single dose 80-20-20 NPK/ha	
Quantities	15 kg seed/ha	40 pieces/m2	planting distance 50 x (70-75) cm
Harvest	seed to be harvested in July	rhizomes preferably from dunes with sound marram	plants to be taken from sound marram (not from wilting marram vegetation)
Harrowing straw	5 ton of straw/ha	5 ton/ha	
Special		length of roots 15 cm (at least 2 viable eyes)	

Table 1. Conditions for application of marram sowing, harrowing in rhizomes and marram planting (Van der Putten and Van Gulik, 1985).

- vegetation-covered dune tops above the minimum profile should be preserved as much as possible;
- the dune pattern that existed before the temporary provisions should be followed as much as possible;
- effective measures should be taken to prevent the sand from drifting away.

The pattern of the new dune landscape, which should be similar to the shapes of the former dunes, was designed on the basis of old contour maps of the area. In order that a survey would be available of those vegetations occurring immediately adjacent to the sea ridge that are most sensitive to sand drift a map was added to the landscape plan covering a strip of 100 m wide behind the sea ridge. On this map the vegetation types sensitive to sand drift were indicated.

Various measures against sand drift could be taken, including planting with marram. Since poor experience had been gained with the latter method in carrying out the temporary reinforcement work, research was conducted into the best methods of establishing an adequately sand-retaining marram vegetation.

Part of this research was done while the reinforcement activities were in progress. The reinforcement was implemented in three stages, enabling the results of the study during the first stage to be applied during the later stages. The results of this study are presented in Section 3.2 of this chapter.

Execution of reinforcement to Delta height. The sand needed to raise and widen the sea ridge (originating from the "Maasvlakte" (The so-called harbour and industrial Meuse plain west of Rotterdam) was put in store on the beach (8 million m^3) and after desalination it was processed into a new dune landscape. Because during execution of the first stage, the north-western coast, the impression was gained that in the areas immediately behind the sea ridge the ground water level rose as a result of water pressure from the store, in the next stage drainage was applied at and parallel with the existing dune toes.

Various kinds of heavy equipment were used for the major earthmoving work after desalination. Subsequently, a small bulldozer did the finishing work to obtain the right profile. In the second part featuring reinforcement at the inner side of the sea ridge there were a few high dune tops. These have been carefully left intact during the reinforcement work. Apart from the fact that these tops lend a more natural aspect to their surroundings than the newly built dune patches, they are also a source area from where plants may recolonize the new dunes. After application of marram vegetation (by both harrowing in rhizomes, planting bundles of marram with bundles of reed culms and sowing and harrowing marram seed) a fence against rabbits was built. To enable juvenile Shelduck to move from their nesting burrows to the sea special Shelduck tracks were made in this fence.

3.4 Dune reinforcement between 's-Gravenzande and Scheveningen

The dune area between Scheveningen and Hook of Holland is a fairly narrow strip as a result of constant erosion by the sea. The area is very valuable because Old, lime-deficient dunes with their characteristic vegetation partly consisting of heaths are located quite near the sea.

To the south the Old dunes are either covered by the Young dunes or have been eaten away in former times by the sea. Towards the sea ridge the Old dunes border the Young ones. In view of this special situation landscaping was an important element of sand supply works in this area. In 1986 the Delfland Polder Board started measures to reinforce the back of the sea ridge between 's-Gravenzande and Scheveningen. The sea ridge concerned ought to be raised to Delta height (i.e. 10.5 m above N.A.P. - the standard sea level) and to be brought to Delta strength before 1990. In this area this implied that the existing sea ridge had to be raised by 1 m on average. On places where the new dune ridge was positioned landward of the existing one the rise amounted to as much as 3.5 m or over. During the first stage about 1.4 million m^3 of sand was supplied to the beach in front of the existing sea ridge over a length of about 8 km. During the second stage (after desalination) the sand was moved on top of or behind the existing sea ridge (raising and widening of the outer dune). In order to shape these artificial dunes in such a way as to offer more chances to a diverse vegetation and fauna without jeopardizing the sea defence function both a vegetation survey and a geomorphological survey of the first 600 m behind the sea ridge were conducted. The results of the two surveys were used as a basis for the landscaping of the reinforcement (Hornstra, 1987).

The major motives for doing so were that levelling and fixation of the relief should be counteracted and geomorphological processes should be given some free play to enhance the landscape and ecological significance of the sea ridge and the adjacent dune area.
By means of aerial photos a vegetation survey was carried out on a 1:1000 scale. With the use of the available contour maps a geomorphological survey was conducted.
Subsequently, the following conditions were formulated within the limits set by the starting points of the advice:

- finishing should be carried out by means of machines;
- the slopes should have a batter of no more than 1 in 3;
- the width of the reinforcement should be kept to a minimum;
- the scope for possible sand drift was very limited in view of the routing of a bicycle track and the adjacent valuable lime-deficient dune area;
- the volume of extra sand for shaping was restricted.

The consultative group, consisting of civil and nature engineers and policy representatives, presented the following starting points to be observed in supplying the sand and shaping the most natural possible relief:

- the relief of the reinforced area should be as consistently in line with the adjacent relief as possible;
- the differences in height should be effected at variable intervals while avoiding any flat parts between the tops to be created;
- slopes should be finished as steeply as possible (without exceeding the 1 in 3 batter);
- the dune tops to be created should be as high as possible in order to achieve a well balanced ratio of the overall profile to the newly created tops;
- finishing of the tops should be sufficiently varied (variable batter, shape of the slope: both convex and concave, and height);
- in long slopes it was desirable to apply some transversal relief by means of a bulldozer.

In applying the vegetation use was made of the experience gained in the Voorne works (see Section 3.2). The methods used were: planting of marram and the rhizomes method. In presenting the advice attention was paid not only to the habitat design but also to the subsequent management and maintenance.
By taking geomorphological processes in the maintenance stage into account (e.g. local allowance for sand blow-out) the landscape and natural value will improve. This will also have the advantage that marram growth will be stimulated by the higher degree of sand dynamics. Experience in the next few years will show whether local stimulus and control of sand drift actually offers perspectives to flora and fauna of the dune area.

3.5 Evaluation of the nature engineering principles applied in the Voorne and 'sGravenzande-Scheveningen projects

Dune reinforcements are major interventions in the landscape. Sand is supplied that is often different in composition (e.g. grain size distribution) from the sand that is naturally present. The new material often has a very high shell content and the silt fraction is sometimes highly variable. From the reinforcements carried out it appears that by sound preparation and careful execution good possibilities can be created for a final appearance that is acceptable in terms of geomorphology and visual landscape perception. It remains to be seen whether there are also enough perspectives for development of vegetation and fauna. Both on Voorne and in the area between 's-Gravenzande and

Scheveningen data is being collected to monitor the developments as well as possible. To this end transects have been plotted at intervals along the entire sea ridge of Voorne (van der Laan, 1989) in which permanent plots are included. In the transects on the north-western part of the coast, which was first finished, vegetation recordings have been made in three successive years. Since the south-western part of the coast was finished later in some plots recordings could not be made before 1988.
In a total of 120 vegetation recordings 78 species in all were located. This is an exceptionally high figure for a sea ridge biotope. Not only the high number of species, but also the species composition shows that the vegetation of the new dunes, at least in this initial stage, strongly differs from a natural outer dune vegetation. Only 11 out of the total of 78 observed species are typical of the (green) beach and outer dune environment (Veenbaas et al., 1989).
Apart from these characteristic outer dune species a number of species were found that do not specifically belong to the vegetation types of beach and outer dune area, but that do belong to certain dune vegetations such as dune grasslands and pioneer stages of dune shrub.
A clear reflection of the artificial character of the formation of this sea ridge is found in the presence of the many species that would not normally be expected in an outer dune.
This relates in particular to species that are typical of such habitats as thickets, nutrient-rich arable fields and fertilized grasslands. From the series of recordings that are now available from three successive years it appears that the average number of species per recordings increases.
The averages of the years 1986, 1987 and 1988 are 8, 10 and 15, respectively. Also with regard to the structure of the vegetation, counting by percentage of cover and height of the vegetation, there is a clear development. The figures for these parameters are about 20, 30 and 35 % and 50, 60 and 65 cm, respectively.

Just as on Voorne the development of the vegetation between ' s-Gravenzande and Scheveningen is being monitored. For this purpose five recordings were made during the summer of 1989. Comparison of the figures with the results obtained on Voorne again shows a large variation of plant species, part of which are not naturally found in outer dunes. Many elements occur in the vegetation that would not normally be expected in the sea ridge. Part of the reinforcement in this area, however, relates to a sand supply behind the sea ridge. Moreover, in this case there is a substrate that is enriched by fertilizer. This is reflected especially in the presence of many rough herbaceous plants.
The study of the development of the vegetation in the reinforced sea ridges will be continued for some years. An essential element to be considered in the final assessment of developments and expectations with regard to future vegetations is the span of time during which the supply is to offer safety.

4. Conclusion/Prospects

In recent years sand supplies in front of, within or behind the sea ridge have become increasingly popular as a means of compensating for local coastal regression. In addition, beach nourishments have been carried out and foreshore nourishments are being considered. Presumably, it is especially the foreshore supplies that offer bright prospects from the point of view of coastal morphology and conservation and development of nature and landscape values, since these supplies do not involve any

intervention in the terrestrial environment (though they do in the aquatic environment). In the context of the Coastal Defence Discussion Paper (Public Works Department, 1989) an extensive policy analysis has been carried out, including an assessment of the effects of coastal development on the natural value and the various utilitarian functions of the dune zone.
Within the next few years it will turn out whether there are really any possibilities for a more dynamic coastal management.
It is hoped that this approach will offer good chances for a more natural development of the sea ridge. The starting point will be the enhancement of the natural values, while maintaining a closed sea front will not in all cases be put forward as a prerequisite. The assets are: low cost and high natural values. The more or less natural landscapes are not favoured by immobilization of their dynamics (Westhoff & van der Maarel, 1982; van der Meulen & van der Maarel, 1988). In static conditions no new primary and secondary dune valleys are formed and succession will increasingly lead to monotonous final stages. Habitat (re)creation offers possibilities for reversing the trend towards impoverishment. Locally allowing dune blow-out, leading to rejuvenation of the succession stages, fits in well with this strategy. Breaking through patterns of immobilization needs accompanying by research, however. Differences between erosion, accretion and stable coasts should be carefully taken into account. Possibilities to obtain a more varied coastal zone are:

- Allowing formation of a notchy sea ridge. This could create opportunities for the development of an optimal dune ecosystem featuring a high degree of self-regulation.
- Allowing local dune blow-outs. Dune blow-outs are an important natural rejuvenation process that has not been given enough room during the last few years. Local blow-outs will enhance the diversity of the dune environment.
- Giving some more free play to formation. of dune breaches and tidal inlets. Studies into the feasibility of such propositions provide opportunities for strengthening the relations between nature engineers and civil engineers in order to create, together with policy decision makers, more scope for nature as far as the safety of the hinterlying polderland admits.

To attain the best possible environment for plants and animals it is important that priority is given to the larger scale physical processes, such as erosion/sedimentation/infiltration, seepage, surface water flow, etc. over the population dynamic processes of plants and animals, since the latter are largely controlled by the former. This implies that larger areas should be viewed in their entirety and that (future) developments should be considered on a much wider time scale.
One means towards this end is the development of management plans for large parts of the coast. Such plans offer scope for the harmonization of wishes from various sectors of management and for the presentation of surveys of practical measures, where conservation, restoration and development of natural values form an integrated part of such plans. The Wadden Islands Coastal Defence Management Plan (Public Works Department Wadden Committee, 1987) is a good example, featuring evaluation and checking of the coastal management conducted so far against existing plans and laying down a vision on how to deal with the coastal area of the Wadden Sea during the next few years. The Plan provides the local manager with tools for tuning in his measures to the values of the larger whole. This approach deserves follow-up along the entire Dutch coast.

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9. Environmentally friendly coasts:

Dune breaches and tidal inlets in the foredunes. Environmental engineering and coastal management.

A case study from The Netherlands

H.D. van Bohemen

Abstract
In the Netherlands historically almost all natural conditions in the coastal zone have been highly influenced by man. In 1990, the Government adopted a new coastal defence policy for the Netherlands for the enduring safety and sustainable preservation of the functions and values in the dunes by "dynamic preservation of the coastline" at its position in 1990 ("the base coastline"). Because of the natural flexibility of a dune coast, some allowance is made for movements of the coastline. Permitting sand drifts or even the formation of dune breaches and tidal inlets are some of the possibilities.
The chapter gives an overview of the value of existing dune breaches and tidal inlets and their potentials, and criteria for engineering tidal inlets. It ends with some conclusions and recommendations for implementing the possibilities of engineering in the foredunes.

1. Introduction

In many parts of the world recognition is given to the issue of natural versus manipulated coastal dune systems (Carter et al., 1992). In this chapter a case study of the situation of coastal dynamics in the Netherlands is presented to give some background on recent developments in this respect.

Sand dunes extend for 254 km along the Dutch coast, making up 72% of our North Sea coast (Fig. 1). In the past, the foredunes in the Netherlands were quite varied due to differences in human influence, in shape and position. Dune breaches and tidal inlets were seen along the coastline, especially after severe storms.

Almost all those features disappeared during the last hundreds of years. Only locally do some dynamic systems still exist. Until recently, foredune management did not allow room for dynamics. Recently, the coastal defence policy was changed.

How the Dutch coast should be managed is laid down in a policy document on coastal protection after 1990 (Ministry of Transport, Public Works and Water Management, 1990). One of the main means of preservation of the coastline is the use of sand nourishment to counteract erosion (dynamic preservation), with the aim of keeping the 1990 coastline (the base coastline) intact. Where it is safe to do so, there are also some possibilities for free scope for natural dynamics within the coastal zone. Promoting natural processes in the coastal zone could mean permitting some wind erosion in the foredunes and allowing natural dune breaches and tidal inlets to form.

2. Current coastal policy

A number of publications have already touched on the implications of a more natural dune management policy. These include the Third Policy Document on Water Management (Ministry of Transport, Public Work and Water Management, 1989), the Nature Policy Plan (Ministry of Agriculture, Nature Management

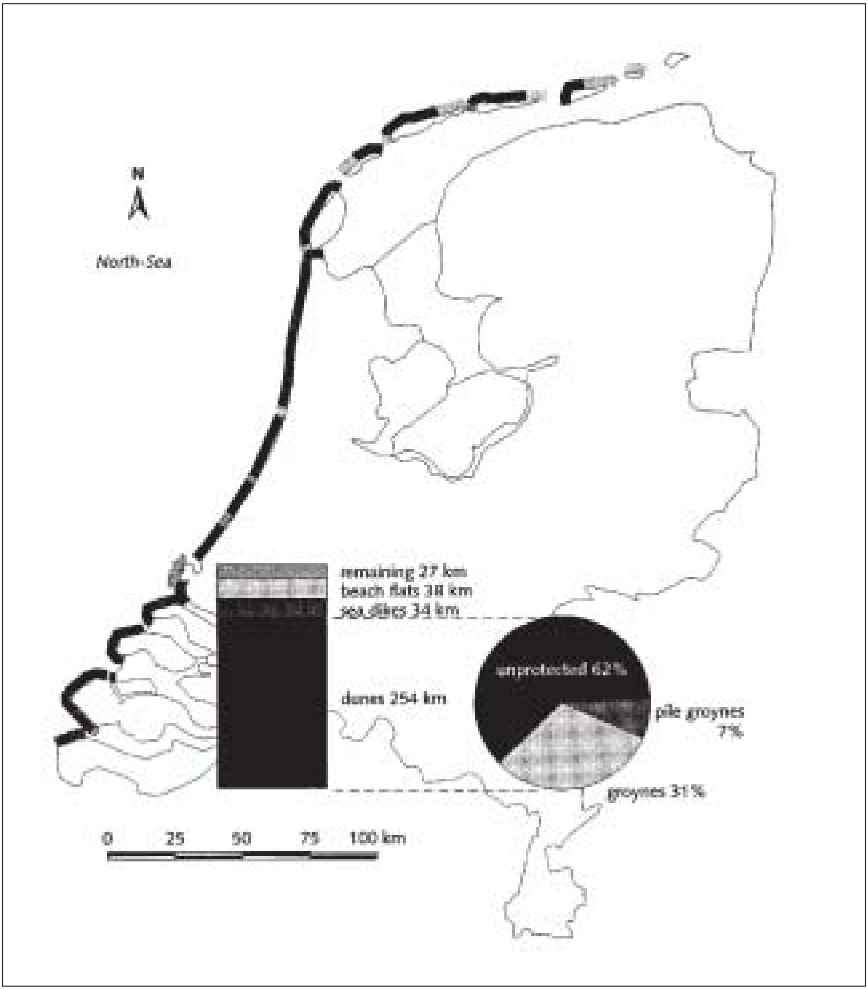

Fig. 1 The location of coast types along the North Sea Coast (map) (Rijkswaterstaat).

and Fisheries, 1990) and the "Dunes for the wind" study (Dune Conservation Organisation, 1992b). There are also various reports on the civil engineering, the ecological and the geomorphological aspects, for instance background studies were carried out for the policy document on coastal protection after 1990 (Ministry of Transport, Public Works and Water Management, 1990; Louisse and van der Meulen, 1991). The National Institute for Coastal and Marine Management, the Road and Hydraulic Engineering Institute (DWW) of Rijkswaterstaat, and the Technical Advisory Committee on Water Defences have also done research on natural coastal management (van Bohemen, 1993; Arens, 1994).

In the Nature Policy Plan, the dunes are designated as a key component in the country's fundamental ecological structure. In recommending a more dynamic, flexible coastal management policy to restore the dune belt, the plan calls for more than only the maintenance of its existing ecological value. Moreover, in the manual for sandy coasts, sand drifts and tidal inlets are mentioned as valuable to increasing the natural and landscape value of the coast, i.e. if safety is not jeopardised. Along coasts with relatively large sand transports parallel to the coast, high management costs will prevent possibilities for tidal inlets to form.

3. Coastal defence

The dune belt in the Netherlands also has an important function in coastal defence, namely by protecting the hinterland from flooding. This is why locally the dune coast has to give way to hard structures which do not occur naturally in the Netherlands. This is the case, for instance, at West-Kapelle and the Hondsbossche sea defences. Elsewhere, the observer will find groynes and rows of wooden piles. An essential precondition for coastal defence activities is

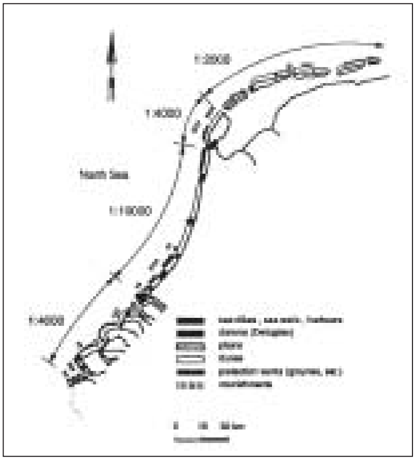

Fig. 2 Coastal protection of the Netherlands (map) (Rijkswaterstaat).

protection against the low frequency storms (Fig. 2); another is the maintenance of the shoreline in its 1990 position. If no economic values are involved and the above-mentioned conditions are set, there will be room for some natural system recovery. This is the case in some wide dune areas along the coast.

4. Ecological value of the land-sea transition zone

The transition from dry land to salt water can vary from a narrow strip to a belt of several kilometers wide. This ecologically important zone is characterised by all kinds of gradients - from dry to wet, higher elevation to low, sand to silt, freshwater to saltwater, and low flooding frequency to high frequency (twice a day). Variations in the diurnal tide give this zone an extra dimension.

The special conditions of the transition zone which is subject to constant change - produce a fascinating diversity of landscapes of ecological significance. Along the sandy North Sea coast the transition zone comprises: the foreshore, tidal flat, beach, coastal dunes and inland dunes. Special plant and animal communities have adapted themselves to the different conditions in each zone. Other important habitats are the dune foot, the dune hinterland, sand flats in the dunes (freshwater dune valleys = dune slacks) and the "green" beach (Hoekstra and Pedroli, 1992).

The plants and animals of the coastal zone have adapted themselves to a dynamic environment where conditions are constantly changing from salt to brackish to fresh, and where there are large temperature variations, a lot of wind, and a surface that is continually shifting (Carter, 1988; Lasserre, 1979).

5. Engineering

In several situations the activities for maintaining the defence function of the foredunes have influenced the ecological values. The question rises what we can do to improve the ecological value of this land-sea transition zone. The new government policy provides several opportunities. It is worth quoting here what the Minister of Transport, Public Works and Water Management said in her covering letter with the policy document on coastal protection after 1990: "There will also be a chance at a regional level to see where there is scope in the management of sea defences to allow the natural dynamics of erosion and even the formation of tidal inlets (tidal inlets are wet dune valleys influenced by the tides; Dutch term: 'slufter').

Fig. 3. Serrated edge of foredunes (photo) (Van Bohemen).

The choice of sand nourishment as the main means of coastal protection is completely consistent with this. Maintaining the coastline in this way does offer the scope for the dynamic maintenance recommended by the Nature Conservation Council" (Minister of Transport, Public Works and Water Management, 1990).

Regional authorities are also considering a more flexible approach to coastal zone and dune management. The following is a quote from the management policy document of the North Holland Dune Reserve: "We have to opt for a differentiated approach to the management of the coastal dune belt, in consultation with the authorities responsible for coastal protection. Some parts of the coastal dune belt must be maintained because they are nature conservation sites or important groundwater sources. In other places, it is recommended that management becomes more liberal, and allows the possible formation of tidal inlets" (PWN, 1990).
Experience has shown that more natural dynamics in the foredune zone will increase the variety of ecotypes (Arens, 1994).
This approach of focusing on the design and reconstruction of ecosystems by man, using small amounts of supplementary energy to control systems in which the main energy drives still come from natural sources, is called environmental/ecological engineering. Environmental/ecological engineering or the building of sustainable and self-designed ecosystems is becoming a useful paradigm in ecology for dealing with environmental issues such as preventing and mitigating the destruction of wetlands, restoring dune ecosystems and adapting to increased sea levels (Mitsch and Jorgensen, 1989).

The case study described in this paper can be seen as an example of environmental/

Fig. 4. Map of the Slufter of Texel (Top. Dienst)

ecological engineering on the scale of ecosystems and landscapes.
Promoting the natural dynamics of the coastal dune belt and the dunes immediately behind it to improve their ecological value will entail: (1) permitting aeolian processes to reshape the coastal dune; (2) allowing gaps to develop in the coastal dune belt to the point where dune breaches, tidal inlets and similar formations are formed.

5.1. Permitting aeolian processes to reshape the coastal dune

This involves: (1) permitting local erosion (deflation) in the coastal dune belt, though monitored and controlled; (2) encouraging a more serrated edge to the coastal dune belt

Fig. 5. View of the Slufter of Texel (photo) (RWS/RIKZ).

(Fig. 3). This would involve new actively migrating parabolic or barchan dunes being created from the coastal dune belt, as well as occasional breaches in the coastal dune belt.

5.2. Allowing gaps to develop in the coastal dune belt to the point where dune breaches, tidal inlets and similar formations are formed

Interest in allowing a wider range of coastal dynamics has increased in recent years. Sand drifts and the development of breaches, tidal inlets and similar formations are often mentioned as examples of how the ecological variety of the dune coast can increase. There are two ways of creating breaches, tidal inlets and similar formations: (1) by controlling ambient littoral processes with measures that mirror natural physical processes, or (2) intervention or by means of environmental engineering.

The most common definitions describe morphological forms such as e.g. the Zwin (a zwin is a small estuarine system) in Zeeuws Vlaanderen in the south-western part of the Netherlands and the Slufter on the island of Texel. (Slufter is Dutch for tidal inlet; Figs. 4 and 5). A wider definition includes bays, as well as tidal flats or tidal marshes behind dunes and dune valleys with a connection to the sea (Eysink et al., 1992).

During a seminar on coastal dynamics in 1992 (van Bohemen and van Schaik, 1993) it was proposed to include in the definition of the Dutch term “slufters” small estuaries or inletlike formations and incidental breaches in the coastal dune belt. The debate about what is a “slufter” should not be limited to tidal inlets,

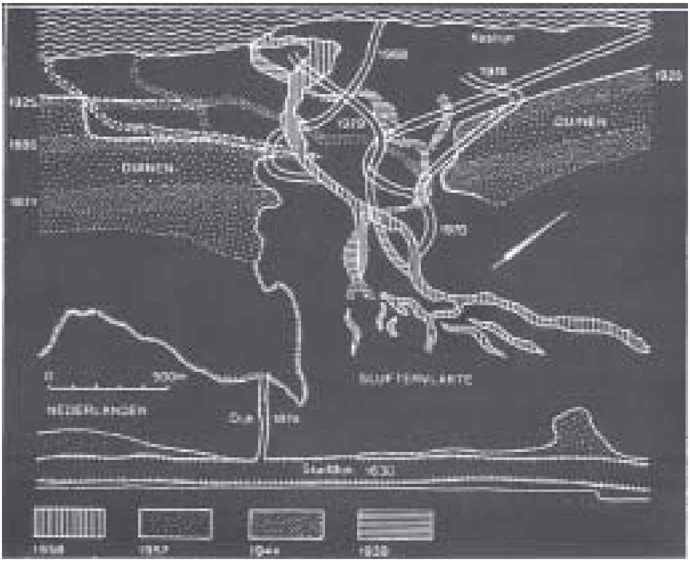

Fig. 6. The tidal inlets in the mouth of the Slufter of Texel during a period of 40 years (map) (KNAG, 1961).

but should also look at opportunities for a more irregular, serrated form of the coastal dune belt. The coastal dune belt would present a more varied morphology of dune tops - some eroding - and valleys with connections with the sea environment parallel to the coast.
On accreting coasts, tidal inlets can form spontaneously by truncation of beach flats. On stable or eroding coasts, tidal inlets can form if the coastal dune belt is breached. Tidal inlets are basically ephemeral stages of a dynamic system. Tidal inlets are affected by the sea, and the degree of erosion or deposition will determine whether they flood on every tide or only on the spring tide. Usually, a bar develops where the tidal inlet meets the sea. At the edge of a tidal inlet, characteristic saltwater and freshwater gradients occur and the sandy substrate becomes more silty or will be covered by a deposit of silt. The tidal inlets usually have a branching system of drainage channels.
In fact, the entire tidal inlet system, with its mouth, drainage channels and mud flats can be thought of as a tidal estuary in miniature (ca. 5-400 ha) on a sandy coast with the characteristics mentioned above (Eysink et al., 1992).

6. Value of tidal inlets

The value of tidal inlets and similar formations is threefold:

1. The continuous process of sedimentation and erosion has a geomorphological and hydrologic value which leads to the presence of a varied pattern of gullies, banks, sand and mud flats, and diurnal/ semi-diurnal exchange of water, nutrients, detritus and larvae etc. between the sea/ bay, tidal flats and tidal marshes.

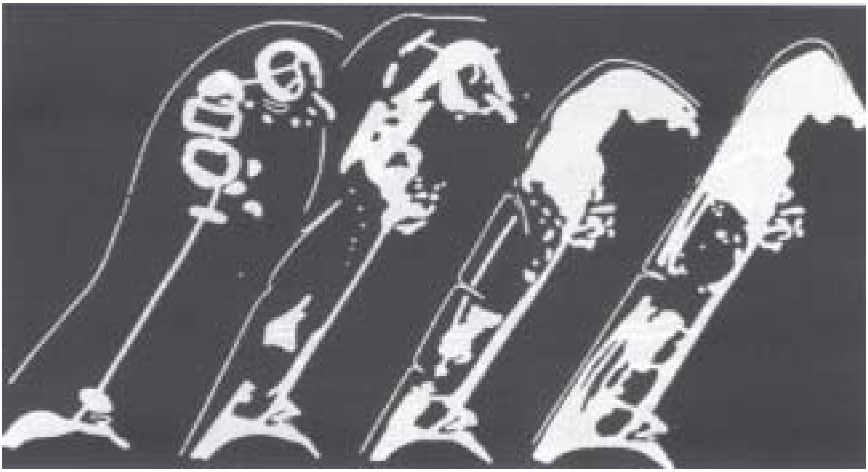

Fig. 7. The building of sand dykes on Texel from 1630 until 1937 (map) (De Levende Natuur 1937)

2. The characteristic elements of the Dutch coastal landscape have a scenic value.
3. Tidal inlets have ecological values. With so many gradients, tidal inlets provide habitats for many kinds of plants and animals, including rare ones.
   This has become relatively more important over the last few decades, as dune areas in the Netherlands have come under increasing pressure due to, among other things, house-building and recreation facilities.

With such a range of elevations, sand and clay areas, low dunes and great variations in flooding frequency, tidal inlets host a mosaic of plant communities. In the lowest areas, some of which are reached daily by the high tide, we find Glasswort (*Salicornia europaea*), Annual sea blite (*Suaeda maritima*), Common saltmarsh grass (*Puccinellia maritima*) and the Common sea lavender (*Limonium vulgare*). Slightly higher up are communities of Common saltmarsh grass as well as Sea plantain (*Plantago maritima*) and Common sea lavender. The highest marshes are then dominated by Thrift (*Armeria maritima*). Sandier places support Sea milkwort (*Glaux maritima*). Channel banks meandering through the inlets will largely be vegetated by communities of Sea couch (*Elytrigia pungens*) and Sea wormwood (*Artemisia maritima*; Westhoff and van Oosten, 1991).

Typical breeding birds are the common eider duck, various kinds of terns, the Kentish plover, ringed plover, avocet and numerous kinds of gulls.

Feeders like the redshank and birds of prey like the harrier and the short-eared owl are also found. Tidal inlets are important resting and feeding places for migrating birds, due to the rich production of soil organisms in the mud, as well as the quiet and shelter.

Tidal inlets are not static elements. It is usually possible to find evidence of tidal inlets turning

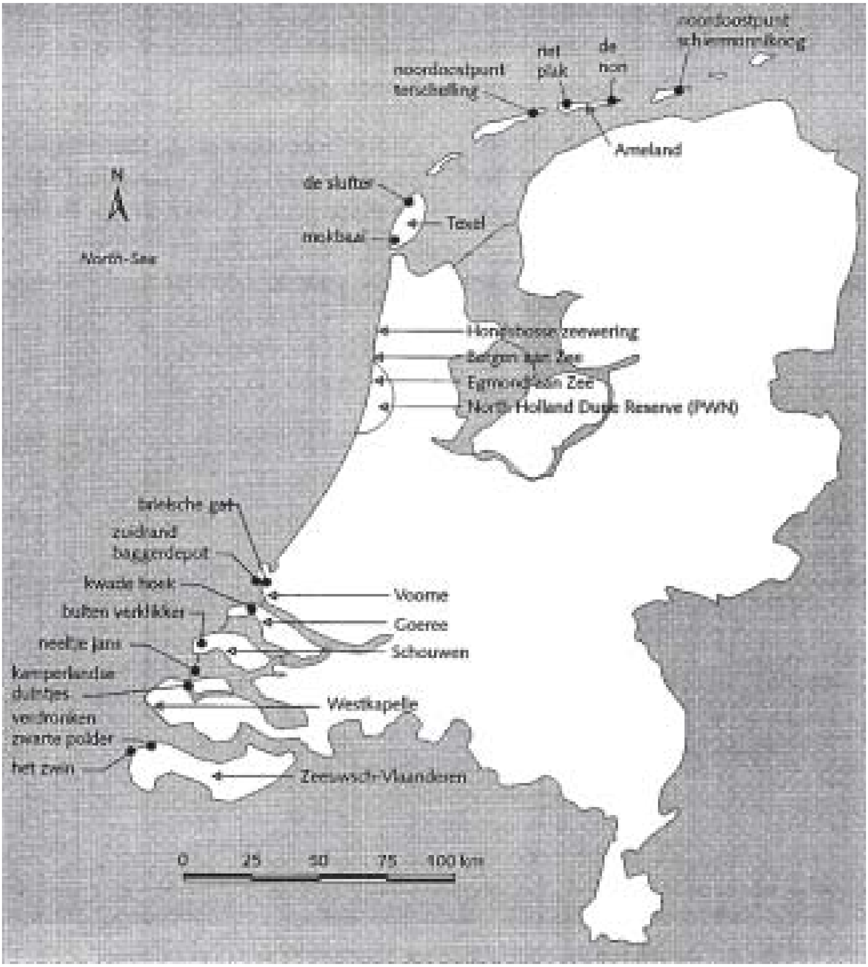

Fig. 8. Map of the Netherlands showing the locations of tidal inlets (•) (map) (Hoekstra and Pedroli, 1992)

Fig. 9. Sealed breahthrough in 1972 (photo) (PWN)

Fig. 10. Tidal inlet on the south side on the Maasvlakte depot (phote) (Van Bohemen)

into inletlike areas and vice versa. The channel pattern at the mouth of the creek is also in a continuous state of flux (Fig. 6). These natural dynamics are one of the valuable aspects of tidal inlets and similar formations.

7. Development of tidal inlets

Tidal inlets can originate in the following ways (Eysink et al., 1992):

1. when a tidal channel between two islands silts up. Example: the first phase in the development of the Slufter on Texel (Fig. 7);
2. by a natural breach of the coastal dune belt (usually on an eroding coast). Example: the second phase in the development of the Slufter on Texel (Fig. 7);
3. by dunes migrating seaward at different rates (on an accreting coast). Example: the Kwade Hoek on Goeree;
4. when a river silts up where it discharges into the sea, for example the Zwin.

Although the Zwin can also be seen as an area of estuarine development and estuarine sedimentation, it can exist because of incomplete sedimentation.
In addition, it is also possible to intervene by creating tidal inlets of similar formations using engineering based on natural physical principles.

8. Former tidal inlets

A study of the former tidal inlet situations may present possibilities for the future. For example, an inletlike area on Schouwen has been reconstructed on Schouwen using old maps (van Hell and van der Schelde, 1992). The so-called Palinck valley must have been situated to the northwest of Renesse. All that remains now is the silted up inlet in the form of a duck decoy known as the Palingsgat. There used to be inletlike formations on Voorne (Windgat), and Goeree (Meinderswaal in the eastern dunes), developed by breaches in the dunes in the 15th and 17th centuries respectively.

8.1 Present-day tidal inlets and similar formations

The map (Fig. 8) shows the locations of present-day tidal inlets in the Netherlands (source: Beijersbergen and Beekman, 1989; Arens and van der Meulen, 1990; van Bohemen, 1991; Hoekstra and Pedroli, 1992). Table 1 gives a short description of some characteristics of tidal inlets.

Area	Type	Coastal type	Size
The Zwin Zeeuwsch Vlaanderen	complete tidal inlet system with tidal channel	accretion	+ 200 ha
Verdronken Zwarte Polder Zeeuwsch Vlaanderen	"green" beach with several dunelike forms	light accretion	+ 25 ha
Kamperlandse dunes Noord-Beverland	beach plain and "green" beach	light accretion	+ 25 ha
Buiten Verklikker Schouwen	beach plain and "green" beach	accretion	+ 100 ha
Neeltje Jans Construction Island Oosterscheldekring	complete tidal inlet with tidal channel	accretion	+ 25 ha
Kwade Hoek Goeree	several elongated, complete tidal inlet systems with short tidal channels	accretion	+ 200 ha
Tidal inlet on the southern border of a depot for dredged materials Maasvlakte	small artificial beach plains behind dunes	accretion	+ 5 ha
Brielse Gat Voorne	large, developing beach plain with tidal channel	accretion	+ 300 ha
Mokbaai Texel	beach plain	accretion	+ 200 ha
De Slufter Texel	large, complete tidal inlet system with tidal channel	erosion	+ 400 ha
Noordoostpunt Terschelling	beach plain and "green" beach	accretion	+ 150 ha
Rietplank Ameland	beach plain and "green" beach	light erosion	+ 150 ha
The Hon Ameland	beach plain and "green" beach	accretion	+ 200 ha
Noordoostpunt Schiermonnikoog	beach plain and "green" beach	accretion	+ 300 ha

Table 1. Table description of tidal inlets and similar areas in the Netherlands (source: Hoekstra and Pedroli, 1992)

9. Locations suitable for natural tidal inlet formation

Tidal inlets and similar formations can form naturally on accreting dune coasts. This is the case, for example, in the Brielse Gat on Voorne and on parts of the sea coasts of Terschelling and Ameland (Fig. 8). A tidal inlet can also occur on an eroding coast, if the sea creates a connection with a dune valley originally cut off from the sea.

On more or less stable coasts - e.g. parts of the North Holland coast - tidal inlets can also be formed by dune breaches at spring tide. A condition for allowing tidal inlets to form in these situations is that the dune belt is wide enough to guarantee the integrity of the dunes inland. The dune belt north of Bergen aan Zee (the Buizerdvlak) was breached in 1953 and 1972, but on both occasions the inlets created were sealed fairly quickly afterwards (Fig. 9). Natural tidal creek formation can be initiated by stopping active maintenance of the foredunes and allowing breaches to form.

10. Actual sites realized by environmental engineering

Natural processes can be accelerated by using bulldozers and draglines to make an artificial breach or to reprofile the sand to develop a tidal inlet. Tidal inlet projects (Fig. 8) which have been constructed to date include the following:

A tidal inlet on the south side of the large Maasvlakte depot used for storing dredging material. Constructed in 1987 (Kuipers, 1989), a line of dunes encircles a tidal flat which is open to the sea on the eastern side.
The inlet is 175 m wide and nearly 300 m long and most of it has been raised to an elevation between +1.75 m and 2.50 m Amsterdam Ordnance Datum (NAP). The flats are partly flooded approx. 1-25 times a year. The original

Fig. 11. The slufter at Neeltje Jans (photo) (Van Bohemen)

design envisaged occasional flooding with saltwater. This turned out to be only a few times a year, and in 1991 the valley was artificially deepened to increase the flooding frequency (Fig. 10). In 1992, outline designs were drawn up (Dune Preservation Organisation, 1992a) for reprofiling the beach flat behind the dunes to achieve a more varied development of flora and fauna. The small size and the relatively high elevation of the present tidal inlet are seen as major limitations on development. The new design therefore aims for a larger tidal inlet surface, more gradual transitions and greater tidal effect.

Neeltje Jans tidal inlet (Fig. 11). A tidal inlet was constructed on the seaward side of Neeltje Jans in 1992, by levelling an artificial dune area (25 ha) which dated from 1972.

11. Potential sites

Other possible sites (Fig. 12) for the "engineered" tidal inlets or similar formations are: (1) the Pyrolavlak (north of Bergen aan Zee); (2) the Buizerdvlak (north of Bergen aan Zee); (3) the Schuitegat/Houtglop (Kennemer dunes); (4) the eastern headland on Terschelling; (5) the southwest coast of Goeree; (6) the Meeuwen dunes on Schouwen.

Rakhorst (1992) has made some preliminary calculations for the Pyrolavlak and Buizerdvlak areas.

As mentioned above, the coastal dune belt has already been breached several times by spring tides (1953 and 1972), flooding the area behind the coastal dune belt.

The elavation in the Pyrolavlak and the

Fig. 12. The potential areas for creating tidal inlets or similar formations (map) (Hoekstra and Pedroli, 1992)

Buizerdvlak rules out flooding at normal tides. This could be overcome by mechanical levelling. One idea being considered is the possibility of using sand obtained by deepening the Pyrolavlak to replenish a stretch of eroding coast between Egmond aan Zee and the Hondsbossche sea defences. This could well be a cheaper option than marine extraction of mineral sand especially for the purpose. The volume of the sand to be excavated is about 200,000 - 300,000 m^3.

12. Criteria for engineering and/or natural formation of tidal inlets

It is very important that predictions of the effect of a proposed breach on coastal development at the site and on the wider environment are as correct as possible. The size of the breach or inlet required should also be determined in advance. And, naturally, flood safety requirements for the areas behind the dunes have to be met.
The best size is that which produces an optimum relationship between wildlife habitats and sustainability. Artificial intervention should generally be kept to a minimum, just enough to create the conditions for nature to run its course. Naturally, the area directly or indirectly affected by the tide has to be relatively large to allow broad, gradual transition zones to develop.

The following criteria should guide the decision on whether to create or allow formation of a tidal creek: (1) will the inland dunes continue to meet the flood safety requirements for the protection of the hinterland? (2) what are the ecological, geomorphological and scenic benefits? A kind of land-use plan should be drawn up first, showing the ecological features of different parts of the area; (3) what will be the hydrologic, ecological and scenic effects on the surrounding area? (4) what are the costs? Does the proposal involve extra work or savings in the coastal defences budget? (5) how much maintenance will be required to keep the tidal creek open? (6) which socio-economic factors are involved? The following aspects, among other variables, can influence the management of a tidal inlet: (1) changes in the water volume at high and low tide; (2) construction of a migrating dune on an accreting coast; (3) fixing the mouth of the creek; (4) grazing to keep down the amount of biomass of grass and rough vegetation. In principle, natural processes should always be preferred; artificial intervention should only be considered if nature takes too long (seen from a human viewpoint).

13. Acquiring and transferring knowledge

The trend in dune coast research in the Netherlands is to emphasize conservation and the development of wildlife and scenery. This is reflected in the Netherlands in several governmental policy documents in which the following objectives are formulated: (1) preservation of present levels of flood defence and amenity values in dune areas (Coastal policy document); (2) preservation of the 1990 coastline (Coastal policy document); some scope is to be given to the natural movement of the dune coast (Coast policy document); (3) conservation, restoration and development of wildlife and scenic values (Nature Policy Plan); (4) development of an integrated but differentiated approach by means of planning and environmental policy (Policy document on differentiated environmental policy).

13.1. Research

We need a better understanding of some aspects of coastal dynamics to achieve the optimum balance between nature and flood defence. The Road and Hydraulic Engineering Institute (DWW) carried out preliminary studies prior to setting up a definitive research programme. First of all there is the study on "Environmental, nature and landscape aspects of water defences" (1992), subcontracted by the DWW to the Bureau SME consultancy. Following this, two studies were carried out by Delft Hydraulics. One was a study of the abiotic and morphological aspects of tidal inlets, the other examined their ecological value (Eysink et al., 1992; Hoekstra and Pedroli, 1992).

The aim of these studies was to find out which knowledge is lacking. In addition, input on the possible design of a research programme came from a seminar on tidal inlets.
The annexe summarises those topics research effort will be concentrated on in the next few years.
This research is all the more pressing as demands are increasingly made by the profession and the public for natural dynamics and ecology to be incorporated in the management of the coastal dunes.

13.2. Information and education

Besides acquiring new understanding through research, dissemination of existing knowledge is important. This means the transfer of knowledge not just to coastal defence authorities, but to the wider public and to educational establishments as well.

14. Conclusions and recommendations

The development of tidal inlets such as the Slufter on Texel and similar formations, including a more serrated belt of coastal dunes, is of great ecological and scenic benefit and will further the conservation and development of nature. These features should be maintained where they already exist and a certain degree of natural dynamics should be encouraged elsewhere. This policy of encouragement of breaches in the most seaward component of the storm protection barrier where the function of the general barriers is not affected, is a new aspect in restoring nature by using natural conditions.

The research programme that has been outlined will be carried out to enable a proper consideration of priorities and the implementation of projects. Some local experiments at selected sites would be useful to gain experience from eroding coastlines. Suitable sites include the Pyrolavlak and the Buizerdvlak, and the Kennemer dunes in North Holland, together with the Meeuwen dunes on Schouwen in Zeeland.

Acknowledgements

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Appendix A. Annexe 1: Planned research

A.1. Uniqueness of Dutch tidal inlets

A.1.1. General objective

1. Better understanding of the significance of tidal inlet formation (and research) in the Netherlands.
2. Better understanding of the ecological value of tidal inlets.

A.1.2. Method

To look at existing information on European tidal inlets. Inventory of the existing tidal inlets of Europe (values, maintenance, research) by means of a questionnaire in cooperation with European Union for Coastal Conservation (EUCC)

A.2. Inland flood protection requirements

A.2.1. General objective

Formulation of premises and boundary conditions, contribution to the proper siting of tidal inlets and development of a serrated coastal dune belt caused by sand drifts.

A.2.2. Method

Based on boundary conditions: inventory of foredunes along the coast where natural dynamic processes may be permitted (in co-operation with the Dutch Institute for Sea Research).

A.3. Survey of the present state of affairs on tidal inlets and siting

A.3.1. General objective

To determine the present state siting tidal creeks (RWS is involved as regards coastal morphogenesis and the flood security of the hinterland).

A.3.2. Method

Discussion with people involved in tidal creek research (including the ministry of agriculture, conservation and fisheries, the north sea working group, the tidal waters division of rijkswaterstaat and the dune preservation organisation).

A.4. Monitoring tidal inlet construction projects

A.4.1. General objective

Evaluation of tidal inlet projects that are being carried out and identification of possible sites for new projects.

A.4.2. Method

Analysis of the objectives of monitoring tidal inlets on Neeltje Jans and the Maasvlakte. Drafting of an outline model for monitoring, showing parameters already measured for other purposes and which could be used, for example in the form of co-ordinating monitoring (which is already being carried out) and integrating (and publishing) the results for evaluation.

A.5. Annual sedimentation in the Texel slufter / hydrodynamics of the Zwin

A.5.1. General objective

Better understanding of the morphological processes in existing tidal exchange systems (in various stages of development).

A.5.2. Method

Analysis of levelling data from the Slufter, possibly by collecting more data. Analysis of the hydromorphological parameters in the Zwin.

A.6. Rate of change of morphological processes involved in sedimentation and erosion of a tidal inlet

A.6.1. General objective

Better understanding of the morphological processes in existing tidal inlet systems (in various stages of development).

A.6.2. Method

Study of morphological processes in existing tidal inlets; a preliminary study is required to establish what we need to know and how it can be measured.

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10. Ecological Engineering and Coastal Dynamics: A Synthesis.

Hein van Bohemen (DWW)

1. Preface

In this section an overview is given of the development of dynamic coastal management between 1989 and 2003 in connection with the knowledge developed in this area.
The Road and Hydraulic Engineering Institute has played a major part in this field by commissioning and performing its own studies. The section also illustrates the interplay between policy, concrete maintenance measures and research and shows what lessons can be learnt from over 10 years of experience with a more environmentally friendly form of coastal management based on ecological engineering.

2. Coastal Policy and Knowledge Development

Coastal memorandums play an important part in the determination and execution of the desired policy. On the basis of policy memorandums on the Dutch coast published in 1990, 1996 and 2000, an overview is given of the development of the implementation of dynamic coastal management (see Table 1).

First Coastal Memorandum:
Introduction of Dynamic Maintenance
In addition to dikes and dams, the Dutch sandy coast plays an important role in the protection of the low-lying hinterland against floods. After continuous shore erosion, in 1990 the Dutch government and parliament opted for the dynamic maintenance of a so-called base coastline, the coastline that was present in 1990 (Anonymous, 1990).
This involves the countering of erosion through sand replenishment to the forebanks or the beach. In this way, it becomes possible in a number of situations to treat the beach ridge less rigidly and to reduce the frequency of maintenance. This means that there is room for drifting sand as well as a more notched beach ridge or the formation of tidal inlets. From an ecological point of view, this results in a more natural beach ridge, that, from a dynamic point of view, has the largest possible number of relationships with the dunes lying behind.

In 1992, Delft Hydraulics (Hoekstra and Pedroli, 1992), at the behest of the Road and Hydraulic Engineering Institute, performed a study into the morphology and history of Dutch tidal inlets and tidal-inlet-like areas, after a study into Dutch sea inlets (Eijsink et al., 1992).
In 1993 (Van Bohemen, 1993, 1996) the Road and Hydraulic Engineering Institute continued the ecologically oriented coastal research. The Technical Advisory Committee on Water Defences, which specialised in the protection of sandy coasts, provided advice.

Apart from this, coastal-morphological phenomena were studied by the University of Amsterdam in particular (Van Bohemen et al., 1989; Van der Meulen and Jungerius, 1989; Arens, 1994; Arens, Jungerius and Van der Meulen, 2001).

Second Coastal Memorandum:
Bergen-Schoorl Pilot Project
In 1995, the second coastal memorandum ‘Kustbalans 1995’ [‘Coast in Balance 1995’] (Anonymous, 1995) was published. In this publication five years of ‘dynamic maintenance’ were evaluated. From the memorandum it becomes apparent that structural loss of beach and dunes has been brought to a stop with the aid of sand replenishment. Restoration and development of natural dynamics within the

beach ridge had occurred only to a very modest extent, but it was stated that 'the opportunities for restoration and development of natural processes within the beach ridge will be seized (extensification of beach-ridge maintenance, execution of the Bergen-Schoorl tidal-inlet pilot project). Landowners and coastal defence management organisations play a leading role in this regard'. It should be noted that 14 possible locations for restoring natural processes were suggested, namely Schiermonnikoog, Terschelling-Oost, Terschelling-West, Texel, Bergen-Schoorl *), Bergen-Egmond *), Egmond-Castricum, Castricum-Heemskerk, Bloemendaal-Kennemerduinen, Noordwijk, Wassenaar-Berkheide, Wassenaar-Meijendel, Schouwen (Verklikkerduinen), Schouwen (Meeuwenduinen).
[(*) to be performed with priority; Bergen-Schoorl as pilot project].

In 1996, the 'Monitoring of dynamic coastal management' project of the Technical Advisory Committee on Water Defences resulted in an evaluation of the various initiatives and experiences with regard to dynamic coastal management within the beach ridge (Löffler, 1996). From this it can be gathered that 'dynamic coastal management' has become a household concept, even though the parties involved do not always interpret it in a unique, non-ambiguous way. Nevertheless, it has led to an extensification of maintenance. It also appears that more area-oriented, integral plans are being drawn up, and that these plans envisage, among others, the stimulation of 'natural processes'.

The policy that was stimulated at the beginning of the nineties (Van Bohemen and Van Schaik, 1993; Stichting Duinbehoud, 1992) led to the foundation of the Bergen-Schoorl workgroup, which consists of representatives responsible for the coastal defence, the dune managers, the province of North Holland, the Ministry of Agriculture, Nature and Fishery and the Ministry of Transport, Public Works and Water Management. In November of 1997, Staatsbosbeheer [the State Forest Service] dug a so-called notch between Bergen and Schoorl (at beach pole 30.50). The construction of 'the notch' had been explicitly incorporated into the second coastal memorandum as one of the area-oriented projects for the restoration of natural processes.

In 1999, an extensive evaluation report bearing the title 'Grasduinen in de waterkering' ('Dabble in the waterdefence') was published. It evaluated 10 years of dynamic coastal management (Löffler and Veer, 1999). From this evaluation it can be concluded that giving free range to coastal zone dynamics has nowhere resulted in the deterioration of coastal safety. From a landscape point of view, benefits have been produced relatively quickly. It is recommended that the possibilities of dynamic coastal management should be explored in more locations along the shore, e.g. along Voorne, Texel and Goeree, on the basis of the wealth of opportunity for more dynamism and increased nature areas. See also Evaluatierapport Dynamisch Kustbeheer (Dynamic Coastal Management Evaluation Report) by the Stichting Duinbehoud (Society for Dune Conservation) (Janssen, 1999).

Third Coastal Memorandum:
Continuation of Dynamic Maintenance
In the third coastal memorandum (Anonymous, 2000) the 'dynamic maintenance' policy is continued, and the policy objective 'dynamic dune management to be further stimulated' has been incorporated once more. Since 1995, a restoration of the natural dynamics of sand dunes has taken place in many areas: a more natural beach ridge, a termination of the planting of marram grass, the marram grass

Policy Effect Studies
Apart from carrying out research and publishing the policy notes mentioned earlier, the development of policy effect studies was gaining ground from the eighties. 'De studie over de kust van Texel' (Baarse, 1984; Van Bohemen, 1982) was one of the first studies in this field. Since expenses had frequently played a dominant role in decision-making, as part of the 'Water-verkenningen' study by the Directorate-General for Public Works and Water Management into salt-water policy, two case studies were performed in order to provide more insight into the expenses as well as the benefits of different kinds of sea defences. One of the more recent studies (Van Beukering, 2001; Van Beukering et al., 2001) concerned the comparison of alternatives for the coastal management of the Hondsbossche Zeewering. In this study, the benefits and drawbacks of certain interventions are evaluated on the basis of a division into ecological ('groen'), economical ('geld') and social-cultural ('gevoel') methods of appraisal. The study on the Hondsbossche Zeewering presents an overview of the expenses and benefits of three alternatives for the Hondsbossche Zeewering; a tidal inlet alternative is discussed as well (Klop, Van Beukering and Stronkhorst, 2003). On the basis of the method of appraisal that was used, the tidal inlet alternative received a high ecological and economic rating and a lower social-cultural rating. According to the researchers, this suggested differing views on what is important by the local population and persons and organisations on a regional or national level.

already present have become more vital in several places due to accumulation of sand. After explorations into dynamic dune management between 1995 and 2000 and the realisation of the notch near Bergen-Schoorl, it is likely that plans will be drawn up for dynamic coastal management along the Dutch coast on Texel and Goeree.
In the third coastal memorandum, the authors mention 'coast moving along'. The note emphasizes the natural sea defence force of the dune area.
The third coastal memorandum also indicates that the local and regional management organisations, especially, are responsible for decision of whether or not to enhance the sea coast dynamics that are desirable from an ecological point of view.

The Future
On the basis of the memorandum published in 2002, 'Naar integraal kustzonebeleid; beleidsagenda voor de kust' (Towards integral coastal zone policy, policy agenda for the coast) (Anonymous, 2002), a major debate will take place that should result in coastal policy guideline by 2004. In the same year, a progress report on coastal management will also appear. As things stand, it can be expected that this report will show that dynamic coastal management is expanding, but that insufficient use is being made of opportunities. It is to be expected that dynamic coastal management will be included as a topic in the coastal policy guideline.

At the instigation of a European Union recommendation, a national strategy for integral coast management will be set out in 2004/2005. This strategy will focus on the weak places within the Dutch coastal defence as well as risk issues: the coastal areas where buildings are situated within the erosion zone from which sand can be removed during super storms - both threats are reinforced by the forecasted accelerated rise of the sea level and the pressure on the coast from side of the land. One may still discern a deterioration of the quality of nature and landscape as well as reduced opportunities for more natural dynamics. Despite a history of floods and insecurity about storm surge risks, there is limited awareness of safety and risk aspects among the Dutch population. This is also the case for the importance of a robust as possible coast that has sufficient resilience and ecological quality.

In 2002, the new ‘Leidraad Zandige Kust’ (Sandy Coast Guideline) (Anonymous, 2002) appeared as a sequel to the outdated version of 1995. This new version of the guideline is better connected to recent developments in Dutch society, such as the improvement of natural and dynamic management and increased interest in so-called LNC (Landscape, Nature and Cultural) values.

As far as the research on the sandy coast is concerned, this should focus on the monitoring and evaluation of long-term effects of dynamic coastal management, from the point of view of both safety and ecological values. With regard to sand replenishment, attention should be paid to the composition of the sand that is derived and replenished as well as the effects on the areas from which sand is obtained. Because of the tendency to carry out more replenishment on underwater sandbanks, more insight into the effects is required. Seaward coastal development should also be put on the agenda, for instance aspects such as the seaward shift of the northern pier of the Nieuwe Waterweg, the plans for a seaward shift of erosion lines and the extension of the temporary or permanent buildings in the dunes. The ‘De Nederlandse Kust in 2030’ (The Dutch Coast in 2030) report (Dorst, 2000) presents an overview of the current knowledge with regard to the Dutch coast. It also sketches the possible development of the coast within the next thirty years.

3. From the Fixing of Dunes to Dynamic Ecosystem Management

Preface

The past thirty years, it has gradually emerged that the foredunes, the inland dunes and the zone in front of the coast make up a coherent system, in which the dynamics of sea, wind, salt, sun and precipitation produce a great variety of landscapes in close proximity to each other. The changing shapes of the beach and beach ridge are caused by erosion and sedimentation at the coast, and in the interior secondary sand-drifting plays an important role in the creation of gradient-rich situations.

Around 1970, experiments took place at a very local level with the stimulation of blown hollows on Schiermonnikoog, and at a later stage also within the inland dunes of the provinces of North Holland, South Holland and Zeeland. Since 1985, the situation and significance of the survival of plants and animals within the beach ridge are placed in a more dynamic context (Van der Putten, 1989; Anonymous, 1990; Arens et al., 2001; Van Bohemen and Veenbaas, 1991).

It was observed that blown hollows were in principle stabilising as a result of a number of natural processes (Van der Meulen and Jungerius, 1989). Locally, as a result of sand replenishment in the forebanks, small primary dunes were created in front of the beach ridge that were not washed away in winter. Gradually, the importance of the survival of plants and animals for a single dynamic dune ecosystem emerged. This ecosystem consists of the following subsystems: forebanks, outer dunes (including the beach ridge) and inner dunes (including the inner-dune edge) (Arens et al., 2001).

Case Study: Beach Ridge Management Amsterdamse Waterleiding Duinen and Duinwaterleiding Zuid-Holland

The management of the beach ridge of the Amsterdamse Waterleiding Duinen (Amsterdam Water Supply Dunes) by the Hoogheemraadschap [District Water Control Board] of Rijnland is geared towards the maintenance of the sea defence function. The first row of dunes is being kept intact artificially. Sand drifting is countered by the planting of marram grass. The key factor behind the entire dune system is drifting sand. However, drifting sand has completely disappeared from the Amsterdamse Waterleiding Duinen. In 1990, the government introduced the principle of 'dynamic maintenance' of the coastline. This made possible an enhancement of the dynamics along the coast that left room for the conservation of the so-called base coastline (the coastline as it was in 1990).

The 'Nota Natuurbeheer 1990-2000' (Nature Management Memorandum 1990-2000) concerning the Amsterdamse Waterleiding Duinen included no action items for the management of the beach ridge. The 'Visie 2001-2010' (Vision 2001-2010) (Anonymous, 2001) states that it is desirable to allow small-scale sand drifting within the beach ridge. An interesting addition is that the beach forms an emphasis component of dynamic coastal management; the creation of a beach reserve is proposed. This recovers (on a very local scale) the connection in the ecological sense of sea and dune area.

For the beach ridge of the dunes of Wassenaar, some room for dynamics has recently been allowed within the beach ridge.

Case study: 'De Kerf'
The construction of 'De Kerf' (hereafter 'The Notch') resulted from the first coastal memorandum 'Kustverdediging na 1990' (Coastal Defence after 1990) (Anonymous, 1990) and the Natuurbeleidsplan [Nature Policy Plan] (Anonymous, 1990).
The term 'notch' has been choosen instead of 'slufter' as an area like the Slufter on the isle of Texel could work negatively by skeptical people.

The 'dynamic maintenance of the high water line' opted for in the first coastal memorandum offered greater room for dynamics within the beach ridge, and in the Nature Policy Plan a 'Herstel en ontwikkeling in het kustduingebied' (Restoration and development within the coastal dune area) project was incorporated with a 'tidal inlet formation' subproject (an example of policy innovation). After 1990, a number of reports were published (see Table 2) on the possibilities of restoring natural processes within the beach ridge and on possible locations. On the basis of the second coastal memorandum from 1995, Bergen-Schoorl (The Notch) was singled out from fourteen locations for a pilot project and further elaborated by a broadly composed project group, stimulated especially by the Stichting Duinbehoud (Society for Dune Conservation). In 1995, a global plan was drawn up for the restoration of dynamic processes in the coastal area of the Schoorl dunes.

It has taken years of intensive negotiation between managers of the Hoogheemraadschap (District Water Control Board), Staatsbosbeheer (State Forest Service), Rijkswaterstaat (Directorate-General for Public Works and Water Management) Provinciale Waterleiding Duinen Noord-Holland (Provincial Water Supply Dunes North Holland), the Province of North Holland, the municipalities of Schoorl and Bergen as well as a massive communication effort: 10,000 brochures, advertisements in newspapers, slide shows, a travelling exhibit, information evenings, field trips, press releases and press excursions, presentations to managers, provincial committees, council committees and local (pressure) groups as well as articles in magazines.

On November 7th, 1997, an administrative agreement was made and the construction of 'The Notch' was started. The 'Evaluatie 'de Kerf' 1997-2002' (Vertegaal et al., 2003) evaluation report presents an overview of the technical as well as more societal and governmental aspects.

4. Comparison of Planned and Performed Research with regard to the Ecological Significance of Dynamic Shoreline Management

Table 2 presents an overview of research planned in 1993 with regard to the promotion of more nature along the Dutch dune coast. Table 3 lists the actual research that was carried out between 1983 and 2003 and has largely been discussed earlier on.

When comparing the overviews presented in Table 2 and Table 3, it becomes apparent that the original focus on 'tidal inlets' has been strongly increased to signify dynamic coastal management for natural values in the broader sense, that is to say, the importance of the dynamics and underlying processes of landscape-ecological (physical, coastal-morphological and ecological) aspects of the dune ecosystem in which the forebanks, the (above-water and underwater) beach, the outer dunes (including a single or double beach ridge) and the inner dunes make up interrelated subsystems. Under natural circumstances, sand transportation between these subsystems may take place as a result of tidal movement, wave movement and wind.

The choice for 'tidal inlets' was then used as a symbol for drawing attention to the importance of dynamic processes within the beach ridge. The symbol has changed from tidal inlets/tidal-inlet-like areas to 'notch', and the research into processes is mainly directed to sand drifting as the key factor behind the development of dunes, and has later been expanded to include the processes of the effects of wind and water on sand transportation in relation to ecological processes.
The relation between sand transportation and vegetation, especially with regard to the vitality of marram grass, was already been a key topic in the second half of the eighties and the beginning of the nineties. In that era, research was carried out in order to investigate which factors determined the vitality of marram grass within the beach ridge (Van der Putten, 1989 and Van der Goes, 1992). The key question in this research was why marram grass grew so badly within the stabilised beach ridge. It was found that sand needed to be aggregated for marram grass to continue its growth in order to prevent the formation of fungi and eelworms in the top-soil layer.

Required Research
Thanks to the studies performed, a more dynamic coast can be handled in a more responsible way. However, some questions remain unanswered, partly due to the expected additional sea-level rising resulting from climate changes as well as the increased pressure of building and intensification of recreational (co-) use of coastal dunes.
Research with regard to dynamic coastal management and natural values should direct itself to the following topics:

- Will the coast become truly dynamic with the help of interventions such as 'The Notch'?
- Evaluating the possibilities of linking existing models that each focuses on a

specific aspect of coastal management. This mainly involves the integration of coastal erosion models and sand transportation models.
- Evaluating the ecological effects of the drifting behaviour of replenished sand of varying composition and grading.
- Evaluating which coastal safety insights need to be changed as a result of the forecasted sea-level rising in connection with contributions from ecology.

Lessons Learnt
On the basis of experiences such as with 'De Kerf', a number of learning points with regard to nature and coastal management are summarised below (after Vertegaal et al., 2003; with adjustments).

- Collaboration between private and government organisations is essential for achieving innovation. In the first instance, the initiative has been that of The Directorate-General for Public Works and Water Management/Road and Hydraulic Engineering Institute as principal of studies by the Stichting Duinbehoud.
- Financing of preliminary studies and plan preparation should in the first instance come from government bodies (Road and Hydraulic Engineering Institute and National Institute for Coastal and Marine Management; RIKZ).
- Outsourcing of research to scientific research centres (Waterloopkundig Laboratorium (Delft Hydraulics), universities, Nederlands Instituut voor Ecologisch Onderzoek (Netherlands Institute of Ecology) in collaboration with societal organisations (Stichting Duinbehoud) is essential.
- It should be realised that to convince all persons and organisations involved of the importance of more dynamics within the foredunes is a long term process.
- Solid, open dialogues between involved parties is essential for the course of the process. Sufficient willingness is required to engage in flexible action whenever circumstances change.
- An intensive communication path towards the public and managers is an essential condition for achieving results.
- A permanent contact point for the coming years as an intermediary between researchers, organisations policy-makers and societal organisations is deemed essential by a number of involved parties for a proper progress of the ecological contribution to dynamic coastal management.

Dynamic coastal management and the enhancement of the dynamics within the foredunes and inland dunes (restoration of natural sand transportation processes) in particular, increasing the ecological value (renewed succession processes), restoration of gradients such as deficient/rich in lime, dry/wet, salt/fresh in close relation to the objectives to be achieved with regard to safety against floods is a form of ecological engineering, in which technical (management) interventions for the benefit of both man and nature are carried out. A close co-operation between civil engineers, ecologists and managers is essential for achieving a result that is acceptable to all parties involved.

Period	Policy notes	Points of departure and activities aimed at the protection of the sandy coast against floods in connection with a more natural beach ridge.
1970 - 1990		Raise sand walls to Delta level; fixing the beach ridge and following the coastal movement (mostly inland); maintaining sand by means of anti-drifting screens, planting of marram grass and inward fortification of the beach ridge.
1990	First coastal memorandum	• Sustainable maintenance of safety • Sustainable maintenance of functions and values of dune areas • Sustainable maintenance of the coastline (in the year 1990)
1995	Second coastal memorandum	• Continuation of dynamic maintenance • Countering sand loss by sand replenishment in deeper water. • Enhancement of natural dynamics within the beach ridge
2000	Third coastal memorandum	• Dynamic coastline maintenance • Sustainable safety with natural dynamics • Where necessary, sand replenishment under water and on the beach • Improved centring on natural processes • Ecological recovery: dynamic maintenance of the dunes must be expanded • Resilience: the coast as a natural 'sea wall' with means of recovery and a certain robustness
2000-2004		• Formulating an integral coastal-zone policy and management: use of space, social, economic, social-cultural and landscape-ecological aspects should be viewed within a more coherent framework
2003-2004	Policy guideline for the coast (under preparation)	• Expectation point of departure Policy Guideline coast: linking safety to quality coast areas and total amount of sand in the dunes instead of just sand in the beach ridge will be essential starting point for the evaluation of necessary coast-protective measures.
2003-2006	Memorandum on integrated management of coastal areas	• Report to the European Union on the Dutch situation, with regard to the implementation of the European recommendations for integrated management of the coastal areas (in 2006).

Table 1. Global Development of Policy and Execution of Sandy Coast Protection in the Netherlands, in Relation to a More Natural Beach Ridge

Uniqueness of Dutch tidal inlets	
General purpose:	Gaining insight into the relevance of tidal inlet formation (and tidal inlet research) in the Netherlands. Gaining insight into the ecological value of tidal inlets.
Method:	To investigate which information exists on European tidal inlets.
Safety demands for hinterland with tidal inlet formation	
General purpose:	Formulating points of departure/boundary conditions and the contribution to a sound choice of location for tidal inlet formation/notched beach ridge.
Review state of affairs with regard to tidal-inlet formation and choices of location	
General purpose:	Determining the current state of affairs with regard to choice of location tidal inlet formation (Rijkswaterstaat is involved in this in the sense of morphogenesis of the coast and the safety of the hinterland.
Method:	Negotiation with the parties involved in tidal inlet research (i.e. NBLF, Werkgroep Noordzee, DGW, Stichting Duinbehoud).
Monitoring of tidal inlet construction projects	
General purpose:	Evaluating the performed tidal inlet construction projects and the possible suggestion of potential locations for new tidal inlet construction projects.
Method:	Analysis of the objectives of tidal inlet monitoring at Neeltje Jans and the Maasvlakte;Drawing up a schedule with parameters for which monitoring is desirable and parameters that are already touched upon by other current research.
Annual sedimentation within the tidal inlet on Texel/hydrodynamic Zwin	
General purpose:	Gaining insight into the morphological processes in existing tidal inlet systems (in various stages of development)
Method:	Analysis of previously performed measurements in the tidal inlets, possibly to be extended with new surveys. Analysis of hydromorphological parameters in Het Zwin.
Rate of morphological processes that play a part in tidal inlet formation and sanding up or erosion of tidal inlets	
General purpose:	Gaining insight into the morphological processes involved in existing tidal inlet systems (in various stages of development).
Method:	Research into morphological processes involved in existing tidal inlets: a preliminary study is needed of the required knowledge and the way this can be measured.
Difference between tidal inlet vegetation and the potential development of vegetation along the Dutch coast	
General purpose:	Gaining insight into the ecological value and processes of tidal inlets
Method:	Comparing vegetation maps/field research.

Table 2. Planned Research (1993) in Connection with Tidal Inlet Formation as an Aspect of Dynamic Coastal Management

Project	Performed yes/no	If not, why not? what result?	If yes, when and with
Uniqueness of Dutch tidal inlets	Partly; finally limited to Dutch tidal inlets	- little response to international questionnaire - confusion about definition on 'tidal inlet'	1993: report with an overview of tidal inlets within the Netherlands with values and problems (unofficial report)
Safety demands and hinterland with regard to dynamic coastal management	Yes		Forms part of the 'Grasduinen in de waterkering' (1999) report
Choice of location dynamic coastal management	Yes		- 'Dynamisch kustbeheer, een verkennende studie naar de mogelijkheden voor herstel van natuurlijke processen in de zeereep' report (Janssen and Van Gelderen 1993, performed by Duin-behoud, commissioned by RIKZ) - "Natuurlijke dynamiek in de zeereep; een onderzoek naar de mogelijkheden op vier locaties" report (bureau D+K, commissioned by DWW Van Gelderen and Löffler, 1994)
Review state of affairs with regard to dynamic coastal management	Yes		- 'Dynamisch kustbeheer' de stand van zaken' report (DWW, 1996) - 'Grasduinen in de waterkering' report (DWW, 1999)

Project	Performed yes/no	If not, why not? what result?	If yes, when and with
Dynamic coastal management monitoring	- Performed investigation into monitoring methodology		- The methodology of monitoring can be found in the 'dynamisch kust-beheer' manual (DWW, 1998). It also presents an exemplary program for Ameland and Schoorl-Bergen
	- Overview of current monitoring projects; Support of project monitoring initiatives in Ameland, Goeree and Schouwen		- An overview of current monitoring projects forms part of the DWW report 'Dynamisch kust-beheer, stand van zaken (1997)
	- Monitoring of sand-drifting project 'Van Limburg Stirumkanaal'		- Various reports have been published with regard to the monitoring of the Limburgstirumkanaal (1996, 1997, 1998, bureau Arens, commissioned by DWW)
	- Setting up and execution of monitoring programme of De Kerf (since 1998, in collaboration with Staatsbosbeheer)		- Various subreports have been published on the monitoring of De Kerf from 1998 to the present day - a report on mushrooms and geomorphology was commissioned by DWW and a report on vegetation and ground beetles was commissioned by Staatsbosbeheer. In 2003 an evaluation of '5 years of 'De Kerf" will be published.

Project	Performed yes/no	If not, why not? what result?	If yes, when and with
Annual sedimentation in the 'Slufter' (tidal inlet) of Texel	Not performed	During the tidal inlet research, the necessity of focusing on natural processes in the broader sense became apparent. Said specific investigation has been abandoned for sand drifting research	
Hydrodynamic research Zwin	Not performed	See above	
Speed of morphological processes	Focused mainly on sand drifting as such		
Research into current and potential vegetation with dynamic coastal management	Not performed as a standalone investigation, but as part of research into suitable locations for dynamic coastal management + research into appropriate indicators for monitoring		- Part of a report on four eligible locations (DWW, 1994) - Part of 'monitoring' manual
Study not mentioned in 1993, which was however carried out between 1993 and 2003:			
Improvement of the vitality of degenerated mass-grass planting by controlled drifting within the beach ridge	Yes		1994, NIOO report commissioned by DWW for TAW-C
Modelling of sand transport within the beach ridge	Yes		- 1994: conceptual model (UvA, commissioned by DWW for TAW) - 1995: calculation procedures for SAFE model

Project	Performed yes/no	If not, why not? what result?	If yes, when and with
Ecological effects of sand replenishment	Yes, directed towards the effects of 'droge natuur'		- in 1995 an evaluative study was published by NIOO and UvA (commissioned by DWW for TAWC) - in 1997 this report was extended with research by Resource Analysis (commissioned by DWW/TAWC)
Possibilities for dynamic coastal management on Schouwen	Yes		DWW advised the Directie Zeeland [Zeeland Directorate] on this in 1999 (Bewogen Duinen report, 1999)
Investigation into dune formation on a Maasvlakte II	Performed on the basis of project organisation Maasvlakte II (to which DWW contributed)		- Commissioned by the project organisation, bureau Waardenburg published a report in 1998 on the development of reference areas and possibilities on the second Maasvlakte - The results were used in 1999 for a 'Mogelijkheden voor de ontwikkeling van nieuwe duinen bij een Maasvlakte 2' report'
Seminars and workshops on dynamic coastal management	Organised by DWW/RIKZ for the purpose of bringing together various involved parties		- Seminars in 1996 and 1998 - Seminar in 2002 (on possibilities in North and South Holland)

Table 3. Research carried out in connection with dynamic coastal management (1993-2003)

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C. Conclusions and Recommendations

Introduction
The hypotheses and research questions included in this thesis have been answered, proven or rejected in the individual chapters. This chapter provides an overview of the most important conclusions and recommendations with regard to the application of ecological engineering in civil engineering works on the basis of the results included in the previous chapters.

The conclusions and recommendations have been divided in three paragraphs;

1. From Road Ecology to Road Systems Ecology and from Nature Technique to Ecological Engineering (chapter 11)

2. From Rigid Coastal Protection to Dynamic Coastal Zone Management with the Aid of Ecological Engineering (chapter 12)

3. Synthesis: Principles of Ecological Engineering (chapter 13)

11. From Road Ecology to Road Systems Ecology and from Nature Technique to Ecological Engineering

1. Introduction

Much of the research described in this thesis is in itself of a monofunctional nature, despite the evaluation of a number of case studies that have multifunctional characteristics.
If one takes into account the many different relationships that are severed or created, the planning, design and construction of a road or coastal defence can be seen as multifunctional as they serve different functions.

Roads, from footpaths to highways and rail lines, from tram to rail lines or local traffic to high-velocity lines, form an important basis of human existence and the economic functioning of our society, and are elements that have become inextricably intertwined with our landscape. In practice, often aspects are involved that need to be studied separately. This fact can be observed, for example, in the many applied sets of environmental, social and economical indicators between which few real connections have be made. More coherent systems of sustainability indicators can be found in the studies commissioned by the Road and Hydraulic Engineering Institute (De Boer et al., 1999; De Boer and Jansen, 2000) as well as the 'sustainable decision model' that is currently under development by the Delft University of Technology and TNO Bouw, and which is aimed at the realisation of sustainability in all phases of a construction process (Hendriks and Seijdel, 2003).

Within the Dutch Ministry of Transport, Public Works and Water Management the integral 'Survey Effects of Infrastructure' (Anonymous, 2000) is in use and will be made more complete including bringing in harmony with the environmental impact assessment procedure.

The studies discussed in this thesis touch on the following topics:

a. The emission, distribution and immission of pollutants into the air, water and soil compartments as a result of roads and road traffic. Additionally, measures are discussed that may limit emissions or lessen their impact with the help of mitigating measures, to be studied on various levels of scale (Chapter 2).

b. The ecological design and construction and management of road verges (Chapter 3).

c. The effects of habitat fragmentation by roads and traffic and the possibility of mitigating measures (fauna provisions) and/or compensatory measures (Chapter 4).

d. The integration of roads into the landscape, both from a visual-landscape and a landscape-ecological point of view (Chapter 5).

e. The possibilities of integration of infra-structure, ecology and art (Chapter 6).

In the sections included in this chapter, the main conclusions of the research are presented. Recommendations are made with regard to areas 'a' up to and including 'e'. On the basis of these, it is investigated to what extent an ecosystem approach to roads and their surroundings is possible and which knowledge gaps can be identified.

2. Summary of the Conclusions and Recommendations from the Preceding Chapters Regarding Air, Water and Soil Pollution, Road Verge Management, Defragmentation and Landscape Integration

2.1 The Influence of Roads and Traffic on the Quality of Air, Water and Soil

Conclusions

- Motorway traffic is an important source for the emission of NOx, VOCs and dust particles such as particulate matter with an aerodynamic size of 10 μm or less (PM10) due to the use of fuels and wear to both vehicles and road surfaces.
- Atmospheric drift of wet and dry particles is a more important flow for contaminants than run-off on DAB-surface (non-porous asphalt):
  20-40% of all pollutions is run-off
  60-80% of all pollution is spread by drift.
  The reverse has been found for ZOAB-surface (porous asphalt):
  70% run-off
  30% drift.
- It has been found that motorway run-off under the present-day situation can directly infiltrate into soil, as it will remain within the surface layer of the soil in verges near the road (approx. 30 cm deep). Monitoring pollutants in the soil will indicate the moment of removing of top soil (up to 3-5 m from the road surface).

Recommendations

- To reduce pollution source-oriented measures (volume and technical) should first be taken into account, as they will have a greater effect on environmental quality than effect oriented measures with regard to treating run-off and aerial drift. More emphasis should be put on technical improvements to engines, tyres and other car parts, as well as the aerodynamic design of vehicles as regards road surfaces (asphalt concrete, zoab and double-layer zoab) in relation to the design of the direct surroundings of the road in question.
- Due to the fact that only part of the pollution from motorways takes place within the run-off, helophyte filters are not recommended in general; if point-pollution takes place they can be helpful as such as well as in the form of function combinations. They can play a role in some situations further away for catching part of the wet and dry drift.
- More attention should be paid to the relationship between pollution caused by traffic and the possibilities of biofiltering in a wide sense: buffer plantings to improve air quality along motorways and if combined with helophyte-filter systems in combination with noise reducing provisions which can absorbe pollutants. If combined with ecological values as well these provisions will enhance the living environment near motorways.

Forcing back the pollution of air, water and soil compartments is done for the sake of the health of human beings and the health the ecosystems.

Careful co-ordination is needed. The road verge should contain sufficient binding opportunities for pollutants, and this may be in contradiction to the reinforcement of the natural quality of road verges that benefit from the use of road-verge soil that is as nutrient poor as possible. The 1-2 m strip along the hard shoulder is less important from an ecological point of view, since it is frequently mowed and its soil scraped every 4-6 years for the removal of deposited (polluted) soil and dust particles.

Futher research is recommended in order to make more efficient use of plantings and modified forms of noise barrier systems that can collect pollutants as well. Here too the search should include ways for the best method of combining different functions in order to achieve the desired ecological quality as well.

From a nature conservation point of view, a decidedly different approach emerges here. Apart from the maintenance of road verge ecosystems for their own sake, the protection of species and biotopes involved here is linked to a new form of use. The extent to which this is possible will have to be observed in practice.

2.2 Habitat Fragmentation, Animal Traffic Victims, Barrier Effect and Disturbance as a Result of Road Infrastructure, Traffic and Transport

Conclusions

- Roads are one of the main causes of habitat fragmentation, (removing and breaking up of habitat patches) and can have a strong influence on the chances of survival of animal populations.
- With regard to the methods used to superimpose road networks on ecological networks, bottlenecks between them can be identified and mitigation and compensation measures can be formulated.
- The impact of habitat fragmentation caused by motorways and traffic can be considerably reduced by mitigation measures, such as fauna passages. Examples of fauna passages are underpasses such as amphibian tunnels, badger pipes or, in general, eco-pipes, co-use of culverts, special adapted culverts and overpasses such as eco-bridges, cables over the road, co-use by fauna of bridges, large-scale landscape bridges, under-tunnelling of roads or roads on viaducts. The provisions should be fully incorporated in the landscape to stimulate use by fauna in the area concerned.
- In the planning and design phase of fauna passages the conditions of the local habitat patch should be fully taken into account to be as effective as possible. These include the surroundings, dimensions (height, width, length), form (rectangle, convex), road on piles or columns, material (concrete, steel, wood), number of passages per km, form and length of fencing. All aspects should be seen in relation to the actual and potential fauna of the area near the provisions as well as further away.

Recommendation

- Make more roads passable for fauna and diaspores (such as seeds) by enhancing the permeability or perforation of roads by single underpasses and overpasses towards roads, which are either fully underground or on piles or columns.
- In determining the significance of habitat fragmentation by roads and defragmentation measures it is important for the success of the effort to take into account the differences in opinion in the sense of the significance of nature and mobility within our society. The weight given to the worth of natural, semi-natural and culture landscapes also plays an important role in this connection. Many of the evaluation methods are based on rarity, international significance and the extent to which animals are endangered, while the integral functioning of ecosystems appears to be given less importance. Compare the west to east cross-cutting of the A1 of 30 km of Veluwe and the construction of a single ecoduct with a width of 30 m.

Solutions to complex problems are reduced to workable technical solutions. The question remains, however, whether sufficient justice is done to all direct, indirect and cumulative ecological effects. What is needed is the implementation of the preventive principle as well as increased use of ecological risk analyses (Jaeger, 2001).

- Analysis on at least three levels of scale is essential. Research has shown that for the determination of habitat preference and the survival of animal species it is necessary to investigate characteristics on different levels of scale (Altmoos, 2003). Detailed knowledge of habitat locations, as well as a large-scale overview of the landscape characteristics, is necessary for getting acquainted with demands of the species in order to further the sustainable existence of the animal populations.
- Three-network analysis in relation to the layered approach should be promoted in environmental planning: Tjallingii (1996) successfully developed a strategy of the two networks, in which the emphasis is put on the strategic role of water networks and traffic networks. The analysis is derived from the 'casco' concept developed in the landscape planning of rural areas (Sijmons, 1990 and 1991; Kerkstra and Vrijland, 1990). On the grounds of other considerations (significance of terrestrially bound biotopes, multifunctional use of space and function linking), following the strategy of the three networks in relation to the layered approach may add value to a terrestrially determined natural environment (Reijs et al., 1997 and this thesis).

2.3 The Ecological Values of Road Verges and their Management and Maintenance

Conclusions

- Vegetated road verges parallel to the road, median strips and within and outside interchanges cover ca. 3-4 ha/km of motorway and consist of grassy vegetation, shrubs, trees and woodlots, hedgerows and ditches.
- Road verges can have a habitat, conduit, filter, barrier and source and sink function (Forman et al., 2003).
- Roads can influence the microclimatic environment.
- Roads can provide conduit for non-native species.
- When properly maintained, road verges can have important vegetational and faunistic values; when not properly maintained values can rapidly decrease (loss of plant and animal species). The relation between the different stages of succession of vegetation in relation to the maintenance regime should be taken into account; for the grassy vegetation, mowing one or two times a year (similar to hay meadow maintenance) has shown optimal results for plant species diversity in road sides.
- The wider and more abiotic variation (gradient situations) the road verge is, the more plants and animal species can occupy the area.
- Spontaneous development of plants and animals in road verges turns out to be a purposeful practice for grassy as well as woodland vegetation.
- The field of nature techniques, nature engineering or ecological engineering has developed methods for ecological design and ecological-based maintenance of road verges.

Recommendations

- When designing and constructing road verges on the basis of ecological values, adequate road-verge maintenance and management should be the rule.

- Including a wider zone along roads on adjacent terrain for improving ecological values (green corridors, greenways, green networks, road reserves) should be possible to increase the nature value as it can reduce isolation effects.
- Good examples of increasing the nature value include changing the standard road verge ditch profile with a wide riparian zone featuring gradient-rich ditch slopes, which is also cheaper to maintain (after an initial investment).
- Integrating visual-landscape and landscape-ecological values in the implementation of roads into the landscape.
- The spontaneous development of vegetation should be promoted. If plant material has to be used, it must have been grown in the vicinity. Incorporate knowledge of native genotypes and plant distribution pattern according to plant geographical districts. In some cases hay from species-rich meadows nearby can be spread over a verge to stimulate plant diversity.
- Nutrient-poor substrates of road verges should be used instead of nutrient-rich soil material.
- Inoculating the top soil with sods from species-rich areas can be helpful to stimulate soil fungi and soil micro-fauna and root herbivores which can reduce biomass production. This approach can reduce the dominance of plants which will provide space for other species (Deyn et al., 2002).
- More knowledge on food webs within the road verge may lead to a further enhancement of the foundation of maintenance measures.
- Combining functions should be promoted in road verges; structures to be built should preferably not only facilitate habitat types and/or fauna passages, but should be designed as eco-structures with multifunctionality (having for instance a function for reducing pollution of road run-off, reducing airborne pollution, as well as higher recreational values).

2.4 A Vision of Ecosystems

The road construction sector increasingly subscribes to an integral approach to the design, construction and maintenance of roads in connection with the abiotic environment, nature (biodiversity) and landscape. Despite the fact that roads and traffic have a considerable impact on nature and the environment, a more integral approach to roads within the landscape has been proven to contribute significantly to the development of biodiversity. By integrating roads in both a landscape and landscape-ecological way, the impact of roads on the environment may be diminished considerably, and local added value may even be developed. The third report of the European Environmental Bureau actually mentions the following: ‘In the transport sector, despite the continuing development of the code of practice for the introduction of biological landscape considerations into the transport sector, the absence of a strong policy framework and then inexorable growth in demand are likely to lead to increasing impacts on biodiversity’ (EEA, 2002).

One of the causes is the sometimes divided (sectoral) approach of political and governmental bodies with regard to nature and environmental issues in the planning, design, construction and maintenance of road infrastructure. In many cases, proposals for expanding mobility facilities are of a political nature, while the input from nature and environmental experts is limited to a separate legal environmental impact evaluation procedure, indicating the often sector-determined effects on air, soil, water, flora, fauna, visual landscape, historical landscape and archaeology. Additionally, separate economical impact evaluations are drawn up and in some cases the social consequences are analysed separately as well. With the help of, inter alia, multi-criteria analysis techniques, an attempt is made to present a complete overview of all effects; however, in many cases social and economic aspects do not enter the equation.

In addition to environmental impact evaluations, during the past few decades research has been performed and proposals made based on more holistic approaches. Examples of this are the 'stolpmodel' (bell-jar model) (De Boer et al., 1996), the ecological space (Opschoor and Weterings, 1994), integral environmental zoning (De Roo, 1999), and the system of sustainability indicators (De Boer, 1999; De Boer and Jansen, 2000). However, these examples have in many cases not been put into practice. Bouwer and Leroy (1995) have laid down the preliminaries for translating the 'environmental-problem chain' into consequences for the use of space; it is doubted (Bouwer, 1997) whether a spatial ecological impact model for societal functions is at all possible because of the complex relational structure between societal and natural subsystems. Priemus (1997) offers a number of building blocks for enhanced evaluation methods for spatial intervention: internalisation of external effects, raising the price of land, making spatial plans three-dimensional, moving from the division of functions to the integration of functions, achieving more coherence and structuring the decision-making with regard to plans in a better way. The Guide "Evaluation of infrastructural projects; a key to Cost-Benefit analysis" (Anonymous, 2000; Eijgenraam et al., 2000) gives a full survey of the relevant direct, indirect and external effects of infrastructure planning. From the contents it gives the suggestion to be complete, but it is a pity that a full connection to the environmental impact assessment procedure is missing and part of the impacts on the environment, landscape, nature and safety became 'pm' post. Also in the new OEI systematics (Research Effects of Infrastructure), although a full step forward, still no real integration of ecological, social and economical sectors of society is taken into account. This is caused by different value orientation, lack of suitable methodology and the difficulty of describing the right indicators. Recently an advice about to tie-up and bring harmony between the by the Ministry of Transport, Public Works and Water Management in use cost-benefit analysis and the environmental impact assessment procedure is under way (J. Visser, 2004).

For a more integral description of roads and their surroundings, the approach of viewing the road and the surroundings as a road ecosystem may provide better insight into the effects than is currently possible: e.g. the road as part of an ecosystem. With the help of integrated eco-system assessment, the effects and possibilities of the promotion of natural values may be made clearer.
These elements should be linked more effectively with social and economic aspects.

The Road Ecosystem
The application of an ecological and ecosystem approach is increasing in different fields of interest. Examples include the industrial ecosystem approach (Van der Laak et al., 1999), techno-ecosystems (Haber, 1990), road systems (Forman et al., 2003; Van Bohemen, 2002), agro-ecosystems, road verge ecosystems (Melman and Verkaar, 1991), and watershed ecosystems (Luijten, 1999). Roads can be seen as ecosystems because they

occupy ecological space (Hall et al., 1992), have structure, support a specialised biota, exchange matter and energy with other ecosystems and experience temporal changes (Lugo and Gucinski). Haber (1990) considered roads as techno-ecosystems because they have structure, support a specialized biota, exchange matter and energy with other ecosystems, experience temporal change and are systems, built and maintained by people.
Van Bohemen (2002) formulated that 'in keeping with the industrial ecology metaphor, roads and railways should be regarded as forming an ecosystem with their surroundings, just like industrial systems, that have had to start functioning as ecosystems'. Dolan (2003) gives a literature overview of 'roads as ecosystems' for the National Roads Authority of Ireland and uses this holistic concept to incorporate landscape ecology in the planning, design and maintenance of roads and road verges.

Lugo and Gucinski (2000) proposed a unified approach to the management and analysis of the functions and effects of roads on forested rural landscapes, considering roads as ecosystems (techno-ecosystems). It provides an unambiguous analysis of all road types irrespective of geographic location, for analysing all aspects of roads, including management and maintenance as a holistic approach and based on spatial concepts. According to Lugo and Guanski (2000) road ecosystems are characterised by open fluxes of energy and matter and a predominance of respiration over photosynthesis, i.e. they are subsidised heterotrophic systems. They defined and described how roads function as ecosystems using the model approach and energy symbols of Odum (1996) in analogue with riparian corridors. They described the ecological space or the environmental gradients within which roads function by axis of the main parameters. The main gradients are climate, geology and use or function and are subdivided into component factors in temperature, rainfall, disturbance events; topography, substrate and slope or maintenance, size and traffic.

The main conclusion from these different approaches is that roads and motorways, as well as other infrastructure, have become a human-made technical component in the landscape, which can also have ecological values, from the continental up to the local level. They have become an intrinsic part of the ecosystems and an ecosystem approach can facilitate analyses of the negative as well as the positive effects of road planning and design.
An important consequence of the ecosystem approach is the description of boundaries with other systems, so that the boundaries may be considered semi-permeable membranes (Naiman and Decamps, 1997). Naiman and Decamps (1997) suggest that these interfaces (described for riparian zones) 'have resources, control energy and material flux, are potentially sensitive sites for interactions between biological populations and their controlling variables, have relatively high biodiversity, maintain critical habitat for rare and endangered species, and are refuge and source areas for pests and predators'.

On the basis of the road ecosystem, it can then be made clear under which boundary conditions and within which boundaries a mobility system is sustainable in the long run.
For the ecosystem components of air, soil, ground water, surface water and the effects of noise, the critical amounts of pollution and disturbance can be calculated on the basis of norms (limiting values, target values, intervention values). On this basis it may be decided which space is available for the proposed transportation system based on the maximum permissible emission in relation to

the intensity and speed of traffic. This is effectively an inversion of the current thinking process, which is based on the mobility system as a given, whereby measures are sought to reduce its impact.

3. Road Ecology, Road-systems Ecology, Transport and Infrastructure Ecology or Infrastructural Ecology

Experience has shown that there is a strict division between traffic and transport principles on the one hand, and natural and environmental aspects on the other, despite the fact that these aspects are moving slowly closer to each other and despite the intensification of more holistic research. In practice, however, traffic and transport planning, spatial planning and nature and environment policy are pointed in several situations in different directions. Although forecasting models occasionally used data from various sectors, the eventual decisions are made primarily on the basis of financial-political considerations. Road ecology or road systems ecology, according to Forman et al. (2003) may help 'to bridge the gap', and this thesis offers insight into the developments and possibilities of better integration of natural and environmental aspects in the design and construction and maintenance of motorways.

In order to achieve full integration of transport sciences, ecology, economy and social sciences, a new discipline, 'transportation and infrastructural ecology' or 'infrastructural ecology', might be developed, in which the ecological relationships between roads, traffic and road verges and their vicinity are viewed on different ecosystematic levels.

12. From Rigid Coastal Protection to Dynamic Coastal Zone Management with the Aid of Ecological Engineering

In the Netherlands, dynamic coastal management has become part of the policy envisaged by the European Commission consisting of an agreed level of maintenance of safety against floods, with as much attention as possible being paid to the promotion of biodiversity by means of integrated coastal zone management. A trusted mean with regard to the conservation of sandy coasts is the replenishment of sand on the forebanks.

Conclusions

- Change in policy and execution of coastal-protection measures that take into account ecological values turn out to be a long-term process.
- It is important for the maintenance of coastal safety and biodiversity to evaluate both small-scale and large-scale effects.
- Sand replenishment on the forebanks reduces the steepness of the increasingly steep forebanks of the sandy coasts in a large number of locations in the Netherlands. But also a positive small-scale impact of the development of primary little sand dunes at the foot of the beach ridge, that was previously turned into a steep beach ridge where sand was taken away during autumn- and winterstorms, as well as a negative small-scale impact by threshold formation within in the mouth of the artificially created 'notch', may occur.

Recommendations

- It is increasingly apparent that sand transport forms the key to the entire coastal ecosystem. The composition of replenished sand should be evaluated on a continuous basis, as should its effects on the ecology of the forebanks, the beach ridge and inner dunes.
- Measures taken within the framework of dynamic coastal management that in part address the promotion of natural quality, must be monitored on a regular basis.
- It is essential to increase the collaboration that has been set in motion between coastal managers, directors, investigators, researchers and representatives of societal organisations in order to achieve optimal results in coastal policy.

13. Synthesis: Principles of Ecological Engineering for use in a Civil Engineering context

When planning, building and using artificial constructions, like civil engineering objects (such as the construction of buildings and roads) or other kinds of human interventions in a landscape, first of all the specific character of the place (the so-called genius locus) must be acknowledged. Wherever possible, the natural elements of the site should be included in the design. This means recognition and integration of biological entities and natural elements and processes, to make use of ecosystem goods and services if possible, to minimize the impact on nature, to improve and to optimize ecological values in a broad sense.
Only then a real ecological solution with high future ecological values (in the widest sense) will result. Generally speaking, the following set of principles can serve as guidelines; they were based on this thesis, as a generalization of the conclusions of chapter 11 and 12, on current ecological research and on some general ethical feelings, like the responsibility that we have towards nature and the future generations. The afore-mentioned ethical feeling may be considered as a kind of message, which is undesirable in a thesis (Boersema, 2003). It has been included, because the principles are based on critical analysis and to make them work a more holistic policy framework can be helpful, given the state of uncertainty.

The principles concern: 1. place and scale, 2. self-regulation processes, 3. dynamic processes, 4. integrity and quality, 5. design and ecosystems, 6. coupling of functions, 7. gradients, 8. visibility and perceptibility, 9. actor involvement, 10. environmental and ecological stewardship as basis for the future.

Set of principles of ecological engineering

1. *Consider a human intervention in the landscape in an ecological context at all levels of scale. The characteristics of the site (the genius locus) should be the point of departure.*

In any case an analysis should take place on the scales the expected impact will have. Looking at a road at least three scale levels should be studied: 1) the road or roadsegment, 2) the road in the wider network and 3) the local habitat patches along the road. For some impacts higher level of scales should be included.

For the three scale levels the following aspects should be studied:

a. The characteristics of the soil and subsoil.
b. The actual and potential relations and network functioning of the plants and animals.
c. The limitations and suitability's for intervention, defined by the landscape-historical significance of the area as well as the local land use pattern.

It should be realized that the characteristics of a certain site (the genius locus) within an ecological context is essential in all planning of interventions. In order to be able to take into account the ecological infrastructure on a local scale as well as the ecological infrastructure on a higher scale, a shift in thinking is needed from an "anthropocentric" towards a more "ecocentric" based approach in land use planning and civil engineering. This approach

should also take into account the value of different nature views. In all human developments natural values of habitat patches, the functions and carrying capacities on all level scale are crucial for sustainable ecological development.
Based upon this principle the impacts, the limitations and suitability of any new plan and mitigation and compensation measures should be defined and designed.

2. *Facilitation of self-regulation of ecological processes should be an objective by planning and construction of civil engineering objects.*

In road verges this implies creating of favourable abiotic conditions for nature development in order to facilitate spontaneous development of native plants and animals.

Good examples of self-regulating systems are the so-called constructed wetlands where road run-off is treated by biological processes; these planted wastewater treatment systems using the self purifying properties of nature have a great potential for all kinds of pollution and can have esthetic, ecological as well as recreational values.
Mitigation measures such as fauna passages like ecoducts, ecopipes and adapted culverts are often needed to defragment separated areas; these facilities enable distribution and dispersal of animals, seeds and other diasporas. In order to facilitate animal movements the dimensions of the eco-pipes and ecoducts, the microclimate, the structure of the surroundings should be adapted to the actual and potential (groups of) target organisms to have optimal performance of the measure. Once a construction for fauna passage has been made, it should perform its function without further human interference.
But mitigation measures should also facilitate all the other ecological processes on a macro-, a meso-, and a microscale level, which form the basis of ecosystem existence and ecosystem development. These processes include surface water and groundwater flow, infiltration of chemicals, subsurface flow, seepage, overland flow and sediment flow.

3. *The design of (road) constructions should be so that 'fast' and 'slow' ecological processes can take place, or formulated differently: what are the chances in dynamic environments for plant and animal species that need a low dynamic environment.*

High dynamic ecosystems are adapted to relatively rapid changes. Examples of high dynamic ecosystems are those with pioneer communities of coastal (fore) dunes, salt marshes, young forests and plantations on homogeneous and unripe soil profile. They consist often of more common, widespread species.
Low dynamic ecosystems have a long development time. Examples are those with communities of floating rich fens, peat moors, dry and wet heath lands, species rich grasslands on nutrient-poor soil, and old-growth woodlands; mainly consisting of more specialized species adapted to specific combinations of environmental factors.
Applying this principle to roadsides requires designing the verge with favourable growing conditions for species depending on low dynamic situations. Consider the situation of species-rich dyke grasslands and river dune-systems near the high dynamics of the river themselves.

4. *In all situations the ecological integrity and quality should be maintained and, if possible, increased. This implies optimisation of abiotic, biotic and other*

conditions to meet the requirements of a well functioning ecosystem as much as possible.

Native plants and animals in their local habitat conditional context should be respected and facilitated to increase where possible. Basic ecological patterns and processes should be respected. This includes (in relevant situations) habitat, corridor, refuge and/or hibernation functions.
Natural, near natural and semi-natural living conditions of plants and animals should be promoted as much as possible.
Improving ecological quality sometimes requires bringing in soil and seeds (inoculation) from more natural or semi-natural areas rich in species nearby.

5. *The design of civil engineering objects should fit within the ecosystem present on the spot. Ecosystem functions should be respected and proper uses should be made of ecosystem goods and ecosystem services.*

A road and its surroundings can be defined as a road ecosystem as they have structure consisting of biological entities exchanging matter and energy. Odum (1969) defined an ecosystem as 'a unit of biological organization, with interactions within its system so that a flow of energy leads to characteristic trophic structures and material cycles within the system'. Within ecosystems we can distinguish ecosystem functions, goods and services. The functions of ecosystems should be respected in a form of ecological planning, design and construction of roads which reduce environmental effects.
The existing knowledge, which is put into the design practice moderately, should be used as much as possible.
In road situations we can make use of natural purification processes (bio-filtering) to clean road runoff (by constructed wetlands) as well as reducing air pollution caused by traffic (by use of trees and shrubs).

6. *Ecosystem services as well as the production of ecosystem goods should be combined as much as possible.*

In relation to the principle 5 the combining of production of ecosystem goods and the use of ecosystem services can have extra value for humans, plant and animal species. There is a great variety of possibilities to combine functions: multifunctional use of space, constructed wetlands for wastewater treatment, 'living machines' for treatment of wastewater or for cleaning contaminated terrestrial, soil or aquatic situations, the production of valuable goods, providing housing in a 'green' context, nature-oriented agriculture in an urban setting.The way of implementation is dependent on the local, regional or national scale. Instead of mono-dimensional approaches in agriculture, housing, infrastructure a more-dimensional approach should be developed.
The use of locally grown renewable material, if possible in relation to waste water treatment, should be promoted instead of the use of non-renewable material.

7. *The civil engineering design, construction and maintenance should aim at preventing negative impact on gradient-rich situations and where possible restore or add gradients instead of aiming at hard boundaries.*

Gradient-rich situations (gradual changes in abiotic conditions) offer a diversity of (potential) habitats for plant and animal species, adapted to specific local environmental conditions.

Gradient-rich situations are important from a nature conservation point of view as they show often species richness and in most cases feature rare species. Under changing environmental conditions plants and animals can 'move' along the gradient, which gives a better chance of survival.

This principle means also that construction of objects with hard unnatural borders, vertical walls or barriers should be used minimal from an ecological viewpoint; if applied more attention should be given to ecological values.

8. *Make (changes in) ecological patterns and processes as visible, perceptible and, if possible, experienceable as possible.*

Making (changes in) ecological patterns and processes visible and perceptible (and, if possible, experienceable) on location (the actual situation), as well as by means of ecological bookkeeping in the planning process or by monitoring, will probably contribute to an increase in ecological awareness.

9. *In the planning, designing, construction and maintaining civil engineering objects, all those directly concerned (customer, designer, builder) as well as indirect actors (future users, manager, demolition contractor) and people who will become affected (neighbours (now and in the future) should participate or should be taken into account.*

Community representatives (from all sectors of the society) should be involved as early as possible in the planning, decision and design processes concerning land-use planning (including roads and motorways).
Citizens, planning experts, business and industry leaders, policymaker, elected officials and representatives of non-governmental organizations should also be involved as they will have an influence now and possibly in the future on the impacts of the use of engineering objects.

10. *Do not shift the negative effects to someone else or somewhere else now or in the future. If, after having taken preventative measures, some impacts still exist, mitigation and compensation measures should be taken to reach at least a situation without net loss and to restore degraded ecosystems if possible.*

The natural capital (ecosystem functions, goods and services of ecosystems) consisting of different forms within a wide variety of terrestrial and aquatic ecosystems on both a local and a global scale, is diminishing (through loss of species, loss of ecosystems, production of long-lived (toxic) waste) due to the increase of human impact. All possible means should be employed to encourage the conservation of biological diversity, the restoration of degraded ecosystems and the establishment of more sustainable agricultural systems.

The following process steps can be of help to reach no net loss as well as restoration of ecological values during the planning and design of civil engineering objects:

	(english)	*(dutch)*
-	prevention	*zich onthouden van/ voorkomen*
-	avoidance	*vermijden/ontwijken*
-	minimizing	*minimaliseren/ verminderen*
-	mitigation	*verzachten*
-	physical compensation close by	*fysieke compensatie in de buurt*
-	physical compensation further away	*fysieke compensatie verder weg*

-	financial compensation	*financiële vergoeding*
-	improvement (restoration, renewal)	*verbeteren (herstellen, vernieuwen)*

In addition to these measures, present and future generations should be encouraged to use resources in a well-balanced manner. Beside the *natural capital*, other forms of capital should become fully integrated in our thinking and building activities that result in *constructed capital* (buildings, tools, infrastructure for water, energy and transportation), *human capital* (accumulated individual abilities, skills and experience), *social capital* (community involvement, engagement, norms) as well as *cultural capital* (visions, myths, role of people in our world) (after: Hackett, 2001).

Finally:
The above mentioned principles are based mainly on the results of studies into the impacts of roads and motorways on the environment and the dynamic coastal zone management experience as well as basic ethical consideration, thus forming a basis for ecological design. Ecological design is a design in which human existence and human use of the natural world is in balance with the natural patterns and processes on different scales, from a very local to a world scale. Human intentions and human actions should become more fully integrated in the patterns and processes of our natural world. This environmental and ecological stewardship will lead to a more sustainable world for humans, as well as plant and animal species.

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Summary

ECOLOGICAL ENGINEERING AND CIVIL ENGINEERING WORKS
A practical set of ecological engineering principles for road infrastructure and coastal management

H.D. van Bohemen

Introduction
This thesis provides a survey of the research results of the relationship between on the one hand the construction, management and maintenance of civil engineering works, and on the other hand the environment, nature and landscape, with the main focus on motorways and coastal protection.

The growing number and increase in size of civil engineering works and the growing need for protection measures of the sandy coasts have led to an ever increasing risk of adverse effects on the nature and landscape of the Netherlands, as well as to an increase in the degree of the impact of these effects. Consequently, such institutions as the Road and Hydraulic Engineering Institute (Dienst Weg- en Waterbouwkunde – DWW -) of the Directorate General of Public Works and Water Management (Rijkswaterstaat) of the Ministry of Transport, Public Works and Water Management have carried out extensive studies of possible adverse effects. Based on these studies were carried out of measures intended to prevent adverse effects, to avoid their impact and to mitigate and/or to compensate for them (i.e. to take measures elsewhere in order to bring about a no net loss of nature values), apart from measures that can produce positive effects.
From a scientific point of view as well as of the interest of society it is important to pay attention to the possibilities for better inserting civil engineering work (e.g. construction and use of infrastructure and such activities as coastal management) into ecosystems in order to conserve and develop biodiversity.

In this thesis the results of conducted research as well as outsources studies are presented in the form of a synthesis. In this context, the focus has been on integrating knowledge concerning the understanding, use and control of patterns and processes of ecosystems into the planning, the design, construction and maintenance of civil engineering works. Special attention was paid to roads, waterways, road verges, slopes, banks and bridges and viaducts related to the main infrastructure. Much attention is paid not only to the results of the research, but also to integrating the knowledge and understanding developed, in combination with other studies in the same field carried out under the responsibility of the Regional Directorates of Rijkswaterstaat.

This thesis was realized in the author's capacity as head (later, former head) of the research section of the environment department of the Road and Hydraulic Engineering Institute and nowadays as coordinator of research into environmental measures for infrastructure; as part-time staff member at the Delft Interfaculty Research Centre for the Sustainable Constructed Environment, especially the research programme 'The Ecological City'; and later as part-time researcher/lecturer at the Faculty of Civil Engineering and Geosciences of the Delft University of Technology.
This thesis discusses applied research, which incorporated original research work intended to extend the available knowledge and especially to solve clearly defined practical problems, which in this thesis are considered in their integral context as much as possible.

The main research questions, which have been subdivided into subquestions, were in which fields and by which means contributions can be made to reduce adverse effects or to increase the ecological significance of civil engineering works, both existing ones and those to be constructed. Studies have also been made whether it would be possible to formulate on the basis of the research results a set of ecological engineering principles to be used in actual practice.

In addition to the systematic collection, analysis and evaluation of data using the available methods and technology in the relevant research fields, research was carried out into the possibilities of creating a synthesis – a combination of not only monofunctional but also multifunctional (interdisciplinary) solutions, since the latter are expected to lead to a larger degree of sustainable development of our actions. Ecological engineering can play an important role in this context. This thesis includes a summary of the knowledge and understanding of the application of ecological engineering in the field of the integration of roads and road systems and natural patterns and processes, the significance of road verges as habitats for plants and animals, the fragmenting effect of roads and the possibilities to adopt mitigating measures, the insertion of roads into the landscape and the management of sandy coasts.

The thesis gives also insight into the way the responsibility for environmental and ecological issues in relation to the primary tasks of Rijkswaterstaat has developed within the organisation.

This thesis highlights some of the important aspects referred to above concerning motorways and nature, environment and landscape. For aspects about environmental impact assessments (EIA) and motorways, reference is made to the thesis by dr. E.J.J.M. Arts, productgroup leader tracé/eia at the Road and Hydraulic Engineering Institute and as far as the subject compensation is concerned, to the soon to be published thesis written by drs. R. Cuperus, productgroup leader nature and landscape at the Road and Hydraulic Engineering Institute. For the fields of noise and roads and air and roads, reference is made to both existing literature and to upcoming publications within the scope of the ongoing 'Noise Innovation Programme' contracted to the DWW and the recently launched 'Airquality Innovation Programme'.

Structure of the thesis
In addition to the introductory chapter 1 (sections a, b, c and d) – which presents the aims of the study, the research methods, a summary of the thesis and an introduction to ecological engineering – this thesis comprises three parts, viz.:

- Road infrastructure and ecological engineering
- Coastal dynamics and ecological engineering
- Conclusions and recommendations, and a synthesis in the form of a set of practical principles for the application of ecological engineering in civil engineering.

Road infrastructure and ecological engineering
The most important aspects of the design, construction, presence and use of motorways are the physical properties and mechanisms of road infrastructures (i.e. those of the foundation and surface layers, as well as noise emission, vibrations, emission of pollutants, lights, etc.) that can cause

changes in the abiotic environment. These can then affect ecological processes, as a result of the loss of habitat patches (little or no life is possible beneath asphalt), barrier effects, disturbances, genetic effects and/or organism mortality (road kills). The ecological effects occur at the population and the ecosystem level in the form of, for example, a decrease in the size of a population, changes to the species composition and possibly local extinction of populations or subpopulations. In addition, the creation of road verges and road ditches provides habitat patches for plants and animals.

Chapter 2 discusses the forming and distribution of pollutants caused by roads, road furniture and road vehicles as well as source-oriented and effect-oriented measures to reduce pollution. Also information is given about application of ecological engineering to collect and treat pollutants.

Chapter 3 reports on studies of the presence and distribution of plants, vegetation and small animals on road verges, and describes the effects of the design, establishment and management of such. RWS manages approximately 12,000 hectares of road verge, which is comparable to the surface area of Noordoostpolder. Among other results, the various studies have reconfirmed that the general richness in species is in general the highest where grassy road verges are mowed twice a year and the cuttings are removed within 7-10 days, part of the plant species that are characteristic of former floristically rich grasslands can survive under such circumstances. Furthermore, reports of the various studies carried out on behalf of the Regional Directorates of Rijkswaterstaat into the occurrence of plants, vegetation, diurnal butterflies, amphibians and small mammals on road verges are also included.

In Chapter 4, the fragmentation effect of roads and traffic and the possibilities for taking defragmentation measures, including studies of their use, are central. Defragmentation policy has received extra attention especially since 1990. This has taken the form of studies of the actual causes and consequences as well as studies into the possibilities for mitigating measures (fauna provisions) in order to reduce the negative effects. The results of the studies have also been used to prioritize projects so as to utilize the available financial resources as effectively as possible. A useful set of tools and a clear assessment method based on bottleneck analyses is now available.

Furthermore, the lessons to be learnt have been put in a coherent context. Beside the commitment of employees the managers within the organisation play an essential role to reach results, as well as cooperation with other authorities and public organisations. The theme ‘defragmentation’ has been elaborated for the different process phases from the start up, the putting on the policy agenda, the formulation and acceptance of goals to be reached in a certain time, planning, design and implementation of concrete provisions for fauna, monitoring of the actual use of the provisions and the evaluation.

Chapter 5 describes the development of the insertion of Dutch motorways into the landscape mainly over the last centuries. It provides not only a fact-based analysis and synthesis, but also a prospective view of the future – which the author hopes will prompt further study into the effects of some of the described possible developments that more or less markedly will affect the insertion of motorways into the landscape in the future.

Chapter 6 discusses the relationship between infrastructure, ecology and art on the basis of various case studies. It is shown that there are excellent possibilities to use the understanding and knowledge of the combination of infrastructure, ecology and art in the design, construction and management of civil engineering objects.

Coastal dynamics and ecological engineering
The section about the coast deals with the question whether 'natural banks' are also possible for the seacoast, following the 'environment-friendly banks' project of Rijkswaterstaat which highlighted the nature of banks of rivers, canals and extensive lakes. In addition to a general consideration of the experiences gained by dynamic coastal management, a research programme that was proposed at the time is compared to the performed studies. From the studies it can be concluded that, ecologically speaking, sand replenishment on the foreshore usually is preferable to terrestrially realized sand supplements before, in or behind the foredunes.
The realization of a more notched coastline with sea-inlet-like areas is also described.

Conclusions and recommendations
The section of the conclusions and recommendations summarizes the main research results as well as recommendations separately for:
a. motorways
b. sandy coasts
At the end (c.) a set of ecological engineering principles for civil engineering – in the form of a synthesis – is presented.

Ad. a. From road ecology to road systems ecology and from nature technique to ecological engineering.

Roads and motorway traffic are important sources of emissions of NOx, VOCs and dust particles (PM10 and PM2,5).
Non-porous and porous asphalt show a difference in the spreading mechanism of pollutants. Non-porous asphalt shows more spreading of pollution by wind spray and porous asphalt shows more spreading by run-off; in the pores of the porous asphalt part of the pollutants is absorbed.
The vegetation and the soil of roadside verges close to the road pavement play a role in absorbing and partly reducing the amount of pollutants.
Source-oriented measures should be taken first before considering effect oriented measures.

Roads and road networks are one of the main causes of habitat fragmentation. To find and to analyse conflict areas (bottlenecks) between roads and nature the road network can be superimposed on mapped ecological networks.
Roads can be made more passable for animals by providing fauna passages, from a single, simple under- or overpasses, via ecoduct(s) to wider landscape bridges. Also tunnelling and roads on piles or columns can be options.

Roadside verges can play an important ecological role and should be properly maintained to conserve and increase ecological values.

Mowing two times a year for grassy vegetation, with removal of the mowed material within 7 – 10 days, is in principle the best option to maintain and to increase plant species diversity. Spontaneous establishment of plants and animals is preferred in combination with adequate design and maintenance; under special circumstances (hydro)seeding or inoculation can be advised.
Including a wider zone along motorways can improve the ecological and esthetic values.

A combination of ecosystem services should be encouraged.
Further research is recommended to integrate noise barriers as well as plantings with ecological values to collect pollutants. Another example of integration of ecoystem services are helophyte filter systems. They can play a role in the removal of nutrients, heavy metals and PAHs. Under certain circumstances production of renewable material is possible.

A three-network (roads, water and nature) analysis in combination with the layer approach of environmental planning will stimulate integration of different aspects of living, working and recreation.

An ecosystem approach can be helpful to integrate ecological, social and economical aspects within road planning and road design.

The development of a new discipline "infrastructural ecology" might be helpful in promoting ecological relationship between roads, traffic, road verges and their surroundings.

Ad. b. From rigid coastal protection to dynamic coastal zone management with the aid of ecological engineering.

During the last decennia a development on sandy coasts has taken place from rigid coastal protection towards a more flexible approach, using sand replenishment in the foreshore.

A more holistic system approach is needed in which the knowledge of movement of sand form the key for sustainable existence and development of entire coastal dune ecosystems.

A set of ecological engineering principles.

1. Consider a human intervention in the landscape in an ecological context at all levels of scale. The characteristics of the site (the genius locus) should be the point of departure.

2. One of the objectives when planning, constructing and managing civil engineering objects should be to facilitate self-regulating ecological processes.

3. The design of road constructions should take into account the significance of relatively 'fast' and 'slow' ecological processes, and whether plant and animal species bound to low environmental dynamics can find opportunities in dynamic environs.

4. An ecologically intact condition should be maintained and, if possible, promoted everywhere. This means optimizing abiotic, biotic and other conditions in order to meet the requirements of a well functioning ecosystem as much as possible.

5. The design of civil-engineering objects should be adapted to the local ecosystems. Ecosystem functions should be respected and proper uses should be made of ecosystem goods and ecosystem services.

6. Ecosystem services as well as the production of ecosystem goods should be combined as much as possible.

7. The civil engineering design, construction and maintenance should aim at preventing negative impact on gradient-rich situations and where possible restore or add gradients instead of aiming at hard boundaries.

8. Ecological patterns and processes or changes to these should be made as visible, perceptible and, if possible, experienceable as possible.

9. All those directly involved (customer, client, designer, builder) and all those indirectly involved (future users, manager, demolition contractor) should be consulted in each phase of the process comprising the planning, design, construction, management and demolition of civil-engineering objects. Also those who may be affected now or in the future should also be involved or at least taken into account.

10. Adverse effects should not be shifted on to others or other places, either now or in the future. Mitigating measures must be taken if adverse effects are expected to occur resulting from an intervention, even though preventive measures were taken and/or an attempt was made to avoid such effects. In spite of all applied efforts, adverse effects still remain, compensation should be used to obtain a no net loss of ecological values. In addition, the restoration of affected values must be promoted wherever possible.

Cover illustration
The cover illustration is ***The road in the landscape*** – an aquarelle based on an idea of H. van Bohemen in cooperation with J.G. de Vries and realized by P. Kerrebijn– which clearly illustrates some of the aspects described in this thesis (figure 1).

The picture is of a motorway intersecting an agricultural area as well as a wetland and watercourse which can be part of the ecological main infrastructure, with indications of which mitigating measures could be taken to reduce the adverse effects of infrastructure and traffic and transportation. In addition to the items labelled A-H, the following aspects are indicated: a helophyte filter (for purifying contaminated runoff), solar panels and road verges.

Figure 1 The road in the landscape (P. Kerrebijn; copyright RWS/DWW)

A. Small-scale agricultural landscape with hedgerows, which can for instance guide badgers and bats.
B. Badger tunnels underneath motorway.
C. Stump banks on an existing viaduct, which can function as a corridor for small mammals, amphibians and insects.
D. Guard rails made of wood.
E. Transparent noise screen provided with horizontal lines to prevent birds from colliding with it (German research has shown that vertical lines of 5 cm wide and 10 cm apart are more effective in preventing such collisions).
F. Landscape bridge – a large ecoduct.
G. Petrol station with growth-covered ('green')roof.
H. Car park with information panel about the significance of the environment, and a watch tower overlooking the landscape bridge.

Samenvatting

ECOLOGICAL ENGINEERING EN CIVIELTECHNISCHE WERKEN
Een praktische set van ecological engineering principes voor wegen en kustbeheer

H. D. van Bohemen

Inleiding
In dit proefschrift wordt een overzicht gegeven van de resultaten van onderzoek op het gebied van de relatie tussen (aanleg, beheer en onderhoud van) civieltechnische werken en natuur, milieu en landschap.
Enerzijds wordt het onderzoek naar bovengenoemde relaties toegespitst op wegen en verkeer en anderzijds richt het zich op het beheer van de kust.
Het aantal waterstaatswerken en de omvang ervan zijn zodanig toegenomen dat de kans dat in Nederland aanwezige natuur en landschap negatief wordt beïnvloed steeds groter is geworden, alsmede de mate waarin de invloed zich kan doen gelden is toegenomen, hetgeen bij onder meer de Dienst Weg- en Waterbouwkunde van Rijkswaterstaat van het Ministerie van Verkeer en Waterstaat heeft geleid tot een omvangrijke studie naar mogelijke negatieve effecten. Op basis daarvan is onderzoek naar maatregelen opgezet om negatieve effecten te voorkomen, te beperken in omvang, te mitigeren (te verzachten), te compenseren (elders maatregelen nemen om 'no net loss' van natuurwaarden te bereiken), dan wel het nemen van maatregelen die een positief effect kunnen sorteren.
Het is wetenschappelijk en maatschappelijk van belang dat vanuit de civiele techniek extra aandacht wordt geschonken aan de mogelijkheden om civieltechnische werken, zoals aanleg en gebruik van infrastructuur, en activiteiten, zoals kustbeheer, beter ingepast worden in het functioneren van ecosystemen ten behoeve van het behoud en de ontwikkeling van de biologische diversiteit.

In dit proefschrift wordt op basis van de resultaten van zelf verrichte, uitbestede en (mede) begeleide en elders binnen de organisatie verrichte onderzoekingen en in dit proefschrift beschreven studies een synthese gepresenteerd op de verschillende genoemde deelterreinen binnen de civiele techniek.
Bijzondere aandacht is besteed aan integratie van kennis op het gebied van het begrijpen, benutten en beheersen van patronen en processen van natuurlijke (eco)systemen in relatie tot het plannen, ontwerpen, bouwen, beheren en onderhouden van civieltechnische systemen. De aandacht heeft zich vooral gericht op wegen, waterwegen, wegbermen, taluds, oevers en kunstwerken (bruggen en viaducten) van en/of langs de hoofdinfrastructuur. Naast het weergeven van de resultaten van verrichte onderzoekingen is veel aandacht besteed aan het integreren van de ontwikkelde kennis en inzichten in combinatie van andere onderzoekingen op hetzelfde werkveld die onder verantwoordelijkheid van Regionale Directies van Rijkswaterstaat hebben plaatsgevonden.
De realisatie van het proefschrift heeft plaats kunnen vinden als (voormalig) hoofd van de afdeling onderzoek bij de (voormalige) hoofdafdeling milieu, als onderzoekscoördinator milieu maatregelen infrastructuur en als parttime medewerker bij het Delfts Interfacultair OnderzoeksCentrum Duurzaam Gebouwde Omgeving in het bijzonder het Onderzoeksprogramma De Ecologische Stad en later als parttime toegevoegd onderzoeker/docent bij de sectie Civieltechnische Materiaalkunde en Duurzaam bouwen bij de Faculteit Civiele Techniek en Geowetenschappen van de Delft University of Technology.

In dit proefschrift is sprake van toegepast onderzoek, dat wel oorspronkelijk ‘speurwerk’ omvat om nieuwe kennis te verwerven als uitbreiding op beschikbare kennis. Het onderzoek is vooral gericht nauwomschreven praktische problemen op te lossen, die in dit proefschrift zoveel mogelijk in een integraal verband worden beschouwd.

De gekozen probleemstelling, die bij elk onderdeel steeds in deelvragen is onderverdeeld, is om na te gaan op welke terreinen en met welke middelen een bijdrage aan het verminderen van negatieve effecten geleverd kan worden en of bijgedragen kan worden aan een vergroting van de ecologische betekenis van waterstaatswerken, niet alleen van nieuw te bouwen werken, maar ook van reeds bestaande.

Tevens diende de vraag beantwoord te worden of een set van voor de praktijk te gebruiken ecological engineering principes geformuleerd zou kunnen worden.

Naast het systematisch verzamelen, analyseren en evalueren van gegevens met beschikbare methoden en technieken op de hierboven beschreven onderzoeksgebieden is voor zover mogelijk ook onderzoek verricht naar synthese mogelijkheden waarbij niet alleen naar de combinatie van monofunctionele oplossingen is gekeken, maar vooral naar multifunctionele (interdisciplinaire) oplossingen, omdat de verwachting is dat daarmee een grotere mate van duurzame ontwikkeling van ons handelen bereikt kan worden. Een belangrijke rol kan daarbij ecological engineering spelen. Dit proefschrift bevat een overzicht van verworven kennis en inzichten over de toepassing van ecological engineering, natuurtechniek in de brede betekenis van het woord, op het gebied van de integratie van wegen en wegennetten en natuurlijke patronen en processen, de betekenis van wegbermen als habitat voor planten en dieren, de versnipperende werking van wegen en de mogelijkheden van het nemen van mitigerende maatregelen, landschappelijke inpassing van wegen alsmede kennis en inzichten op het gebied van maatregelen in het kader van het beheer van zandige kusten.

Het proefschrift geeft eveneens inzicht op welke wijze de verantwoordelijkheid voor milieu- en natuuraspecten in relatie tot de primaire taken van Rijkswaterstaat zich binnen de eigen organisatie heeft ontwikkeld.

Het accent in dit proefschrift ligt op de hierboven genoemde aspecten betreffende hoofdwegen en natuur, milieu en landschap. Voor het aspect milieu effect rapportage en hoofdwegen wordt verwezen naar het proefschrift van Dr. E.J.J.M. Arts, productgroepleider tracé/m.e.r. (milieu effectrapportage) bij de Dienst Weg- en Waterbouwkunde en voor het onderwerp compensatie naar het binnenkort te verschijnen proefschrift van Drs. R. Cuperus, productgroepleider natuur en landschap bij de Dienst Weg- en Waterbouwkunde. Voor de terreinen geluid en wegen en lucht en wegen wordt naar bestaande literatuur verwezen alsmede naar de te verschijnen publicaties in het kader van het lopende, bij de Dienst Weg- en Waterbouwkunde ondergebrachte Innovatie-programma Geluid en het recent opgestarte, eveneens bij de Dienst Weg- en Waterbouwkunde ondergebrachte Innovatieprogramma Luchtkwaliteit.

Opbouw van het proefschrift
De hoofdindeling van het proefschrift bestaat naast het inleidend hoofdstuk 1 (a, b, c en d) waarin het doel van de studie, de gekozen onderzoeksmethoden, een overzicht van het proefschrift en een introductie over ecological engineering is opgenomen, uit drie delen:

- Weginfrastructuur en ecological engineering
- Kust dynamiek en ecological engineering
- Conclusies en aanbevelingen en een synthese in de vorm van een set praktische principes voor toepassing van ecological engineering in de civiele techniek

Weginfrastructuur en ecological engineering
Bij de aanleg, de aanwezigheid en het gebruik van wegen gaat het allereerst om de fysische eigenschappen en mechanismen bij weginfrastructuur (van het cunet en de deklagen, respectievelijk geluidemissie, trillingen, emissie van vervuilende stoffen, verlichting) die veranderingen van het abiotische milieu kunnen veroorzaken. Zij kunnen vervolgens ecologische processen beïnvloeden, door verlies van habitat plekken (onder asfalt is weinig/geen leven mogelijk), door barrièrewerking, door verstoring, door genetische veranderingen en beschadiging dan wel de dood van organismen betekenen als gevolg van aanrijdingen. De uiteindelijke ecologische effecten spelen zich op populatie- en ecosysteemniveau af, zoals afname van de omvang van populaties, wijzigingen in de soortensamenstelling en mogelijk lokaal uitsterven van (deel)populaties.
Daarnaast biedt bij wegen de aanleg van bermen en bermsloten habitat plekken voor planten en dieren.

In het hoofdstuk 2 wordt ingegaan op het ontstaan en de verspreiding van milieuvervuilende stoffen die van de weg, het wegmeubilair, de voertuigen en als gevolg van beheer en onderhoud in het milieu kunnen terechtkomen.
Tevens worden de mogelijkheden van bron- en effectgerichte maatregelen behandeld. Tot slot wordt inzicht gegeven in toepassingen van ecological engineering bij de opvang en verwerking van milieuvervuilende stoffen.

In het hoofdstuk 3 wordt verslag gedaan van het onderzoek naar het voorkomen van planten en dieren in de wegbermen en de effecten van ontwerp, inrichting en beheer daarop, op basis van het door of in opdracht van de Dienst Weg- en Waterbouwkunde uitgevoerde onderzoek.
Rijkswaterstaat beheert ongeveer 12.000 ha wegbermen dat vergelijkbaar is met de oppervlakte van de Noordoostpolder. Uit het onderzoek blijkt onder meer, in de vorm van een herbevestiging, dat voor wat betreft het beheer van grazige bermen in principe twee keer per jaar maaien en binnen 7-10 dagen afvoeren van het maaisel de soortenrijkdom in zijn algemeenheid het hoogst is en de voor bermen karakteristieke plantensoorten zich kunnen handhaven. Voorts wordt verslag gedaan van onderzoeken die in opdracht van de Regionale Directies van Rijkswaterstaat zijn gedaan, naar het voorkomen van planten, vegetatie, dagvlinders, amfibieën en kleine zoogdieren in de bermen.

De versnipperende werking van wegen en verkeer en de mogelijkheden van het nemen van ontsnipperende maatregelen, inclusief onderzoek naar het gebruik ervan, staat centraal in hoofdstuk 4. Het beleid op het gebied van ontsnippering heeft vooral na 1990 een impuls gekregen. Zowel op het gebied van onderzoek naar de feitelijke oorzaken en gevolgen alsmede naar de mogelijkheden om met behulp van mitigerende maatregelen (fauna voorzieningen) de negatieve effecten te verminderen. De resultaten van het onderzoek zijn mede gebruikt voor de prioritering van projecten om een zo doelmatig mogelijke besteden van de beschikbare financiële middelen te kunnen bereiken. Er is thans een bruikbaar instrumentarium en een helder afwegingskader op basis van knelpuntenanalyses, zowel op landelijke, regionale als lokale schaal, beschikbaar. Voorts zijn de geleerde lessen in een samenhangend kader geplaatst. Voor de implementatie van de gewenste maatregelen op het gebied van ontsnippering blijkt de betrokkenheid van medewerkers, maar vooral ook van leidinggevende personen binnen de organisatie, alsmede samenwerking met andere overheden en maatschappelijke organisaties essentieel voor het bereiken van een resultaat. Voor het thema ontsnippering is dit nader uitgewerkt voor de procesfasen van opstarten, het op de beleidsagenda krijgen, formuleren van doelen, voorstellen van concrete maatregelen, het uitvoeren, het monitoren van het gebruik ervan en het uitvoeren van evaluaties, die weer aanleiding kunnen geven van het bijstellen van in de toekomst te nemen maatregelen.

Als intermezzo is als hoofdstuk 5 een essay opgenomen over de ontwikkeling door de eeuwen heen van de landschappelijke inpassing van wegen in Nederland, als een uitleiding naar een inleiding, omdat naast analyse en synthese op basis van feiten, eveneens een vooruitblik wordt gegeven van mogelijke toekomsten, als een aansporing voor nader onderzoek naar de effecten van een aantal beschreven mogelijke ontwikkelingen die meer of minder sterke invloed op de landschappelijke inpassing van hoofdwegen in de toekomst kunnen hebben.

In hoofdstuk 6 wordt ingegaan op de relatie tussen infrastructuur, ecologie en kunst aan de hand van een aantal case studies. Hieruit blijkt dat er goede mogelijkheden zijn om inzichten en kennis op het gebied van de combinatie van infrastructuur, ecologie en kunst te gebruiken bij het ontwerp, de bouw en het beheer van civieltechnische objecten.

Kustdynamiek en ecological engineering

In het gedeelte over de kust (hoofdstuk 7, 8, 9, en 10) wordt de vraag beantwoord of milieuvriendelijke oevers ook voor de zeekust mogelijk zijn. Dit naar analogie van het project milieuvriendelijke oevers van Rijkswaterstaat waar het accent lag op oevers van rivieren, kanalen en grote wateren. Naast een algemene beschouwing over de ervaringen met dynamisch kustbeheer wordt een indertijd voorgesteld onderzoeksprogramma vergeleken met het uiteindelijk uitgevoerde onderzoek. Hieruit blijkt dat zandsuppleties in de vooroever uit ecologisch oogpunt veelal te prefereren is boven terrestrisch uitgevoerde zandaanvullingen achter, in of direct voor de zeereep.Voorts wordt het proces van het totstandkomen van een gekerfde zeereep met slufterachtige gebieden beschreven.

Conclusies en aanbevelingen

In de 'conclusies en aanbevelingen' (hoofdstuk 11 en 12) zijn voor zowel de weg (a) als voor de kust (b) de belangrijkste conclusies en aanbevelingen van het onderzoek samengevat. Het geheel wordt besloten met een set ecological engineering principes voor de praktijk van de civiele techniek (c).
Hieronder volgen voor (a) de weg, (b) de kust en (c) de synthese een korte samenvatting.

Ad. a. Van de ecologie van wegbermen naar een ecosysteem benadering van de weg en zijn omgeving, en van natuurtechniek naar ecological engineering.

Wegen en verkeer zijn een belangrijke bron van emissie van o.m. NOx, VOCs en zwevende deeltjes (PM10 en PM 2,5).

Dicht en open asfalt verschillen in de mate van verspreiding van milieu vervuilende stoffen door verwaaiing en run-off. Dicht asfalt vertoont meer verwaaiing dan open asfalt. Bij open asfalt heeft run-off een belangrijker aandeel in de verspreiding van water en milieu vervuilende stoffen. In de poriën van open asfalt blijft de vervuiling grotendeels achter. Door het regelmatig reinigen van de vluchtstrook blijft de doorstroming in het zoab gewaarborgd.
De vegetatie en de bodem van het bermgedeelte dichtbij het wegoppervlak spelen een belangrijke rol in het opnemen en deels onschadelijk maken van vervuilende stoffen van de weg en het verkeer. Brongerichte maatregelen hebben de voorkeur boven effectgerichte maatregelen.

Wegen en wegennetwerken vormen één van de belangrijkste oorzaken van versnippering van habitat plekken. Om de knelpunten tussen wegen en natuur te achterhalen zijn 'overlay'technieken zeer nuttig; door het wegenpatroon over de gekarteerde ecologische netwerken te leggen kunnen knelpunten aangewezen en verder geanalyseerd worden.
Wegen kunnen door middel van speciale voorzieningen meer doorlaatbaar worden gemaakt voor dieren. Faunapassages kunnen bijvoorbeeld bestaan uit eenvoudige, enkelvoudige buizen onder of over de weg, uit ecoducten of uit brede landschapsbruggen. Ook ondertunneling en wegen op palen behoren tot de mogelijkheden om de versnipperende werking van wegen te verminderen.

Wegbermen spelen een belangrijke ecologische rol en dienen met aandacht te worden onderhouden om de ecologische waarden te behouden en zo mogelijk te vergroten. Grazige begroeiing vereist in principe twee keer maaien per jaar waarna het maaisel binnen 7 – 10 dagen verwijderd dient te worden om de verscheidenheid aan planten te behouden dan wel te vergroten.
Spontane vestiging en ontwikkeling van planten en dieren worden in principe aanbevolen in combinatie met een adequate beheerregime.
Onder bijzondere omstandigheden kan (hydro)seeding of zgn. inoculatie geadviseerd worden.
Het betrekken van extra zones parallel aan de berm in het aangrenzende land kan van betekenis zijn om de biodiversiteit te kunnen verhogen.

Een zgn. drie netwerken (wegen, water en natuur) analyse in combinatie met de lagenbenadering uit de milieuplanning en ruimtelijke ordening kan integratie van genoemde aspecten met andere activiteiten (wonen, werken en recreëren) worden bevorderd.

Het bevorderen van het combineren van ecosysteemdiensten is gewenst. Meer onderzoek in dit verband is gewenst, zoals naar integratie mogelijkheden van geluidwerende voorzieningen alsmede beplantingen met ecologische waarde voor de opvang en verwerking van luchtvervuilende stoffen. Een ander voorbeeld van de mogelijkheid van integratie van ecosysteemdiensten en productie van ecosysteeem goederen zijn helofytenfiltersystemen. Zij maken afbraak, omzetting en opname van verontreinigingen in planten mogelijk alsmede productie van hernieuwbare stoffen.

Een ecosysteembenadering kan behulpzaam zijn bij het integreren van ecologische, sociale en economische aspecten binnen de planning en het ontwerp van wegen.

De ontwikkeling van een nieuw vakgebied "infrastructurele ecologie" kan nuttig zijn voor het vergroten van het inzicht in de relatie tussen wegen, verkeer, wegbermen en de omgeving van de weg.

Ad. b. Van starre kustbescherming naar dynamisch kustbeheer met behulp van ecological engineering.

Gedurende de laatste decennia heeft zich bij de bescherming van zandige kusten een verandering voltrokken van een vorm van starre kustbescherming door het aanbrengen van zand achter, in of voor de zeereep, naar een meer flexibele benadering waarbij zandsuppletie op de vooroever wordt toegepast.

Een meer holistische benadering is gewenst waarbij de kennis over zandtransport de sleutel vormt voor duurzame instandhouding en ontwikkeling van het gehele kustduinecosysteem van de vooroever tot en met de landinwaarts gelegen duinen.

Ad. c. Synthese: een set van principes van ecologische engineering voor toepassing in de civiele techniek.

In de vorm van een synthese (hoofdstuk 13) wordt op basis van de verkregen resultaten uit het onderzoek en een aantal voor het werkveld relevant geachte ethische principes een set van principes van ecological engineering voor toepassing in de civiele techniek gepresenteerd. De ethische principes zijn opgenomen omdat naar de mening van de auteur die kunnen bijdragen meer integrale oplossingen te kunnen realiseren.

Het betreft:

1. Een menselijke ingreep in een landschap dient in een ecologische context op alle schaalniveaus beoordeeld te worden. De genius locus is daarbij het uitgangspunt.

2. Bij het plannen, bouwen en beheren van civieltechnische objecten dient het faciliteren van zelf-regulerende ecologische processen één van de doelstellingen te zijn.

3. Bij het ontwerp van constructies dient rekening gehouden te worden met de betekenis van 'snelle' en 'langzame' ecologische processen, of wel welke kansen zijn er in dynamische milieus voor planten en dieren die gebonden zijn aan een lage milieudynamiek.

4. Het is voor het behoud en de ontwikkeling van planten en dieren gewenst zoveel mogelijk een ecologisch ongeschonden toestand te handhaven en zo mogelijk te bevorderen. Dit betekent optimaliseren van abiotische, biotische en andere condities om aan de eisen van een zo volwaardig mogelijk functionerend ecosysteem te voldoen.

5. Het is uit ecologisch oogpunt van belang ontwerpen van civieltechnische objecten aan te passen aan de ter plaatse aanwezige ecosystemen. Ecosysteem functies behoren te worden gerespecteerd en een gepast gebruik zal van ecosysteem goederen en ecosyteem diensten worden gemaakt.

6. De combinatie van ecosysteem diensten en de productie van ecosysteem goederen zal zoveel mogelijk worden gecombineerd.

7. Bij het ontwerp van civieltechnische objecten zullen gradiëntrijke situaties worden gerespecteerd en waar mogelijk worden hersteld dan wel worden toegevoegd in plaats van te streven naar harde grenzen.

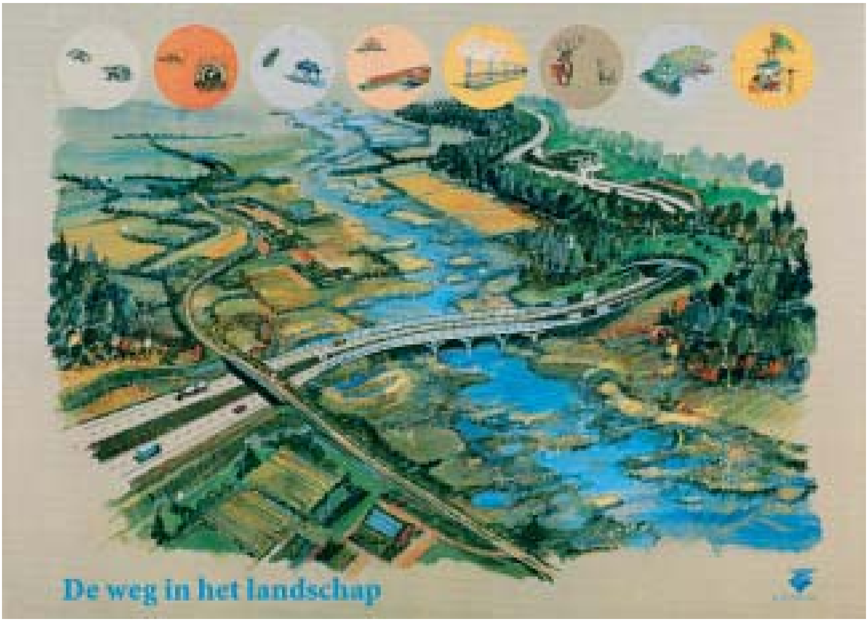
8. Maak (veranderingen in) ecologische patronen en processen zo zichtbaar en beleefbaar mogelijk.

9. Betrek in alle fasen van het proces van de planning, ontwerp, constructie, beheer en sloop van civieltechnische objecten alle betrokken actoren (opdrachtgever, ontwerper, bouwer), zowel als indirect betrokken actoren (toekomstige gebruiker, beheerder, sloper). Ook mensen die nu en in de toekomst beïnvloed kunnen worden zullen betrokken respectievelijk mee worden rekening gehouden.

10. Negatieve effecten zouden niet bij anderen of elders, nu of in de toekomst 'neergelegd' moeten worden. Als na het voorkómen van, dan wel het nemen van preventieve maatregelen nog negatieve effecten van een ingreep overblijven dan zullen mitigerende maatregelen genomen moeten worden. Wanneer daarna nog negatieve effecten overblijven kan via compensatie een 'no net loss' van ecologische waarden zoveel als mogelijk worden bereikt. Daarnaast zou zo mogelijk herstel van aangetaste waarden moeten kunnen worden bevorderd.

Beschrijving van de omslag van het proefschrift
Als omslag van dit proefschrift is gekozen voor een naar het idee van H. van Bohemen en in samenwerking met J.G. de Vries door P. Kerrebijn te Wateringen vervaardigd aquarel **'De weg in het landschap'**, dat een heldere illustratie vormt van een aantal aspecten die in dit proefschrift zijn beschreven (figuur 1).

De plaat verbeeldt een snelweg die het landelijke gebied doorsnijdt en waarop is aangegeven welke mitigerende maatregelen ter vermindering van negatieve effecten van infrastructuur en verkeer en vervoer genomen kunnen worden.
Naast de genummerde elementen (A t/m H) zijn weergegeven: een helofytenfilter voor zuivering van vervuild wegwater, zonnepanelen, bermen en geluidswallen. De snelweg doorsnijdt voorts een natte as van de Ecologische Hoofdstructuur.



Figuur 1: De weg in het landschap (P. Kerrebijn; copyright RWS/DWW)

A. Kleinschalig agrarisch cultuurlandschap met houtsingels die bijvoorbeeld als geleidingsbaan door dassen of vleermuizen gebruikt kunnen worden.
B. Dassentunnels onder de snelweg.
C. Stobbenwallen op een bestaand viaduct die een functie als corridor voor kleine zoogdieren, amfibieën en insecten kan vervullen.
D. Een van hout vervaardigde vangrail.
E. Doorzichtig geluidsscherm voorzien van horizontale strepen ter voorkoming van vogelaanvaringen (onderzoek uit Duitsland heeft uitgewezen dat vertikale strepen van 5 cm breedte en 10 cm van elkaar effectiever zijn in het voorkómen van vogelaanvaringen).
F. Landschapsbrug, een omvangrijk ecoduct.
G. Tankstation met een begroeid dak.
H. Parkeerplaats met informatie paneel over de betekenis van de omgeving en een uitkijktoren die uitzicht biedt op de landschapsbrug.

Curriculum Vitae

In short
Drs. Ing. Hein van Bohemen is research coordinator environment and infrastructure at the Road and Hydraulic Engineering Institute of the Directorate-General for Public Works and Water Management of the Ministry of Transport, Public Works and Water Management in The Netherlands.
He has been working as deputy-secretary of the Natural Science Commission of the National Conservation Council and former head of the environmental research department of the Road and Hydraulic Engineering Institute.
For two years he has been working two days a week at the Delft Interfaculty Research Centre, which concentrates on pioneering innovative research on sustainable building, entitled 'The Ecological City' and nowadays working one day a week at the Delft University/ Section Civil Engineering.
He has special interests in ecology, landscape ecology and ecological engineering in relation to civil engineering.
He is member of the executive board of the International Ecological Engineering Society.

In more detail *(in Dutch)*

Naam:
H.D.van Bohemen

Geboren:
10 maart 1946 te Den Haag

Opleiding:
- Rijks Hogere Tuinbouwschool te Utrecht
- L-II akte (onderwijsbevoegdheid) te Roermond
- Doctoraal biologie aan de Vrije Universiteit te Amsterdam met als hoofdvak: Plantenoecologie en vegetatiekunde en als bijvakken: fysische geografie met landschapsonderzoek en dieroecologie
- Deelname (en presentaties) op vele nationale en internationale bijeenkomsten en congressen op het gebied van de landschapsoecologie, vegetatiekunde, versnippering en ontsnippering van habitats, duurzaam beheer van natuur, milieu en landschap, ecological engineering, restoratie-oecologie, botanische tuinen, nationale parken, natuur- en milieueducatie
- Deelname Management Leergang Verkeer en Waterstaat (MLV 92-03)
- Deelname aan de Leergang Beleidskunde II van de Stichting Publiek Domein 1994/1995
- Postgraduate Course Ecological Engineering (RU-Utrecht; 11/10 - 14/10/93
- Deelname in 2002 aan de Cursus Ecological Design: Context, Theory and Practice aan het Schumacher college, Dartington, Totnes, U.K.

Werkervaring:

- 1975 - 1977 (Min. L en V) Staatsbosbeheer/Inspectie Natuurbehoud/gedetacheerd bij de Natuurwetenschappelijke Commissie (N.W.C.) van de Natuurbeschermingsraad
- 1977 - 1987 (Min. C.R.M./Min. L en V) Wetenschappelijk medewerker N.W.C.; vanaf 1978 lid en ambtelijk adj.-secretaris van de N.W.C.; 1986-1987 waarnemend secretaris van de N.W.C.
- 1987 - 1990 (Min. V en W) hoofd van de onderafdeling natuurlijk milieu en landschap van de Dienst Weg- en Waterbouwkunde
- 1990 - 1995 (Min. V en W) hoofd van de afdeling onderzoek milieu van de Dienst Weg- en Waterbouwkunde
- 1995 - heden (Min. V en W) coördinator onderzoeksveld milieumaatregelen infrastuctuur
- 2000 - 2002 twee dagen per week werkzaam bij het DIOC/TUD De ecologische stad
- 2003 - heden een dag per week werkzaam bij de sectie materiaalkunde van Civiele Techniek van de TUD, verantwoordelijk voor inbreng ecological engineering in de Master of Science opleiding
- 1994 - 2004, jaarlijks gastcolleges over “Ecological engineering, natuurtechniek en waterstaats-werken” in de Cursus Toegepaste Oecologie aan de Vrije Universiteit te Amsterdam en gastcolleges Rijksuniversiteit Leiden over ontsnippering van wegen
- 1996 Gastcollege over “Infrastructure and habitat fragmentation: mitigation and compensation measures” aan de Graduate School of Design van de Harvard Universiteit
- 1996 Overview lecture Graduate School of Design over “Ecological Engineering; mitigation and compensation”.

Bestuurlijke ervaring buiten de werksfeer:

- eindredakteur, secretaris resp. voorzitter (gedurende een periode van 23 jaar tot 1/4/98) van de Stichting Uitgeverij van de K.N.N.V.
- voorzitter van de Stichting voor (sub)antarctisch onderzoek (tot 1/1/96)
- lid van het bestuur van de Stichting Heimans en Thijsse (tot 1/1/98)
- lid van het bestuur van de Fondation Yves Rocher (tot 1/1/98)
- lid van het bestuur van de Vereniging Midden-Delfland (tot 1/3/2000)
- voorzitter werkgroep onverharde paden in Midden-Delfland

Deelname in stuur- en werkgroepen vanuit zijn huidige functie

- lid van het bestuur van de International Ecological Engineering Society
- lid van de Task Force Natural Resources and Infrastructure and Transport van de U.S. Transportation Research Board
- lid van de Commissie Maintenance of Roadside Verges van de U.S. Transportation Research Board

Tot 1/1/95

- lid van de Rijkswaterstaatscommissie voor kustonderzoek (RKO)
- lid van de Werkgroep rivierdijken D10 van de Technische Adviescommissie Waterkeringen
- lid van de CUR-Stuurgroep B37 Alternatieve materialen in de waterbouw
- lid van de CROW-Stuurgroep Duurzaam bouwen
- lid van het Periodiek Overleg Remote Sensing Rijkswaterstaat (PORS)
- lid van de Stuurgroep Ontsnipperingsbeleid LNV, VROM en VenW
- lid van de Werkgroep Werkrelaties in kader van RWS 200 jaar
- lid van de Werkgroep Milieu effect rapportage van de OECD
- lid van de Gebruikerscommissie van het IBN-Project Plantengemeenschappen
- lid van de Commissie van advies Milieustatistieken van het CBS
- voorzitter van de Stuurgroep Milieuzorg RWS-breed
- lid van het Organising Committee van het Internationale Jubileum Congres RWS 200 jaar
- lid van de Commissie van toezicht bijzonder hoogleraar oecologie van infrastructuur

Bestuursactiviteiten buiten de werksfeer vóór 1996

- lid van het bestuur van de International Youth Federation for Environmental Studies and Conservation
- lid van het Hoofdbestuur van de Koninklijke Nederlandse Natuurhistorische Vereniging
- lid van de Natuurbeschermingscommissie van de KNNV
- lid van het Hoofdbestuur van het Instituut voor Natuurbeschermingseducatie
- Expeditieleider van de Nederlandse Wetenschappelijke South Georgia Expeditie (1986/1987)
- vice-voorzitter van de Stichting Heimans- en Thijsse Fonds

Publications, Articles and Miscellaneous Writings

Publications, articles and miscellaneous writings of Hein van Bohemen appeared between 1964 and 1/1/2004.

The following list gives an idea of published articles, papers, reports and miscellaneous writings which gives a picture of the involvement of the author in the field of field biology, nature conservation and ecological engineering during 40 years.

The survey includes a separate section about the work as scientific worker and later deputy-secretary of the former Natural Science Commission of the National Conservation Council, an advisory body of the Ministry of Agriculture, Nature and Fisheries. Only the reports and advices have been included where the author has been responsible for the concepts. These advices have played a role in forming a conservation policy in general and in the conservation input in re-allotmens in the Dutch rural landscape.

1964

Verslag van het Biologisch Werkkamp voor het Onderwijs aan de Hogeweg nabij Burgh op Westerschouwen van 21 - 31 juli 1964; onderdeel cultuur.

Praktijk/stageverslag Rijkshogere Tuinbouwschool: Fruitteelt en Bloementeelt.

1965

Praktijk/stageverslagen Rijkshogere Tuinbouwschool: Groenteteelt, Technologie (Thomassen en Drijver), Plantsoenendienst Amsterdam.

1966

De plantengroei op opgespoten en braakliggende terreinen; waargenomen plantensoorten in de Buitenveldert te Amsterdam seizoen 1964 en 1965, in de Eenhoorn, NJN dIV, afdeling 1.

Impressions of the vegetation of the Lüneburger Heide; in: Verslag van de internationale leergang voor natuurbescherming en landschapsverzorging op de Lüneburger Heide 1966 (co-author: Fr. Prochazka).

1967

Verslag General Assembly International Youth Federation for Environmental Studies and Conservation (I.Y.F.), 1967, Oxford, Engeland (co-author: F. van der Vegte).

IYF, In Natura, november 1967, blz.211.

1968

Verslag General Assembly International Youth Fedration for environmental studies and conservation (I.Y.F.), 1968, Kuusamo, Finland.

IYFcamps, Reisnatura, februari 1968.

IYF, in: Natura 1968, blz.116 en 167.

1969

Contributions (three presentations concerning youth and nature) to the All-Russia Youth Nature Protection Seminar 1969 te Voronezh.

IYF, in: Natura 1969, december.

1970

Natuur- en landschapsbescherming in Nederland; opkomst en ontwikkeling en huidige organisatie, Wetenschappelijke Mededeling KNNV, nr. 85 (co-author: P. Zonderwijk).

Current situation of the Flora of the Netherlands with special regard to Orchids; lecture at the working conference "Flora and Man in the 20th century; actual problems of flora preservation" Pardubice, Czechoslovakia.

J.P. Thijsse park in Amstelveen and its importance for education of youth, lecture at the working conference "Flora and Man in the 20th century; actual problems of flora preservation", Pardubice, Czechoslovakia.

Verslag van het 3e Tsjecho-Slowaakse Intercamp en de 2e international conferentie "Jeugd en Nationale Parken" (co-author: Mw. B.L. van Leeuwen).

1971

Out-of-school education and activities of children and youth, session report at the European Working Conference on Environmental Conservation Education, Rüschlikon, Switzerland; in: Final Report I.U.C.N. Morges (1972).

Voluntary service and conservation, special education programmes about environmental problems and conservation for volunteers who are going to developing countries, paper towards General Assembly of the International Youth Federation for Environmental Studies and Conservation and Stichting Nederlandse Vrijwilligers.

1972

Report August 1971 - August 1972 Development officer International Youth Federation for Environmental Studies and Conservation (I.Y.F.) presented to the I.Y.F. General Assembly 1972 in Zweden.

Report Attendance 2e World Conference on National Parks which took place in Yellowstone Park and Grand Teton National Park U.S.A.

1974

Bodemalgenvegetatie in de strandvlakte van Schiermonnikoog, verslag van een oriëntatie in het kader van doctoraalstudie aan de Vrije Universiteit van Amsterdam.

Voorlopige determinatietabel en beschrijvingen van de belangrijkste mariene blauwwieren (Cyanophyceae) van de Strandvlakte van Schiermonnikoog en de inlagen van Zeeland ten behoeve van de Cursus Vegetatiekunde en Plantenoecologie aan de Vrije Universiteit van Amsterdam (samengesteld in het kader van een studentassistentschap).

Prakticumhandleiding "Inleiding tot de plantkunde voor fysisch-geografen: overzicht van het plantenrijk, de flora van Nederland, beschrijving van de vegetatie en plantkundige aspecten van het Nederlandse landschap", Vrije Universiteit te Amsterdam (co-author H. Hillebrand).

Out-of-school nature conservation education; lecture, In: Report Eastern Africa Youth Course in Environmental Conservation, Nairobi, Kenya.

Vegetatiekundig onderzoek van Dennenbossen in Drente, verslag doctoraal onderzoek Vrije Universiteit te Amsterdam/Biologisch Station

Wijster (hoofdvak vegetatiekunde en plantenoecologie).

Een tafelvormige stuifzandheuvel (“Fort”) in Drente, verslag van een kartering van een “fort”, een typische plateauvormige stuifzandheuvel in het Landgoed Berkenheuvel, Vrije Universiteit te Amsterdam in het kader van een bijvak fysiche geografie aan de Vrije Universiteit te Amsterdam.

Energie-budget van laboratorium-populaties van Orchesella cincta (L.), verslag van een doctoraal onderzoek aan een springstaartsoort in het kader van een bijvak dieroecologie aan de Vrije Universiteit van Amsterdam.

1978

Impressies van een bezoek aan Groenland, in: Natura, december 1978, pg. 286 - 291.

1979

Nieuws van de Natuurbeschmingscommissie, in: Natura, september 1979, pg. 219 - 221.

Het belang van en mogelijkheden tot botanisch onderzoek door amateurs voor het natuurbehoud, in Natura juni 1979, pg. 149 - 155.

De Falkland eilanden, in: Natura, november/ december 1979, pg.298 - 304.

Oase in een steenwoestijn, hoofdstuk in de Spectrumatlas Nederlandse Landschappen, pg.186 - 194.

1980

Spitsbergen; enige informatie en indrukken van een voettocht, in: Natura, februari/maart 1980 pg. 74 - 82.

Atlas van de Nederlandse Flora, in: Natura, november 1980, pg. 315 - 321.

1982

Natuur en landschap op Baffin eiland, in: Natura, oktober 1982, pg, 189 - 195.

Moet de Zwarte Zee-eend wijken? Geen Rotterdams Baggerslib voor de kust van Voorne, in: Natuurbehoud, pg. 42 - 45.

1983

Muy en Slufter, in Waddenbulletin 1983, pg. 11 - 15.

Report of the Dutch Natural History Expedition to North East Greenland (met bijdragen in rapport Vogelwaarnemingen door O.Plantema).

Hoofdstuk “Het Groene Midden”, in Prisma Wegwijzer Zuid-Holland, pg. 20 - 25.

1984

Ruilverkavelingen en de (mogelijke) rol van de KNNV daarbij, in: Natura, juli/augustus 1984, pg. 205 213 (co-author P. Veen). Tevens verschenen in Amoeba, oktober 1984.

Morgen is het nog niet te laat; de strategie van de veldbioloog voor de jaren ’80 en ’90, in: Natura, februari 1984, pg. 38 - 45.

Geef de natuur de ruimte zodat zij haar toekomst kan beleven, in: Natura, april 1985 pg. 303 - 308.

Compensatie voor milieuschade nodig bij verbreding van kust, in: Opiniepagina van NRC Handelsblad van 29 oktober 1984.

1986

Natuur en mens, in: Verslag themadag “Bezig zijn met natuurbehoud”, in: Natura, januari/ februari pg. E20 - E30.

1987

Oecologische aspecten van natuurtechnisch oeverbeheer, syllabus t.b.v. Cursus natuurtechnisch oeverbeheer RWS.

Houtproductie bij RWS, notitie, Delft.

Verslag deelname aan het 14e Internationale Botanische Congres te Berlijn.

Natuurbehoud dichtbij en verweg, tekst voordracht tijdens afscheid als adj.-secretaris van de NWC.

Landschapsecologische aspecten van geluidwerende voorzieningen, startnotitie t.b.v. evaluatie onderzoek naar de effectiviteit van groene geluidwerende voorzieningen (co-author P. Heemskerk).

1988

Nederlandse Wetenschappelijke South Georgia Expeditie, in: Circumpolar Journal 1-2, pg. 3 - 6.

Natuurbehoud subantarctische eilanden, in: Circumpolar Journal, 1-2, pg. 36 - 38.

Nederlandse Wetenschappelijke South Georgia Expeditie, Expeditieverslag (co-authors: D.A.G. Buizer, N.J.NM. Gremmen, J. de Korte and A.F. van Olphen).

Cases geluidswallen, notitie kosten, DWW/ RWS, Delft.

Reaktie op concept-onderzoeksplan Rottumeroog/Rottumerplaat,notitie. DWW/ RWS, Delft.

Projectplan inbreng DWW-MI t.b.v. Kustnota, DWW/RWS, Delft.

De zorg voor natuur en landschap, syllabus t.b.v. de Cursus milieukundig adviseur RWS.

Ecologische infrastructuur: toepassing in de planvorming, syllabus discussiedag RWS en afd. Verkeerswegen van Ministerie LNV.

Verslag deelname aan het 5e symposium “Synanthropic Flora and Vegetation” in Martin te Tsjecho-Slowakije.

Oecologische aspecten van oeverbegroeiingen, syllabus t.b.v. Cursus natuurtechnisch oeverbeheer 1988.

1989

Herstel, ontwikkeling en beheer van landschapsecologische processen op het strand en in de buitenduinen, In: Duin 12(3) 88 - 96/ De Levende Natuur 90(5) 134 - 142, co-authors: P.D. Jungerius en F. van der Meulen.

Opzet voor een 3-daagse Cursus insektenvriendelijk beheer, notitie RWS/DWW.

Verslag deelname aan Europees duincongres 1989, Sevilla, Spanje.

Landschapsecologische inpassing duinverzwaringen, tekst voordracht 3e Kust- en Oeverdag RWS te Middelburg.

Milieuvriendelijke oevers in de praktijk, verslag van de studiedag gehouden op 1 november 1989, Rapport nr. 15 Project Milieuvriendelijke oevers.

Cursusmap Natuurtechnische oeverbeheer: Inrichting en beheer van milieuvriendelijke oevers; ook hier weer samenwerking tussen gebiologeerde civielen en geciviliseerde biologen, eindredaktie: H.D. van Bohemen en R.G. Smits. Rapport nr. 10 Project Milieuvriendelijke Oevers.

Inleiding in de oecologie, in: Cursusmap Natuurtechnische oeverbeheer 3.1, 1 - 20.

Ecologische aspecten van het oevermilieu, in: Cursusmap Natuurtechnisch oeverbeheer 3.2, pg. 1 - 16.

Verslag deelname aan het 5e Europese Ecologie Symposium in Sienna, Italië.

Documentatie t.b.v. het terreinbezoek van de leden van de voormalige begeleidingsgroep verzwaring zeewering tussen Ockenburgh en Ter Heijde op 13 september 1989.

1990

Hoofdstuk Beplantingen in de Handleiding beheersplannen wegbermen, co-authors: J.W. de Jager en G. van Tol.

Groene elementen van waterstaatwerken en hun (potentiële) ecologische betekenis, co-author: J. van der Sluijs. In: Natuurtechniek en Waterstaatswerken W.M. 199 van de KNNV, pg. 21 - 33.

Inrichting en beheer van oevers en oeververdedigingen van rijkswateren, co-author: G.J. Bekker In: Natuurtechniek en Waterstaatwerken W.M. 199 van de KNNV, pg. 105 - 124.

Inrichting en beheer van zeewerende duinen, co-author G. Veenbaas, in: Natuurtechniek en Waterstaatswerken W.M. 199 van de KNNV, pg. 125 - 141.

De kleine uitgever en zijn boeken, in: Bladeren in de natuur, Uitgave Stichting Uitgeverij KNNV.

De uitgeverij van de KNNV, in: Bladeren in de natuur, Uitgave Stichting Uitgeverij KNNV.

Verslag van een 4-daags bezoek aan enkele instituten in Niedersachsen en Nordrhein-Westfalen die betrokken zijn bij de aanleg en beheer van oevers, co-authors P. Aanen en G.J. Bekker.

Educatie in een Tsjechisch nationaal park, in: Mens en Natuur, pg. 37 - 39.

Verslag deelname internationale conferentie over het beheer van beschermde gebieden onder invloed van atmosferische depositie van 3-9 juni 1990 te Krkokonose, Tsjecho-Slowakije.

Verslag tweede workshop versnippering gehouden op 16 oktober 1990 in Den Haag, co-author W. Alberts, verschenen als nr. 1 in de DWW- Versnipperingsreeks.

Onderzoeksprogramma DWW/MI 1990, co-author A.W.J. van Schaik en J.J. van Houdt.

Beheer van vegetatie en insektenfauna: afwegingscriteria, syllabus t.b.v. Cursus Insektenvriendelijk beheer.

Voorwoord als voorzitter van de begeleidingscommissie van het rapport "Mitigerende en compenserende maatregelen aan het hoofdwegennet voor het bevorderen van natuurwaarden", CML/DWW, Leiden/Delft.

1991

Beheer en ontwikkeling van de zeewerende duinen, nu en in de toekomst; zeereepbeheer en sluftervorming, tekst van een voordracht uitgesproken op het symposium Kustontwikkeling en duinbeheer van het Instituut voor Oecologisch Onderzoek en de Oecologische Kring op 11 april 1991 te Amsterdam.

Voorwoord als voorzitter van de Klankbordgroep Remote Sensing/Gis toepassingen (landschapsecologische kaartontwikkeling) t.b.v. van m.e.r.

Green elements of civil engineering works and their (potential) ecological importance, coauthor: J. van der Sluijs, in: Nature engineering and civil engineering works.

Shaping and management of banks and bank protection structures of state-owned waters, co-author G.J. Bekker, in: Nature engineering an civil engineering works.

Layout and management of sea dunes, coauthor G. Veenbaas, in: Nature engineering and civil engineering works.

Onderzoeksprogramma milieu 1991, coauthors: A.W.J. van Schaik en J.J. van Houdt.

Structuurplan Milieu van de Hoofdafdeling Milieu van de DWW in kader van op te stellen plan voor de Droge Infrastructuur in samenwerking met bureau Wuust en partners.

Ecological engineering and coastal defence, tekst van een voordracht uitgesproken op het 3e Europees Duincongres te Galway, Ierland, co-author H.J.N. Meesters.

Verslag van het derde Europees Duincongres, Galway, Ierland, co-author: H.J.N. Meesters

Verslag van deelname aan het 34e symposium van de International Association for Vegetation Science (IAVS) over Mechanismen in de vegetatie-dynamiek, 26-30 augustus te Eger, Hongarije.

Natuurtechniek en wegbermen, nota stand van zaken, co-author C.J. van de Watering.

Ecologische waarde wegberm groeit door extensief beheer, in Land+Water nr. 9 september 1991, pg. 38-44, co-author C.J. van de Watering.

Tweehonderd Wetenschappelijke Mededelingen van de KNNV, in: Natura 1991(1), pg. 15 - 17.

Toepassingen van Remote Sensing in de droge waterstaat, tekst van een voordracht op een symposium Water- en Landtoepassingen van Remote Sensing te Utrecht.

1992

Onderzoeksprogramma Hoofdafdeling Milieu van de Dienst Weg- en Watyerbouwkunde, 1992, co-authors: A.W.J. van Schaik en J.J. van Houdt.

Een bijzonder boek: Atlas van de Nederlandse zoogdieren, in: Natura 7 pg. 154-157 (tekst uitgesproken tijdens de aanbiedingsbijeenkomst van de atlas).

Natuurtechniek en Waterstaatwerken, in: OTAR nr. 2, pg. 35 - 44.

Beheer van vegetatie en insektenfauna, in: Insektenvriendelijk beheer van wegbermen, pg. 106 - 119.

Voorwoord Landschapsecologie en GIS in Milieu-Effectrapportage, als voorzitter van de klandbordgroep.

Milieu-effectrapportage bij RWS, tekst korte inleiding op de studiemiddag landschaps-ecologie en GIS in m.e.r.

De Nationale Parken van Europa, boek-bespreking in Groen nr.6, pg. 47.

Conservation education and South Ocean/ Subantarctic Islands; principles, guidelines and actions. Contribution (report/presentation) to the 4th World Congress on National parks and protected areas. Caracas, Venezuela, 10 - 21 February 1992.

1993

Conservation Education and Southern Ocean/ Subantarctic Islands: Principles, Guidelines and Actions, in: Circumpolar Journal 1-2, pg. 2-14.

Verslag van een discussiedag "Slufters en slufterachtige gebieden", voorwoord en redaktie (co-author: A.W.J. van Schaik).

Environmentally friendly coasts; Environmental engineering and coastal mangement; case study from the Netherlands, tekst voordracht international conference on the science and management of coastal dunes in Port Elizabeth, South Africa.

Versnippering ...... ontsnippering, tekst voordracht op de WLO-studiedag over Mitigerende en compenserende maatregelen te Utrecht, co-author; H. de Vries.

Voorwoord bij het rapport Infrastructuur en compensatie van natuurwaarden als voorzitter van de klankbordgroep.

Natuurvriendelijke oevers ook voor de zeekust?!, in: OTAR 7/8, pg. 215 - 228.

Environmental Impact Assessment methods for highway planning -, tekst voordracht 2e international conference of environmental impact assessments in Prague, september 1993, co-author P. Visser, in: Proceedings vol. I, 2e International Conference EIA of all economical activities, Praha, CSSR. September 1993.

1994

Verslag van deelname aan de Internationale Conferentie DUNES '94 te Zuid-Afrika.

Inleiding visie op bermbeheer, tekst voordracht uitgeproken op het symposium Bermbeheer op 14 april 1994 te Ede.

Strategic Environmental Impact Assessments Methods for transport and highway planning , tekst voordracht uitgesproken op internationaal OECD-symposium Environmental impact assessment of roads; strategic and integrated approaches te Palermo in Italië.

De ontwikkeling van het stadsecologisch onderzoek en de toepassing van ecologische kennis, voordracht tijdens de presentatie van het boek Van Muurbloem tot Straatmadelief te Amsterdam.

Verslag deelname aan het 6e internationale ecologencongres te Manchester.

Versnippering-Ontsnippering; beleid en onderzoek bij verkeer en waterstaat, in: Landschap 11, pg. 15-26, co-authors J.G. de Vries en C.J. Padmos.

Habitat fragmentation and roads; mitigation and compensation: strategy, objectives and practical measures - tekst voordracht op de jaarlijkse bijeenkomst van de Transportation Research Board in Washington.

Mitigation and compensation of construction works; korte inleiding op de internationale workshop “Ecological engineering for ecosystem restoration” op 29 november 1994 te Zeist.

Remote Sensing and GIS t.b.v. de verkeer en vervoersector, rivier-, polder- en dijkbeheer, kust- en zeereepbeheer; “een discussiestuk”. Co-auteur R. Allewijn. RWS/MD//DWW/Delft.

1995

Verslag van deelname aan de 74e Vergadering van de Transportation Research Board in Washington, U.S.A.

Natuurtechniek en Waterstaatswerken, in: Het Vogeljaar 43(3). pg. 121 - 127.

Stadsecologie; Van Muurbloem tot Straatmadelief, in: Natura 92(1), 14 en 15.

Diverse presentaties als dagvoorzitter van het vier dagen durende International symposium Habitat Fragmentation and Infrastructure in Maastricht en Den Haag.

1996

Habitat fragmentation and Roads; mitigation and compensation, in: Ecotechnics for a sustainable society, pg. 81 - 93.

Verslag van deelname aan de 75e jaarlijkse vergadering van de Transportation Research Board, 6-11 januari 1996 te Washington, USA.

Ecological Engineering for Ecosystem Restoration, in: Ekotecknikos Biuletenis, nr. 1, pg. 20, Ostersund Sweden.

Kort verslag van deelname aan de eerste International Conference Restoration Ecology and Sustainable development, 27-29 maart 1996, Zürich, Zwitserland.

Verslag van een bezoek aan de Graduate School of Design van de Harvard University van 24/27 april 1996. Hier werd een aantal colleges verzorgd over infrastructure and habitat fragmentation en een honorary/overview lecture over de betekenis van mitigerende en compenserende maatregelen voor het bereiken van no-net-loss of biodiversity voor de hele faculteit gehouden.

Environmentally friendly coasts; dune breaches and tidal inlets in the foredunes. Environmental engineering and coastal management. A case study from the Netherlands; in: Landscape and Urban Planning 34 (1966), pg. 197 - 213.

Kort verslag International Conference on Ecological Engineering van 7 - 11 oktober 1996 (ICEE’96), Beijing, China.

1997

Auto(snel)wegen en Ecologie, In: Infrastructurele Ontwikkelingen 1997 (co-author D.M. Teodorascu)

Preface (pg. 9 t/m 11) and Infra Eco Declaration (pg. 439 t/m 441) in Proceedings International Conference Habitat Fragmentation and Infrastructure 17-21 september 1995 (published in july 1997).

1998

Kort verslag deelname aan de 77ste Jaarlijkse Transportation Research Board Meeting 11-15 januari 1998 in Washington.

Kort verslag deelname Transportation Research Board Mid Year Workshop van 28-31 juli 1998 te Salt Lake City.

Infrastructuur en Meervoudig Ruimtegebruik; de weg naar integraal ruimtegebruik (co-author A.C. Maagdenberg). In: Infrastructurele Ontwikkelingen 1998.

1999

Kort verslag deelname aan de 78ste Jaarlijkse vergadering van de Transportation Research Board 10-14 januari 1997 in Washington.

Kort verslag deelname 42ste Jaarlijkse Symposium van de International Association of Vegetation Science, 26-30 juli 1999 te Bilbao (Spanje).

Verslag 11e International Conferentie van de Society for Ecological Restoration te San Fransisco (co-author P. Duijn).

Binnendoor en Buitenom (Boekbespreking) in: Midden-Delfkrant, 23e jaargang, nr.1, p.11.

2000

Kort verslag deelname aan de 79ste Jaarlijkse vergadering van de Transportation Research Board 9-14 januari 2000 te Washington.

Kort verslag EcoSummit 2000 van 18-22 juni 2000 te Halifax.

2001

Hoofdstuk Sustainable road infrastructure in: Sustainable Construction (Prof. Dr. Ir. Ch.F. Hendriks, co-authors: H.D. van Bohemen. B.J.H. te Dorsthorst, A.J. Dijkstra, E.P.H. van Keeken, H.S. Pietersen and J.Voglaender) uitgave van Aeneas Technical Publishers.

Discussienotitie ten behoeve van een nadere invulling en concretesering van het "Referentiekader voor de Standing Committee Natuur en Milieu; tevens als bijdrage aan de notitie 'Kansen voor Natuur en Milieu in lopende Habiform projecten', 27 april 2001.

Kort verslag deelname aan het 44th symposium van de Internationale Vegetatiekundige Vereniging van 29 juli - 4 augustus 2001 te Freising-Weihenstephan (Duitsland).

Paden in Midden-Delfland; Verslag van een studiemiddag op 2 november 2000, in: Midden-Delfkrant, 25e jg., p. 17-21.

Vlinders in de Broekpolder (Boekbespreking), in: Midden-Deflkrant, 25e jg., nr. 1, pg. 10-12.

2002

Een bezoekerscentrum in Midden-Delfland, in: Midden-Delfkrant, 26e jg. no. 4, pg. 30-32.

Kort verslag deelname aan 8e Internationale Ecologen Congres (Intecol) van 11-18 augustus 2002 te Seoul.

Kort verslag deelname 5e Internationale Eco-city Conferentie in Shenzhen (China 19-23 augustus 2002).

"Eerst chaos maken" ; Ecological engineering doorbreekt traditionale denkpatronen, in: DWW Projector Jubileumeditie 75 jaar Dienst Weg- en Waterbouwkunde.

2003

Kort verslag deelname 82nd Annual Meeting of the Transportation Research Board (TRB), 12-16 January 2003 te Washington D.C.

Ecological engineering and road infrastructure, collegedictaat onderdeel ecological engineering CT4100 MSc course Materials and ecological engineering 2003/2003, TUD/Faculteit Civiele Techniek en Geowetenschappen/Sectie Civieltechnische Materiaalkunde.

The influence of Road Intrastructure and Traffic on Soil, Water, and Air Quality, in: Environmental Management, Vol. 31, no. 1, pp.50-68 (co-author: W.H. Janssen van de Laak).

Kort verslag deelname 46ste Symposium van de Internationale Vegetatiekundige Vereniging "Water Resources and Vegetation", juni 2003, te Napels.

De Ecologische kwaliteit in Midden-Delfland, in: Midden-Delfkrant, no. 109, april 2003, pg. 15-22.

Gedurende de periode werkzaam bij de Natuurwetenschappelijke Commissie van de Natuurbeschermingsraad van 1975 tot 1987 heeft H.D. van Bohemen, als wetenschappelijk medewerker/adj.secretaris de onderstaande concept-adviezen samengesteld en na toetsing door de commissie de definitieve tekst geconcipieerd en in overleg met voorzitter en secretaris van de commissie vastgesteld:

1975

NWC-advies Ruilverkaveling Bathmen (Ov.).

NWC-advies Ruilverkaveling Haaksbergen (Ov.).

Notitie A-2 werk ter verbetering van de afwatering Polderdirstrict Arkemheen.

Notitie A-2 werk ter verbetering van de afwatering van het Schaarsbeekgebied (Ov.).

1976

Advies aan de Dienst der Domeinen over aanleg ruiterpad op Schiermonnikoog.

NWC-advies Ruilverkaveling Winterswijk-West (Geld.).

1977

NWC-advies Waterland (N.H.).

NWC-advies ruilverkaveling Midden-Opsterland (Fr.).

NWC-advies Eemland (N.H.).

Aanvullend NWC-advies Ruilverkaveling Leeuwarderadeel (Fr.).

Nota m.b.t. de aangevraagde ruilverkaveling Baarle-Nassau op basis van recent verzamelde inventarisatiegegevens.

NWC-advies Demmerikse Polder (Utr.).

1978

Notitie beheer krijthellinggraslanden van het Gerendal.

NWC-advies aan de Dienst der Domeinen over de camping in de duinen van Katwijk.

NWC-advies aan de Dienst der Domeinen over het beheer van het landgoed Zorgvliet te ‘sGravenhage.

Notitie n.a.v. het Schetsontwerp van de Landinrichting Waterland.

NWC-advies ruilverkaveling Limmen-Heiloo (N.H.).

NWC-advies Polder Katwoude (onderdeel van het landinrichtingsgebied Waterland).

NWC-advies betreffende de deelgebieden Wijde en Enge Wormer, Wormer- en Jisperveld en Polder Oostzaan van het landinrichtingsgebied Waterland.

NWC-advies aan de Dienst der Domeinen betreffende het Duinterrein tussen Katwijk en Noordwijk (Z.H.).

Kort verslag van het 2e internationale oecologische congres te Jerusalem Israël.

NWC-advies Reconstructiegebied Midden-Delfland (Z.H.).

1979

NWC-advies betreffende de ruilverkavelingsaanvrage De Hilver (N.Br.).

NWC-advies betreffende de ruilverkavelingsaanvrage Rossum-Oost (Ov.).

NWC-advies Baarle-Nassau en Alphen en Riel (N.Br.).

NWC-advies ruilverkaveling Sorremorre (Fr.).

1980

NWC-reaktie op de ontwerp-structuurschets Reconstructie Midden-Delfland.

Rapport Bufferzones ter regulatie van de waterhuishouding van natuurgebieden bij cultuurtechnische ingrepen (als secretaris van de Werkgroep Waterstandnormen van de NWC).

Lijst en toelichtende tekst van gewenste hydrologische gegevens t.b.v. natuur en landschap in landinrichtingsprojecten.

NWC-advies ruilverkaveling Reek (N.Br.).

NWC-advies aan de Natuurbeschermingsraad betreffende de situatie van natuurgebieden op Ameland.

NWC-advies aan de Dienst der Domeinen betreffende de Heide van Terlet (G.).

Notitie t.b.v. NWC-bezoek Grevelingen.

Botanische bijdragen aan verslag excursie van het NWC-secretariaat naar enkele natuurgebieden langs de Donau en de March, Oostenrijk.

NWC-advies aan de Dienst der Domeinen betreffende het beheer van natuurterreinen winterbed Boven-Merwede onder Woudrichem.

1981

NWC-advies betreffende de ruilverkaveling Zundert (N.Br.).

NWC-advies betreffende de ruilverkaveling Moersche Heide (N.Br.) (co-author H. Boeschoten).

NWC-advies betreffende de Grevelingen.

NWC-advies aan de Dienst der Domeinen betreffende het Duinterrein tussen Katwijk en Noordwijk (Z.H.).

NWC-advies aan de Dienst der Domeinen betreffende de Sleeuwijkerwaard.

NWC-advies betreffende de kustafslag van Texel.

1982

NWC-advies aan de Rijksplanologische Dienst betreffende concept-Voorontwerp Programma Reconstructie Midden-Delfland.

Rapport betreffende de berging van baggerspecie uit het Rijnmondgebied t.b.v. een door de Natuurbeschermingsraad uit te brengen advies.

Notitie t.b.v. NWC-bezoek aan een aantal natuurterreinen in Zuid-Limburg.

1983

Reactie op concept-rapport van de Werkgroep terrestrische milieu-aspecten onderzoek haalbaarheid kustuitbreiding Zuid-Holland

NWC-advies betreffende de staatsnatuurreservaten en andere natuurgebieden op Vlieland.

NWC-advies aan de Dienst der Domeinen betreffende het landgoed Zorgvliet (Z.H.).

NWC-advies betreffende het duinterrein tussen Katwijk en Noordwijk (Z.H.).

NWC-advies betreffende het Ontwerp-Programma Reconstructie Midden-Delfland.

1984

Notitie betreffende het onderzoek naar de mogelijkheden van kustuitbreiding tussen Hoek van Holland en Scheveningen t.b.v. de Natuurbeschermingsraad.

NWC-advies aan de Natuurbeschermingsraad betreffende aanvraag vergunning ex. art. 12 en 13 natuurbeschermingswet Mispeleindse en Netelse Heide met aangrenzende beekdalen.

NWC-advies t.b.v. de Natuurbeschermingsraad betreffende de Verlengde poot van Metz (RW 69) (mede auteur A.A.M. van Marrewijk).

NWC-advies betreffende de gebieden Castelré en Chaamse beken.

Bijdrage aan verslag van een excursie naar East-Anglia en de Fenlands met de bureaumedewerkers van de NWC.

1985

NWC-advies aan de Natuurbeschermingsraad betreffende Beheersvisie Kievitsbloemterreinen (gem. Hasselt en gem. Zwolle).

1986

NWC-advies aan de Dienst der Domeinen betreffende de Uiterwaarden Wageningen.

NWC-advies aan de Directeur van het Staatsbosbeheer betreffende Natuurgebieden Ameland.

NWC-advies aan de Directeur Natuur, Milieu en Faunabeheer van het Ministerie van Landbouw, Natuur en Visserij betreffende de Brunssumerheide (gem. Onderbanken) m.n. betreffende het gebied van het zgn. Zweef-vliegveld e.o.

NWC-advies aan de Directeur Natuur, Milieu en Faunabeheer van het Ministerie van Landbouw, Natuur en Visserij betreffende het Hijkerveld-landgoed Hooghalen (Dr.).

Bijdrage aan NWC-advies Herinrichting Krimpenerwaard.

Bijdrage als secretaris van de Werkgroep lagere planten aan het advies van de Natuur-beschermingsraad over een beschermingsbeleid voor lagere plantesoorten (Paddestoelen, mossen en korstmossen).