1.31

The Netherlands

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1.31.1 INTRODUCTION

Soil erosion by water and wind occurs in The Netherlands (Figure 1.31.1). However, soil erosion is not a problem on a national scale. The total surface area of The Netherlands is 41 500 km^2, of which 23 500 km^2 was agricultural land in 1996 (Statistics Netherlands). The greater part of the country is flat or almost flat land. Soil erosion by water only occurs on 40 000 ha of loess soils in the region of South-Limbourg, which has a hilly topography. Wind erosion is more widespread than water erosion. Eppink (1982) mentions that wind erosion occurs on 97 000 ha of agricultural land in The Netherlands, of which 75 000 ha is seriously affected.

1.31.2 WIND EROSION

Wind erosion is an active process in The Netherlands (Knottnerus, 1979; Eppink, 1982; Eppink and Spaan, 1989). It occurs on (a) the beaches and coastal dunes along 250 km of sandy North Sea coast, (b) part of the sandy arable soils behind the coastal dunes, (c) arable cut-over raised peat bog soils with a sandy subsoil in the provinces of Groningen and Drente in the north-eastern part of the country, (d) sandy arable soils in the

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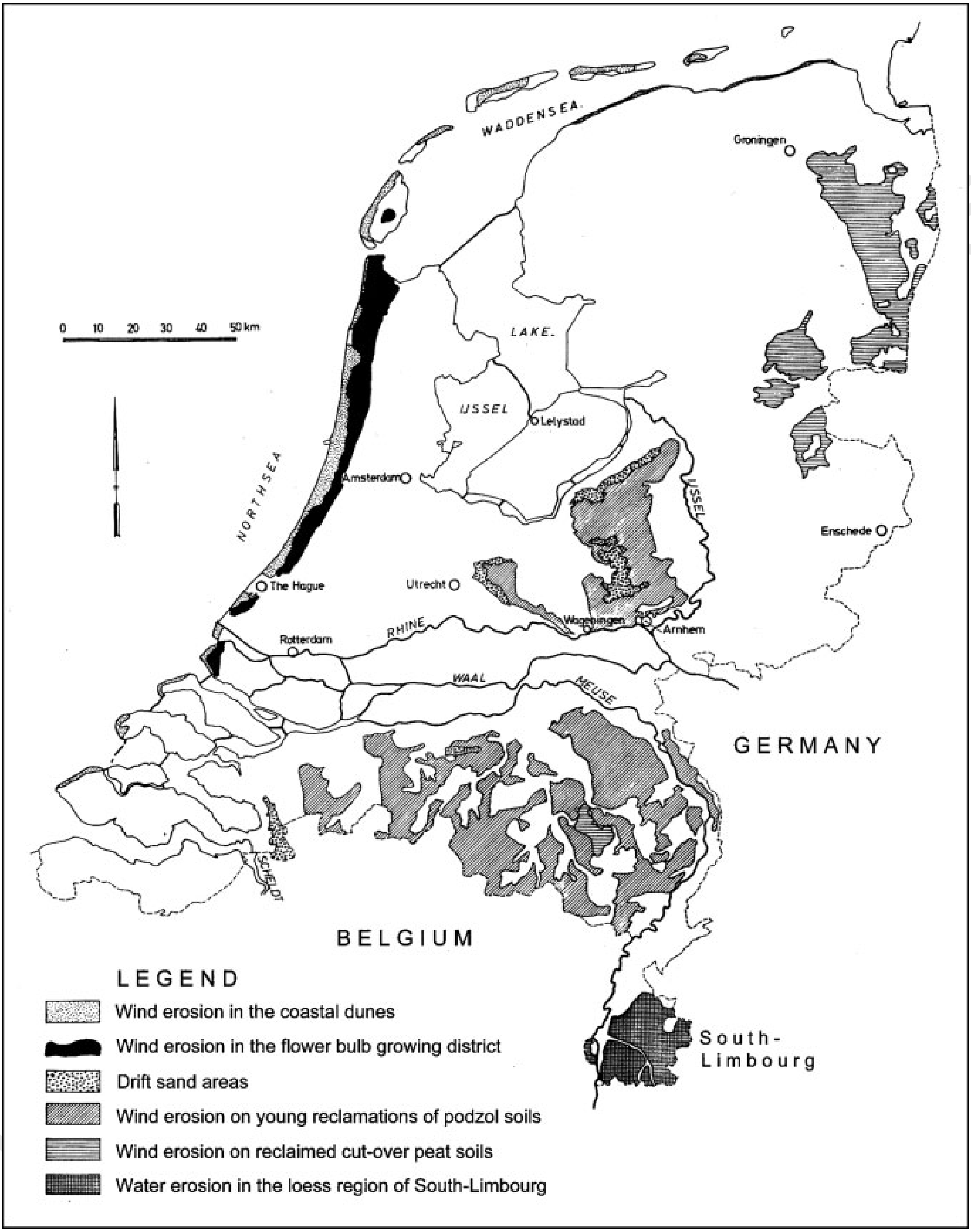

Figure 1.31.1 Erosion hazard map of the Netherlands. [Reproduced from Eppink LAAJ, Spaan WP, Agricultural wind erosion measure in The Netherlands. In *Soil Protection Measures in Europe*, Schwetmann U, Rickson RJ, Auerswald K (eds), Soil Technology Series 1, 1989; 1–13, by permission of Catena Verlag]

province of North-Brabant and along the river Meuse in the province of Limbourg in the south of the country and (e) in aeolian drift sand areas in the centre and north-eastern part of the country (Koster, 1978; Castel, 1991).

Wind erosion along the Dutch North Sea coast has been studied fairly extensively over the past 20 years, with a view to arriving at sound management practices of the coastal zone (Van Bohemen, 1990). Examples of subjects of study in the coastal zone are the development of blowouts in the coastal dunes (Jungerius *et al.*, 1981; Van den Ancker *et al.*, 1985; Pluis, 1993), the testing of an acoustic sediment sensor (Spaan *et al.*, 1991), the sand budget of the foredunes (Arens, 1994), the aeolian transport of beach nourishment sand (Van der Wal, 1999) and the modelling of air flow and sand transport across transverse dunes (Van Boxel *et al.*, 1999; Van Dijk *et al.*, 1999). A main issue in coastal management is stabilization versus so-called 'dynamic' or 'integrated' management of the coastal zone, coastal defence and safety being only one of the management aims. However, as sea beaches and coastal dunes are outside the scope of the present book, they will not be discussed further in this chapter.

In spite of the relatively widespread occurrence of wind erosion on arable land in The Netherlands, little scientific study has been devoted to it, in contrast to water erosion (Eppink and Spaan, 1989; Riksen and De Graaff, 2001). According to Brussel (1980), quoted by Eppink and Spaan (1989), wind erosion occurs on 4–5 days per year every 3–4 years, and on 10 days per year every 15 years. Short-term wind erosion damage to crops was estimated by Eppink (1982) at €9 million €100 ha^{-1} yr^{-1}. This does not include the cost of cleaning roads and ditches and the long-term loss of topsoil and soil productivity. Quantitative data on soil losses by wind erosion on arable land are lacking. According to Eppink and Spaan (1989), measures to combat wind erosion in 1989 comprised the application of straw cover, winter cover crops, grasses, natural soil stabilizers (feed lot manure, manure slurry) and the use of plastic foil.

1.31.3 SOIL EROSION BY WATER

Soil erosion by water is restricted to the region of South-Limbourg in the south of the country, where land use has been mainly agricultural since 1300 AD (Renes, 1988).

Long-term evidence of erosion in South-Limbourg includes truncation of soil profiles, the occurrence of (sub)recent colluvial deposits and the widespread presence of so-called 'lynchets', which are ascribed to deposition of colluvium behind hedgerows on slopes. In 1910, 200 km of lynchets were present in the area. As evidenced by soil profile truncation, the long-term average rate of surface lowering by soil erosion has been of the order of 1 mm yr^{-1} or 15 t ha^{-1} yr^{-1} since the Middle Ages (Bouten *et al.*, 1985). On slopes of 2–8 %, the original A-horizon is removed by erosion. On slopes >8 %, the B-horizon is also removed.

The frequency of occurrence of soil erosion events has increased since the 1970s (Schouten *et al.*, 1985; Schouten and Rang, 1987; Van der Helm, 1988). Soil erosion events with associated off-site effects of flooding and siltation are reported from various sites in South-Limbourg almost every year now. The main forms of damage are (a) (ephemeral) gullying of arable fields and (b) flooding and deposition of mud on arable fields in dry valley bottoms, on roads, in roadside ditches, in culverts and sewers, in the gardens, basements and cellars of houses and in the streets of built-up and residential areas. These are short-term effects that require re-sowing and immediate clean-up action. In a cost–benefit analysis of soil conservation measures in South-Limbourg, Van Eck *et al.* (1995) estimated the cost of the off-site effects at €1.2 million annually. However, no detailed knowledge of the damage of soil erosion and related off-site effects is available for the region. Demands to mitigate erosion mainly come from outside agriculture.

The increased frequency of soil erosion events in recent decades is ascribed to rationalization of agriculture (e.g. increased field size by re-allotment of land) and the increased acreage of row crops, especially silage maize. At the same time, the surface area of erodible land (= farmland) has decreased significantly. An erosive effect is also ascribed by some to the increased surface area of built-up land and increased number of paved roads in rural parts of the region, no infiltration of rain water being possible on stone-covered surfaces.

1.31.3.1 Description of the Area

South-Limbourg is a fluvially dissected area of hilly relief, that is dominated by numerous dry valleys. It is part of the drainage basin of the River Meuse. Land surface elevations range from 40 to 321 m. The surface area of undulating terrain is 690 km^2. The centre of the region is at latitude 50° 54′ N and longitude 5° 51′ E. The dry valleys are Pleistocene periglacial relic forms and now act as drainage ways for surface runoff during high-magnitude/low-frequency rainfall events (Kwaad, 1993).

Loess covers 40 000 ha of the region (Van den Broek, 1966; Kuyl, 1980; Mücher, 1986). It overlies coarse-grained Quaternary fluviatile sediments, Tertiary sands and Cretaceous chalk. The thickness of the loess ranges Q2 from 2 to 20 m. The loess is mainly Weichselian and was deposited after the main phase of (dry) valley formation. South-Limburg is part of the European loess belt, which extends across south-east England, north-west France, Belgium, parts of Germany and into Poland and Russia.

Luvisols (FAO, 1989) formed in the loess during the Holocene (Stiboka, 1970). The loess soils are highly erodible, owing to their low structural stability and susceptibility to crusting (Kwaad and Mücher, 1994).

The climate of the area is temperate oceanic, with rainfall in all seasons and an annual average precipitation of 750 mm. High-intensity rainfall is restricted to the period April–October (Levert, 1954). The 30-min Q3 intensity that is exceeded once a year is 24 mm h^{-1} (Buishand and Velds, 1980). Erosion risk is highest in April–June, when the surface coverage by crops is small and high-intensity rainfall may occur. Prolonged wet weather and rapid snowmelt may cause surface runoff in winter.

1.31.3.2 History of Land Use in South-Limbourg

The natural vegetation of South-Limbourg in the Holocene before the impact of humans was deciduous forest (Janssen, 1960). A first period of deforestation and cultivation included Late Neolithic, Bronze Age, Iron Age and Roman times (1700 BC–300 AD). From about 300 until 1000 AD, forest regrowth took place. Then, medieval deforestation set in, and by 1300 AD the area was completely cultivated and has remained cultivated ever since.

Some data on the history of land use in South-Limbourg are as follows (Jansen, 1979; Philips *et al.*, 1965; Renes, 1988). By 1300, the area was fully cultivated. Over 90 % of the total land surface (69 000 ha) was agricultural land (62 000 ha), of which about 70 % was arable crop land (43 500 ha) and 30 % meadow land (18 500 ha). The dominant arable crops were small grains. Cattle were mainly kept for manuring the arable fields. Grasslands were mostly found in the wet valley bottoms along brooks and rivers. The land use situation remained more or less unchanged until around 1900, when the use of artificial fertilizers became common practice.

Land use in 1910, 1960 and 2002 is described in Table 1.31.1. Silage maize was introduced in the region in the 1970s.

Two contrasting effects on soil erosion of the changes in land use between 1910 and 2002 can be distinguished:

1. The 28 000 ha decrease in the area of agricultural land and the 24 000 ha decrease in arable crop land meant a decrease in the total surface of erodible and eroded land, or a decrease in the number of sites or locations where erosion (can) occur(s).
2. The shift from small grains to sugar beet and silage maize on arable land meant an increase in the rate of soil erosion per hectare of (remaining) arable crop land, or an increase in the frequency of occurrence of erosion events on arable crop land sites.

The effect on erosion of the 5750 ha decrease in grassland depended on whether the considered area of grass was turned into arable land or became part of the built-up surface (urban sprawl).

TABLE 1.31.1 Changes in land use (ha) in South-Limbourg

	1910	1960	2002	Increase/decrease
Total surface area	69000	69000	69000	0
Agriculture	60000	?	32000	−28000
Arable crop land	42700	22450	18700	−24000
Small grains	30300	15000	6800	−23500
Potatoes	5340	1900	1200	−4140
Sugarbeet	250	2150	4150	+3900
Silage maize	0	0	4150	+4150
Grass and orchards	17250	?	11500	−5750

From 1300 onwards, soil erosion will have occurred widely in South-Limbourg, albeit at a lower rate per hectare than nowadays, owing to the dominance of small grains, small fields and many lynchets. The frequency of occurrence of erosion events on arable land will have been lower in the past (1300–1960) than at present. Since 1910, the total surface area of erodible and eroded land has strongly decreased. At the same time, the rate of erosion per hectare of eroded land has increased, owing to a shift from small grains to row crops and to rationalization of agriculture (e.g. larger fields).

1.31.3.3 Erosion and Conservation Research in South-Limbourg

Early reports of soil erosion in South-Limbourg are scarce. Not until the late 1960s did publications begin to appear on the problem of soil erosion in South-Limbourg: Breteler and van den Broek (1968) on the formation of lynchets by sheetwash and deposition of colluvium behind hedgerows, Kierkels (1971) on the effect of re-allotment of land on erosion and Poelman (1971) on factors of soil erosion of loess soils. A decade later, the Landinrichtingsdienst (1983) published a first inventory of 153 flooding locations in South-Limbourg. Schouten et al. (1985) gave a first account of the extent, spatial distribution, rate, causes, damage and control of erosion and Van Eysden and Imeson (1985) of the erodibility of loess soils. Bouten et al. (1985) published an overview of the origin and erosion of loess soils. Van der Helm and Schouten (1986) presented a detailed inventory of 600 erosion sites. Schouten and Rang (1987) drew attention to the costs of soil erosion outside agriculture. Finally, the Provincie Limbourg (1987) gave soil erosion and conservation due consideration in the new regional plan for South-Limbourg.

Until 1985, few quantitative data on the rate of erosion and the cost of the damage were available for South-Limbourg. From the inventory of locations with soil erosion by Van der Helm and Schouten (1986) that covered the whole of South-Limbourg, it appeared that soil erosion and related flooding occur widely in the region. Schouten *et al.* (1985) gave some preliminary and tentative figures of the rate of erosion. They mentioned an average amount of 6.7 t ha^{-1} of displaced soil in rills and gullies during the winter of 1983–84 in 18 first-order catchments in a 1060-ha area (Ransdalerveld) where re-allotment of land had recently been carried out, and 3–30 t ha^{-1} of displaced soil in 6 months on some 30 arable field sites throughout South-Limbourg. The most recent data on the rate of erosion under row crops were collected during an experimental plot study from 1986 to 1993 (Kwaad, 1991; Kwaad *et al.*, 1998). Sediment output on a catchment level was measured during a field project from 1991 to 1994 (De Roo *et al.*, 1995; Van Dijk and Kwaad, 1996b). Q4

Immediately following the preliminary assessment of the extent of the erosion problem, research was undertaken in the period 1985–95 that was aimed at the development of measures and procedures to combat erosion. Different farming systems of silage maize and sugar beet were compared on Wischmeier plots, and small nested drainage basins were instrumented. Plot measurements were carried out under natural rainfall and with a large field rainfall simulator. A typical soil loss rate on 6 % and 22-m long plots under natural rainfall in

1987–89 was 16 t ha^{-1} yr^{-1} on fallow plots and 10.8 t ha^{-1} yr^{-1} under conventional maize cropping. This could be reduced to 1.7 t ha^{-1} yr^{-1} by direct drilling of maize in winter rye residue (Kwaad, 1994). During a Q5 comparative plot study of seven cropping systems of silage maize in 1992 and 1993 on 8 % and 22-m long plots, summer soil losses ranged from 0.2 to 4.8 t ha^{-1} and winter soil losses from 1.9 to 4.0 t ha^{-1}, both under natural rainfall. Autumn tillage reduced erosion in winter by 90 %, compared with untilled maize stubble. Applying a surface mulch of finely cut straw (3 t ha^{-1}) after maize sowing consistently gave the lowest soil loss in summer of the seven tested farming systems of silage maize (Kwaad *et al.*, 1998) (Table 1.31.2).

TABLE 1.31.2 Soil loss data from runoff plots, length 22 m, slope 8.5 %, natural rainfall, mean of three replications (g m^{-2})

Cropping system[a]	Winter 1991–92	Summer 1992	Winter 1992–93	Summer 1993
A	28.2	28.7	37.6	147.8
B	58.4	57.5	25.4	292.9
C	19.0	61.6	26.7	127.5
D	79.9	484.8	44.8	300.7
E	34.6	26.6	25.2	110.8
F	405.9	23.6	347.8	20.9
G	84.0	209.1	16.5	179.7

[a]By combining the use of winter rye as a winter cover crop with various times and types of soil tillage, seven cropping systems of fodder maize were devised (Geelen *et al.*, 1996), which were compared in triplicate on 21 plots. Continuous cultivation of maize was applied in all cropping systems for the duration of the plot study (4 years). The cropping systems can be described as follows:

System A: Ploughing, seedbed preparation and drilling of winter rye in October/November after previous maize harvest. Drilling of maize without any form of spring soil tillage in chemically killed winter rye residue in early May (direct drilling).

System B: Ploughing, seedbed preparation and drilling of winter rye in October/November. Maize sown in killed winter rye residue after spring tillage with a Howard paraplough. With this implement, the topsoil is cut loose from the subsoil without disturbing it. The soil is not inverted but lifted by pulling the plough knife through the soil at 25–30 cm depth.

System C: Ploughing, seedbed preparation and drilling of winter rye in October/November. Maize sown in superficially mulched (5 cm deep) winter rye residue.

System D: Only autumn soil tillage (ploughing). No winter cover crop. Direct drilling of maize in spring.

System E: Ploughing, seedbed preparation and drilling of winter rye in October/November. Maize sown in strip tilled winter rye residue. In spring a strip 6 cm wide and 8 cm deep was tilled which was used for sowing. In this way, only 8 % of the total surface area was tilled. Only in the row was a seedbed prepared. A Gaspardo machine was used for the combined tillage and maize sowing operation.

System F: No autumn tillage and no winter cover crop. Maize stubble field in winter. Conventional spring tillage (ploughing and rotary harrowing). Surface mulch of finely cut straw (3 t ha^{-1}) applied after sowing of maize.

System G (reference system): Loosening of maize stubble field in autumn with a cultivator. No winter cover crop. Maize sown after conventional spring tillage (ploughing and rotary harrowing). Since 1990 this is the usual system of maize cultivation in the region. Until 1990, it was usual to leave land untilled during winter under continuous maize growing (i.e. the winter condition of system F). During the trial phase of the development of a maize conservation cropping system autumn tillage greatly decreased winter runoff and erosion (Kwaad, 1994). Therefore, since 1990, local farmers are obliged to carry out autumn tillage on maize fields.

TABLE 1.31.3 Catchment data: rainfall, runoff and sediment output for catchment St Gillistraat 2 (4.8 ha)

Date	Rainfall (mm)	Runoff (m^3)	Sediment output ($t\,ha^{-1}$)
5 June 1992	19.8	5.9	0.087
4 July	5.8	3.6	0.031
5 July	6.2	5.4	0.031
5 July	6.8	11.1	0.061
17 July	7.4	2.9	0.004
13 August	22.6	1.1	0.001
22 November	4.4	24.9	0.035
2 December	8.4	98.3	0.720
11 December	18.4	213.0	0.149
13 January 1993	4.0	24.0	0.128
22 January	11.6	528.3	5.829

Research was also aimed at identifying the mechanism(s) of overland flow generation. In South-Limbourg, Hortonian overland flow, due to surface slaking, crusting and sealing of the structurally unstable loess soils, is generally considered as the prime cause of soil erosion. In the course of the work, however, overland flow was also observed under conditions of low-intensity rainfall. Using various types of evidence, Kwaad (1991, 1993, 1998) and Van Dijk and Kwaad (1996) convincingly showed the occurrence of saturation overland flow in the region. In Table 1.31.3 some results on a storm by storm basis in the St. Gillistraat-2 catchment (4.8 ha) are given. An important erosion event in that catchment occurred on 22 January 1993. During a 10.8-mm storm in 83 min, a runoff percentage of 84.3 % and a sediment output of 28 t or 5.8 $t\,ha^{-1}$ were measured. The return period of the maximum 5-min intensity (52.8 $mm\,h^{-1}$) of that storm was 4.6 years and that of the maximum rainfall amount in 60 min was 1.8 years (Van Dijk and Kwaad, 1996). Q6

Outcomes of research for soil conservation in practice were (a) the formulation of conservation cropping systems of row crops, including silage maize, and (b) the Limbourg Soil Erosion Model (LISEM).

Based on the outcomes of research, a conservation ordinance was issued in 1990, which farmers in the region are obliged to observe. This and other regulations are still in the process of amendment by various authorities today (see below).

1.31.3.4 LISEM: Limburg Soil Erosion Model

LISEM is a physically based runoff and erosion model for research, planning and conservation purposes. LISEM simulates runoff and sediment transport in catchments caused by individual rainfall events. The model uses and produces maps based on the freeware GIS PCRaster. The department of Physical Geography of the University of Utrecht and the Soil Physics Division of the Winand Staring Centre in Wageningen cooperated in the development of this model, assisted by experimental field work of the University of Amsterdam and the Limburg Waterboard (De Roo *et al.*, 1995).

Processes incorporated in the model (Figure 1.31.2) are rainfall, interception, surface storage in micro-depressions, infiltration, vertical movement of water in the soil, overland flow, channel flow, detachment by rainfall and throughfall, detachment by overland flow and transport capacity of the flow. For a detailed description of the processes incorporated in the model the reader is referred to De Roo *et al.* (1996a), Jetten and De Roo (2001) and the website http://www.geog.uu.nl/lisem. LISEM can be applied on small fields and in catchments of up to 10 km^2 using time steps of 5–60 s. A sensitivity analysis and validation are presented in

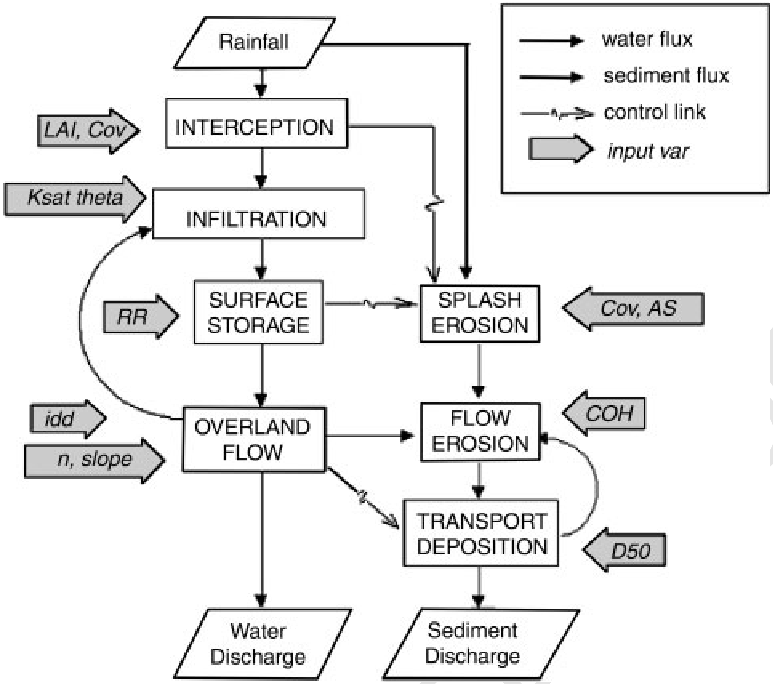

Figure 1.31.2 Flowchart of LISEM. The left-hand column shows the hydrological processes, and the right-hand side the erosion processes calculated per grid cell. Main variables: *LAI* = leaf area index; *Cov* = ground cover; *Ksat* = hydraulic conductivity; *theta* = initial moisture; *RR* = random roughnes; *n* = Manning's *n*; *AS* = aggregate stability; COH = cohesion; *D50* = particle size

De Roo *et al.* (1996b) and Jetten *et al.* (1998). Major conclusions are that the quantitative results of the model are strongly influenced by the knowledge of the spatial and temporal variability of soil moisture content and hydraulic conductivity in the catchment. Examples of use and details on the spatial prediction strength of the model can be found in De Roo (1996), Takken *et al.* (1999) and Jetten *et al.* (2003).

During the LISEM project, all land use types present in the area have been monitored: grassland, winter wheat, winter barley, sugar beet, potatoes and maize. On special trial fields, the influence of 'mulching' and direct sowing has been measured. Variables included in the monitoring were soil cover by vegetation, leaf area index, crop height, random roughness, soil physical parameters, soil texture, aggregate stability and soil cohesion. Thus, a large database has been created on the monthly variation of these variables.

Particular attention is paid in the model to agricultural features: drainage by tillage direction, influence of tractor wheelings, small paved roads, ditches, grass strips and grassed waterways. Because LISEM was designed to model the effect of field level conservation measures such as grass strips, mulch application and changes in crop rotation, one of its more advanced features is the ability to cope with gridcells that consist of different surface types. For each surface type (a particular crop, compacted wheeltracks or crusted parts) a parallel Richards infiltration system is used. The differences in infiltration in a gridcell produce a weighted average of surface water available for runoff. The surface roughness also plays a large role: it determines not only the surface storage but also the hydraulic radius. Current developments in LISEM are the simulation of runoff losses of nitrogen and phosphorus in solution and suspension and the incision and development of ephemeral gullies (Jetten *et al.*, in press).

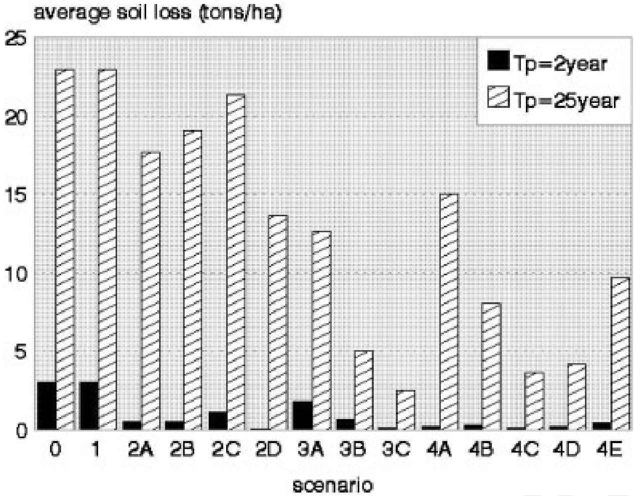

Figure 1.31.3 Effects of 14 scenarios on total event soil loss in the St Gillisstraat drainage basin (Ransdaal, The Netherlands, size 40 ha) for summer storms (20-min duration) with return periods of 2 and 25 years. Scenario 0 is the actual land use in 1990; scenario 1 is the land use in 1993; scenarios 2 are different tillage techniques; scenarios 3 are conservation measures such as field buffer strips and grassed waterways; scenarios 4 are combinations of 2 and 3. Tp = return period

The agricultural features play a large role in Limburg: in certain seasons more than 25 % of the area of agricultural fields consists of compacted wheel tracks with a low infiltration capacity, whereas paved roads make up 2–3 % of the surface area. Moreover, these tracks may influence greatly the connectivity in a catchment. During the LISEM project, it was estimated that roads and wheeltracks may be responsible for 10–25 % of the runoff in a catchment.

LISEM was used to calculate a number of land-use scenarios using summer and winter design storms of 2 and 25 years recurrence time (Figure 1.31.3). The scenarios encompassed different degrees of conservation measures: mulching, cover crops in winter and the application of grass strips on fields with certain slope angles. The results of the scenarios are still used in the present day analysis.

Currently, LISEM is used on a regular basis by the Waterboard to simulate the effect of changes in land use, the application of conservation measures or the design of water retention buffers. Since LISEM produces raster maps with the spatial distribution of erosion and deposition patterns, the effect of different within-field conservation methods can be compared (Figures 1.31.4 and 1.31.5). The south of Limburg is at present (2003) undergoing a major land reallocation operation and the local government is constructing more than 200 water buffers for water and sediment retention. The buffers have a slow-release system and are designed in such a way that they will be filled up in one 25-year event and empty in 24–48 h to the nearest ditch or waterway. At the same time, the government is trying to introduce field-level conservation measures (such as grass strips), for which an elaborate point system is constructed in cooperation with the farmers.

1.31.3.5 Policy and Regulations to Combat Erosion

The objective of soil conservation in South-Limbourg, as elsewhere, is to reduce soil loss and related damage to ‘a level that is acceptable to society’. No soil loss tolerance is specified for the region in terms of an acceptable average long-term rate of soil loss in t ha^{-1} yr^{-1}. Instead, recurrence intervals of 10 years (for rural

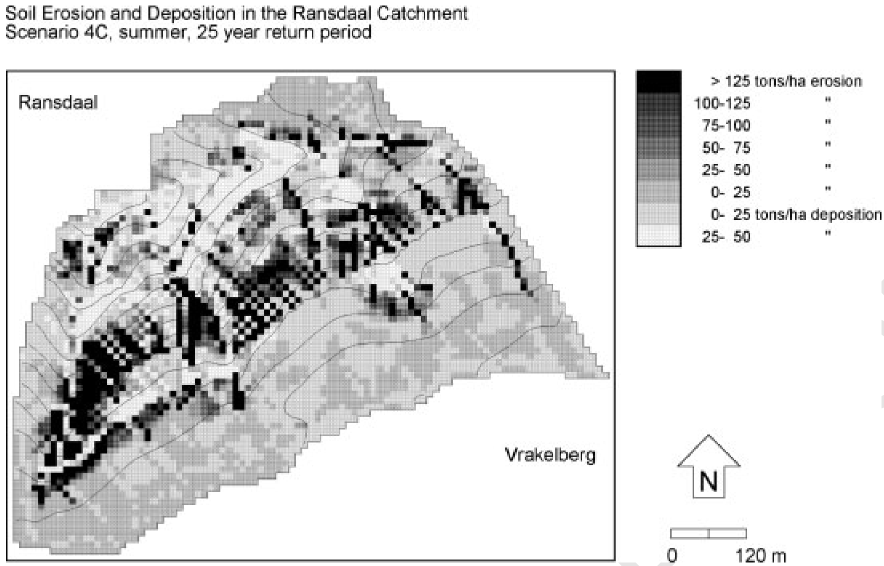

Figure 1.31.4 Soil erosion and deposition in the St Gillisstraat drainage basin (Ransdaal, The Netherlands) for a scenario with field buffer strips and grassed waterways

areas) and 25 years (for residential or built-up areas) are mentioned for erosion events that should be effectively prevented. This includes the cumulative damage of all smaller and more frequent events than once in 10 or 25 years. Farmers consider it their responsibility and obligation to provide a level of protection on their land that is equal to the protection that is provided by small grain, e.g. winter wheat. The farming

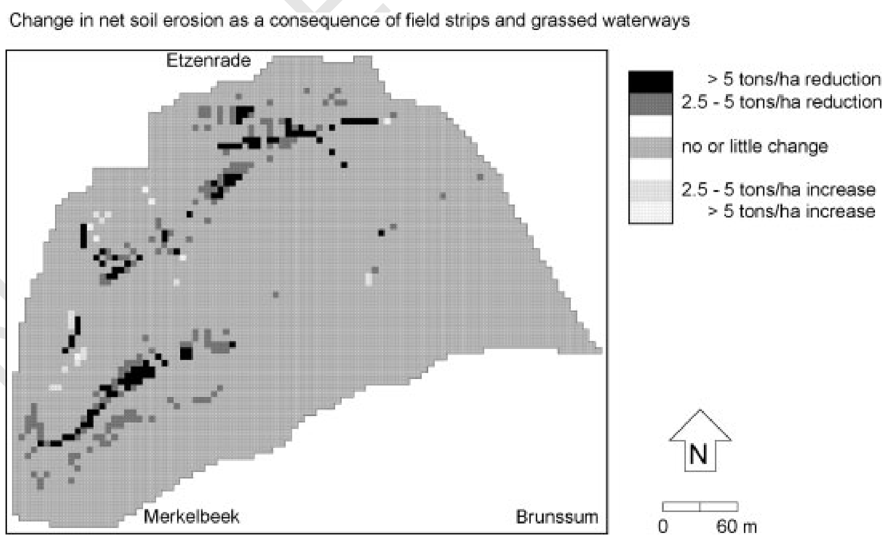

Figure 1.31.5 Change of net erosion as a consequence of one of the land-use scenario in Figure 1.31.3 compared with the actual land use of 1993

community feels that it cannot be held responsible for damage that occurs in spite of conservation measures having been taken by them that provide a level of protection similar to that of small grain. They consider such damage a calamity that exceeds a conservation effort that can be reasonably expected from them. The level of protection offered by small grain is now the goal of farm conservation plans (see below).

In 1990, a first conservation ordinance was issued in South-Limbourg, in which generic land-use measures were specified to be followed by all farmers in the region. In later years, the ordinance of 1990 proved not effective enough and was revised several times. As of 1 July 2003, the latest revision is in force. On a higher level, additional measures are taken by the municipalities and the Waterboard. Moreover, a site-specific approach was introduced to complement the generic approach. Soil conservation in South-Limbourg is now characterized by (a) a multi-level approach (farmers and municipalities) and (b) the application of generic measures and site-specific measures. Site-specific measures apply both to individual farms and to certain locations in the landscape where erosion and flooding constitute a recurring problem. Actors that must carry out the conservation work are the farmers, the municipalities and the Waterboard. Soil conservation must also be given due consideration in plans for spatially rearranging parts of the region (re-allottment of land).

Ideally, the implementation of conservation measures should be preceded by and based on a cost–benefit analysis. A rigorous cost–benefit analysis, however, is hampered in most cases by a lack of sufficient 'hard' data on the cost of short- and long-term, on- and off-site damage of soil erosion. A slightly different approach to conservation planning, that is followed in South-Limbourg, is to specify a certain return period of events that must be prevented (e.g. 10 or 25 years), and to model the erosion of the 10- or 25-year storm under different land-use scenarios with LISEM, without exactly knowing the cost of the damage of the 10- or 25-year event. Kraak and Van Oorschot (1998) solved the problem of not having sufficient knowledge of the on- and off-site damage of soil erosion as follows. They introduced the cost-effectiveness of a conservation measure, which is defined as the annual cost of the measure per ton reduction of modelled soil loss from a catchment during the 25-year storm. The modelled soil loss reduction is a surrogate variable or index for the cost of the damage that would occur if the measure is not taken. Kraak and Van Oorschot (1998) placed the break-even point between costs and benefits at €140 per ton reduction of modelled soil loss. They advise against measures that cost more than that. It should be remembered in this context that land-use scenarios, which provide sufficient protection against the 25-year event, also curb the (cumulative) damage of all smaller and more frequent events than those that occur once in 25 years.

The main points of the 'Conservation Ordinance' that all farmers in the region are obliged to follow are as follows:

- to perform a post-harvest tillage operation to a depth of 20 cm or more;
- to remove or erase tractor wheelings after the sowing of silage maize or sugar beet, unless direct drilling is used;
- to apply a green manure crop after the harvest of maize or small grain, unless sufficient straw remains on the field that is not worked into the soil by post-harvest tillage;
- to construct a water-retaining barrier of at least 3 m width at the lower end of fields with erodible crops;
- on slopes of 2–5 %, to restrict the field length of an erodible crop to 400 m, or apply one of the techniques of direct sowing, mulch sowing or straw cover after sowing;
- on slopes of 5–18 %, to restrict the field length of an erodible crop to 300 m, or apply one of the techniques of direct sowing, mulch sowing or straw cover after sowing;
- on slopes >18 %, only grassland is allowed.

Instead of applying these generic measures, individual farmers are allowed to draft a conservation plan that is geared to the specific conditions on their farm. An individual farmer múst make a conservation plan for their farm when they want to convert existing grassland that is located in a 'problem area', into arable land.

‘Problem areas’ are areas with recurring erosion damage that are designated as such by the authorities. Because grass provides the maximum attainable level of protection against erosion, the maintenance or introduction of grassland at strategic points in the landscape is considered an important instrument of soil conservation in the region, especially in a 100-m zone upslope of residential areas and roads. Judgement of the effectiveness of individual farm plans is based on a point scoring system. A detailed list of conservation measures with scores is presented to the farmers to choose from. A score of at least 40 points per hectare should be made. This corresponds to 80 % of the level of protection that is provided by winter wheat (50 points per hectare). Base reference of the scoring system is permanent grass land (100 points per hectare). For fields within 100 m upslope of buildings and roads, a score of 100 points per hectare must be attained.

Municipalities and the Waterboard are responsible for the maintenance and/or construction of (a) linear elements in the landscape (lynchets, grass buffer strips), (b) grassed waterways, (c) grass berms along roads and (d) retention basins for water and sediment.

In addition to the application of generic measures by all farmers in the region and conservation plans for individual farms, site-specific measures are devised for locations where soil erosion and related damage (flooding, deposition of mud) are known to constitute a recurring problem from year to year. The measures for these acknowledged problem areas or erosion hot spots are carried out by the water board and the involved municipalities and farmers (concerted action).

REFERENCES

Arens SM. 1994. Aeolian processes in the Dutch foredunes. PhD Thesis, University of Amsterdam.

Bouten W, Van Eijsden G, Imeson AC, Kwaad FJPM, Mücher HJ, Tiktak A. 1985. Ontstaan en erosie van de lössleemgronden in Zuid-Limburg. *Geografisch Tijdschrift* **19**: 192–208.

Breteler HGM, Van den Broek JMM. 1968. Graften in Zuid-Limburg. *Boor en Spade* **16**: 119–130.

Castel IY. 1991. Late Holocene eolian drift sands in Drenthe (The Netherlands). PhD Thesis, Utrecht University.

De Roo APJ. 1996. Validation problems of hydrologic and soil erosion catchment models: examples from a Dutch erosion project. In *Advances in Hillslope Processes*, Anderson MG, Brooks S (eds). John Wiley & Sons, Ltd, Chicheste; 669–683.

Q8 De Roo APJ, Jetten VG. 1999. Calibrating and Validating the LISEM model for two data sets from the Netherlands and South Africa. *Catena* **37**: 477–493.

De Roo APJ, Van Dijk PM, Ritsema CJ, Cremers NHDT, Stolte J, Oostindie K, Offermans RJE, Kwaad FJPM, Verzandvoort MA. 1995. *Erosienormeringsonderzoek Zuid-Limburg. Veld- en Simulatiestudie.* Rapport 364.1. DLO Staring Centrum, Wageningen.

De Roo APJ, Wesseling CG, Ritsema CJ. 1996a. LISEM: a single event physically-based hydrologic and soil erosion model for drainage basins. I: Theory, input and output. *Hydrological Processes* **10**: 1107–1117.

De Roo APJ, Offermans RJE, Cremers NHDT. 1996b. LISEM: a single event physically-based hydrologic and soil erosion model for drainage basins. II: Sensitivity analysis, validation and application. *Hydrological Processes* **10**: 1119–1126.

Q9 Eppink LAAJ. 1982. *A survey of wind and water erosion in The Netherlands and an inventory of Dutch erosion research.* Florence, 19–21 October, 1982.

Eppink LAAJ. 1986. Water erosion in The Netherlands: damage and farmers’ attitude. In *Soil Erosion in the European Community: Impact of Changing Agriculture*, Chisci G, Morgan RPC (eds). Balkema, Rotterdam; 173–182.

Q10 Eppink LAAJ, Spaan WP. 1989. Agricultural wind erosion control measures in The Netherlands. In *Soil Protection Measures in Europe*, Schwertmann U, Rickson RJ, Auerswald K (eds). Soil Technology Series **1**; 1–13.

Geelen PMTM, Kwaad FJPM, van Mulligen EJ, Wansink AG, van der Zijp M, van den Berg W. 1996. *The Impact of Soil Tillage on Crop Yield, Runoff and Soil Loss Under Various Farming Systems of Maize and Sugarbeet on Loess Soils.* PAGV Lelystad, Verslag 211.

Jansen JCGM. 1979. *Landbouw en Economische Golfbeweging in Zuid-Limburg 1250–1800. Een Analyse van de Opbrengst van Tienden.* Maaslandse Monografieën 30. Van Gorcum, Assen.

Jetten V, De Roo APJ. 2001. Spatial Analysis of erosion conservation measures with LISEM. In *Landscape Erosion and Evolution Modeling*, Harmon R, Doe WW (eds). Kluwer Academic/Plenum, New York; 429–445.

Jetten V, De Roo A, Guérif J. 1998. Sensitivity of the model Lisem to variables related to agriculture. In *Modelling Soil Erosion by Water*, Boardman J, Favis-Mortlock D (eds). NATO ASI Series I 55. Springer, Berlin; 339–349.

Jetten V, Govers G, Hessel R. 2003. Erosion models: quality of spatial predictions. *Hydrological Processes* **17**: 887–900.

Q11 Jetten V, Poesen J, Nachtergaele J, van de Vlag D. In press. Spatial modelling of ephemeral gully incision, a combined empirical and physical approach. In *Soil Erosion and Sediment Redistribution in River Catchments*, Owens P, Collins A (eds). CAB International, Wallingford.

Q12 Jungerius PD, Van der Meulen F. 1989. The development of dune blowouts, as measured with erosion pins and sequential air photos. *Catena* **16**: 369–376.

Jungerius PD, Verheggen AJT, Wiggers AJ. 1981. The development of blowouts in 'De Blink', a coastal dune area near Noordwijkerhout, The Netherlands. *Earth Surface Processes and Landforms* **6**: 375–396.

Kierkels MHH. 1971. Erosie en verkaveling in de ruilverkaveling 'Ransdalerveld'. *Cultuurtechnisch Tijdschrift* **11**: 78–84.

Knottnerus DJC. 1979. *Wind Erosion Research by Means of a Wind Tunnel. Measures to Control Wind Erosion of Soil and Other Materials for Reasons of Economy and Health.* Institute of Soil Fertility, Haren.

Koster EA. 1978. De stuifzanden van de Veluwe; een fysisch-geografische studie. PhD Thesis, University of Amsterdam.

Kraak TA, Van Oorschot GM. 1998. *Knelpuntgerichte Aanpak Erosie en Wateroverlast. Deelproject Centraal Plateau.* Dienst Landelijk Gebied voor Ontwikkeling en Beheer.

Kuyl OS. 1980. *Toelichting bij de Geologische Kaart van Nederland 1:50.000, Blad Heerlen 62 W en 62 O.* Rijks Geologische Dienst, Haarlem.

Kwaad FJPM. 1991. Summer and winter regimes of runoff generation and soil erosion on cultivated loess soils (The Netherlands). *Earth Surface Processes and Landforms* **16**: 653–662.

Kwaad FJPM. 1993. Characteristics of runoff generating rains on bare loess soil in South-Limbourg (The Netherlands). In *Farmland Erosion in Temperate Plains Environment and Hills*, Wicherek S (ed.). Elsevier, Amsterdam; 71–86.

Kwaad FJPM. 1994a. Cropping systems of fodder maize to reduce erosion of cultivated loess soils. In *Conserving Soil Resources, European Pespectives,* Rickson RJ (ed.). CAB International, Wallingford; 354–368.

Kwaad FJPM. 1994b. A splash delivery ratio to characterize soil erosion events. In *Conserving Soil Resources, European Pespectives*, Rickson RJ (ed.). CAB International, Wallingford; 264–272.

Kwaad FJPM. 1998. Saturation overland flow on loess soils in The Netherlands. In *Modelling Soil Erosion by Water*, Boardman J, Favis-Mortlock D (eds). Proceedings of NATO Advanced Research Workshop, Oxford. NATO ASI Series, Series I, 55. Springer, Berlin; 225–235.

Kwaad FJPM, Mücher HJ. 1994. Degradation of soil structure by welding – a micromorphological study. *Catena* **23**: 253–268.

Kwaad FJPM, Van der Zijp M, Van Dijk PM. 1998. Soil conservation and maize cropping systems on sloping loess soils in The Netherlands. *Soil and Tillage Research* **46**: 13–21.

Landinrichtingsdienst, 1983. *Lokaties met Periodieke Wateroverlast in Zuid-Limburg.* Landinrichtingsdienst, 83–11 vH.

Philips JFR, Jansen JCGM, Claessens ThJAH. 1965. *Geschiedenis van de Landbouw in Limburg 1750–1914.* Maaslandse Monografieën 4. Van Gorcum, Assen.

Pluis JLA. 1993. The role of algae in the spontaneous stabilization of blowouts. PhD Thesis, University of Amsterdam.

Poelman JNB. 1971. Erosie van lössgronden. *Boor en Spade* **17**: 177–187.

Provincie Limburg 1987. *Streekplan Zuid-Limburg. Algehele Herziening.* Provincie Limburg, Maastricht.

Renes J. 1988. *De geschiedenis van het Zuidlimburgse Cultuurlandschap*. Van Gorcum, Assen.

Riksen MJPM, De Graaff J. 2001. On-site and off-site effects of wind erosion on European light soils. *Land Degradation and Development* **12**: 1–11.

Schouten C, Rang M. 1987. Bodemerosie in Zuid-Limburg. *Natuur en Milieu* **11**: 9–13.

Schouten CJ, Rang MC, Huigen P.M.J. 1985. Erosie en wateroverlast in Zuid-Limburg. *Landschap* **2**: 118–132.

Spaan WP, Van Dijk PM, Eppink LAAJ. 1991. *Wind Erosion Measurements on the Island of Schiermonnikoog. On the Use of Acoustic Sensors and Sediment Catchers.* Department of Irrigation and Soil and Water Conservation, Wageningen Agricultural University, Wageningen.

Q13 Stolte J, Ritsema CJ, De Roo APJ. 1997. Effects of crust and cracks on simulated catchment discharge and soil loss. *Journal of Hydrology* **195**: 279–290.

Takken I, Beuselinck L, Nachtergaele J, Govers G, Poesen J, Degraer G. 1999. Spatial evaluation of a physically based distributed erosion model (LISEM). *Catena* **37**: 431–447.

Van Bohemen HD. 1990. Beheersaspecten van het duin- en kustmilieu in relatie tot de kustverdediging. *Geografisch Tijdschrift* **24**: 433–438.

Van Boxel JH, Arens SM, Van Dijk PM. 1999. Aeolian processes across transverse dunes. I: Modelling the airflow. *Earth Surface Processes and Landforms* **24**: 255–270.

Van den Ancker JAM, Jungerius PD, Mur LR. 1985. The role of algae in the stabilization of coastal dune blow-outs. *Earth Surface Processes and Landforms* **10**: 189–192.

Van der Helm PPM. 1988. Erosie op zijn Limburgs bekeken. *Limburgs Milieu* **2** (4/5): 9–11.

Van der Helm PPM, Schouten CJ. 1986. *Bodemerosie en Wateroverlast in Zuid-Limburg. Een Voorlopige Inventarisatie per Gemeente*. Geografisch Instituut, Rijksuniversiteit Utrecht, Utrecht.

Van der Wal D. 1999. Aeolian transport of nourishment sand in beach–dune environments. PhD Thesis, University of Amsterdam.

Q14 Van Dijk PM. 2001. Soil erosion and associated sediment supply to rivers. Seasonal dynamics, soil conservation measures and impacts of climate change. PhD Thesis, University of Amsterdam.

Van Dijk PM, Kwaad FJPM. 1996a. Effects of grass strips on sediment load and hydraulics of shallow flow. In *Buffer Zones. Their Processes and Potential in Water Protection*, Haycock N (ed.). Quest Environmental, Harpenden; 66.

Q15 Van Dijk PM, Kwaad FJPM. 1996b. Runoff generation and soil erosion in small agricultural catchments with loess derived soils. *Hydrological Processes* **10**: 1049–1059.

Van Dijk PM, Kwaad FJPM, Klapwijk M. 1996a. Retention of water and sediment by grass strips. *Hydrological Processes* **10**: 1069–1080.

Van Dijk PM, van der Zijp M, Kwaad FJPM. 1996b. Soil erodibility parameters under various cropping systems of maize. *Hydrological Processes* **10**: 1061–1067.

Van Dijk PM, Arens SM, Van Boxel JH. 1999. Aeolian processes across transverse dunes. II: Modelling the sediment transport and profile development. *Earth Surface Processes and Landforms* **24**: 319–333.

Van Eck W, Slothouwer D, Sprik JB, IJkelenstam GFP. 1995. *Erosienormeringsonderzoek Zuid-Limburg. Kosten en Baten van Erosiebestrijdingsmaatregelen in Zuid-Limburg*. Rapport 364.2. DLO, Staring Centrum, Wageningen.

Van Eijsden GC, Imeson AC. 1985. De relatie tussen erosie en enkele landbouwgewassen in het Ransdalerveld, Zuid-Limburg. *Landschap* **2**: 133–142.

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