Vegetation succession in floodplain flats

Inventarisation and modelling of measured data and expert judgement

B.S.J. Nijhof

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ABSTRACT

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Literature study and expert judgement are used to develop succession schemes per vegetation structure type of the Dutch floodplain flats. The occurrence of a vegetation type is said to be mainly related to flooding duration and frequency. The third factor taken into account is the management, for example mowing or grazing. Per vegetation structure type the relation between vegetation types and time span needed for developing from one into another is given.

Keywords: Vegetation succession, floodplain flats, flooding, sedimentation, modelling

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1 Introduction

This report is part of two projects, being the ‘Cyclic rejuvenation of floodplains: a new strategy based on floodplain measures for both risk management and enhancement of the biodiversity of the river Rhine’ within the IRMA-SPONGE Umbrella Program and the Biogeomorphological Developments of Floodplains program with Delft Cluster.
Within these projects two seemingly contrary goals are united: on the one hand creating a situation with as much space as possible for natural processes and its related morphological and ecological development, and on the other hand safeguarding the present safety level along the rivers.

In short the idea is as follows. After arranging a floodplain flat morphological and ecological development is left to nature. As soon as these developments (among others sedimentation in secondary channels, development of floodplain forest) reached a level at which safety of the surrounding areas can not be guaranteed anymore, new action is undertaken. These actions can be performed in the concerning floodplain flat as well as in other areas. Actions can range from again opening the secondary channel, digging a new secondary channel to lowering the floodplain flat or removing the floodplain forest. In other words artificially accelerating the cyclic rejuvenation.
The ultimate aim is that within a river course a diversity of succession stages develops. The arrangement of the floodplain flats and the actions taken will differ between the areas. The ecological possibilities of the area are the starting point for the definition and design of the arrangement. A set condition is safeguarding the safety level along the river.

The research within this report is part of this bigger idea. The aim is to improve the knowledge concerning the interactions between geomorphological processes and the ecotope development in high and low dynamic environments in the floodplain flats along the Dutch large rivers. The project should result in a scientifically justified bond between hydraulic and landscape ecological models used in spatial planning. Or more specific, in the planning of lowering the floodplain flats to enable nature development and adjusted superficial mining.

Alterra opted for the description of the different vegetationtypes present in the floodplain flats and their succession in relation to disturbances, in this case being flooding. The flooding again can be linked to sedimentation rates. This report is the result of a research involving literature study and expert knowledge.

2 Methodology

After a thorough study of the literature present on vegetation and vegetation succession in floodplain flats it could be concluded that most of the research done resulted in qualitative statements concerning vegetation succession in floodplain flats. Little data are quantified (De Graaf et al., 1990). Many assumptions are made when these data are used in for example models predicting vegetation development. Within this research an attempt is made to design a model showing the vegetation development after flooding. Again quantification of certain steps taken is difficult. A quantification of abiotic data determining where which vegetation type can occur as well as the time span needed for the vegetation to develop from one community into the other, with or without a certain management, is very important.

2.1 Defining vegetationtypes

Within the researches done different descriptions of vegetation communities are used. Usually the communities described by Westhoff & Den Held (1969) were used as a basis, but more often new communities are developed to be able to describe the vegetation in the concerning study more accurate. We aim at developing a scheme that can be used in the whole Dutch river system and therefore decided to standardise the communities. We used the classification defined in the most recent work on the vegetation of the Netherlands (Schaminée et al., 1995; Schaminée et al., 1996; Schaminée et al., 1998; Stortelder et al., 1999).
A study of this work resulted in a selection of communities to be found in the Dutch floodplain flats. The communities are ordered according to vegetation structure type, which relates to the different plant sociological classes. Six groups were found:
W water vegetation;
P pioneer vegetation;
S swamp vegetation;
G grassland;
R ruderal vegetation;
F forest and shrubland.

2.2 Relation to the abiotic environment

Specific vegetation is growing on a certain place because of a combination of abiotic conditions present. Also the management, among others grazing and/or fertilisation, influences what grows where. In the floodplain flats of rivers among the following factors are considered the most important ones: duration of flooding (inundation time), frequency of flooding, morpho-dynamics (erosion, transportation and sedimentation), soil texture, lime content, exposure, influence of groundwater. Within this first trial to develop a scheme for vegetation succession the factors duration of flooding (inundation time), morpho-dynamics and management are used

(De Graaf et al., 1990; Brongers et al., 1993; Rademakers & Wolfert, 1994; pers. comm. P.W.F.M. Hommel, Alterra).
To enhance the overview where which vegetation type might be found a drawing of a fictional floodplain flat showing all physiotopes possible (Figure 1) was made. From this drawing the minimal time a vegetation structure type needs to develop, starting from bare soil, on a certain physiotope can be read. Per vegetation structure type a separate scheme is made showing in what way and due to which abiotic and/or antropogenic factors a vegetation community in the relevant physiotope changes/develops into another (Schemes W, P, S, G, R, F). These data partly are real measured data from researches and partly expert judgement (indicated with a '*'). The measured data per vegetation type is combined and a best judgement is made to define its value within the scheme. Arrows indicate in which direction vegetation can develop. If such a development is due to another event than natural succession it is explained next to the arrow.

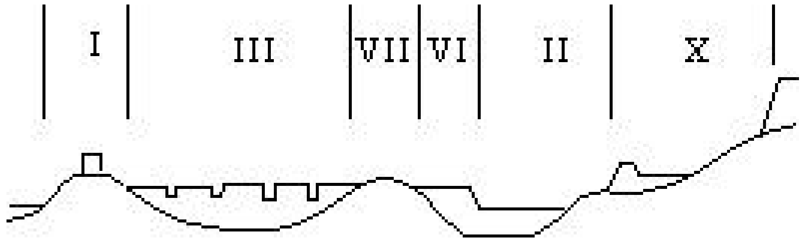
3 Succession

The succession of the vegetation in the floodplain flats of the Dutch rivers is described per vegetation structure type. These vegetation structure types can occur on several locations in floodplain flats with differing abiotic circumstances, defined as physiotopes (Harms & Roos-Klein Lankhorst, 1994; Wolfert, 1998). Figure 1 shows the location of the different physiotopes in a range from a more or less natural situation towards a strongly antropogenic influenced situation. Table 1 describes the abiotic parameters within these physiotopes.

Table 1. Physiotopes of the Dutch river system with their abiotic circumstances according to the RijksWateren-Ecotopen-Stelsel (Maas, 1998; Van der Molen et al., 2000).

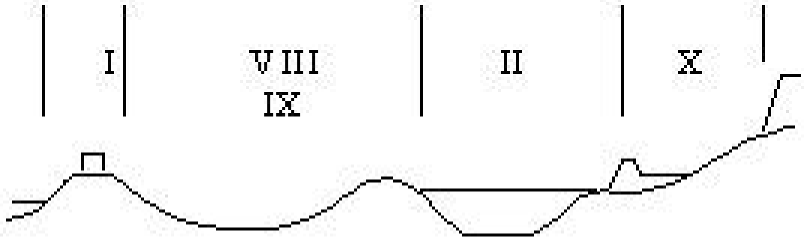
Inundation time (days per year) Texture	>20 clay	<20 clay	150-364 clay/sand	50-150 clay	20-50 clay/silt	<20 silt/sand	<2 sand
I River beaches/Shores of sloughs and secondary channels			■				
II Low floodplain flats				■			
III Low floodplain flats with quick drainage				■			
IV Sloughs		■					
V Abandoned channels/Isolated waters			■				
VI Moderately high floodplain flats					■		
VII Natural levees and bases of slopes						■	■
VIII Clay pits	■	■					
IX Sand pits	■	■					
X High natural levees/High (sandy) floodplain flats/Aeolian dunes							■

A



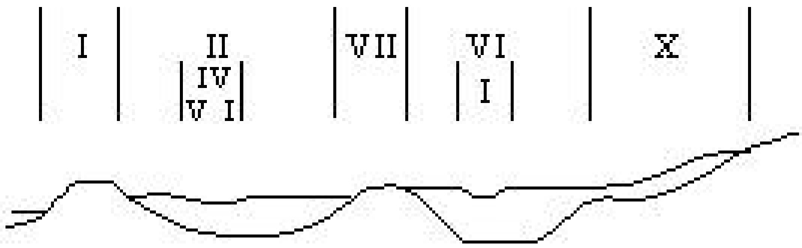
Water vegetation	-	-	-	-	-	-
Pioneer vegetation	1	-	1	1	-	1
Swamp vegetation	-	-	-	-	-	-
Grassland	3	2	3	2	2	3
Ruderal vegetation	2	2	-	-	2	2
Forest and shrubland	-	5	5	5	5	5

B



Water vegetation	-	1	-	-
Pioneer vegetation	1	3	-	1
Swamp vegetation	-	2	-	-
Grassland	3	-	2	3
Ruderal vegetation	2	-	2	2
Forest and shrubland	-	-	5	5

C



Water vegetation	-	- (1)	-	- (-)	-
Pioneer vegetation	1	- (3)	1	1 (1)	1
Swamp vegetation	-	- (2)	-	- (-)	-
Grassland	3	2 (-)	3	2 (3)	3
Ruderal vegetation	2	2 (-)	-	- (2)	2
Forest and shrubland	-	5 (-)	5	5 (-)	5

Figure 1. Cross-section through a floodplain flat of a river with an indication of the physiotopes defined and minimum amount of years (by expert judgement) needed for the vegetation structure types to develop. Three situations are sketched: a) antropogenic influenced situation; b) strongly antropogenic influenced situation; c) a more or less natural situation

I — *River beaches/Shores of sloughs and secondary channels*
II — *Low floodplain flats*
III — *Low floodplain flats with quick drainage*
IV — *Sloughs*
V — *Abandoned channels/Isolated waters*
VI — *Moderately high floodplain flats*
VII — *Natural levees and bases of slopes*
VIII — *Clay pits*
IX — *Sand pits*
X — *High natural levees/High (sandy) floodplain flats/Aeolian dunes*

The figures between brackets in part C relate to the ecotopes between the shorter lines.

3.1 Water vegetation

Almost permanent water of a certain depth is essential for water vegetation. Dehydration for a short period of time should not be a problem when the substrate remains sufficiently moist. Next to this rather deep water is an asset because of competition with swamp vegetation. Sloughs and abandoned channels as well as the artificial clay pits have the demanded abiotic circumstances, a combination of the before mentioned factors with a low to no stream velocity.
Important in determining which is the lower limit for a species to be able to establish itself are the high waters during the summer season. This because of the floating away of species not embedded in the soil and starvation of embedded species due a too highly raised waterlevel. Another factor hampering the settlement of species are the reduced light conditions due to sediment material floating in the water (De Graaf, 1990).

The water vegetation exists of two main vegetation classes (Table W), according to the vegetation of the Netherlands as described by Schaminée et al. (1995): *Charetea fragilis* (Kranswieren klasse, part 2-page 45 in Schaminée et al. (1995)) and *Potametea* (Fonteinkruiden klasse, 2-65).

Table W. Classification of the water vegetation in the Dutch river system. Based on Schaminée et al.. (1995).

Class			
	Order		
		Alliance	
			Association
CHARETEA FRAGILIS			
	Charetalia hispidae		
	CHARION VULGARIS		
			Charetum vulgaris
			Lemno-Nitelletum capillaris
			Tolypelletum proliferae
ROMPGEMEENSCHAP			
	Chara globularis – [Charetea fragilis]		
POTAMETEA			
	Numparo-Potametalia		
	NYMPHAEION		
	Potametum lucentis		
	Myriophyllo-Nupharetum		
	Potameto-Nymphoidetum		
	HYDROCHARITION MORSUS-RANAE		
	Urticularietum vulgaris		
	PARVOPOTAMION		
	Myriophyllo verticillati-Hottonietum		
Rompgemeenschap			
	Ceratophyllum demersum – [Nupharo-Potametalia]		
	Potamogeton pusillus en Elodea nuttalli-[Parvopotamion]		
	Potamogeton trichoides-[Parvopotamion]		

In the class of the *Charetea fragilis* the vascular plants have a low importance. This vegetation is almost always completely submerged and is very sensitive to water pollution. The vegetation grows in the Netherlands to a maximum depth of ‘only’ 6-8 meters, due to the low cleanliness of the water. The *Potametea* are found in less deep open waters. They are more common than the vegetations of the *Charetea fragilis*.
These vegetations are the pioneers of waters of which the existence is guaranteed by disturbance due to waves in large waters or human activities like regular cleaning of ditches and channels. Otherwise it can, within years, develop into swamp vegetation. An indication for this succession usually is the presence of helophytes in the *Charetea* vegetation.

Quantitative data

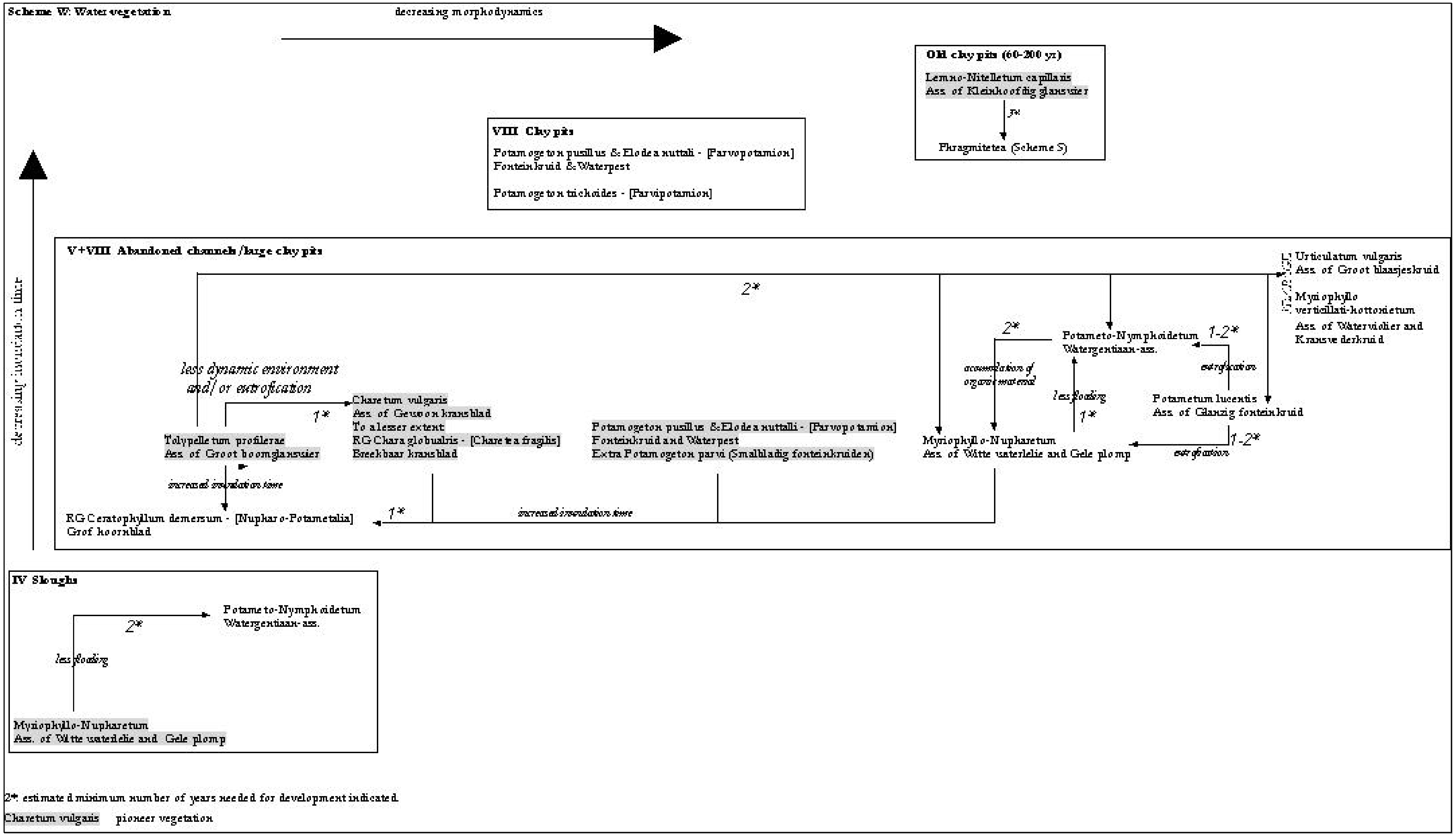
No quantitative data referring to vegetation types is available at the moment. In Van den Brink (1994) a relation between four macrophyte species in still waters and inundation frequency in classes is described (Table 2). In Table 3 inundation frequencies in two classes per species are shown (Van den Brink, 1990). Van Geest et al. (in prep.) are studying the succession of waterplants in several waters along the rivers in The Netherlands at the moment.

Table 2. The occurrence of selected aquatic macrophyte species in floodplain waters along the river Rhine in relation to the frequency of inundation. Classes: 0 = not inundated; 1 = 0-20 days per year (long term annual average); 2 = 21- >40 (modified after Van den Brink, 1994).

Inundation class Number of waterbodies	0 14	1 28	2 14
Nuphar lutea	3	4	1
Nymphaea alba	2	2	1
Nymphoides peltata	1	3	2
Potamogeton lucens	2	3	0

Table 3. Waterplants that are encountered significantly more often at a certain inundation frequency. Inundation frequency in days per year (long-year average over 1901-1985) (Van den Brink, 1990).
Occurrence: + = present, - = not present.
Significance: p = degree of significance (Fisher’s exact test). +++/--- = p<0,001; ++/-- = 0,001<p<0,001; +/- = 0,001<p<0,05.

Inundation frequency Number of locations	<20 61	>20 25
Fontinalis antipyretica	+	-
Lemna minor	+++	---
Lemna trisulca	++	--
Myriophyllum spicatum	+	-
Nuphar lutea	+++	---
Potamogeton lucens	+++	---
Ranunculus circinatus	+++	---


Scheme W: Water vegetation
decreasing morphodynamics
decreasing inundation time
Old clay pits (60-200 yr)
Lemno-Nitelletum capillaris
Ass. of Kleinkoofdig glansvier
3*
Phragmitetea (Scheme S)
VIII Clay pits
Potamogeton pusillus & Elodea nuttali - [Parvopotamion]
Fonteinkruid & Waterpest
Potamogeton trichoides - [Parvipotamion]
V+VIII Abandoned channels/large clay pits
2*
Urticulatum vulgaris
Ass. of Groot blaasjeskruid
Myriophyllo verticillati-hottonietum
Ass. of Watervioler and Kransvederkruid
less dynamic environment and/or eutrofication
1*
Charetum vulgaris
Ass. of Gewoon kransblad
To a lesser extent
RG Chara globualris - [Charetea fragilis]
Breekbaar kransblad
Tolypelletum profilerae
Ass. of Groot boomglansvier
increased inundation time
RG Ceratophyllum demersum - [Nupharo-Potametalia]
Grof hoornblad
Potamogeton pusillus & Elodea nuttalli - [Parvopotamion]
Fonteinkruid and Waterpest
Extra Potamogeton parvi (Smalbladig fonteinkruiden)
Potameto-Nymphoidetum
Watergentiaan-ass.
2*
accumulation of organic material
less flooding
1*
1-2*
eutrofication
Potametum lucentis
Ass. of Glanzig fonteinkruid
1-2*
eutrofication
Myriophyllo-Nupharetum
Ass. of Witte waterlelie and Gele plomp
IV Sloughs
Potameto-Nymphoidetum
Watergentiaan-ass.
2*
less flooding
Myriophyllo-Nupharetum
Ass. of Witte waterlelie and Gele plomp
2*: estimated minimum number of years needed for development indicated.
Charetum vulgaris pioneer vegetation

3.2 Pioneer vegetation

Pioneer vegetations are very common on shores of waters in river areas. This very dynamic and harsh environment creates the circumstances pioneer species need. Bare soil is one of the most important factors. The processes in the floodplain flats can lead to very different pioneer environments, giving rise to many pioneer communities. On the shores of rivers and waters that are connected to the river perennial species can survive to only a certain level because of long-time and deep flooding. Below this level a zone exists which falls dry in summertime. If the soil does not hydrate too quickly pioneer species can germinate. Most species are annuals or bi-annuals. In the more isolated parts of the floodplain flats, where the water level fluctuations are much lower, the pioneer species will only have the change to invade after very warm and dry years. Besides this sedimentation and erosion are important processes.
Also determing the lower limit of settlement for pioneer vegetations are the humidity conditions during the vegetation season. They influence the germination and settlement of species. Furthermore, after a stable substrate has established, wave action will enhance the competition strength of the pioneer species (De Graaf et al., 1990).

River shores, secondary channels and sloughs are the dynamic environments for pioneer vegetations, whereas abandoned channels or other waters in the floodplain flats represent the less dynamic areas.

Pioneer vegetations incorporate two classes (Table P) within the classification system of Schaminée et al. (1998), being *Bidentetea tripartitae* (Tandzaad-klasse; part 4-page 173) en *Artemisietea vulgaris* (Klasse der ruderale gemeenschappen; 4-247). The *Bidentetea tripartitae* are pioneer communities from as well natural as antropogenic locations, ranging from shores of rivers to clay pits. Especially on wet places where digging has been done the vegetation of this class can develop. It needs an environment with sufficient humidity and nutrients in combination with a bare soil. In winter the locations are flooded for a longer period of time. In the summer they can be dry, but should not hydrate. The greatest difference between the two classes of *Bidentetea tripartitae* and the *Artemisietea vulgaris* is the humidity. The latter one avoids permanent moist to wet situations. Furthermore it occurs on locations where in some way material from elsewhere is introduced, for example silt. In general the *Bidentetea tripartitae* communities are found more on clayey substrate, whereas the *Artemisietea vulgaris* communities occur on sandier substrate.
The pioneer vegetations share their abiotic environment with communities of the *Phragmitetea* and *Convolvulo-Filipenduletea*, both also demanding wet and nutrient rich locations. The pioneers will only stand a chance where ever these long-living communities can not establish themselves or where such vegetations disappeared completely (including the parts in the soil).

Quantitative data

The amount of quantitative data available is very limited. De Graaf et al. (1990) shows the most accurate data, although an aberrant nomenclature was used. Furthermore data was found in Jongman & Leemans (1982) and De Boer (1990). The resulting limits per vegetation type can be found in Table 4.

Table P. Classification of the pioneer vegetation in the Dutch river system. Based on Schaminée et al. (1998).

Class
    Order
        Alliance
            Association

BIDENTETEA TRIPARTITAE
    Bidentetalia tripartitae
        BIDENTION TRIPARTITAE
            Polygono-Bidentetum
            Chenopodietum rubri
            Eleocharito acicularis-Limoselletum

Rompgemeenschap
    Ranunculus scleratus – [Bidentetea tripartitae / Phragmitetea]

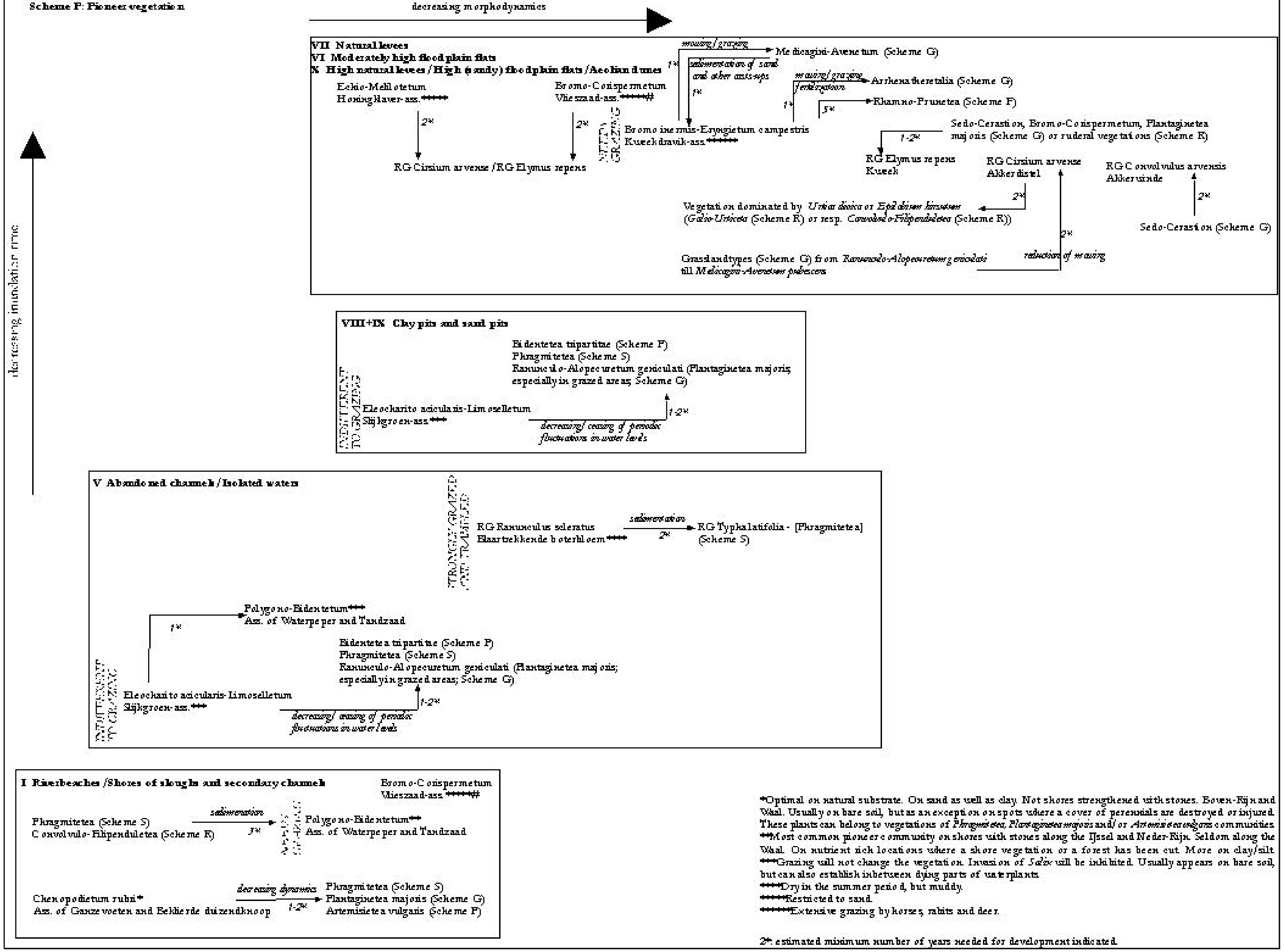
ARTEMISIETEA VULGARIS
    Chenopodio-Urticetalia
        SALSOLION RUTHENICAE
            Bromo-Corispermetum
    Onopordetalia acanthii
        ONOPORDION ACANTHII
            Echio-Verbascetum
    Agropyretalia repentis
        DAUCO-MELILOTION
            Echio-Melilotetum
            Bromo inermis-Eryngietum campestris

ROMPGEMEENSCHAP
            Convolvulus arvensis – [Artemisietea vulgaris]
            Elymus repens – [Artemisietea vulgaris]
            Cirsium arvense – [Artemisietea vulgaris]

Table 4. The upper and lower limit (in days of inundation) for the vegetation types of the grasslands (following Schaminée et al. (1998)). The numbers are estimated with reference to the measured data from De Graaf et al. (1990), Jongman & Leemans (1982) and De Boer (1990).

Vegetation type	Upper limits in days of inundation per year	Lower limits in days of inundation per year
Polygono-Bidentetum	3	110
Chenopodietum rubri	50	250
Eleocharito acicularis-Limoselletum	130	300
RG Ranunculus scleratus – [Bidentetea tripartitae / Phragmitetea]	?	?
Bromo-Corispermetum	?	?
Echio-Verbascetum	?	?
Echio-Melilotetum	?	?
Bromo inermis-Eryngietum campestris	?	?
RG Convolvulus arvensis – [Artemisietea vulgaris]	?	?
RG Elymus repens – [Artemisietea vulgaris]	10	50
RG Cirsium arvense – [Artemisietea vulgaris]	?	?

Scheme P: Pioneer vegetation



*Optimal on natural substrate. On sand as well as clay. Not shores strengthened with stones. Boven-Rijn and Waal. Usually on bare soil, but as an exception on spots where a cover of perennials are destroyed or injured. These plants can belong to vegetations of *Phragmitetea*, *Plantaginetea majoris* and/or *Artemisietea vulgaris* communities.
**Most common pioneer community on shores with stones along the IJssel and Neder-Rijn. Seldom along the Waal. On nutrient rich locations where a shore vegetation or a forest has been cut. More on clay/silt.
***Grazing will not change the vegetation. Invasion of *Salix* will be inhibited. Usually appears on bare soil, but can also establish inbetween dying parts of waterplants.
****Dry in the summer period, but muddy.
*****Restricted to sand.
******Extensive grazing by horses, rabits and deer.

2*: estimated minimum number of years needed for development indicated.

3.3 Swamp vegetation

Those parts of the floodplain flat that are prolonged wet have the suitable environment for the development of swamp vegetation. The presence or absence of species is strongly related to the accidentally very high waterlevels during the vegetation season. An example is the *RG Phalaris arundinacea*, which is more tolerant towards these high waterlevels than is the *Caricetum gracilis* (De Graaf et al., 1990). These waterlevels are also an important factor determining the lower limit to where a species can occur. Complete submergence, for example, is the only limiting factor for the *Typho-Phragmitetum* (De Graaf et al., 1990). The upper limit of the swamp vegetation is related to the amount of moisture the environment can give and the amount of moisture needed by a species. For example, the *RG Typha latifolia* usually falls dry during the vegetation season.

The presence of swampy vegetations on shores of waters that have a direct connection to the river is limited. The flooding frequency and depth are hampering their establishment. Small line-shaped vegetations might be found in isolated parts of for example sloughs. Environments with a less dynamic character, like abandoned channels, contain more swamp species due to their better and more continuos moisture supply.

The swamp vegetation belongs to the class of the *Phragmitetea* (Riet-klasse; part 2-page 161; Table S; Schaminée et al., 1995). Pioneer communities are very well represented within this class.

Table S. Classification of the swamp vegetation in the Dutch river system. Based on Schaminée et al. (1995).

Class	Order	Alliance	Association
PHRAGMITETEA			
	Nasturtio-Glycerietalia		
		OENANTHION AQUATICAE	
			Rorippo-Oenanthetum aquaticae
	Phragmitetalia		
		PHRAGMITION AUSTRALIS	
			Scirpetum lacustris
			Alismato-Scirpetum maritimi
			Typho-Phragmitetum
		CARICION GRACILIS	
			Caricetum gracilis
Rompgemeenschappen			
			Glyceria maxima - [Phragmitetea]
			Rorippa amphibia - [Phragmitetea]
			Typha latifolia - [Phragmitetea]
			Phalaris arundinacea - [Phragmitetea]

The swamp communities usually occur in a mosaic-like pattern with waterplant communities, although no real succession from water to swamp vegetation can be seen.Both establish more or less at the same time on the same spot.In dynamic environments with flowing water the *Phragmitetea* are the final stadium of succession, whereas in parts flooded every now and then and without strong influences by streaming the communities, without a mowing regime, will develop into scrub and floodplain forests.

Quantitative data

Quantitative data on inundation time and frequency limiting the development of swamp vegetations is available. De Graaf et al. (1990) collected data along the Upper-Rhine, Waal and IJssel in The Netherlands. The nomenclature they use differs from the one used mostly then (Westhoff & Den Held, 1969) and the one within this research (Schaminée et al., 1995). More quantitative data, although as well using a different nomenclature, can be found in De Boer (1990) and Jongman & Leemans (1982). These data result in the limits set in Table 5.
In Tables 6 and 7 measurements for single helophyte species in still waters are shown (Van den Brink, resp. 1994 and 1990).

Table 5. The upper and lower limit (in days of inundation) for the vegetation types of the grasslands (following Schaminée et al. (1995)). The numbers are estimated with reference to the measured data from De Graaf et al. (1990), Jongman & Leemans (1982), De Boer (1990) and Van de Steeg (1992).

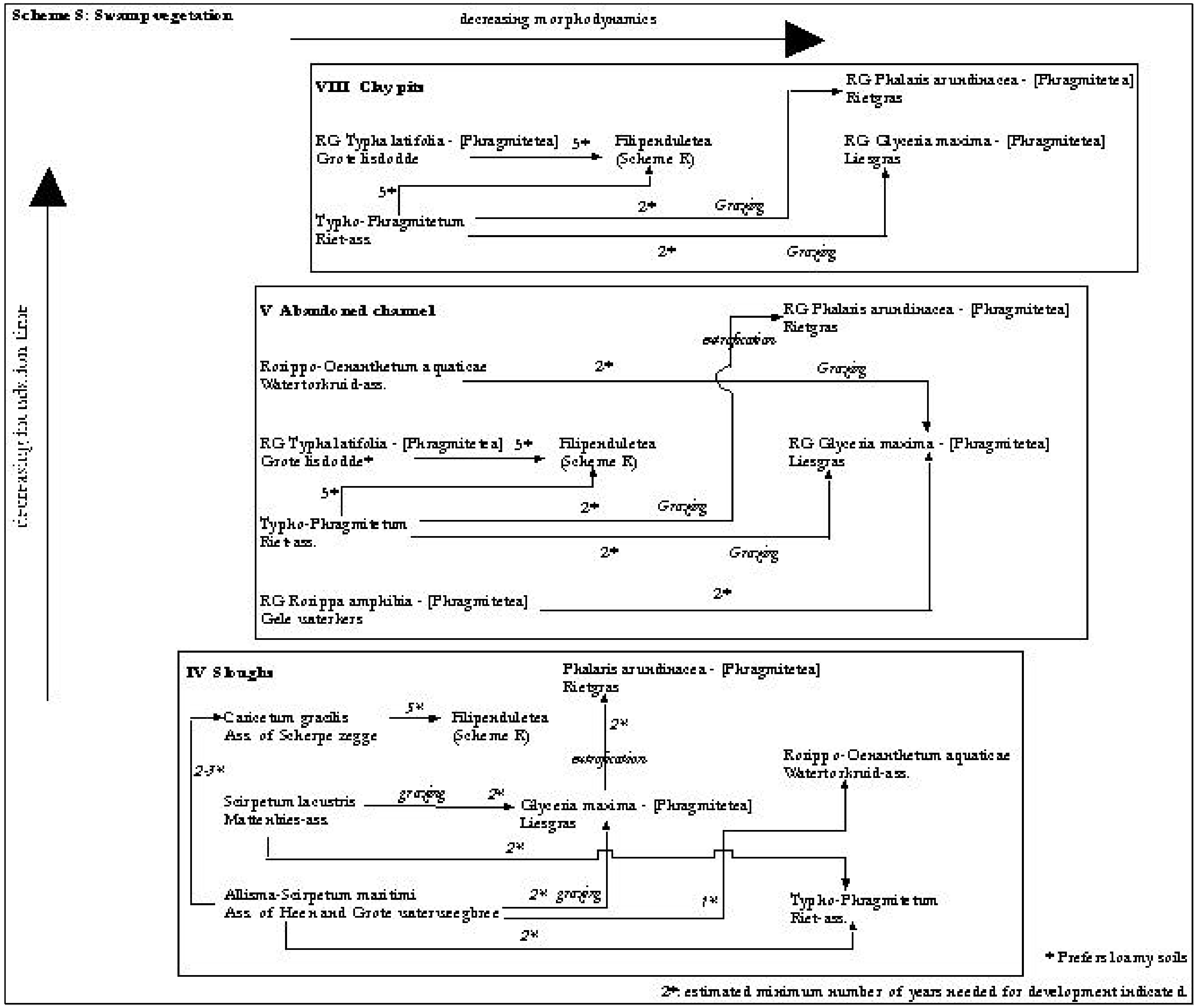
Vegetation type	Upper limit in days of inundation per year	Lower limit in days of inundation per year
Rorippo-Oenanthetum aquaticae	20	>40
Scirpetum lacustris	20	>40
Alismato-Scirpetum maritimi	?	?
Typho-Phragmitetum	15	300+
Caricetum gracilis	30	135
RG Glyceria maxima - [Phragmitetea]	20	>40
RG Rorippa amphibia - [Phragmitetea]	?	?
RG Typha latifolia - [Phragmitetea]	15	>40
RG Phalaris arundinacea - [Phragmitetea]	25	130

Table 6. The occurrence of selected helophyte species in floodplain waters along the river Rhine in relation to the frequency of inundation. Classes: 0 = not inundated; 1 = 0-2 days per year (long term annual average); 2 = 3-20; 3 = 21-40; 4 = >40 (Van den Brink, 1994).

Inundation class Number of waterbodies	0 14	1+2 28	3+4 14
Equisetum fluviatile	1	1	0
Oenanthe aquatica	1	2	0
Polygonum amphibium	4	4	4
Sparganium erectum	2	2	0
Typha angustifolia	3	2	0
Typha latifolia	1	1	0

Table 7. Swamp plants that are encountered significantly more often at a certain inundation frequency. Inundation frequency in days per year (long-year average over 1901-1985) (Van den Brink, 1990).
Occurrence: + = present, - = not present.
Significance: p = degree of significance (Fisher's exact test). +++/--- = p<0,001; ++/-- = 0,001<p<0,001; +/- = 0,001<p<0,05.

Inundation frequency Number of locations	<20 61	>20 25
Alisma plantago-aquatica	+++	---
Iris psuedacorus	+	-
Mentha aquatica	+++	---
Myosotis palustris	+++	---
Oenanthe aquatica	++	--
Phalaris arundinacea	-	+
Rumex hydrolapathum	+	-
Scirpus lacustris	+++	---
Sparganium erectum	+++	---
Typha angustifolia	++	--


Scheme 8: Swamp vegetation
decreasing morphodynamics
VIII Clay pits
RG Typha latifolia - [Phragmitetea]
Grote lisdodde
5*
Filipenduletea
(Scheme K)
5*
Typho-Phragmitetum
Riet-ass.
2*
Grazing
2*
Grazing
RG Phalaris arundinacea - [Phragmitetea]
Rietgras
RG Glyceria maxima - [Phragmitetea]
Liesgras
V Abandoned channel
RG Phalaris arundinacea - [Phragmitetea]
Rietgras
eutrofication
Rorippo-Oenanthetum aquaticae
Watertorkruid-ass.
2*
Grazing
RG Typha latifolia - [Phragmitetea]
Grote lisdodde*
5*
Filipenduletea
(Scheme K)
RG Glyceria maxima - [Phragmitetea]
Liesgras
5*
Typho-Phragmitetum
Riet-ass.
2*
Grazing
2*
Grazing
RG Rorippa amphibia - [Phragmitetea]
Gele waterkers
2*
IV Sloughs
Phalaris arundinacea - [Phragmitetea]
Rietgras
Caricetum gracilis
Ass. of Scherpe zegge
5*
Filipenduletea
(Scheme K)
2*
eutrofication
2-3*
Rorippo-Oenanthetum aquaticae
Watertorkruid-ass.
Scirpetum lacustris
Mattenbies-ass.
grazing
2*
Glyceria maxima - [Phragmitetea]
Liesgras
2*
Allisma-Scirpetum maritimi
Ass. of Heen and Grote waterweegbree
2* grazing
1*
Typho-Phragmitetum
Riet-ass.
2*
* Prefers loamy soils
2*: estimated minimum number of years needed for development indicated.

3.4 Grassland

Grasslands are the main vegetation structure in the floodplain flats of the upper rivers. They are, in large parts of Europe, a semi-natural vegetation type resulting from the activities by humans and his cattle. The commencement and existence of grassland is guaranteed by the regular removal of the above ground biomass during the vegetation season. Sufficient grazing and mowing will hamper the development of shrubs and forests and lead to low vegetation. The effect of grazing and mowing on the vegetation structure and species composition differs. With grazing the vegetation will be eaten and trampled. Species that remain short and are trampling resistant will profit and become dominant. Cattle prefers certain species. The non-eaten species, usually with thorns, can spread. Whereas without mowing and trampling sensitive species determine the look of the then higher vegetation. Grazing and mowing lead to two very different vegetation types, resp. the *Lolio-Cynosuretum* (Kamgras-weide) and *Arrhenatheretum elatioris* (Glanshaver-ass.).

Grasslands are found in a wide range of abiotic circumstances in the floodplain flats of the Dutch rivers. The grasslands closer to the river contain species resistant to a dynamic environment of flooding, whereas the more inland grassland is flooded maybe only once a year. Especially flooding in the growing season determines the lower limits of vegetation types. For grasslands the management is of high importance. Mowing or grazing by either cows or horses is an important factor in the maintenance of this vegetation structure. Without them the grasslands would develop, dependent on the abiotic circumstances, into for example ruderal vegetations or forests.

Physiotopes for grasslands are for example: shores of rivers, secondary channels and sloughs or the floodplain flats or natural levees.

The grasslands contain three classes, according to Schaminée (1996; Table G), being: *Plantaginetea majoris* (Weegbree-klasse; part 3-page 13), *Koelerio-Cornephoretea* (Klasse der droge graslanden op zandgrond; 3-61) and *Molinio-Arrhenatheretea* (Klasse der matig voedselrijke graslanden; 3-163). All three have their own zone within the floodplain flat of the river.
The *Plantaginetea majoris* resists yearly long-lasting flooding. It is a rather stable vegetation on nutrient rich to moderate nutrient rich environments. Grazing is common. Whereas the *Koelerio-Corynephoretea* is a pioneer vegetation on dry, more or less nutrient poor sandy substrate. These vegetations are strongly reduced due to destruction of their ecotope and fertilisation. Sand dunes along the river are their typical physiotope.
The *Molinio-Arrhenatheretea* are the mowed or grazed grasslands of nutrient rich to moderately nutrient poor locations. The environment is not particularly very wet or very dry. These vegetations represent a wide range of structures and have an intermediate position in-between the two before mentioned vegetation classes. Due to drainage and fertilisation these vegetations have become poor in species diversity and changed into production grasslands.

Table G. Classification of the grassland vegetation in the Dutch river system. Based on Schaminée et al. (1996).

Class / Order / Alliance / Association	
PLANTAGINETEA MAJORIS	
Agrostietalia stoloniferae	
LOLIO-POTENTILLION ANSERINAE	
	Ranunculo-Alopecuretum geniculati
ROMPGEMEENSCHAPPEN	
	Poa trivialis-Lolium perenne – [Plantaginetea majoris/Cynosurion cristati]
	Festuca arundinacea – [Lolio-Potentillion anserina]
	Agrostis canina – Ranuculus repens – [Lolio-Potentilloin/Molinietalia]
KOELERIO-CORYNEPHORETEA	
Trifolio-Festucetalia ovinae	
SEDO-CERASTION	
	Sedo-Thymetum pulegioidis
	Medicagini-Avenetum pubescentis
ROMPGEMEENSCHAPPEN	
	Euphorbia cyparissias- [Koelerio-Corynephoretea]
	Festuca ovina subsp. cinerea- [Trifolio-Festucetalia ovinae]
MOLINIO-ARRHENATHERETEA	
Arrhenatheretalia	
ALOPECURION PRATENSIS	
	Fritillario-Alopecuretum pratensis
	Sanguisorbo-Silaetum
ARRHENATHERION ELATIORIS	
	Arrhenatheretum elatioris
CYNOSURION CRISTATI	
	Lolio-Cynosuretum
ROMPGEMEENSCHAP	
	Alopecurus pratensis-Elymus repens – [Arrhenatheretalia]
	Alopecurus pratensis-Lychnis flos-cuculi- [Alopecution/Molinietalia]
	Alopecurus pratensis-Hordeum secalinum- [Alopecurion/Cynosurion]

Vegetation of the *Arrhenatheretum* does not colonise artificial soils in former clay pits that are filled with sand after excavation. They are only found on non-excavated soils. Whereas vegetation of the *Lolio-Cynosuretum* is usually found on excavated rather then recultivated soils. The *Lolio-Potentillion* distribution is associated with excabated and recultivated soils and not with untouched soils (Jongman, 1992).

Quantitative data

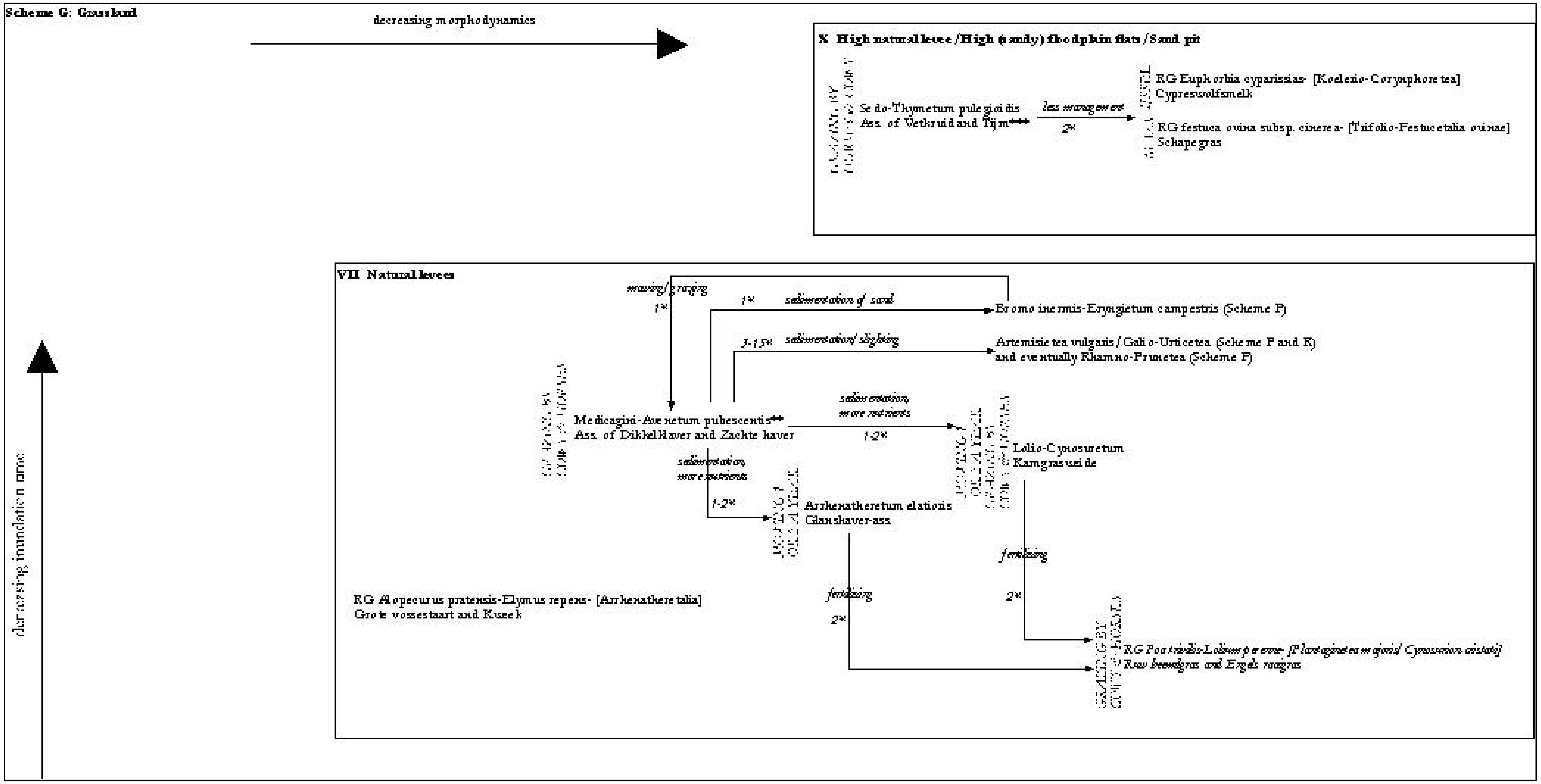
Quantitative data about inundation duration and/or frequency is very limited, although for the grasslands the largest amount of data is available. Most of the researches deal with only a part of the floodplain vegetation and furthermore no standard vegetation typology was used. These available data are used to define limits for the grassland vegetations shown in Table 8.

The several associations within the grasslands show a gradient from wet to dry. The amount of days vegetation stays flooded is an important indicator for this gradient. Furthermore the effect of inundation on the vegetation is stronger on heavy clayey substrate than on sandy soils. The limits given go further down when the vegetation types occur on sandy soils (Sýkora & Liebrand, 1987).

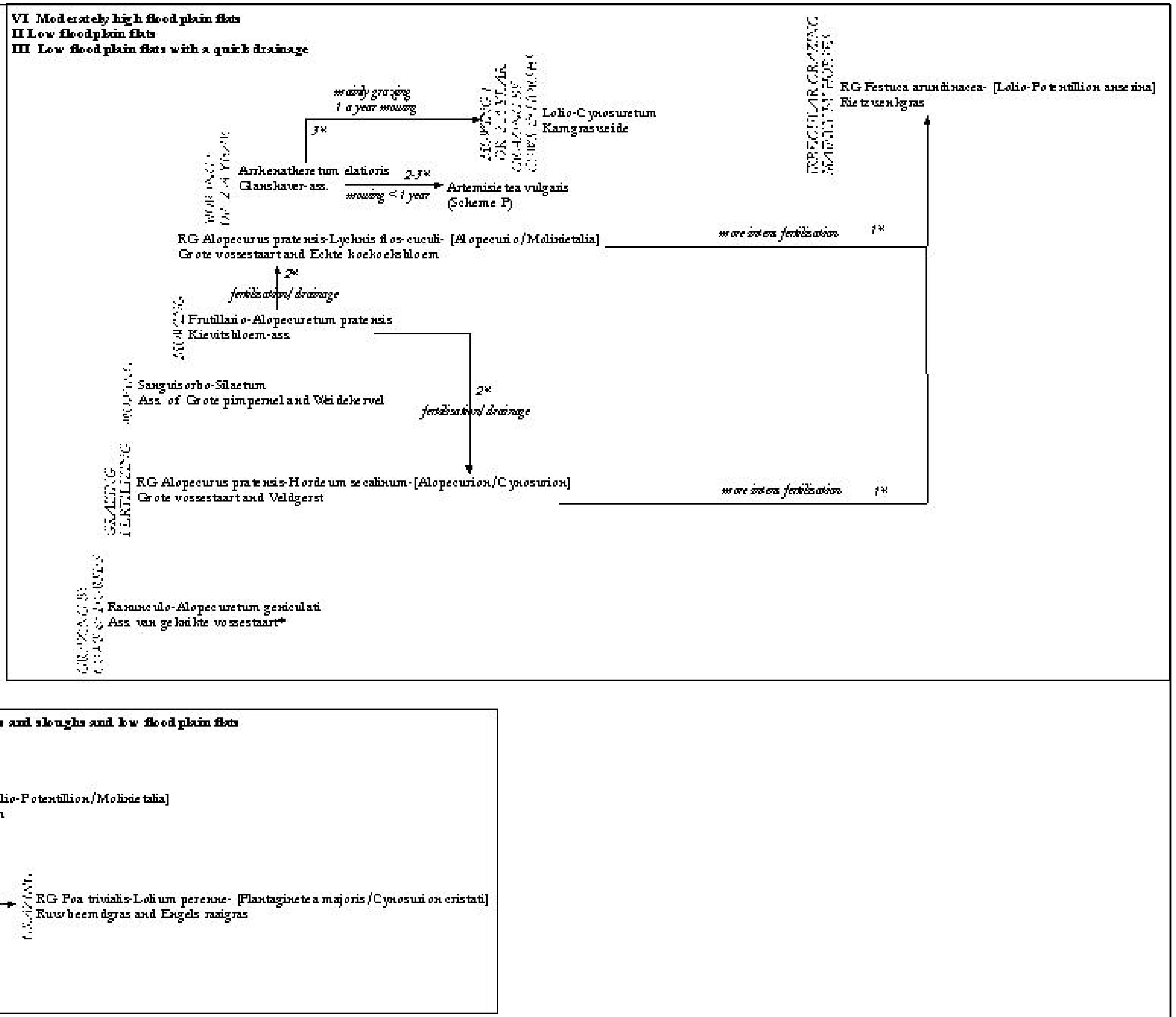
The *Ranunculo-Alopecuretum geniculati* (Ass. of Geknikte vossestaart) is a typical vegetation for the lower wetter parts of the floodplain flats. The average period of time the vegetation is flooded lies between 15 to 60 days (Jongman & Leemans, 1982; Jongman, 1992; De Boer, 1990; Drok, 1992). This vegetation manages well and its species will increase their cover due to short as well as long lasting inundations. The upper limit of this vegetation lies close to the maximum water levels reached in 1983 and 1984 (Sýkora & Liebrand, 1987). The next vegetation type found in the zonation is the *Lolio-Cynosuretum* (Kamgrasweide) which survives an average amount of inundation days between 2 to 25 (De Graaf et al., 1990; Jongman & Leemans, 1982; Jongman, 1992; De Boer, 1990; Van de Steeg, 1992). Slightly more sensitive to longer inundations is the *Arrhenatheretum elatioris* (Glanshaver-ass.) which is found on locations flooded between 0 to 20 days per year (De Graaf et al., 1990; Jongman & Leemans, 1982; Jongman, 1992; De Boer, 1990; Van de Steeg, 1992). The lower limit of this vegetation type coincides more or less with the flooding limit of 1984 (Sýkora & Liebrand, 1987). The *Medicagini-Avenetum pubescentis* (Ass. of Sikkelklaver and Zachte haver) occurs in the defined classes of <2 and 2-20 days flooding per year (Jongman & Leemans, 1982; Jongman, 1992). Here the lower limit is set on 5 days. According to Sýkora & Liebrand (1987) the lower limit of the *Medicagini-Avenetum pub*escentis more or less equals the maximum water levels reached in 1983 and 1984. These vegetations can stand short inundations during the vegetation season. Long floodings however will decrease their cover.

Table 8. The upper and lower limit (in days of inundation) for the vegetation types of the grasslands (following Schaminée et al. (1996)). The numbers are estimated with reference to the measured data from De Graaf et al. (1990), Jongman & Leemans (1982) Jongman (1992), De Boer (1990) and Van de Steeg (1992).

Vegetation type	Upper limit in days of inundation per year	Lower limit in days of inundation per year
Ranunculo-Alopecuretum geniculati	15	60
RG Poa trivialis-Lolium perenne – [Plantaginetea majoris/Cynosurion cristati]	<2	>40
RG Festuca arundinacea – [Lolio-Potentillion anserina]	?	?
RG Agrostis canina – Ranuculus repens – [Lolio-Potentilloin/Molinietalia]	?	?
Sedo-Thymetum pulegioidis	-	<2
Medicagini-Avenetum pubescentis	-	<5
Arrhenatheretum elatioris	0	20
Lolio-Cynosuretum	2	25
RG Alopecurus pratensis-Elymus repens – [Arrhenatheretalia]	10	50



Scheme G: Grassland
decreasing morphodynamics
decreasing inundation time
X High natural levee / High (sandy) floodplain flats / Sand pit
Sedo-Thymetum pulegioidis
Ass. of Vetkruid and Tijm***
less management
2*
RG Euphorbia cyparissias- [Koelerio-Corynphoretea]
Cypresswolfsmelk
RG festuca ovina subsp. cinerea- [Trifolio-Festucetalia ovinae]
Schapegras
VII Natural levees
mowing/grazing
1*
1*
sedimentation of sand
Bromo inermis-Eryngietum campestris (Scheme P)
3-15*
sedimentation/ slighting
Artemisietea vulgaris / Galio-Urticetea (Scheme P and R)
and eventually Rhamno-Prunetea (Scheme P)
Medicagini-Avenetum pubescentis**
Ass. of Dikkelhaver and Zachte haver
sedimentation,
more nutrients
1-2*
Lolio-Cynosuretum
Kamgrasweide
sedimentation,
more nutrients
1-2*
Arrhenatheretum elatioris
Glanshaver-ass.
fertilising
2*
fertilising
2*
RG Alopecurus pratensis-Elymus repens- [Arrhenatheretalia]
Grote vossestaart and Kweek
RG Poa trivialis-Lolium perenne- [Plantaginetea majoris/ Cynosurion cristati]
Ruw beemdgras and Engels raaigras



* outside the vegetation season flooded for a longer period of time. Mozaic-vegetation with Bidentetea tripartica (Scheme P)
** short periods of flooding during winter time or at least high river water levels
*** flooding for a short period of time or high water levels in the winter and early spring are tolerated

2*: estimated minimum number of years needed for development indicated.

3.5 Ruderal vegetation

These vegetations are found on wet, nutrient rich locations that are flooded every now and then. They establish there where swampy forest vegetations are cut or wet meadows (of the *Molinio-Arrhenatheretea*) are left unused. Productive species dominate in this high herb vegetation. When the inundation time increases again, the vegetation changes into swamps dominated by *Phragmitetea*.

The *Convolvulo-Filipenduletea* are found along shores of lakes, ditches and channels, on places where organic material is dropped, the usual management is stopped or swamp forest is cut down. The *Galio-Urticcetea* naturally occurs on natural levees along rivers.
These vegetations mostly function as an intermediate between lower vegetation structures and forests.

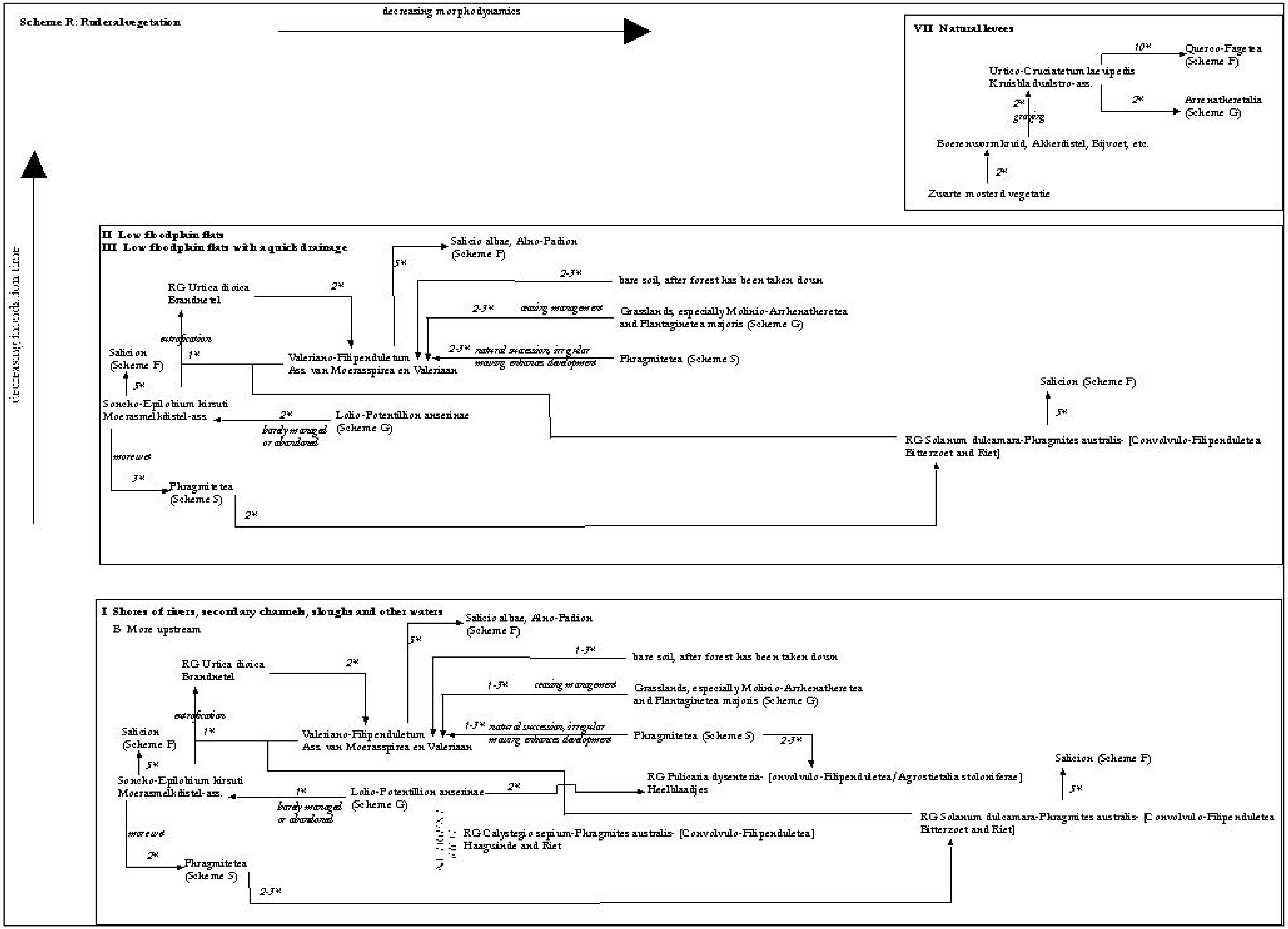
Two classes of the vegetation classification according to Stortelder et al. (1999; Table R) represent the ruderal vegetation: *Convolvulo-Filipenduletea* (Klasse der natte strooiselruigten; part 5-page 13) and *Galio-Urticetea* (Klasse der nitrofiele zomen; 5-41). Of these two classes the latter one represents the dryer variant. It is seldom or never flooded. Eventually the communities of the *Convolvulo-Filipenduletea* will turn into a shrub or forest. The time scale depends on the circumstances, ranging from a couple of years to decades.

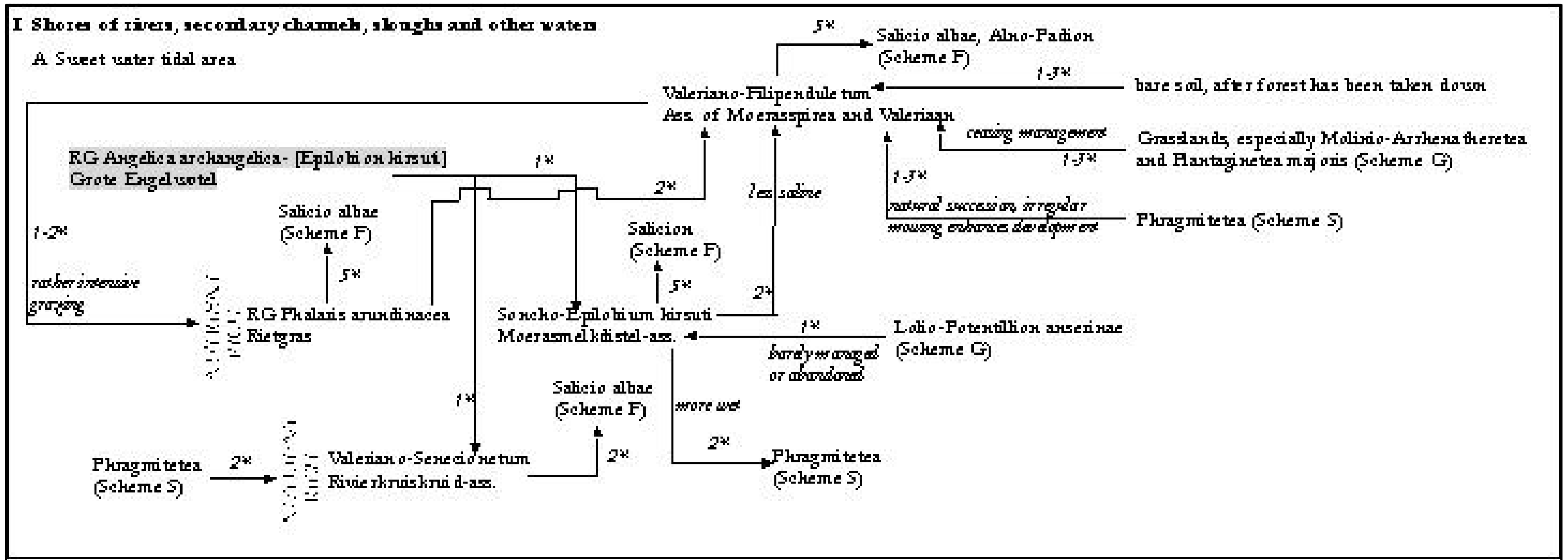
Table R. Classification of the ruderal vegetation in the Dutch river system. Based on Stortelder et al. (1999).

Class	Order	Alliance	Association
CONVOLVULO-FILIPENDULETEA			
	Filipenduletalia		
		FILIPENDULION	
			Valeriano-Filipenduletum
	Convolvuletalia sepium		
		EPILOBION HIRSUTI	
			Valeriano-Senecionetum fluviatilis
			Soncho-Epilobiotum hirsuti
ROMPGEMEENSCHAPPEN			
			Calystegia sepium-Phragmites australis – [Convolvulo-Filipenduletea]
			Solanum dulcamara-Phragmites australis – [Convolvulo-Filipenduletea]
			Phalaris arundinacea – [Convolvulo-Filipenduletea]
			Urtica dioica – [Convolvulo-Filipenduletea]
			Pulicaria dysenteria – [Convolvulo-Filipenduletea / Agrostietalia stoloniferae]
			Angelica archangelica [Epilobion hirsuti]
GALIO-URTICETEA			
	Glechometalia		
		GALIO-ALLIARION	
			Urtico-Cruciatetum laevipedis

Quantitative data

No quantitative data, related to flooding duration and/or frequency or sedimentation, are found on the distribution of ruderal vegetations in the floodplain flats.


Scheme R: Ruderal vegetation
decreasing morphodynamics
decreasing inundation time
VII Natural levees
Urtico-Cruciatetum laevipedis
Kruisbladualstro-ass.
Querco-Fagetea (Scheme F)
Arrenatheretalia (Scheme G)
Boerenwormkruid, Akkerdistel, Bijvoet, etc.
Zwarte mosterd vegetatie
grazing
II Low floodplain flats
III Low floodplain flats with a quick drainage
Salicio albae, Alno-Padion (Scheme F)
bare soil, after forest has been taken down
RG Urtica dioica
Brandnetel
ceasing management
Grasslands, especially Molinio-Arrhenatheretea and Plantaginetea majoris (Scheme G)
eutrofication
Salicion (Scheme F)
Valeriano-Filipenduletum
Ass. van Moerasspirea en Valeriaan
natural succession, irregular mowing enhances development
Phragmitetea (Scheme S)
Soncho-Epilobium hirsuti
Moerasmelkdistel-ass.
Lolio-Potentillion anserinae (Scheme G)
barely managed or abandoned
more wet
RG Solanum dulcamara-Phragmites australis- [Convolvulo-Filipenduletea
Bitterzoet and Riet]
I Shores of rivers, secondary channels, sloughs and other waters
B More upstream
RG Pulicaria dysenteria- [onvolvulo-Filipenduletea/Agrostietalia stoloniferae]
Heelblaadjes
RG Calystegio sepium-Phragmites australis- [Convolvulo-Filipenduletea]
Haagwinde and Riet



2*: estimated minimum number of years needed for development indicated.

RG Angelica archangelica- [Epilobion hirsuti] pioneer vegetation

3.6 Forest and shrubland

Softwood floodplain forest is the natural vegetation of shores of rivers and waters. They flood periodically and grow on a nutrient rich substrate. The dynamics of the water determine the environment of these forests, with important factors being: amplitude, duration and frequency of inundation. Grazing caused the disappearance of these forests. Ceasing the grazing shows a rather rapid development of softwood floodplain forest dominated by *Salix alba* (Schietwilg). Hardwood floodplain forest is the natural vegetation type of floodplain flats with a not too large water influx, but can stand periodical flooding. It occurs on all kinds of substrate, though when on sand and with periodic flooding a supply of nutrients via the ground water is necessary to prevent acidification. Due to the agricultural pressure this vegetation type has almost completely disappeared a while ago. The tree species within this vegetation type have a certain resistance to flooding, for example *Fraxinus excelsior* (Gewone Es) and *Ulmus minor* (Gladde Iep).

Forests and shrublands are found in all zonations of the floodplain flat. In general the softwood floodplain forest occurs on lower, more dynamic locations than the hardwood floodplain forest. Shrubland usually borders the forest.

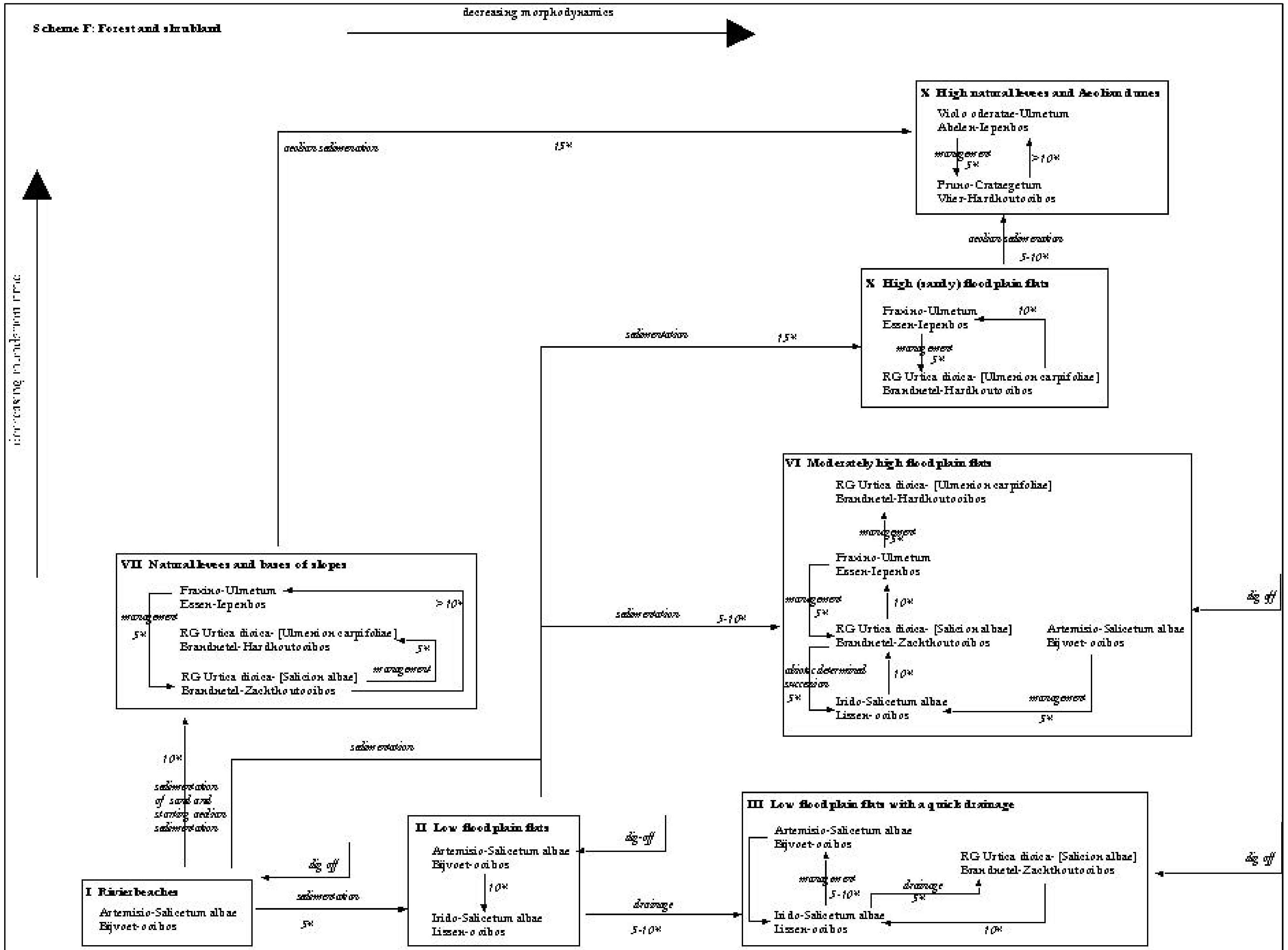
Three main classes are present within this vegetation structure type (Stortelder et al., 1999; Table F). The *Rhamno-Prunetea* (Klasse der doornstruwelen; part 5-page 121) is the shrubby category of this forest and shrubland vegetation structure type. They occur on a slightly humid to dry substrate. They are mostly found on clayey loamy soils, but are present on sand along rivers as well, because of the relatively high lime content. Originally the *Rhamno-Prunetea* is found along the borders of natural forests and on open places in forests.
The *Salicetea purpurea* (Klasse der wilgenvloedbossen en -struwelen; 5-165) and *Querco-Fagetea* (Klasse der eiken- en beukenbossen op voedselrijke grond; 5-287) are the two real forest categories. The first one is the vegetation of the more dynamic and humid environments.

Table F. Classification of the forest and shrubland in the Dutch river system. Based on Stortelder et al. (1999).

Class	Order	Alliance	Association
RHAMNO-PRUNETEA			
	Prunetalia spinosae		
		CARPINO-PRUNION	
			Pruno-Crataegetum
SALICETEA PURPUREAE			
	Salicetalia purpureae		
		SALICION ALBAE	
			Artemisio-Salicetum albae
			Irido-Salicetum albae
			Cardamino armarae-Salicetum
ROMPGEMEENSCHAPPEN			
			Urtica dioica – [Salicion albae]
			Impatiens glandulifera – [Salicion albae / Alno-Padion]
QUERCO-FAGETEA			
	Fagetalia sylvaticae		
		ALNO-PADION	
			Violo odoratae-Ulmetum
			Fraxino-Ulmetum
ROMPGEMEENSCHAPPEN			
			Urtico dioica – [Ulmenion carpinfoliae]

Quantitative data

The Projectgroep Bosecosystemen (1997) did a comprehensive study on forest ecosystems. The scheme in that report as well as the abiotic data presented is used again in this research.



In the sweat water tidal area the *Cardamino amarae-Salicetum* (Veldkers-Ooibos) occurs from the lower locations strongly influenced by the tide to the higher areas with a moderate influence. Relations (usually less flooding) with the Hardwood an Softwood variant of the *Urtica dioica* vegetation are found. The change will take 5* years or more.

Impatiens glandulifera- [Salicion albae/Padion] occurs in the sweat water tidal area as well. It needs yearly flooding.

2*: estimated minimum number of years needed for development indicated.

4 Usefulness

4.1 Modelling

The standardised definition of the vegetation communities should enable the use of this scheme in the whole of the Dutch river system. In combination with the defined physiotopes this can be useful in among others the development of the 'Decision Support System - Large Rivers' (Van Eupen et al., 2002) or a further elaboration of the 'Ecotopenstelsel' (Rademakers & Wolfert, 1994; Maas, 1998).

4.2 Missing data

Very apparent after the literature study, consulting experts and developing the succession scheme is the fact that accurate, measured abiotic data (especially flooding duration and frequency) in relation to vegetation communities is lacking. The same counts for the time needed for vegetation to develop from one community into another.

The data presented in this report are mainly expert judgement and partly measured data from researches. The measured data for certain vegetation types shows different ranges in several researches. This might be due to different vegetation typologies used, but of course is also related to the location where the investigations have been done. Using expert judgement the eventual range is defined.
Research for the coming years should focus on filling in these gaps in knowledge with accurate measured data. Within the Biogeomorphological Developments of Floodplains program of Delft Cluster Alterra is studying the effects of sedimentation on the development of grasslands along Dutch rivers (Project Verstoring & Successie). The amount of sedimentation was measured after floodings in the winter of 2000-2001. The former development of the floodplain flat was describes and vegetation relevées were made.

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3. Baptist, M.J., 2001. Review on biogeomorphology in rivers: processes and scales. CFR project report 3. Delft University of Technology.

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