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A model to estimate timing of aquatic weed control in drainage canals. Part 1

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Abstract. In many parts of the Netherlands a dense network of water courses is necessary to drain the land. A related aspect is the changing transport capacity of the water courses due to the growth of aquatic plants in the growing season. In turn this phenomenon requires aquatic weeds to be controlled by water boards in order to maintain the water course's required capacity. The procedure outlined in this paper can be used to determine the frequency of weed control based on hydrological and hydraulic conditions. The drainage from groundwater gives an expected variation in discharge over the growing season. The permissible flow rate is governed by both the growth of weeds and the permissible water levels in the water course. Weed control is necessary during the growing season when the expected discharge is more than the permissible flow rate. This procedure has been incorporated in the model MWW (Maintenance of Water courses by Water boards). An example how to use MWW is given.

Key words: scheduling weed control, expected discharge, flow rate, weed growth, flow resistance, groundwater model, drainage canals

Introduction

There are many ditches, brooks, canals and rivers in the Netherlands. All this water plays an important role in daily life and serves many purposes, such as discharge, water supply, transport and recreation. The smaller water courses, whether of natural origin or man-made, serve to drain the land and to prevent flooding. The larger water courses generally serve as channels conveying water and as shipping routes. Whereas the presence of water is essential, there often are periods with a surplus of water and periods with a deficit. Action is therefore required to control the water and to maintain suitable hydrological conditions. Farming areas require relatively dry conditions in winter and spring that promote workability and heavy crop yields, whereas nature areas require wetter conditions all year long so that the valued aquatic and terrestrial vegetation can be maintained.

In many parts of the Netherlands the water-table is shallow. The country's dense network of water courses is primarily to drain the land, but also to supply water to agricultural areas. As a result of these different functions the water levels vary over the year. In winter surface water levels are kept low to encourage quick drainage and in spring they are allowed to rise, to conserve water for dry periods in the coming summer. A related aspect is the reduced transport capacity of the water courses due to the growth of aquatic plants in the growing season. In turn this phenomenon requires aquatic weeds to be controlled in order to maintain the water course's required capacity.

Aquatic weed control has a great ecological impact. Growing awareness of the link between the environment and water management also underlines the importance of carrying out the weed control in a way that minimizes ecological damage. The feasibility of having various degrees of weed control suitable for both agriculture and nature conservation needs to be determined. To include environmental aspects explicitly in the decision making process for weed control would mean an integrated approach. Such an approach is beyond the scope of this paper, but can be found elsewhere (Querner 1993).

To date the frequency of weed control has been determined by rule of thumb. This may result in too much weed control or the failure to carry out the weed control during periods in which ecological damage can be kept to a minimum. Similar problems were reported by Skutsch (1993). To be able to formulate rules about weed control, the weed growth characteristics and the hydraulic and hydrological aspects involved must be understood.

In this paper the weed control practices in the Netherlands are discussed and the model MWW is described in which hydrological and hydraulic aspects are used to determine the necessary weed control. The flow resistance and the obstruction caused by aquatic weeds can be found in Querner (1997). To demonstrate the use of the model, it has been applied to two water courses in the Netherlands.

Aquatic weed control practices in the Netherlands

The water boards are responsible for the water management in rural areas. Their main task is to prevent flooding and to supply water for agriculture. This is often combined with water quality control. In the last twenty years other interests such as nature conservation and recreation, have become increasingly important. In the past hundred years the water boards improved water management considerably and at present they maintain approximately 55,000 km of water courses themselves while another 125,000 km are maintained by the land owners under their supervision. Maintenance by means of aquatic weed control is one of the major activities of the water boards. The yearly costs of weed control in the Netherlands have been estimated as about 200 million Dutch guilders. In general, weed control in water courses is done between once and five times a year.

Weed control is generally done according to a strict time schedule, slightly modified or improved over the years according to experience. It has usually been done in a way that avoids causing damage to agriculture. In practice, certain problems related to weed control are frequently found:

- water courses may be choked by aquatic weeds within a very short period;
- there are seasonal and annual variations in hydrological conditions (irregular wet and dry periods, different discharge characteristics);
- flooding can cause great damage to agricultural areas, so it should not occur frequently and too long;
- weed control needs to be carried out as efficiently as possible, while trying to minimize the cost of equipment and labour.

A weed control programme is also governed by the equipment available. Heavy weed growth is difficult to clear with light equipment and the result is more frequent weed control than strictly necessary to maintain the water course's required capacity.

The design of drainage channels must be based on certain rules, such as the design flow, minimum freeboard and maximum velocity. One single value for the flow rate and flow resistance is commonly used to calculate the required dimension of a water course. This implies that very little weed growth can be tolerated. The design discharge or specific discharge (for instance 1.2 $\mathrm{l \cdot s^{-1} \cdot ha^{-1}}$) often occurs in winter or springtime. In summer the maximum discharge is often less, because more incoming water is retained in the soil. In practice this has led to situations where some weed growth can be tolerated.

Excessive weed growth primarily reduces the capacity of the water courses to transport water, and results in higher surface water levels. Secondary effects are higher groundwater levels and less evapotranspiration. These hydrological changes could affect the workability of the land and depress crop yields. The environmental impact of weed control involves ecological changes and various secondary effects related to flora and fauna.

To maintain an adequate discharge capacity of the water courses during the summer period, weed control is carried out regularly. Figure 1 shows the important factors and goals influencing weed control. The discharge characteristics are influenced by the groundwater system (seepage, drainage, storage capacity) and meteorological factors (precipitation and evapotranspiration). The discharge capacity depends on the dimensions of the water course. The growth of weeds depends on factors such as water quality, water temperature, air temperature and substratum. Other factors such as land use, layout of the drainage network and the function of the water course are also important for the required weed control.

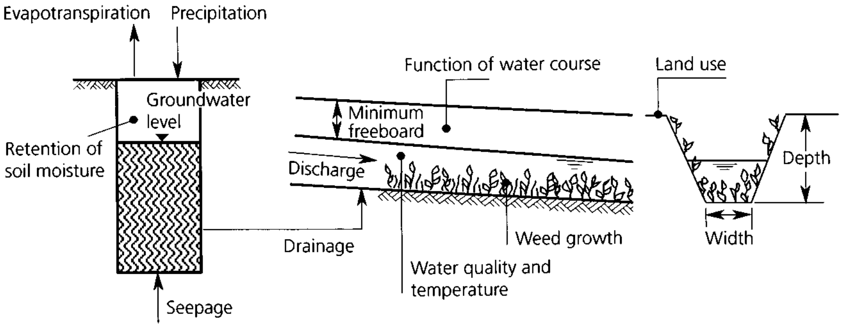

Figure 1. Main goals and physical factors related to groundwater and surface water flow that influence the scheduling of weed control in drainage systems.

The discharge from an area is in general governed by groundwater conditions encountered, such as drainage, depth of the groundwater level, seepage and land use. The discharge also varies over the year too in response to the weather conditions. In the summer period the discharge will generally be less than in the winter or early spring. On the other hand, weed growth reduces the effective flow area in summer (Fig. 2). The variation in discharge and weed growth over time depend on local conditions and will stipulate which period of the year will have the worst potential situation. The discharge characteristics, hydraulic capacity and weed growth that are important when deciding on weed control in a water course are shown in Figure 3. The procedure shown gives the hydrological and hydraulic factors related to weed control. In the following sections the procedure will be outlined in detail.

Model MWW: estimating the timing of weed control during the growing season

The basic concept of the model MWW is that drainage from groundwater gives an expected variation in discharge over the growing season. The permissible flow rate is governed by both the growth of weeds and the permissible water levels in the water course. Weed control is necessary during the growing season, when the expected discharge Q_p is more than the permissible flow rate Q_m. Therefore weed clearing is necessary when:

$$Q_p > Q_m \tag{1}$$

where:
Q_p = maximum expected discharge ($m^3 \cdot s^{-1}$)
Q_m = maximum permissible flow rate ($m^3 \cdot s^{-1}$)

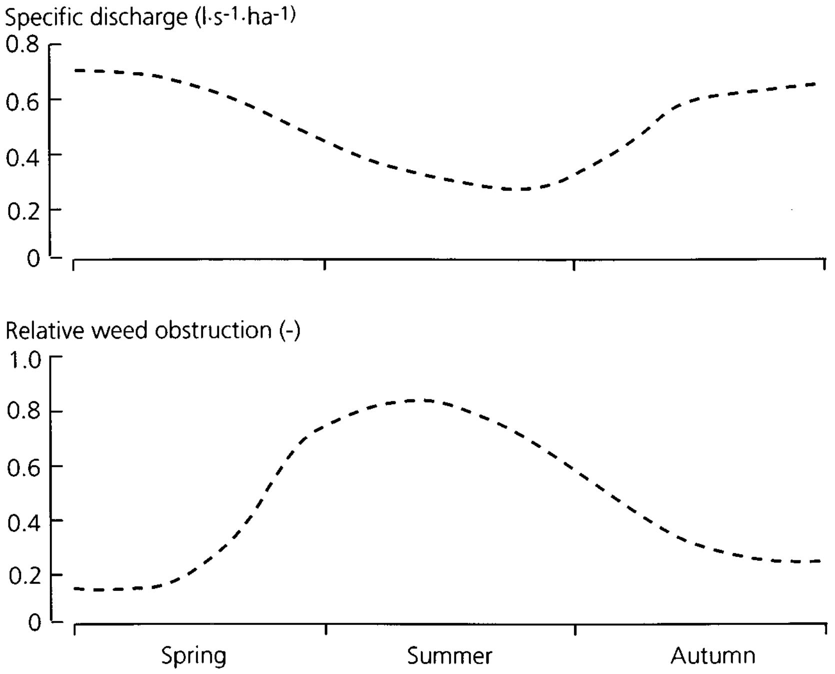

Figure 2. Variation in specific discharge and weed obstruction in a hypothetic water course during the annual cycle. These variations make it difficult to estimate which periods will have the worst potential situation.

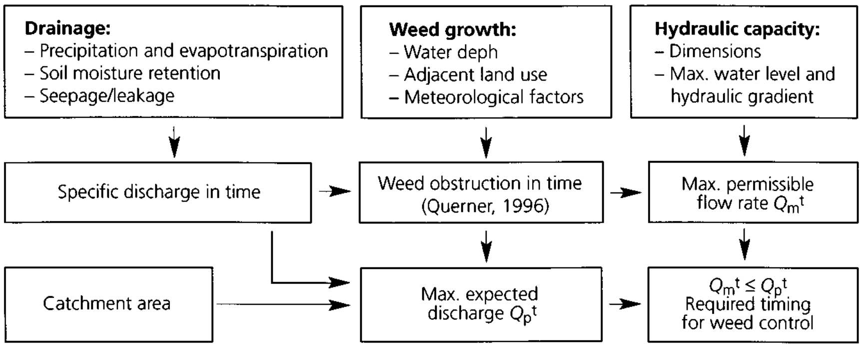

Figure 3. Procedure to estimate periods in which weed control is required, based on information of drainage from groundwater, the weed growth (obstruction) and the hydraulic capacity of a water course.

It may be acceptable that the expected discharge Q_p exceed the permissible capacity Q_m for a short duration.

The maximum expected discharge Q_p must be calculated for a certain recurrence interval. For a particular water course in a catchment this maximum discharge is:

$$Q_p^t = 10 q_p^t A_c F_c + Q_u^t \tag{2}$$

where:

q_p = expected specific discharge for recurrence interval (factor 10 is needed to convert units from $\mathrm{m}^3 \cdot \mathrm{s}^{-1}$ to $\mathrm{l} \cdot \mathrm{s}^{-1} \cdot \mathrm{ha.}^{-1}$)

A_c = catchment area (m^2)

F_c = reduction factor for specific discharge to account for very large catchments (–)

Q_u = additional discharges, such as effluent from sewage treatment works or sewer emergency overflow ($\mathrm{m}^3 \cdot \mathrm{s}^{-1}$)

The maximum permissible capacity Q_m required for the procedure of Figure 3, can be estimated for the unobstructed part using Manning's formula as (Querner 1997):

$$Q_m^t = W_r^t A_s k_M^0 R_o^{2/3} S_m^{1/2} \tag{3}$$

where:

W_r = relative weed obstruction (–)

A_s = wetted area for high flow stage (m^2)

k_M^0 = roughness coefficient for unobstructed part ($\mathrm{m}^{1/3} \cdot \mathrm{s}^{-1}$)

R_o = hydraulic radius for unobstructed part (m)

S_m = maximum hydraulic gradient (–)

The reduction in flow area, $W_r \cdot \mathrm{A}_s$, due to weed growth should be derived from field measurements such as given by Querner (1997). The roughness coefficient for the weed free part, k_M^0, remains for such cases about constant in the order of 30 to 34. The hydraulic radius for the unobstructed part of the cross-section was derived from the field measurements as described by Querner (1997). The hydraulic gradient required in Eq. (3) will be different for each water course and can also vary during the year. The minimum freeboard required depends on the adjacent land use.

Equation (2) gives the maximum expected discharge in time and Eq. (3) the maximum permissible flow rate. Weed control should be carried out when the maximum permissible flow rate, Q_m, is less than the maximum expected discharge Q_p (Fig. 3). This analysis yields the actual timing of weed control.

Based on the procedure outlined by Figure 3 the MWW model (Maintenance of Water courses by Water boards) was developed. MWW calculates the times of aquatic weed control for a water course during the growing season. These times depends on the expected discharges (eq. 2) in relation to the permissible flow rate (eq. 3).

The model requires data of the water course and the catchment area. Also required are data on the specific discharge within the catchment and the aquatic weed growth. Part of the data should be given interactive and part in data files.

Instead of calculating the times of weed control, MWW can be used by specifying actual times of weed control. In this way the transport capacity of the water course during the growing season is calculated and these results show the possible risk of too high water levels or flooding.

Application

Study area

The Poelsbeek and Bolscherbeek catchments, in size 64 km^2, are located in the east of the Netherlands (Fig. 4). The ground surface slopes from about 30 m above NAP (reference level in the Netherlands) in the south-east to about 12 m above NAP in the north-west. The area consists of sandy soils. Land use is predominantly agricultural; about 48% is pasture, 20% is arable land (mainly silage maize), 24% is woodland and 8% is residential. Both catchments are part of a bigger area controlled by the water board ‘Regge en Dinkel’. This board is responsible for managing water quantity and quality.

Hydrological modelling

To illustrate the procedure outlined in Figure 3 the frequency of weed control for two water courses was calculated. The maximum expected discharges for a certain recurrence interval were calculated using the one-dimensional model SIMFLOW (Querner 1993). The unsaturated zone in SIMFLOW is considered by means of two reservoirs, one for the root zone and one for the subsoil (Fig. 5). If the equilibrium moisture storage for the root zone is exceeded, the excess water will percolate to the saturated zone. If the moisture storage is less than the equilibrium moisture storage, then the result will be an upward flow from the saturated zone. The height of the phreatic surface is calculated from the water balance of the subsoil, using a storage coefficient which is dependent on the depth of the groundwater level below soil surface. The unsaturated zone is modelled one-dimensionally per land use (Querner

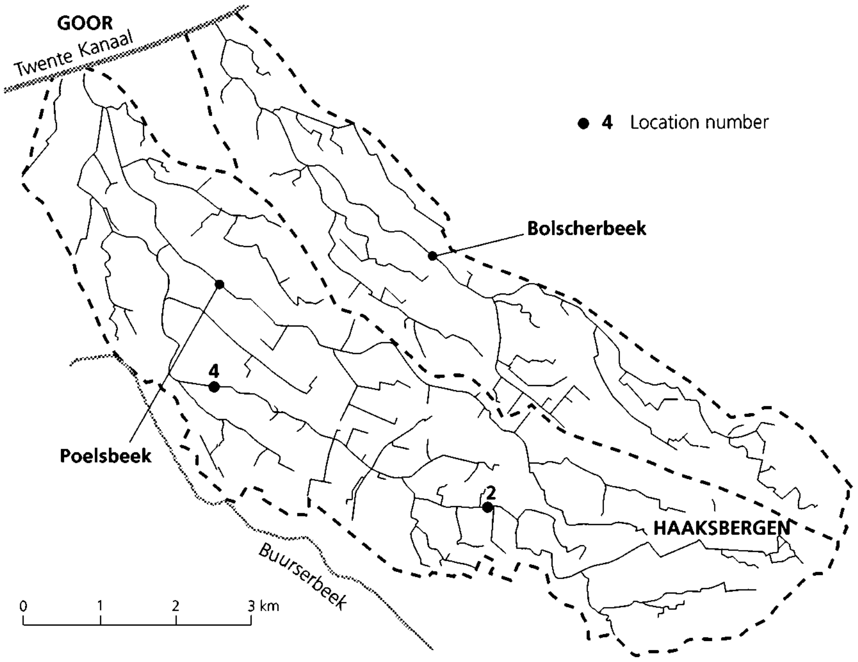

Figure 4. Water courses of the Poelsbeek and Bolscherbeek catchments located in the eastern part of the Netherlands. For locations 2 and 4 the required weed control was calculated.

1988). Special processes are included in the unsaturated zone model, i.e., surface runoff, perched water-tables, hysteresis and preferential flow.

The often dense network of water courses, related to size and density, is important for the interaction between surface water and groundwater. Three drainage subsystems are used in SIMFLOW for the modelling of the interaction between surface water and groundwater. The water courses primarily involved in this interaction are: the secondary system, the tertiary system and the trenches. The drainage is calculated for each subsystem using a drainage resistance and the difference in water level between groundwater and surface water (Ernst 1978).

Calculation of discharges with SIMFLOW

SIMFLOW uses a prescribed surface water level and a lower boundary condition to represent the regional flow component (Fig. 5). The hydrological data for SIMFLOW are given in Table 1. The calculations were carried out for three typical situations defined by the ‘water-table fluctuation classes’, commonly used in the Netherlands (Table 2). In Figure 5 the lower boundary flux versus the groundwater table depth is given for each water-table class.

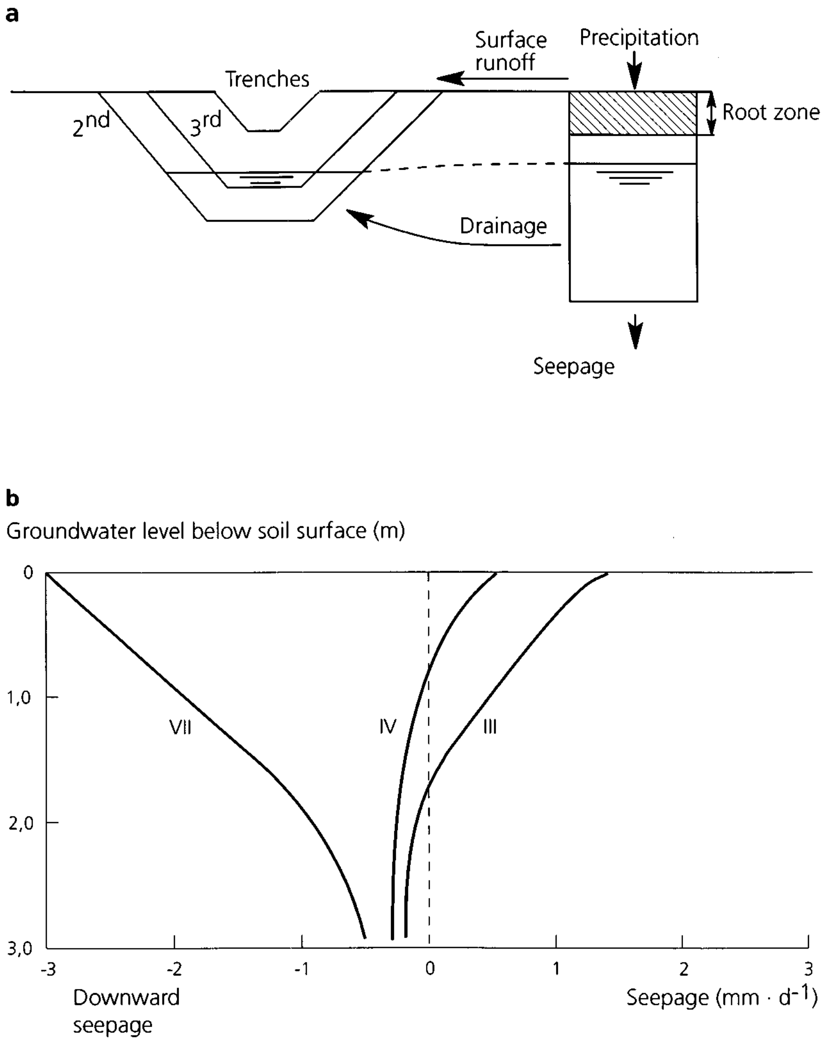

Figure 5. Unsaturated zone model SIMFLOW (a) used to calculate the drainage to the surface water system (secondary and tertiary water courses plus trenches) and the lower boundary flux (b) required for the model.

This boundary condition of the model represents the link with the regional hydrological system and was derived from calculations with a regional groundwater flow model (Querner 1993).

The simulations with the SIMFLOW model were carried out for a 40 year period (1951–1990), using daily meteorological data from the Royal Dutch Meteorological Office (weather station De Bilt) and a time step of one day.

Table 1. Data for the unsaturated zone model SIMFLOW (Fig. 5) for an agricultural area. The hydrological situation is defined by three water-table fluctuation classes described in Table 2 (Querner 1993).

Water-table fluctuation class (Table 2)	Soil unit*	Depth of water course (m)		Water level below soil surface (m)**		Drainage resistance *** (d)	
		Second.	Tert.	Winter	Summer	Second.	Tert.
III	4	1.2	0.6	1.0	0.9	500	100
IV	1	1.4	0.8	1.2	1.0	750	200
VII	2	–	1.2	–	–	–	3000

[*] Soil unit: 1 = reclaimed areas; 2 = ridges and 4 = valleys of the brooks
[**] Water can be supplied in summer to guarantee this level
[***] Drainage resistance of trenches = 75 d

Table 2. Seasonal fluctuation of Dutch groundwater levels, as a depth below soil surface. This is defined in terms of ‘mean highest’ and ‘mean lowest’ groundwater level (Van Der Sluis & De Gruijter 1985).

Groundwater level	Depth of seasonal fluctuation below soil surface (m)		
	III	IV	VI
‘Mean highest’	< 0.4	> 0.4	0.8–1.4
‘Mean lowest’	0.8–1.2	0.8–1.2	> 1.2

The specific discharge obtained during the year is shown in Figure 6. Results are given for discharges occurring once a year and once in five years. A sudden decrease in discharge can be noted between the three water-table fluctuation classes. Class VII represents situations with deep groundwater levels (Table 2), resulting in drainage of about 0.05 $\mathrm{l{\cdot}s^{-1}{\cdot}ha^{-1}}$. For the classes III and IV the specific discharge in summer is much less than in winter (Fig. 6). In summer this reduction can be used to tolerate a fair amount of weed growth in the water courses.

Timing of weed control

Two water courses in which the weed growth had been measured were selected for the analysis with the MWW model (locations 2 and 4 in the Poelsbeek catchment; for location see Figure 4, for hydraulic data see Table 3). The roughness coefficient for the open water part, k_M^0, was taken as 32 (Querner, 1997). For the weed growth the relative obstruction measured in the field was taken (Querner, 1997).

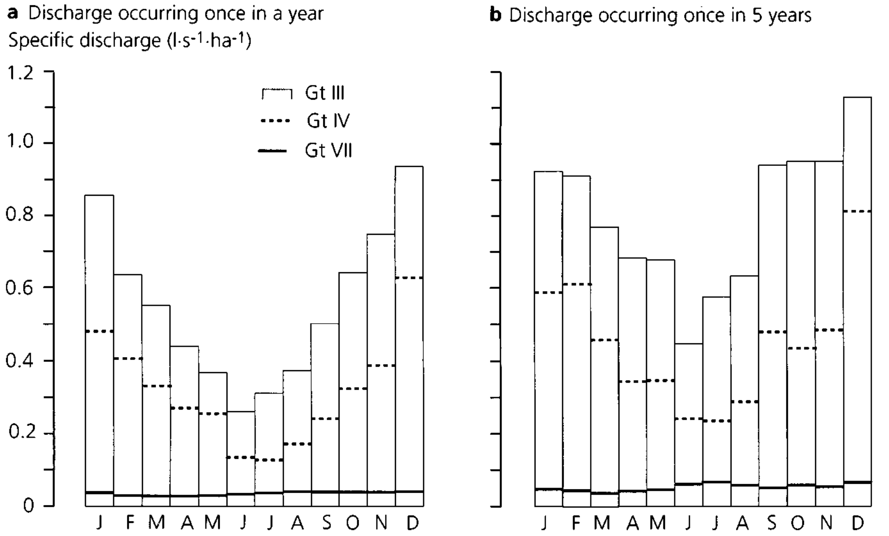

Figure 6. Specific discharge calculated with the SIMFLOW model for the three water-table classes (definition given in Table 2), using the data from Table 1 (meteorological data from 1951 to 1990).

Table 3. Hydraulic design data for two water courses in the Poelsbeek area (locations 2 and 4 are shown on Figure 4).

Parameter	Location 2	Location 4
Maximum hydraulic gradient (m·km^{-1})	0.85	0.35
Base width (m)	1.4	2.2
Wetted area for high flow stage (m^2)	2.0	4.4
Design discharge (l·s^{-1}·ha^{-1})	1.2	1.2
Weed category*	Ia	IIIm
Catchment area (ha)	866	1603

*a = average obstruction of the observed range (Querner 1997: Fig. 10)
m = maximum obstruction of the observed range

The weed control required was calculated for the actual groundwater fluctuation classes present in the catchment area. The specific discharge with a recurrence interval of five years (Fig. 6b) was chosen to indicate the weed control required. For the summer period this recurrence interval was considered to be appropriate in relation to the economic risk. The sewer emergency excess flow from the town of Haaksbergen was also included (Fig. 4). The maximum excess flow for design purpose is 30 mm of rainfall from the imper-

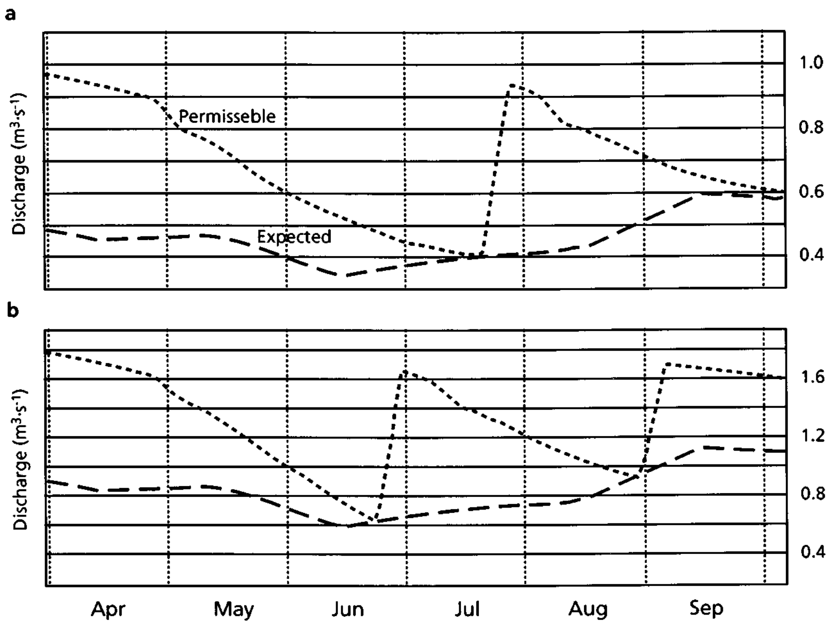

Figure 7. Timing of weed control for two locations in the Poelsbeek calculated with the MWW model. When the maximum expected discharge exceeds the maximum permissible flow rate, weed control is necessary (locations 2 and 4 are shown on Fig. 4). (a) Location 2; (b) Location 4.

meable areas, lasting 75 minutes. This excess flow is generally assumed not to coincide with the maximum drainage. Instead an amount of 10 mm.d^{-1} (1.16 l·s^{-1}·ha^{-1}) was assumed to occur at the same time as the peak discharges from drainage. For location 2 and 4 the areas to be drained are given in Table 3 (approximately 45% is class III and 34% is class IV). The results of the calculations with MWW are shown in Figure 7. This figure shows the maximum expected discharge and the maximum permissible flow rate during the growing season. For location 2 weed control is necessary in July and for location 4 in June and the end of August. Location 4 requires earlier clearance, because the maximum hydraulic gradient is less than at location 2.

The frequency is dependent on the assumptions used in the groundwater model. If, for instance, more surface runoff occurs than assumed at present, this would increase the specific discharge and also the required frequency of weed control (Fig. 7). If a specific discharge with a recurrence interval of one year is chosen, then the necessity of weed control will be reduced.

Conclusions

The procedure outlined in this paper can be used to determine the frequency of weed control based on hydrological and hydraulic conditions. The model MWW developed for this purpose enables the clearing periods to be determined for different situations within the surface water system or river basin. This information can be used by water authorities to adjust their weed control programme so that equipment is used as efficiently as possible. Also the timing of weed control can be adjusted in order to keep the environmental impact to a minimum.

A one-dimensional model of the unsaturated zone (SIMFLOW) was used to compute the expected discharges during the year. Expected discharge is lower in summer and this enables a fair amount of weed obstruction to be tolerated.

The discharge capacity depends on the dimensions of the water course. Therefore weed control should already be considered when new water courses are being designed. At this stage it is easy to modify the design in order to minimize the cost of construction and the recurrent annual maintenance costs. A water course with a greater capacity than required needs less weed control and the exact timing of weed control is less important. Their may be other drawbacks, but the resulting benefits include being able to carry out the maintenance with less expensive equipment and less man power, or at a time more favourable for nature conservation.

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