5 COUPLING OF HYDROLOGICAL TO ECOLOGICAL MODELS

P.E.V. van Walsum, P.C. Jansen , F.J.E van der Bolt, & A.A. Veldhuizen

5.1 Introduction

For use as input to ecological submodels the raw output data of the regional model SIMGRO have to be postprocessed. This postprocessing is necessary for a variety of reasons, involving:

- downscaling of watertables to the appropriate spatial scale
- explicitation of the ecologically relevant upward seepage flux
- computation of the moisture stress
- computation of discharge statistics

The developed procedures are described in Sections 5.2 through 5.5

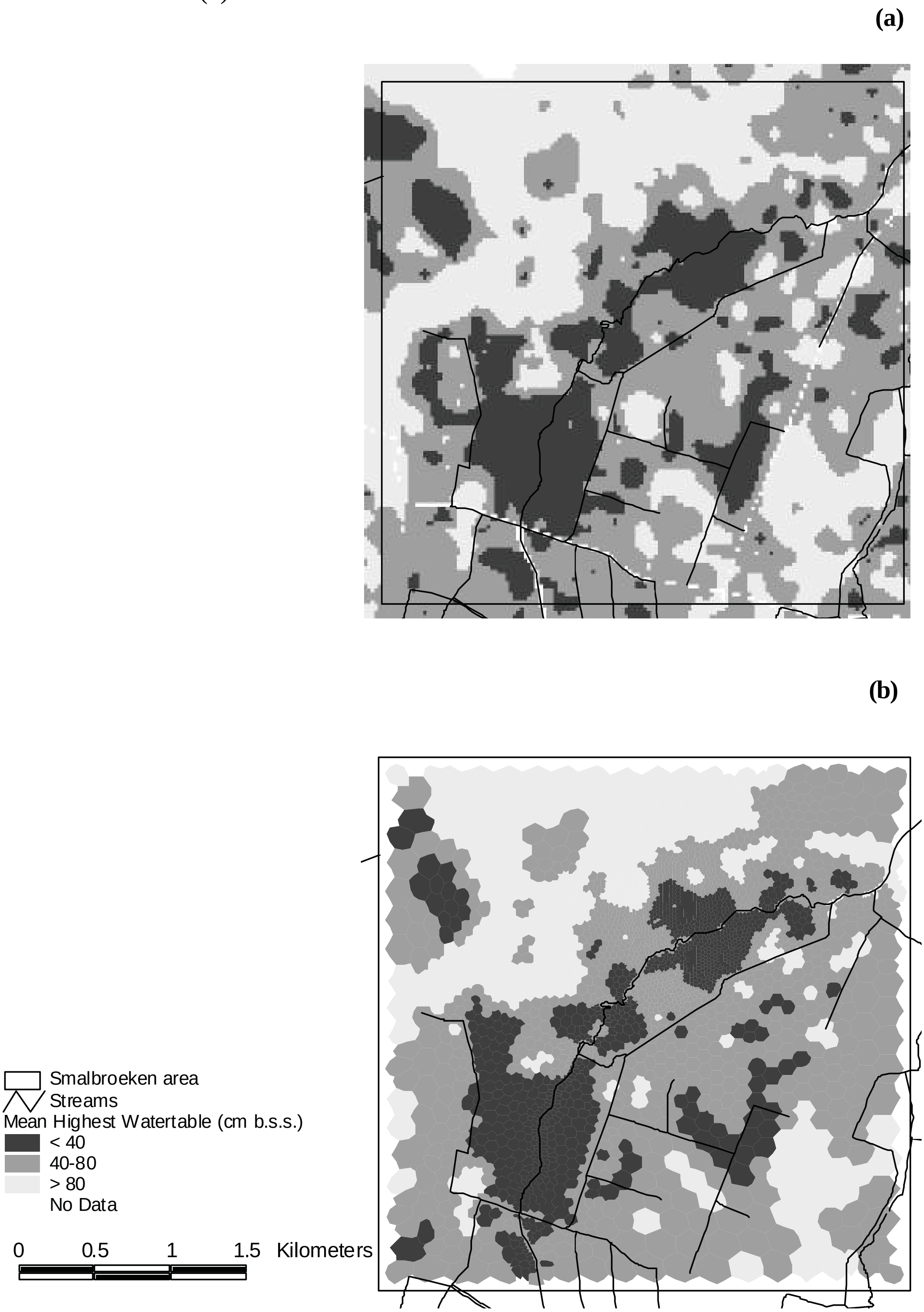
5.2 Downscaling of watertables

The NATLES evaluation model (Section 7) for the terrestrial ecology uses a 25 x 25 m grid. In order to do justice to that fine spatial scale the watertables computed by SIMGRO have to be downscaled from the values for the nodal subdomains that have a cross-section of at least 100 m, and a mean diameter of 240 m. The employed downscaling method is based on the notion that at the scale of 25-100 m the topography is the determining factor for the local variations of the watertable depth with respect to the soil surface. Thus the procedure involves the following steps:

- the watertables for the nodal subdomains are considered to be point values at the nodal points of the finite-element network
- using the GIS-software ArcInfo a spline surface is interpolated between the watertables at the nodal points, and then converted to the 25 x 25 m grid
- the obtained watertables are subtracted from the Digital Terrain Model of the region, that also has a grid with 25 x 25 m

This method has been verified by making a so-called zoom model for a 3.5 x 3.5 km block in the 'Smalbroeken' area (for the location see Figure 1.2). The mean diameter of the 3000 nodal subdomains is 60 m. As can be seen from the comparison made in Figure 5.1 for the current situation, the verification shows that the downscaling procedure works well.

Figure 5.1 Simulated maps of Mean Highest Waterable in the Smalbroeken area: simulated with the model for the whole region, then downscaled (a) and simulated with the zoom-model (b).

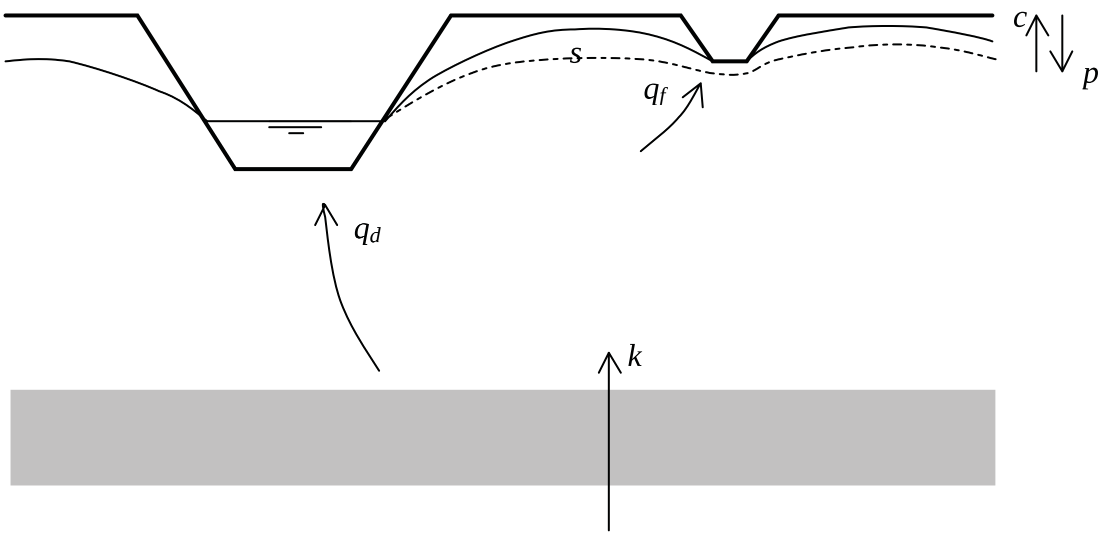


5.3 Seepage to the rootzone

For the ecological evaluation with NATLES we need to know the *gross upward seepage flux to the root zone*, because this flux determines to what extent the sites are buffered against acidification. The buffering substance is the bicarbonate contained in the groundwater. The mentioned flux is not the same as the gross seepage flux passing through the bottom of the first aquifer, because most of that water directly flows into the deeper ditches and does not reach the root zone at all. The mechanism at play involves the build-up of a precipitation lense on top of the groundwater that seeps up from the deeper aquifer (area enclosed by watertable and dotted line in Figure 5.2). This lense is thickest in winter and becomes thinner during the summer half-year. Only when the lense completely vanishes does the seepage reach the root zone. For an accurate calculation of the amount of water that actually reaches the root zone it would be necessary to use a fully three-dimensional model of groundwater flow and not a so-called quasi-3D model that is used here. But that is not all, because it would also require the modelling of every deep ditch in an explicit manner, and without any 'lumping' that inherently is done by using the concept of a drainage resistance based on the average density of conduits forming the drainage system.

In this study a simplified approach is followed, that aims at making an upper bound estimate of the gross seepage to the root zone. Such a *max*-estimate is perhaps less accurate than a method that aims at a 'best' estimate, but has the advantage that one can say more about the

Figure 5.2 Schematisation for calculation of the gross upward seepage flux to the root zone. The precipitation lense with storage volume s_t has to vanish before any seepage to the root zone can take place.



uncertainty interval: in the case of the *max*-estimate, the (unknown) real value is clearly not higher. In the case of a 'best'-estimate nothing at all can be said about the uncertainty interval (unless of course the results are compared to a study involving every single ditch in the model). In the approach described here the assumption is made that *as long as there is water in the precipitation lense and at the same time there is drainage to ditches, the drainage water will purely consist of precipitation water stored in the lense*. In reality some of the drainage water to ditches will consist of deep seepage water long before the precipitation lense has completely vanished. So the lense will exist longer than is predicted in the simplified approach, and thus the seepage to the root zone will in reality be less than what is calculated.

The implementation of the method involves making a day-to-day water balance of the water in the precipitation lense:

$$s_t = s_{t-\Delta t} + (p_t - c_t - \Sigma_i \, q_{i,t}) \cdot \Delta t \qquad (5.1)$$

in which:

- s_t : volume of water in the precipitation lense at time t (m)
- p_t : percolation from the root zone to the watertable (m/d)
- c_t : capillary rise from the watertable to the root zone (m/d)
- $q_{i,t}$: drainage flux to i^{th} order of drainage media (m/d)
- Δt : time interval of 0.25 day (d)

If the computed value drops below zero, the storage is set to zero. Seepage to the root zone is only computed for periods with $s_t = 0$. That seepage is set equal to the net capillary rise plus the flux to the shallow trenches:

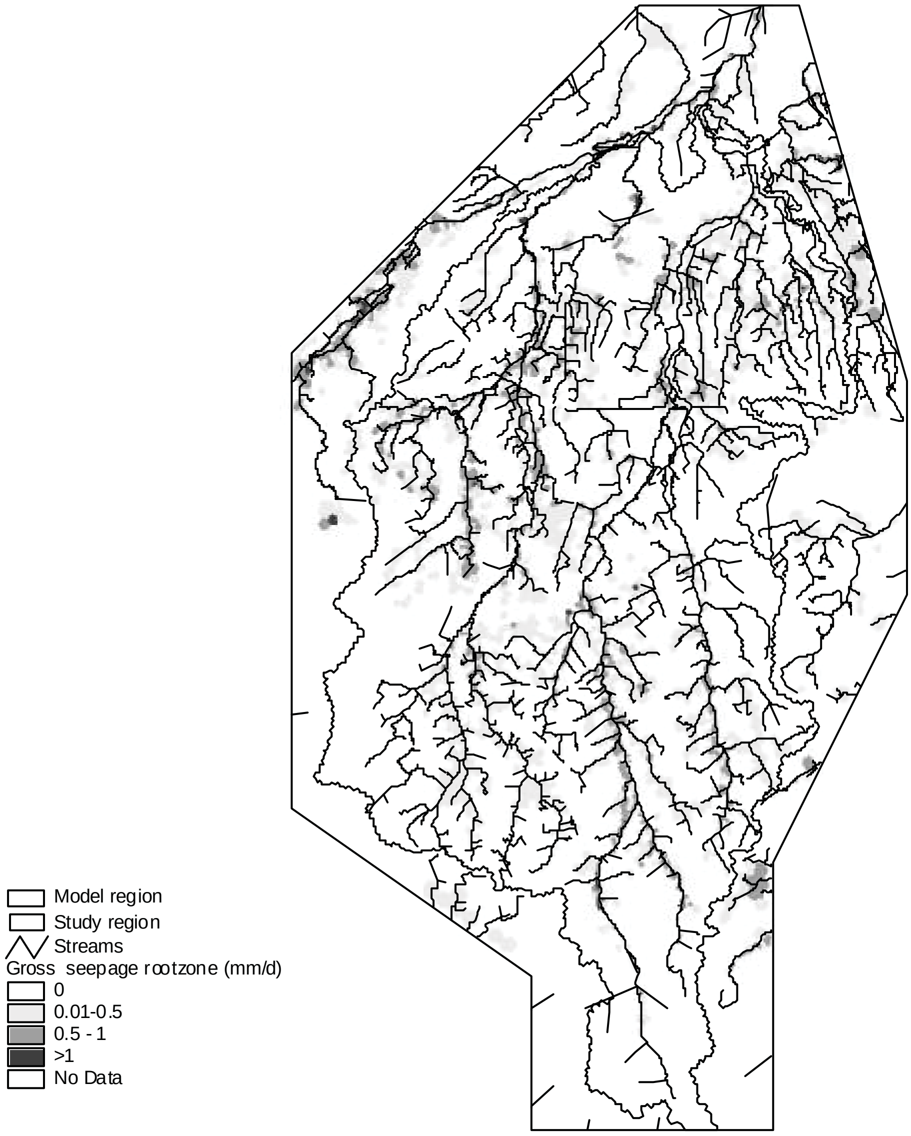
$$w_t = w_{t-?t} + \mathbf{max}\ \{0, (c_t - p_t + q_{f,t}) \cdot \Delta t\ \} \qquad (5.2)$$

in which

- w_t : the gross upward seepage to the root zone at time t (m)
- $q_{f,t}$: drainage flux to shallow trenches (m/d)

The max-operator is to ensure that only positive contributions are counted. The reason for including the flux to small trenches is that this water out of necessity passes near to the roots

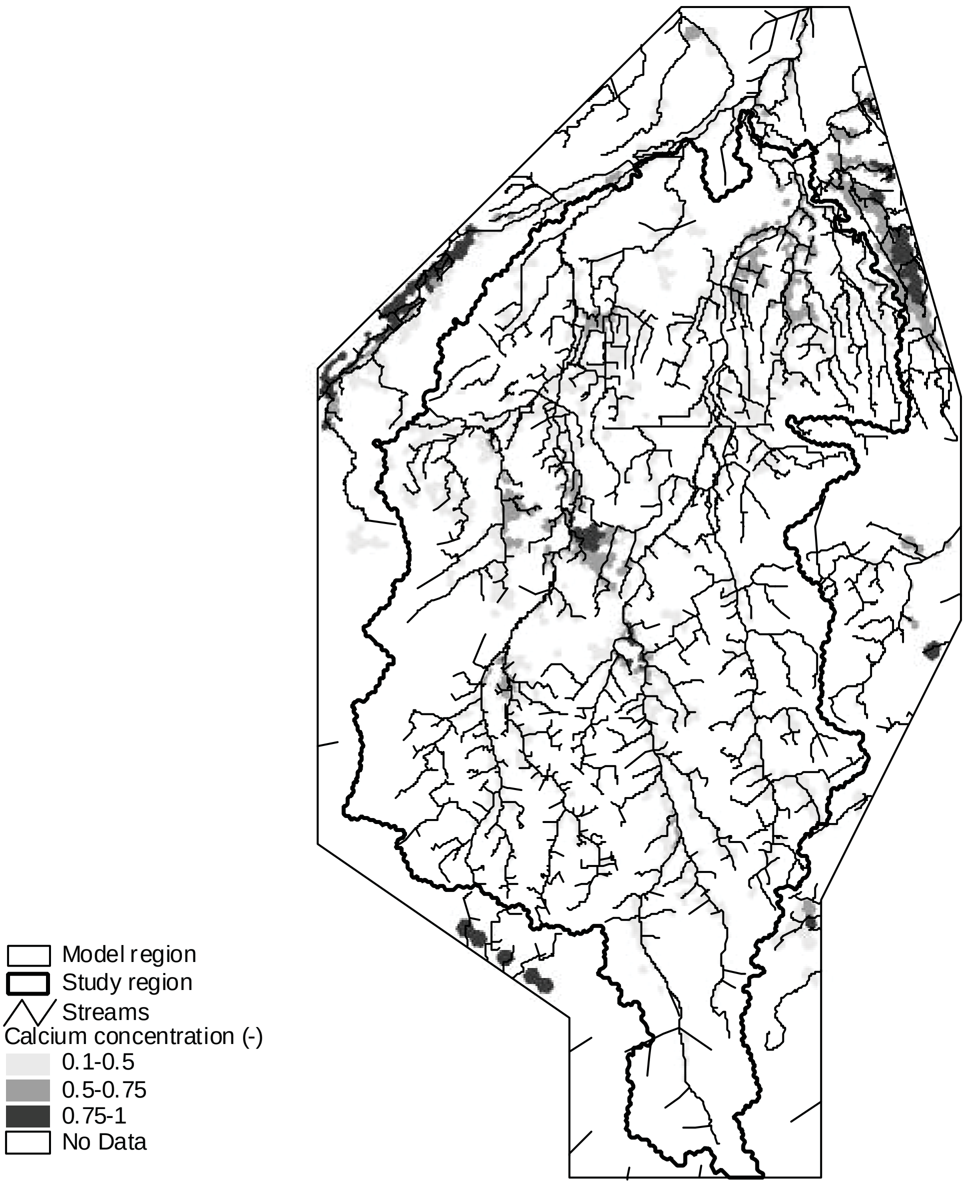
Figure 5.3 Gross upward seepage to the root zone (maximum value estimate), computed for the current situation.



of plants, because the trenches are shallow and more evenly distributed than the ditches. The computed seepage for the current situation is given in Figure 5.3.

Another reason for the overestimation of the seepage to the rootzone is that in the balance given in Eq. 5.1 no distinction is made between the saturated and the unsaturated zone: the balance is made for the total system volume including both zones, starting from the bottom boundary of the precipitation lense and ending at the bottom of the root zone. This means that according to the balance equation drainage of water to ditches can effectively 'remove' *all* of the water in the unsaturated zone, whereas in reality that only holds true for the water that will freely drain from the soil under the force of gravity. Removal of the water that does not drain under gravity forces is only possible by flushing the system from below by seepage that drains through the trenches or from above by sucking water through the zone in the form of capillary rise. In many instances one of these mechanisms will indeed be active. And since the unsaturated zone is relatively thin in the wet stream valleys, the error made by this type of overestimation will not be very substantial.

Figure 5.4 Computed calcium concentrations of seepage water (that reaches the root zone), presented as a fraction of the saturated concentration



For the ecological evaluation not only the amount of seepage is relevant, but also the calcium content of the seepage water. Calcium enrichment of groundwater takes place during contact with calciferous sediments in the deep subsoil. We have assumed that the calcium solution process is governed by a first order differential equation of the form:

$$\frac{dc}{dt} = \frac{1}{T} \cdot (1 - c) \tag{5.3}$$

in which:

- c : dimensionless concentration, as a fraction of the saturated concentration (-)
- t : time (y)
- T : characteristic time of the solution process (y)

This equation is of course a simplification of reality, but suffices for obtaining an idea of the sensitivity for the various climate scenarios. The above equation has been implemented for the discretisation of nodal subdomains, for the 15 layers of the subsoil. A mixing-cell approach (semi-implicit for the time discretisation) has been used for the calculation scheme, assuming perfect mixing per time step of one year. For computing the end-concentrations such an approach provides satisfactory results, and that is all that is required in this study. The computed concentrations are given in Figure 5.4. The high concentrations just left to the center of the region are caused by deep groundwater that is forced to the surface by the Feldbiss fault that cuts right across the center of the study region from East to West.

5.4 Moisture stress of natural vegetation

5.4.1 Introduction

For evaluating the effects of climate scenarios on the natural terrestrial vegetation it is necessary to quantify the relationship between the climax vegetation and the soil moisture conditions. For very moist and moist conditions there is a high correlation between vegetations consisting of hygrophytes and mesophytes and the Mean Spring Watertable. (Runhaar *et al*. 1997). (The Mean Spring Watertable MSW is here defined as the average watertable in March-April) Hygrophytes are adapted to wet and periodically anaerobic circumstances. Mesophytes, however, need less moist conditions, but can not survive under extremely dry conditions (Londo 1975). Xerophytes are adapted to dry conditions, and their presence is well correlated to the so-called moisture stress (Jansen *et al*. 2000). The moisture stress is defined as the number of days (on average) that the pressure head in the rootzone is lower than –12 m. The relationship that has been found is:

$$Y = 0.38 \cdot X + 13.11 \qquad (5.4)$$

in which:
- X : percentage of xerophytes according to the moisture classification of species by Runhaar (1987) (%)
- Y : mean number of days with a pressure head < -12 m in the middle of the root zone (d)

In the standard version of NATLES (version 1.2) the moisture stress is related to the Mean Lowest Watertable. In that relationship the current climate is implicitly included in the coefficients. That means that the relationship is not suitable for use in a study involving impacts of climate *change*. So for this study we had to follow a different approach.

The SIMGRO model computes moisture contents that can be translated to pressure heads if required. However, these heads are only available at the scale of nodal subdomains. For interpolation to the pixels of 25 x 25 m needed for the ecological evaluation, the moisture contents are not very suitable. But the downscaling of watertables has proven to be a viable option (Section 5.2). For this reason we have sought relationships that make use of available watertables per 25 x 25 m in combination with the meteorological conditions.

5.4.2 Moisture stress as a function of watertable conditions and weather

The computational experiments for deriving the relationships were performed with the model SWAP (Van Dam *et al*. 1997). These experiments were done for soils classified according to the loam fraction, the coarseness, and the thickness of the top soil (A-layer). The soil physical data for the used series of soil profiles were taken from Wösten *et al*. (1994). The saturated moisture contents of the soil units have, however, been reduced by 20%, to account for processes like delayed rewetting (Van Walsum, pers. comm.). The choice of regression variables for deriving the relationships was based on physical notions about what can cause the dry conditions needed for letting the pressure head in the root zone drop below –12 m. The main notion is that extremely dry conditions can only prevail if the following two conditions are met:

- there is a limited supply of water from below, involving limited capillary rise from the watertable
- there is a large demand of water from above, involving a prolonged period with a precipitation deficit

For quantifying the limitation of supply from the watertable the soil physical characteristics have been analyzed with a steady-state version of SWAP. The watertable depth has been determined that allows a maximum capillary rise of 0.5 mm/d. This depth is here called the z-level. For coarse sandy soils a value of about 80 cm b.s.s. is found, for sandy soils with high loam content the z-level is around 250 cm b.s.s. The notion behind the choice of 0.5 mm/d is that for higher values the drying out of the profile is not likely, whereas for lower values it becomes possible. For estimating the limitation of supply from below the longest *continuous* period that the watertable drops below the z-level is determined. This is done for each year of the simulation period.

For quantifying the limitation of water supply from above a day-to-day cumulative balance of the precipitation deficit is made:

$$d_t = d_{t-1} + E_t - P_t \qquad (5.5)$$

in which:
- d_t : cumulative precipitation deficit at time t (mm)
- E_t : potential evapotranspiration on day t (mm)
- P_t : precipitation on day t (mm)

For each year of the simulation period the maximum value of the cumulative deficit is determined.

Various regression models were tried for fitting to the data of the experiments with SWAP. In the end the following model was found to give the most satisfactory results for relating the moisture stress X to the regression variables:

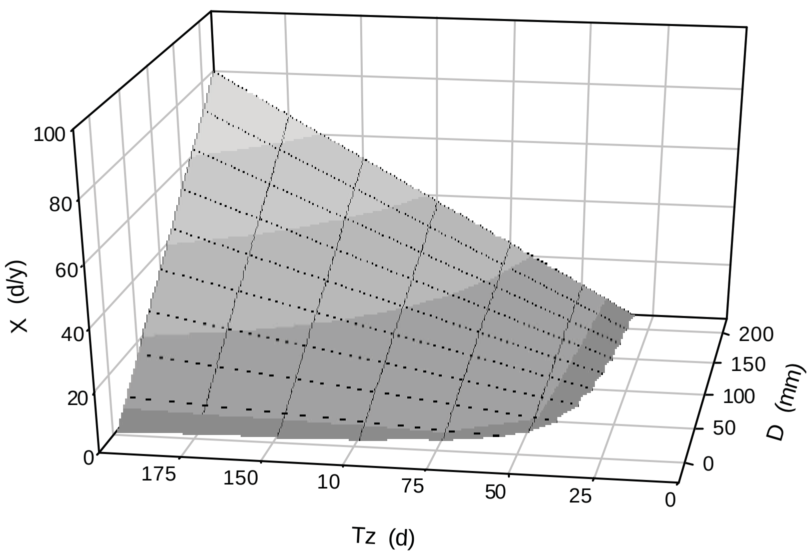
$$X = c_1 T_z + c_2 D + c_3 T_z D \qquad (5.6)$$

in which
- X : number of days that the pressure head in the root zone drops below –12 m (d/y)

- T_z. : number of consecutive days with the watertable below the z-level (d)
- D : maximum cumulative precipitation deficit (mm)
- c_1, c_2, c_3 - regression coefficients

The hyperbolic term ($c_3 T_z D$) is crucial because it models the interplay between the two factors involved: moisture stress develops if water supply from below and from above are both limiting in the *same* year. For loamy sand the explained variance is only 50%, but for the rest the explained variance is 85-90%. In Figure 5.5 an example is given of the regression function.

Figure 5.5 Example of a regression function for the moisture stress (X) as a function of:
- T_z. : number of consecutive days with the watertable below the z-level (d)
- *D* : maximum cumulative precipitation deficit (mm)



5.4.3 Application on a regional scale

For application on a regional scale the watertable results of the SIMGRO-model are interpolated from the nodal points to the 25 x 25 m pixels for each time step of the simulation, the same way as for downscaling of the watertables using ArcInfo in Section 5.2 But since the procedure had to be repeated more than 5 000 times per simulation run of 30 years (summer half years), a FORTRAN-program was written to speed up the computation process. The regression formula (Eq. 5.6) was applied for each pixel and each year *separately,* and then the values were averaged. The results for the current situation in the study region are presented in Figure 5.6.

Figure 5.6 Simulated moisture stress for the current situation.

5.5 Discharge statistics for aquatic ecology

For making the aquatic-ecological evaluation of the scenarios a number of discharge statistics are computed involving the median discharge. These statistics have been chosen with a view to quantifying the variability of the discharge, with special attention paid to the extremes at the low and high end of the discharge spectrum. The lower and upper bounds of the classes are defined in terms of a factor times the median discharge Q_{50}.

Table 5.1 Discharge extremity classes for evaluating the variability of the discharge. The lower and upper bounds are defined in terms of a factor times the median discharge Q_{50}. Per class the percentage of discharges is determined that falls within the interval defined by the lower and upper bounds

Discharge extremity class	Lower bound of discharge class (-)	Upper bound of discharge class (-)
O5	16.00	*8*
O4	8.00	16.00
O3	4.00	8.00
O2	2.00	4.00
O1	1.00	2.00
U1	0.90	1.00
U2	0.70	0.90
U3	0.30	0.70
U4	0.05	0.30
U5	0.00	0.05

By way of example, the class O_3 is graphically illustrated in Fig. 5.7. O_3 is the percentage of discharges in the interval:

$$4\,Q_{50} < Q < 8\,Q_{50} \qquad \text{(interval } O_3\text{)}$$

In some instances the values are in the text given in [days/year] which corresponds to 0.274%.

In terms of extremes the aggregated parameters are used:

$$R_i = U_i + O_i \quad , \quad \text{for } i=1....5 \qquad (5.8)$$

Figure 5.7 Graphical illustration of the discharge extremity class O_3. O_3 is the percentage of discharges between 4 and 8 times the median discharge Q_{50}.