8 EFFECTS ON REGIONAL HYDROLOGY AND STREAM MORPHOLOGY

P.E.V. van Walsum and J.W.J. van der Gaast

8.1 Introduction

The results of the ‘abiotic’ modelling are for the most part only of interest as intermediate variables that partly determine the outcome of ecological evaluation procedures. But for a good interpretation of the ecological effects it is essential to gain some understanding of the underlying hydrological effects.

8.2 Effects on the soil water and groundwater system

The main water balance terms of the ‘top’ system are presented in Table 8.1. The water balance ‘error’ term ΔB is the amount of water that leaves the region through extractions (37 mm/yr) and through the boundaries (15 mm/yr in the current situation). From the results for the diverse scenarios it becomes clear that the variation of the amount leaving the region is small in absolute terms. Most of the variations of precipitation are directly translated to changes of the discharge, with effects on the evapotranspiration acting as an attenuating term:

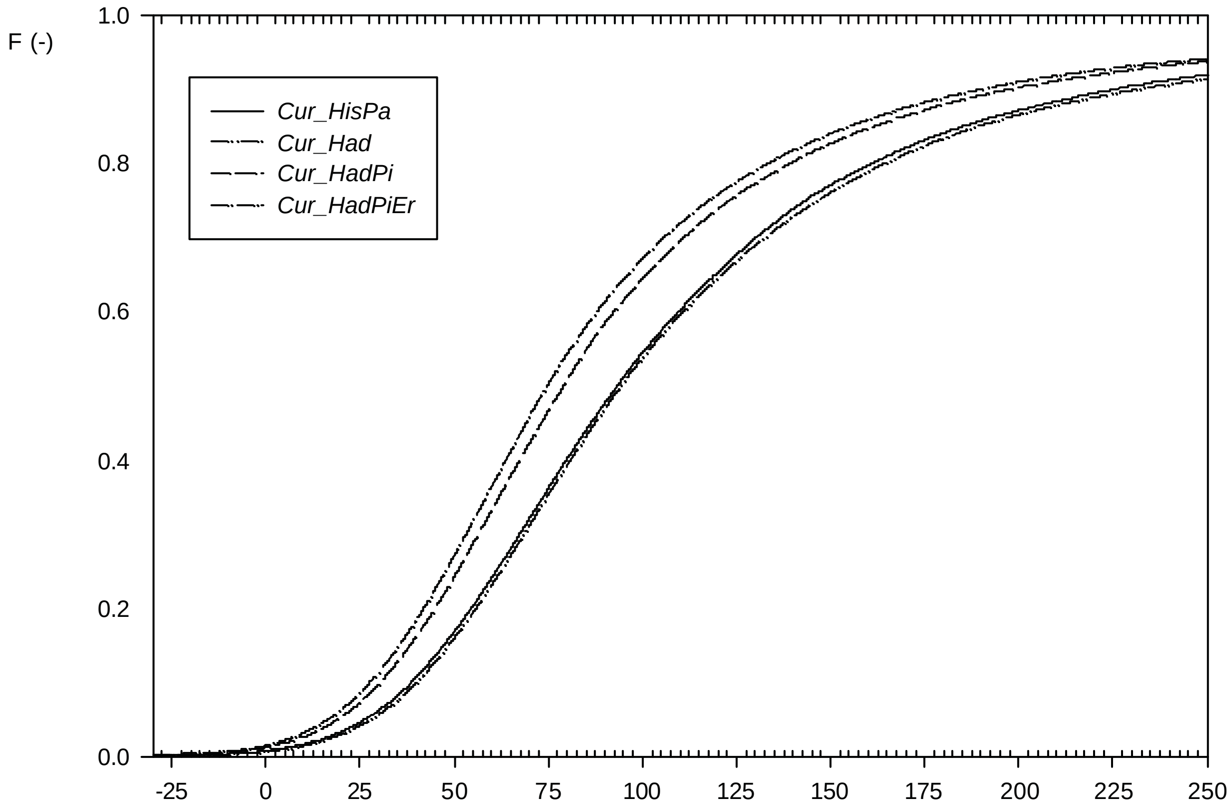
Table 8.1 Water balance terms of scenarios. The balance ΔB is the amount of groundwater water that leaves the regional system through deep extractions and through the boundaries.

Scenario code	P_{winter} (mm/½yr)	P_{summer} (mm/½yr)	P (mm/yr)	E (mm/yr)	Q (mm/yr)	ΔB (mm/yr)
Cur_His	414	381	795	480	263	52
Cur_HisPa	410	380	790	485	250	55
Cur_Had	420	351	771	500	222	49
Cur_HadPi	486	390	876	530	287	59
Cur_HadEr	420	351	771	465	253	53
Cur_HadPiEr	486	390	876	490	324	62
Ehs_His	414	381	795	480	264	51
Ehs_HadPi	486	390	876	529	286	61
EhsBuf_His	414	381	795	476	261	58
EhsBuf_Had	420	351	771	495	220	56
EhsBuf_HadPi	486	390	876	527	285	64
EhsBuf_HadEr	420	351	771	471	242	58
EhsBuf_HadPiEr	486	390	876	498	312	66
EhsBufM_His	414	381	795	477	257	61
EhsBufM_Had	420	351	771	499	214	58
EhsBufM_HadPi	486	390	876	528	283	65

variations of the precipitation are ‘contradicted’ by variations of the evapotranspiration. When comparing the scenarios *EhsBuf_ ..* (with part of the agricutural area turned into a buffer zone) to the rest, it should be realized that not only are the ditches made shallower, but also the sprinkling of the affected agricultural area is turned off. The first factor causes an increase of the evapotranspiration, the second a decrease. In some instances the latter dominates (*EhsBuf_HadPi* has a lower evapotranspiration than *Cur_HadPi*) and in others the former dominates (*EhsBuf_HadPiEr* has a higher evapotranspiration than *Cur_HadPiEr*).

Especially the scenarios with increased precipitation have a large impact on the groundwater regime. In Figure 8.1 this is shown in terms of the cumulative frequency curves of the Mean Highest Watertable as computed for the 25 x 25 m grid used in the downscaling of watertables (Section 5). The increased evapotranspiration of scenario *Cur_Had* only slightly lowers the Mean Highest Watertables (lowest curve in Figure 8.1). As can be seen from the difference between the curves for scenarios *Cur_HadPi* and *Cur_HadPiEr* the possible

Figure 8.1 Cumulative frequency distributions of Mean Highest Watertables (MHW) for pixels of 25 x 25 m, for several climate scenarios



reduction of crop evapotranspiration factors has a substantial impact: apparently the evapotranspiration during the preceding summer influences the Mean Highest Watertables, even though they occur in the following spring.

In Table 8.2 an overview is given of the effects that the scenarios have on the area $A_{0.5}$ where the ecologically critical level of 0.5 mm/d is reached. An example of changes in the latter is given in Figure 8.2. The results are best analysed by comparing scenarios that differ only in terms of precipitation or only in terms of evapotranspiration. That reveals the separate effects.

Figure 8.2 Increase of the gross upward seepage to the rootzone, for scenario *Cur_HadPi* - scenario *Cur_His*, showing changes for areas with a seepage > 0.5 mm/d.

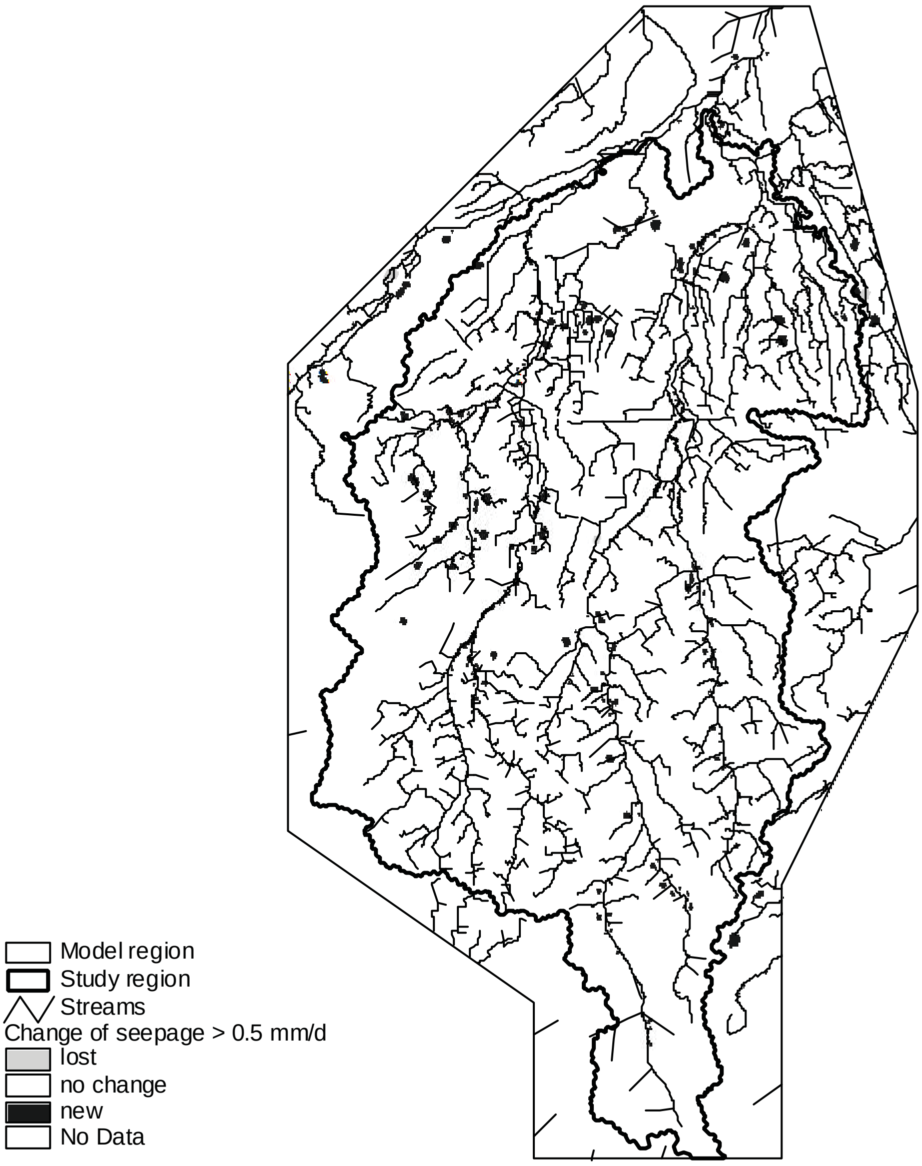


Table 8.2 Simulation results for the gross upward seepage to the root zone. $A_{0.5}$ is the total area with a mean upward seepage to the rootzone exceeding 0.5 mm/d, within the part of the region that is nature area (14 620 ha).

Scenario code	Land and water use, climate scenario (see for a complete description Table 2.7)	$A_{0.5}$ (ha)
Cur_His	Current situation, historic precipitation	798
Cur_HisPa	Current situation, regionally averaged precipitation	763
Cur_Had	Current situation, Hadley downscaled climate data	1073
Cur_HadPi	Current situation, Hadley and KNMI rule-of-thumb	1149
Cur_HadEr	Current situation, Hadley, reduced crop factors	875
Cur_HadPiEr	Current situation, Hadley & KNMI, reduced crop factors	950
Ehs_His	Implemented ecological network Ehs	680
Ehs_HadPi	Implemented ecological network Ehs	980
EhsBuf_His	Ehs and buffer zone of extensive grassland	736
EhsBuf_Had	Ehs and buffer zone of extensive grassland	917
EhsBuf_HadPi	Ehs and buffer zone of extensive grassland	998
EhsBuf_HadEr	Ehs and buffer zone of extensive grassland	878
EhsBuf_HadPiEr	Ehs and buffer zone of extensive grassland	954
EhsBufM_His	Ehs and buffer zone and free meandering main streams	855
EhsBufM_Had	Ehs and buffer zone and free meandering main streams	1030
EhsBufM_HadPi	Ehs and buffer zone and free meandering main streams	1097

Scenario *Cur_HadPi* has a 14% increase of precipitation compared to scenario *Cur_Had*. Increased precipitation raises the watertables in the infiltration areas, and thus increases the upward seepage in the stream valleys. On the other hand increased precipitation also increases the maximum thickness of the precipitation lense in the stream valleys. It then takes longer for the precipitation lense to vanish during the summer period, and thus the gross upward seepage to the root zone becomes less. So the question is which of the two processes has the upper hand. From the results given in Table 8.2 it appears that the influence of the higher watertables in the infiltration areas has the upper hand, but the net effect is not very big: the area $A_{0.5}$ with more than 0.5 mm/d seepage increases from 1073 ha to 1149 ha.

Scenario *Cur_HadEr* has a 7% lower evapotranspiration than *Cur_Had* (Table 8.1). This leads to a large 19%-drop of $A_{0.5}$ from 1073 ha to 875 ha (Table 8.2). This reduction is due to less ‘evaporative pull’ by the vegetation in the stream valleys, which affects the capillary rise term in Equation 5.2. This evapotranspiration-effect also explains the large increase of $A_{0.5}$ from 798 ha in *Cur_His* to 1073 ha in *Cur_Had*. But if the reduction of crop factors as assumed in the *Er*-scenarios really takes place, the positive seepage effects of climate change are nearly neutralized.

With respect to the land and water use scenarios the most interesting question is what the effects are on the gross seepage to the root zone, as compared to the climatological effects. It appears that in scenario *Ehs_His* (implemented National Ecological Network the EHS) compared to *Cur_His* the $A_{0.5}$ decreases from 798 ha to 680 ha (Table 8.2). On the one hand the higher watertables in *Ehs_His* cause a higher counter-pressure on the deeper groundwater, so one would expect a lower $A_{0.5}$ area. But the removal of ditches in *Ehs*-scenarios also means that less of the deep seepage is diverted towards ditches, and more is available for reaching the root zone. Apparently the first mentioned effect has the upper hand.

Creating a buffer zone in the agricultural area (comparison of *Ehs_His* and *EhsBuf_His*) causes only a slight increase of the $A_{0.5}$ area from 680 to 736 ha. But the free meandering of streams (*EhsBufM_His*, see also Section 8.3) causes a substantial increase to 855 ha. The reduced depth of the streams causes this, meaning that less of the deep seepage is directly drawn towards the stream, and more of it reaches the terrestrial riverine vegetation in the stream valleys. Notwithstanding this substantial effect, the seepage to the rootzone is more sensitive to the climatological factors than to the man-made influences. But the seepage is of course not the only determining factor, as will be further explained in Section 9.2 (‘Effects on terrestrial ecology’).

For the ecological effects the residence times of the seepage are relevant too. The increased fluxes caused by increased precipitation will decrease the residence times. However this mechanism appears to have only a very small effect on the mean ‘dimensionless’ concentration of calcium as computed with Equation 5.3 (Section 5.) : the mean concentration drops from 0.40 in scenario *Cur_His* to 0.39 in scenario *Cur_HadPi*.

8.3 Effects on the surface water system

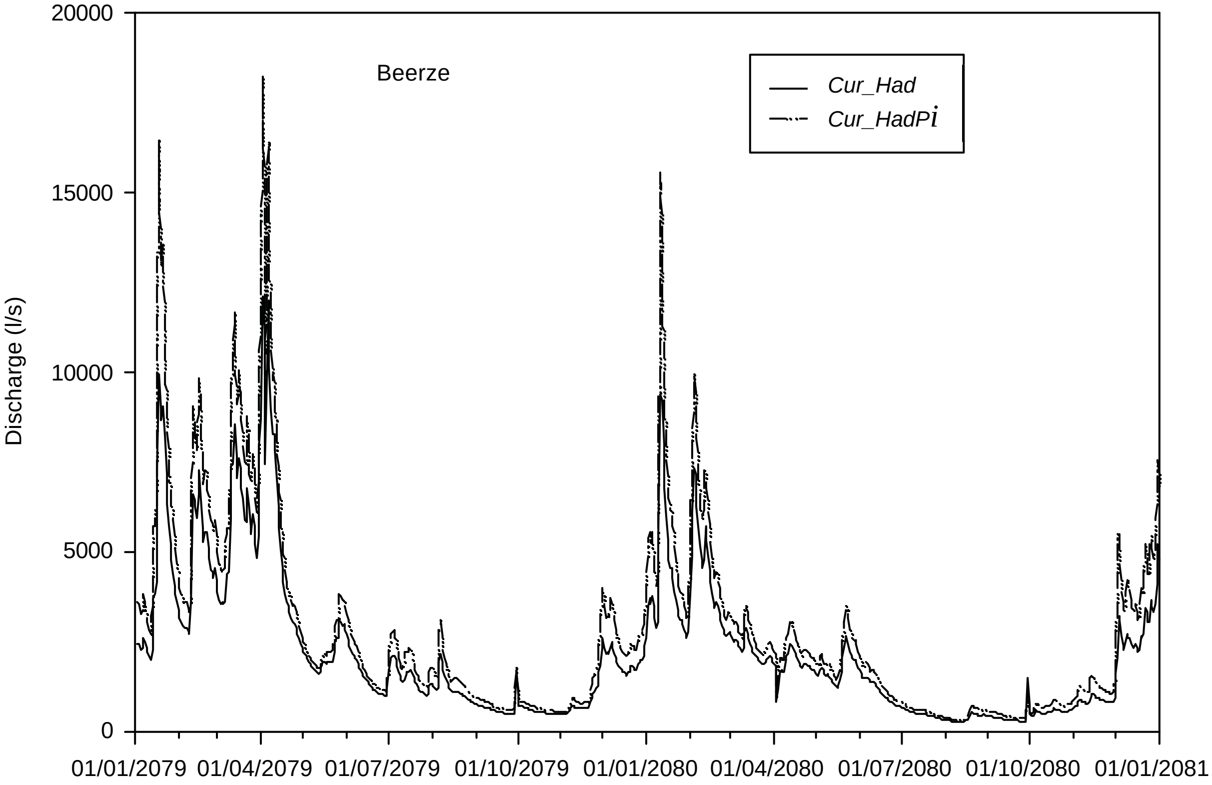
For purposes of dimensioning the surface water system the discharge with a recurrence frequency of 1 year plays an important role in the Netherlands. For the stream morphology the bank-full discharge with a recurrence interval of 1.6 years is relevant (Section 4). For dimensioning based on the most extreme events a recurrence interval of 10 years is often used. Since only 15 years of meteorological data were available for the current situation the results presented in Table 8.3 for extreme discharges are for discharges with a recurrence interval of 5 years. The presented results are for the Beerze, but the ones for the Reusel are comparable if the scenario *Cur_HisPa* is used as a reference (see also Section 2.1). If the results for the Reusel are compared to the current situation (*Cur_His*), then one must take into account that there is a 20% difference of discharge between the current situation (*Cur_His*) and the current situation with averaged precipitation (*Cur_HisPa*).

Table 8.3 Discharge statistics of the Beerze. For comparing results (Δq) *Cur_His* is used as reference. The subscript of q indicates the recurrence interval in years

Scenario code	q_1 (l/s/ha)	$q_{1.6}$ (l/s/ha)	q_5 (l/s/ha)	Δq_1 (%)	$\Delta q_{1.6}$ (%)	Δq_5 (%)
Cur_His	0.44	0.52	0.69	0	0	0
Cur_HisPa	0.45	0.52	0.69	-2	-4	-2
Cur_Had	0.47	0.54	0.68	6	4	-2
Cur_HadPi	0.70	0.80	1.09	58	55	57
Cur_HadEr	0.51	0.58	0.74	16	12	7
Cur_HadPiEr	0.73	0.85	1.16	65	65	68
Ehs_His	0.45	0.52	0.69	2	0	0
Ehs_HadPi	0.70	0.80	1.10	58	55	58
EhsBuf_His	0.45	0.53	0.71	3	3	3
EhsBuf_Had	0.49	0.56	0.74	10	8	7
EhsBuf_HadPi	0.72	0.84	1.18	63	63	70
EhsBuf_HadEr	0.51	0.58	0.77	15	13	12
EhsBuf_HadPiEr	0.74	0.88	1.22	68	71	76
EhsBufM_His	0.45	0.52	0.69	2	1	0
EhsBufM_Had	0.47	0.54	0.67	6	5	-3
EhsBufM_HadPi	0.70	0.80	1.11	58	55	60

As can be seen from Table 8.3 the results for the downscaled Hadley scenario (*Cur_Had*) are very similar to those for the current situation. From the results of scenario *Cur_HadPi* it is clear that the extreme discharges react very strongly to the 17% higher winter precipitation.

Figure 8.3 Simulated discharges of the discharges of the Beerze, for scenario *Cur_Had* (downscaled Hadley) and *Cur_HadPi* with a 17% raised winter precipitation. The plotted values are daily averages of discharges computed with a time interval of 0.025 d.
The sharp drop of the discharge on April 1 is due to the raising of weirs.



This sensitivity is partly caused by the statistical characteristics of the Hadley-precipitation series and partly by the increase of wet zones along the stream valleys. As can be seen from Table 2.5 in Section 2.1.6, the scenario *HadPi* has a more than proportionately higher 10-day moving average than the historic precipitation series: the 10-day moving average increases by 25%, whereas the mean winter precipitation increases by 17%, and the mean yearly precipitation by 10%. This 10-day moving average is known to determine the peak discharges, and not the extreme precipitation events. The reason for this being that the peak discharges involve a build-up of watertables in the streamvalleys, leading to saturated conditions, which generates surface runoff. This build-up is well predicted by the 10-day moving average of the precipitation. That the change of 10-day moving average is so different from the changes of the means is due to the way the series has been generated. It was not generated by transforming the historic series – like is done in many studies – but by modifying a series generated by a General Circulation Model. Analysis on basis of the average precipitation is apparently at fault when making predictions with respect to the peak discharges. In this case the increase of the peak discharge with a recurrence interval of 1 year is double the increase of the 10-day moving average. This still seems a very large increase. That it nevertheless is plausible is due to the influence of shallow watertables on the processes at the soil surface, as is explained below.

When the watertables become very high and reach the drainage base of the shallow trenches and furrows, the flux-discharge relationship given in Figure 3.5 is activated. The inference that this indeed is the mechanism causing the sharp increase of peak discharges is confirmed by the cumulative frequency curves of the Mean Highest Watertables given in Figure 8.1: for the scenario *Cur_HadPi* the area percentage with a MHW higher than 25 cm b.s.s. (the drainage base depth of the trenches) increases from 4.6% in scenario *Cur_His* and *Cur_HisPa* to 7.3% in scenario *Cur_HadPi.* That is a relative increase of 59%, which is virtually the same as the increase of the extreme discharges. The field ditches also play a role, but are far less important: the percentage increase of areas with a Mean Highest Watertable above 1 m b.s.s. (the drainage depth of most ditches) increases from 55% in scenario *Cur_His* to 65% in scenario *Cur_HadPi.* That is a relative increase of only 18%. So the conclusion seems justified that the trenches cause the highly nonlinear effects. It is of course interesting to know whether the computed increase is very sensitive to the assumed drainage resistance of the trenches. At the calibration stage the choice was made to set the resistance at 20 d, whereas a value of 30 d could also have been justified (Section 3.3.4, Figure 3.10). It turns out that a resistance of 30 d affects the discharges of scenario *Cur_His* and *Cur_HadPi* in the same manner, so that the relative increase of *Cur_HadPi* is virtually the same: for scenario *Cur_His* the discharge with recurrence interval of 1 year becomes 0.43 l/s/ha (was 0.44) and for scenario *Cur_HadPi* it becomes 0.68 l/s/ha (was 0.70). In Figure 8.3 an example is given of simulated discharges for scenario *Cur_Had* and *Cur_HadPi,* for a time period involving discharges with a recurrence interval of 1 year and more.

As can be seen from Table 8.3 the simulated land and water use scenarios hardly influence the discharge statistics. Even the free meandering of streams in scenarios *EhsBufM_His*, *EhsBufM_Had* and *EhsBufM_HadPi* has a small impact. Before considering those scenarios, in Figure 8.4 the results are shown for the depth of the stream cross-profile for the current situation and for the situation that the profile is allowed to develop towards the natural dimensions as follows from the calculation method described in Section 4. This natural situation was reached after running the SIMGRO-model three times in an iteration cycle of

Figure 8.4 Depth profiles of stream Reusel, for scenarios *EhsBufM_His* and *EhsBufM_HadPi*

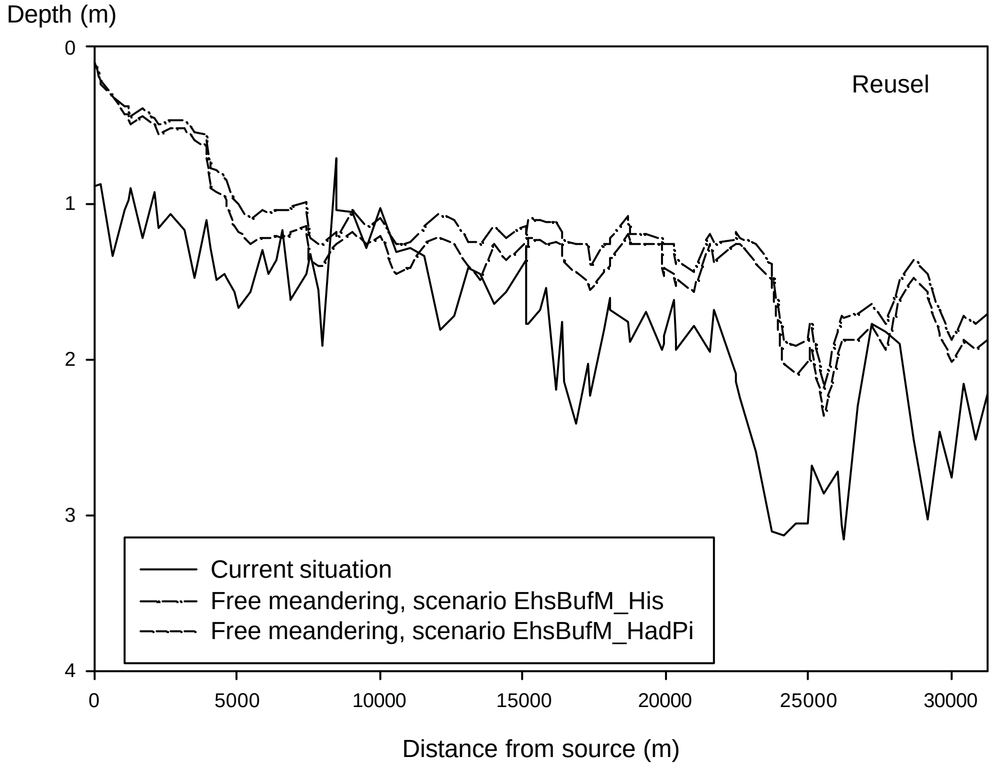
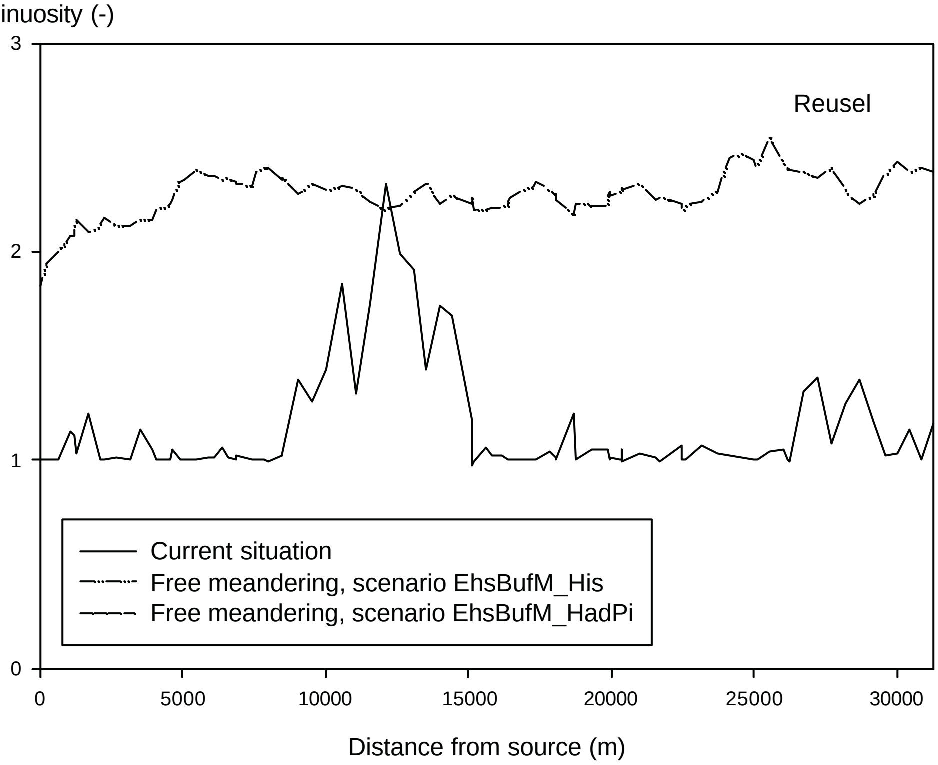


Figure 8.5 Sinuosity of stream Reusel, for scenarios *EhsBufM_His* and *EhsBufM_HadPi*



30-year runs, and each time applying the calculation method. The depth profiles of the stream the Reusel as calculated for scenarios *EhsBufM_His* and *EhsBufM_HadPi* are shown in Figure 8.4.

Figure 8.4 shows a shallow stream depth for the meandering stream. In the Netherlands most streams are dimensioned for a bank-full situation with a recurrence interval of 10 to 100 years. In freely meandering stream systems the bank-full discharge has a recurrence interval of 1.6 years. Therefore the shallow depth for meandering streams could be expected. The difference in depth between the current situation and the meandering situation at the upper part of the stream seems to be higher compared to the middle and lower part of the stream. The over- dimensioning of the upper part of the stream is most likely caused by practical circumstances: the machine that is used for digging the trench has a minimum depth. At a distance of 10 to 15 km from the source the depth of the stream in the current situation is roughly the same as the calculated depth. This part of the Reusel has never been normalized and therefore still has its natural course. The good correspondence between predicted dimensions and actual dimensions gives confidence in the predictions made with the model StreaMES.

The mean sinuosity of the meandering stream is about 2.3. Figure 8.5 shows a slightly increasing sinuosity with increasing distance from the source. Compared to the current situation the sinuosity will roughly increase by a factor 2.

The free meandering involves a substantial reduction of the depth of the stream. That leads to shallow watertables in the stream valleys, and one would expect higher peak discharges. Since that does not appear to happen, there must be a compensating factor at play. The storage in the stream itself does not change much, because on the one hand the storage is reduced by the shallowing of the cross-profile, and on the other hand it is increased by the lengthening of the stream due to the increased sinuosity. The increased sinuosity does still something else, however, and that is the reduction of the water level gradient. It is this factor that makes the stream more sluggish, and thus the stream itself becomes the bottleneck in the discharge process. That in turn causes a backwater-effect in the form of inundations on the soil surface involving the storage of water and a reduced drainage resistance of trenches. But as indicated above, the quick runoff is blocked by the sluggish flow in the stream. In this context it is relevant to mention the way the discharge is computed for water levels above the soil surface of the stream-valley bottom. In the preprocessing of the Q-h relationships the discharge is first computed as if the trapezoidal profile continues above soil surface. Then the value for a certain water level is compared to the bank-full discharge. The difference is multiplied by two and added to the discharge for the considered level. In this manner the model takes into account the extra increase of the discharge capacity when the valley bottom becomes inundated.