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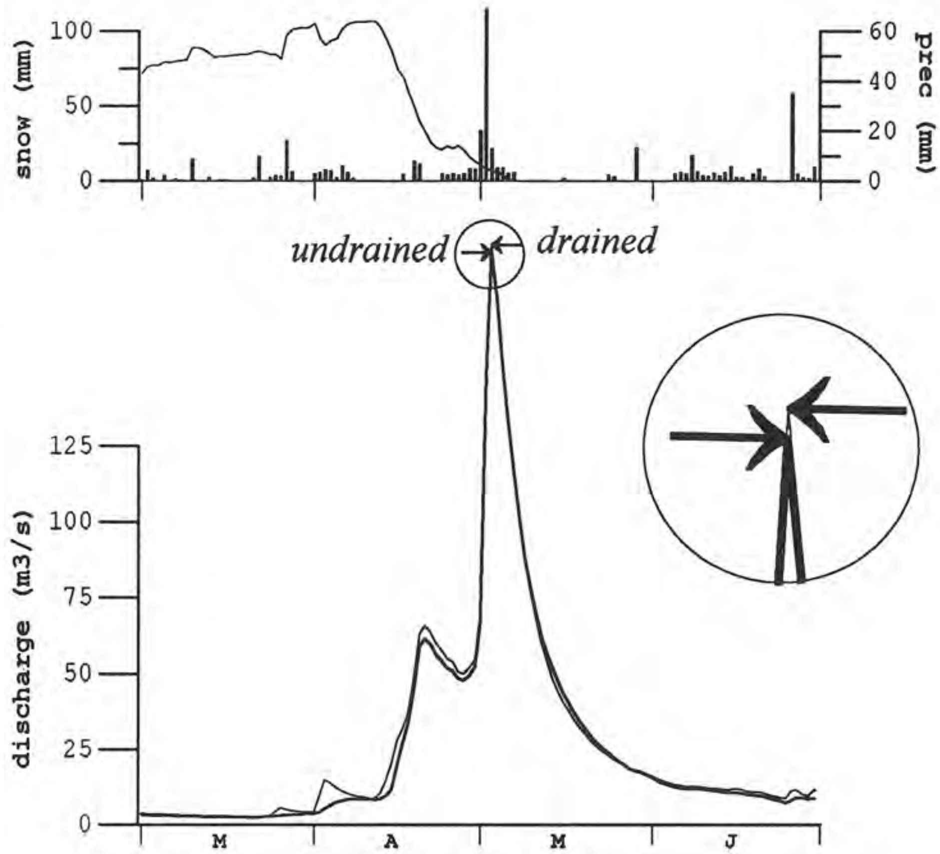

MODELLING THE EFFECTS OF WETLAND DRAINAGE ON HIGH FLOWS

Barbro Johansson

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Modelling the effects of wetland drainage on high flows.

Abstract

The effects of drainage on high flows have been studied by means of a conceptual runoff model (HBV/PULSE). To find parameters, typical for drained wetlands, the model was calibrated for two small catchments, one in central Sweden and one in south eastern Finland, where runoff data were available for drained and undrained conditions. The catchments had different characteristics, and the calibration procedure yielded two different parameter sets.

The drainage effects in these small basins were studied by simulating the runoff, for a specific period, using model parameters for drained and undrained conditions. In the Swedish catchment, the effects on the runoff were almost negligible. In the Finnish catchment, the peak and low flows, as well as the total runoff volume increased considerably during the first 10 years after drainage.

The drainage parameters found for the small experimental basins, were also used to simulate the drainage of a 1000 km^2 catchment in central Sweden, with a 20 % coverage of swamps. Hardly any effects could be seen when the parameters from the small Swedish basin were used. With the Finnish parameters there was a slight increase in peak and low flows, and the total runoff volume increased by 3.5 %. When extreme flows were simulated, by entering a design area rainfall sequence into the model, the differences between peak flows for drained and undrained conditions were fully negligible.

Key words

Wetland drainage, runoff modelling, high flows.

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1. BACKGROUND

In the autumn of 1985, severe floods occurred in central Sweden causing, among many other problems, the collapse of some small dams, the best known of them being the Noppikoski dam on a tributary of the river Dalälven. The question arose whether the increased forest drainage had caused the floods to be higher than they would otherwise have been. In the project described in this report an attempt was made to answer that question, by means of a conceptual runoff model.

Drainage of wetlands and its effect on streamflows have been discussed for a number of years. Robinson (1989), for instance, refers to a paper by Bailey Denton from 1862 on the discharge from underdrainage, and since then a number of investigations have been carried out. Considering this, one should expect the consequences to be well known, but this is not case. The results seem to vary greatly with the objects studied, so that some investigations show an increase in peak flows after drainage (e.g. Seuna, 1980, Robinson, 1989) and others a decrease (e.g. Burke, 1972). Lundin (1992) has found both increasing and decreasing peaks. The results are more homogeneous when it comes to low flows, which tend to increase after drainage (e.g. Seuna, 1980, Sirin et al., 1991, Bergquist et al., 1984, Robinson 1986).

In theory, it is possible to predict the most likely effects of drainage. The aim of the drainage is to lower the groundwater table, which should lead to lower evaporation and, consequently, a higher total runoff. If the drainage is followed by increased forest growth however, a gradual increase can be expected in the evapotranspiration, which eventually may reach higher values than before drainage. The lowering of the groundwater table creates an unsaturated soilwater zone, which acts as a buffer, damping the peak flows, especially after dry periods. On the other hand, the denser stream network may lead to a quicker response to rainfall, especially when the initial conditions are wet. Depending on whether the downstream or upstream parts of a catchment are drained, the quicker response time may give higher or lower peaks at the catchment outlet (e.g. Braekke, 1970, Mustonen and Seuna, 1971). In practice, it is difficult to tell which effects that would be the most dominant in a specific catchment.

2. METHOD

The method used in most investigations in this field is to study the observed runoff, from a well-defined catchment, before and after drainage. A neighbouring catchment is often left untouched for comparison.

In this project the effects of drainage were studied by means of a conceptual runoff model (HBV/PULSE). Such a model can be used to hypothetically drain different parts of a large catchment, to simulate forest growth and extreme weather conditions. However, it may only give such results that the modeller has anticipated, and it is therefore necessary to have good data sets, to define model parameters typical for wetlands under drained and undrained conditions. The method has earlier been used to study the effect of clear-cutting (Brandt et al., 1988).

Parallel to this study, two other projects were carried out, with the same aim, but using different methods. Lundin (1993) made field investigations, and used reference basins to study streamflows and groundwater levels before and after drainage. Iritz (1993) also used a runoff model to hypothetically drain a catchment, but in this case the physically based SHE model. The conceptual model is probably more fit to study effects on a larger scale, while the physically based model can be used to simulate the effect of, e.g. varying drainage density and depth on a small scale.

2.1 Model description

The HBV-model was developed at the Swedish Meteorological and Hydrological Institute in the 1970s, and a slightly modified version, the PULSE-model, in the 1980s (Bergström et al., 1985). Both models have since then been widely used for a number of applications (Bergström, 1992). Recently the PULSE-model was developed further, taking into consideration the concept of recharge and discharge areas (Bergström and Lindström, 1992).

Schematically the original PULSE-model can be described by Figure 1. Input data are daily precipitation and temperature, and monthly mean values of potential evaporation.

The snow routine is based on a threshold temperature and a degree day factor.

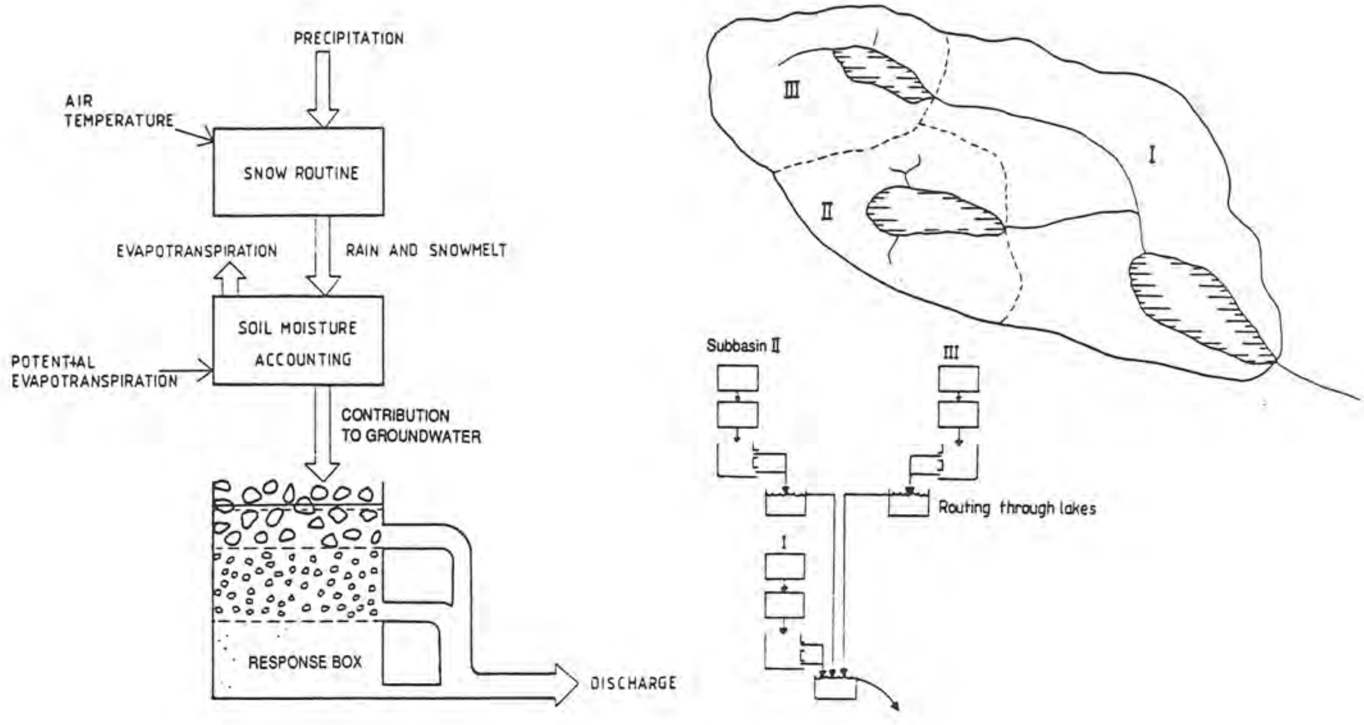

Figure 1. *a) Original model structure.* *b) Divisions into subbasins.*

The soil moisture accounting routine, is based on three parameters, β, L_p, and Fc as shown in Figure 2. β is controlling the contribution to the response box (ΔQ/ΔP) and increase in the soil moisture storage (1-ΔQ/ΔP) from rainfall or snowmelt, L_p is a value above which evapotranspiration reaches its potential value, and Fc is the maximum soil moisture storage in the model. The soil moisture may also increase by a contribution from the response box (capillary rise), directly proportional to the soil moisture deficit.

Sm - computed soil moisture storage
ΔP - contribution from rainfall or snowmelt
ΔQ - contribution to the response function
Fc - maximum soil moisture storage
β - empirical coefficient
E_p - potential evapotranspiration
E_a - computed actual evapotranspiration
L_p - limit for potential evapotranspiration

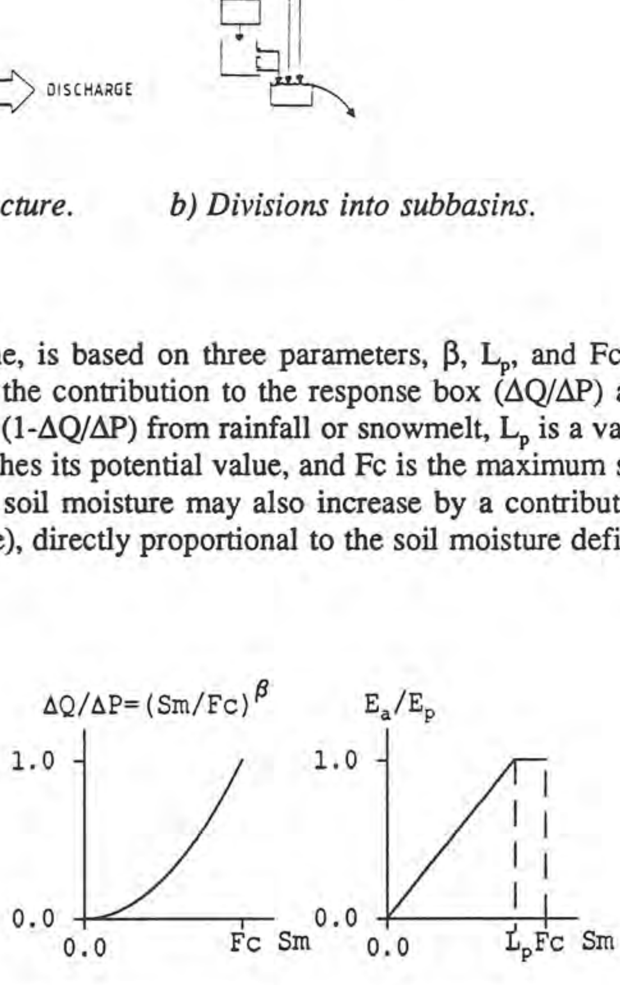

Figure 2. *Schematic presentation of the soil moisture accounting routine.*

The lumped response box of the original model, has in the latest version been converted into a more realistic, distributed response function (Figure 3). Recharge areas are separated from discharge areas by the use of two submodels. These are linked together by the water flow from the saturated zone of the upper submodel into the saturated zone of the lower submodel. The wetness of the soil in the discharge area is then maintained by an upward flux, which is related to the soil moisture deficit and the level of the modelled groundwater table according to:

CFLUX=SMDEF if GRWCOM $\leq$ CAPFR
CFLUX=SMDEF·exp(-α·(GRWCOM-CAPFR) if GRWCOM > CAPFR

where:

CFLUX	=the wetting of the soil from the groundwater
SMDEF	=the soil moisture deficit
α	=a model parameter
GRWCOM	=the computed depth of the groundwater table, and
CAPFR	=a model parameter which describes the extent of the capillary fringe.

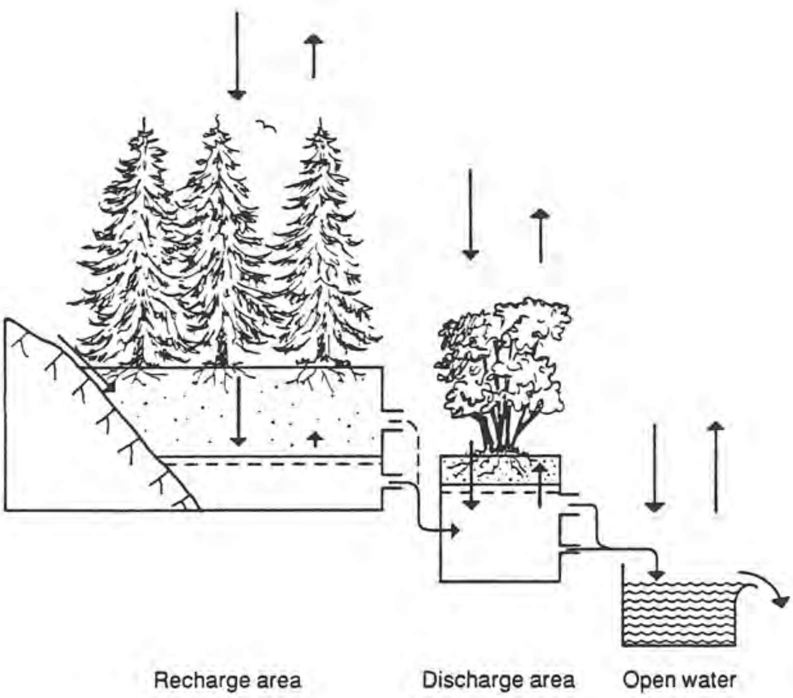

Figure 3. The new model structure, based on recharge and discharge areas (from Bergström and Lindström, 1992).

The idea behind this procedure is that any soil moisture deficit will disappear when the groundwater level approaches the soil surface and that the upward flux will decrease exponentially with a falling groundwater level. The procedure is identical for both subareas, but the effect will be stronger in the discharge area because of its superficial groundwater. Thus the wetness of the discharge area will be maintained throughout long dry spells.

When applying this latest version of the model to the problem of drainage, the wetlands are represented by the lower subarea - the discharge area. During undrained conditions, there is little subsurface flow in peat, except close to the soil surface. Consequently the deeper recession coefficients (the lower holes in the response box) are very small. Drainage may be simulated by an increase in this deeper recession, which will result in a deeper groundwater table, and therefore a smaller upward flux and a lower evaporation.

2.2 Data base and simulation strategy

As mentioned above, it is necessary to calibrate the model against runoff data to find the wetland parameters typical for drained and undrained conditions. The data used for this purpose came from two small catchments, one in the south-eastern part of Finland, and one in central Sweden (Figure 4). Earlier investigations have shown that the runoff from the Finnish catchment changed considerably after drainage (Seuna, 1980), while the effects in the Swedish catchment were smaller and not so easy to detect (Bergquist et al, 1984, Brandt, 1987). For both catchments one calibration was made for the period with no artificial drainage in the catchment, and one for the period after drainage had been carried out. This gave two parameter sets, representing catchments with different characteristics.

Figure 4.
Locations of catchments where model simulations have been made.

The simulated runoff volumes and peak flows for drained and undrained conditions were then compared for each catchment. To see the effects of drainage, comparing two simulated hydrographs is preferable to comparing one simulated and one observed. The agreement between observed and computed runoff does not depend only on the model parameters, but also on input data. If, for instance, the temperature data, during a few days of the snow melt, is not representative for the catchment, the form of the simulated spring flood hydrograph may differ considerably from the observed one.

The two parameters sets were also used to hypothetically drain the Svartån basin in central Sweden, illustrating possible effects of drainage in a large catchment (978 km^2). In order to see what the maximum effects could be, all swamps within the basin were assumed to be drained. To simulate a very extreme flow, a regional 14-day design areal rainfall sequence, used to determine design floods for large dams, was entered into the model (Flödeskommittén, 1990). It was applied in conjunction with the spring flood, with dry summer conditions and with autumn flows.

3. RESULTS

3.1 Small catchment simulations

3.1.1. Huhtisuo - basin description

The Huhtisuo basin, was described by Seuna (1980). The catchment area is 5.02 km^2, and approximately 45% is covered by open bogs and swamps with a poor growth of pine. The peat layer is about 1.5 m thick, and the underlying mineral soil is mostly sand and gravel. The altitude varies between 100 and 125 m.a.s.l. Mean annual precipitation is 700 mm. For this study data from 1954 to 1980 have been available.

The first draining activities took place in 1956, when 4% of the catchment was drained, but the principal draining was carried out in 1958-1960. Main ditches, 130 cm deep, were dug in 1958 and forest ditches, 60 cm deep, in 1960. The drainage density was 80 m of main ditch and 225 m of forest ditch per drained hectare. Almost all of the peatland was drained (40% of the catchment).

For the years immediately after drainage the runoff volume was exceptionally high. This is obvious from Figure 5, which shows the annual precipitation and observed runoff from 1954 to 1980. The small differences between precipitation and runoff in particularly 1958-1959 and 1961-1962 can only be explained by decreasing storage in the peat. This is a temporary effect, which is not possible to model with the present version of the PULSE, and no effort was made to calibrate the model for this period.

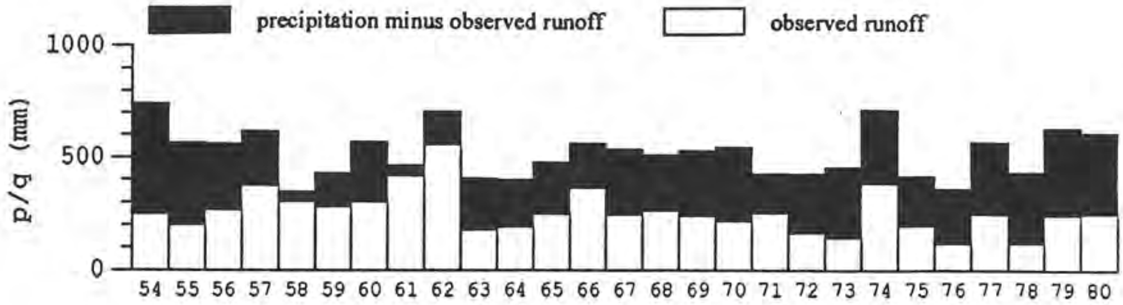

Figure 5. Annual precipitation and runoff, 1954-1980. Huhtisuo.

During the studied period the Huhtisuo catchment was not only drained but also clear-cut. In 1956 12% of the area was clearcut. After that there is no detailed information on when and to which extent clearcutting was carried out, but from 1958 to 1970 the volume of growing stock decreased by 30%. From 1971 to 1980, it is assumed that the volume of growing stock was not changed, but the area covered by trees might have increased, due to forest growth on the drained peatland.

The fact that both drainage and clearcutting were carried out during the same period, makes it difficult to separate the effects. To account for the effects of clearcutting in the model simulations, it was assumed that 12% of the catchment was cut in 1956, 20% in 1960 and 10% in 1962. Model parameters for clearcut areas were taken from Brandt et al (1988). They found that the snowmelt started earlier and proceeded faster after clearcutting, and that the Fc parameter of the soil moisture routine should be lowered considerably, in order to account for the decreasing evapotranspiration.

3.1.2 Huhtisuo - model calibration

To determine the parameters for undrained conditions the model was calibrated for 1954-1955. A longer calibration period had been preferable but the available data were limited. The model was also run for 1956-1957, with the parameters for undrained conditions. The results are shown in Figure 6. It is clear that the model parameters would have been different had 1956-1957 been the calibration period. There may be several reasons for this, one of course that a calibration period of two years is too short. Others may be that the parameters chosen to represent the 12% of the catchment that was clearcut in 1956 were not correct, and that the drainage of 4% of the catchment the same year led to a significant change in the runoff.

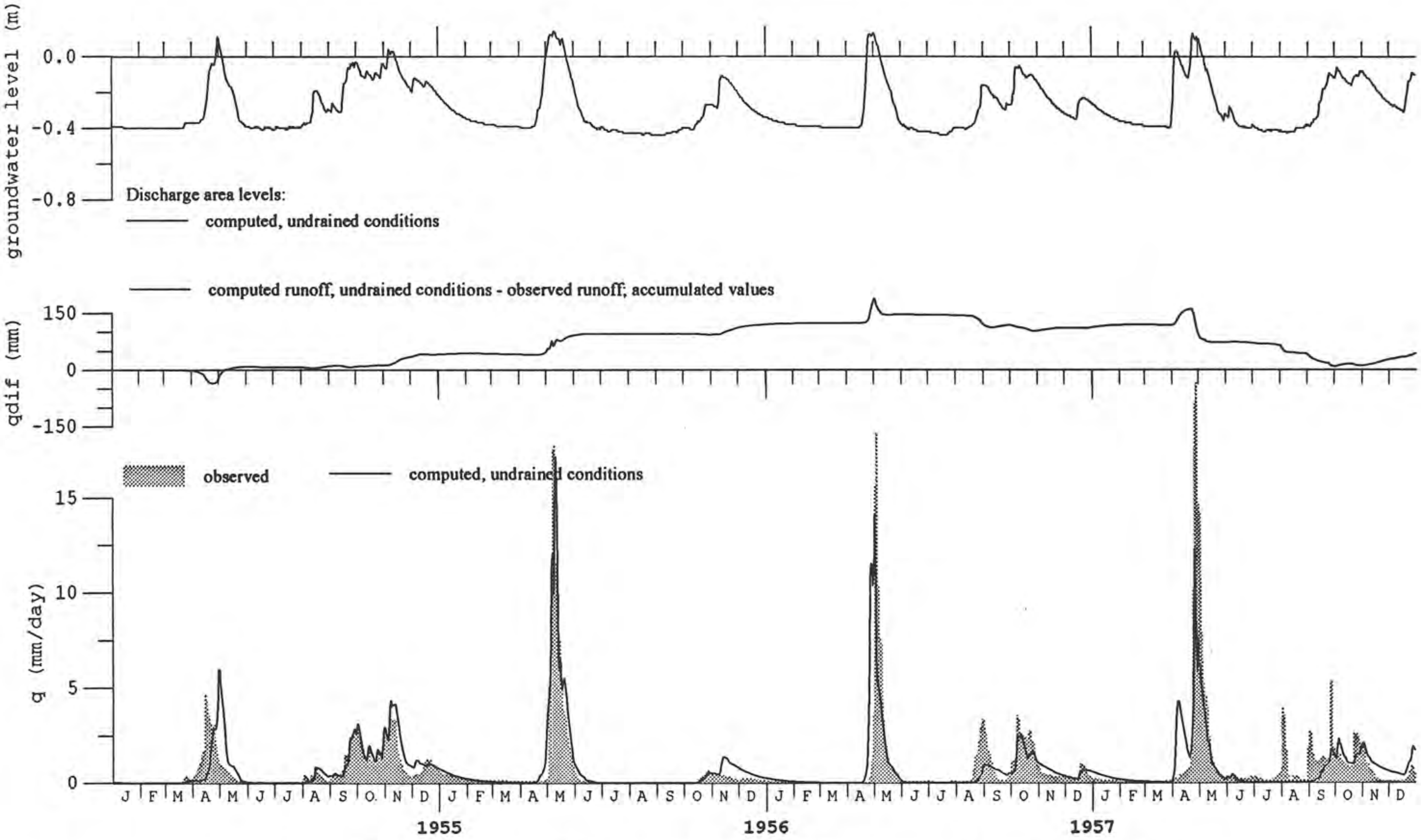

Figure 6. *Observed runoff and simulated runoff and groundwater levels for the period before drainage. Huhtisuo.*

Seuna (1980) found that the effects on runoff were largest during the first years after drainage, and that towards the end of the 70s the runoff volumes and peak flows were back to predrainage values. Because of this, two sets of model parameters were sought for drained conditions, one for the period 1963-1970, and one for 1971-1980. To simulate the drainage the recession parameters were adjusted. The increased forest growth on the bogs in the 1970s was simulated with a lower value of the model parameter α (see section 2.1), causing an increased wetting of the soil from the groundwater, and with a lower degree day factor in the snow melt routine. A higher upward flux from the groundwater is a consequence of the higher transpiration from a forest, and the lower degree day factor reflects the fact that the snow melts slower in a forest than in an open field.

The relationship between groundwater levels in the discharge area and streamflow can be presented as a rating curve, where the slope of the curve is proportional to the recession coefficient. Such rating curves for the three calibration periods are given in Figure 7. The upper recession coefficient for 1971-1980 is much lower than for the two earlier periods. A physical explanation for this could be a reduced capacity of the ditches to convey the water, as reported by Seuna (1980). It is also possible that it does not reflect any true differences, but only that the meteorological conditions were such that no really high flows occurred in the 1970s, and that the recession could not be determined properly. Simulating extreme weather conditions is consequently not to recommend with this parameter set.

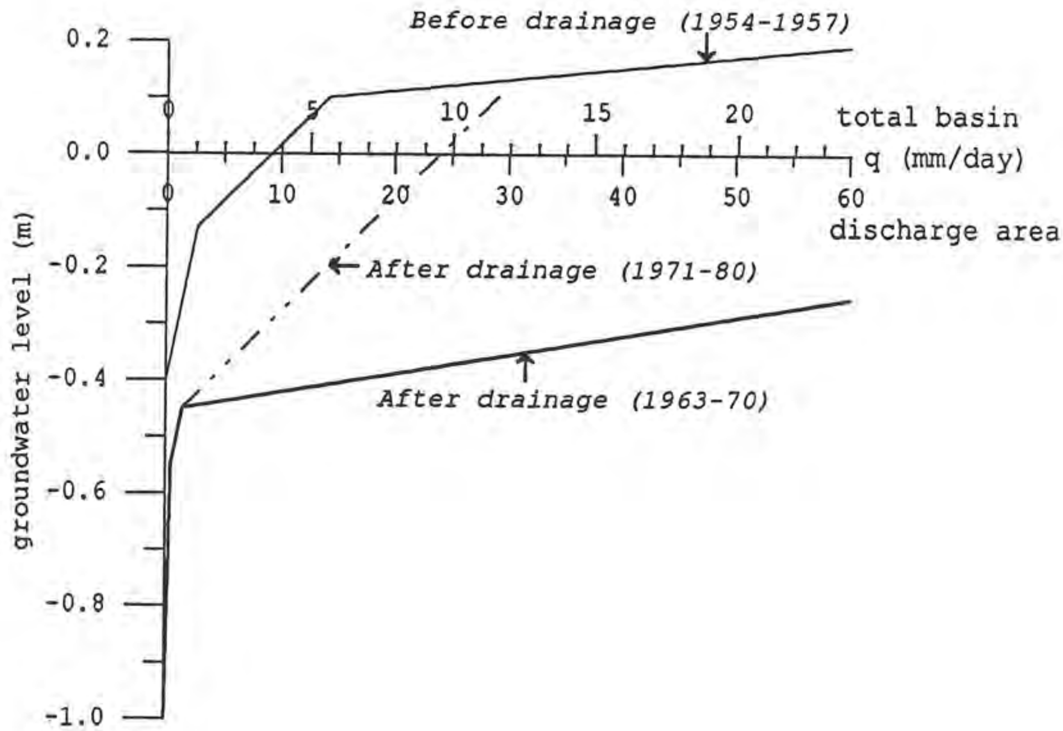

Figure 7. Rating curve for streamflow generation from the discharge area. Huhtisuo.

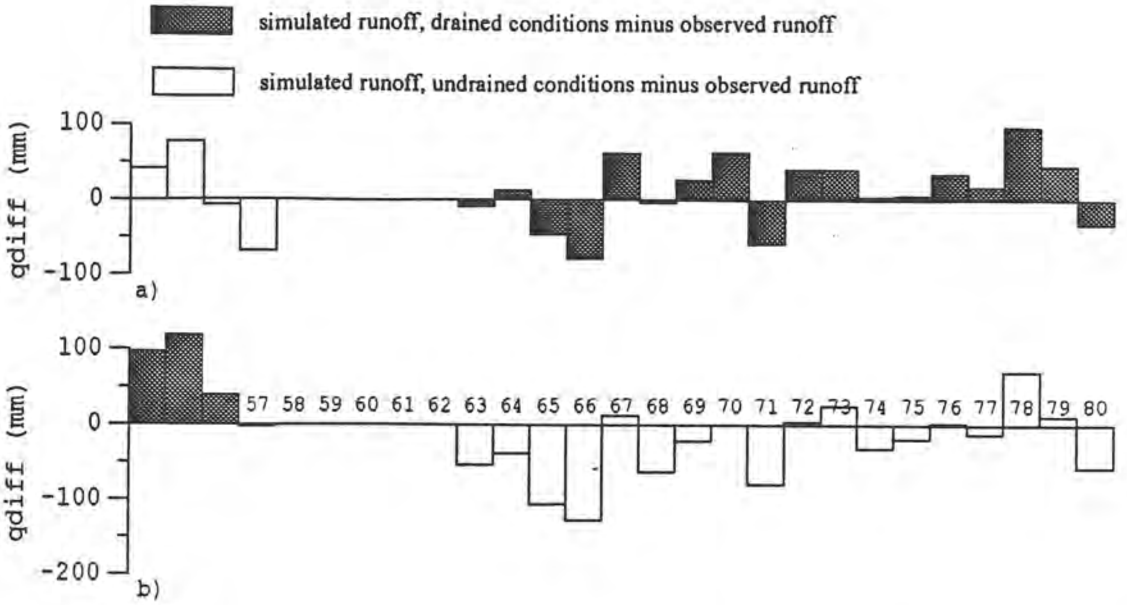

Figure 8. *Differences between simulated and observed annual runoff with different parameter sets. Huhtisuo.*
a) calibrated parameter sets (i.e. one set for 1954-57, one for 1963-70 and one for 1971-80)
b) 1954-1957 - parameter set for drained conditions (1963-70)
1963-1980 - parameter set for undrained conditions

Figure 8, showing the differences between simulated and observed annual runoff for the separate parameter sets, and Figure 9, being a plot of simulated against observed runoff peaks, are attempts to illustrate the accuracy of the model calibration. Even with the calibrated parameter sets, the simulated runoff volumes and peak flows differed considerably form the observed ones (Figures 8a and 9a). In order to see if the calibrated parameters really yielded better results than any other parameters, the model was run for 1954-1957 with the parameters determined for 1963-1970, and for 1963-1980 with the parameters determined for 1954-1957 (Figures 8b and 9b). From a visual inspection it appears that the agreement between simulated and observed runoff is better with the calibrated parameters, but this is not true on a statistically significant level (5%). This is partly due to the short calibration period before drainage, and it means that no figures given below, on the effects of drainage, are statistically proved. They are rather to be taken as qualitative measures.

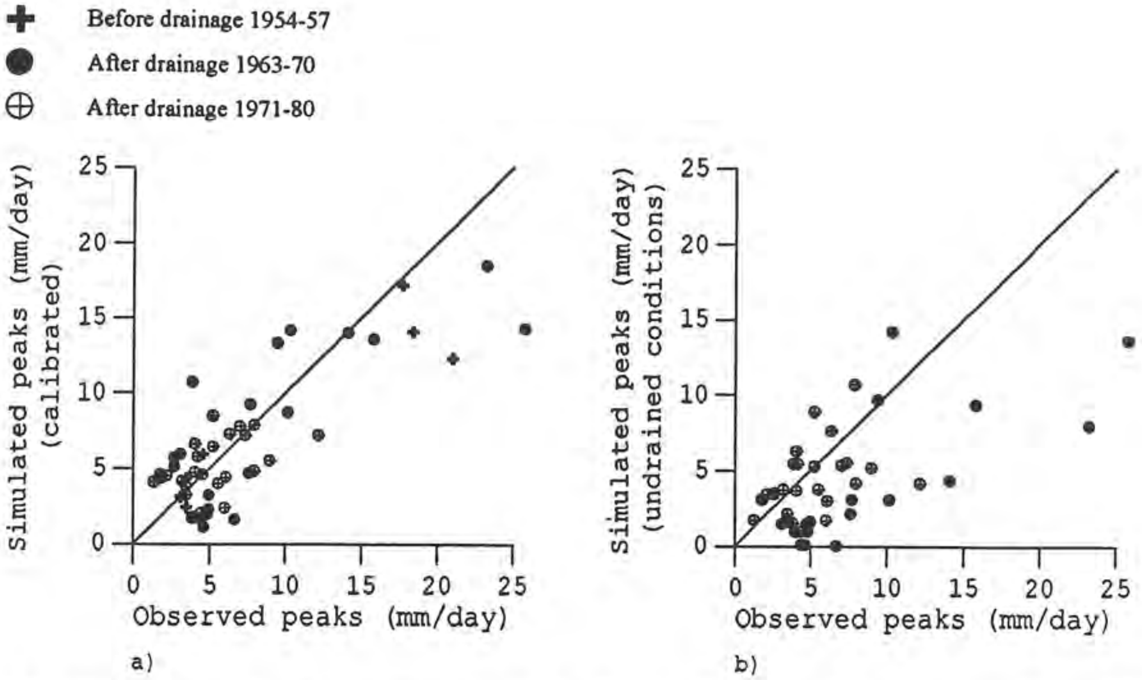

Figure 9. *Simulated against observed runoff peaks with different parameter sets. Huhtisuo.*
a) calibrated parameter sets (i.e. one set for 1954-57, one for 1963-70 and one for 1971-80)
b) parameter set for undrained conditions

3.1.3. Huhtisuo - drainage effects

As mentioned above, the model was not calibrated for the period 1958-1962. The observed runoff was just plotted together with the simulated runoff for undrained conditions, to show the obvious effects of the drainage; higher runoff volumes, higher summer flows and higher peak flows (Figure 10).

From 1963 and onwards it was possible to compare computed values for drained and undrained conditions. Figures 11 and 12 show simulations for 1963-1966 and 1972-1975 respectively.

In 1963-1966 the flow peaks were generally higher for drained conditions, and so were the total runoff volumes. The curve of the accumulated difference demonstrates that especially during summer the volumes were higher after drainage. The computed groundwater levels were approximately 20-40 cm lower after drainage. Data given by Mustonen and Seuna (1971), for 1961-1969, indicate that this is in agreement with observations.

For 1972-1975, neither the peaks nor the runoff volumes differed noticeably for the drained and undrained state. Possibly the summer low flows were slightly higher for drained conditions.

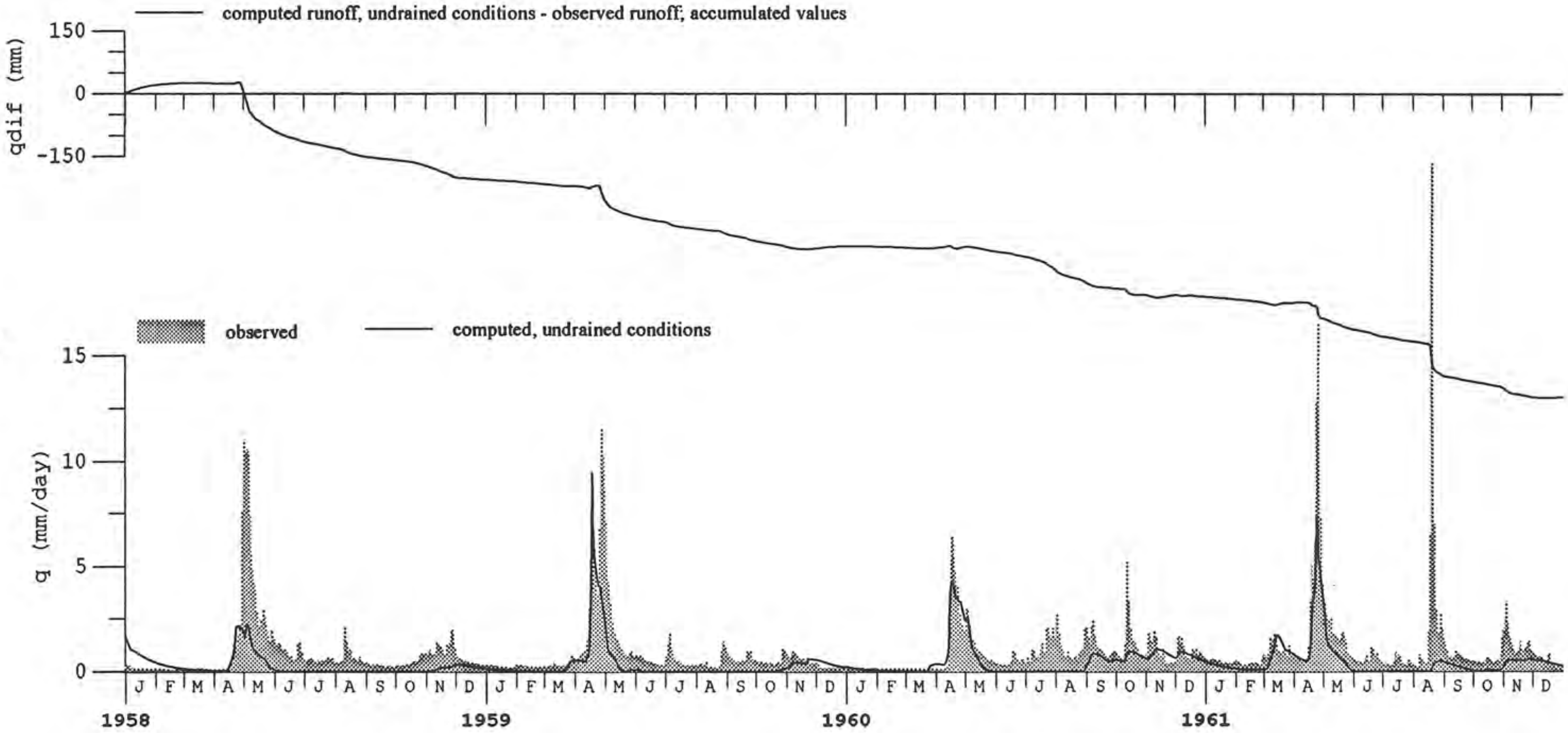

Figure 10. *Simulated runoff for undrained conditions and observed runoff, 1958-1961. Drainage was carried out in 1958 and 1960. Huhtisuo.*

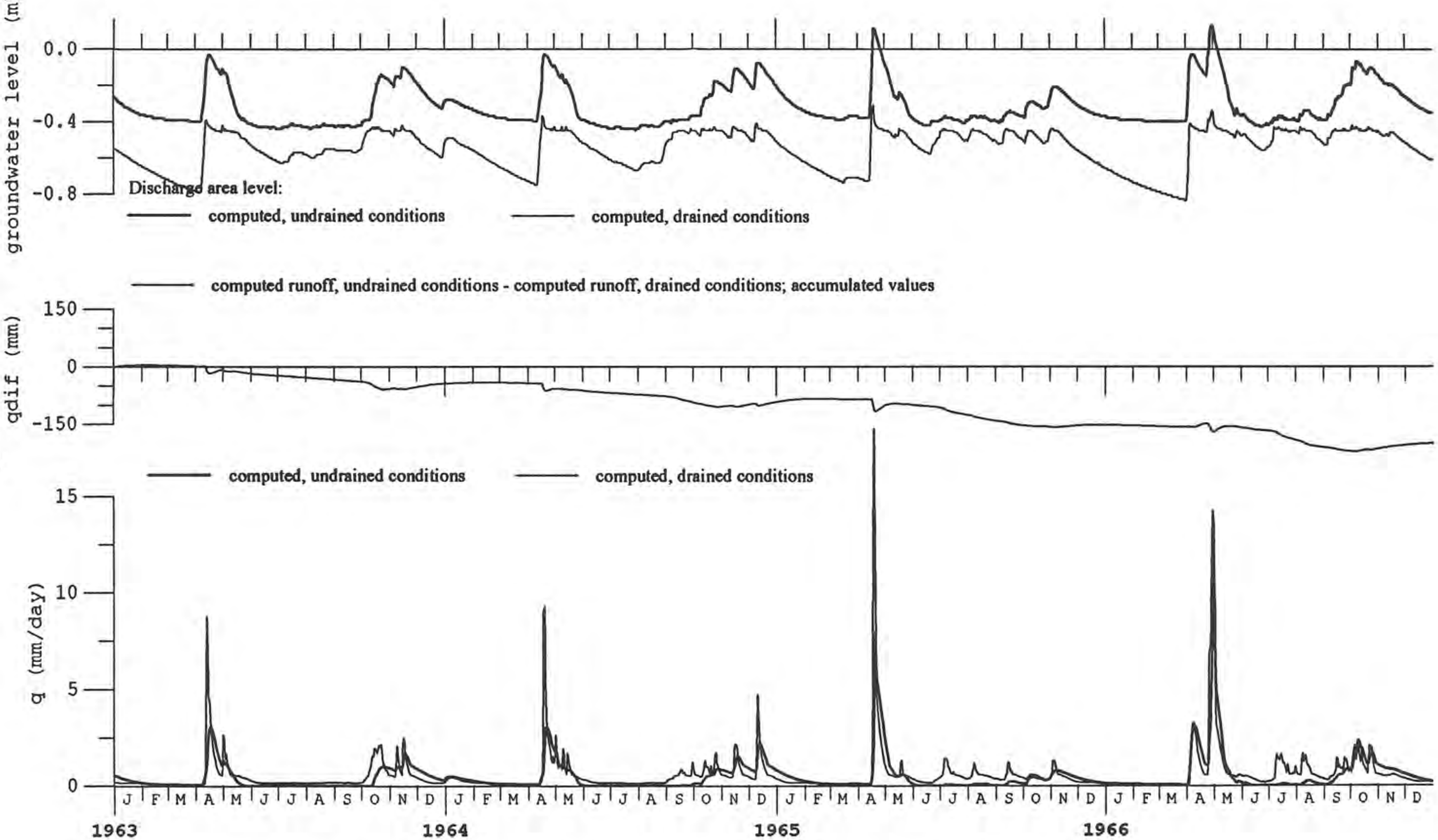

Figure 11. Simulated runoff and groundwater levels for drained and undrained conditions, 1963-1966. Huhtisuo.

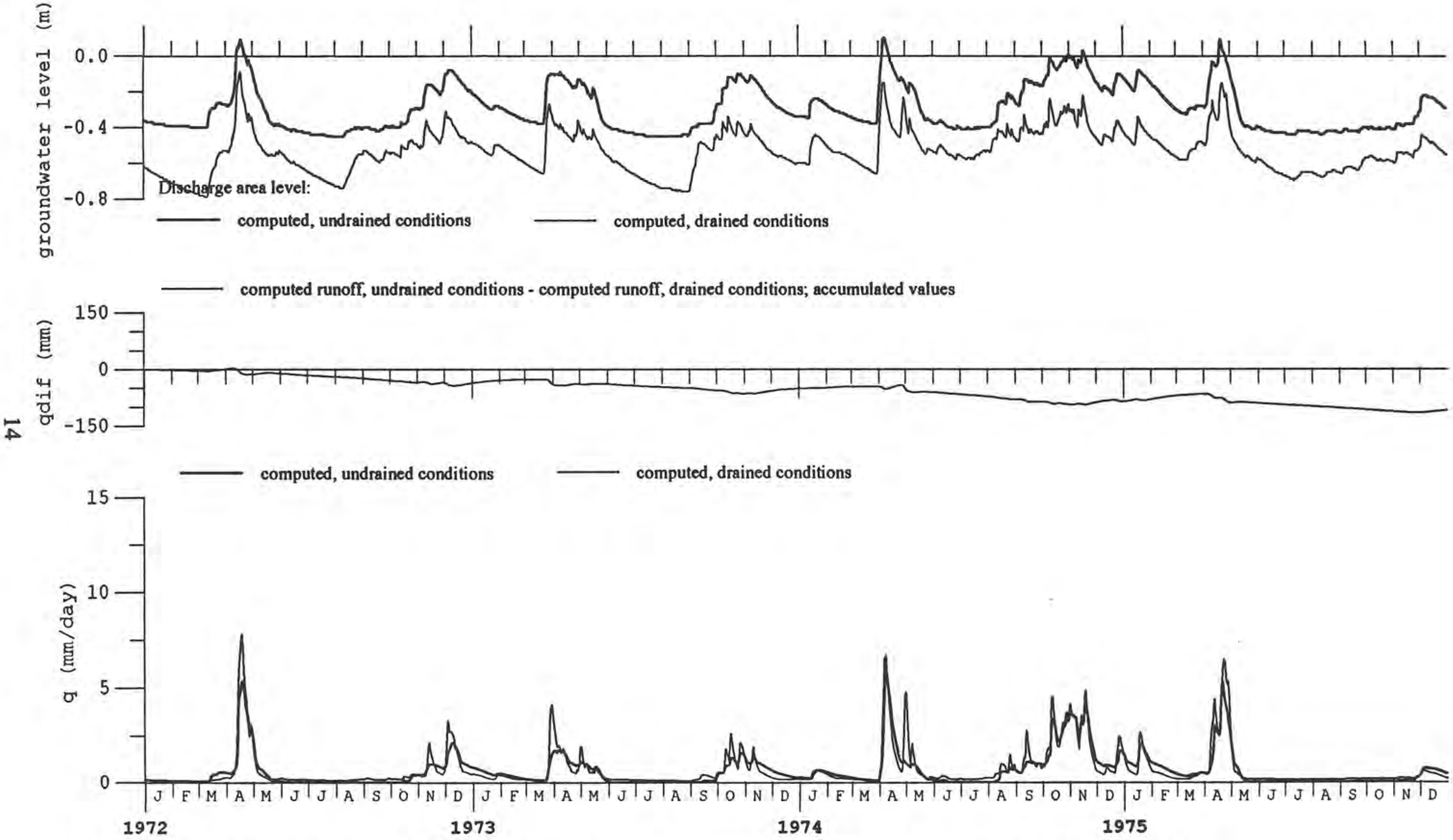

Figure 12. Simulated runoff and groundwater levels for drained and undrained conditions, 1972-1975. Huhtisuo.

The changes in runoff volumes caused by drainage, according to the model simulations, are summarized in Figure 13. The differences for 1971-1980 were not significant (on a 5% level). For 1963-1970 the mean annual runoff was 50 mm or 20% higher for drained conditions. Looking at seasonal changes, the spring flow volume (March to May) was 20% higher and the summer flow (July-August) 95% higher. No significant differences were detected for the autumn runoff (October-November).

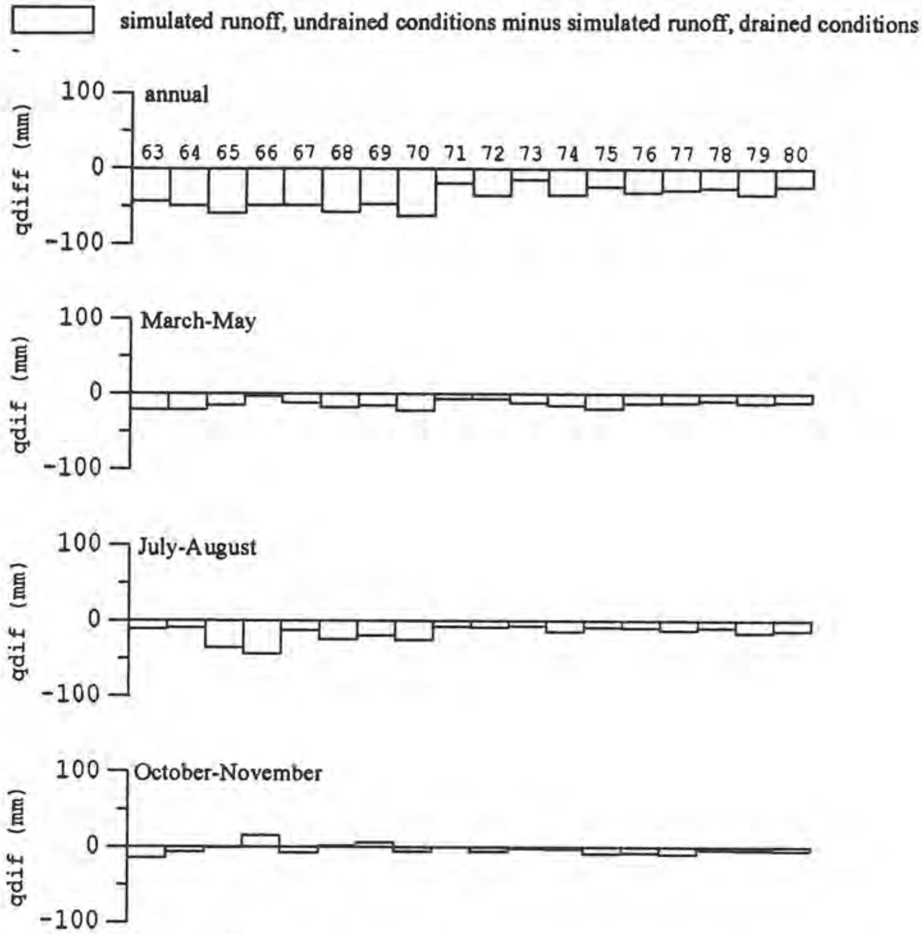

Figure 13. Changes in runoff volumes caused by drainage. Summary of model simulations. Huhtisuo.

In Figure 14 the simulated flow peaks for undrained conditions are plotted against those for drained conditions. As an average the peaks for drained conditions are 65% higher (1963-70), but there is a large variety, with a few peaks even being higher for the undrained conditions.

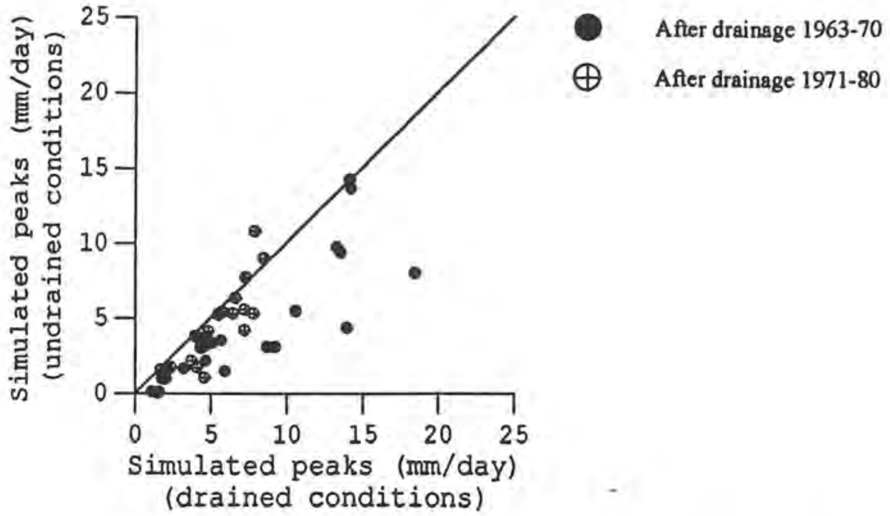

Figure 14. Simulated changes in peak flows caused by drainage. Huhtisuo.

From 1963 to 1980, all large peaks occurred during the spring flood. Figure 15a and b show some of them in detail. It seems that with a low groundwater table before the actual onset of the peak, a drained area will give a higher peak flow, while the peaks will be of a similar size or even higher for undrained conditions if the groundwater table is close to the soil surface. In 1966 for instance, when there is a premelting period raising the groundwater table, there is very little difference in the main peaks, but in 1965 when the snowmelt occurs in one single step, the peak is considerably higher for drained conditions.

3.1.4. Huhtisuo - effects of forest growth

To quantify the effects of forest growth on runoff volumes, the period 1971-80 was run with the model parameters for 1963-70. The ratio of the volume computed in this way to the volume computed with the parameters for 1971-80 was 1.08. Of course this ratio does not really reflect the differences between an open bog and a forested one, as there was a continuous growth of the forest during the whole period. Figures given by Robinson et al. (1991) indicate much higher differences when comparisons are made between a plot with open moorland and plots with forests of a given age. At experimental sites in Germany, the runoff from a plot with a 10-year old forest was observed to be 40% lower than from an open mooreland.

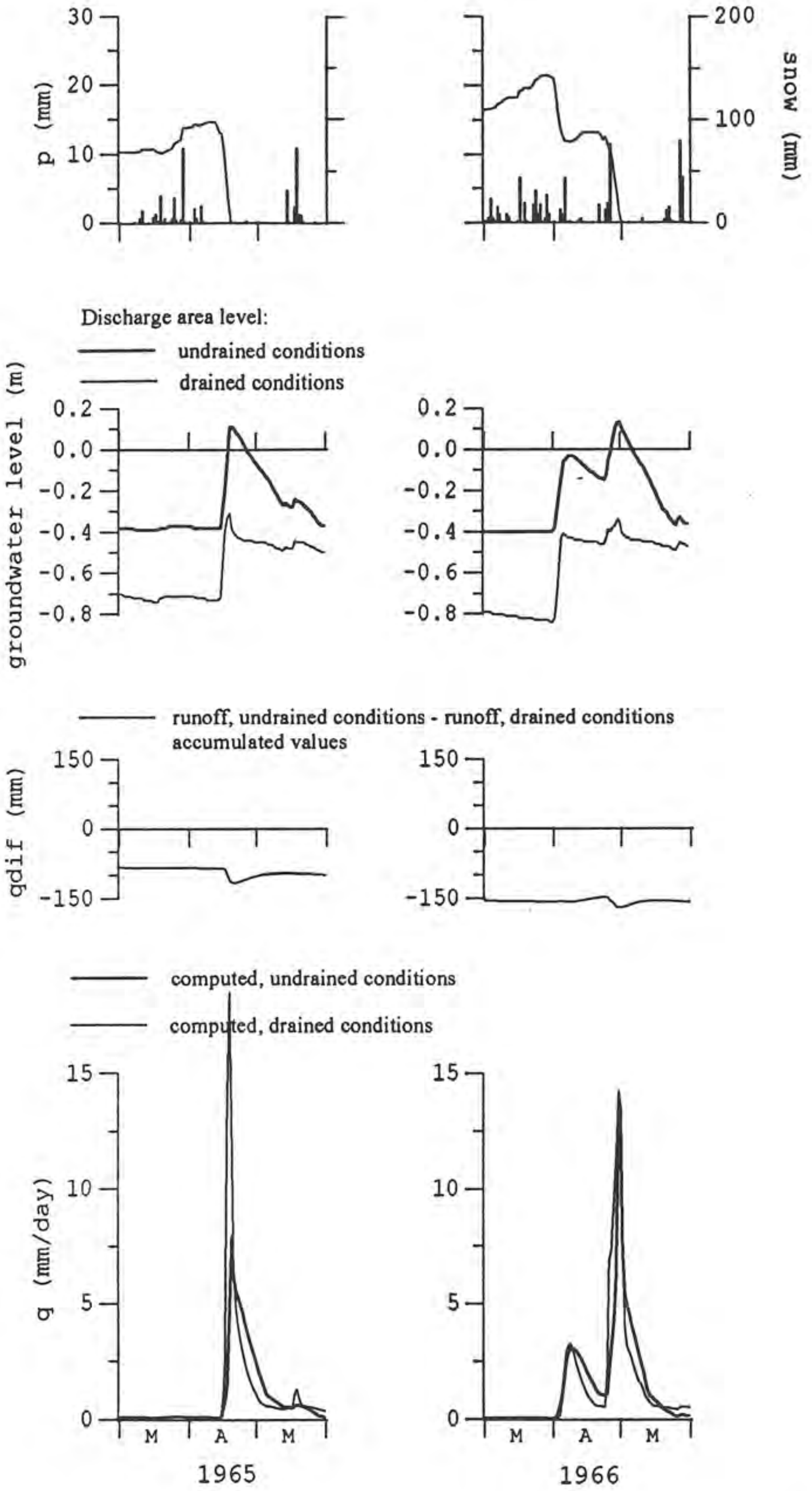

Figure 15a. Simulated spring floods, 1965 and 1966. Huhtisuo.

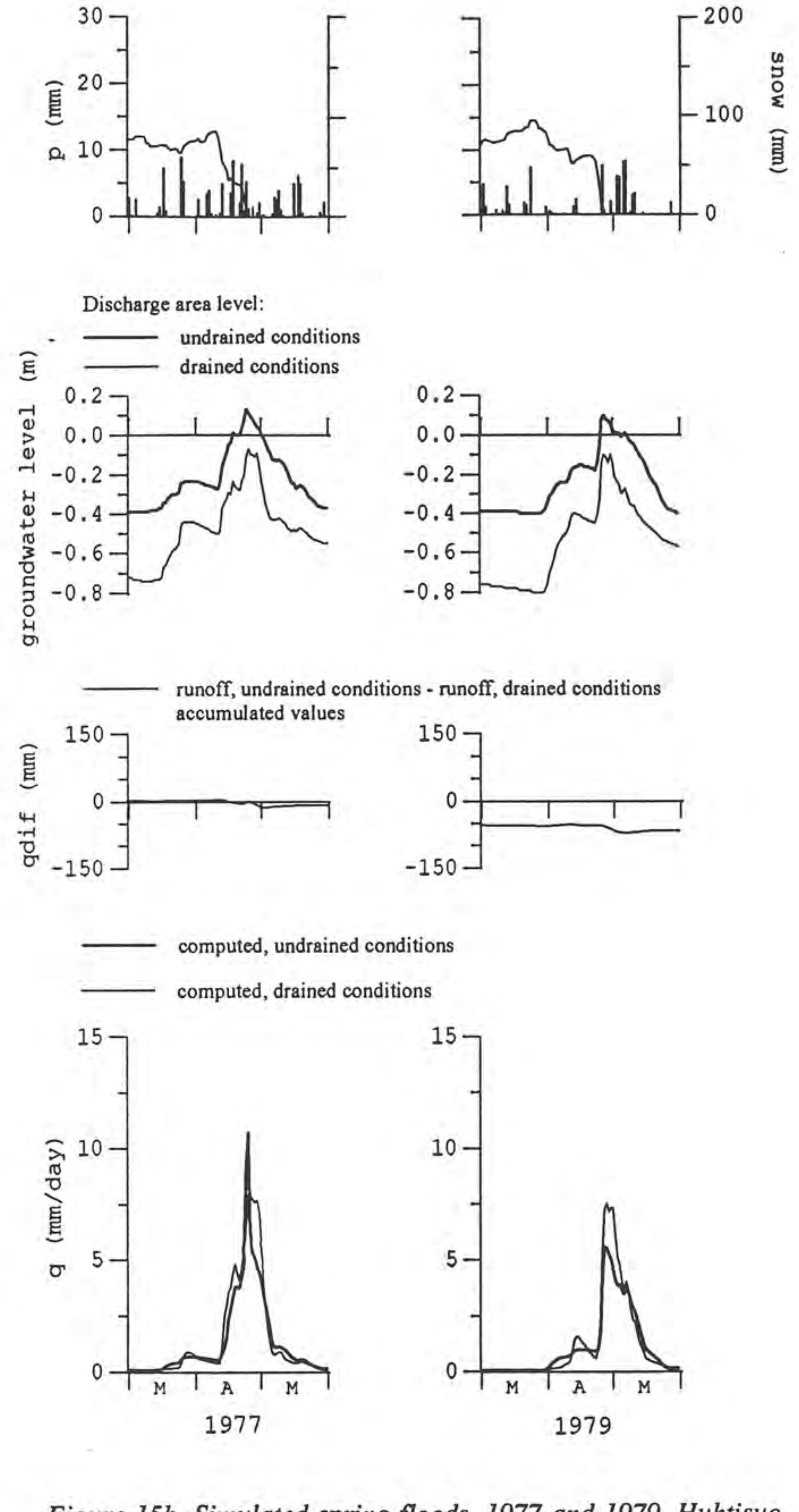

Figure 15b. Simulated spring floods, 1977 and 1979. Huhtisuo.

3.1.5. Letjärn - basin description

Letjärn is part of the Siksjöbäcken basin, described by Bergquist et al. (1984). The catchment area is 1.4 km^2. Unlike in the Huhtisuo basin, the swamps are not continuous, but consist of a number of small fens, spread out in a hilly landscape. The elevation varies between 325 and 400 m.a.s.l. The thickness of the peat layer is between 2 and 3 m, and the mineral soil is till mixed with some gravel. Some of the fens have a poor growth of pine. The total peatland area constitutes 25% of the catchment. In April 1981 14% was drained.

The mean annual precipitation is 750 mm (not corrected for observation losses), and the basin is normally covered by snow from November to the end of April.

Runoff gaugings, as well as weekly observations of the groundwater levels, started in the catchment in 1979. Precipitation and temperature data have been taken from the nearest meteorological stations (some 15 km away). Hydrological data were collected up to 1985, when there was a break until 1991. For this project only data for 1979-1985 have been used.

3.1.6. Letjärn - model calibration

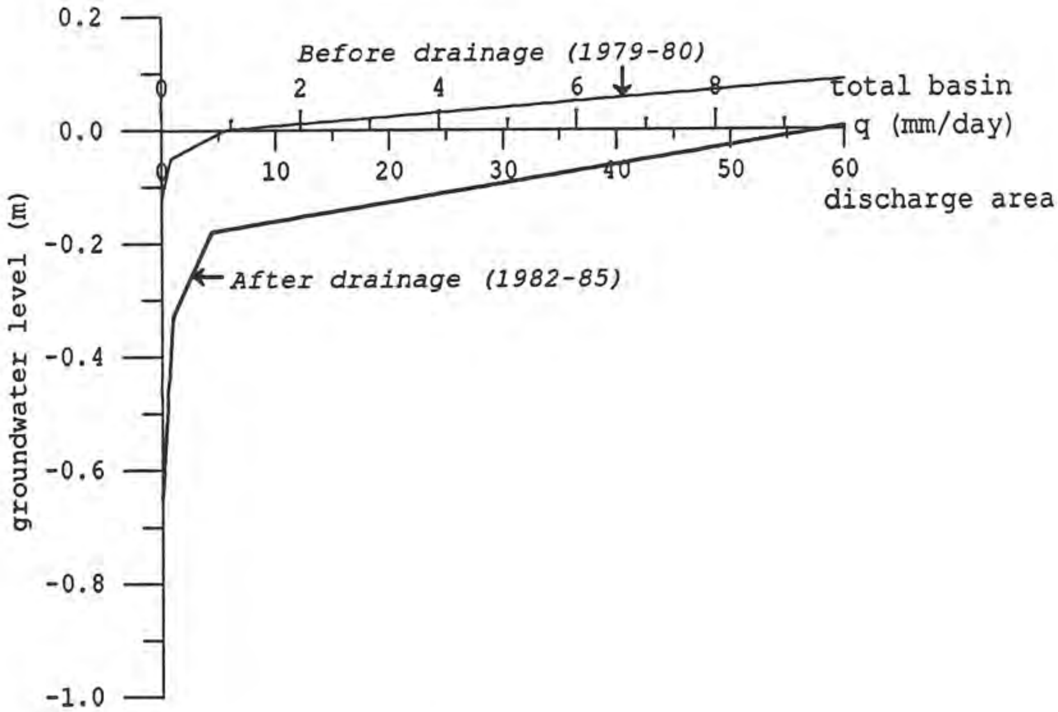

Figure 16. Rating curve for streamflow generation from the discharge area. Letjärn.

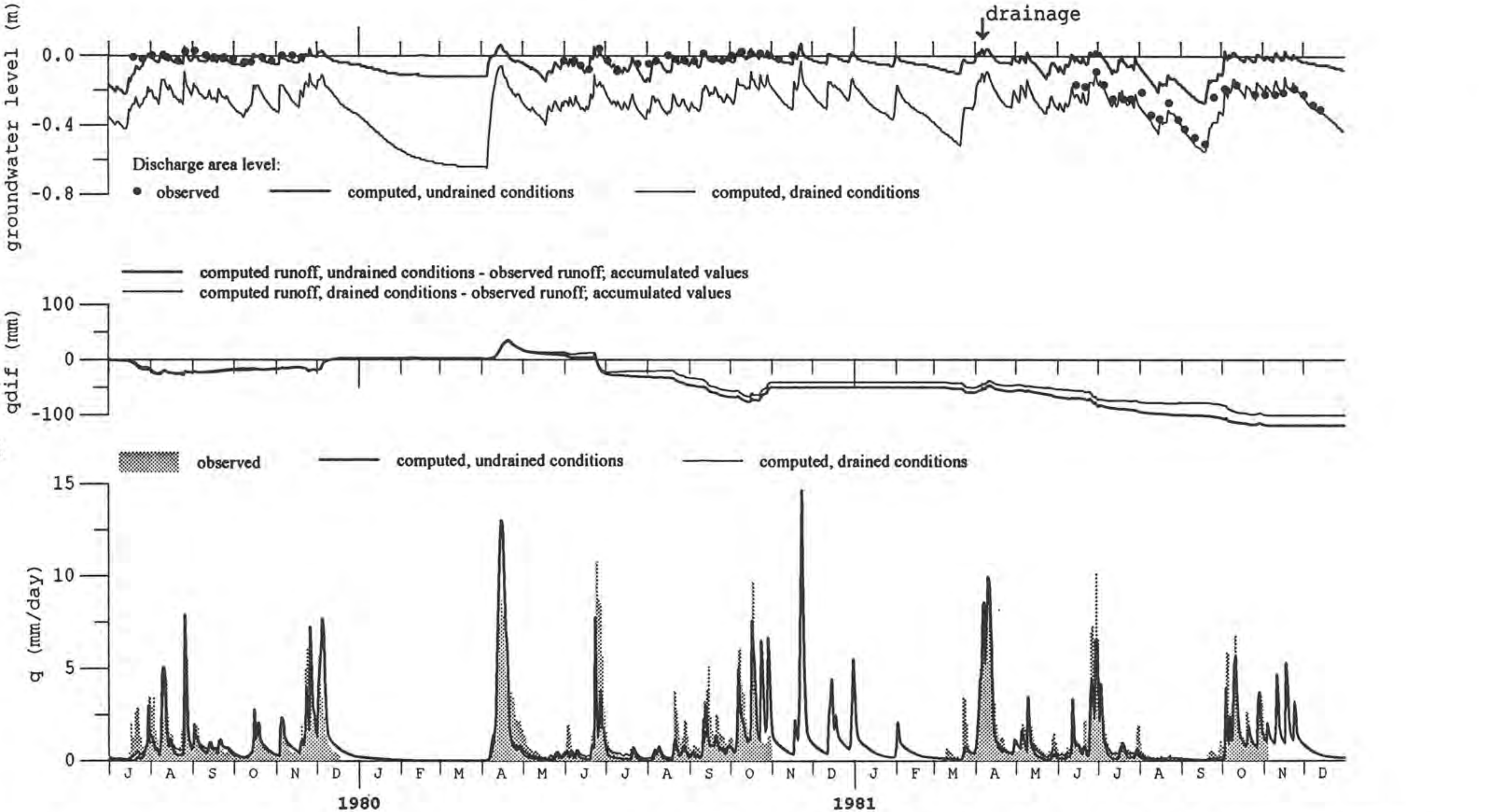

Figure 17. Observed and simulated runoff and groundwater levels for drained and undrained conditions, 1979-1981. Drainage was carried out in April 1981. Letjärn.

When calibrating the model against runoff observations only, it was not really possible to distinguish between the periods before and after drainage. Instead groundwater observations were used to find separate parameter sets for drained and undrained conditions. As data on groundwater levels were available, a first estimate of the recession parameters could be made by comparing observed runoff and groundwater levels. This greatly simplified the calibration process. The final rating curve is shown in Figure 16. For the range of flows in the calibration period, the simulated hydrograph was not sensitive to variations in the upper recession coefficient.

Figure 17 exemplifies the good agreement between computed and observed groundwater levels, as well as the similarity between the runoffs simulated with the two parameter sets. The simulated peaks are plotted against the observed in Figure 18. They differ considerably, which in a small basin like this one can, apart from the inadequacy of the model, be explained by the meteorological data not being representative.

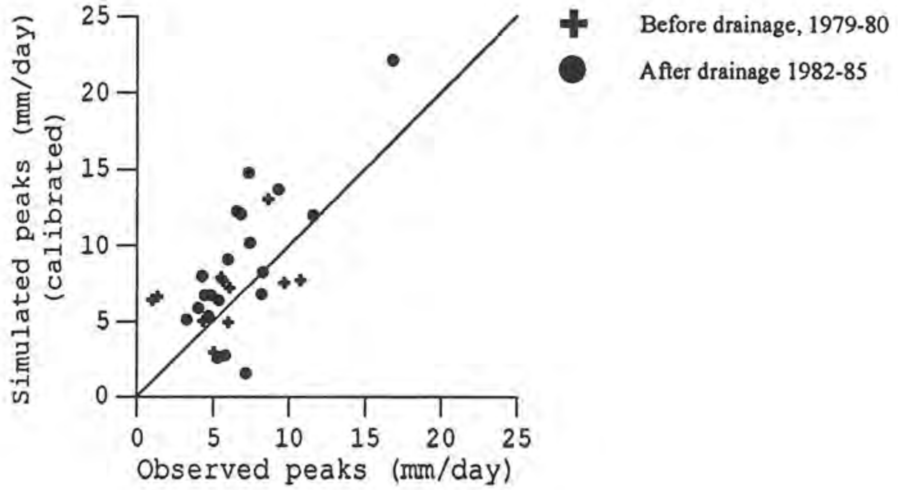

Figure 18. Simulated against observed runoff peaks. Letjärn. Calibrated parameter set.

3.1.7. Letjärn - drainage effects

During the calibration procedure, it was necessary to use groundwater levels to separate the parameters for drained and undrained conditions, so obviously the effects of drainage on runoff were small. This is illustrated by Figure 19, were simulated runoffs are shown in detail for March to December 1982. The differences, both in runoff volumes and flow peaks, were hardly noticeable and not really significant in relation to the accuracy of the calculations. Comparing the peak flows, no differences at all could be noted, except for the smallest peaks which were slightly lower for drained conditions (Figure 20). The summer low flows became a little higher after drainage. It seems like the desirable effect of drainage, a lowered groundwater table, has been achieved without any undesirable effects on streamflow runoff.

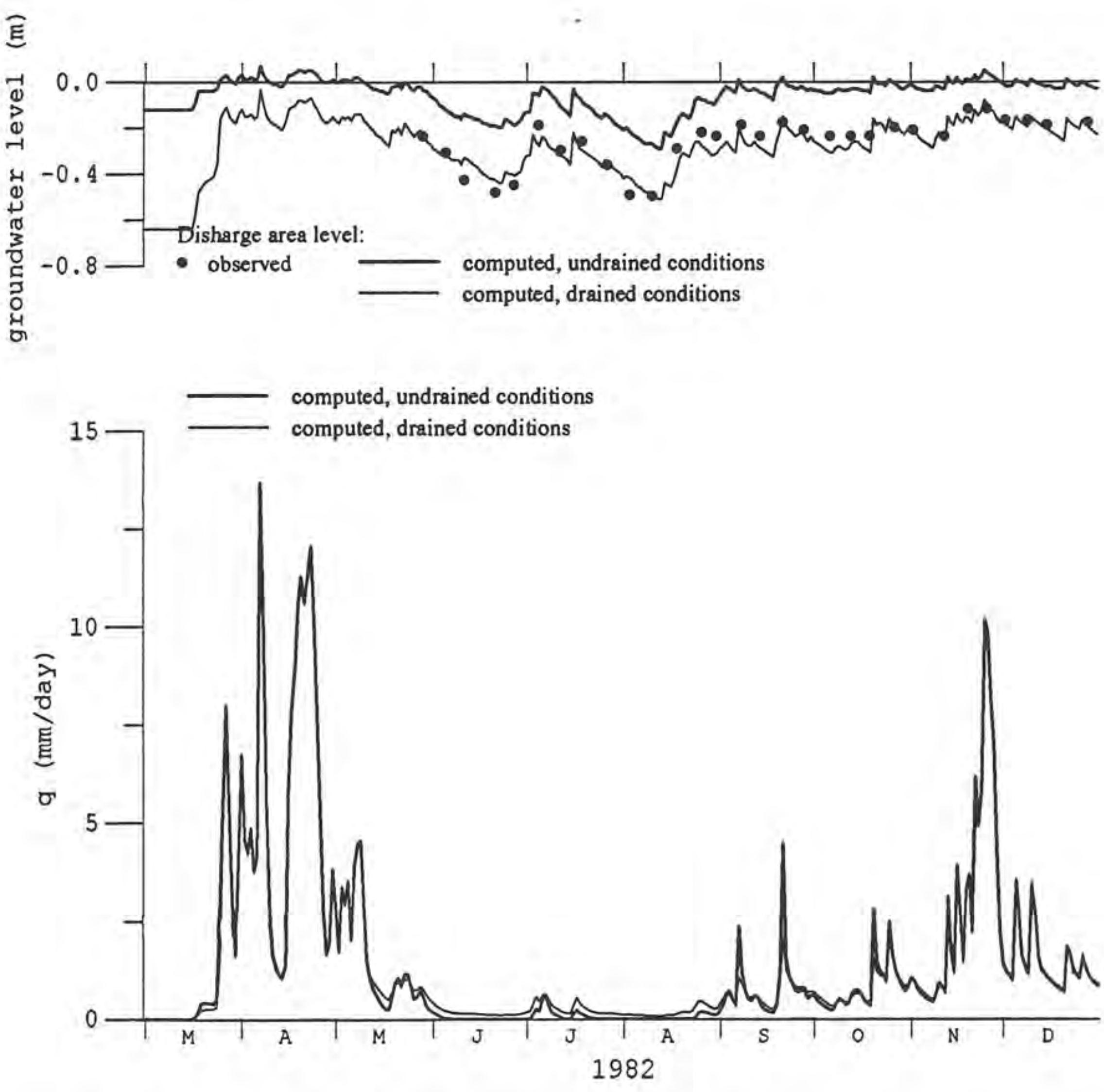

Figure 19. Simulated runoff and groundwater levels for drained and undrained conditions, March-December 1982. Letjärn.

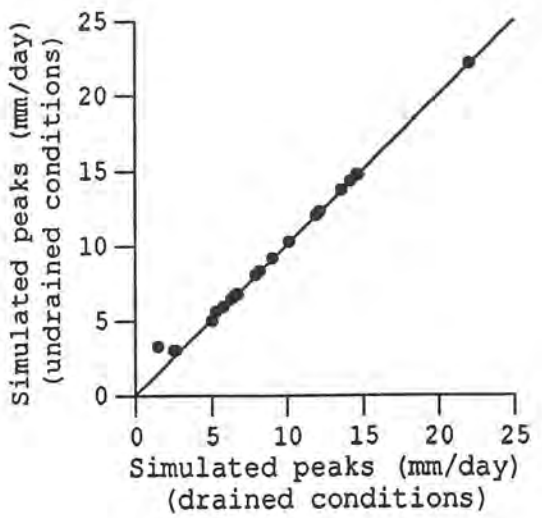

Figure 20.
Simulated changes in peak flows caused by drainage. Letjärn 1982-1985.

3.1.8. Discussion, Letjärn - Huhtisuo

There are several possible reasons to the effects of drainage being so much more pronounced in the Huhtisuo than in the Letjärn basin. However, it cannot only be explained by the fact that the drained area was smaller in the Letjärn catchment (14% as compared to 40% in the Huhtisuo). There were no effects at all on the high peak flows in the Letjärn, and the lower peaks decreased after drainage, while both high and low peak flows increased in the Huhtisuo. Other factors that could be of importance are, e.g., the drainage density (which was probably higher in the Huhtisuo), hydraulic conductivity of the peat and topography.

In section 1, two possible results of drainage were outlined:

- The lowering of the groundwater table creates an unsaturated soilwater zone, which acts as a buffer, damping the peak flows, especially after dry periods.
- The denser stream network leads to a quicker response to rainfall and higher peaks, especially when the initial conditions are wet.

According to the model simulations (supported by observations), the groundwater levels before drainage were very close to the surface in the Letjärn area, while they in the Huhtisuo swamps, lay at a depth of about 40 cm below the ground surface during winter and summer low flows. The drainage of the Letjärn basin then created a soil water buffer zone, damping the flows after dry periods. In the Huhtisuo however, such a buffer zone existed already before drainage, and instead the increased density of the streamflow network, led to higher peak flows. The theory of the effects of drainage being dependent on groundwater levels before drainage, was brought forward by Robinson (1989). He analyzed data from eight catchments, some showing decreasing and some increasing peak flows after drainage. He found that one common factor for the catchments where the peak flows increased, was that the groundwater table before drainage was at a depth between 30 and 40 cm during the winter months. The catchments where peak flows decreased had very shallow groundwater tables.

A reason to why the highest peak flows did not increase in the Letjärn, could be a very high hydraulic conductivity in the surface layers of the peat. This would mean that at high groundwater levels, the ditches had little effect on the flow of water.

One of the aims of drainage is to prevent inflow to the peat from the surrounding areas (Lars Lundin, personal communication). This is achieved by means of the cut off ditches that let the water bypass the swamps. In the simulations described above, it was assumed that the drainage only affected the passage of water through the swamps, but an attempt was also made to simulate the bypass of some water. This led to a slightly better simulation of the very small variations in the summer low flows, but it did not affect the level of the low flows or the size of the peak flows. As it introduced one more uncertain factor (the portion of the water passing through the swamps), it was therefore discarded.

Another possibility, which has not been considered in this study, is that the water divide is changed as a result of the drainage. This would most likely increase the catchment area, and consequently lead to a higher streamflow.

3.2. Large catchment simulations

3.2.1. Svartån - basin description

The Svartån basin is situated in central Sweden, not so far from Letjärn. The catchment area is 978 km^2, with a lake percentage of 8%. According to the 1:50,000 topographical map, slightly less than 20% of the catchment is covered by swamps.

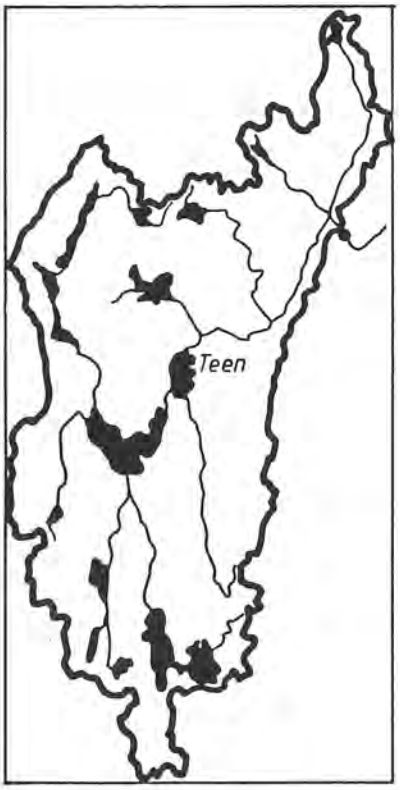

Figure 21. The Svartån basin (978 km^2).

3.2.2. Svartån - model calibration

The parameters for the swamps were fixed as they were taken from the Letjärn and Huhtisuo areas. A gauging station, Hidingebro, was constructed at the catchment outlet in 1989, which made it possible to roughly calibrate the parameters for the recharge areas. Two calibrations were made. With the Letjärn parameters for the swamps, the R^2-value (Nash and Sutcliffe, 1970) for the runoff was 0.87 for 1989-1991, while the Huhtisuo parameters gave an R^2-value of 0.89.

3.2.3. Svartån - drainage effects

As a first step, the worst possible situation was simulated, i.e. drainage of almost all the swamps in the catchment (17%). When assuming that the swamps were of the Letjärn type, there were hardly any drainage effects at all, only a slight increase in the summer low flows (Figure 22).

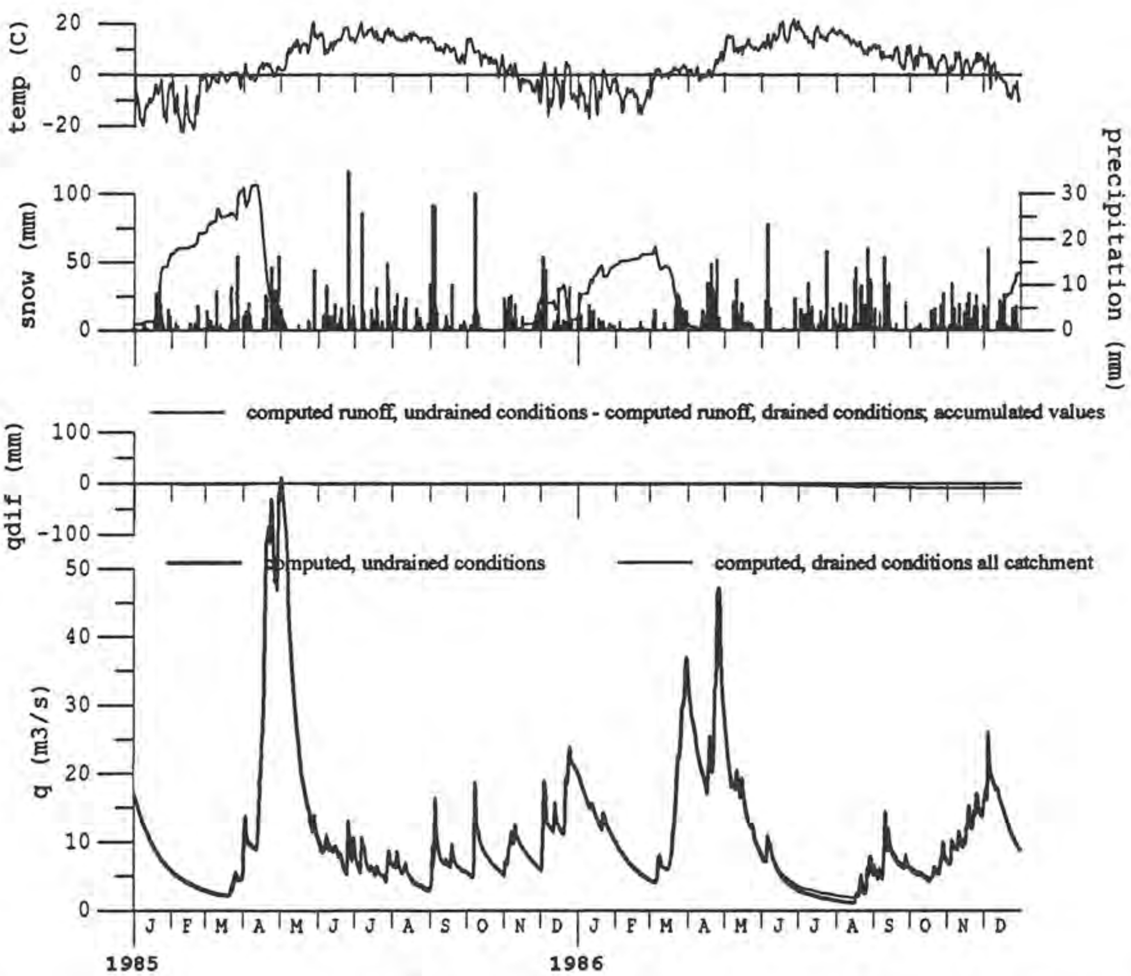

Figure 22. Simulated runoff for drained and undrained conditions for the Svartån, with model parameters from the Letjärn basin used for the swamps. All swamps drained.

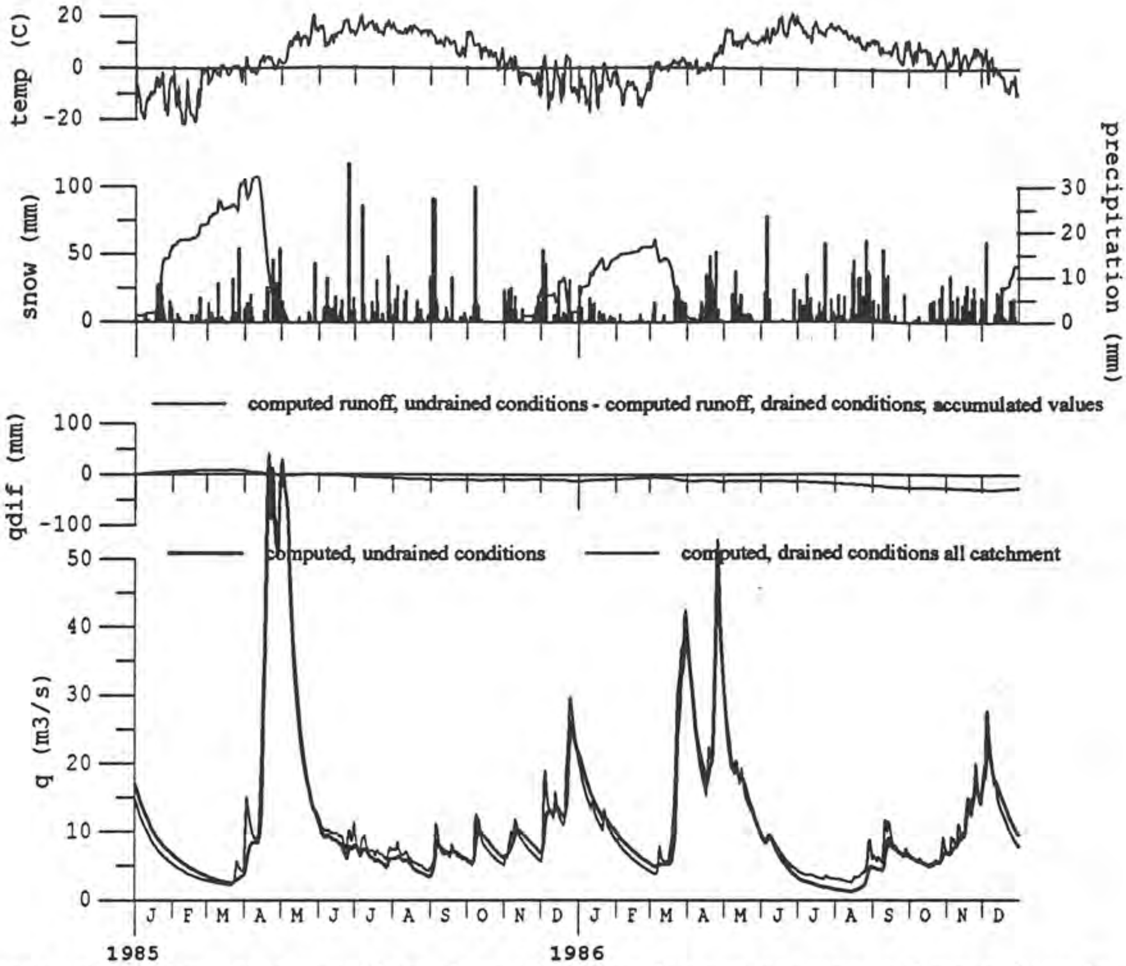

Figure 23. *Simulated runoff for drained and undrained conditions for the Svartån, with model parameters from the Huhtisuo used for the swamps. All swamps drained.*

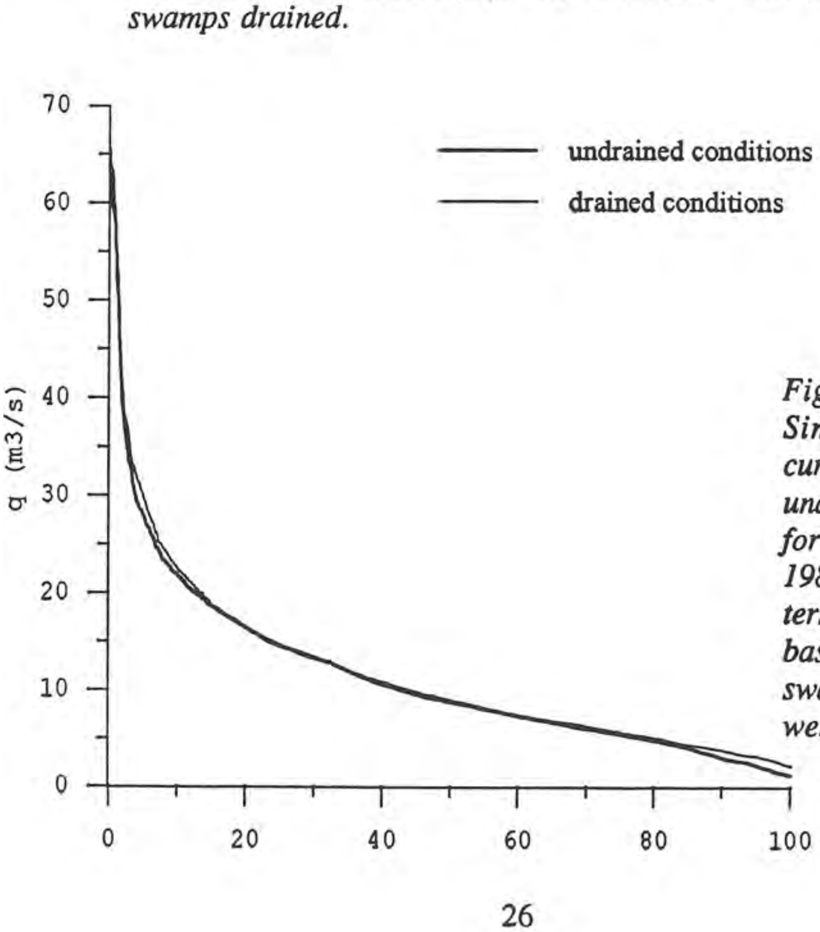

Figure 24. *Simulated duration curves for drained and undrained conditions for the Svartån, 1984-1987. Model parameters from the Huhtisuo basin were used for the swamps. All swamps were drained.*

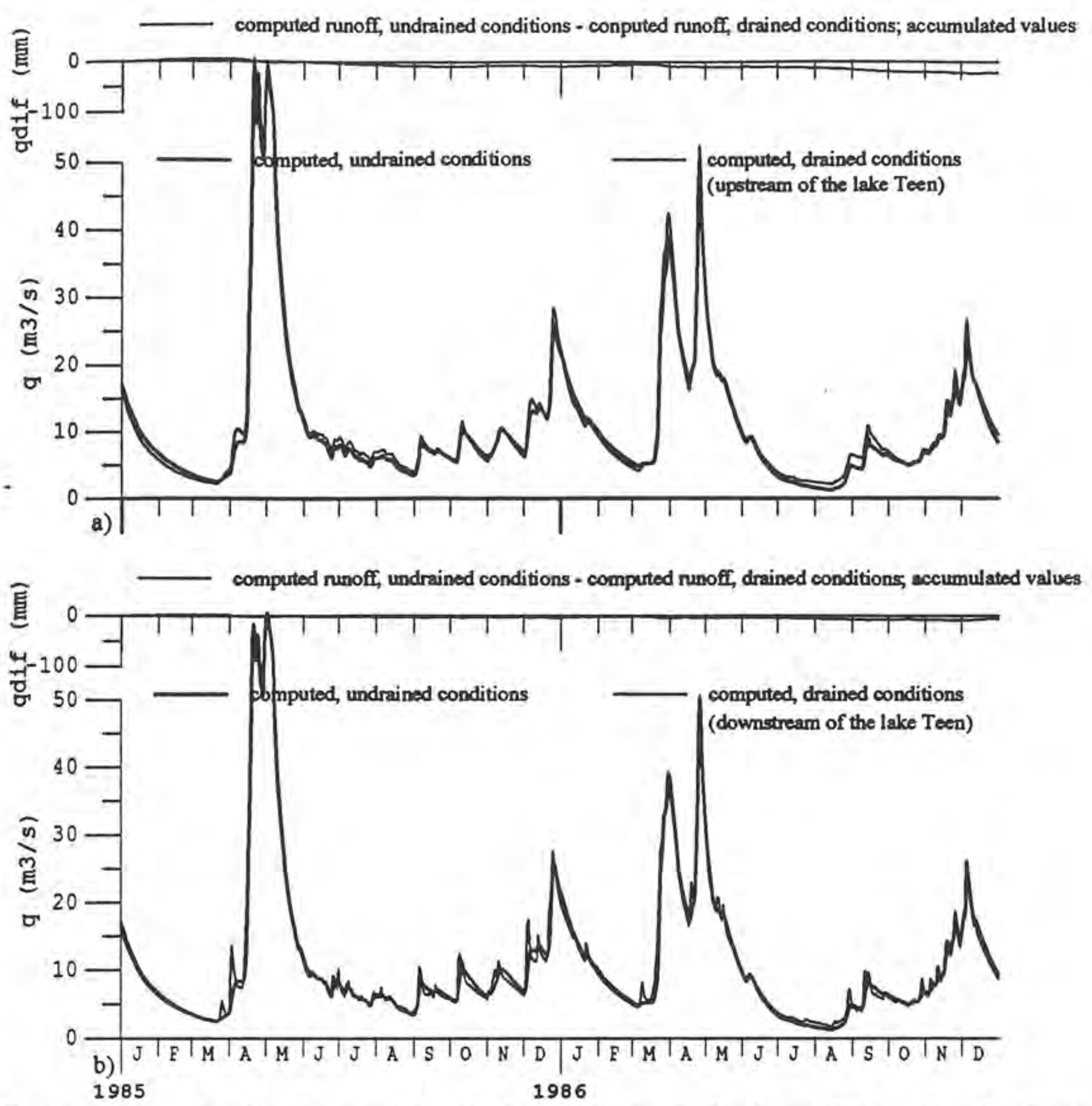

Figure 25. Simulated runoff for drained and undrained conditions for the Svartån, with model parameters from the Huhtisuo basin used for the swamps.
a) All swamps upstream of the lake Teen drained.
b) All swamps downstream of the lake Teen drained.

With swamps of the Huhtisuo type, the effects were clearer, but still small. Low flows and peak flows became a little higher, recession a bit faster, and the runoff volume increased by 3.5% (Figure 23). This is also illustrated by the duration curve in Figure 24.

70% of the wetland area is upstream of the lake Teen (Figure 21). It can be assumed that the effects of drainage in these parts are damped by the lakes, and of little importance further downstream. To study this, two separate model runs were made, simulating drainage of the swamps upstream and downstream of the lake Teen respectively (using the Huhtisuo parameters). The results are shown in Figures 25a and b. The increase in the low flows, in the large runoff peaks and in the runoff volume is mainly explained by the drainage upstream of the lake Teen, where the wetland area is larger. The increased pointedness in the smaller peaks however, is caused by the drainage downstream of the lake.

The damping effects of the lakes is further illustrated by Figure 26, which shows model runs with the lakes removed. In these simulations there were considerable effects of the drainage on low flows and on small and medium-sized peaks. The highest peaks however, were still of the same size for drained and undrained conditions.

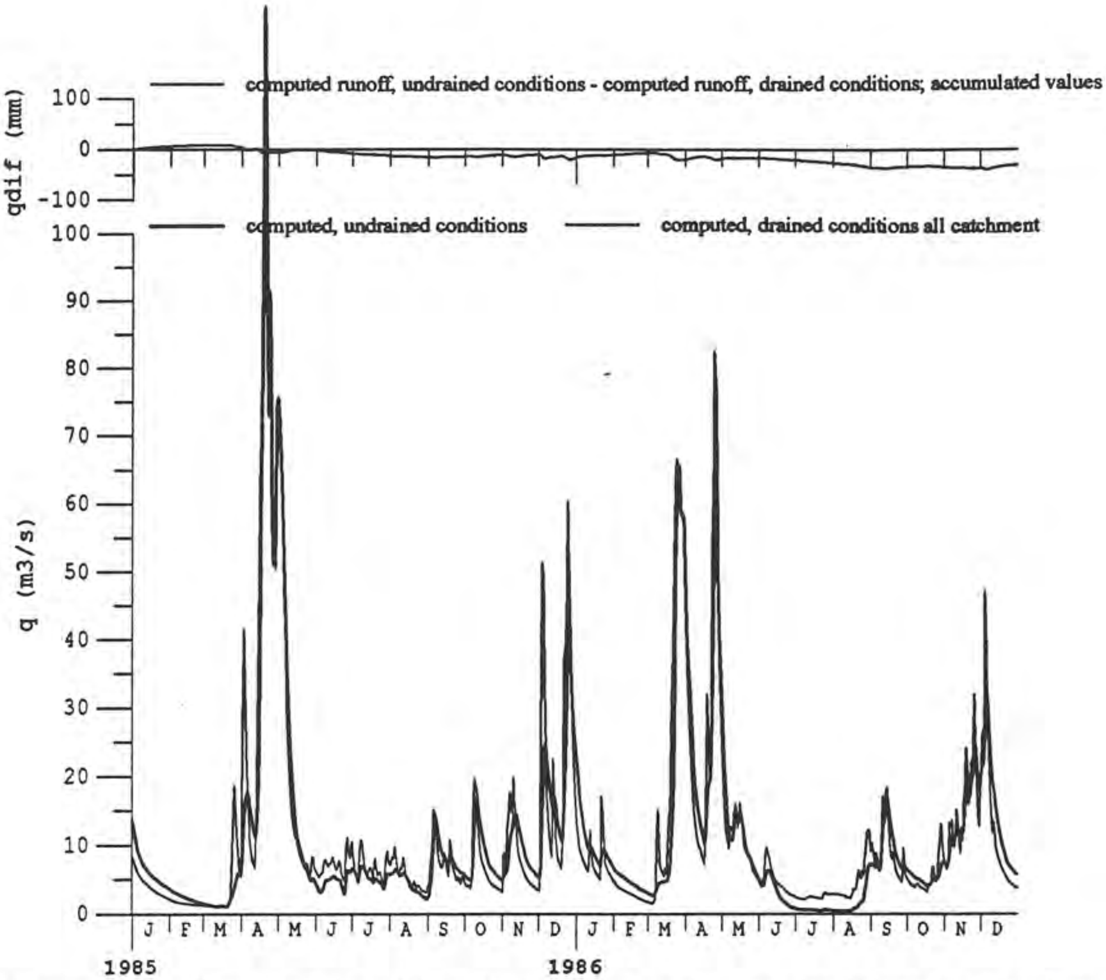

Figure 26. Simulated runoff for drained and undrained conditions for the Svartån, with the lakes removed, and with model parameters from the Huhtisuo basin used for the swamps. All swamps drained. (Cf Figure 23.)

3.2.4. Svartån - simulation of extreme weather conditions

A 14-day design areal rainfall sequence was entered into the model on three dates in 1984-1987, representing autumn, spring and summer. The sequence was taken from the Swedish guidelines for the design of large dams (Flödeskommittén 1990) and varies with the time of the year. It represents a very extreme event, assumed to be valid for safety evaluation of high hazard dams. The dates when it was applied were chosen to give the highest possible peak flows.

Figure 27 shows the results of the simulations for drained and undrained conditions, assuming swamps of the Huhtisuo type. The differences between the simulations are very small. The largest differences were found during the autumn sequence in 1984. The

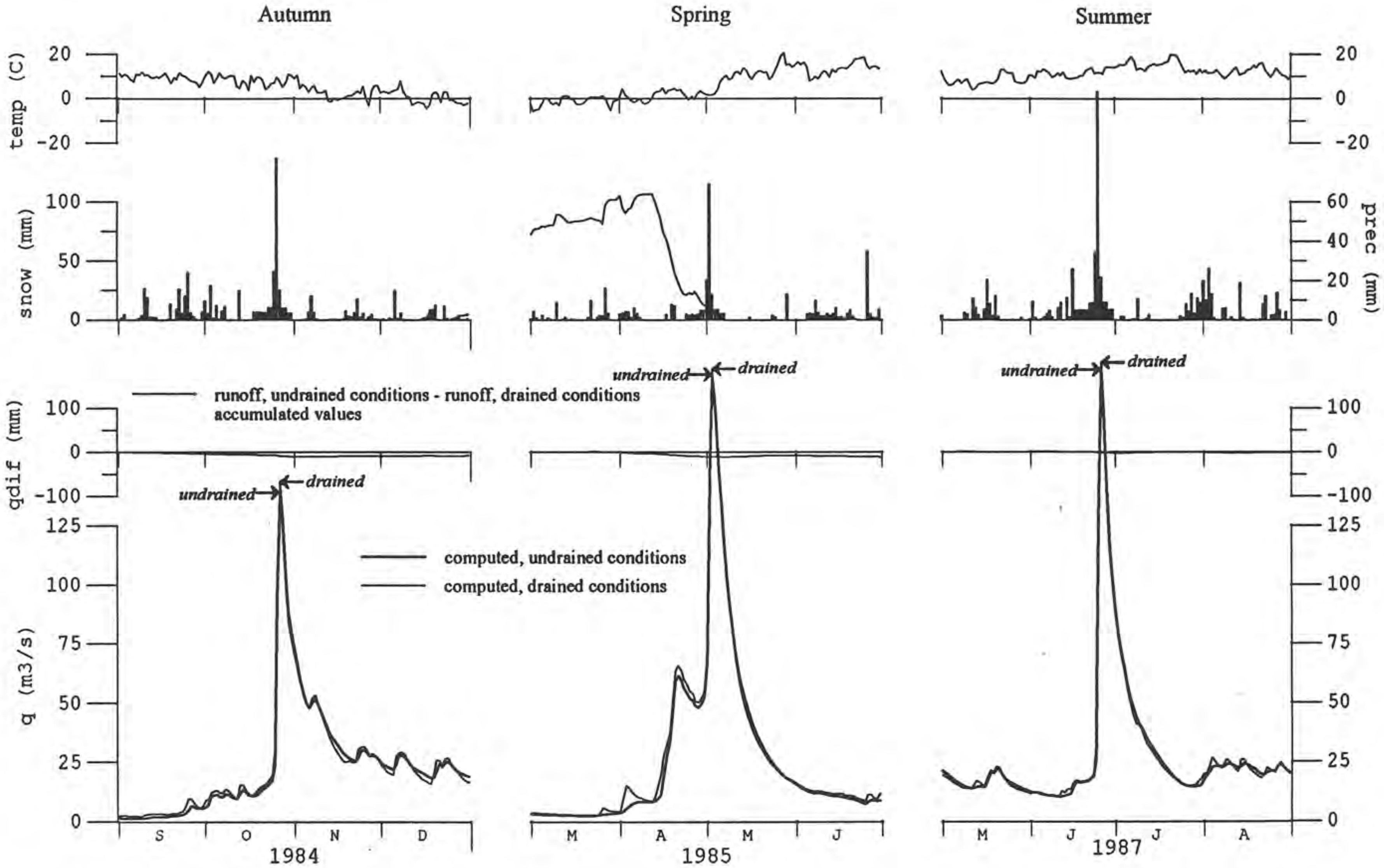

Figure 27. *Simulation of extreme flows for the Svartån for drained and undrained conditions, with parameters from the Huhtisuo used for the swamps. All swamps drained.*

simulated peak for undrained conditions was then 139 m^3/s, while the peak for drained conditions was 144 m^3/s. These differences are smaller than the accuracy of observations during extreme flows. The runoff volume for the drained conditions was 2.5 mm higher for the week around the peak, which corresponds to a mean flow of 4.8 m^3/s. The results were similar when simulations were made with the lakes removed.

Simulations of extreme flows for the Letjärn type of swamps gave virtually no differences between drained and undrained conditions.

3.2.5. Svartån - discussion

The simulated effects of drainage in a large basin were small, and even more so during extreme flows when the soil and groundwater reservoirs were filled up. As mentioned earlier it was not possible to simulate the conditions immediately after drainage for the Huhtisuo swamps. This was the period when the effects of drainage were greatest. However, it is unlikely that in a large basin a high proportion of the area is drained within the same year, and it is therefore not of great interest to simulate such conditions.

4. SUMMARY AND CONCLUSIONS

The effects of drainage on high flows have been studied by means of a conceptual runoff model (HBV/PULSE). To find parameters, typical for drained wetlands, the model was calibrated for two small catchments, one in central Sweden and one in south eastern Finland. Field investigations on the effects of drainage had been carried out in the catchments, and runoff data were available for drained and undrained conditions. The catchments had different characteristics, and the calibration procedure yielded two different parameter sets.

The drainage effects in these small basins were studied by simulating the runoff, for a specific period, using model parameters for drained and undrained conditions. In the Swedish catchment, the effects on the runoff were almost negligible. To differ between the two simulations, it was necessary to look at the groundwater levels. In the Finnish catchment, the peak and low flows, as well as the total runoff volume increased considerably during the first 10 years after drainage. Based on the model simulations, it was only possible to speculate on why the catchments reacted so differently to the drainage. One reason could be that the groundwater table before drainage in the Swedish catchment was, on average, closer to the soil surface than in the Finnish catchment. The creation of an unsaturated zone, damping the peak flows, therefore balanced the increased drainage density in the Swedish catchment, while this was not the case in the Finnish one. Directly from the observations, it was obvious that the effects in the Finnish catchment were very large the first year after drainage, with an extremely high runoff volume in relation to the precipitation. This could only be explained by a decrease in soil and ground water reservoirs, and was not simulated.

The drainage parameters found for the small experimental basins, were also used to simulate the drainage of a 1000 km^2 catchment with a 20% coverage of swamps, the Svartån in central Sweden. As could be expected, hardly any effects could be seen when parameters from the small Swedish basin were used, but neither the Finnish parameters gave any substantial effects. There was a slight increase in peak and low flows, and the total runoff volume increased by 3.5%. When extreme flows were simulated, by entering a design area rainfall sequence into the model, the differences between peak flows were fully negligible. The very large effect that could be seen in the small Finnish catchment the first year after drainage could not be simulated for the Svartån basin. This is however not of much interest, as it is unlikely that more than a small portion of a fair-sized catchment will be drained in one year.

Consequently, with the technique used in this study, it is not possible to identify any significant effects of drainage on the extremely high flows in large catchments.

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