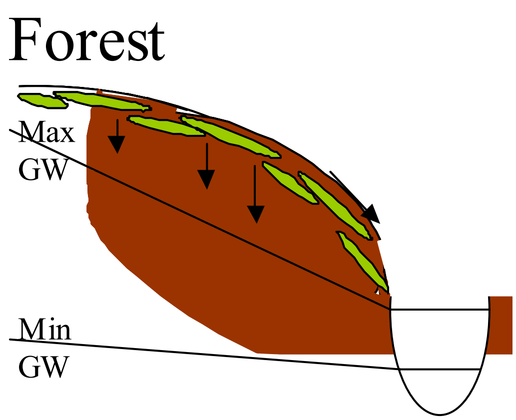
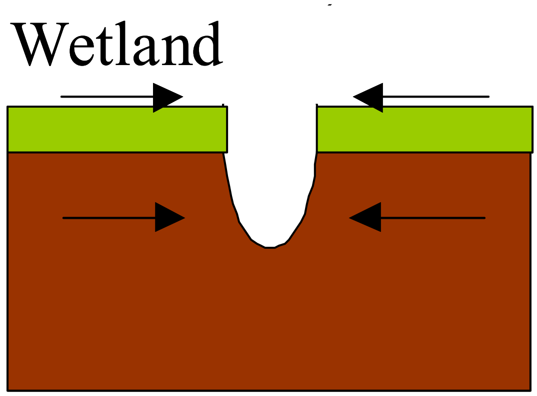
Swedish University of Agricultural Sciences
Department of Forest Ecology
Graduate Thesis in Soil Science 2005

The role of catchment scale for determining hydrological flow paths during spring flood





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This report presents an MSc thesis in Soil Science, carried out at the Department of Forest Ecology, Faculty of Forest Sciences, SLU. The work has been supervised and reviewed by supervisors, and been approved by the examinator. However, the author is the sole responsible for the content.

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Abstract

The purpose of this study was to explore the pathways of melt water during the spring flood. Snow melt is a complex process of great importance for boreal ecosystems, and there are major challenges remaining to fully understand the stream flow generation. The study was carried out at Vindeln Experimental Forests, Vindeln in northern Sweden. The hydrological pathways were traced by measuring the $\delta^{18}O$-signals for event water and stream water during the spring flood and the pre-event water $\delta^{18}O$-signal before the snow melt. These $\delta^{18}O$-signals differ because of isotope fractionation, allowing for the separation of different water sources. Event water is defined as melt and rain water entering the catchment during the snow melt episode while pre-event water is water that was present in the catchment prior to snow melt. The separation of the stream water into event water and pre-event water fractions was done using isotopic hydrograph separation. The focus of this study was on comparing the importance of wetlands and scale for the portion of event and pre-event water using 15 streams ranging in catchment size between 3 and 6784 ha with extra focus on small catchments. Small catchments with a substantial wetland part had a bigger event water fraction in the streams and a quicker and greater response to snow melt than small forest dominated catchments. An explanation could be extensive and homogeneous soil frost in wetland areas that caused surface flow paths where less water was lost due to soil infiltration as compared to forest dominated catchments. The stream water during spring flood was dominated by pre-event water. This could be explained by event water entering the soil that increased the ground water flow that consisted of pre-event water.

Sammanfattning

Syftet med denna studie var att kartlägga smältvattnets flödesvägar under vårfloden. Snösmältning är en komplex och viktig process för boreala ekosystem. Det återstår mycket att lära i fråga om hur tillskottet av vatten till avrinningsområdet påverkar vattnet i bäcken under vårfloden. Avrinningsområdet är det område kring ett vattendrag från vilket vattendraget får sitt vatten. Studien gjordes vid Vindelns försökspark Svartberget i norra Sverige. Vattnets flödesvägar kartlades genom att under hela vårfloden mäta $\delta^{18}O$-signalerna för det regn- och smältvatten som tillfördes avrinningsområdet under vårfloden (=nytt vatten) och bäckvattnet samt $\delta^{18}O$-signalen för det vatten som fanns i avrinningsområdet innan snösmältningen började (=gammalt vatten). Dessa $\delta^{18}O$-signaler varierar på grund av isotopfraktionering vilket gör att man kan spåra vattnets ursprung i avrinningsområdet. I denna studie studerades vikten av andelen våtmark i avrinnings-området och avrinningsområdets storlek för bäckvattnets sammansättning av vatten med olika ursprung. Bäckar med små våtmarksdominerade avrinningsområden hade en större andel nytt vatten och en snabbare och kraftigare reaktion på snösmältning än små skogsdominerade avrinningsområden. Detta kan förklaras med att en homogen tjäle i våtmarksområden tvingade smältvattnet att ta en ytlig flödesväg till bäcken vilket också ledde till att en mindre mängd vatten förlorades till marken genom infiltration jämfört med ett skogsdominerat avrinningsområde. Samtliga vattendrag dominerades i princip av gammalt vatten. Detta kan förklaras med att tillskottet av smältvatten till marken ökade grundvattenflödet som består av gammalt vatten.

Introduction

Background and aim

During the spring flood a large part of the annual runoff is discharged. As the study area has an annual spring flood the timing and contribution of melt water during the spring is an important issue related to management of water resources, transport of contaminants and biogeochemical cycling (Laudon et al., 2002). Contributing factors to the stream flow generation in boreal catchments are still not too well understood, especially not for the spring flood (Laudon et. al., 2004a). The purpose of this study was to better understand hydrological flow pathways and sources of water and to test how catchment scale and wetland % area affect the stream water during the spring flood. This is important for this region because 25% of the land area is covered by wetlands (Laudon et al., 2004b). As the ground surface in wetlands is water saturated the soil frost get more homogeneous than forest soil frost (Rodhe, 1998). The hypothesis was that as wetlands often have homogenous soil frost the melt water can not infiltrate into the soil and hence use surface flow paths to reach the stream. This effect was assumed to increase the contribution of event water in wetland-dominated catchments. Most previous studies have concluded that the stream water during spring flood is dominated by pre-event water (Rodhe, 1998 and Buttle, 1998).

Runoff pathways and water storage are particularly sensitive during the spring flood. As small streams are the main contributor of water to larger rivers understanding the spatial variability in hydrological pathways is important for understanding variability and sensitivity in receiving surface waters down stream. For example, in wetlands a small change in water storage and runoff pathways is of great importance for the carbon cycle due to accumulation and decomposition rates. The hydrological regime of catchments in larger rivers is important for their water input to oceans. This could affect the thermohaline circulation which in turn could affect the global climate (Hayashi et al., 2004).

Spring flood

In high latitude regions snow accumulates during the winter due to low temperatures. Most snow melts during a concentrated time period in the spring. When the snow melts the streams get water both from ground water sources and surface water sources. There is a quick contribution of water and solutes to groundwater and streams. Salts and acids are stored in the snow pack and as they tend to redistribute in snow crystals they leave the snow pack with the first melt water to a high extent. This means that the early melt water typically contains more solutes than the original snow pack did on average. The large water input results in an increased ground water level, which leads to shallower and faster flow paths (Rodhe, 1998).

Soil frost reduces the infiltration capacity but all melt water may still infiltrate in the heterogeneous soils of forested catchments (Nyberg et. al. 2001). The infiltration capacity in frozen soils is governed by water content in the upper soil layers. A water saturated soil like wetlands causes a more homogenous soil frost as the large pores that are the most important for infiltration gets blocked by ice. This may give rise to overland flow in a higher extent in wetlands than in forests (Rodhe, 1998).

Site description, time period and performance of research

The field work was performed in the Krycklan catchment, Vindeln Experimental Forests, during spring flood of 2004. Krycklan is located in the boreal region in northern Sweden about 50 km inland from the Baltic Sea coast. At Vindeln Experimental Forests, basic and applied research takes place in the areas of forest management, ecology, ecophysiology and meteorology (http://www.vfp.slu.se/index.asp).

The snow melt began on the 7th of April and finished the 8th of May. The research included 15 catchments, most of which were dominated by pine and spruce forests. The study focused on small forest dominated catchments and small catchments with a substantial wetland part. The study was a part of a whole-catchment research project involving more than 20 sub-projects related to water quality, hydrology, stream biodiversity and climate effects. The Krycklan catchment is one of the most investigated catchments in Sweden. (http://ccrew.sek.slu.se/krycklan/index.html and http://www.vfp.slu.se/index.asp). The ground consists of a locally derived glacial till with a general thickness of 10-15 meters overlaying gneissic bedrock. Soils are mostly iron podzols with peat deposits in the riparian zone close to the stream channel (Laudon et al., 2002).

Table 1. Catchment characteristics. Originally there were 15 sites but four were excluded because of having a substantial lake part of the catchment, which severely affects the base flow δ^{18}O-signal. One was excluded before the study because of being too small.

			Part of the catchment (%):	
Site No:	Catchment size (ha)	Pine forest	Spruce forest	Wetlands
1	66	7	92	1
2	13	40	60	0
3	3	51	12	37
4	19	52	8	40
7	50	37	48	15
8	248	59	29	11
10	294	57	17	26
12	540	58	26	16
13	721	57	32	11
14	1360	70	21	10
16	6784	67	21	12

Literature review

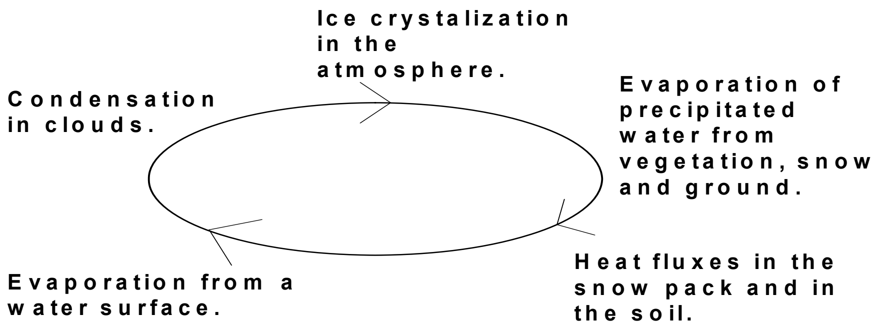

Figure 1. Simplified model of the water cycle and some processes causing fractionation between the isotopes ^{16}O and ^{18}O in water.

The water cycle and isotope fractionation

Precipitation that falls in a catchment will eventually leave it. Water ending up in the vegetation or a similar surface can easily evaporate. Water that falls on saturated areas close to streams will leave the catchment through the streams (Buttle, 1998). Other water will infiltrate the soil where it is held as soil- and groundwater until it leaves the ground by evaporation, transpiration, ground water flow or as stream water (Buttle, 1998) Precipitation will infiltrate the soil unless the soil is saturated or the water supply is too quick. The movement of water is governed by the gradient in water potential and the conductivity of the soil (Barnes and Turner, 1998).

There are a number of fractionating processes influencing the isotope ratio from the moment the water leaves a water surface until it returns. The water molecule $H_2{}^{16}O$ has the oxygen isotope ^{16}O that is lighter than the oxygen isotope ^{18}O that is a constituent of $H_2{}^{18}O$. This makes the water molecule $H_2{}^{16}O$ evaporate more easily than $H_2{}^{18}O$. This causes a fractionation as the water vapour contains a lower load of heavy molecules. If moist air condenses in a cloud there will be an enrichment of heavy water molecules in the liquid phase. The amount of heavy isotopes will decrease with increasing altitude and increasing distance from the source. The fractionation will give the precipitated water a $\delta^{18}O$-signal different from the $\delta^{18}O$-signal of the pre-event water (Kendall and Caldwell, 1998 and Ingraham, 1998). The $\delta^{18}O$-signal in the snow pack is governed by the $\delta^{18}O$-signal of different precipitation events. Fractionation also occurs as a result of thawing and refreezing of snow. As snow melts with a different rate depending on isotope content, an enrichment of $\delta^{18}O$ will take place in the melting snow pack as light water molecules melts easier, faster and therefore earlier. In dense forests a great deal of the snow will stick to needles resulting in fractionation as some evaporates before it even enters the snow pack. There is also evaporation at the surface of the snow pack causing the snow to be enriched in heavy isotopes (Cooper, 1998 and Rodhe, 1998). The soil heat will push light molecules upwards by evaporation which makes the basal snow contain more heavy isotopes (Friedman et al., 1991). In case of rain heavy isotopes will be added to the snow pack but normally the $\delta^{18}O$-signal of the snow soon returns to the value prior to the rain event (Maclean et al.,1995). Soil water will be enriched in heavy isotopes due to evaporation (Barnes and Turner, 1998).

Stream flow generation and the transmissivity feedback

Stream flow generation is the process that transforms rain water and melt water into stream flow. These water sources result in an increasing groundwater outflow to the streams. Most previous studies have concluded that the stream water during spring flood is dominated by pre-event water (Rodhe, 1998 and Buttle, 1998). This could be explained by the transmissivity feedback that commonly occurs in glacial till soils as in the study area. In these soils the hydraulic conductivity increases closer to the surface where an increasing groundwater table, in this case caused by substantial melt water contribution, leads to an increased soil water flow that predominantly consists of pre-event water (Rodhe, 1998, Hayashi et. al., 2004 and Laudon et. al. 2004).

The use of tracers in hydrological research

Using the oxygen isotope ^{18}O as a tracer is considered as one of the best methods for separating event and pre-event water. Some examples of when isotope analysis can be used are: identifying mechanisms that create streams, testing pathways and water budget models, exploring water pathways and tracing a water source. The reasons why these isotopes can give this information are that a water mass that has left a water source at a certain moment has a certain isotopic signal. Stable isotopes do not degrade over time as do radioactive isotopes, and thus ^{16}O and ^{18}O can be used as tracers as they fractionate causing special ^{18}O-signals for different water sources during spring flood. (Kendall and Caldwell, 1998 and Hayashi et. al., 2004).

The $\delta^{18}O$-signal of event water, pre-event water and base flow

The $\delta^{18}O$-signal describes the ratio between the oxygen isotopes ^{18}O and ^{16}O and is expressed relative to the Standard Mean Ocean Water (SMOW) which is used as a reference for $\delta^{18}O$-values (Kendall and Caldwell, 1998). Event water in this study means rain and melt water that affects the catchment during the snow melt episode and it generally has a low $\delta^{18}O$-signal during snow melt which means that it has a low $^{18}O/^{16}O$ ratio. Pre-event water was present in the catchment prior to the snow melt and it normally has a higher $\delta^{18}O$-signal than event water. Base flow is the water in the streams prior to the snow melt and it has a higher $\delta^{18}O$-signal than event water. Thus “light water” has a low $\delta^{18}O$-signal and “heavy water” has a high $\delta^{18}O$-signal.

Methods

Sampling procedure

Sample water was collected in washed or acid-washed 250 ml high-density polyethylene bottles. Before sampling the bottles were rinsed with the sample water and refilled to the top of the bottle. All the samples were subsequently sub sampled into clean 25 ml narrow mouth glass bottles that were kept cold and dark with no headspace until $\delta^{18}O$-analysis.

Collection of event water $\delta^{18}O$-samples

The autumn 2003 before the first snow, three groups with three (1,2m x 1,2m) snow lysimeters each were placed in pine forest, spruce forest and at an open field. By doing this the event water signal could be calculated with respect to the melt water contribution from different land types in a given catchment. The event water signal was weighted depending on how large part of the catchment that was covered by respective land type. During snow melt all melt water was collected in plastic bags, weighted to obtain volume and melt intensity, and then sampled. At a few occasions leakage was suspected and those samples were excluded. The snow lysimeters were sampled at a one to three-day interval during heavy melt and less frequent during low melt intensity. The samples were pooled for the three land types, apart from three occasions when the samples were analyzed separately.

Collection of mire water $\delta^{18}O$-samples

Eleven ground water tubes at a mire in the Krycklan catchment were sampled with a pump that was rinsed between the sample occasions. The tubes were emptied and subsequently left to refill before sampling. The tubes ranged from 0,75 to 4,5 meters of depth in the mire in the catchment of stream 4. Samples were taken at five occasions between the 5th of April, i.e. before the snow melt, and the 30th of May.

Collection of stream water $\delta^{18}O$-samples and discharge measurements

Stream water samples were taken from eleven sites at one to two-day intervals during heavy melt and less frequent during base flow conditions. Discharge was calculated from water height (recorded hourly using Tru-track wthr loggers or Cambpell CR10x loggers equipped with pressure transducers) calibrated with site-specific height-discharge relationships. Three periods of the spring flood were chosen to compare the event water fraction in streams with respect to catchment characteristics and different flow levels. First a period between April 7th and may 30th was chosen representing the whole spring flood. Then a period of clearly increased flow between April 17th and May 17th was chosen. Finally a period of about 7 days of individual peak flow for each stream was chosen that typically occurred at the end of April or at the beginning of May.

$\delta^{18}O$-analysis, CO_2-H_2O isotopic exchange equilibration

Pre-evacuated glass vials were filled with CO_2 and sample water and shaken. CO_2 was used for equilibration; a dry ice/alcohol mixture was used for trapping water and liquid nitrogen for transferring the CO_2. Before the analysis all the used CO_2 was analyzed for oxygen- and carbon-isotopes. After 90 minutes of shaking the $\delta^{18}O$ of the CO_2 was equalized with the $\delta^{18}O$ of the sampled water. Following the same procedure with standard water samples the isotopic signal was decided (Socki et al. 1999).

Isotopic hydrograph separation (IHS) and the runCE-method

The IHS was used to separate the spring flood runoff water into event and pre-event water sources. The method is based on the mass balance of water and a tracer mass balance equation:

$$Q_sC_s = Q_pC_p + Q_eC_e$$

Q is discharge and C is the concentration of a tracer, in this case expressed in $\delta^{18}O$ per mil (‰) with respect to the standard Standard Mean Ocean Water (SMOW). The subscripts s, p and e refers to stream water (sampled runoff water), pre-event water (water in the stream before the snow melt) and event water (melt or rainwater), respectively.

The pre-event water contribution (f_p) was calculated as follows:

$$f_p = (\delta^{18}O_s - \delta^{18}O_e) / (\delta^{18}O_p - \delta^{18}O_e) \quad (1)$$

$\delta^{18}O_e$ was defined using the runCE-method, (equation 2). Due to isotope fractionation during snow melt the input signal of the event water will vary. In this study snow lysimeters were used that measure the timing of $\delta^{18}O$-change in snow melt and any rain contributions. There are uncertainties remaining associated with the variation of the ^{18}O-signal in melt water. The runCE-method used here is a method that accounts for timing and magnitude of melt water that reaches soil and surface water storages and outputs runoff at hourly intervals during the snow melt episode (Laudon et al. 2002). At every time step a volume weighted, runoff-corrected $\delta^{18}O$-value of the event water was calculated. The isotopic composition of this event water was created by comparing cumulative snow melt and rain water contributions from snow lysimeters and the cumulative volume of melt water that has left the snow pack but that has not yet reached the stream. By doing this the lag between the melting of snow and its arrival to the streams is taken into account.

$$\delta^{18}O_e(t) = \left(\sum_{i=1}^{t} M(i)\ \delta^{18}O_m(i) - \sum_{i=1}^{t} E(i)\delta^{18}O_e(i)\right) \Big/ \left(\sum_{i=1}^{t} M(i) - \sum_{i=1}^{t} E(i)\right) \quad (2)$$

M(i) is the incrementally collected melt water depth and E(i) is the incrementally calculated event water discharge at a time t. $\delta^{18}O_e(i)$ and $\delta^{18}O_m(i)$ are the isotopic signals for the event and melt water, respectively (Laudon et al., 2004).

The stream flow was normalized into mm h^{-1} for the catchments. The ^{18}O-signal for the stream water was also interpolated into an hourly basis. The same was done with the $\delta^{18}O$-signal for the event water and the incrementally collected melt water depth was calculated by summarizing the melt water volume up to the current time step. Isotopic data was calculated for the catchment with respect to the relative event water contributions, as well as the $\delta^{18}O$-signal, for open field, spruce- and pine forests. This resulted in hydrographs where the pre-event water fraction of the runoff was plotted, see attachment 1 for examples.

The following conditions need to be fulfilled when using the IHS-method:
* There is a significant difference between the isotopic content of the event and the pre-event components.
* The isotope signature of event water is constant in space and time, or any variations can be accounted for.
* The isotope signature of pre-event water is constant in space and time, or any variations can be accounted for.
*Contributions of water from the unsaturated zone to storm flow must be negligible, or the isotopic content of soil water must be similar to that of ground water.
*Contributions to stream flow from surface storage are negligible
(Buttle,1994)

Results

Snow melt took place between the 7th of April and the 8th of May causing an increase of runoff. The discharge started to increase about a week after the onset of snow melt. The stream water during the episode was dominated by pre-event water. In this study small catchments with a substantial wetland part had a larger event water fraction in the streams and a greater response to snow melt than small forest dominated catchments. The event water fraction in the streams was changed by wetland part of the catchment rather than catchment size.

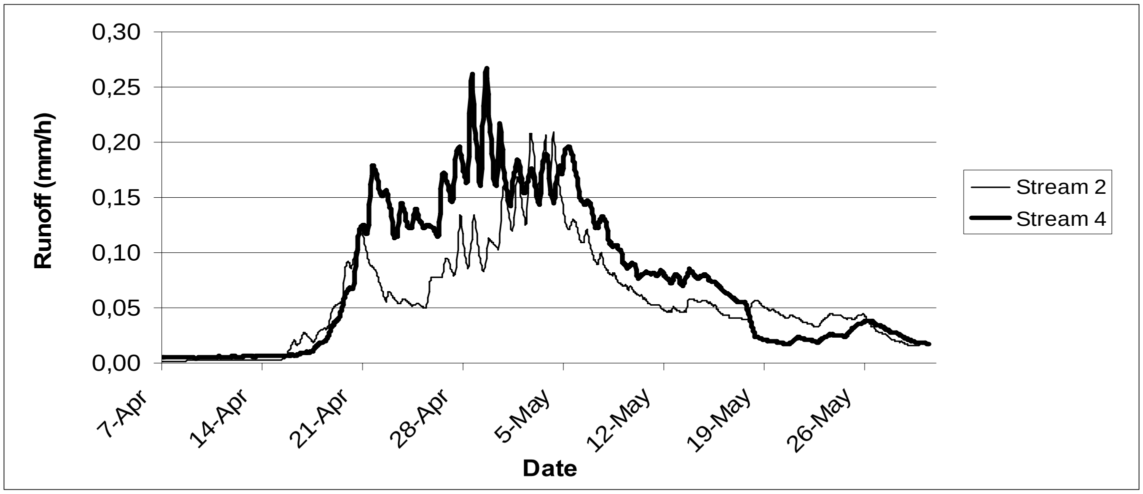

Figure 1. Spring flood development of runoff. Stream 2 has a small forest-dominated catchment. Stream 4 has a small catchment with a substantial wetland part, (see table 1 for catchment characteristics and attachment 1 for separation of event and pre-event water during the spring flood using isotope hydrograph separation for these streams).

There were variations of the timing of runoff between different sites. The discharge started to increase about a week after the onset of snow melt. The first peak came slightly earlier at site 2. The second peak lasted longer due to the heavy snow melt during that period (fig.1 and 2). The pattern for the stream 2 was general for small forest dominated catchments. The flow was generally higher and the main peak earlier at stream 4 that has a catchment with a substantial wetland part (fig. 1)**.** The total runoff during the episode was 99 mm for site 4 and 75 mm for site 2. This indicated a greater recharge of the subsurface water storage for the catchment of site 2 (fig. 1).

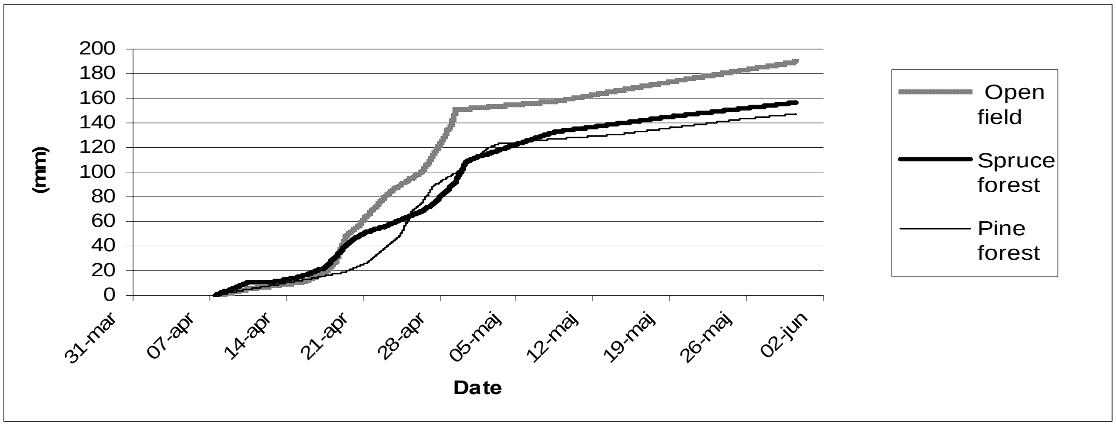

Figure 2. Cumulative snow melt and precipitation during the episode at three sites.

There was a concentrated time period of heavy snow melt. Snow melt began the 7th of April after about 5 months of snow cover and lasted until the 8th of May. The snow was all gone the 29th of April apart from the spruce site that had some snow until the 8th of May. After that the event water contribution to the catchment was from precipitation only (fig. 2). Heavy snow melt took place between the17th and 30th of April. The open field had the largest amount of snow and the fastest snow melt. The spruce forest was denser than the pine forest but had a comparable amount of snow (fig. 2). Precipitation occurred at the 25th of April and the 4th, 12th, 18th, 24th and 26th of May. The volumes ranged from 5 to 7 mm per event.

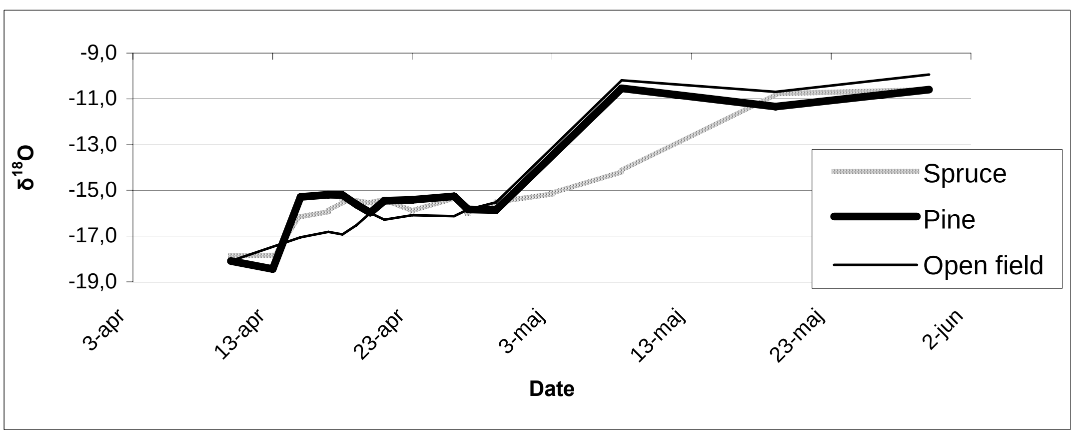

Figure 3. Change in $\delta^{18}O$-signal for melt water and precipitation water from the snow lysimeters at three different land types during snow melt.

The $\delta^{18}O$-signal for the event water varied during the episode. The early event water had a low $\delta^{18}O$-signal. Then the $\delta^{18}O$-signal increased some and stabilized during heavy snow melt and after the peak flow the event water got even heavier (fig. 3). The first and only rain-on-snow event during the episode occurred at the 25th of April. After the 8th of May the event water was only precipitation. The $\delta^{18}O$-signals for separate precipitation analysis ranged from -7,64 to -16,14 which means that data from the snow lysimeters represented a mean value of the late precipitation events that caused an increasing $\delta^{18}O$-signal towards the end of the episode (fig. 3).

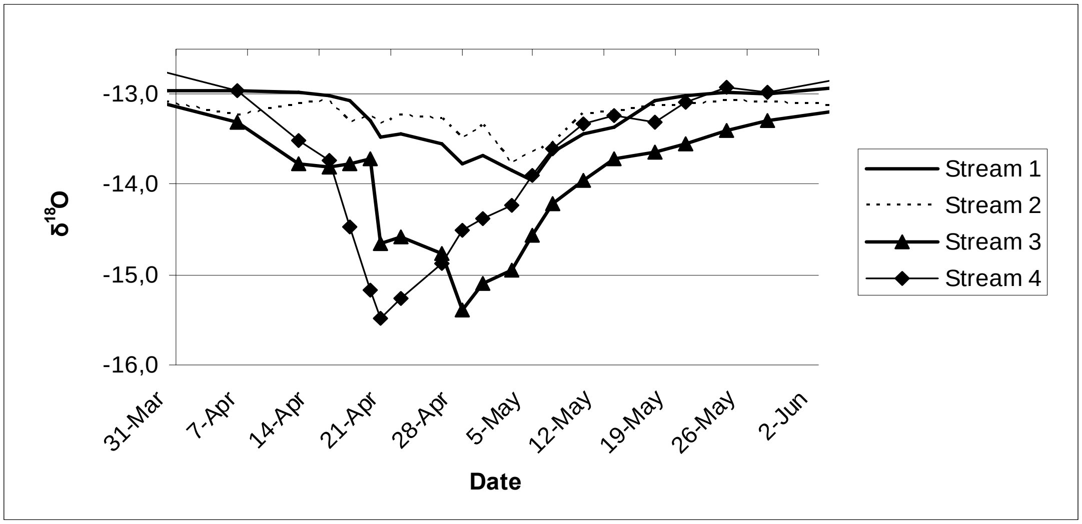

Figure 4. Isotopic development for the stream water during the snow melt. Two small forest dominated catchments (site 1 and 2) compared with two catchments with substantial wetland parts (site 3 and 4).

The isotopic development during the episode was dependent on catchment composition. Small catchments with substantial wetland parts got an earlier and more emphasized effect of snow melt than forest dominated catchments (fig. 4). The first peak came at about the same time for site 2 and 4 but at site 4 there was a far larger event water fraction in the stream (fig.1 and 4). After the snow melt the stream water $\delta^{18}O$-signal slowly returned to a level close to the base flow (fig. 2 and 4). The $\delta^{18}O$-signal of the 31st of March is considered to be base flow which means that it is not affected by event water (fig. 4).

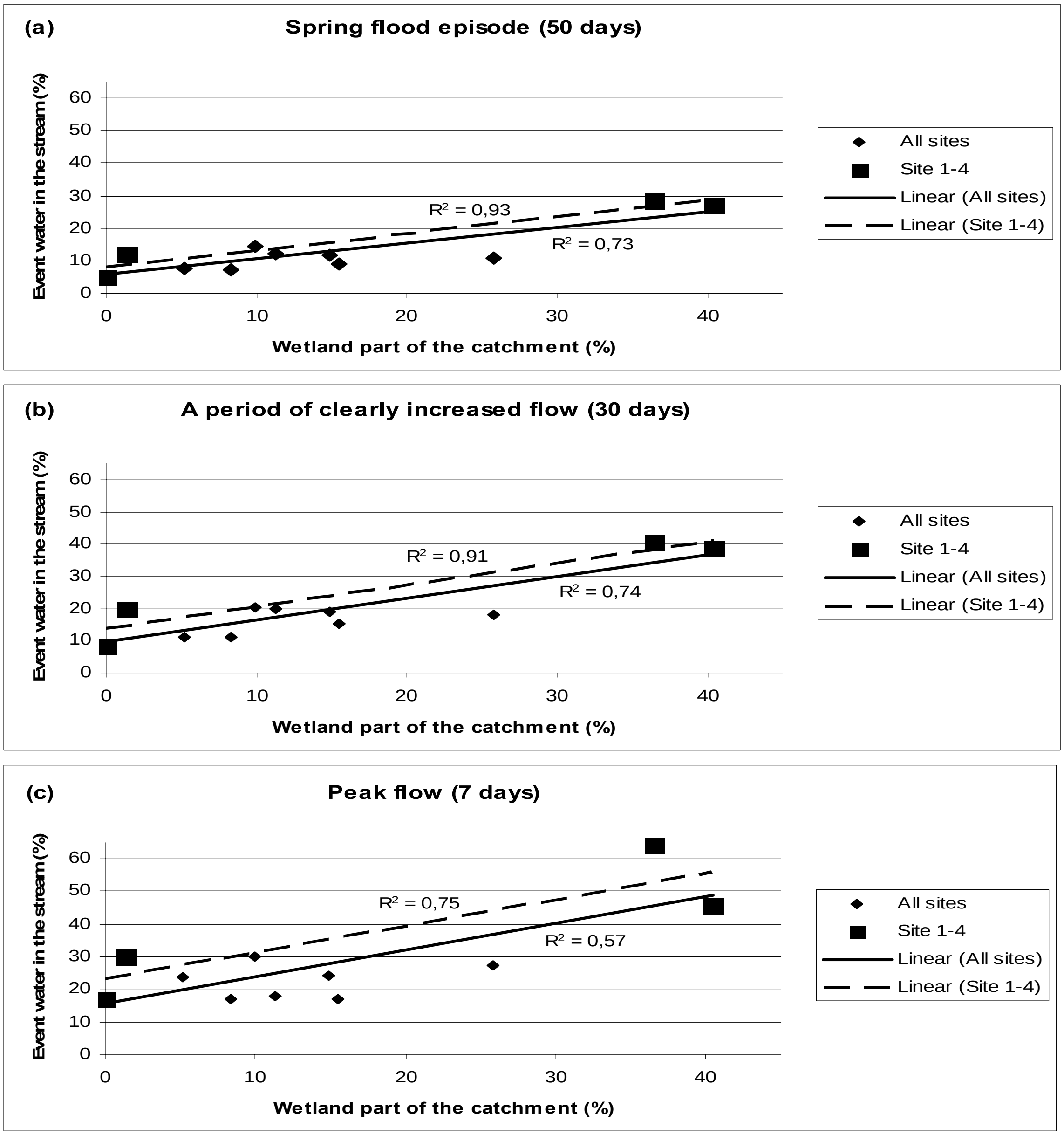

Figure 5. Wetland importance for the event water fraction in the streams during (a) the entire spring flood (50 days), (b) the period of clearly increased flow (30 days) and (c) a period of about 7 days of individual peak flow for each stream. Large squares show two small catchments with almost no wetlands (site 1 and 2) and two catchments with substantial wetland parts (Site 3 and 4), (see table 1 for details).

For small catchments the event water fraction in the stream was dependent on the wetland part of the catchment. A substantial wetland part caused an increased event water fraction in the stream. The event water fraction in the streams increased with increasing flow (fig. 5 a-c). The pre-event water fraction dominated the stream water during the episode. The event water fraction of the stream water was never more than 30% except for catchment 3 and 4 that are small with a substantial wetland part (fig. 5 a-c).

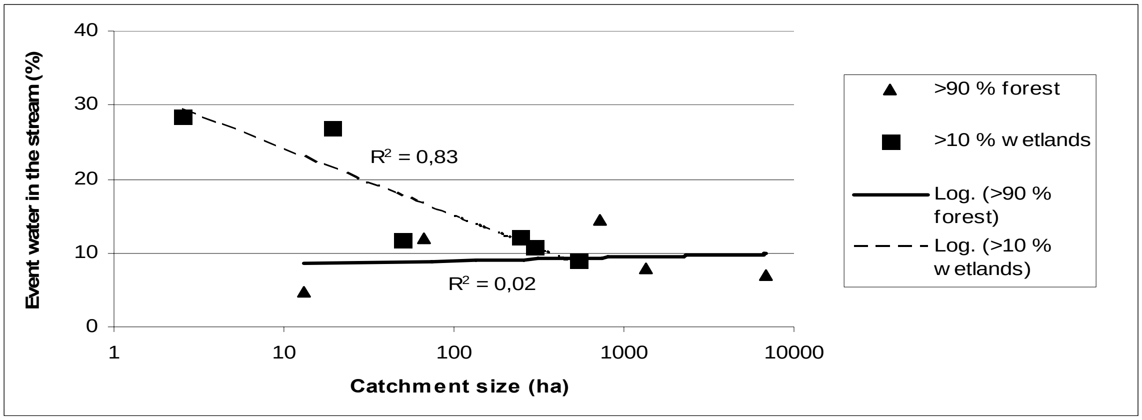

Fig 6. Event water part of the stream water during the spring flood for all streams with respect to catchment size and catchment composition.

The event water fraction in the streams changed according to proportion of wetlands rather than catchment size. For catchments with more than 10 % of wetlands the tendency was a decreasing event water fraction with increasing catchment size. For forest dominated catchments catchment size was not important for the event water fraction in the streams (fig. 6).

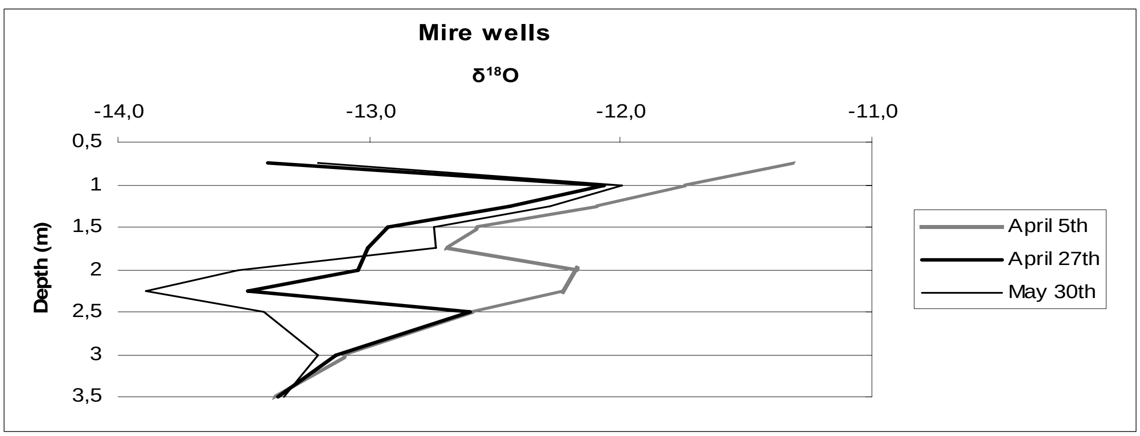

Figure 7. Isotopic development for the mire water during the spring flood. The 5th of April is just before the onset of the snow melt, the 27th of April is after the first peak flow and the 30th of May is after the main spring flood.

There were variations in the mire water during the spring flood. The shallow mire water got a lower δ^{18}O-signal after the onset of snow melt. The δ^{18}O-signal in the mire water also dropped between 1,75 and 3 meters of depth where much of the flow seems to have taken place (fig. 7).

Discussion

Spring flood development of runoff

Because the rapid increase in runoff started about a week after the onset of the snow melt it was apparent that it took some time for the first melt water to affect the flow in the stream no matter which pathway it took (fig. 1 and 2). The response to snow melt was slightly faster at site 2 (fig. 1) because the subsurface pathways were already partly filled with water. When the event water contributed to these pathways, quite a distance from the stream, water that was present closer to the stream along the same pathway was pushed out which caused a fast discharge response. At site 4 the first peak consisted of a substantial amount of event water that had to go all the way to the stream to cause a discharge response. This means that surface pathways were faster at transporting the water but the response was faster for subsurface pathways (fig 8). The first peak in stream 2 was smaller indicating that some water remained in the soil and the heavy δ^{18}O-signal could be explained by a mixture between event water and heavier pre-event water in the soil (fig. 1 and 4). Metcalfe and Buttle (2001) suggested that the amount of surface storage decided how fast the stream responded to input and that frozen saturated soils gave a quicker discharge response to snow melt. Greater pre-melt storage could therefore lead to a more synchronized initial flow in different catchment types as observed in this study (fig. 1).

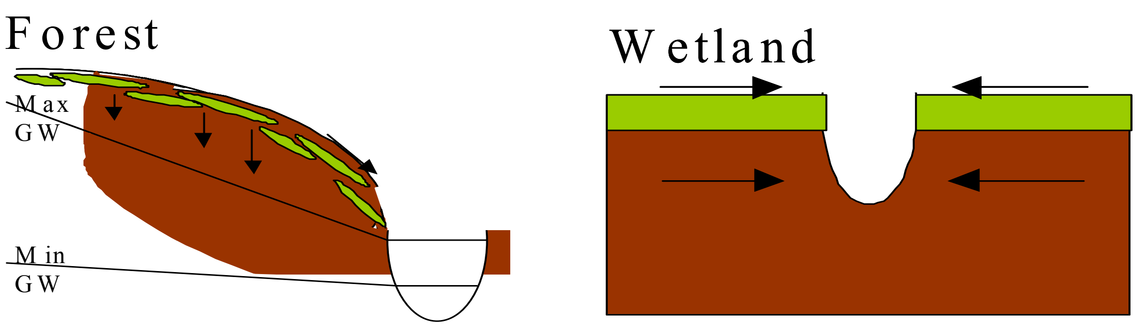

Fig 8. Assumed subsurface pathways in forests and surface pathways at wetlands. GW indicates groundwater. Figures: Hjalmar Laudon.

In this study surface flow paths were assumed to transmit water to the stream more quickly than subsurface flow paths which would lead to recharge of the ground water instead (fig. 8). This was indicated by the greater flow for stream 4 (fig. 1). Surface path ways caused by homogenous soil frost in wetlands was an explanation suggested by Woo and Winter (1993), (Cooper, 1998), (Hayashi et al. (2004) and Laudon et. al. (2004). The higher total runoff and the earlier second peak at site 4 was explained by surface flow paths and the slightly larger amount of snow and heavier snow melt intensity due to a larger open field part of the catchment (fig. 1 and 2). Apart from some evaporation the lower total runoff and a later second peak at site 2 (fig. 1) indicated a greater recharge of the subsurface water storage for the catchment and deeper and slower subsurface pathways. Stream 4 had the peak flow at about the 28th of April and stream 2 had the peak flow at about the 3rd of May (fig. 1) partly due to rain events at the 25th of April and the 4th of May.

Snow melt intensity and precipitation

It was reasonable that the open field had the most snow and the heaviest snow melt (fig. 2) as the distribution and exposure to sun was not disturbed by vegetation. Similar to this study Metcalfe and Buttle (2001) found that snow underlying a close canopy had a more prolonged melt episode. Open areas faced a faster snow melt. This was confirmed by the pattern of snow melt for open field and the dense spruce forest (fig. 2).

Change in δ^{18}O-signal for melt water

The first melt water leaving the snow pack was depleted from heavy molecules as indicated by the low δ^{18}O-signal. (fig. 3). As the heavy melt occurred during only two weeks the rest of the snow pack seemed to have melted without any major fractionation (fig. 2 and 3). Metcalfe and Buttle (2001) found that there was an isotopic enrichment going on in a melting snow pack but that was not apparent in this study. Towards the end of the episode the event water δ^{18}O-signal increased due to rain fall influence. If an increase of the melt water δ^{18}O-signal took place in the end of the melt period it may have been disguised by the precipitation contribution on April 25th that happened to have a δ^{18}O-signal close to the general melt water δ^{18}O-signal during heavy melt. After the snow was gone the event water ^{18}O-signals (fig. 3) reflected the mean signals of the sub-sequent rain events. The spruce snow lysimeters were empty the 8th of May resulting in a slower but similar response to the rain events due to an influence of melt water (fig. 3).

Isotopic development in the stream water

There was a quicker and greater response to snow melt for streams with substantial wetland parts. This could be explained by surface flow paths leading to a quick contribution of early light event water (fig. 3 and 4) (Cooper,1998). Hayashi et. al. (2004) explained the lower δ^{18}O-signal during the spring flood by a higher contribution of fresh snow melt water. Similar to this study (fig. 4) Woo and Winter (1993) found a quicker response in streams with catchments with large wetland parts, suggesting surface flow paths in frozen wetland areas. Metcalfe and Buttle (2001) suggest that filling the surface store was the main regulator of the time it takes for melt water to reach the stream and as soon as the storage capacity was exceeded the runoff increased rapidly.

The isotopic signal in stream 2 showed a slower and less emphasized response to snow melt probably due to subsurface pathways. The δ^{18}O-signal in the streams increased towards the end of the episode (fig.4). This can be explained by late rain events and an increased pre-event water contribution due to increased infiltration in turn caused by thawing of the top soil.

Wetland importance for event water contribution to stream water

The low event water fraction in forested streams (fig. 5a-c) could be due to a generally higher soil infiltration. This increased the normal groundwater flow activating pre-event water in the catchment. Hayashi et al. (2004) demonstrated that the event water contribution to stream water was less than half of the total discharge during spring flood emphasizing the importance of water stored over winter in soil reservoirs. Similar to this study Metcalfe and Buttle (2001) found that the event water part in the streams increased with increasing flow (fig. 5a-c). This may be due to an increasing water table that forced the event water to take a flow path close to the surface where the water conductivity was far higher than deeper in the soil (Rodhe, 1998 and Hayashi et. al., 2004). This led to a higher concentration of event water in the upper soil layers causing a quicker and greater transport of event water to the stream (Metcalfe and Buttle, 2001). High flow induced by event water still consists of primarily pre-event water (fig. 5a-c). This can be explained by the transmissivity feedback described earlier (Shanley et.al. 2002).

A substantial wetland part of the catchment was important for the high amount of event water in small streams (fig. 5a-c). Hayashi et al. (2004) suggested that the event water supply was higher than the infiltration capacity in frozen saturated soils. This forced the melt water to take a surface flow path. Metcalfe and Buttle (2001) found that the event water runoff potential was higher over frozen soil surfaces. Wetlands close to streams and saturated low slope areas could also cause substantial overland flow that increased the event water fraction in the stream (Maclean, 1995). According to Hayashi et al. (2004) the top 5-10 cm of wetlands melt during the spring flood. This may enable the early melt water to infiltrate the top soil and thereby making it impermeable to later soil melt water in turn leading to surface flow paths. Metcalfe and Buttle (2001) suggested that even if the melt water flowed via the shallow thawed soil it was still to be considered as a surface flow path as it was dominated by event water.

The role of catchment size for the event water part in the streams

The tendency of decreasing event water fraction in the streams with increasing catchment size (fig. 6) may be explained by the wetland importance that could be dependent on the distance from the stream. In larger catchments the general distance between the wetland areas and the stream was probably longer. In that case the melt water had a possibility to infiltrate the soil before it reached the stream which decreased the importance of event water in the stream. The difference in wetland part of the catchments differed from 10 to 40 % (table. 1) with the largest wetland part represented by small catchments (fig 6). This strengthened the tendency of a greater wetland importance in smaller catchments. Laudon et al. (2004) suggested that wetlands normally are located close to the streams. However, even though the larger catchments had more wetlands than some of the smaller catchments they did not have a larger event water fraction (Figure 5 a-c). Shanley et.al. (2002) has found that event water contribution increased with catchment size and open land cover. This study may confirm the point of open land as that often is wetland (fig 5a-c). A pattern of increasing contribution with increasing size was not found (fig. 6).

Appropriateness of the method

Separate data of snow, melt water, mire water, soil water, ground water and stream base flow showed that there was a difference between the isotopic content of the event and the pre-event components. As the calculations were based on catchment characteristics and as the sampling was carried out with respect to flow and snow melt intensity the variations of the $\delta^{18}O$-signals for the event and the pre-event water with respect to space and time were accounted for. The initial $\delta^{18}O$-signal for soil and ground water was similar. Contributions from surface storage were negligible as the catchments with substantial lake parts were excluded. The variations in $\delta^{18}O$-signals of the mire water before and after the onset of snow melt indicated differences in $\delta^{18}O$-signals between event and pre-event water as the $\delta^{18}O$-signals fell just after the influence of event water due to snow melt (fig. 7). As the base flow $\delta^{18}O$-signals differed from later stream water $\delta^{18}O$-signals this indicated differences between the event water and the pre-event water $\delta^{18}O$-signals (fig.4). This means that the correctness of the assumptions for using the IHS-method mentioned earlier was good enough to motivate the use of this method.

Conclusions

The stream flow in small catchments with a substantial wetland part got an earlier and greater response to snow melt probably due to surface flow paths caused by an extensive soil frost in wetland areas. The stream flow in forest dominated catchments got a slower and less emphasized effect during snow melt due to considerable soil infiltration causing a recharge of the soil water reservoirs. Hence the contribution of event water in forest dominated streams was much less compared to streams with a large wetland part in their catchments. The pre-event water fraction dominated the episode at all sites partly due to an increasing ground water flow activating previously unsaturated pre-event water in the soil. The fraction of event water in the streams changed due to catchment composition, with the greatest influence seen in the smallest catchments. Wetland influence was not as clearly seen in large catchments, possibly because the mean distance between the wetlands and the streams may be longer in larger catchments. This provides possibilities for soil infiltration and mixture between event and pre-event water which lowers the event water fraction in the stream. This study confirmed the importance of wetlands for increasing the event water fraction in the streams, and thus the results could be used to describe parameters affecting the water chemistry during spring flood. Surface flow paths likely result in event water chemistry which is less changed on the way to the stream. This caused a dilution of the stream water rather than a contribution of pollutants Laudon et. al. (2004). Subsurface pathways give the soil the possibility to absorb contaminants before they reach the streams.

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Attachment 1. IHS-figures of separation of event and pre-event water during the spring flood**.**

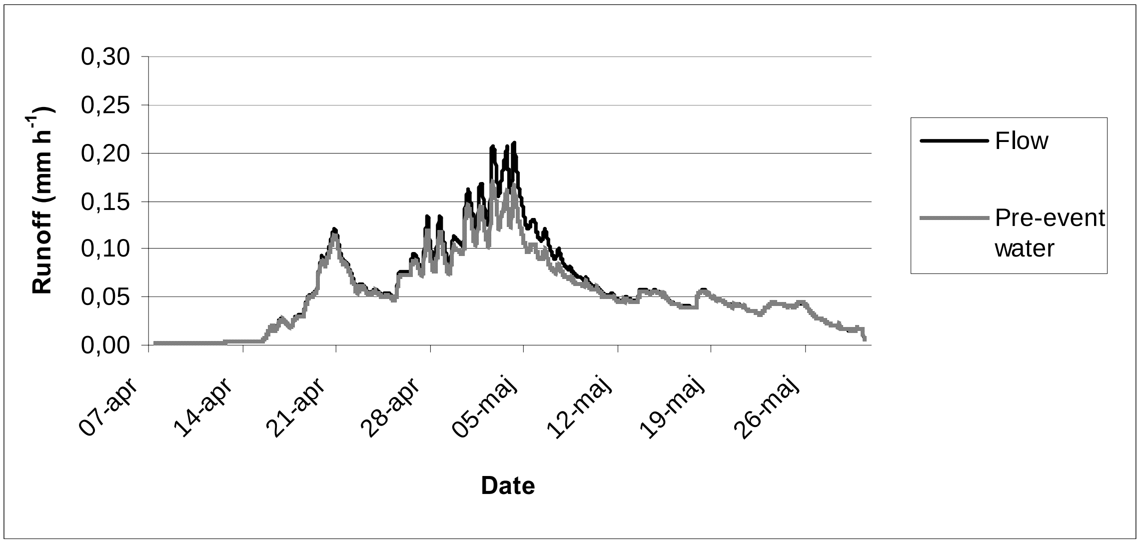

Figure 8. Isotope hydrograph separation for site 2.

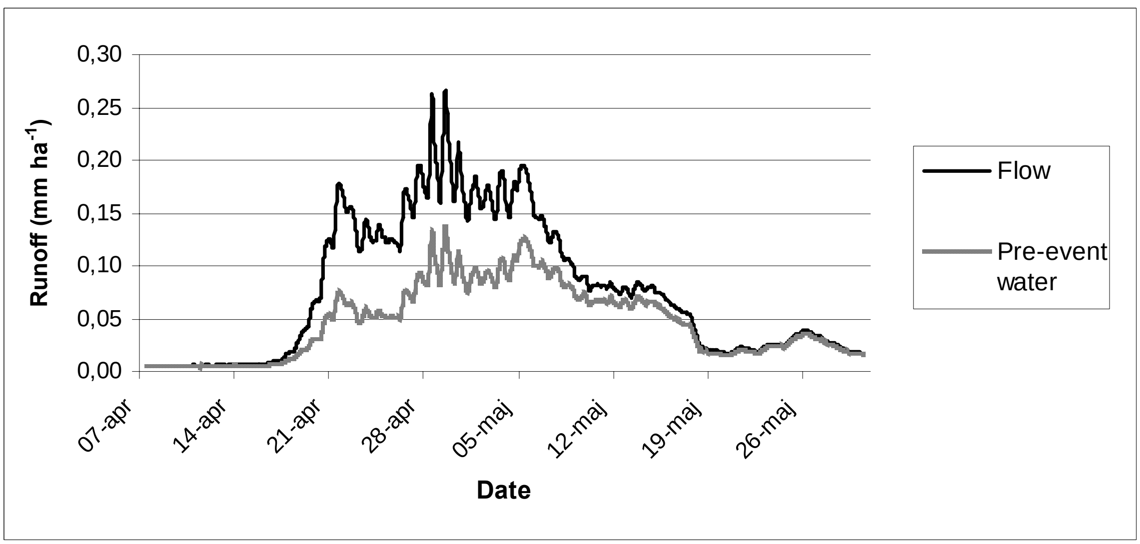

Figure 9. Isotope hydrograph separation for site 4.