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Comparison of hydrology in selected catchments in Poland and Norway with focus on dominating flow paths and time resolution

JOHANNES DEELSTRA[1] & KAZIMIERZ BANASIK[2]

[1] Bioforsk – Norwegian Institute for Agricultural and Environmental Research, Soil and Environment Division, N-1432 Aas, Norway, Johannes.Deelstra@bioforsk.no
[2] Warsaw University of Life Sciences – SGGW, Faculty of Civil and Environmental Engineering, Department of Water Engineering, 166 Nowoursynowska St., PL-02-787 Warsaw

Introduction

Agriculture contributes a significant portion of the nutrient supply to the environment, being to a large degree responsible for the eutrophication of inland waters and coastal zones. Agricultural practices, climatic conditions, topography and geological conditions are important factors in determining these losses. However, also hydrological flow processes and pathways play an important role in the nutrient and soil loss processes. This chapter presents the results of a comparison of the hydrology in three catchments, two of which are located in Norway and one in Poland.

Different methods to characterize hydrology and flow paths can be carried out. The analysis on recession periods is a well known method of obtaining information about flow process, an extensive overview of which was given by Tallaksen (1995). In addition to the analysis on recession periods, other methods to obtain information about flow processes are available. A well known method is one which consists in differentiating between fast and slow flow processes in the catchment through the determination of the Base Flow Index (BFI) (Gustard et al. 1992, Arnold and Allen, 1999). Baker et al. (2004) developed an index to describe the catchment response to rainfall and/or snowmelt, called the flashiness index (FI) and used this to describe changes in the hydrological behavior of rivers in response to changes in land use. By using the FI and BFI, Deelstra et al. (2007a) showed that the flow regime of a main river had changed, suggesting the most likely reason for this being a climate change leading to a change in the winter hydrology with a decrease in the spring snow melt runoff and an increase in winter runoff. Deelstra et al. (2008) concluded that the FI and BFI could be used as explanatory factors for differences in nutrient loss between Estonian and Norwegian catchments. Input to the calculation of hydrological characteristics are existing discharge measurements carried out at catchment outlets. Deelstra et al. (2007b) showed that significant changes in characteristics occurred when calculated using different time resolutions. For example, a significant increase in the FI occurred when calculated based on hourly discharge measurements instead of average daily measurement which was an indication that large diurnal variations in discharge occurred. It is important to take these diurnal variations in discharge into account when analyzing the hydrology in catchments. Also for the design of hydro-technical structures the maximum daily discharge values are very relevant, especially when large diurnal variations exist. A study carried out in Spain showed, among other factors that large differences existed between annual maximum instantaneous discharge and its corresponding value based on average daily discharge values and which therefore should be taken into account for design purposes (Taguas et al. 2008).

Knowledge about the dynamics of hydrology is important with respect to: 1) its impact on nutrient and soil loss processes in agriculturally dominated catchments, 2) the choice and implementation of suitable mitigation measures to abate present and future pollution problems and 3) the design of hydro-technical implementations. This knowledge becomes even more important when considering climate change, which in addition to an increase in the air temperature, leads to changes in precipitation and probably changes in hydrology.

Catchment description

The Skuterud catchment is located in Ås in Akershus county in Norway. It is located approximately 30 km south from Oslo. The catchment is part of the national environmental monitoring program (JOVA) and is in operation since 1993. The main objective of JOVA program is to quantify the nutrient and soil loss from agricultural dominated catchments. The discharge is measured using a triangular profile two-dimensional weir referred to in the literature as the Crump weir, credited to the E.S.Crump (1952). Water levels were recorded automatically using a pressure transducer in combination with a Campbell data logger. Based on the head-discharge relation for the measurement structure, the discharge is recorded and stored in the data logger. Composite water samples are collected automatically on a volume proportional basis (Deelstra and Øygarden 1998; Deelstra et al. 1998). The nutrient and suspended soil load are calculated based on the measured discharge and concentrations of compounds in the composite water samples. In addition, detailed information about farming practices are collected on a yearly basis to be able to interpret, analyze and explain any observed trend in nutrient and soil loss from the catchment. The total area of the catchment is 4.49 km^2 and arable land occupies 61% of the total area while forest covers 29%, the rest being peat and urban area. Soil types of the arable land in the Skuterud catchment are dominated by marine silt clay loam deposits in addition to a lesser part with marine sand and moraine deposits. The elevation in the catchment ranges from 91–146 m above mean sea level (a.m.s.l.).

The Høgfoss catchment is part of the larger Vansjø-Hobøl catchment. The runoff from the Vansjø-Hobøl catchment is based on discharge measurements carried out at the Høgfoss location. The principle of discharge measurement is the same as for the Skuterud catchment, the difference being that the discharge is calculated based on a rating curve, established for the measurement location. The station is operated by Glommens og Laagens Brukseierforening (GLB). At the Høgfoss catchment water samples are collected on a fortnightly basis and taken as grab samples. The total area of the catchment is 295.0 km^2. Compared to Skuterud, the agriculture is less dominating in the Høgfoss catchment, occupying 19% of the total catchment area. The soil types of the arable land in the Høgfoss and Skuterud catchment show much similarity. In both Skuterud and the Høgfoss catchment, most of the agricultural land in the catchment is artificially drained, with drain spacings varying from 8–10 m and a drain depth of 0.80––1 m. The elevation in the catchment ranges from 35–170 m above mean sea level.

The Zagożdżonka catchment in Poland is located approximately 100 km south of Warsaw and is part of a monitoring program carried out under the supervision of the Department of River Engineering, Warsaw University of Life Sciences – SGGW. The discharge is measured at the gauging sites at Płachty, using a calibrated rating curve. Arable land occupies 59% of the total area while forest is covering 40%. The elevation in the catchment ranges from 148–185 m above mean sea level. In contrast to Norway, only a limited area of the arable land in the Zagożdżonka has been provided with drainage systems, covering a total area of 3.73 km^2 while the drainage system consist of open drains. More detailed characteristics of the Zagożdżonka catchment is given in the former chapter (Banasik & Hejduk 2011) and some data on long term variability of climatic parameters and nutrient outputs were discussed in previous works (Banasik et al. 1999; Byczkowski et al. 2001). The main land use in the catchments is agriculture and forest (Table 5.1).

There is considerable variation in the long term mean annual temperature and long term annual precipitation. The topography of the catchments varies from flat to hilly, with the largest differences in elevation in the Norwegian catchments.

TABLE 5.1. Catchment characteristics

Catchment	Size (km^2)	Long term mean annual temperature (°C)	Long term annual precipitation (mm)	Land use (%)	Observation period
Skuterud	4.5	5.3	785	agr[1]. (61), for[2]. (29), other[3] (10)	1994–2009
Høgfoss	295.0	5.6	829	agr. (19), for. (80), other (1)	1988–2010
Zagożdżonka	82.4	7.6	611	agr. (59), for. (40), other (1)	1963–2009

[1] Agriculture. [2] Forest. [3] Urban/housing area, peat soils.

Results

Precipitation and catchment runoff

There are different approaches in calculating the yearly runoff. For the agricultural catchments in operation within the JOVA-program the runoff, nutrient and soil loss is calculated for the agro-hydrological year, covering the period from 1 May – 30 April. However runoff can also be calculated for the hydrological year being the period from the 1 November to 31 October. A third option is that runoff is calculated for the calendar year, being the period from 1 January to 31 December. The last option was chosen for this case. Whether this has any effect on the values of hydrological characteristics being calculated in the context of this chapter will be dealt with in a chapter dealing with the flashiness index.

Skuterud and Høgfoss are both located south of Oslo and have the same climatological conditions. Therefore, in the comparison of precipitation between the Norwegian and Polish catchments, the precipitation data collected at the Dept. of Mathematical Sciences and Technology at the Norwegian University of Life Sciences at Ås, was considered representative for both catchments. There is a significant difference in precipitation, the largest yearly precipitation occurring in the Norwegian catchments (Table 5.2). In addition, there is a large variation in the annual precipitation for the individual catchments, exemplified by the large difference between the maximum and minimum precipitation, in addition to the coefficient of variation.

The larger yearly runoff occurs at the Norwegian catchments which is a reflection of the difference in the annual precipitation between the Polish and Norwegian catchments (Table 5.3). Significant variation also exists in the yearly runoff, exemplified by the large difference between the maximum and minimum runoff.

TABLE 5.2. Yearly (Jan.-Dec.) average, maximum and minimum precipitation in addition to coefficient of variation for Skuterud and Zagożdżonka catchments

Catchment	Yearly precipitation (mm)			CV(%)[1]
	mean	maximum	minimum	
Skuterud	883	1200	651	18
Zagożdżonka	611	989	422	22

[1] The CV is the coefficient of variation, calculated as the standard deviation (of all yearly precipitation) divided by mean (of all yearly precipitation) × 100%.

TABLE 5.3. Yearly average, maximum and minimum catchment runoff in addition to coefficient of variation

Catchment	Yearly runoff (mm)			CV(%)
	mean	maximum	minimum	
Skuterud	546	919	278	33
Høgfoss	492	804	276	30
Zagożdżonka	106	241	52	40

Yearly distribution in precipitation and runoff

When comparing the yearly distribution of precipitation there are marked differences between the Skuterud and Høgfoss catchment on the one hand and the Zagożdżonka catchment on the other hand (Figure 5.1). Compared to the Norwegian catchments, a larger portion of the yearly precipitation occurs from April – September in the Zagożdżonka. In the Norwegian catchments, October and November are the months with the highest precipitation.

There is much similarity in runoff generation between the Polish and Norwegian catchments with the highest runoff contribution during the period before and after the

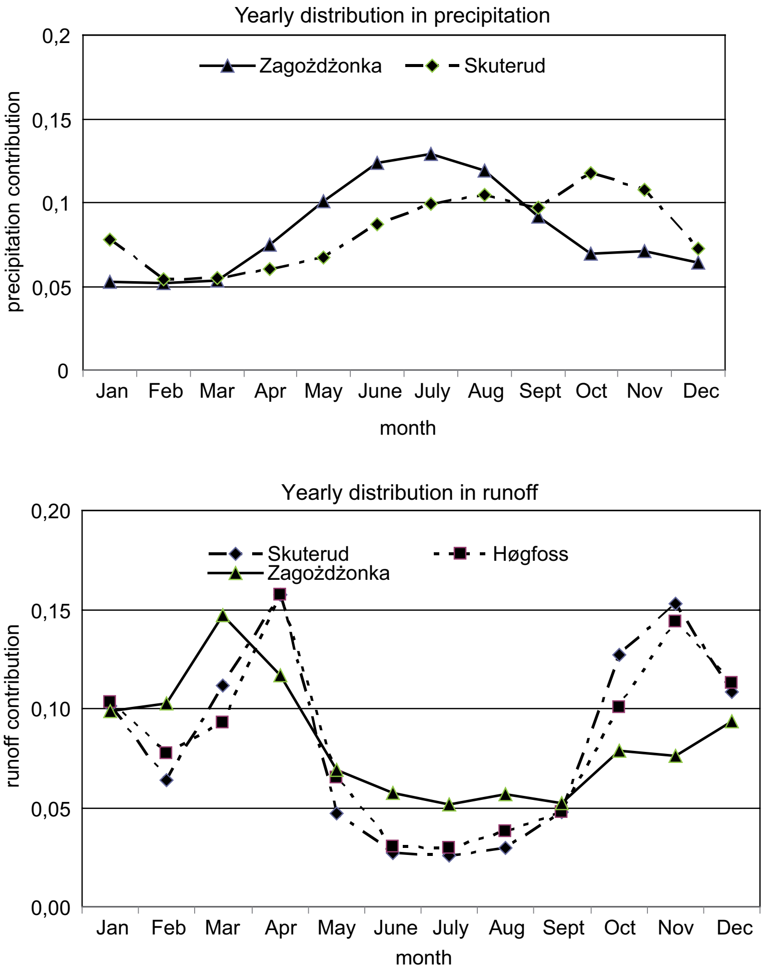

FIGURE 5.1. Yearly distribution in rainfall and runoff at Zagożdżonka, Skuterud and Høgfoss catchment

growing season (Figure 5.1). For both the Norwegian and Polish catchments the runoff contribution is lowest during April – September, caused by the increased evapotranspiration during this period. It seems that the end of the winter starts one month earlier for the Polish catchment, showing the highest runoff contribution during the months of March compared to April for the Norwegian catchments.

The Flashiness Index (FI)

There are many different ways to describe the hydrology in catchments depending on the objectives one has. Insight in the hydrological behavior of a catchment can be necessary for a number of reasons. Knowledge about the reaction of a catchment to precipitation or snowmelt can be important for design purposes but is also a prerequisite in understanding erosion and nutrient loss processes. One way to describe hydrological behavior is through the flashiness index (FI, eq. 1), in which flashiness is a measure of variation in discharge. The FI was first introduced by Baker et al. (2004) and describes in a way how quickly flow changes from one condition to the other. The FI describes these changes and is defined as:

$$\mathrm{FI}_{\mathrm{day}} = \frac{\sum_{i=1}^{n} \left| Q_i - Q_{i-1} \right|}{\sum_{i=1}^{n} Q_i} \tag{1}$$

where:
Q_i and Q_{i-1} are the average daily discharges on day (i) and day (i–1), respectively. The pathlength is equal to the sum of the absolute values of the day-to-day changes in average daily discharge values. The index is derived by dividing this pathlength by the sum of the average daily discharge values for the year, as shown in Equation (1). The index is dimensionless, its value being independent of input chosen to represent the flow, i.e., the value of the index is the same whether the values of Q are treated as daily discharge volumes (m^3), as average daily discharge values ($m^3 \cdot s^{-1}$) or as unit area runoff (mm). The FI is usually calculated for the period of one year.

The flashiness index and time period

Hydrological characteristics can be calculated for different time periods. In the national environmental monitoring program (JOVA), the period from 1 May until 30 April the following year is used when calculating nutrient and soil loss. This is considered the agro-hydrological year, the main reason for this being that it covers the cropping calendar with sowing/fertiliser application in the spring, crop development and harvesting, followed by the off-season period starting in the autumn and lasting until the next start of the agro hydrological year. A hydrological year can cover different time periods but in Poland is normally taken as the period from 1 November until 31 October in the following year. Another time period which can be considered is a calendar year from the 1 Jan – 31 Dec. The choice of time period should not have any influence on the calculation of the flashiness index as the discharge is the same, the only difference being a slight shift in the time period. In subsequent calculations of hydrological characteristics for the Polish and Norwegian catchments, the period from 1 Jan to 31 Dec has been being considered.

The flashiness index and time resolution

When the flashiness index is based on average daily discharge values, it does not take into account the diurnal variation in discharge, which under specific conditions can vary considerably during a day. To obtain the FI for alternative, higher time resolutions, a modification to the calculation of the total flow path, or pathlength, can be made. For example when the FI is calculated based on hourly discharge values (eq. 2); the total path length in equation 1 will be equal to the sum of the differences between the hourly discharges (Q_{ii}) as:

$$\mathrm{FI} = \frac{\sum_{ii=1}^{n} \left|\Delta Q_{ii}\right|}{\sum_{i}^{n} Q_i} \qquad (2)$$

while the denominator remains the same, being the sum of the average daily discharge values. One actually obtains improved information about the total variation in discharge values relative to average daily discharge values. Baker et al. (2004) tested the effect of using hourly instead of average daily discharge values and found the FI to an increase by a factor 1–3. Deelstra et al. (2010) had similar results when calculating the FI for a number of catchment using different time resolutions for discharge as input. In this chapter the FI has been calculated based on three different time resolutions, the results of which are presented Table 5.4. In principle, for the Zagożdżonka catchment, average daily discharge values are available. However, for a period of two years (1 November 2007 – 31 October 2009), the discharge has also been recorded at a 10 minute interval. For Skuterud average hourly and average daily discharge values have been used to calculate the FI previously (Deelstra et al. 2007). However in this case the FI has also been calculated based on half-hour discharge values for the period from 1 January 2008 – 1 January 2010. For the Høgfoss catchment no recordings are available with a time resolution less than 1 hour.

The results show that the Skuterud catchment has the highest values for the FI, irrespective of the time resolution used, while the Zagożdżonka catchment has the lowest values (Table 5.4). For both the Skuterud and Zagożdżonka catchments, the

TABLE 5.4. Flashiness index at different time resolutions and baseflow index

Catchment	Period	Flashiness index at various time resolution (–)				Base flow index (–)
		10 min	30 min	60 min	day	
Skuterud	94–10	–		1.83	0.57	0.19
	08–09		2.03	1.91	0.59	
Høgfoss	88–09	–	–	0.42	0.25	0.43
Zagożdżonka	63–09				0.20	0.67
	07–09	0.71	0.54	0.45	0.13	

FI decreases with an increase in time resolution, with the largest decrease occurring when changing from an hourly to a daily time resolution. Deelstra et al. (2010), when studying the hydrological behavior of agricultural dominated catchments in Norway, Estonia and Latvia, pointed out that characteristics such as topography, scale, soil types but also artificial subsurface drainage systems most likely have a marked influence on the FI. Baker et al. (2004) found that the FI tends to decrease with increasing catchment size, confirming the fact that in general smaller streams have a flashier behavior than larger streams. In our case the Skuterud catchment is the smallest, has a high percentage of agricultural land which is artificially drained which might explain the high value for the FI. Høgfoss, being the largest catchment, should have the lowest FI-value if scale would have been the dominating factor. However, it has approximately the same value compared to Zagożdżonka, which downplays the role of the size of the catchment. In this case topography and soil type might have played an important role.

For Skuterud, a slight increase in the FI occurs when considering a 30-minute time resolution instead of an hourly resolution in the discharge. Based on this result, calculating the FI for the whole observation period of 30-minute time resolution should be considered to study whether a significant increase.

The influence of instability in discharge on the flashiness index

A more detailed investigation of the discharge data for Zagożdżonka shows that there is a considerable variability in the recorded discharge at 10-minute interval. Figure 5.2a shows an example of this for the period from 1–8 November 2007. The sudden increase in discharge on the 6 November might have been caused by a natural event like precipitation. However, there is an additional, continuous variation or instability in the 10-minute discharge values, shown in more detail in Figure 5.2b. This variation is unlikely to having been caused by natural events like precipitation but might well be due to an instability in the technical implementation for the discharge measurement. This instability however significantly influences the calculation of the flashiness index as it does increase the calculation of the pathlength, i.e. the sum of the differences in the recorded discharge, especially when calculating the FI based on the 10-minute

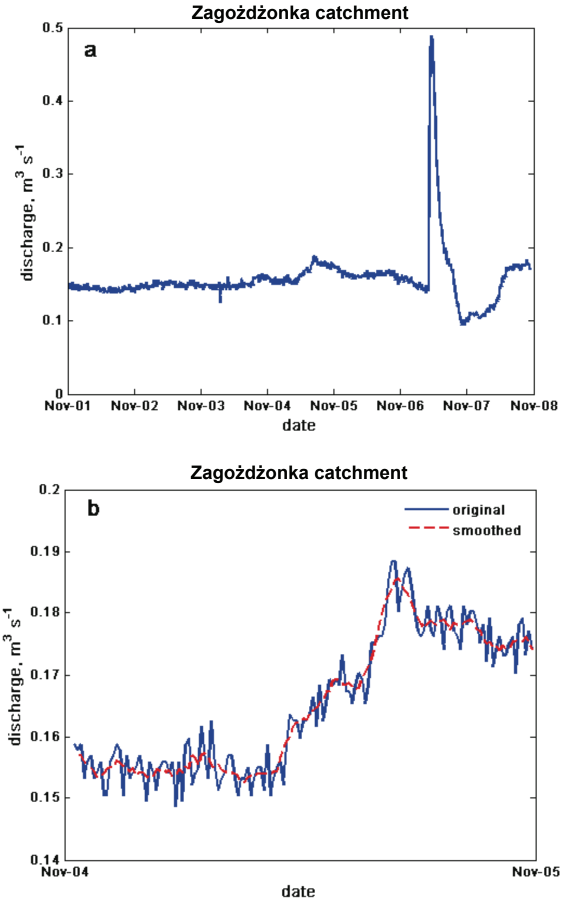

FIGURE 5.2. Discharge at Zagożdżonka during 1–8 November 2007

time resolution, and which is shown in Table 5.5. Based on the original data, a very high FI values was obtained for the 10-minute time resolution, while at the same time the difference between the 10- and 30-minute time resolution is large. This is because the pathlength becomes very large due to the instability in the measurement, or the pathlength becomes unnaturally long because of this. The 30-, 60- and daily discharge values are obtained as an average of the available data and the instability becomes less, or in a way is averaged out.

To remove the instability in discharge, the original time series for discharge for the period 1 November 2007 – 31 October 2009 have been corrected using a filter. The new time series consists of a moving average of the original discharge such that:

$$Q_t^{new} = \sum_{T=t-2}^{T=t+3} Q_T^{old} / 6 \tag{3}$$

TABLE 5.5. Flashiness for original and filtered discharge data for Zagożdżonka catchment

Time resolution	Year	Original data		Smoothed data		Sum of average daily discharge ($m^3 \cdot s^{-1}$)
		pathlength ($m^3 \cdot s^{-1}$)	FI	pathlength ($m^3 \cdot s^{-1}$)	FI	
10-minute	07–08	142.1	2.63	34.0	0.63	54.1
	08–09	175.7	2.77	49.8	0.78	63.4
30-minute	07–08	38.4	0.71	24.5	0.45	54.1
	08–09	54.2	0.85	39.8	0.63	63.4
60-minute	07–08	22.1	0.41	19.8	0.37	54.1
	08–09	36.9	0.58	34.7	0.55	63.4

One can clearly see the effect of the smoothing algorithm on the discharge is showing a more “natural” behavior (Figure 5.2b). The effect of the filter on the flashiness index is significant (Table 5.5).

As can be seen, there is a considerable decrease in the FI when using filtered, smoothed discharge data. The main reason for this is the significant reduction in the pathlength, (sum of difference in discharge). As expected, this reduction is most pronounced for the 10-minute resolution discharge data, showing a reduction in the flow path from 142.1/175.7 to 34/49.8 for the original and smoothed discharge data in 2007 and 2008 respectively. This instability has less influence on the FI at 30 and 60-minute time resolution, but still significant differences in FI – values exists, especially for the 30-minute time resolution, when using the original and smoothed discharge values.

Base flow index

Another way to characterize the hydrology of the catchment is by means of the base flow index (BFI). The BFI represents that part of the discharge not attributable to direct runoff caused by precipitation and/or snowmelt. The BFI is defined as

$$\mathrm{BFI}(\%) = \frac{Q_t - Q_d}{Q_t} \times 100 \tag{4}$$

where Q_t and Q_d are the total and direct runoff respectively at the catchment outlet.

The direct runoff is the sum of surface and subsurface runoff where subsurface runoff can represent runoff generated through the artificial subsurface drainage system in agricultural fields. Deelstra et al. (2010a) showed that high values for FI correspond to low BFI or *vice versa*. They also found that larger catchments had the highest BFI while the highest FI values were found at the smaller catchments. In a comparison of nutrient loss between agricultural catchments, Vagstad et al. (2004) concluded that catchments having a high BFI generally had lower nitrogen loss. In our case the BFI is based on a method developed by Gustard et al. (1992) and called a smooth minima technique, which uses the minima of 5-day non-overlapping periods derived from the hydrograph. The baseflow hydrograph is generated by connecting a subset of points selected from this minima series. Standard software (BFI – A Computer Program for determining an Index to Base Flow) developed by Wahl and Wahl (2010) was used to calculate the BFI.

The results show that the larger catchments Høgfoss and Zagożdżonka have the highest BFI (Table 5.4). The Skuterud catchment has the lowest value for the BFI while at the same time having the largest value for the FI. Important factor playing a role here is the size of the catchment, which is small compared to the Høgfoss and Zagożdżonka. Another important contributor, most likely, is the subsurface drainage system (Deelstra et al. 2010b). In general for the three catchments one can conclude that the larger catchments have the lower BFI, while a low BFI coincides with high FI values and *vice versa* (Table 5.4).

For the larger catchments Zagożdżonka and Høgfoss there seems to be a kind of relation between the annual FI and – BFI values, showing that an increase in the BFI leads to a decrease in the FI (Figure 5.3). For the Høgfoss catchment it appears that this relation is also valid when considering the annual FI values based on hourly discharge values. In a way this is an expected result, as a less flashy behavior must be due to a higher residence time for water in the catchment, caused by, among other factors, infiltration and which also must lead to an increase in the BFI. However,

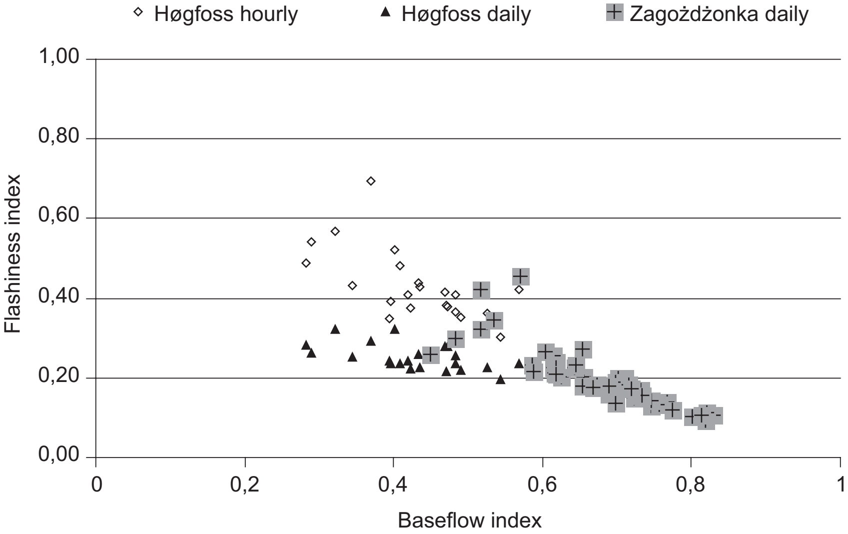

FIGURE 5.3. BFI and FI for Høgfoss and Zagożdżonka catchment

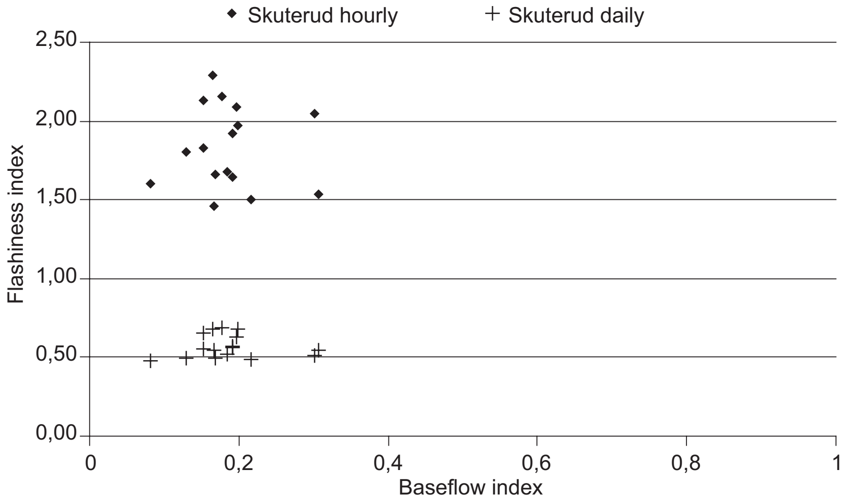

FIGURE 5.4. BFI and FI for the Skuterud catchment

a relation between BFI and FI is completely absent for the Skuterud catchment (Figure 5.4). This might implicate that the hydrological behavior in smaller catchment is less predictive, or more challenging.

The specific discharge

The maximum yearly specific discharge values (l $s^{-1}\cdot ha^{-1}$) have been calculated on hourly – and average daily discharge values respectively. Table 5.6 presents the average specific discharge value of all the years observations were available. In the Polish case the specific discharge was calculated for the two years for which discharge data at a 10 minute time resolution were available. For comparison also for Skuterud, a two year period was selected having discharges values with 30-minute time resolution. The average yearly specific discharge values are highest in the Skuterud and lowest in the Zagożdżonka catchment. As can be seen, in all cases there is a decrease in the

TABLE 5.6. Average values for annual maximum specific discharges (l $s^{-1}\cdot ha^{-1}$) and time resolutions

Catchment	Time resolution				Time period
	10 min	30 min	hour	daily mean	
Skuterud			6.11	3.12	94–09
		7.10	7.10	4.37	08–09
Høgfoss	–	–	1.87	1.50	94–10
Zagożdżonka				0.37	63–09
	0.12	0.11	0.11	0.08	08–09

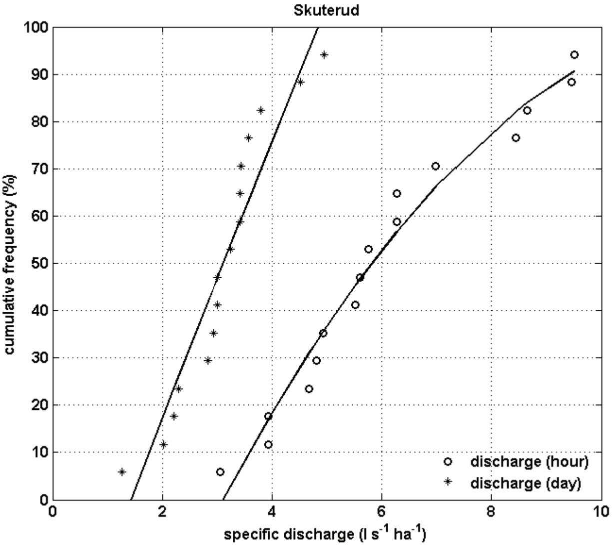

FIGURE 5.5. Frequency distribution of the maximum annual specific discharges obtained with different time resolutions in Skuterud catchment

values for the specific discharge with an increase in time resolution. And again, as for the FI, when changing the time resolution, the largest differences occur in the Skuterud catchment which indicates that large diurnal variations in discharge occur. Only average values for the whole observation period are given in Table 5.6 not showing the variation between years. To obtain an improved insight in this variation, all the yearly maximum values for specific discharge for the Skuterud catchment are presented in Figure 5.5.

As can be seen, large differences exists when using hourly and average daily discharge values. For the Zagożdżonka catchment, only two years with detailed data were available to calculate maximum yearly specific discharge values for difference time resolutions, the results of which are presented in Table 5.6 and showing only small differences. Also for the Skuterud catchment, specific discharge values were calculated based on 30 minute time resolution discharge data. When compared to specific discharge using hourly discharge values, no major differences exist (Table 5.6).

Discussion and conclusions

Hydrological flow processes and pathways play an important role in the nutrient and soil loss processes in agricultural dominated catchments. Knowledge about their relative importance and magnitude is necessary in the choice and implementation of mitigation measures. In this chapter, hydrological characteristics like specific discharge, flashiness – and baseflow index was calculated for two Norwegian and one Polish catchment.

Compared to the Norwegian catchments, the specific discharge value in the Zagożdżonka catchment is small. A possible reason for this can be the low yearly precipitation leading to less runoff as compared to the Norwegian catchments. However, if the yearly runoff would have been discharged during a limited number of days in a year, this still could have lead to high specific discharge values. But this is unlikely to occur as an analysis of the yearly precipitation and runoff in the Zagożdżonka catchment showed that these are distribution throughout the year, although runoff generation is less during summer in both the Zagożdżonka as well as the Skuterud and Høgfoss catchment, the main reason for this being the evaporation. Another indication of low extremes in the Zagożdżonka catchment is the values obtained for the baseflow (BFI) and flashiness index (FI) which are significantly higher, respectively lower compared to the Norwegian catchments. A high value for the BFI indicates that a large porting of the runoff is generated as groundwater runoff, leading to less fast runoff generation. The low value for the FI compared to the Norwegian catchments indicates that the day to day variation in discharge is significantly less. The analysis also showed that diurnal variations in discharge were relatively small in the Zagożdżonka catchment, exemplified by the small differences in maximum specific discharge when calculated using 10-, 30-minutes, hourly and average daily discharge values. The specific discharge values for the Skuterud catchment indicated significant diurnal variations in discharge, which was confirmed by the low and high values for the BFI and FI respectively and further confirmed by the significant increase in FI when using higher time resolutions for discharge.

Deelstra et al. (2010a), when analyzing the hydrology in agricultural dominated catchments in Norway, Estonia and Latvia concluded among other things that an increase in scale might lead to a decrease in the FI. Based on this, the FI value for the Høgfoss catchment should be less compared to the one obtained for Zagożdżonka. However, they have approximately the same FI while at the same time they have a significantly different BFI with Zagożdżonka having the higher value. The relatively high – and low value for the FI and BFI respectively in the Høgfoss catchment indicates that other factors, like topography and soil type, might have lead to different faster flow process in the Høgfoss catchment.

Skuterud showed the lowest and highest BFI and FI respectively while in addition a significant increase in the FI occurred when using a higher time resolution for discharge in the calculation of the FI. This indicates that groundwater contribution is low in the total catchment runoff. The high FI indicates that runoff generation is reacting quickly to input, either in the form of direct precipitation and/or in combination with snowmelt. The main reasons for this are most likely related to the catchment scale, topography, soil types and the presence of an artificial drainage system.

A negative correlation can be observed between the FI and BFI values for the Høgfoss and Zagożdżonka catchments, i.e. high FI leading to low BFI and *vice versa*, while such a relation was absent for the Skuterud catchment. It is unknown what the reasons are but possible causes might be differences in hydrological behavior due to winter condition and seasonal precipitation distribution among others...

Flow paths are extremely important in the generation of nutrient and soil loss. Deelstra et al. (2010b) showed that subsurface drainage systems might contribute significantly in the total runoff and that this can have implications for their contribution in nutrient losses and therefore also in the choice and selection of appropriate mitigation measures. Deelstra et al. (2009) showed that indeed at the level of small fields like Bye and Vandsemb their contribution was significant in nutrient loss, especially nitrogen. Kværnø and Bechmann (2010) confirmed this through an inventory on all the available measurements from small plot research, carried out in Norway. Generally, artificial drainage of agricultural land can lead to an increase in nitrate-nitrogen runoff. Subsurface drainage systems at the same time significantly reduce surface runoff and thereby soil and phosphorus loss. When comparing nutrient loss in small agricultural catchments in the Baltic and Nordic countries, Vagstad et al. (2004) found that hydrology played an important role in explaining differences in nitrogen loss between catchments, with catchments having a large contribution of groundwater runoff in the total runoff in general having a lower nitrogen losses.

The analysis has shown that significant differences in hydrological behavior exist between the catchments while at the same time significant diurnal variations in discharge can occur. The understanding of hydrological processes and their effects on nutrient and soil loss generation is necessary in the implementation of cost effective river basin management plans within the EU Water Framework Directive and in the selection of adequate measures to achieve at least good ecological status of water bodies by 2015 and to be able to effectively deal with climate change.

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