

Using official map data on topography, wetlands and vegetation cover for prediction of stream water chemistry in boreal headwater catchments

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Abstract. A large part of the spatial variation of stream water chemistry can be related to inputs from headwater streams. In order to understand and analyse the dominant processes taking place in small and heterogeneous catchments, accurate data with high spatial and temporal resolution is necessary. In most cases, the quality and resolution of available map data are considered too poor to be used in environmental assessments and modelling of headwater stream chemistry. In this study 18 forested catchments (1–4 km²) were selected within a 120×50 km region in the county of Värmland in western Sweden. The aim was to test if topographic and vegetation variables derived from official datasets were correlated to stream water chemistry, primarily the concentration of dissolved organic carbon (DOC), but also Al, Fe and Si content. GIS was used to analyse the elevation characteristics, generate topographic indices, and calculate the percentage of wetlands and a number of vegetation classes. The results clearly show that topography has a major influence on stream water chemistry. There were strong correlations between mean slope and percentage wetland, percentage wetland and DOC, mean slope and DOC, and a very strong correlation between mean topographic wetness index (TWI) and DOC. The conclusion was that official topographic data, despite uncertain or of low quality and resolution, could be useful in the prediction of headwater DOC-concentration in boreal forested catchments.

1 Introduction

The chemistry of headwater streams is influenced by several landscape factors which are related to geology, topography, climate, and vegetation. During the 20th century, human impacts have also been significant, even for the smallest stream systems. These include direct impacts from land use measures and indirect impacts from atmospheric deposition.

In Nordic boreal forests, some landscape factors are especially important for the development of stream water chemistry. One of these is the dominance of acidic bedrock (granite and gneiss), which results in acid-sensitive waters with a low content of dissolved substances. Another factor is the multitude of wetlands, which increase dissolved organic matter, resulting in increased natural acidity. Andersson and Nyberg (2008), for example, reported that approximately 60% of 68 randomly selected boreal headwater streams had a water colour above 100 mg Pt/l at medium flow. This corresponds to the highest of five classes in the Environmental Quality Criteria established by the Swedish Environmental Protection Agency (SNV, 2003).

Severe acidification has been a dominant environmental condition in forested areas in Sweden and Norway for several decades. Separating anthropogenic causes from natural acidity has recently become a focus (SEPA, 2003), and there is an interest in understanding how landscape factors influence stream water chemistry, especially those factors that govern stream acidity.

The forested landscape in Sweden also experiences a long-term increase in dissolved organic matter. This could be exemplified by the trend for absorbance in River Klarälven



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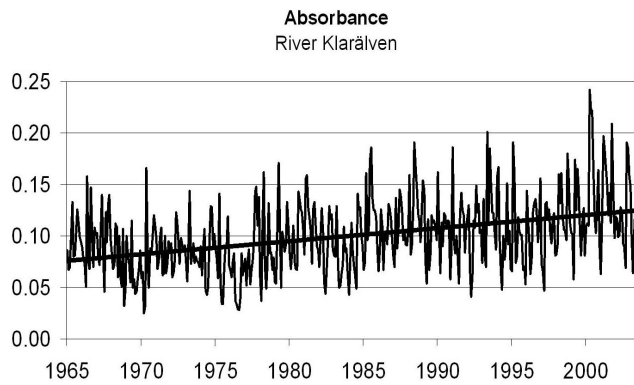


Fig. 1. Absorbance measured monthly at Edsforsen in River Klarälven, Sweden, between 1965 and 2003. The catchment area upstream the sampling point is 8570 km² (Monitoring data from the Swedish University of Agricultural Sciences, www.ma.slu.se)

(Fig. 1), which is a larger river situated adjacent the region studied in this paper. The increase has been +50% over 40 years. The reason for the increase in this particular case is not fully understood, but climate change (Clair et al., 1994; Freeman et al., 1995; Moore, 1998; Tranvik et al., 2002; Worall et al., 2003; Löfgren et al., 2003) and intensified forestry (Rosén et al., 1996; Lundin, 1999) are suggested as factors. A third potential factor can be decreased deposition of sulphur (Monteith et al., 2007).

There seems to be a gap between hydrological process-oriented research and the institutions that are dependent on research methods and results for their work of solving regional and national environmental problems. The process knowledge is mostly available from studies of soil profiles, hillslopes or smaller catchments, whereas the need for management tools is most obvious at a larger scale. One reason for the dominance of small-scale studies is the large spatial and temporal variability of factors that determine hydrology and hydrochemistry. Wolock et al. (1997), for example, showed that stream chemistry variability significantly decreased beyond catchment sizes of 3–4 km². Another reason is the lack of tools to measure at larger scales. Hooper (2001), for example, concluded that “the instruments measure at a scale of decimetres when we need to understand the landscape at the scale of hectares or square kilometres”. A third reason might be that research on boreal forest hydrology has been closely linked to acidification research for several decades, and that most of the acidification problems are found at higher elevations near small headwater streams.

There is a need for simpler, less time-consuming and less costly methods to predict headwater chemistry to evaluate the natural state of water quality, in order to make correct decisions for protection and restoration measures (SNV, 2003).

To reduce the gap between small-scale process knowledge and demands for better understanding at larger scales, one can study smaller elements that are aggregated into larger

systems (Sivapalan and Kalma, 1995; Blöschl and Sivapalan, 1995). In doing this up-scaling, it is necessary to integrate new tools and data, such as the latest developments of GIS and official regional or national databases, into the analysis. For hydrology and hydrochemistry, the process knowledge gained from hillslope studies and small experimental catchments first needs to be evaluated at the next larger scale, i.e. larger first-order and second-order streams. Blöschl (2001) suggested that instead of trying to capture everything when upscaling it would be better to identify dominant processes that control hydrological response at different scales, and then develop models to focus on these dominant processes. When increasing scale, in-stream and hyporheic processes will be more important, and a crucial scale-step is when the streams flow into the first lake, which, depending on size, could have a large impact on hydrology and hydrochemistry.

1.1 Topography

Research results from past twenty years clearly show an influence of topography and wetland on stream water chemistry. The influence of topography is important because it controls the water subsurface contact time (Beven and Kirkby, 1979; Wolock et al., 1990; Dillon and Molot, 1997; McGuire et al., 2005). Since the beginning of 1990's many methods for deriving attributes from elevation data have been developed for use in hydrological applications. These attributes can be divided in two groups: primary and secondary topographic attributes.

Topography is of great significance in hydrology, affecting soil water content, flowpaths and residence times (Nyberg, 1995), and subsequently the chemical composition of surface waters (Beven, 1986; Wolock et al., 1989). Mean slope, based on a DEM with 50 m grid, was a variable that correlated with headwater chemistry in a previous study in the same region as in this paper (Andersson and Nyberg, 2008).

A secondary attribute is the topographic wetness index (TWI), $\ln(a/\tan \beta)$, where a is the upslope area per unit contour length and $\tan \beta$ is the local slope (Beven and Kirkby, 1979; Quinn et al., 1995). The TWI represents the wetness distribution in a catchment, and it has frequently been used in modelling. A high value of the index means that the groundwater table is likely to be close to the ground surface. Subsequently, wetlands occur in areas with high values of the topographic wetness index, and it would be possible to predict locations of these by calculating topographic wetness indices over catchments. The possibility of doing this successfully, however, depends on the relation between the spatial resolution of the data used in the index calculation and the typical length scales of the topography in the catchment (Rodhe and Seibert, 1999). The scale and terrain roughness of the analysed landscape and the resolution of the elevation data sets limits for the quality of the result (Moore et al., 1993; Wolock et al., 1994; Zhang and Montgomery, 1994; Tarboton, 1997). The calculation of wetness indices is, however, sensitive to

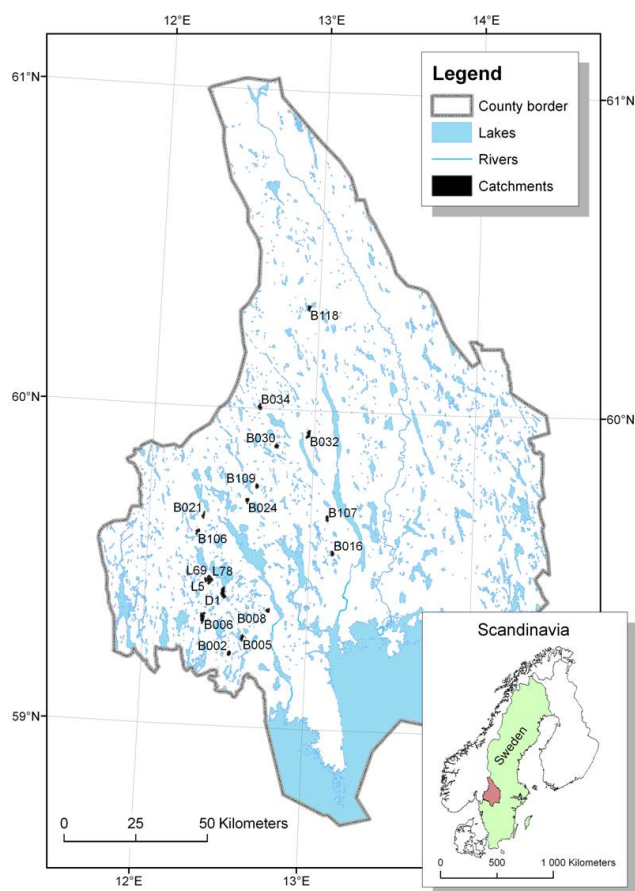


Fig. 2. Study region with 18 catchments in a 120×50 km area in the county of Värmland, Sweden.

the algorithm that is used (Güntner et al., 2004). The calculation of the upslope contributing area is especially crucial for the resulting pattern of saturated areas.

1.2 Wetlands, vegetation cover and dissolved organic matter

In the Swedish boreal landscape, mires, divided into bogs, fens and mixed mires, is the most common wetland group (Löfroth, 1991). There are also a number of sub-divisions of mire types that are classified by areal photo interpretation and presented on vegetation maps. The occurrence of mires in boreal headwater catchments has been shown to be significantly correlated with stream chemistry. Processes in peat and other frequently saturated organic soils produce humic substances that are transported to streams (Clair et al., 1994; Dillon and Molot, 1997; Mulholland and Kuenzler, 1979; Eckhardt et al., 1990; Koprivnjak and Moore, 1992; Hope et al., 1994; Mulholland, 1997). Hemond (1990) suggested that the most important processes take place in the riparian zone, and that they depend on stream flow generation. These results were supported by Bishop et al. (1994) but questioned

by Köhler et al. (1999), who concluded that the question of how organic acids enter streams still was open. Andersson and Nyberg (2008) concluded, from a study of 68 headwater streams, that it did not seem possible to predict humic substances in headwater streams by simply looking at the occurrence and locations of wetlands that are shown on official maps. Many small or hidden wetlands, or *cryptic wetlands* (Creed et al., 2003), with shallow peat cover are not shown on official topographic maps because they are difficult or impossible to locate on aerial photos. Still, they are possible sources of production of dissolved organic matter in headwater catchments. There are also vegetation types other than mires that may include thin layers of peat, i.e. moist and wet coniferous and deciduous forest. The distributions of these are normally only included in vegetation cover maps.

1.3 Objectives

The main objective of this study was to analyse the relationships between 1) topography and 2) wetland and vegetation cover, as represented by available official landscape data (topographic maps, a digital elevation model and vegetation data), versus water chemistry in boreal headwater streams in western Sweden. The aim was to determine “dominant landscape variables” that control the transport of both dissolved organic matter, which is closely associated with natural acidification, and metals such as Fe and Al. This study, which included catchments on the scale of 1–4 km², was a follow-up of an earlier study with catchment sizes 0.5–1.5 km² (Andersson and Nyberg, 2008).

2 Study region

The 18 studied catchments were located within a 120 x 50 km region in the county of Värmland in western Sweden, between latitude 59 and 61 degrees N and longitude 12 and 14 degrees E (Fig. 2).

The dominant landform in the region where the catchments are located is a hilly relief with some occurrence of faults and bare bedrocks in the south, and higher but gentler hills in the north. The igneous bedrock consists mainly of acidic granites and gneisses with local occurrence of outcrops of magmatic hyperite and other rock types (Lundegårdh, 1995). The dominant soil type is till (>65%), peat (~20%) and some areas with sand and silt. The region contains lakes and wetlands while only a small part (<10%) is covered by farmland. The average elevation is approx. 200 m a.s.l. and the highest marine shoreline lies between 170 and 210 m a.s.l. within the region (Lundqvist, 1958, 1961). The annual mean temperature is 3–5°C, precipitation 800–900 mm, runoff 400–450 mm and evapotranspiration 400–450 mm. The precipitation normally falls as snow between November and mid March. The peak runoff normally occurs during the snowmelt period (Raab and Vedin,

Table 1. Catchment and topographic characteristics.

	Area [km ²]	Lowest elevation [m a.s.l.]	Highest elevation [m a.s.l.]	Mean elevation [m a.s.l.]	Mean slope [%]	Mean TWI
Mean	1.56	172	282	236	8.9	11.8
Std dev	0.78	45	54	51	2.8	0.3
Min	0.97	86	201	150	4.1	11.2
Max	3.81	244	400	316	14.7	12.4
n	18	18	18	18	18	18

1995). Coniferous forests (*Picea abies* and *Pinus sylvestris*) dominates. Within the region, forestry is main direct human impact, but the studied catchments have little or no impact from recent forestry. The region has also suffered from deposition of sulphur and nitrogen (Lundström et al., 1998). Characteristics of the studied catchments are shown in the result chapter (Table 1.).

3 Methods

1:250 000 and 1:100 000 scale official topographic maps from the Swedish Land Survey were used to delimit a study region within the western part of the county of Värmland. Eighteen first-order streams were selected within the region for this study. The selected streams were part of two previous studies: 14 of the catchments were taken from a study of 76 first-order streams, described by Andersson and Nyberg (2008). The 14 largest of the 76 catchments were selected from that study. The other four were taken from a hydrological restoration project called “The Laskerud Project” (unpublished data). The streams were first or second order. No arable or urban land was included in the 18 catchments. Forestry occurs in the catchments but was estimated not to be of the magnitude of influence to be considered in this study.

3.1 Spatial datasets

1:50 000 and 1:20 000 scale official topographic maps from the Swedish Land Survey were scanned and used for delineation of the catchments. Streams, wetlands and contour lines were digitized. The contours were used for delineation of catchments. The topographic maps were rather coarse in relation to the size of the catchments in this study. The maps show larger wetlands (>0.5 ha) and the generalization is rather strong.

An official 50 m resolution digital elevation model (DEM) and vegetation data were obtained from the Swedish Land Survey. The DEM has a mean elevation error of 2.5 m. The vegetation data was produced by visual interpretation of infrared aerial photos (4600 m) and has comparatively high spatial accuracy.

Data on soil (type, texture) and bedrock (type) were not included in the study as spatial datasets, since the available official maps have too low accuracy and spatial resolution. In the region the bedrock and quaternary deposits are, however, fairly homogenous. Furthermore, data on vegetation cover generally reflects the distribution of soil types well (Moore et al., 1991).

3.2 GIS analysis

ArcInfo GIS was used for calculations of layers for area, elevation, slope and TWI for each catchment. The calculation of the upslope area was based on the commonly used deterministic 8 (D8) model (O’Callagan and Mark, 1984) for flow over a terrain surface represented by the DEM. The mean value of the slope and TWI was calculated for each catchment and used in the statistical analysis.

The percentage of each vegetation type within the catchments was calculated. The digitized wetlands from the 1:50,000 scale maps were managed in the same way and compared with the mire types extracted from the vegetation data. The mires were classed into fens, bogs and mixed mires.

3.3 Water sampling and chemical analysis

Water samples were collected at the outlet of each catchment four times at different flow situations during different seasons: summer low flow, summer medium flow (#1), autumn medium flow (#2) and spring high flow. Fourteen of the streams were sampled in 1998 and 1999 during four sampling events. The chemistry data from the four streams in the Laskerud Project were selected from a time series from 2003 and 2004. The selection was based on season and specific discharge. The filtered samples were kept dark and cool until the concentration of DOC [mg/l] was determined. The instrument used for measuring the DOC-concentration was a Shimadzu 500 carbon-analyser. Fe, Al and Si were analysed with ICP-OES (Varian).

The runoff was estimated by simple methods (bucket or float) when the samples were taken. The specific runoff was in average 0.8 l/s/km² at the low flow situation, 13 l/s/km² at the medium flow #1 situation, 11,1 l/s/km² at the medium

Table 2. Descriptive statistics for wetland coverage estimated from topographic maps and from the vegetation database.

	Topo.map		Vegetation data			
			Fen	Bog	Mixed	Sum
%						
Mean	7.7	1.6	2.3	3.1	7.0	
Std dev	7.5	1.5	1.9	2.4	6.2	
Min	0.5	0	0	0.2	0.2	
Max	20.3	5.1	10.9	8.6	21.1	
n	18	18	18	18	18	

flow #2 situation and $301\text{ l}/\text{km}^2$ at the high flow situation. During the high flow sampling round, seven streams were not sampled due to snow covered roads that made the sites inaccessible.

3.4 Statistical analysis

PCA analysis was initially performed to study the overall relations between topographic, wetland and vegetation variables. Correlation (Pearson) and linear regression analyses were then performed in order to investigate the covariation between landscape variables and water chemistry at different flow situations.

4 Results

4.1 Topographic characteristics

The mean size of the 18 catchments was 1.56 km^2 (Table 1). Catchment L5 has been selected to demonstrate the spatially distributed data used in the analysis (Fig. 3a–c). L5 was the catchment with highest percentage of wetland, 20%. It was also the catchment with lowest mean slope, 4.1%. The topographic wetness index for single $50\times 50\text{ m}$ cells ranged from 9.6 to 19.1 with a mean of 12.4.

Mean slope and mean topographic wetness index were strongly (negatively) correlated to each other, which was expected since the calculation of TWI includes the slope in the denominator. The correlation coefficient of -0.95 indicated that the slope has a dominant influence in the TWI, compared to the upstream drainage area per contour length a .

4.2 Wetland characteristics

In average 7% of the total area of the 18 studied catchments were covered with wetland (Table 2). The wetland percentage on the 1:50,000 scale maps was 0.7% larger than the percentage in the vegetation data. About 40% of the wetland was mixed mire according to the vegetation data.

There were only small differences in the distribution and location of wetlands in the two types of data sources. The errors were mainly caused by misinterpretations between wet

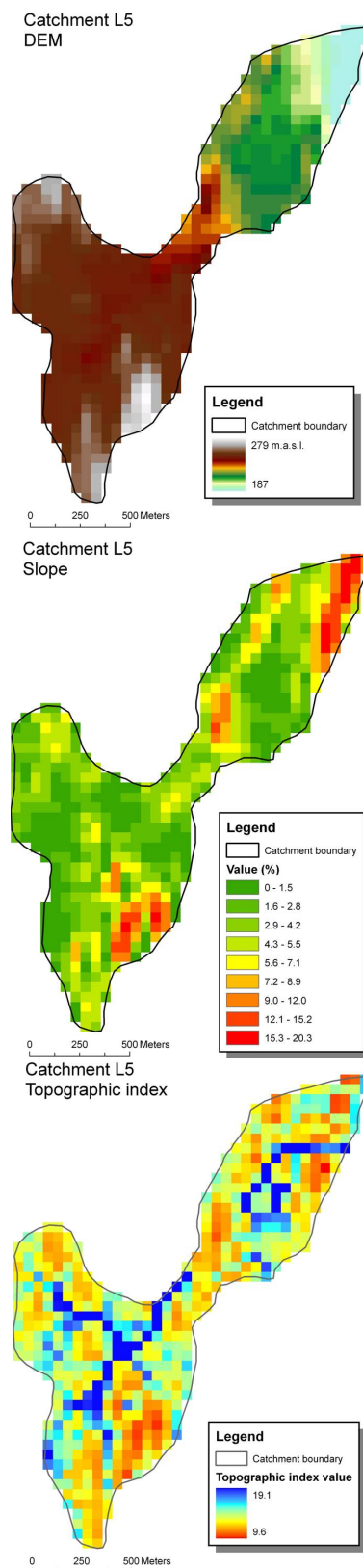
**Fig. 3.** Topographic description of example catchment L5. (a) Elevation [m a.s.l.], (b) Slope [%] and (c) Topographic wetness index.

Table 3. Vegetation types, total percentages (for all 18 catchments) and descriptions.

Vegetation type	Area [%]	Description
1 Coniferous forest, dry	8.1	Bare rocks, thin soil layer, lichens, mosses, mainly pines
2 Coniferous forest, mesic	76.8	Mosses, dwarf shrubs, blueberry, mainly spruce
3 Coniferous forest, moist	4.1	Mosses incl. forest Sphagna, dwarf shrubs, mainly spruce
4 Coniferous forest, wet	1.7	Mosses, low herbs, dwarf shrubs, spruce, waterlogged
5 Coniferous forest, mire	2.7	Fen or bog, Sphagnum spp, Ledum, pine and spruce
6 Deciduous forest, mesic	0.2	Cultivated soil, birch, aspen and other deciduous species
7 Deciduous forest, wet	0.1	Thick forest with birch, alder, viden, wet hummocky ground
8 Deciduous forest, mire	0.2	Fen, sparse vegetation, birch and viden
9 Dwarf shrub hummock mire	0.9	<i>Hummocky peat, Sphagnum spp, shrubs and dwarf pines</i>
10 Mire of lawn type	2.0	Fen or bog, lawn-like vegetation
11 Mire of carpet type	1.1	<i>Fen or bog, wet, soft, carpet-like vegetation</i>
12 Mire of peat mud type	0.1	Fen or bog, mudbottom vegetation, flarks
13 Plantation	0.7	Tree plantation on former open land, spruce or pine
14 Water	0.9	Open water or water with sparse vegetation
15 Others	0.3	Meadow, arable land, grassland, garden etc.

Table 4. Occurrence of vegetation types in the catchments.

Catchment	Vegetation type															n
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
B002	×	×		×							×		×			5
B005	×	×	×	×	×	×		×			×		×	×	×	11
B006	×	×	×	×	×		×		×	×	×		×	×	×	12
B008	×	×	×	×	×											5
B016	×	×	×	×	×			×	×	×	×					9
B021		×	×		×	×	×			×	×					8
B024	×	×	×	×	×					×		×		×		8
B030		×	×		×	×			×				×			6
B032		×	×	×	×			×	×	×	×					8
B034	×	×	×	×	×	×				×						8
B106	×	×	×	×	×	×		×	×				×	×	×	11
B107	×	×	×	×	×					×	×					7
B109		×	×		×				×		×					5
B118		×	×		×				×		×		×		×	7
D1	×	×	×	×	×				×	×	×	×		×	×	11
L5	×	×	×	×	×			×	×	×	×			×	×	12
L69	×	×	×	×	×			×	×	×	×			×	×	10
L78		×	×	×	×			×	×	×	×			×	×	11
n	12	18	17	14	17	5	5	8	11	10	13	2	6	8	8	

coniferous forest and coniferous mire. There is no distinction between mire classes in the topographic map. The map examples show the distribution of fen, bog and mixed mire (Fig. 4) and the mire types represented in the vegetation database (Fig 5) in catchment L5.

4.3 Vegetation characteristics

The vegetation database included 22 vegetation types within the catchments, of which the 7 types with smallest percentage were merged and categorized as “others”. The catchments were dominated by mesic coniferous forest (77 %) of total area. Dry coniferous forest covered 8.1% and moist coniferous forest 4.1%. Of the mire vegetation types the lawn

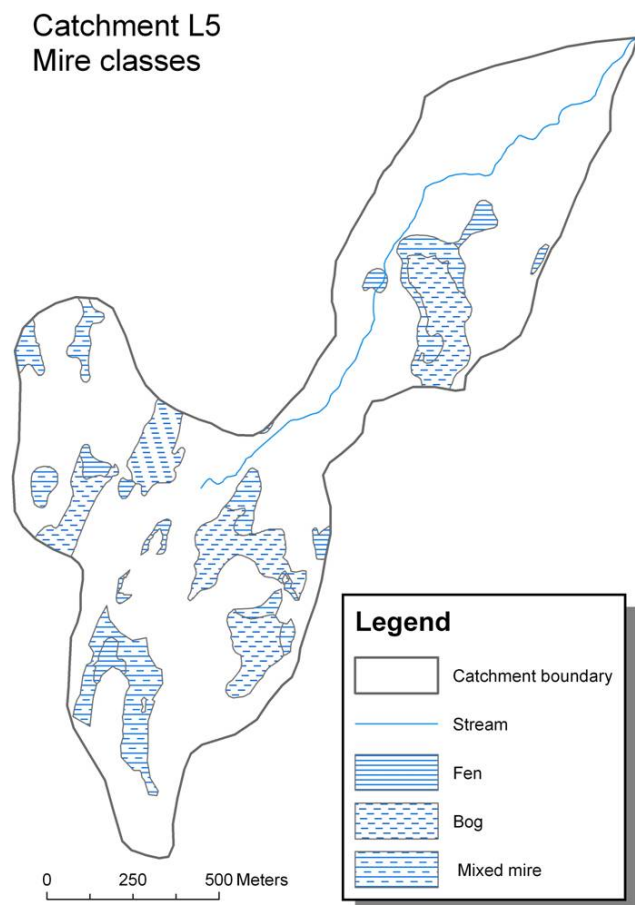


Fig. 4. Mire classes in catchment L5.

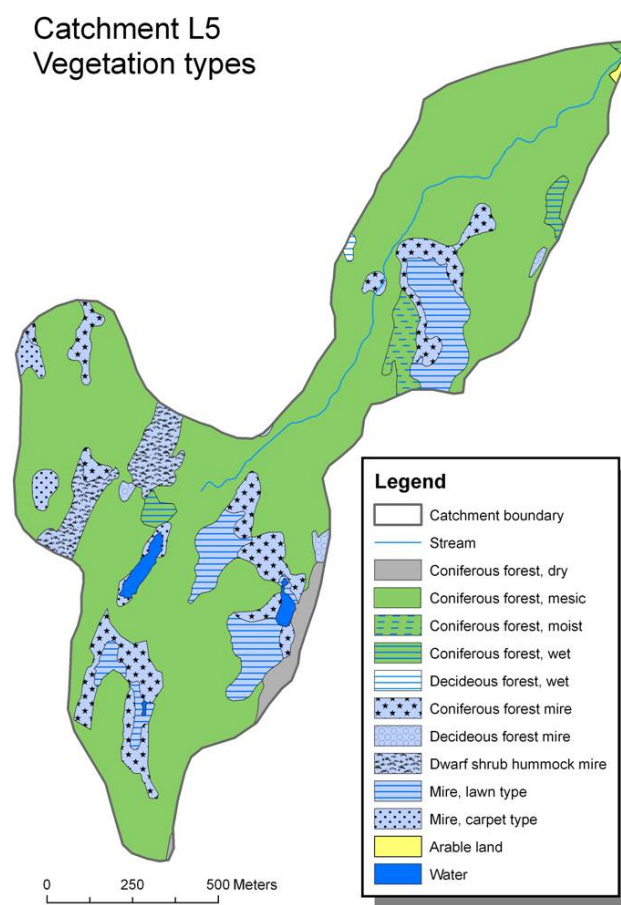


Fig. 5. Vegetation types in catchment L5.

type (2.0 %) and carpet type (1.1%) was most common (Table 3). In Table 4 the occurrences of the different vegetation types in each catchment are listed.

There was a large heterogeneity regarding vegetation types within and between the catchments (Table 4). Catchment B008 and B109 only comprised five vegetation types while catchment B006 and L5 had twelve. The table also shows the frequency of the vegetation types. Mesic coniferous forest was found in every catchment. Moist coniferous forest was found in all but one, while others were less frequent.

4.4 Chemical characteristics

DOC-concentration was used as a measure of dissolved organic matter. The DOC-concentration in the studied catchments were relatively high (Table 5), and the temporal and spatial variations were large (Fig. 7). The highest levels were found for the low and autumn medium flow samplings. The high and summer medium flow samplings had lower levels of DOC.

Fe (Fig. 6) and Al were correlated to DOC (Table 6), and had similar seasonal patterns as DOC. Si, which is a measure

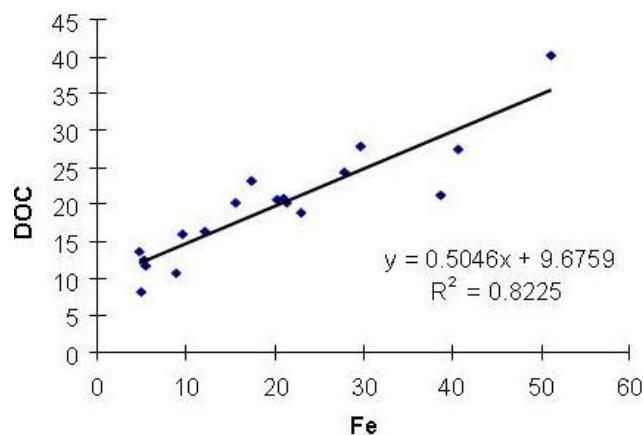


Fig. 6. Regressions showing the significant relationship between iron and DOC in the medium #1 flow situation. Units for DOC is mg/l and for Fe $\mu\text{mol/l}$.

of silicate weathering, had highest concentrations during the autumn medium flow and lowest during the spring flood.

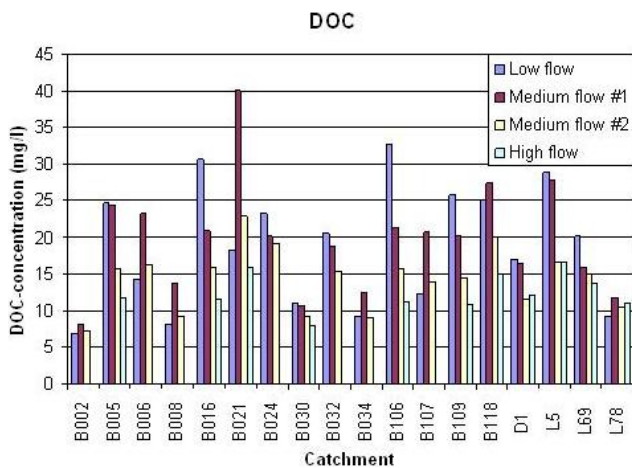
The greatest temporal variability was found in catchment B021 where the DOC-concentration ranged from 15.9 mg/l

Table 5. Descriptive statistics for stream chemistry for four flow situations: low flow (L), medium flow (M1 and M2) and high flow (H). The unit for DOC is mg/l and for Al, Fe and Si it is $\mu\text{mol/l}$.

	DOC				Al				Fe				Si			
	L	M1	M2	H	L	M1	M2	H	L	M1	M2	H	L	M1	M2	H
Mean	18.8	19.7	14.4	12.6	18.8	19.6	14.9	9.1	26.4	19.4	12.2	8.3	106.0	105.2	115.1	81.8
Std dev	8.2	7.5	4.2	2.6	10.7	8.8	5.3	1.9	18.5	13.0	6.6	4.0	30.7	26.5	16.6	11.6
Min	6.8	8.2	7.3	7.9	3.9	5.9	6.9	5.8	2.5	4.7	2.7	2.6	54.4	70.0	93.5	68.2
Max	32.6	40.1	22.8	16.7	36.0	42.1	23.6	11.9	62.8	51.2	25.0	16.1	150.4	167.8	152.6	102.1
n	18	18	18	11	14	18	17	11	14	18	17	11	13	17	17	11

Table 6. Pearson correlations between the measured chemical constituents at medium flow #1 (M#1) and high flow (H). $n=18$ for M#1 and $n=11$ for H. The strongest correlations are highlighted with bold numbers. (* $p<0.05$, ** $p<0.01$).

	DOC (M#1)	DOC (H)	Al (M#1)	Al (H)	Fe (M#1)	Fe (H)
DOC (M#1)	1.00					
DOC (H)		1.00				
Al (M#1)	0.72**		1.00			
Al (H)		0.23		1.00		
Fe (M#1)	0.79**		0.52*		1.00	
Fe (H)		0.68*		0.67*		1.00
Si (M#1)	-0.13		-0.16		0.19	
Si (H)		0.14		0.62*		0.49

**Fig. 7.** DOC-concentrations for the 18 catchments during four flow situations.

at high flow to 40.1 mg/l at medium flow #1. In B021 the mean DOC-concentration was 24.5 mg/l while it was as low as 7.3 mg/l in catchment B002.

4.5 Relations between topography, wetland and vegetation

A principal component analysis (PCA) including all topographic and vegetation variables was carried out to investigate the relations between those two groups of variables (Fig. 8). The first principal component explained 40% of the total variation, and captured primarily the slope-related variation. The second component explained 22%, and described the variation related to elevation.

There was a group of variables that contributed most to PC1: mean slope, mean TWI, total wetland and coniferous forest of mire type. These four variables were also strongly correlated to each other. A further analysis of the relation between coniferous mire type and total wetland showed that a rather stable proportion of 40% of the total wetland in each catchment was of coniferous mire type.

In PC2, dry coniferous forest had the strongest (negative) correlation with altitude. This was probably a side-effect of the weak correlation between altitude and latitude. The mean altitude of the catchments was slightly higher in the northern part of the study region, where the soil cover is somewhat deeper.

Not surprisingly there were several strong correlations between wetland, slope and TWI variables (Table 7, Fig. 9).

Table 7. Correlations between topographic and wetland/mire class variables. $n=18$. The strongest correlations are highlighted with bold numbers ($p<0.01$).

	Mean slope	Mean TWI	Wetland (Topo. map)	Wetland (Veg. data)	Fen	Bog	Mixed mire
Mean slope	1.00						
Mean TWI	-0.95	1.00					
Wetland (Topo. Map)	-0.84	0.88	1.00				
Wetland (Veg. Map)	-0.83	0.90	0.96	1.00			
Fen	-0.69	0.64	0.54	0.62	1.00		
Bog	-0.66	0.68	0.86	0.86	0.47	1.00	
Mixed mire	-0.66	0.79	0.78	0.82	0.27	0.49	1.00
Coniferous forest mire	-0.72	0.79	0.84	0.92	0.59	0.82	0.70
Mire, lawn type	-0.61	0.63	0.70	0.64	0.23	0.64	0.54
Mire, carpet type	-0.58	0.62	0.56	0.62	0.63	0.34	0.60
Dwarf shrub hum. mire	-0.42	0.50	0.58	0.67	0.42	0.51	0.60

Table 8. Correlations between topographical/wetland variables and stream chemistry variables (L represents low flow, M#1 and M#2 medium flow and H high flow). The strongest correlations are highlighted with bold numbers ($p<0.01$).

		Mean slope	Mean TWI	Wetland (Topo. map)	Wetland (Veg. data)	Fen	Bog	Mixed mire
DOC (L)	<i>r</i>	-0.52	0.49	0.37	0.36	0.24	0.30	0.29
	<i>n</i>	18	18	18	18	18	18	18
DOC (M#1)	<i>r</i>	-0.73	0.76	0.58	0.69	0.56	0.36	0.71
	<i>n</i>	18	18	18	18	18	18	18
DOC (M#2)	<i>r</i>	-0.72	0.73	0.60	0.62	0.49	0.29	0.67
	<i>n</i>	18	18	18	18	18	18	18
DOC (H)	<i>r</i>	-0.92	0.97	0.85	0.88	0.52	0.61	0.85
	<i>n</i>	11	11	11	11	11	11	11
Al (L)	<i>r</i>	-0.21	0.17	0.01	-0.02	-0.12	-0.30	0.28
	<i>n</i>	15	15	15	15	15	14	15
Al (M#1)	<i>r</i>	-0.24	0.31	0.03	0.14	0.11	-0.31	0.50
	<i>n</i>	18	18	18	18	18	17	18
Al (M#2)	<i>r</i>	-0.16	0.22	0.02	0.05	-0.03	-0.40	0.48
	<i>n</i>	17	17	17	17	17	16	17
Al (H)	<i>r</i>	-0.05	0.10	-0.14	-0.08	-0.22	-0.48	0.47
	<i>n</i>	11	11	11	11	11	10	11
Fe (L)	<i>r</i>	-0.40	0.28	0.17	0.20	0.35	0.13	0.11
	<i>n</i>	15	15	15	15	15	14	15
Fe (M#1)	<i>r</i>	-0.58	0.60	0.39	0.52	0.40	0.19	0.61
	<i>n</i>	18	18	18	18	18	18	18
Fe (M#2)	<i>r</i>	-0.67	0.69	0.56	0.61	0.39	0.28	0.73
	<i>n</i>	17	17	17	17	17	17	17
Fe (H)	<i>r</i>	-0.81	0.86	0.71	0.77	0.45	0.42	0.82
	<i>n</i>	11	11	11	11	11	11	11
Si (L)	<i>r</i>	-0.16	0.19	0.35	0.25	-0.35	0.06	-0.16
	<i>n</i>	15	15	15	15	15	14	15
Si (M#1)	<i>r</i>	0.23	-0.32	-0.46	-0.34	-0.23	-0.48	0.23
	<i>n</i>	18	18	18	18	18	17	18
Si (M#2)	<i>r</i>	-0.16	0.02	0.17	0.15	0.06	0.24	-0.16
	<i>n</i>	17	17	17	17	17	16	17
Si (H)	<i>r</i>	0.04	-0.22	-0.28	-0.18	0.04	0.01	0.04
	<i>n</i>	11	11	11	11	11	10	11

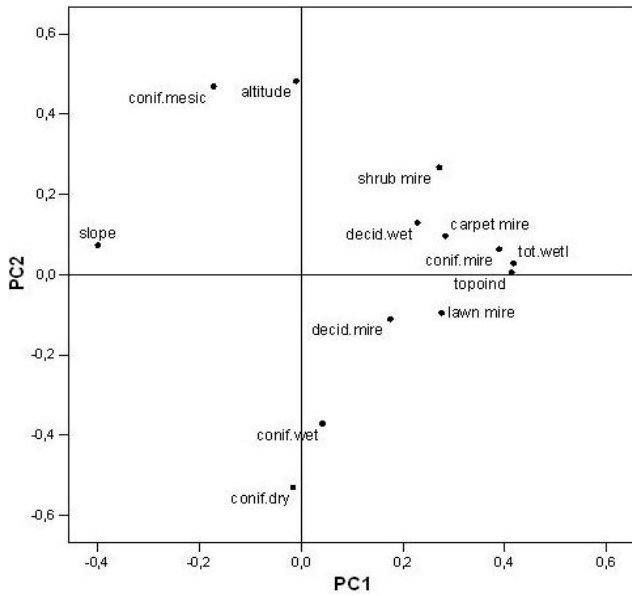


Fig. 8. PCA analysis of the most significant topographic and vegetation variables. The axes represent loadings for PC1 and PC2. The topographic variables included were mean altitude, mean slope and mean TWI. The vegetation variables were total wetland and variables no. 1–2, 4–5 and 7–11 in Table 3 (calculated as percentages of each catchment).

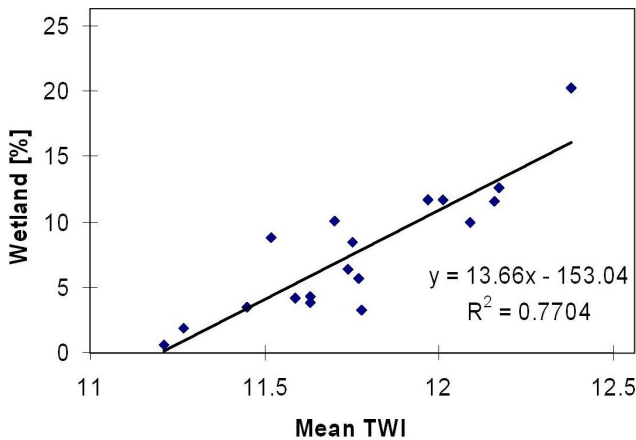


Fig. 9. Relationship between mean TWI and wetland percentage.

4.6 Relations between topography-wetland-mires classes and water chemistry

A correlation analysis including topography, wetland percentages and water chemistry (Table 8) showed moderate and strong pair-wise correlations between topography-wetland (as mentioned above), wetland-chemistry and topography-chemistry. The chemistry referred to here is DOC- and Fe-concentration during medium and high flow.

The classification of wetlands into bogs and fens did not give any stronger correlations in relation to water chemistry

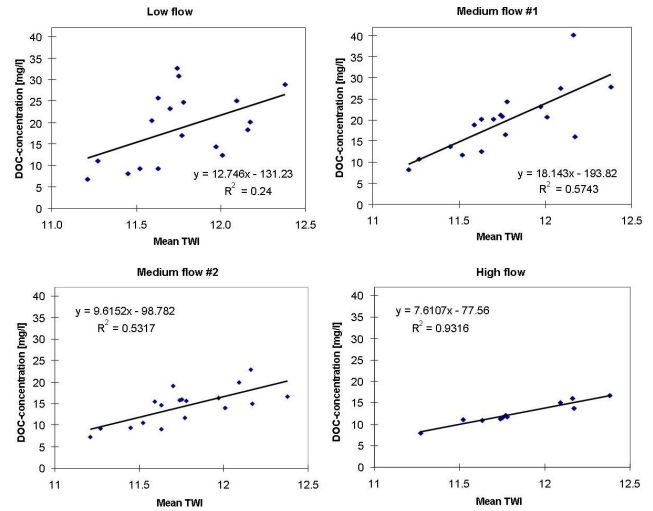


Fig. 10. Regressions between mean topographic wetness index and DOC in the four flow situations.

(Table 8). The class *Mixed mire* had stronger correlations than *Fen* and *Bog*.

Si was not significantly correlated to topography or wetland.

There were strong correlations between mean topographic wetness index and DOC-concentration (Table 8, Fig. 10). It was strongest at the high flow situation and decreasing with decreasing flow. The fact that mean TWI gave the strongest correlation can be explained by that it includes other surfaces with peat layers than only mapped mires, e.g. so called cryptic wetlands.

5 Discussion

Is it possible to predict stream water chemistry by analyzing official maps and map data? This question would probably get a negative answer from many researchers. With respect to the complexity and high number of relationships and varied landscape elements that influence stream water chemistry, several of them are not covered by available official maps and map data. The maps are also, in general, too coarse compared to the scale of most process studies. The results of this study, however, where catchments in the scale 1–4 km² were investigated, show that official topographic maps and elevation data (50 m DEM) can be used for prediction of DOC-concentration at four different flow situations. Other variables measured, such as concentrations of Fe, Al and Si, did not show the same clear relations at all flow situations, probably because they are more closely related to the geology, which was not included in the map data. The elevation data, recalculated as mean slope and mean TWI, showed very strong correlations with DOC-concentration, increasing with increasing flow. Mean slope and mean TWI are measures of the catchment's topographic characteristics, which

explain to what extent the groundwater is fluctuating at or near the ground surface where many chemical processes take place. Using the mean values makes random errors in the map information less important.

In addition to topographic map data, wetland data were also useful in predicting stream water chemistry. Both topography and wetland variables were more strongly correlated to water chemistry at medium (summer and autumn) and high flow (spring flood) than they were at low flow (summer). This indicated that, within the 120×50 km region, the connection between the sources of dissolved organic carbon and the stream was weaker during low flow. One possible reason was the longer retention times for water in the ground and streams which could give more time for biological degradation of organic matter. The low flow situation also occurred during summer when the biological activity was high.

The vegetation map data did not add much to the results, even if there were some significant correlations with water chemistry variables. The vegetation database was, however, useful for validation of the topographic map data that were produced by interpretation of black and white aerial photos taken from a higher altitude, and thus less accurate, especially fuzzy objects like wetlands. Our findings are contradictory to the statement by Rodhe and Seibert (1999) that good maps over mires already exist.

This study includes catchments larger in scale, from 0.5–1.5 to 1–4 km², compared to the previous study by Andersson and Nyberg (2008). A comparison showed a substantially larger variation in water chemistry for smaller catchments, which supports the results in other similar studies (e.g. Wolock et al., 1997). That is probably the main reason for the stronger correlations between percentage wetland, mean slope and mean TWI vs. DOC-concentration at the larger scale.

It is widely recognized that topographic analyses are sensitive to the resolution of the data source used. This affects all topographic attributes, but in varying ways. The resolution-dependence of slope and specific catchment area has been most intensively studied because of their regular application in hydrological modelling. In this study a 50 m DEM grid was used for deriving the variables *slope* and *topographic wetness index*. Beven (1997) criticized modellers deriving topographic indices from DEMs with grid sizes exceeding slope lengths in the landscape. In our study the comparison between TWI grid with the wetland layer was not a success when considering spatial location and distribution. However, mean values seem to be useful in regression analyses.

In a few years time, official high-resolution laser-based elevation data will be available. If DEM's with different grid resolution show considerable differences in the TWI pattern, further studies of catchments would be of interest. The algorithm used for calculating the TWI is also crucial, and different types should be tested in a similar way, in order to find the best method for prediction of water chemistry at different catchment scale ranges.

There is still a large gap between process knowledge in small versus large hydro-chemical scales. Many studies have been carried out in few and small catchments, where it has been possible to measure and control many spatial and temporal variables with high accuracy. Environmental institutes and agencies are, however, in need of simple and cost efficient methods for monitoring stream water chemistry. Therefore, studies of the potential to use official map data in the up-scaling of local process knowledge are of crucial importance.

6 Conclusion

Official map data could be used for predictions of DOC-concentration in boreal headwater catchments. This conclusion was supported by strong correlations between mean wetland percent, mean slope, mean topographic wetness index and DOC-concentration for different flow situations at different seasons. Mean TWI gave the strongest correlation, which shows that the relatively coarse elevation data (50 m DEM) can be used for predictions of DOC-concentration in boreal catchments in the range of 1–4 km².

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