# Langtidstrender i jordbrukspåvirkede bekker

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## Sammendrag

Siden slutten av 1980-tallet har det i Norge vært gitt tilskudd til tiltak for å redusere erosjon fra jordbruksarealene, det vil si transport av jord og fosfor (P) bundet til jordpartikler. I perioden 1991 til 2001 førte tilskuddene til en firedobling av arealet som ikke ble pløyd om høsten. Dessuten ble forbruket av P i mineralgjødsel redusert med 60 % fra midten av 80-tallet til midten av 90-tallet, med særlig stor reduksjon i områder med stor husdyrtetthet. Midt på 80-tallet ble det fokusert på å fjerne punktkilder av P fra gjødsel- og fôrlagringsplasser, bl.a. ved hjelp av en informasjonskampanje. Vi har her evaluert effekten av disse tiltakene på konsentrasjoner av suspendert stoff (SS) og total fosfor (TP) i tre jordbruksdominerte vassdrag på henholdsvis Romerike, Hedmarken og Jæren (87, 3 og 1 $km^2$). Resultater fra statistiske trendanalyser (14-17 years) viste statistisk signifikante ($p<0.05$), nedadgående trender i konsentrasjoner av TP and SS, der konsentrasjonene i utgangspunktet var høye. Et vassdrag på Romerike, som representerer et område med stor erosjon og P tap, viste signifikant reduksjon i både SS- og TP-konsentrasjon. Et nedbørfelt på Hedmarken med liten erosjon og middels husdyrtetthet hadde lave konsentrasjoner av både SS og TP og viste ingen endringer i trendene. Nedbørfeltet på Jæren hadde høy husdyrtetthet og liten erosjon, og avrenningen viste høye TP-konsentrasjoner og lave SS-konsentrasjoner i utgangspunktet. Avrenning fra dette feltet viste en signifikant nedgang i TP-konsentrasjonen. Resultatene fra denne analysen illustrerer at de gjennomførte tilskuddsordninger og tiltak kan bidra til å redusere konsentrasjonen av SS og TP i vassdrag med stor forurensningsgrad, men at ytterligere tiltak må settes inn for å oppnå større reduksjoner. Resultatene viser også den store betydningen og informasjonsverdien av langsiktig overvåking av vannkvalitet, noe som for eksempel vil bli svært sentralt i utarbeidelsen av tiltaksplaner for vannregioner ved implementering av vannrammedirektivet.

Denne artikkelen er en forkortet versjon av artikkelen:
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## Introduction

In 1985, the national authorities introduced the National Action Plan against Agricultural Pollution (1985-1988), which in the late 1980s resulted in practical measures and increased political interest (Lundekvam et al., 2003). Priority was first given to the establishment and improvement of municipal wastewater treatment facilities to mitigate point sources of P. To mitigate sources of diffuse P, during the late 1980s and 1990s, several economic incentives (e.g., subsidies and direct payment) were introduced to stimulate the farmers to implement measures to reduce soil and P losses. Measures were separated into addressing P source and P transport factors, and included measures like reduced autumn tillage, nutrient management planning and increased area of vegetated buffer zones and grassed waterways (Lundekvam et al., 2003). Agricultural legislations were also changed, i.e., (i) the maximum livestock density on each farm was set to 2.5 livestock units (LU) $ha^{-1}$ and, (ii) the time and method of manure application were regulated, e.g., on arable land manure must be incorporated within 18 hours after application; as well as seasonal regulations. As a result, the proportion of manure spread during spring and the growing season increased in Norway during the 1990s, and constituted 80 % of the total amount of manure spread on agricultural fields in 2002 (Bye et al., 2003). In addition, the new regulations also required the farmers to establish an annual nutrient management plan, based on analyses of soil P status every 5th to 8th year. Moreover, in the late 1980s, authorities inspected the farms in order to identify sources of loss from manure and fodder storage facilities.

In order to gauge the effectiveness of policy changes, it is essential to determine if and how successful these environmental measures are, and how long time it may take to detect the response in agricultural streams. During the 1990s, trends in losses of suspended sediment (SS) and total phosphorus (TP) were difficult to detect in Norwegian streams dominated by agricultural contributions, since the most efficient measures were implemented before this period (Stålnacke and Bechmann, 2002). Investigation of long-term time series (from before 1990) are important for the detection of trends in Norwegian streams.

The aim of this study is to evaluate the effect of measures implemented to reduce losses of SS and TP from agricultural areas. We analysed three long-term time series (14-17 years) of data on SS and TP concentrations in agricultural streams representing areas with i) cereal production, high erosion risk and low livestock density,

ii) cereal production, low erosion risk and medium livestock density and iii) grass production and high livestock density. The relationship between implemented measures within the catchments and the stream concentrations was evaluated. In this reduced version of the paper, the implementation of measures has been left out.

## Materials and methods

### Site description

The studied catchments are located in south-eastern (Rømua and Kolstad) and south-western (Time) Norway (Figure 1). Characteristics of the three catchments are presented in table 1.

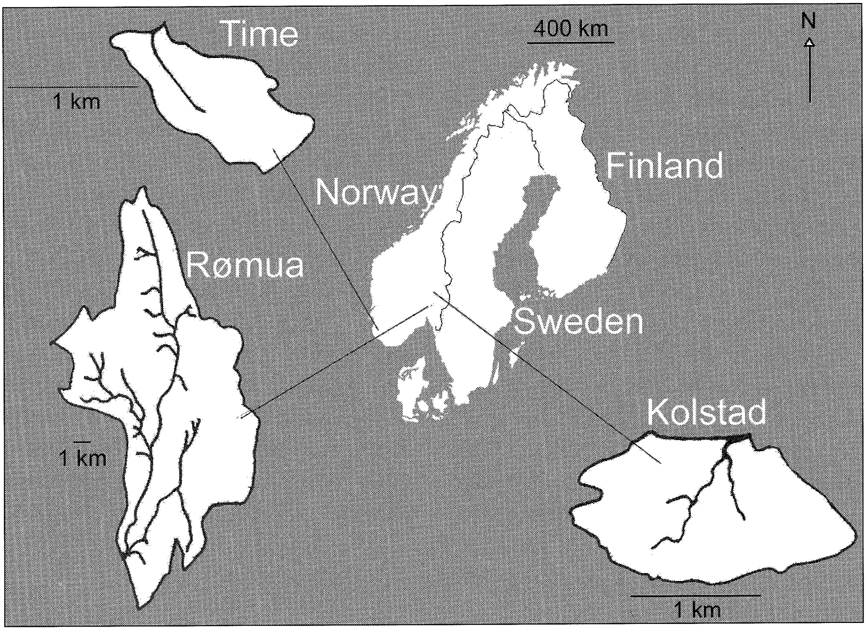


*Figure 1. Map of Norway and the Rømua, Kolstad and Time catchments.*

*Table 1. Characteristics of the Rømua, Kolstad and Time catchments. Catchment size, agricultural area, Dominating production, livestock units (LU), population equivalent (p.e.), P-AL is plant available phosphorus by Ammonia-Lactate extraction and soil texture.*

| | Catchment size, ha | % agric. area | Production | Livestock density, LU $ha^{-1}$ | Estimated point source, p.e. $ha^{-1}$ | P-AL, mg 100 $g^{-1}$ | Soil |
|---|---|---|---|---|---|---|---|
| Rømua | 8710 | 41 | Cereal | 0.3 | 0.38 | 8 | Silt and clay |
| Kolstad | 308 | 68 | Cereal/pigs | 1.0 | 0.21 | 14 | Loam |
| Time | 114 | 85 | Grass/cows | 2.0 | 0.45 | 17 | Silty sand |

## Catchment monitoring

The Rømua, Kolstad and Time catchments were monitored from 1983-2000, 1985-2001 and 1985-2000, respectively. Monitoring of the catchments consisted of discharge measurement, water quality analysis and a survey of agricultural practice within the catchments (table 2). At the outlet of each catchment, discharge measurements were carried out in a cross-section of the stream by measuring the flow depth with a pressure transducer. Data loggers recorded flow data. The cross-section in Rømua was a natural control section and the flow curve was built based on the relationship between a series of periodic stage height measurements and their corresponding in-stream flow measurements. In the streams of Kolstad and Time a V-notch and a Crump weir, respectively, were used (table 2). The discharge measurements during summer in the Time stream are inaccurate because of plant growth in the stream, which raised the water level in the Crump weir. Hence flow data in the Time stream is not presented in this paper. In Rømua, flow proportional (1983-1996) and time equidistant (1996-2000) water quality samples were collected to form composite samples. The different sampling strategy in different periods may cause a systematic underestimation in the latter period (Haraldsen and Stålnacke, 2002). Hence, for Rømua only the period 1983-1996 is included in this analysis. In the Kolstad and Time streams, flow proportional composite samples were collected throughout the respective monitoring periods (table 2). In all three streams flow proportional subsamples were taken automatically and collected in a bucket, from which a representative sample was taken after thorough mixing about once every two weeks. Hence, continuous data are available for all three steams.

*Table 2. Measurements in the Rømua, Kolstad and Time catchments.*

| | Discharge measurem | Sampling | No. of samples per year | Source of farming practice information | Temp. normal°C | Precip. normal mm | Monitoring period |
|---|---|---|---|---|---|---|---|
| Rømua | Natural control section | Volume proportional mixed samples | 51 | Statistical data | 4.3 | 665 | 1983 -1996 |
| Kolstad | V-notch | Volume proportional mixed samples | 29 | Questionnaire | 4.2 | 585 | 1985-2000 |
| Time | Crump weir | Volume proportional mixed samples | 29 | Questionnaire | 7.4 | 1154 | 1985-2001 |

### Statistical methods

Weather conditions often cause natural fluctuation in the nutrient concentration time series, which may impede the detection of a human induced trend (Stålnacke and Grimvall, 2001). To account for spurious trends due to water discharge, we used the Partial Hirsch-Slack (PHS) test for detection of trends (Libiseller and Grimvall,2002). Moreover, since seasonal trends were of particular interest in our study and the fact that the temporal behaviour may shift between years due to the prevailing hydro meteorological situation, we aggregated the nutrient concentrations into tertiary data; e.g., snowmelt may occur in January or in March depending on the hydro meteorological conditions in a particular year. Thus, we divided the year into the following three seasons: January-April (winter and early spring season), May-August (growing season) and September-December (autumn period). For each tertiary season, flow-weighted tertiary concentrations and water flow were calculated. Finally, the tertiary data were used to statistically analyse time trends using the PHS statistic (one sided test).

## Results and discussion

### Annual concentrations of suspended sediments and total phosphorus

Summary data on mean annual concentrations of SS and TP for the respective monitoring periods are given in table 3. The Rømua is a large scale catchment, and hence, may show a lower connectivity for this catchment compared to the other, smaller catchments in this study. However, among the three streams, the highest annual mean concentration of SS was observed in the Rømua stream (91 mg $l^{-1}$). Annual mean concentration of TP in the Rømua stream was 147 µg $l^{-1}$, although instantaneous concentrations were much higher. The temporal variability in SS and TP concentrations in Rømua showed a close relationship ($r^2 = 0.9$; $p<0.001$), which indicates that erosion was probably the main process of TP transfer.

Mean concentrations of SS (32 mg $l^{-1}$) in the Kolstad stream were low compared to the Rømua catchment (table 3), despite the great differences in size of the catchments. The correlation between TP and SS concentrations in the Kolstad stream was statistically significant but substantially weaker ($r^2 = 0.35$; $p<0.001$) than in Rømua, suggesting that erosion is not the dominating process causing P loss. The homogeneous light textured and well-structured moraine soils in the Kolstad catchment cause high infiltration capacity and may partly explain the relative low erosion rate. The TP mean concentration in Kolstad was 108 µg $l^{-1}$, which was 2/3 of the Rømua concentration.

In the Time stream, the mean concen-

*Table 3. Mean annual flow-weighted concentrations and loads of suspended sediments (SS) and total phosphorus (TP) from the Rømua, Kolstad and Time catchments.*

| Catchment | Period | Concentration SS, mg $l^{-1}$ | Concentration TP, µg $l^{-1}$ |
|---|---|---|---|
| Rømua | 1983-1996 | 91 | 147 |
| Kolstad | 1985-2000 | 32 | 108 |
| Time | 1985-2001 | 12 | 195 |

n.d. no data available

tration of SS was 12 mg $l^{-1}$, which is only 13% of the observed SS concentration in the Rømua stream (table 3). The Time catchment is dominated by grassland and gently sloping fields with a low erosion risk. Mean concentration of TP was 195 µg $l^{-1}$. Generally, there is a weak relationship, though significant, ($r^2$ = 0.55, $p<0.001$) between TP and SS concentrations for Time (both with and without the outlier), indicating that erosion may not be the dominating process of TP transfer within the catchment. Incidental P losses, desorption of P from soil and erosion of soil particles with a high P content are probably contributing to the P transfer in the Time catchment.

**Trends**

No significant changes in discharge were found during the respective monitoring periods (table 4, Figure 2). Time series of tertiary data for concentrations of SS and TP from the three streams were tested for significant trends during two decades (table 4, Figure 2). In general, significant downward trends ($p<0.05$) were only detected for the streams with high concentration levels. Rømua had the highest annual mean concentration of SS, and the downward trend in annual SS concentration was significant. Reduced autumn tillage and other measures against erosion are likely to be the main causes for this downward trend in SS. The stop of the land levelling practise in the end of the 1980s may also have had an influence on erosion in all seasons. The significant downward trends in TP in Rømua are most likely due to decreased erosion, since erosion is the main P transport mechanism in this catchment. However, the trends were significant for TP for all seasons, which may suggest that additional factors are important. Improved wastewater treatment may explain the reduction in P concentrations during summer and low flow winter periods. The relative point source contribution has been estimated to be around 20% in the Rømua catchment in 1996 (Wivestad, 1996). Using the general reduction in TP contribution from point sources (55%) estimated by Borgvang et al. (2002), this indicates that the point source reductions can only explain a minor part of the observed improvements in the water quality. This is underlined by the significant reductions in SS concentration.

Trends for the Kolstad stream were difficult to detect statistically. For the annual data, only the TP/SS ratio showed a statistically significant trend (table 4, Figure 2). The decrease in TP/SS is a result of the increasing SS concentration, which was significant for the winter period. The statistical method used here accounted for fluctuations in water discharge. Although it cannot be ruled out whether other types of hydro meteorological conditions have influenced the trend test results, such as changes in snowmelt pattern. Øygarden (2000) found that the highest losses of SS in the Rømua region occurred during snowmelt. Changing climate in the Kolstad region from stable winters to a climate with more frequent freeze-thaw cycles may increase the number of serious snowmelt and erosion events (Skaugen, T.E., www.met.no, pers.com). In Rømua, serious erosion events were observed. The resulting high SS concentrations (SS concentrations > 500 mg $l^{-1}$) were more frequent early in the studied period than in recent years, suggesting that no such effect of climate change has impeded the detection of trends.

The concentration of SS did not reveal

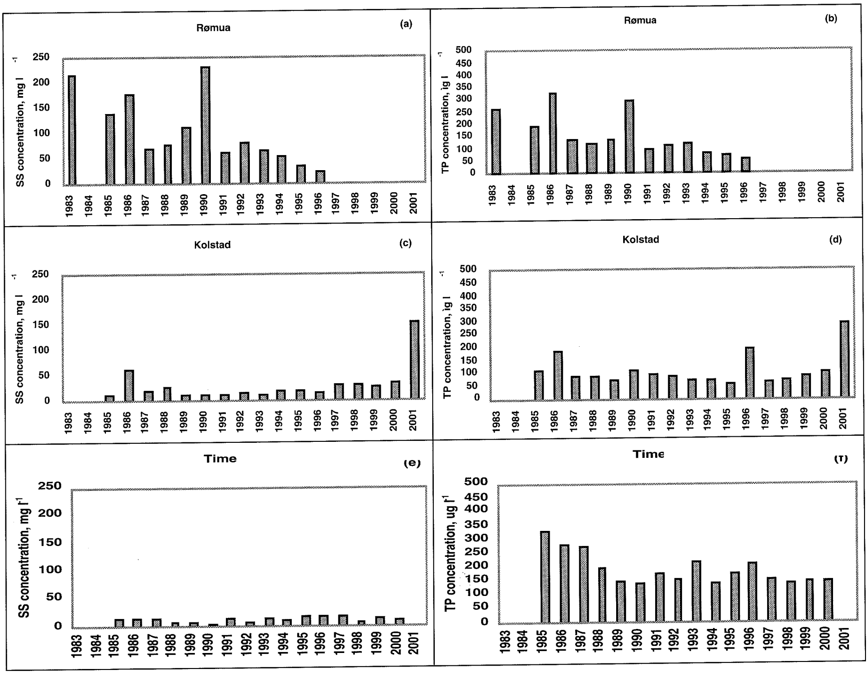


*Figure 2. Mean annual concentrations of suspended sediments and total phosphorus from the Rømua (a and b) (flow-weighted), Kolstad (c and d) (flow-weighted) and Time catchments (e and f) (arithmetical mean).*

*Table 4. Test of significance of changes in tertiary data for water discharge (Q), concentration of suspended sediments (SS) and total phosphorus (TP) and TP/SS ratio for the Rømua catchment 1983-1996, Kolstad catchment 1985-2001 and Time catchment 1985-2000.*

| Catchment | | Jan-Apr | May-Aug | Sep-Dec | Annually |
|---|---|---|---|---|---|
| Rømua | Q | -0.357 | -0.313 | -0.232 | -0.151 |
| | TP | **-0.060** | **-0.001** | **-0.002** | **-0.0003** |
| | SS | -0.122 | **-0.003** | **-0.015** | **-0.0007** |
| | TP/SS | 0.311 | **0.038** | 0.137 | 0.034 |
| Kolstad | Q | -0.528 | 0.934 | 0.207 | 0.687 |
| | TP | -0.921 | -0.237 | -0.411 | -0.291 |
| | SS | **0.012** | 0.953 | 0.291 | 0.127 |
| | TP/SS | **-0.002** | -0.105 | **-0.016** | **-0.002** |
| Time | TP | -0.054 | 0.882 | **-0.002** | **-0.025** |
| | SS | -0.458 | 0.586 | -0.216 | -0.507 |
| | TP:SS | -0.586 | -0.182 | -0.102 | -0.089 |

Statistically significant trends ($p<0.06$) marked in bold font

any trends in the Time stream, neither on an annual basis nor for single seasons. It should though be noted that the SS concentrations generally are at a low level. The TP concentrations –normally at relatively high level- showed a significant downward annual trend (table 4, Figure 2). The measures in the Time catchment has been related to improved management of animal manure. A reduced P application rate may explain at least part of the decrease in TP concentration. Additionally, the incorporation of manure spread during autumn application may have contributed to the indications of decreased TP concentration in the stream during autumn (significant) and winter (nearly significant).

## Conclusions

The main conclusions that can be drawn from the present results are as follows:

- Policy induced measures resulted in a weak, but statistically significant ($p<0.05$), decrease in concentrations of SS and TP for catchments with high concentration levels of SS and TP.
- Catchments with low concentration levels of SS and TP did not show statistically significant trends ($p>0.05$).
- The difference in concentration levels between catchments reflected varying agricultural management practice and geological conditions.
- The political strategies in the agricultural sector resulted in changed management practices within the catchments during the 1980s and 1990s.

Though changes in agricultural management practice were followed by significant decreasing trends in concentrations of SS and TP in the streams with the highest concentrations, additional measures may be needed to further improve water quality. Focusing measures on high-risk areas within the catchments may improve the cost-efficiency of subsidies used to implement measures in agricultural management practice.

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