Statistical Analysis of Specific Runoff, Suspended Solids, Total Phosphorus and Total Nitrogen from The Agricultural Environmental Monitoring Programme in Norway (JOVA)

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Time series of specific runoff ($q$), concentrations of suspended solids ($SS$), total phosphorous ($Tot-P$) and total nitrogen ($Tot-N$) are explored. We were able to identify catchment specific features as process memory; periodicities; and lag effects. In general there are significant positive correlations between $q$, $SS$ and $Tot-P$. This confirms the concept of phosphorous being adsorbed to particles and transported in the solid phase. We identify some significant exceptions from this rule, indicating that some of the phosphorous are dissolved and are transported independent of the solid phase. This study reveal no simple relations between $q$ and $Tot-N$. In two of the catchments there are negative correlations between $q$ and $Tot-N$, which may indicate that some nitrogen derives from point sources. In other catchments there are significant periodicities of the $Tot-N$ signal due to seasonal fluctuations.
1 Introduction

Modern agriculture affects the environment and there is an increasing demand to quantify these impacts. To meet this demand there is a need for validated methodology at a catchment scale. In the present paper we are focusing on some main response variables namely: specific runoff, $q$, suspended solids, $SS$, total phosphorous, $Tot-P$, and total nitrogen, $Tot-N$, which are monitored as a part of the Agricultural Environmental Monitoring Programme in Norway (JOVA).

The main purpose of this study was exploratory data analysis. In this case it means pure statistical quantification of hydrological processes. The intention was to formulate flow and transport hypotheses. We analyzed for each individual catchment: (i) large scale trends of specific runoff and concentrations, and (ii) the statistical pattern of the time series. To achieve (i) we applied a moving average (MA) filter, while (ii) was obtained by calculating auto-correlation and cross-correlation coefficients as a function of time. In addition the simultaneous (or lumped) correlation and cross-correlation coefficients were calculated.

The (JOVA) program was established in 1992, and is monitoring input-, transfer-, and environmental response variables related to agricultural practice in a number of small catchments in Norway. The catchments convey a spectrum of agricultural practices, soil types, and climatic conditions [Haraldsen et al, 1995; Stålnecke and Bechmann, 1995]. The following catchments are included in this study (Fig. 1 and Tab. 1): Grimestadbekken 1 (East Norway, Stokke municipality) Hotran-kanalen 2 (Mid Norway, Levanger municipality) Kolstadbekken (East Norway, Ringsaker municipality) Mørdrebekken (South East Norway, Nes municipality) Naurstadbekken (North Norway, Bodo municipality) Skuterudbekken (South-East Norway, Ås/Ski municipality) Volbubekken - Eik (Mid Norway, Øystre Slidre municipality).

Table 1: Field characteristics of the JOVA catchments. Temperature and Precipitation are given as Annual Averages. Fraction of agricultural area are given in parenthesis in the Area column.

<table>
<thead>
<tr>
<th>Catchment name</th>
<th>Climate type</th>
<th>Area km²</th>
<th>Soil type</th>
<th>Altitude m a.m.s.l</th>
<th>Temp. °C</th>
<th>Precip. mm/y</th>
<th>Obs. period</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Grimestadbekken</td>
<td>Coastal</td>
<td>1.8 (0.45)</td>
<td>silty fine- medium sand</td>
<td>15 - 100</td>
<td>7.4</td>
<td>1080</td>
<td>1992-2002</td>
</tr>
<tr>
<td>2. Hotran-kanalen</td>
<td>Inland/ Coastal</td>
<td>20.0 (0.60)</td>
<td>silty loam and silty clay</td>
<td>10 - 282</td>
<td>5.3</td>
<td>692</td>
<td>1992-2004</td>
</tr>
<tr>
<td>3. Kolstadbekken</td>
<td>Inland</td>
<td>3.1 (0.68)</td>
<td>clayey- sandy silt</td>
<td>200 - 318</td>
<td>4.2</td>
<td>585</td>
<td>1985-2004</td>
</tr>
<tr>
<td>4. Mørdrebekken</td>
<td>Inland</td>
<td>6.8 (0.65)</td>
<td>clay and silt</td>
<td>130 - 230</td>
<td>4.0</td>
<td>665</td>
<td>1991-2004</td>
</tr>
<tr>
<td>5. Naurstadbekken</td>
<td>Coastal</td>
<td>1.5 (0.35)</td>
<td>fine sand and silt</td>
<td>5 - 70</td>
<td>4.5</td>
<td>1020</td>
<td>1994-2004</td>
</tr>
<tr>
<td>6. Skuterudbekken</td>
<td>Inland/ Coastal</td>
<td>4.5 (0.61)</td>
<td>silty-clay</td>
<td>91 - 146</td>
<td>5.5</td>
<td>785</td>
<td>1993-2004</td>
</tr>
<tr>
<td>7. Volbubekken</td>
<td>Inland</td>
<td>1.7 (1.00)</td>
<td>sandy silt</td>
<td>440 - 675</td>
<td>1.6</td>
<td>575</td>
<td>1991-2002</td>
</tr>
</tbody>
</table>

All observations in the present paper are sampled as time averages. If the time interval is less than one day it is called a grab sample in this paper. Some of the grab sample represents extreme events that may bias the statistical analysis. Of that reason we decided to filtered out the grab samples for estimation of statistical moments and simultaneous correlation-and cross correlations. MA-filtering was done twice: with and without grab samples.

There are significant lumped correlation coefficients between $SS$ and $Tot-P$ varying between 0.4 - 0.7, and between $q$ and concentration of $SS$ varying between absolute 3 values of 0.3 - 0.5. The memory 4 for $Tot-N$ varies between max. 65 days for the Kolstadbekken catchment to less than 10 days for the Naurstadbekken catchment. The memory for $Tot-P$ varies from approx. 65 days (Kolstadbekken) to less than 10 days (Naurstadbekken). Bi-yearly periodicity in runoff ($q$) is apparent for the inland catchments. For some catchments there are significant lag effects (> 180 days) between $q$ and $Tot-N$, and $q$ and $SS$ and a yearly periodicity for $Tot-N$ concentrations. The time series are too short to reveal any large scale periodicity of MA filtered data. In the following we discuss briefly the methods we applied, and we highlight some of the results presented above. For further details see Kitterød and Engeland (2004).

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1 The Grimestad brook in English
2 The Hotran canal
3 Note that one station: Volbubekken-Eik, has a negative correlation coefficient of -0.38 between (Tab.4)
4 here the memory denotes the time from $t = t_0, \ldots, t$ where the (auto) correlation coefficient $\rho(t) > 0.4$
Figure 1: Location of monitoring stations for the Agricultural Environmental Monitoring Programme in Norway (JOVA).

2 Method

The recorded data represents total runoff from the entire catchment, agricultural as well as non-agricultural land. In the present study we made no correction with respect to the fact that the fraction of agricultural to non-agricultural land varies from catchment to catchment. (Tab. 1). If the purpose is to estimate runoff from arable land only, a correction has to be implemented.

The time series recorded in the JOVA-program represent a methodological challenge: All observations $Y$ are sampled as time averages: $Y = \frac{1}{\Delta t} \int_{t}^{t+\Delta t} y dt$ where the sampling period $\Delta t$ usually is 1 - 3 weeks. In geostatistical terms this is called sample averages by variable support [Clarke, 1979; Journel and Huibregts, 1978]. This fact implies that all the average samples should be weighted with $\Delta t$. Here, this problem is partially evaded by filtering out samples with $\Delta t < 1$ day, refereed to as grab samples, and partially by applying a representative time average for each day. By having one $Y$ pr. day, each sampling period $\Delta t$ will automatically be given the correct weight. As a general rule $\Delta t$ is long if $q$ is low.

Another practical problem is observations equal to zero. In this study we interpret zero-value for SS, Tot-N and Tot-P as concentrations below the detection limit. These measurements are disregarded in calculating the lumped correlations and cross-correlations. The same is true for cases where no observations were made. We introduce gaps in the time series when we remove days of: i) no observations; ii) observations equal to zero; or iii) event samples. Gaps in the time series were filled in with the most resent value before MA-filtering; or calculation of auto- and the cross-correlation functions.

For convenience let us call the true processes $Y = \{q; SS; Tot - P; Tot - N\}_n$, where $q$ is specific runoff, SS is concentration of Suspended Solid, Tot-P is concentration of Total Phosphorous, and Tot-N is concentration of Total Nitrogen. The index $n$ indicate the different catchments ($n=1,...,7$ where: 1 = Grimestadbekken, 2 = Hotran kanalen, 3 = Kolstadbekken, 4 = Mørdrebekken, 5 = Naurstadbekken, 6 = Skuterudbekken, and 7 = Volubekken - Eik ). Recall that $Y$ is sampled as time averaged values with variable sampling period $\Delta t$. In the present study three similar time series were derived: the reduced (i); the filled (ii) and the complete (iii) time series.

For the reduced time serie $Y_r$, we removed: grab samples, zero values, and no observation. $Y_r$ was used for calculation of lumped statistics (simultaneous correlation coefficients and statistical moments). Thus different time support was neglected. For the filled time series $Y_f$, all gaps in $Y_r$, were filled in by the most resent observation. For the complete time series $Y_c$, grab samples, zero values, and no observation were included as it was recorded and stored in the database.
Histograms for \( X = \ln(Y_r) \) indicate that \( X \) is similar to a Gaussian probability density function. The simultaneous (or lumped) correlation and cross-correlation coefficients were calculated according to the standard equation:

\[
\rho(X_i, X_j) = \frac{\text{Cov}(X_i, X_j)}{\text{std}(X_i) \times \text{std}(X_j)},
\]

(1)

where \( i, j = 1, 2, 3, 4 \) indicating \( \ln(q), \ln(SS), \ln(Tot-P) \) and \( \ln(Tot-N) \).

Sample mean and standard deviation of \( X \) \( (E\{X\} = m_X \text{ and } \text{std}\{X\} = s_X) \) \( Y_r \) is a lognormal probability density function, then sample mean and standard deviation of \( Y_r \) are given by (Christakos, 1992):

\[
E[Y_r] = \exp \left( m_X + \frac{s_X^2}{2} \right),
\]

(2)

\[
\text{std}Y_r^2 = E[Y_r]^2 \left[ \exp \left( s_X^2 - 1 \right) \right].
\]

(3)

For each day \( t \), a moving average \( Y_a(t) \) is calculated according to:

\[
Y_a(t) = \frac{1}{2v + 1} \sum_{t' = -v}^{t + v} Y'(t'),
\]

(4)

where the window \( W = 2v + 1 \), and \( t = t_{\text{min}} + v, \ldots, t_{\text{max}} - v \). For example if \( v = 3 \) day, the MA-filter calculates an average value over \( W = 7 \) days. Here \( Y'(t) \) is equal to \( Y_f(t) \); \( Y_c(t) \); and \( Y_a(t) \).

Memory and periodicities are calculated according to:

\[
\rho(Y^*_i(t), Y^*_j(t')) = \frac{\text{Cov}(Y^*_i(t), Y^*_j(t'))}{\text{std}(Y^*_i) \times \text{std}(Y^*_j)},
\]

(5)

where \( i, j = 1, 2, 3, 4 \) and \( t \) is the total length of the time series, and \( t' \) is stepped forward with one day throughout the time series. If \( i = j \), we get the auto- correlation functions and if \( i \neq j \) we get cross-correlation functions. Here \( Y^* \) denotes firstly the filled timeseries \( Y_f \), and then secondly the MA-filtered time series \( Y_a \).

Because of the variable sampling period \( \Delta t \) the estimated memory \( Y_f \) has to be considered as maximum values of the real processes \( Y \). Normally, there is some variance during \( \Delta t \). For example if the sampling interval is constant \( \Delta t = P \) days, and the real memories of the processes \( Y \) are less than \( P \) days, the estimated memory of \( Y \) is estimated to be at least \( P \) days.

3 Results

In this section we highlight some main characters of the response functions. The auto- and cross-correlation functions give us an opportunity to span the the involved processes according to (i) memory and (ii) periodicity. The four extrem are visualized by a correlograms. The numbers 1:10 on the vertical axis of the correlogram indicate the auto- and cross-correlations between each time series as a function of time lag: 1 is auto-correlation of specific runoff \( (q:\ln(q)) \); 2 is cross correlation between specific and Suspended Solids \( (q:SS) \); 3 is cross correlation between specific runoff and of total Phosphorous \( (q:Tot-P) \); 4 is cross correlation between specific runoff and total Nitrogen \( (q:Tot-N) \); 5 is auto correlation of Suspended Solids \( (SS:SS) \); 6 is cross correlation between Suspended Solids and total Phosphorous \( (SS:Tot-P) \); 7 is cross correlation between Suspended Solids and total Nitrogen \( (SS:Tot-N) \); 8 is auto correlation of total Phosphorous \( (Tot-P:Tot-P) \); 9 is cross correlation between total Phosphorous and total Nitrogen \( (Tot-P:Tot-N) \); 10 is auto correlation of total Nitrogen \( (Tot-P:Tot-N) \).

3.1 Minimum memory - minimum periodicity

The Naurstadbekken catchment represents the first case: minimum memory - minimum periodicity. The catchment has very short memory (less than 10 days) and has virtually no periodicity (Fig. 2). This is consistent to a small catchment with coastal climate and relatively high permeable soils (Tab. 1). Note the low (lumped) correlation coefficients between \( q, Tot-P \); and \( Tot-N \) (Tab.2)
Table 2: Correlations coefficients $\rho$ for the Naurstadbekken catchment in upper triangular, and probabilities $P$ for significant correlations in lower triangular. $\rho$ is not significant if $P > 0.05$.

<table>
<thead>
<tr>
<th></th>
<th>$\ln q$ mm/d</th>
<th>$\ln SS$ kg/m$^3$</th>
<th>$\ln \text{Tot}_P$ g/m$^3$</th>
<th>$\ln \text{Tot}_N$ g/m$^3$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\ln q$</td>
<td>1.000000</td>
<td>0.341217</td>
<td>0.130343</td>
<td>-0.125484</td>
</tr>
<tr>
<td>$\ln SS$</td>
<td>0.000000</td>
<td>1.000000</td>
<td>0.524997</td>
<td>0.249731</td>
</tr>
<tr>
<td>$\ln \text{Tot}_P$</td>
<td>0.043220</td>
<td>0.000000</td>
<td>1.000000</td>
<td>0.610696</td>
</tr>
<tr>
<td>$\ln \text{Tot}_N$</td>
<td>0.051702</td>
<td>0.000089</td>
<td>0.000000</td>
<td>1.000000</td>
</tr>
</tbody>
</table>

Figure 2: Auto- and cross correlations as a function of time lag for the Naurstad catchment based on the filled time series ($Y_f$). The image indicate short memory and no periodicity in the time series.

3.2 Maximum memory - minimum periodicity

The second case is represented by the Hotran-kanalen catchment. The Hotran-kanalen drains the largest area of the JOVA catchments included in this study. Together with the relatively fine grained soils, this explains the relatively long memory of $\text{Tot}_N$ and $\text{Tot}_P$, $\sim 40$ days with $\rho > 0.4$ for $\text{Tot}_N$ and $\sim 20$ days of $\text{Tot}_P$ (Fig. 3). The climate has a coastal component, which explains the minor regularity of the response functions. The lumped correlation coefficients for the Hotran-kanalen shows a strong relation between SS and $\text{Tot}_P$, $\rho \sim 0.8$ (Tab.3).

Table 3: Correlations coefficients $\rho$ for the Hotran-kanalen catchment in upper triangular, and probabilities $P$ for significant correlations in lower triangular. $\rho$ is not significant if $P > 0.05$.

<table>
<thead>
<tr>
<th></th>
<th>$\ln q$ mm/d</th>
<th>$\ln SS$ kg/m$^3$</th>
<th>$\ln \text{Tot}_P$ g/m$^3$</th>
<th>$\ln \text{Tot}_N$ g/m$^3$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\ln q$</td>
<td>1.000000</td>
<td>0.512851</td>
<td>0.335502</td>
<td>0.115717</td>
</tr>
<tr>
<td>$\ln SS$</td>
<td>0.000000</td>
<td>1.000000</td>
<td>0.775009</td>
<td>0.182099</td>
</tr>
<tr>
<td>$\ln \text{Tot}_P$</td>
<td>0.000001</td>
<td>0.000000</td>
<td>1.000000</td>
<td>0.246338</td>
</tr>
<tr>
<td>$\ln \text{Tot}_N$</td>
<td>0.102739</td>
<td>0.009859</td>
<td>0.000438</td>
<td>1.000000</td>
</tr>
</tbody>
</table>
Figure 3: Auto- and cross correlations as a function of time lag for the Hotran catchment based on the filled time series ($Y_f$). A weak seasonal periodicity may be seen for the concentrations of total Nitrogen.

3.3 Minimum memory - maximum periodicity

The Volubekken (Eik) catchment represents the third case. This is the most characteristic catchment in this study. The lumped correlation coefficients have significant weak negative correlation between $q$ and $SS$ ($\rho \sim -0.4$) and $q$ and $Tot-P$ ($\rho \sim -0.3$, Tab.4). The strongest relation exists between $SS$ and $Tot-P$.

Table 4: Correlations coefficients $\rho$ for the Volubekken catchment in upper triangular, and probabilities $P$ for significant correlations in lower triangular. $\rho$ is not significant if $P > 0.05$.

<table>
<thead>
<tr>
<th></th>
<th>ln q $mm/d$</th>
<th>ln SS $kg/m^3$</th>
<th>ln Tot_P $kg/m^3$</th>
<th>ln Tot_N $kg/m^3$</th>
</tr>
</thead>
<tbody>
<tr>
<td>ln q</td>
<td>1.000000</td>
<td>-0.382115</td>
<td>-0.274710</td>
<td>0.117531</td>
</tr>
<tr>
<td>ln SS</td>
<td>0.000000</td>
<td>1.000000</td>
<td>0.714184</td>
<td>0.082301</td>
</tr>
<tr>
<td>ln Tot_P</td>
<td>0.0000001</td>
<td>0.000000</td>
<td>1.000000</td>
<td>0.252989</td>
</tr>
<tr>
<td>ln Tot_N</td>
<td>0.041926</td>
<td>0.155041</td>
<td>0.000009</td>
<td>1.000000</td>
</tr>
</tbody>
</table>

The Volubekken catchments has more memory than the Naurstadbekken catchments ($\sim 55$ days of memory for $Tot-P$ and $Tot-N$ time series, and $\sim 20$ days for $SS$ and $q$), but the most significant result is the strong yearly and bi-yearly periodicity in $q$. This is due to the inland climate and high altitude of this catchment. Both factors indicate to the importance of snow and frozen ground in this catchment. The cross-correlation functions indicate a time lag between $q$:SS ($\sim 40$ days), $q$:Tot-P ($\sim 40$ days), $q$:Tot-N ($\sim 20$ days) (Fig. 4).

3.4 Maximum memory - maximum periodicity

The fourth case is represented by the Kolstadbekken catchment. The Kolstadbekken has not as clear periodicity as the Volubekken catchment, but Kolstadbekken has most memory of the studied catchments. The periodicity is due to the
Figure 4: Auto- and cross correlations as a function of time lag for the Volubekken catchment based on the filled time series ($Y_f$). A strong bi-yearly periodicity is seen in the specific stream runoff and a weaker yearly periodicity for the concentrations of total nitrogen. There is also a significant time lag between specific stream runoff and concentrations of suspended solids and total phosphorous, but less time lag between specific stream runoff and concentrations of total nitrogen.

inland climate. The significant memory is probably due to low permeable sediments. The highest lumped correlation coefficient is between SS and Tot-P ($\rho \sim 0.7$, Tab.5). The auto correlation for the time series indicate a memory of $\sim 20$ days for $q$ and SS, while Tot-P and Tot-N has memory $> 60$ days for. The specific runoff ($q$) for the Kolstadbekken catchment shows a clear bi-yearly periodicity. This periodicity is also revealed in the cross correlations between $q$:SS, $q$:Tot-P, $q$:Tot-N (Fig. 5).

Table 5: Correlations coefficients $\rho$ for the Kolstadbekken catchment in upper triangular, and probabilities $P$ for significant correlations in lower triangular. $\rho$ is not significant if $P > 0.05$.

<table>
<thead>
<tr>
<th></th>
<th>ln Q (mm/d)</th>
<th>ln SS (kg/m³)</th>
<th>ln Tot_P (g/m³)</th>
<th>ln Tot_N (g/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ln Q</td>
<td>1.000000</td>
<td>0.326621</td>
<td>0.226887</td>
<td>0.416999</td>
</tr>
<tr>
<td>ln SS</td>
<td>0.000000</td>
<td>1.000000</td>
<td>0.707087</td>
<td>0.037100</td>
</tr>
<tr>
<td>ln Tot_P</td>
<td>0.000001</td>
<td>0.000000</td>
<td>1.000000</td>
<td>-0.111678</td>
</tr>
<tr>
<td>ln Tot_N</td>
<td>0.000000</td>
<td>0.430351</td>
<td>0.017292</td>
<td>1.000000</td>
</tr>
</tbody>
</table>

3.5 Transport of Total Phosphorous

One of the main environmental problems in Norway are related to transport of phosphorus and eutrophication of lakes (Bechmann et al., 2005). Most of the phosphorous are usually adsorbed on sediments, and transported in the solid phase. That means that SS and Tot-P is correlated. This is clearly seen in most of the Jøva catchments, and the runoff curves for the Kolstad catchments may serve as an example (Fig. 6).
In the Naurstadbekken catchment there is another transport process taking place. In periods with low $q$ there is an increase of Tot-$P$ and vice versa (Fig. 7). The fluctuations is apparently independent of Tot-$P$. The Naurstadbekken catchment is the northmost catchments in this study, the climate is coastal, and the organic content of the soil is very high. The most likely mechanism is release of phosphate during periods of frost. Unlike most of the Tot-$P$, phosphate is transported in the liquid phase.
Figure 7: Moving average (MA) filtering of the complete time series $Y_c$ for the Naurstad catchment. The moving window ($W$) is 365 days. Note the significant fluctuations in the MA-filtered time series for the specific stream runoff ($q$) and the concentrations of total phosphorus, which is not associated with any fluctuations in the concentrations of suspended solids (SS).

**Discussion and further analysis**

The general high simultaneous correlation coefficients between SS and Tot-P indicate the most important transport mechanism of phosphorous, namely transport in the solid phase. There are some exceptions from this general pattern, most clearly seen in the Naurstadbekken time series. From 1999 there are significant fluctuations in Tot-P concentrations, but a similar signal is not recorded in the SS time series. The hydrological and the geochemical conditions for the apparent shift in the transport process should be investigated in more detail.

In previous studies, the climatic pattern of the different JOVA catchments is characterized, and some of the recorded trends and fluctuations are obviously connected to the climatic variables (Eggestad, 2003). Before starting extensive physical modeling of the recorded time series it would be useful to explore the connections to the climatic variables as precipitation and temperature. One hypothesis that should be tested is the impact of freezing and thawing on transport of Tot-P. In the present study we have not included variables expressing changes of the agricultural practice for the different catchments. Efforts are made to implement such variables for a future JOVA-study where also climatic timeseries are included.

The significant spreading (variance) in all the processes involved in this study indicate strong stochastic components. The randomness is partly due to the natural heterogeneity of the soil and the variable character of the Norwegian climate. In addition there is also a random component in the agricultural practice in each catchment. These stochastic components should be included in future physical modeling of the processes in the JOVA catchments in order to understand runoff of SS, Tot-P and Tot-N.
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