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Phosphorus losses from the Mørdre catchment

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Dominika Krzeminska, Marianne Bechmann
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FORFATTER(E)/AUTHOR(S)
Dominika Krzeminska og Marianne Bechmann

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Phosphorus, drainage, agriculture, grain areas, erosion, soil loss	Sediment and phosphorus losses, environmental monitoring

SAMMENDRAG/SUMMARY:

Mørdre nedbørfelt er en del av Program for jord- og vannovervåking i landbruket (JOVA) som rapporterer årlig om jordbruksdrift, avrenning og tap av partikler, næringsstoffer og plantevernmidler. I perioden fra 2010 til 2016 ble det observert de høye tap av fosfor i Mørdre-feltet. Denne rapporten presenterer en analyse av en lang tidsserie av observerte data for avrenning, suspendert sediment og fosfor tap som tar sikte på å undersøke årsakene til høye fosfortap samt eventuelt identifisere en permanent endring. Utfordringen er: (1) tidsavhengighet, (2) sammenkobling mellom prosessene i nedbørfelt og (3) nøyaktig informasjon om all aktiviteter i nedbørfeltet. Disse kan ikke identifiseres direkte fra gjeldende datasett. Forfattere identifiserte komplementære målinger og / eller tiltak som tar sikte på å undersøke og forstå vannets veier og transportprosesser for sediment og næringsstoffer i nedbørfeltet, og omfatter undersøkelser koblet til ekstreme hendelser.

The Mørdre catchment is a part of the Norwegian Agricultural Monitoring Programme (JOVA) that records and reports on farming practices and the extent of erosion and nutrients and pesticides losses. During the six-year period, from 2010 to 2016, high losses of phosphorus were observed in the Mørdre catchment. This report presents an analysis of long-term changes in runoff, suspended sediment and phosphorus losses that aim to investigate the reasons for the identified extremes as well as potential permanent shifts. The challenge is: (1) time dependencies, (2) interconnection between the processes within the catchment and (3) the exact information about all human activities within the catchment. These cannot be directly identified from the current data set. The authors identified complementary measurements and/or actions aiming to investigate and understand the water, sediment and nutrient

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pathways within the catchment as well as capturing the unusual behaviours connected to extremes events.

LAND/COUNTRY:	Norge
FYLKE/COUNTY:	Akershus
KOMMUNE/MUNICIPALITY:	Nes
STED/LOKALITET:	Mørdre

GODKJENT /APPROVED	**PROSJEKTLEDER /PROJECT LEADER**
Stolte	Marianne Bechmann
JANNES STOLTE	**MARIANNE BECHMANN**

Preface

The Mørdre catchment is part of the Norwegian Agricultural Environmental Monitoring programme (JOVA).

During the period from 2012/2013-2015/2016 high losses of phosphorus has been registered at Mørdre catchment. This report presents data analyses that was initiated in order to improve our understanding of the cause-relationship of the high losses during these years.

Ås, 04.01.19

Marianne Bechmann

Innhold

1 Introduction

1.1 Pathways for phosphorus transport from agricultural areas to the stream

Water reaches stream and rivers directly via rainfall and indirectly by: (1) water passing over the land surface, i.e. surface runoff, (2) piped drainage systems installed on farmed land to remove excess water or (3) through intermediate horizontal runoff from the soil profile. On naturally drained land water seeps vertically through the soil until it meets an impermeable layer, it then moves sideways until it discharges as a spring or though the drainage systems.

The amount and quality of the water reaching a stream (i.e. total phosphorus (TP), suspended sediment (SS), etc.), depends on many criteria such as precipitation, hydrology, geology, topography and land use. Nutrients can be lost from land to water in various ways: (1) in eroded soil (sliding stream banks, gully erosion); (2) in surface runoff which can carry fine particles of soil, organic material and nutrients in solution (sheet erosion); (3) in water which, while percolating through the soil to drains has dissolved soluble nutrients or detached soil particles from macropores in the soil; (4) in water from municipalities, industries and storm water discharged into sewers.

Phosphorus loss from agriculture land can come from both point and diffuse sources. Point sources include wastewater from farms and dairies and seepage from manure stores. Diffuse sources of phosphorus are a consequence of soil erosion, surface runoff and drainage.

Soil erosion can be caused by wind and rainfall and either detaches mineral and organic particles from the body of the soil. Surface runoff may carry nutrients, including phosphorus bound to mineral soil particles, in inorganic phosphorus compounds and in organic matter. The concentration of phosphorus in water percolating through the soil to drains and springs is usually very small as phosphorus is bound to soil particles (Kværnø and Bechmann 2010), especially in the top cultivated soil layer. However, cracks, channels and manholes allow some phosphorus to by-pass the soil filter and enter directly into drains.

Surface erosion is imposed by the soil texture and thus the particle size distribution of the soil. The small size soil particles (clay and silt) are more easily transported with the flowing water. Moreover, the small particles have larger surface area with higher holding capacity of nutrients such as phosphorus. Therefore, eroded sediments can contain more fine particles (clay and silt) and higher total phosphorus (TP) content compared to the original surface soil (Øygarden, 2000; Zhang et al., 2011).

1.2 JOVA programme

The Norwegian Agricultural Environmental Monitoring programme (JOVA - programme) is a national programme for soil and water monitoring in agriculture dominated catchments in Norway that started in 1992. The purpose of JOVA - programme is to document the impact of agriculture on water quality as well as the effect of changes in agricultural practices and implementation of mitigation measures. The JOVA - programme catchments represent the most important agricultural areas in the country with regard to climate, soil and management practices. The runoff from the JOVA catchments is measured continuously and flow proportional water samples are taken for analysis of nutrients and soil particles from all catchments throughout the year. Information on agricultural management is obtained either from the farmers or from Statistics Norway. The monitoring data are regularly published in form of annual reports (e.g. Brod, 2018) concentrating on particular catchments as well as summary reports (e.g Bechmann et al., 2017) describing general trends observed within JOVA - programme catchments.

1.3 The purpose of the report

The Mørdre catchment is part of the JOVA - programme. The Mørdre catchment experienced high losses of phosphorus over a six year period from 2010 to 2016. The the average annual phosphorus loss from Mørdre catchment is 340 g/daa with all the above average annual losses registered after agro hydrological year 2010/2011.

The purpose of this report is to perform additional data analysis in order to improve our understanding of the cause-relationship of the high losses during these years.

2 Methods and material

2.1 Mørdre catchment

The Mørdre catchment is 68 km^2 large with 65 % agricultural land and it is situated in northern Akershus. More details is shown in the table 1, adapted from Brod (2018).

Table 1: Main characteristics of Mødre catchment (Brod, 2018)

Location:	Nes commune, Akershus
Area:	6.8 km 65% of agricultural land (44400 ha) Crops: grain, some potatoes, meadow and pasture as well as turf grass.
Soil type: Topography:	Silt and clay Undulating landscape with ravines along the stream 130-230 m a.s.l.
Climate:	Continental 665 mm yearly precipitation

2.2 Monitoring of Mørdre catchment

The Mørdre catchment is part of the JOVA - programme. The runoff from the Mørdre catchments is measured continuously and flow proportional water samples are taken every c.a. 14 days and send for analysis of nutrients, soil particles and pesticides (during the growing season). Information on agricultural management is obtained either from the farmers or from Statistics Norway. The standard laboratory analysis to assess nutrient loss and soil erosion includes pH, suspended solids (SS), total phosphorus (TP), dissolved reactive phosphorus (DRP), total nitrogen (TN) and nitrate (NO_3). The analytical methods used to assess pesticide loss include GC Multi-M60, GC/MS Multi-M15 and LC-MS/MS Multi M91 (from 2011), and cover a total of 112 pesticide active ingredients and primary metabolites. Only SS, TP and DRP are reported here.

3 Analysis of available data

3.1 Initial analysis

The average annual losses of TP during the years 2010/2011 to 2015/2016 (372 - 846 g/daa of agricultural land) were much higher compared to the former monitoring period (100- 364 g/daa) (Figure 1).

For suspended sediment (SS) the corresponding trend is not obvious and the absolute values for SS are not much higher during studied period (176-390 kg/daa for year 2010/2011-2015/2016) in comparison with observation from previous years (111-421 kg/daa) (Figure 1).

Figure 2 shows the ratio between particulate phosphorus (PP) and SS. PP is calculated as difference between TP and dissolved reactive phosphorus (DRP) (PP =TP-DRP). While a significant change can be see for PP/SS trend after the year 2009, no change is observed for the DRP/TP trend.

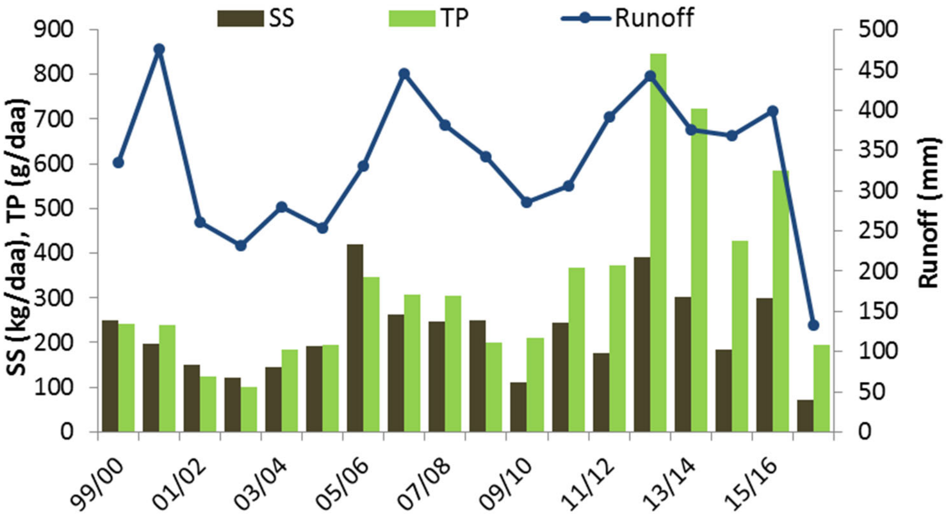

Figure 1. Runoff (mm) and losses of total phosphorus (TP) (g) and suspended sediment (SS) (kg) per dekar of agricultural land in the Mørdre catchment (Brod, 2018).

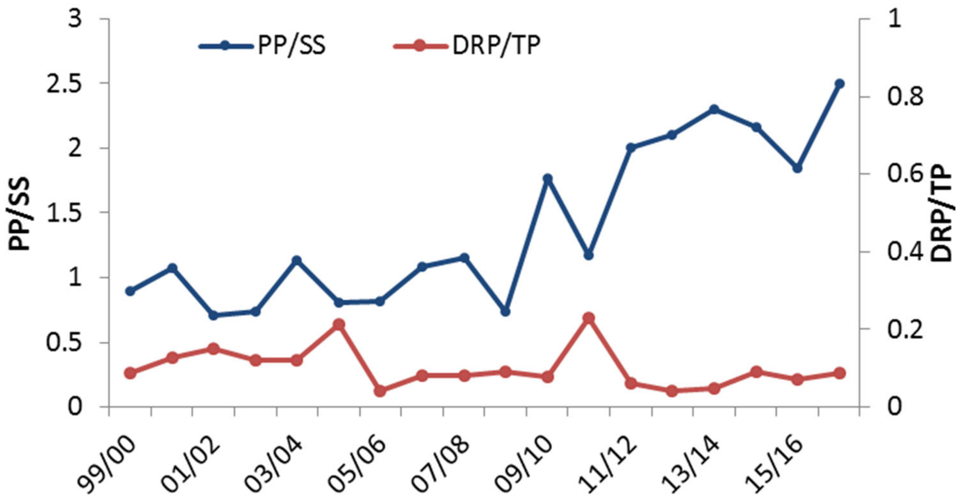

Figure 2. **Development of the ratio of particulate phosphorus (total phosphorus (TP) minus dissolved reactive phosphorus (DRP) and suspended sediment (SS), and dissolved reactive phosphorus (DRP) and total phosphorus (TP) (Brod, 2018).**

Based on the data from Figure 1 and Figure 2 we can list the following statements that form the base for further analysis of runoff and nutrients losses from Mørdre catchment:

- there is a strong increase in TP losses in the period from 2012/2013-2015-2016.
- there is an increase in PP losses in the period from 2010/2011 to 2015/2016,
- the upward trend in runoff is not sufficient to explain the increased PP in this period.
- the SS losses have remained at about the same level with annual variations.

3.2 Long-term trends and dependences in measured parameters at Mørdre catchment

The Figure 3 shows that there is no change in the relationship between runoff and SS, whereas there is a change in the slope of the relationship between TP and runoff. This means that there is no trend in SS concentrations over the period whereas there is a trend in TP losses with a change from May 2010.

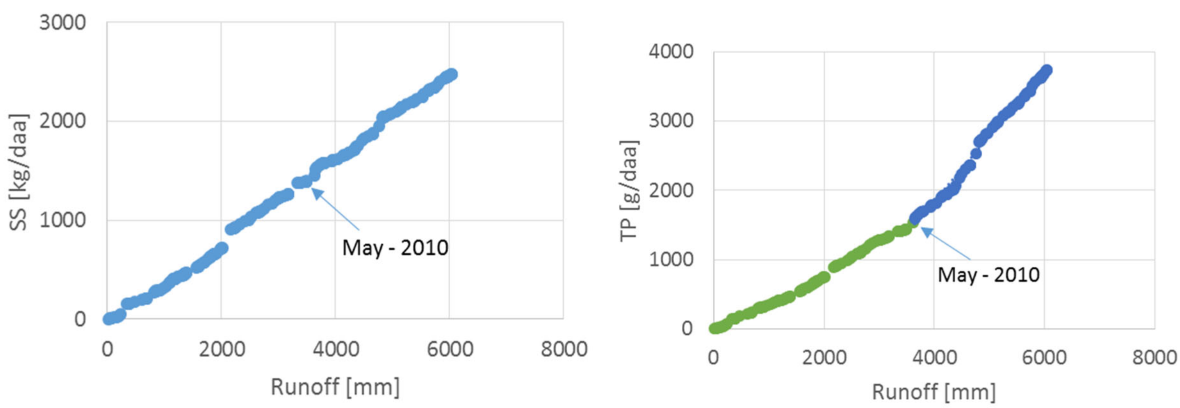

Figure 3. **The amount of suspended sediment (SS) (kg/daa) and total phosphorus (TP) (g/daa) in relation to observed runoff (mm) presented in the form of accumulation graph with monthly time step.**

Figure 4 shows the development of several relationships between parameters measured at the Mørdre catchment outlet. One can see the increasing trend in the relationship between TP and SS (blue line), corresponding to the trend in PP/SS in Figure 2, while there is only a slight increase in the trend in the relationship between TP and runoff (green line). On the other hand, the relationship between DRP and TP (yellow line) shows slightly decreasing trend, if the two maximum picks (2004/2005 and 2010/2011) are excluded. This indicates an increase in the total amount of particulate phosphorus (PP) transported by the same amount of sediment (Figure 5).

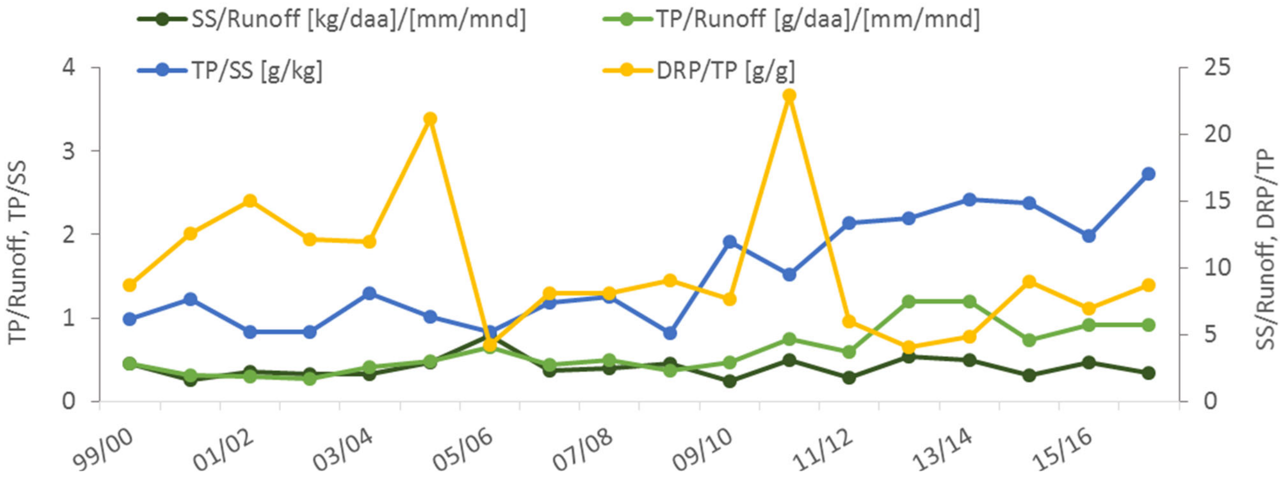

Figure 4. **Development of the relationships between suspended sediment (SS) and runoff, total phosphorus load (TP) and runoff, total phosphorus load (TP) and suspended sediment (SS), and dissolved reactive phosphorus (DRP) and total phosphorus (TP).**

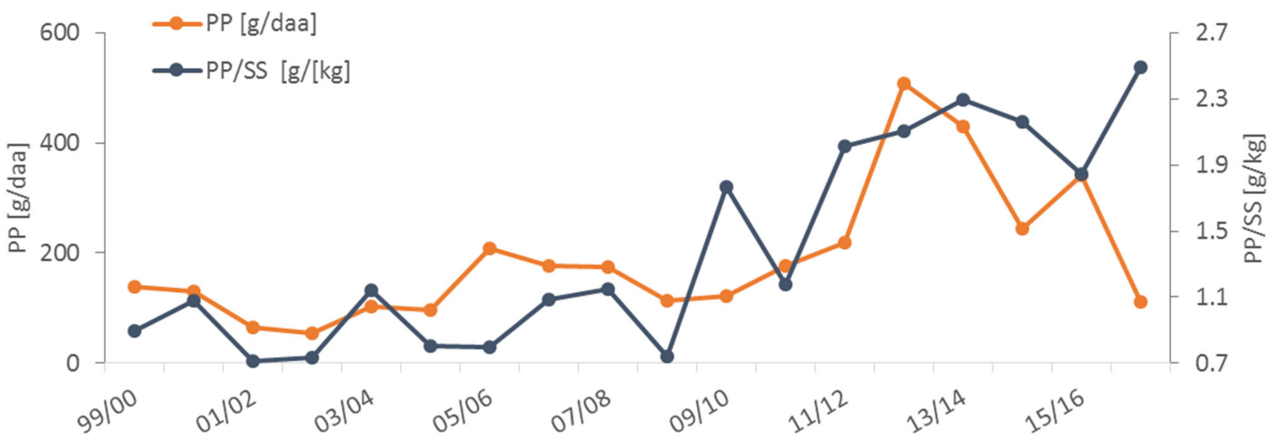

Figure 5. **Yearly loses of particular phosphorus (PP) and development of the relationships between particular phosphorus (PP) and suspended sediment (SS).**

3.3 Seasonality analysis

Figure 6 present the parameters measured at Mørdre with the distinction between the seasons within the agro-hydrological year. From the year 2010/2011 one can see the clear change in the runoff distribution, followed by changes in distribution of SS and TP losses: an increase in runoff, SS, TP, PP during the growing seasons (May – Sept) in comparison to previous years (1999/2000 – 2009/2010).

The only exception is year 2014/2015 where there was almost no runoff during the growing season and consequently marginal SS and no TP loses.

Figure 7 shows the relationships between DRP and TP, TP/SS and PP/SS taking into account division into seasons. Again, in year 2010/2011 we can observe changes in the behaviour of both relationships:

(1) The general contribution of DRP in TP decreased with the year 2010/2011 onwards

(2) The overall relation between TP and SS changes indicates that the same amount of SS transport more TP.

(3) There is no clear pattern for the behaviour of TP/SS relationship within agro-hydrological years.

The high losses of DRP in 2010/2011 occurs due to a runoff event in May after sowing and fertilizer application.

Figure 8 presents the average monthly concentrations of TP (µg/L), SS (mg/L) and corresponding runoff intensity (mm/h). It is clearly visible that from the agro-hydrological year 2010/2011 there is more variation in measured concentrations of TP within single year with more often occurrence of extreme concentrations (>1500 µg/L). The concentrations of SS is not changing significantly. However, there are few months with extremes observed in SS concentration: May and July 2010, June 2012, May 2013 and August 2015. In majority of cases, the extreme SS concentrations correspond to extreme TP concentrations (observed either in the same month or in the following month). However, there are months with relatively low SS concentrations but high TP concentrations, e.g.: July 2011, March, April, December 2013, March, July, August 2014 and February, March 2016.

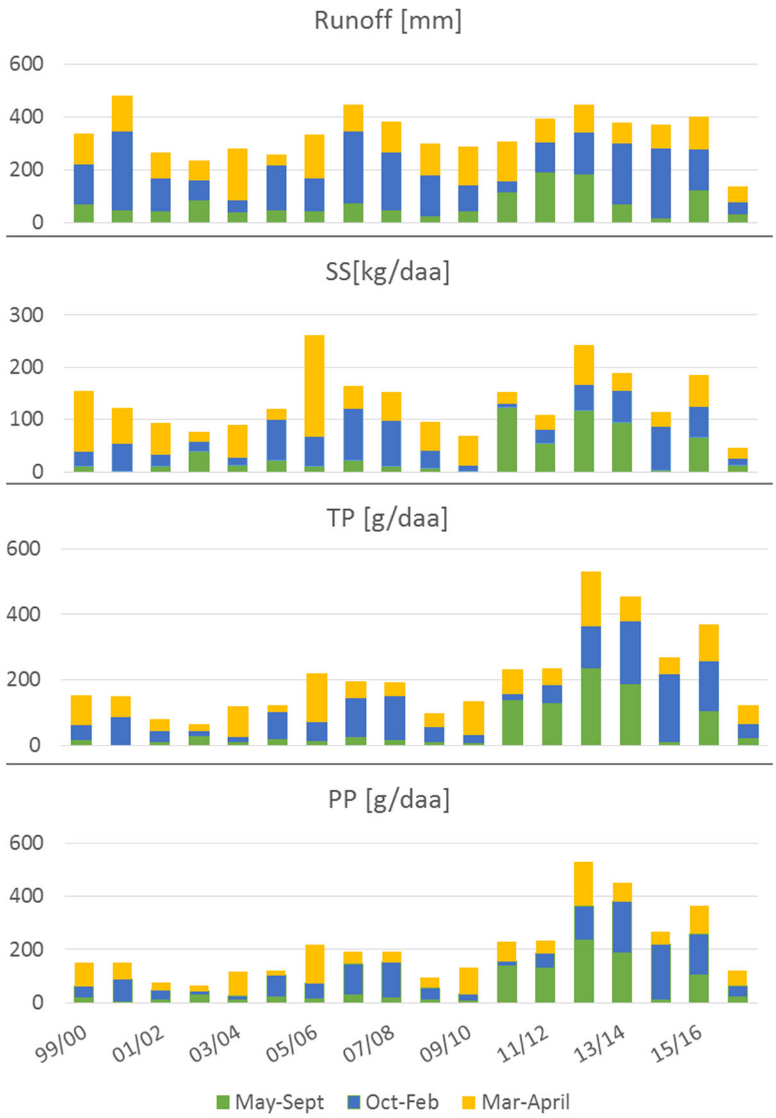

Figure 6. Yearly data on runoff (mm), suspended sediment (SS) (kg/daa), total phosphorus (TP) (g/daa) loses and particulate phosphorus (PP) losses measured at the outlet of Mørdre catchment showed with the breakdown for seasons: May – September - growing season (green), October – February – autumn/winter season (blue), Mars-April – spring (yellow).

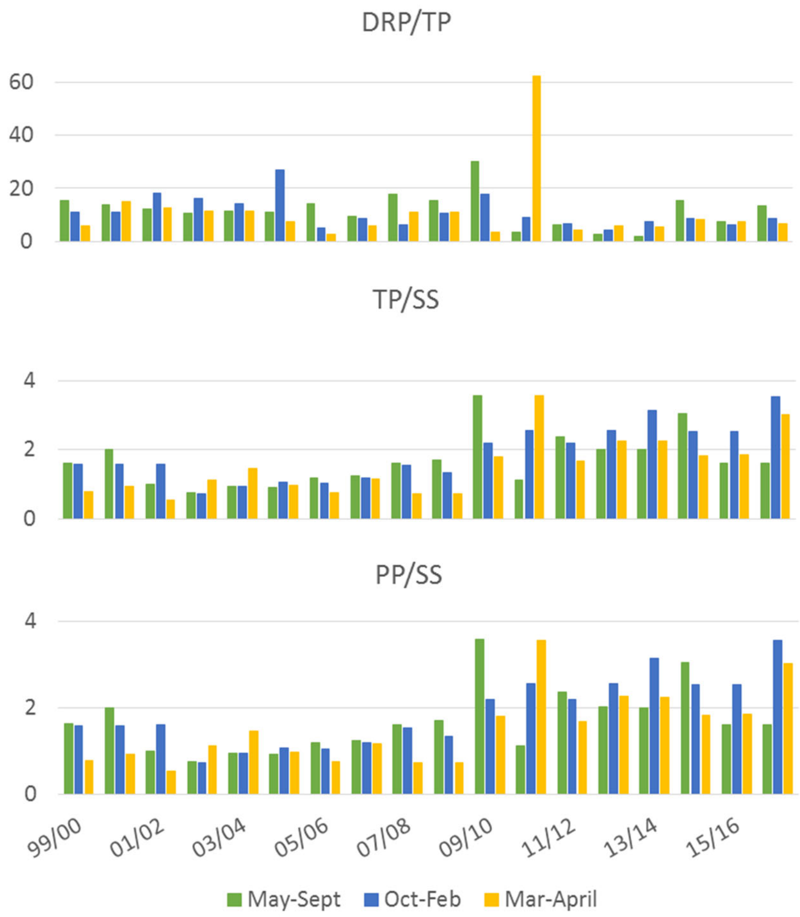

Figure 7. **The relationship between losses of a) dissolved phosphorus (DRP) (g/daa) and total phosphorus (TP) (g/daa), b) total phosphorus (TP) (g/daa) and suspended sediment (SS) (kg/daa) and c) particulate phosphorus (PP) (g/daa) and suspended sediment (kg/daa) with the breakdown for seasons: May – September - growing season (green), October – February – autumn winter season (blue), Mars-April – spring (yellow).**

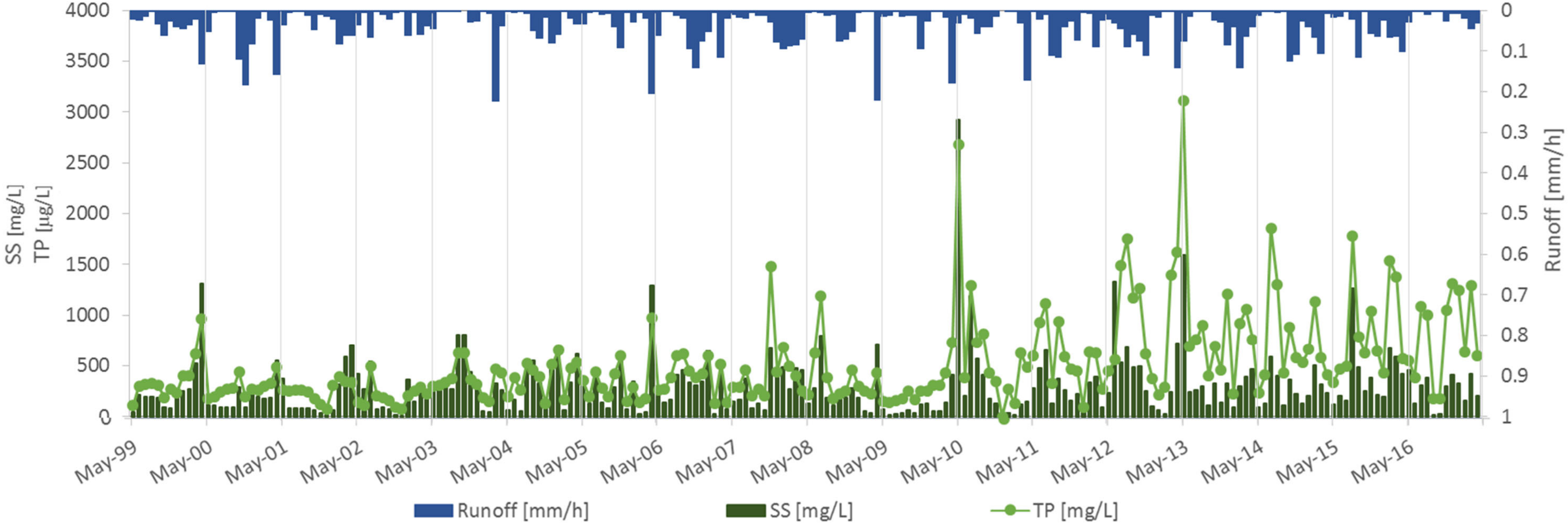

Figure 8. **Monthly averaged concentrations of suspended sediments (SS) and total phosphorus (TP) losses and corresponding runoff conentrations.**

4 Disscusion

Based on currently available monitoring data (JOVA), it is possible to elaborate on following possible explanation of the observed increased in the total phosphorus losses (TP) from Mødre catchment:

- Changes in precipitation, and consequently runoff patterns

Based on Figure 1 and Figure 5 the general pattern of total phosphorus loses (TP) follows the pattern of measured: low in 2009/2010, increasing from the year 2010/2011 until 2012/2013 and slowly decreasing in following year, with exception of 2015/2016. However, it is necessary to stress that the increase in runoff and suspended sediments is less extreme in comparison with observed increase in total phosphorus (TP) concentration.

It is interesting to see that similar pattern in both runoff and total phosphorus (TP) losses is observed in Skuterud catchment as well, while there is no change in the long term trend of PP/SS relationship (Figure 9). This confirms that when looking at long term monitoring data (JOVA) in order to interpret observed hydrological and hydrochemical patterns one need to account for more global changes in weather conditions, including precipitations patterns and intensities, snow cover, temperature, freezing and thawing cycles etc. as well as more detailed information about agricultural management.

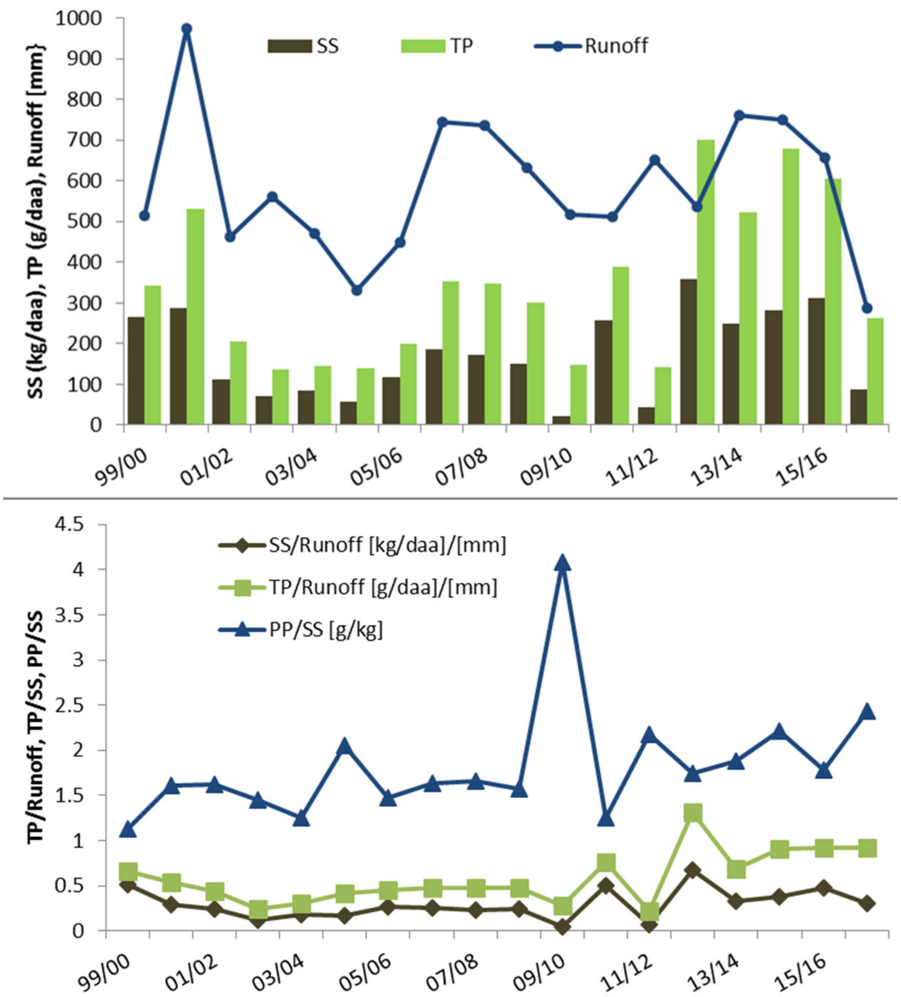

Figure 9. (Upper) Runoff (mm) and losses of total phosphorus (TP) (g) and suspended sediment (SS) (kg) per dekar of agricultural land in the Skuterud catchment (Deelstra, 2018); (lower) Development of the relationships between suspended sediment (SS) and runoff, total phosphorus load (TP) and runoff amd particulate phosphorus (PP) and suspended sediment (SS).

- Timing of precipitations (runoff) and agricultural activities.

The important aspect that may significantly influence surface erosion, and so concentration of SS and TP observed in agricultural dominated catchments, is the timing of precipitation and ploughing and/or application of fertilisers. Heavy rainfall can mobilize cropland soil particles. When uncovered farmland (just after ploughing) is exposed to heavy rainfall, erosion processes results in the loss of the fertile, organic matter rich soils that are indispensable for crop yields, while at the same time the nutrients and pollutants bound to soil particles are deposited in nearby waterbodies and ecosystems. For example, this situation was observed on May 2010 in Mørdre catchment (see Figure 10) and can be an explanation for high concentrations of TP observed during this period (Figure 1).

Figure 10. Mørdre catchment, May 2010 (Photo: Stine Vandsemb)

- Changes in the land management within the catchment

Figure 11 shows the changes in the land use and land management within Mørdre catchment. In the 2010 – the year when we see changes in TP and TP/SS behaviour (Figure 3 and 4), there are no particular changes in land management that could be directly connected to the increased losses of PP total phosphorus (TP) or to change in the relation between total phosphorus losses and suspended sediments (TP/SS). However in the following years, from 2012 onwards once can observe two main changes: 1) decreased of the percentage of the agricultural area covered with stubbles as a consequence of autumn ploughing 2) increases of the agricultural area used for the TURF-grass. The autumn ploughing and lack of stubbles could increase the surface erosion as shown in plot studies (ref) since the same amount and intensity of precipitation could mobilise and transport more soil particles into the stream. Increase in TURF-grass can have twofold influence. First, the TURF-grass needs more weekly fertilisation meaning continuous application of phosphorus in the area. Second, when the grass is removed, relatively large areas of land is left with bare soil – in connection with intense precipitation it can contribute to increase of observed surface erosion.

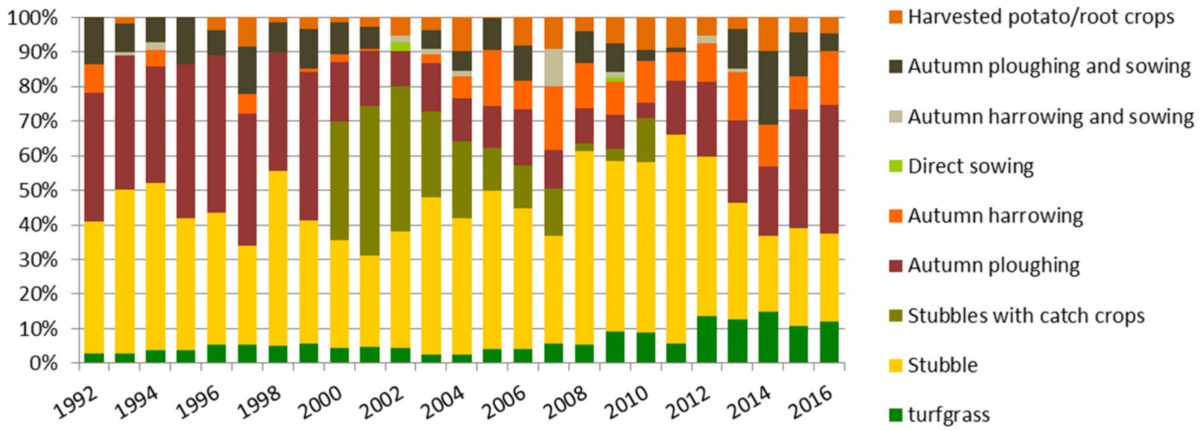

Figure 11. Land mangement (as per 31 December) reported for agricultural areas witihn Mørdre catchment in the years 1992-2016 (Brod, 2018).

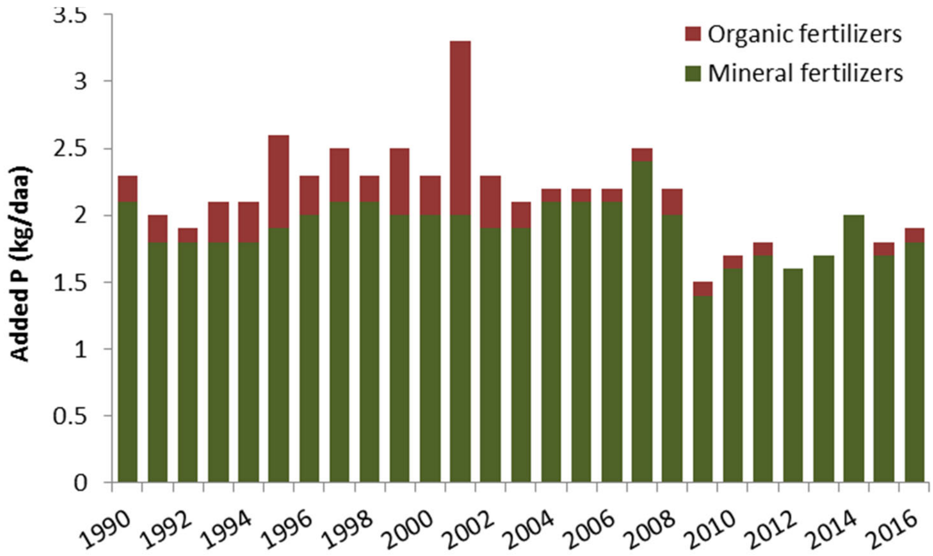

Figure 12. Total P fertilizer application in Mørdre catchment (Brod, 2018)

When considering the changes in the land management, one should also look at the total P fertilizer application. This may give an idea of the changes in the amounts of applied phosphorus fertilizes. However, in case of Mødre catchment the decreasing trend in the total phosphorus fertilizer application does give direct explanation of the TP and PP behaviour (Figure 12).

- Investments in or renovation of hydrotechnical measures

In 2009 and 2010, there was a renovation of hydrotechnical measures done in some farms within Mødre catchment. The renovation of hydrotechnical solutions aimed to prevent gully erosion and it involved mostly building new or restoring old manholes and cleaning of the drainage system. This action can be linked to a shift from earlier influence of gully erosion (coarser sediment) more to sheet erosion (finer sediment).

Figure 13. Restored manholes in Mørdre (photo: Stine Vandsemb)

Indeed, several studies have shown that phosphorus is primarily adsorbed to soil particles in the upper surface soil layers and that surface area can be used as a reasonable proxy for phosphorus sorption (Al-Kanani and MacKenzie 1991; Wang et al. 2001). Small suspended sediments in particular can be enriched in phosphorus due to the preferential erosion and mobilization of fine particles from surface soils (Massey and Jackson 1952; Sharpley 1980).

5 Conclusions

Monitoring data from the JOVA-programme gives information on the hydrological and hydro - geochemical catchment behaviour. This gives a possibility to observe long-term patterns of both runoff and nutrient losses, and elaborate on possible explanations of changes and/or extremes.

The studies of trends in phosphorus losses from the Mørdre catchment showed elevated losses of total phosphorus (TP) during 6 years from 2010/2011-2015/2016, while soil losses (SS) and dissolved reactive phosphorus (DRP) remained at about the same level with annual variations. This indicates that the increase in phosphorus losses are mainly in the form of particulate phosphorus (PP). The increase in annual phosphorus losses (TP, PP) is valid for almost all months except the period of snow melting. Previously (period from 1999/2000 to 2009/2010), the period of snowmelt was the most important period of phosphorus loss. From the year 2010/2011 there is a strong increase in phosphorus losses observed during the growing season (May-September). The corresponding increase is observed in the runoff from Mørdre catchment, however it is not is not sufficiently high to explain the increased phosphorus losses in Mørdre. This suggests that there may be agronomic causes of the upward trend in phosphorus loss, but this is not yet fully understood. While some extremes can be explained quite easily, for example the particularly high phosphorus loss in May 2010 and 2013, due to high runoff after sowing and fertilization, others have no unique explanations and can be the effect of several actions, , e.g. decrease of the area covered with stubbles, increase in turf grass production or/and (improvement of) hydrotechnical measures .

The challenge is the relationship between weather conditions and agricultural practices (e.g. precipitation vs sowing and fertilization, location of hydrotechnical measures within the catchments etc) as well as interconnection between the processes within the catchment (e.g. installing manholes reduced surface runoff but allow some phosphorus to by-pass the soil filter and enter directly into drains). Therefore, there is a need to identify complementary measures and/or actions that should be introduced either directly to the framework of JOVA - programme or as a recommended/obligatory additional. These measures should aim to investigate and understand the water and sediment pathways within the catchments as well as capturing the unusual behaviours connected to extremes events. This could be achieved with:

- Continuous visual observation of the area with the use of fixed cameras;
- Intensify monitoring in time and space including the use of sensors to identify short-term changes in concentrations in response to changes in runoff;
- Hydrological (scenario) modelling of monitored catchments.

One need to be aware that setting up hydrological model has to precede with:

- Investigation of the available models, depending on the needed input parameters as well as expected model outputs;
- Selection of the most suitable model for the area and for investigation purposes;
- Performing addition measures/collecting information needed for model parametrisation.

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Etterord

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Key words:	Runoff from small agricultural catchments, sediment and phosphorus losses
Andre aktuelle publikasjoner fra prosjekt:	www.nibio.no/jova

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Norsk institutt for bioøkonomi (NIBIO) ble opprettet 1. juli 2015 som en fusjon av Bioforsk, Norsk institutt for landbruksøkonomisk forskning (NILF) og Norsk institutt for skog og landskap.

Bioøkonomi baserer seg på utnyttelse og forvaltning av biologiske ressurser fra jord og hav, fremfor en fossil økonomi som er basert på kull, olje og gass. NIBIO skal være nasjonalt ledende for utvikling av kunnskap om bioøkonomi.

Gjennom forskning og kunnskapsproduksjon skal instituttet bidra til matsikkerhet, bærekraftig ressursforvaltning, innovasjon og verdiskaping innenfor verdikjedene for mat, skog og andre biobaserte næringer. Instituttet skal levere forskning, forvaltningsstøtte og kunnskap til anvendelse i nasjonal beredskap, forvaltning, næringsliv og samfunnet for øvrig.

NIBIO er eid av Landbruks- og matdepartementet som et forvaltningsorgan med særskilte fullmakter og eget styre. Hovedkontoret er på Ås. Instituttet har flere regionale enheter
og et avdelingskontor i Oslo.

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