

# Implementation of automatic sensors for continuous monitoring of runoff quantity and quality in small catchments

---

---

Jarmo Linjama<sup>1</sup>, Markku Puustinen<sup>1</sup>, Jari Koskiahho<sup>1</sup>, Sirkka Tattari<sup>1</sup>, Helmi Kotilainen<sup>2</sup>  
and Kirsti Granlund<sup>1</sup>

<sup>1</sup>*SYKE, Finnish Environment Institute, PO Box 140, FI-00251 Helsinki, Finland*

<sup>2</sup>*Southwest Finland Regional Environment Centre, Itsenäisyydenaukio 2,*

*PO Box 47, FI-20801 Turku, Finland*

*<sup>1</sup>firstname.lastname@ymparisto.fi*

Development of new automatic sensor-based techniques has expanded the possibilities for intensive monitoring of water quality in small catchments. In this study turbidity and concentration of nitrate-N were monitored with probes in the Savijoki catchment, which has been observed with traditional methods for decades. Particular attention was paid to implementation of the equipment, calibration of the probes and calculation methods. All equipment functioned technically well during the one year monitoring period. Calibration of turbidity and nitrate-N proved that the sampled values agree well with the probe results. However, it seems that loading estimates made with the traditional method are not very reliable for individual years. The research period in this study was exceptional with its many runoff peaks in winter. It is not possible to catch the peaks with traditional monitoring, why the results and comparisons between automatic probes and traditional monitoring cannot be generalized. However, the results proved that novel monitoring techniques have to be continued and extended. In further studies the calculation methods need developed and improved to be to get reliable loading estimations from the sensor data as simply as possible. In a changing climate, the monitoring, loading estimations, and consequently the assessment of the effect of agricultural water protection measures will probably turn even more difficult and challenging.

*Key-words:* monitoring, probes, turbidity, nitrate, agriculture, catchments, runoff, erosion, phosphorus

## Introduction

Nutrient loading from catchments in Finland has been studied by monitoring drainage basins of different sizes and types for several decades (Seuna 1983, Rekolainen, 1993, Vuorenmaa 2002). Streamflow measurements have been based on weirs, where the water level is monitored by a stage recorder, and discharge is determined by a stage-discharge relation curve. The method is suitable for small catchments, where the discharges at their highest are a few cubic meters per second. Depending on the accuracy of the stage-discharge curve, the stage recorder gives reliable data about the discharge and its temporal variation (e.g. Mustonen 1965). Measuring streamflow in larger river basins is based on the same principle as in small catchments. If the cross section area of a river is known, streamflow can be easily calculated.

Determining suspended solids and nutrient concentrations in runoff waters has been based on water samples taken with various sampling strategies. The samples can be either temporal or composite samples representing specific periods. Detection of short time variations of water quality calls for frequent and intensive sampling, which is usually too expensive. For these reasons collection of water samples is scheduled to flood periods, when most of the loading from catchments occurs. This strategy has been useful, because the annual streamflow has typically been distributed to two major flood periods in autumn and spring. In these conditions water samples have been collected at intervals during relatively short periods.

Long term monitoring of catchments has produced fairly reliable results of the level and variability of annual loading. The loading values have been in the same order of magnitude both in catchment monitoring and in experimental field studies (Rekolainen 1993, Turtola 1999, Vuorenmaa et al. 2002, Granlund et al. 2005, Puustinen et al. 2005, 2007). However, when based on water sampling, frequent monitoring of water quality is economically heavy due to the high costs of laboratory analyses and large amount of work. Hence the intensity of monitoring has decreased to a rather low level. This means

that unforeseeable, short-term peaks of runoff and loading remain unobserved almost without exception. This is why the annual loading values based on occasional sampling include measuring errors with either over- or underestimation of loading. Because of the large annual hydrological variation, small influences of environmental acts cannot be observed (Puustinen et al. 2007). This is a major problem in the assessment of the effects of agricultural water protection measures. Moreover, in larger catchments including various types of land uses and human activity, uncertainty is further increased because different sources of water pollution, e.g. urban runoff, forestry, and point sources cannot be positively distinguished from agricultural loading. Among others, Lewis (1996) and Gippel (2006) have studied the potential of turbidity monitoring for measuring transport of sediment in streams.

Recently, new sensor-based techniques for monitoring water quality have been developed, with increased possibilities to monitor catchments intensively and economically. Continuous measuring enables observing all short-term and sporadic loading events. Automatic water quality measuring brings the reliability of monitoring of small catchments to a new level. Moreover, continuous water quality data provide new insights for calibrating catchment scale water quality models (Valkama et al. 2007, Koskiahio et al. 2009). In this study implementation of turbidity and nitrate-N sensors at the Savijoki catchment is examined. The aim of this survey was to compare the characteristics of different commercial sensors, their applicability to field conditions, and to assess their reliability and need of maintenance. This publication presents the results from the first year of research, and compares them with the results based on water samples.

## Material and Methods

### Description of the catchment

The Savijoki catchment is a small (15.4 km<sup>2</sup>), agriculture dominated basin located in coastal southwestern

Finland (60°36' N, 22°40' E). It is a sub-catchment of the River Aurajoki, which discharges directly into the Baltic Sea. The prevailing soil types are moraine (57%), clay (34%), and peat soils (7%). More than half of the area is classified as forest (57%) and the agricultural land covers 39% of the total area. Scattered settlements cover only 4% of the total area (Granlund et al. 2004). The agricultural land is concentrated near the river banks of the river Savijoki. The Savijoki catchment has a long traditions as a study site, it was established in 1971 (Seuna 1983). The dominating crops are spring cereals (Granlund 2004). The portion of grass and green fallow is minor in the area. The mean slope of the whole area is 4.8% (Vuorenmaa et al. 2002), but typically the agricultural field slopes are more gentle. According to digital elevation model (DEM, 25 × 25 m) approximately 40% of the slopes are less than 1%, and 10% are steeper than 6%. Drainage depth is typically 1.2 m and spacing 20 m. Spacing is naturally dependent on prevailing soil characteristics. There are no lakes in the Savijoki catchment and the fields are drained, which leads to minor retention processes inside the catchment.

The mean annual runoff during 1991–1995 was 354 mm (Vuorenmaa et al. 2002). The total runoff during the measurement period (June 2007–June 2008) was 350 mm. Due to the seasonal sampling strategy the nutrient losses of the Savijoki catchment have been calculated by combining two interpolation methods (Vuorenmaa et al. 2002). The average annual total phosphorus ( $P_{\text{tot}}$ ) load for the period 1991–1995 was 0.63 kg ha<sup>-1</sup>, of which 16 % was dissolved reactive phosphorus (DRP). The average annual total nitrogen (N) load for the same period was 7.9 kg ha<sup>-1</sup>, of which around 60% was nitrate-N (including nitrite N). The rest was mostly organic N. In the period 1971–2008 the concentration of nitrate-N has varied between 0 and 7000 µg/l, and turbidity between 7 and 1500 FTU.

The measuring weir of the Savijoki catchment is made of concrete and the sharp-crested weir notch is lined with a steel plate. Water level, which varies between 0 and 1000 mm, determines the discharge according to the weir specific stage-discharge curve. The chilled water sampler, datalogger, and other

observation equipment are installed in a thermally insulated shed beside the weir.

## Installing the study equipment

In this study two sensors were used, the S::can Nitrolyser probe (S::can Measuring Systems, probe 1), and the OBS3+ probe (Campbell Scientific Inc., probe 2). With probe 1 nitrate-N and turbidity were measured with a 5 mm measuring pathlength. The measuring range for nitrate-N is 0.3–70 mg l<sup>-1</sup>, and for turbidity 5–1400 FTU (Formazin Turbidity Unit). The accuracy and measuring range for nitrate-N depend on turbidity. The whole scale is available in clear water. If turbidity rises to 250 FTU, a nitrate-N concentration of 5 mg l<sup>-1</sup> can still be measured. If turbidity rises to near the upper limit of the scale, nitrate-N cannot be measured. The probe was calibrated for the local conditions with the help of comparable readings from laboratory analyses. The nitrate-N was analysed by reduction of nitrate (Hg-Cd or Cu-Cd column) to nitrite followed by colorimetric determination.

The measuring path and the windows of probe 1 were cleaned with compressed air before each measurement. In summertime the duration of each cleaning was set to 4 seconds, and the cleanings were timed to 120 seconds before the measurement. In winter the duration was 1 second, and the probe was cleaned only at every fourth measurement. This was done to prevent icing of the measuring path. Once per month the probe was taken up and cleaned manually. The probe was also checked and calibrated twice a year with distilled water.

With probe 2 only turbidity was measured. This probe type has no automatic cleaning system, and one objective of this research was to compare the two different probes in turbid, nutrient-rich water.

Water level was measured with a pressure probe (Keller AG) with 1 mm resolution. Water level determines the discharge according to a weir specific stage-discharge curve, and discharge was then converted to runoff (mm). The data of water level and temperature, and those of probe 2 were collected into a data collector, which transmitted the data au-

tomatically to the office daily. The data from probe 1 were collected with a laptop computer about once a month.

The research period lasted one year. Water level, turbidity, and nitrate-N were monitored in Savijoki from June 13, 2007 to June 12, 2008. Temperatures of water and air were also monitored.

## Collection of water samples

The probes were calibrated for local conditions with the help of comparative readings from laboratory analyses. Turbidity and nitrate-N (including nitrite) were analysed from all calibration samples. Water samples were taken both manually and with an automatic refrigerator-equipped ISCO water sampler. The automatic water sampler was set to take samples every eight hours. The sampler contained 24 bottles, and the bottles were changed once a week. The hydrograph of the past week was checked before changing the bottles, and based on the water level, 0–4 bottles were taken for laboratory analyses. The total number of samples was 169. The aim was to get samples of different discharge situations, i.e. from rising and falling curves as well as from the peaks of the hydrograph.

Before calibrating the nitrate-N and turbidity values of the probe 1, the raw data was filtered. The filtering was done for the whole dataset: from nitrate-N data only the maximum values, and from turbidity data only the minimum values of three consecutive observations were selected. The purpose of the filtering was to remove anomalous observations caused by occasional foreign matter (e.g. plant residue, larvae or soil aggregates) in the lens of the probe. These filtered values were then calibrated with comparable laboratory analyses.

Part of the calibration samples ( $n=24$ ) were used for nutrient loading calculations in traditional catchment monitoring. The traditional method is described in the next chapter. The total suspended solid (TSS) values and results of the phosphorus (P) analyses of these samples were also used to create regressions, which linked probe data to loading calculation (see next chapter).

## Loading calculations

Loading calculations were done with (i) the traditional method based on water samples (e.g. Kauppila and Koskiaho 2003), and (ii) with continuous data from the probes. Water level, turbidity, and nitrate-N observations at 30 minute intervals were used in the probe-based calculations. TSS concentrations were determined according to two regressions: (i) between probe recorded turbidity and sampled turbidity, and (ii) between the sampled turbidity and sampled TSS.  $P_{\text{tot}}$  concentrations were determined from calculated TSS (as mentioned before) by the regression between sampled TSS and  $P_{\text{tot}}$ . PP (Particle-bound P) concentrations were determined from calculated TSS (as mentioned before) by the regression between sampled TSS and PP. TSS and nutrient loadings were then calculated for every 30 minutes by multiplying the concentrations with the discharge determined from the recorded water level. Total loading for the whole year was calculated by adding up these 30-minute values.

The traditional calculation was made by linear interpolation. Thirteen water samples were selected from the whole set of 169 samples. This corresponds to the flow-proportional sampling strategy which was used in Finland in 1962–1980 (Vuorenmaa et al. 2002). Nitrate-N concentration and turbidity were interpolated linearly between the samples. Daily runoff was determined as an average of the 30-minute values recorded by the water pressure probes. Loading values were calculated using daily values of runoff, TSS and nutrient concentrations.

## Results and discussion

### Installing the sensors

All observation equipment was technically reliable. During the one year monitoring period there were no breaks in the observations caused by technical problems. Ice, foreign matter, and contamination caused some short breaks. Some breaks in the

nitrate-N observation were caused by excessive turbidity.

The cleaning system of probe 1 proved to be worthwhile (Fig. 1), but despite cleaning, foreign matter was occasionally found in the measuring path. In a situation like this the measuring was clearly out of line and faulty data were easy to find. These anomalous observations were, as previously described, filtered and removed. The filtering cut slightly the sharpest peaks of turbidity and nitrate-N, but the effect was very small, because the real loading peaks in Savijoki always last a minimum of 12 hours (20–30 observations) due to mixing and retention of water.

Using probe 2 without a cleaning system was very problematic especially in summer. The probe got so dirty in one day that the measurements were – as revealed by the unrealistically high, rapidly growing readings – obviously unreliable. The probe was not faulty, but it was not satisfactory for nutrient-rich water without continuous, mechanical cleaning. The probe suits fairly for cold waters where the nutrient content is relatively low. In addition, the gauging site should be selected to avoid sunlight which can damage the optical lens or give rise to algae blooming on it.

In the beginning of the research period (June 2007) probe 1 was installed about 50 cm below the zero level of the weir. Icing of the measuring path of the sensor caused occasional problems when the

temperature of the water was close to zero, and the air temperature was below  $-5^{\circ}\text{C}$ . In these situations the compressed air which was used to clean the sensor was so cold that water in the measuring path froze during the cleaning. However, these situations were easy to recognize by checking visually nitrate-N, turbidity and temperature. When air and water temperatures were very low, and turbidity suddenly increased and nitrate-N decreased, it was very probable that the probe was frozen. The icing problem was solved in January 2008, when the probe was installed near the bottom of the river (Fig. 2) at the depth of 120 cm. At the same time the cleaning procedure was changed so that the measuring path was cleaned only at every fourth measuring.

Icing caused nine breaks both in turbidity and nitrate-N measurements, and the breaks were normally 2–7 hours long. Missing values were estimated later by linear interpolation. The error in the loading values caused by these breaks is insignificant, because in icing situations runoff, turbidity, and nitrate-N concentration were all very small.

## Calibration of sensor data

The reliability of the values obtained from sensors during the first monitoring period was high. This



Fig. 1. The cleaning of the optical lens was done with compressed air before measurements.



Fig. 2. In early winter the sensor was anchored near the bottom of the river to prevent icing.



was verified by the large amount of water samples (169), and their laboratory analyses. Nitrate-N and turbidity data from the sensors were calibrated with a simple regression. Coefficients of determination ( $r^2$ ) of regression lines, where the turbidity of the water samples was explained by turbidity values of the sensor (Fig. 3), and the nitrate-N concentrations by the nitrate-N data from the sensor (Fig. 4), were high.

All turbidity results of the laboratory analyses were consistent with the calibrated turbidity curve of the sensor (Fig. 5). The highest turbidity values could not be observed by the water sampler due to a very short culmination of turbidity and the timing of sampler steps (8 h). Typically, two water samples were taken just before and after the turbidity peaks (Fig. 5), where the concentration of TSS was rising or decreasing. However, this is not very obvious in Fig. 5, because the dataset is so large and the resolution of the picture is not high enough. The water sampler performed well at observing lower peaks of turbidity.

The similarity of nitrate-N values based on sensor recordings and laboratory analyses was also at least satisfactory. The biggest differences were observed mostly when the concentrations were low, below the sensor's capacity of measuring and resolution power. A situation like this was observed in June–August 2007 (Fig. 6), when results of laboratory analyses were slightly lower than those measured by the sensor. In March–April (2008) the sensor showed a slightly higher concentration of nitrate-N than the analysed concentration. However, differences were rather small. The sensor responded readily to rapid and large variations of nitrate-N concentration.

The resolution power of the nitrate-N sensor is 0.3–70 mg l<sup>-1</sup>. Based on the water samples the nitrate-N concentration in June–August 2007 was clearly below the accuracy of the sensor. Because of this the measured nitrate-N concentration deviated from the concentrations of the samples. This had little effect on the loading values, because the discharge in June–August was very low.

During the highest runoff peaks the turbidity was so high that probe 1 was not capable of measuring nitrate-N. There were 8 similar periods, of

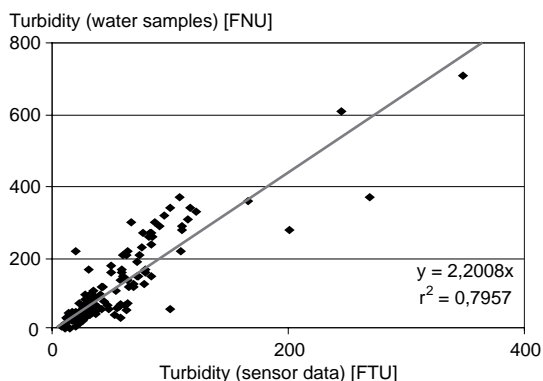


Fig. 3. Relationship between sensor-based and sampling-based turbidity (n=169)

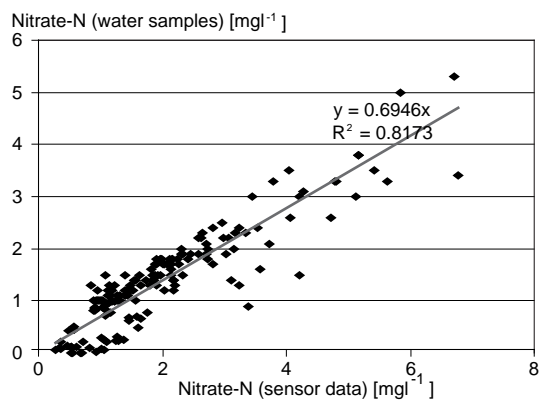


Fig. 4. Relationship between sensor-based nitrate-N and sampling-based nitrate-nitrite-N (n=169).

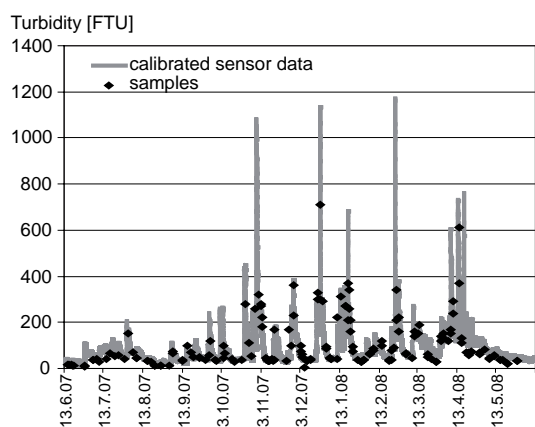


Fig. 5. Turbidity values based on water samples (n=169) and calibrated sensor data.

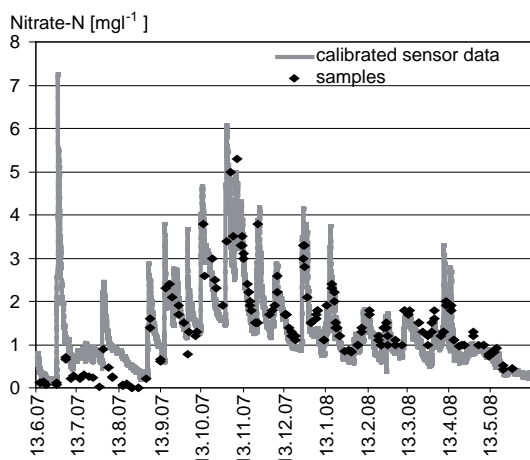


Fig. 6. Nitrate-N values based on water samples ( $n=169$ ) and calibrated sensor data.

which 6 lasted 6–11 hours. The longest break in the nitrate-N measuring was during the very strong runoff peak in November 2007, when the break was 33 hours. Nitrate-N concentrations during these periods were estimated by linear interpolation. This method did probably not affect the loading values very much, because the highest nitrate-N concentration did not coincide with the runoff, but rose to the maximum shortly after the highest runoff peak. As a result it is likely that the linear interpolation gave a relevant estimation of the concentration during the runoff peak.

The number of calibration samples was very large, about 8 times higher than that collected in traditional monitoring schemes. One reason for the reliable results (Figs 5 and 6) might be the relatively small peat soil area in the catchment (7%), and because erosion material from this kind of catchments usually is mainly mineral substances. Due to this the correlation between turbidity and TSS based on water samples was high, which means a practically reliable correlation between probe recorded turbidity and real TSS concentration in water. A high content of organic material in water probably decreases the correlation due to a different dependence between turbidity and the specific weight of erosion material. It seems that 10–20 samples is a satisfactory number for calibration

during the first monitoring year. After that only occasional control samples are necessary. But in terms of the loading values, as presented in this paper, even 24 water samples per year are too few, which leads to rather unreliable results. However, it should be noted that these implications are relevant for cases with mineral (clayey) soils. For other soil types further studies with an adequate number of calibration samples are needed.

## Conversions of sensor data

Coefficients of determination ( $r^2$ ) of regression lines, where the TSS concentration of the water samples was explained by the turbidity of the water samples and  $P_{\text{tot}}$  and PP concentrations by the concentration of TSS, respectively, were high (Figs 7–9). Using these regression models TSS,  $P_{\text{tot}}$  and PP concentrations were then calculated based on the calibrated turbidity curve of sensor data (Fig. 3) and calculated TSS concentration curve (Fig. 7), respectively. The nitrate-N concentration was identical to the calibrated sensor data (Fig. 4). The final database used in the load calculations included runoff and the concentrations of TSS,  $P_{\text{tot}}$ , PP and nitrate-N measured in half hour steps.

## Runoff and water quality

The monitoring period in Savijoki was exceptional due to heavy rains and high temperatures during late autumn and winter. Indeed, some parts of southwestern Finland had no thermal winter at all (Finnish Meteorological Institute 2009). On water-saturated soil, rain and wet snow produced rapidly runoff, and the number of runoff peaks was very high. The runoff from the catchment started at the beginning of November and continued periodically until the end of March the following year.

The maximum values of the occasional turbidity peaks were observed at the same time as those of the occasional runoff peaks. Overlapping of runoff and turbidity peaks might be due to prompt

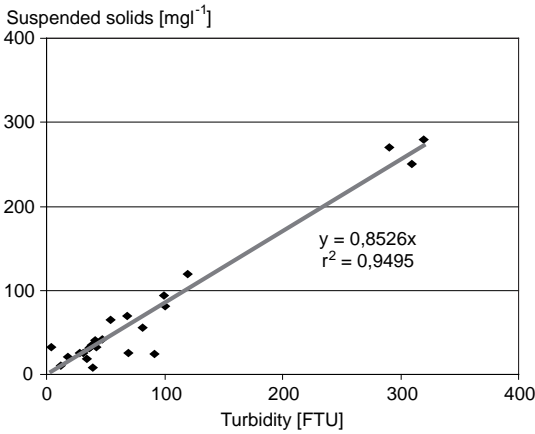


Fig. 7. Relationship between sampling-based turbidity and suspended solids (n=24).

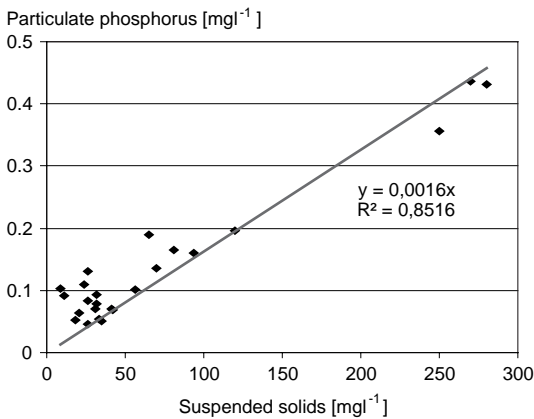


Fig. 8. Relationship between sampling-based suspended solids and total phosphorus (n=24).

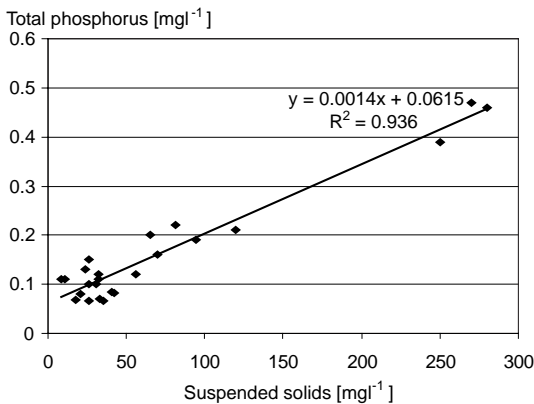


Fig. 9. Relationship between sampling-based suspended solids and particulate phosphorus (n=24).

resuspension of sediment from the bottom of the channel during the rising runoff. After the highest runoff, resuspension from the channel decreased, while erosion from the fields still continued. Yet sedimentation of suspended solids lowered the TSS concentration during decreasing runoff. The level of turbidity did not follow the runoff variation unambiguously. For instance, in November–December 2007 turbidity was quite low regardless of high runoff (Fig. 10). A similar event was repeated in January. The main reason for this was that the soil surface was slightly frozen and erosion thereby prevented.

Maximum concentrations of the observed occasional nitrate-N peaks had about a one day delay compared with the occasional runoff peaks (Fig. 11). During rising runoff, resuspended material from the bottom of the channel did not raise the nitrate-N concentration. When the nitrate rich water began to flow from local field drainage systems into the river, the nitrate-N concentration of the stream water began to increase. This delay was approximately equal to the time the drainage water needed to flow from the fields into the stream. In the autumn of the monitored period both the average and maximum of the nitrate-N concentrations were systematically higher than in the spring. In this respect the nitrate-N concentration curve differed from the runoff curve, which rose with the arriving winter–spring period.

### Preliminary loading results

Annual erosion and nutrient loadings were calculated as a cumulative sum of the halfhour values. Total erosion and nutrient loadings from the catchment were equalized over the field area (ha) as such. Calculated with this approach annual erosion was 1452 kg ha<sup>-1</sup>, P<sub>tot</sub> loading 2.61 kg ha<sup>-1</sup>, PP loading 2.37 kg ha<sup>-1</sup>, and nitrate-N loading 17.3 kg ha<sup>-1</sup>. By traditional monitoring (13 water samples) annual erosion was 985 kg ha<sup>-1</sup>, P<sub>tot</sub> loading 1.81 kg ha<sup>-1</sup>, PP loading 1.61 kg ha<sup>-1</sup>, and nitrate-N loading 15.0 kg ha<sup>-1</sup>.



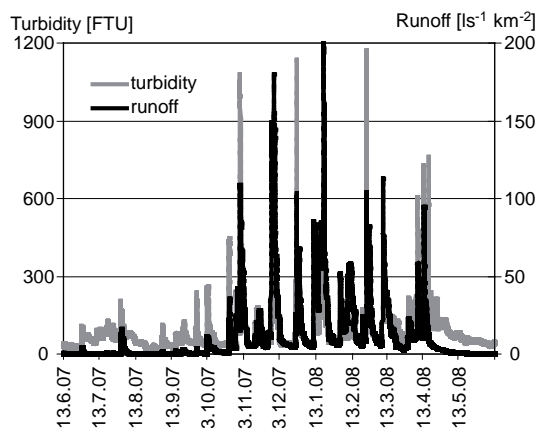


Fig. 10. Runoff and sensor-based turbidity.

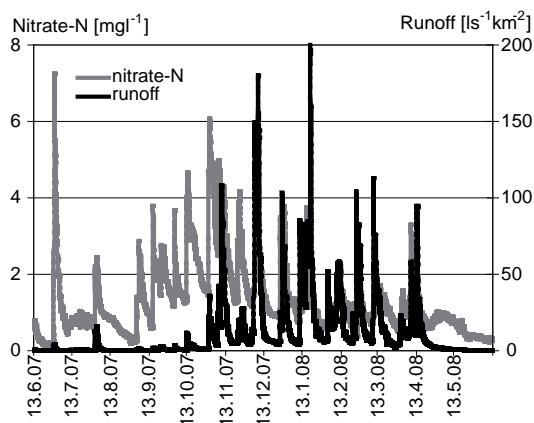


Fig. 11. Runoff and sensor-based nitrate-N.

In both cases - based on sensors or water samples - the specific loading values were overestimates, because solid matter and nutrient loading are also discharged from forest and other nonagricultural land. The loading from these soils was not defined or taken into account, because the main aim was to compare the new sensor-based technology with traditional monitoring based on water sampling, and to find differences between them. In this respect both monitoring results are completely comparable. Large differences between the results are easy to detect. Sensor-based erosion is 47 %, PP loading 47 %, and nitrate-N loading 15 % higher than the figures based on the traditional

method. One reason might be the hydrologically exceptional monitoring period. In a study in the Yläneenjoki river basin in 2006–2007, in southwestern Finland, the results were very similar to these (Koskiahio et al. 2009). In Yläneenjoki the sensor-based method gave a 2-fold estimate for TSS as compared with the manual method, and a 1.3-fold for  $P_{tot}$ , respectively. The main reason is that sensors can observe all concentration peaks and quality variations. The traditional monitoring based on water samples cannot observe temporary events, and the calculated results are thus easily underestimates of the reality.

The Watershed Simulation and Forecasting System (WSFS) of the Finnish Environment Institute simulates the hydrological cycle for the whole land area of Finland (Vehviläinen and Huttunen 2002). Recently, a total phosphorus load model has been developed as part of the WSFS (Huttunen et al. 2007). The WSFS-P model can be classified as conceptual nutrient transport model laying between physically based nutrient transport models and simple source apportionment assessment tools. The P transport is based on a simplified conceptual method, and calibration against measured concentration data is used to estimate the parameters describing the P transport. WSFS-P is applied to the whole territory of Finland, and almost all river catchments are calibrated so far. For the small river basin of Savijoki the simulated WSFS-P annual P load varied between 700–500 kg a<sup>-1</sup> during 2000–2008. This means 1.17–2.50 kg ha<sup>-1</sup> a<sup>-1</sup>, presuming that all P loading would come from fields. These values are at the same level as or just a little lower than the loading values calculated in this paper.

Along with this, the static agricultural nutrient load assessment tool, called VIHMA, estimated the average annual erosion from fields to be 810 kg ha<sup>-1</sup> a<sup>-1</sup> which falls smoothly into the above mentioned range. PP loading is 1.18, DRP loading 0.4 and nitrogen loading 17.1 kg ha<sup>-1</sup> a<sup>-1</sup>, respectively. Average results by VIHMA are net results from one hectare of field, and they are not directly comparable with the preceding monitoring results.

The Water Framework Directive calls for more accurate loading measurements in order to estimate e.g. the effects of water protection measures in

changing hydrological conditions. The data collected by continuously recording sensors provide more accurate loading estimates than those obtained by water sampling. Moreover, the more frequent data better clarify the mechanisms behind the loading in different seasons. Until now the estimates of the reductions achieved by currently implemented measures have included a great deal of uncertainty and it is thus possible that real benefits of the measures have merged into the hydrological variability.

## Conclusions

In monitoring of water quality in catchments automatic sensors improve significantly significantly the accuracy and reliability of the loading estimates. Most importantly, automatic sensors observe temporary and large concentration peaks which coincide almost without exception strongly with the runoff peaks. Thus the influence of these events on the annual loading values is very large. However, the observation period in this study was hydrologically exceptional. As a result, the significantly higher sensor-based loading values compared with the traditional results cannot be generalized over all different years. During a hydrologically normal year, when runoff increases in autumn due to rain, and in spring due to melting, comparison of the two approaches might give a totally different result. The accuracy of sampling-based loading values depends on the coverage of water samples related to runoff peaks. For this reason it is very important not only to continue the sensor-based monitoring of water quality in the current network, but also to apply it in other catchments differing in erosion level, timing of runoff and nitrate-N concentrations and different agricultural production systems.

Automatic sensor-based monitoring needs further development. One of the most important questions is how to estimate phosphorus concentration from the probe-detected turbidity. Is it more accurate to use one regression between turbidity and P, or would it be more reasonable to use two regressions stepwise as in this paper? Here,

the concentration of suspended solids was based on the one-regression approach, and the estimate for nitrate-N directly on the sensor data after the calibration of nitrate-N curve. Using as simple and direct calculations as possible may decrease uncertainty and improve reliability of the results.

In selecting sensors reliability and the need for maintenance are particularly important features. Self-cleaning is one of the key properties for the reliability of the results.

*Acknowledgements.* This study is a part of the SeMaTo-project, "Development of monitoring and applying model tools for practical work in real watershed conditions". The financial support for this project provided by the Finnish Ministry of Agriculture and Forestry is gratefully acknowledged. We also wish to thank Ms. Carita Nybom for revising the English language.

## References

- Finnish Meteorological Institute 2009. *Homepage of Ilmatieteenlaitos* (Finnish Meteorological Institute). (in Finnish). Cited 2 February 2009. Available on the internet: [http://www.fmi.fi/saa/tilastot\\_174.html#2](http://www.fmi.fi/saa/tilastot_174.html#2).
- Gippel, C. J. 2006. Potential of turbidity monitoring for measuring the transport of suspended solids in streams. *Hydrological Processes* 9: 83–97.
- Granlund, K., Rankinen, K. & Lepistö, A. 2004a. Testing INCA model in a small agricultural catchment in southern Finland. *Hydrology & Earth System Sciences* 8: 717–728.
- Granlund, K. 2004b. Variation of runoff and nitrogen leaching in a small agricultural catchment in southern Finland. *Nordic Hydrology* 35: 335–345.
- Granlund, K., Räike, A., Ekholm, P., Rankinen, K. & Rekolainen, S. 2005. Assessment of water protection targets for agricultural nutrient loading in Finland. *Journal of Hydrology* 304: 251–260.
- Huttunen, I., Huttunen, M., Vehviläinen, B. & Tattari, S. 2007. Large-scale phosphorus transport model. In: Heckrath, G., Rubæk, G.H. and Kronvang, B. (eds.) *Diffuse Phosphorus Loss – Risk Assessment, Mitigation Options and Ecological Effects in River Basins. The 5th International Phosphorus Workshop (IPW5)*, 3–7 September 2007 in Silkeborg, Denmark. *DJF Plant Science* 130: 215–218.
- Koskiaho J., Lepistö A., Tattari S. & Kirkkala T. 2009. Online measurements provide new information on nutrient leaching processes in the Yläneenjoki river basin, SW Finland. *Proceedings: IWA 13th Int Conf on Diffuse Pollution and Integrated Watershed Management*, Oct 12–5 2009, Seoul, Korea.

- Lewis, J. 1996. Turbidity-controlled suspended sediment sampling for runoff-even load estimation. *Water Resources research* 32: 2299–2310.
- Mustonen, S. 1965. *Hydrologic investigations by the Board of Agriculture during the years 1957 to 1964*. Helsinki. 144 p.
- Puustinen M., Koskiaho J. & Peltonen K. 2005. Influence of cultivation methods on suspended solids and phosphorus concentrations in surface runoff on clayey sloped fields in boreal climate. *Agriculture, Ecosystems and Environment* 105: 565–579.
- Puustinen, M., Tattari, S., Koskiaho, J. & Linjama, J. 2007. Influence of seasonal and annual hydrological variations on erosion and phosphorus transport from arable areas in Finland. *Soil & Tillage Research* 93: 44–55.
- Rekolainen, S. 1993. Assessment and mitigation of agricultural water pollution. *Publications of the Water and Environment Research Institute* 12. National Board of Waters and Environment, Helsinki, Finland. 34 p.
- Seuna, P. 1983. Small basins – a tool in scientific and operational hydrology. *Publications of the Water Research Institute* 51. National Board of Waters, Finland. 61 p.
- Turtola, E. 1999. *Phosphorus losses in surface runoff and drainage water affected by cultivation practices*. Academic Dissertation. University of Helsinki. 47 p.
- Valkama, P., Lahti, K. & Särkelä, A., 2007. Automated water quality monitoring in the river Lepsämäinjoki. *Terra* 119: 195–206.
- Vehviläinen, B. & Huttunen, M. 2002. The Finnish watershed simulation and forecasting system (WSFS). *Proceedings of the XXI<sup>st</sup> Conference of the Danubian countries on the hydrological forecasting and hydrological bases of water management*. Bucharest-Romania. 2–6 September 2002.
- Vuorenmaa, J., Rekolainen, S., Lepistö, A., Kenttämies, K. & Kauppila, P., 2002. Losses of nitrogen and phosphorus from agricultural and forest areas in Finland during the 1980s and 1990s. *Environmental Monitoring and Assessment*. 76: 213–248.

## SELOSTUS

### Jatkuvatoimisten antureiden soveltuvuus veden määrän ja laadun seurantaan pienillä valuma-alueilla

Jarmo Linjama, Markku Puustinen, Jari Koskiaho, Sirkka Tattari, Helmi Kotilainen ja Kirsti Granlund

*Suomen ympäristökeskus*

Automaattisten antureiden viimeaikainen kehittyminen on avannut uusia mahdollisuuksia pienten valuma-alueiden monitorointiin. Tässä tutkimuksessa kymmenien vuosien ajan seuratulle valuma-alueelle, Savijoelle, asennettiin sameus- ja nitraattianturi ja tehtiin kuormituslaskenta sekä antureiden tulosten perusteella että perinteiseen harvaan näytteenottoon perustuvien menetelmin. Huomiota kiinnitettiin erityisesti laitteiden asentamiseen ja antureiden kalibrointiin. Huolellisen asentamisen jälkeen laitteet toimivat vuoden mittaisen havaintojakson ajan teknisesti moitteettomasti. Sameuden ja nitraattikäyrien kalibrointi vesinäytteiden perusteella osoitti, että vesinäytteiden ja anturidatan vastaavuus on erittäin hyvä. Alustavien tulosten mukaan perinteiseen seurantaan perustuva kuormitusarvio ei ole yksittäisten vuosien osalta

kovin luotettava. Tämän tutkimuksen seurantavuosi oli kuitenkin poikkeuksellinen useiden talviaikaisten valuntapiikkien vuoksi, joita harvan, perinteisen seurannan vesinäytteet eivät olisi tavoittaneet. Tässä esitettyä automaattiantureiden ja vesinäytteiden tuloksiin perustuvaa kuormituslukujen vertailua ei voida yleistää. Tulos kuitenkin osoittaa, että tämänkaltaista monitorointia on tärkeä jatkaa ja laajentaa. Jatkotutkimuksissa huomiota tulee kiinnittää laskentamenetelmien kehittämiseen, erityisesti siihen, kuinka anturiaineistosta päästään mahdollisimman yksinkertaisesti luotettavaan kuormitusarvioihin. Ilmaston muuttuessa valuma-alueiden seuranta ja kuormitusarviointi ovat todennäköisesti entistä vaativampia ja maatalouden vesiensuojelutoimenpiteiden vaikutusten havaitseminen myös entistä haasteellisempää.