

# Suspended solids and total phosphorus loads and their spatial differences in a lake-rich river basin as determined by automatic monitoring network

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Received: 19 June 2014 / Accepted: 4 March 2015 / Published online: 18 March 2015  
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**Abstract** Turbidity datasets recorded by sensors during 2009–2012 were collected in five observation sites in the 2046-km<sup>2</sup> Karjaanjoki River Basin in southern Finland. From these and water sample-based data, total phosphorus (TP) and total suspended solids (TSS) fluxes were determined. Based on calculations made with combined sensor- and water sample-based dataset, the annual loading from the Karjaanjoki Basin in 2009–2012 varied between 11,400 and 23,700 kg of TP and 3300–8400 t of TSS. As compared with two other river basins discharging into the Baltic Sea in southern Finland, the TP loading from Karjaanjoki was low because the summed retention in the two major lakes Hiidenvesi and Lohjanjärvi was high: 48 and 49 % of the TSS and TP loadings generated in their upstream catchments, respectively. Depending on how water sampling took place in relation to peak flow events, differences of annual fluxes as determined by “water samples only” vs. “sensors and water samples” data varied between –22 and 26 for TP and –31 and 39 % for TSS. This study proved automatic monitoring being useful when spatial differences and lake retention of riverine fluxes are explored. Moreover, the loading estimates calculated on the base of well-functioning and well-maintained automatic monitoring system, supported with water sampling during periods when devices were off, are undoubtedly more accurate than those based on manual grab water sampling only. The findings of this

study were in line with, and well contribute to, earlier Finnish and international research on automatic water quality monitoring.

**Keywords** River basin · Catchment · Automatic monitoring · Turbidity sensor · Sediment · Phosphorus

## Introduction

The use of sensors with wireless data transmission in water quality monitoring has increased in recent years in Finland (Kotamäki et al. 2009; Linjama et al. 2009) and elsewhere (e.g., Horsburgh et al. 2010; O’Flynn et al. 2010; Tena et al. 2011; Pellerin et al. 2014). The sensor technology with different functioning principles, such as bulk optics, laser optics, pressure difference, and acoustic backscatter, is rapidly evolving (Gray and Gartner 2009). An advantage with automatic monitoring compared with the occasional, manual grab sampling is the continuous, e.g., hourly, data which greatly improves the accuracy of the environmental loading calculated out of the monitored parameters. The Finnish experiences gained e.g., in a 100 % agricultural catchment of 0.012 km<sup>2</sup> (Koskiaho et al. 2009) and in a 15-km<sup>2</sup> catchment with 39 % of the area in agricultural use (Linjama et al. 2009), have been promising. Furthermore, e.g., Australian (Grayson et al. 1996), American (Glysson and Gray 2003; Lewis 2003), Japanese (Yamamoto and Suetsugi 2006), Italian (Viviano et al. 2014), and Norwegian (Skarbøvik and Roseth 2015) studies suggest that in many cases with

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catchments of a different size and various forms of land-use, turbidity can well be used as a surrogate of total suspended solids (TSS) and total or particulate phosphorus (TP or PP) concentrations and thereby as a component in calculations of material fluxes. When sensors are decently calibrated and the correlation between sensor-recorded turbidity and concentration is high, the monitoring results of e.g., wetland studies are reliable and the use of automatic monitoring may become economically feasible (Garfi et al. 2014).

When several automatic monitoring stations are strategically located in an area (e.g., catchment) and connected to a collective data management system, they can form a network providing precise information from the study area in real time (Hart and Martinez 2006; Kotamäki et al. 2009; Postolache et al. 2014). The objective of this study was to find out the suitability and advantages of a network of automatic water quality monitoring in a 2046-km<sup>2</sup> lake-rich river basin. Here, not only the river mouth was monitored with a turbidity sensor but also four strategically important sites in the upper reaches were equipped with similar devices. Another aim was to assess TSS and TP loading on the base of automatically measured data and to compare the results with the loading based on water sampling only. Moreover, lake retention and source apportionment were assessed by processing the data from different locations in the catchment. For example, Viviano et al. (2014) could distinguish between point and other sources of TP by using surrogates and automatic monitoring.

In order to gain wider perspective of the TSS and TP loading from the Karjaanjoki Basin, comparisons were made with the loading estimated for two other significant river basins in southern Finland: Aurajoki and Vantaanjoki. The Aurajoki Basin (874 km<sup>2</sup>) has Finland's most intensive agricultural production, and the Vantaanjoki Basin (1686 km<sup>2</sup>) is not only rich in agricultural production but also located in the most densely populated area of Finland.

## Material and methods

### Study basin and the used sensors

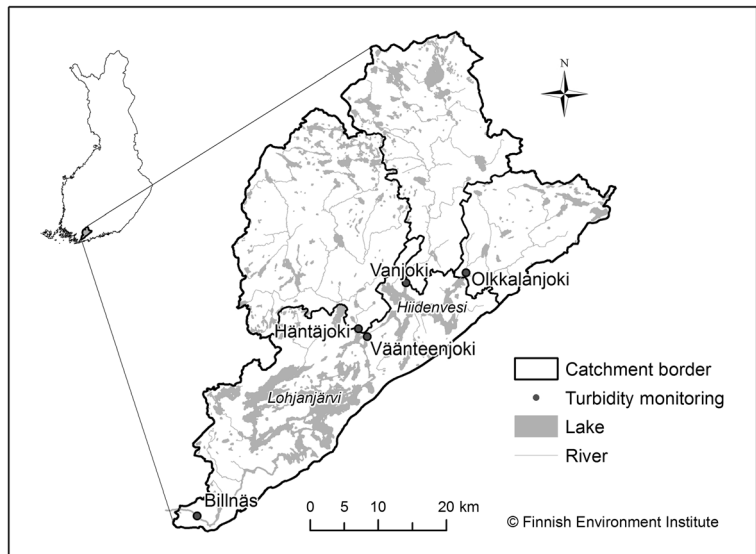
Turbidity sensors were assembled in the Karjaanjoki River Basin (2046 km<sup>2</sup>) in southern Finland (Fig. 1)

during the years 2007 and 2008 in the Soil Weather project (Kotamäki et al. 2009). The river basin is mainly covered by forest (60 %), the rest of the area being agricultural (13 %), lakes and rivers (12 %), and population centers (9 %). The rivers Vanjoki and Olkkalanjoki bring waters from the northern parts of the basin and the lake-adjacent areas from other directions into the lake Hiidenvesi (area 29 km<sup>2</sup>, mean depth 6.7 m), from which waters flow via the river Väänteenjoki into the lake Lohjanjärvi (area 92 km<sup>2</sup>, mean depth 12.7 m), which receives waters also via the river Häntäjoki from northwestern areas of the basin. Finally, the river Mustionjoki transports water from the entire river basin into the Gulf of Finland. The soil in the Karjaanjoki Basin mainly consists of clay (Vertic Cambisol), silt (Aquic Dystricryept), and glacial till (Dystric Regosol) (FAO 1974, 1988).

There were two types of sensors used (s::can and OBS3+), of which the manufacturers and suppliers are presented in Table 1. The sensor types were different in terms of their functioning principle. OBS3+ sensor works by emitting a near-infrared light into the water and then measuring the light that bounces back from the suspended particles. The functioning of s::can nitro::lyser is based on a continuous optical spectrum reaching from low ultraviolet to visible light. The substances contained in water weaken a light beam emitted by a lamp. After contact with water, the intensity of the light beam is measured by a detector over a range of wavelengths specific to different substances. The cleaning systems of the sensors' lenses were also based on different approaches; while OBS3+ sensors were equipped with mechanical wiper brushes, s::can sensors used bursts of compressed air for cleaning. The cleaning was done just before each hourly measurement.

The outflow of the entire river basin in the river Mustionjoki (at the site called Billnä), the inflow into the Lake Lohjanjärvi in the rivers Väänteenjoki and Häntäjoki, and the inflow into the lake Hiidenvesi in the rivers Olkkalanjoki and Vanjoki (Fig. 1) were all measured with OBS3+ sensors. At Olkkalanjoki and Vanjoki measurement sites, there were also s::can sensors, of which the data was primarily used. However, the s::can data was supplemented with OBS3+ data in the river Olkkalanjoki for spring-summer 2012 and in the river Vanjoki for the whole year 2012, when the s::can measurements were ceased.

**Fig. 1** Locations of the five turbidity measurement stations in the Karjaanjoki River Basin. Rivers flowing into the measurement stations are shown only



Calibration of the sensors and conversions of turbidity to TSS and TP concentrations

Turbidity recorded by the OBS3+ sensors was calibrated against the turbidity determined from water samples. Calibration equations were determined according to linear regression between the values of the water samples and the simultaneous values of the “raw data.” As for s::can sensors, the data was similarly calibrated by the device supplier who thus delivered us “user-ready” data. The calibration equations and the coefficients of determination ( $r^2$ ) of each measurement site are presented in Table 2. Although the slopes of the calibration equations varied rather highly (1.08–5.23), the  $r^2$  values were high (0.86–0.97) in all sites, which suggests that the error of the raw data was systematic and the calibrated data could be thus considered reliable. In terms of OBS3+ data, there came out events when raw turbidity jumped into the maximum (250 NTU) without plain reason (e.g., a storm event followed by rapidly increasing flow) and stayed there for some hours, in few occasions for a day or two, until it dropped back to the original level. These obviously erroneous results had to be checked, removed, and replaced by interpolated values before

further processing of data. The most common reason for such rejected data was the contamination of sensor lenses with algae and/or suspended material. It is also possible that debris from plants and tree leaves, or even molluscs or maggots got stuck in the narrow slot between the lenses. This suggests that in addition to automatic cleaning system, regular checking of data and careful on-site maintenance of sensors is a necessary part of an automatic monitoring.

Because turbidity does not denote the content of a substance in water, it cannot be directly used in calculations of material fluxes. Thus, correlations of turbidity with the concentrations of TSS and TP were determined from the 2009–2012 water sample data collected at corresponding measurement sites to convert the sensor-based, calibrated turbidity data to hourly concentrations of TSS and TP. The conversion equations based on these correlations are presented in Table 2.

The data checking/calibration/conversion procedure is a necessary part of the work when riverine material fluxes are estimated on the base of automatic monitoring. However, it is also a very toilsome and time-consuming task. Thus, efforts have been made in a joint project to automatize this process (Rönkkö et al. 2014).

**Table 1** The sensors of the monitoring network used in this study

Sensor type	Manufacturer	Finnish supplier	Measurement sites
OBS3+	Campbell Scientific, Inc. ( <a href="http://www.campbellsci.com">www.campbellsci.com</a> )	A-lab Ltd ( <a href="http://www.a-lab.fi">www.a-lab.fi</a> )	All sites
s::can nitro::lyser	scan Messtechnik GmbH ( <a href="http://www.s-can.at">www.s-can.at</a> )	Luode Consulting Oy ( <a href="http://www.luode.net">www.luode.net</a> )	Olkkalanjoki and Vanjoki

**Table 2** Calibration equations and coefficients of determination ( $r^2$ ) derived from the relation between the sensor recordings and water samples, and equations to convert the calibrated turbidity to total suspended solids (TSS) and total phosphorus (TP) concentrations

Measurement site	Calibration equation ( $r^2$ )	Number	Conversion equation for the concentration of	
			TSS [ $\text{mg l}^{-1}$ ] ( $r^2$ )	TP [ $\mu\text{g l}^{-1}$ ] ( $r^2$ )
Billnäs	$y=2.71 \times x$ (0.94)	59	$1.7+0.73 \times y$ (0.95)	$19.8+1.04 \times y$ (0.86)
Väänteenjoki	$y=2.8+2.12 \times x$ (0.86)	45	$1.6+0.78 \times y$ (0.74)	$14.3+1.76 \times y$ (0.82)
Häntäjoki	$y=0.5+5.23 \times x$ (0.90)	65	$0.82 \times y$ (0.85)	$36.8+1.39 \times y$ (0.59)
Olkalanjoki <sup>a</sup>	$y=2.51 \times x$ (0.97)	70 (11)	$0.87 \times y$ (0.95)	$34.1+1.29 \times y$ (0.78)
Vanjoki <sup>a</sup>	$y=1.08 \times x$ (0.93)	64 (8)	$0.84 \times y$ (0.98)	$22.4+1.30 \times y$ (0.87)

Conversion equations were derived from the water sample dataset of the period 2009–2012. If constant term was negligible, an equation with only slope term was used

$x$  recorded turbidity, NTU (raw data),  $y$  calibrated turbidity, NTU (final data for load calculations),  $n$  number of water samples taken during 2009–2012 (figure in parentheses denotes the number of samples used for OBS3+ sensor calibration)

<sup>a</sup> Calibration equation applies for the data collected by OBS3+ sensor only. S::can data was obtained ready calibrated from the device supplier

The aim is to integrate sensor-recorded and water sample-based data into a data platform, from which a researcher can reliably obtain TSS and TP concentrations in a measurement site. For this, both calibration of the raw turbidity data and conversions from turbidity to the concentrations will be made automatically for the user-requested data retrieved from the databases of Finnish Environment Institute (SYKE). The platform will assure the data quality by

1. Comparing the sensor data with laboratory analyses, as well as with hydrological and meteorological data
2. Real-time quality assurance methods executed in the field
3. Carrying out tests for
  - Missing observations
  - Changes in the measurement results
  - Limit value exceedings
  - Gradual drifting of the values off from the correct level

The system will provide information on how the data is processed and on the key performance indicators (error variance, the contribution of the different sources of error, coefficients of determination between sensor- and water sample values and between turbidity and the concentrations, etc.) so that the end-user can assess the reliability and uncertainty of the data. Documentation of

the data quality will be presented for the end-user in a user-friendly form.

#### Calculation of material fluxes of TSS and TP

Because the flow data was only available on a daily basis, we used daily averages of the TSS and TP concentrations converted (see Table 2) from hourly measured turbidity for the calculations of material fluxes. Except for TSS in Väänteenjoki and TP in Häntäjoki, the  $r^2$  values of the conversion equations (Table 2) were higher than those reported for an agricultural catchment in Norway by Skarbøvik and Roseth (2015). The flow data was obtained from the water quality database (OIVA) of the Finnish environmental administration. Material fluxes for each measurement site were calculated by multiplying daily flow with daily mean concentration and summing up the daily fluxes as annual values. For the periods when the sensors were not operating, material fluxes were calculated based on water samples as described later in this chapter.

The measurement sites do not cover 100 % of the Karjaanjoki Basin leaving lake-adjacent areas of Hiidenvesi and Lohjanjärvi, as well as a small area between Billnäs and the Gulf of Finland unmonitored. For these areas, an equation (1) was selected from an array of statistical regression equations developed at Finnish Environment Institute (Jaakkola et al. 2013). The equation (1) selected here determines annual TP

loading ( $\text{kg km}^{-2} \text{ year}^{-1}$ ) on the base of the percentages of agricultural land and lake areas as follows:

$$TP = 10.7 + 1.35 \cdot \text{field pctg} - 1.09 \cdot \text{lake pctg} \quad (1)$$

Coefficient of determination ( $r^2$ ) of equation (1) was 0.79, and its model efficiency coefficient (Nash and Sutcliffe 1970) in validation was 0.74 (Jaakkola et al. 2013). The result of equation (1) represents average of a longer term period. Thus, relative differences between the yearly 2009 and 2012 loadings of the nearest measurement site were used to derive annual values for each unmonitored area. TSS loadings for the unmonitored areas were assessed by multiplying the corresponding TP loading with mean TSS/TP ratio of the nearest upstream measurement site(s): for Hiidenvesi-adjacent area that of Vanjoki and Olkkalanjoki, for Lohjanjärvi-adjacent area that of Häntäjoki and Väänteenjoki, and for sea-adjacent area that of Billnäs. Due to their rather large areas combined with high share of agricultural land-use, the lake-adjacent areas were responsible for almost one third of the estimated fluxes into the two lakes. Meanwhile, the significance of the small unmonitored area between Billnäs and Baltic Sea was negligible.

The water samples taken during 2009–2012 (for  $n$ , see Table 2) were used not only for calibration of the sensors and conversions between turbidity and the concentrations but also for the assessments of the difference between the estimates of material fluxes as calculated by sensor- and sampling-based data. For this, daily material fluxes were calculated by multiplying daily flow with daily mean concentration. Concentrations for the “missing” days were obtained by linearly interpolating between the values of the sampling days. Also, here, yearly values were obtained by summing up the daily fluxes. All water samples were analyzed in an accredited laboratory for turbidity, TSS and TP. Turbidity was determined by comparing the sample and the known reference solution under the given conditions caused by light scattering intensity. TSS were determined gravimetrically according to the European standard EN872 (Finnish Standards Association SFS 1996), except for the filters used. In all filtrations made for this study, Nuclepore polycarbonate membranes with  $0.4\text{-}\mu\text{m}$  pore size were used. In TP determination, the sample was digested with  $\text{K}_2\text{S}_2\text{O}_8$  before analysis with ammonium molybdate.

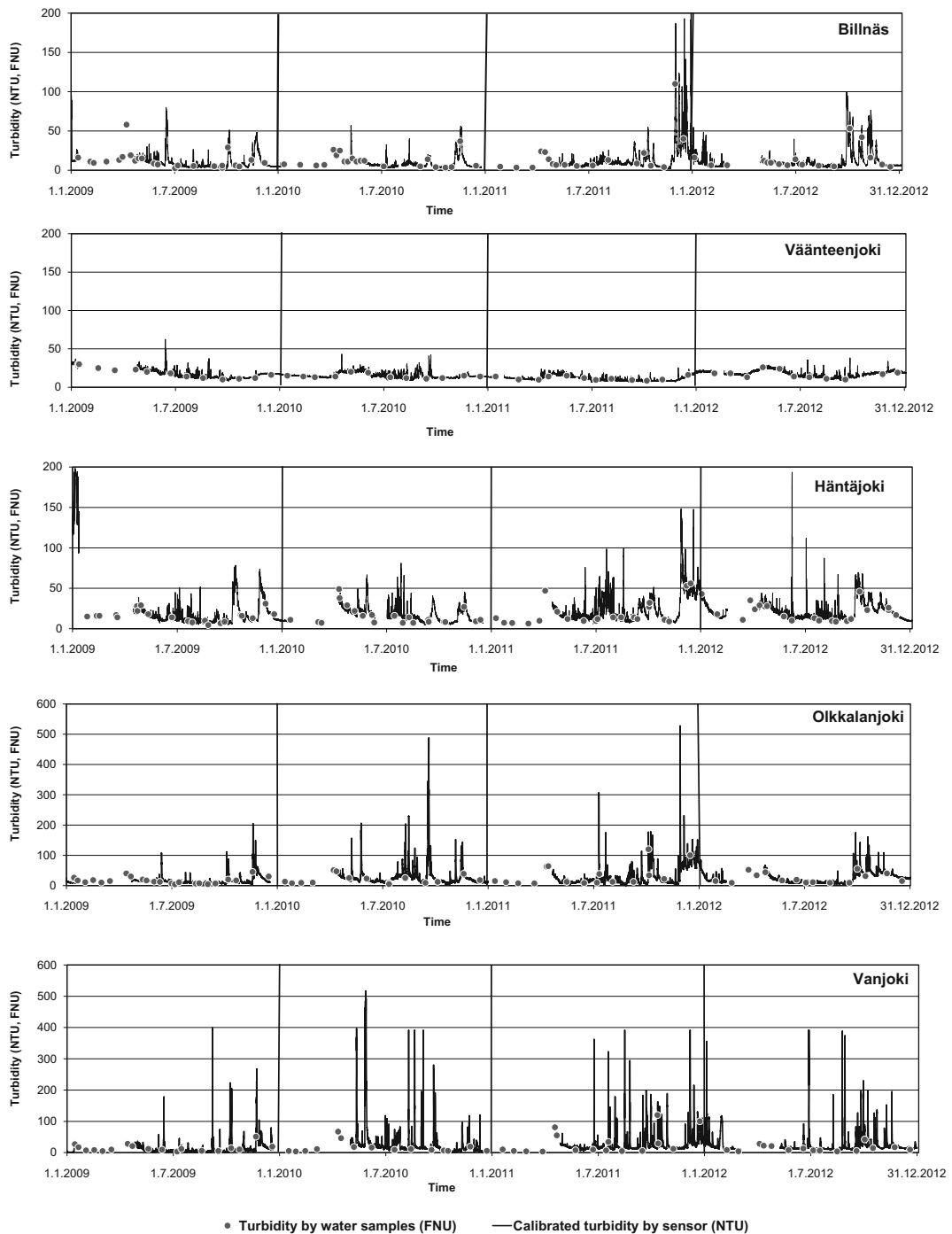
The results of nutrient loading model VEMALA developed for Finnish watersheds (Huttunen et al. 2015) were used as reference data for our sensor-based estimations. VEMALA was also employed when the Karjaanjoki Basin was compared with the Aurajoki and Vantaanjoki Basins.

## Results and discussion

### Turbidity time series

Hourly time series of the calibrated turbidity measured by sensors (curves) together with turbidity analyzed from water samples (dots) are presented in Fig. 2. As suggested by the equality of sampled and sensor-based values, calibration of the sensors was successful. Moreover, the produced turbidity time series appear to be realistic with the flow peaks (Fig. 3) following storm and melt events. Figure 2 also reveals the winter/spring periods when sensors were not functioning as they were taken up and stored due to freezing hazards. The length of these periods varies (Fig. 2) according to the coldness of the weather and to the susceptibility to freezing of the measurement site. Nevertheless, during these “devices off” periods, it is crucial to take water samples to compliment the sensor-based water quality time series. For example, in spring 2009 in Billnäs, there was an obvious snow melt-induced flow peak when a sample with 58 FNU was caught. However, in lack of continuous sensor-monitoring, it remains unknown how high the actual peak turbidity climbed during that period.

The turbidity curve of the river Väänteenjoki with clearly smoother general form and lower peak values differs strongly from those of other measurement sites (Fig. 2). This is an explicit indication of the retention effect of the lake Hiidenvesi and the close proximity of the Väänteenjoki measurement site to the lake. In other measurement sites, the distance to the upstream lakes was much longer (Billnäs and Häntäjoki), or the lakes were small (Vanjoki and Olkkalanjoki). Thus, the solid material eroded from the areas right upstream from the measurement sites during storm and snow-melt events was reflected as rapid increases of turbidity. Similarly, Ruzycki et al. (2014) detected short-term responses of flashy Lake Superior tributaries to highly variable weather and



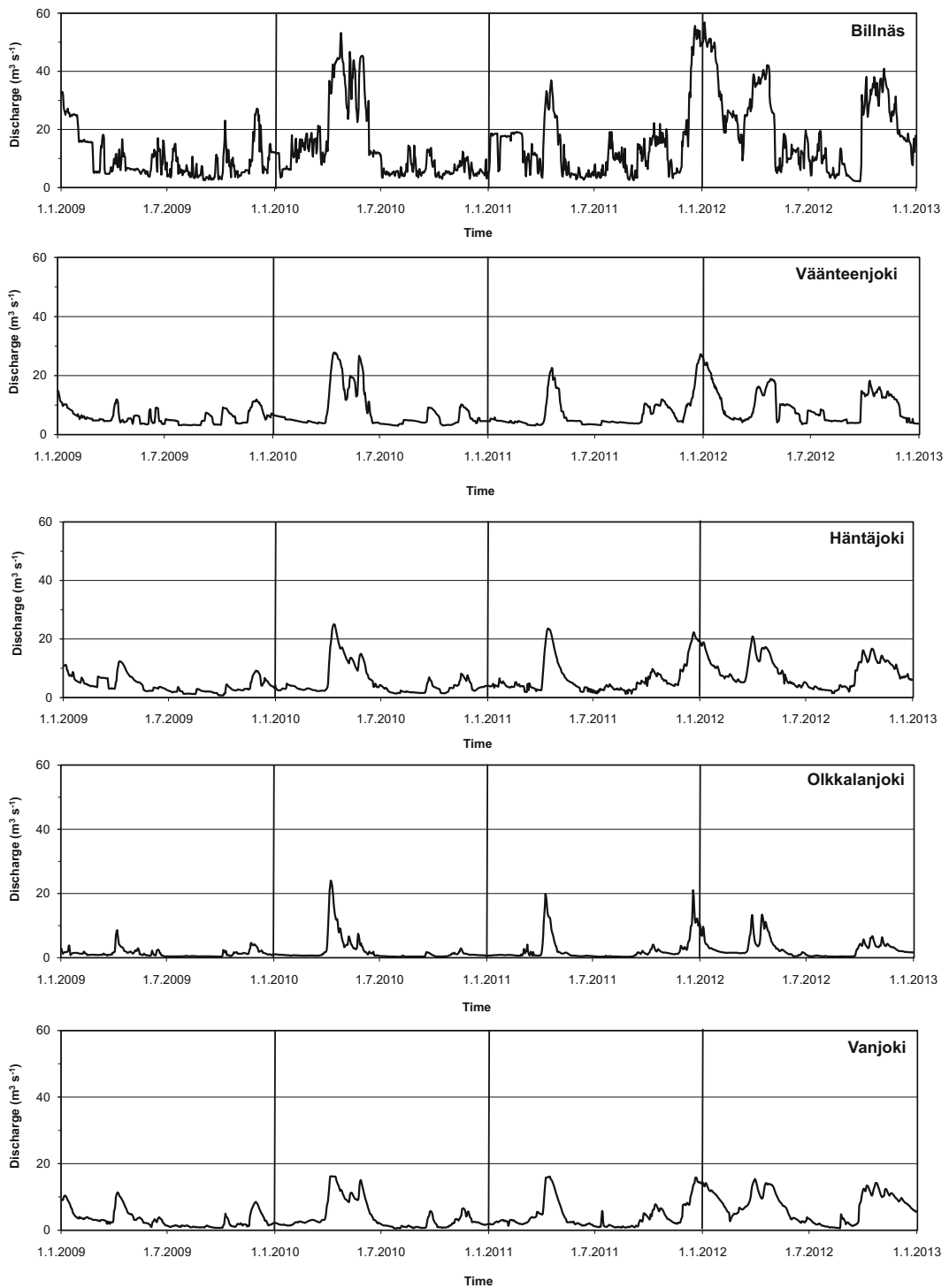
• Turbidity by water samples (FNU) — Calibrated turbidity by sensor (NTU)

**Fig. 2** Hourly time series of the calibrated turbidity measured by sensors (NTU) together with turbidity analyzed from water samples (FNU) in Billnäs, Väanteenjoki, Häntäjoki, Olkkalanjoki, and

Vanjoki measurement stations. Note the different scales of the graphs of Olkkalanjoki and Vanjoki

hydrologic conditions. In Olkkalanjoki and Vanjoki, the highest peaks of turbidity were much higher than in the other three measurement stations. This reflects

the faster (flashier) response of turbidity to flow events and lesser retention due to long distance to and/or small relative area of the upstream lakes.



**Fig. 3** Daily time series of the discharge measured in 2009–2012 by the Finnish environmental authorities in Billnäs, Väänteenjoki, Häntäjoki, Olkkalanjoki, and Vanjoki measurement stations

## TSS and TP fluxes to the Baltic Sea and the role of lake retention

TSS loading from the Karjaanjoki Basin into the Baltic Sea in 2009–2012, as based on a combination of automatic monitoring, water sampling, and the estimated transport from the unmonitored areas, ranged between 3300 and 8300 t year<sup>-1</sup> (Table 3). For TP, similarly estimated loads varied between 11,300 and 23,900 kg (Table 3), while the modeled estimations of VEMALA showed higher yearly TP loading (14,600–30,200 kg) for the same period. The difference was partly due to underestimated lake retention in the present version of the VEMALA system (M. Huttunen. pers. comm.).

When the TP loading (as calculated by the VEMALA system) of the Karjaanjoki River Basin was compared with Aurajoki and Vantaanjoki River Basins, the difference was obvious (Table 4). In spite of their smaller areas, the rivers Aurajoki and Vantaanjoki discharged 2.3 and 3.3 times more P into the Baltic Sea than the Karjaanjoki Basin, respectively. Especially the agriculture-rich and lake-poor Aurajoki Basin showed high specific TP loading value of 53.8 kg km<sup>-2</sup> yr<sup>-1</sup> (Table 4). The share of agricultural area has been reported to significantly increase TP loading from a river basin

(e.g., Vuorenmaa et al. 2002). In Karjaanjoki Basin, the share of agricultural area is the lowest of the three river basins (Table 4). Another reason for the clearly lowest loading from the Karjaanjoki Basin is lake retention, which played a lesser role in Vantaanjoki and, particularly, in Aurajoki where lake percentage was negligible (Table 4). The two large lakes situated in the mid and lower reaches of the Karjaanjoki Basin retained up to 48 and 49 % of the input TSS and TP loading, respectively (Table 3). The latter percentage is somewhat lower than the TP retention of 58 % in the lake Pyhäjärvi in southwestern Finland reported by Ventelä et al. (2007). Table 3 shows TSS and TP fluxes into the lakes Hiidenvesi and Lohjanjärvi, TSS and TP retentions in these lakes, and finally the fluxes into the Baltic Sea from the Karjaanjoki Basin in 2009–2012. Lake retention in Hiidenvesi was calculated by subtracting the material flux measured in the river Väänteenjoki from the total material flux into the lake Hiidenvesi. Correspondingly, lake retention in Lohjanjärvi was calculated by subtracting the material flux measured at Billnäs from the total material flux into the lake Lohjanjärvi.

Interestingly, in year 2009 retention of TP in the lake Hiidenvesi was only 15 % and that of TSS close to zero (Table 3). This was due to the big difference in

**Table 3** Material fluxes of total suspended solids (TSS) and total phosphorus (TP) in the Karjaanjoki River Basin in 2009–2012

Material flux	TSS (t)					TP (kg)				
	2009	2010	2011	2012	Mean	2009	2010	2011	2012	Mean
Via Vanjoki	1544	3573	3727	3522	3092	5063	7864	8770	10,659	8089
Via Olkkalanjoki	745	2037	3121	2805	2177	2771	5222	7330	7367	5672
From lake-adjacent area <sup>a</sup>	775	2825	3537	2684	2455	2651	6588	8314	7647	6300
To Hiidenvesi	3063	8435	10,385	9011	7724	10,485	19,674	24,414	25,673	20,061
Via Häntäjoki	1986	3004	4710	6077	3944	8371	10,848	15,441	19,403	13,516
Via Väänteenjoki	3095	3570	2552	4794	3503	8928	10,627	8151	14,028	10,433
From lake-adjacent area <sup>a</sup>	1771	2369	2573	4112	2706	6030	7740	8358	12,645	8693
To Lohjanjärvi	6853	8943	9835	14,983	10,153	23,328	29,215	31,949	46,076	32,642
Via Mustionjoki (Billnäs)	3285	4573	6659	8220	5677	11,079	13,735	16,839	23,378	16,258
From the area between Billnäs and sea <sup>a</sup>	58	90	156	171	84	195	271	395	486	300
To the Baltic Sea	3342	4664	6816	8391	5769	11,274	14,007	17,234	23,865	16,595
Lake retention (% of the influx)										
In Hiidenvesi	–1 %	58 %	75 %	47 %	55 %	15 %	46 %	67 %	45 %	48 %
In Lohjanjärvi	51 %	48 %	31 %	44 %	43 %	52 %	52 %	46 %	48 %	49 %
In total in these two major lakes	35 %	53 %	54 %	45 %	48 %	40 %	50 %	55 %	47 %	49 %

<sup>a</sup> Fluxes for the unmonitored areas adjacent to the lakes and seashore were estimated with a statistical equation taking into account the catchment characteristics (Jaakkola et al. 2013)



**Table 4** Average annual total phosphorus fluxes in the Karjaanjoki, Vantaanjoki, and Aurajoki River Basins in 2009–2012 as estimated by the VEMALA system

Basin	Area (km <sup>2</sup> )	Lake pctg.	Field pctg.	Total P loading		Mean total P concentration at the outlet in 2009–2012 <sup>a</sup> µg l <sup>-1</sup>
				kg	kg km <sup>-2</sup> yr <sup>-1</sup>	
Karjaanjoki	2046	12.2 %	13.4 %	20,200	11.2	34
Vantaanjoki	1686	2.5 %	24.4 %	67,200	40.8	95
Aurajoki	874	0.25 %	37.5 %	46,900	53.8	169

<sup>a</sup>Data from the water quality database (OIVA) of the Finnish environmental administration

hydrology between the years 2008 and 2009. While 2009 was an exceptionally dry year with very low material fluxes into the lake Hiidenvesi, year 2008 was wet with over 800-mm precipitation in the area (data of Finnish Meteorological Institute) and obviously high material fluxes into the lake. Thus, part of the non-lake-retained flux of 2008 was measured at Väänteenjoki site in 2009. Moreover, Hiidenvesi is a regulated lake, and some of the excess water of 2008 was probably released in the beginning of 2009 in order to maintain the target water level, which for that time further increased the material flux observed at the Väänteenjoki site in relation to the flux into the lake. Annual lake retention varied much less in Lohjanjärvi than in Hiidenvesi (Table 3). The most probable reason for this is that the residence time of water in Lohjanjärvi is more than 2 years, which levels out the annual variation of lake retention more effectively than in Hiidenvesi with clearly less than 1-year residence time.

Sources of variation in TP loading from sub-catchments

The comparison made with the large river basins in terms of the effects of agricultural land use and lake percentage on TP loading was analogous when we looked at the average TP loading of the period 2009–2012 in the sub-catchments upstream Vanjoki, Olkkalanjoki, and Häntäjoki measurement sites. The Vanjoki sub-catchment with the highest lake percentage (8.0 %) and the lowest field percentage (15.1 %) showed the lowest area-specific TP loading (18.2 kg km<sup>-2</sup>). Meanwhile, the Häntäjoki sub-catchment with respective percentages of 6.8 and 20.7 % showed higher area-specific TP loading (24.1 kg km<sup>-2</sup>, Table 5). Surprisingly, the area-specific TP loading from the Olkkalanjoki basin was, in spite of somewhat lower lake- and higher field-percentages, slightly lower than

that of the river Häntäjoki. One reason for this may be the retention effect of the lake Averia some 3 km upstream of the Olkkalanjoki measurement station. In Häntäjoki, the distance into the nearest upstream lake was similar, but the area of the lake in relation to the total catchment area was clearly smaller. It is probable that not only the lake percentage of the upstream area but also the proximity from the measurement site to the nearest upstream lake and its relative size play a role in area-specific TP loading.

Comparison of material fluxes based on water sampling and automatic monitoring

The annual material fluxes through the measurement sites in 2009–2012 presented in Table 4 were compared with those calculated on the base of the water sampling only (Fig. 4). The differences varied from year to year and, in general, the differences in TSS fluxes (-31... 39 %) varied more than TP fluxes (-22...26 %). On average, the fluxes were higher (save TP flux in Vanjoki and TSS flux in Vanjoki and Billnäs) when calculated with samples and automatic monitoring. The results utilizing automatic monitoring can be considered more accurate because of lesser time of unmonitored, “interpolated” periods. When sampling is timed, e.g., in two consecutive peaks of turbidity (and concentrations), the period between the samples becomes overestimated in terms of turbidity (and concentration), leading to overestimation of material flux. Then again, in a more common case, when samples are taken in low-turbidity situations and the peaks are missed, material fluxes will become underestimated. In practice with limited resources, it is very challenging to collect a well-balanced time series of water samples with both high- and low-flow situations realistically represented. Although the water sample datasets presented in this

**Table 5** Characteristics and total phosphorus (TP) loading in 2009–2012 in the subwatersheds above the Vanjoki, Olkkalanjoki, and Häntäjoki measurement sites in the Karjaanjoki River Basin

	Vanjoki	Olkkalanjoki	Häntäjoki
Area (km <sup>2</sup> )	484	268	602
Lake percentage (%)	8.0	5.9	6.8
Agricultural land use (%)	15.1	21.7	20.7
TP loading in 2009–2012 (kg)	8089	5672	13,516
<sup>a</sup> Data from the water quality database (OIVA) of the Finnish environmental administration			
Specific TP loading in 2009–2012 (kg km <sup>-2</sup> yr <sup>-1</sup> )	18.2	22.5	24.1
Average TP concentration in 2009–2012 <sup>a</sup>	47	65	61

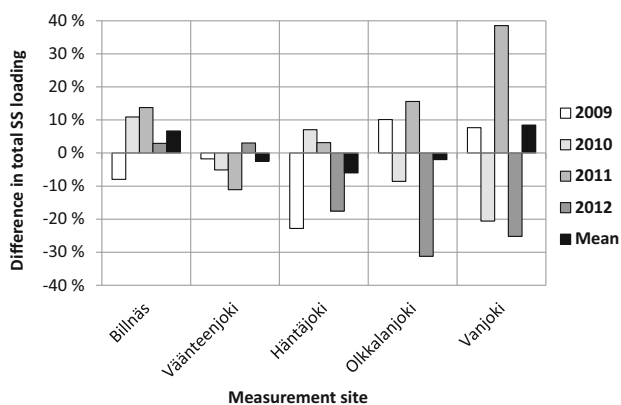
study are, at least in Finnish monitoring context, rather frequent, the errors (over and underestimates of actual fluxes) are at their worst quite high, as suggested in Fig. 4.

#### Discussion on cost-effectiveness of automatic monitoring

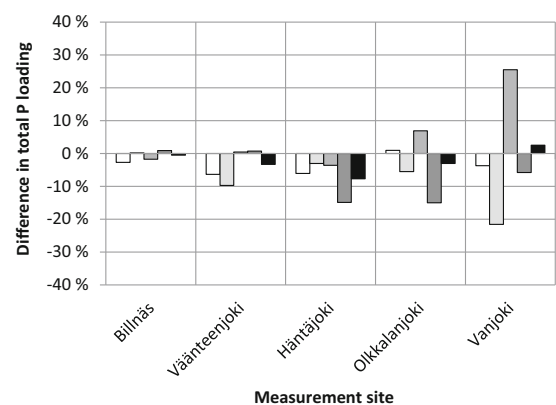
In their recent paper, Garfi et al. (2014) stated that continuous monitoring of wastewater quality could be technically feasible and even cheaper than traditional chemical-based monitoring. Our experiences of the automatic monitoring suggest that although the number of grab samples can be decreased, it does not necessarily translate into lower monitoring costs due to two facts: (i) To some extent, water samples are still needed, and (ii) automatic monitoring systems (sensors, dataloggers, wireless data transmitters etc.) and their maintenance are not always particularly inexpensive. Moreover, monitoring programs related to e.g., EU Water Framework Directive (WFD) include many water quality parameters

that are not measurable with sensors presently available. Longer term experiences and rigorous economic analyses will show how long automatic monitoring has to be exercised until (or if ever) the monitoring costs will reach the break-even point, when compared with traditional monitoring by water sampling. For now, we can only say that automatic monitoring undoubtedly improves the accuracy of loading estimates, but the cost savings are at least in the short run questionable. Thus, implementation of these systems can be truly recommended, provided that the funding of the monitoring program is not a crucial constraint.

In this study, part of the raw data produced by the turbidity sensors had to be strongly filtered and calibrated before the final calculations, which was rather time-consuming. Such “extra” work reduces the cost-efficiency of automatic monitoring. However, efforts have been made to automatize the quality assurance—calibration process (Rönkkö et al. 2014). During winter, the automatic monitoring usually had to be ceased due to the freezing hazards and damage risk of the sensors.



**Fig. 4** Difference in the material fluxes of total suspended solids (left) and total phosphorus (right) in five measurement sites in the Karjaanjoki River Basin in 2009–2012 as calculated on the bases of (i) automatic monitoring and water sampling, and (ii) water



sampling only. Negative values denote that water sampling only has yielded lower estimates than automatic monitoring and water sampling, and vice versa

This is a clear disadvantage of automatic monitoring in cold winters. On the other hand, the benefits gained in mild winters may be remarkable (Koskiaho et al. 2010). Data quality can be assured only with proper automatic cleaning and painstaking maintenance of the sensors.

## Conclusions

In terms of total loading from a large, lake-rich river basin such as in this study, the advantages of automatic monitoring were obvious and in line with those reported in several Finnish and international papers. Especially, automatic monitoring proved its usability in explorations of spatial differences in loading and lake retention. The TP loading estimates obtained by utilizing sensor data are typically higher than those based on solely water sampling, when high-flow (and turbidity) periods are often missed and the actual loading thus underestimated. However, it is also possible that sampling-based monitoring leads to overestimation. Indeed, well-functioning automatic monitoring system provides more accurate estimates of nutrient loading than traditional water sampling, but only when combined with well-balanced set of water samples for site-specific calibration of the sensors. In other words, automatic monitoring does not mean that water sampling can be omitted. In addition to calibration of sensors, water samples are needed for determination of substances (e.g., dissolved P) that cannot be detected with presently available sensors. Thus, even if the number of water samples may be decreased, a changeover from traditional to automatic monitoring does not necessarily lead to direct cost savings. Nevertheless, the distinct benefits of automatic monitoring evidently improve its price/quality ratio.

**Acknowledgments** The authors wish to thank the EU Baltic Sea Region Programme 2007–2013 and the Tekes project CLEEN/MMEA for the funding of this work and the staff of Agrifood Research Finland for the maintenance of the sensors.

## Compliance with ethical standards

**Disclosure of potential conflicts of interest** No conflicts of interest.

**Research involving human participants and/or animal** No human participants and/or animals were involved.

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