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Abstract

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To test the suitability of the model PLEASE for prediction of P losses at site scale the model has been applied to a number of intensive and more extensive monitoring sites. The results of the model application to the individual sites showed that the model is able to show relative differences in leaching fluxes between sites i.e. to distinguish low leaching sites from sites with intermediate and high leaching fluxes. Poor results are obtained for peat soils and heavy clay soils due to the fact that processes like release of P from eutrophic peat layers and preferential flow through shrinkage cracks in clay soils are not accounted for in the model. In other soils major deviations between measured and simulated fluxes are often due to differences in measured and simulated concentration profiles.

Keywords: Phosphorus leaching, validation, runoff, concentrations

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Inhoud

Preface

In this report the model PLEASE is applied to a number of intensive and extensive monitoring sites to prove its validity for application at site scale. This study wouldn't have been possible without the assistance of the people who collected the site data. We would like to thank Hanneke Heesmans and Marius Heinen for help with the buffer strip data, Christy van Beek for providing data of the DOVE peat site. Arjan Hooijboer (RIVM) provided data for the Koeien en Kansen sites.

To validate the model at the Koeien en Kansen sites and the sites in the Quarles van Ufford catchment some additional data were collected in the field. We would like to thank the farmers for access to their fields and Matheijs Pleijter and Meint Veninga for help with the data collection.

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Summary

The model PLEASE has been designed to distinguish fields with high P losses to surface water from sites with low or intermediate losses. A first validation of the model was performed for a sandy catchment (Schuitenbeek) in the central part of the Netherlands. P leaching predictions by the model for the catchment of the Schuitenbeek were close to measured phosphorus losses. However, the outcome of the model at catchment scale is determined by the sum of the estimated losses from individual fields. Underestimation of leaching fluxes at certain sites may be compensated by overestimation of the leaching fluxes at other sites. To be able to use the model for individual fields, information on the validity of the model at site scale is indispensable.

Measurements of nutrient losses to surface water at field scale are relatively scarce. In this study we used data of a number of intensive monitoring sites where fluxes and concentration were measured over a period of at least two years. These sites included the monitoring data of the DOVE sites (Diffuse emissions of dairy farms to surface water) and a project on the effectiveness of buffer strips. These two data sets comprised eight sites including different soil types (sand, peat, clay) and different hydrological conditions. As an extension to these datasets the model was also applied to a number of extensive monitoring locations (Koeien en Kansen sites) where drainwater was measured incidentally. The measurement at the Koeien en Kansen sites were carried out over a period of three to ten years.

Predicted overall phosphorus fluxes were generally comparable with the measured fluxes at the DOVE and buffer strip locations (intensive monitoring projects) except for sites with shrinkage cracks, presence of eutrophic peat layers in the subsoil or incidental high losses by overland flow. This is not surprising as processes like the release of phosphorus form eutrophic peat layers and preferential transport through cracks are not dealt with in the model PLEASE. The predictions for the extensive monitoring sites are generally less accurate but generally in the right order of magnitude, though standard values of the Langmuir parameters were used.

The model PLEASE was designed to use soil data of three layers: topsoil, upper part of the subsoil and the deep subsoil. To test whether the use of more soil layers lead to better results we applied the model using both three soil layers and four soil layers. In our study, the use of four soil layers never gave a better prediction than modeling with three layers, and adjusting the vertical schematization to the breaking-points in Pw profile did not give better results than a standard schematization. The better performance of the three layer configuration is mostly due to the fact that an exponential decline in P contents is assumed in the model. This exponential decline fits better the measured decline in the 20-50 cm layer than it does for smaller layers. However, the modeling of drainwater concentrations could be improved by including the Pw values of the soil layer of 50-100 cm. This is not surprising since drains were generally located in this layer. Adapting the soil sampling strategy to the depth of the drainage system should thus be recommended.
The results of the model application to the individual sites showed that the model is able to show relative differences in leaching fluxes between sites i.e. to distinguish low leaching sites from sites with intermediate and high leaching fluxes. Poor results are obtained for peat soils, and heavy clay soils. The poor performance for heavy clay soils is due to preferential flow through shrinkage cracks, which is a dominant pathway for P losses in these soils. In other soils major deviations between measured and simulated fluxes are often due to differences in measured and simulated concentration profiles. The simulation of the concentration profile might be improved by adapting the procedure to calculate changes in P concentrations with depth to local conditions by introducing different interpolation schemes depending on the expected profile of P accumulation in the soil.

Moreover, the use of soil type specific or even local adsorption characteristics might improve the results. Other aspects for model improvement are the estimates of runoff. Improvements can also be obtained by adapting the sampling and vertical schematization of the soil profile according to the main depth of the drainage system

1 Introduction

PLEASE (Phosphorus Leaching from Soil to the Environment) is a simple model to predict P losses to surface water (Schoumans et al., 2008). Only easily available data are necessary to run the model: soil data (water extractable P (Pw), oxalate extractable Al, Fe and P (Fe_{ox}, Al_{ox} and P_{ox}) and bulk density) and hydrological data. The amount of phosphorus which is flowing laterally through the soil to surface water is determined by P concentration in the soil and the lateral water flow (determined by hydrological characteristics and meteorological conditions) (Schoumans et al., 2008). PLEASE aims to give a good prediction of P fluxes for a wide range of soil types and P pollution intensities. Therefore, validation must be achieved for diverse situations in order to determine the limits of use of the model. A first validation of the model has already been performed (Schoumans et al., 2008) at the sandy catchment of the Schuitenbeek in the central part of the Netherlands. P leaching predictions by the model for the catchment of the brook Schuitenbeek were close to measured losses in the field. Validation at a catchment scale gives a first impression on the validity of the model results. The outcome of the model at catchment scale is determined by scaling of the calculated fluxes at the individual sample sites to the catchment scale. Underestimation of leaching fluxes at certain sites may be compensated by overestimation of the leaching fluxes at other sites. To obtain more detailed information on the validity of the model tests on site scale are indispensable.

In this study, the model PLEASE has been tested with data from a number of sites from three different monitoring projects carried out throughout the Netherlands on different soil types (sand, clay, peat) and with different degree of phosphate saturation. Two of them are intensive monitoring programs where leaching fluxes and concentrations are measured continuously for a period of at least two years: DOVE (Van Beek et al., 2009b) and buffer strips (Noij et al., 2008). The other monitoring project: Koeien & Kansen (Hooijboer, in prep.) is a more extensive measurement program where concentrations in drain water are measured four times a year. The latter might be less reliable for the validation of the model, but gave the opportunity to check the model for a wider range of conditions. However, as only drain water concentrations were available this data set could only be used to compare measured and simulated concentrations as fluxes were not measured.

2 Presentation of the monitoring sites

2.1 Intensive monitoring programs

To validate PLEASE, two complete datasets (soil data and P leaching data) were available: data from the Dove projects (Van Beek et al., 2004, 2009a; Torenbeek 2003; van der Salm et al., 2006) and from the buffer strips project (Noij et al., 2008). These are intensive monitoring programs where leaching fluxes and concentrations were measured continuously for a minimum period of two years.

2.1.1 The DOVE sites

The DOVE (Diffuse Verontreiniging Oppervlaktewater vanuit de Veehouderij, in dutch) projects are intensive monitoring programs focusing on diffuse pollution of surface water in dairy farms. Soil and water sampling were performed between 1999 and 2005 in the Netherlands and have led to a number of reports and articles published between 2006 and 2009 (Van Beek et al., 2007, 2009a,b; Torenbeek 2003; van der Salm et al., 2006). The project comprises three locations on different soil types: they are described in Van Beek et al. (2009b). The first location (Den Pol, eastern part of the Netherlands) has a non-calcareous sandy soil with a 3.5m deep loam layer which prevents exchanges with deep groundwater. The second location (de Vlietpolder, western part of the Netherlands) has a peat subsoil underneath a sandy clay topsoil rich in organic matter. A clay layer, at a depth of 3 m below the surface, prevents exchanges with deep groundwater bodies. The third location (Waardenburg, center of the Netherlands) consists of a heavy clay soil. It is artificially drained by tile drains and heavy clay prevents transfer of water and solutes to deep ground water bodies. The measurements and experiments performed at each location are described in detail in van Beek et al. (2009b). Discharge of water and solutes was measured for each site with a flow meter connected to a flow proportional sampling device (using a V-weir). For the clay site, discharge of water and solutes from tile drains to the ditches was measured. Surface run-off was measured using catchment plates at the sand and peat sites, and by flow proportional sampling of trenches at the clay site. Composition of soil solution was determined by using suction cups (sand and peat sites). Shallow groundwater was sampled for each site (using groundwater wells) to determine its composition. P adsorption experiments were performed to determine P sorption characteristics (Langmuir parameters), and oxalate extractable Al and Fe where measured. Soil sampling was performed at different depths depending on the sites (see Table 1). Available data were oxalate extractable Fe and Al concentration, bulk density, groundwater level, seepage, rainfall surplus, Langmuir parameters. As for phosphorus content, Pw was measured for the clay and sand sites and oxalate extractable P for all three sites. P concentrations in seepage were obtained from Rozemeijer et al. 2005.

Table 1

Measured P status and amount of oxalate extractable Fe and Al of the Dove sites.

Location and soil type	Soil depth cm	Al_{ox} mmol/kg	Fe_{ox} mmol/kg	$(Al + Fe)_{ox}$ mmol/kg	P_{ox} mmol/kg	Pw mg P_2O_5/l
De Vlietpolder	0- 10	107.60	165.20	272.80	28.85	-
Peat	10- 20	134.30	196.20	330.50	27.75	-
	20- 30	160.40	260.10	420.50	21.25	-
	30- 40	172.80	216.10	388.90	19.60	-
	45- 55	202.40	247.00	449.40	22.62	-
	65- 75	110.50	113.50	224.00	7.97	-
Den Pol	0- 5	62.75	11.43	74.18	19.25	53.00
Sand	5- 10	65.42	11.46	76.88	17.56	43.00
	10- 15	65.51	11.62	77.13	17.55	41.00
	15- 20	65.47	11.03	76.50	17.16	42.00
	20- 30	68.47	7.80	76.27	13.97	29.00
	30- 40	60.11	2.70	62.81	4.25	17.00
	40- 50	-	-	-	-	11.00
	50 60	-	-	-	-	10.00
	60- 80	-	-	-	-	17.00
	80-100	-	-	-	-	11.00
	100-120	-	-	-	-	16.00
Waardenburg	0- 10	66.18	102.31	168.48	-	5.30
Clay	0- 25	67.32	95.52	162.84	-	2.32
	25- 95	66.40	84.85	151.25	-	1.35
	95-126	50.79	84.13	134.92	-	2.25
	126-150	37.76	54.82	92.58	-	1.69

Table 2

Bulk densities of the DOVE sites.

	Depth cm	Bulk density kg m^{-3}
De Vlietpolder	0- 10	801
Peat	10- 20	843
	20- 30	661
	30- 40	473
Den Pol	3- 8	1441
Sand	13- 18	1408
	30- 35	1424
Waardenburg	7- 17	1166
Clay	35- 45	1377
	65- 75	1279
	100-110	1247

Measurements of solute fluxes were performed from 1999 to 2001 in Den Pol, from 1999 to 2002 in the Vlietpolder and from 2002 to 2005 in Waardenburg. Among these years, 2003 was particularly dry and hot (van Beek et al., 2004). Total P losses from these sites were 2, 5 and 3 kg P ha^{-1} yr^{-1} for respectively the sandy site, the peat site and the clay site considering the calendar year (van Beek et al., 2003a) and 1.8, 1.9 (+3 kg ha^{-1} yr^{-1} deeper layers) and 4 kg P ha^{-1} yr^{-1} considering the hydrological year (from 1st April to 1st April). Measured values of ortho-P are only available for the clay site; for the peat and sandy sites, a concentration ratio of ortho-P:total-P of 2:3 was used. This approximation is commonly used although variations can be huge.

Table 3

Mean highest groundwater level (MHG), mean lowest groundwater level (MLG), mean precipitation surpluses (PS) and seepage for the monitoring period at the DOVE sites.

	MHG	MLG	PS	Seepage
	cm	cm	mm	mm
Peat	0	59	572	-25
Sand	20	130	353	0
Clay	20	120	297	0

2.1.2 The Buffer strip sites

Full soil and P leaching data were also available for the "Buffer strip" project (van Bakel et al., 2007; Noij et al., 2008; Heinen & van Kekem, 2010). The aim of this project is to test the effectiveness of dry, unfertilized buffer strips in reducing nutrient losses to surface water in the Netherlands. Five field locations were selected for this experiment that are representative of the most important geohydrological situations in the Netherlands (Figure 1; van Bakel et al., 2007; Noij et al., 2008).

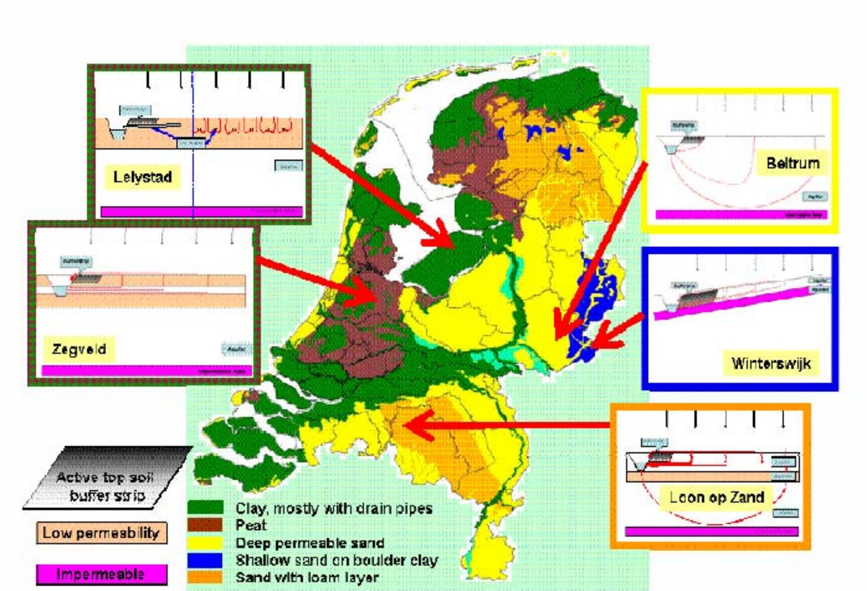

Figure 1

Geohydrological situations in the Netherlands and location of the sites in the Buffer strip project.

The Beltrum site is located in the province Gelderland (eastern Netherlands), it consists of a deep permeable sandy soil with a 1% slope. It is used as arable land where maize is grown (grass in winter as a catchment crop). At the location Lelystad (province Flevoland, Central Netherlands), the soil consists of light clay and is tile drained. This experimental field is used as arable land (and cropped with maize during the experiment) and was flat. The Loon op Zand field location (province Noord Brabant, southern Netherlands) consists of sandy soil with a less permeable loam layer at about 2 m depth. The field is flat and was used for grassland. The Winterswijk site (province Gelderland, eastern Netherlands) consists of a shallow sandy soil on top of an impermeable clay layer. The field has a 2% slope and was used for grassland. The Zegveld field location is in the province Utrecht, (central part of the Netherlands): it is a peat soil drained by ditches, typically 30-60 m apart. This experimental field was a flat grassland. In Beltrum and Zegveld, three replicated flow-proportional discharge set-ups were installed (one installation in 2006, and two replicates in 2007) and the soil was initially sampled and analyzed at the start of the measurements (either in 2006 or 2007) at 2.5 m and 20 m from the ditch. In Lelystad, Loon op Zand and Winterswijk, one replicate was installed in 2006 and the soil was initially sampled in 2005 at 2.5 m and 20m from the ditch. Soil sampling was performed at different depth intervals to a maximum depth of 2 m (not exceeding the water table). The data, which were used for the study were taken from the control (reference) plots of the buffer strip experiments, therefore these plots did not have buffer strips. Discharge of water and solutes for each location was measured by collecting water outflow from the soil profile into reservoirs placed in the ditches. It was assumed that the water running to this reservoir was coming from the adjacent part of the field. The part of the field feeding the reservoir was in most situations considered to be 5 m broad (width of the reservoir) except for Winterswijk (12.5 m) and Lelystad (16 m) where the reservoir was broader. The length of the field draining to the reservoir depended on the position of the water divide. The surface area of this strip was estimate as 300 m^2 in Beltrum, 2400 m^2 in Lelystad, 75 m^2 in Loon op Zand, 750 m^2 in Winterswijk and 150 m^2 in Zegveld. Water discharge was measured continuously from October 2006 to December 2008 and samples were taken from the reservoir regularly using an automated discharge proportional sampling device. These samples were analyzed amongst others for total phosphorus (unfiltered and filtered) and ortho-phosphate after filtration. Available soil data were oxalate exactable Fe and Al, Pw, bulk density, mean highest and lowest groundwater level (derived from the description of the profile), precipitation surplus (official data of the nearest KNMI station). P concentrations in groundwater were obtained from Rozemeijer et al. (2005). In the following tables (4 to 8), input data for each location (Beltrum, Winterswijk, Loon op Zand, Lelystad and Zegveld), replicate numbers A, B, C, and distance from the ditch (2.5 m or 20 m) are indicated.

Table 4

Measured P status and oxalate extractable Fe and Al at the Buffer strips site at Beltrum (sand) after Heinen & van Kekem (2010).

Location/ Replicate/distance	Soil depth cm	Al_{ox} mmol/kg	Fe_{ox} mmol/kg	Pw mg P_2O_5/l	Location/ Replicate/distance	Soil depth cm	Al_{ox} mmol/kg	Fe_{ox} mmol/kg	Pw mg P_2O_5/l
Beltrum/A/2.5	0-30	76.1	18.4	26.9	Beltrum/A/20	0- 30	92.7	13.2	37.5
	30-40	88.2	15.9	5.2		30- 40	112.9	6.4	3.4
	40-50	69.0	9.4	1.7		40- 50	95.3	6.5	1.9
	50-60	62.4	9.2	1.1		50- 60	70.7	4.4	1.5
	60-70	55.3	5.0	0.7		60- 70	55.6	4.1	1.3
	70-100	41.1	2.2	-		70- 100	43.4	3.0	-
	100-150	27.3	1.1	-		100- 150	30.9	1.0	-
Beltrum/B/2.5	0-30	96.3	12.8	26	Beltrum/B/20	0- 30	78.5	21.5	38
	30-40	107.7	5.7	2		30- 40	62.6	16.3	8
	4050	69.7	3.2	0		40- 50	49.0	16.2	1
	50-60	56.1	2.3	0		50- 60	48.6	12.7	0
	60-70	48.6	1.8	0		60- 70	41.8	11.0	0
	70-100	42.6	1.4	-		70- 100	33.3	9.4	-
	100-150	26.1	1.0	-		100- 150	23.8	7.5	-
	150-200	12.9	1.2	-		150- 200	15.0	3.2	-
Beltrum/C/2.5									
	0-30	97.9	13.9	26		0- 30	94.1	21.9	35
	30-40	111.8	9.0	4		30- 40	83.4	23.2	2
	40-50	92.4	10.9	0		40- 50	66.2	21.1	0
	50-60	57.4	10.1	0		50 -60	57.1	25.9	0
	60-70	57.9	13.5	0		60- 70	52.6	20.1	0
	70-100	29.2	17.0	-		70- 100	38.8	19.5	-
	100-150	14.3	6.3	-		100- 150	23.6	11.2	-
	150-200	10.6	2.0	-		150- 200	15.9	5.8	-

Table 5
Measured P status and oxalate extractable Fe and Al at the Buffer strips site at Winterswijk, Loon op Zand and Lelystad after Heinen & van Kekem, (2010).

Location/ Replicate/distance	Soil depth cm	Al_{ox} mmol/kg	Fe_{ox} mmol/kg	Pw mg P_2O_5/l	Location/ Replicate/distance	Soil depth cm	Al_{ox} mmol/kg	Fe_{ox} mmol/kg	Pw mg P_2O_5/l
Winterswijk/A/2.5 (sand on clay)	0– 10	30.4	53.2	41.3	Winterswijk/A/20 (sand on clay)	0- 10	32.5	38.2	66.9
	10- 20	30.8	46.1	34.6		10 20	35.5	40.6	47.9
	20- 30	32.8	45.3	25.0		20- 30	38.5	41.9	49.6
	30- 40	40.2	48.5	16.0		30- 40	40.3	46.3	28.4
	40- 50	39.8	50.9	6.4		40- 50	41.0	50.0	14.8
	50- 60	43.4	54.0	1.0		50- 60	33.7	35.0	8.1
	60- 70	-	-	-		60- 70	50.3	51.1	4.0
Loon op Zand /A/2.5 (sand)	0- 10	34.3	12.7	65.7	Loon op Zand /A/20 (sand)	0- 10			49.6
	10- 20	33.3	8.7	50.7		10- 20	30.2	12.2	51.0
	20- 30	39.8	4.6	26.7		20- 30	35.3	13.1	45.7
	30- 40	44.4	1.1	9.6		30- 40	34.5	12.4	36.3
	40- 50	40.4	1.1	8.6		40- 50	35.2	10.6	21.6
	50- 60	43.0	1.6	6.8		50- 60	34.5	6.0	6.0
	60- 70	45.0	1.6	10.0		60- 70	34.9	2.5	3.5
	70-100	42.3	1.3	-		70- 100	43.5	1.7	-
	100-150	60.5	5.5	-		100- 150	44.5	1.4	-
	150-200	54.4	8.1	-		150- 200	40.9	1.4	-
Lelystad/A/2.5 (clay)	0- 30	10.8	47.6	38.4	Lelystad/A/20 (clay)	0- 30	35.3	15.0	40.6
	30- 40	10.0	55.6	12.7		30- 40			15.1
	40- 50	9.1	58.5	5.4		40- 50	11.0	45.5	4.1
	50- 60	8.7	57.1	2.6		50- 60	8.4	42.9	2.2
	60- 70	8.3	58.8	1.3		60- 70	7.2	40.7	1.4
	70-100	5.7	43.2	-		70- 100	8.3	59.1	-
	100-150	5.5	15.6	-		100- 150	7.9	60.6	-
	150-200	7.3	28.1	-		150- 200	5.8	41.6	-

Table 6

Measured P status and oxalate extractable Fe and Al at the Buffer strips site at Zegveld (peat) after Heinen & van Kekem (2010).

Location/ Replicate/distance	Soil depth cm	Al_{ox} mmol/kg	Fe_{ox} mmol/kg	Pw mg P_2O_5/l	Location/ Replicate/distance	Soil depth cm	Al_{ox} mmol/kg	Fe_{ox} mmol/kg	Pw mg P_2O_5/l
Zegveld/A/2.5	0- 10	151.9	212.6	30.7	Zegveld/A/20	0- 10	148.1	210.5	21.6
	10- 20	232.9	287.8	7.9		10- 20	227.9	300.2	5.1
	20- 30	246.0	265.8	4.5		20- 30	224.0	246.4	2.4
	30- 40	215.8	234.3	5.1		30- 40	182.2	225.5	2.6
	40- 50	151.0	173.3	3.0		40- 50	139.0	207.5	1.7
	50- 60	125.5	120.3	1.6		50- 60	117.9	149.6	1.4
	60- 70	109.7	74.6	1.2		60- 70	109.5	114.0	1.5
	70-100	92.2	29.5	-		70-100	102.6	71.3	-
	100-150	89.8	9.8	-		100-150	90.1	23.2	-
Zegveld/B/2.5	0- 10	147.0	215.9	21	Zegveld/B/20	0- 10	174.7	257.3	16
	10- 20	212.0	245.1	10		10- 20	229.2	307.8	3
	20- 30	213.0	275.3	4		20- 30	210.7	265.7	3
	30- 40	188.1	224.8	1		30- 40	155.3	211.1	6
	40- 50	151.6	135.5	2		40- 50	117.3	140.5	2
	50- 60	127.5	114.5	2		50- 60	106.1	105.6	2
	60- 70	110.9	77.7	2		60- 70	98.6	64.2	0
	70-100	103.7	49.4	-		70-100	98.3	50.9	-
	100-150	97.0	28.2	-		100-150	99.4	30.0	-
Zegveld/C/2.5	0- 10	187.2	186.9	14	Zegveld/C/20	0- 10	168.6	231.5	12
	10- 20	204.8	216.9	7		10- 20	223.9	275.4	2
	20- 30	215.5	276.4	2		20- 30	227.1	284.6	2
	30- 40	175.2	325.8	1		30- 40	162.7	215.4	2
	40- 50	191.6	246.7	2		40- 50	141.4	170.0	1
	50- 60	147.9	142.5	0		50- 60	112.4	112.4	2
	60- 70	111.7	90.7	0		60- 70	102.0	91.6	1
	70-100	110.5	89.5	-		70-100	95.9	50.8	-
	100-150	93.7	32.2	-		100-150	95.5	30.8	-

Table 7

Bulk densities of the Buffer strips sites after Heinen & van Kekem (2010).

Location	Depth (cm)		Bulk density (kg m^{-3})
Beltrum	10- 20		1174
	35- 45		1712
	95-105		1687
Lelystad	10- 20		1586
	55- 65		1353
	55- 65		1323
	55- 65		1382
Loon op Zand	10- 20		1549
	50- 60		1568
	90-100		1702
Winterswijk	10- 20,	close to ditch	1388
	50- 60,	close to ditch	1386
	10- 20,	field	1468
	55- 65,	field	1430
Zegveld	30, horizontal		232
	60, horizontal		142
	85, horizontal		128
Zegveld, Europeat	0- 25		562
	10- 20		562
	35- 45		233
	55- 65		142
	85- 95		128
	100-110		131

Table 8

Mean highest groundwater level (MHG) and mean lowest groundwater level (MLG) at the Buffer strip sites (van Bakel et al., 2007).

Location	Parent material	Distance to ditch (m)	MHG (cm)	MLG (cm)	Distance to ditch (m)	MHG (cm)	MLG (cm)
Beltrum/A/2.5	Sand	2.5	60	150	20	50	160
Beltrum/B/2.5	Sand	2.5	40	130	20	30	130
Beltrum/C/2.5	Sand	2.5	40	130	20	35	130
Lelystad/A/2.5	Clay	2.5	70	120	20	70	120
Loon op Zand/A/2.5	Sand	2.5	60	>180	20	100	>180
Winterswijk/A/2.5	Sand on clay	2.5	25	>200	20	30	>220
Zegveld/A/2.5	Peat	2.5	30	80	20	35	75
Zegveld/B/2.5	Peat	2.5	20	80	20	0	80
Zegveld/C/2.5	Peat	2.5	20	80	20	0	80

2.2 Extensive monitoring sites

2.2.1 The Koeien en Kansen project

The Koeien en Kansen project is a national project including 16 dairy farms. It aims at investigating the effectiveness of environmental measures, as well as the economical and technical consequences of their implementation. The Koeien en Kansen farms comprise a wide range of soil types and observed P concentrations in drain water. Drain water was sampled and analyzed for P concentration as part of the monitoring project since 1999 (except for Nieuweroord where sampling started in 2006). The farms which were sampled were located in Bedum (province Groningen, northern Netherlands), Eijbergen (province Gelderland, eastern Netherlands), Ysselsteyn (province Limburg, southern Netherlands), Zeewolde (Flevoland province, western Netherlands), Nieuweroord (Drenthe province, northern Netherlands) and Haskerdijken (province Friesland, northern Netherlands). At Bedum, the soil consists of quite heavy non-calcareous clay (Poldervaagrond (NL), Fluvisol (FAO). Eijbergen is a loamy sandy site (Arenosol). Acdording to the dutch soil typology the sites could be classified as a Veldpodzol and a beekeergrond. Ysselsteyn is also located on sandy material and the soil consisted for 50% of a dampodzol soil (peaty podzol) and for 50% as a Veldpodzol (gleyic podzol). The site at Zeewolde is a poldervaaggrond (NL) or Fluvisol (FAO). The soil at Nieuweroord location consists of fine to quite fine sand (Arenosol). Haskerdijken soil consists of peat with a clay layer on top of the profile; the thickness of this clay layer ranges form 20 cm (weideveengrond or Histosol) to 40 cm (liedeerdgrond or Histosol). All fields were used as grassland (except for one of the fields at Zeewolde where tulips were grown). On each farm, 10 sampling points were generated at random. Four soil layers were sampled: 0-20 cm, 20-30 cm, 30-50 cm and 50-100 cm. Drain water was collected from the same fields where soil samples were taken, provided that tile drains were flowing and were above the ditch water level. Methods and data of soil and water analysis are presented in Chapter 3.

3 Analyses of soil and water samples

At part of the monitoring sites additional water and soil samples have been collected for this study. This chapter describes the methods used. Collected soil data are presented chapter 4. Results of water analyses are given in Annex 1.

3.1 Soil Analyses

Soil Sample preparation
After sampling, collected soil samples were dried and sieved. Two extraction types were performed: an extraction with ammonium oxalate to determine oxalate extractable Fe, Al and P, and a water extraction to determine Pw.

Ammonium oxalate extraction
1.5 g of soil was transferred to polyethene shaking tubes and 30 mL of the extraction solution (ammonium oxalate) was added. Then, the tubes were shaken for 2 hours in a darkened room at 20 degree Celsius. They were centrifuged for 10 min at 3000 rpm and diluted 10 times with hydrochloric acid (0.01M). The concentration of Fe, Al, and P were measured with an ICP-EAS.

Water extraction - determination of Pw
1.2 mL of soil was transferred to dry 100 mL plastic bottles and 2 mL demineralised water was added. Theses bottles were kept 22 hour in a conditioned room at 20 ºC. Then, 70 mL demineralised water was added and the bottles were shaken one hour in the conditioned room. Ten minutes later, 30 mL of the solution was transferred to polyethene shaking tubes and 0.10 mL NaCl solution (3M) was added. The tubes were centrifuged at 3000 rpm during 10min. Finally, 10 mL of the solution was filtered (0.45 μm filter) and orthophosphate concentration was determined by flow injection analyses.

3.2 Water analyses

At the extensive monitoring sites of the Koeien en Kansen project, drainwater samples were collected in March 2009. Electrical conductivity and pH were measured in the field right after taking the samples. In the laboratory, samples were filtered over 0.45μm filters; filters were weighted before and after filtration to determine the amount of sediment. Filters were dried during 6 days in a furnace at 50 ºC and weighted again 3 days later so they re-equilibrate with the atmosphere humidity. All the filtered solutions for one location (one farm) were mixed together and sent for analysis of DOC, orthophosphate and chloride (flow injection analysis), P, Fe, Al, S, Ca (ICP-analyses Inductively Couple Plasma Atomic Emission Spectrometer). When water samples had to be analyzed the day after the sampling, they were acidified (for ICP-EAS) and stored in a fridge overnight at 5 ºC. Results are presented in Annex 1.

4 Application of PLEASE to the sites

4.1 The model PLEASE

PLEASE (Phosphorus LEAching from Soils to the Environment) is a simple model to predict P leaching to surface waters. PLEASE is a static model based on the well know kinetics of inorganic P in soils and the lateral water flow from soils to surface waters. The P load by leaching from a field to the surface water is determined by the soluble P concentration profile in the soil and the distribution of the lateral water flow with depth during the year:

$$P_{load} = \psi \int_{x1}^{x2} \int_{t1}^{t2} C(x,t) \bullet J(x,t)\, dt\, dx$$

P_{load} = P loss by leaching from the field to surface water (kg ha^{-1} yr^{-1})
C = P concentration (kg m-3)
J = water flow (m s-1)
 = conversion factor (kg m-2 s-1 to kg ha-1 yr-1)
x = depth (m)
t = time (s)

Concentration profile
The phosphorus concentration in the soil solution can be calculated by the Langmuir isotherm (Van der Zee, 1988) according to:

$$C(z) = \frac{Q(z)}{K\ (Q_m - Q(z))}$$

C(z) = P equilibrium concentration in solution at depth z (mg l^{-1})
Qm = adsorption maximum (mmol kg^{-1})
Q(z) = adsorbed amount of P at depth z (mmol kg^{-1})
K = Langmuir affinity constant (l mg^{-1})

For non-calcareous sandy soils, clay soils and peat soils, the adsorption maximum (Qm) is related to the total amount of oxalate extractable Al and Fe (Van der Zee, 1988). The amount of reversible adsorbed P (Q) is rather complex to determine (Pi method; van der Zee, 1988; Manon et al., 1989). However, Q is also related to the amount of water extractable P (Pw-value). The Pw-value (Sissingh, 1971) is commonly used for the fertilizer recommendations in The Netherlands. The amount of water extractable P can be related to the P equilibrium concentration in soil solution (Schoumans, 1997 and Schoumans en Groenendijk, 2000):

$$Pw = 137{,}42 \bullet C_e \bullet \left(1 - 0.9722\, e^{-K\, k_d\, Q_m \left(1 - \frac{K C_e}{1 + K C_e}\right) t\, y} \right)$$

Pw = Pw-value (mg P_2O_5 l^{-1})
Ce = P equilibrium concentration in solution (mg l^{-1})
kd = Langmuir desorption rate (d^{-1})
t = reaction time (d^{-1})
y = conversion factor based on experimental conditions of the procedure to determine Pw (0.67 kg l^{-1} mg $mmol^{-1}$)

So, if the Pw-value of a layer and the oxalate extractable Al and Fe are determined, the P equilibrium concentration in soil solution can be assessed and consequently also the amount of adsorbed P (Q), according to the Langmuir equation:

$$Q = \frac{K\, C_e\, \beta\, (Al + Fe)_{ox}}{1 + K\, C_e}$$

The phosphorus concentration as a function of depth may be described by analyses of the soil profile on Pw, oxalate extractable Al, Fe and P. Samples of two soil layers (for example 0-0.2 m depth and 0.2 – 0.5 m depth) are probably sufficient to describe the phosphorus profile in soils that received regular fertilization over the past 30 years. In the top layer it is assumed that the soil is homogeneous due to management. For the second layer (0.2 – 0.5 m) a homogeneous distribution of P is unlikely as this layer is not ploughed. As phosphate is highly sorbed to the soil a block front can be expected in this layer. However due to diffusion and dispersion the front will be somewhat stretched out. For this reason, it is assumed that the amount of adsorbed P will reduce exponentially with depth according to:

$$Q(z) = Q_b\, e^{-k\, z}$$

z = depth within the observed layer (m)
Q_b = amount of adsorbed P at the top of the observed layer (at z=0) (mmol kg^{-1})

The concentrations in the soil layer below 0.5 m are derived by: (i) the absorbed amount at 0.5 m, (ii) the concentration of P in the deeper groundwater and (iii) the sorption capacity of the soil assuming again an exponential decline with depth.

Lateral water fluxes

Please calculates lateral water fluxes using the long term mean highest and lowest ground water level, the annual precipitation surplus and the upward and downward seepage. The lateral drainage fluxes are derived using a groundwater – drainage - relationship (Van Bakel, 1986):

$$q_{dr} = 10 * \left(\frac{\max(0, Gwl - h_{d,1})}{r_1} + \frac{\max(0, Gwl - h_{d,2})}{r_2} \right)$$

q_{dr} = drainage flow (mm d^{-1})
$h_{d,1}$ = drainage level of the drainage system 1 (cm)
$h_{d,2}$ = drainage level van of the drainage system 2 (cm)
r_1 = drainage residence of the drainage system 1 (d)
r_2 = drainage residence of the drainage system 2 (d)
Gwl = groundwater level (cm)
The factor 10 is a conversion factor

A full description of the calculation procedure of the concentration and flux profiles can be found in Schoumans et al. (2008).

4.2 Data required by the model

The PLEASE model is build to predict P losses using a limited number of input data. To run the model, we need at least local data on: oxalate extractable Al and Fe, bulk density (all layers), Pw (all layers except the bottom layer), mean highest and lowest groundwater level and depth of the drain pipes (Schoumans et al., 2008). Other data may be based on literature data: background P concentration, precipitation surplus, seepage and ratio between the distance of both drainage system (ditches and trenches). In addition, the Langmuir adsorption parameters may be adjusted according to the local conditions.

The model uses three input files: general.inp (general information, Langmuir parameters), soil.inp (soil data), hydro.inp (hydrological data). PLEASE was designed to be run with only three soil layers: the top soil (0-50 cm) which is divided in two layers (0-20 cm and 20-50 cm) and the subsoil (down to 1 m below the lowest mean groundwater level). But PLEASE can also process more layers, which is likely to give more accurate outcomes. Therefore, two runs of the model were performed: a standard application using three layers and an application with four layers. Accordingly, two soil data files (one with three soil layers and one with four layers) were derived from the available data, using the method described below. For the Koeien en Kansen sites, the layers were 0-20 cm, 20-30 cm, 30-50 cm and 50-100 cm and for the Quarles van Ufford site, it was 0-20 cm, 20-35 cm, 35-50 cm and 50-100 cm. For the sites with readily available soil data (Dove, Buffer strip project), two runs of the model were also performed: one with ‘optimized’ layers (four layers which fit best with the Pw breaking points along the profile) and one with the three ‘standard’ layers (0-20 cm, 20-50 cm and 50-bottom). Sometimes, it was necessary to adjust the available data to make them fit into the chosen vertical schematization because they had been sampled at other depths. The method used consisted of assessing the characteristics of a given soil layer using depth weighted averages. The model considers a soil profile ranging from the surface to 1 meter below the lowest mean ground water level. However, the soil was never sampled down to this depth. Therefore, we assumed that soil characteristics remained constant below the deepest sampled layer (usually 1 m) and we used this data as an estimate for the deeper layers.

The hydrological fluxes in PLEASE are calculated based on the mean highest and mean lowest ground water level and the net precipitation surplus or data about resistance and basis of the drainage system. In the site studies described here the option calibration of drainage resistance was used because no data about resistance and basis of the drainage system were available.

4.2.1 DOVE

In the hydrological input file for the DOVE sites (Table 9) values for the mean highest and lowest groundwater level, precipitation surplus and seepage flux are supplied, based on measurements at the individual sites.

Table 9
Input file with hydrological data for the DOVE sites.

Location	MHG[1]	MLG[1]	PS[2]	Seepage[3]	Drain depth
	cm	cm	mm	mm	m
De Vlietpolder	0	59	572	-25	0
Den Pol	20	130	353	0	0
Waardenburg	20	120	297	0	-0.55

[1] MHG and MLG = mean highest and lowest groundwater level
[2] PS = mean precipitation surplus
[3] Seepage = positive is downward and negative upward fluxes

In the soil data files, data are directly derived from the original dataset according to the methods described above. Pw was measured directly for the clay site (Waardenburg) and sand site (Den Pol) and derived from oxalate extractable P for the peat site (De Vlietpolder) sites.
The formula which was used was $Pw=481 * (Pox/(Al+Fe)_{ox})^{1.43}$ (Chardon 1994). Table 10 shows the soil input file with four layers, and Table 11 the file with three layers.

To obtain data for the three layer models measured data were averaged taking into account the thickness of the soil layers. This is not fully correct as bulk density should have been taken into account. However, the error introduced by neglecting the bulk density will be small as (i) bulk density has not been measured at the same depth as the soil samples and (ii) the differences in bulk density are small. Pw values should have been averaged by recalculating them to adsorbed amounts. Like the other parameters Pw was derived by depth averaging because of the gradual change in Pw and the uncertainty in Pw measurements and sorption characteristics associated to a recalculation procedure using adsorbed amounts. Seepage concentrations were not locally determined but based on Rozemeijer et al. (2005).

Table 10
Input file with soil data for DOVE using four layers.

Location	Horizon	Depth	Bulk density	$Al+Fe_{ox}$[1]	Pw	Seepage concentration
		cm	kg/m^3	mmol/kg	mg P_2O_5 l^{-1}	mg/l
De Vlietpolder	1	10	801	272.8	19	
	2	20	843	330.5	14	
	3	50	536	419.6	7	
	4	160	473	224.0		0.398
Den Pol	1	5	1441	74.2	53	
	2	20	1406	76.8	42	
	3	30	1416	76.3	29	
	4	230	1424	62.8		0.016
Waardenburg	1	10	1166	168.5	5	
	2	25	1166	162.8	2	
	3	125	1195	144.7	2	
	4	220	1247	92.6		0.036

1 Oxalate extractable Al and Fe

Table 11
Input file with soil data for DOVE using three layers.

Location	Horizon	Depth	Bulk density	$Al+Fe_{ox}$	Pw	Seepage concentration
		cm	kg/m^3	mmol/kg	mg P_2O_5 l^{-1}	mg/l
De Vlietpolder	1	20	822	302.4	17	
	2	50	536	419.7	7	
	3	160	473	224.0		0.398
Den Pol	1	20	1424	76.2	45	
	2	50	1416	67.3	19	
	3	230	1424	62.8		0.016
Waardenburg	1	20	1166	165.7	4	
	2	50	1301	153.0	2	
	3	220	1247	114.9		0.036

Langmuir parameters (Table 12) were determined by laboratory P sorption experiment (Schoumans and Zweers, 2000; van Beek et al, 2003b and van der Salm et al., 2006).

Table 12
Langmuir adsorption parameters for the DOVE.

Parameter	Den Pol	De Vlietpolder	Waardenburg
	Sand	Peat	Clay
K (l/mmol)	11.5	4	7.1
β	0.21	0.096	0.2
K_d (d^{-1})	0.053	0.155	0.05

4.2.2 Buffer strip sites

Hydrological data used for the buffer strip sites are given in (Table 13). Like the other sites drainage resistance were calibrated on precipitation surpluses. The only location that was drained was Lelystad, the drains were at a depth of 80 cm. The precipitation surplus in this table is based on standard meteorological data (precipitation minus evaporation according to the method of Makkink (Makkink, 1957)). Seepage was calculated by subtracting the actual lateral flow, measured as output from the boxes, to the official precipitation surplus given by the meteorological station. We assumed that the precipitation surplus which is not flowing laterally to the ditch is infiltrating as seepage. In the input files, a location may be represented several times to present the situation of the various replicates (see 2.1.2. The buffer strips sites).

Table 13
Input file with hydrological data for the buffer strip sites.

Location	MHG	MLG	PS	Seepage	Drain depth
	cm	cm	mm	mm	m
Beltrum/A/2.5	60	150	336.6	-176.4	0
Beltrum/A/20	50	160	336.6	-176.4	0
Beltrum/B/2.5	40	130	336.6	-176.4	0
Beltrum/B/20	30	130	336.6	-176.4	0
Beltrum/C/2.5	40	130	336.6	-176.4	0
Beltrum/C/20	35	130	336.6	-176.4	0
Winterswijk/A/2.5	25	200	443.9	-254.8	0
Winterswijk/A/20	30	220	443.9	-254.8	0
Loop op Zand/A/2.5	60	180	341.6	-64.9	0
Loop op Zand/A/20	60	180	341.6	-64.9	0
Lelystad/A/2.5	70	120	315.6	4.8	-0.8
Lelystad/A/20	70	120	315.6	4.8	-0.8
Zegveld/B/2.5	30	80	421.7	144.7	0
Zegveld/B/20	35	75	421.7	144.7	0
Zegveld/C/2.5	20	80	421.7	144.7	0
Zegveld/C/20	0	80	421.7	144.7	0
Zegveld/D/2.5	20	80	421.7	144.7	0
Zegveld/D/20	0	80	421.7	144.7	0

Standard Langmuir parameters (Table 14) for sandy soils (van der Zee et al., 1990b) were used because no sorption experiment has been performed with the soils of the buffer strip locations.

Table 14
Standard Langmuir adsorption parameters.

Parameter	Value
K (l/mmol)	35
β	0.17
K_d (d-1)	0.2

In the soil data files (table 15 and 16), oxalate extractable Fe and Al, and Pw were readily available and no derivation of data was necessary. Bulk density was determined at different depths for each location and these data were simply used (using weighted averages) to estimate bulk density at the depth we used. Seepage concentrations were not locally determined but based on Rozemeijer et al. (2005).

Table 15
Input file with soil data for Buffer strips using four layers.

Location	Depth at bottom of soil layer (cm)				Bulk density (kg/m3)			
Horizon number ->	1	2	3	4	1	2	3	4
Beltrum/A/2.5	30	40	100	250	1174	1712	1691	1687
Beltrum/A/20	30	40	100	260	1174	1712	1691	1687
Beltrum/B/2.5	30	40	100	230	1174	1712	1691	1687
Beltrum/B/20	30	40	100	230	1174	1712	1691	1687
Beltrum/C/2.5	30	40	100	230	1174	1712	1691	1687
Beltrum/C/20	30	40	100	230	1174	1712	1691	1687
Winterswijk/A/2.5	30	40	100	300	1388	1386	1386	1386
Winterswijk/A/20	30	40	100	330	1468	1430	1430	1430
Loop op Zand/A/2.5	20	30	100	280	1549	1552	1568	1702
Loop op Zand/A/20	20	30	100	280	1549	1552	1568	1702
Lelystad/A/2.5	30	40	100	220	1586	1486	1353	1353
Lelystad/A/20	30	40	100	220	1586	1486	1353	1353
Zegveld/B/2.5	10	40	100	180	562	418	142	131
Zegveld/B/20	10	40	100	180	562	418	142	131
Zegveld/C/2.5	10	40	100	180	562	418	142	131
Zegveld/C/20	10	40	100	180	562	418	142	131
Zegveld/D/2.5	10	40	100	180	562	418	142	131
Zegveld/D/20	10	40	100	180	562	418	142	131

Location	Oxalate extractable Fe+Al				Pw			Seepage concentration
	mmol/kg				mg P_2O_5/l			mg P/l
Horizon number ->	1	2	3	4	1	2	3	
Beltrum/A/2.5	94.5	104.0	56.7	28.4	26.9	3.4	0.9	0.0163
Beltrum/A/20	105.9	119.3	62.7	32.0	37.5	2.6	1.5	0.0163
Beltrum/B/2.5	109.1	113.4	52.2	19.1	26.0	2.0	0.0	0.0163
Beltrum/B/20	100.0	78.8	51.2	23.3	38.0	8.0	0.2	0.0163
Beltrum/C/2.5	111.8	120.8	63.5	15.7	26.0	4.0	0.0	0.0163
Beltrum/C/20	116.1	106.7	69.7	26.7	35.0	2.0	0.0	0.0163
Winterswijk/A/2.5	79.6	88.7	99.0	101.4	33.6	16.0	1.9	0.0163
Winterswijk/A/20	75.7	86.6	94.2	101.4	54.8	28.4	6.5	0.0163
Loop op Zand/A/2.5	44.5	44.4	44.1	63.5	58.2	26.7	9.3	0.0016
Loop op Zand/A/20	45.4	46.9	43.8	48.1	50.3	45.7	11.2	0.0016
Lelystad/A/2.5	58.5	65.6	57.9	29.4	38.4	12.7	2.2	0.0196
Lelystad/A/20	56.5	51.3	54.3	27.9	40.6	15.1	2.0	0.0196
Zegveld/B/2.5	364.5	494.2	186.6	100.9	30.7	5.8	1.6	0.398
Zegveld/B/20	358.6	468.7	226.5	112.0	21.6	3.3	1.5	0.398
Zegveld/C/2.5	363.0	452.8	196.1	122.2	21.0	5.0	2.0	0.398
Zegveld/C/20	432.0	459.9	180.0	132.9	16.0	4.0	0.7	0.398
Zegveld/D/2.5	374.1	471.5	255.2	120.4	14.0	3.3	0.3	0.398
Zegveld/D/20	400.1	463.0	194.9	122.9	12.0	2.0	1.2	0.398

Table 16
Input file with soil data for Buffer strips using three layers.

Location	Depth at bottom of soil layer			Bulk density		
	cm			kg/m3		
Horizon number ->	1	2	3	1	2	3
Beltrum/A/2.5	20	50	250	1174	1712	1687
Beltrum/A/20	20	50	260	1174	1712	1687
Beltrum/B/2.5	20	50	230	1174	1712	1687
Beltrum/B/20	20	50	230	1174	1712	1687
Beltrum/C/2.5	20	50	230	1174	1712	1687
Beltrum/C/20	20	50	230	1174	1712	1687
Winterswijk/A/2.5	20	50	300	1388	1388	1386
Winterswijk/A/20	20	50	320	1468	1468	1430
Loop op Zand/A/2.5	20	50	280	1549	1559	1702
Loop op Zand/A/20	20	50	280	1549	1559	1702
Lelystad/A/2.5	20	50	220	2586	1353	1353
Lelystad/A/20	20	50	220	2586	1353	1353
Zegveld/B/2.5	20	50	180	562	233	130
Zegveld/B/20	20	50	175	562	233	130
Zegveld/C/2.5	20	50	180	562	233	130
Zegveld/C/20	20	50	180	562	233	130
Zegveld/D/2.5	20	50	180	562	233	130
Zegveld/D/20	20	50	180	562	233	130

Location	Oxalate extractable Fe+Al			Pw		Seepage concentration
	mmol/kg			mg P205/l		mg P/l
Horizon number ->	1	2	3	1	2	
Beltrum/A/2.5	94.5	91.2	34.4	26.9	3.4	0.0163
Beltrum/A/20	105.9	110.6	37.4	37.5	2.6	0.0163
Beltrum/B/2.5	109.1	93.1	27.1	26.0	1.0	0.0163
Beltrum/B/20	100.0	72.0	26.0	38.0	4.5	0.0163
Beltrum/C/2.5	111.8	112.0	26.7	26.0	2.0	0.0163
Beltrum/C/20	116.1	97.0	37.7	35.0	1.0	0.0163
Winterswijk/A/2.5	79.6	89.7	101.3	33.6	11.2	0.0163
Winterswijk/A/20	75.7	88.8	100.2	54.8	21.6	0.0163
Loop op Zand/A/2.5	44.5	43.5	59.3	47.7	9.1	0.0163
Loop op Zand/A/20	45.9	43.2	47.2	48.7	29.0	0.0163
Lelystad/A/2.5	58.5	66.6	37.2	38.4	9.0	0.0196
Lelystad/A/20	56.5	49.6	36.1	40.6	9.6	0.0196
Zegveld/B/2.5	465.7	387.2	130.6	14.3	4.0	0.398
Zegveld/B/20	452.4	377.1	155.5	9.7	2.1	0.398
Zegveld/C/2.5	436.1	350.0	149.4	11.7	1.5	0.398
Zegveld/C/20	481.8	312.1	148.8	7.3	4.0	0.398
Zegveld/D/2.5	429.2	469.7	165.7	7.7	1.5	0.398
Zegveld/D/20	470.3	344.7	146.6	5.3	1.5	0.398

4.2.3 Koeien en Kansen

For the Koeien en Kansen sites mean highest and mean lowest groundwater levels and drain depth were based on observation at the sites (Table 17). For the Koeien en Kansen sites no discharge fluxes were available and hence the model results could only be compared to measured concentrations. Precipitation surplus and seepage were set to standard values of respectively 300 mm and 0 mm because in a static model like PLEASE the fluxes do not influence the calculation of concentrations.

Table 17
Input file with hydrological data for the Koeien en Kansen sites.

Location	MHG	MLG	PS	Seepage	Drain depth
	cm	cm	mm	mm	m
Zeewolde	70	150	300	0	-1.0
Eibergen	12	150	300	0	-0.8
Nieuweroord	20	120	300	0	-0.95
Ysselsteyn	60	150	300	0	-0.8
Haskerdijken	12	85	300	0	-0.55
Bedum	60	100	300	0	-0.95

Soil data in the file soil.inp (Table 18 and 19) were based on analysis of the collected soil samples (Ch. 3). Bulk densities were calculated based on soil texture and organic matter content, according to the equations developed by Hoekstra en Poelman (1982). Seepage concentrations were not locally determined but based on Rozemeijer et al. (2005). For the PLEASE application using three soil layers the data from layer two and three were averaged taking into account the thickness of the soil layers.

Table 18
Input file with soil data for Koeien en Kansen sites using three layers.

Location	Depth at the bottom of soil layer (cm)			Bulk density (kg/m^3)		
Horizon number ->	1	2	3	1	2	3
Zeewolde	20	50	250	1512	1512	1512
Eibergen	20	50	250	1390	1045	741
Nieuweroord	20	50	220	1281	1392	1460
Ysselsteyn	20	50	250	1335	1330	1520
Haskerdijken	20	50	185	1387	748	182
Bedum	20	50	200	1387	1281	1281

Location	Oxalate extractable Fe+Al			Pw		Seepage concentration
	mmol/kg			mg P_2O_5/l		mg P/l
Horizon number ->	1	2	3	1	2	
Zeewolde	108.3	144.9	230.7	37.9	19.9	0.0196
Eibergen	59.5	58.9	49.1	35.2	15.5	0.0163
Nieuweroord	65.0	67.1	52.8	45.8	34.0	0.0098
Ysselsteyn	73.4	68.1	32.3	27.0	21.9	0.0000
Haskerdijken	317.7	303.3	278.0	5.6	5.4	0.0065
Bedum	148.0	122.5	55.4	25.6	4.7	0.0065

Table 19

Input file with soil data for Koeien en Kansen sites using four layers.

Location	Depth layer				Bulk density			
	cm				kg/m3			
Horizon number ->	1	2	3	4	1	2	3	4
Zeewolde	20	35	50	250	1512	1512	1512	1512
Eibergen	20	35	50	250	1390	1445	644	741
Nieuweroord	20	35	50	220	1281	1339	1445	1460
Ysselsteyn	20	35	50	250	1335	1330	1330	1520
Haskerdijken	20	35	50	185	1387	1315	182	182
Bedum	20	35	50	200	1387	1281	1281	1281

Location	Oxalate extractable Fe+Al				Pw			Seepage concentration
	mmol/kg				mg P_2O_5/l			mg P/l
Horizon number ->	1	2	3	4	1	2	3	
Zeewolde	108.3	117.2	172.7	230.7	37.9	32.1	7.8	0.0196
Eibergen	59.5	61.0	56.9	49.1	35.2	22.2	8.8	0.0163
Nieuweroord	65.0	68.4	65.9	52.8	45.8	36.3	31.7	0.0098
Ysselsteyn	73.4	71.6	64.7	32.3	27.0	28.8	15.0	0.0000
Haskerdijken	317.7	308.1	298.6	278.0	5.6	6.2	4.6	0.0065
Bedum	148.0	127.2	117.8	55.4	25.6	6.0	3.4	0.0065

Standard Langmuir parameters for sandy soils (van der Zee et al., 1990b) were used in the general.inp file for these sites (table 16).

4.3 Results and Discussion

4.3.1 DOVE

The three sites of the DOVE project were subject to an intensive monitoring program for phosphorus leaching over a period of at least two years. However, ortho-P was measured only at Waardenburg (clay site); for the other two sites, we assumed that the ortho-P:total-P ratio was 2:3 (Van der Zee 1990a and 1990b). Therefore, the comparison of measured and simulated ortho-P fluxes is less accurate for these two sites. At Den Pol (sandy site) and De Vlietpolder (peat site), the model gives a very good prediction of ortho-P and total P fluxes when run with three layers (Figure 2), and it overestimates these fluxes when run with four layers (Figure 3). At Waardenburg (clay site), predicted ortho-phosphate and total P fluxes are much lower than the measured values (for both runs of the model with three layers and four layers).

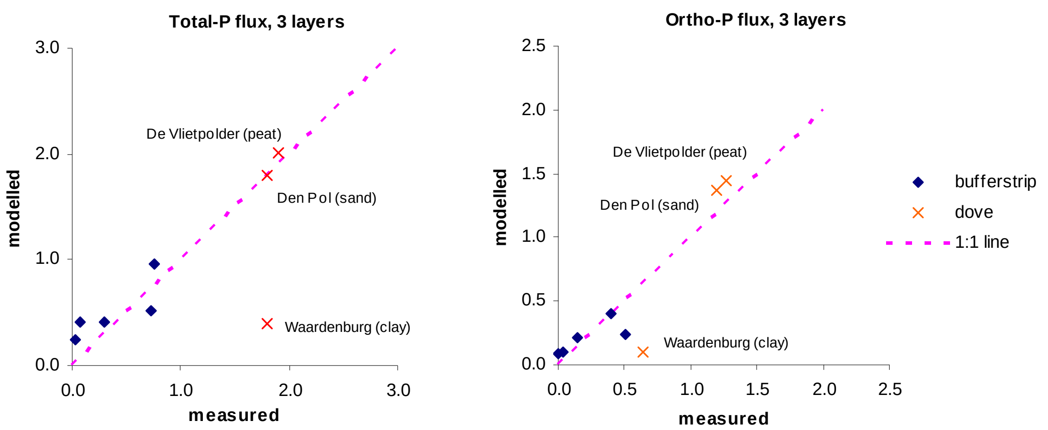

Figure 2
Modeled and measured phosphorus fluxes (total-P and ortho-P) in kg/ha/year using three soil layers.

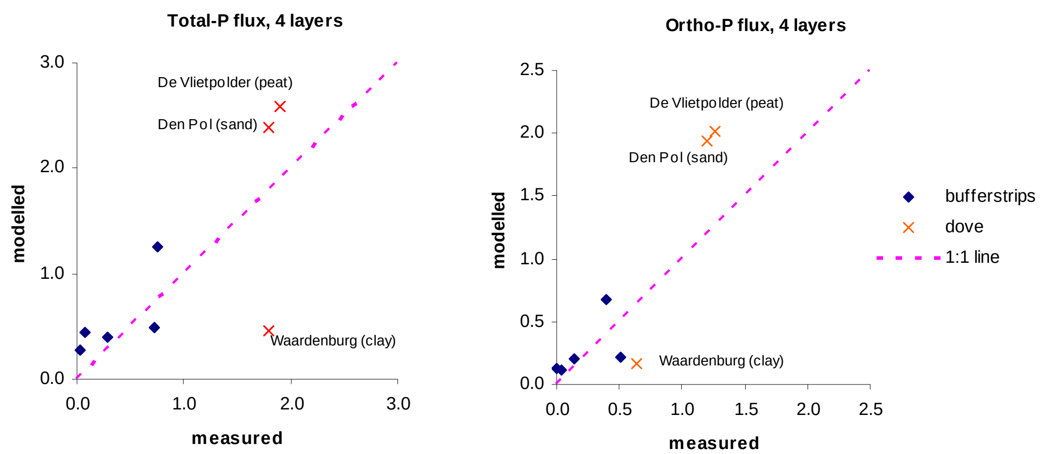

Figure 3
Modeled and measured phosphorus fluxes (total-P and ortho-P) in kg/ha/year using four layers.

There are two main reasons why the model underestimates the P fluxes at Waardenburg (clay site): first, there were shrinkage cracks in the soil, leading to preferential flow which prevents phosphorus from being retained in the soil. Secondly, mineral fertilizer and manure were applied shortly before a rainy period in 2005 and has led to massive ortho-P leaching to surface water by overland flow. Management practices and losses due to preferential flow are not taken into account in the model. As far as Den Pol (sand) and De Vlietpolder (peat) sites are concerned, prediction of total-P fluxes and ortho-P fluxes are satisfactory when the three layers schematization is used. However, one should not rule out the fact that the measured value of ortho-P is actually an estimation based on the assumption that the ortho-P:total-P ratio in leaching water is 2:3. Nevertheless, the estimation of total-P remains excellent for both sides.

In Torenbeek (2003), actual total P fluxes based on simulated water fluxes and measured P concentrations are available for the top 40 cm and for the layers below 40 cm (average of the years 1999/2000 and 2000/2001, and for two fields in Den Pol). This more detailed study shows also similar results for modeled and measured fluxes (table 20).

Table 20
Total-P fluxes from surface, shallow and bottom layer (kg P/ha/year).

	Total P fluxes (kg P ha^{-1} yr^{-1})		
	< 40 cm depth	> 40 cm depth	Total
Modeled	1.23	0.54	1.77
'Measured'[1]	1.60	0.20	1.80

[1] Based on measured concentrations and simulated water fluxes

However, data from suction cups placed at eight different depth in the soil and simulated fluxes shows that total-P concentration and fluxes in the top layers are actually overestimated by the model (Figure 4). Measured runoff, based on measured concentrations in runoff and simulated fluxes, accounts for almost 100% of the P losses from the top 40 cm, whereas measured P fluxes between 0 cm and 40 cm are close to zero. However, it has to be kept in mind that the 'measurements' are based on simulated waterfluxes and contain some uncertainty. The model PLEASE does not explicitly estimate runoff but it is included in the leaching fluxes from the upper soil layers (above Mean Highest Groundwater level).

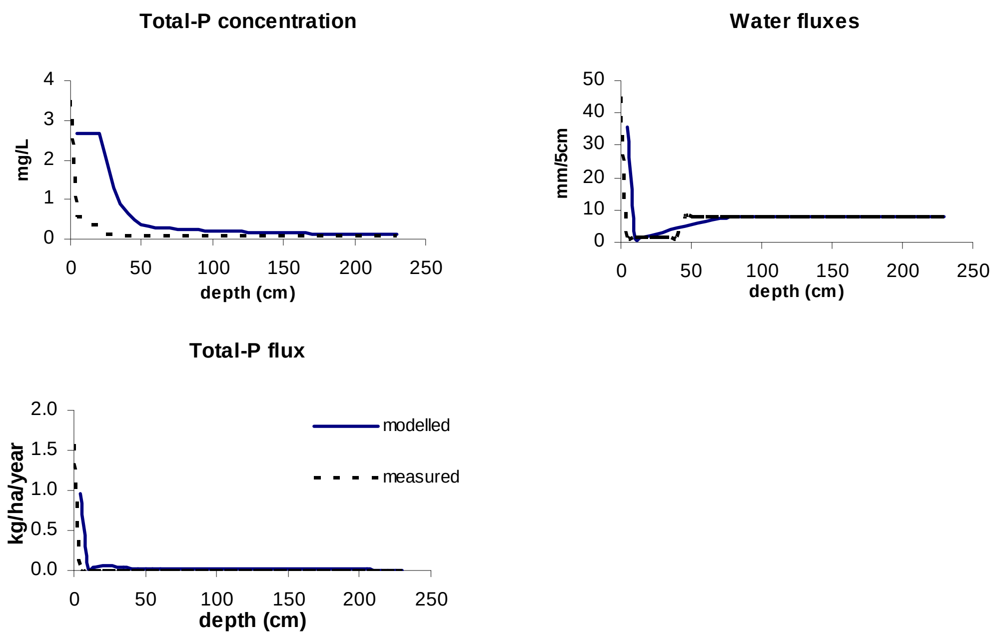

Figure 4
Measured and predicted profiles of Total-P concentration, water fluxes and P-fluxes at den Pol.

The fact that the three layer schematization gives a better result than the four layers schematization is by coincidence, as illustrated in the total-P concentration profile (Figure 5). In the four layer version, the 0-5 cm layer and the 5-20 cm layer are treated as separate layers whereas in the three layer version this part of the soil column is treated as one layer. Averaging the two top layers leads to a lower average total-P concentration (Figure 5), which gives a better result in this case (because it balances the slight overestimation of the water flow and total-P concentration in the deeper part of the topsoil).

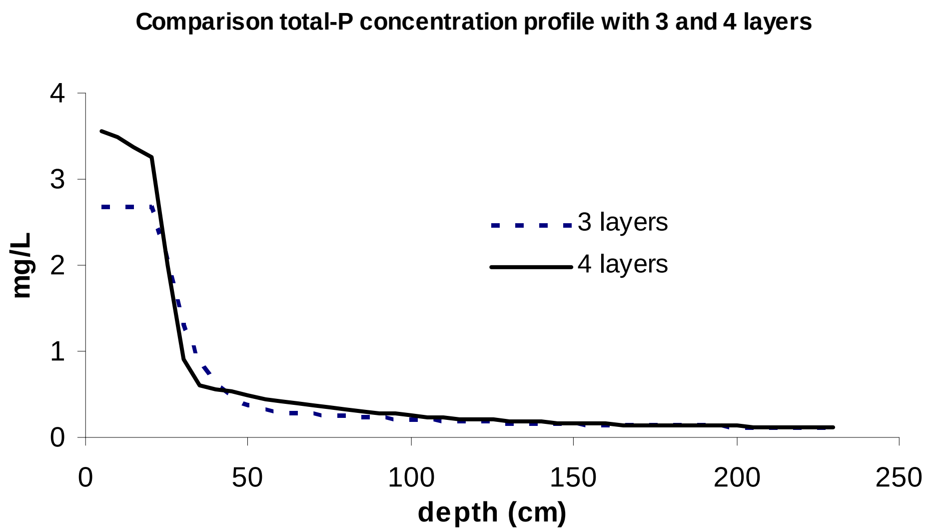

Figure 5
Predicted concentration profile using three and four layers at den Pol.

At ‘De Vlietpolder’, predicted P fluxes for the whole profile are also close to the measured fluxes. In Figure 2, we did not consider the 3 kg/ha/year coming out of the bottom soil layer (> 70 cm, table 21) because this high flux results from the replacement of water from the eutrophic peat layers, and release of P by peat is not predicted by PLEASE. Consequently, predicted values for leaching are close to the actual leaching of 1.9 kg/ha/year from the top layers.

Nevertheless, predicted distribution of these fluxes with depth differs from the measured ones. Measured P fluxes from surface, shallow and deep layers of the profile are available in van Beek et al.(2003a) (table 21). Simulated total-P fluxes from the surface layer (0-10 cm) are quite close to measured values but fluxes for the subsurface layer (10-70 cm) and the subsoil (>70) are underestimated by the model.

Table 21
Total-P flux distribution (kg/ha/year) at de Vlietpolder.

	0-10 cm	10-70 cm	>70 cm	Total
Modeled	0.43	0.59	1.00	2.02
Measured[1]	0.60	1.30	3	4.90

[1] Based on measured concentrations and simulated water fluxes

Differences between measured and simulated fluxes with depth are confirmed when looking at the P concentration profile based on measurement with suction cups. At ‘De Vlietpolder’, suction cups were placed at six different depths (15, 25, 35, 50, 70 and 120 cm) and at six different distances from the ditch (van Beek et al. 2009a). We used an average of these six distances to compare measured and predicted P concentration profile (Figure 6).

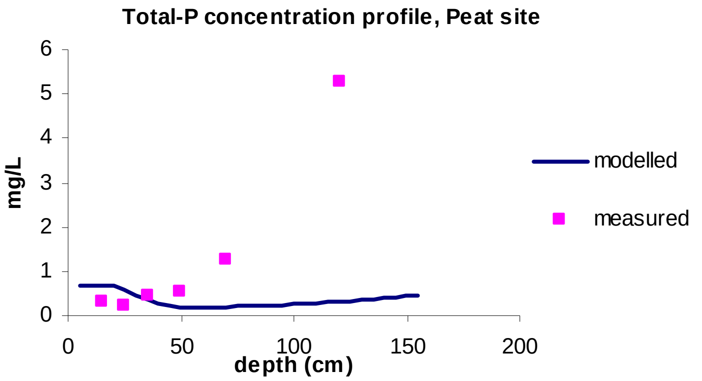

Figure 6
Measured and modeled total-P concentration profile at de Vlietpolder.

There is a clear mismatch between measured and modeled values of total-P concentration. No data are available to compare measured and modeled water flow profiles, but it obviously compensates the error in P concentration profile so the estimation of global P flow is satisfactory (see Figure 2).

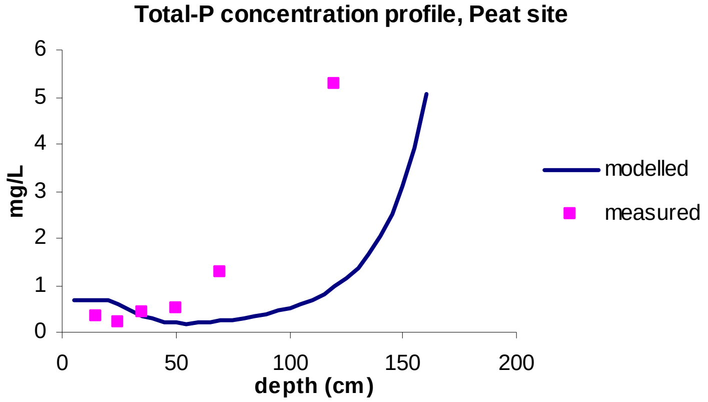

Figure 7
Measured and modeled total-P concentration profile at de Vlietpolder using corrected P background concentration.

The main reason why measured and simulated concentrations profiles differ (Figure 6) is that we used a P background concentration based on regional concentration in seepage water (Rozemeijer et al, 2005), whereas the actual on-site concentration is higher (5.2 mg/l at 120 cm). The leaching of P from the eutrophic peat layer can be included in the model by using this higher value for the background concentration of P (measured on the site). In Figure 7, a P background concentration of 5.2 mg/l was used equal to the P concentration measured in cups at 120 cm. In the model this background concentration is reached at 1 m. below the deepest groundwater table (160 cm). The modeled curve is closer to the measured one when this higher concentration is used, but the increase with depth is still too low. This discrepancy is inherent to the model that assumes an exponential decline or increase of concentrations and adsorbed amounts with depth.

The mismatch between measured and simulated fluxes may be not only caused by misestimates of the P concentration but it has to be kept in mind that at den Pol and de Vlietpolder, water fluxes were not measured but calculated based on simulations and P fluxes were derived from the latter.

At den Pol, the predicted P concentration profile does not fit perfectly the measured one whereas PLEASE simulates a fairly comparable profile of the lateral water fluxes and the resulting P flux distribution is satisfactory. At de Vlietpolder, inaccurate estimation of water fluxes and P concentration leads to P flux profiles which were different from the measured ones. But predictions of global P losses were satisfactory, despite a different distribution.

4.3.2 Buffer strips

For the buffer strip sites, actual ortho-P and total-P fluxes are available and can be compared with the values predicted by the model. Differences are most likely due to differences in concentration or drainage distribution with depth because measured total drainage is input to the model. As for the DOVE sites, estimations by the model including three layers are better than with four layers (see table 22, sum of squares). When three layers are used ortho-P and total-P fluxes (Figure 8) are overestimated for four sites (Beltrum, Lelystad, Winterswijk and Zegveld) and underestimated for Loon op Zand.

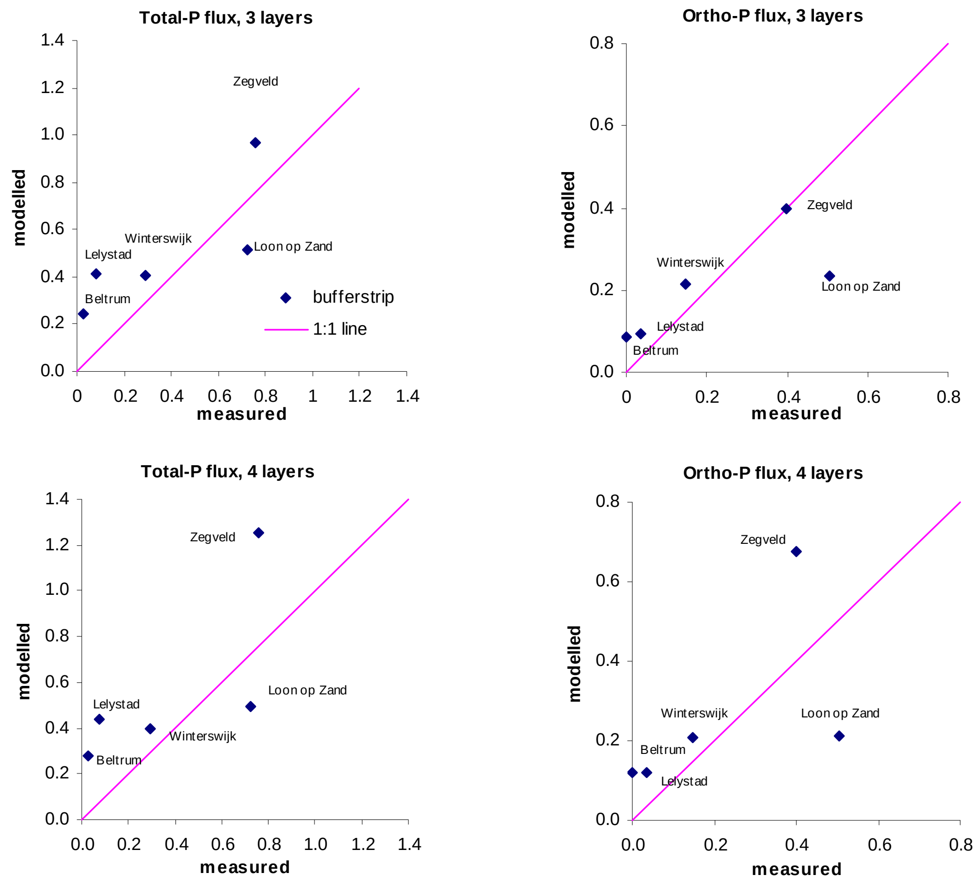

Figure 8

Modeled and measured phosphorus fluxes (total-P and ortho-P) at the Buffer strips sites.

As far as Beltrum, Lelystad, Winterswijk and Zegveld are concerned, predicted values of ortho-P and total-P fluxes are too high (from 1.4 to 98 times higher than the measured fluxes) but one should keep in mind that the measured fluxes are very low (ortho-P fluxes of 1.2 10^{-3} kg/ha/year at Beltrum, 0.03 kg ha^{-1} yr^{-1} at Lelystad and 0.14 kg ha^{-1} yr^{-1} at Winterswijk) compared to the other two buffer strip sites and to the Dove sites. At the scale used in Figure 8, the prediction for these buffer strip sites seems disappointing but when looking at the graph including all the intensively monitored sites (Figure 2), we see that at these three sites, the absolute P losses are very low. This are actually sites were both predicted and measured values are close to zero: even when there is a relative difference by a factor of 98, the absolute difference is very low. At Beltrum, the model overestimates total-P losses by 0.22 kg ha^{-1} yr^{-1}, at Lelystad by 0.34 kg ha^{-1} yr^{-1} and at Winterswijk by 0.11 kg ha^{-1} yr^{-1}.

For Zegveld (peat site), the ortho-P flux is comparable to the measured flux for the three layers version and higher than measured fluxes for the four layers version of the model (70% too high). Modeled total-P fluxes for Zegveld are too high: 1.3 times higher than the measured ones when three layers are used and 1.7 times when four layers are used. It seems that derivation of total-P from ortho-P using the equation of Chardon et al. (2007) is not valid for this type of (peat) soil, although data from the topsoil (0-30 cm) of Zegveld have been used to validate this equation.

Loon op Zand is the only site where all fluxes are underestimated: using three layers, total-P is 29% too low and ortho-P is 54% too low. When four soil layers are used, total-P is 32% too low and ortho-P is 58% too low. Total-P prediction is closer to the line than ortho-P but this is by accident because total-P is derived from ortho-P in the model. This site seems to release relatively much phosphorus whereas the model predicts a P release that is hardly higher than at

Lelystad and Winterswijk. A reason might be that the K value of this site differs considerably from the standard value of the Langmuir parameters that were used in this application.

Measurement of ortho-P concentration in the soil solution at different depths (using suction cups) can be compared with the modeled ortho-P concentration profile (Figure 9). At Beltrum, measured ortho-P concentrations (at any distance from the ditch) are almost zero at a depth of 50 cm and more, and the modeled ones are also very low at this depth (less than 0.05 mg/l). Unfortunately, no suction cups were placed in the first 50 cm (where modeled ortho-P concentration is high): uncertainty at this depth might be a reason for the slight overestimation by the model. Nevertheless, we can say that both measured and modeled ortho-P concentrations are quite low for the site. Thus, phosphorus fluxes are low and quite well estimated (Figure 9).

At Winterswijk, results for suction cups placed 0.5 m and 20 m away from the ditch are different: concentrations measured at 20 m from the ditch are much higher than those measured at 0.5 m from the ditch. Measured ortho-P concentrations (20 m away from the ditch) are lower than the modeled ones in upper 0.5 m of the soil and higher between 0.5 m and 0.9 m. However, overestimation of ortho-phosphate flux is dominant in the top layers and this might be the reason why P fluxes are somewhat overestimated for the Winterswijk site.

At Loon op Zand, measured ortho-P concentration are close to zero for the deep layers. However, measured ortho-phosphate concentration at 0.5 m (20 m from the ditch) is higher than the modeled concentrations. This might indicate that actual ortho-phosphate concentrations are higher than what is predicted by the model. As the top layers are contributing much to P leaching (due to large water flows), it explains why the model underestimates fluxes at Loon op Zand.

At the Lelystad location, the model fits well the measured values below 40 cm. Unfortunately, the modeled concentrations in the top layers which are much higher can not be validated as data for the upper layers are not available.

At Zegveld, measured data are negligible at 30-40 cm depth and show an increase in ortho-phosphate concentration with depth. In the topsoil simulated concentrations are higher than measured values which are almost zero. The increase in concentrations with depth is simulated by the model, but the measured increase in concentrations occurs at a more shallow depth compared to the model predictions. This phenomenon was also found at the DOVE peat location in the Vlietpolder, where subsoil concentrations were underestimated by the model.

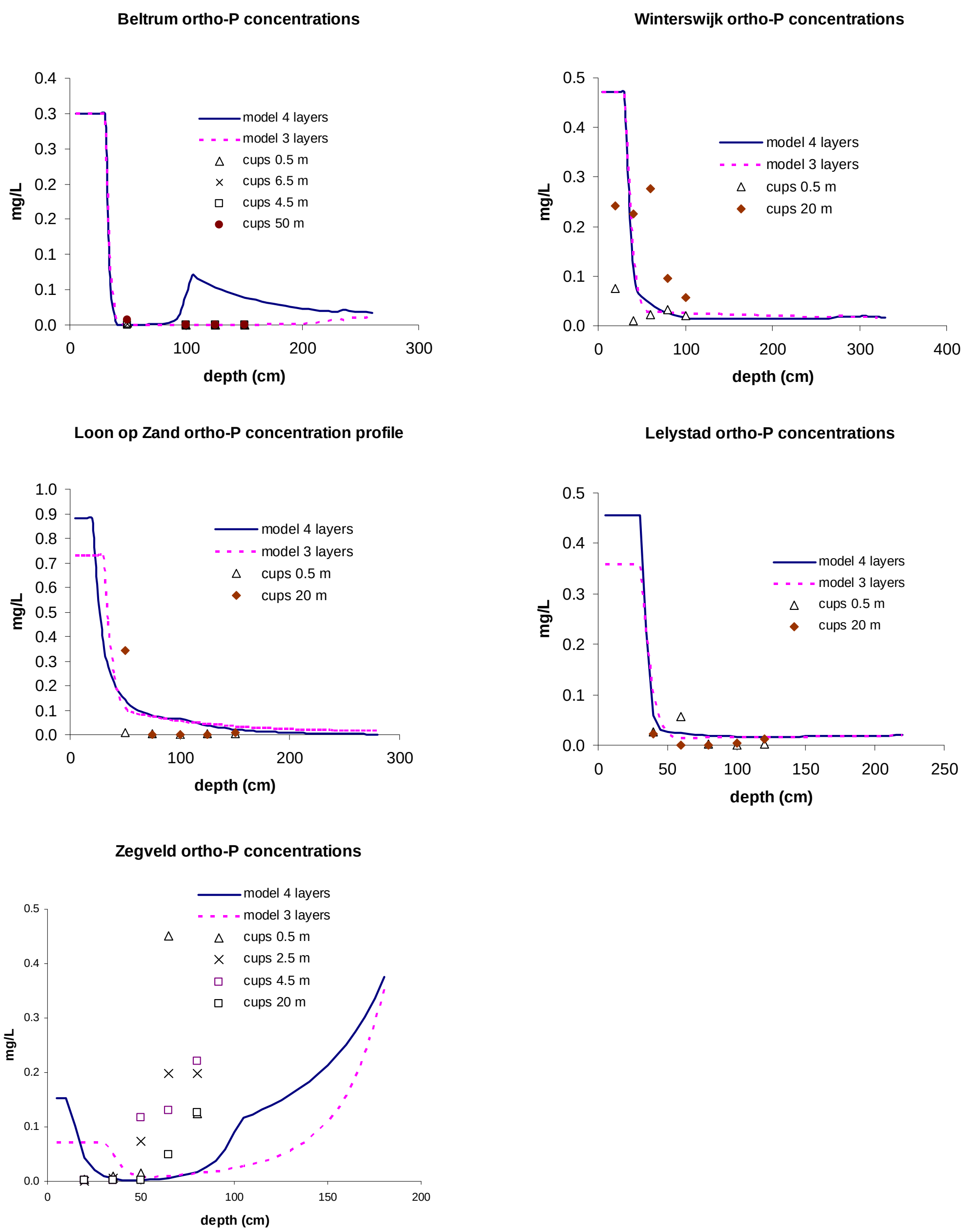

Figure 9

Measured (average over two year period) and simulated ortho-P concentrations for the buffer strip locations.

Despite the deviation between measured and simulated concentrations, predicted ortho-phosphate fluxes were close to measured fluxes when using the three layers model. When using four soil layers the modeled concentrations were closer to measured values but fluxes were overestimated. This unexpected result may be due to (i) in the three layer model overestimation of the concentrations at 30-40 cm depth may be compensated by the underestimation of the concentrations at 60-70 cm depth or (ii) difference in the distribution of vertical water fluxes may counterbalance the mismatch in predicted concentrations.

As a conclusion, overestimation of total-P and ortho-P fluxes for Beltrum, Lelystad and Winterswijk may be due to too high estimated ortho-P concentrations (although data for the top soil are missing). At Loon op Zand, the modeled ortho-P concentration profile is quite good, but still predicted fluxes are underestimated. At Zegveld, modeled concentrations in the topsoil were too high whereas concentrations in the subsoil increased too little with depth never the less predictions of ortho-P fluxes were quite good using three layers. In general, prediction of ortho-P concentration profiles are quite good (apart from Zegveld), but derivation of this data to obtain total-P concentration, or inaccurate estimation of water fluxes profile lead to less accurate predictions of P fluxes. Nevertheless, the order of magnitude was always correct for the Buffer strips sites.

4.3.3 Koeien en Kansen

For the Koeien en Kansen sites no fluxes were measured, hence only drain water concentrations (total-P and ortho-P) were compared. In the graphs below (Figure 10), 'model drain' data were obtained considering the ortho-P and total-P concentrations within +/- 20 cm of the drain depth. As an alternative also so called 'Model profile' data are presented. These data are based on fluxweighted average concentrations for the soil profile as given in file plek.out and include losses by runoff. 'Measured drain average' are average concentrations in the drain water sampled since 1999. 'Measured drain March 2009' are the concentrations in the drain water sampled in March 2009. In the description below, we compared 'model drain' and 'measured drain average' unless otherwise indicated.

At Zeewolde, good results were obtained for prediction of total-P concentrations in drain water (overestimated by 14.5% when three layers are used and underestimated by -15.0% when four layers are used). Nevertheless, total-P concentration is derived from ortho-P, and the latter is strongly underestimated by the model when four layers are used (-82.8%), which suggests that good prediction of total-P using four layers is by chance. Predicted ortho-P concentration using three layers is only 13.6% too low. Thus, prediction was generally better when using three layers (because of a very bad prediction of ortho-P concentration with four layers), and the best prediction for total-P were obtained for this location.

For the Eibergen location, the model overestimates all the concentrations (ortho-P by 74.7% and 120.1%, and total-P by 379.4% and 415.3% respectively for three and four layers). Predicted values are more satisfactory when compared with the drain water collected in March 2009 (i.e. 35.5% difference for the estimation of ortho-P concentration using three layers).

For Nieuweroord, predicted concentrations in drain water are higher than the drain concentrations measured in March 2009 but lower than the average measured concentration. The underestimation with respect to the average measured drain concentrations when three layers are used is -60.9% for ortho-P concentration -44 % for total-P. When four layers are used, ortho-P concentration is underestimated by -44% and total-P by -32%.

At IJsselstein, predicted values are quite good for ortho-P concentration (+52.4% and -44% respectively for three and four layers, but with a small absolute difference since both estimated and measured concentrations were extremely low). Predicted values of total-P are too high (overestimated by 570% when using three layers and 469% when using four layers).

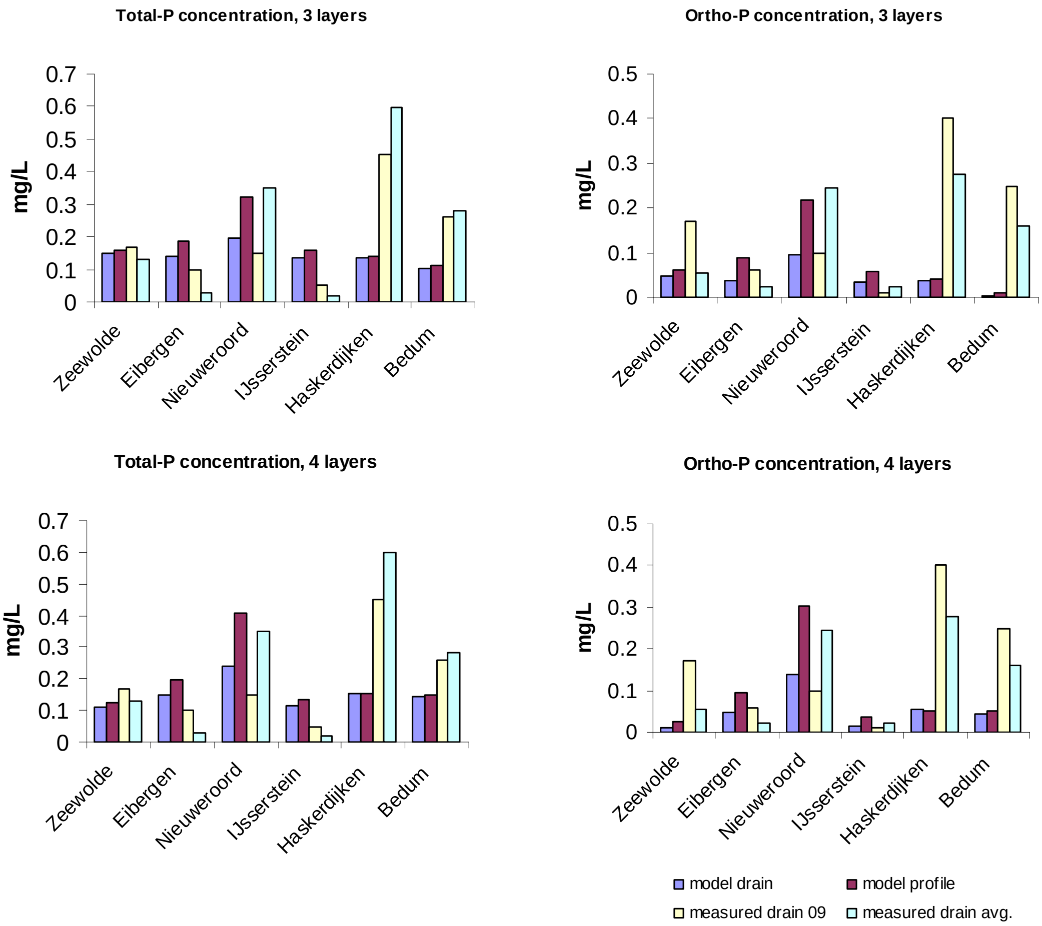

Figure 10
Phosphorus concentration in the drain and from the profile; measured and modeled.

For Haskerdijken and Bedum, total-P and ortho-P were underestimated (for both three layers and four layers schematizations) and absolute difference was huge for Haskerdijken site. At Haskerdijken, the soil is an eutrophic peat and the latter might generate a release of nutrients which is not predicted by the model. A similar mismatch was also found for the intensively monitored peat sites in Zegveld (cf. 4.2.2. Buffer strips) and the Vlietpolder (cf. 4.2.1. DOVE). For Bedum estimation of total-P concentration is satisfactory but ortho-P concentrations are far too low. Another peculiar result is the difference between three and four layers estimation of ortho-P concentration: it is 0.0021 mg/l when three layers schematization is used and 0.102 g/l when four layers are used (46 times higher). This is due to a malfunctioning of the model related to a too steep exponential decrease of the P concentration profile. In the graph below, Pw decrease between the 20-35 cm layer and the 35-50 cm layer is so sharp that the model draws an odd profile (Figure 11, four layers). In this case, the three layers schematization gives a more logical concentration profile, even though final prediction is closer to reality when four layers are used (Figure 13).

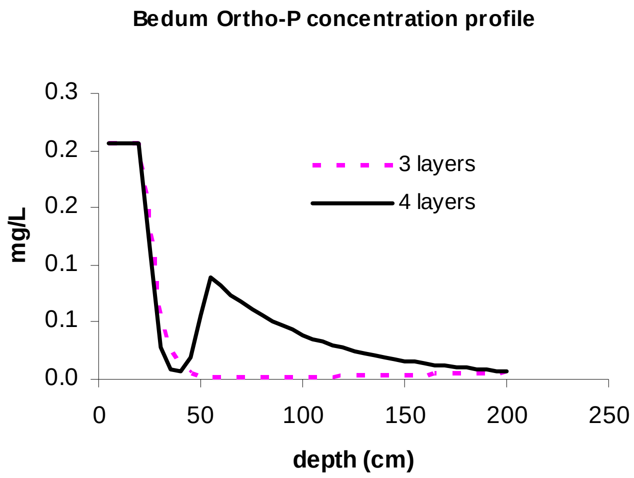

Figure 11
Bedum ortho-P concentration profile modeled with three layers and four layers.

In summary the above results showed that values were quite close to measured data for Zeewolde and Eibergen. The largest absolute deviations between measured and simulated values were found for Nieuweroord, Haskerdijken and Bedum. For the other three sites relative deviation may be substantial but the absolute error is relatively small as concentrations at these three sites are low. The available data allow some further adaption's of the input by: (i) including measurements of Pw values for the subsoil (50-100 cm) and (ii) using P background concentrations that are not corrected for precipitation of phosphorus with available Fe in the seepage water

In the standard simulations one soil layer was used for the soil beneath 50 cm and background concentrations were used to calculate the decline in P concentrations in the soil between 50 cm and a depth of 1m below the mean lowest groundwater table. For the Koeien en Kansen sites Pw values for the 50-100 cm were measured and could be used to improve the estimates of P concentrations in the soil layer around the drains (55-95 cm). In all applications in this report we assumed that upon aeration in the soil the phosphorus in seepage water will precipitate with Fe present in the seepage water. We thus corrected the regional background concentrations for instantaneous precipitation of phosphorus with available Fe in the seepage water. In reality all or part of the P may be leached together with Fe and precipitate in ditches or streams. The effect of these changes in model input are shown in Figure 12.

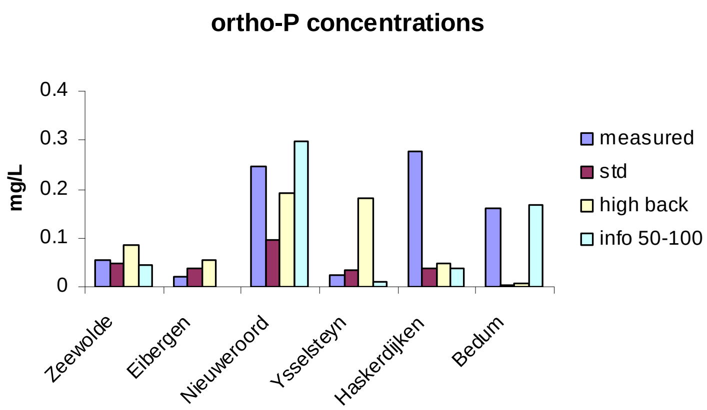

Figure 12
Bedum ortho-P concentration profile modeled with three layers and four layers.

The use of higher background concentration (no precipitation of P) leads to better results for Nieuweroord but less good results for Ysselsteyn, Zeewolde and Eibergen. For Haskerdijken a slight improvement is found but concentrations are still far too low. The use of Pw data of the 50-100 cm soil layer improves the results in all cases except for Eibergen where concentrations are overestimated. The results indicate that the collection and use of Pw values of the soil layers which contribute most to the leaching improves the results.

4.4 Comparison of three layers and four layers schematization

In all the presented model application we used both input files based on three soil layers and on four soil layers. We assumed that the use of more soil layers would improve the description of the concentration profile and thus lead to better results. To proof this hypothesis the root mean squared errors (RMSE) were calculated for the DOVE sites, the buffer strip sites and the Koeien en Kansen sites (table 22). The table shows that in our examples, the 'four layers' input data generally did not give better results than the 'three layers' ones. On the contrary, the sum of squares was often lower when three layers were used in the input file. Most probably, this is due to the assumption of an exponential decline in P content with depth. This assumption leads to a better correspondence when three layers are used compared to four layers.

An exception is formed by the validation of PLEASE on drain water concentrations at the Koeien en Kansen sites. For these sites the model results using four layer is comparable or slightly better compared to the results using three layers. At the Koeien en Kansen sites a further improvement was obtained by using Pw values of the 50-100 cm soil layer (Figure 12). This improvement led to a RMSE of 0.10 compared to resp. 0.11 for a four layer application without Pw data of the subsoil and 0.13 for a three layer application.

Table 22
Root Mean Squared errors (RMSE) for the deviation between measured and simulated P fluxes (kg/ha/year) and P concentration (mg/l) using three soil layers and four soil layers.

	Flux				Concentration			
	Total-P		Ortho-P		Total-P		Ortho-P	
	4 layers	3 layers	4 layers	3 layers	4 layers	3 layers	4 layers	3 layers
Buffer strip	0.32	0.23	0.19	0.13	0.11	0.10	0.07	0.06
DOVE all sites	0.93	0.81	0.66	0.34	0.29	0.27	0.17	0.11
DOVE (peat and sand)	0.64	0.09	0.74	0.18	0.15	0.02	0.18	0.04
Koeien en Kansen	-	-	-	-	0.20	0.22	0.11	0.13

5 Discussion, conclusions and recommendations

Although it requires only a limited amount of input data, the PLEASE model proves to give reasonable prediction of phosphorus losses to surface waters. The results showed that the model was able to show relative differences in leaching fluxes between sites i.e. to distinguish low leaching sites from sites with intermediate and high leaching fluxes. Predicted phosphorus fluxes were generally comparable with the measured fluxes at the intensive monitoring sited of the DOVE and Buffer strip projects. Exceptions were sites with shrinkage cracks, high losses by overland flow or presence of eutrophic peat layers in the subsoil. Processes like release of nutrients by eutrophic peat layers, preferential flow due to the presence of cracks and incidental losses due to overland flow are not explicitly included in the model. The estimation for drain water concentrations at the more extensive monitoring sites at the Koeien en Kansen sites were also in the right order of magnitude, though standard values of the Langmuir parameters were used. Exceptions are the peat site at Haskerdijken and the clay site at Bedum where concentrations were underestimated by the model.

In our study, the use of four soil layers generally did not give a better prediction than modeling with three layers, and adjusting the vertical schematization to the breaking-points in Pw profile did not give better results than a standard schematization. The better performance of the three layers configuration is mostly due to the fact that an exponential decline in P contents is assumed in the model. This exponential decline fits better the measured decline in the 20-50 cm layer than it does for smaller layers. Thus, a standard schematization of the soil profile considering two layers for the top soil (0-20 cm and 20-50 cm) and a sample for the deep soil (50-100 cm) seems to be a good option. The modeling of drain water concentrations could be improved by including the Pw values of the soil layer of 50-100 cm. This is not surprising since drains were generally located in this layer. Adapting the soil sampling strategy to the depth of the drainage system should thus be recommended.

Deviation between measured and simulated fluxes may be due to the fact that part of the input data was based on generic information. For example generic P adsorption isotherms for sandy soils were used for all buffer strip and Koeien en Kansen sites and regional data on background concentrations of phosphorus were used instead of local data in all studies. Another reason for deviations can be found in the general relationship between ortho-P and total-P that is used in the model (Chardon et al., 2007). In some cases ortho-P concentrations and fluxes are well simulated whereas total-P fluxes are not.

Detailed examination of the results on basis of simulated and measured concentration profiles showed that sometimes large deviations between both profiles occur. Such deviations mostly occur in situations were sharp changes in P concentrations occur in the soil profile. For example the strong increase in P concentrations in the subsoil of the peats sites in de Vlietpolder and Zegveld due tot the presence of eutrophic peat layers could not be simulated. The results from the sandy site at Loon op Zand and the clay sites at Lelystad showed that P concentration in the subsoil (> 50-100 cm) declined sharper than predicted by the model. The model assumes an exponential decrease or increase in concentrations with depth leading to gradual changes with depth. This assumption does not always match reality. To improve the model it might be considered to adapt this formulation according to regional circumstances.

Based on the above results it can be concluded that the model is able to show relative differences in leaching fluxes between sites i.e. to distinguish low leaching sites from sites with intermediate and high leaching fluxes. Further improvement of the results may be obtained by:
– adapting the procedure to calculate changes in P concentrations with depth to local conditions;
– the use of soil type specific or even local adsorption characteristics;
– improvement of the estimates of runoff;
– adapting the sampling and vertical schematization of the soil profile according to the main depth of the drainage system.

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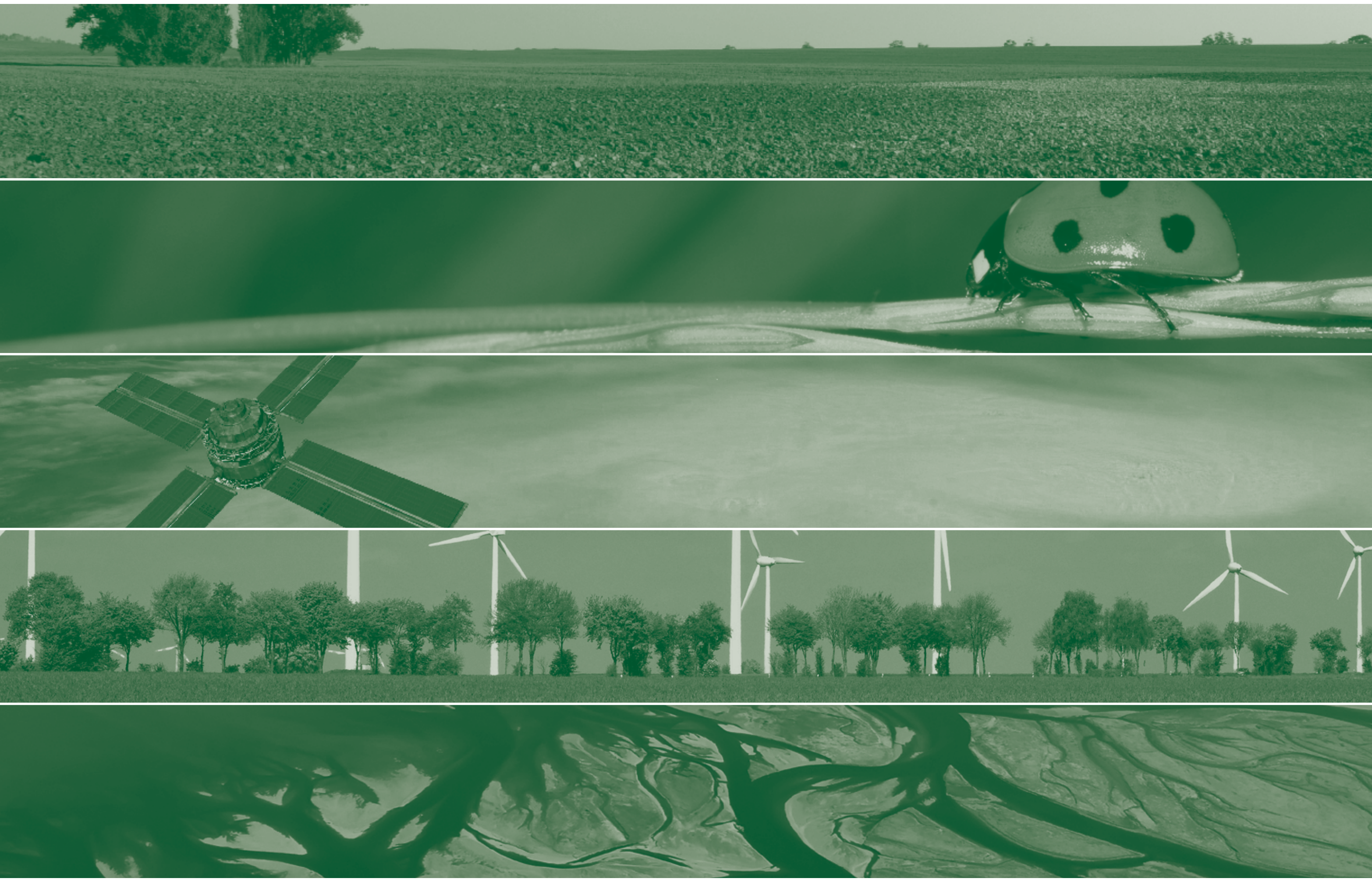
Annex 1. Analysis of drain water at the Koeien en Kansen sites

Table A1
Drain water analysis sampled in march 2010, Koeien en Kansen sites.

Location	EC	pH	Sediment	Cl	Al	Ca	Fe	P	S	C	P-PO4
	(mS/cm)		g/kg water	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)
Eibergen	0.57	5.47	0.1	98	1	39.3	1.71	0.1	16.7	28.8	0.06
Zeewolde	1.38	7	0.08	31.3	0.02	231	0.01	0.17	110	18.6	0.17
Ysselstein	0.41	5.41	2.03	28.7	2.85	37.4	0.22	0.05	29.5	79.4	0.01
Bedum	1.64	6.89	0.24	186	0.05	169	0.15	0.26	41.9	15.8	0.25
Nieuweroord	0.19	4.74	0.33	18.5	4.12	19.8	0.43	0.15	8.05	100	0.10
Haskerdijken	0.35	6.77	0.34	21.2	0.76	29.8	1.85	0.452	17.3	56.5	0.40
Average	0.76	6.04	0.52	72.5	1.61	99.3	0.51	0.15	41.23	48.52	0.12
Standard deviation	0.6	0.96	0.75	70.82	1.81	94.81	0.69	0.08	40.53	38.6	0.1



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