The feasibility of iron-coated sand reducing phosphorus discharge to the surface water

Bachelor Thesis International Land and Water Management

Version of June 05, 2013

Zijing Cao (901022102), caozijing.cao@wur.nl

Yuan Zhang (900204003), zhangyuan.zhang@wur.nl

Alterra-Wageningen University

Supervisors: Hans Van Den Dool (VHL) and Groenenberg Bert-Jan (WUR)

Bachelor Thesis

Reducing phosphorus discharge to the surface water by using iron-coated sand

Zijing Cao

Yuan Zhang

Bachelor Thesis International Land and Water Management

Supervisors：

Hans Van Den Dool	Groenenberg Bert-Jan
The Netherlands	The Netherlands
Van Hall Larenstein University	Alterra, Wageningen University
Tel: 026 3695717	Tel: 0317-486532
Email: hans.vandendool@wur.nl	Email: bertjan.groenenberg@wur.nl

Preface

The bachelor thesis focuses on “the feasibility of reducing phosphorus discharge from agricultural land to the surface water by using the enveloped drain with iron-coated sand in the Netherlands”. Phosphorus loss from agricultural soils, which is a main source of P in surface waters, causes surface water quality impairment in many regions of the world, the Netherlands as well. Moreover, the phosphorus leaching is more serious in the sandy soil compared with other soil types. Therefore, we decided to carry out the research on sandy soils.

The measures dealing with this problem never loses our attention all over the world. The Major International Water Management and Minor International Agri-business Trade support us the knowledge base and let us analyze the situation from the view of both natural and social sciences. Alterra gave us an opportunity to understand the problem deeply, reasonably and comprehensively. The thesis supports the primary analysis of the enveloped drainage system with iron-coated sand for the project started by the water board of Rijnland in cooperation with Alterra in fall 2012 which will continue for two years.

Besides, the thesis tutor Mr. Hans Van Den Dool and the thesis supervisor Mr. Bert Jan Groenenberg directed us with professional suggestions, practical advises and innovative guides during the whole thesis process. Moreover, they helped and assisted us to implement our plan and to finish the project. On no account can we deny that whole the assistance supporting help us to learn a lot and improve ourselves both knowledge and practical area, giving us a new and comprehensive view to see, to judge and to decide.

In addition, thanks for all attentions from readers of our thesis, criticism and correction are both welcomed; it will be valuable to us not only present but also future.

Yuan Zhang and Zijing Cao

June, 2013

Table of contents

Summary

Phosphorus loading from agricultural land is the main Phosphorus source in surface waters which causes surface water quality impairment in the Netherlands. In order to solve this problem, the Equilibrium fertilization which aims to reduce the P surplus in the soil was established. However there is already so much Phosphorus stored in agricultural land due to the previous agricultural activity. As a consequence, even reducing the input of Phosphorus there will be substantial P leaching from soil. For the reasons above, it will be difficult to reach the surface water quality standards of the European Water Framework Directive in 2015.

To solve the problem of Phosphorus leaching, the new method which uses iron-coated sand to absorb the ortho-P through the drainage pipes was generated recently. However, the method still need more research to apply it in practice. For this purpose, a main question of the thesis is generated: how is the feasibility of iron-coated sand applied in sandy soil in the Netherlands.

In order to find out the answer to the main question, the research was separated into two parts. On the one hand, the lifespan of iron-coated sand was concerned in the report. Through the application of the Lifespan model combining with the adsorption model, the life time of the iron-coated sand in different situations were used to estimate. On the other hands, the PLEASE model was applied to research the effectiveness of iron-coated sand installing with pipes. Through calculating and summarizing the results, the method of iron-coated sand enveloped drain was proved to have the relatively high efficiency of removing P from the drainage water in sandy soil conditions in the Netherlands.

According to the results provided by two models, generally speaking the lifespan of the iron-coated sand was supposed around 20-40 year. When the concentration of phosphorus decreases the lifespan could be longer. For the most of the situations the efficiency of the iron-coated sand is inferred more than 40% and even a half of the cases higher than 60%.

Additionally, through the combination of two parts researches, the conclusions of the feasibility of iron-coated sand were illustrated in the report. It can be concluded that the iron-coated sand have a high level of efficiency for phosphorus concentration reduction during this lifespan time. In most of the cases the lifespan of iron-coated sand is long enough with the lifespan of the drainage pipes. The iron-coated sand is a suitable and sustainable solution for application the phosphorus loss problem.

1. Introduction

1.1. Background information

This thesis aims to report a research on the feasibility of iron-coated sand applied in the agricultural sandy soil in the Netherlands.

The catchment area Schuitenbeek is located between Putten, Nijkerk and Voorthuizen in the Netherlands (Figure1.1.1). The northwest borders of the catchment area near to the Nuldernauw, Randmeer (lake) is located along the Flevopolders. The catchment area Schuitenbeek, which is a rural region without big cities, is around 7500 ha. The total agricultural area occupied around 51% of the total land and the rest land (49%) is almost natural area[1] [Pleijter, 2010]. The soil types of this area are almost only sandy soils, but on the banks of the Nuldernauw are clay soils with peat in the surface are also present. The most common soil is "podzol" soil on the uplands and "Beekeerd" soil on low-lying lands (typical Dutch soils, more organic rich soils with fluctuating ground water table). Comparing with these main two types of soil in this area, the "Beekeerd" soil has higher organic contents with fluctuating high ground water level.

Moreover, due to the application of fertilizer and manure inefficiently, the concentration of total P in the soil is extremely high in this area. And there is a large variation in Pw (the amount of water extractable P), for some locations very high total P concentration (see Figure1.1.2 below) which is much higher than the surface water quality standards of the European Water Framework Directive (EC 2000/60/EC) in 2015.

Therefore, the main problem for this area is the high phosphorus leaching form the agricultural land to deeper soil layers or running off to the surface water, due to the fluctuating high groundwater table and seepage.

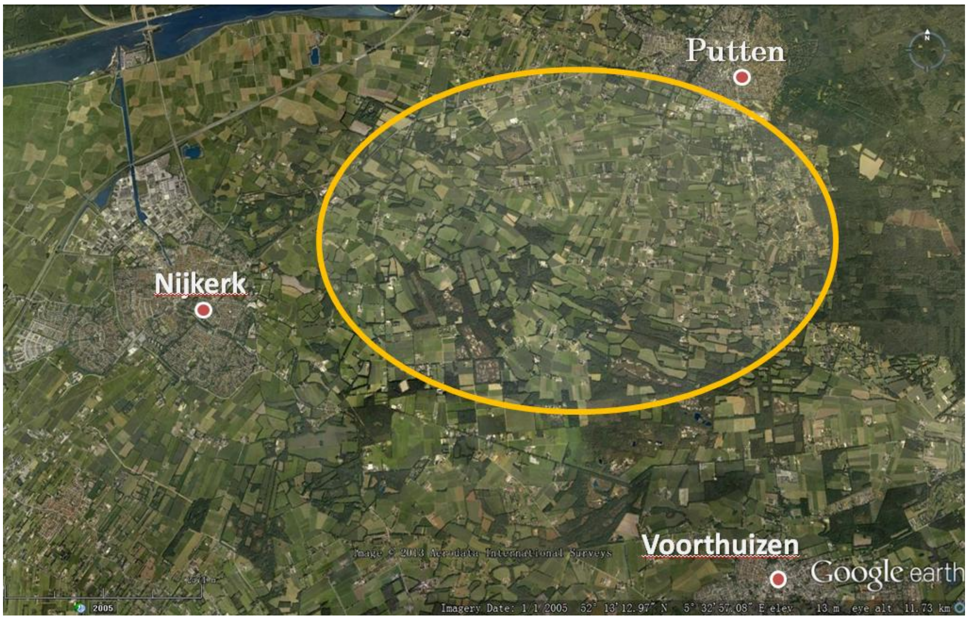


Figure1.1.1. the location of Study area: ***Schuitenbeek***

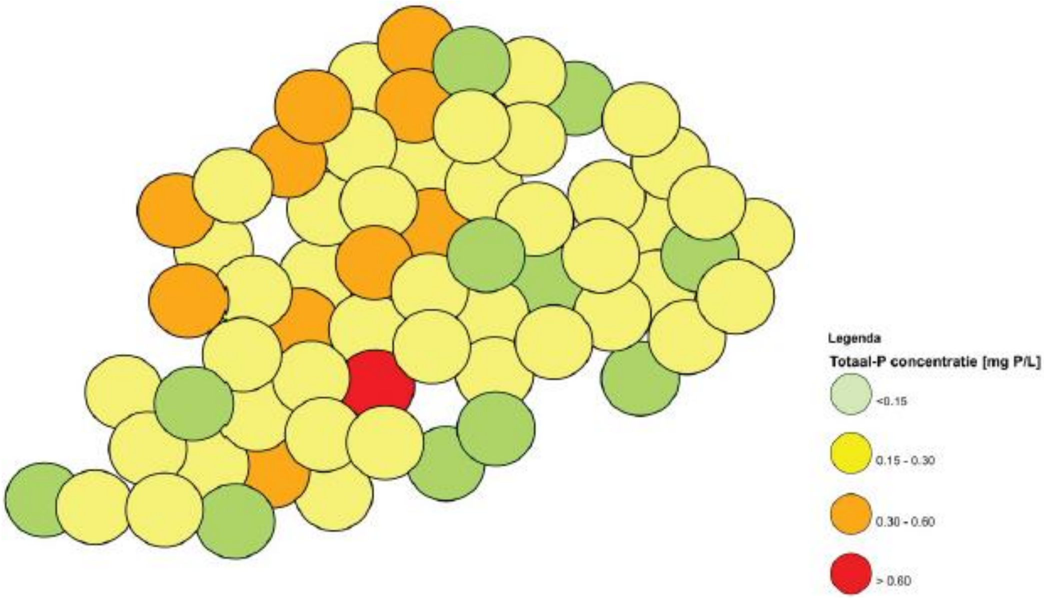


Figure1.1.2. the total P concentrations (mg/L) in leaching water for the catchment area [Alterra report 1968.3]

1.2. Problem statement

The Phosphorus leaching from agricultural soil is an important source of P in surface waters which causes surface water quality impairment in many regions of the world, including the Netherlands. The main problem is the high level of Phosphorus leaching to surface water systems. The main reason is phosphorus leaching or running off with the water to the deeper soil layers or to the surface water systems (Fig1.2.1). Moreover, due to the large amounts of P accumulated in Dutch soils P leaching may continue for a prolonged time when P inputs to the soil are decreased drastically. Therefore the policy of restricting the application of fertilizers and manure will not be effective in a short term.

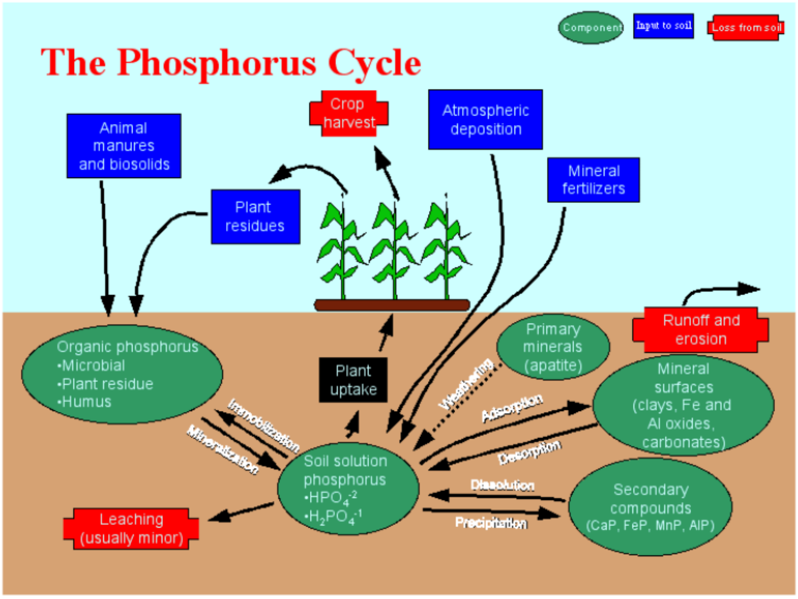


Fig1.2.1. the P cycle in the soil [Hans Van Den Dool, Environmental Science, Lecture 6, "Eutrophication"]

Therefore in order to reach the Surface Water Quality Standards of the European Water Framework Directive[2] [Chardon*, Belder2, Groenenberg1, Koopmans 2011] in time, several research institutes and companies have explored some methods to reduce the on-going phosphorus load. Recently, Alterra found out that the normal pipes cause the P-discharge to surface water. After several years research, Alterra confirmed that the method of iron-coated sand enveloped drain can remove P from the drainage water in two soil conditions in the Netherlands with the efficiency of 94%[3] [Groenenberg, Chardon*, Koopmans, 2012] However, the long-term performance of this measure and the feasibility for various types of soils in the Netherlands still need further experimental research. In other words, the method of the enveloped drain with iron-coated sand needs further research in order to be applied in practice.

1.3. Purpose

The objective of the research is to research: "what is the feasibility of iron-coated sand applied in sandy soil in the Netherlands?"

In order to explore the main research question step by step, the main research divided into two levels:

- What is the lifespan of iron-coated sands in the P-reduction process compared with the lifespan of normal pipes?

- What is the effectiveness of the enveloped drain with iron-coated sand applying in the catchment area with different phreatic levels and different P concentration in top soil?

Specifically, the first level of research is the lifespan of iron-coated sand. There is no doubt that only the lifespan of iron-coated sand is equal to (or longer than) that of normal pipes, the method of reducing phosphorus is worthy to be applied in the real life. That is to say that it is possible to persuade the local farmers to use this method without extra labour comparing with normal pipes. If the lifespan of the iron-coated sand is too short, the renewal activities will be more frequently, which means costs more costs, labour and time. As a result, the length of lifespan affects the acceptance of iron-coated sand. To make matters worse, it certainly affects the feasibility of iron-coated sand as well.

Furthermore, the second level of research is the relationship between the efficiency of iron-coated sands and different phreatic levels or different P concentration in top soil. Through the comparison of different conditions, it should be figure out: if applying the enveloped drain with iron-coated sand in the research area, how much phosphorus can be absorbed in different phreatic levels or different P concentration in top soil? And how many percentages of the total amount of phosphorus can be reduced in different conditions? The efficiency of iron-coated sand directly shows the effect of the measure. With high level of efficiency to reduce the phosphorus loss proves install the iron-coated sand is effective and worth. In other words means it has feasibility for measure application.

Additionally through combining the results of these two levels, the feasibility of iron-coated sand could be explored which is the mean target of the thesis.

1.4. Restrictions

There were many constraints for the study even though the topic has been well-defined and the data of previous experiments is available. It is a matter of fact that the research of the lifespan of this mitigation measure needs a long term study to prove. It is impossible to accomplish a complete field research during the six-month thesis study. Therefore, the lifespan was estimated by two models. Moreover, it is true that there are gaps between the model and reality. More field work needs to be done to prove. Some ideas also included in the original plan, but as the different situations and sudden changes during the whole process, they cannot be reached. For these reasons the project cannot be 100% satisfactory but the outcomes might support the further research.

1.5. Audience

The audiences of this research will be three groups of people: the project researchers, students and teachers who are interested in or doing the research related to this topic, the local governments and the native farmers. To explain particularly, the relative researchers are the direct audiences who might use the results for the further research. Moreover, the local government might decide whether to apply the solution because they take charge of the water system management, if the method is feasible and appropriate. Farmers are also the direct users of the measures. Because the solution maybe will change the condition of their field and structure of their planting plan, it is essential to persuade them for measurement application.

1.6. Guidance for reading

In this report, firstly, the background information was shown to give a basic knowledge. And then, the problems and purpose descried that the main idea of this thesis is to prove the feasibility of iron-coated sand applied in the agricultural sandy soil in the Netherlands. After that, the Chapter2: Methodology revealed a comprehensive explanation of the data collection and the implementation of models. Preparation and the model operation is one of the main parts within the thesis. Additionally, the results analysis and estimation generated step by step to show the working processing in the Chapter3. Moreover, the Chapter4: Evaluation and Discussion analyzed the outcomes of two models. After that, the conclusions were summarised to answer the main research question. Additionally, there were some advises for further research showed in the Chapter6: recommendations. Finally, the provenance of literature, detail information and figures can be found in Reference. Moreover, there were some appendixes attached.

2. Methodology

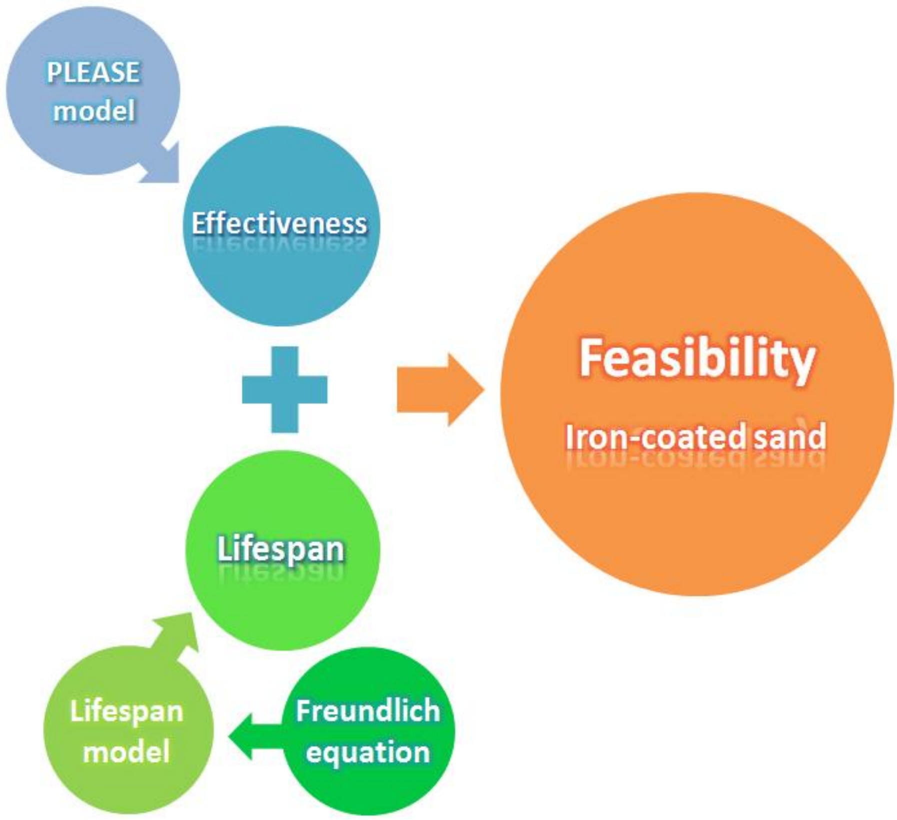
2.1. Preparatory work

The literature research was critical at the beginning of the project, in order to acquire the basic knowledge about the P characteristics and soil processes and set up a small scale knowledge system for building up a proper and reasonable study plan and further practical research. The plenty of literature about the basic knowledge of soil chemistry and current technologies of reducing P leaching from soil was needed as initial step of the research. Moreover, before the model experiments, the principle of models and the manual of model operation were studied by reading the related documents. Additionally, the documents about the results of the lab researches on the adsorption capacity of iron-coated sand were also studied for acquiring the knowledge of the effectiveness of this kind of by-products. The preparatory work resulted in a plan of approach (see Appendix1.).

2.2. Methodology for models design

After the literature research as the methodology base, some practical researches were also needed to apply. In terms of the research objectives mentioned above, the model operation was one of the most essential works to address the research questions.

To be more specific, there were two main models which correspond to two-level researches: the lifespan model calculated the lifespan of iron-coated sands to reduce P leaching to the desired level; and the PLEASE model provided the results of adsorption effectiveness of iron-coated sands in the sandy soils. Additionally, through combination of the results provided by the two models, the feasibility of iron-coated sands concluded. The models implementations were included in the research as shown in the flow chart below.



Flow chart 2.2.1.: The models implementations

The first research level is the lifespan of iron-coated sand. If the lifespan of the iron-coated sand is shorter than that of normal pipes, the renewal activities will be more frequently, which mean more costs, labour and time. And if the lifespan of iron-coated sand is equal to (or longer than) that of normal pipes, the method of reducing phosphorus is worthy to be applied by the farmers. As a result, the length of lifespan certainly affects the feasibility of iron-coated sand. To find out the lifespan and the tendency of the adsorption capacity changing by the time, the Lifespan model were used with some parameters supported by Freundlich equation.

Moreover, the other research level is the efficiency of iron-coated sand in sandy soil. The PLEASE model were applied for providing the results of different satiations. The model PLEASE designed for calculating the present profile of phosphorus concentrations and lateral water fluxes as a function of depth using simple chemical and hydrological parameters.[8] [Caroline, T. B.-J. G., 2011]. And in this case, the PLEASE model simulated three scenarios of different phosphorus loading causing by different pipe systems. Specific speaking, the different situations were classified into:

1. the current situation: without drainage pipes
2. the normal drainage pipes

3. the drainage pipes enveloped with iron-coated sand

After the calculation, the outcomes were classified according to different phreatic levels and different P concentration in top soil respectively to analyze the effectiveness of iron-coated sand in sandy soil.

Additionally, after the analyzing the results of two models, the conclusions were combined to support the feasibility discussion.

2.3. Methodology of lifespan research

2.3.1. The Implementation of Freundlich equation

In this case, the first step is calculate adsorbed amount in mg P/g Fe-sludge and plot in graph determine the Freundlich adsorption parameters after linearization for the different equilibration times, 30 mg iron sludge + 30 ml solution in centrifuge tube are used and equilibration (shaking) time are 1, 3, 8 and 21 days. The principle equation is $Q=(C_fV_f)-(C_0V_0)/m$. By this equation Q and C_f are calculated for the further work. Then principle equation LogQ=LogK+(1/n)LongC (coming from Q=KC^1/n) are used to derive the parameters "Logk" and "1/n". They can be used in the lifespan model. After the operation of lifespan model, the lifetime of iron-coated sand were estimated.

Next, it is needed to calculate adsorbed amount in mg P/g Fe-sludge and plot in graph determine the Freundlich adsorption parameters after linearization for the different equilibration times, 30 mg iron sludge + 30 ml solution in centrifuge tube are used and equilibration (shaking) time are 1, 3, 8 and 21 days. The principle equation is:

$$Q=(C_fV_f)-(C_0V_0)/m$$

Where Q is the amount of adsorption (adsorbed per unit mass of adsorbent) in mol/kg, C_f and C_0 are the final and initial adsorptive concentrations, respectively, in mol/; V_f and V_0 are the final and initial adsorptive volumes, respectively, in liters; and m is the mass of the adsorbent in kilograms. In this equation Q and C_f are calculated for the further work.

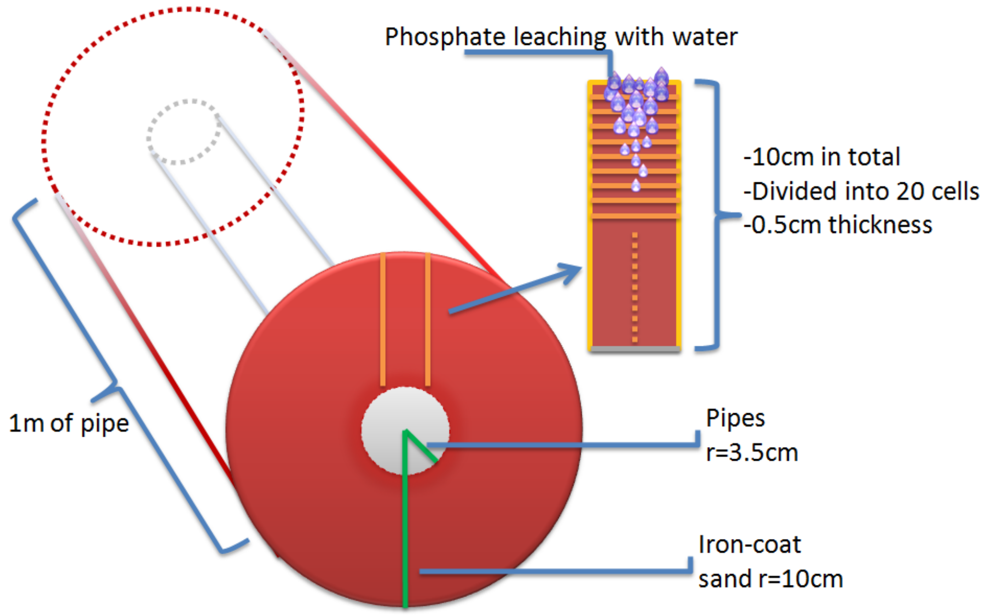
Then principle equation is used to figure out the other parameters:

$$LogQ=LogK+(1/n)LogC \quad \text{(coming from } Q=KC\text{^}1/n)$$

Where Q and C were defined earlier, K is the distribution coefficient, and n is a correction factor. LogK and 1/n can be used in the lifespan model. After the operation of lifespan model, the lifetime of iron-coated sand were estimated.

2.3.2. The Implementation of Lifespan model

In order to operate the Lifespan model, there are several additional data should be collected. In the lifespan model the processes of iron-coated sand is schematized as the percolation through a 1-dimensional column of 10 cm, the thickness of the layer around the drain. The column is divided in 20 cells of 0.5 cm thickness. And the time step of 12 hours is used.[9] [Chardon, Groenenberg, Temminghoff, Koopmans, 2012] (Shown schematically below) Each time step the first cell in the column is fed with a constant volume of the solution depending on the flux of water entering the column. An equal volume is transported to the next cell, which is repeated to the last cell of the column. Within each cell complete mixing is assumed, this means that the concentration phosphorus is equal within a cell. After each transport step the phosphate in solution is equilibrated with the iron-coated sand. Phosphate sorption to the iron coated sand is calculated with the Freundlich equation.



Sketch map 2.3.2.1: The sketch of the enveloped drain with iron-coated sand

To evaluate the life time, various scenarios were simulated with the model in which the flux through the column varied the concentration of P in the drainage water and the drainage parameters. It is assumed that there is a distance of 10 m between the pipe drains in the field. This means that 1m of pipe drain receives the drainage water for a 10m^2 area. The surface area of 1 m pipe drain is 0.85 m^2 for a cylinder with a radius of 10 cm (thickness of the iron coated sand) + 3.5 cm (radius of the pipe drain) = 13.5 cm.

The flux through the drain is therefore 10/0.85 = 11.8 times the flux per 1 m^2 area land.[9] [Chardon, Groenenberg, Temminghoff, Koopmans, 2012]

Calculation of the life time of the enveloped pipe drain for input concentrations of 1mg P/L and 3mg P/L (which were taken from the table below, designed by tutor Mr Groenenberg) similar to field concentrations, We evaluated scenarios with water fluxes through the pipe drain equivalent with 300 mm/year (The annual precipitation surplus in the Netherlands is around 300 mm.[10]) and for 500 mm assuming an additional seepage flux of 200 mm/year. And the flux through the drain is 11.8 times the flux which means 300*11.8=3539 mm/year and 500*11.8=5898 mm/year.

Furthermore two sets of Freundlich parameters were evaluated, one set for 3 days equilibration time and another determined for 21d equilibration time[9][Chardon, Groenenberg, Temminghoff, Koopmans, 2012]. With the time ongoing, the adsorption of phosphorus will increase by slow reaction.

Situations	Water flux (mm/y)	Water flux through drain (mm/y)	Feed conc. (mg P/L)	Freundlich (day)	Life time (year)
A	300	3539	3	21d	?
B	300	3539	3	3d	?
C	500	5898	3	21d	?
D	300	3539	1	21 d	?

Table 2.3.2.2.: The four options of input

(The results of Lifespan model which shown below)

2.3.3. Data collection of Lifespan model

For more details information, the adsorption capacity changing data have been already test and recorded in the laboratory by staffs in WUR/Alterra (collected from the ongoing research by the supervisor Groenenberg Bert-Jan in Alterra). The Equilibration (shaking) points are 1, 3, 8 and 21 days for calculate adsorbed amount in mg P/g Fe-sludge and plot in graph. Concentration and Volume of phosphorus solution in the beginning point and recording point, quality of the iron sludge solution, amount of the adsorbed phosphorus solution were tested for calculation. Finally, through the calculation of Freundlich equation two parameters "LogK" and "1/n" were figured out for the lifespan model. (The specific process of calculation were attached in Appendix2)

During the processing of lifespan model, water flux (mm/year), feed concentration (mg/L), experiment days and Life time ranges (year) were designed for operation. In the

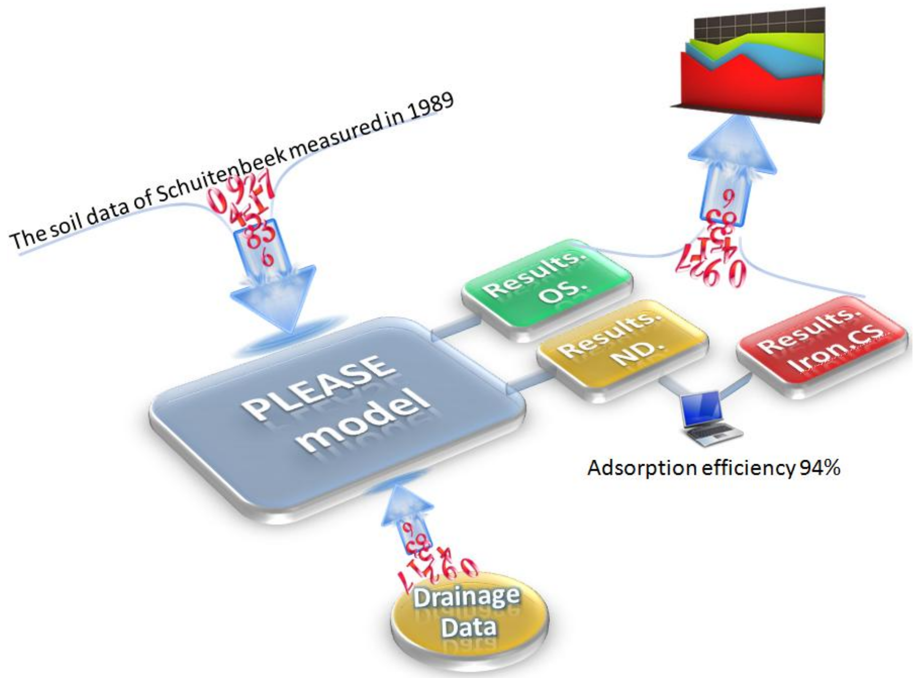
Netherlands the general the water flux amount were defined as 300 and 500 mm/year, feed concentration of phosphorus were 1 and 3 mg/L for this case. The experiment days are taken from the 21 days experiment and the data from day 3 and 21 were chosen for model. Life time ranges were considered since 100 years as the estimated lifespan of the iron-coated sand will less than 50 years. From the output files of lifespan model the working time limitation can be evaluated.

2.4. Methodology for efficiency research

2.4.1. The implementation of PLEASE model

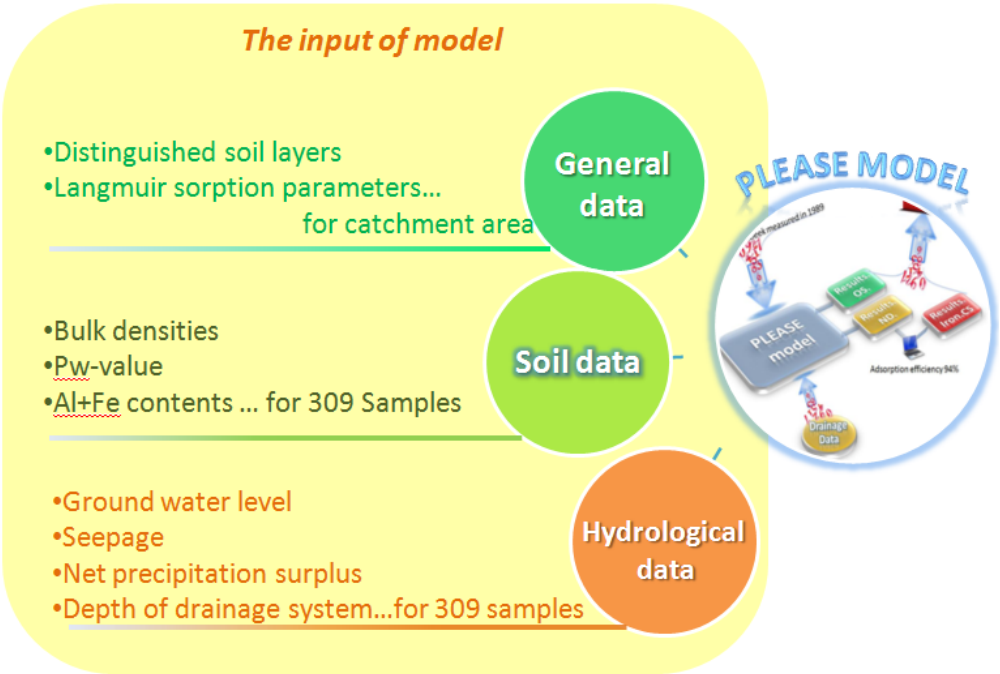
In order to explore the efficiency of iron-coated sands grounded in reality, the comprehensive data of study area were applied in the model. Schuitenbeek was catchment area for the research. The data of Schuitenbeek measured in 1989[1] [Pleijter, 2010] were used to operate the model. In this case, according to the data, the PLEASE model was used to prove the drainage system with iron-coated sand has the high capacity to reduce the phosphorus leaching to the surface water system. Moreover, the efficiency of iron-coated sands was estimated, through comparing the situations of different phosphorus loading causing by with or without iron-coated sands.

Generally speaking, in order to compare three situations (original situation, the situation with normal pipes and the situation with the enveloped pipe with iron-coated sands), firstly the data for original situation in 1989 were filled into the PLEASE model. And then, the results of original situation were generated. And after that, the specific data of normal pipes were filled into the model. And through the operation of model, the results of normal pipes were provided. However, the situation of installing iron-coated sand cannot be estimated by the PLEASE model directly. The results of iron-coated sands were calculated by Microsoft Office Excel. The process was described below with the flow chart 3.1.



Flow chart 2.4.1.1.: The PLEASE models implementations (OS.: Original Situation; ND.: Normal Drainage situation; Iron.CS.: Iron-coated sand Situation)

Firstly, for the original situation, the general data, soil data and hydrology data of Schuitenbeek were filled into the model. To be more specific, the general data contain general parameters of the catchment area. And the soil data contain the number of locations and the soil properties per location. For each location all data for the distinguished soil layers were given on one record separated by blanks. The hydrological data contain the ground water level, seepage and other data for each location. (The specific processes of filling in the database are shown in Appendix3.) And through the model operation, the results including the water fluxes, Ortho-P concentrations and total-P concentrations of original situation were generated.



Sketch Map2.4.1.2. The data for the PLEASE model

For the situation with imaginary drainage systems, exactly the same general data and soil data were used. And for the hydrological data, the specific depth of drainage pipes for each location was generated according to the depth of ground water level. In other words, the drainage pipes were "modelled" at selected locations where there is the requirement to drain the ground water to the surface water systems. Therefore, only the locations were selected with MHG (Mean High Groundwater) less than 0.6 m. The depth of drainage pipes was set at MHG plus 0.6m. For example, if the MHG of a location is 0.2m, the depth of the drainage system is set at 0.2+0.6=0.8m. The requirement of installing pipes is essential factor for the situation with drainage pipes which could influence all the hydrology conditions in the soil. Moreover, it is also important factor for the situation with iron-coated sands, because the locations of drainage pipes are also where the iron-coated sand installed.

There were two examples in catchment area to explain which places are unnecessary to install drainage pipes and which places should apply in pipes which showed below:

1. The first horizontal number location "2124", the MHG is deeper than 0.6m. All numbers which MHG is deeper than 0.6m show the same structure. Location number (2124)

   - Depth of drainage system (pipe) (0, because there were no drainage system in this area)

2. For the situation of drainage system, the second horizontal number location "2125" was explained as the example, as mentioned before the depth of drainage system will be (0.2+0.6) m because the MHG is lower than 0.6m. The rest group numbers which MHG is lower than 0.6m will be show in the same structure.

   - Location number (2125)
   - Depth of drainage system (pipe) (80, because the drainage system depth would be 0.2+0.6=0.8 as mentioned before)

Additionally, for the situation of enveloped drain with iron-coated sand, it is impossible to get the results from PLEASE model directly, because the PLEASE model is only applicable for general research of the phosphorus concentrations and lateral water fluxes in the soil. Therefore, the results of iron-coated sand were calculated based on the data from the results of normal drainage, which means the data from normal pipes will be used and adjusted to imitate the data from the situation of after apply the iron-coated sand. The reason of that is iron-coated sands need to be instated around the drainage system. Moreover, according to the conclusion from the relative professional literature: Applying iron-coated sand to remove P from the drainage water proved an effectiveness of 94%[3]. Therefore, owning to the limitation of adsorption, iron-coated sand only effect around drainage system. On the basis of this argument, after collecting the results of normal pipes from PLEASE model, the concentration of ortho-P around the enveloped drain with iron-coated sands for each location reduced by multiplying (1-94%). Moreover, it should be mentioned that iron-coated sands only absorb the ortho-P from soil. Therefore, for the calculation of total-P concentration, the formula showed below.

The tP concentration $_{\text{(installed the iron-coated sand)}}$ = {$tP_{\text{(normal drainage)}}$ - $oP_{\text{(normal drainage)}}$ +{$oP_{\text{(normal drainage)}}$ *(1-94%)}. In another words, the amount of total phosphorus left after install the iron-coated sand = the amount of P do not moving + the iron-coated sand adsorbs the ortho-P from soil.

2.4.2. Data collection of PLEASE model

For carrying out the research on the first level mentioned above, the thesis used the soil data of research area and the conclusions from previous researches to set up the models' data base. The soil data of Schuitenbeek which have been measured in 1989[1] [[Pleijter, 2010] were used to imitate the situation the water flowing through the three soil layers and the phosphorus loading problem. Additionally, applying iron-coated sand to remove P from the drainage water proved an effectiveness of 94%[3][Groenenberg, Chardon*, Koopmans, 2012] by the several years' research carried out at Alterra.

3. Model results

3.1. The results of lifespan model

After inputting all the data into the model, which includes "LogK" and "1/n" and other designed data: the four situations, there were four results files shown the life time of the iron-coated sand below.

Situations	Water flux (mm/y)	Water flux through drain (mm/y)	Feed conc. (mg/L)	Freundlich (day)	Life time (year)
A	300	3539	3	21d	**40**
B	300	3539	3	3d	**20**
C	500	5898	3	21d	**20**
D	300	3539	1	21 d	**70**

Table 3.1.1.: The results of four situations

The table above showed the results provided by the Lifespan model, the first column represents four situations which were explained in the next four columns. Moreover, the last column illustrated the different lifespan in four situations. Therefore, from the table above, it is evidence that the iron-coated sand in different situations represented the different life times.

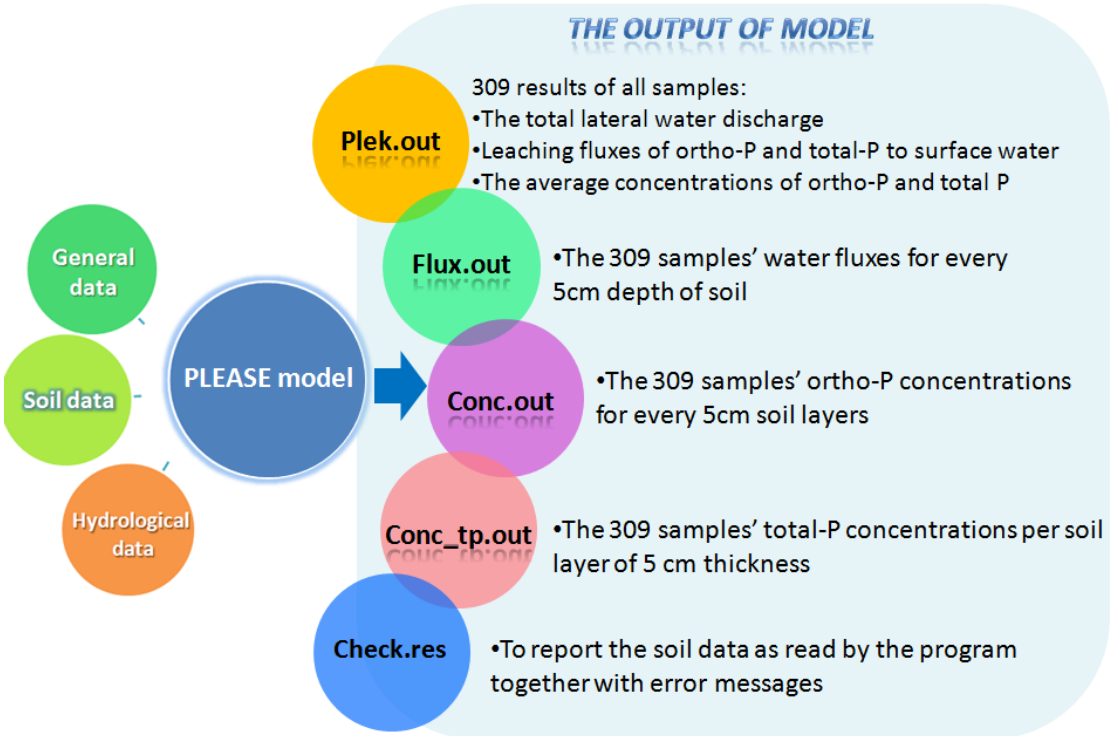
year	A	B	C	D
0. 04	0. 1708083	0. 6372711	0. 1708083	0. 1708083
5. 01	0. 1708083	0. 6372711	0. 1708083	0. 1708083
10. 03	0. 1708083	0. 6372711	0. 1708083	0. 1708083
15. 00	0. 1708083	0. 6372711	0. 1708083	0. 1708083
20. 01	0. 1708083	0. 6505287	0. 1709203	0. 1708083
25. 03	0. 1708083	1. 552679	1. 015447	0. 1708083
30. 00	0. 1708083	2. 945878	2. 995898	0. 1708083
35. 01	0. 1722614	2. 999268	2. 99975	0. 1708083
40. 03	0. 4703107	2. 999621	2. 99975	0. 1708083
45. 00	2. 79444	2. 999621	2. 99975	0. 1708083
50. 01	2. 997204	2. 999621	2. 99975	0. 1708083
60. 00	2. 999421	2. 999621	2. 99975	0. 1723937
70. 03	2. 999421	2. 999621	2. 99975	0. 229253
80. 01	2. 999421	2. 999621	2. 99975	0. 7538725
90. 00	2. 999421	2. 999621	2. 99975	0. 9855999
99. 99	2. 999421	2. 999621	2. 99975	0. 999141

Table 3.1.2.: The results of four situations provided by the lifespan model

To be more specific, the table above shown the results of four situations, the first column represents the year and the other four columns represent the amount of Phosphorus losing from the pipes. It is obvious that if the figure starts to increase, the iron-coated sands will starts to lose the capacity of absorption which causes more phosphorous losing from pipes. Therefore, from the table above, it is evidence that the results of different situations increasing from different time. And the period before the first year of iron-coated sand start to losing capacity would be the lifespan, because during the service life, the effectiveness of iron-coated sand should be stable. Moreover, it should be mentioned that the table above was a part of results and the whole output of lifespan model described the more phosphorous losing from pipes every 15 days which means 24 results of each year and there were 100 years results for every situation. And in order to show the results clearly, most of detail information was remained under cover.

3.2. The results of PLEASE model

After input all these data, the model can be operated, and the files “plek.out”, “flux.out”, “conc.out”, “conc_tp” and “check.res” were generated. More information is demonstrated in the flow chart below.



Flow chart3.2.1. The output of PLEASE model

The file “plek.out” gave each location information on the total lateral water discharge (m), leaching fluxes of Ortho-P and total-P to surface water (kg P ha^{-1} yr^{-1}) and the flux weighted Ortho-P and total P concentrations (mg/L). For example, the table below illustrated the results of seven locations in the catchment area. Actually, there should be

309 groups of results, but the most of results were omitted here which were showed in the Appendix 3.

To mention one group of results, the total lateral water discharge of location “2124” was 3.09E-01 m (scientific notation); the total phosphorus flux and average total phosphorus flux were 5.29E-01 kg/ha/year and 1.71E-01 mg/L respectively; the ortho-phosphorus flux and average ortho-phosphorus flux were 2.17E-01 kg/ha/year and 7.02E-02 mg/L respectively. It should be mentioned that the tP-flux and oP-flux are essential factors for researching the efficiency of iron-coated sand.

(Nature)plot	Lat drain (m)	tP-flux (kg/ha/yr)	oP-flux (kg/ha/yr)	avg c tP (mg/l)	avg c oP (mg/l)
2124	3.09E-01	5.29E-01	2.17E-01	1.71E-01	7.02E-02
2125	4.29E-01	7.79E-01	3.49E-01	1.81E-01	8.12E-02
2126	3.10E-01	1.04E+00	7.14E-01	3.35E-01	2.30E-01
2127	3.96E-01	8.26E-01	4.28E-01	2.09E-01	1.08E-01
2128	8.18E-02	1.38E-01	5.70E-02	1.68E-01	6.97E-02
2129	4.30E-01	1.16E+00	7.19E-01	2.70E-01	1.67E-01
2130	7.10E-02	2.44E-01	1.69E-01	3.44E-01	2.38E-01

Table3.2.2.: The results file named plek.out. , which illustrated the results of five locations

Moreover, the files “flux.out”, “conc.out” and “conc_tp.out” are provided for a detailed analysis of the profiles of the water fluxes (mm), Ortho-P concentrations (mg/L) and total-P concentrations (mg/L) as a function of depth in the soil profile. The files report the location number and fluxes/concentrations per soil layer of 5 cm thickness. For instance, there were three tables below illustrated the results groups for seven locations respectively. And there were different amount of results for each location, because the soil depth of each location is different. For example, the soil depth of location “2124” is 2.60 m. So there were 52 results to describe the water fluxes, Ortho-P and total-P respectively. (The tables below only showed a part of results for each location.) Furthermore, these three files of normal drainage were used to calculate the situation with iron-coated sand, which were shown in Chapter 2.3.1.

Additionally, the results of these three files can be used to verify the outcomes in the file “plek.out”. For example of “2124”, the first number 4.39E+00 in file “flux.out” times the first number 1.01E+00 in file “conc.out” equal to the oP-flux for the location “2124” in ground level 5 cm. And through sum of product for each soil layer, the oP-flux for “2124” was generated which showed in “plek.out”. The similar processing could be used for the total-flux calculation according to files “flux.out” and “conc_tp.out”.

soildepth(cm)	5	10	15	20	25	30	35	40	45	50	55	60	65
2124	4. 39E+00	1. 89E+00	1. 89E+00	1. 89E+00	1. 89E+00	1. 89E+00	1. 89E+00	1. 89E+00	1. 89E+00	6. 76E-01	1. 16E+00	1. 61E+00	2. 02E
2125	1. 92E+01	1. 67E+01	8. 84E-01	1. 66E+00	2. 42E+00	3. 22E+00	4. 07E+00	4. 96E+00	5. 87E+00	6. 79E+00	7. 67E+00	8. 48E+00	9. 2
2126	7. 08E+00	4. 58E+00	4. 58E+00	4. 58E+00	4. 58E+00	5. 10E-01	9. 56E-01	1. 37E+00	1. 75E+00	2. 12E+00	2. 50E+00	2. 90E+00	3. 31E
2127	6. 04E+00	3. 54E+00	3. 54E+00	3. 54E+00	3. 54E+00	3. 54E+00	7. 05E-01	1. 32E+00	1. 89E+00	2. 41E+00	2. 91E+00	3. 43E+00	3. 98E+0
2128	4. 79E+00	2. 29E+00	2. 29E+00	2. 29E+00	2. 29E+00	2. 29E+00	2. 29E+00	2. 29E+00	1. 30E-01	2. 24E-01	3. 12E-01	3. 92E-01	4. 69E-
2129	4. 26E+01	2. 10E+00	2. 83E+00	3. 61E+00	4. 43E+00	5. 29E+00	6. 17E+00	7. 03E+00	7. 84E+00	8. 57E+00	9. 21E+00	9. 75E+00	1. 02E
2130	2. 81E+00	3. 13E-01	3. 13E-01	3. 13E-01	3. 13E-01	3. 13E-01	3. 13E-01	3. 13E-01	3. 13E-01	3. 13E-01	3. 13E-01	3. 13E-01	3. 1

Table3.2.3.: The results file named flux.out. There should be 309 location points, partly omitted. (More information can be found in the Appendix3)

soildepth(cm)	5	10	15	20	25	30	35	40	45	50	55	60	65
2124	1. 01E+00	1. 01E+00	1. 01E+00	1. 01E+00	4. 98E-01	2. 85E-01	1. 74E-01	1. 11E-01	7. 20E-02	4. 75E-02	4. 70E-02	4. 62E-02	4. 54E
2125	2. 65E-01	2. 65E-01	2. 65E-01	2. 65E-01	2. 44E-01	2. 26E-01	2. 09E-01	1. 94E-01	1. 80E-01	1. 67E-01	1. 59E-01	1. 44E-01	1. 31
2126	6. 00E-01	6. 00E-01	6. 00E-01	6. 00E-01	6. 65E-01	7. 40E-01	8. 28E-01	9. 32E-01	1. 06E+00	1. 21E+00	1. 11E+00	9. 38E-01	8. 03E-
2127	4. 22E-01	4. 22E-01	4. 22E-01	4. 22E-01	3. 97E-01	3. 74E-01	3. 53E-01	3. 34E-01	3. 16E-01	2. 99E-01	2. 88E-01	2. 67E-01	2. 48E-01
2128	2. 36E-01	2. 36E-01	2. 36E-01	2. 36E-01	1. 66E-01	1. 19E-01	8. 59E-02	6. 29E-02	4. 63E-02	3. 42E-02	3. 41E-02	3. 37E-02	3. 34E-0
2129	5. 82E-01	5. 82E-01	5. 82E-01	5. 82E-01	5. 26E-01	4. 76E-01	4. 33E-01	3. 95E-01	3. 61E-01	3. 31E-01	3. 06E-01	2. 61E-01	2. 25E
2130	1. 81E+00	1. 81E+00	1. 81E+00	1. 81E+00	1. 63E+00	1. 47E+00	1. 34E+00	1. 22E+00	1. 12E+00	1. 03E+00	9. 76E-01	8. 76E-01	7. 91

Table3.2.4: The results file named conc.out. There should be 309 location points, partly omitted. (More information can be found in the Appendix3)

soildepth(cm)	5	10	15	20	25	30	35	40	45	50	55	60	65
2124	1. 14E+00	1. 14E+00	1. 14E+00	1. 14E+00	6. 08E-01	3. 88E-01	2. 76E-01	2. 11E-01	1. 72E-01	1. 48E-01	1. 47E-01	1. 46E-01	1. 46E
2125	3. 68E-01	3. 68E-01	3. 68E-01	3. 68E-01	3. 47E-01	3. 28E-01	3. 11E-01	2. 96E-01	2. 81E-01	2. 68E-01	2. 60E-01	2. 45E-01	2. 32
2126	7. 15E-01	7. 15E-01	7. 15E-01	7. 15E-01	7. 82E-01	8. 61E-01	9. 54E-01	1. 06E+00	1. 20E+00	1. 36E+00	1. 25E+00	1. 07E+00	9. 28E-
2127	5. 30E-01	5. 30E-01	5. 30E-01	5. 30E-01	5. 04E-01	4. 81E-01	4. 59E-01	4. 39E-01	4. 20E-01	4. 03E-01	3. 91E-01	3. 70E-01	3. 50E-01
2128	3. 39E-01	3. 39E-01	3. 39E-01	3. 39E-01	2. 67E-01	2. 19E-01	1. 86E-01	1. 63E-01	1. 46E-01	1. 34E-01	1. 34E-01	1. 34E-01	1. 33E-0
2129	6. 96E-01	6. 96E-01	6. 96E-01	6. 96E-01	6. 37E-01	5. 86E-01	5. 41E-01	5. 02E-01	4. 67E-01	4. 36E-01	4. 10E-01	3. 65E-01	3. 27E
2130	2. 01E+00	2. 01E+00	2. 01E+00	2. 01E+00	1. 81E+00	1. 64E+00	1. 50E+00	1. 37E+00	1. 26E+00	1. 17E+00	1. 11E+00	1. 01E+00	9. 16

Table3.2.5: The results file named conc_tp.out. There should be 309 location points, partly omitted. (More information can be found in the Appendix3)

After whole of these procedure, the comparative research of the feasibility of iron-coated sand was distinguished the differences between the situations with or without the drainage system and with or without iron-coated sand. Owning to the detailed results getting from the PLEASE model, the results were analyzed and summarized by aggregating the samples which have the similar characteristics. As a consequence, the results of three conditions mentioned above were divided into six groups classified by the MHG (Mean Highest Groundwater level) and Pw- value (the amount of water extractable P) respectively. For the classification of MHG are not considers all 309 locations. Therefore, in the 309 samples, there were 175 samples which meet the requirements to set up the drainage systems. Therefore, only the desirable samples would be used to analyze in the research. The mean point of this is the relationships between the MHG and the leaching fluxes of total Phosphorus and Ortho-P (oP) concentration. As a results, for the MHG classification, the advantage is only the places which can install the drainage systems (MHG<60cm) were used, which could reduce the influence of the results of the samples which are not appropriate to install drainage. Meanwhile, for the classification of Pw-value all the locations are being considered and the effect factor of various level of Pw value will be found out.

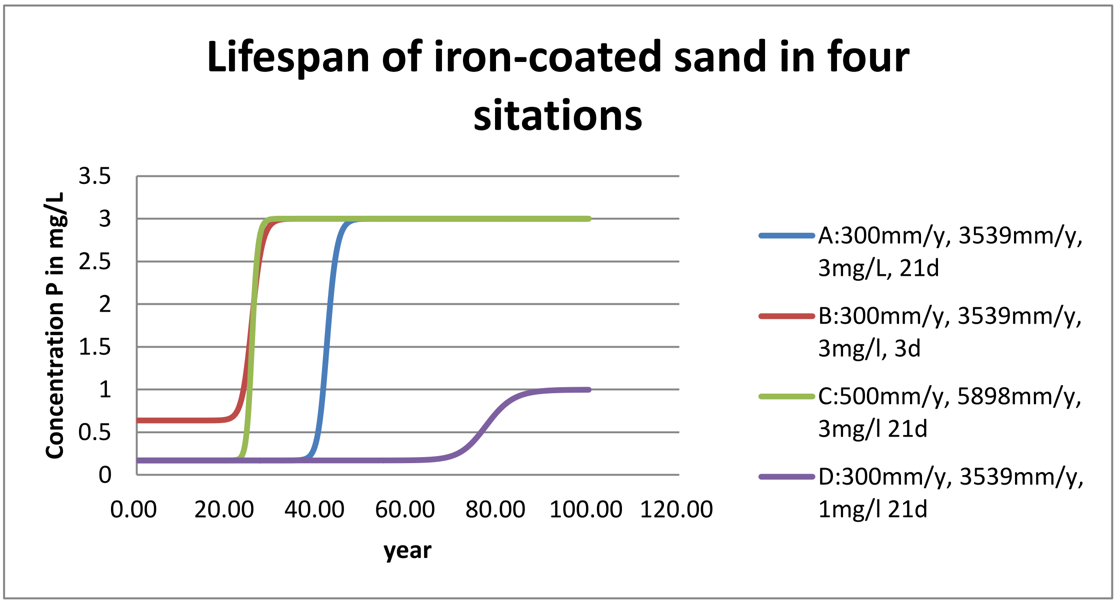
First of all, the results of 175 samples were classified into 6 groups according to the MHG value, in other words there were 0-10, 10-20, 20-30, 30-40, 40-50 and 50-60 cm 6 different groups. And according to the MHG classification, the results of the total-P fluxes and Ortho-P fluxes for the different groups of samples were averaged respectively and were shown by the bar charts 6.2.1 below, evaluation and discussion were generated based on these data.

Owning to the limitation of MHG classification, another way (the values of Pw in the top soil: the first soil layer 0-20cm) which used all results of 175 samples was provided to analyze the efficiency of iron-coated sand. For the Pw classification, after the results of three conditions provided through the calculation, the results of three conditions were divided into 6 groups according to the Pw values of the first soil layer (0-20cm, the top soil), in other words 1-9, 10-49, 50-65, 66-85, 86-99and 100-426 mg P 6 different Pw value groups. And according to the Pw classification, the leaching fluxes of total phosphorus and ortho-Phosphorus to surface water were analyzed from another perspective respectively and showed as groups of bar charts below.

4. Evaluation and Discussion

4.1. The analysis of Lifespan model

From the figure shown below, there are some points can be concluded:



Line chart 4.1.1: The comparison of the lifespan of iron-coated sand in the four situations

First of all, the line chart illustrates that the four lines experiences similar trends during test period. To be more specific, there was a gentle and stable trend in every situation at the start. In other words, the amount of phosphorus loss kept in a very low value which means the iron-coated sand had a high efficiency of absorbing the phosphorus from the soil. After that each line above rocketed significantly since a specific time. It is obvious that if the line starts to increase, the iron-coated sands will starts to lose the capacity of absorption which causes more phosphorous losing from pipes. In other words, the iron-coated sand started to lose the capacity of phosphorus adsorption. Finally the lines stopped climbing and maintained stable where were the points of the iron-coated sand losing the capacity completely. Owning to the requirements of the stable efficiency of iron-coated sands, the time before the Phosphorus losing from drainage increased, is the lifespan of iron-coated sand

Specifically, comparing the starting points between these four situations, it is clear that, except the red line (situation B), the other three lines started from same level of P which was lower than red one. The difference was caused by the different measures interval chose. In other words, other things being equal, the situation B chose the interval of measure P drain from pipes every 3 days, while situation A chose 21 days as the time interval. It shows that in the same situation, the P loss is lower by using 21 days as measurement interval than by 3 days interval. That due to the use of different Freundlich parameters, the Freundlich parameters used in model run B were based on an equilibration time of 3 days, whereas the Freundlich coefficients for the other model runs were based on 21 days equilibration. The time spent on the P adsorption of iron-coated sand should be taken into account. Moreover, iron-coated sands were supposed to be used for long time. Therefore, through the comparison, the situation of 21 days measurement interval is closer to reality. This result is also consistent with the results of a field experiment in which measured concentrations in the leachate of the iron coated drain were generally below 0.1 mg/L[9] [Chardon, W. J., Groenenberg, J.E., Tecminghoff, E., Koopmans, G.F, 2013]. That is compared to the situation closer together 21d and reality.

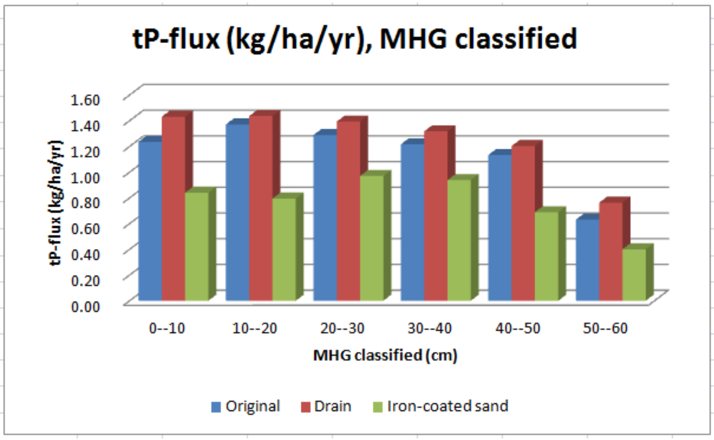
For the three lines with the same measurement interval (21 days), in the one hands, comparing with the lifespan of the blue line (situation A), the green line (situation C) was only around a half of that of blue line, with about 40 years' validity of the situation B and approximately 20-year validity of the situation C. The reason of the difference is that it was supposed more seepage drain through the drainage system in the situation C which caused the lifespan cut down significantly. On the other hand, by contrast the blue and purple line, which represents the situation A and situation D respectively, the lifespan of situation D (almost 80 years), was much longer than the former one. According to the research, it is obvious that the situation D suffered from lower concentration of phosphorus than situation A. And with the increase of the phosphorus adsorption, iron-coated sands lose efficacy gradually. Therefore, the owing to the high concentration of Phosphorus in the situation A, the lifespan of it was lower.

Additionally, it should be mentioned that the designed value: C_{feed} =3 mg/L, which is concentration of phosphorus in soil. It is relative high for the normal soil condition of the Netherlands. Therefore, it might infer that the lifespan of iron-coated sands would be around the lifespan of situation A and situation D when there is not a lot of seepage, which is between 40 years and 80 years.

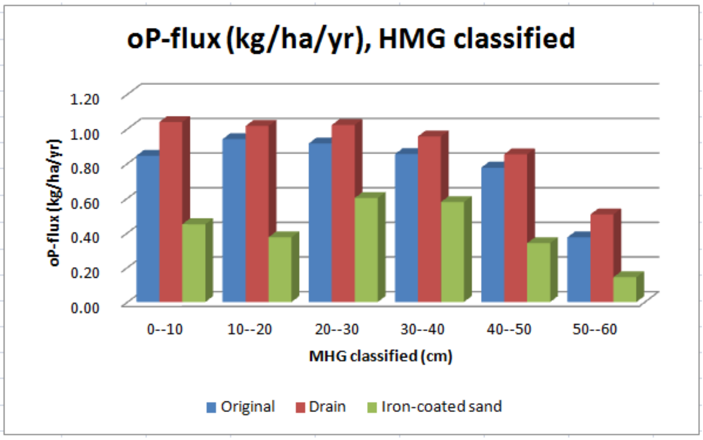
To sum up, the lifespan of the iron-coated sand should be between the 40 and 80 years with normal precipitation level (300cm/year) and relative high value of phosphorus concentration. And if taken 200cm/year seepage into account, the lifespan of it would be between 20-40 years which is still high. And if either of the criteria decreasing, the lifespan will keep longer than before, vice versa. Moreover, the lifespan of normal drainage pipes is around 10-30 years [oral information according to the interviews did by Groenenberg] which related to the maintenance of equipments by the farmers. That is because of the reason mentioned before, the lifespan of iron coated sand is equal to (or longer than) that of normal pipes, the method of reducing phosphorus is worthy to be applied by the farmers. Therefore, the lifespan of iron-coated sand is higher than that of normal pipes, which means the iron-coated sand is appropriated to apply with normal pipes with of too much extra work to replace.

4.2. The analysis of PLEASE model

From the bar charts below, the situation of tP-flux and op-flux classified by MHG were shown.



Bar chart 4.2.1.: The leaching fluxes of total Phosphorus to surface water



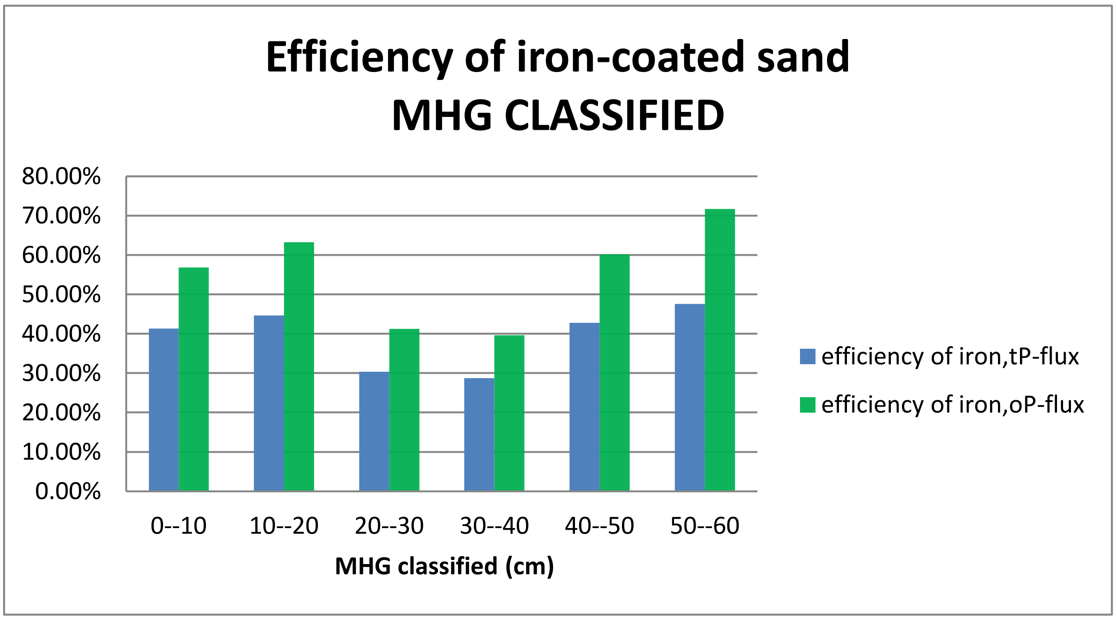
Bar chart 4.2.2.: The leaching fluxes of ortho-Phosphorus to surface water

To be more specific, on the basis of the results of the leaching fluxes of total Phosphorus provided by the PLEASE model, the three different conditions can be found: the original local environment, the situation with drainage system and the situation with iron-coated sand. It is obvious that the phosphorus fluxes of different MHG groups vary from 0.14kg/ha/yr to 1.44kg/ha/yr. Moreover, the problem of phosphorus leaching is more serious especially in the samples which the MHG values are around 10 to 30 cm. Furthermore, compared to the original situation (without drainage systems), the situation with drainage system were supposed to drainage more phosphorus from the soil, which probably means the normal drainage system stimulate more phosphorus leaching from soil to the water system. While, after setting up the iron-coated sand around normal drainage, the total phosphorus concentration for every group was supposed decrease dramatically, this is lower than a half of that in the original situation.

For the comparison between the three conditions' results of the leaching fluxes of ortho-Phosphorus, the tendency MHG is almost same as that of the total phosphorus shown above. From the bar chart above, the phosphorus problem is more serious especially in the MHG 10-30cm. And it is evidence that three groups classified by MHG

(0-30cm) were shown the more significantly high oP-flux in the situations without iron-coated sand. And when the place installed the iron-coated sand around normal drainage, the oP-flux drops rapidly to above a half of normal drainage. Additionally, the two groups also showed the same situations in the leaching fluxes of total Phosphorus. Therefore, it may seem to imply that the places which the MHG is around 10 to 30cm are more appropriate to install the enveloped drain with iron-coated sand to reduce the phosphorus leaching.

To more detail, the bar chart below illustrates the efficiency of iron-coated sand reducing the leaching fluxes of total Phosphorus and ortho-Phosphorus in different MHG levels. The value calculated from the results of the leaching fluxes of Phosphorus in the situation with iron-coated sand divides in the situation without iron-coated sand.



Bar chart 4.2.3.: The comparison between the efficiency of iron-coated sand for tP and ortho-P, Classified according to MHG

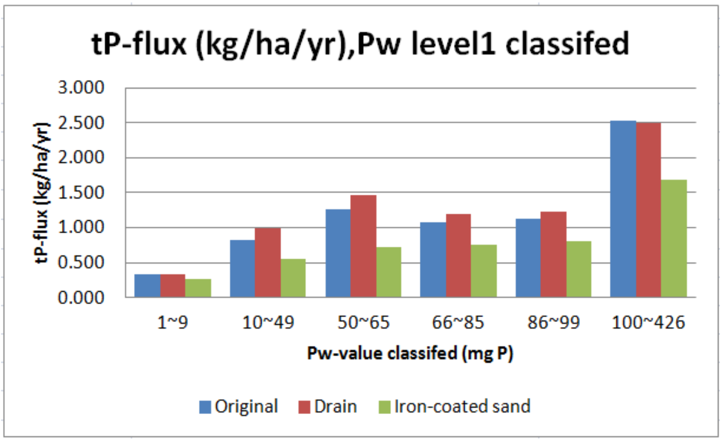
Generally speaking, the bar chart above describe that the efficiency of iron-coated was quite high which the lowest efficiency is about 40% in MHG 20-40cm of oP and 0-20cm, 40-50cm the absorption efficiency of the oP-fluxes are around 60%; others are more than 60%, in the 50-60cm it is even more than 70%. For total-phosphorus whole layers classified by MHG are around 40%.

However, it is not means that the place which the MHG is around 50-60cm is more appropriate to install the enveloped drain with iron-coated sand, because the amount of the leaching fluxes of total Phosphorus is much larger in the places which the MHG are around 10-50 cm. It infers that the places with the MHG around 10-50cm are still appropriate to apply the iron-coated sand which could reduce the plenty of Phosphorus leaching, although the efficiency is not extremely high compared with the 72% efficiency in the places of MHG 50-60 cm.

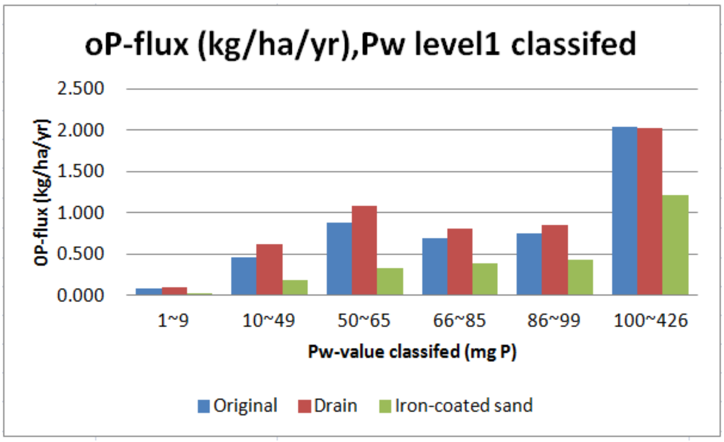
The efficiency of the leaching fluxes of ortho-Phosphorus in the MHG groups 0-10 cm, 10-20 cm and 40-50 cm are around 60%, in the 50-60 cm it is still high with value more than 70%. So it still can be concluded that iron-coated sand have a high level of efficiency for reduce the tP fluxes and oP fluxes, although it is not as significant as the total and ortho-phosphorus situation.

To sum up, according to the results of tP-flux, oP-flux and efficiency of iron-coated sand in the 175 desirable samples classified by MHG, a conclusion can be concluded for the practical condition. For the tP-flux situation and oP-flux situation, they prove that on the sampling location with MHG 10-20cm and 40-50cm the reduction of phosphorus are more significant; meanwhile for the efficiency part, also the sampling location with MHG 10-20cm and 40-60cm have more level of efficiency. To research specifically, the details number of the phosphorus should be considered. According to all the data above, the locations with MHG 10-20cm seems to be the best choice to set up the iron-coated sand for the current situation. Comparing with other 5 MHG classifications it reduced the phosphorus the most (absolute number is 1.75 kg/ha/yr for tP-flux and oP-flux respectively) with second highest level of efficiency (45% for tP and 62%for oP), the MHG level 40-50cm has no significant problem so not chosen as the best location for measurement application.

After the discussion about the tP-flux and op-flux classified by MHG, the situation of these two classified by Pw value were shown as bar chart below.



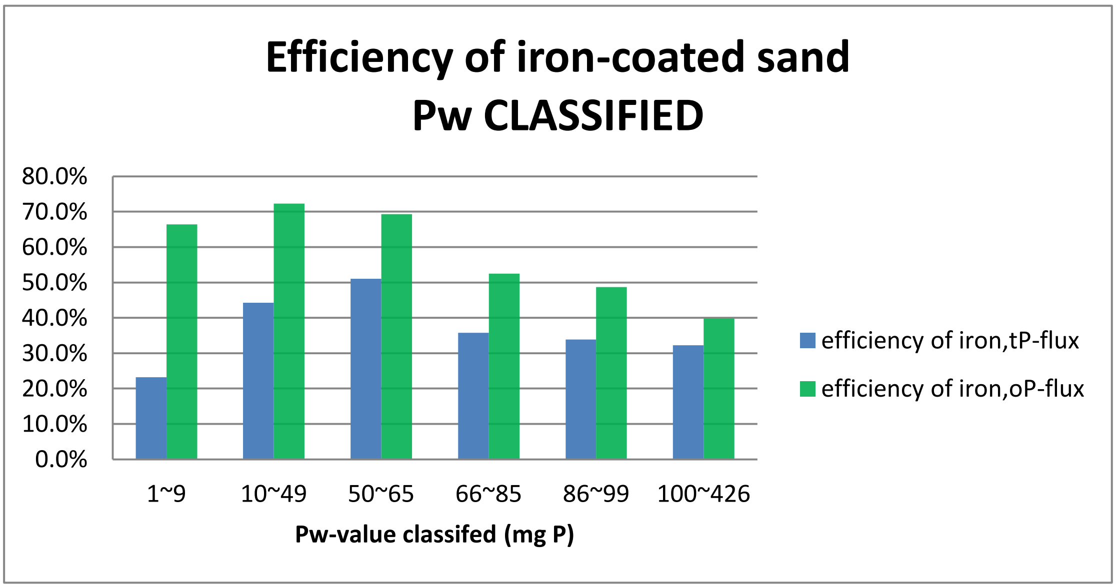
Bar chart 4.2.4.: The leaching fluxes of total Phosphorus to surface water



Bar chart 4.2.5.: The leaching fluxes of ortho-Phosphorus to surface water

Specifically, the bar chart 4.2.4 illustrates that the total phosphorus fluxes for three conditions increased from lower than 0.1 kg/ha/yr to around 2.5 kg/ha/yr through the Pw of top soil increasing, except a small fluctuation shown in the 50-65 mg P Pw group. Moreover, the phosphorus loading problem is more serious especially in the places which the Pw are around 100-426 mg P and other places which the Pw lower than 100mg P the tP-fluxes and oP-fluxes are lower than 1.7 kg/ha/yr. For the results of oP-fluxes, the tendency is almost same with that of total phosphorus fluxes. However, through the comparison of two charts above, it is evidence that the amount of oP-fluxes for every group is slightly lower than the amount of tP-fluxes. It is reasonable, because the total amount of the ortho-phosphorus in soil is a part of the total phosphorous.

Additionally, comparing with the original situation (without drainage systems), it is obvious that the results of situation with drainage system reflected more phosphorus loading than the original situation. And after setting up the iron-coated sand, not only the oP-fluxes but also the tP-fluxes for the six Pw classified group decreased significantly with different efficiencies.



Bar chart 4.2.6.: The comparison between the efficiency of iron-coated sand for tP and oP, Classified according to Pw CLASSIFIED

The figure describes the efficiency of iron-coated sand in different Pw in the top soil. The values calculated from the tP-fluxes results of iron-coated sand divide that of results without iron-coated sand. And the same process was done in calculating the efficiency of iron-coated sand absorbing the ortho-P in sandy soil. To more detail, the bar chart above shows that the efficiency of tP –fluxes in the group of Pw 66-426 mg P is more than 30%, the efficiency of oP –fluxes in the groups Pw 10-65 mg P are around 70%, the highest efficiency happened in 50-65 mg P of tP-flux with 51% and in 1-9 mg P of op-flux with 77%. So it might be concluded that the enveloped drain with iron-coated sand is more appropriate applying in the places where the top soil Pw lower than 66 mg P.

Additionally, the efficiency of oP-fluxes in the group Pw 100-426 mg P is 40%, the efficiency in the places where the top soil Pw are around 66 to 99 mg P is around 50% and the efficiency of the samples' groups Pw 1-9 mg P and Pw 50-65 mg P are more than 65%. And it should be mentioned that the efficiency of the samples' group Pw 10-49 mg P is more than 70% which is really high efficiency to reduce the phosphorus in the soil significantly. Therefore, it may seem to imply that the places which the Pw is around 1-65 mg P are more appropriate to install the enveloped drain with iron-coated sand to reduce the phosphorus leaching.

To sum up the results of Pw classification, on the one hand, according to the results of tP-flux and oP-flux, it might be concluded that in the places of Pw-value 50-65 mg P and 100-426 mg P have more serious phosphorus loading problem. On the other hand, from the perspective of the efficiency, iron-coated sand installing under the places, which the Pw-values were around 1 mg P to 65 mg P, were supposed to reduce more phosphorus in the soil.

However, according the calculation of absolute number of reducing the phosphorus, the samples groups of Pw-value 50-65 mg P and 100-426 mg P were assumed to be the most suitable location to set up the iron-coated sand. The absolute numbers of the phosphorus reducing in these two groups were both more than 0.8 kg/ha/yr, which were larger than the rest groups. Meanwhile, the efficiencies of these two groups were still relative high. Therefore, it is difficult to conclude that which group is the most suitable one to install iron-coated sand, because generally speaking, the performances of iron-coated sand in the six Pw groups were quiet good.

It should be mentioned that in the efficiency comparison figure for both classification, the efficiency of Op are always higher than tP, which is just like the thesis planed. That is because the tP includes the Op which can be absorbed by iron-coated sand and also includes the phosphorus cannot be adsorbed. The efficiency of tP-flux lowers than that of oP-flux. It was caused by the immobile Phosphorus which cannot be absorbed by iron-coated sand.

5. Conclusion

According to the results came from two professional model，the report analyzed the feasibility of iron-coated sand applied in the sandy soil in the Netherlands. The research was concerned through two views: the lifespan and the efficiency of iron-coated sand.

On the one hand, based on the data from lifespan, the range of lifespan of iron-coated sand was generated. For the normal precipitation and high phosphorus concentration in the soil, the lifespan of the iron-coated sand should be around 20 to 40 years. Comparing with the lifespan of normal pipes (10-30 year) [oral information according to the interviews did by Groenenberg]. It is obvious that the lifespan of iron-coated sand and normal pipes are matching. Therefore, iron-coated sand is appropriate to use with normal pipes for reducing P leaching in the soil. It means that there will not be extra work for installing iron-coated sand, the only thing the farmers need to do is when they replace the new pipes, replace iron-coated sand at the same time. To conclude, the iron-coated sands do have the feasibility, in the respect of lifespan.

On the other hand, through applying the PLEASE model, the efficiency of iron-coated sand were analyzed. Firstly, in order to research the efficiency of the enveloped drain with iron-coated sand applying at different phreatic levels, the result of each location was classified into six groups, according to the different ground water levels. Through the analysis, it can be concluded that the all the places in the catchment area with different MHG have a relative high efficiency of reducing the phosphorus leaching. The efficiency of adsorbing Op-flux in different MHG (Mean Highest Groundwater level) conditions are higher than 40%, and even half of results showed the efficiency are higher than 60%, compared with the situation with normal pipes. However, the results shows that the different ground water levels do not directly related to the efficiency of iron-coated sand. After that, the results were classified again according to the amount of phosphorus in the soil layers, in order to analyze the relationship between the efficiency of iron-coated sand and the concentration of Phosphorus in the top soil. Generally speaking, the efficiency of iron-coated sand is relatively high in different Pw-value (the amount of water extractable P) in the top soil which higher than 40%. Moreover, it should be mentioned that the efficiency of absorbing oP-flux is more than 65% when Pw-Value in the top soil is around 1mg P to 65mg P, which the places were assumed to be the suitable location to install the iron-coated sand. According to the results analysis, it can prove that the adsorption efficiency of iron-coated sand showed a decreasing trend with the increase of Pw-value in the top soil, vise versa. Therefore, it is inferred that the concentration of P in the soil do impact the efficiency of iron-coated sand. The constraint condition about efficiency is the iron-coated sands only adsorb the ortho-phosphorus nearby the drainage pipes, and the other phosphorus probably released with the surface runoff to ditch directly.

To conclude the results of two models, the iron-coated sand was proved to be a high feasibility in the terms of lifespan and efficiency. And during the lifespan, it can be concluded that the phosphorus leaching problem would be solved with high level of efficiency and high cost performance. Therefore, it is worth to develop the project of iron-coated sand application in the Netherlands.

6. Recommendations and Further research

According to the conclusions analysis of the research, we advise that the local government in the Netherlands should embrace the measure and persuade the local farmers to apply for the iron-coated sand in most agriculture area suffer from the phosphorus loss problem in the Netherlands.

And some further research should be set up to support the measure. The influence factors of efficiency of iron-coated sand also need further exploration. Moreover, the solutions for maintain the high efficiency of iron-coated sand when the places suffer from emergency such as: big storms or flooding will be the key word for the further study. Then some measurement for decreasing phosphorus in different kinds of soil should be found. Besides, some research needs to start to explore how to extend the lifespan of the drainage pipes. Only long lifespan of the iron-coated sand cannot solve the problem for long term.

References

1. Pleijter, M. a. C. v. d. S. (2010). "Validatie van PLEASE op regionale schaal; Berekeningen van de fosfaatbelasting van het oppervlaktewater met behulp van PLEASE voor de stroomgebieden Quarles van Ufford, Drentse Aa, Krimpenerwaard en Schuitenbeek." Alterra-rapport **1968.3**: P7- P92.

2. W.J. Chardon*, P. Belder2, J.E. Groenenberg1 and G.F. Koopmans (2011). "Removal of phosphorus from drainage water using an enveloped tile drain." P1.

3. 3Jan E. Groenenberg, W. J. C., and Gerwin F. Koopmans (2012). "Reducing Phosphorus Loading of Surface Water Using Iron-Coated Sand." P250-P255.

4. Caroline van der Salm, R. D., Ruth Grant, Goswin Heckrath, Bo V. Iversen, Brian Kronvang, Clémentine Levi, Gitte H. Rubaek, and Oscar F. Schoumans (2011). "Predicting Phosphorus Losses with the PLEASE Model on a Local Scale in Denmark and the Netherlands." P1-P10.

5. "The principle of Langmuir adsorption model." came from http://en.wikipedia.org/wiki/Langmuir_adsorption_model

6. "The principle of Freundlich equation model ". came from http://en.wikipedia.org/wiki/Freundlich_equation

7. Gerwin Koopmans, W. C., Jan Groenenberg (2011). "Use of reactive materials to bind phosphorus." P1-P2.

8. Caroline van der Salm, T. B.-J. G. (2011). "Short manual of the model PLEASE vs.1.0." P3-P6.

9. Chardon, W. J., Groenenberg, J.E., Tecminghoff, E., Koopmans, G.F (2013). "Use of reactive materials to bind phosphorus." Journal of Environmental Quality 41: P636-P646.

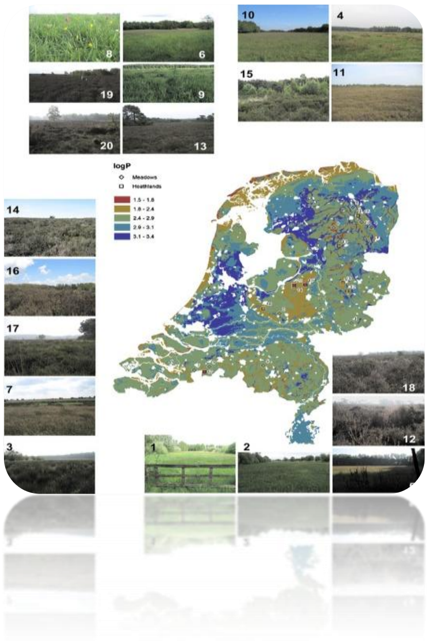
10. " 3.6 Phosphorus leaching.", came from: http://www.fao.org/WAIRDOCS/LEAD/X6113E/x6113e06.htm

Appendix1. Plan of approach

Reducing phosphorus discharge to the surface water by using iron-coated sand

Bachelor thesis research project

Plan of approach



Cao Zijing (901022102)
Zhang Yuan (900204003)
Email: caozijing.cao@wur.nl zhangyuan.zhang@wur.nl

February 2013

Major Instructors:

Van Hall Larenstein University of Applied Science	Hans Van Den Dool
Alterra, Wageningen University	Groenenberg Bert-Jan

Table of contents

1. Introduction

1.1. General

This document is written for the preparations of our final thesis in the Netherlands from February to the July of 2013. This document will be used as a guideline for the thesis research for completing our Bachelor degree. And the internship for the thesis will take place at Alterra, which is a research institution of Wageningen University Research Centre in the Netherlands. At Alterra we will deal with applying iron-coated sand to reduce the phosphorus in surface water drained from farmland. The research is to study the effectiveness of iron-coated sand in different kinds of soil in the Netherlands to reduce phosphorus load to surface water systems through pipes. Besides, the perspective on the feasibility of application of the technology will be addressed.

1.2. Research background

Phosphorus loss from agricultural soils is an important source of P in surface waters which causes surface water quality impairment in many regions of the world, including the Netherlands. The main problem is the high level of P leaching of water and soil. The main reason of these problems is the phosphorus leaching from the agricultural land to other soil layers or to the surface water systems through the drainages (Fig1.). Moreover, owning to the large amounts of P accumulated in Dutch soils, the policy of restricting the application of fertilizers and manure will not be effective in the short term. Therefore, it is a problem that reaching the Surface Water Quality Standards of the European Water Framework Directive[1] in time.

Recently, Alterra found out through several years' research that applying iron-coated sand to remove P from the drainage water already proved an effectiveness of 94%[2] in two soil conditions in the Netherlands. However, the long-term performance of this method and the feasibility for various types of soils in the Netherlands still need further experimental research. In other words, the sustainable and further application of this P-reducing method should be concerned, in order to find out it's effectiveness in the long run.

1 Removal of phosphorus from drainage water using an enveloped tile drain, W.J. Chardon*,1, P. Belder2, J.E. Groenenberg1 and G.F. Koopmans

2 Reducing Phosphorus Loading of Surface Water Using Iron-Coated Sand, Jan E. Groenenberg,* Wim J. Chardon, and Gerwin F. Koopmans

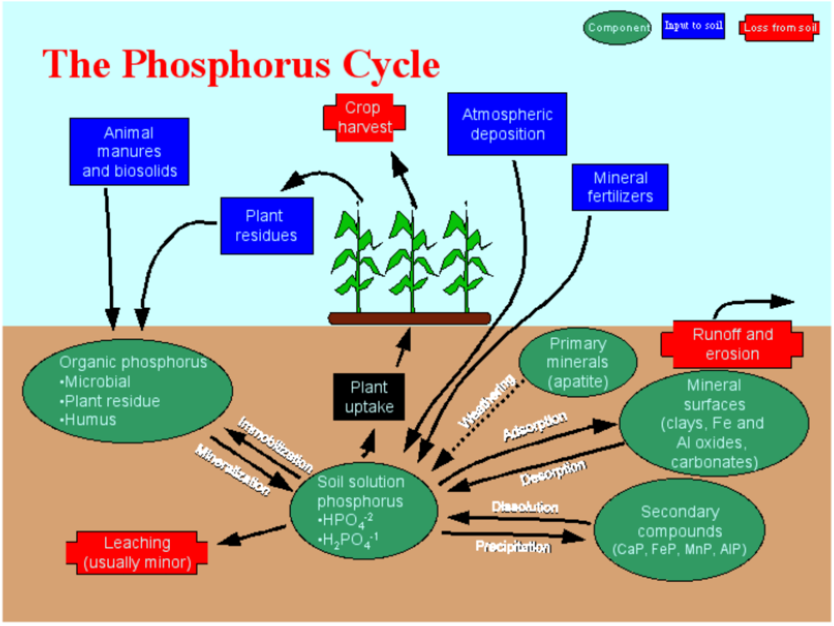


Fig1. P cycle in the soil[3]

1.3. Scientific context

In 2009 Alterra started to develop a technique to reduce P loading of surface waters by using iron rich P binding materials.[4] The materials are a residue of the drinking water industry. Materials were tested in the laboratory. From the tested materials iron coated sand was the most promising material because of its high P binding capacity and good hydrologic properties.

In 2010 a field experiment was started with a pipe drain enveloped with iron coated sand (see article Groenenberg et al., 2013). The P-rich water passes the iron coated sand before entering the pipe drain. Enveloping a pipe drain with Fe-coated sand resulted in an average DRP (Dissolved Reactive P) removal of 94%, resulting in effluent concentrations that were below the Dutch water quality criterion of 0.15 mg TP (Total P) L−1. Therefore, most P was retained by the iron coated sand and good quality water is discharged to the surface water. Monitoring of the field experiment will be continued until spring 2014[5].

In fall 2012 a similar experiment was started by the waterboard of Rijnland in cooperation with Alterra. This experiment will continue for 2 years.[6] The thesis is a

[3] The figure collected from the presentation of Hans Van Den Dool, Environmental Science, Lecture 6, “Eutrophication”
[4] Reducing Phosphorus Loading of Surface Water Using Iron-Coated Sand, Jan E. Groenenberg,* Wim J. Chardon, and Gerwin F. Koopmans
[5] Reducing Phosphorus Loading of Surface Water Using Iron-Coated Sand, Jan E. Groenenberg,* Wim J. Chardon, and Gerwin F. Koopmans
[6] Reducing Phosphorus Loading of Surface Water Using Iron-Coated Sand, Jan E. Groenenberg,* Wim J. Chardon, and Gerwin F. Koopmans

extra research based on the project which, however, has the practical values. The thesis will support the primary analysis of the enveloped drainage system with iron-coated sand for the project. To be more specific, the thesis will provide the elementary evidences of the feasibility of the enveloped drainage system with iron-coated sand applied in sandy soil in the Netherlands.

2. Research statement

2.1. Problem description

The method of the enveloped drainage with iron-coated sand needs further research in order to be applied in practice. The main problem of research can be divided into two levels. The first level is the lifespan of iron-coated sands in the P-reduction process compared with the lifespan of normal pipes. The other level is the effectiveness of iron-coated sand in different hydrologic conditions and in different sandy soils. And through combining these two levels, the feasibility of iron-coated sand could be explored which is the main target of the thesis.

The other level of research is the lifespan of iron-coated sand. There is no doubt that only the lifespan of iron-coated sand is equal to (or longer than) that of normal pipes, the method of reducing phosphorus is worthy to be applied in the real life. That is to say that it is possible to persuade the local farmers to use this method without extra labour comparing with normal pipes. If the lifespan of the iron-coated sand is too short, the renewal activities will be more frequently, which means costs more expenses, labour and time. As a result, the length of lifespan affects the popularization of iron-coated sand. To make matters worse, it certainly affects the feasibility of iron-coated sand as well.

To find out the effectiveness in the long run the following should be researched:

- The Freundlich adsorption parameters after linearization for the different equilibration times
- The tendency of the adsorption capacity changing by the time

Additionally, for carrying out the research on the first level mentioned above, the Schuitenbeek catchment area will be the case study to research the effectiveness of iron-coated sand grounded in reality. The soil types of the case study are two types of sandy soils, which the problem of phosphorus loading is more serious compared with other types of soil. For this reason the phosphorus loading problem in this area never lose the people's attention. In 1989, there was a comprehensive soil measurement in this area to survey the soil problems. However, the phosphorus loading problems have not ready been solved until now. During this thesis the data measured in 1989 will be used to operate the PLEASE model as fundamental data.

In order to meet the purpose, three key points need to be considered during the research processing:

- The amount of phosphorus will be released into the surface water system after install a normal drainage system in the research area?
- The amount of phosphorus will be reduced through passing the iron coated sand before entering the pipe drain after apply the enveloped drain with iron-coated sand in the research area. And the percentage it occupies with the total amount of phosphorus.
- According to the comparison to prove the value of the enveloped drain with iron-coated sand.

3. Research questions

3.1. Central research question

The study examines the question: what is the feasibility of iron-coated sand applied in Schuitenbeek in the Netherlands with two types of sandy soil: "podzols" and "beekeerd"? This is the crucial question for the thesis, as the answer firstly an indication of the lifespan of iron-coated sand will be provided. For this purpose the Lifespan model and the Freundlich equation[7] will be used for calculating the tendency of effectiveness changing as time goes on. Additionally, it is also need to provide the results of the efficiency of iron-coated sands through comparing the situations between with and without applying the enveloped drain with iron-coated sand imitated by the PLEASE models[8] (P leaching from Soil to Environment).

[7] The principle of **Freundlich equation model** came from http://en.wikipedia.org/wiki/Freundlich_equation

8 Predicting Phosphorus Losses with the PLEASE Model on a Local Scale in Denmark and the Netherlands, Caroline van der Salm,* Remi Dupas, Ruth Grant, Goswin Heckrath, Bo V. Iversen, Brian Kronvang, Clémentine Levi, Gitte H. Rubaek, and Oscar F. Schoumans

3.2. Sub-questions

In order to explore the answer to the main research question deeply, there are two sub questions developed according to manage the working process. The feasibility will be divided into two details aspect: whether iron-coated sand can reduce the concentration of phosphorus and how long the method can operate.

- What is the lifespan of iron-coated sands in the P-reduction process compared with the lifespan of normal pipes?

- What is the effectiveness of iron-coated sand applied at different phreatic levels and at different P concentrations in sandy soil in the Netherlands?

4. Methodology

4.1. Preliminary desk research

The literature research is needed at the beginning of the project, in order to know basic knowledge about the P characteristic and soil operation process and set up a small scale of knowledge system for building up a proper and reasonable study plan and further practical research. The plenty of literatures about the basic knowledge of soil chemistry and current technologies of reducing P leaching from soil are need as basic step of research. Moreover, before the model experiments, the principle of PLEASE model and the manual of model operation will be studied by reading the relative documents. Additionally, the documents about the results of the lab researches on the adsorption capacity of iron-coated sand will also be concerned, in order to acquire the knowledge of the effectiveness of this kind of by-products.

✓ **Documents**

a) *Internal eutrophication: How it works and what to do about it – a review*[9]
b) *Use of Reactive Materials to Bind Phosphorus*[10]
c) *Characteristics and adsorption properties of iron-coated sand*[11]
d) *Phosphorus removal from aqueous solution using iron coated natural and engineered sorbents*[12]

9 Department of Ecology, Institute forWater andWetland Research, Radboud University Nijmegen, Toernooiveld 1, 6525 ED Nijmegen, The Netherlands, 16 January 2006, Internal eutrophication: How it works and what to do about it – a review

10 Wim J. Chardon,* Jan E. Groenenberg, Erwin J. M. Temminghoff, and Gerwin F. Koopmans, Use of Reactive Materials to Bind Phosphorus

11 Graduate Institute of Environmental Engineering, National Taiwan University, 71 Chou-Shan Road, Taipei, Chinese Taiwan, Characteristics and adsorption properties of iron-coated sand

12 Journal of Hazardous Materials, Volume 151, Issue 1, 28 February 2008, Pages 103–110, Phosphorus removal from aqueous solution using iron coated natural and engineered sorbents

e) *Predicting phosphorus losses with the PLEASE model on a local scale in Denmark and the Netherlands*[13]

✓ **Some information from website**

a) www.agronomy.org

b) www.crops.org

c) www.soils.org

d) http://www.wageningenur.nl/en/Expertise-Services/Research-Institutes/alterra.htm

4.2. Data collection

Information from the field trials[14] in the Netherlands need to be collected, selected, operated and analyzed to set up the data base for the later laboratory research. As the reason the agenda from the professional researchers will not very suitable for the students, students will not be the field work every time. But the process and data can be share with them and some add work in the lab can be finished by the students.

The Schuitenbeek catchment area locates between Putten, Nijkerk and Voorthuizen, with area 7500ha[15]. It is almost completely sandy soils. In higher parts are podzols and in lower parts are “beekeerd” soils (typical Dutch soils, more organic rich soils with fluctuating ground water table). More detail information will be included in the report.

4.3. Model operation and analysis

After the literature research as the methodology base, some practical actions also need to apply. The field work and lab experiment mean to support the later research, which means model operation. In terms of the research objectives mentioned above, the model operation is one of the most essential works to address the research questions. There are two main parts of the model will be applied for the research analyse: the lifespan model and PLEASE (P leaching from Soil to Environment) Model. Some information of the model will be concluded as following.

To carry out the main research question steps by steps, the plan of the thesis are going to use the soil data of research area and the conclusions from previous researches to set up the models’ data basin. First of all the research will provide the results of feasibility

---

13 Caroline van der Salm *a, Remi Dupasa, Ruth Grantb, Goswin Heckrathc, Bo V. Iversenc, Brian Kronvangb,Clémentine Levib, Gitte H. Rubaekc and Oscar F. Schoumansa, Predicting phosphorus losses with the PLEASE model on a local scale in Denmark and the Netherlands

14 Validatie van PLEASE op regionale schaal-Fosfaatbelasting van het oppervlaktewater in de stroomgebieden, Quarles van Ufford, Drentse Aa, Krimpenerwaard en Schuitenbeek, Alterra-rapport 1968.3, ISSN 1566-7197

15 The detail information collected and translanted from: ***Validatie van PLEASE op regionale schaal***, Pleijter, M. and C. van der Salm, 2010. Validatie van PLEASE op regionale schaal; Berekeningen van de fosfaatbelasting van het oppervlaktewater met behulp van PLEASE voor de stroomgebieden Quarles van Ufford, Drentse Aa, Krimpenerwaard en Schuitenbeek. Wageningen, Alterra, Alterra-rapport 1968.3

of iron-coated sands applying in the two kinds sandy soils, “podzols” and “beekeerd ” soils in Schuitenbeek which is the catchment area of thesis. The Freundlich equation and the lifespan model will estimate the lifespan of the iron-coated sand.Then, the PLEASE Model will be used to assess and compare with the situations of different phosphorus loading cuasing by diiferent pipe systems. Specific speaking, the different situation will be classified into: the current situation (without drainage pipes); with normal drainage pipes; with iron-coated sand surrounding the drainage pipes. The compraration will be done to prove wether the iron-coated sand can reduce the free phosphorus from soil effectivelly.

A. Lifespan model

It is very important to equilibrate the adsorbent and adsorptive long enough to ensure that steady state has been reached. Different soil and hydrology conditions impacts on the efficiency for P reduction process. In this study, the Freundlich equation will combine with the lifespan model to estimate the lifespan of iron-coated sand with the different situations. There will be two steps to assume the lifespan of iron-coated sand. Firstly, the Freundlich adsorption equation will be applied to evaluate some parameters. The Freundlich equation or Freundlich adsorption isotherm is an adsorption isotherm, which is a curve relating the concentration of a solute on the surface of an adsorbent, to the concentration of the solute in the liquid with which it is in contact. After that various scenarios were simulated with the lifespan model in which the flux through the column varied the concentration of P in the drainage water and the drainage parameters. The data calculated by these procedures will be used for analysis.

B. PlEASE model

Due to the difficulties of field experiments nowadays, the PLEASE model is a simple mechanistic model designed to simulate P losses by leaching at the field scale using a limited amount of local field data.

In other words, for this study, the PLEASE Model could simulate measured fluxes and phosphorus concentrations in water from pipe drains, suction cups, and groundwater quite well[16]. To do so, the specific data of the research area are essential for set up the PLEASE model. And the data have already been measured by some lab-analysis and field

[16] Predicting Phosphorus Losses with the PLEASE Model on a Local Scale in Denmark and the Netherlands, Caroline van der Salm,* Remi Dupas, Ruth Grant, Goswin Heckrath, Bo V. Iversen, Brian Kronvang, Clémentine Levi, Gitte H. Rubaek, and Oscar F. Schoumans

work by the professional staffs of research center for getting the primary and secondary data for the model input. The collected data and model analysis will be reported in the thesis report and presented at the colloquium.

4.4. Time table

Activities			February			March				April				May					June			
Week	Start	Finish	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	5	1	2	3	4
Literature study1	11-Feb-13	21-Feb-13																				
Discuss with tutors1	22-Feb-13	26-Feb-13																				
Literature study2	27-Feb-13	1-Mar-13																				
Modeling1	4-Mar-13	22-Mar-13																				
Analyzing1	20-Mar-13	29-Mar-13																				
Literature study3	1-Apr-13	10-Apr-13																				
Discuss with tutors2	11-Apr-13	12-Apr-13																				
Modeling2	15-Apr-13	26-Apr-13																				
Analyzing2	29-Apr-13	15-May-13																				
Modeling3	16-May-13	31-May-13																				
Discuss with tutors3	3-Jun-13	7-Jun-13																				
Document	11-Feb-13	21-Feb-13																				
Plan of approach	22-Feb-13	26-Feb-13																				
Framework	27-Feb-13	10-Apr-13																				
Writing	11-Apr-13	1-Jun-13																				
Finalization	20-May-13	6-Jun-13																				
Presentation	7-Jun-13	28-Jun-13																				

5. Products envisaged

The research for thesis includes two parts: first, through the practical work in Alterra from February in 2013 to beginning of June in 2013, the data will be collected from the field experiments and model tests. Moreover, the effectiveness of the iron-coated sand applying in sandy soil will be analyzed using the models. Meanwhile, there will be the analysis of environmental factors that may affect the effectiveness and life time of iron-coated sand, such as the thickness of iron-coated sand, the phosphorus concentration in the pore water, and the inundating time etc.

Secondly, there will be some summaries for every stage and new ideas recorded, through the constantly communication with the instructors, as well as the discussion between two students. Additionally, the report for thesis will be written during these six months.

a) Preliminary table of contents of report

Contents	Explanation
Background information	The generic Dutch fertilizer and manure policy, which strives to wards equilibrium fertilization in 2015, will not be sufficient to

	reach the surface water quality standards of the European Water Framework Directive in 2015.[17] Therefore, there is an urgent need to find measures to remove the p which are effective and less impact on the soil environment. Previous studies have found that iron-coated sand can fix the mobilized phosphorus in the soil, thereby reducing the pollution of soil and water environment which caused by excessive application of phosphate fertilizers. Through the combination of iron-coated sand and draining pipes, the mobilized P is adsorbed effectively. In this way, it can not only reduce the excess P in soil, but also is able to decontaminate the surface water from the pollution source. However, this method is not mature which means more experiments still need to be researched. And there are two fields to test the effectiveness of iron-coated sand in practice in previous studies.
Problem descrebtion	To find out the effectiveness in the long run and it's feasibility for various soils the following should be researched: 1. Chemical and physical characteristics of iron-coated sand, the effect factors of adsorption etc. 2. Performance of the enveloped drain, both in terms of its ability to remove P to a sufficiently low level and the tendency of efficiency changed through more and more adsorption occurred not only on the surface but also the inside of iron-coated sand.
Objective	The purpose of the thesis is to explore the feasibility of this method of iron-coated sand. In other words, according to the experiments and models studies for the two levels mentioned, there will has the analysis on the feasibility of iron-coated sand in the practical situation.
Methodology	To research on the project, firstly, the literature research as the preparatory work is needed at the beginning of the project, in order to know the basic knowledge about the preliminary results and the technologies about reducing the Phosphorus Loading of

[17] Use of reactive materials to bind phosphorus.Gerwin Koopmans, Willem Chardon, Jan Groenenberg, Alterra， October 31 - November 4, 2010，Annual Meeting Abstracts

	surface water in the Netherlands. Because of the different agenda so the practical and field work part will be carried out by other staff but the results can be shared. After the literature research as the methodology base, some practical actions also need to apply. There are two main parts of the model will be applied for the research analyses: the lifespan model and the PLEASE (P leaching from Soil to Environment) Model. The lifespan model is the model to estimate the effectiveness and lifespan of iron-coated sand in different hydrology conditions to reduce the P concentration with the enveloped drains. Moreover, the PLEASE Model is a simple mechanistic model designed to simulate P losses by leaching at the field scale using a limited amount of local field data. An imaging drainage system will be used in this case and the PLEASE model will prove the effectiveness of it.
The efficiency of iron-coated sand	The analysis of the lifespan and adsorption effect, according to the model research: *(the Lifespan model and PLEASE model)* 1. The lifespan of iron-coated sand. (The factors that affect the lifespan: the concentration of P in the soil, the amount of water draining from pipes etc.) 2. The range of adsorption. (the amount of adsorption per unit, and the speed of adsorption, and the restriction conditions of the adsorption efficiency)
The feasibility of iron-coated sand	The lifetime limited and effectiveness of iron-coated sand in sandy soil will be estimated by the lifespan and PLEASE model, then to analyze the feasibility of iron coated sand in reality. Based on the data, how suitable of iron coated sand in different groundwater environmental locations can be measured. Besides, the efficiency and influence factors can be found during the field experiments different groundwater level.
Conclusion	According to the analysis above, the conclusion will answer the main question.
Reference	The list of references

b) Constraints

There are many constraints for the study even though the topic has been well-defined and the data of previous experiments is available. It is a matter of fact that the research of the lifespan of this mitigation measure needs a long term study. It is impossible to complete the research in the six-month thesis. Therefore, the lifespan will be estimated using a model. Moreover, there are gaps between the model and reality.

2. Project organisation

There are four actors involved in the thesis assignment:

- **The employees:** Cao Zijing and Zhang Yuan work together as a group for carrying out the thesis research.
- **The employer: Bert-Jan Groenenberg** is the external coach of this group who is carrying out the project (Removing P in the soil by iron-coated sand) in Alterra, Wageningen University. He will provide technical assistance and support.
- **Van Hall Larenstein University of Applied Sciences**: **Hans Van Den Dool** represented as the VHL-internal coach who takes charge of coaching the process and providing feedback on the intermediate products the board of assessors: (during the colloquium and the criterion-based interview), consisting of the VHL-internal coach and an independent external assessor.

To be specific，the group of students (Cao Zijing and Zhang Yuan) is one of the core parts of this final thesis, they will take charge of the research work. The responsibility of them is the implementation of the thesis assignment according to the approved project plan. Cao Zijing and Zhang Yuan should write and timely submit the thesis reports. Moreover, the presentation, explanation and defence of the results should be done.

Besides, they will also hold the job of communication. The initiative to contact the coaches must be taken by the students.

To enable the VHL internal and external coaches to play their roles effectively. To keep records of discussions with the coaches. Not only research processing communication but also research problem and new ideas are needed frequently to make contribution to the project.

The responsibility of the external coach (Bert-Jan Groenenberg) is to provide technical guidance to the students, on behalf of the company, organisation or project commissioning the thesis assignment. And he should provide information, means and logistical support to the students to make the implementation of assignment possible. Additionally， the discussion of the draft thesis report with the students should be done by the external coach.

The VHL internal coach (Hans Van Den Dool) has the responsibility of the evaluation of the project. Moreover, it is important to keep contact with the external coach and students about the process during the thesis assignment and the functioning of the team.

Additionally, the internal coach should check the main lines of the draft thesis report, guided by the project plan, and inform the students be on time to do the research based on the timetable.

a) Allocation of tasks

During the procedure of the project, Cao Zijing and Zhang Yuan will work and cooperate together and help each other. As a whole, main part of the project will be finished by them both. Besides, according to the personality and knowledge background, personal advantages will also be made use of to do the research.

To be specific, according to the timetable designed, the work for Cao Zijing and Zhang Yuan will base on characteristics to work.

Preliminary study			
Activity	**Method**	**Person in charge**	**Deadline**
Select and conclude the previous research achievement about Iron coated sand	Literature study	Tommy	March 1st
Describe the principle of P-fixation to Iron coated sand	Literature study	Yuan	March 1st
Write a summary of article research	Descriptive study	Yuan and Tommy	March 15th
Describe the principle and formulas of P-adsorption model	Literature study	Tommy	March 20th
Describe the principle and formulas of PLEASE model	Literature study	Yuan	April 15th
Research			
Use the recent data to practice how to use the P-adsorption model to caculate the adsorption effeciency of iron coated sand	Experimental study	Yuan and Tommy	March 20th
Collect the data of experiments	Investigation study	Tommy	March 30th
Use the model to analyze the adsorption effeciency of iron coated sand	Experimental study	Yuan and Tommy	April 5th
Conclude and analyze the results of P-adsorption model and write into the report	Information Studies	Yuan	April 15th
Collect the data of soil	Investigation study	Tommy	April 26th
Use PLEASE model to analyze the feasibility of the Iron coated sand	Experimental study	Yuan and Tommy	May 10th
Conclude and analyze the results of PLEASE model and write into the report	Information Studies	Yuan	May 20th
Conclude the contents of report	Information Studies	Yuan and Tommy	May 25th
Finalize the report	Descriptive study	Tommy	June 6th
Generate the presentation	Descriptive study	Yuan and Tommy	June 20th
Check up the presentation	Descriptive study	Yuan	June 23th
Communication			
Communicate the progress of work with external coach weekly	Email	Tommy	every week
Communicate the progress of work with internal coach weekly	Email	Yuan	every week
Have a meeting with external coach weekly	Meeting	Yuan and Tommy	every week
Have a meeting with internal coach	Meeting	Yuan and Tommy	at least every month
Discuss the content of report with external coach	Meeting	Yuan and Tommy	April 26th
Discuss the content of report with external coach	Meeting	Yuan and Tommy	April 26th
Discuss the content of report with external coach	Meeting	Yuan and Tommy	May 28th
Discuss the content of report with external coach	Meeting	Yuan and Tommy	May 28th
Discuss the content of report and presentation with internal coach	Meeting	Yuan and Tommy	May 30th

8. References

1. viewed in 11/2/2013
   http://www.sciencedirect.com/science/article/pii/S0273122397001157
2. viewed in 11/2/2013
   http://www.sciencedirect.com/science/article/pii/S0304389407007753
3. viewed in 11/2/2013
   https://www.agronomy.org/publications/jeq/articles/40/5/1617
4. Removal of phosphorus from drainage water using an enveloped tile drain, W.J. Chardon*,1, P. Belder2, J.E. Groenenberg1 and G.F. Koopmans
5. Reducing Phosphorus Loading of Surface Water Using Iron-Coated Sand, Jan E. Groenenberg,* Wim J. Chardon, and Gerwin F. Koopmans
6. The priciple of P cycle came from: the presentation of Hans Van Den Dool, Environmental Sceince, Lecture 6, "Eutrophication"
7. Predicting Phosphorus Losses with the PLEASE Model on a Local Scale in Denmark and the Netherlands, Caroline van der Salm,* Remi Dupas, Ruth Grant, Goswin Heckrath, Bo V. Iversen, Brian Kronvang, Clémentine Levi, Gitte H. Rubaek, and Oscar F. Schoumans
8. The principle of **Freundlich equation model** came from
   http://en.wikipedia.org/wiki/Freundlich_equation
9. Department of Ecology, Institute forWater andWetland Research, Radboud University Nijmegen,Toernooiveld 1, 6525 ED Nijmegen, The Netherlands, 16 January 2006, ***Internal eutrophication: How it works and what to do about it – a review***
10. Pleijter, M. and C. van der Salm, 2010. Validatie van PLEASE op regionale schaal; Berekeningen van de fosfaatbelasting van het oppervlaktewater met behulp van PLEASE voor de stroomgebieden Quarles van Ufford, Drentse Aa, Krimpenerwaard en Schuitenbeek. Wageningen, Alterra, Alterra-rapport 1968.3
11. Graduate Institute of Environmental Engineering, National Taiwan University, 71 Chou-Shan Road, Taipei, Chinese Taiwan, ***Characteristics and adsorption properties of iron-coated sand***
12. Journal of Hazardous Materials, Volume 151, Issue 1, 28 February 2008, Pages 103–110, ***Phosphorus removal from aqueous solution using iron coated natural and engineered sorbents***
13. Caroline van der Salm *a, Remi Dupasa, Ruth Grantb, Goswin Heckrathc, Bo V. Iversenc, Brian Kronvangb,Clémentine Levib, Gitte H. Rubaekc and Oscar F. Schoumansa, ***Predicting phosphorus losses with the PLEASE model on a local scale in Denmark and the Netherlands***
14. Use of reactive materials to bind phosphorus.Gerwin Koopmans, Willem Chardon, Jan Groenenberg, Alterra， October 31 - November 4, 2010，
    Annual Meeting Abstracts

Appendix 2.The process of calculation of adsorption parameters

As the preparation of the lifespan model, the adsorption research should be finished at first to support essential parameters and condition for the lifespan study. The adsorption experiment of Iron sludge was generated in the laboratory by professional institution staff. 30 mg iron sludge was put into a 30 ml solution in centrifuge tube. The observation period was set and classified into 4 steps: 1, 3, 8 and 21days. During the observation the variation in the solution were reported and after that some calculation with principal were generated for calculate adsorbed amount in mg P/g Fe-sludge and plot in graph and determine Freundlich adsorption parameters after linearization for the different equilibration times.

C-init mg/L	0 d	1 d	3 d	8 d	21 d
1	2.495	0.063	0.038	0.016	0.01
1’	2.495	0.066	0.039	0.017	0.011
2	4.135	0.473	0.281	0.129	0.087
2’	4.135	0.491	0.239	0.136	0.083
3	8.06	2.27	1.69	0.943	0.639
3’	8.06	2.14	1.59	0.948	0.725
4	16.14	8.15	6.76	5.53	4.15
4’	16.14	7.86		5.43	4.33
5	31.84	21.9	20.3	18.4	17
5’	31.84	22.5	20.3	18.8	17
6	64.8	51.6	49.9	48.4	45.2
6’	64.8	52	50.5	47.6	45.2
7	130.24	114	107	109	107
7’	130.24	114	108	110	107

*Flow chart a1.: The data of the adsorption experiment on iron sludge**

(There is a mistake of data: sample4’ at 3d. The measurements below used the same number of sample 4 at 3d, in order to avoid error)

As it is shown in the table, 7 different groups of experiment processing were reported in the pointed day. There was a significant decrease in the day 1 and the slowed down gradually during the 21days.

The first main principle formulation for the adsorption model is $Q= (C_fV_f)-(C_0V_0)/m$ The Q is the amount of adsorption (absorb per unit mass of adsorbent) in mol/kg, C_f (C-init) and C_0 are the final and initial adsorptive concentrations, respectively in mol/l, V_f and V_0 are the final and initial adsorptive volumes, respectively in l, and m is the mass of the adsorbent in kg.

Q(mol/mg)	0d	1d	3d	8d	21d
1	0	2.432	2.457	2.479	2.485
1'	0	2.429	2.456	2.478	2.484
2	0	3.662	3.854	4.006	4.048
2'	0	3.644	3.896	3.999	4.052
3	0	5.79	6.37	7.117	7.421
3'	0	5.92	6.47	7.112	7.335
4	0	7.99	9.38	10.61	11.99
4'	0	8.28	-	10.71	11.81
5	0	9.94	11.54	13.44	14.84
5'	0	9.34	11.54	13.04	14.84
6	0	13.2	14.9	16.4	19.6
6'	0	12.8	14.3	17.2	19.6
7	0	16.24	23.24	21.24	23.24
7'	0	16.24	22.24	20.24	23.24

Table a2.: The quantity of the phosphorus adsorbed with time

After the calculation through the Microsoft Office Excel, the result were calculated and shown in the model. The general trends for these data demonstrated the adsorbed phosphorus climbed with the time rising.

Next step, another essential equation was used: LogQ=LogK+(1/n)*LogC (derived from equation Q=KC^1/n). In this formulation, the "LogK" and "1/n" can be figured out which are the two parameters for lifespan model. To calculate the value more accurate, all 7 groups of Q and C were averaged respectively to reduce the errors.

After the calculation, there were 4 lines which illustrate the different slops (1/n) and intercepts (LogK) of the linear equation: LogQ=LogK+(1/n)*LogC. And because only the data in day 3 and day 21 were supposed to be selected for the further model operation, the line graphs of these two groups were showed below.

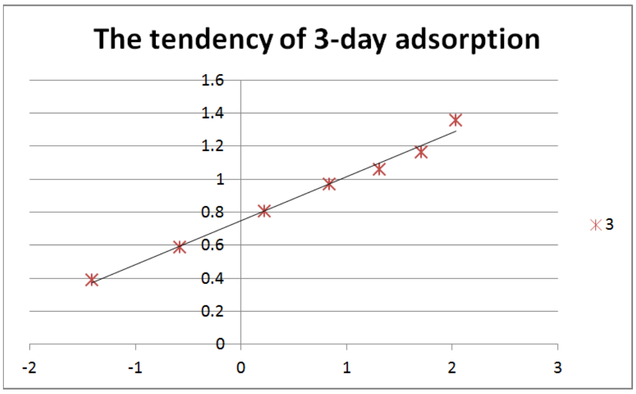


Table a3.: *The tendency of 3-day adsorption*

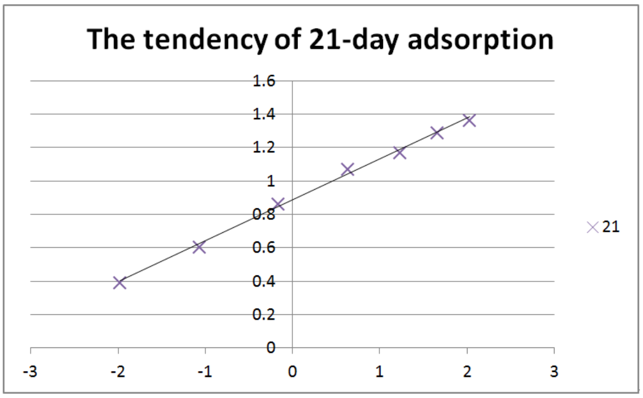


Table a4.: *The tendency of 11-day adsorption*

In other words, through using the function of the trend line in the Excel, the best line fitting the data above could be figured out. And after that, according to the line chart below, the slops and intercepts were calculated by using linear regression. To be more specific, based on these 2 graphs an equation was generated: y=ax+b (x= LogC, y=LogQ). The idea to figure out the “1/n” and “LogK” was using formulation to calculate the slope and intercept which means figure out “a” and “b”. By using the instructions of slope and intercept in the Excel the LogK and 1/n in day 3 and day 21 were calculated respectively with number 0.751, 0.266 for day3 and 0.887, 0.245 for day21.

Appendix3. The process of PLEASE model operation

For carrying out the research on the first level mentioned above, the soil data of Schuitenbeek which have been measured in 1989[18] would be used to imitate the situation the water flowing through the three soil layers and the phosphorus loading problem. In this case, the PLEASE model was used to compare the situations of different phosphorus loading causing by different pipe systems.

In order to compare three situations mentioned, firstly, the general data, soil data and hydrology data were filled into the PLEASE model. And then, the profiles of the water fluxes, ortho-P concentrations and total-P concentrations of catchment area were imitated. After that, the results provided by the PLEASE model were used to compare the current situation (without drainage pipes to keep the suitable dry condition for farming activities in the root area); with normal drainage pipes; with iron-coated sand surrounding the drainage pipes. The comparison will be generated to find the situation of phosphorus loading situation in the surface water.

In the case of this thesis, the first step would be input the all general data into the file general.inp.

soil layers	K	k_d	β	drainage resistance
3	35	0. 2	0. 1667	0. 25

Table1. The general data file

As described in the last chapter, the number here means

- record 1: number of distinguished soil layers (3)
- record 2: Langmuir sorption parameters K(35), k_d(0.2), β(0.166667)

18 Validatie van PLEASE op regionale schaal-Fosfaatbelasting van het oppervlaktewater in de stroomgebieden, Quarles van Ufford, Drentse Aa, Krimpenerwaard en Schuitenbeek, Alterra-rapport 1968.3, ISSN 1566-7197

- record 3: ratio between drainage (ditch) distances and drainage resistance(0.25)

After that, the next step is input the all distinguished soil data into the file soil.inp.

locationNO.	ayers' depth			Bulk desityL1	Bulk desityL2	Bulk desityL3	Al+Fe L1	Al+Fe L2	Al+Fe L3	Pw L1	Pw L2	Pw L3
2124	20	50	260	1413. 374	1483. 524	1599. 08	78. 9	51. 033	26. 654	79	20	0. 023
2125	20	50	210	1353. 349	1486. 811	1195. 032	97. 5	83. 027	114. 819	29	23	0. 023
2126	20	50	250	1411. 09	1435. 526	1600. 653	64. 722	56. 6	41. 005	49	58	0. 023
2127	20	50	250	1413. 374	1463. 907	1606. 172	84. 2	85. 92	30. 108	42	37	0. 023
2128	20	50	260	1405. 983	1454. 866	1603. 892	46. 5	80. 55	74. 287	19	11	0. 023
2129	20	50	200	1372. 478	1359. 985	1592. 343	39. 9	63. 047	18. 6	35	37	0. 023
2130	20	50	340	1370. 528	1370. 528	1421. 386	57. 7	64. 533	72. 595	89	82	0. 023

Table2： 309 location points in the catchment area (the table above is an example, the others group numbers were show in the same stractrue which were attached in Appendix)

As described in the last chapter, the number here means :(the first row was explain as the example, other 308 group number will be show in the same structure)

- Location number, (2124)
- lowest depth(cm –mv) of the soil layer,(20 50 260, because there are 3 different layers)
- bulk densities of the soil layers 1 - *n*, (1413.374 1483.524 1599.080)
- Al+Fe contents of the soil layers 1- *n* ,(78.900 51.033 26.654)
- Pw-value of the soil layers 1 t/m *n-1* (79 20, and the final one is 0)
- Background concentration/concentration in seepage water (0.023)

Next step would be input the all distinguished hydrological data into the file hydro.inp.

locationNO.	Indicator	MHG	MLG	Resis 1st	Resis 2nd	D basis 1st	D basis 2nd	precipitation	Seepage	Depth of D
2124	1	65	160	1	1	-999	-999	314	-5	0
2125	1	20	110	1	1	-999	-999	332	98	0
2126	1	45	150	1	1	-999	-999	314	-5	0
2127	1	50	150	1	1	-999	-999	401	-5	0
2128	1	60	160	1	1	-999	-999	87	-5	0
2129	1	10	100	1	1	-999	-999	332	98	0
2130	1	135	240	1	1	-999	-999	245	-174	0

Table3： 309 location points in the catchment area (partly omitted), hydrological data

As described in the last chapter, the number here means :(the first row number will be explain as the example, other 308 group number were shown in the same structure)

- Location number (2124)
- Indicator for calibration drainage resistances (1)
- Mean Highest Groundwater level (MHG, GHG in Dutch)(65)
- Mean Lowest Groundwater level (MLG, GLG in Dutch)(160)
- Resistance 1st drainage system(1)

- Resistance 2nd drainage system(1)
- Drainage basis 1st (deep) system(-999)
- Drainage basis 2nd (shallow) system(-999)
- Net precipitation surplus(314)
- Seepage(-5)
- Depth of drainage system (pipe) (0, because there were no drainage system in this area)

After input all these data, the model can be operated, and the files plek.out, flux.out, conc.out, conc_tp and check.res were generated.

The file plek.out gave each location information on the total lateral water discharge (m), leaching fluxes of ortho-P and total-P to surface water (kg P ha^{-1} yr^{-1}) and the flux weighted ortho-P and total P concentrations (mg/L).

The files flux.out, conc.out and conc_tp.out are meant for a detailed analysis of the profiles of the water fluxes (cm), ortho-P concentrations (mg/L) and total-P concentrations as a function of depth in the soil profile. The files report the location number and fluxes/concentrations per soil layer of 5 cm thickness.

In the file plek.out, the number would be shown like:

(Nature)plot	Lat drain (m)	tP-flux (kg/ha/yr)	oP-flux (kg/ha/yr)	avg c tP (mg/l)	avg c oP (mg/l)
2124	3.09E-01	5.29E-01	2.17E-01	1.71E-01	7.02E-02
2125	4.29E-01	7.79E-01	3.49E-01	1.81E-01	8.12E-02
2126	3.10E-01	1.04E+00	7.14E-01	3.35E-01	2.30E-01
2127	3.96E-01	8.26E-01	4.28E-01	2.09E-01	1.08E-01
2128	8.18E-02	1.38E-01	5.70E-02	1.68E-01	6.97E-02
2129	4.30E-01	1.16E+00	7.19E-01	2.70E-01	1.67E-01
2130	7.10E-02	2.44E-01	1.69E-01	3.44E-01	2.38E-01

Table4: The results file named plek.out. There should be 309 location points, partly omitted.

The 2124 location was explained as the example for all 309 locations. As mentioned before, the number total lateral water discharge (0.309E+00, m), leaching fluxes of ortho-P (0.217E+00, kg/ha/yr) and total-P to surface water (0.529E+00, kg/ha/yr) and the flux weighted ortho-P (0.702E-01, mg/L) and total P concentrations (0.171E+00, mg/L) can be found in this file.

In the file **flux.out, conc.out** and **conc_tp.out ,** the number would be shown like:

soildepth(cm)	5	10	15	20	25	30	35	40	45	50	55	60	65
2124	4.39E+00	1.89E+00	1.89E+00	1.89E+00	1.89E+00	1.89E+00	1.89E+00	1.89E+00	1.89E+00	6.76E-01	1.16E+00	1.61E+00	2.02E
2125	1.92E+01	1.67E+01	8.84E-01	1.66E+00	2.42E+00	3.22E+00	4.07E+00	4.96E+00	5.87E+00	6.79E+00	7.67E+00	8.48E+00	9.2
2126	7.08E+00	4.58E+00	4.58E+00	4.58E+00	4.58E+00	5.10E-01	9.56E-01	1.37E+00	1.75E+00	2.12E+00	2.50E+00	2.90E+00	3.31E
2127	6.04E+00	3.54E+00	3.54E+00	3.54E+00	3.54E+00	3.54E+00	7.05E-01	1.32E+00	1.89E+00	2.41E+00	2.91E+00	3.43E+00	3.98E+0
2128	4.79E+00	2.29E+00	2.29E+00	2.29E+00	2.29E+00	2.29E+00	2.29E+00	2.29E+00	1.30E-01	2.24E-01	3.12E-01	3.92E-01	4.69E-
2129	4.26E+01	2.10E+00	2.83E+00	3.61E+00	4.43E+00	5.29E+00	6.17E+00	7.03E+00	7.84E+00	8.57E+00	9.21E+00	9.75E+00	1.02E
2130	2.81E+00	3.13E-01	3.13E-01	3.13E-01	3.13E-01	3.13E-01	3.13E-01	3.13E-01	3.13E-01	3.13E-01	3.13E-01	3.13E-01	3.1

Table5: The results file named flux.out. There should be 309 location points, partly omitted.

soildepth(cm)	5	10	15	20	25	30	35	40	45	50	55	60	65
2124	1.01E+00	1.01E+00	1.01E+00	1.01E+00	4.98E-01	2.85E-01	1.74E-01	1.11E-01	7.20E-02	4.75E-02	4.70E-02	4.62E-02	4.54E
2125	2.65E-01	2.65E-01	2.65E-01	2.65E-01	2.44E-01	2.26E-01	2.09E-01	1.94E-01	1.80E-01	1.67E-01	1.59E-01	1.44E-01	1.31
2126	6.00E-01	6.00E-01	6.00E-01	6.00E-01	6.65E-01	7.40E-01	8.28E-01	9.32E-01	1.06E+00	1.21E+00	1.11E+00	9.38E-01	8.03E-
2127	4.22E-01	4.22E-01	4.22E-01	4.22E-01	3.97E-01	3.74E-01	3.53E-01	3.34E-01	3.16E-01	2.99E-01	2.88E-01	2.67E-01	2.48E-01
2128	2.36E-01	2.36E-01	2.36E-01	2.36E-01	1.66E-01	1.19E-01	8.59E-02	6.29E-02	4.63E-02	3.42E-02	3.41E-02	3.37E-02	3.34E-0
2129	5.82E-01	5.82E-01	5.82E-01	5.82E-01	5.26E-01	4.76E-01	4.33E-01	3.95E-01	3.61E-01	3.31E-01	3.06E-01	2.61E-01	2.25E
2130	1.81E+00	1.81E+00	1.81E+00	1.81E+00	1.63E+00	1.47E+00	1.34E+00	1.22E+00	1.12E+00	1.03E+00	9.76E-01	8.76E-01	7.91

Table6: The results file named conc.out. There should be 309 location points, partly omitted.

soildepth(cm)	5	10	15	20	25	30	35	40	45	50	55	60	65
2124	1.14E+00	1.14E+00	1.14E+00	1.14E+00	6.08E-01	3.88E-01	2.76E-01	2.11E-01	1.72E-01	1.48E-01	1.47E-01	1.46E-01	1.46E
2125	3.68E-01	3.68E-01	3.68E-01	3.68E-01	3.47E-01	3.28E-01	3.11E-01	2.96E-01	2.81E-01	2.68E-01	2.60E-01	2.45E-01	2.32
2126	7.15E-01	7.15E-01	7.15E-01	7.15E-01	7.82E-01	8.61E-01	9.54E-01	1.06E+00	1.20E+00	1.36E+00	1.25E+00	1.07E+00	9.28E-
2127	5.30E-01	5.30E-01	5.30E-01	5.30E-01	5.04E-01	4.81E-01	4.59E-01	4.39E-01	4.20E-01	4.03E-01	3.91E-01	3.70E-01	3.50E-01
2128	3.39E-01	3.39E-01	3.39E-01	3.39E-01	2.67E-01	2.19E-01	1.86E-01	1.63E-01	1.46E-01	1.34E-01	1.34E-01	1.34E-01	1.33E-0
2129	6.96E-01	6.96E-01	6.96E-01	6.96E-01	6.37E-01	5.86E-01	5.41E-01	5.02E-01	4.67E-01	4.36E-01	4.10E-01	3.65E-01	3.27E
2130	2.01E+00	2.01E+00	2.01E+00	2.01E+00	1.81E+00	1.64E+00	1.50E+00	1.37E+00	1.26E+00	1.17E+00	1.11E+00	1.01E+00	9.16

Table7: The results file named conc_tp.out. There should be 309 location points, partly omitted.

To prove the drainage system with Iron-coated sand has the function to reduce the concentration of the phosphorus, meanwhile, estimate the efficiency of this measure, an imaginary drainage system were used with detail data to input into the model. To implement this program, some hydrological conditions need to be met for the restrictions. To adjust the input to include drains for wet soils, soils with MHG <0.6 meter would be added an imaginary drainage system with depth of number MHG+0.6m. For example, if the MHG of a location is 0.2m, the depth of the drainage system would be 0.2+0.6=0.8m, by parity of reasoningby.

Back to the PLEASE model, the first step would be still to input the data into the files. Owing to the exactly same general data and soil data, the two files were not changed here.

Next step would be input the all distinguished hydrological data into the file hydro.inp.

locationNO.	Indicator	MHG	MLG	Resis 1st	Resis 2nd	D basis	D basis	precipitation	Seepage	Depth of D
2124	1	65	160	1	1	-999	-999	314	-5	0
2125	1	20	110	1	1	-999	-999	332	98	80
2126	1	45	150	1	1	-999	-999	314	-5	105
2127	1	50	150	1	1	-999	-999	401	-5	110
2128	1	60	160	1	1	-999	-999	87	-5	0
2129	1	10	100	1	1	-999	-999	332	98	70
2130	1	135	240	1	1	-999	-999	245	-174	0

Table8: 309 location points in the catchment area (partly omitted), hydrological data

As described in the last chapter, the number here means :(the first row number was explain as the example, the rest group numbers which MHG is deeper than 0.6m were shown in the same structure.)

- Location number (2124)
- Indicator for calibration drainage resistances (1)
- Mean Highest Groundwater level (MHG, GHG in Dutch)(65)
- Mean Lowest Groundwater level (MLG, GLG in Dutch)(160)
- Resistance 1st drainage system(1)
- Resistance 2nd drainage system(1)
- Drainage basis 1st (deep) system(-999)
- Drainage basis 2nd (shallow) system(-999)
- Net precipitation surplus(314)
- Seepage(-5)
- Depth of drainage system (pipe) (0, because there were no drainage system in this area)

For the drainage system, the second row was explained as the example, the rest group numbers which MHG is lower than 0.6m will be show in the same structure.

- Location number (2125)
- Indicator for calibration drainage resistances (1)
- Mean Highest Groundwater level (MHG, GHG in Dutch)(20)
- Mean Lowest Groundwater level (MLG, GLG in Dutch)(110)
- Resistance 1st drainage system(1)
- Resistance 2nd drainage system(1)
- Drainage basis 1st (deep) system(-999)
- Drainage basis 2nd (shallow) system(-999)
- Net precipitation surplus(332)
- Seepage(98)
- Depth of drainage system (pipe) (80, because the drainage system depth would be 0.2+0.6=0.8 as mentioned before)

After input all these data, the model can be operated, and the files plek.out, flux.out, conc.out, conc_tp and check.res can be generated.

The 2124 location were explained as the example for all 309 locations. As mentioned before, the number total lateral water discharge (0.309E+00, m), leaching fluxes of ortho-P (0.217E+00, kg/ha/yr) and total-P to surface water (0.529E+00, kg/ha/yr) and the flux weighted ortho-P (0.702E-01, mg/L) and total P concentrations (0.171E+00+00, mg/L) can be found in this file.

In the file plek.out, the number would be shown like:

(Nature)plot	Lat drain (m)	tP-flux (kg/ha/yr)	oP-flux (kg/ha/yr)	avg c tP (mg/l)	avg c oP (mg/l)
2124	3.09E-01	5.29E-01	2.17E-01	1.71E-01	7.02E-02
2125	4.29E-01	9.28E-01	4.97E-01	2.16E-01	1.16E-01
2126	3.10E-01	1.38E+00	1.05E+00	4.44E-01	3.39E-01
2127	3.96E-01	9.99E-01	5.99E-01	2.52E-01	1.51E-01
2128	8.18E-02	1.38E-01	5.70E-02	1.68E-01	6.97E-02
2129	4.30E-01	1.49E+00	1.05E+00	3.46E-01	2.43E-01
2130	7.10E-02	2.44E-01	1.69E-01	3.44E-01	2.38E-01

Table9：The results file named plek.out. There should be 309 location points, partly omitted.

In the file **flux.out, conc.out** and conc_tp.out **,** the number would be shown like:

soildepth(cm)	5	10	15	20	25	30	35	40	45	50	55	60	65
2124	4.39E+00	1.89E+00	1.89E+00	1.89E+00	1.89E+00	1.89E+00	1.89E+00	1.89E+00	1.89E+00	6.76E-01	1.16E+00	1.61E+00	2.02E
2125	1.92E+01	1.67E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.34E+01	4.
2126	7.08E+00	4.58E+00	4.58E+00	4.58E+00	4.58E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.0
2127	6.04E+00	3.54E+00	3.54E+00	3.54E+00	3.54E+00	3.54E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E
2128	4.79E+00	2.29E+00	2.29E+00	2.29E+00	2.29E+00	2.29E+00	2.29E+00	2.29E+00	1.30E-01	2.24E-01	3.12E-01	3.92E-01	4.69E
2129	4.12E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.29E+01	4.29E+01	4.29E+01	4.2
2130	2.81E+00	3.13E-01	3.13E-01	3.13E-01	3.13E-01	3.13E-01	3.13E-01	3.13E-01	3.13E-01	3.13E-01	3.13E-01	3.13E-01	3.

Table10：The results file named flux.out. There should be 309 location points, partly omitted

soildepth(cm)	5	10	15	20	25	30	35	40	45	50	55	60	65
2124	1.01E+00	1.01E+00	1.01E+00	1.01E+00	4.98E-01	2.85E-01	1.74E-01	1.11E-01	7.20E-02	4.75E-02	4.70E-02	4.62E-02	4.5
2125	2.65E-01	2.65E-01	2.65E-01	2.65E-01	2.44E-01	2.26E-01	2.09E-01	1.94E-01	1.80E-01	1.67E-01	1.59E-01	1.44E-01	1.3
2126	6.00E-01	6.00E-01	6.00E-01	6.00E-01	6.65E-01	7.40E-01	8.28E-01	9.32E-01	1.06E+00	1.21E+00	1.11E+00	9.38E-01	8.03E
2127	4.22E-01	4.22E-01	4.22E-01	4.22E-01	3.97E-01	3.74E-01	3.53E-01	3.34E-01	3.16E-01	2.99E-01	2.88E-01	2.67E-01	2.48E-
2128	2.36E-01	2.36E-01	2.36E-01	2.36E-01	1.66E-01	1.19E-01	8.59E-02	6.29E-02	4.63E-02	3.42E-02	3.41E-02	3.37E-02	3.34E
2129	5.82E-01	5.82E-01	5.82E-01	5.82E-01	5.26E-01	4.76E-01	4.33E-01	3.95E-01	3.61E-01	3.31E-01	3.06E-01	2.61E-01	2.
2130	1.81E+00	1.81E+00	1.81E+00	1.81E+00	1.63E+00	1.47E+00	1.34E+00	1.22E+00	1.12E+00	1.03E+00	9.76E-01	8.76E-01	7.9

Table11：The results file named conc.out. There should be 309 location points, partly omitted

soildepth(cm)	5	10	15	20	25	30	35	40	45	50	55	60	65
2124	1.14E+00	1.14E+00	1.14E+00	1.14E+00	6.08E-01	3.88E-01	2.76E-01	2.11E-01	1.72E-01	1.48E-01	1.47E-01	1.46E-01	1
2125	3.68E-01	3.68E-01	3.68E-01	3.68E-01	3.47E-01	3.28E-01	3.11E-01	2.96E-01	2.81E-01	2.68E-01	2.60E-01	2.45E-01	2
2126	7.15E-01	7.15E-01	7.15E-01	7.15E-01	7.82E-01	8.61E-01	9.54E-01	1.06E+00	1.20E+00	1.36E+00	1.25E+00	1.07E+00	9.2
2127	5.30E-01	5.30E-01	5.30E-01	5.30E-01	5.04E-01	4.81E-01	4.59E-01	4.39E-01	4.20E-01	4.03E-01	3.91E-01	3.70E-01	3.50E
2128	3.39E-01	3.39E-01	3.39E-01	3.39E-01	2.67E-01	2.19E-01	1.86E-01	1.63E-01	1.46E-01	1.34E-01	1.34E-01	1.34E-01	1.3
2129	6.96E-01	6.96E-01	6.96E-01	6.96E-01	6.37E-01	5.86E-01	5.41E-01	5.02E-01	4.67E-01	4.36E-01	4.10E-01	3.65E-01	3
2130	2.01E+00	2.01E+00	2.01E+00	2.01E+00	1.81E+00	1.64E+00	1.50E+00	1.37E+00	1.26E+00	1.17E+00	1.11E+00	1.01E+00	9.

Table12：The results file named conc_tp.out. There should be 309 location points, partly omitted.

After whole of this procedure, the latter comparative research would continue to distinguish the different between the situation with and without the drainage system.