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Blind Inlet as a Possible Technology for the Remediation of Phosphorus from Surface Runoff

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Abstract

Phosphorus is an essential element for plant life, but too much phosphorus in runoff water can cause eutrophication and harmful algal blooms. Hence, mitigation of agricultural phosphorus losses into the water cycle is a very important issue. Instream phosphorus treatment is difficult to implement because large amounts of storm runoff needs to be treated in short durations. In this research, we evaluated the potential to use blind inlet as an in-field phosphorus treatment technology. A box system was built to simulate hydrological and chemical processes occurring in a blind inlet. Current blind inlets, which are already installed in the field, use a bed of limestone with a sand/pea gravel layer on the top. In this study, steel slags were tested, which have a very high phosphorus sorption potential, as the filter media through a series of adsorption and desorption runs. The total mass of phosphorus which was adsorbed by the limestone was 16 % of the phosphorus input into the system whereas 26 % phosphorus was adsorbed by the steel slags. Therefore the steel slags show potential to sequester dissolved phosphorus. Additional research is on-going to test different filter media and to come up with a design criteria for field implementation.

Kurzfassung

Phosphor ist ein essentielles Element für das Leben von Pflanzen. Befindet sich jedoch zu viel Phosphor im Wasser, kommt es zur Nährstoffanreicherung und somit zur Eutrophierung des Gewässers. Aufgrund des hohen Nährstoffgehalts im Wasser kommt es zu rascher Algenbildung. Diese Algen sondern toxische Substanzen ab wodurch wiederum die Wasserversorgung stark beeinträchtigt wird oder sogar völlig zum Erliegen kommt. Aus diesen Gründen ist es unerlässlich, Nährstoffauswaschungen in Oberflächengewässer zu verhindern oder zumindest einzuschränken, damit es zu keinem Überangebot an gelöstem Phosphor im Gewässer kommt. Da die Nährstoffeinträge in Gewässer jedoch stark mit dem Hydrographen korrelieren ist eine „In-Stream-Reinigung“ aufgrund der hohen Wassermenge innerhalb kurzer Zeit nach einem Starkregenereignis nicht oder kaum möglich. Deshalb ist man auf der Suche nach kleinräumigen Lösungen. Eine Möglichkeit ist ein Sickerkörper, ein sogenanntes „Blind Inlet“. Im Rahmen dieses Forschungsprojektes wurde die potentielle Verwendung eines Blind Inlet evaluiert. Dazu wurde ein Testapparat entwickelt um die hydrologischen und chemischen Prozesse innerhalb eines derartigen Sickerkörpers unter Laborbedingungen nachzustellen. Weiters wurden verschiedene Filtermedien (Schlacke, Sandstein) getestet. Die Ergebnisse zeigen, dass die Aufnahme- und Bindekapazitäten für Phosphor von Schlacke (26 % des Phosphoreintrages) wesentlich höher sind als jene von Sandstein (16 % des Phosphoreintrages), welcher bei den bereits installierten Sickerkörpern zum Einsatz kommt. In Zukunft sollen weitere Filtermedien mit demselben Testapparat getestet werden und es soll ein Standard für die Planung und Bauausführung solcher „Blind Inlets“ erarbeitet werden.

1 Introduction

1.1 Phosphorus and its influence on the water quality

Phosphorus is an essential element for plant life, but when the content in water is too high, it causes eutrophication. Eutrophication is defined as a reduction in dissolved oxygen in water bodies caused by an increase of mineral and organic nutrients in rivers and lakes (US Department of Interior, 2014). This phenomenon occurs all over the world and affects China (Chen et al., 2007), the United States (Rabalais et al., 2001) or Europe (Haygarth et al., 2000). This oversupply of dissolved phosphorus is highly bio-available and causes an excessive growth of algae. The effects of this immense growth of aquatic vegetation reduce the transmission of solar radiation and produce harmful toxins. The increase of minerals and decrease in dissolved oxygen is a result of the decomposition of dead aquatic vegetation. These toxins have great impact on aquatic ecosystems – they can cause foul water, kill fish and can create dead zones in fresh water bodies (Carpenter, 2008). Especially in regions where people depend on drinking water from surface water sources, they can become highly affected by algae blooms.



Figure 1 — Massive algae bloom in Lake Erie in 2014 (earthobservatory.nasa.gov, 2014)

In 2014, a massive algae bloom was floating over the water intake in Lake Erie (see light green areas in Figure 1) and therefore forced the City of Toledo, Ohio, USA to shut down their domestic water supply system for two days. As a result was 400,000 people were without drinking water.

There are different ways phosphorus enters the biosphere, some are natural and others are caused by human activities. An example for a natural input is the weathering of rocks. Mining and other human induced disturbances have greatly increased the input of reactive phosphorus into the biosphere. Mined phosphorus enters the biosphere in form of fertilizers used in agriculture. In pre-industrial times the total phosphorus flux was 10 Mt to 15 Mt per year and was mainly caused by weathering. At the time human induced input was negligible. In the year 2000 the global phosphorus flux was 33 Mt to 39 Mt and it was mainly caused by human activity. This development means the total global phosphorus flux has more than doubled in 150 years (Bennet et al., 2001). The high amount of phosphorus added to the cropland in form of fertilizers, which accumulates in soil or is washed out by surface runoff, contributes significantly to spread and expansion of eutrophication of inland waters (ditches, rivers, lakes) and coastal waters.

Due to the facts mentioned above agriculture is a major source of phosphorus getting into rivers, lakes and then also into coastal waters or even groundwater. Hence, mitigation of agricultural phosphorus losses into the water cycle is a very important issue in future decades. Despite all the efforts in recent years to control agricultural phosphorus losses into surface waters, e.g. implementation of soil conservation, prevention of soil erosion or best management practices there is still a lack of water quality improvements worldwide. For this reason the European Union's Water Framework Directive (European Commission, 2000) and also the U.S. Environmental Protection Agency's Executive Order 13508 (Federal Leadership Committee for the Chesapeake Bay, 2009) requires limits for the maximum daily load of phosphorus into surface waters.

In order to achieve these water quality conditions significant reductions in phosphorus pollution are unavoidable. In addition to the above-mentioned strategies new innovative technologies are necessary. The following chapter 1.2 addresses some of these approaches and gives a short overview on the research on the remediation technologies of phosphorus from surface waters. Since the present study focuses on the treatment of concentrated agricultural runoff and filtration systems, only those technologies are mentioned in detail in the following chapter. Preventive measures for controlling phosphorus loss at the source are not addressed.

1.2 Phosphorus removal technologies and state of research

As mentioned in 1.1 this Chapter deals only with technologies to remove dissolved phosphorus after it has been mobilized in agricultural drainage waters. Therefore it focuses on the technology used for the treatment of runoff and drainage water before reaching the receiving surface waters.

An option for the remediation of phosphorus is the use of industrial by-products such as steel slags or fly ash or naturally occurring materials like limestone in a phosphorus removal structure. For this purpose several studies for the treatment of concentrated surface runoff have been conducted. Weber et al. (2007) conducted a study using steel slags in a constructed wetland or Penn et al. (2012) and Agrawal et al. (2011) studied the remediation of phosphorus from golf course runoff. The study of Smith and Livingston (2013), which was at the same time the motivation for this study, is about the management of farmed closed depressions to minimize nutrient losses into surface waters.

Most of the studies mentioned above come to the conclusion that the removal of phosphorus works quite well but is highly dependent on the actual discharge rate. At low discharge rates the removal efficiency reaches up to 60 % but high discharge rates are showing a different picture (<25 %). On the one hand this is related to the retention time and on the other hand it is also related to the actual phosphorus load. A study from Livingston (2015) shows that

- 10 % of days account for 50 % of runoff and those 10 % of days account for 70 % of phosphorus load.

This means very high variability in nutrient loads between low and high discharge rates. Therefore it is even more challenging to find a proper solution to cope with such large amounts of storm runoff within short durations. Due to these facts an in-field technology of a small scale is needed to remove phosphorus efficiently from runoff water. This approach is the so-called “Blind Inlet”, see Figure 3. In the following, the functioning of this technology is explained in detail and how the present study was derived from this field scale experiment.

In the field study of Smith and Livingston (2013) blind inlets were used to investigate how effective phosphorus can be removed from surface runoff. Therefore blind inlets (yellow stained area without grass in Figure 2) were installed additionally to tile risers (yellow pipe in Figure 2). Normally, a tile riser would be removed but for experimental purposes; in this case both practices are installed. Tile risers are vertical tubes with holes of approximately 2 cm in diameter, which are installed at the lowest point of a closed depression of a field to drain surface water. Those tile risers are connected to the subsurface tile drainage network.



Figure 2 — Tile riser and blind inlet in a closed depression

Since they are directly connected to the drainage network there is almost no filtration before the water reaches the stream network.

The study was conducted in the St. Joseph River catchment where the condition for conducting such a field study was available. After the adequate place was found the blind inlet was constructed. For this purpose, a volume of 18 m³ (4.25 m x 4.25 m x 1 m) of soil was replaced by coarse limestone gravel (60 cm in

depth) as the bottom layer and coarse-textured soil material was used to cover the area of the blind inlet. Figure 3 shows a photograph of the installation of a blind inlet.



Figure 3 — Installation of a blind inlet construction (Smith & Livingston, 2013)

The results are promising, since the reduction of phosphorus load over a 2-year period for which the study was scheduled, was significant. In the year 2010 the load of dissolved phosphorus decreased by 71.9 % relative to the tile riser.

The authors of the study conclude the installation of blind inlets could be one way to reduce the phosphorus loading to Lake Erie, a freshwater resource for hundred thousands of people.

1.3 Objectives of this study

As shown in 1.2 the principles of an in-field technology to remove phosphorus from runoff water is working, but it needs more research in respect to following objectives:

- the development of a laboratory prototype (box system) which can be used to simulate hydrologic/chemical processes occurring in a blind-inlet,
- in testing of P sorption material, e.g. steel slags, for phosphorus sorption efficiency in a blind inlet.

Currently a blind inlet uses a bed of limestone with sand/pea gravel on top. It should be tested whether steel slags, which have very high phosphorus sorption potential, can be used in the blind inlet construction for increased phosphorus sorption.

The study was carried out between February 2015 and June 2015 at the Agricultural Research Service, the in-house research service of the USDA (United States Department of Agriculture) in West Lafayette, IN, USA. In this study a laboratory flow through experiment was designed and first tests on limestone and steel slags were carried out.

1.4 Outline of this thesis

This thesis is divided into four chapters. Chapter one includes the introduction with some background information about technologies to remediate phosphorus from surface runoff and a more detailed information to blind inlets. The included objectives are the start for the following research project within this master thesis.

The first step is to develop and build the test equipment to simulate the on-site hydrological and chemical processes occurring in a blind inlet in interaction with the surrounding soil. This part is described in chapter two.

As a second step tests are carried out; once to verify the reliability of the test results with the test results on site. A second test series shall examine the efficiency of steel slags for the remediation of phosphorus from runoff water. These results are discussed in chapter three.

Besides the application of the test equipment for closed depressions, as a third step of this master thesis the usage for other applications shall be investigated. In this

chapter also the advantages and disadvantages, which came up during the experiment are included. This summary, conclusion and suggestions for further research are given in chapter four.

In Annex A, Annex B and Annex C further background information is given to support the traceability of this thesis.

2 Methods

2.1 Overview

This experiment was conducted as a laboratory experiment. For this reason, a blind inlet test box was developed, which represents only a section of a blind inlet. An important requirement for the design was that the test box reproduces the conditions in nature as closely as possible and must account for all vectors happening in such a system. In order to meet these requirements and before the detailed design of the test box began, the following design criteria were defined:

- the blind inlet test box should reproduce the flow of the runoff water through the system (soil and filter media) and the interactions between both media,
- it should be possible to control hydrological parameters (constant head, flow rate, saturated conditions),
- minimize influences of the materials used to build the test equipment,
- the ability to sample over time.

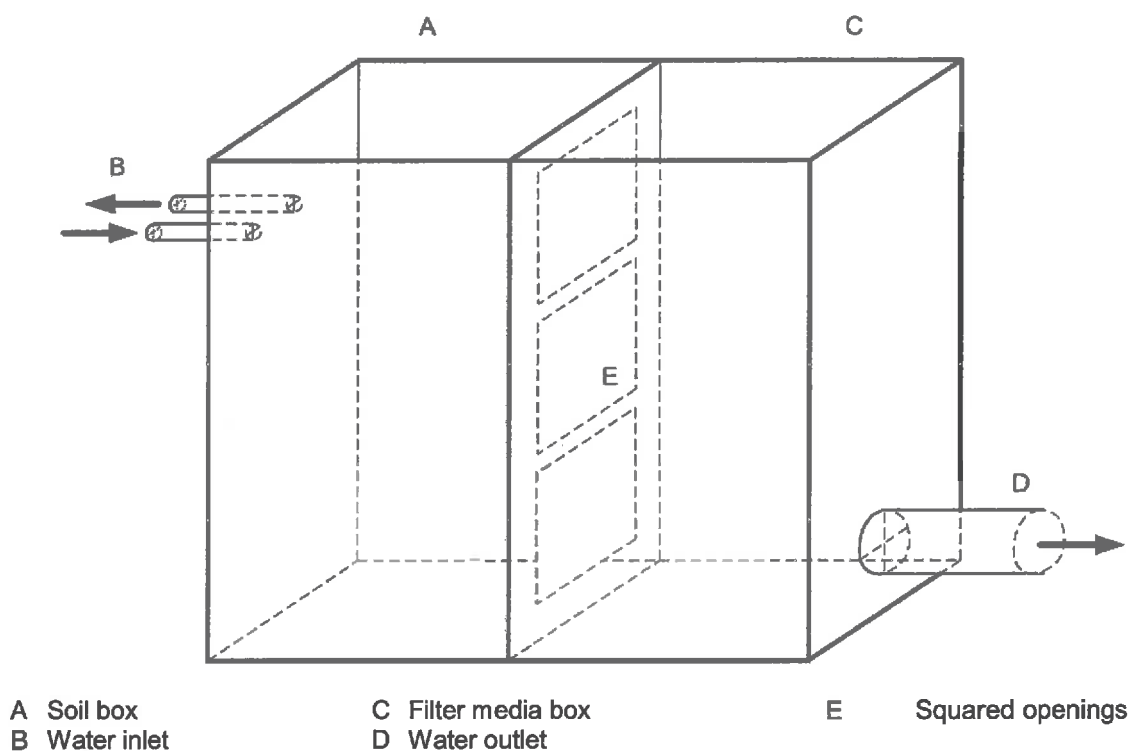


Figure 4 — Schematic of the blind inlet test box

As it can be seen in Figure 4 the test box is created as a box system which can be roughly divided into two main units: the soil box (A) with the water inlet (B) and the filter media box (C) with the water outlet (D). The actual design of the test box can be seen in Figure 5.



Figure 5 — Design of the blind inlet test box

2.2 Design of the test equipment

2.2.1 Design of the boxes

The boxes are made of stainless steel sheet with a thickness of about 1 mm (0.04 inch). Since the seams of the boxes are not welded, the corners and edges were sealed with Hydro Ban (Laticrete International, Inc., Bethany, Connecticut, USA). In total three layers of the thin, waterproofing membrane were applied. The last layer was applied after the boxes were connected. In addition, a glass fiber tape was used to prevent any cracks if the test box was moved, see Figure 6.

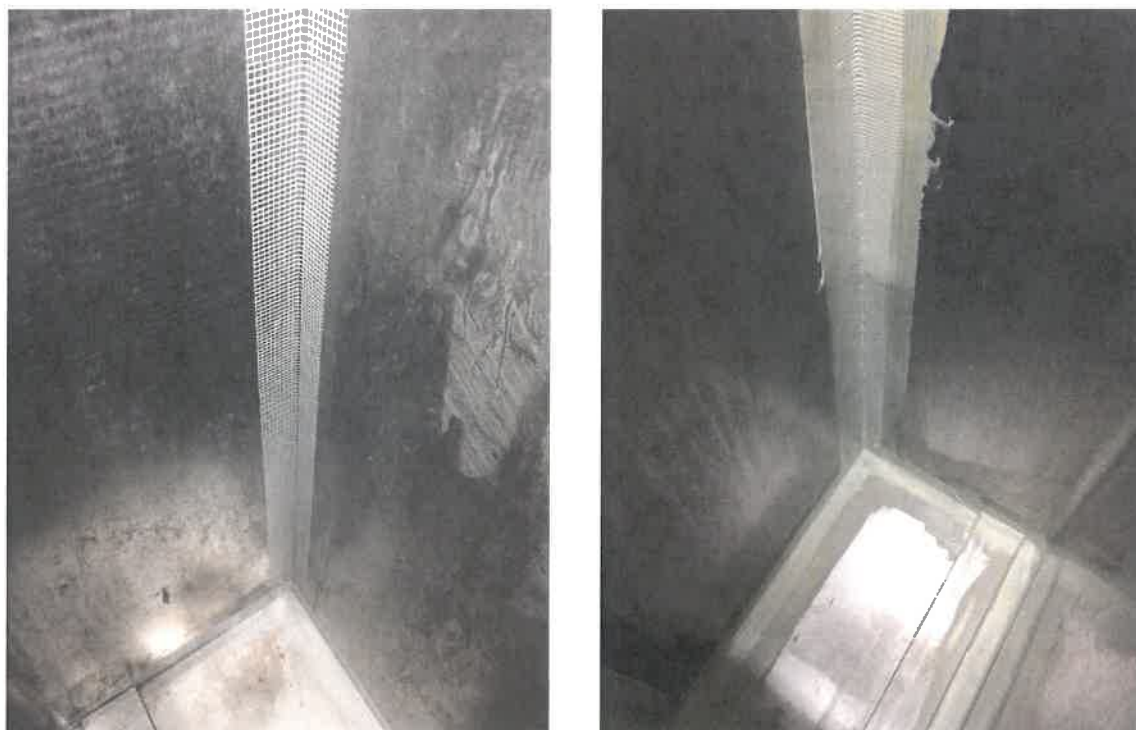


Figure 6 — Fixing of glass fiber tape (left); sealing of the boxes (right)

To ensure optimal water flow between the boxes three squared openings with a side length of 15.24 cm (6 inch) were cut out, see (E) in Figure 4. In order to simplify the filling procedure and to make sure the material (soil/filter media) stays in the designated box a coated wire mesh was installed next to the three square openings.

The boxes were bolted together using 14 stainless steel screws. To make sure the boxes are water tight a stripe of silicone was applied at the outer side of the boxes before they were bolted. In addition, a stripe of geotextile DrainKnit (Dickson Industries, Inc., Des Moines, Iowa, USA) was put next to the mesh to avoid sedimentation and mixing of the materials.

Before the pipes were built in the holes for the fittings of the water inlet, water outlet and soil pore samples were punched out using a knockout punch.



Figure 7 — Box with squared openings (left); boxes connected together (right)

2.2.2 Installation of water inlet

The water inlet unit consists of two parts, one is the inlet and the other one is the overflow to keep a specific water level, see Figure 8 (left). Therefore a bulk head union with a diameter of 3/4 inch was installed in each of the punched holes. Next to this bulk head union an elbow with a coupling was fixed; in addition, the inlet also includes a ball valve. Through the coupling with the ball valve, the system was connected to the domestic water supply system or to the tank with the phosphorus containing water. The other coupling, without the ball valve, served as the overflow, which was connected to the sink using a hose with 2 m in length.

To ensure the process of wetting the soil and the flow throughout the whole soil column the inlet was connected to a pipe which was perforated with 60 staggered 12.7 mm (0.5 inch) holes, see Figure 8 (right). The perforated pipe has a diameter of 7.62 cm (3 inch) and is made of PVC. The pipe was also covered with the same type of geotextile as it was used for the boxes. Because the connection of the inlet was 10 cm below the top end of the pipe, the inflowing water distributes in two directions: first to the top end, which was already above the soil level and flooding over the soil

through the square opening into the filter media box; second through the holes of the perforated pipe into the soil column and into the filter media box.

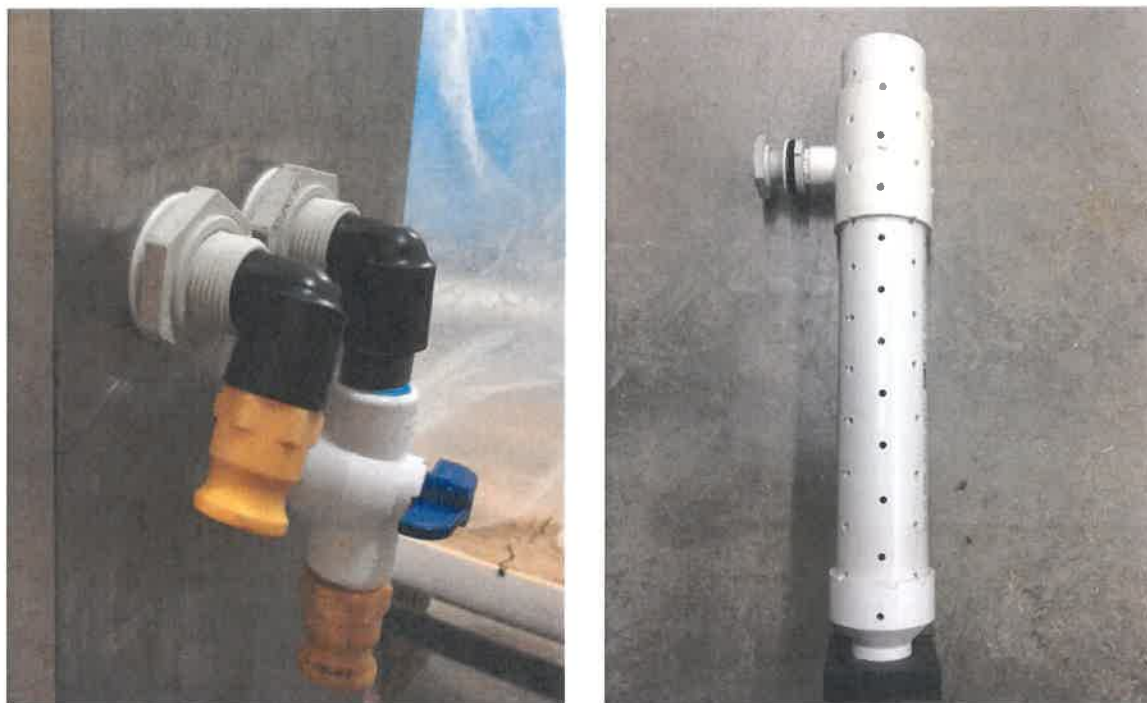


Figure 8 — Arrangement of the water inlet unit (left); perforated pipe (right)

2.2.3 Installation of the water outlet

The installation of the water outflow consists of three main parts, the drainage pipe inside the filter media box, the valves-unit for the regulation of the flow rate and the water quality sampling unit outside the box.

The drainage pipe, see Figure 9 (left), in form of a T is made of PVC and has a diameter of 7.62 cm (3 inch) with four holes at the bottom. The holes have a diameter of 12.5 mm (0.5 inch) and a spacing of 12.7 cm (5 inch). The holes are drilled parallel to the pipe axis and are 120° apart. This pipe configuration is according to ASTM D 2729 and similar to the perforated pipes which are used in current blind inlets.

The valves-unit, see Figure 9 (right), consists of a pipe with a diameter of 7.62 cm (3 inch) with a length of 17.78 cm (7 inch) followed by a gate valve, a 90°-elbow, a reducer from 7.62 cm (3 inch) to 1.91 cm (3/4 inch) and a needle-valve in between two pieces of a 1.91 cm-pipe (3/4 inch) with a length of 12.7 cm (5 inch) each. The valves-unit and the drainage pipe are connected by a bulk head unit of the same di-

ameter. The installed gate valve is needed to control the water flow in the system and the more sensitive needle-valve is needed to set the flow rate to a certain discharge.



Figure 9 — T-formed drainage pipe (left); Valve-unit and Water quality sampling unit (right)

The water quality sampling unit consists of 90°-elbow and a 1.91 cm-pipe (3/4 inch) with a length of 50.8 cm (20 inch) and an open outflow to the sink. In the pipe 3 brass nipples are installed, two are connected via a hose to the auto sampler and one is open and drains into a small bucket for measuring the electrical conductivity.

2.2.4 Water quality monitoring system

The collection of water quality samples was carried out in two different ways, by an automatic water quality sampler and manually.

The water quality sampler which was used for in the study was originally designed and built for the study of Colton E. Y. in 2014. It was originally controlled by computer but in order to use them more independently it was rebuilt and further developed. For this reason, an Arduino microcontroller was installed as a control module. This controller is based on an open-source platform used for building electronic projects and consists of a physical programmable circuit board and a software, or IDE (Integrated Development Environment) which is used to write and upload the computer code to the physical controller unit (Arduino LLC, 2015). One major advantage is that the au-

to sampler runs in 12-volt mode and can be operated independently of the country-specific voltage.

A carousel tray, in which 20 60 ml bottles can be placed, moves with a stepper motor. This motor is connected to the circuit unit with the microcontroller which is programmed to move on a certain time schedule. To stop the carousel tray precisely, the position of the sample bottle is controlled by a photoelectric sensor which senses the notch corresponding to each sample bottle. At the upper end a 3-way-valve is installed to place the right amount of water into the bottle. This valve is connected to the tube at water outlet via two small hoses with a diameter of 6.35 mm (0.25 inch). In order to get real time samples and avoid “dead water” in the hoses, a flow-through pump is installed, see Figure 10, to pump water constantly through the system. This ensured that no water which was left over from the previous time step could contaminate the following sample.



Figure 10 — Water quality sampling unit with auto sampler

Because for some experiments 20 bottles which can be placed on the tray are not enough for conducting an experiment, the auto sampler is designed as an open-concept. Filled bottles can be easily replaced by empty ones during an experiment.

For the determination of the phosphorus content in the water flowing through the soil column and for checking the hydrology three bulk head units were installed at three

different levels in the soil box, see Figure 11 (left). Inside the soil box three perforated (36 staggered 3.57 mm (9/64 inch) holes), geotextile covered tubes with a diameter of 1.91 cm (0.75 inch) are connected to the bulk head units, see Figure 11 (right). Outside, slip ball valves (1.91 cm (3/4 inch)) were installed which were operated manually.

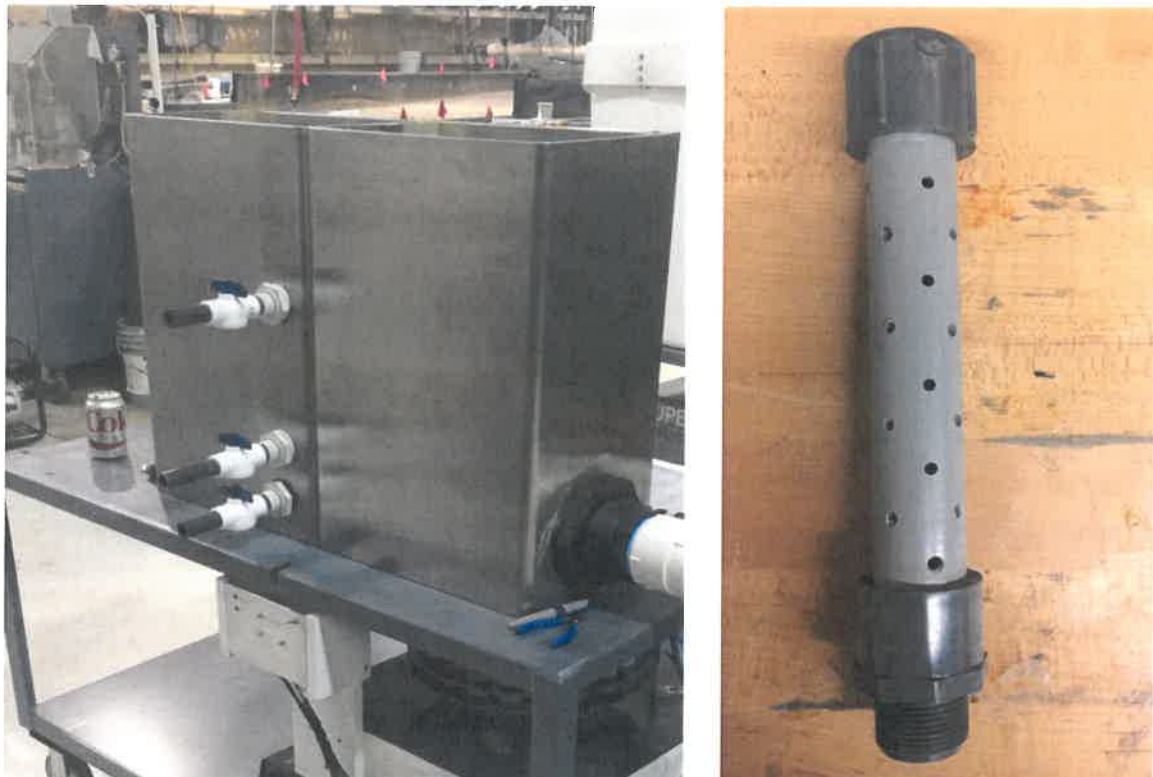


Figure 11 — Water quality pore sampling unit (left); perforated pipe (right)

2.2.5 Geometry and sizes of the test equipment

Figure 12 shows a schematic overview of the blind inlet test box with all parts except the auto sampler and with all measurements. The measurements are given in inches and to scale.

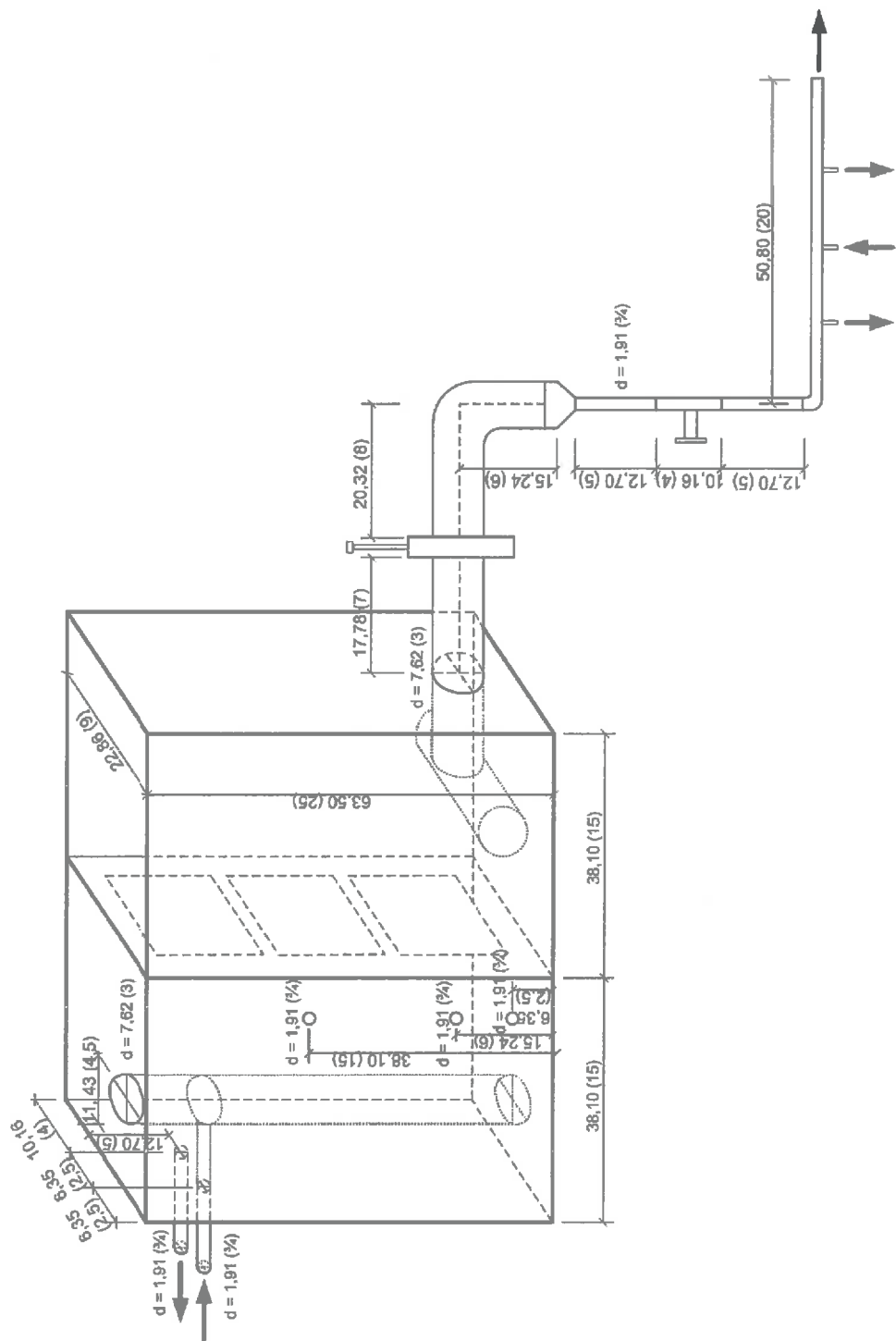


Figure 12 — Schematic overview of the blind inlet test box (Measurements in cm (inch))

2.3 Description of the Soil

The soil for the study was collected in the St. Joseph River catchment in Northeast Indiana, USA. The site is located at 41° 28' 20.56" N and 84° 59' 30.70" W. It was collected from the soil depth between 0 cm and 20 cm, filled into closed plastic buckets and transported to the laboratory where it was stored at room temperature. Afterwards the soil was air-dried and sieved through a 5 mm sieve. The soil type is loam, all other basic physical and chemical properties of the soil are given in Table 1. All analysis, except the soil moisture content, was carried out by Midwest Laboratories Inc., Omaha, Nebraska, USA, according to the recommended standard methods by North Dakota State University (NCR, 2012), American Society of Agronomy (ASA, 1982) and United States Department of Agriculture (USDA, 1954). The soil moisture content was determined in the Lab using the gravimetric method according to Black (1965). In Figure 13 a sample of the used soil is shown.

Table 1 — Basic physical and chemical soil properties

Parameter	Units	Results	Method	Reference
pH	-	6.3	1:1, Soil:Water mixture/combination electrode	NCR, 2012
Electrical Conductivity	meq/100 g	10.2	1:1, Soil:Water mixture, conductivity meter	USDA, 1954
Soil moisture content	%	3.64	Gravimetric method	Black, 1965
Organic Matter	%	2.9	Loss of Weight on Ignition	NCR, 2012
Sand	%	50	Hydrometer method	ASA, 1982
Silt	%	38	Hydrometer method	ASA, 1982
Clay	%	12	Hydrometer method	ASA, 1982



Figure 13 — Sample of the used soil

2.4 Description of the filter media

2.4.1 General

In recent years, various filter media have been tested for their ability to retain phosphorus all over the world. The media tested include various sands and gravels, light expanded clay aggregates, shale, bauxite, zeolite, half-burnt dolomite, marble, calcite, crushed concrete, blast furnace slag (Drizo et al., 2002). An ideal material serving as filter media needs to be locally available at low prices or for free and should have suitable physical and chemical properties such as hydraulic conductivity, porosity, granulometry, specific surface area, Al-, Fe- or Ca-content. All these characteristics should make it possible to react with the dissolved Phosphorus in order to remove it from the solution (Penn et al., 2011). Other factors include the pH value which should be well buffered, or the temperature. That means not every filter media is suitable in every region in the world and the filter media should be selected carefully.

2.4.2 Limestone

The limestone which was selected for this study came from Wrede Rocks, Lafayette, Indiana, USA. According to the dealer the limestone came either from the Delphi Limestone Quarry or from the Monon Quarry, both in Northwest Indiana, USA. Unfortunately there is no further information available about the composition, bulk density,

porosity or the content of calcium. This information would be helpful, since these properties can influence the performance significantly (Strang and Wareham, 2002). The only information which is available, is the grain size, which is # 4. Table 2 shows the exact distribution of the grain sizes and Figure 14 shows a picture of the used limestone.



Figure 14 — Sample of the used limestone # 4

2.4.3 Steel slags

There are several industrial by-products which can be used as a filter media for the remediation of phosphorus. These by-products are usually cheap or even available for free since many companies are interested to sell/provide them for free instead of depositing them. In this study electric arc furnace steel slags was used. The slags which were used in this study came from a steel mill in Crawfordsville, Indiana, USA (Nucor Corporation). The slag used was sieved and mixed according to the grain size distribution which is given in Table 2. There were two types of slags used in the experiment. The # 4 for the actual filter layer at the bottom and the # 9 as the top layer. A picture of the used slags can be seen in Figure 15 and Figure 16.



Figure 15 — Sample of the used steel slags # 4



Figure 16 — Sample of the used steel slags # 9

Table 2 — Size of coarse aggregate (AASHTO M 43)

Size	Nominal size square openings ¹	Amounts finer than each laboratory sieve (square openings), percent by weight														
		100	90	75	63	50	37,5	25	19	12,5	9,5	4,75	2,36	1,18	300 μm	150 μm
1	90 to 37,5	100	90 to 100		25 to 60		0 to 15		0 to 5							
2	63 to 37,5			100	90 to 100	35 to 70	0 to 15		0 to 5							
24	63 to 19,0			100	90 to 100		25 to 60		0 to 10	0 to 5						
3	50 to 25,0				100	90 to 100	35 to 70	0 to 15		0 to 5						
357	50 to 4,75				100	95 to 100		35 to 70		10 to 30		0 to 5				
4	37,5 to 19,0					100	90 to 100	20 to 55	0 to 15		0 to 5					
467	37,5 to 4,75					100	95 to 100		35 to 70		10 to 30	0 to 5				
5	25,0 to 12,5						100	90 to 100	20 to 55	0 to 10	0 to 5					
56	25,0 to 9,5						100	90 to 100	40 to 75	15 to 35	0 to 15	0 to 5				
57	25,0 to 4,75						100	95 to 100		25 to 60		0 to 10	0 to 5			
6	19,0 to 9,5							100	90 to 100	20 to 55	0 to 15	0 to 5				
67	19,0 to 4,75							100	90 to 100		20 to 55	0 to 10	0 to 5			
68	19,0 to 2,36							100	90 to 100		30 to 65	5 to 25	0 to 10	0 to 5		
7	12,5 to 2,36								100		40 to 70	0 to 15	0 to 5			
78	9,5 to 2,36								100		40 to 75	5 to 25	0 to 10	0 to 5		
8	9,5 to 1,18									100	85 to 100	10 to 30	0 to 10	0 to 5		
89	4,75 to 1,18									100	90 to 100	20 to 55	5 to 30	0 to 10	0 to 5	
9	4,75 to 1,18										100	85 to 100	10 to 40	0 to 10	0 to 5	
10	4,75 to 0 ²										100	85 to 100			10 to 30	

¹⁾ In millimeters, except where otherwise indicated.

²⁾ Screenings.

Note: Where standard size of coarse aggregate designated by two or three digit numbers are specified, obtain the specified gradation by combining the appropriate single digit standard size aggregates by a suitable proportioning device which has a separate compartment for each coarse aggregate combined. Perform the blending as directed by the Laboratory.

2.5 Water quality monitoring system sampling scheme and additional measurements

As already mentioned, the samples were taken in two different ways. They were taken automatically by an auto sampler and manually. The auto sampler was located next to the water outlet and almost at the same level as the water outlet. Since the pump, which was used for circulating the water, had limited capacity. The samples at the water outlet (MB) were taken every 3 minutes for run # 1 to # 24 and every 6 minutes for run # 25 to # 28, starting at time 0. Since obtaining a representative sample is important and homogeneity is one of the primary concerns, the whole sample of approximately 60 ml was not taken at once but as 3 sub-samples. This means there were approximately 20 ml taken at minute 0, 1 and 2, which means in a broader sense, the sample was taken over a 3-minute time period.

The water quality soil pore samples, the samples from the water reservoir and the ones from the discharge water were taken manually. The soil pore samples were taken every 26 minutes from location SB1, SB2 and SB3 at three different levels of the soil profile, the samples from the water reservoir (WR) at the beginning and at the end of each run and the sample from the discharge water (WD) was taken once from the collected discharge water at the end of a run. In Table 3 an overview of the sampling scheme can be seen. In Figure 17 the positions of the sample locations are shown.

Table 3 — Sampling scheme for one run

Number of samples	Sample ID	Sample location	Time-lag [min]
40 Samples	001-040	MB	3 and 6
5 Samples	041-045	SB1	26
5 Samples	046-050	SB2	26
5 Samples	051-055	SB3	26
2 Samples	056-057	WR	120
1 Sample	058	WD	120

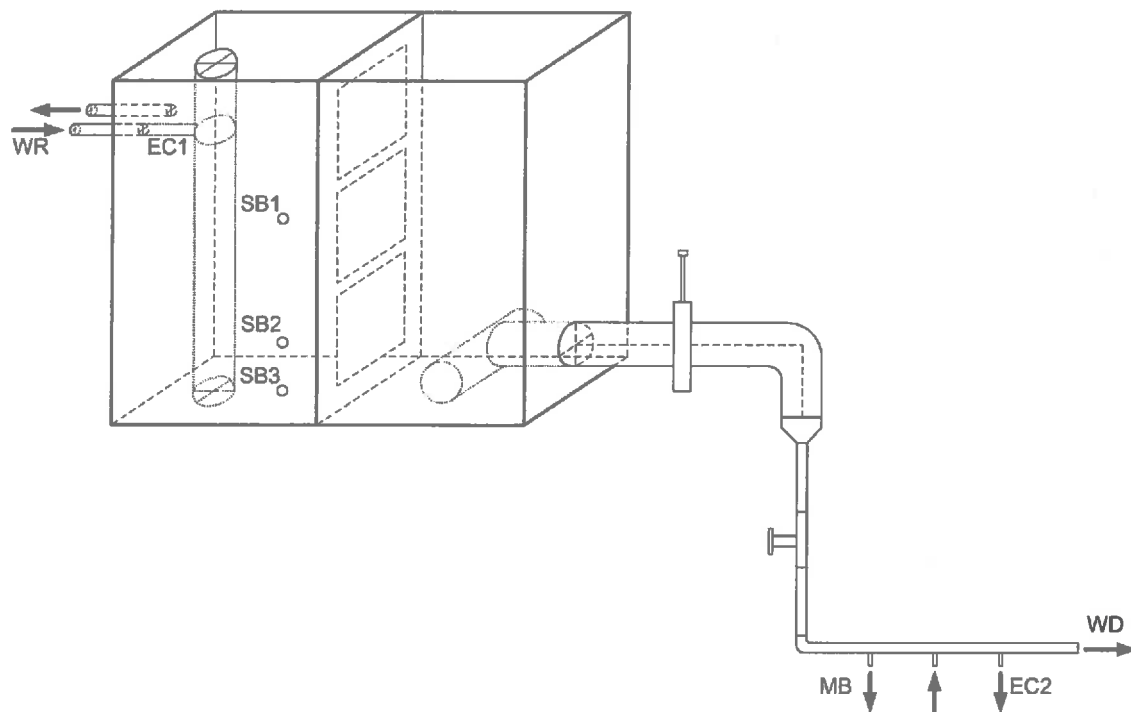


Figure 17 — Schematic overview with sample locations

Furthermore two electrical conductivity meters, EC1 and EC2, (Reed SD-4307 Conductivity/TDS/Salinity Meter and Datalogger, Quebec, Canada) were mounted on the test box (see Figure 17). One at the water inlet and the other one at the water outlet, immediately after the hose for the backflow from the automatic water sampler. The meters were set to record the electrical conductivity measurement every 5 s automatically.

In order for being able to calculate a mass balance discharge measurements at the water outlet were taken every 13 minutes. To carry out these measurements the simple bucket method was chosen.

To ensure further analysis and to avoid confusion of samples during sample processing, the samples were labeled uniformly. The code and the key can be seen in Figure 18, where *BIS 2015* is the project name, *12* is the actual number of run, *MB* is the sample location, *1* is the number of the sample, the *barcode* is a combination of the number of the sample and the number of the actual run. *Desorption* is the objective of the actual run. The colour code, in Figure 18 green, stands for the objective *desorption*. For adsorption it is red and for baseline it is blue.



Figure 18 — Labelling of the samples

2.6 Test Procedures

2.6.1 Overview

During the whole experiment in total 28 runs were conducted, where in 17 runs limestone was used as filter media and in 11 runs steel slags were used. Table 4 contains an overview of all runs carried out during the study. The table also includes specific information for each run. For being able to conduct the runs in shorter intervals and almost in parallel, two blind inlet test boxes of the same design were built. For each test box (limestone, steel slags) the experiment was started with a baseline as well as several adsorption and desorption runs using tap water from the domestic water supply system. For the baseline and desorption runs (except run # 27 and # 28) the test box was directly connected to the facility's water supply system. For the desorption runs a tank with a maximum capacity of 946.35 l (250 gal) was used. The tank was filled with tap water and by adding a solution with potassium phosphate (KH_2PO_4) the concentration of P in the water was brought to about 5 mg/l (5 ppm). Due to the fact that the used tap water had a background concentration of P in the range of 0.23 ppm to 0.67 ppm, the desired concentration averaged 5.07 ppm. The range was between 4.07 ppm and 5.52 ppm. For detailed results, see 3.1. Due to the background concentration the desorption runs # 27 and # 28 were carried out with deionized water. The aim was to compare how much phosphorus was leached, when water without any background concentration of Phosphorus was used.

Table 4 — Overview of all runs carried out

Number of run	Filter media	Objective	Date	Start time	End time
1_LS_B	Limestone	Baseline	24/04/2015	11:35	13:35
2_LS_AD	Limestone	Adsorption	27/04/2015	13:41	15:41
3_LS_DE	Limestone	Desorption	28/04/2015	11:35	13:35
4_LS_AD	Limestone	Adsorption	29/04/2015	09:50	11:50
5_LS_DE	Limestone	Desorption	05/05/2015	11:58	13:58
6_LS_AD	Limestone	Adsorption	06/05/2015	11:58	13:58
7_SS_B	Steel slags	Baseline	07/05/2015	10:48	12:48
8_LS_DE	Limestone	Desorption	07/05/2015	14:00	16:00
9_LS_AD	Limestone	Adsorption	08/05/2015	10:10	12:10
10_SS_AD	Steel slags	Adsorption	08/05/2015	16:50	18:50
11_SS_DE	Steel slags	Desorption	09/05/2015	11:58	13:58
12_LS_DE	Limestone	Desorption	09/05/2015	15:11	17:11
13_LS_AD	Limestone	Adsorption	10/05/2015	11:54	13:54
14_SS_AD	Steel slags	Adsorption	10/05/2015	15:01	17:01
15_SS_DE	Steel slags	Desorption	11/05/2015	12:35	14:35
16_LS_DE	Limestone	Desorption	11/05/2015	15:20	17:20
17_LS_AD	Limestone	Adsorption	12/05/2015	11:52	13:52
18_SS_AD	Steel slags	Adsorption	12/05/2015	14:49	16:49
19_SS_DE	Steel slags	Desorption	13/05/2015	10:08	12:08
20_LS_DE	Limestone	Desorption	13/05/2015	13:49	15:49
21_LS_DE	Limestone	Desorption	03/06/2015	10:40	12:40
22_SS_DE	Steel slags	Desorption	03/06/2015	14:03	16:03
23_SS_AD	Steel slags	Adsorption	04/06/2015	12:20	14:20
24_LS_AD	Limestone	Adsorption	04/06/2015	14:57	16:57
25_LS_DE	Limestone	Desorption	08/06/2015	10:35	12:35
26_SS_DE	Steel slags	Desorption	08/06/2015	15:35	17:35
27_LS_DE_DI	Limestone	Desorption ¹	09/06/2015	09:25	13:25
28_SS_DE_DI	Steel slags	Desorption ¹	10/06/2015	09:38	13:38
¹) Deionized water was used.					

In the following chapters, the main experiment and the steps taken before and after the experiment are described in detail. Since the procedure of the runs for the test box filled with limestone or steel slags is the same, the procedure is described only once.

2.6.2 Pre-experimental procedures

In this section a detailed account of the pre-experimental steps is discussed.

2.6.2.1 Water tightness

In order to make sure the test boxes are water tight a leakage test was carried out. Therefore the water outlet (MB) was closed by the gate valve and the ball valves at the sample locations SB1, SB2 and SB3 were also closed. After that, the test box was connected to the public water supply system and filled with water until the water ran over the overflow. In this test, it was found the test box filled with the limestone was watertight. At the test box, filled with the steel slags, a water loss of about 100 ml per minute was found. This amount of water loss (3 % – 4 %, depending on the flow rate) was neglected in the further analysis.

2.6.2.2 Filling with soil and compaction procedure

To make sure the soil column is homogeneous the whole column was divided into 12 individual sections also called lifts of 3.81 cm (1.5 inch) in height. For each section the necessary amount of soil was calculated taken into account the volume of the section minus volume of the pipe and the bar (ID 1 only), the soil moisture and the desired bulk density. The calculation is given in Table 5.

Table 5 — Calculation of the used amount of soil for each section

ID	Description	Length [cm]	Width [cm]	Height [cm]	Volume [cm ³]	Soil moisture [%]	Bulk density [g/cm ³]	Amount of Soil [g]
1	Section	35.56	22.86	3.81	3097.16			
	Pipe	-4.45	-3.14	-3.81	-53.26			
	Bar	-35.56	-5.08	-1.02	-184.26			
	Total				2859.63	3.6	1.3	3851
2 to 12	Section	35.56	22.86	3.81	3097.16			
	Pipe	-4.45	-3.14	-3.81	-53.26			
	Total				3043.89	3.6	1.3	4099

After inserting the specific amount of soil the lift was compacted with a smoothing trowel to the designated line. During the filling procedure also the perforated pipes for the water quality pore sample were connected to the before installed bulk head units. The volume of these pipes was not considered for calculating the amount of soil.



Figure 19 — Filling procedure lift # 1 (left) and lift # 12 (right)

2.6.2.3 Filling with filter media

In contrast to the soil, the filter media was not compacted. The filter column consists of two layers, the bottom layer with the coarse aggregates (# 4 limestone and # 4 steel slags, respectively) and the top layer with fine aggregates (pit-run gravel and # 9 steel slags, respectively). The height was 30.48 cm (12 inch) for the bottom layer and 15.24 cm (6 inch) for the top layer. To avoid sedimentation into the bottom layer a geotextile DrainKnit was placed in between the two layers. The specific amount of the used filter media is given in Table 6. In Figure 20 the filling of the bottom layer for both test boxes can be seen.

Table 6 — Amount of used filter media for both blind inlet test boxes

	Amount of filter media [g]	
	Test box with limestone	Test box with steel slags
Bottom layer	32254	43262
Top layer	25921	28770
Total amount	58175	72032



Figure 20 — Filling of the bottom layer with limestone (left) and steel slags (right)

2.6.2.4 Saturation procedure

Before the saturation process started all valves of the test box were closed. In order to saturate the soil column uniformly the water was added manually with a small bucket from the upper end of the perforated pipe of the water inlet unit. The saturation process extended over a period of about 25 hours for the test box with the limestone and about 21 hours for the test box with the steel slags. The water was slowly added in very small amounts of about 2 l. The water was refilled after the water table in the pipe has lowered. To check if the soil was evenly saturated from the bottom to the top of the column, the valves SB1, SB2 and SB3 were opened from time to time. When water leaked the saturation was considered uniform. This process continued until water was visible at the top layer of the box with the filter media. The total amount of water added to the test box with the limestone was 42 l, for the test box with the steel slags it was 47 l.

2.6.2.5 Pretesting and setting of the flowrate

As already mentioned in the objectives of the study, the blind inlet test box should represent the conditions occurring in the field as closely as possible. Therefore it was necessary to find the corresponding flow rate. In order to meet this requirement, the flowrate occurring in the blind inlets which are already installed was divided by the surface area and then apportioned among the surface area in the test box. A decent high flow rate during an event is approximately 10 l/s through a blind inlet and the surface area covered by the media is about 21 m² (Livingston, 2015). The surface area of the filter media box is 0.09 m². Based on those numbers 0.04 l/s or 2.57 l/min is needed. Since the experiment was conducted under saturated conditions with a constant head the flow rate was controlled at the water outlet unit by the needle-valve. The flow rate was set at the beginning of every run to keep the fluctuations between the various runs low.

2.6.3 Main experimental procedures

Before the beginning of each run the soil column had to be saturated, therefore all valves of the test box were closed. According to the objective of the specific run either tap water or tap water spiked with phosphorus (KH₂PO₄) from the tank was used. The saturation process was started approximately 30 min in advance. During this process all bottles were serially numbered and the first 20 sample bottles were placed on the auto sampler. The bottles for the samples taken manually were located next to the test box.

Once the soil column was saturated and the soil surface was flooded by 3.5 cm (1.38 inch) the test box was connected via a spiral hose to the domestic water supply system and to the tank, respectively. Before connection, the sample from the water reservoir (WR) was taken. Then the electrical conductivity meters were checked for correct timing, if the data storage card was in place and the meters were recording.

After all these steps were taken the input flow water was turned on and the gate valve were opened. At the same time the auto sampler was started and the starting time was recorded. Immediately after that the first measurement for the flow rate was conducted and calibrated by the needle-valve to the designated discharge rate. Also the first three water quality soil pore samples were taken.

One run had a duration time of approximately 120 min, during this period the water table in the test box was checked permanently, the flow rate measurements were recorded and the manually samples were taken according to schedule. Once the first samples in the water sampler were collected they were removed and replaced by empty bottles. All samples were capped and placed right next to the test box for further processing.

After 120 min the input water flow was shut off and the second sample from the water reservoir was taken. At the same time the gate valve was closed and the auto sampler was turned off. In order to fulfil the requirements for calculating the mass balance the discharge water needed to be collected. This was done using a bucket and the mass was recorded afterwards. Also the required sample from the discharge water was taken at that time. Finally the electrical conductivity meters were shut off, the SD cards were collected and the data was stored.

Once the full run was finished in total 58 water quality samples had collected.

For each run data, e.g. the amount of water for the process of saturation, the measured flow rate, the amount of the collected discharge water was recorded. An example of the used measurement report is given in Annex A.

2.6.4 Post-experimental procedures

2.6.4.1 Water quality sample analysis

After each run when all samples were taken, 20 ml of each sample (about 40 ml to 50 ml per sample) were filtered using a syringe through a 45- μ m phosphorus-free membrane filter into a plastic nalgene bottle (see Figure 21).

Since the analysis was not carried out on the same day, the filtered samples were acidified and preserved with sulphuric acid (H_2SO_4). Then the samples were stored in the freezer at -18°C until the analyses were performed. After the samples were taken out from freezer and were thawed they were analysed on Konelab Aquakem 20 (Thermo Fisher Scientific Inc., Waltham, Massachusetts) using the EPA (Environmental Protection Agency) method 365.2 (U.S. EPA, 1983) for soluble Phosphorus (OPO_4).

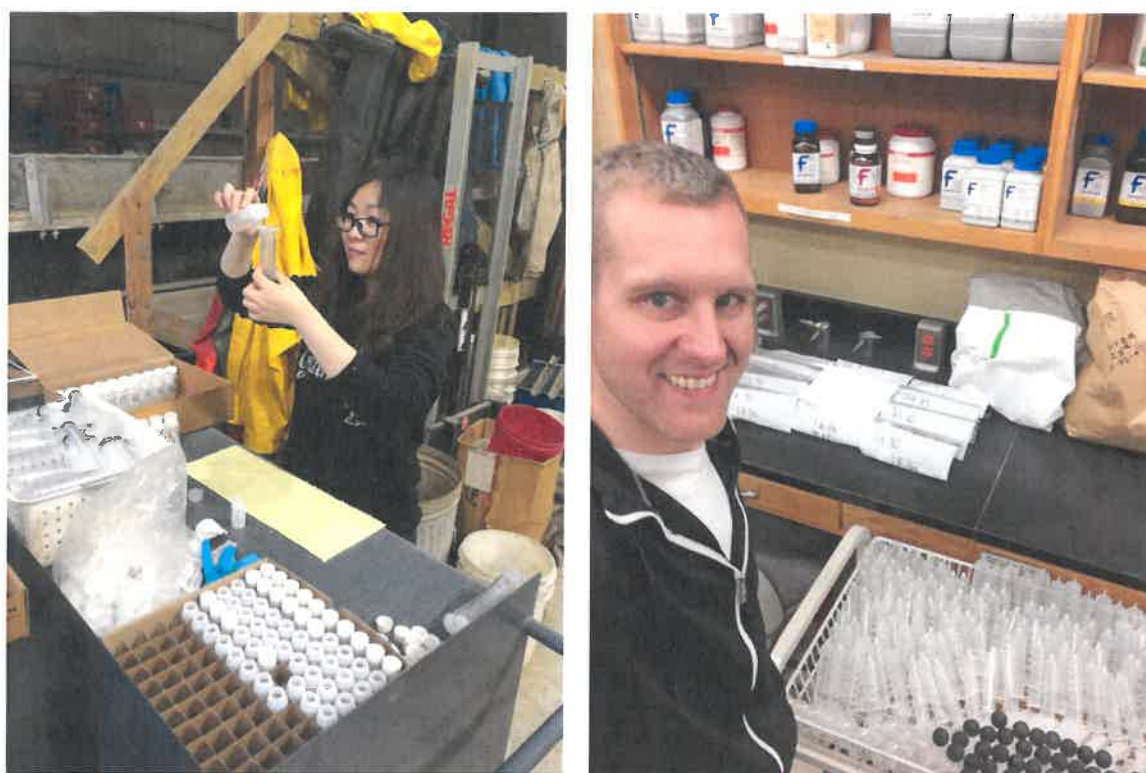


Figure 21 — Processing of the water quality samples

Additionally the pH value of each sample was measured by the Mettler Toledo SevenEasy S20.



Figure 22 — Measurement of the pH value

The remaining sample was placed in a freezer at -18°C for the case of re-runs or further analysis.

2.6.4.2 Data analysis and statistics

After the analysis of the water quality samples further analysis have been carried out. For the uptake and release of phosphorus by the filter media the mass balance was calculated.

In general the mass balance of the phosphorus can be calculated according to equation (1),

$$\Delta P = P_{in} - P_{out} \quad (1)$$

where

ΔP phosphorus release (–) or uptake (+) [mg]

P_{in} phosphorus mass flowing in during the run [mg]

P_{out} phosphorus mass flowing out during the run [mg]

In this experiment, where the phosphorus is measured at the water inlet unit (P_{in}) and at the water quality sampling unit (P_{out}), both values can be calculated according to equation (2) and (3),

$$P_{in,i} = C_i \cdot q_i \cdot t_i \quad (2)$$

$$P_{out,i} = C_i \cdot q_i \cdot t_i \quad (3)$$

where

$P_{in,i}$ phosphorus mass (load) at time interval i at the water inlet unit [mg/l]

$P_{out,i}$ phosphorus mass (load) at time interval i at the water quality sampling unit [mg/l]

C_i phosphorus concentration of the sample at the time interval i [mg/l]

q_i flow rate at the time interval i [l/min]

t_i time interval i of the sample: for $P_{in,i}$: 60 min or 120 min, for $P_{out,i}$: 3 min or 6 min [min]

According equation (1) and together with equations (2) and (3) the total release or uptake of a specific run total P_{adsorbed} can be calculated as follows:

$$\text{total } P_{\text{adsorbed}} = \sum_{i=1}^2 P_{\text{in},i} - \sum_{j=1}^{40} P_{\text{out},j} \quad (4)$$

Since a mass balance can only be calculated for the water quality samples the soil pore samples were not considered for further analysis, except pH value. A detailed calculation of one run can be found in Annex B.

Due to the fact that the variation of the flow rate was very, high a Studentized Tukey's test was performed. Furthermore analyses of variance (ANOVA) for the flow rate were carried out. These statistical tests were done using SAS. The detailed results are compiled in Annex C.

Furthermore the pH values were averaged by using the negative logarithm, since it is not mathematically correct to calculate simple averages or other summary statistics (Michaud, 1994).

3 Results and discussion

3.1 Overview

In Table 7 the results for the mass balance and the flow rate is shown.

Table 7 — Results for the mass balance for each run including the average flowrate

Number of run	Concentration of P input	Total P [mg]		Total P adsorbed		Average flowrate [l/min]
	[ppm]	input	output	[mg]	[%]	
Limestone - Adsorption						
1_LS_B ¹	0,24	60,69	27,82	32,88	54	1,83
2_LS_AD ¹	0,50	122,73	67,96	54,77	45	1,84
4_LS_AD ¹	0,61	186,02	126,21	59,81	32	2,36
6_LS_AD	4,46	1213,57	886,54	327,03	27	2,04
9_LS_AD	4,52	1121,05	991,72	129,33	12	2,49
13_LS_AD	5,27	1458,04	1108,63	349,42	24	2,09
17_LS_AD	5,23	1463,84	1199,67	264,17	18	2,11
24_LS_AD	5,25	1391,79	1154,39	237,40	17	1,99
Limestone - Desorption						
3_LS_DE ¹	0,30	79,59	51,60	27,98	35	2,02
5_LS_DE ¹	0,33	104,10	80,06	24,03	23	2,33
8_LS_DE	0,30	81,36	104,06	-22,70	-28	2,05
12_LS_DE	0,33	89,77	133,66	-43,89	-49	2,06
16_LS_DE	0,60	171,15	190,80	-19,65	-11	2,17
20_LS_DE	0,65	175,59	182,01	-6,42	-4	2,04
21_LS_DE	0,44	119,97	143,42	-23,46	-20	2,01
25_LS_DE ²	0,31	56,53	79,66	-23,13	-41	1,27
27_LS_DE_DI ²	0,00	1,25	53,96	-52,71	-4210	2,11
Steel Slags - Adsorption						
7_SS_B ¹	0,27	99,56	81,02	18,54	19	2,75
10_SS_AD	5,16	1514,75	1237,31	277,43	18	2,16
14_SS_AD	5,00	1586,63	1230,59	356,05	22	2,33
18_SS_AD	5,15	1558,78	1258,58	300,20	19	2,21
23_SS_AD	5,25	1606,90	1258,32	348,58	22	2,24
Steel Slags - Desorption						
11_SS_DE	0,33	101,84	109,00	-7,17	-7	2,24
15_SS_DE	0,57	183,41	173,29	10,12	6	2,34
19_SS_DE	0,66	194,39	190,29	4,10	2	2,13
22_SS_DE	0,58	175,23	149,96	25,27	14	2,25
26_SS_DE ²	0,29	85,93	105,50	-19,57	-23	2,14
28_SS_DE_DI ²	0,00	1,36	35,29	-33,92	-2486	2,23
1) not considered for further analysis						
2) duration of run extended to 240 min						

As can be seen in Table 7 the values for the input concentration of phosphorus in run # 2 and # 4 are much too low compared to the other runs where adsorption was simulated. The reason for the low values is that the amount of KH_2PO_4 added to the water in the tank was calculated in a wrong way. Therefore run # 2 to run # 5 were not taken into account for further analysis.

The values of the input concentration of phosphorus for the desorption-runs are unequal to zero. As mentioned in 2.6.1 tap water from the domestic water supply system was used for conducting the whole study. During the design of the experiment the question regarding the concentration of P in the tap water never came up. In the further data analysis, the background concentration was presumed to be present and was not subtracted for calculating the mass balance. The reason for this decision is that the higher the concentration of phosphorus is in the solution, the higher the affinity of the media for binding phosphorus.

Because the background concentration varied from one run to the other, this concentration had a significant influence in particular for the analysis of the desorption runs. Therefore the background concentration has to be taken into account for the interpretation of the given results. Due to this fact the desorption runs # 27 and # 28 were performed with deionized water. The given results for the total adsorbed phosphorus should only be compared to the other values where tap was used by using the total amount in mg (and not in %).

Table 7 also shows a big difference of the total phosphorus input between all runs, especially for the runs where the filter media was limestone. This is due to the high variation of the flow rate itself and due to the decrease of the flow rate over time during a specific run with limestone.

In the following chapters some detailed interpretations concerning the flow rate and the behaviour of the different filter media during adsorption and desorption are given. Furthermore the results of the pH value and the electrical conductivity are analysed.

3.2 Adsorption and desorption

The total performance of adsorbed phosphorus after adsorption runs and desorption runs over time, respectively is shown in Figure 23 and Figure 24. In both cases the

performance decreases with time, which means that a continuous flow through approach has higher significance than batch or column experiments within a short period of time. This is already mentioned in Penn et al, 2011.

In Figure 23 a steep decrease (from more than 50 % to below 20 %) of phosphorus uptake in both filter media can be seen in the first 20 min. In the further 100 min the uptake varies between 10 % and 20 %. A reason for this effect could be the longer retention time in the filter media during saturation of the test box.

The performance for the retention of phosphorus for both filter media (limestone and steel slag) is quite similar.

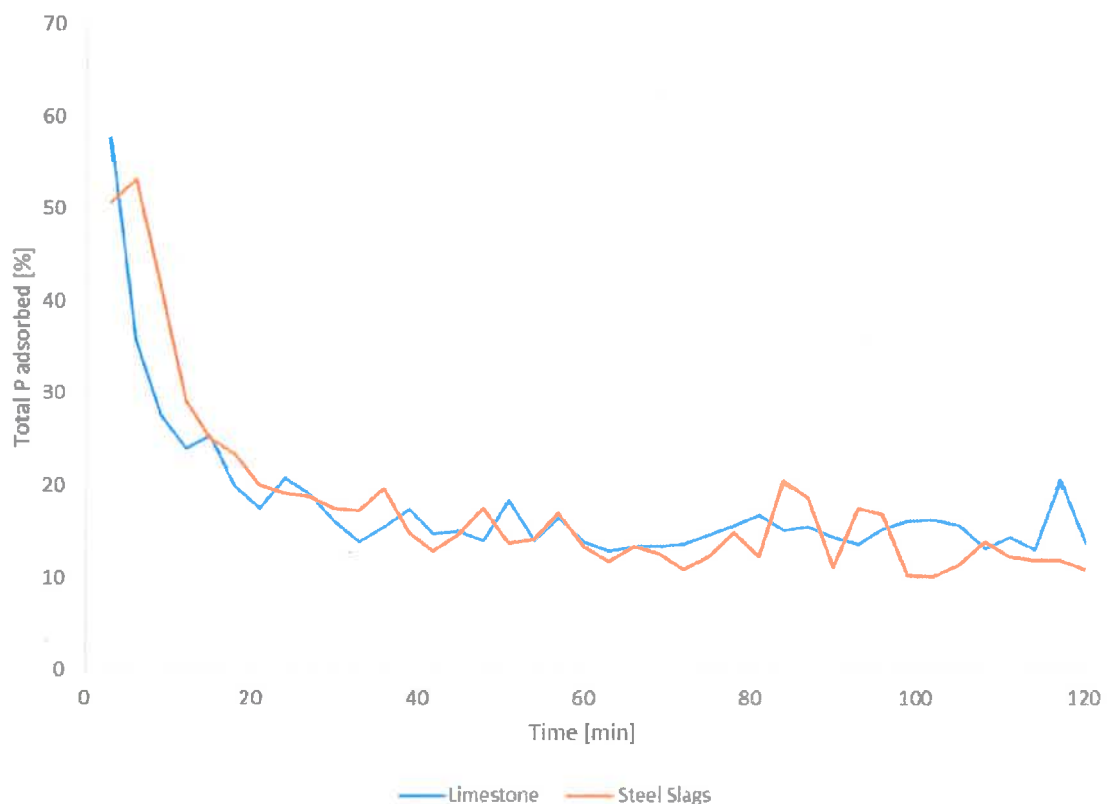


Figure 23 — Performance of phosphorus uptake after adsorption runs within 120 min

In contrast Figure 24, where desorption runs are complied, a significant difference between the performance of limestone and steel slags is visible. While steel slags varies between +20 % and -10 % during the whole experiment, limestone releases up to 80 % of phosphorus. This means steel slags have a much higher potential to sequester dissolved phosphorus.

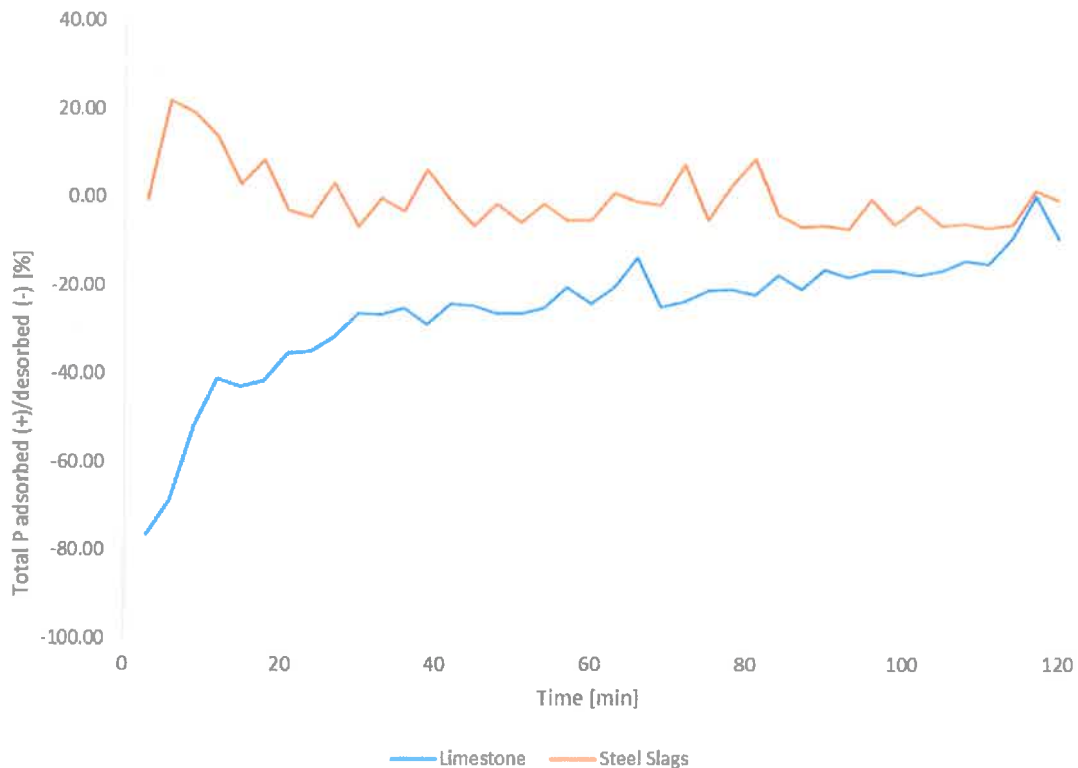


Figure 24 — Performance of phosphorus release after desorption runs within 120 min

As already mentioned, the adsorption capacity for limestone and steel slags are rather similar. The big difference lays in the affinity to bind phosphorus during desorption. The very high amount of phosphorus released from limestone is the main effect for the lower performance. As Table 8 shows the total mass of phosphorus which was adsorbed by the limestone was 16 % of the phosphorus input into the system whereas 26 % phosphorus was adsorbed by the steel slags.

Table 8 — Results for mass balance for all used runs

Filter media	Total P [mg]		Total P Adsorbed	
	input	output	[mg]	[%]
Limestone	7342,66	6174,55	1168,11	16
Steel Slags	7007,84	5183,95	1823,89	26

Figure 25 shows the adsorption and desorption in total mg of phosphorus for limestone and steel slags for four different cycles:

Cycle # 1: 6_LS_AD, 8_LS_DE (limestone); 10_SS_AD, 11_SS_DE (steel slags)

Cycle # 2: 9_LS_AD, 12_LS_DE (limestone); 14_SS_AD, 15_SS_DE (steel slags)

Cycle # 3: 13_LS_AD, 16_LS_DE (limestone); 18_SS_AD, 19_SS_DE (steel slags)

Cycle # 4: 17_LS_AD, 20_LS_DE (limestone); 23_SS_AD, 22_SS_DE (steel slags)

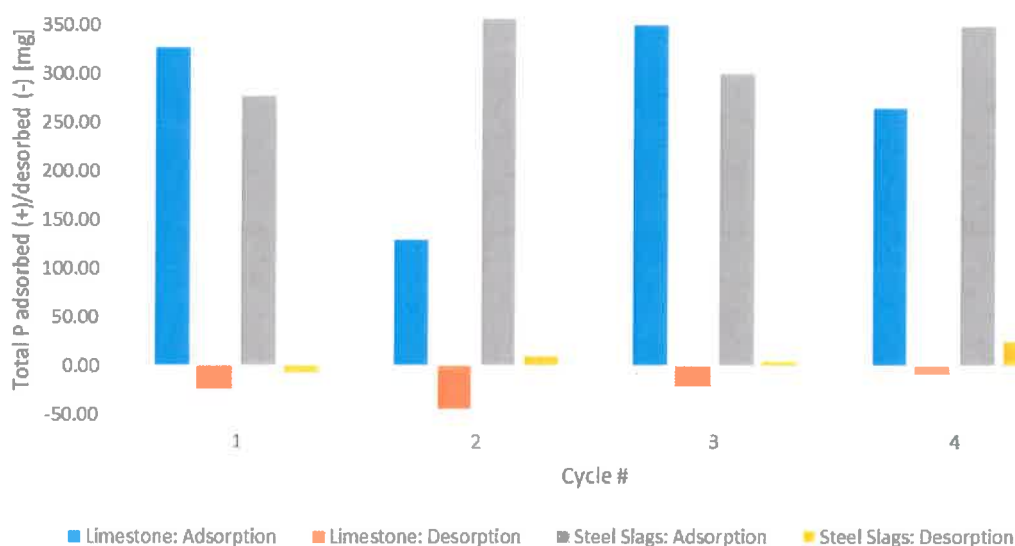


Figure 25 — Distribution of adsorption of phosphorus for several cycles for the blind inlet test box with limestone and steel slags

As described above the adsorption rates are quite similar, except limestone in Cycle # 2, where only half of the usual amount of phosphorus was taken up. This might be due to the very high flow rate of 2.49 l/min in this specific run.

The desorption rate (–) for the limestone is in every cycle higher than the desorption rate (–) for the steel slags. Even during desorption runs steel slags are taking up phosphorus. This is caused by the background concentration in the tap water.

Figure 26 shows the influence of the flow rate (x-axis) on the performance of adsorbed phosphorus by both media (y-axis). A lower flow rate results in a higher retention time, which means in turn a higher flow rate causes lower retention time.

Therefore the amount of adsorbed phosphorus is decreasing when the flow rate is high. This dependency can be derived from the test box of limestone (see blue trend line). Since the flow rate in the test box with steel slags was more or less stable, no conclusion concerning this matter can be given (see grey trend line).

On the opposite a lower flow rate results in higher desorption rates. This can be seen for both filter media (see orange and yellow trend line).

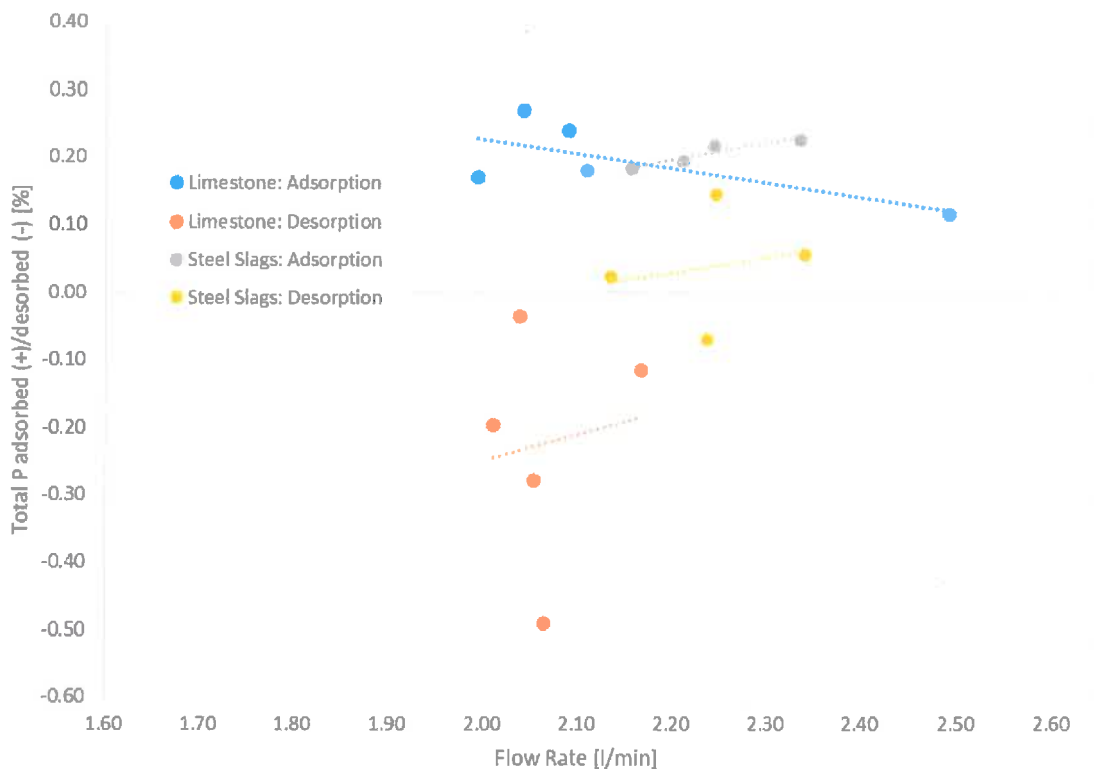


Figure 26 — Adsorption vs. flow rate for the blind inlet test box with limestone and steel slags

To eliminate the influence of the flow rate on the amount of phosphorus during desorption the calculated amount of phosphorus for each run was divided by the relevant flow rate (P^*). The results are shown in Figure 27. In most runs limestone releases phosphorus while steel slag takes phosphorus up. As already mentioned this is caused by the background concentration in the used tap water.

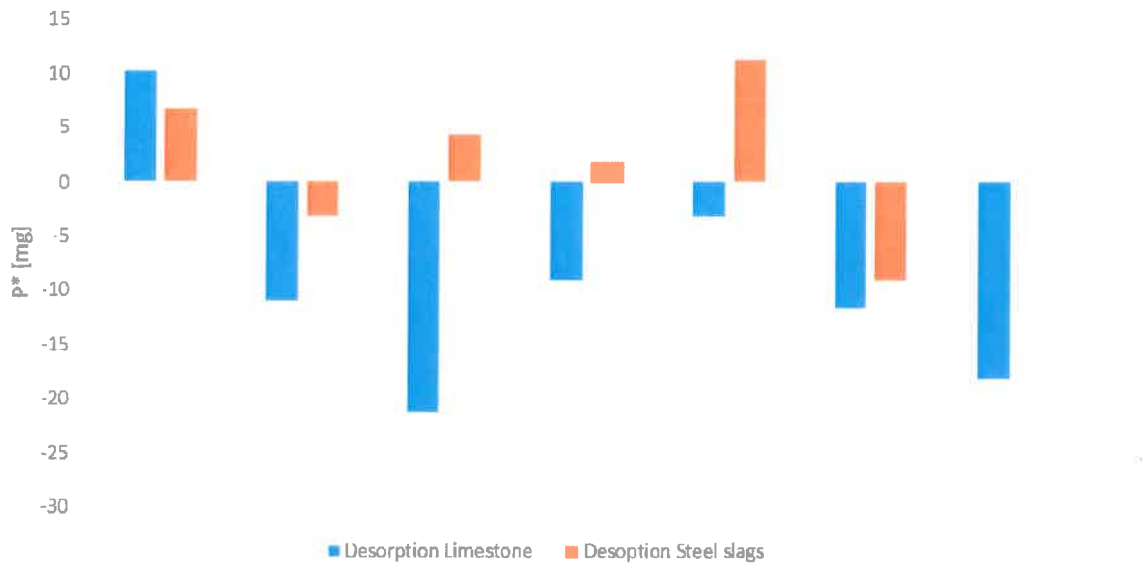


Figure 27 — Desorption of phosphorus adjusted for flow rate for several cycles for the blind inlet test box with limestone and steel slags

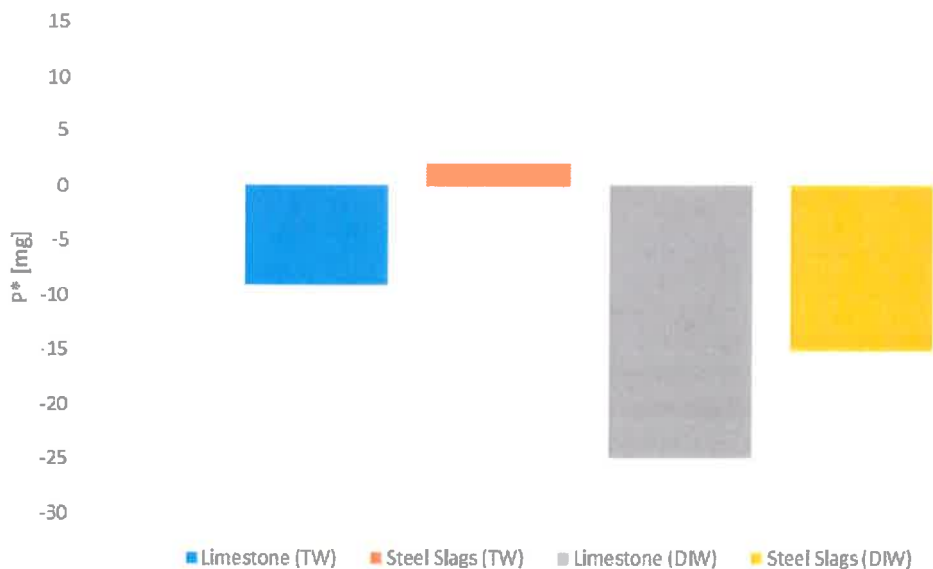


Figure 28 — Phosphorus release after desorption runs, adjusted for flow rate for tap water (TW) and deionized water (DIW) for the blind inlet test box with limestone and steel slags

A comparison of tap water (TW) and deionized water (DIW) used during desorption is shown in Figure 28. In this graph also the calculated P^* adjusted for the flow rate is used. The shown values are compiled from all desorption runs with tap water, while the result for deionized water only represents one specific run for each test box. Nev-

ertheless the results show the same picture: limestone releases more phosphorus than steel slags, but at a different level.

3.3 Flow rate

The results for the analysis of all measured flow rates (in total 240 values) of the runs with a duration time of 120 min are shown in Table 9. The runs with a duration time of 240 min are not considered in this analysis because they would influence the results due to the strong decrease of the flow rate in the test box where limestone was used. The lowest value in this case is 0.89 l/min.

Table 9 — Results for flow rate [l/min]

Flow rate	Limestone	Steel Slags
Average value	2.11	2.30
Minimum value	1.70	2.07
Maximum value	2.70	2.83
Standard deviation	0.24	0.18

As mentioned in 2.6.2.5 the target value for the flow rate was 2.57 l/min. This aim could not be reached although some adaptations of the regulation mechanism of the flow rate were made. After conducting the first runs, it was difficult to reach this target value. Thus, a new target value was defined.

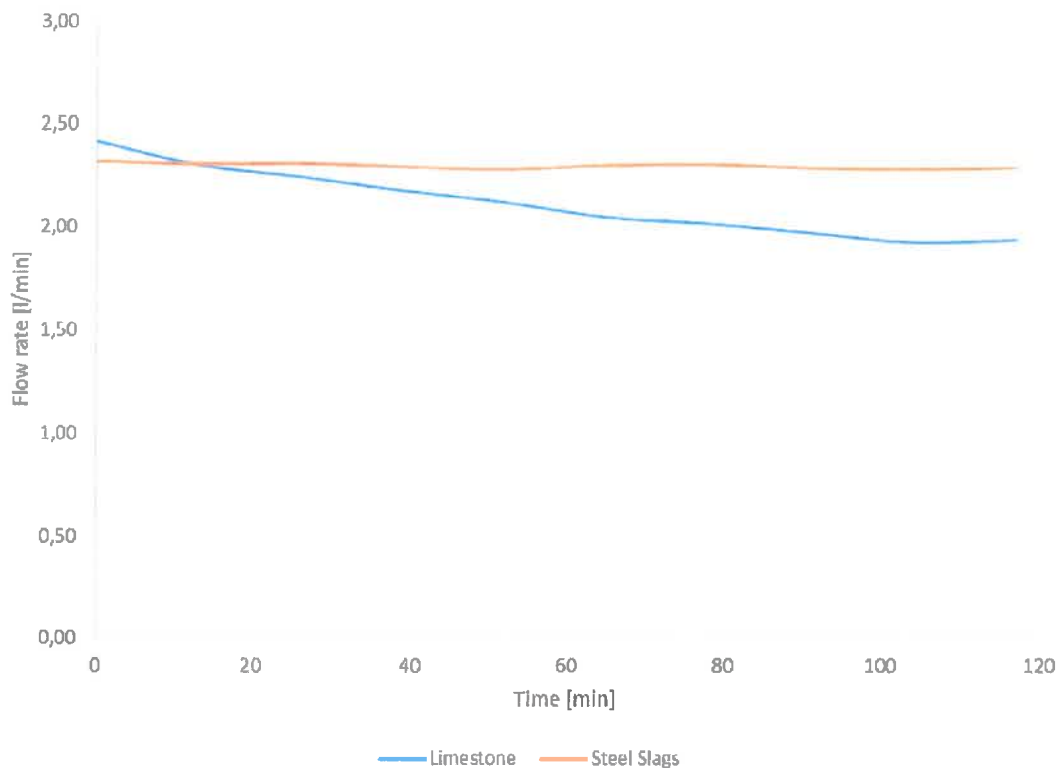


Figure 29 — Comparison of flow rate for the blind inlet test box with limestone and steel slags over time

In Figure 29 the average values over all 240 measurements for the flow rate in the test box with limestone and steel slags are shown for 120 min. As already described above the decrease of the flow rate in the test box with limestone is rather significant. It decreases from nearly 2.4 l/min to 1.95 l/min. The reasons for this effect could be as follows:

- The top layer in the test box with the limestone was fine grained pit-run gravel while it was coarse grained steel slags in the other test box. It is supposed that the infiltration rate into the pit-run gravel decreases over time,
- Permanent cycles of wetting and drying during the whole study.

On the other side the flow rate in the test box with steel slags is almost constant over time.

Another illustration of the different flow rates in the two test boxes can be seen in Figure 30. The boxplots also show the broad distribution in the test box with limestone.

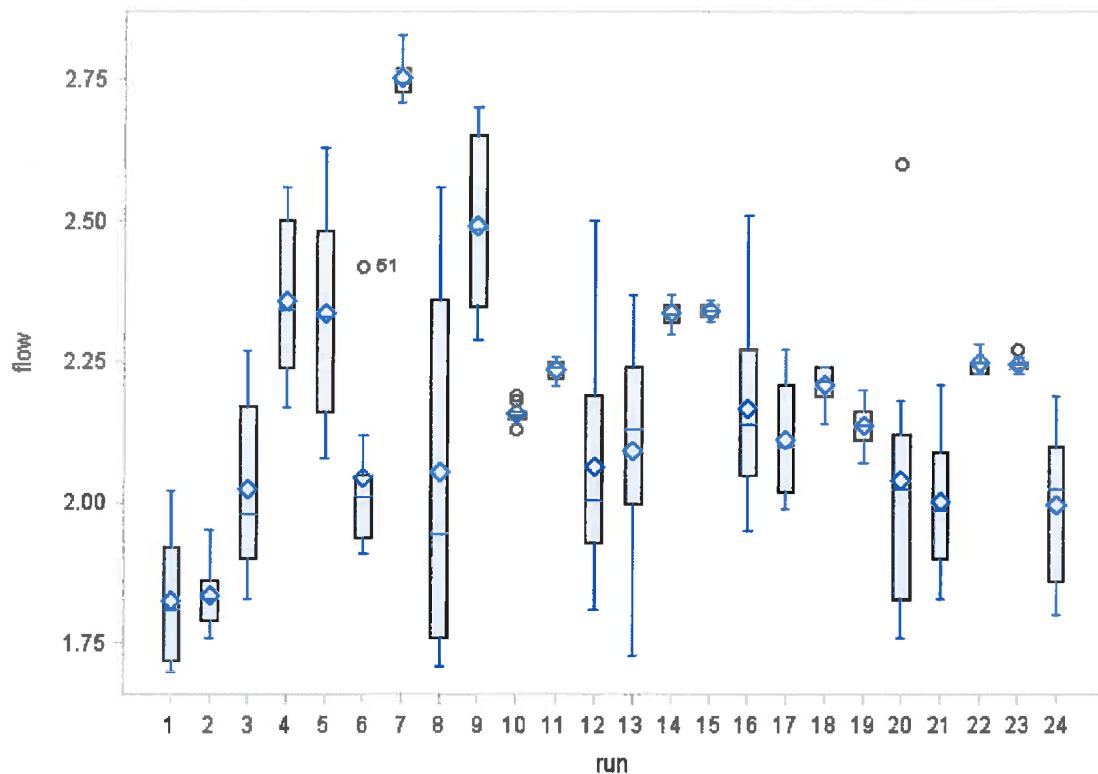


Figure 30 — Distribution of flow rate for all runs with duration time of 120 min

A statistical test performed using SAS (SAS Institute Inc., Cary, North Carolina, USA) showed that 68 % of the measurements are explained by a linear model ($R^2 = 0.68$). Despite the high variation Tukey's Studentized Range Test showed that most of the measured flow rates are not significantly different ($\alpha = 0.05$). Detailed results for can be found in Annex C.

3.4 pH value

The results for the analysis of all pH measurements are shown in Table 10. All given values are average values.

The pH value for the inflowing water is between 8.18 and 8.28 and increased slightly after the phosphorus treatment (8.71 and 8.73) in the filter media box. Therefore it can be derived both filter media increased the pH value. However there is almost no difference between limestone and steel slags.

Concerning the soil it can be seen the initial pH value of 6.30 increased. The highest values were measured at location SB 1 where the distance from the soil surface is lowest. With increasing depth the values were approaching the initial pH value of the soil.

Table 10 — Results for pH value

Location	Test box with Limestone	Test box with Steel Slags
Water reservoir (WR)	8.28	8,18
Soil pore sample (SB1)	8.42	8,18
Soil pore sample (SB2)	7.92	7,88
Soil pore sample (SB3)	7.71	7,70
Water outlet (MB)	8.73	8,71
Soil	6.30	

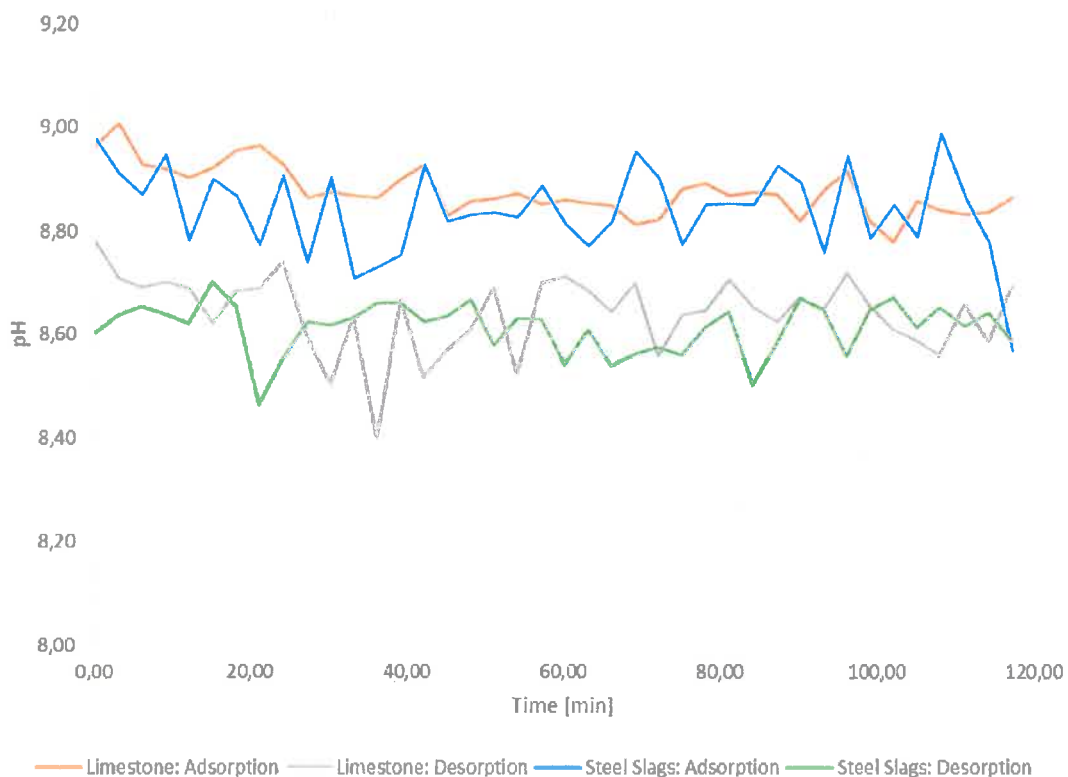


Figure 31 — pH value at water outlet

The graphs in Figure 31 show the pH values measured at the water outlet. There is no significant difference between the limestone and the steel slags. The only difference which can be derived from the graph is, that the pH values measured during adsorption runs are higher than those for desorption runs.

3.5 Electrical conductivity

Table 11 shows the results for the analysis of electrical conductivity. All given values are average values.

As it can be seen there are almost no differences between the test runs.

Table 11 — Results for electrical conductivity

Location	Test box	Objective	Electrical Conductivity [mS]
Water reservoir (WR)	Limestone	Adsorption	0.685
Water reservoir (WR)	Limestone	Desorption	0.663
Water reservoir (WR)	Steel Slags	Adsorption	0.680
Water reservoir (WR)	Steel Slags	Desorption	0.662
Water outlet (MB)	Limestone	Adsorption	0.674
Water outlet (MB)	Limestone	Desorption	0.658
Water outlet (MB)	Steel Slags	Adsorption	0.657
Water outlet (MB)	Steel Slags	Desorption	0.650

4 Summary, conclusion and future research

4.1 Summary

Although phosphorus is essential for plant life, too much phosphorus in runoff water can cause eutrophication and harmful algal blooms. This problem is apparent, especially in areas of high agricultural activity. Agriculture is one of the main sources of phosphorus released into surface waters, beside sources from urban and suburban areas. Also climate change contributes, as it increases the number of events with high discharges in short time periods. Especially those events with very high discharge rates are a big issue for the remediation of phosphorus from agricultural surface runoff. Sewage treatment plants, such as those used in urban areas are not suitable, because of the large amount of water within a short period of time or unavailable space for such a construction. For this reasons an on-site construction for the remediation of phosphorus could be an appropriate solution to solve the problem.

Since 2007 the Agricultural Research Service, the in-house research service of the USDA (United States Department of Agriculture) in West Lafayette, IN, USA carried out investigations how to construct such an on-site solution. Therefore the so-called “Blind Inlet” was built. A “Blind Inlet” is a construction where at the lowest point of a field an area of approximately 4.25 x 4.25 m with a depth of 1 m of soil is replaced by filter media. In this filter body the surface runoff is collected and purified before it discharges into the receiving river. For blind inlets which are installed in Northern Indiana limestone serves as the filter media.

In recent years besides limestone other filter media were tested for the remediation of phosphorus (Penn et al., 2012). Due to the fact that there are many materials available to serve as a filter media, there is an urgent need to test the behaviour of these materials in a laboratory experiment before they are used in the field. That was the motivation to conduct this study.

Between February 2015 and June 2015 a test box was designed, built and also the first experiments were conducted. This experiment simulates a part of a blind inlet to investigate the hydrological and chemical processes occurring in such an on-site construction. During the design of the experiment high attention was paid on perform-

ing the study as realistic as possible. The first experiments (28 runs) with the test box were performed with limestone and steel slags as filter media.

4.2 Conclusion

Although the number of variables in this 28 runs were very large e.g. filter media, objective (adsorption/desorption), flow rate, type of inflowing water, duration time of one run first results could be obtained. The main findings of the study are:

- Concerning adsorption of phosphorus limestone and steel slags have nearly the same potential for the uptake of phosphorus. The adsorption capacity varies between 10 % and 20 % of the total phosphorus input.
- During desorption the performance of limestone is significantly different from steel slags. Limestone releases up to 80 % of the former retained phosphorus, while steel slags releases only 10 %.
- As a result steel slags are recommended for use in blind inlets.
- The flow rate, linked to retention time, has a significant influence on the retention capacity of phosphorus.
- Since the capacity for retaining phosphorus decreases over time, flow-through-experiments are more suitable than batch/column experiments.

4.3 Future Research

Despite many advantages of a realistic study, some shortcomings should also be mentioned, which could be addressed in further research. These improvements are:

- The effect of the retention time shall be more investigated. Therefore more information about the used filter media such as pore volume is needed.
- Since this experiment was conducted under saturated conditions it should be attempted to perform experiments under unsaturated conditions.
- To increase the performance of the filter media smaller grained material could be used but under consideration of the infiltration rate.

Summary, conclusion and further research

- To gain the amount of phosphorus which can be theoretically taken up by the media, isotherm experiments should be carried out.
- To gain more information about the hydraulic conditions within the blind inlet test box especially in the soil box, it could be attempted to simulate the occurring processes by computer simulations using suitable software.
- Since controlling the flow rate was quite difficult for limestone, further investigations to replace the top filter layer by other materials could be done. Another attempt to increase the comparability could be the re-design of the water quality sampling unit.
- To ensure comparability of the results it might be better to use deionized water instead of tap water.

Further research could also be done to extend the application of the blind inlet test box. These research areas could be the retention of heavy metals, acids or salts from infrastructure surfaces.

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Annex A
Measurement Report

BIS 2015 Run #: _____ Fluid: _____ Media: _____ Date: _____

Start: _____ Stop: _____

Saturation Process

Time	Amount of water [ml]	Time	Amount of water [ml]

Discharge Measurements

Time	Discharge [ml/min]	Time	Discharge [ml/min]
00:00 (00:00)		00:65 (00:05)	
00:13 (00:13)		00:78 (00:18)	
00:26 (00:26)		00:91 (00:31)	
00:39 (00:39)		01:04 (00:44)	
00:52 (00:52)		01:17 (00:57)	

(Time in brackets shows time on the stopwatch which restarts after 60 minutes)

Drain Water

Amount of water [ml]		

Notes

Annex B

Analysis Report (example)

Project	Date	Trial Sample		Barcode	Location	Interval	Objective	pH	OPO4 Flow			Interval	P OUT	P Adsorbed	Performance	Ca / P IN	P IN	Saturation	Drainage
		#	ID						(ppm)	rate	Time	(min)	(mg)	(mg)	(%)	(mg)	(mg)	(l)	(l)
BIS 2015	06/05/2015	6	1	*6001*	MB	0,00	Adsorption	8,88	1,92	2,04	0,00	3,00	8,11	19,22	70,82	4,46	27,39	27,00	19,55
BIS 2015	06/05/2015	6	2	*6002*	MB	3,00	Adsorption	8,91	2,47	2,04	3,00	3,00	15,12	12,21	44,88	4,46	27,39		
BIS 2015	06/05/2015	6	3	*6003*	MB	6,00	Adsorption	8,97	2,68	2,04	6,00	3,00	16,42	10,50	39,80	4,46	27,39		
BIS 2015	06/05/2015	6	4	*6004*	MB	9,00	Adsorption	8,98	2,68	2,04	9,00	3,00	16,28	11,05	40,42	4,46	27,39		
BIS 2015	06/05/2015	6	5	*6005*	MB	12,00	Adsorption	8,79	2,18	2,04	12,00	3,00	16,93	14,00	50,22	4,46	27,39		
BIS 2015	06/05/2015	6	6	*6006*	MB	15,00	Adsorption	8,89	1,87	2,04	15,00	3,00	17,57	9,76	35,71	4,46	27,39		
BIS 2015	06/05/2015	6	7	*6007*	MB	18,00	Adsorption	8,90	3,95	2,04	18,00	3,00	20,52	6,82	24,90	4,46	27,39		
BIS 2015	06/05/2015	6	8	*6008*	MB	21,00	Adsorption	8,95	3,25	2,04	21,00	3,00	19,77	7,55	27,94	4,46	27,39		
BIS 2015	06/05/2015	6	9	*6009*	MB	24,00	Adsorption	8,99	3,98	2,04	24,00	3,00	20,70	8,65	24,25	4,46	27,39		
BIS 2015	06/05/2015	6	10	*6010*	MB	27,00	Adsorption	8,93	3,51	2,04	27,00	3,00	21,47	1,86	21,46	4,46	27,39		
BIS 2015	06/05/2015	6	11	*6011*	MB	30,00	Adsorption	8,88	3,60	2,04	30,00	3,00	22,08	3,23	19,21	4,46	27,39		
BIS 2015	06/05/2015	6	12	*6012*	MB	33,00	Adsorption	8,89	3,59	2,04	33,00	3,00	20,77	6,55	28,99	4,46	27,39		
BIS 2015	06/05/2015	6	13	*6013*	MB	36,00	Adsorption	8,86	2,89	2,04	36,00	3,00	17,70	9,69	36,24	4,46	27,39		
BIS 2015	06/05/2015	6	14	*6014*	MB	39,00	Adsorption	8,94	3,66	2,04	39,00	3,00	22,42	4,92	18,00	4,46	27,39		
BIS 2015	06/05/2015	6	15	*6015*	MB	42,00	Adsorption	9,05	3,47	2,04	42,00	3,00	21,27	6,06	22,27	4,46	27,39		
BIS 2015	06/05/2015	6	16	*6016*	MB	45,00	Adsorption	8,85	3,62	2,04	45,00	3,00	22,15	5,18	18,94	4,46	27,39		
BIS 2015	06/05/2015	6	17	*6017*	MB	48,00	Adsorption	8,94	2,90	2,04	48,00	3,00	17,78	3,54	34,92	4,46	27,39		
BIS 2015	06/05/2015	6	18	*6018*	MB	51,00	Adsorption	8,85	3,59	2,04	51,00	3,00	21,60	5,79	20,66	4,46	27,39		
BIS 2015	06/05/2015	6	19	*6019*	MB	54,00	Adsorption	8,94	3,55	2,04	54,00	3,00	22,95	4,98	19,22	4,46	27,39		
BIS 2015	06/05/2015	6	20	*6020*	MB	57,00	Adsorption	8,85	3,70	2,04	57,00	3,00	22,67	4,66	27,06	4,46	27,39		
BIS 2015	06/05/2015	6	21	*6021*	MB	60,00	Adsorption	8,78	3,62	2,04	60,00	3,00	22,20	5,13	15,79	4,46	27,39		
BIS 2015	06/05/2015	6	22	*6022*	MB	63,00	Adsorption	8,84	3,54	2,04	63,00	3,00	21,69	5,54	20,62	4,46	27,39		
BIS 2015	06/05/2015	6	23	*6023*	MB	66,00	Adsorption	8,88	3,74	2,04	66,00	3,00	22,89	4,44	18,25	4,46	27,39		
BIS 2015	06/05/2015	6	24	*6024*	MB	69,00	Adsorption	8,81	3,79	2,04	69,00	3,00	22,83	4,50	16,48	4,46	27,39		
BIS 2015	06/05/2015	6	25	*6025*	MB	72,00	Adsorption	8,94	3,25	2,04	72,00	3,00	19,90	7,42	27,15	4,46	27,39		
BIS 2015	06/05/2015	6	26	*6026*	MB	75,00	Adsorption	8,85	3,28	2,04	75,00	3,00	19,79	7,55	27,62	4,46	27,39		
BIS 2015	06/05/2015	6	27	*6027*	MB	78,00	Adsorption	8,98	3,70	2,04	78,00	3,00	22,68	4,64	16,99	4,46	27,39		
BIS 2015	06/05/2015	6	28	*6028*	MB	81,00	Adsorption	8,94	3,26	2,04	81,00	3,00	19,96	7,97	26,97	4,46	27,39		
BIS 2015	06/05/2015	6	29	*6029*	MB	84,00	Adsorption	8,88	3,60	2,04	84,00	3,00	22,05	5,27	19,90	4,46	27,39		
BIS 2015	06/05/2015	6	30	*6030*	MB	87,00	Adsorption	8,84	3,72	2,04	87,00	3,00	22,76	4,57	16,72	4,46	27,39		
BIS 2015	06/05/2015	6	31	*6031*	MB	90,00	Adsorption	8,65	3,61	2,04	90,00	3,00	23,32	4,01	14,68	4,46	27,39		
BIS 2015	06/05/2015	6	32	*6032*	MB	93,00	Adsorption	8,88	3,99	2,04	93,00	3,00	20,74	6,59	24,10	4,46	27,39		
BIS 2015	06/05/2015	6	33	*6033*	MB	96,00	Adsorption	8,85	3,88	2,04	96,00	3,00	20,97	6,96	25,47	4,46	27,39		
BIS 2015	06/05/2015	6	34	*6034*	MB	99,00	Adsorption	8,73	3,13	2,04	99,00	3,00	16,14	8,18	29,95	4,46	27,39		
BIS 2015	06/05/2015	6	35	*6035*	MB	102,00	Adsorption	8,84	3,95	2,04	102,00	3,00	20,88	6,74	24,68	4,46	27,39		
BIS 2015	06/05/2015	6	36	*6036*	MB	105,00	Adsorption	8,88	3,70	2,04	105,00	3,00	22,67	4,66	17,04	4,46	27,39		
BIS 2015	06/05/2015	6	37	*6037*	MB	108,00	Adsorption	8,94	3,65	2,04	108,00	3,00	22,97	4,96	18,19	4,46	27,39		
BIS 2015	06/05/2015	6	38	*6038*	MB	111,00	Adsorption	8,86	3,68	2,04	111,00	3,00	22,54	4,78	17,51	4,46	27,39		
BIS 2015	06/05/2015	6	39	*6039*	MB	114,00	Adsorption	8,86	3,99	2,04	114,00	3,00	24,04	3,26	12,02	4,46	27,39		
BIS 2015	06/05/2015	6	40	*6040*	MB	117,00	Adsorption	8,85	3,99	2,04	117,00	3,00	24,41	2,92	10,67	4,46	27,39		
BIS 2015	06/05/2015	6	41	*6041*	S&S	0,00	Adsorption	8,76	1,91										
BIS 2015	06/05/2015	6	42	*6042*	S&S	26,00	Adsorption	8,51	3,84						P IN (Flow)	1093,12			
BIS 2015	06/05/2015	6	43	*6043*	S&S	52,00	Adsorption	8,04	3,89						P OUT (Flow)	327,05			
BIS 2015	06/05/2015	6	44	*6044*	S&S	78,00	Adsorption	8,91	4,09						P IN (Saturation)	120,45			
BIS 2015	06/05/2015	6	45	*6045*	S&S	104,00	Adsorption	8,48	4,15						P OUT (Drain)	69,51			
BIS 2015	06/05/2015	6	46	*6046*	S&S	0,00	Adsorption	7,69	0,28						P IN	1219,57			
BIS 2015	06/05/2015	6	47	*6047*	S&S	26,00	Adsorption	7,82	0,17						P OUT	886,54			
BIS 2015	06/05/2015	6	48	*6048*	S&S	52,00	Adsorption	7,94	0,11						P Adsorbed	327,03			
BIS 2015	06/05/2015	6	49	*6049*	S&S	78,00	Adsorption	7,67	0,19						Performance	0,90			
BIS 2015	06/05/2015	6	50	*6050*	S&S	104,00	Adsorption	7,72	0,50										
BIS 2015	06/05/2015	6	51	*6051*	S&S	0,00	Adsorption	7,72	0,05										
BIS 2015	06/05/2015	6	52	*6052*	S&S	26,00	Adsorption	7,44	0,04										
BIS 2015	06/05/2015	6	53	*6053*	S&S	52,00	Adsorption	7,60	0,05										
BIS 2015	06/05/2015	6	54	*6054*	S&S	78,00	Adsorption	7,49	0,05										
BIS 2015	06/05/2015	6	55	*6055*	S&S	104,00	Adsorption	7,42	0,04										
BIS 2015	06/05/2015	6	56	*6056*	WR	0,00	Adsorption	8,49	4,12										
BIS 2015	06/05/2015	6	57	*6057*	WR	117,00	Adsorption	8,45	4,80										
BIS 2015	06/05/2015	6	58	*6058*	DW	117,00	Adsorption	8,57	3,79										

Annex C

GLM (General linear model) Procedure for flow

Obs.	run	flow	Obs.	run	flow	Obs.	run	flow	Obs.	run	flow	Obs.	run	flow
1	1	2.02	49	5	2.12	97	10	2.15	145	15	2.33	193	20	2.12
2	1	1.95	50	5	2.08	98	10	2.16	146	15	2.35	194	20	2.03
3	1	1.92	51	6	2.42	99	10	2.14	147	15	2.35	195	20	2.06
4	1	1.87	52	6	2.12	100	10	2.13	148	15	2.34	196	20	1.98
5	1	1.83	53	6	2.02	101	11	2.26	149	15	2.32	197	20	2.02
6	1	1.79	54	6	2.05	102	11	2.24	150	15	2.34	198	20	1.81
7	1	1.77	55	6	2.00	103	11	2.24	151	16	2.51	199	20	1.76
8	1	1.72	56	6	1.99	104	11	2.25	152	16	2.41	200	20	1.83
9	1	1.70	57	6	1.94	105	11	2.21	153	16	2.27	201	21	2.21
10	1	1.70	58	6	1.91	106	11	2.24	154	16	2.16	202	21	2.16
11	2	1.95	59	6	1.94	107	11	2.24	155	16	2.12	203	21	2.09
12	2	1.92	60	6	2.05	108	11	2.21	156	16	1.96	204	21	2.04
13	2	1.85	61	7	2.77	109	11	2.22	157	16	2.19	205	21	2.00
14	2	1.86	62	7	2.72	110	11	2.25	158	16	2.07	206	21	1.97
15	2	1.84	63	7	2.83	111	12	2.50	159	16	2.05	207	21	1.93
16	2	1.82	64	7	2.77	112	12	2.29	160	16	1.95	208	21	1.90
17	2	1.79	65	7	2.74	113	12	2.19	161	17	2.27	209	21	1.88
18	2	1.80	66	7	2.75	114	12	2.10	162	17	2.21	210	21	1.83
19	2	1.77	67	7	2.77	115	12	2.03	163	17	2.23	211	22	2.25
20	2	1.76	68	7	2.71	116	12	1.98	164	17	2.13	212	22	2.24
21	3	2.27	69	7	2.74	117	12	1.94	165	17	2.13	213	22	2.25
22	3	2.22	70	7	2.73	118	12	1.87	166	17	2.05	214	22	2.23
23	3	2.17	71	8	2.56	119	12	1.81	167	17	2.07	215	22	2.23
24	3	2.11	72	8	2.36	120	12	1.93	168	17	2.02	216	22	2.25
25	3	2.00	73	8	2.54	121	13	2.37	169	17	2.00	217	22	2.27
26	3	1.96	74	8	2.19	122	13	2.32	170	17	1.99	218	22	2.28
27	3	1.91	75	8	2.07	123	13	2.24	171	18	2.24	219	22	2.23
28	3	1.90	76	8	1.76	124	13	2.19	172	18	2.24	220	22	2.25
29	3	1.85	77	8	1.71	125	13	2.15	173	18	2.22	221	23	2.27
30	3	1.83	78	8	1.82	126	13	2.11	174	18	2.23	222	23	2.25
31	4	2.56	79	8	1.74	127	13	2.06	175	18	2.14	223	23	2.24
32	4	2.54	80	8	1.81	128	13	2.00	176	18	2.24	224	23	2.25
33	4	2.50	81	9	2.70	129	13	1.75	177	18	2.19	225	23	2.26
34	4	2.44	82	9	2.70	130	13	1.73	178	18	2.20	226	23	2.24
35	4	2.37	83	9	2.54	131	14	2.34	179	18	2.19	227	23	2.23
36	4	2.32	84	9	2.65	132	14	2.36	180	18	2.21	228	23	2.25
37	4	2.26	85	9	2.46	133	14	2.32	181	19	2.20	229	23	2.23
38	4	2.24	86	9	2.51	134	14	2.34	182	19	2.17	230	23	2.24
39	4	2.20	87	9	2.35	135	14	2.35	183	19	2.16	231	24	2.19
40	4	2.17	88	9	2.35	136	14	2.33	184	19	2.07	232	24	2.17
41	5	2.63	89	9	2.36	137	14	2.37	185	19	2.11	233	24	2.10
42	5	2.59	90	9	2.29	138	14	2.33	186	19	2.13	234	24	2.09
43	5	2.48	91	10	2.19	139	14	2.32	187	19	2.16	235	24	2.03
44	5	2.40	92	10	2.16	140	14	2.30	188	19	2.10	236	24	2.02
45	5	2.43	93	10	2.15	141	15	2.34	189	19	2.14	237	24	1.87
46	5	2.26	94	10	2.18	142	15	2.36	190	19	2.13	238	24	1.86
47	5	2.22	95	10	2.15	143	15	2.35	191	20	2.60	239	24	1.80
48	5	2.16	96	10	2.16	144	15	2.32	192	20	2.18	240	24	1.83

Class Level Information		
Class	Levels	Values
run	24	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24

Number of Observations Read	240
Number of Observations Used	240

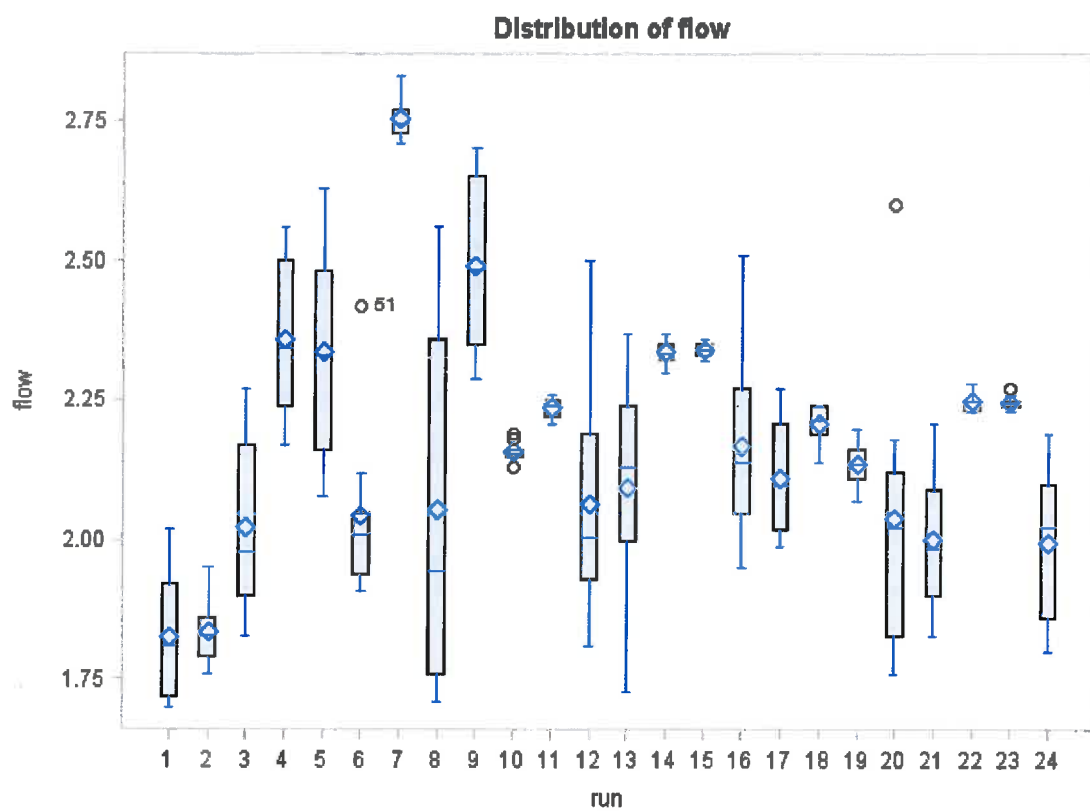
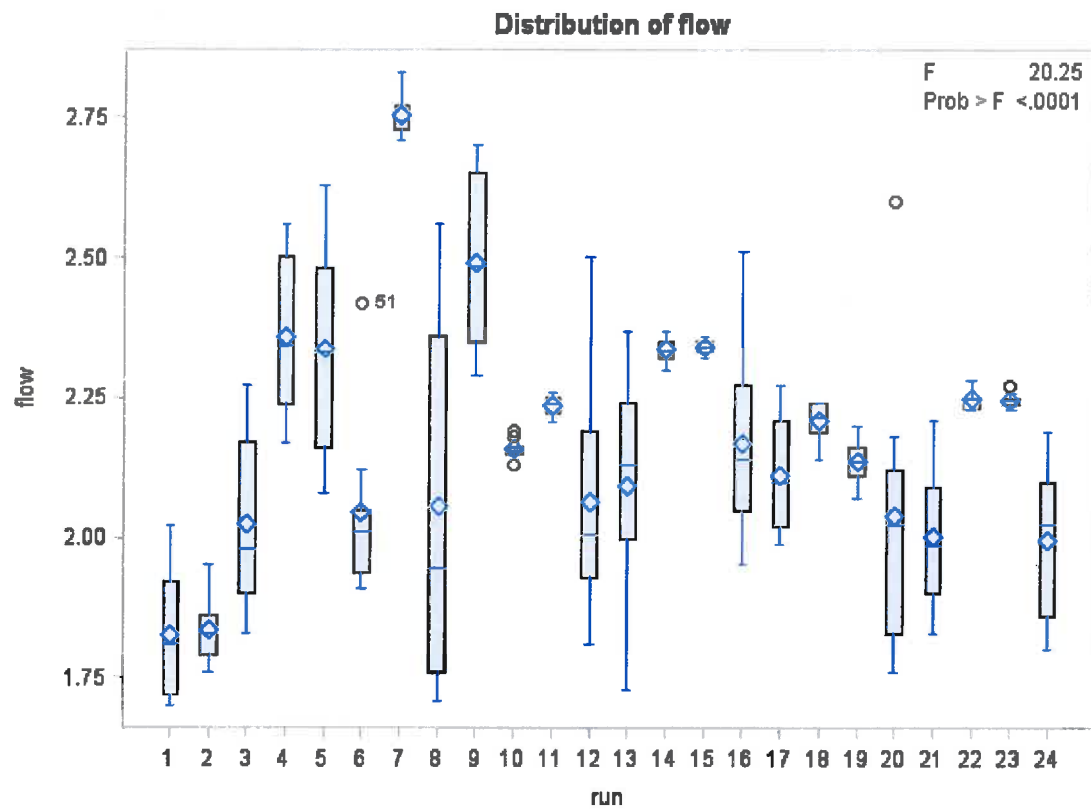
Dependent Variable: flow

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	23	9.59318625	0.41709505	20.25	<.0001
Error	216	4.44841000	0.02059449		
Corrected Total	239	14.04159625			

R-Square	Coeff Var	Root MSE	flow Mean
0.683198	6.609836	0.143508	2.171125

Source	DF	Type I SS	Mean Square	F Value	Pr > F
run	23	9.59318625	0.41709505	20.25	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
run	23	9.59318625	0.41709505	20.25	<.0001



Tukey's Studentized Range (HSD) Test for flow

Note: This test controls the Type I experimentwise error rate, but it generally has a higher Type II error rate than REGWQ.

Alpha	0.05
Error Degrees of Freedom	216
Error Mean Square	0.020594
Critical Value of Studentized Range	5.21169
Minimum Significant Difference	0.2365

Means with the same letter are not significantly different.							
Tukey Grouping					Mean	N	run
			A		2.75300	10	7
			B		2.49100	10	9
			B				
	C		B		2.36000	10	4
	C		B				
	C		B	D	2.34000	10	15
	C		B	D			
	C		B	D	2.33700	10	5
	C		B	D			
	C		B	D	2.33600	10	14
	C			D			
	C		E	D	2.24800	10	22
	C		E	D			
	C		E	D	2.24600	10	23
	C		E	D			
	C	F	E	D	2.23600	10	11
	C	F	E	D			
G	C	F	E	D	2.21000	10	18
G	C	F	E	D			
G	C	F	E	D	2.16900	10	16
G	C	F	E	D			

Means with the same letter are not significantly different.							
Tukey Grouping					Mean	N	run
G	C	F	E	D	2.15700	10	10
G	C	F	E	D			
G	C	F	E	D	2.13700	10	19
G		F	E	D			
G		F	E	D	2.11000	10	17
G		F	E				
G		F	E		2.09200	10	13
G		F	E				
G	H	F	E		2.06400	10	12
G	H	F	E				
G	H	F	E	I	2.05600	10	8
G	H	F	E	I			
G	H	F	E	I	2.04400	10	6
G	H	F	E	I			
G	H	F	E	I	2.03900	10	20
G	H	F	E	I			
G	H	F	E	I	2.02200	10	3
G	H	F		I			
G	H	F		I	2.00100	10	21
G	H			I			
G	H			I	1.99600	10	24
	H			I			
	H			I	1.83600	10	2
				I			
				I	1.82700	10	1