INDUSTRIAL BY-PRODUCT CHARACTERIZATION FOR PHOSPHORUS REMOVAL IN ENVIRONMENTAL CONTAMINANT FILTERS

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IN ENVIRONMENTAL CONTAMINANT FILTERS

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CHAPTER I

INTRODUCTION

The United States Environmental Protection Agency (USEPA) reports that 40,235 water systems (waters on the 303(d) list) are impaired in this country. Nutrients are the cause for 7,003 of the impairments with phosphorus (P) being the sole contributor to 2,161 impaired water systems (USEPA, 2011). Phosphorus is often limited in aquatic systems and when extra P enters the system in runoff waters it stimulates algal growth and following their death and decomposition oxygen levels drop which can degrade the overall quality of that system. Best management practices (BMPs) have been used to reduce particulate P losses from the soil by controlling runoff and erosion. However these practices do little to reduce dissolved P levels. Dissolved P is immediately available to aquatic organisms, thus it is important to control this form of P to help prevent impairment of water systems. One solution is the application of industrial by-products to manures or directly to the soil which demonstrated the ability to reduce the solubility of P (Dao et al., 2001; Gallimore et al., 1999; Watts and Torbert, 2009). However this reduction in solubility is only temporary and over time P can be released back into solution. A proposed solution to this problem is incorporating the by-products into P removal structures that are built to treat high P runoff waters that pass through

them. Yet, research is limited for P removal structures and how to properly construct them.

Focusing on the characterization of industrial by-products through this paper will provide information regarding the reaction mechanism that is responsible for P sorption and the safety of the material to the environment. The sorption maximum for a material can be estimated by conducting a P sorption isotherm; however this may not be the appropriate method to use as materials will be subjected to flowing waters. A more reliable method may be to conduct a flow-through experiment to determine the P sorption kinetics of a material which better represents the conditions seen in a P removal structure. The development of a model for individual by-products would be useful in the construction and prediction of structure performance. The goal of a P removal structure is to remove the material once it is saturated; therefore the model should be able to predict the longevity of a material under particular P load and flow conditions. Proper removal and replacement of materials based on these models will provide the most economical use of the structures and materials.

Use of P removal structures to reduce dissolved P losses in runoff has great potential to be an effective alternative BMP. Information gathered and discussed below is important to properly design and incorporate these structures into the landscape while remaining economical.

Literature Review

Phosphorus movement and effects on the environment

Movement of phosphorus (P) from the terrestrial system into aquatic systems has been identified as a key cause for the degradation of water quality. Phosphorus in water can come from several different sources. Rainfall causes the "washout" of atmospheric particulate materials and depending on the quantity and composition of the particulates, can supply P to surface water bodies. Overland runoff is a major source of P and is dependent upon the amount of P in the soil, topography, vegetative cover, quantity and duration of runoff, and land use. Waste waters are another major contributor and include both industrial and municipal sources (Keup, 1968). The source of P can be divided into two categories, point and nonpoint. Point source is P pollution that can be easily traced back to its origin at a single point while nonpoint cannot be traced to a single source. A major nonpoint source of pollution in water is surface and subsurface runoff P from agricultural land.

Two forms of P that enter water are dissolved and particulate. The two can be separated by filtering runoff water through 0.45-µm pore diameter membrane filters (Sharpley et al., 1994). In conventionally tilled systems the largest portion of P (75-95%) transported in surface runoff is particulate P which includes P that is sorbed onto organic matter and soil minerals. Dissolved P is immediately available for algal growth and is mostly in the orthophosphate form. Sharply et al. (1992) found that of the total P transported in runoff, 14-88% was bioavailable. For dissolved P to be transported it must first be desorbed or dissolved from soil, crop residue, or surface applied fertilizers or

manures. Interaction with rainfall and runoff allows for these processes to occur. The magnitude of the rainfall and management factors both determine the amount of runoff and erosion that will take place.

Particulate P concentrations in runoff increase as erosion is increased. Clays and colloidal organic matter will preferentially erode due to their smaller size (Sharpley et al., 1994). With no obstructions the eroded material will make its way to surface water bodies. In less disturbed water bodies P is found in low concentrations and is usually the most limiting nutrient for biological productivity. When a flux of P enters the system it leads to the enrichment of the water body which is a contributing factor to eutrophication (Sharpley et al., 1994). The excess P stimulates algal and rooted aquatic plant growth and upon their death and decomposition causes a depletion in the dissolved oxygen in the water (Boesch et al., 2001). As a result, the water becomes impaired and thus has serious ecological and economical impacts for that region.

The U.S. Environmental Protection Agency (USEPA) found that of the impaired water bodies assessed in this country, 16% of rivers, 19% of lakes, and 14% of estuaries are impaired due to nutrients (USEPA, 2009). The Chesapeake Bay is one of the most studied and largest estuaries in the United States. Its watershed is 167,000 km^2 in size and encompasses over six states and the District of Columbia. Supporting more than 15 million people, the Bay is very important economically and socially for the region (Boesch et al., 2001). Problems arise when the Bay experiences decreased dissolved oxygen concentrations during the months of May to September when the water becomes stratified in early spring (Officer et al., 1984). In 1985 it was realized that the 338 million pounds of nitrogen (N) and 27.1 million pounds of P that flowed into the Bay

annually needed to be reduced in order to combat the problem, so nutrient reduction practices were initiated (Commonwealth of Virginia, 2005). The reduction practices continue today with proposed reductions in N from 277 million pounds to no more than 175, and P from 19.4 million pounds to 12.8 (Commonwealth of Virginia, 2005). With these reductions the Bay should return to a quality that was seen in the 1950's (Commonwealth of Virginia, 2005). Much attention has also been drawn to the upper Midwest agricultural watersheds that deposit large amounts of nutrients into the Mississippi River and thus Gulf of Mexico. Tile drainage is important to farming operations in the Midwest and approximately 20 million hectares of cropland have artificial drainage that releases into the Mississippi River Basin (Royer et al. 2006). Tile drainage allows for the direct transport of nutrients to surface waters. For this reason, tile drainage along with overland flow contributes the most to dissolved reactive phosphorus export.

Overland flow is the main source of particulate P loss from the landscape. The majority of particulate P loss in agricultural systems occurs when there are extreme discharge events. The increased water flow from these events detaches P from the soil surface. Once P is in solution the increased discharge does not give the P enough time to react with the benthic sediments and thus is transported further downstream. In one study, over 80% of P exported was from extreme discharges (Royer et al. 2006).

Phosphorus and agricultural Production

Phosphorus is often the most limiting nutrient for development and growth of plants. Phosphorus availability limits crop yields on 30-40% of the world's arable land

(Vance et al., 2003). Therefore, P nutrition is vital for agricultural producers everywhere. Concentrations in plants usually range between .05 to .5% of dry weight. Early and accelerated growth is achieved when an adequate amount of P is available to the plant. Numerous processes rely on P, including energy generation, photosynthesis, glycolysis, respiration, redox reactions, and nitrogen fixation. Plants take up P in the orthophosphate forms of $H_2PO_4^-$ and HPO_4^{2-} which are found in very low concentrations in the soil. All P must be in solution before it can be taken up by the plant. With a majority of soil P being non available, plants will adjust the rhizosphere in order to alter the availability of P. Plants will release phosphatases, organic acids, and chelating agents from their roots in order to make soil phosphate more soluble and available for plant uptake (Raghothama, 1999; Vance et al., 2003). Plants can also increase root growth and root hair development in order to reach more P (Raghothama, 1999). Diffusion rather than mass flow is the dominant way inorganic P is supplied to the plant roots. Diffusion predominates due to the strong reaction of P to soil components. To enhance soil P availability and increase crop yields application of P-containing fertilizers is often recommended (Vance et al., 2003).

Soil Phosphorus

Phosphorus is a critical nutrient that contributes to the growth of all organisms. The mobility and availability of P is low compared to other key nutrients (Hinsinger, 2001). Phosphorus can be found in many different forms and exists in three major pools in the soil: solution P, active P and fixed P. Solution P makes up a very small portion of total P and is most often found in the orthophosphate form (PO_4^{3-}). Solution P is important in the fact that it is the only pool that has quantifiable mobility and plants

directly take up. Active P is in solid form but can be easily released into soil solution when the concentration of phosphates decreases due to plant uptake. Inorganic and easily mineralized organic P can be found in this pool which constitutes the major source of P for crops due to the small percentage of solution P. Phosphorus in the fixed P pool can remain fixed and thus unavailable for years. Insoluble inorganic P and mineralization resistant organic compounds make up this pool which does little for the fertility of the soil (Busman et al., 2008). Natural sources of P are derived from the weathering of different minerals such as apatite (calcium phosphate mineral) (Bandel et al. 1994).

Soil pH is an important factor in regard to the availability of P. Calcium is the main cation that will react with P in alkaline soils. Dibasic calcium phosphate dihydrate, octocalcium phosphate, and hydroxyapatite are the major compounds formed when pH is greater than 7. These compounds are highly stable and insoluble in high pH environments. As the soil becomes more acidic, the compounds will become unstable and soluble. In acid soils phosphate will react with Al and Fe and become unavailable for plant uptake. Amorphous Al and Fe phosphates will be the first products formed and later will slowly transform into compounds that resemble crystalline variscite (Al phosphate) and strengite (Fe phosphate) (Busman et al., 2008). All of these compounds fix P due to their insolubility at low pH. As pH rises P is released as these compounds become unstable and soluble. Phosphorus will also absorb with Al and Fe minerals found in acid soils. These complexes are the result of surface reactions between phosphate ions and amorphous hydroxy polymer coatings on soil particles (Brady and Weil, 2007). As a general rule P availability is highest within the pH range of 6 and 7

due to the higher solubility of iron, aluminum and calcium phosphates in mineral soils (Busman et al., 2008).

Application of phosphorus to agricultural land and high P soils

Organic and inorganic fertilizers are applied to crops when natural sources of P are not sufficient to achieve maximum yield. Manures such as poultry litter, swine effluent, dairy and beef manure are the main type of organic fertilizers applied. Biosolids is also an organic source of fertilizer. Soluble phosphate, organic phosphate, and inorganic phosphate compounds found in manures are relatively available. Inorganic P fertilizers can come in granulated, blended, or liquid forms. The three main types of inorganic P used are triple superphosphate, monoammonium phosphate (MAP), and diammonium phosphate (DAP) (Beegle, 2010). These materials come from the mining of phosphate rock apatite (insoluble) that is then treated to thermal or acidulation processes to make it 100% soluble and available for plant uptake (Bowman 2002). When a fertilizer comes into contact with soil, water will start to dissolve the particle. In solution the phosphate can move short distances away from the solid fertilizer granule. To increase movement into the soil, irrigation water or applications around rainfall events can be applied. However as the phosphate moves away from the fertilizer particle it will react by adsorbing to soil minerals or combining with elements like calcium, magnesium, iron, aluminum to form solids (Busman et al., 2008). Soil minerals that have a larger anion exchange capacity will be able to sorb more phosphate ions due to the attraction of the negatively charged phosphate to the positively charged mineral. Thus, the order of phosphate fixing minerals in order of increasing extent and degree of fixation is: 2:1 clays << 1:1 clays < carbonate crystals < crystalline Al, Fe, Mn oxides < amorphous Al, Fe,

Mn oxides, allophane. The amorphous materials are the best due to their high number of variable charged sites which allows for optimum ligand exchange. Clay and organic matter content in soils impact phosphate fixation. Soils with high clay content will fix more P due to the reasons explained above. Organic matter has minimal ability to fix P and can actually reduce P fixation if added to soils. Humic materials found in organic matter will adhere to sorptive sites in the soil and mask phosphate ions from the surface. Organic compounds can also react with Al and Fe to form chelates which renders the metals unavailable to phosphate ions. Soil pH also controls the amount of phosphate fixation that will occur. At low pHs Fe and Al precipitate with phosphate while Ca precipitates at high pHs. Fixation is minimal between soil pH of 6 and 7 because Fe, Al, and Ca phosphates are soluble in this range (Brady and Weil, 2007). Due to the high reactability of phosphate ions with the soil, an estimated one-third of phosphorus applied per year as fertilizer is available to the plant that growing season (Bandel et al. 1994).

Increases in phosphorus concentrations in the soil can come from long term applications of manures as an N source for plants. Most producers will apply manure based off the crops nitrogen requirement. This practice leads to the over application of P and potential P "loading" of the soil. For example, applying poultry broiler litter (manure and bedding) to bermudagrass. The typical grade of poultry broiler litter is 3-3-2 (N-P_2O_5-K_2O) and the average forage N-P_2O_5-K_2O uptake of bermudagrass (yield = 5 tons/A) is 250-64-216 lbs/A (Mitchell and Tu, 2006; Zhang et al., 2007). Based off these numbers and applying to meet N needs you would apply three times the amount of P needed resulting in an increase in soil P which can cause a corresponding increase in solution P. Increased solution P can result in the loss of phosphate in runoff or leaching

through the soil profile and transport to nearby surface water bodies (Busman et al., 2008). Agricultural producers see no harm to crops with the excess P but future concerns come from the fact that rock phosphate reserves may be depleted in less than 100 years (Vance et al., 2003).

Best management practices (BMPs) for reducing P losses

Best management practices are accepted agricultural practices that protect or improve water quality and are at least as profitable as systems already in place (Feather and Amacher, 1994). A producer can incorporate BMPs in either source or transport management. Source management BMPs minimize P applications to soils that are already above levels for optimal crop growth. Management of rate, method, and timing of P applications can greatly reduce losses from the soil. Higher rates of fertilizer or manure will lead to increased runoff as the concentration of P in that system will be higher (Sharpley et al., 2001). Livestock producers can reduce P intake to their animals in order to decrease P levels in the manure. This helps reduce P loading of soils around livestock production facilities where the manure is normally transported no more than 10 miles (Sharpley et al., 2001). Composting of manure will reduce the volume and allow for further transport of the material. Another benefit of composting is that physical and chemical properties are more uniform in the manure so it becomes easier to spread.

Transport management involves controlling the movement of P from soils to sensitive areas like fresh water bodies. Examples include conservation tillage, crop residue management, buffer strips, terracing, cover crops, and contour tillage. These methods help reduce the impact of rainfall on the soil surface and slow the velocity of

running water over the surface of the land to encourage infiltration. While they are efficient at removing sediment bound P from runoff, dissolved P is minimally impacted by these practices (Sharpley et al., 2001). For example, no-till systems are effective at reducing sediment loss and therefore reducing total P losses (Bundy et al., 2001), but may increase dissolved P losses due to the accumulation of P at the soil surface. Plowing occasionally will help incorporate that surface P further into the profile and reduce dissolved P losses (Sharpley and Withers, 1994). Total P in runoff can be reduced by as much as 90% when buffer strips are used (Hansen et al., 2002). However, weeds and pests have been shown to be a problem when buffer strips were used. During larger storm events the effectiveness of buffer strips is reduced due to the inability of the grass to withstand the larger quantity of water (Dorioz et al., 2006). Intense storms account for the majority of annual P losses, so farmers should time applications outside of those periods to reduce runoff. BMPs are effective at reducing particulate P losses from the landscape, but don't fully solve the problem. Sharpley et al. (2009) described BMPs as "band-aids" to reducing the environmental effects of land management.

Industrial by-products as alternative BMP

Phosphorus sorbing materials (PSMs) along with by-product materials that have the ability to sorb P have been applied to soils to reduce P losses (Leader et al., 2008). Direct application of the materials to the terrestrial surface is done to tie up dissolved P onto reactive elements found on the PSMs. The reactive elements found on these products are usually aluminum (Al), iron (Fe), calcium (Ca), and/or magnesium (Mg). The elements precipitate and/or adsorb to soluble P to remove it from solution. Many of these products are also applied directly to buffer strips where it reacts and reduces soluble

P. Several of these have been studied for their ability to sorb P and include water treatment residuals (Penn and Bryant, 2006; Gallimore et al., 1999; Wagner et al., 2008), fly-ash (Penn and Bryant, 2006; Pathan et al., 2003), gypsum (Penn and Bryant, 2006; Watts and Torbert, 2009; Brauer et al., 2005), acid mine drainage residuals (Han et al., 2005), aluminum sulfate (alum) (Malecki-Brown et al., 2009; Moore et al., 1998), bauxite residues (Udeigwe et al., 2009), and electric arc furnace steel slag (Drizo et al., 2006, 2008). Research has shown that all of these products can be effective at removing P from solution. For example, Drizo et al. (2006) found that electric arc furnace steel slag was nearly 100% efficient in removing P from effluent (20 and 400 mg P/L) over a time span of 180 days. There was an accumulation of 2.2 mg P/g of slag that most likely occurred through the processes of precipitation as hydroxyapatite and adsorption onto metal hydroxides. Another study by Drizo et al. (2008) found that applying a resting period to slag before it reaches its P saturation point increases the P retention capacity by as much as 49.5%. This would allow for greater P reduction efficiency from diffuse sources. Gypsum has been shown to be very effective at removing soluble P when applied to grass buffer strips. Watts and Torbert (2009) showed that after poultry litter applications, gypsum is very useful in buffer strips in initial runoff events but not in ones thereafter. The effectiveness of the gypsum was not dependent on the quantity of material so lower application rates would allow for the greatest benefit. Fly ash applied to sandy soils altered texture, increased water holding capacity, and provided P and nutrient aid retention by increasing the cation exchange capacity (CEC) (Pathan et al., 2003). Water treatment residuals (WTRs) that were applied to a pasture reduced dissolved P from 15.0 mg L^{-1} to 8.60 mg L^{-1} when broadcasted and 8.12 mg L^{-1} when in a buffer strip (Gallimore

et al., 1999). However, another study with WTRs showed no benefit with application due to the insufficient contact time (~30s) with the material and runoff water (Wagner et al., 2008). A column study that applied alum at a rate of 0.81 g Al m^{-2} d^{-1} resulted in significant reductions in all measured water column nutrients except ammonium, which stayed the same, and particulate P, which increased (Malecki-Brown et al., 2009). When applied directly to manure alum reduced concentrations of arsenic (As), copper (Cu), iron (Fe), and zinc (Zn), but increased calcium (Ca) and magnesium (Mg) concentrations (Moore et al., 1998). Han et al. (2005) precipitated Fe hydroxide from acid mine drainage residuals onto the surface of juniper fiber and found that the phosphorus removal efficiency was about 41 percent at 59 mg/L of influent P concentration. With applications of 40 ton ha^{-1} on manure impacted soils, bauxite residues were shown to reduce up to 95% of water-extractable P, 98% of Cu, and 90% of Zn (Udeigwe et al., 2009). As stated above, these materials all show great potential at removing soluble P. The future need is now finding ways to implement these products to high risk P areas at economically viable costs to the producer. Another major focus needs to be placed on P removal from the system. All of the research above is centered on applying the PSMs directly to the soil or manures. The materials sorb the soil or manure P but remain in the system where after time it can become soluble again. Finding a way to implement these materials so they can be removed from the watershed once saturated would go a long way towards protecting water bodies.

P removal structures

Phosphorus removal structures are designed to allow water to enter and pass through a PSM. There are various designs for P removal structures, but all are based off

the simple concept of an inflow of high P waters into a container filled with a PSM allowing for optimum reaction time. Following the reaction with the material, the filtered water will exit the structure and resume its normal flow throughout the watershed. These structures should be placed in key locations, such as drainage ditches, where P runoff has a direct path to nutrient sensitive waterways. Drainage ditches are commonplace in many agricultural systems throughout this country. These ditches that are used to take away surface runoff or connected to subsurface drainage can act as channels for the transport of P from agricultural lands to downstream water bodies (Nguyen and Sukias, 2002). Once saturated with P, the ditch sediments can become a source of P to receiving waters. A high P status ditch will require proper management to reduce losses from the system. Incorporation of a P removal structure within the drainage ditch allows for the filtering of runoff water and protection of downstream water bodies. Research has been conducted using various different industrial by-products as PSMs in drainage structures. McDowell et al. (2008) installed slag into tile drains receiving effluent and found that dissolved reactive P concentrations were significantly reduced (0.086 mg P L^{-1} vs. .531 mg P L^{-1}). They recommended slag to be backfilled into tile drains to help reduce P loss. In another experiment, Penn et al. (2007) used acid mine drainage residuals in a P removal structure during a 24-hour runoff event and were able to sequester 99% (0.54 kg) of dissolved P that flowed through the structure. Along with P the material removed 63% of As, 99% of Cu, and 94% of Zn. One limitation to their system was that during an extreme storm event the structure was only able to treat 9% of the flow. The major benefit for such structures is that once P saturated, the material can be removed from the watershed.

Information needed for P removal structures

Selection of PSMs must take into account different key factors that include cost, availability, potential contaminants, P sorption characteristics and physical properties. Cost and availability is an important factor in determining the feasibility of each material. Some products such as waste gypsum are inexpensive and often locally available (Penn et al., 2007). Potential for environmental contamination via discharge from industrial by-products must be determined in advance to ensure no detrimental effects on the environment. Potential problems can include altering of pH, discharge of soluble salts, and heavy metal additions to the environment. When determining the P sorption mechanism it is important to take into account not only the total amount of reactive elements but also the chemical forms present to better predict P reactivity (Dayton and Basta, 2005). Knowledge of system pH is of great importance as it is the master variable that determines if P sorption/precipitation can occur and will differ depending on reactive elements present. Generally, Mg and Ca are most effective at a pHs above 7.5, and Al and Fe at a pH below 7.5 (Lindsay, 1979; Rhoton and Bingham, 2005).

Assessment of P sorption kinetics is needed to determine which materials work better under short or long contact times. Structures that sorb P via chemisorption/ligand exchange will work under short contact times due to the fast reaction time. A structure that sorbs via precipitation will be less effective in a low retention time system due to the slower reaction time. Knowledge of the life expectancy of the material is important for making decisions on when to remove it from the structure. Uniformity and hydraulic conductivity are important physical properties to consider when selecting the appropriate material. Addressing these factors is vital for the design and implementation of P removal structures.

Objectives

The objective of this study is to conduct laboratory experiments to characterize various PSMs in order to evaluate and determine the materials best suited for use in P removal structures. This includes the ability of the material to remove nutrients including kinetics of reactions, potential for causing contamination, cost effectiveness, and end use.

The specific objectives of this study are:

1) Determine physical and more importantly chemical properties of PSMs using various laboratory techniques.

2) Determine kinetics of P removal: effect of concentration and retention time on P removal.

3) Create an empirical model for predicting the P removal capacity of PSMs that will be used in landscape drainage structures.

Methodology

Objective 1: Characterization of PSMs

- P sorption isotherms
- Water extraction
- Total digestion
- Exchangeable aluminum
- Toxicity characteristic leaching procedure (TCLP)
- X-ray diffraction
- pH buffer capacity
- Total nitrogen and total carbon (TN/TC)
- Ammonium oxalate extraction
- pH and electrical conductivity (EC)

Extracted solutions will be submitted to Soil, Water and Forage Analytical Laboratory (SWFAL) at Oklahoma State University for analysis of the following elements phosphorus (P), sodium (Na), magnesium (Mg), potassium (K), calcium (Ca), chromium (Cr), manganese (Mn), iron (Fe), nickel (Ni), copper (Cu), zinc (Zn), cadmium (Cd), arsenic (As), and aluminum (Al).

Objective 2: P sorption kinetics

A flow-through set-up (Figs. 1-3) will be assembled to test the PSMs abilities to sorb P at different concentrations and flow rates. Flow rate will be varied to achieve different "retention times", and expressed as a unit time. A total of 5 retention times will be tested: 0.5, 3, 6, 8, and 10 minutes and will be controlled by a single channel pump. Different inflow concentrations of P will be used in this experiment. Phosphorus sorbing materials will have a "relative saturation", based on the inflow P concentration and the equilibrium P concentration of the PSM. Therefore, the maximum amount of P that PSMs will remove is equal to the sorbed P at the particular equilibrium concentration. Concentrations of 0.5, 1, 5, 10, and 15 mg P L^{-1} will be used. The solutions will also contain Na, K, Ca, Mg, and Sulfur (S), in order to simulate typical ditch water runoff. A constant head will be provided to the flow-through column via use of a Mariotte bottle. Flow-throughs will be conducted on 15 different PSM's with a total of 5 grams of material (PSM + sand) in the column. The benefit of this experiment over the traditional batch system is that it will allow for the evaluation of kinetics as limited by increasing P sorption and contact time. Samples collected will be measured for pH, EC, and inorganic P using the Murphy-Riley method (Murphy and Riley, 1962).

Objective 3: Empirical model

A design curve (Figs. 4 and 5) needs to be developed in order to predict the effectiveness of a P removal structure and also aid in the development of one. Using the information gained from the characterization and flow-through experiments a multi linear regression (MLR) equation will be developed to predict parameters of the design curve. This model will allow for the prediction of how much P will be removed by a particular PSM from a P removing structure and thus when the material needs to be removed from the system. Each curve will be unique for a certain inflow of P concentration, retention time, and material. Predicting the slope and intercept of the curve will allow for the recreation of a design curve for a particular material- P concentration- retention time combination.

Materials

- Fly ash is a fine silt-size particle material that contains many unburnt residuals. It is generated from coal-fired power plants and the reactive elements present are Ca, Fe, and Al. Three fly ash materials will be examined in this experiment.

- Gypsum ($CaSO_4$) is a very soluble agricultural amendment and has Ca as a reactive element. Two will be tested, one being produced through the process of flue gas desulfurization in power plants and the other coming from the US gypsum company.

- Slag is a by-product of smelting ore and comes in various sizes and compositions. It can have Fe, Al, and Ca as reactive elements. Three slags of different sizes will be tested.

- Acid mine drainage residuals (AMDRs) come from treating acid mine drainage. Depending on the original source the reactive element could be Fe, Al, or Ca. Four AMDRs from different locations will be included.

- Water treatment residuals (WTRs) are the settling products from the treatment of drinking water. Reactive elements include Al, Fe, or Ca. Four WTRs from three different locations will be examined.

- Foundry sand of three different methods will be used and have Al, Fe, and Ca as reactive elements.

- Bauxite mining waste (Al, Fe, Ca), La Ash, Green sand, Excel minerals (Ca), Haydite, Ultra-Phos, Leonardite, and paper mill pulp (Ca) are other by-products that will be examined in this experiment.

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Fig. 1.1: Single channel pump and collection of sample.

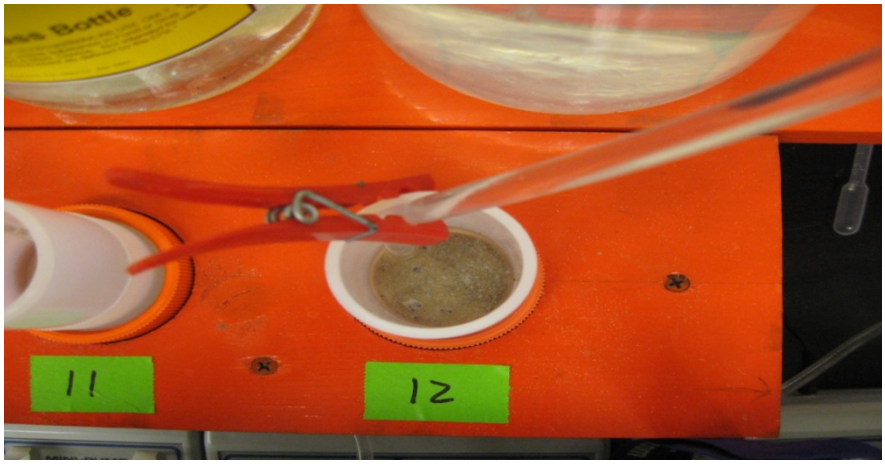

Fig. 1.2: Material in flow-through column and constant head being applied.

Fig. 1.3: Complete flow-through set-up with Mariotte bottle, flow-through column, and single channel pump.

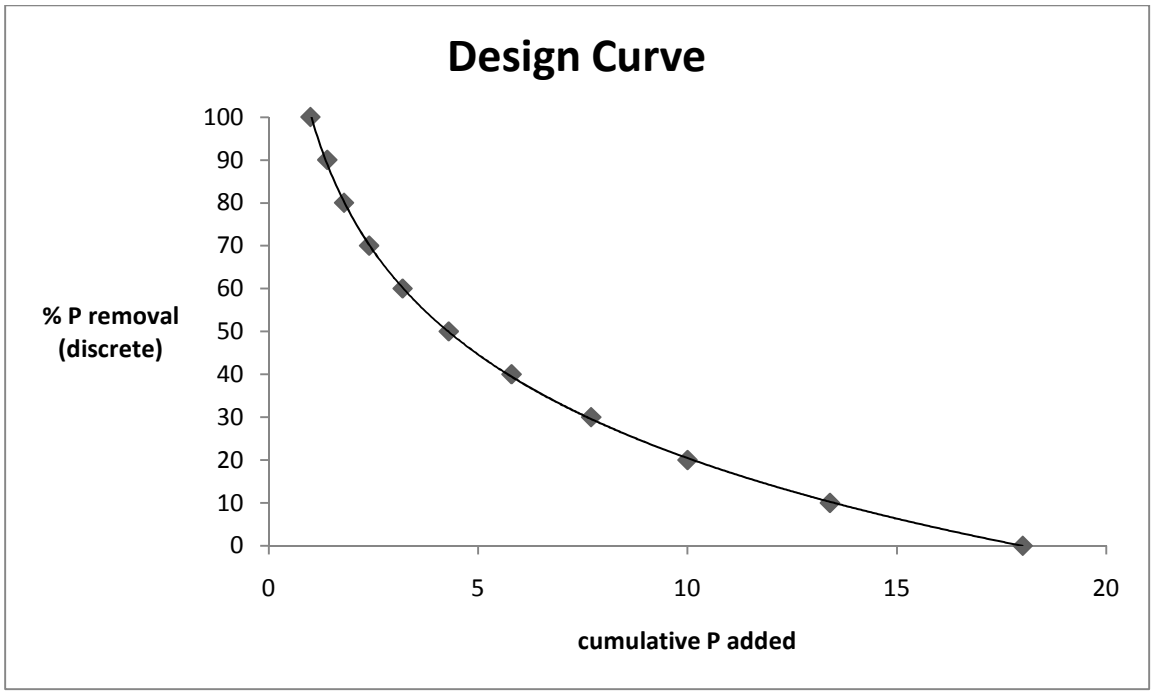

Fig. 1.4: Design curve that shows for a given amount of cumulative P added, one could predict how well the filter is working and also integrate for overall % removal.

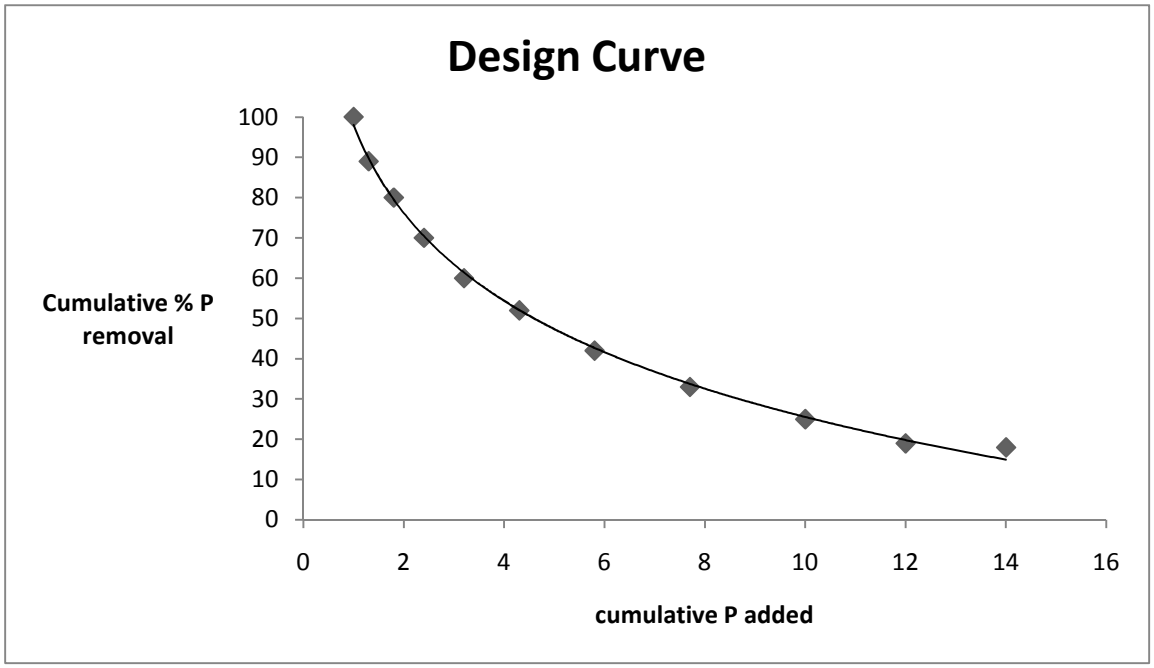

Fig. 1.5: Overall % removal for a material and is determined from Fig. 1.4.

CHAPTER II

INDUSTRIAL BY-PRODUCT CHARACTERIZATION AND PHOSPHORUS REMOVAL

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ABSTRACT

A multitude of industrial by-products have been shown to sorb large amounts of dissolved phosphorus (P) from runoff waters making them suitable P sorption materials (PSMs). The objectives of this study were to characterize various industrial by-products for chemical properties to determine which materials would work best as PSMs, conduct a flow-through experiment to determine P sorption capabilities of by-products and compare results to batch isotherm results, and determine the safety of these materials with regards to the environment. Utilizing chemical characterization data, materials with elevated levels of total calcium (Ca), iron (Fe), aluminum (Al), oxalate extractable Al, Fe, and water soluble (WS) Ca were determined to have the greatest potential to be effective PSMs. An Al/Fe material requires a lower pH (< 8) while a Ca material works better when pH is above 8. A Ca material was also determined to be more effective if it could buffer the pH above 6.5 (high buffer index). Extracted solutions used to determine whether a material would release trace metals contained concentrations lower than

the limits set by the EPA for almost all materials. In comparison to the flow-throughs, isotherms did a poor job of predicting the amount of P the materials could sorb when at equilibrium with a P solution. The isotherms under predicted P sorption for Ca materials and over predicted for Al/Fe materials. Amount of P added to reach equilibrium was also under predicted by isotherms for most materials when compared to the flow-through data. For almost all materials, sorption maximum (Smax) for isotherms was approximately double the flow-through values. Flow-throughs were determined to be a more suitable predictor of a materials ability to sorb dissolved P in runoff waters.

INTRODUCTION

Fluxes of phosphorus (P) to sensitive water bodies are a cause of eutrophication (Correll, 1998). Phosphorus will be transported to and deposited in water as either particulate or dissolved P with the latter being 100% biologically available to aquatic organisms (Sonzogni et al., 1982). Best management practices (BMPs) are used to reduce P losses from the landscape. While BMPs are effective at reducing particulate P losses by controlling erosion they do little to reduce dissolved P losses (Sharpley et al., 2001).

An alternative BMP is using industrial by-products as P sorption materials (PSMs) to sorb with P and reduce solubility (Leader et al., 2008). By-products such as electric arc furnace steel slag, fly-ash, drinking water treatment residuals, and acid mine drainage residuals contain reactive elements such Ca, Al, and Fe which allow them to precipitate and/or adsorb P. Past research has shown that, when applied directly to soils or manures, PSMs significantly reduced dissolved P concentrations (Gallimore et al., 1999; Moore et al., 1998). Although the form of P has changed from soluble to insoluble, the P remains in the system and has potential to be released at a later time (Penn et al., 2006). Therefore, the method of applying these materials directly to soils or manures does not necessarily solve the problem of removing P from the watershed.

Incorporating PSMs into P removal structures is a way to sorb and remove P from the system when the materials are replaced following P saturation. A P removal structure is constructed to allow high P water to flow in, move through a PSM and exit the

structure as treated water. Penn et al. (2007) installed a P removal structure in a drainage ditch on the eastern shore of Maryland and used an acid mine drainage residual as the PSM. In a 24 hour runoff event they were able to remove 99% (.54 kg) of dissolved P that flowed through the structure. However due to the low hydraulic conductivity of the material they were only able to treat 9% of the flow during large runoff events. In another study by Penn et al. (2011) they constructed a P removal structure on a golf course that was located in a residential area. This structure removed 25.2% (25.9 mg P kg^{-1}) of the dissolved P that passed through it. They also found that P transported in irrigation waters was more efficiently removed compared to rainfall events (62 vs 21% P removal). They concluded that runoff from irrigation events had lower P loads and flow rates (higher RT) which resulted in the higher efficiency.

With a large number of by-products being available for use in these structures, it is important to evaluate their effectiveness. Traditional batch isotherm experiments have been conducted on many PSMs to provide an estimate of sorption capacity. However, Penn and McGrath (2011) found that this approach poorly predicts the capabilities of these materials in a P removal structure. A more viable method is a flow-through approach that takes into account the constant replenishment of a low P solution while reaction products are simultaneously being removed. Flow-through experiments also allow for a retention time to be manipulated to best simulate conditions in a structure. Information regarding the chemical composition of PSMs is also important to better understand the reactive elements present and safety of these materials.

The objectives of this study were to (i) characterize various industrial by-products to determine which materials would be best suited for use in a P removal structure; (ii)

conduct a flow-through experiment to determine P sorption capabilities of by-products and compare results to batch isotherm results; and (iii) determine the safety of these materials with regards to the environment.

MATERIALS AND METHODS

Material characterization

A total of four acid mine drainage residuals (AMDRs) collected from Pennsylvania were characterized. AMDR1 and AMDR3 were formed by natural processes when acid mine drainage water rose to the surface and the iron became oxidized and precipitated. AMDR2 and AMDR4 came from engineered facilities where they used calcium carbonate to remove acidity and precipitate Fe from acid mine drainage water.

Coal fired power plants utilize a fluidized bed combustion process that results in a by-product called fly-ash. Fly-ash1, Fly-ash2, and Fly-ash3 were collected from power plants located in Muskogee, Oklahoma, Red Rock, Oklahoma, and Anadarko, Oklahoma, respectively. Coal fired power plant also use lime or calcium oxide to "scrub" sulfur in the flue gas. The resulting material is a relatively pure gypsum ($CaSO_4$) called flue gas desulfurization gypsum (FGD). The FGD gypsum1 was obtained from Baltimore, Maryland and FGD gypsum2 from a plant in Pennsylvania.

Electric arc furnace (EAF) steel slag is a by-product from the steel production industry. Slag fines and Slag3 were collected from a steel production facility located in Ft. Smith, Arkansas (Tube City, IMS). Slag fines were also sieved to <5mm in size.

Slag1, Slag2, and Slag4 were obtained from facilities located in Pittsburgh, Pennsylvania and Wilmington, Delaware.

Drinking water treatment residuals (WTRs) from three different treatment facilities were collected. Ca-WTR1 and Ca-WTR2 were collected from the Stillwater treatment facility in Stillwater, Oklahoma where calcium hydroxide was used as a flocculating agent. Aluminum sulfate was the flocculating agent at the AB-Jewell and Mohawk facilities located in Tulsa, Oklahoma where Al-WTR1 and Al-WTR2 were produced.

Foundry sands are produced by the metal casting industry and used to make casting molds. Foundry Sand1 and Foundry Sand3 were obtained from AccuCast located in Tulsa, Oklahoma, while Foundry Sand2 was collected from Metal Dynamics Corporation also in Tulsa, Oklahoma. A Green Sand, also used in metal casting, was provided by AccuCast.

A soil amendment that provides silica to growing plants called Excell Minerals was characterized. Paper mill pulp was collected from Georgia Pacific located in Muskogee, Oklahoma. Leonardite is an oxidation product of lignite and was collected from Texas. A porous synthetic rock called Haydite was tested. Ultra-Phos is a product manufactured to retain large amounts of phosphorus and was collected from Florida. Red mud is a bauxite processing waste that was collected from Virotech International. A calcined limestone product called LA Ash was obtained from LA Ash, Inc.

Analyses were run in duplicate on air-dried samples sieved to 5 mm. A 1:5 solid to deionized (DI) water ratio was used to measure the materials pH and electrical

conductivity (EC) (same solution) by separate meters. Materials were extracted with DI water in a 1:10 solid:solution ratio for 1 hour. Samples were filtered using a 0.45 μm filter and analyzed for Ca, Mg, Al, Fe, Ni, Zn, As, Cr, and Cd by inductively coupled plasma atomic emission spectroscopy (ICP-AES). An EPA 3051 digestion method (U.S. Environmental Protection Agency, 1997) was performed to determine total elements. Solutions were analyzed for Ca, Mg, Al, and Fe by ICP-AES. Toxicity characteristic leaching procedure was conducted using a 0.129M sodium hydroxide and 0.0174M glacial acetic acid solution in a 1:20 material:extractant ratio. Samples were shaken for 17.5 hours and analyzed for As, Cr, and Cd by ICP-AES. Materials were extracted for amorphous Al and Fe (Oxalate Al and Fe) using 0.2M acid ammonium oxalate (pH 3) in a 1:40 solid:solution ratio. Solutions were analyzed for Al and Fe by ICP-AES following a 2 hour reaction time in the dark (McKeague and Day, 1966). An automatic titrator (TitriLab 865; Radiometer Analytical, Villeurbanne Cedex, France) was used to determine the ability of the materials to maintain a pH above 6.0. Two grams of material were suspended in 10 mL of DI water and titrated to a pH of 6.0. This method will be referred to as buffer index (BI)(IUPAC, 1977).

Standard batch isotherms were conducted on the materials using 2 grams of sample per 30 ml of solution and a 16 hour equilibration (shaking) time. Solutions of 0, 1, 5, 10, 25, 50, 100, 200, 400, 800, 1600, 3200, and 4000 mg P L^{-1} were made using KH_2PO_4. Following equilibration, samples were centrifuged and filtered using 0.45 μm filter paper and analyzed for P using ICP-AES. Sorption maximum (Smax) and K (binding coefficient) were determined using a transformed Langmuir equation where equilibrium concentration divided by amount of P sorbed at equilibrium was plotted

against the equilibrium concentration. This yielded a straight line with a slope of 1/Smax and a y-intercept of 1/Smax*K (Essington, 2004).

Flow-Through Experiments

Twelve materials were chosen for flow-through analysis. A flow-through set up allows for the evaluation of varying retention times (RT) and P concentrations on P sorption. Retention time is the amount of time the material is in contact with the solution and is calculated by pore volume (ml) / flow rate (ml min^{-1}). Pore volume was determined from the lab-grade sand (pure Si sand, 14808-60-7; Acros organics, Morris Plains, New Jersey) that was used to bring the total weight of phosphorus sorption material and sand up to 5 grams. The pore volume achieved from this mixture was 3.2 cm^3 (5g of sand; 40% porosity). Amount of sand used varied between materials due to different sorption capacities. A less sorptive material would require less sand to bring the mixture up to the desired weight. Mass of materials used varied between .001 g for highly sorptive materials and 2 g for less sorptive and was determined by trial and error. A suitable amount would allow for the development of a curve that showed the decreasing capacity of the material to sorb over time (≈ 100% sorption to ≈ 0%). A 0.45 μm filter was placed in the bottom of a flow through cell with the material being placed on top of it. Phosphorus solutions were supplied to the flow through cell at a constant rate using a Mariotte bottle. Five different P solutions were used; 0.5, 1, 5, 10, 15 mg L^{-1} to best represent typical runoff water concentrations. Along with P, the solutions also contained 5.6, 132, 110, 10, and 17 mg L^{-1} of Mg, Ca, S, Na, and K and adjusted to a pH of 7. This solution mixture was determined based off past research by Penn et al., 2007 who found it to best represent runoff water in drainage ditches of Eastern Maryland.

Solutions were pulled through the cell using plastic tubing connected to the bottom of the cell and a single channel peristaltic pump (VWR variable rate "low flow" and "ultra low flow", 61161-354 and 54856-070). Desired retention times were achieved by varying the pump speed at which it pulled the solution through. Flow rates used were 0.32, 0.4, 0.53, 1.1, and 6.4 ml min^{-1} which provided RT's of 10, 8, 6, 3, and 0.5 minutes, respectively. Materials were tested for 5 hours and samples were collected at 0, 30, 60, 90, 120, 150, 180, 210, 240, 270, and 300 minutes. Samples were analyzed for pH, EC, and inorganic P using the Murphy-Riley molybdate blue method (Murphy and Riley, 1962). All RT and P concentration combinations were duplicated for every material.

A design curve was created by plotting P added (mg kg^{-1}) on the x-axis and discrete P removed (%) on the y-axis, which can be used to predict longevity and amount of P removed at saturation for each material. Results from the flow-through experiments were used to create a model that would predict the "design curve" for each of the 12 materials. Two multiple linear regression (MLR) models were produced to predict the slope and y intercept of the design curve. Development of the model is discussed in detail in chapter 3 of this paper.

RESULTS AND DISCUSSION

Materials Characterization

Inorganic materials will dominantly sorb P by either Ca precipitation reactions and/or Al/Fe ligand exchange or precipitation reactions. With this being said the materials were divided into three different categories, Al/Fe dominated materials (Table 2.1), Ca dominated materials (Table 2.2), and materials that fit criteria for both

mechanisms (Table 2.3). For a material to be considered Al/Fe it must contain more total Al+Fe than total Ca and have a pH below 8. A material was considered Ca based if it contained more total Ca than total Al + total Fe and had a pH above 8. A pH of 8 was used as the divider as Ca oxides and silicates will function and are found above pH 8. Hsu (1976) found that P removal by Al and Fe was best when pH was below 8.

An effective Al/Fe material will contain high amounts of total Al and total Fe along with considerable quantities of amorphous Al and Fe (oxalate extractable Al/Fe) (Penn et al., 2011a). All materials analyzed contained low amounts of soluble Al/Fe (water extractable Al/Fe), indicating that the Al/Fe mechanism most responsible for P sorption was ligand exchange. Past research has shown the ability of AMDRs to sorb P (Han et al., 2005; Sibrell et al., 2009). As expected AMDR1 and AMDR3 contained high amounts of total Fe due to its formation when iron became oxidized and precipitated after acid mine drainage water rose to the surface. Along with appreciable amounts of Al, these materials had pH's well below 8 which allows for the Al/Fe present to be reactive with P. The AMDR2 material had less total Fe compared to the previous AMDRs but contained over 10 times more Al along with more oxalate extractable Al. The higher Al content in this material could be the contributing factor to why the sorption maximum (Smax) that was determined from the P sorption isotherms was double that of the other two AMDRs. AMDR2 also had the highest total Ca among the Al/Fe AMDRs which would allow for Ca precipitation, but with a pH around 7 this material will also react with P by Fe/Al mechanisms. The Al-WTR1 had the highest amount of total Al and oxalate Al among all materials analyzed. Al-WTR2 also contained high amounts of total Al, but was around half that of Al-WTR1 which again could have contributed to the lower Smax

just as was seen with the AMDRs. Al-WTR2 also had considerably more total Ca compared to Al-WTR1, however with a low pH and low buffer index the Ca precipitation will most likely not occur. Ultra-Phos and Leonardite both had sufficient amounts of Al and Fe with pHs well below 8. However, the Smax was the lowest among the Al/Fe materials. For this reason flow-throughs were not conducted on these two materials as they would not be as beneficial in a P removal structure as compared to other materials.

An effective Ca material will contain large quantities of soluble Ca (water Ca) that can take part in precipitation reactions and is buffered at a high pH (i.e. high BI). All fly ash materials contained high amounts of total Mg, Fe, and Al but were dominated with total Ca. With pHs above 11 and high buffer indices these materials are well suited for P removal. Fly-ash1 and Fly-ash2 were chosen for flow-through experiments since they had more soluble Ca then Fly-ash3. Sources of the coal used at the different power plants could explain the differences between the elemental composition of the fly-ash materials and why Fly-ash3 had significantly less soluble Ca. Ugurlu and Salman (1998) found that fly ash was efficient at sorbing with P most likely due to the high amount of calcite it contains. The AMDR4 material found in this group demonstrates the diversity of AMDRs to sorb P by both Ca and Fe/Al mechanisms. This AMDR contained high total Ca and total Fe due to the method in which it was produced where calcium carbonate was used to precipitate Fe out of solution. It also had the highest Smax among all materials which might be explained by the high amounts of both Ca and Fe. An elevated pH along with a relatively high BI and high total Ca was found in the Ca-WTRs. The FGD gypsums contained high amounts of total and soluble Ca which was expected. FGD gypsum1 was set apart from the other FGD gypsum by having a much larger Smax

among the two. Slag fines had more total and soluble Ca along with more total Mg, Al, and Fe than the other Ca slag materials. Excell minerals had a high Smax and contained large amounts of total Ca and had an elevated pH with the largest buffer index. Therefore this material will likely be effective at precipitating with P. Factors such as cost and availability must also be taken into account when choosing a material. For this reason LA Ash would not be suitable for use in a P removal structure even though it contained high amounts of Ca. Paper mill pulp had high amounts of soluble and total Ca with a high Smax but when compared to the other Ca materials in which flow-throughs were conducted on it had the lowest pH and lower soluble Ca. The foundry sand3 material contained low amounts of all P sorbing elements and the lowest Smax among Ca materials, thus would be ineffective in a structure.

Materials that fit criteria for both P sorption mechanisms were combined in table 2.3. The slag materials found in this group contained high amounts of Ca, Mg, Al, and Fe and an elevated pH, but were not used in the flow-through experiment as the fines slag was determined to be a more suitable slag material as it had more soluble and total Ca which is more important at the higher pH. The foundry sands, green sand, and haydite materials contained low amounts of Ca, Mg, Al, and Fe and small Smax's which means P sorption would be minimal. Bauxite had high total Al and Fe but with a pH above 10 the Al/Fe would be ineffective at sorbing P.

Flow-through experiments and comparison to batch isotherms

Two comparisons were used to examine the differences between flow-throughs and batch isotherms. Figure 2.1 represents the amount of P that will be removed at a

given concentration after the material is saturated. This is also important when incorporating a structure as it shows how effective the material will be at removing P at different in-flow concentrations. Figure 2.2 allows for the determination of the longevity of the material which is an important factor when predicting how long a material will last in a structure.

In figure 2.1 P sorbed (mg kg^{-1}) is plotted against equilibrium P concentration (mg L^{-1}) and includes the results from the batch isotherms and flow-through experiments under two retention times. In the flow-through setting the equilibrium concentration is determined when the inflow P concentration equals the outflow P concentration. The equilibrium concentration in the isotherms is determined by the amount of P remaining in solution after an equilibration period (i.e. shaking) with the material. Differences are seen between the isotherm data and flow-through data along with differences between retention times.

Retention time had little effect on amount sorbed at equilibrium for 3 of the 4 AMDRs. AMDR1 showed a higher sorption when at a longer RT. Higher equilibrium concentrations also had little effect on the amount sorbed for the AMDRs. AMDR2 showed the highest sorption at equilibrium and may be explained by it having the highest total and oxalate Al. At an equilibrium concentration around 5 mg P L^{-1} AMDR1 had similar results between isotherm and flow-through. The other three AMDRs had higher P sorption from the isotherms once the equilibrium concentration rose above 2 mg P L^{-1}. The longer contact time and higher P concentrations added to materials as used in the batch isotherm experiments may account for the higher sorption compared to flow throughs. With AMDR1 having the lowest amount of Al it could explain why the flow-

throughs and isotherm were similar at higher equilibrium concentrations. The Al bonding sites on the material were filled and higher amounts of P were unable to sorb even when the retention time was higher.

Isotherms behaved similarly for both fly-ash materials and showed a lower amount sorbed at all equilibrium concentrations when compared to the flow-throughs. Increasing the equilibrium concentration led to an increase in the amount sorbed when looking at the flow-throughs for both materials. Retention time was a factor with Fly-ash1 as it sorbed more at a lower RT.

Retention time and equilibrium P concentration had little effect on the Al-WTRs while having an impact on the Ca-WTR. Ca-WTR1 sorbed more at a lower RT and lower equilibrium concentrations. A possible reason why the lower concentrations sorbed more is that higher concentration P solutions had an acidification effect and the Ca mechanism was unable to proceed.

Equation 2.1: $H_2PO_4^- + Ca^{2+} \rightarrow CaPO_4(s) + 2H^+$

The acidification effect can be explained using equation 2.1. When more $H_2PO_4^-$ is in the system it will push the reaction to the right and thus produce more H^+ in solution. This will cause the pH to drop and prevent Ca precipitation to occur. This can be seen in table A.9 in appendix A where the pH of the outflow solution goes down with increases in P concentration. Isotherms for the Al-WTRs showed more sorption at higher equilibrium concentrations compared to the flow-throughs which is comparable to the Al dominated AMDRs. The Ca-WTR however showed more sorption with the flow-throughs when compared to the isotherms which is similar to the Ca rich fly ash materials. Al-WTR1

also sorbed higher amounts of P compared to Al-WTR2 when looking at the flow-throughs and is probably because Al-WTR1 contains a lot more total and oxalate Al.

The Ca dominated FGD gypsum1 showed a strong response to RT as equilibrium concentration increased. A longer RT allowed for more precipitation. The longer contact time provided with the longer RT time may have been needed for the Ca to precipitate with with P. Also as equilibrium concentration increased so did the amount sorbed. The isotherm fell between the two RTs which could mean that a longer RT is needed but the reaction products need to be removed in order for the Ca reaction to continue. Slag fines showed little response to RT but had a drastic increase in sorption as equilibrium concentration increased. Flow-throughs predicted higher sorption once the equilibrium concentration exceeded 5 mg P L^{-1}. Excell Minerals followed the same trend of other Ca materials with high pH and BI where the lower RT led to higher sorption. Effects were most noticeable with this material however and could be explained by it having the highest BI which would allow it to keep the pH in a suitable range even as more solution passes through it. The longer RT had similar results to the isotherm. Overall, isotherms seemed to underestimate the amount of P sorbed for Ca materials and slightly overestimate in Al materials. Underestimation for the Ca materials could be due to the fact that reaction products are not removed in an isotherm which doesn't allow for the reaction to proceed. In a flow-through the reaction products are removed from the system which allows for the reaction to continue thus allow more sorption. Overestimation for the Al materials may occur because the longer RT allowed for the slower precipitation reaction to occur. The limited RT with the flow-throughs may not allow enough time for precipitation to occur and results in slightly less sorption. Results

also showed that several Ca materials (Fly-ash1, Ca-WTR1, and Excell Minerals) seemed to work better at the shorter RT, while Al materials seemed to be minimally effected by RT.

Isotherms would not be a good way to estimate the maximum amount of P these materials could sorb at a given concentration. The long retention time that isotherms use to reach equilibrium is not what is seen in the natural setting. Several materials showed the importance of limited retention time on sorption which only a flow-through can represent. Also, to reach an equilibrium concentration of say 15 mg P L^{-1}, in a batch setting, it may take an 800 mg P L^{-1} solution which is not possible in a natural setting. The flow-through approach is more suited to provide information on the maximum amount of P these materials can sorb.

In figure 2.2 P added (mg kg^{-1}) is plotted against equilibrium P concentration (mg P L^{-1}) and includes the results from the batch isotherms and flow-through experiments under two retention times. The P added (mg kg^{-1}) represents the amount needed to reach equilibrium and gives an estimate of how long a material will last in a structure. For almost all materials the isotherms underestimated the amount of P that would be needed to reach equilibrium. For example, at an equilibrium P concentration of 1 mg P L^{-1} the isotherm for AMDR1 predicted that equilibrium would be reached when approximately 500 mg kg^{-1} P was added to the material. At a RT of 10 minutes the flow-through method predicted that approximately 27000 mg kg^{-1} of P would be needed. Using the isotherm to predict longevity of the material would result in the premature removal from the structure. The closed system of the isotherm along with the long equilibration time and high P concentrations most likely led to the underestimation. In a flow-through

setting the limited RT will lead to less contact time between the material and incoming water resulting in less water being treated. Therefore, more water will pass through the material before saturation is reached. The same solution is in contact with the material in an isotherm leading to a higher P removal efficiency and thus an underestimation of P needed to reach equilibrium. P removal efficiency is simply P sorbed/P added*100 and can be calculated using data from figures 2.1 and 2.2. For the same example using AMDR1, the isotherm had a P removal efficiency around 95% while the 10 minute RT was around 18%. The 0.5 minute RT had a P removal efficiency around 11% which probably explains why more P is needed before saturation is reached.

Clearly isotherms are not a good method to use to predict longevity of a material. The overestimation of P removal capacity with isotherms results in a less efficient use of materials in a structure as they would be removed before saturation is reached. Using flow-through data accounts for the lower P removal efficiency observed in a flow-through setting, thus would provide a better estimate of longevity.

Another comparison between isotherms and flow-throughs is to look at the maximum amount of P sorbed between both methods. Smax was calculated for the isotherms and the maximum amount of P sorbed was retrieved from figure 2.1 using a RT of 10 minutes and a P concentration of 15 mg P L^{-1}. All Smax values were substantially higher than the flow-through values except for Slag fines where the flow-through value was almost double the Smax (49,000 to 28875 mg kg^{-1}). Slag fines most likely benefited from the reaction products being removed in the flow-throughs. For Excell Minerals if the 0.5 minute RT is used instead of the 10 minute the flow-through value exceeds the Smax value. This shows the importance of RT to alter the sorption capacity of this

material. For all other materials Smax was always double or larger than the flow-through value. Comparison of these two values is a simple way to demonstrate the differences between the two methods and show how Smax is not a reliable value to use when incorporating materials into a P removal structure.

Environmental Implications

Environmental safety is an issue that must be addressed when considering incorporating these materials into P removal structures. The pH values shown in tables 2.1, 2.2, and 2.3 range from 3.24 to 12.51 indicating that waters passing through these materials have the potential to have their pH's altered. However these solutions will most likely not be well buffered and will return to normal pH ranges when coming into contact with sediment and waters downstream. In a study by Penn et al. (2011) they observed that pH of water was elevated from 7.7 to 9.2 after passing through slag in a P removal filter. However the alkalinity remained almost the same (77 to 81 mg $CaCO_3$ L^{-1}) which they concluded would have no impact to the ecosystem. Results from the water extraction for trace elements and TCLPs are shown in table 2.4. All Ni, As, Cr, Cd values from the water extraction came back below the fresh water limits set by the Environmental Protection Agency (EPA). Only the green sand Zn level (0.16 › 0.12) came back higher than the EPA limit, however, this material was not considered for use in a P removal structure based on its characterization. All materials TCLP As, Cr, Cd levels fell under the EPA limits which indicates these materials would not be considered hazardous wastes.

CONCLUSION

Characterization showed that a material that has high total concentrations of reactive elements (Ca, Fe, Al), with a pH suitable for those elements (pH > 8 = Ca; pH < 8 Al/Fe), will work best in a P removal structure. Along with a suitable pH, Ca materials must have a high buffer index to keep the pH in a range suitable for the reaction mechanism to take place. The form in which the reactive element is in was also important. Soluble Ca and amorphous Al/Fe were important forms for P sorption. Although P sorption capacity was easily estimated by results from the P sorption isotherms, the estimate produced was not realistic to conditions seen in a P removal structure. In isotherms large amounts of P (up to 4000 mg P L^{-1}) and RTs (16 hrs) are used to estimate Smax which does not represent real conditions. When looking at P sorbed at a certain equilibrium concentration, isotherms had varying results between the materials. For Ca materials isotherms underestimated the amount of P sorbed and overestimated for Al materials when compared to the flow-throughs. Isotherms also underestimated the amount of P needed to reach saturation which would result in a premature removal of the material from a structure if you used the isotherm data to predict longevity. Results from the water and TCLP extractions indicate that these materials will not have detrimental effects in the environment they are placed in. Using characterization and flow-through data will allow for proper construction of P removal structures and provide information for effective removal and replacement of P sorbing materials, which will help prevent P transport to sensitive water bodies downstream.

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Table 2.1: Characterization Results Important for Material Selection for Flow-Through Experiments (Aluminum and Iron Dominant Materials).

Material	Water* Ca	Water Mg	Water Fe	Water Al	Total# Ca	Total Mg	Total Fe	Total Al	Oxalate Al	Oxalate Fe	BI†	pH	EC‡	Smax	K
	mg kg^{-1}										Eq kg^{-1}		mS cm^{-1}	mg kg^{-1}	
AMDR1	97.3	24.7	1.28	13.4	220	123	455681	2033	136	25951	0.000	3.24	0.51	25815	0.00035
AMDR2	6705	437	0.35	0.64	23006	1555	189871	98282	46784	30415	.208	7.09	2.79	53789	0.039
AMDR3	3727	237	0.34	0.48	8342	1167	338805	9292	353	39809	.009	6.35	1.98	23170	0.00053
Al-WTR1	424	20.2	0.23	0.81	3277	1644	16824	157325	57739	2515	.026	7.26	0.45	57713	0.018
Al-WTR2	2179	25.6	0.22	0.59	18661	1857	14487	81375	37420	2108	.064	7.32	2.14	30256	0.015
Ultra-Phos	4437	275	1.31	0.31	16643	610	168740	4709	932	51922	ND	6.19	3.75	20014	0.0047
Leonardite	867	226	0.86	7.91	8251	1073	4368	13413	3934	1963	ND	4.10	1.16	5654	0.0018

† Buffer index; equivalents of acid kg^{-1} required to decrease pH to 6.0
‡Electrical Conductivity
*Water extractable
#EPA 3051 Digestion

Table 2.2: Characterization Results Important for Material Selection for Flow-Through Experiments (Calcium Dominant Materials).

Material	Water* Ca	Water Mg	Water Fe	Water Al	Total# Ca	Total Mg	Total Fe	Total Al	Oxalate Al	Oxalate Fe	BI†	pH	EC‡	Smax	K
	mg kg^{-1}										Eq kg^{-1}		mS cm^{-1}	mg kg^{-1}	
AMDR4	709	2123	0.33	0.80	204779	34853	118259	16651	5389	32818	1.779	8.39	2.97	157183	0.00009
Fly-ash1	1136	0.84	0.29	536	150941	25961	41821	86898	27090	8619	.638	11.44	1.35	21390	0.012
Fly-ash2	1042	0.93	0.31	733	153547	28469	36637	64934	29281	10001	.941	11.40	1.32	26910	0.0062
Fly-ash3	23.6	0.74	0.27	348	175907	40352	38877	79079	26505	7078	ND	11.16	1.82	34365	0.0056
Ca-WTR1	751	2181	0.22	0.28	286629	19060	7177	14166	5210	998	.931	8.89	6.30	28658	0.0017
Ca-WTR2	3490	0.78	0.27	6.93	314668	9462	4836	16367	.	.	ND	8.79	0.28	21101	0.0024
FGD gypsum1	6520	37.1	0.31	0.83	209000	1501	1791	782	56.3	610	.032	8.12	2.15	45008	0.00021
FGD gypsum2	6670	2.39	0.10	0.42	147053	466	1101	427	55.4	432	ND	9.00	2.21	11101	0.00027
Slag fines	611	1.22	0.31	87.8	272452	90142	155062	36843	931	4402	.677	11.30	0.66	28875	0.012
Slag3	253	1.72	0.25	19.3	236484	63703	139330	26697	1360	15974	ND	.	.	.	.
Slag4	261	1.11	0.25	57.1	237616	68374	146654	27462	842	4707	ND	12.09	4.84	.	.
Excell Minerals	203	1.88	0.22	2.34	268523	62408	70475	20723	2301	19183	2.335	10.99	0.40	31775	0.019
LA Ash	12252	0.19	0.12	0.26	242130	1826	14618	32506	9703	1967	ND	12.51	10.85	.	.
Foundry Sand3	6.31	1.59	3.25	10.84	483	157	200	273	8.04	20.9	ND	10.38	1.45	5781	0.00017
Paper mill pulp	590	98.5	2.48	15.2	162998	1804	933	18430	948	140	ND	8.07	0.59	130821	0.000038

† Buffer index; equivalents of acid kg^{-1} required to decrease pH to 6.0
‡Electrical Conductivity
*Water extractable
#EPA 3051 Digestion

Table 2.3: Characterization Results Important for Material Selection for Flow-Through Experiments (Aluminum, Iron, and Calcium Dominant Materials).

Material	Water* Ca	Water Mg	Water Fe	Water Al	Total# Ca	Total Mg	Total Fe	Total Al	Oxalate Al	Oxalate Fe	BI†	pH	EC‡	Smax	K
	mg kg^{-1}										Eq kg^{-1}		mS cm^{-1}	mg kg^{-1}	
Slag1	339	1.02	0.25	26.9	176318	58075	235602	32195	2718	15011	ND	10.91	0.37	28790	0.0082
Slag2	168	2.09	0.29	8.47	199741	41531	221292	17163	188	2223	ND	9.64	0.08	.	.
Foundry Sand1	65.9	2.79	1.26	6.20	669	3283	889	721	35.8	132	ND	8.97	0.09	6930	0.00003
Foundry Sand2	0.53	0.41	0.78	3.94	13.7	37.8	118	139	11.0	31.5	ND	9.12	0.52	10550	0.00007
Green Sand	133	119	126	285	9434	75787	19977	7571	928	3695	ND	9.15	0.46	19044	0.00019
Haydite	356	12.1	0.37	1.63	3500	1918	22310	18090	441	564	ND	9.24	0.22	1047	0.001
Bauxite	34.35	9.26	25.5	89.3	15000	1663	213217	98493	35089	272	ND	10.02	2.40	.	.

† Buffer index; equivalents of acid kg^{-1} required to decrease pH to 6.0
‡Electrical Conductivity
*Water extractable
#EPA 3051 Digestion

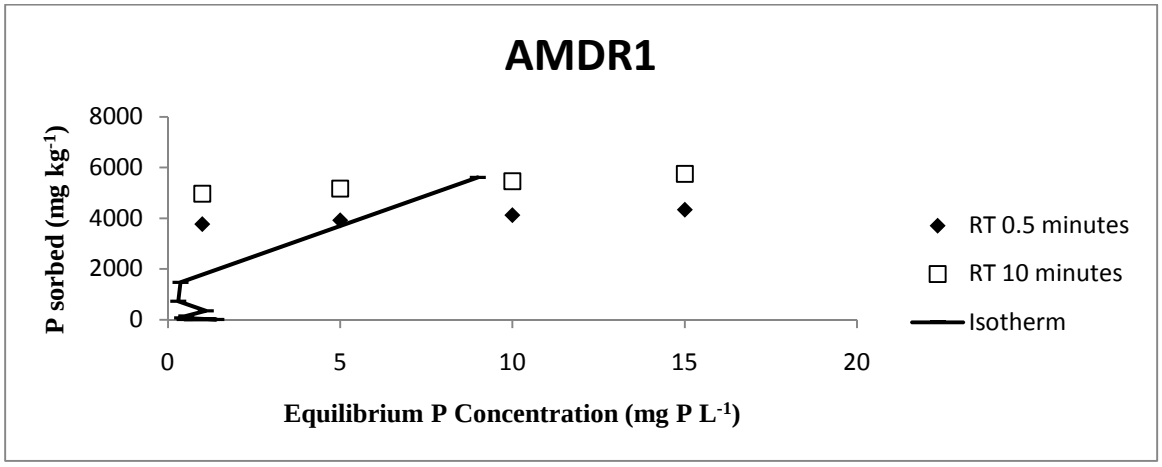
Table 2.4: Water Extraction and Toxicity Characteristic Leaching Procedure Results for Comparison to Environmental Protection Agency Limits to Determine Safety of Materials.

Material	Water[#] Ni	Water Zn	Water As	Water Cr	Water Cd	TCLP As	TCLP Cr	TCLP Cd
	mg L^{-1}							
AMDR1	0.00	0.10	0.00	0.00	0.000	0.00	0.00	0.00
AMDR2	0.01	0.00	0.00	0.00	0.000	0.01	0.00	0.01
AMDR3	0.00	0.00	0.00	0.00	0.001	0.01	0.00	0.00
AMDR4	0.02	0.02	0.01	0.00	0.000	0.01	0.00	0.00
Fly-ash1	0.00	0.00	0.00	0.16	0.000	0.17	0.36	0.02
Fly-ash2	0.00	0.00	0.00	0.10	0.000	0.05	0.33	0.00
Fly-ash3	0.00	0.00	0.01	0.04	0.000	0.10	0.20	0.00
Al-WTR1	0.00	0.00	0.00	0.00	0.000	0.02	0.05	0.00
Al-WTR2	0.00	0.00	0.02	0.00	0.001	0.02	0.00	0.00
Ca-WTR1	0.00	0.02	0.01	0.00	0.000	0.02	0.00	0.00
Ca-WTR2	0.00	0.00	0.00	0.01	0.000	0.08	0.00	0.00
FGD gypsum1	0.01	0.00	0.00	0.00	0.001	0.01	0.00	0.00
FGD gypsum2	0.01	0.00	0.00	0.00	0.000	0.03	0.00	0.00
Slag fines	0.00	0.00	0.01	0.02	0.000	0.01	0.01	0.00
Slag1	0.00	0.00	0.00	0.04	0.000	0.01	0.00	0.00
Slag2	0.00	0.00	0.00	0.04	0.000	0.01	0.00	0.00
Slag3	0.00	0.00	0.00	0.01	0.000	0.01	0.00	0.00
Slag4	0.00	0.00	0.00	0.02	0.000	0.01	0.00	0.00
Excell Minerals	0.00	0.00	0.00	0.16	0.000	0.00	0.10	0.00
LA Ash	0.01	0.00	0.01	0.13	0.000	0.00	0.08	0.00
Foundry Sand1	0.00	0.00	0.00	0.00	0.000	0.00	0.00	0.00
Foundry Sand2	0.00	0.00	0.00	0.00	0.000	0.00	0.00	0.00
Foundry Sand3	0.00	0.00	0.01	0.00	0.001	0.00	0.00	0.00
Green Sand	0.07	0.16*	0.01	0.02	0.001	0.01	0.00	0.00
Haydite	0.00	0.00	0.04	0.00	0.000	0.05	0.00	0.00
Ultra-Phos	0.01	0.01	0.00	0.00	0.000	0.00	0.00	0.00
Bauxite	0.01	0.00	0.04	0.02	0.001	0.04	0.00	0.00
Leonardite	0.00	0.02	0.01	0.00	0.001	0.01	0.00	0.00
Paper mill pulp	0.01	0.01	0.01	0.01	0.000	0.02	0.00	0.00

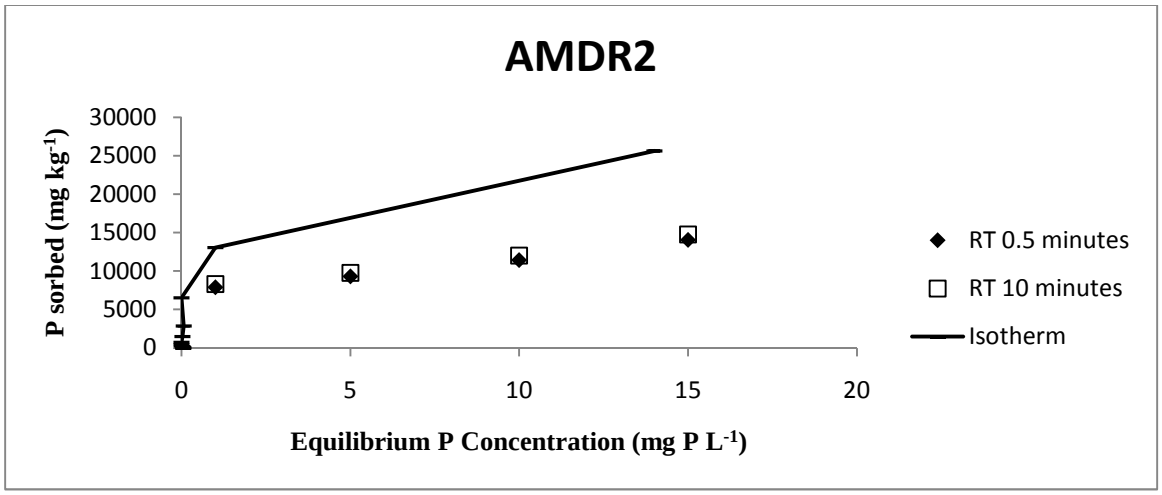
EPA water limits Ni: 0.47; Zn: 0.12; As: 0.34; Cr: 0.57; Cd: 0.002
EPA TCLP limits As: 5.00; Cd: 1.00; Cr: 5.00
* Value exceeds EPA limit
# Water extractable

Figure 2.1: Results from Isotherms and Flow-Through Experiments for the Twelve Materials in which Flow-Throughs were Conducted on for Comparison of P Sorbed at Different In-Flow Equilibrium P Concentrations (Flow-throughs) or Equilibrium Concentrations after Equilibration Period (Isotherms) to Detect Maximum Amount of P Sorption Differences Between Flow-Throughs and Isotherms and Among Different Retention Times.

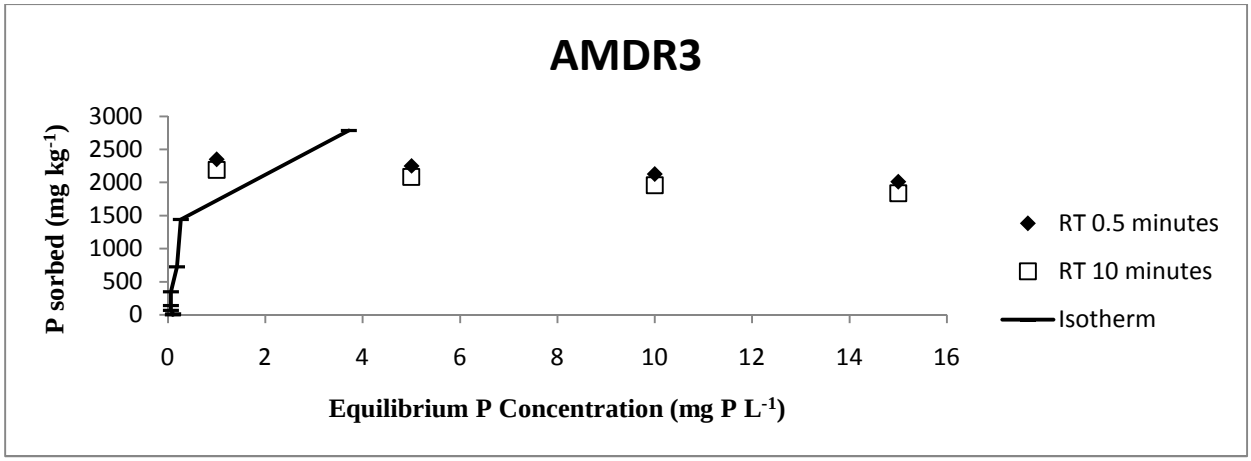
a.



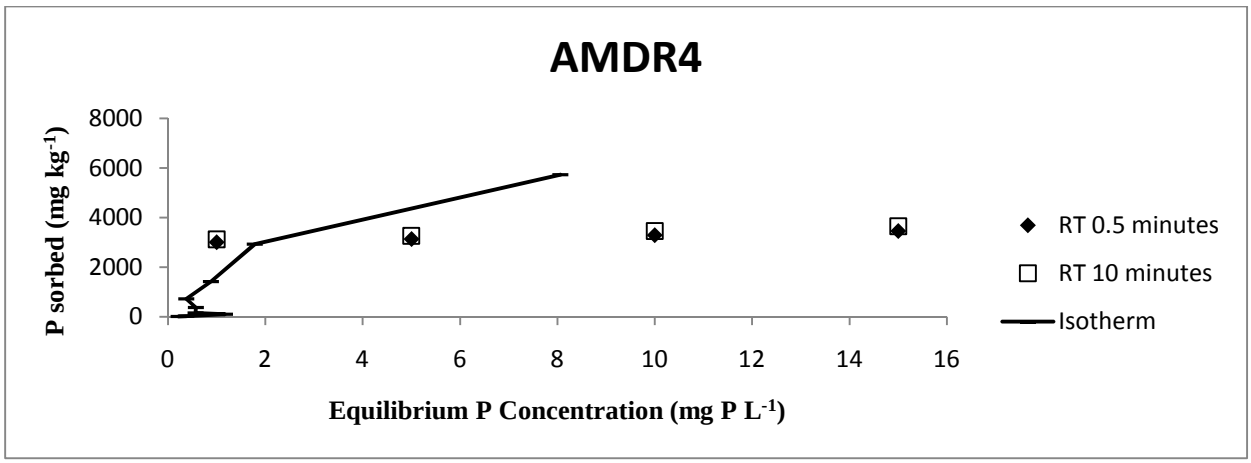
b.



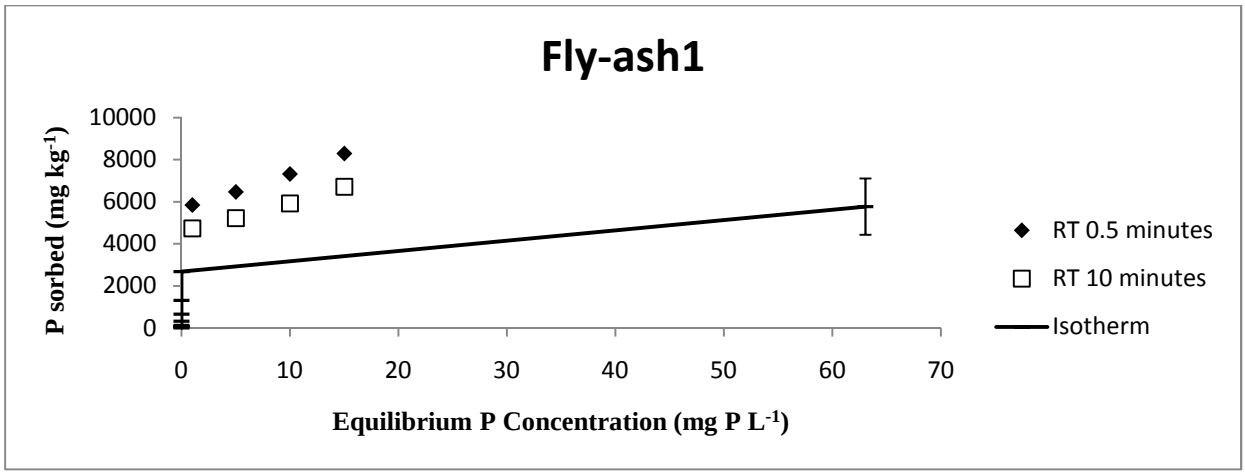
c.


AMDR3
P sorbed (mg kg-1)
3000
2500
2000
1500
1000
500
0
0
2
4
6
8
10
12
14
16
Equilibrium P Concentration (mg P L-1)
RT 0.5 minutes
RT 10 minutes
Isotherm

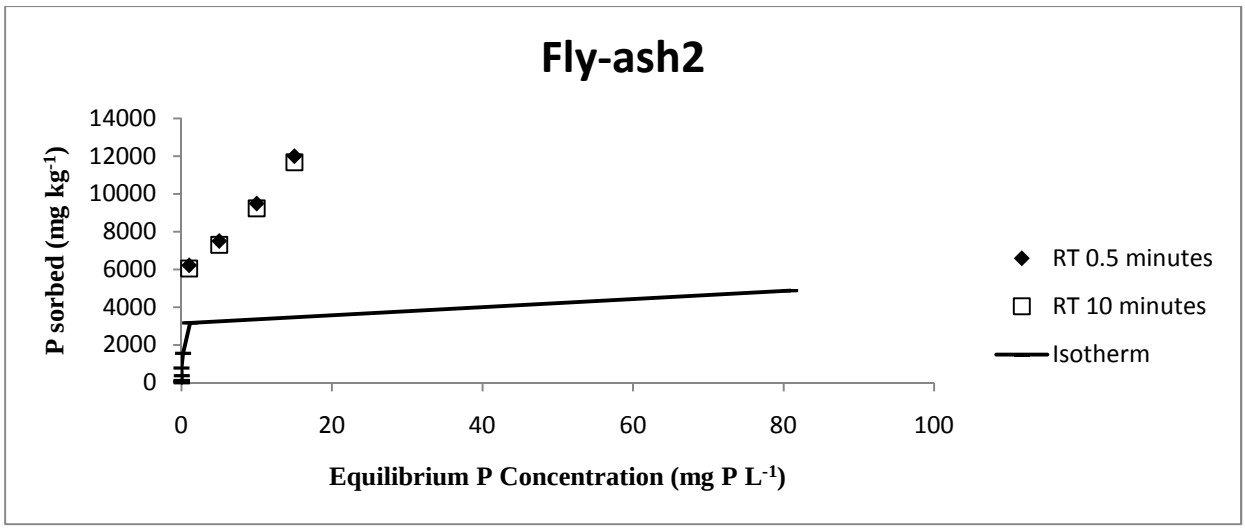
d.


AMDR4
P sorbed (mg kg-1)
8000
6000
4000
2000
0
0
2
4
6
8
10
12
14
16
Equilibrium P Concentration (mg P L-1)
RT 0.5 minutes
RT 10 minutes
Isotherm

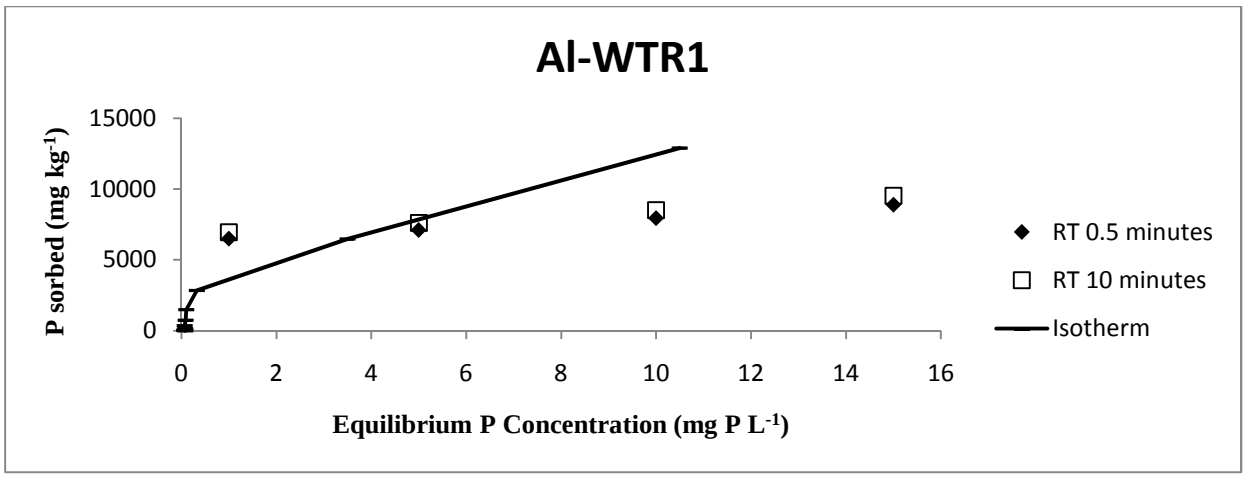
e.


Fly-ash1
P sorbed (mg kg-1)
10000
8000
6000
4000
2000
0
0
10
20
30
40
50
60
70
Equilibrium P Concentration (mg P L-1)
RT 0.5 minutes
RT 10 minutes
Isotherm

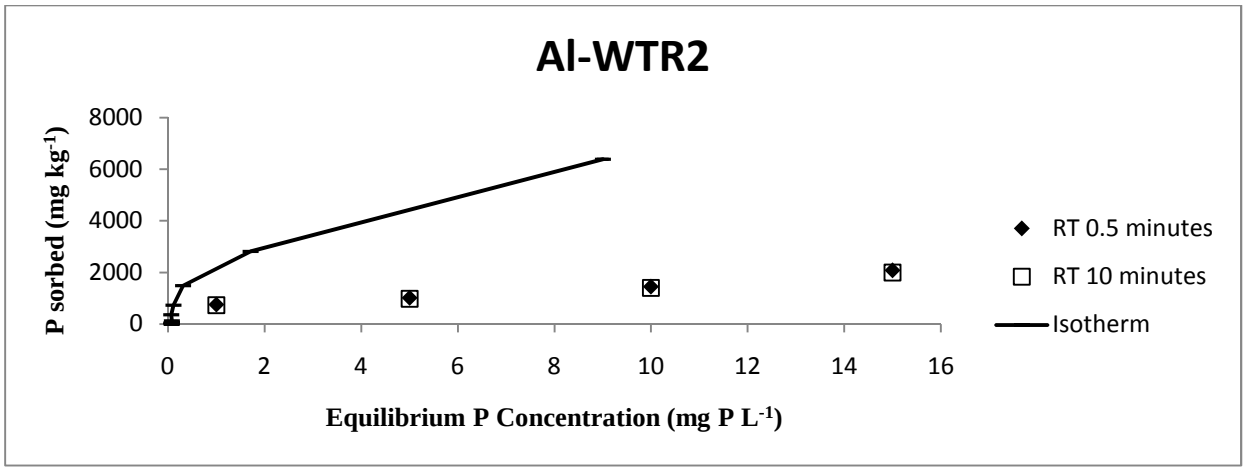
f.


Fly-ash2
P sorbed (mg kg-1)
14000
12000
10000
8000
6000
4000
2000
0
0
20
40
60
80
100
Equilibrium P Concentration (mg P L-1)
RT 0.5 minutes
RT 10 minutes
Isotherm

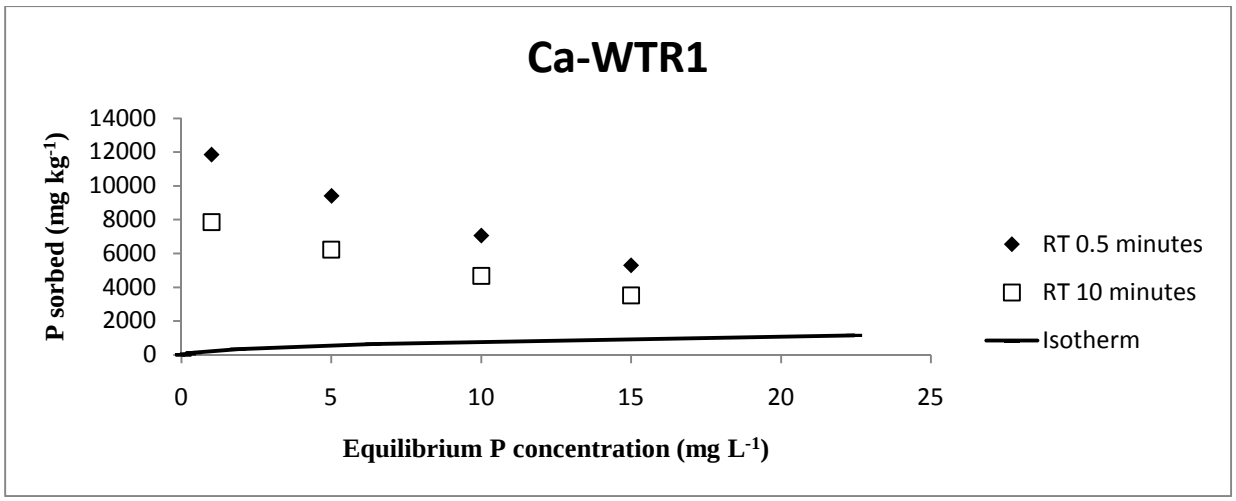
g.


Al-WTR1
P sorbed (mg kg-1)
15000
10000
5000
0
0
2
4
6
8
10
12
14
16
Equilibrium P Concentration (mg P L-1)
RT 0.5 minutes
RT 10 minutes
Isotherm

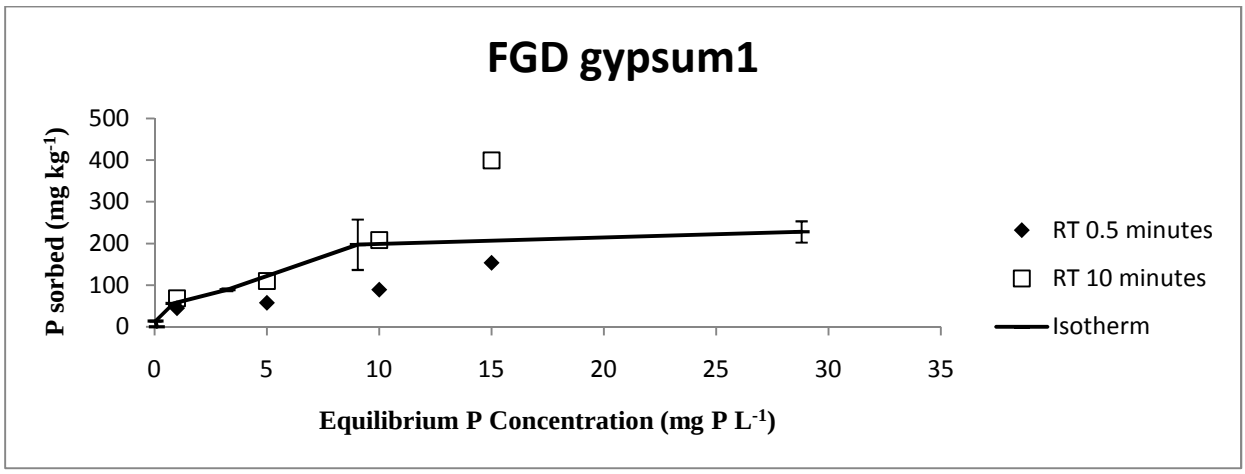
h.


Al-WTR2
P sorbed (mg kg-1)
8000
6000
4000
2000
0
0
2
4
6
8
10
12
14
16
Equilibrium P Concentration (mg P L-1)
RT 0.5 minutes
RT 10 minutes
Isotherm

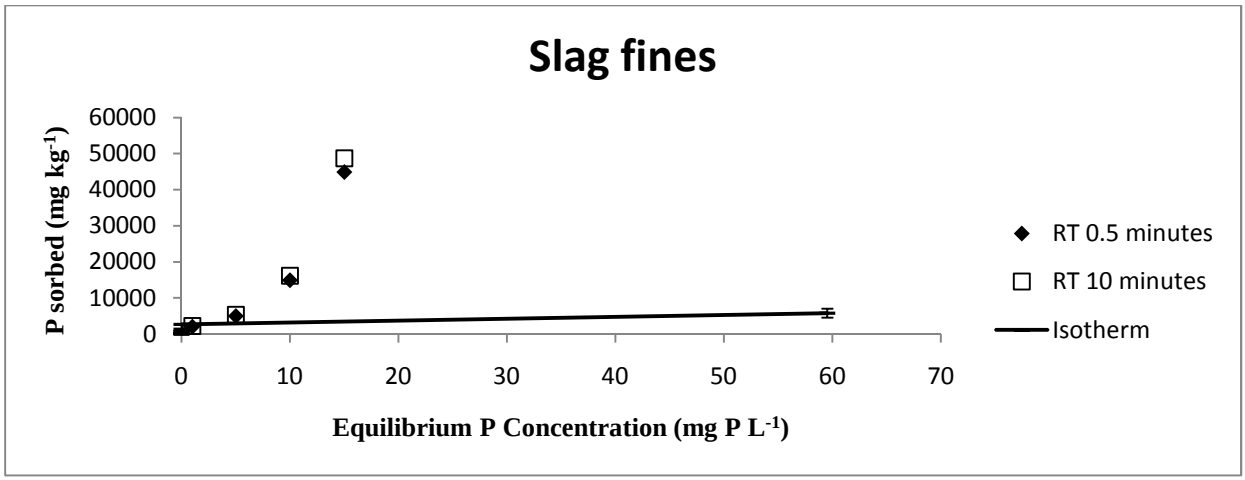
i.


Ca-WTR1
P sorbed (mg kg-1)
14000
12000
10000
8000
6000
4000
2000
0
0
5
10
15
20
25
Equilibrium P concentration (mg L-1)
RT 0.5 minutes
RT 10 minutes
Isotherm

j.


FGD gypsum1
P sorbed (mg kg-1)
500
400
300
200
100
0
0
5
10
15
20
25
30
35
Equilibrium P Concentration (mg P L-1)
RT 0.5 minutes
RT 10 minutes
Isotherm

k.


Slag fines
P sorbed (mg kg-1)
60000
50000
40000
30000
20000
10000
0
0
10
20
30
40
50
60
70
Equilibrium P Concentration (mg P L-1)
RT 0.5 minutes
RT 10 minutes
Isotherm

l.

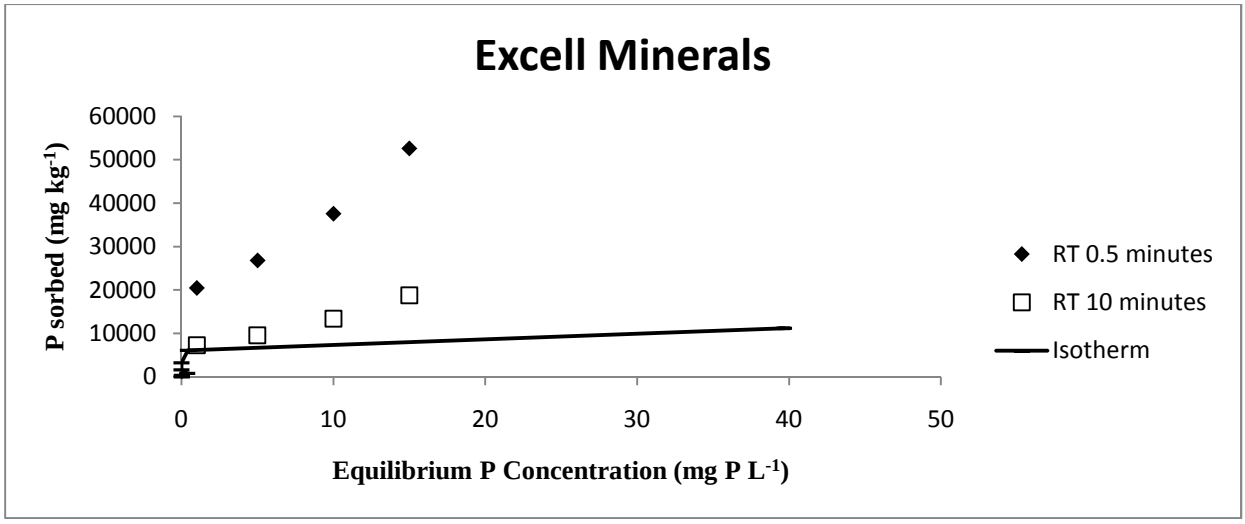
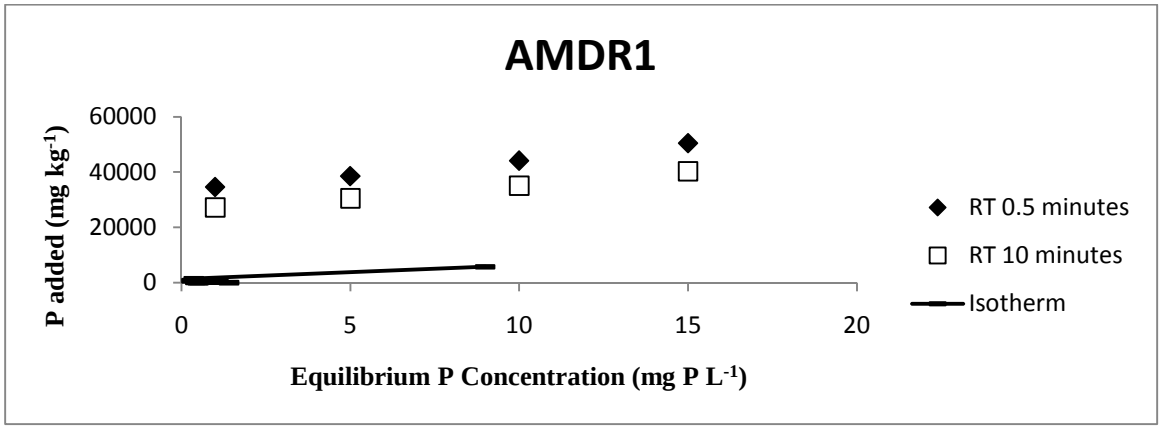
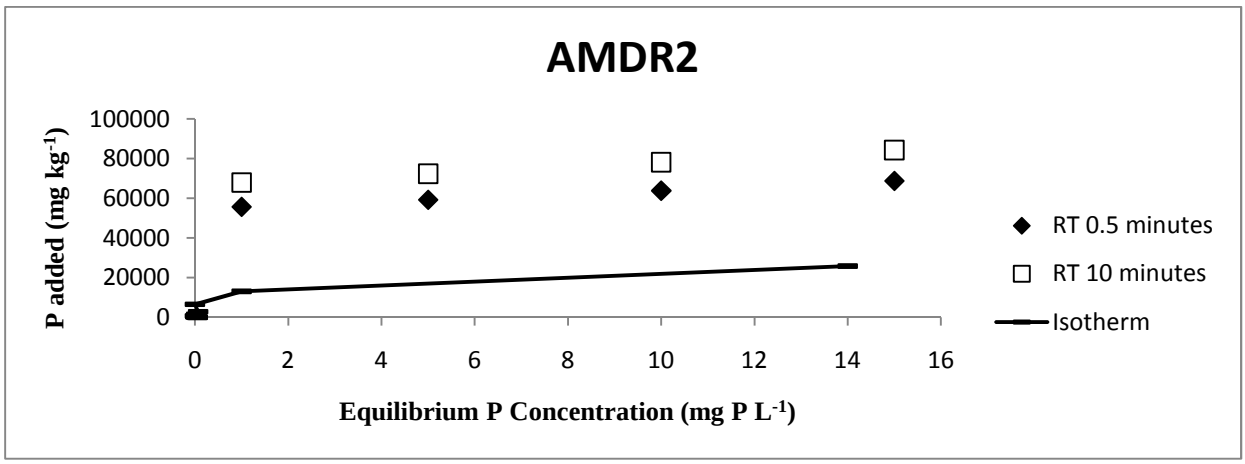

Excell Minerals
60000
50000
40000
30000
20000
10000
0
P sorbed (mg kg-1)
0
10
20
30
40
50
Equilibrium P Concentration (mg P L-1)
RT 0.5 minutes
RT 10 minutes
Isotherm

Figure 2.2: Results from Isotherms and Flow-Through Experiments for the Twelve Materials in which Flow-Throughs were Conducted on for Comparison of P Added at Different In-Flow Equilibrium P Concentrations (Flow-throughs) or Equilibrium Concentrations after Equilibration Period (Isotherms) to Detect Differences in the Amount of P Added to Reach Saturation (Longevity of Material) Between Flow-Throughs and Isotherms and Among Different Retention Times.

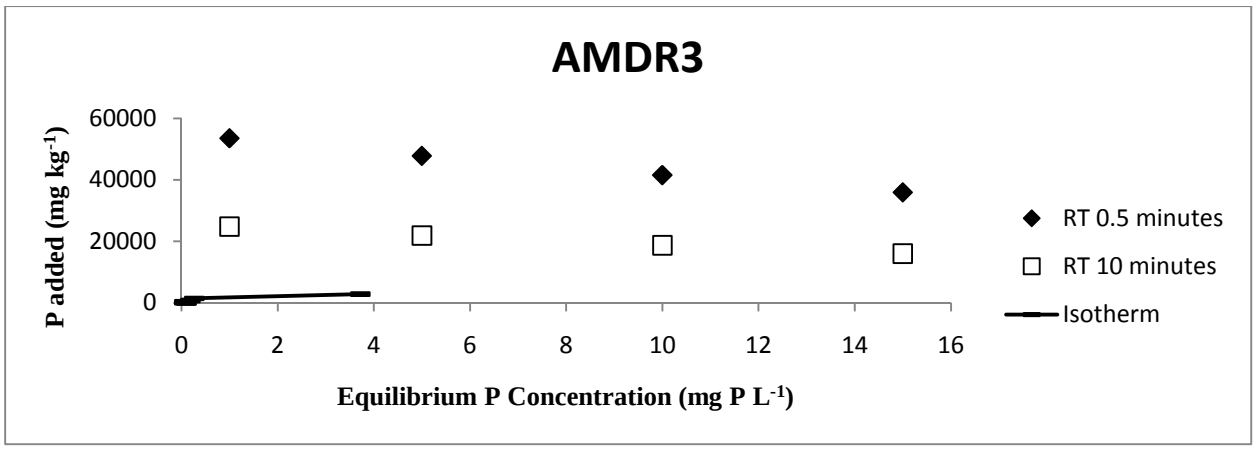
a.



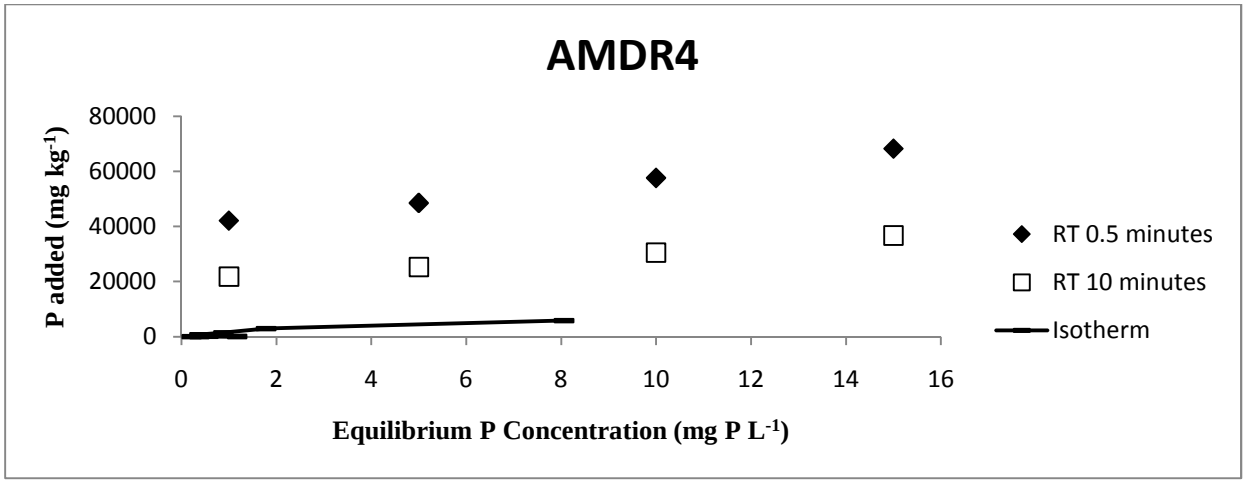
b.



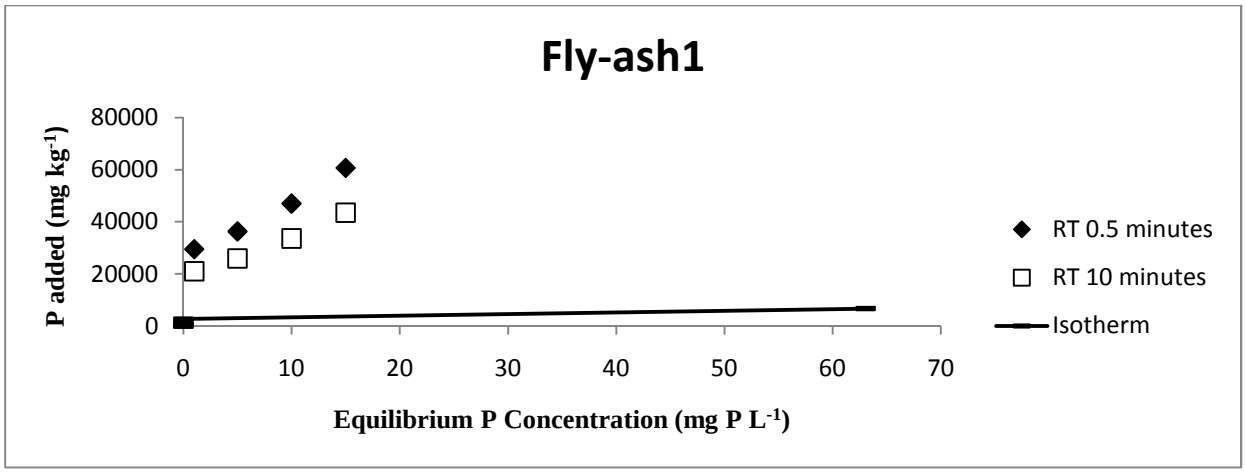
c.


AMDR3
P added (mg kg-1)
60000
40000
20000
0
0
2
4
6
8
10
12
14
16
Equilibrium P Concentration (mg P L-1)
RT 0.5 minutes
RT 10 minutes
Isotherm

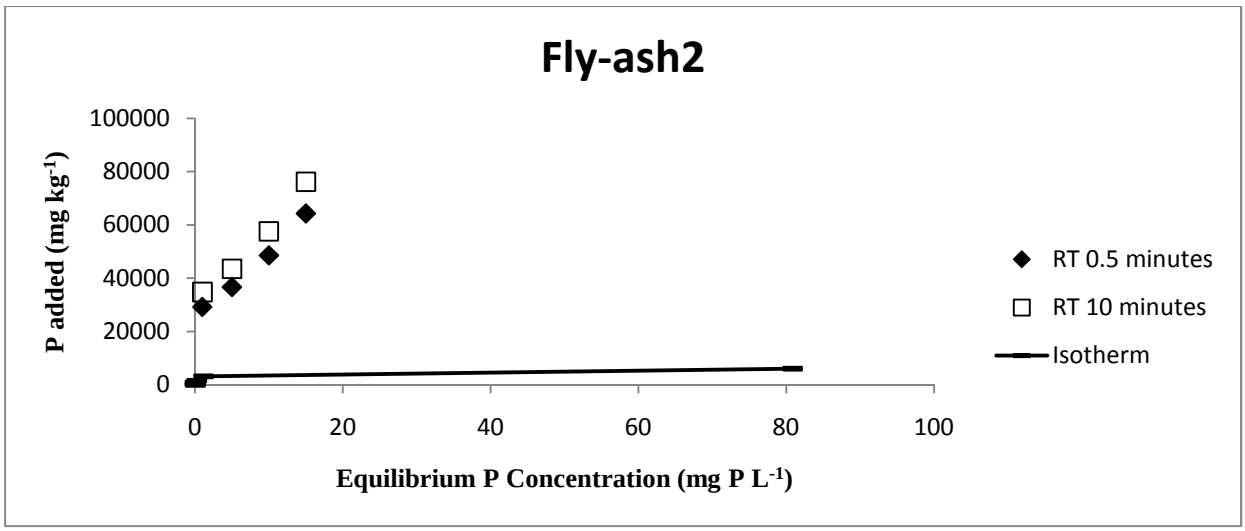
d.


AMDR4
P added (mg kg-1)
80000
60000
40000
20000
0
0
2
4
6
8
10
12
14
16
Equilibrium P Concentration (mg P L-1)
RT 0.5 minutes
RT 10 minutes
Isotherm

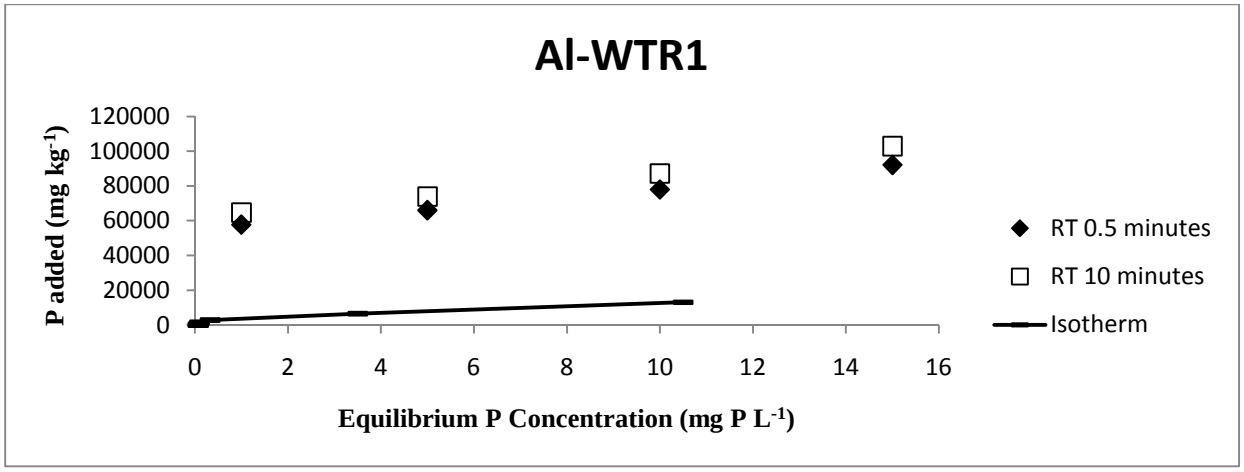
e.


Fly-ash1
P added (mg kg-1)
80000
60000
40000
20000
0
0
10
20
30
40
50
60
70
Equilibrium P Concentration (mg P L-1)
RT 0.5 minutes
RT 10 minutes
Isotherm

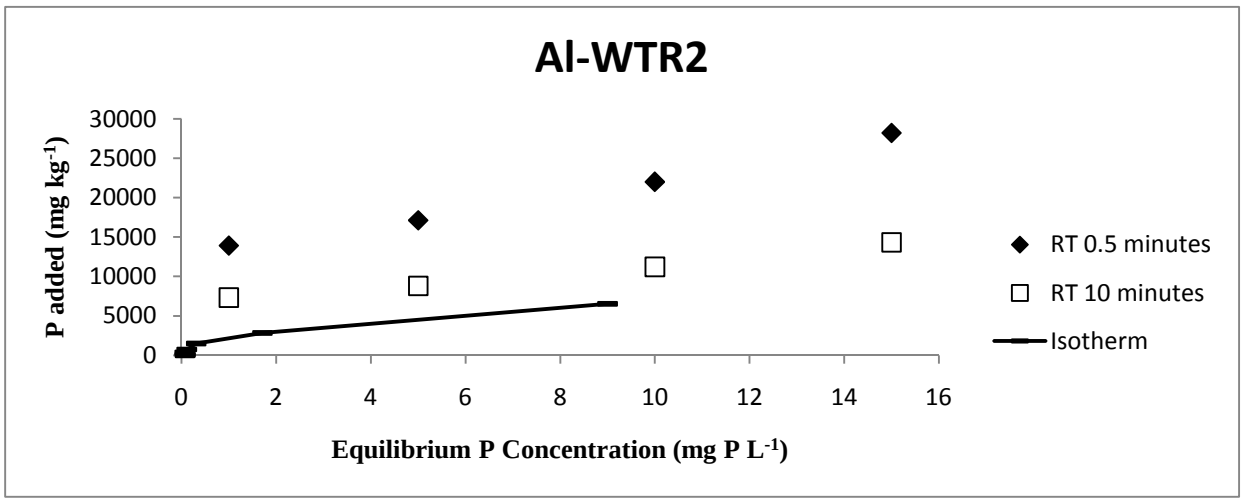
f.


Fly-ash2
P added (mg kg-1)
100000
80000
60000
40000
20000
0
0
20
40
60
80
100
Equilibrium P Concentration (mg P L-1)
RT 0.5 minutes
RT 10 minutes
Isotherm

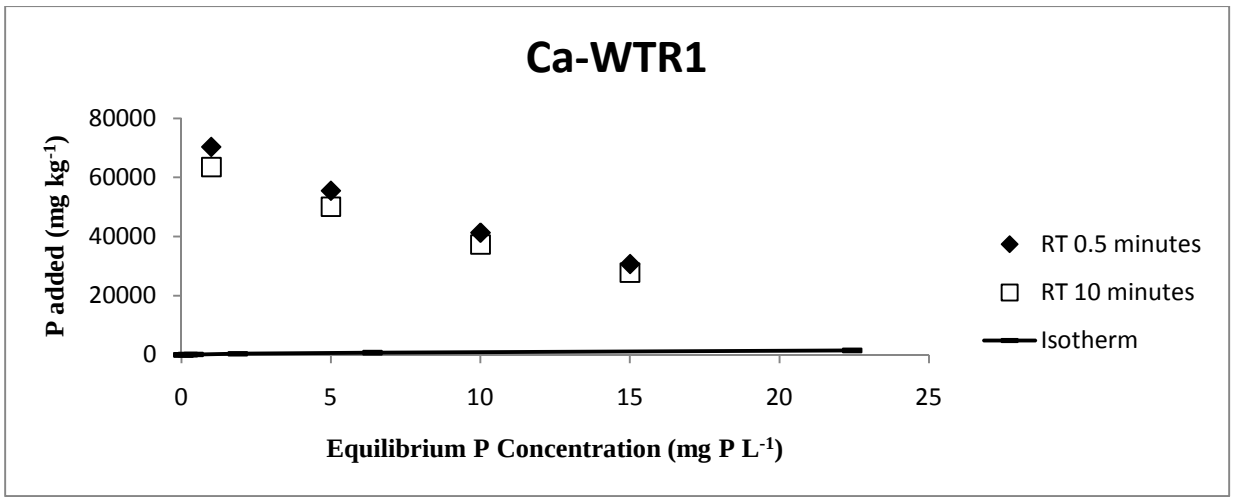
g.


Al-WTR1
P added (mg kg-1)
120000
100000
80000
60000
40000
20000
0
0
2
4
6
8
10
12
14
16
Equilibrium P Concentration (mg P L-1)
RT 0.5 minutes
RT 10 minutes
Isotherm

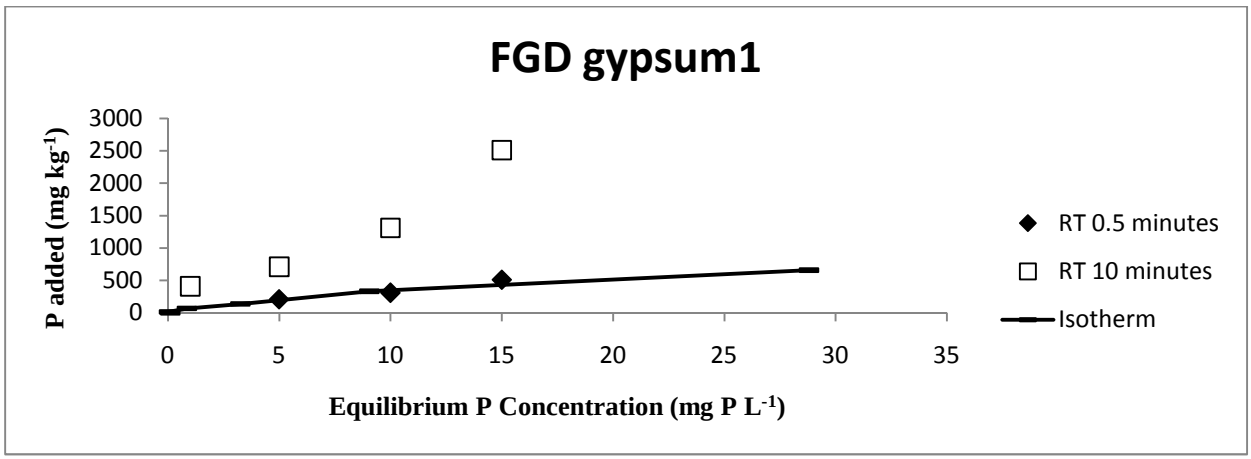
h.


Al-WTR2
P added (mg kg-1)
30000
25000
20000
15000
10000
5000
0
0
2
4
6
8
10
12
14
16
Equilibrium P Concentration (mg P L-1)
RT 0.5 minutes
RT 10 minutes
Isotherm

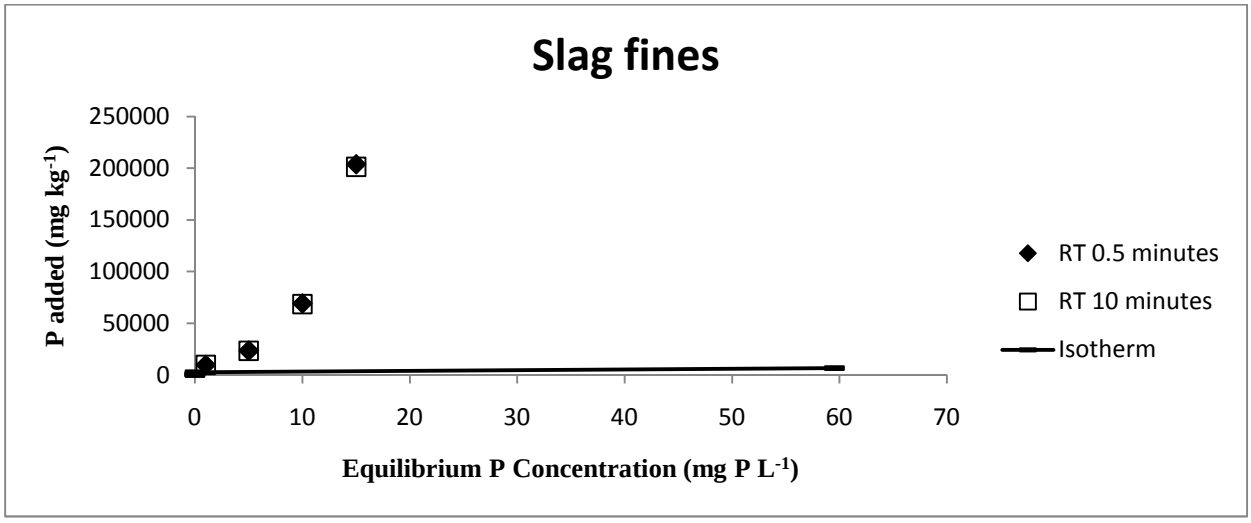
i.


Ca-WTR1
P added (mg kg-1)
80000
60000
40000
20000
0
0
5
10
15
20
25
Equilibrium P Concentration (mg P L-1)
RT 0.5 minutes
RT 10 minutes
Isotherm

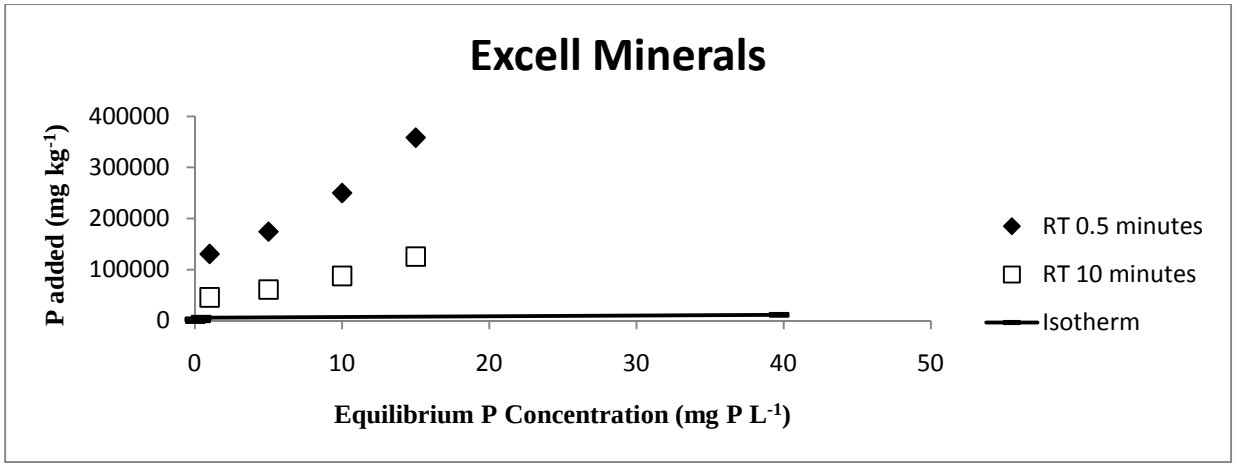
j.


FGD gypsum1
P added (mg kg-1)
3000
2500
2000
1500
1000
500
0
0
5
10
15
20
25
30
35
Equilibrium P Concentration (mg P L-1)
RT 0.5 minutes
RT 10 minutes
Isotherm

k.


Slag fines
P added (mg kg-1)
250000
200000
150000
100000
50000
0
0
10
20
30
40
50
60
70
Equilibrium P Concentration (mg P L-1)
RT 0.5 minutes
RT 10 minutes
Isotherm

l.


Excell Minerals
P added (mg kg-1)
400000
300000
200000
100000
0
0
10
20
30
40
50
Equilibrium P Concentration (mg P L-1)
RT 0.5 minutes
RT 10 minutes
Isotherm

CHAPTER III

PHOSPHORUS SORPTION ONTO BY-PRODUCTS IN A FLOW-THROUGH SETTING: EFFECT OF MATERIAL PROPERTIES

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ABSTRACT

Many industrial by-products have been shown to sorb large amounts of phosphorus (P). An alternative best management practice (BMP) is to incorporate these materials into a structure that would filter high P flowing runoff, however, little research has been done regarding the sorption capabilities of these materials in a flow-through setting. The objectives of this study were to establish what material chemical properties have the highest impact on P sorption in a flow-through setting, investigate how retention time (RT) and P concentration affect P sorption, and create an empirical model to predict the design curve for each material. Characterization for chemical properties were conducted on twelve industrial by-products which included four acid mine drainage residuals, two fly-ash samples, three drinking water treatment residuals, flue gas desulfurization gypsum, electric arc furnace steel slag, and Excell Minerals (commercial product). These

materials were also subjected to a flow-through experiment where five different RT and P concentrations were used to determine the sorption characteristics of the materials. Creation of a "design curve" using flow-through data will allow for prediction of the longevity and amount of P removed at saturation for each material. For many of the materials, RT and P concentration had a significant impact on P sorption and prediction of the Y intercept and slope of the design curve. Of the material properties tested, water soluble calcium, oxalate extractable iron and aluminum, and the ability to maintain a pH above 6 had the biggest impact on P sorption and the design curve. Screening for these material properties and use of the model will allow for the prediction of a design curve for an individual material. The design curve will allow for proper use of a material in a flow-through setting.

INTRODUCTION

Additions of dissolved phosphorus (P) to surface water bodies stimulate aquatic organisms which is a key cause of eutrophication (Sharpley et al., 1994). The majority of P is transported to surface waters by surface runoff as phosphate binds to eroded soil particles and sediments (Correll, 1998). Best management practices (BMPs) are used to reduce the loss of P in surface waters by controlling erosion. Sediment bound P is efficiently removed in these systems, however, dissolved P is minimally affected.

Incorporation of a P removal structure into the landscape is a new BMP that can potentially decrease dissolved P loads from surface runoff. A P removal structure works by utilizing the P sorption capabilities of P sorbing materials (PSMs). PSMs are rich in Ca, Al, and Fe (Cucarella and Renman, 2009), which allow for the removal of P by precipitation (Ca, Al, and Fe) or ligand exchange (Al and Fe) reactions. Advantages of a P removal structure are that it can be placed in strategic locations where high concentration P waters flow and once the material is saturated with P it can be removed and replaced with a fresh PSM. Removal of the saturated PSM allows for the removal of the sorbed P from the system. Shilton et al., (2006) used slag in an 'active' filter at a waste water treatment plant and removed 22.4 tonnes of total P over an 11 year period. However, almost 88% of the P was removed in the first 5 years. They concluded that research must be done to better predict the longevity of a material in a structure. Bioretention cells are another device that have been studied to remove P from stormwater (Christianson et al., 2004). Zhang et al., (2006) conducted a study to find an inexpensive

material to use in a bioretention cells that would have high P sorption capabilities. They found that when fly-ash (5% by weight) was added to Dougherty sand the maximum sorption capacity predicted by a Langmuir isotherm increased from 23.8 mg kg^{-1} to 385 mg kg^{-1}.

Characterization of PSMs along with information regarding the P sorption capacity of the materials is necessary before insertion into a P removal structure. Leader et al., (2008) conducted traditional batch isotherms and a variety of extractions of P sorbing elements to characterize PSMs. However, as was discussed in chapter II, isotherms are not a good way to predict the P removal capacity of a material in a flow-through setting. Penn and McGrath (2011) found that a flow-through model better predicted the performance of a P removal structure when compared to a batch isotherm Langmuir model. A flow-through experiment is a better predictor as it is more suited to conditions in a P removal structure. Isotherms often rely on long retention times (RT) and high P concentrations to reach equilibrium, which are not realistic to natural conditions. Flow-through experiments allow for the simulation of a realistic P concentration and RT. They also allow for the constant replenishment of a P solution to the material while a simultaneous removal of reaction products is occurring. For proper construction of a P removal structure a "design curve" must be produced. The design curve plots P added (mg kg^{-1}) on the x-axis and discrete P removed (%) on the y-axis (figure 3.1) and is necessary to predict the longevity and amount of P removed at saturation for a given material.

The objectives of this study were to (i) establish what material chemical properties have the highest impact on P sorption in a flow-through setting; (ii) investigate

how RT and P concentration affect P sorption; and (iii) create an empirical model to predict the design curve for each material.

MATERIALS AND METHODS

Materials characterization

Materials best suited for flow-through experiments were chosen based on results from chapter II. Twelve materials were used and include four acid mine drainage residuals (AMDR1, AMDR2, AMDR3, and AMDR4), two fly-ash materials (Fly-ash1 and Fly-ash2), three drinking water treatment residuals (Al-WTR1, Al-WTR2, and Ca-WTR1), a flue gas desulfurization gypsum (FGD gypsum1), one electric arc furnace steel slag (Slag fines), and Excell Minerals.

Analyses were conducted in duplicate on air-dry samples sieved to 5 mm. Electrical conductivity (EC) and pH were measured in a 1:5 solid to DI water ratio solution. Total element analysis was found by using the EPA 3051 digestion method (U.S. Environmental Protection Agency, 1997). Inductively coupled plasma atomic emission spectroscopy (ICP-AES) was used to analyze the digestion solutions for Ca, Mg, Fe, and Al. A water extraction with a ratio of 1:10 solid:solution was used to determine soluble Ca and Mg (ICP-AES). A 0.2*M* acid ammonium oxalate (pH 3) and 2 hour reaction time in the dark was used to determine amorphous Al and Fe (Oxalate Al and Fe) using a 1:40 solid:solution ratio (McKeague and Day, 1966). Solutions were analyzed for Al and Fe by ICP-AES. Buffer index was determined using the method described in chaper II. Crystalline minerals in the materials were determined by X-ray diffraction using a Philips (now PANayltical; Almelo, Netherlands) powder x-ray

diffractometer. A flow-through P sorption experiment was conducted to test the effect of RT and P concentration on P sorption. Five RT's were used (0.5, 3, 6, 8, and 10 minutes) along with 5 P concentrations (0.5, 1, 5, 10, and 15 ppm P). Samples were collected every 30 minutes for 5 hours and analyzed for pH, EC, and inorganic P using the Murphy-Riley molybdate blue method (Murphy and Riley, 1962). The flow-through method used is described in more detail in chapter II.

Data analysis

Using results from the flow-through experiment, a design curve was developed where discrete P sorption (%) was averaged among the 2 replications and expressed as a function of P added to the materials (mg kg^{-1}) using an exponential model:

Discrete P sorption (%) = be^{-mx}

(1)

m is the slope of the design curve, b is the Y intercept and x is P added (mg kg^{-1}) (x-axis value). Figure 3.1 illustrates an example of a design curve.

For every RT and P concentration combination a SAS (SAS, 2003) "proc reg" command was used to test the significance of the relationship between discrete P sorption and P added. All combinations were significant at $p < 0.05$. To predict the slope and intercept of the "design curve" (Fig. 3.1) as a function of P concentration and RT, two multiple linear regression (MLR) models were constructed. The slopes were log transformed (log –slope) before producing the MLR model since they were not normally distributed. Log transformation was also done on the Y intercepts. A SAS "proc reg" command was used to produce the MLR model using RT and P concentrations as the

independent variables. A SAS "stepwise" procedure was then used to determine which material properties had an effect on the design curve parameters. The characteristics that were statistically significant had the greatest influence on the model parameters used to predict the design curve slope and Y intercept.

RESULTS AND DISCUSSION

Material characteristics

For an industrial by-product to be an effective P sorber it must contain high amounts of reactive elements (Ca, Mg, Al, or Fe). A PSM will react with P by either Ca/Mg (precipitation) or Al/Fe (ligand exchange and precipitation) sorption mechanisms (Penn et al., 2011). In addition to possessing high total concentrations of reactive elements, the form in which the element is in is also important. For Ca/Mg materials it is important for them to be highly water soluble. It is also important for these materials to have a high pH and be well buffered (high BI) at the higher pH for the precipitation reactions to occur. An Al/Fe material should contain large amounts of amorphous Al/Fe (oxalate Al/Fe) and not have an elevated pH.

AMDR1 and AMDR3 contained high amounts of total and oxalate Fe (table 3.1). This is not a surprise as these materials formed as acid mine drainage water rose to the surface and the Fe became oxidized and precipitated. They also had low pHs and were poorly buffered at a pH above 6. They both also contained the iron hydroxide mineral goethite, along with some considerable amounts of Al. Thus these two materials will most likely remove P by Al/Fe mechanisms. The AMDR2 and AMDR4 materials were quite different than the other two. These two materials contained high amounts of total

and water soluble Ca and Mg. Both materials had pHs above 7 and AMDR 4 was highly buffered at a pH above 6. X-ray diffraction results showed these materials contained the Ca minerals gypsum (AMDR2) and calcite (AMDR4) which can probably be explained by their formation where calcium carbonate was used to precipitate Fe from acid mine drainage water. Total and oxalate Al and Fe is also high in these materials which means that they can most likely react with P by either mechanism. Penn et al., (2011) found that AMDR materials can sorb large amounts of P by both mechanisms.

Slag fines, Fly-ash1, and Fly-ash2 all contained large amounts of total Ca, Mg, Al, and Fe. However the fly-ash materials contained larger amounts of water soluble Ca and oxalate Al and Fe than did Slag fines. These three materials had pHs above 11 and had a relatively high BI. Therefore the mechanism most likely involved here is Ca/Mg precipitation as the pH is too high for Al and Fe to be effective. Another Ca material that contained high amounts of total and soluble Ca was FGD gypsum, but it should be pointed out that this material is poorly pH buffered compared to the other Ca materials.

The Ca-WTR was produced from a drinking water treatment plant that used calcium hydroxide as a flocculating agent. Therefore this material contained a large amount of Ca and had elevated pH and good BI. The two Al-WTRs were produced from drinking water treatment plants that utilized aluminum sulfate as a flocculating agent. These two materials had near neutral pHs and low BIs to go along with high amounts of total and oxalate Al.

Excell Minerals contained a large amount of Ca along with considerable amounts of Mg, Al, and Fe. Water soluble Ca was however not very high for this material. With

a pH around 11 and the highest BI among the by-products analyzed, this material will primarily sorb with P via the Ca/Mg mechanism.

Effects of retention time and P concentration

A design curve is used to predict the longevity and P removal capacity of a PSM. An example of a design curve is shown in figure 3.1 where P added (mg kg^{-1}) is on the x-axis and discrete P removal (%) is on the y-axis. When the curve approaches the x-axis or zero percent discrete P removal it means the material is saturated and will no longer sorb P. The shape of the design curve will give insight into how much P a material will remove. A steep curve with a small Y intercept will not be able to remove as much P as a less steep curve with a large Y intercept. Also, cumulative P removed (mg kg^{-1}) can be found by integrating the area under the design curve. All flow-through curves produced were statistically significant at $p < 0.05$.

As shown in tables 3.2 and 3.3, RT and P concentration were statistically significant variables for predicting the slope (table 3.2) and Y intercept (table 3.3) of the design curve. For 6 out of the twelve materials RT showed a significant effect ($p < 0.1$) on the slope of the design curve. Phosphorus concentration had a greater influence on the slope as significance was shown on 10 of the materials. Overall model p values for the design curve slope were significant for all materials except AMDR2 and Fly-ash2. When looking at the prediction of the Y intercept (table 3.3), RT was significant for 7 materials while P concentration was significant for 6. The overall model was significant for predicting the Y intercept for 8 materials.

In discussion of the statistically significant parameters for predicting the slope and Y intercept, only one RT parameter for predicting the slope (table 3.2) had a negative value (FGD gypsum1). The negative value indicates that as RT is increased the slope will be less steep. So a material with a positive RT parameter for predicting the slope will have a larger decrease in P sorption as more P is added compared to a material with a negative RT parameter.

A more positive RT parameter for predicting the Y intercept (table 3.3) means that as RT increases so does the Y intercept. So increasing RT will improve the initial efficiency of P removal. Therefore, the steeper design curve slope from large RT parameters for predicting the slope will be counteracted by the increase in the Y intercept. AMDR1 is an example of a material whose Y intercept was significantly impacted by RT and is shown in figure 3.1a. On the other hand, the Y intercept of Al-WTR1 was not significantly impacted by RT and is shown in figure 3.1b.

Negative values observed for P concentration parameters for predicting the design curve slope indicate that as inflow P concentration goes up, the design curve slope becomes less steep. This means that sorption will not decrease as much with further P loading when the concentration is increased. However a less negative P concentration parameter value for predicting the Y intercept means that high P concentrations will not decrease the Y intercept of the design curve as much when compared to a more negative parameter.

Material chemical properties that effect parameters of the design curve

Table 3.4 provides the material chemical properties that were found to be significant in regards to predicting the parameters of the design curve using the SAS "stepwise" program. The RT parameter for predicting the slope was significantly impacted by water soluble Ca and oxalate Fe. The negative parameter value for water soluble Ca means that as Ca increases RT has less of an effect on the slope. More soluble Ca in solution prevents complete depletion of Ca as precipitation reactions occur with P, so this helps prevent a decrease in the slope as RT changes. Johansson and Gustafsson (2000) studied blast furnace slags and found they were able to efficiently retain P. They concluded that P removal is dependent on large quantities of soluble Ca along with alkaline conditions. The positive value of the oxalate Fe indicates that as Fe goes up so does the ability of RT to have an impact on the slope. The P concentration parameter for predicting the slope was affected by total and water soluble Mg. Total Mg had a negative parameter while water soluble Mg was positive.

The intercept parameter for predicting the slope is a good way to compare slopes between materials without confounding effects of RT and P concentration. Materials with less negative intercept parameters will have a steeper negative slope compared to materials with a more negative slope. With this being said, FGD gypsum1 will have the steepest slope of all the materials as it has the least negative intercept parameter (table 3.2). Oxalate Fe and Al showed negative parameter values for slope (table 3.4) meaning that materials that have more oxalate Fe and Al will have less negative slopes. This indicates that oxalate Fe and Al play a major role in sorbing with P as they are they reactive forms of Fe and Al. High P sorption capacities were discussed by Dayton and

Basta (2005) in drinking water treatment residuals that contained high amounts of amorphous Al and Fe oxides.

Oxalate Fe was a significant property when looking at the RT parameter for predicting the Y intercept (table 3.4). An increase in oxalate Fe will allow for an increase in the Y intercept with increasing RT. Increased water soluble Ca had the same impact for the P concentration parameter for estimating the Y intercept (table 3.4). Materials with more water soluble Ca will be able to keep the intercept higher even as P concentration increases compared to materials with less water soluble Ca.

A greater Y intercept was observed for materials with a higher BI when looking at the intercept parameter for predicting the design curve Y intercept (table 3.4). Buffer index is important because a material has to have the ability to maintain a pH in a range suitable for their mechanism to work. For example a Ca material has to keep a pH above 6 to be effective. Kostura et al., (2005) studied blast furnace slags and showed the release of P from materials as pH dropped. They found that more pH buffered samples could sorb more P. Also found to be important in this group was water soluble Mg.

CONCLUSION

Retention time and P concentration had a significant impact on P sorption for most materials. The flow-through approach allows for the manipulation of these parameters unlike an isotherm. This is important for constructing a design curve that will predict the sorption capacity and longevity of materials when used in a P removal structure. Materials that are high in water soluble Ca, oxalate Fe and Al, and BI had the biggest impact on P sorption and the design curve. Precipitation reactions are the main

mechanism in which Ca reacts with P and Ca must be in solution for this to occur. This is why soluble Ca is an important characteristic. Penn et al., (2011) found that materials with high total calcium were most effective at precipitating P when the Ca was highly soluble. The same can be said for oxalate Fe and Al, Elliott et al., (2002) found that oxalate Fe and Al was a good predictor of the P-fixing capacity of WTRs. A materials ability to maintain a pH above 6 (high BI) is also important for Ca precipitation to take place (Lindsay, 1979). Materials analyzed for these properties will allow for insight into their abilities to function in a P removal structure.

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Table 3.1: Properties of by-products used in the flow-through experiments

	Total Ca	Total Mg	Total Al	Total Fe	Water soluble Ca	Water soluble Mg	Oxalate Al	Oxalate Fe	BI†	pH	EC‡	Crystalline minerals
Material	mg kg^{-1}								Eq kg^{-1}		mS cm^{-1}	
AMDR1	220	123	2033	455681	97	24.7	136	25951	0.000	3.24	0.51	Goethite
AMDR2	23006	1555	98282	189871	6705	436.8	46784	30415	0.208	7.09	2.79	Hematite, Gypsum
AMDR3	8342	1167	9292	338805	3727	237.0	353	39809	0.009	6.35	1.98	Goethite
AMDR4	204779	34853	16651	118259	709	2122.9	5389	32818	1.779	8.39	2.97	Calcite
Slag fines	272452	90142	36843	155062	611	1.2	931	4402	0.677	11.30	0.66	Portlandite
Fly-ash1	150941	25961	86898	41821	1136	0.8	27090	8619	0.638	11.44	1.35	Quartz
Fly-ash2	153547	28469	64934	36637	1042	0.9	29281	10001	0.941	11.40	1.32	Quartz
FGD gypsum1	209000	1501	782	1791	6520	37.1	56	610	0.032	8.12	2.15	Gypsum
Ca-WTR1	286629	19060	14166	7177	751	2181.3	5210	998	0.931	8.89	6.30	Calcite
Al-WTR1	3277	1644	157325	16824	424	20.2	57739	2515	0.026	7.26	0.45	Quartz
Al-WTR2	18661	1857	81375	14487	2179	25.6	37420	2108	0.064	7.32	2.14	Quartz
Excell Minerals	268523	62408	20723	70475	203	1.9	2301	19183	2.335	10.99	0.40	Tri-calcium magnesium orthosilicate

† Buffer index; equivalents of acid kg^{-1} required to decrease pH to 6.0
‡ Electrical conductivity

Table 3.2: Model parameters for predicting slope of the design curve for each by-product as a function of flow-through retention time and phosphorus (P) concentrations. Slope values are log transformed (log –slope).

	Retention time		P concentration		Intercept		Overall Model
Material	Parameter	p value	Parameter	p value	Parameter	p value	p value
AMDR1	0.01838	0.0195	-0.01443	0.0034	-3.9627	<0.0001	0.0013
AMDR2	-0.01143	0.1087	-0.00315	0.4682	-4.2162	<0.0001	0.2118
AMDR3	0.05033	0.01	0.01646	0.1528	-4.37742	<0.0001	0.0051
AMDR4	0.04191	<0.0001	-0.02003	<.0.0001	-4.12699	<0.0001	<0.0001
Slag fines	0.0174	0.9243	-0.09297	0.0001	-3.24951	<0.0001	<0.0001
Fly-ash1	0.01703	0.3288	-0.02851	0.0122	-3.80047	<0.0001	0.0252
Fly-ash2	-0.0104	0.6741	-0.02546	0.087	-3.77582	<0.0001	0.2215
FGD gypsum1	-0.07616	< 0.0001	-0.05743	<0.0001	-1.1482	<0.0001	<0.0001
Ca-WTR1	0.000208	0.9907	0.02585	0.0228	-4.24064	<0.0001	0.0722
Al-WTR1	-0.00764	0.503	-0.01881	0.0107	-4.12499	<0.0001	0.0297
Al-WTR2	0.04167	0.0052	-0.01725	0.0549	-3.70686	<0.0001	0.004
Excell Minerals	0.04811	0.0133	-0.03181	0.0088	-4.48647	<0.0001	0.0021

Table 3.3: Model parameters for predicting the Y intercept of the design curve for each by-product as a function of flow-through retention time and phosphorus (P) concentrations. Y intercept values are log transformed.

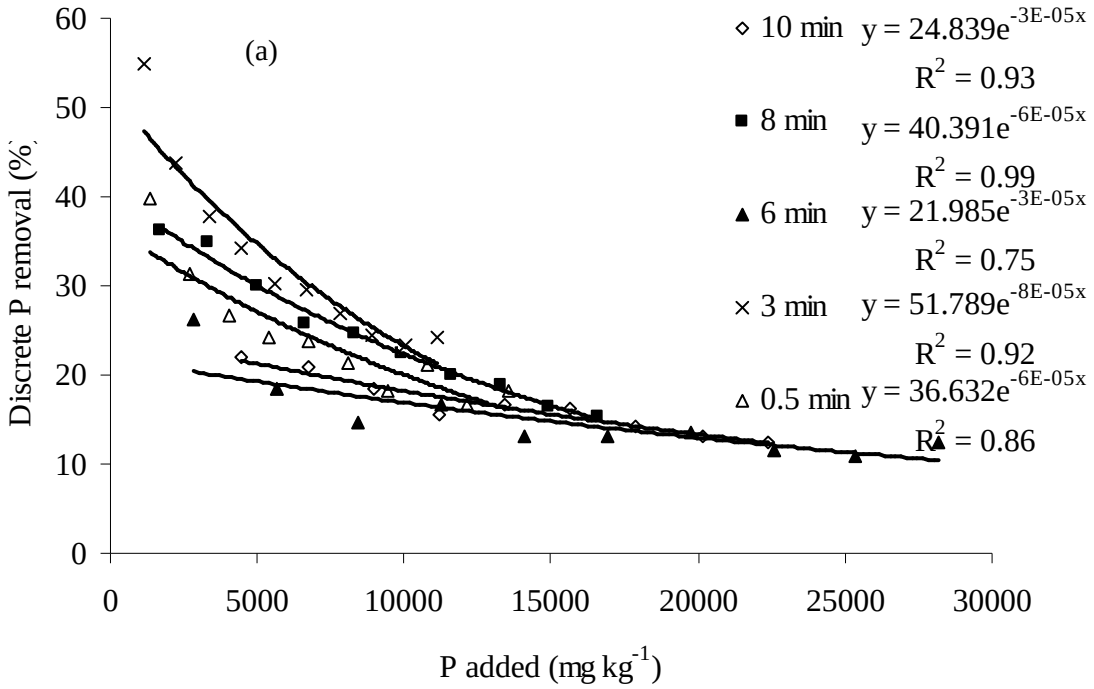
	Retention time		P concentration		Intercept		Overall Model
Material	Parameter	p value	Parameter	p value	Parameter	p value	p value
AMDR1	0.03045	<0.0001	-0.00974	0.0009	1.61596	<0.0001	<0.0001
AMDR2	-0.00905	0.0599	0.01453	<0.0001	1.75964	<0.0001	<0.0001
AMDR3	0.04451	<0.0001	0.01079	0.0409	1.04106	<0.0001	<0.0001
AMDR4	0.04247	<0.0001	-0.01485	0.0025	1.36396	<0.0001	<0.0001
Slag fines	0.00542	0.1795	0.00283	0.2556	1.96974	<0.0001	0.1988
Fly-ash1	0.00726	0.4187	-0.01478	0.0119	1.96512	<0.0001	0.0284
Fly-ash2	-0.01149	0.231	-0.00502	0.3752	2.00253	<0.0001	0.3637
FGD gypsum1	-0.02957	0.0001	-0.00028579	0.941	2.13484	<0.0001	0.0004
Ca-WTR1	-0.01832	<0.0001	0.00086459	0.7394	1.87339	<0.0001	0.004
Al-WTR1	-0.00314	0.6561	-0.00644	0.1479	1.4957	<0.0001	0.3117
Al-WTR2	0.03853	<0.0001	0.01352	0.0024	1.1708	<0.0001	<0.0001
Excell Minerals	0.0009471	0.8948	-0.00254	0.569	4.82065	<0.0001	0.8416

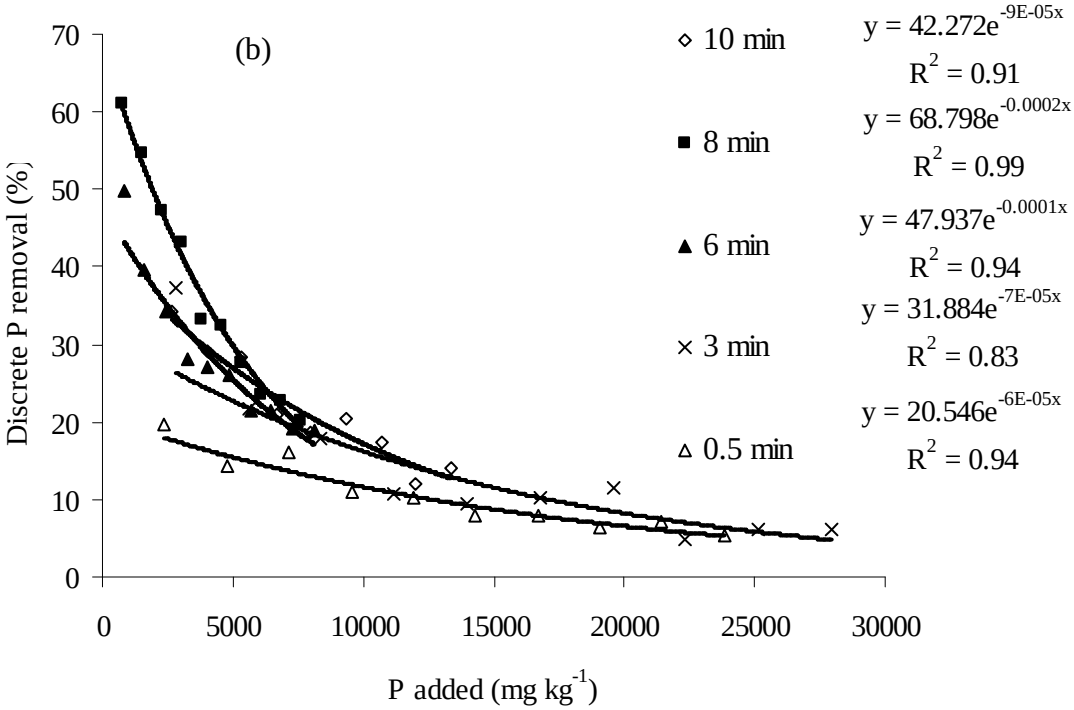
Table 3.4: By-product properties most influential on the design curve model parameters (equation X) listed in Tables 2 and 3 as determined by the SAS "stepwise" procedure.

Variable	Parameter	Partial R^2	Model R^2	p Value
	Design curve slope equation: retention time parameter			
Water soluble Ca	-9.4E-06	0.29	0.29	0.072
Oxalate Fe	1.4E-06	0.33	0.62	0.022
	Design curve slope equation: P concentration parameter			
Total Mg	-6.86E-07	0.4	0.40	0.029
Water soluble Mg	1.74E-05	0.21	0.61	0.056
	Design curve slope equation: intercept parameter			
Oxalate Fe	-4.27E-05	0.31	0.55	0.033
Oxalate Al	-1.92E-05	0.19	0.64	0.042
	Design curve Y intercept equation: retention time parameter			
Oxalate Fe	1.00E-06	0.33	0.33	0.049
	Design curve Y intercept equation: P concentration parameter			
Water soluble Ca	2.48E-06	0.34	0.34	0.046
	Design curve Y intercept equation: intercept parameter			
BI†	1.15	0.48	0.48	0.012
Water soluble Mg	-6.42E-04	0.25	0.73	0.018

† Buffer index; equivalents of acid kg^{-1} required to decrease pH to 6.0

Figure 3.1: Example of experimentally determined flow-through phosphorus (P) sorption curves at 5 different retention times for AMDR1 at 10 mg P L^{-1} inflow solution (a) and Al-WTR1 at 5 mg P L^{-1} inflow solution (b).


(a)
10 min y = 24.839e-3E-05x
R2 = 0.93
8 min y = 40.391e-6E-05x
R2 = 0.99
6 min y = 21.985e-3E-05x
R2 = 0.75
3 min y = 51.789e-8E-05x
R2 = 0.92
0.5 min y = 36.632e-6E-05x
R2 = 0.86
Discrete P removal (%)
P added (mg kg-1)
0
10
20
30
40
50
60
0
5000
10000
15000
20000
25000
30000


(b)
10 min y = 42.272e-9E-05x
R2 = 0.91
8 min y = 68.798e-0.0002x
R2 = 0.99
6 min y = 47.937e-0.0001x
R2 = 0.94
3 min y = 31.884e-7E-05x
R2 = 0.83
0.5 min y = 20.546e-6E-05x
R2 = 0.94
Discrete P removal (%)
P added (mg kg-1)
0
10
20
30
40
50
60
70
0
5000
10000
15000
20000
25000
30000

CHAPTER IV

DESIGN AND HYPOTHETICAL IMPLEMENTATION OF PHOSPHORUS REMOVAL STRUCTURES

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ABSTRACT

Use of industrial by-products to reduce dissolved phosphorus (P) losses from the landscape has been widely studied. However, past research has been devoted to applying the by-products directly to soil or manures which does not remove the P from the system, only making it temporarily unavailable. Incorporation of industrial by-products into a structure that could filter high P runoff water and have the ability to remove the material once saturated would allow for removal of P from the system. Little information is published on the design and implementation of this type of structure. The purpose of this paper is to give an overview of the information needed to build a structure and to use industrial by-product chemical and sorption characteristics to construct a hypothetical structure. Phosphorus loads and concentrations, maximum and average flow rates, and slope are all things that must be taken into account before building a structure at a

specific location. Materials must be screened for P sorption abilities and safety before used in a structure. The ultimate goal is to remove dissolved P from runoff water while remaining safe and economically sound. Presented in this paper is an example design of a P removal structure for an agricultural watershed.

INTRODUCTION

Phosphorus (P) loading of soils from over applications of organic and inorganic fertilizers increases the risk of P loss in runoff waters from the terrestrial system. Degradation of freshwater bodies by eutrophication is controlled by phosphorus loaded runoff that enters the system (Sharpley et al., 1999). Source and transport of P are the two factors that must be addressed when evaluating a locations susceptibility to P loss (Bottcher et al. 1995). The source factor relates to soil P levels and can be managed by controlling livestock P intake along with minimizing organic and inorganic fertilizer applications to fields already high in soil test P (Penn and Bryant, 2006; Sharpley et al., 1994). The transport factor relates to soil properties and cover, which can be managed by controlling runoff and erosion from the landscape (Sharpley et al., 2001). Best management practices (BMPs) can be incorporated to help reduce runoff and erosion. A BMP is an economical on-farm action that helps reduce nutrient levels in drainage water (Bottcher et al. 1995). Practices that have been used include conservation tillage, crop residue management, buffer strips, terracing, cover crops, and contour tillage. All of these methods encourage infiltration by reducing the impact of rainfall and slowing the velocity of surface water flow. While these practices are effective at reducing particulate P losses by reducing sediment loss, they do little to prevent dissolved P loss. Dissolved P is more of a concern due to the fact that it is 100% biologically available to aquatic organisms thus it can more easily promote eutrophication (Sonzogni et al., 1982). A possible alternative BMP that has shown great promise is using industrial by-products as phosphorus sorbing materials (PSMs) to react and sorb with dissolved P and remove it

from solution. Research has shown that by-products such as electric arc furnace steel slag (Drizo et al., 2006; Shilton et al., 2006), drinking water treatment residuals (Penn and Bryant, 2006; Novak and Watts, 2004), acid mine drainage residuals (Han et al., 2005; Penn et al., 2007), gypsum (Watts and Torbert, 2009; Brauer et al., 2005), and fly-ash (Pathan et al., 2003; Urgurlu and Salman, 1998) are effective PSMs. These materials are effective as they contain large quantities of Ca, Mg, Al, and Fe which allow them to react with P. Precipitation (Ca, Mg, Al, and Fe) and ligand exchange (Al and Fe) reactions are the two mechanisms in which these materials will interact with P. In the past, research has been devoted to applying these materials directly to the field or manures. One such study by Dayton and Basta (2005) showed that WTRs reduced dissolved reactive P losses from a field that had received poultry litter applications. They also found reductions in soluble and Mehlich III extractable P when WTRs were applied to a high P soil. It is important to point out that while the solubility of P is reduced when applied to soils or manures the form of P is only changed and not actually removed from the system. Therefore the P can be released at a later time and be potentially transported to sensitive water systems. A possible solution is to incorporate industrial by-products into a structure (P removal structure) designed to allow high P water to enter, pass over the material and exit the structure as low P water. Materials incorporated into a P removal structure would allow for the sorption and removal of P from the system when the material is removed following saturation. Little information has been published on designing and using industrial by-products in P removal structures. Shilton et al. (2006) constructed and monitored an 'active' slag filter at a waste water treatment plant for 11 years and found that 77% of total P that passed through it was removed from solution.

However, this high performance was only observed in the first 5-year period, the efficiency dropped off in the remaining 6 years of the study. They concluded that "future research is recommended in terms of refining a methodology for predicting the longevity and for improving the design and understanding of the filter removal mechanisms". Flow-through experiments allow for the simulation of conditions that would be seen in a P removal structure. Using flow-through data a design curve that plots P added (mg kg^{-1}) on the x-axis and discrete P removed (%) on the y-axis can be created. This design curve can help predict the longevity and amount of material needed to remove a certain percentage of P thus assisting in properly constructing a P removal structure. Therefore the objectives of this study were to (i) discuss the information needed to construct a P removal structure; and (ii) use the model from flow-through data to predict the amount of material needed to remove a certain percentage of P in order to construct a hypothetical P removal structure.

IMPORTANT FACTORS FOR FILTER CONSTRUCTION

A P removal structure follows the simple concept of channeling high concentrated P water into it, water moves through a PSM and exits the box with lower concentrations of P. The ultimate goal is to remove the PSM once saturated thus removing the P from the system. Designing and installing a P removal structure must take into account many factors in order to be cost effective and efficient.

Site selection is an important first step to constructing a filter. An ideal location will have high concentration P waters flowing at an almost constant rate and be hydrologically connected to a receiving water body. High concentrated P water is an

important factor as treatment of this flow will have more of an impact for protecting downstream water systems. Treatment of low P systems would have minimal effects and not be cost effective. Drainage water must pass through the material to work, so flow at the location has to have the ability to be directed into the structure. This requires the gradient at the location to be suitable for channeling flow into a filter. An example of a well suited location is agricultural drainage ditches. Drainage ditches are used to lower water tables and prevent ponding on agricultural fields (Nguyen and Sukias, 2002). However, these ditches can also be a channel for high concentrated P water especially in areas where there is high soil test P due to over fertilization of organic fertilizers or animal production operations (Kleinman et al., 2007). The form in which P is in is another important factor as particulate P can be reduced by controlling erosion therefore runoff water at a location should consist mostly of dissolved P. Penn et al. (2007) studied a ditch on the eastern shore of Maryland and found that 75 to 95% of total P was in the dissolved form. For a P removal structure to be installed the site must have available space along with a slope and channel depth conducive for construction. Accessibility to the site is also vital as the goal is to remove and replace PSMs once they are saturated.

After a location is determined, a structure must be built to handle the dynamic features of the site. Features that must be considered at a desired location include the average and maximum flow rates and concentration of the typical P loads (Penn et al., 2010). A structure must be designed to handle a large % of water that passes through it, therefore the size and dimensions of the structure must be constructed to handle the flow rates that occur. Flow rates will vary with time due to storm events or other weather conditions. Therefore it is important to not only determine the maximum flow rate but

the flow rates that occur a majority of the time. For example if a majority (≈ 75%) of the flow rate at a site is less than 15 L sec^{-1}, the structure would need to be built to handle that maximum flow rate. This will provide the best efficiency as the structure is built for the flow rates that occur most at that location. Along with flow rate, P load concentration is important as it will help determine the amount of sorbing material needed. Combining flow rate and P concentration provides an estimate of the total load of P that will move through the structure in a given time period. Hydrological transport models are useful tools to predict the amount of dissolved P at a site. One such model is the Soil and Water Assessment Tool (SWAT), which is an internationally accepted watershed modeling device (Gassman et al., 2007). The output data from this model can be used as an input into the model that was discussed in chapter III, the model can then predict how much P a material will remove in a structure. The curve number method created by the Natural Resources Conservation Service is another widely used and helpful tool to predict surface runoff amounts (Grove et al., 1998).

A screening process must be used when determining what material should be used in a structure. Availability, cost and transport, potential contaminants, physical and chemical properties, and P sorption kinetics must all be taken into account when selecting a material (Penn et al., 2007). As mentioned above these structures must be cost effective so the goal is to find a material that is in abundance, inexpensive (or even free), and close to the structure location. Companies that produce by-product materials often have no other choice but to landfill the material so finding an alternate use for their waste would be of benefit to them. Coal fired power plants (fly-ash and gypsum), drinking water treatment facilities (water treatment residuals), steel industry (electric arc furnace steel

slag), and the mining industry (acid mine drainage residuals) have locations throughout the United States. It is important to find the closest available unit as this will reduce the transportation cost and overall cost of the structure. A material must also not have negative impacts to the environment it is placed in. By-products should be screened for pH, alkalinity, and trace metals. Many materials have elevated pHs which could alter the pH of the system, however if the alkalinity is low they will be weakly buffered and have little impact. Since these materials come from industrial processes they have potential to contain high amounts of trace metals. Trace metal release must be quantified before placing a material into a filter.

Physical and chemical properties of the materials will aid in designing a structure and estimating its performance. Bulk density will provide information on how much area a material will take up for a given site. Hydraulic conductivity must be known to determine how fast water will be able to move through the material and will help calculate the size parameters of the structure. Finally, porosity is needed to calculate the retention time. Retention time is the amount of time the material is contact with the solution and is important in determining how well a material will work in a structure. As was discussed in chapters I and II, many chemical properties play an important role in determining a materials ability to sorb P. Total reactive elements and chemical forms contained in the material will give insight into which mechanism will be responsible for P sorption. The pH of the material is also important in determining what mechanism will occur. A material high in Ca and Mg will precipitate with P if the pH is high enough (> 8), but the Ca and Mg mechanism will not function as well as the pH drops further below 8. The same but opposite can be said for Al and Fe materials. Precipitation and/or ligand

exchange mechanisms with Al/Fe materials will occur as long as the pH stays below 8. Therefore, a materials ability to buffer the pH to a desirable range for P sorption to take place is also important. More important than total elements is the form in which the element is in. Soluble Ca and Mg are important for promoting P precipitation (Johansson and Gustafsson, 2000; Penn et al., 2011) while amorphous (oxalate extractable) Al and Fe (Elliott et al., 2002; Dayton and Basta, 2005a) will be more capable of precipitating or sorbing with P. Information about the mineralogy of crystalline minerals contained in the by-products is also important as it can provide insight into the solubility of the materials.

Phosphorus sorption capabilities of a material can be estimated using batch isotherms or flow-through experiments. As was discussed in chapter II, batch isotherms are not the best method to estimate the P sorption capacity. A flow-through approach is more realistic to conditions that are seen in a P removal structure. Flow-throughs allow for the constant replenishment of a P solution while reaction products are simultaneously being removed. The varying retention time provides a closer estimate of the amount of P a material can handle. Utilizing the physical, chemical, and sorption data for a material along with site factors will allow for proper design of a structure.

Hypothetical Construction of a P Removal Structure

Site Description

Easton et al. (2008) discussed a 164-ha watershed located in the Cannonsville basin in Delaware County, NY. The watershed drains into the West Branch of the Delaware River which drains into New York City's Cannonsville reservoir. A single dairy farm is located on the watershed where manure is spread on the farm and pastures

nearby. Snow accumulation and melting dominates the hydrology of the site and the topography is steep (Bishop et al., 2005). They found that 300 kg of dissolved P was exported from this watershed over 7 years (42.86 kg yr^{-1}).

Structure Development

This location would be ideal for constructing a P removal structure as there is a large load of dissolved P and protection of the downstream reservoir is crucial. Acid mine drainage residuals (AMDRs) are common in coal mining areas on the east coast (Skousen and Ziemkiewicz, 2005); therefore this material would be suitable as it would minimize transportation costs. Drinking water treatment residuals (WTRs) can also be found throughout the United States and would be worth considering at this location. Using flow-through and characterization data from chapters II and III, AMDRs 1, 2, 4 and Al-WTR1 were determined to be suitable materials to utilize at this location. Table 4.1 provides valuable characterization data that shows why these materials are effective at sorbing with P. AMDR1has high amounts of total and oxalate extractable Fe and a pH that is suitable for the Fe mechanism to occur. AMDR2 has high total and oxalate Fe but total and oxalate Al are also high in this material. AMDR4 would be considered a Ca material as it has high amounts of total Ca with a good buffer index and pH above 8. Al-WTR1 has high total and oxalate Al which makes it a suitable material to remove large quantities of P from solution.

A quick comparison can be made between the materials to see the amount of space required to build a structure to remove a certain percentage of total P. For this example we will assume that the RT is 10 minutes and the inflow P concentration is 0.5

mg P L^{-1}. A target P reduction of 30% will also be set. At this 30% reduction level, the models created from flow-through data for AMDRs 1, 2, 4 and Al-WTR1 predict that 3.11, 2.71, 5.62 and 4.14 tons of material on an annual basis would be needed to reach this goal. Using the bulk density of the material along with the mass of the material needed to reach the goal, the area in which the structure will occupy can be calculated (table 4.2). AMDR1 has the smallest "footprint" of the four materials, meaning it will require less area to remove the same amount of P. Changing the depth of the material also alters the total area needed. A structure with a shallow depth of material (i.e. more spread out) will be able to handle a higher maximum flow rate but will have a lower RT. On the other hand, a structure with a deep depth (smaller footprint) will have an increased RT but will treat less water at higher flow rates, this will be discussed further below.

Using the Darcy equation (equation 4.1) the flow rate through the structure can be estimated which will allow for an estimation of the RT of the structure.

Equation 4.1: $Q = KA * \Delta H/L$

Q is the flow rate (volume/time), K is the hydraulic conductivity (HC), A is the cross sectional area of the material, ΔH is the hydraulic head, and L is the assumed depth of the material.

Considering AMDR1 had the smallest footprint of the three AMDRs it will be used along with Al-WTR1 for this example. We will assume that the HC is 0.001 cm sec^{-1} and the porosity is 60% for these materials. A hydraulic head of 12 in. will be used for this example as well. Retention time was calculated using equation 4.2.

Equation 4.2: Retention time (min.) = total structure pore space (L) / flow rate at outlet (L min^{-1})

Total pore space is calculated by dividing the total mass of material needed for the structure by the density and multiplying that value by the porosity of the material. Flow rate at the outlet is Q from the Darcy equation.

Table 4.3 shows the different flow rates of a structure when different depths of material are used. As the depth of the material is increased, the flow rate through the structure decreases. However, the decreased flow rate leads to a higher RT. So as explained above, to increase the flow rate the structure needs to be more spread out with a thinner layer of material or increase the hydraulic head. To increase the RT, a structure must have the material stacked deeper. However, the site characteristics will have a major impact on what type of structure is built. The slope will have a major impact on the amount of head possible for a structure. Therefore, depth of material would have to be manipulated to achieve a desired head, flow rate, and RT. A site may also be too small to incorporate a spread out structure, so multiple structures may need to be constructed in order to reach the desired flow rates and RTs. With RT, certain materials may need long RTs in order to efficiently remove P as they have slow reaction kinetics. It is important to know this before construction as a spread out structure filled with this type of material would not be very effective.

For this particular site it would most likely be beneficial to construct multiple structures at different hot spots across the watershed. The 164-ha of land is big enough to constitute multiple structures as the P load in the runoff required a large mass of material

to reduce the concentration to a more desired level. For example the AMDR1 material at a 2 in. depth (2 in. depth is ≈ 10 min RT)(table 4.3) would require a structure of 73 m^2. This would be a relatively large structure if placed at one location and with the steep slopes may not be possible. Also, since there are many locations where manure is applied it is safe to assume that there are different locations where P loads are higher than the rest. Distributing the material throughout the watershed in hot spots would allow for easier design of structures as you don't have to distribute the large area on one structure. Therefore installing multiple structures may make it easier to reach the flow rate or RT required for this situation.

A real life example showing the importance of properly designing and incorporating P removal structures to reach a certain flow rate or RT is shown in a study by Penn et al. (2007). They constructed a P removal structure on the Delmarva Peninsula in Maryland and used an acid mine drainage residual as the PSM. They were able to sequester 99% of dissolved P that passed through the structure during a 24 hour runoff event. However when a tropical storm passed through it increased ditch flow rates beyond what the structure could handle resulting in only 9% of the flow being treated. This helps to show how there is a tradeoff between building a structure to handle large flow rates or building one to increase the RT. Once again this relates back to a specific site and shows the importance of knowing the specific parameters of that location and constructing a filter to maximize P sorption.

CONCLUSION

Phosphorus sorbing materials have shown great ability to sorb with P. Incorporation of these materials into P removal structures allows for the removal of the dissolved P from the system when the material is removed once saturated. Constructing a structure must take into account many factors with regard to the site location and the material used. A location must warrant the use of a structure by having elevated dissolved P levels in runoff. A flow-through P sorption model is an important tool to predict how much material will be needed to remove a certain percentage of P at a location. Dimensions of the box must be set to allow for high flow rates or high RTs and will depend on the location and material used. Materials must be locally available and safe to the environment they are placed in. The ultimate goal is to build a structure that is economical, safe, and efficient at reducing dissolved P levels in order to protect sensitive water bodies from P loading.

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Table 4.1: Material Characteristics Important for Phosphorus Sorption in a Phosphorus Removal Structure.

Material	Water Ca	Water Mg	Water Fe	Water Al	Total Ca	Total Mg	Total Fe	Total Al	Oxalate Al	Oxalate Fe	BI†	pH	EC‡
	mg kg^{-1}										Eq kg^{-1}		mS cm^{-1}
AMDR1	97.3	24.7	1.28	13.4	220	123	455681	2033	136	25951	0.000	3.24	0.51
AMDR2	6705	437	0.35	0.64	23006	1555	189871	98282	46784	30415	.208	7.09	2.79
AMDR4	709	2123	0.33	0.80	204779	34853	118259	16651	5389	32818	1.779	8.39	2.97
Al-WTR1	424	20.2	0.23	0.81	3277	1644	16824	157325	57739	2515	.026	7.26	0.45

† Buffer index; equivalents of acid kg^{-1} required to decrease pH to 6.0
‡Electrical Conductivity

Table 4.2: Phosphorus Removal Structure Footprint Based on the Bulk Density and Mass of Material Needed to Remove a Percentage of Phosphorus at Different Material Depths.

Material	Bulk Density	Mass of Material	Area of Structure at Different Material Depths						
			1 Inch	2 Inch	3 Inch	4 Inch	5 Inch	6 Inch	12 Inch
	g/cm^3	kg	m^2						
AMDR1	0.756	2818	147	73	49	37	29	24	12
AMDR2	0.335	2462	289	145	96	72	58	48	24
AMDR4	0.726	5096	276	138	92	69	55	46	23
Al-WTR1	0.652	3756	227	113	76	57	45	38	19

Table 4.3: Retention Times and Flow Rates of Phosphorus Removal Structures at Different Material Depths.

	Material Depth (in.)	1	2	3	4	5	6	12
	Retention Time (min.)	2.1	8.5	19	34	53	76	305
AMDR1	Flow Rate ($L\ min^{-1}$)	1057	264	117	66	42	29	7.3
Al-WTR1		1633	408	181	102	65	45	11

CHAPTER V

SUMMARY

There is a need to slow the loss of P from the terrestrial system in order to protect sensitive downstream water bodies. One solution is to use industrial by-products to remove dissolved P from runoff waters. Use of these materials in P removal structures will allow for the removal of P from the system once the material is removed following saturation. Proper incorporation of these structures could help prevent eutrophication and therefore have major economical benefits to the region in which they are installed.

Industrial by-products that contained high concentrations of total Ca, Mg, Al, and Fe along with water soluble Ca, Mg, Al, Fe and oxalate extractable Al and Fe were found to be the most effective at removing P. The pH of a material was also important as the pH had to be suitable for the reaction mechanism to occur (Ca/Mg pH > 8; Fe/Al pH < 8). For Ca materials it was also important for the material to buffer the pH above 6 in order for the Ca to remain effective at reacting with P. Materials were determined to be safe to use in the environment as all the trace metals analyzed following extractions were below the limits set by the EPA.

Flow-through experiments were determined to be a more effective method for predicting the P sorption capabilities of a material over traditional batch isotherms. Flow-throughs were able to better predict the amount of P sorbed at equilibrium and also the amount of P needed to reach equilibrium. Using flow-through data would provide a better estimate of structure performance compared to isotherms.

The varying retention times and P concentrations tested in the flow-throughs were shown to have a significant impact on P sorption for most of the materials tested. The design curve constructed from flow-through data was significantly impacted by soluble Ca, oxalate Fe and Al, and buffer index. Therefore materials should be screened for those properties to better predict the design curve for the material.

Many factors regarding the site location and material used must be taken into account when designing and constructing a P removal structure. An ideal location will be easy to access, contain a gradient that channels flow, and have elevated dissolved P levels in runoff. Materials used should have high P sorption capabilities, be locally available to minimize transportation costs, and be safe to use in that particular environment. Flow-through experiment data is useful when determining the dimensions of the structure. Depending on the location and material used the dimensions of the box must be set to allow for high flow rates or high RTs. Proper construction of P removal structures will allow for efficient and economical reductions in dissolved P levels which will help in protecting sensitive water bodies.

APPPENDIX A

Flow-through experiment data collected for 12 industrial by-product materials (AMDR-acid mine drainage residual; Fly-ash; WTR- drinking water treatment residual; Slag; FGD gypsum- flue gas desulphurization gypsum; Excell Minerals). Flow-throughs were conducted at room temperature in the Agro-Environmental Chemistry Laboratory, Oklahoma State University, Stillwater, OK. Five different phosphorous concentrations were used (0.5, 1, 5, 10, and 15 ppm) along with five different retention times (0.5, 3, 6, 8, and 10 minutes). Experiment was conducted over a five hour period with samples collected at every 30 minute interval. Samples were analyzed for pH, electrical conductivity, and inorganic phosphorus.

Table A.1: Results of AMDR1 flow-through experiment.

Retention Time	Collection Time	Inflow P Concentration	Outflow P concentration	Cumulative P Added	Cumulative P Sorbed	Discrete removal	Cumulative Removal	pH	EC
----- minutes -----		------ ppm ------		------ mg kg^{-1} ------		------ % ------			mS cm^{-1}
10	60	0.49	0.29	893	633	41.83	70.91	6.8	
10	120	0.49	0.19	1785	1094	61.45	61.28	6	
10	180	0.49	0.24	2678	1601	52.11	59.78	5.85	
10	240	0.49	0.28	3570	2029	43.93	56.84	5.85	
10	300	0.49	0.31	4463	2387	36.22	53.49	6.15	
10	60	0.48	0.38	871	529	21.42	60.71	5.9	
10	120	0.48	0.18	1741	894	62.60	51.36	5.8	
10	180	0.48	0.19	2612	1427	59.74	54.63	5.85	
10	240	0.48	0.22	3482	1918	53.08	55.07	5.85	
10	300	0.48	0.25	4353	2353	46.89	54.06	5.8	
10	60	0.99	0.58	1692	1199	41.69	70.84	5.6	
10	120	0.99	0.44	3385	2026	56.05	59.86	5.4	
10	180	0.99	0.56	5077	2873	44.00	56.58	5.6	
10	240	0.99	0.65	6769	3539	34.74	52.28	5.65	
10	300	0.99	0.71	8462	4075	28.60	48.16	5.7	
10	60	1.00	0.64	1704	1161	36.23	68.11	5.65	
10	120	1.00	0.44	3408	1945	55.78	57.06	5.45	
10	180	1.00	0.56	5112	2799	44.51	54.75	5.55	
10	240	1.00	0.65	6817	3477	35.08	51.01	5.7	
10	300	1.00	0.71	8521	4028	29.56	47.27	5.75	
10	30	5.05	3.53	688	448	30.15	65.08	5.8	
10	60	5.05	2.47	1376	728	51.19	52.88	5.4	
10	90	5.05	2.23	2064	1096	55.83	53.09	5.25	
10	120	5.05	2.60	2752	1455	48.54	52.86	5.55	
10	150	5.05	2.95	3440	1765	41.70	51.31	5.55	
10	180	5.05	3.21	4128	2034	36.38	49.27	5.55	
10	210	5.05	3.50	4816	2265	30.76	47.02	5.6	
10	240	5.05	3.62	5504	2468	28.33	44.84	5.65	
10	270	5.05	3.81	6192	2650	24.53	42.79	5.75	
10	300	5.05	3.89	6880	2814	23.01	40.89	5.85	
10	30	4.97	3.63	678	431	27.07	63.54	5.75	
10	60	4.97	2.32	1355	703	53.29	51.86	5.4	
10	90	4.97	2.10	2033	1079	57.77	53.08	5.2	
10	120	4.97	2.37	2710	1452	52.29	53.57	5.55	
10	150	4.97	2.68	3388	1785	46.04	52.69	5.5	
10	180	4.97	2.95	4066	2079	40.80	51.15	5.5	
10	210	4.97	3.11	4743	2345	37.56	49.44	5.6	
10	240	4.97	3.33	5421	2584	33.09	47.67	5.6	
10	270	4.97	3.46	6098	2799	30.47	45.91	5.65	
10	300	4.97	3.65	6776	2993	26.61	44.17	5.8	
10	30	9.80	7.74	1335	808	21.06	60.53	5.9	
10	60	9.80	6.45	2669	1176	34.16	44.07	5.75	
10	90	9.80	6.96	4004	1598	29.01	39.91	5.65	
10	120	9.80	7.02	5338	1981	28.39	37.10	5.6	
10	150	9.80	7.74	6673	2311	21.06	34.63	5.6	
10	180	9.80	7.98	8007	2575	18.56	32.16	5.6	
10	210	9.80	7.80	9342	2835	20.43	30.35	5.65	

Table A.1: Continued

Retention Time	Collection Time	Inflow P Concentration	Outflow P concentration	Cumulative P Added	Cumulative P Sorbed	Discrete removal	Cumulative Removal	pH	EC
----- minutes -----		------ ppm ------		------ mg kg^{-1} ------		------ % ------			mS cm^{-1}
10	240	9.80	8.10	10676	3087	17.31	28.91	5.7	
10	270	9.80	8.61	12011	3283	12.09	27.33	5.75	
10	300	9.80	8.42	13346	3457	14.04	25.91	5.75	
10	30	9.76	7.84	1329	795	19.65	59.82	5.95	
10	60	9.76	6.15	2659	1172	37.03	44.08	5.9	
10	90	9.76	5.49	3988	1709	43.76	42.85	5.65	
10	120	9.76	5.89	5317	2264	39.69	42.57	5.6	
10	150	9.76	6.48	6647	2751	33.59	41.39	5.6	
10	180	9.76	7.12	7976	3154	27.01	39.54	5.65	
10	210	9.76	7.54	9305	3484	22.78	37.45	5.7	
10	240	9.76	7.92	10635	3761	18.87	35.37	5.8	
10	270	9.76	8.06	11964	4003	17.46	33.46	5.8	
10	300	9.76	8.35	13293	4215	14.48	31.71	5.8	
10	30	15.66	13.97	2133	1182	10.83	55.42	5.6	
10	60	15.66	11.77	4267	1563	24.84	36.63	5.5	
10	90	15.66	12.38	6400	2051	20.94	32.05	5.5	
10	120	15.66	13.12	8533	2448	16.25	28.68	5.55	
10	150	15.66	14.02	10667	2733	10.47	25.62	5.65	
10	180	15.66	13.23	12800	3010	15.52	23.51	5.75	
10	210	15.66	14.53	14933	3253	7.22	21.78	5.65	
10	240	15.66	14.65	17067	3399	6.50	19.92	5.8	
10	270	15.66	14.70	19200	3534	6.14	18.40	5.85	
10	300	15.66	14.98	21333	3645	4.33	17.09	5.85	
10	30	15.55	13.06	2118	1228	16.00	58.00	5.6	
10	60	15.55	10.91	4236	1714	29.82	40.46	5.45	
10	90	15.55	12.10	6354	2264	22.18	35.64	5.45	
10	120	15.55	13.18	8472	2661	15.27	31.41	5.55	
10	150	15.55	13.85	10590	2938	10.91	27.75	5.65	
10	180	15.55	14.08	12708	3154	9.46	24.82	5.65	
10	210	15.55	14.82	14826	3304	4.73	22.29	5.6	
10	240	15.55	14.87	16943	3400	4.36	20.07	5.8	
10	270	15.55	14.98	19061	3485	3.64	18.28	5.85	
10	300	15.55	15.04	21179	3558	3.27	16.80	5.9	
8	42.5	0.49	0.22	780	608	55.87	77.94	6.35	
8	85	0.49	0.22	1561	1043	55.64	66.85	5.8	
8	127.5	0.49	0.22	2341	1472	54.26	62.88	5.7	
8	170	0.49	0.24	3122	1885	51.51	60.38	5.8	
8	212.5	0.49	0.25	3902	2275	48.52	58.31	5.7	
8	255	0.49	0.27	4683	2641	45.07	56.39	5.8	
8	297.5	0.49	0.29	5463	2975	40.70	54.46	5.8	
8	42.5	0.49	0.19	773	624	61.34	80.67	6.35	
8	85	0.49	0.19	1547	1101	62.04	71.18	5.85	
8	127.5	0.49	0.20	2320	1573	59.93	67.78	5.85	
8	170	0.49	0.22	3093	2018	55.25	65.23	5.85	
8	212.5	0.49	0.25	3867	2422	49.16	62.63	5.85	
8	255	0.49	0.27	4640	2783	44.25	59.97	5.85	
8	297.5	0.49	0.29	5413	3114	41.44	57.53	5.85	
8	42.5	0.96	0.45	1140	872	53.00	76.50	6.65	
8	85	0.96	0.49	2280	1454	49.16	63.79	6.75	

Table A.1: Continued

Retention Time	Collection Time	Inflow P Concentration	Outflow P concentration	Cumulative P Added	Cumulative P Sorbed	Discrete removal	Cumulative Removal	pH	EC
-----	minutes -----	------	ppm ------	------	mg kg^{-1} ------	------	% ------		$mS\ cm^{-1}$
8	127.5	0.96	0.59	3420	1952	38.13	57.08	5.9	
8	170	0.96	0.65	4559	2352	32.02	51.58	5.8	
8	212.5	0.96	0.70	5699	2686	26.62	47.12	5.8	
8	255	0.96	0.75	6839	2964	22.18	43.34	5.85	
8	297.5	0.96	0.78	7979	3198	18.95	40.08	6.1	
8	42.5	0.98	0.48	1167	882	51.17	75.59	6.6	
8	85	0.98	0.53	2334	1449	45.90	62.06	6.8	
8	127.5	0.98	0.61	3502	1939	38.18	55.39	5.9	
8	170	0.98	0.67	4669	2349	31.97	50.31	5.8	
8	212.5	0.98	0.71	5836	2697	27.75	46.22	5.85	
8	255	0.98	0.75	7003	2998	23.77	42.81	5.85	
8	297.5	0.98	0.77	8170	3265	21.90	39.96	6.1	
8	30	4.74	1.91	664	531	59.84	79.92	5.95	
8	60	4.74	2.12	1329	913	55.23	68.73	5.1	
8	90	4.74	2.47	1993	1256	47.87	63.00	5.05	
8	120	4.74	2.75	2657	1554	41.97	58.48	5.1	
8	150	4.74	2.96	3321	1818	37.60	54.74	5.1	
8	180	4.74	3.24	3986	2048	31.62	51.39	5.25	
8	210	4.74	3.33	4650	2252	29.84	48.44	5.25	
8	240	4.74	3.51	5314	2438	26.12	45.88	5.4	
8	270	4.74	3.67	5978	2600	22.56	43.49	5.4	
8	300	4.74	3.73	6643	2746	21.43	41.34	5.5	
8	30	4.88	1.66	683	567	66.06	83.03	5.75	
8	60	4.88	1.78	1366	1010	63.54	73.92	5.1	
8	90	4.88	2.16	2049	1417	55.68	69.15	4.9	
8	120	4.88	2.45	2732	1777	49.78	65.04	4.95	
8	150	4.88	2.77	3415	2095	43.25	61.34	5	
8	180	4.88	3.03	4098	2372	37.91	57.88	5.1	
8	210	4.88	3.25	4781	2615	33.34	54.70	5.15	
8	240	4.88	3.45	5464	2829	29.26	51.77	5.3	
8	270	4.88	3.53	6148	3024	27.68	49.19	5.3	
8	300	4.88	3.73	6831	3199	23.59	46.83	5.4	
8	30	9.95	3.88	760	612	61.01	80.50	5.5	
8	60	9.95	4.51	1520	1051	54.68	69.17	5	
8	90	9.95	5.25	2279	1438	47.20	63.10	4.9	
8	120	9.95	5.64	3039	1782	43.27	58.63	5.3	
8	150	9.95	6.64	3799	2073	33.24	54.56	5.4	
8	180	9.95	6.72	4559	2322	32.47	50.94	5.5	
8	210	9.95	7.21	5319	2550	27.53	47.95	5.6	
8	240	9.95	7.61	6078	2744	23.52	45.15	5.7	
8	270	9.95	7.69	6838	2920	22.75	42.70	5.8	
8	300	9.95	7.95	7598	3083	20.13	40.57	5.85	
8	30	10.03	3.23	766	642	67.81	83.91	5.6	
8	60	10.03	4.07	1531	1129	59.39	73.75	4.85	
8	90	10.03	4.89	2297	1553	51.20	67.60	4.8	
8	120	10.03	5.40	3063	1926	46.15	62.87	5.1	
8	150	10.03	5.72	3828	2267	42.94	59.21	5.25	
8	180	10.03	6.80	4594	2554	32.22	55.60	5.35	
8	210	10.03	7.26	5360	2783	27.63	51.93	5.6	
8	240	10.03	7.55	6125	2984	24.72	48.71	5.75	

Table A.1: Continued

Retention Time	Collection Time	Inflow P Concentration	Outflow P concentration	Cumulative P Added	Cumulative P Sorbed	Discrete removal	Cumulative Removal	pH	EC
----- minutes -----		------ ppm ------		------ mg kg^{-1} ------		------ % ------			mS cm^{-1}
8	270	10.03	7.69	6891	3168	23.34	45.97	5.85	
8	300	10.03	7.98	7657	3335	20.44	43.56	5.95	
8	30	15.10	7.06	1015	777	53.21	76.61	5.7	
8	60	15.10	8.03	2029	1285	46.84	63.32	5.5	
8	90	15.10	8.97	3044	1728	40.61	56.78	5.4	
8	120	15.10	9.82	4059	2112	34.99	52.04	5.4	
8	150	15.10	10.20	5073	2454	32.41	48.37	5.55	
8	180	15.10	10.85	6088	2761	28.16	45.36	5.6	
8	210	15.10	10.80	7103	3049	28.47	42.92	5.65	
8	240	15.10	11.65	8117	3309	22.85	40.77	5.75	
8	270	15.10	11.17	9132	3557	26.04	38.95	5.8	
8	300	15.10	11.37	10146	3814	24.67	37.59	5.8	
8	30	15.16	5.72	1018	826	62.24	81.12	5.65	
8	60	15.16	7.47	2037	1402	50.74	68.80	5.25	
8	90	15.16	8.65	3055	1879	42.95	61.49	5.15	
8	120	15.16	9.91	4074	2274	34.64	55.81	5.2	
8	150	15.16	10.14	5092	2619	33.12	51.43	5.4	
8	180	15.16	11.40	6111	2914	24.80	47.68	5.5	
8	210	15.16	11.51	7129	3163	24.05	44.36	5.6	
8	240	15.16	12.23	8148	3383	19.28	41.52	5.75	
8	270	15.16	11.83	9166	3593	21.93	39.20	5.75	
8	300	15.16	12.02	10185	3810	20.72	37.41	5.8	
6	30	0.49	0.25	582	433	48.67	74.33	6.5	0.8
6	60	0.49	0.26	1164	712	47.25	61.15	5.9	0.8
6	90	0.49	0.29	1746	968	40.67	55.42	5.65	0.76
6	120	0.49	0.31	2328	1195	37.38	51.32	5.55	0.78
6	150	0.49	0.32	2910	1401	33.38	48.13	5.5	0.79
6	180	0.49	0.34	3492	1588	31.03	45.48	5.55	0.78
6	210	0.49	0.34	4074	1764	29.39	43.30	5.55	0.81
6	240	0.49	0.36	4656	1925	25.86	41.34	5.65	0.88
6	270	0.49	0.37	5238	2071	24.45	39.54	5.7	0.81
6	300	0.49	0.37	5819	2211	23.74	38.00	5.7	0.8
6	30	0.49	0.25	581	433	49.25	74.63	6.45	0.79
6	60	0.49	0.26	1161	710	45.95	61.11	5.9	0.8
6	90	0.49	0.27	1742	970	43.60	55.67	5.7	0.79
6	120	0.49	0.29	2322	1213	40.30	52.24	5.6	0.82
6	150	0.49	0.31	2903	1433	35.35	49.35	5.6	0.8
6	180	0.49	0.32	3483	1633	33.70	46.88	5.65	0.82
6	210	0.49	0.34	4064	1816	29.46	44.70	5.65	0.79
6	240	0.49	0.34	4645	1989	29.93	42.82	5.65	0.83
6	270	0.49	0.36	5225	2150	25.45	41.14	5.75	0.84
6	300	0.49	0.36	5806	2297	25.21	39.56	5.75	0.81
6	30	0.95	0.43	865	670	54.93	77.46	6.25	0.8
6	60	0.95	0.52	1730	1106	45.79	63.91	5.8	0.81
6	90	0.95	0.56	2595	1482	41.17	57.10	5.6	0.82
6	120	0.95	0.64	3459	1801	32.74	52.07	5.75	0.83
6	150	0.95	0.70	4324	2059	26.93	47.62	5.75	0.775
6	180	0.95	0.75	5189	2270	21.83	43.75	5.65	0.785
6	210	0.95	0.76	6054	2454	20.76	40.54	5.65	0.81
6	240	0.95	0.77	6919	2626	18.98	37.96	5.8	0.84

Table A.1: Continued

Retention Time	Collection Time	Inflow P Concentration	Outflow P concentration	Cumulative P Added	Cumulative P Sorbed	Discrete removal	Cumulative Removal	pH	EC
----- minutes -----		------ ppm ------		------ mg kg^{-1} ------		------ % ------			mS cm^{-1}
6	270	0.95	0.79	7784	2782	17.08	35.74	5.75	0.82
6	300	0.95	0.81	8649	2922	15.19	33.78	5.8	0.8
6	30	0.99	0.39	898	719	60.23	80.12	6.2	0.82
6	60	0.99	0.49	1795	1215	50.18	67.66	5.75	0.82
6	90	0.99	0.57	2693	1629	42.06	60.48	5.6	0.85
6	120	0.99	0.65	3591	1972	34.40	54.92	5.75	0.8
6	150	0.99	0.69	4488	2264	30.63	50.44	5.8	0.83
6	180	0.99	0.71	5386	2527	28.00	46.92	5.7	0.77
6	210	0.99	0.74	6284	2766	25.26	44.02	5.65	0.8
6	240	0.99	0.76	7182	2984	23.20	41.55	5.8	0.85
6	270	0.99	0.78	8079	3184	21.49	39.41	5.75	0.8
6	300	0.99	0.79	8977	3369	19.66	37.53	5.75	0.83
6	30	4.85	2.19	1375	1065	54.86	77.43	6	0.86
6	60	4.85	3.02	2750	1702	37.81	61.88	5.6	0.82
6	90	4.85	3.37	4125	2172	30.55	52.65	5.5	0.83
6	120	4.85	3.67	5501	2550	24.39	46.35	5.7	0.84
6	150	4.85	3.87	6876	2857	20.28	41.55	5.65	0.77
6	180	4.85	3.93	8251	3127	19.02	37.90	5.65	0.8
6	210	4.85	4.01	9626	3377	17.29	35.08	5.7	0.8
6	240	4.85	4.12	11001	3599	15.00	32.71	5.7	0.81
6	270	4.85	4.10	12376	3807	15.39	30.76	5.85	0.81
6	300	4.85	4.20	13751	4006	13.42	29.13	5.95	0.8
6	30	4.74	2.43	1343	998	48.67	74.33	5.95	0.82
6	60	4.74	3.07	2685	1561	35.17	58.13	5.6	0.9
6	90	4.74	3.45	4028	1980	27.24	49.15	5.4	0.82
6	120	4.74	3.72	5370	2306	21.42	42.95	5.7	0.81
6	150	4.74	3.81	6713	2581	19.48	38.45	5.6	0.775
6	180	4.74	3.84	8055	2838	18.84	35.23	5.8	0.79
6	210	4.74	4.16	9398	3046	12.13	32.41	5.75	0.79
6	240	4.74	4.24	10741	3198	10.51	29.78	5.7	0.84
6	270	4.74	4.31	12083	3328	8.89	27.54	5.9	0.81
6	300	4.74	4.28	13426	3453	9.70	25.72	5.95	0.81
6	30	9.64	4.85	810	606	49.74	74.87	5.4	0.81
6	60	9.64	5.83	1620	968	39.55	59.76	4.9	0.82
6	90	9.64	6.34	2430	1267	34.30	52.15	4.95	0.8
6	120	9.64	6.93	3240	1520	28.09	46.91	5.2	0.8
6	150	9.64	7.04	4050	1743	26.98	43.03	5.2	0.83
6	180	9.64	7.12	4860	1958	26.18	40.29	5.3	0.82
6	210	9.64	7.56	5670	2152	21.57	37.95	5.35	0.82
6	240	9.64	7.58	6480	2326	21.41	35.89	5.45	0.84
6	270	9.64	7.79	7290	2490	19.18	34.16	5.5	0.83
6	300	9.64	7.82	8100	2644	18.86	32.64	5.6	0.83
6	30	9.34	5.87	784	537	37.07	68.54	5.2	0.82
6	60	9.34	6.57	1568	799	29.67	50.95	5.05	0.84
6	90	9.34	6.93	2353	1016	25.73	43.20	5.15	0.8
6	120	9.34	7.24	3137	1205	22.44	38.42	5.3	0.84
6	150	9.34	7.73	3921	1361	17.18	34.70	5.4	0.8
6	180	9.34	7.85	4705	1490	15.86	31.67	5.45	0.84
6	210	9.34	8.07	5490	1606	13.56	29.25	5.55	0.84
6	240	9.34	7.87	6274	1720	15.70	27.42	5.6	0.82

Table A.1: Continued

Retention Time	Collection Time	Inflow P Concentration	Outflow P concentration	Cumulative P Added	Cumulative P Sorbed	Discrete removal	Cumulative Removal	pH	EC
----- minutes -----		------ ppm ------		------ mg kg^{-1} ------		------ % ------			mS cm^{-1}
6	270	9.34	7.99	7058	1838	14.38	26.05	5.7	0.83
6	300	9.34	8.18	7842	1943	12.33	24.78	5.7	0.82
6	30	14.69	6.29	1041	819	57.18	78.59	5.4	0.84
6	60	14.69	8.31	2083	1343	43.48	64.46	4.7	0.83
6	90	14.69	9.50	3124	1753	35.33	56.11	4.7	0.83
6	120	14.69	11.05	4166	2066	24.83	49.60	5.25	0.82
6	150	14.69	11.09	5207	2323	24.52	44.62	5.4	0.8
6	180	14.69	11.92	6249	2549	18.88	40.80	5.5	0.76
6	210	14.69	12.28	7290	2733	16.45	37.49	5.7	0.79
6	240	14.69	12.56	8332	2894	14.49	34.74	5.8	0.82
6	270	14.69	12.80	9373	3037	12.93	32.40	5.9	0.8
6	300	14.69	12.85	10415	3170	12.53	30.44	6	0.77
6	30	14.92	5.69	1058	856	61.86	80.93	5.1	0.85
6	60	14.92	7.64	2116	1441	48.82	68.13	4.6	0.84
6	90	14.92	8.81	3173	1916	40.95	60.38	4.55	0.83
6	120	14.92	9.78	4231	2315	34.48	54.72	5.1	0.83
6	150	14.92	11.11	5289	2633	25.53	49.77	5.35	0.84
6	180	14.92	11.34	6347	2894	23.99	45.60	5.55	0.76
6	210	14.92	11.78	7405	3133	21.06	42.31	5.7	0.81
6	240	14.92	12.28	8462	3338	17.74	39.44	5.85	0.82
6	270	14.92	12.80	9520	3507	14.27	36.84	5.9	0.82
6	300	14.92	11.76	10578	3695	21.21	34.93	6	0.81
3	30	0.49	0.18	634	516	62.77	81.38	6.5	
3	60	0.49	0.24	1269	880	52.03	69.39	5.55	
3	90	0.49	0.28	1903	1184	43.87	62.25	5.3	
3	120	0.49	0.31	2537	1443	37.57	56.86	5.1	
3	150	0.49	0.34	3171	1662	31.50	52.40	5.5	
3	180	0.49	0.35	3806	1853	28.93	48.70	5.55	
3	210	0.49	0.37	4440	2024	24.97	45.59	5.7	
3	240	0.49	0.38	5074	2179	23.80	42.94	5.75	
3	270	0.49	0.39	5708	2323	21.47	40.69	5.9	
3	300	0.49	0.37	6343	2471	25.43	38.96	6	
3	30	0.49	0.16	630	530	68.14	84.07	6.35	
3	60	0.49	0.22	1260	920	55.93	73.05	5.6	
3	90	0.49	0.26	1889	1247	47.94	66.01	5.35	
3	120	0.49	0.28	2519	1532	42.53	60.82	5.2	
3	150	0.49	0.31	3149	1782	36.66	56.57	5.6	
3	180	0.49	0.33	3779	1999	32.43	52.90	5.65	
3	210	0.49	0.35	4409	2192	28.67	49.71	5.7	
3	240	0.49	0.36	5039	2368	27.49	47.00	5.8	
3	270	0.49	0.37	5668	2534	25.14	44.71	5.95	
3	300	0.49	0.39	6298	2676	19.97	42.49	6.05	
3	30	0.97	0.32	975	815	67.15	83.57	6.45	
3	60	0.97	0.47	1949	1396	52.10	71.60	5.85	
3	90	0.97	0.58	2924	1848	40.69	63.20	5.75	
3	120	0.97	0.64	3899	2213	34.22	56.76	5.6	
3	150	0.97	0.69	4873	2523	29.52	51.78	5.6	
3	180	0.97	0.71	5848	2797	26.69	47.84	5.65	
3	210	0.97	0.76	6822	3034	21.87	44.47	5.65	
3	240	0.97	0.78	7797	3240	20.46	41.56	5.65	

Table A.1: Continued

Retention Time	Collection Time	Inflow P Concentration	Outflow P concentration	Cumulative P Added	Cumulative P Sorbed	Discrete removal	Cumulative Removal	pH	EC
----- minutes -----		------ ppm ------		------ mg kg^{-1} ------		------ % ------			mS cm^{-1}
3	270	0.97	0.79	8772	3432	18.93	39.13	5.75	
3	300	0.97	0.81	9746	3605	16.46	36.99	5.75	
3	30	0.98	0.29	978	835	70.82	85.41	6.3	
3	60	0.98	0.45	1956	1448	54.37	74.00	5.9	
3	90	0.98	0.56	2934	1921	42.47	65.47	5.85	
3	120	0.98	0.62	3912	2307	36.52	58.98	5.85	
3	150	0.98	0.67	4890	2642	31.97	54.03	5.75	
3	180	0.98	0.71	5868	2933	27.42	49.97	5.7	
3	210	0.98	0.74	6846	3186	24.50	46.54	5.7	
3	240	0.98	0.78	7824	3407	20.53	43.54	5.75	
3	270	0.98	0.79	8803	3600	18.90	40.89	5.7	
3	300	0.98	0.80	9781	3783	18.67	38.68	5.25	
3	30	5.16	2.87	1162	839	44.46	72.23	5.85	
3	60	5.16	3.44	2324	1291	33.36	55.57	5.55	
3	90	5.16	3.95	3486	1621	23.43	46.51	5.45	
3	120	5.16	4.20	4648	1866	18.61	40.14	5.5	
3	150	5.16	4.28	5810	2074	17.15	35.69	5.6	
3	180	5.16	4.47	6972	2252	13.50	32.29	5.55	
3	210	5.16	4.50	8134	2404	12.77	29.56	5.45	
3	240	5.16	4.62	9296	2540	10.58	27.32	5.65	
3	270	5.16	4.64	10458	2661	10.22	25.44	5.65	
3	300	5.16	4.64	11620	2780	10.22	23.92	5.65	
3	30	5.18	3.09	1166	818	40.29	70.15	5.75	
3	60	5.18	3.82	2333	1207	26.33	51.73	5.45	
3	90	5.18	4.17	3499	1475	19.64	42.15	5.45	
3	120	5.18	4.35	4665	1682	16.00	36.07	5.5	
3	150	5.18	4.28	5831	1878	17.46	32.20	5.6	
3	180	5.18	4.58	6998	2047	11.64	29.26	5.55	
3	210	5.18	4.66	8164	2174	10.18	26.64	5.5	
3	240	5.18	4.66	9330	2293	10.18	24.58	5.7	
3	270	5.18	4.69	10496	2408	9.46	22.94	5.7	
3	300	5.18	4.67	11663	2520	9.82	21.61	5.65	
3	30	9.32	5.83	2795	1920	37.39	68.69	5.85	
3	60	9.32	7.29	5591	2747	21.78	49.14	5.65	
3	90	9.32	7.64	8386	3303	18.00	39.39	5.5	
3	120	9.32	8.32	11182	3704	10.68	33.13	5.7	
3	150	9.32	8.44	13977	3985	9.45	28.51	5.7	
3	180	9.32	8.36	16773	4261	10.27	25.40	5.8	
3	210	9.32	8.25	19568	4565	11.50	23.33	5.75	
3	240	9.32	8.86	22364	4795	4.93	21.44	5.75	
3	270	9.32	8.74	25159	4950	6.16	19.68	6	
3	300	9.32	8.74	27955	5122	6.16	18.32	6	
3	30	9.89	5.59	2968	2129	43.50	71.75	5.8	
3	60	9.89	7.52	5936	3131	23.99	52.75	5.65	
3	90	9.89	7.79	8903	3802	21.21	42.70	5.6	
3	120	9.89	8.21	11871	4369	17.03	36.80	5.8	
3	150	9.89	8.51	14839	4828	13.93	32.54	5.85	
3	180	9.89	8.71	17807	5213	12.00	29.28	5.95	
3	210	9.89	8.67	20774	5575	12.38	26.84	5.95	
3	240	9.89	8.63	23742	5948	12.77	25.05	5.9	

Table A.1: Continued

Retention Time	Collection Time	Inflow P Concentration	Outflow P concentration	Cumulative P Added	Cumulative P Sorbed	Discrete removal	Cumulative Removal	pH	EC
----- minutes -----		------ ppm ------		------ mg kg^{-1} ------		------ % ------			mS cm^{-1}
3	270	9.89	8.90	26710	6287	10.06	23.54	6.1	
3	300	9.89	8.78	29678	6603	11.22	22.25	6.05	
3	30	14.87	6.19	1045	828	58.38	79.19	5.15	
3	60	14.87	8.54	2091	1356	42.58	64.84	4.9	
3	90	14.87	9.25	3136	1776	37.78	56.62	5	
3	120	14.87	10.19	4181	2137	31.43	51.12	5.25	
3	150	14.87	11.44	5227	2422	23.07	46.34	5.35	
3	180	14.87	10.65	6272	2691	28.34	42.90	5.4	
3	210	14.87	11.53	7317	2956	22.45	40.40	5.45	
3	240	14.87	11.51	8363	3192	22.61	38.17	5.55	
3	270	14.87	11.18	9408	3440	24.78	36.56	5.6	
3	300	14.87	11.97	10453	3671	19.51	35.12	5.65	
3	30	14.41	6.74	1013	776	53.21	76.61	5.15	
3	60	14.41	8.31	2026	1260	42.35	62.19	4.9	
3	90	14.41	9.20	3039	1657	36.11	54.54	5	
3	120	14.41	10.54	4052	1976	26.85	48.77	5.2	
3	150	14.41	9.92	5065	2270	31.16	44.82	5.35	
3	180	14.41	10.61	6078	2561	26.37	42.14	5.45	
3	210	14.41	11.58	7091	2795	19.66	39.41	5.45	
3	240	14.41	11.51	8104	2996	20.13	36.97	5.55	
3	270	14.41	11.99	9117	3183	16.78	34.91	5.6	
3	300	14.41	11.87	10130	3357	17.58	33.14	5.7	
0.5	30	0.48	0.22	652	505	55.06	77.53	6.45	
0.5	60	0.48	0.27	1304	830	44.57	63.67	5.4	
0.5	90	0.48	0.30	1956	1099	37.90	56.19	5.3	
0.5	120	0.48	0.31	2608	1338	35.27	51.29	5.3	
0.5	150	0.48	0.34	3260	1551	30.03	47.56	5.35	
0.5	180	0.48	0.35	3912	1739	27.89	44.46	5.45	
0.5	210	0.48	0.35	4564	1919	27.17	42.04	5.5	
0.5	240	0.48	0.37	5216	2086	24.07	39.99	5.5	
0.5	270	0.48	0.38	5868	2234	21.45	38.08	5.6	
0.5	300	0.48	0.38	6520	2372	20.74	36.38	5.7	
0.5	30	0.49	0.24	666	505	51.57	75.78	6.35	
0.5	60	0.49	0.28	1332	823	44.10	61.81	5.4	
0.5	90	0.49	0.31	1998	1091	36.17	54.58	5.4	
0.5	120	0.49	0.34	2664	1312	30.33	49.25	5.4	
0.5	150	0.49	0.36	3330	1505	27.53	45.19	5.45	
0.5	180	0.49	0.37	3996	1679	24.73	42.01	5.5	
0.5	210	0.49	0.39	4662	1833	21.70	39.33	5.55	
0.5	240	0.49	0.40	5328	1970	19.37	36.98	5.6	
0.5	270	0.49	0.41	5994	2094	17.73	34.93	5.65	
0.5	300	0.49	0.42	6660	2204	15.40	33.09	5.75	
0.5	30	0.99	0.62	1074	738	37.52	68.76	6.15	
0.5	60	0.99	0.70	2147	1099	29.64	51.17	5.6	
0.5	90	0.99	0.60	3221	1469	39.37	45.62	5.35	
0.5	120	0.99	0.77	4294	1801	22.47	41.94	5.2	
0.5	150	0.99	0.80	5368	2026	19.45	37.75	5.6	
0.5	180	0.99	0.82	6441	2225	17.60	34.54	5.6	
0.5	210	0.99	0.84	7515	2404	15.75	31.99	5.75	
0.5	240	0.99	0.84	8589	2571	15.29	29.93	5.8	

Table A.1: Continued

Retention Time	Collection Time	Inflow P Concentration	Outflow P concentration	Cumulative P Added	Cumulative P Sorbed	Discrete removal	Cumulative Removal	pH	EC
----- minutes -----		------ ppm ------		------ mg kg^{-1} ------		------ % ------			mS cm^{-1}
0.5	270	0.99	0.85	9662	2730	14.36	28.25	5.9	
0.5	300	0.99	0.86	10736	2878	13.20	26.80	5.6	
0.5	30	0.98	0.60	1061	738	39.01	69.51	6	
0.5	60	0.98	0.69	2122	1105	30.23	52.06	5.55	
0.5	90	0.98	0.72	3183	1405	26.36	44.14	5.35	
0.5	120	0.98	0.77	4245	1658	21.21	39.05	5.65	
0.5	150	0.98	0.80	5306	1867	18.28	35.19	5.65	
0.5	180	0.98	0.81	6367	2057	17.57	32.31	5.65	
0.5	210	0.98	0.83	7428	2231	15.23	30.04	5.7	
0.5	240	0.98	0.85	8489	2384	13.59	28.08	5.8	
0.5	270	0.98	0.84	9550	2535	14.76	26.54	5.9	
0.5	300	0.98	0.84	10611	2690	14.53	25.35	6	
0.5	30	4.77	3.33	1287	837	30.06	65.03	5.95	
0.5	60	4.77	3.58	2573	1190	24.77	46.22	5.75	
0.5	90	4.77	3.97	3860	1457	16.76	37.74	5.65	
0.5	120	4.77	4.10	5147	1655	14.03	32.15	5.55	
0.5	150	4.77	4.12	6433	1833	13.63	28.49	5.55	
0.5	180	4.77	4.21	7720	1995	11.62	25.84	5.55	
0.5	210	4.77	4.27	9007	2137	10.42	23.73	5.6	
0.5	240	4.77	4.25	10294	2274	10.82	22.09	5.6	
0.5	270	4.77	4.25	11580	2413	10.82	20.84	5.65	
0.5	300	4.77	4.17	12867	2563	12.43	19.92	5.65	
0.5	30	4.88	3.10	1318	900	36.56	68.28	5.85	
0.5	60	4.88	3.55	2635	1321	27.32	50.11	5.7	
0.5	90	4.88	3.77	3953	1651	22.78	41.76	5.65	
0.5	120	4.88	3.83	5271	1943	21.53	36.86	5.55	
0.5	150	4.88	4.04	6588	2198	17.30	33.37	5.55	
0.5	180	4.88	4.12	7906	2416	15.66	30.55	5.55	
0.5	210	4.88	4.23	9223	2606	13.31	28.26	5.6	
0.5	240	4.88	4.12	10541	2797	15.66	26.54	5.7	
0.5	270	4.88	4.27	11859	2983	12.53	25.15	5.7	
0.5	300	4.88	4.04	13176	3178	17.14	24.12	5.65	
0.5	30	10.59	8.52	2383	1425	19.57	59.79	5.65	
0.5	60	10.59	9.09	4767	1828	14.24	38.35	5.5	
0.5	90	10.59	8.90	7150	2188	16.02	30.61	5.5	
0.5	120	10.59	9.42	9534	2511	11.03	26.34	5.5	
0.5	150	10.59	9.50	11917	2765	10.32	23.20	5.6	
0.5	180	10.59	9.76	14301	2982	7.83	20.85	5.6	
0.5	210	10.59	9.76	16684	3168	7.83	18.99	5.55	
0.5	240	10.59	9.91	19067	3338	6.41	17.51	5.7	
0.5	270	10.59	9.84	21451	3499	7.12	16.31	5.7	
0.5	300	10.59	10.03	23834	3647	5.34	15.30	5.7	
0.5	30	10.59	8.04	2383	1478	24.06	62.03	5.6	
0.5	60	10.59	8.93	4767	1952	15.66	40.94	5.55	
0.5	90	10.59	9.27	7150	2287	12.46	31.98	5.6	
0.5	120	10.59	9.46	9534	2562	10.68	26.88	5.65	
0.5	150	10.59	9.50	11917	2813	10.32	23.60	5.75	
0.5	180	10.59	9.76	14301	3029	7.83	21.18	5.75	
0.5	210	10.59	9.91	16684	3199	6.41	19.17	5.7	
0.5	240	10.59	9.80	19067	3364	7.47	17.64	5.85	

Table A.1: Continued

Retention Time	Collection Time	Inflow P Concentration	Outflow P concentration	Cumulative P Added	Cumulative P Sorbed	Discrete removal	Cumulative Removal	pH	EC
----- minutes -----		------ ppm ------		------ mg kg^{-1} ------		------ % ------			mS cm^{-1}
0.5	270	10.59	9.80	21451	3542	7.47	16.51	5.9	
0.5	300	10.59	9.76	23834	3725	7.83	15.63	5.85	
0.5	30	14.84	8.52	2504	1785	42.57	71.29	5.7	
0.5	60	14.84	10.27	5008	2704	30.81	53.99	5.7	
0.5	90	14.84	10.80	7512	3431	27.25	45.67	5.7	
0.5	120	14.84	11.92	10016	4018	19.66	40.11	5.8	
0.5	150	14.84	12.22	12520	4485	17.65	35.82	5.85	
0.5	180	14.84	12.04	15024	4942	18.89	32.90	5.95	
0.5	210	14.84	13.06	17528	5329	12.00	30.40	5.95	
0.5	240	14.84	12.77	20032	5654	13.93	28.22	5.95	
0.5	270	14.84	13.00	22536	5983	12.38	26.55	6.1	
0.5	300	14.84	12.43	25040	6342	16.25	25.33	6.1	
0.5	30	15.50	9.19	2615	1840	40.72	70.36	5.6	
0.5	60	15.50	10.51	5230	2793	32.18	53.40	5.65	
0.5	90	15.50	11.81	7845	3525	23.78	44.93	5.65	
0.5	120	15.50	12.30	10461	4105	20.62	39.25	5.65	
0.5	150	15.50	12.64	13076	4616	18.41	35.30	5.7	
0.5	180	15.50	11.63	15691	5183	24.96	33.03	5.75	
0.5	210	15.50	12.30	18306	5779	20.62	31.57	5.75	
0.5	240	15.50	12.42	20921	6308	19.88	30.15	5.75	
0.5	270	15.50	13.22	23536	6761	14.73	28.72	5.75	
0.5	300	15.50	12.36	26152	7218	20.25	27.60	5.75	

Table A.2: Results of AMDR2 flow-through experiment.

Retention Time	Collection Time	Inflow P Concentration	Outflow P concentration	Cumulative P Added	Cumulative P Sorbed	Discrete removal	Cumulative Removal	pH	EC
----- minutes -----		------ ppm ------		------ mg kg^{-1} ------		------ % ------			mS cm^{-1}
10	60	0.48	0.25	1863	1379	48.04	74.02	7.5	
10	120	0.48	0.22	3726	2327	53.78	62.46	7	
10	180	0.48	0.25	5589	3278	48.28	58.65	6.5	
10	240	0.48	0.30	7452	4073	37.05	54.66	6.35	
10	300	0.48	0.32	9315	4730	33.46	50.78	6.15	
10	60	0.48	0.32	1876	1252	33.46	66.73	7.5	
10	120	0.48	0.32	3753	1887	34.17	50.27	7	
10	180	0.48	0.33	5629	2499	31.09	44.39	6.55	
10	240	0.48	0.36	7505	3024	24.92	40.29	6.35	
10	300	0.48	0.37	9381	3474	23.02	37.03	6.2	
10	60	0.95	0.53	3701	2670	44.33	72.16	6	
10	120	0.95	0.59	7401	4183	37.44	56.52	6.3	
10	180	0.95	0.64	11102	5491	33.21	49.46	6.2	
10	240	0.95	0.67	14802	6648	29.35	44.91	6.25	
10	300	0.95	0.71	18503	7654	25.00	41.37	6.2	
10	60	0.94	0.58	3665	2534	38.29	69.15	6	
10	120	0.94	0.64	7330	3828	32.32	52.23	6.3	
10	180	0.94	0.67	10994	4950	28.90	45.02	6.25	
10	240	0.94	0.71	14659	5929	24.51	40.44	6.3	
10	300	0.94	0.75	18324	6753	20.49	36.86	6.3	
10	30	4.94	2.97	2689	1880	39.84	69.92	6.15	
10	60	4.94	2.84	5377	2987	42.53	55.55	6.35	
10	90	4.94	3.20	8066	4033	35.25	50.00	6.15	
10	120	4.94	3.38	10755	4932	31.60	45.86	6.1	
10	150	4.94	3.59	13444	5722	27.17	42.56	6.15	
10	180	4.94	3.76	16132	6408	23.84	39.72	6.1	
10	210	4.94	3.95	18821	6995	19.88	37.17	6.15	
10	240	4.94	4.09	21510	7492	17.03	34.83	6.15	
10	270	4.94	4.01	24199	7973	18.77	32.95	6.1	
10	300	4.94	4.23	26887	8417	14.26	31.30	6.1	
10	30	5.01	2.86	2731	1952	42.96	71.48	6.25	
10	60	5.01	2.67	5463	3178	46.78	58.18	6.3	
10	90	5.01	3.06	8194	4348	38.91	53.07	6.25	
10	120	5.01	3.31	10925	5343	33.92	48.90	6.1	
10	150	5.01	3.50	13657	6218	30.17	45.53	6.15	
10	180	5.01	3.84	16388	6948	23.31	42.40	6.1	
10	210	5.01	3.95	19119	7558	21.29	39.53	6.1	
10	240	5.01	4.03	21851	8116	19.57	37.14	6.15	
10	270	5.01	4.19	24582	8606	16.37	35.01	6.1	
10	300	5.01	4.19	27313	9054	16.37	33.15	6.15	
10	30	10.26	5.27	3494	2596	48.61	74.30	6.6	
10	60	10.26	5.47	6988	4261	46.70	60.98	6.3	
10	90	10.26	6.63	10482	5696	35.43	54.34	6.3	
10	120	10.26	7.24	13976	6830	29.48	48.87	6.3	
10	150	10.26	7.45	17470	7823	27.35	44.78	6.25	
10	180	10.26	7.88	20964	8707	23.24	41.53	6.2	
10	210	10.26	8.03	24458	9492	21.71	38.81	6.2	

Table A.2: Continued

Retention Time	Collection Time	Inflow P Concentration	Outflow P concentration	Cumulative P Added	Cumulative P Sorbed	Discrete removal	Cumulative Removal	pH	EC
----- minutes -----		------ ppm ------		------ mg kg^{-1} ------		------ % ------			mS cm^{-1}
10	240	10.26	8.28	27952	10208	19.28	36.52	6.2	
10	270	10.26	8.28	31446	10882	19.28	34.60	6.2	
10	300	10.26	8.19	34940	11571	20.19	33.12	6.2	
10	30	10.14	4.90	3454	2620	51.71	75.86	6.5	
10	60	10.14	5.34	6908	4331	47.32	62.69	6.35	
10	90	10.14	6.02	10362	5851	40.69	56.46	6.25	
10	120	10.14	6.61	13816	7155	34.83	51.79	6.3	
10	150	10.14	6.83	17271	8321	32.68	48.18	6.25	
10	180	10.14	7.77	20725	9290	23.43	44.83	6.2	
10	210	10.14	8.10	24179	10043	20.19	41.54	6.2	
10	240	10.14	8.31	27633	10703	18.03	38.73	6.2	
10	270	10.14	8.25	31087	11337	18.65	36.47	6.2	
10	300	10.14	8.46	34541	11945	16.57	34.58	6.15	
10	30	15.13	6.94	4121	3176	54.15	77.08	5.9	
10	60	15.13	7.09	8242	5387	53.13	65.36	5.9	
10	90	15.13	8.95	12363	7323	40.85	59.23	5.9	
10	120	15.13	10.19	16484	8838	32.66	53.61	5.9	
10	150	15.13	10.35	20605	10161	31.56	49.31	6	
10	180	15.13	11.90	24726	11251	21.33	45.50	6.1	
10	210	15.13	11.83	28847	12140	21.80	42.08	6.1	
10	240	15.13	12.26	32968	12980	18.97	39.37	6.1	
10	270	15.13	12.28	37089	13758	18.81	37.10	6.1	
10	300	15.13	13.10	41210	14421	13.38	35.00	6.1	
10	30	16.14	7.10	4397	3429	55.99	78.00	6	
10	60	16.14	7.46	8793	5842	53.78	66.44	5.9	
10	90	16.14	9.78	13190	7891	39.39	59.82	5.95	
10	120	16.14	10.26	17587	9558	36.44	54.35	5.95	
10	150	16.14	10.76	21983	11092	33.34	50.46	6.1	
10	180	16.14	11.81	26380	12415	26.85	47.06	6.15	
10	210	16.14	12.12	30777	13554	24.93	44.04	6.1	
10	240	16.14	12.19	35173	14640	24.49	41.62	6.1	
10	270	16.14	12.69	39570	15649	21.39	39.55	6.15	
10	300	16.14	12.35	43967	16635	23.46	37.84	6.1	
8	42.5	0.41	0.19	968	746	54.17	77.08	6	
8	85	0.41	0.18	1936	1279	55.92	66.06	6.1	
8	127.5	0.41	0.20	2904	1792	50.07	61.71	6.2	
8	170	0.41	0.22	3872	2259	46.55	58.36	6.3	
8	212.5	0.41	0.23	4839	2693	43.04	55.65	6.25	
8	255	0.41	0.24	5807	3104	41.87	53.45	6.2	
8	297.5	0.41	0.24	6775	3501	40.11	51.67	6.3	
8	42.5	0.47	0.33	1128	734	30.16	65.08	7.4	
8	85	0.47	0.30	2257	1109	36.20	49.13	7.2	
8	127.5	0.47	0.33	3385	1482	29.92	43.77	6.75	
8	170	0.47	0.37	4514	1771	21.24	39.23	6.5	
8	212.5	0.47	0.34	5642	2051	28.48	36.35	6.3	
8	255	0.47	0.33	6771	2379	29.68	35.14	6.25	
8	297.5	0.47	0.33	7899	2713	29.44	34.34	6.2	
8	42.5	1.04	0.63	2478	1724	39.16	69.58	6.2	
8	85	1.04	0.71	4957	2608	32.18	52.62	6.1	

Table A.2: Continued

Retention Time	Collection Time	Inflow P Concentration	Outflow P concentration	Cumulative P Added	Cumulative P Sorbed	Discrete removal	Cumulative Removal	pH	EC
-----	minutes -----	------	ppm ------	------	mg kg^{-1} ------	------	% ------		$mS\ cm^{-1}$
8	127.5	1.04	0.72	7435	3385	30.49	45.53	6.3	
8	170	1.04	0.74	9913	4124	29.14	41.60	6.4	
8	212.5	1.04	0.76	12391	4824	27.34	38.93	6.4	
8	255	1.04	0.74	14870	5520	28.80	37.12	6.3	
8	297.5	1.04	0.77	17348	6196	25.77	35.71	6.35	
8	42.5	0.99	0.59	2356	1657	40.72	70.36	6.2	
8	85	0.99	0.67	4711	2512	31.84	53.32	6.1	
8	127.5	0.99	0.70	7067	3236	29.60	45.79	6.3	
8	170	0.99	0.74	9422	3887	25.69	41.25	6.4	
8	212.5	0.99	0.77	11778	4447	21.90	37.76	6.35	
8	255	0.99	0.77	14133	4963	21.90	35.12	6.3	
8	297.5	0.99	0.77	16489	5480	22.02	33.24	6.3	
8	30	5.04	2.61	2824	2092	48.22	74.11	6	
8	60	5.04	2.87	5647	3381	43.05	59.87	6.15	
8	90	5.04	3.12	8471	4528	38.19	53.46	6.25	
8	120	5.04	3.41	11294	5525	32.42	48.92	6.25	
8	150	5.04	3.64	14118	6376	27.87	45.16	6.25	
8	180	5.04	3.79	16941	7120	24.83	42.03	6.25	
8	210	5.04	3.94	19765	7780	21.94	39.37	6.25	
8	240	5.04	4.03	22588	8374	20.12	37.07	6.3	
8	270	5.04	4.10	25412	8921	18.60	35.11	6.2	
8	300	5.04	4.16	28235	9430	17.46	33.40	6.2	
8	30	4.98	2.81	2788	2002	43.59	71.79	7.6	
8	60	4.98	2.95	5576	3176	40.68	56.96	7.2	
8	90	4.98	3.18	8364	4246	36.08	50.77	7.05	
8	120	4.98	3.43	11152	5184	31.18	46.48	6.85	
8	150	4.98	3.67	13941	5985	26.28	42.93	6.6	
8	180	4.98	3.88	16729	6660	22.14	39.81	6.4	
8	210	4.98	4.03	19517	7235	19.07	37.07	6.35	
8	240	4.98	4.08	22305	7751	18.00	34.75	6.25	
8	270	4.98	4.18	25093	8227	16.09	32.78	6.2	
8	300	4.98	4.29	27881	8643	13.79	31.00	6.15	
8	30	10.18	3.02	2138	1821	70.32	85.16	6.2	
8	60	10.18	3.27	4277	3299	67.87	77.13	6.3	
8	90	10.18	4.11	6415	4662	59.65	72.67	6.2	
8	120	10.18	4.80	8554	5866	52.90	68.57	6.15	
8	150	10.18	5.55	10692	6918	45.53	64.70	6.15	
8	180	10.18	6.33	12831	7810	37.85	60.87	6.1	
8	210	10.18	6.83	14969	8566	32.94	57.23	6.1	
8	240	10.18	7.22	17108	9230	29.10	53.95	6.15	
8	270	10.18	7.55	19246	9817	25.87	51.01	6.1	
8	300	10.18	7.75	21385	10349	23.88	48.40	6.1	
8	30	10.22	2.29	2147	1906	77.55	88.77	6.2	
8	60	10.22	2.82	4293	3515	72.43	81.88	6.3	
8	90	10.22	3.59	6440	4989	64.85	77.47	6.2	
8	120	10.22	4.26	8587	6311	58.35	73.50	6.1	
8	150	10.22	5.15	10734	7471	49.63	69.60	6.1	
8	180	10.22	6.08	12880	8438	40.53	65.51	6.15	
8	210	10.22	5.84	15027	9333	42.83	62.11	6.1	
8	240	10.22	7.11	17174	10120	30.44	58.92	6.1	

Table A.2: Continued

Retention Time	Collection Time	Inflow P Concentration	Outflow P concentration	Cumulative P Added	Cumulative P Sorbed	Discrete removal	Cumulative Removal	pH	EC
----- minutes -----		------ ppm ------		------ mg kg^{-1} ------		------ % ------			mS cm^{-1}
8	270	10.22	7.45	19320	10737	27.07	55.57	6.1	
8	300	10.22	7.58	21467	11305	25.85	52.66	6.1	
8	30	15.63	3.29	2625	2349	78.95	89.47	6.6	
8	60	15.63	4.17	5251	4348	73.32	82.80	6.45	
8	90	15.63	5.08	7876	6196	67.46	78.67	6.3	
8	120	15.63	6.98	10501	7807	55.31	74.35	6.25	
8	150	15.63	8.32	13126	9147	46.75	69.68	6.25	
8	180	15.63	9.12	15752	10307	41.65	65.44	6.2	
8	210	15.63	10.10	18377	11318	35.35	61.59	6.2	
8	240	15.63	10.81	21002	12187	30.84	58.03	6.2	
8	270	15.63	11.23	23628	12961	28.14	54.86	6.15	
8	300	15.63	11.67	26253	13662	25.29	52.04	6.1	
8	30	16.27	3.96	2734	2401	75.67	87.84	6.5	
8	60	16.27	4.90	5467	4391	69.91	80.31	6.4	
8	90	16.27	6.21	8201	6192	61.84	75.50	6.3	
8	120	16.27	7.73	10935	7754	52.47	70.91	6.25	
8	150	16.27	9.47	13668	9042	41.80	66.16	6.2	
8	180	16.27	10.13	16402	10130	37.76	61.76	6.2	
8	210	16.27	10.50	19136	11131	35.46	58.17	6.2	
8	240	16.27	11.42	21869	12023	29.84	54.98	6.2	
8	270	16.27	11.06	24603	12868	32.00	52.30	6.15	
8	300	16.27	12.35	27337	13635	24.07	49.88	6.1	
6	30	0.51	0.26	1158	862	48.90	74.45	6.6	0.87
6	60	0.51	0.31	2317	1378	40.18	59.50	6.55	0.78
6	90	0.51	0.34	3475	1805	33.52	51.95	6.45	0.69
6	120	0.51	0.33	4634	2202	34.90	47.51	6.4	0.656
6	150	0.51	0.32	5792	2617	36.74	45.17	6.4	0.72
6	180	0.51	0.33	6950	3034	35.36	43.65	6.3	0.665
6	210	0.51	0.34	8109	3433	33.52	42.34	6.3	0.681
6	240	0.51	0.35	9267	3812	31.91	41.13	6.3	0.697
6	270	0.51	0.36	10426	4171	30.08	40.01	6.3	0.793
6	300	0.51	0.36	11584	4516	29.39	38.98	6.3	0.835
6	30	0.50	0.28	1142	825	44.47	72.23	6.6	0.794
6	60	0.50	0.30	2285	1312	40.74	57.42	6.5	0.734
6	90	0.50	0.32	3427	1757	37.25	51.28	6.4	0.695
6	120	0.50	0.32	4570	2183	37.25	47.77	6.4	0.684
6	150	0.50	0.32	5712	2602	36.08	45.55	6.4	0.672
6	180	0.50	0.33	6855	3006	34.69	43.86	6.3	0.705
6	210	0.50	0.34	7997	3389	32.36	42.38	6.3	0.69
6	240	0.50	0.34	9140	3756	31.89	41.10	6.3	0.726
6	270	0.50	0.34	10282	4121	31.89	40.08	6.3	0.67
6	300	0.50	0.35	11425	4476	30.26	39.18	6.3	0.693
6	30	0.97	0.20	551	494	79.46	89.73	6.4	0.911
6	60	0.97	0.26	1101	914	73.20	83.03	6.05	0.703
6	90	0.97	0.32	1652	1299	66.70	78.67	6.05	0.729
6	120	0.97	0.35	2202	1659	63.88	75.33	6.05	0.703
6	150	0.97	0.41	2753	1995	58.00	72.45	6.2	0.715
6	180	0.97	0.44	3304	2305	54.93	69.79	6.25	0.696
6	210	0.97	0.45	3854	2603	53.34	67.55	6.25	0.708
6	240	0.97	0.48	4405	2890	50.64	65.60	6.3	0.673

Table A.2: Continued

Retention Time	Collection Time	Inflow P Concentration	Outflow P concentration	Cumulative P Added	Cumulative P Sorbed	Discrete removal	Cumulative Removal	pH	EC
----- minutes -----		------ ppm ------		------ mg kg^{-1} ------		------ % ------			mS cm^{-1}
6	270	0.97	0.50	4955	3163	48.68	63.83	6.25	0.62
6	300	0.97	0.51	5506	3429	47.82	62.27	6.3	0.675
6	30	0.95	0.24	537	470	74.92	87.46	6.35	0.73
6	60	0.95	0.33	1074	847	65.49	78.83	6.05	0.68
6	90	0.95	0.40	1611	1177	57.32	73.02	6.05	0.891
6	120	0.95	0.45	2148	1472	52.54	68.50	6.05	0.685
6	150	0.95	0.50	2685	1740	47.51	64.81	6.15	0.723
6	180	0.95	0.52	3223	1989	45.00	61.71	6.25	0.732
6	210	0.95	0.55	3760	2222	41.73	59.09	6.25	0.683
6	240	0.95	0.56	4297	2444	41.10	56.88	6.3	0.692
6	270	0.95	0.58	4834	2658	38.72	55.00	6.25	0.665
6	300	0.95	0.58	5371	2866	38.46	53.36	6.35	0.682
6	30	4.94	2.12	2801	2199	57.01	78.50	6.1	0.725
6	60	4.94	2.81	5601	3601	43.17	64.30	6.05	0.72
6	90	4.94	3.29	8402	4673	33.37	55.62	6.15	0.748
6	120	4.94	3.57	11203	5528	27.67	49.35	6.1	0.656
6	150	4.94	3.76	14003	6250	23.88	44.63	6.25	0.711
6	180	4.94	3.77	16804	6916	23.72	41.16	6.3	0.711
6	210	4.94	4.01	19605	7512	18.82	38.32	6.25	0.712
6	240	4.94	4.09	22405	8017	17.24	35.78	6.35	0.686
6	270	4.94	4.13	25206	8486	16.29	33.67	6.2	0.697
6	300	4.94	4.26	28007	8908	13.84	31.81	6.25	0.73
6	30	5.12	2.07	2900	2313	59.48	79.74	6.1	0.735
6	60	5.12	2.85	5801	3816	44.21	65.79	6.05	0.708
6	90	5.12	3.40	8701	4943	33.52	56.81	6.15	0.731
6	120	5.12	3.67	11601	5838	28.17	50.32	6.1	0.674
6	150	5.12	3.63	14502	6668	29.09	45.98	6.3	0.68
6	180	5.12	3.88	17402	7441	24.20	42.76	6.35	0.704
6	210	5.12	4.07	20302	8088	20.39	39.84	6.3	0.699
6	240	5.12	4.16	23202	8655	18.71	37.30	6.35	0.705
6	270	5.12	4.24	26103	9175	17.18	35.15	6.2	0.725
6	300	5.12	4.15	29003	9698	18.86	33.44	6.3	0.725
6	30	9.62	2.44	2729	2382	74.62	87.31	6	0.832
6	60	9.62	3.32	5457	4294	65.48	78.68	6.2	0.674
6	90	9.62	4.18	8186	5959	56.57	72.79	6.2	0.727
6	120	9.62	5.01	10914	7385	47.97	67.66	6.2	0.738
6	150	9.62	6.02	13643	8551	37.47	62.67	6.25	0.7
6	180	9.62	6.58	16371	9493	31.58	57.98	6.2	0.705
6	210	9.62	7.04	19100	10289	26.81	53.87	6.25	0.71
6	240	9.62	7.35	21828	10977	23.63	50.29	6.25	0.68
6	270	9.62	7.61	24557	11585	20.92	47.18	6.25	0.663
6	300	9.62	7.87	27286	12119	18.22	44.42	6.25	0.547
6	30	10.05	2.49	2848	2495	75.23	87.62	6	0.76
6	60	10.05	3.73	5696	4462	62.88	78.34	6.2	0.73
6	90	10.05	4.56	8544	6136	54.65	71.81	6.2	0.752
6	120	10.05	5.62	11392	7541	44.06	66.20	6.2	0.733
6	150	10.05	6.46	14240	8676	35.67	60.93	6.25	0.706
6	180	10.05	6.72	17088	9655	33.08	56.51	6.2	0.632
6	210	10.05	7.26	19936	10522	27.74	52.78	6.25	0.685
6	240	10.05	7.61	22784	11262	24.24	49.43	6.25	0.698

Table A.2: Continued

Retention Time	Collection Time	Inflow P Concentration	Outflow P concentration	Cumulative P Added	Cumulative P Sorbed	Discrete removal	Cumulative Removal	pH	EC
----- minutes -----		------ ppm ------		------ mg kg^{-1} ------		------ % ------			mS cm^{-1}
6	270	10.05	7.78	25632	11928	22.56	46.54	6.25	0.66
6	300	10.05	7.99	28479	12540	20.43	44.03	6.3	0.733
6	30	15.16	2.23	2022	1873	85.26	92.63	6.15	0.9
6	60	15.16	3.23	4044	3531	78.68	87.30	6.25	0.775
6	90	15.16	4.78	6067	5019	68.47	82.72	6.2	0.733
6	120	15.16	6.39	8089	6296	57.87	77.84	6.1	0.685
6	150	15.16	7.39	10111	7399	51.22	73.18	6.15	0.763
6	180	15.16	8.53	12133	8359	43.71	68.89	6.1	0.673
6	210	15.16	9.38	14156	9187	38.14	64.90	6.1	0.727
6	240	15.16	9.82	16178	9928	35.20	61.37	6.1	0.689
6	270	15.16	10.36	18200	10604	31.64	58.26	6.1	0.655
6	300	15.16	10.60	20222	11228	30.10	55.52	6.15	0.659
6	30	15.04	1.91	2007	1879	87.33	93.66	6.15	0.912
6	60	15.04	2.79	4013	3573	81.48	89.03	6.25	0.78
6	90	15.04	3.83	6020	5138	74.54	85.36	6.2	0.642
6	120	15.04	6.03	8026	6487	59.88	80.82	6.1	0.762
6	150	15.04	7.62	10033	7583	49.35	75.58	6.15	0.668
6	180	15.04	8.41	12039	8520	44.05	70.77	6.15	0.685
6	210	15.04	9.45	14046	9335	37.19	66.46	6.15	0.713
6	240	15.04	9.96	16053	10047	33.76	62.59	6.1	0.627
6	270	15.04	10.55	18059	10685	29.86	59.17	6.15	0.708
6	300	15.04	11.02	20066	11253	26.74	56.08	6.1	0.67
3	30	0.44	0.28	999	689	38.04	69.02	6.4	
3	60	0.44	0.30	1998	1039	31.96	52.01	6.5	
3	90	0.44	0.32	2996	1341	28.53	44.76	6.3	
3	120	0.44	0.33	3995	1616	26.42	40.44	6.2	
3	150	0.44	0.34	4994	1866	23.78	37.37	6.25	
3	180	0.44	0.34	5993	2102	23.51	35.08	6.25	
3	210	0.44	0.34	6992	2338	23.78	33.45	6.25	
3	240	0.44	0.34	7991	2572	22.98	32.19	6.2	
3	270	0.44	0.35	8989	2795	21.66	31.09	6.2	
3	300	0.44	0.35	9988	3006	20.61	30.10	6.3	
3	30	0.48	0.29	1082	752	39.01	69.51	8.1	
3	60	0.48	0.31	2165	1151	34.73	53.19	7.4	
3	90	0.48	0.34	3247	1494	28.54	46.00	7.2	
3	120	0.48	0.34	4329	1801	28.31	41.61	7	
3	150	0.48	0.35	5411	2099	26.64	38.78	6.8	
3	180	0.48	0.37	6494	2370	23.55	36.50	6.6	
3	210	0.48	0.38	7576	2616	21.88	34.53	6.45	
3	240	0.48	0.38	8658	2849	21.17	32.91	6.4	
3	270	0.48	0.38	9741	3078	21.17	31.60	6.3	
3	300	0.48	0.38	10823	3307	21.17	30.56	6.2	
3	30	0.94	0.11	422	397	88.05	94.02	6.6	
3	60	0.94	0.15	844	760	83.92	90.01	6.5	
3	90	0.94	0.19	1266	1104	79.42	87.23	6.4	
3	120	0.94	0.23	1688	1431	75.54	84.79	6.35	
3	150	0.94	0.26	2110	1744	72.67	82.65	6.35	
3	180	0.94	0.29	2532	2044	69.54	80.73	6.3	
3	210	0.94	0.30	2954	2333	67.79	79.01	6.3	
3	240	0.94	0.33	3375	2614	65.04	77.43	6.3	

Table A.2: Continued

Retention Time	Collection Time	Inflow P Concentration	Outflow P concentration	Cumulative P Added	Cumulative P Sorbed	Discrete removal	Cumulative Removal	pH	EC
----- minutes -----		------ ppm ------		------ mg kg^{-1} ------		------ % ------			mS cm^{-1}
3	270	0.94	0.35	3797	2884	63.04	75.94	6.3	
3	300	0.94	0.37	4219	3145	60.53	74.53	6.25	
3	30	0.93	0.12	418	392	87.55	93.78	6.6	
3	60	0.93	0.17	835	745	81.61	89.18	6.5	
3	90	0.93	0.23	1253	1073	75.55	85.65	6.45	
3	120	0.93	0.27	1671	1378	70.49	82.49	6.4	
3	150	0.93	0.31	2089	1664	66.45	79.69	6.4	
3	180	0.93	0.35	2506	1934	62.79	77.18	6.3	
3	210	0.93	0.37	2924	2191	60.01	74.92	6.25	
3	240	0.93	0.39	3342	2437	57.99	72.93	6.25	
3	270	0.93	0.42	3759	2673	54.83	71.10	6.25	
3	300	0.93	0.44	4177	2896	52.18	69.34	6.25	
3	30	5.06	0.45	1139	1089	91.18	95.59	6.1	
3	60	5.06	1.15	2278	2048	77.22	89.89	6	
3	90	5.06	1.72	3417	2864	66.09	83.81	6.05	
3	120	5.06	2.07	4556	3578	59.19	78.52	6	
3	150	5.06	2.34	5695	4221	53.70	74.11	6.1	
3	180	5.06	2.57	6835	4807	49.16	70.33	6.2	
3	210	5.06	2.76	7974	5345	45.47	67.04	6.15	
3	240	5.06	2.95	9113	5842	41.71	64.11	6.25	
3	270	5.06	3.07	10252	6304	39.36	61.49	6.15	
3	300	5.06	3.18	11391	6739	37.16	59.17	6.25	
3	30	5.28	0.47	1188	1135	91.02	95.51	6.4	
3	60	5.28	1.22	2376	2132	76.89	89.73	6	
3	90	5.28	1.74	3565	2987	67.04	83.81	6	
3	120	5.28	2.11	4753	3742	59.98	78.73	5.95	
3	150	5.28	2.36	5941	4427	55.39	74.52	6.1	
3	180	5.28	2.67	7129	5051	49.53	70.85	6.15	
3	210	5.28	2.75	8317	5629	47.88	67.68	6.15	
3	240	5.28	2.92	9506	6180	44.72	65.01	6.2	
3	270	5.28	3.06	10694	6695	42.01	62.60	6.2	
3	300	5.28	3.23	11882	7175	38.86	60.39	6.25	
3	30	10.15	4.82	5711	4356	52.55	76.27	6.15	
3	60	10.15	6.77	11421	6807	33.31	59.60	6.05	
3	90	10.15	7.69	17132	8451	24.24	49.33	6.05	
3	120	10.15	8.13	22843	9712	19.93	42.52	6.1	
3	150	10.15	8.59	28553	10720	15.39	37.54	6.15	
3	180	10.15	8.82	34264	11533	13.08	33.66	6.25	
3	210	10.15	8.90	39974	12258	12.31	30.66	6.2	
3	240	10.15	9.29	45685	12851	8.46	28.13	6.3	
3	270	10.15	9.02	51396	13411	11.16	26.09	6.25	
3	300	10.15	9.41	57106	13938	7.31	24.41	6.25	
3	30	9.76	4.77	5491	4149	51.13	75.57	6.2	
3	60	9.76	6.85	10982	6372	29.85	58.03	6.1	
3	90	9.76	7.44	16473	7844	23.77	47.62	6.05	
3	120	9.76	8.07	21964	8974	17.36	40.86	6.15	
3	150	9.76	8.51	27455	9802	12.80	35.70	6.25	
3	180	9.76	8.75	32946	10439	10.40	31.68	6.3	
3	210	9.76	8.94	38437	10955	8.40	28.50	6.2	
3	240	9.76	9.06	43928	11383	7.20	25.91	6.3	

Table A.2: Continued

Retention Time	Collection Time	Inflow P Concentration	Outflow P concentration	Cumulative P Added	Cumulative P Sorbed	Discrete removal	Cumulative Removal	pH	EC
----- minutes -----		------ ppm ------		------ mg kg^{-1} ------		------ % ------			mS cm^{-1}
3	270	9.76	8.98	49419	11801	8.00	23.88	6.25	
3	300	9.76	9.33	54910	12141	4.40	22.11	6.25	
3	30	15.13	1.69	3403	3213	88.84	94.42	6.05	
3	60	15.13	3.93	6807	5985	74.03	87.93	6.25	
3	90	15.13	6.79	10210	8183	55.13	80.15	6.2	
3	120	15.13	8.61	13613	9854	43.05	72.38	6.15	
3	150	15.13	9.90	17017	11174	34.55	65.67	6.2	
3	180	15.13	10.89	20420	12239	28.02	59.94	6.2	
3	210	15.13	11.58	23823	13115	23.46	55.05	6.2	
3	240	15.13	12.08	27227	13857	20.12	50.89	6.2	
3	270	15.13	12.66	30630	14477	16.33	47.26	6.2	
3	300	15.13	11.99	34033	15107	20.73	44.39	6.3	
3	30	15.13	2.86	3403	3082	81.10	90.55	6.05	
3	60	15.13	4.90	6807	5612	67.58	82.44	6.25	
3	90	15.13	7.22	10210	7651	52.24	74.93	6.2	
3	120	15.13	8.50	13613	9285	43.81	68.21	6.15	
3	150	15.13	9.72	17017	10639	35.76	62.52	6.25	
3	180	15.13	10.77	20420	11738	28.78	57.48	6.2	
3	210	15.13	11.30	23823	12658	25.29	53.13	6.25	
3	240	15.13	11.71	27227	13472	22.55	49.48	6.25	
3	270	15.13	12.25	30630	14178	18.98	46.29	6.25	
3	300	15.13	12.37	34033	14812	18.22	43.52	6.3	
0.5	30	0.50	0.23	1127	870	54.36	77.18	6.1	
0.5	60	0.50	0.28	2253	1421	43.58	63.08	6.15	
0.5	90	0.50	0.30	3380	1897	40.83	56.12	6.35	
0.5	120	0.50	0.31	4506	2340	37.85	51.92	6.3	
0.5	150	0.50	0.31	5633	2762	37.16	49.04	6.35	
0.5	180	0.50	0.32	6760	3170	35.10	46.89	6.35	
0.5	210	0.50	0.33	7886	3564	34.87	45.19	6.35	
0.5	240	0.50	0.33	9013	3954	34.41	43.87	6.4	
0.5	270	0.50	0.33	10140	4335	33.26	42.75	6.35	
0.5	300	0.50	0.34	11266	4702	31.88	41.74	6.3	
0.5	30	0.49	0.28	1101	789	43.43	71.72	6.05	
0.5	60	0.49	0.31	2202	1233	37.09	55.99	6.2	
0.5	90	0.49	0.32	3302	1629	34.98	49.34	6.3	
0.5	120	0.49	0.33	4403	2005	33.34	45.54	6.25	
0.5	150	0.49	0.34	5504	2362	31.46	42.91	6.3	
0.5	180	0.49	0.34	6605	2707	31.22	40.99	6.4	
0.5	210	0.49	0.34	7705	3049	30.99	39.57	6.35	
0.5	240	0.49	0.34	8806	3387	30.28	38.46	6.3	
0.5	270	0.49	0.35	9907	3713	29.11	37.48	6.3	
0.5	300	0.49	0.34	11008	4038	29.82	36.68	6.3	
0.5	30	0.96	0.41	1297	1021	57.35	78.67	6.4	
0.5	60	0.96	0.50	2595	1705	48.20	65.72	6.5	
0.5	90	0.96	0.54	3892	2301	43.56	59.11	6.3	
0.5	120	0.96	0.60	5190	2829	37.83	54.50	6.2	
0.5	150	0.96	0.60	6487	3316	37.22	51.11	6.25	
0.5	180	0.96	0.63	7785	3779	34.29	48.55	6.25	
0.5	210	0.96	0.64	9082	4218	33.31	46.44	6.25	
0.5	240	0.96	0.66	10380	4636	31.11	44.66	6.15	

Table A.2: Continued

Retention Time	Collection Time	Inflow P Concentration	Outflow P concentration	Cumulative P Added	Cumulative P Sorbed	Discrete removal	Cumulative Removal	pH	EC
----- minutes -----		------ ppm ------		------ mg kg^{-1} ------		------ % ------			mS cm^{-1}
0.5	270	0.96	0.68	11677	5029	29.53	43.07	6.15	
0.5	300	0.96	0.68	12975	5411	29.28	41.70	6.2	
0.5	30	0.96	0.36	1301	1060	63.05	81.53	6.4	
0.5	60	0.96	0.46	2601	1809	52.10	69.55	6.5	
0.5	90	0.96	0.52	3902	2446	45.89	62.70	6.25	
0.5	120	0.96	0.60	5203	2991	37.86	57.49	6.2	
0.5	150	0.96	0.61	6503	3475	36.64	53.44	6.2	
0.5	180	0.96	0.64	7804	3930	33.23	50.36	6.15	
0.5	210	0.96	0.66	9104	4353	31.89	47.82	6.2	
0.5	240	0.96	0.67	10405	4761	30.80	45.76	6.2	
0.5	270	0.96	0.69	11706	5142	27.87	43.93	6.25	
0.5	300	0.96	0.71	13006	5497	26.66	42.27	6.25	
0.5	30	5.19	1.06	1401	1258	79.55	89.77	6.6	
0.5	60	5.19	1.43	2802	2322	72.39	82.87	6.45	
0.5	90	5.19	1.69	4203	3302	67.49	78.56	6.35	
0.5	120	5.19	1.84	5605	4227	64.48	75.42	6.35	
0.5	150	5.19	2.02	7006	5106	61.09	72.89	6.25	
0.5	180	5.19	2.25	8407	5932	56.72	70.56	6.3	
0.5	210	5.19	2.38	9808	6709	54.16	68.40	6.3	
0.5	240	5.19	2.62	11209	7435	49.49	66.33	6.3	
0.5	270	5.19	2.88	12610	8093	44.44	64.18	6.25	
0.5	300	5.19	2.99	14011	8701	42.33	62.10	6.2	
0.5	30	5.05	1.23	1364	1198	75.66	87.83	6.6	
0.5	60	5.05	1.80	2728	2154	64.45	78.94	6.5	
0.5	90	5.05	2.10	4093	2992	58.41	73.11	6.3	
0.5	120	5.05	2.40	5457	3749	52.53	68.70	6.35	
0.5	150	5.05	2.64	6821	4433	47.74	64.98	6.25	
0.5	180	5.05	2.82	8185	5059	44.18	61.81	6.3	
0.5	210	5.05	2.86	9549	5657	43.40	59.24	6.25	
0.5	240	5.05	3.13	10914	6212	37.99	56.92	6.2	
0.5	270	5.05	3.27	12278	6712	35.36	54.67	6.3	
0.5	300	5.05	3.35	13642	7183	33.65	52.65	6.15	
0.5	30	9.81	3.08	2648	2233	68.63	84.32	6	
0.5	60	9.81	4.07	5296	3916	58.52	73.95	5.95	
0.5	90	9.81	4.72	7944	5378	51.88	67.70	6	
0.5	120	9.81	5.55	10592	6639	43.38	62.68	6	
0.5	150	9.81	6.17	13240	7705	37.07	58.19	6.15	
0.5	180	9.81	6.74	15889	8609	31.24	54.18	6.25	
0.5	210	9.81	7.19	18537	9376	26.71	50.58	6.25	
0.5	240	9.81	7.65	21185	10021	22.01	47.30	6.2	
0.5	270	9.81	8.03	23833	10553	18.13	44.28	6.15	
0.5	300	9.81	8.09	26481	11024	17.48	41.63	6.1	
0.5	30	10.05	2.81	2712	2334	72.06	86.03	6	
0.5	60	10.05	3.84	5425	4149	61.79	76.48	6	
0.5	90	10.05	4.92	8137	5679	51.05	69.79	6	
0.5	120	10.05	5.66	10850	6963	43.62	64.18	6.1	
0.5	150	10.05	6.27	13562	8065	37.61	59.46	6.15	
0.5	180	10.05	6.74	16274	9020	32.87	55.43	6.25	
0.5	210	10.05	7.12	18987	9861	29.08	51.93	6.25	
0.5	240	10.05	7.62	21699	10583	24.18	48.77	6.25	

Table A.2: Continued

Retention Time	Collection Time	Inflow P Concentration	Outflow P concentration	Cumulative P Added	Cumulative P Sorbed	Discrete removal	Cumulative Removal	pH	EC
----- minutes -----		------ ppm ------		------ mg kg^{-1} ------		------ % ------			mS cm^{-1}
0.5	270	10.05	7.89	24411	11202	21.49	45.89	6.2	
0.5	300	10.05	7.60	27124	11824	24.34	43.59	6.2	
0.5	30	15.35	5.06	4143	3460	67.04	83.52	6.2	
0.5	60	15.35	6.46	8287	6048	57.87	72.99	6.05	
0.5	90	15.35	8.35	12430	8191	45.58	65.90	6	
0.5	120	15.35	9.99	16573	9858	34.89	59.48	6.1	
0.5	150	15.35	11.09	20716	11156	27.72	53.85	6.25	
0.5	180	15.35	11.73	24860	12218	23.59	49.15	6.2	
0.5	210	15.35	12.29	29003	13120	19.93	45.24	6.2	
0.5	240	15.35	13.00	33146	13849	15.27	41.78	6.25	
0.5	270	15.35	13.65	37290	14395	11.07	38.60	6.1	
0.5	300	15.35	13.65	41433	14854	11.07	35.85	6.05	
0.5	30	14.53	5.33	3922	3203	63.32	81.66	6.35	
0.5	60	14.53	6.98	7844	5463	51.95	69.65	6.05	
0.5	90	14.53	8.51	11766	7293	41.38	61.99	6.1	
0.5	120	14.53	9.12	15687	8834	37.19	56.31	6.2	
0.5	150	14.53	10.98	19609	10042	24.44	51.21	6.1	
0.5	180	14.53	11.68	23531	10906	19.60	46.35	6.25	
0.5	210	14.53	12.89	27453	11511	11.29	41.93	6.15	
0.5	240	14.53	13.06	31375	11931	10.08	38.03	6.25	
0.5	270	14.53	13.00	35297	12334	10.49	34.94	6.1	
0.5	300	14.53	13.12	39219	12729	9.68	32.46	6.2	

Table A.3: Results of AMDR3 flow-through experiment.

Retention Time	Collection Time	Inflow P Concentration	Outflow P concentration	Cumulative P Added	Cumulative P Sorbed	Discrete removal	Cumulative Removal	pH	EC
----- minutes -----		------ ppm ------		------ mg kg^{-1} ------		------ % ------			mS cm^{-1}
10	30	5.14	4.84	701	371	5.84	52.92	5.9	
10	60	5.14	3.99	1401	470	22.54	33.55	6	
10	90	5.14	3.99	2102	628	22.39	29.86	6.05	
10	120	5.14	4.34	2803	761	15.68	27.15	5.95	
10	150	5.14	4.54	3504	857	11.67	24.46	6	
10	180	5.14	4.73	4204	926	8.02	22.02	6	
10	210	5.14	4.81	4905	977	6.57	19.92	6.05	
10	240	5.14	4.83	5606	1022	6.20	18.23	6.05	
10	270	5.14	4.92	6307	1059	4.38	16.79	6.05	
10	300	5.14	4.96	7007	1087	3.65	15.51	6.15	
10	30	5.31	4.81	724	396	9.53	54.77	5.85	
10	60	5.31	4.09	1447	514	22.95	35.51	5.95	
10	90	5.31	4.32	2171	665	18.72	30.62	6	
10	120	5.31	4.51	2895	787	15.19	27.20	5.9	
10	150	5.31	4.69	3619	885	11.65	24.44	5.95	
10	180	5.31	4.81	4342	961	9.53	22.14	5.95	
10	210	5.31	4.88	5066	1025	8.12	20.23	6	
10	240	5.31	4.98	5790	1077	6.36	18.61	6	
10	270	5.31	4.79	6514	1136	9.89	17.44	6.05	
10	300	5.31	4.81	7237	1207	9.53	16.67	6.1	
10	30	9.58	8.70	1305	713	9.23	54.61	6.15	
10	60	9.58	7.76	2611	897	19.02	34.37	6.25	
10	90	9.58	8.01	3916	1129	16.45	28.82	6.2	
10	120	9.58	8.32	5222	1323	13.24	25.33	6.3	
10	150	9.58	8.78	6527	1464	8.43	22.43	6.4	
10	180	9.58	8.89	7832	1566	7.22	20.00	6.35	
10	210	9.58	9.08	9138	1647	5.22	18.03	6.35	
10	240	9.58	9.20	10443	1708	4.01	16.35	6.35	
10	270	9.58	9.28	11748	1755	3.21	14.94	6.4	
10	300	9.58	9.55	13054	1778	0.40	13.62	6.4	
10	30	9.51	8.85	1295	692	6.88	53.44	6.3	
10	60	9.51	8.18	2590	827	13.99	31.94	6.3	
10	90	9.51	8.32	3885	999	12.54	25.71	6.3	
10	120	9.51	8.58	5180	1143	9.71	22.07	6.3	
10	150	9.51	8.97	6475	1242	5.66	19.19	6.4	
10	180	9.51	8.93	7769	1318	6.07	16.97	6.4	
10	210	9.51	9.28	9064	1373	2.43	15.15	6.4	
10	240	9.51	9.35	10359	1400	1.62	13.51	6.4	
10	270	9.51	9.39	11654	1418	1.21	12.17	6.45	
10	300	9.51	9.39	12949	1434	1.21	11.07	6.45	
10	30	14.49	13.91	1974	1026	3.98	51.99	6.25	
10	60	14.49	12.76	3948	1183	11.94	29.98	6.25	
10	90	14.49	12.93	5921	1407	10.75	23.76	6.25	
10	120	14.49	12.65	7895	1639	12.74	20.76	6.2	
10	150	14.49	13.11	9869	1859	9.55	18.84	6.3	
10	180	14.49	12.53	11843	2087	13.53	17.62	6.35	
10	210	14.49	13.57	13816	2283	6.37	16.53	6.3	
10	240	14.49	13.86	15790	2389	4.38	15.13	6.35	
10	270	14.49	14.03	17764	2464	3.18	13.87	6.4	

Table A.3: Continued

Retention Time	Collection Time	Inflow P Concentration	Outflow P concentration	Cumulative P Added	Cumulative P Sorbed	Discrete removal	Cumulative Removal	pH	EC
----- minutes -----		------ ppm ------		------ mg kg^{-1} ------		------ % ------			mS cm^{-1}
10	300	14.49	13.80	19738	2542	4.78	12.88	6.45	
10	30	14.95	12.53	2037	1183	16.20	58.10	6.25	
10	60	14.95	12.53	4073	1513	16.20	37.15	6.25	
10	90	14.95	12.70	6110	1831	15.04	29.98	6.25	
10	120	14.95	12.47	8147	2154	16.59	26.44	6.2	
10	150	14.95	12.99	10183	2456	13.12	24.12	6.25	
10	180	14.95	12.47	12220	2759	16.59	22.57	6.3	
10	210	14.95	13.28	14256	3041	11.19	21.33	6.25	
10	240	14.95	12.76	16293	3305	14.66	20.28	6.3	
10	270	14.95	14.26	18330	3501	4.63	19.10	6.35	
10	300	14.95	14.03	20366	3611	6.17	17.73	6.45	
8	30	4.96	2.50	490	366	49.47	74.74	6	
8	60	4.96	2.93	979	587	40.88	59.96	5.85	
8	90	4.96	3.36	1469	766	32.21	52.15	5.85	
8	120	4.96	3.65	1959	910	26.32	46.43	5.85	
8	150	4.96	3.77	2449	1032	23.85	42.16	5.8	
8	180	4.96	3.95	2938	1141	20.29	38.81	6.05	
8	210	4.96	4.06	3428	1235	18.12	36.01	6	
8	240	4.96	4.07	3918	1323	17.81	33.76	6	
8	270	4.96	4.25	4408	1401	14.32	31.79	6	
8	300	4.96	4.21	4897	1473	15.10	30.08	6	
8	30	4.86	2.64	480	350	45.71	72.86	6	
8	60	4.86	3.00	961	552	38.29	57.43	5.85	
8	90	4.86	3.28	1441	722	32.45	50.08	5.85	
8	120	4.86	3.51	1921	866	27.71	45.08	5.85	
8	150	4.86	3.69	2401	990	24.08	41.24	5.85	
8	180	4.86	3.81	2882	1100	21.55	38.17	6.05	
8	210	4.86	4.09	3362	1190	15.79	35.39	6	
8	240	4.86	4.09	3842	1265	15.79	32.94	6	
8	270	4.86	4.23	4322	1335	13.03	30.88	6	
8	300	4.86	4.21	4803	1398	13.42	29.11	6	
8	30	10.70	7.31	719	474	31.70	65.85	5.85	
8	60	10.70	7.99	1438	679	25.39	47.20	5.95	
8	90	10.70	8.68	2158	838	18.94	38.85	6	
8	120	10.70	8.71	2877	973	18.59	33.83	5.95	
8	150	10.70	9.24	3596	1089	13.68	30.29	6	
8	180	10.70	9.61	4315	1175	10.17	27.23	6	
8	210	10.70	9.73	5034	1244	9.12	24.72	6.05	
8	240	10.70	9.73	5754	1310	9.12	22.77	6.1	
8	270	10.70	9.84	6473	1372	8.07	21.19	6.1	
8	300	10.70	9.69	7192	1435	9.47	19.95	6.15	
8	30	10.63	6.11	714	509	42.52	71.26	5.85	
8	60	10.63	6.93	1428	785	34.75	54.95	5.95	
8	90	10.63	8.08	2142	995	24.01	46.42	6	
8	120	10.63	8.64	2857	1147	18.72	40.16	6	
8	150	10.63	9.01	3571	1268	15.19	35.52	6.05	
8	180	10.63	9.13	4285	1373	14.13	32.04	6.1	
8	210	10.63	9.69	4999	1455	8.83	29.10	6.1	
8	240	10.63	9.84	5713	1513	7.42	26.48	6.1	
8	270	10.63	9.88	6427	1565	7.06	24.34	6.15	

Table A.3: Continued

Retention Time	Collection Time	Inflow P Concentration	Outflow P concentration	Cumulative P Added	Cumulative P Sorbed	Discrete removal	Cumulative Removal	pH	EC
----- minutes -----		------ ppm ------		------ mg kg^{-1} ------		------ % ------			mS cm^{-1}
8	300	10.63	9.76	7142	1619	8.12	22.67	6.2	
8	30	13.91	9.24	935	625	33.58	66.79	6.3	
8	60	13.91	10.05	1870	911	27.77	48.73	6.25	
8	90	13.91	11.09	2805	1136	20.31	40.50	6.3	
8	120	13.91	12.93	3740	1264	7.05	33.80	6.3	
8	150	13.91	12.88	4675	1332	7.46	28.49	6.35	
8	180	13.91	13.17	5611	1392	5.39	24.81	6.35	
8	210	13.91	13.28	6546	1439	4.56	21.98	6.35	
8	240	13.91	12.88	7481	1495	7.46	19.98	6.35	
8	270	13.91	13.91	8416	1530	1.50	18.18	6.35	
8	300	13.91	13.74	9351	1535	1.24	16.42	6.4	
8	30	15.07	9.84	1013	682	34.68	67.34	6.25	
8	60	15.07	11.23	2025	987	25.49	48.71	6.2	
8	90	15.07	11.97	3038	1220	20.59	40.16	6.25	
8	120	15.07	12.24	4050	1419	18.76	35.04	6.3	
8	150	15.07	11.85	5063	1622	21.36	32.04	6.35	
8	180	15.07	13.11	6076	1796	13.02	29.57	6.3	
8	210	15.07	13.91	7088	1901	7.66	26.82	6.3	
8	240	15.07	13.22	8101	2002	12.25	24.71	6.3	
8	270	15.07	13.97	9114	2101	7.27	23.05	6.35	
8	300	15.07	13.63	10126	2186	9.57	21.59	6.4	
6	30	0.50	0.33	1141	767	34.39	67.20	6.55	0.827
6	60	0.50	0.38	2282	1103	24.53	48.33	6.3	0.8
6	90	0.50	0.40	3424	1356	19.72	39.59	6.2	0.8
6	120	0.50	0.46	4565	1515	8.25	33.19	6.35	0.77
6	150	0.50	0.44	5706	1637	13.07	28.69	6.2	0.8
6	180	0.50	0.44	6847	1785	12.84	26.06	6.25	0.8
6	210	0.50	0.43	7989	1940	14.44	24.29	6.25	0.875
6	240	0.50	0.44	9130	2095	12.61	22.94	6.25	0.82
6	270	0.50	0.42	10271	2260	16.28	22.00	6.25	0.8
6	300	0.50	0.43	11412	2437	14.90	21.36	6.3	0.89
6	30	0.51	0.39	1150	710	23.55	61.78	6	
6	60	0.51	0.41	2300	960	19.93	41.76	5.95	
6	90	0.51	0.42	3449	1176	17.67	34.11	5.9	
6	120	0.51	0.43	4599	1364	14.95	29.66	5.8	
6	150	0.51	0.43	5749	1532	14.27	26.65	5.75	
6	180	0.51	0.45	6899	1682	11.78	24.38	5.9	
6	210	0.51	0.45	8049	1816	11.55	22.56	5.9	
6	240	0.51	0.44	9199	1958	13.14	21.28	5.8	
6	270	0.51	0.45	10348	2097	11.10	20.26	5.75	
6	300	0.51	0.45	11498	2223	10.87	19.34	5.75	
6	30	0.99	0.84	1492	854	14.50	57.25	6.5	0.8
6	60	0.99	0.91	2983	1021	7.95	34.24	6.45	0.85
6	90	0.99	0.94	4475	1119	5.15	25.01	6.3	0.808
6	120	0.99	0.92	5967	1205	6.31	20.19	6.35	0.78
6	150	0.99	0.93	7458	1294	5.61	17.34	6.3	0.815
6	180	0.99	0.92	8950	1383	6.31	15.45	6.3	0.815
6	210	0.99	0.90	10442	1492	8.42	14.29	6.35	0.82
6	240	0.99	0.91	11934	1615	7.95	13.53	6.3	0.82
6	270	0.99	0.90	13425	1740	8.89	12.96	6.3	0.81

Table A.3: Continued

Retention Time	Collection Time	Inflow P Concentration	Outflow P concentration	Cumulative P Added	Cumulative P Sorbed	Discrete removal	Cumulative Removal	pH	EC
----- minutes -----		------ ppm ------		------ mg kg^{-1} ------		------ % ------			mS cm^{-1}
6	300	0.99	0.90	14917	1871	8.65	12.54	6.4	0.85
6	30	0.99	0.72	1497	950	26.90	63.45	5.95	
6	60	0.99	0.83	2995	1275	16.46	42.56	5.95	
6	90	0.99	0.86	4492	1495	12.99	33.28	5.9	
6	120	0.99	0.89	5990	1667	9.97	27.83	5.8	
6	150	0.99	0.90	7487	1808	8.81	24.14	5.75	
6	180	0.99	0.91	8985	1933	7.88	21.51	5.9	
6	210	0.99	0.93	10482	2035	5.80	19.42	5.85	
6	240	0.99	0.94	11980	2120	5.57	17.70	5.8	
6	270	0.99	0.94	13477	2202	5.33	16.34	5.8	
6	300	0.99	0.93	14975	2287	6.03	15.27	5.8	
6	30	4.64	3.56	1315	811	23.27	61.63	6.15	0.84
6	60	4.64	4.06	2631	1046	12.54	39.77	6.2	0.863
6	90	4.64	4.20	3946	1191	9.49	30.18	6.3	0.805
6	120	4.64	4.18	5262	1319	9.90	25.06	6.35	0.78
6	150	4.64	4.43	6577	1414	4.54	21.49	6.25	0.78
6	180	4.64	4.51	7893	1463	2.89	18.53	6.2	0.785
6	210	4.64	4.45	9208	1509	4.13	16.38	6.2	0.76
6	240	4.64	4.47	10523	1560	3.71	14.83	6.25	0.78
6	270	4.64	4.54	11839	1598	2.06	13.50	6.15	0.788
6	300	4.64	4.28	13154	1663	7.84	12.64	6.3	0.8
6	30	4.81	3.43	1364	878	28.72	64.36	6.05	0.83
6	60	4.81	3.83	2729	1213	20.45	44.47	6.15	0.76
6	90	4.81	4.20	4093	1440	12.73	35.18	6.2	0.8
6	120	4.81	4.16	5457	1619	13.52	29.66	6.25	0.82
6	150	4.81	4.35	6821	1776	9.55	26.04	6.15	0.806
6	180	4.81	4.43	8186	1896	7.96	23.16	6.15	0.785
6	210	4.81	4.53	9550	1991	5.97	20.84	6.2	0.811
6	240	4.81	4.45	10914	2083	7.56	19.08	6.2	0.81
6	270	4.81	4.53	12279	2175	5.97	17.71	6.15	0.8
6	300	4.81	4.58	13643	2248	4.77	16.48	6.25	0.778
6	30	9.18	5.19	651	467	43.46	71.73	6	0.9
6	60	9.18	6.46	1302	705	29.67	54.15	5.9	0.85
6	90	9.18	6.98	1952	879	23.99	45.04	5.9	0.85
6	120	9.18	7.46	2603	1019	18.80	39.13	5.9	0.82
6	150	9.18	7.98	3254	1122	13.12	34.50	5.9	0.83
6	180	9.18	8.18	3905	1201	10.86	30.74	6.15	0.82
6	210	9.18	8.02	4556	1277	12.62	28.03	6.1	0.82
6	240	9.18	8.49	5206	1342	7.52	25.79	6.1	0.79
6	270	9.18	8.26	5857	1400	10.03	23.90	6.3	0.7
6	300	9.18	8.72	6508	1449	5.01	22.26	6.1	0.81
6	30	9.49	4.48	673	514	52.81	76.40	6	0.95
6	60	9.49	5.92	1345	818	37.60	60.80	5.9	0.87
6	90	9.49	6.58	2018	1047	30.65	51.91	5.95	0.85
6	120	9.49	7.23	2690	1231	23.86	45.75	6.05	0.82
6	150	9.49	7.78	3363	1372	18.03	40.79	6.1	0.8
6	180	9.49	7.96	4035	1486	16.09	36.83	6.2	0.8
6	210	9.49	8.04	4708	1592	15.28	33.81	6.2	0.8
6	240	9.49	8.05	5380	1694	15.12	31.49	6.2	0.81
6	270	9.49	8.22	6053	1790	13.34	29.57	6.25	0.82

Table A.3: Continued

Retention Time	Collection Time	Inflow P Concentration	Outflow P concentration	Cumulative P Added	Cumulative P Sorbed	Discrete removal	Cumulative Removal	pH	EC
----- minutes -----		------ ppm ------		------ mg kg^{-1} ------		------ % ------			mS cm^{-1}
6	300	9.49	8.12	6726	1883	14.48	28.00	6.25	0.84
6	30	15.94	11.51	1130	722	27.83	63.91	5.85	0.89
6	60	15.94	12.45	2260	1003	21.89	44.39	5.9	0.83
6	90	15.94	13.41	3389	1216	15.89	35.89	6	0.79
6	120	15.94	14.31	4519	1364	10.24	30.18	6.05	0.76
6	150	15.94	14.87	5649	1460	6.71	25.84	6.05	0.78
6	180	15.94	14.42	6779	1552	9.53	22.89	6.1	0.78
6	210	15.94	14.76	7909	1647	7.42	20.83	6.15	0.79
6	240	15.94	15.15	9039	1717	4.94	19.00	6.15	0.79
6	270	15.94	14.76	10168	1787	7.42	17.57	6.2	0.77
6	300	15.94	14.65	11298	1875	8.12	16.59	6.2	0.8
6	30	16.17	10.72	1146	766	33.71	66.85	5.9	0.89
6	60	16.17	12.90	2292	1075	20.20	46.90	5.95	0.84
6	90	16.17	13.07	3437	1300	19.15	37.83	6.05	0.81
6	120	16.17	14.20	4583	1480	12.19	32.29	6	0.8
6	150	16.17	13.63	5729	1639	15.67	28.62	6.1	0.79
6	180	16.17	14.53	6875	1787	10.10	25.99	6.1	0.77
6	210	16.17	14.48	8021	1905	10.45	23.75	6.15	0.86
6	240	16.17	14.14	9166	2036	12.54	22.22	6.15	0.8
6	270	16.17	14.25	10312	2176	11.84	21.10	6.15	0.76
6	300	16.17	13.69	11458	2332	15.32	20.35	6.2	0.78
3	30	0.49	0.36	1284	802	24.83	62.42	6.15	
3	60	0.49	0.42	2568	1049	13.69	40.84	6.15	
3	90	0.49	0.42	3852	1228	14.16	31.87	6.15	
3	120	0.49	0.41	5136	1423	16.25	27.70	5.95	
3	150	0.49	0.41	6421	1627	15.55	25.34	5.95	
3	180	0.49	0.41	7705	1821	14.62	23.63	6	
3	210	0.49	0.42	8989	1997	12.77	22.21	6.1	
3	240	0.49	0.42	10273	2164	13.23	21.06	6.1	
3	270	0.49	0.42	11557	2333	13.23	20.19	6.05	
3	300	0.49	0.42	12841	2500	12.77	19.47	6.2	
3	30	0.48	0.40	1272	745	17.20	58.60	5.95	
3	60	0.48	0.42	2544	938	13.14	36.89	5.95	
3	90	0.48	0.43	3816	1083	9.56	28.37	5.9	
3	120	0.48	0.44	5088	1195	8.12	23.49	5.85	
3	150	0.48	0.45	6360	1288	6.45	20.25	5.8	
3	180	0.48	0.45	7633	1370	6.45	17.95	5.95	
3	210	0.48	0.45	8905	1449	5.97	16.27	5.9	
3	240	0.48	0.45	10177	1531	6.93	15.05	5.85	
3	270	0.48	0.46	11449	1607	5.02	14.04	5.8	
3	300	0.48	0.45	12721	1682	6.69	13.22	5.8	
3	30	1.00	0.76	1494	921	23.29	61.64	6.45	
3	60	1.00	0.81	2987	1233	18.54	41.28	6.35	
3	90	1.00	0.86	4481	1477	14.13	32.96	6.45	
3	120	1.00	0.88	5975	1667	11.35	27.91	6.4	
3	150	1.00	0.89	7468	1835	11.12	24.57	6.35	
3	180	1.00	0.90	8962	1988	9.27	22.18	6.35	
3	210	1.00	0.92	10456	2112	7.41	20.20	6.4	
3	240	1.00	0.92	11950	2226	7.88	18.63	6.4	
3	270	1.00	0.93	13443	2334	6.49	17.36	6.4	

Table A.3: Continued

Retention Time	Collection Time	Inflow P Concentration	Outflow P concentration	Cumulative P Added	Cumulative P Sorbed	Discrete removal	Cumulative Removal	pH	EC
----- minutes -----		------ ppm ------		------ mg kg^{-1} ------		------ % ------			mS cm^{-1}
3	300	1.00	0.94	14937	2425	5.79	16.24	6.45	
3	30	0.98	0.74	1468	914	24.52	62.26	5.95	
3	60	0.98	0.83	2937	1206	15.25	41.07	5.9	
3	90	0.98	0.90	4405	1380	8.45	31.33	5.9	
3	120	0.98	0.90	5873	1499	7.74	25.52	5.85	
3	150	0.98	0.92	7342	1602	6.33	21.82	5.75	
3	180	0.98	0.91	8810	1702	7.27	19.32	5.95	
3	210	0.98	0.94	10279	1783	3.75	17.35	5.85	
3	240	0.98	0.92	11747	1854	5.86	15.78	5.8	
3	270	0.98	0.95	13215	1921	3.28	14.54	5.75	
3	300	0.98	0.92	14684	1988	5.86	13.54	5.75	
3	30	4.73	3.30	1065	694	30.38	65.19	6.3	
3	60	4.73	3.91	2131	949	17.38	44.53	6.4	
3	90	4.73	4.22	3196	1100	10.97	34.41	6.25	
3	120	4.73	4.16	4261	1223	12.18	28.70	6.25	
3	150	4.73	4.33	5326	1333	8.53	25.03	6.25	
3	180	4.73	4.35	6392	1422	8.12	22.25	6.25	
3	210	4.73	4.37	7457	1506	7.72	20.20	6.3	
3	240	4.73	4.41	8522	1584	6.90	18.59	6.35	
3	270	4.73	4.33	9587	1667	8.53	17.38	6.35	
3	300	4.73	4.48	10653	1740	5.28	16.33	6.45	
3	30	4.79	3.87	1078	643	19.34	59.67	6.2	
3	60	4.79	4.29	2156	804	10.43	37.28	6.3	
3	90	4.79	4.39	3235	906	8.43	27.99	6.15	
3	120	4.79	4.33	4313	1003	9.63	23.25	6.15	
3	150	4.79	4.45	5391	1094	7.22	20.29	6.15	
3	180	4.79	4.50	6469	1165	6.02	18.01	6.25	
3	210	4.79	4.45	7548	1236	7.22	16.38	6.3	
3	240	4.79	4.50	8626	1308	6.02	15.16	6.3	
3	270	4.79	4.70	9704	1351	2.01	13.92	6.3	
3	300	4.79	4.62	10782	1381	3.61	12.81	6.35	
3	30	9.78	8.25	2933	1696	15.66	57.83	6.05	
3	60	9.78	8.97	5867	2047	8.22	34.89	6.2	
3	90	9.78	8.82	8800	2311	9.79	26.26	6.25	
3	120	9.78	9.24	11733	2535	5.48	21.60	6.3	
3	150	9.78	9.09	14667	2719	7.05	18.54	6.2	
3	180	9.78	9.28	17600	2897	5.09	16.46	6.25	
3	210	9.78	9.51	20533	3011	2.74	14.67	6.25	
3	240	9.78	9.36	23466	3115	4.31	13.27	6.2	
3	270	9.78	9.47	26400	3224	3.13	12.21	6.15	
3	300	9.78	9.09	29333	3373	7.05	11.50	6.25	
3	30	9.78	8.55	2933	1650	12.53	56.26	6.2	
3	60	9.78	8.71	5867	1995	10.96	34.01	6.25	
3	90	9.78	9.09	8800	2259	7.05	25.67	6.4	
3	120	9.78	9.36	11733	2426	4.31	20.67	6.4	
3	150	9.78	9.09	14667	2592	7.05	17.67	6.35	
3	180	9.78	9.28	17600	2770	5.09	15.74	6.35	
3	210	9.78	9.28	20533	2920	5.09	14.22	6.4	
3	240	9.78	9.28	23466	3069	5.09	13.08	6.35	
3	270	9.78	9.32	26400	3212	4.70	12.17	6.3	

Table A.3: Continued

Retention Time	Collection Time	Inflow P Concentration	Outflow P concentration	Cumulative P Added	Cumulative P Sorbed	Discrete removal	Cumulative Removal	pH	EC
----- minutes -----		------ ppm ------		------ mg kg^{-1} ------		------ % ------			mS cm^{-1}
3	300	9.78	9.28	29333	3356	5.09	11.44	6.45	
3	30	13.66	9.04	946	633	33.80	66.90	6	
3	60	13.66	10.03	1891	918	26.55	48.53	6	
3	90	13.66	11.14	2837	1131	18.46	39.86	6	
3	120	13.66	11.60	3782	1289	15.09	34.09	6	
3	150	13.66	12.62	4728	1396	7.58	29.54	6.05	
3	180	13.66	12.68	5674	1466	7.16	25.84	6.25	
3	210	13.66	12.91	6619	1526	5.48	23.05	6.25	
3	240	13.66	12.74	7565	1584	6.74	20.94	6.2	
3	270	13.66	12.51	8510	1655	8.43	19.45	6.05	
3	300	13.66	12.74	9456	1727	6.74	18.27	6.2	
3	30	14.98	9.27	1037	716	38.11	69.05	6	
3	60	14.98	10.79	2074	1059	27.97	51.05	6	
3	90	14.98	11.85	3112	1312	20.90	42.17	6.1	
3	120	14.98	12.39	4149	1510	17.29	36.40	6.05	
3	150	14.98	11.64	5186	1716	22.28	33.08	6.15	
3	180	14.98	11.85	6223	1940	20.90	31.16	6.3	
3	210	14.98	12.68	7261	2128	15.37	29.30	6.25	
3	240	14.98	13.08	8298	2273	12.68	27.39	6.25	
3	270	14.98	11.64	9335	2454	22.28	26.29	6.15	
3	300	14.98	12.80	10372	2646	14.60	25.51	6.2	
0.5	30	0.50	0.44	1947	1105	13.45	56.73	6.4	
0.5	60	0.50	0.45	3894	1342	10.94	34.46	6	
0.5	90	0.50	0.45	5842	1555	10.94	26.62	5.9	
0.5	120	0.50	0.45	7789	1768	10.94	22.70	5.95	
0.5	150	0.50	0.46	9736	1968	9.58	20.22	5.95	
0.5	180	0.50	0.44	11683	2179	12.08	18.65	6	
0.5	210	0.50	0.47	13630	2370	7.52	17.39	6	
0.5	240	0.50	0.46	15578	2523	8.21	16.20	6.05	
0.5	270	0.50	0.44	17525	2725	12.54	15.55	6	
0.5	300	0.50	0.46	19472	2932	8.66	15.06	6	
0.5	30	0.51	0.45	1978	1113	12.57	56.28	6.3	
0.5	60	0.51	0.45	3957	1355	11.90	34.26	6	
0.5	90	0.51	0.47	5935	1562	8.98	26.32	5.95	
0.5	120	0.51	0.46	7913	1755	10.55	22.18	5.95	
0.5	150	0.51	0.46	9891	1959	10.10	19.81	5.95	
0.5	180	0.51	0.47	11870	2148	8.98	18.10	6	
0.5	210	0.51	0.47	13848	2314	7.86	16.71	6.05	
0.5	240	0.51	0.47	15826	2465	7.41	15.58	6.05	
0.5	270	0.51	0.46	17805	2632	9.43	14.78	6	
0.5	300	0.51	0.47	19783	2810	8.53	14.20	6	
0.5	30	0.97	0.91	2624	1396	6.38	53.19	5.9	
0.5	60	0.97	0.93	5249	1535	4.25	29.25	5.9	
0.5	90	0.97	0.94	7873	1635	3.31	20.76	5.95	
0.5	120	0.97	0.91	10498	1759	6.14	16.75	5.8	
0.5	150	0.97	0.95	13122	1873	2.60	14.28	5.75	
0.5	180	0.97	0.94	15747	1951	3.31	12.39	5.85	
0.5	210	0.97	0.94	18371	2031	2.84	11.06	5.8	
0.5	240	0.97	0.96	20996	2084	1.18	9.93	5.8	
0.5	270	0.97	0.97	23620	2109	0.71	8.93	5.7	

Table A.3: Continued

Retention Time	Collection Time	Inflow P Concentration	Outflow P concentration	Cumulative P Added	Cumulative P Sorbed	Discrete removal	Cumulative Removal	pH	EC
----- minutes -----		------ ppm ------		------ mg kg^{-1} ------		------ % ------			mS cm^{-1}
0.5	300	0.97	0.96	26245	2131	0.95	8.12	5.75	
0.5	30	0.99	0.92	2686	1439	7.16	53.58	5.9	
0.5	60	0.99	0.94	5373	1613	5.77	30.02	5.9	
0.5	90	0.99	0.95	8059	1749	4.39	21.71	5.8	
0.5	120	0.99	0.97	10746	1845	2.77	17.17	5.8	
0.5	150	0.99	0.97	13432	1920	2.77	14.29	5.75	
0.5	180	0.99	0.96	16119	2000	3.23	12.41	5.85	
0.5	210	0.99	0.97	18805	2081	2.77	11.07	5.85	
0.5	240	0.99	0.97	21492	2156	2.77	10.03	5.8	
0.5	270	0.99	0.94	24178	2261	5.08	9.35	5.7	
0.5	300	0.99	0.97	26865	2360	2.31	8.79	5.75	
0.5	30	4.75	3.83	1283	766	19.33	59.67	6.25	
0.5	60	4.75	4.18	2567	968	12.13	37.70	6.25	
0.5	90	4.75	4.41	3850	1092	7.28	28.37	6.2	
0.5	120	4.75	4.52	5134	1170	4.85	22.79	6.45	
0.5	150	4.75	4.52	6417	1233	4.85	19.21	6.35	
0.5	180	4.75	4.58	7701	1287	3.64	16.71	6.4	
0.5	210	4.75	4.62	8984	1329	2.83	14.79	6.4	
0.5	240	4.75	4.64	10268	1362	2.43	13.27	6.4	
0.5	270	4.75	4.68	11551	1388	1.62	12.02	6.45	
0.5	300	4.75	4.70	12835	1406	1.21	10.96	6.45	
0.5	30	4.91	4.18	1325	761	14.89	57.44	6.2	
0.5	60	4.91	4.22	2650	953	14.10	35.97	6.25	
0.5	90	4.91	4.23	3975	1138	13.71	28.62	6.2	
0.5	120	4.91	4.45	5300	1291	9.40	24.35	6.3	
0.5	150	4.91	4.52	6625	1405	7.84	21.21	6.3	
0.5	180	4.91	4.58	7950	1501	6.66	18.88	6.3	
0.5	210	4.91	4.75	9275	1566	3.13	16.88	6.3	
0.5	240	4.91	4.73	10600	1610	3.53	15.19	6.35	
0.5	270	4.91	4.64	11925	1670	5.49	14.00	6.35	
0.5	300	4.91	4.60	13250	1748	6.27	13.19	6.35	
0.5	30	9.66	8.07	2174	1266	16.48	58.24	6.3	
0.5	60	9.66	8.74	4348	1549	9.55	35.63	6.3	
0.5	90	9.66	8.89	6521	1739	7.96	26.67	6.25	
0.5	120	9.66	8.93	8695	1908	7.56	21.94	6.25	
0.5	150	9.66	9.08	10869	2055	5.97	18.91	6.25	
0.5	180	9.66	9.08	13043	2185	5.97	16.75	6.25	
0.5	210	9.66	8.93	15216	2332	7.56	15.33	6.25	
0.5	240	9.66	8.93	17390	2496	7.56	14.35	6.35	
0.5	270	9.66	8.97	19564	2656	7.16	13.58	6.35	
0.5	300	9.66	9.08	21738	2799	5.97	12.88	6.4	
0.5	30	9.24	7.90	2079	1190	14.49	57.24	6.4	
0.5	60	9.24	8.74	4157	1397	5.41	33.60	6.4	
0.5	90	9.24	8.70	6236	1513	5.83	24.27	6.35	
0.5	120	9.24	8.78	8314	1626	5.00	19.56	6.35	
0.5	150	9.24	8.82	10393	1725	4.58	16.60	6.4	
0.5	180	9.24	8.74	12472	1829	5.41	14.67	6.4	
0.5	210	9.24	9.28	14550	1881	0.00	12.93	6.4	
0.5	240	9.24	9.20	16629	1881	0.42	11.31	6.45	
0.5	270	9.24	9.01	18707	1911	2.50	10.22	6.5	

Table A.3: Continued

Retention Time	Collection Time	Inflow P Concentration	Outflow P concentration	Cumulative P Added	Cumulative P Sorbed	Discrete removal	Cumulative Removal	pH	EC
----- minutes -----		------ ppm ------		------ mg kg^{-1} ------		------ % ------			mS cm^{-1}
0.5	300	9.24	9.05	20786	1959	2.08	9.42	6.55	
0.5	30	14.44	11.76	2436	1444	18.54	59.27	6.15	
0.5	60	14.44	12.94	4872	1796	10.34	36.85	6.2	
0.5	90	14.44	13.46	7309	2004	6.76	27.42	6.35	
0.5	120	14.44	13.75	9745	2145	4.77	22.01	6.3	
0.5	150	14.44	13.86	12181	2251	3.98	18.48	6.3	
0.5	180	14.44	12.54	14617	2460	13.13	16.83	6.25	
0.5	210	14.44	13.86	17053	2668	3.98	15.64	6.3	
0.5	240	14.44	14.09	19490	2745	2.39	14.09	6.25	
0.5	270	14.44	14.61	21926	2760	1.00	12.59	6.25	
0.5	300	14.44	14.32	24362	2755	0.80	11.31	6.3	
0.5	30	14.90	12.37	2514	1470	16.96	58.48	6.2	
0.5	60	14.90	13.12	5027	1833	11.95	36.47	6.2	
0.5	90	14.90	12.25	7541	2207	17.73	29.26	6.35	
0.5	120	14.90	13.75	10055	2526	7.71	25.13	6.35	
0.5	150	14.90	13.63	12569	2730	8.48	21.72	6.3	
0.5	180	14.90	13.75	15082	2933	7.71	19.45	6.3	
0.5	210	14.90	13.58	17596	3142	8.87	17.85	6.25	
0.5	240	14.90	14.09	20110	3321	5.40	16.51	6.25	
0.5	270	14.90	14.03	22624	3462	5.78	15.30	6.3	
0.5	300	14.90	13.35	25137	3665	10.41	14.58	6.4	

Table A.4: Results of AMDR4 flow-through experiment.

Retention Time	Collection Time	Inflow P Concentration	Outflow P concentration	Cumulative P Added	Cumulative P Sorbed	Discrete removal	Cumulative Removal	pH	EC
----- minutes -----		------ ppm ------		------ mg kg^{-1} ------		------ % ------			$mS\ cm^{-1}$
10	60	0.49	0.35	891	570	27.99	63.99	6.4	
10	120	0.49	0.28	1781	884	42.57	49.64	6.4	
10	180	0.49	0.32	2672	1231	35.28	46.07	6.4	
10	240	0.49	0.36	3563	1510	27.28	42.37	6.35	
10	300	0.49	0.37	4454	1737	23.76	39.00	6.35	
10	60	0.49	0.30	887	618	39.46	69.73	6.45	
10	120	0.49	0.24	1773	1020	51.28	57.55	6.45	
10	180	0.49	0.29	2660	1428	40.65	53.69	6.45	
10	240	0.49	0.32	3546	1760	34.27	49.63	6.4	
10	300	0.49	0.35	4433	2037	28.12	45.94	6.4	
10	60	1.01	0.74	1843	1170	27.00	63.50	6.55	
10	120	1.01	0.68	3686	1723	33.01	46.75	6.45	
10	180	1.01	0.75	5528	2264	25.75	40.96	6.45	
10	240	1.01	0.80	7371	2698	21.33	36.60	6.35	
10	300	1.01	0.83	9214	3062	18.15	33.23	6.5	
10	60	1.02	0.71	1860	1219	31.14	65.57	6.5	
10	120	1.02	0.63	3719	1868	38.67	50.24	6.45	
10	180	1.02	0.68	5579	2537	33.27	45.48	6.45	
10	240	1.02	0.73	7438	3111	28.44	41.83	6.4	
10	300	1.02	0.79	9298	3591	23.16	38.62	6.5	
10	30	4.90	3.89	556	335	20.60	60.30	6.2	
10	60	4.90	2.67	1112	519	45.51	46.68	6.45	
10	90	4.90	2.80	1668	765	42.85	45.85	6.35	
10	120	4.90	3.20	2224	980	34.70	44.08	6.35	
10	150	4.90	3.43	2780	1160	30.00	41.73	6.35	
10	180	4.90	3.69	3336	1312	24.68	39.33	6.35	
10	210	4.90	3.77	3892	1444	22.95	37.12	6.35	
10	240	4.90	3.80	4448	1571	22.48	35.32	6.35	
10	270	4.90	3.90	5003	1690	20.29	33.77	6.35	
10	300	4.90	4.13	5559	1790	15.67	32.19	6.35	
10	30	4.88	3.95	554	330	19.03	59.52	6.1	
10	60	4.88	2.78	1108	501	42.94	45.25	6.4	
10	90	4.88	2.35	1661	764	51.83	45.96	6.4	
10	120	4.88	2.64	2215	1034	45.85	46.68	6.4	
10	150	4.88	2.86	2769	1275	41.37	46.07	6.4	
10	180	4.88	3.07	3323	1493	37.12	44.93	6.4	
10	210	4.88	3.37	3876	1681	30.83	43.36	6.4	
10	240	4.88	3.42	4430	1849	29.88	41.74	6.4	
10	270	4.88	3.54	4984	2008	27.37	40.28	6.4	
10	300	4.88	3.66	5538	2153	25.01	38.87	6.4	
10	30	10.03	8.13	1050	625	18.90	59.45	6.2	
10	60	10.03	7.39	2101	862	26.25	41.02	6.4	
10	90	10.03	5.97	3151	1212	40.49	38.47	6.4	
10	120	10.03	6.11	4202	1630	39.11	38.80	6.4	
10	150	10.03	6.70	5252	2010	33.14	38.26	6.55	
10	180	10.03	7.30	6303	2327	27.17	36.91	6.6	
10	210	10.03	7.70	7353	2591	23.19	35.24	6.55	

Table A.4: Continued

Retention Time	Collection Time	Inflow P Concentration	Outflow P concentration	Cumulative P Added	Cumulative P Sorbed	Discrete removal	Cumulative Removal	pH	EC
----- minutes -----		------ ppm ------		------ mg kg^{-1} ------		------ % ------			mS cm^{-1}
10	240	10.03	7.92	8404	2823	21.05	33.60	6.5	
10	270	10.03	7.98	9454	3041	20.44	32.17	6.55	
10	300	10.03	8.01	10505	3254	20.13	30.98	6.55	
10	30	9.95	8.49	1042	598	14.65	57.33	6.15	
10	60	9.95	7.69	2085	793	22.75	38.02	6.4	
10	90	9.95	5.64	3127	1137	43.27	36.35	6.45	
10	120	9.95	5.97	4170	1571	40.03	37.67	6.45	
10	150	9.95	6.60	5212	1955	33.70	37.51	6.65	
10	180	9.95	7.39	6255	2265	25.68	36.21	6.65	
10	210	9.95	7.41	7297	2532	25.53	34.69	6.6	
10	240	9.95	7.98	8339	2768	19.82	33.19	6.55	
10	270	9.95	8.18	9382	2964	17.74	31.59	6.6	
10	300	9.95	8.04	10424	3156	19.20	30.28	6.6	
10	30	14.40	13.13	1635	889	8.83	54.41	6.2	
10	60	14.40	13.30	3269	1024	7.63	31.32	6.3	
10	90	14.40	12.67	4904	1185	12.04	24.16	6.35	
10	120	14.40	12.90	6538	1368	10.44	20.93	6.35	
10	150	14.40	13.25	8173	1519	8.03	18.59	6.4	
10	180	14.40	13.48	9808	1637	6.42	16.69	6.4	
10	210	14.40	13.42	11442	1746	6.82	15.26	6.45	
10	240	14.40	13.71	13077	1841	4.82	14.08	6.4	
10	270	14.40	13.94	14711	1906	3.21	12.96	6.4	
10	300	14.40	13.36	16346	1992	7.22	12.18	6.35	
10	30	14.29	13.01	1621	883	8.90	54.45	6.2	
10	60	14.29	13.01	3243	1027	8.90	31.68	6.3	
10	90	14.29	11.55	4864	1255	19.18	25.80	6.35	
10	120	14.29	12.24	6486	1527	14.32	23.54	6.4	
10	150	14.29	12.17	8107	1763	14.81	21.74	6.45	
10	180	14.29	13.01	9729	1955	8.90	20.09	6.45	
10	210	14.29	13.82	11350	2053	3.24	18.09	6.45	
10	240	14.29	13.77	12972	2109	3.64	16.26	6.45	
10	270	14.29	13.25	14593	2198	7.28	15.06	6.4	
10	300	14.29	13.88	16215	2280	2.83	14.06	6.35	
8	42.5	0.49	0.13	727	630	73.32	86.66	6.4	
8	85	0.49	0.18	1454	1124	62.44	77.27	6.35	
8	127.5	0.49	0.26	2181	1518	46.12	69.61	6.6	
8	170	0.49	0.30	2908	1823	37.61	62.67	6.45	
8	212.5	0.49	0.33	3635	2080	33.11	57.21	6.55	
8	255	0.49	0.36	4362	2296	26.49	52.64	6.5	
8	297.5	0.49	0.37	5089	2480	24.13	48.74	6.35	
8	42.5	0.49	0.20	730	584	60.03	80.02	6.45	
8	85	0.49	0.25	1461	986	49.91	67.49	6.4	
8	127.5	0.49	0.32	2191	1297	35.31	59.20	6.65	
8	170	0.49	0.34	2922	1538	30.60	52.64	6.45	
8	212.5	0.49	0.37	3652	1740	24.72	47.64	6.6	
8	255	0.49	0.38	4383	1916	23.54	43.72	6.5	
8	297.5	0.49	0.38	5113	2087	23.07	40.81	6.4	
8	42.5	1.00	0.36	1188	976	64.38	82.19	6.5	
8	85	1.00	0.53	2375	1636	46.70	68.86	6.45	

Table A.4: Continued

Retention Time	Collection Time	Inflow P Concentration	Outflow P concentration	Cumulative P Added	Cumulative P Sorbed	Discrete removal	Cumulative Removal	pH	EC
-----	minutes -----	------	ppm ------	------	mg kg^{-1} ------	------	% ------		$mS\ cm^{-1}$
8	127.5	1.00	0.65	3563	2122	35.14	59.55	6.5	
8	170	1.00	0.71	4751	2499	28.43	52.61	6.5	
8	212.5	1.00	0.76	5939	2809	23.69	47.30	6.45	
8	255	1.00	0.78	7126	3081	22.19	43.24	6.4	
8	297.5	1.00	0.80	8314	3333	20.11	40.08	6.4	
8	42.5	0.98	0.38	1169	943	61.44	80.72	6.5	
8	85	0.98	0.48	2337	1602	51.34	68.56	6.5	
8	127.5	0.98	0.60	3506	2131	39.12	60.78	6.5	
8	170	0.98	0.68	4674	2538	30.55	54.30	6.5	
8	212.5	0.98	0.72	5843	2873	26.90	49.18	6.45	
8	255	0.98	0.76	7011	3163	22.67	45.12	6.45	
8	297.5	0.98	0.76	8180	3429	22.79	41.92	6.4	
8	30	4.84	3.94	542	321	18.55	59.27	6.4	
8	60	4.84	3.98	1084	420	17.76	38.71	6.4	
8	90	4.84	4.06	1626	512	16.17	31.46	6.35	
8	120	4.84	4.21	2169	591	13.08	27.25	6.4	
8	150	4.84	4.21	2711	662	13.08	24.42	6.3	
8	180	4.84	4.11	3253	738	15.06	22.69	6.4	
8	210	4.84	4.28	3795	810	11.49	21.35	6.3	
8	240	4.84	4.21	4337	877	13.08	20.22	6.3	
8	270	4.84	4.25	4879	946	12.29	19.38	6.55	
8	300	4.84	4.34	5421	1007	10.30	18.57	6.4	
8	30	4.97	3.94	557	336	20.75	60.37	6.3	
8	60	4.97	4.07	1114	445	18.12	39.90	6.4	
8	90	4.97	4.13	1672	542	16.97	32.45	6.35	
8	120	4.97	4.13	2229	637	16.97	28.58	6.4	
8	150	4.97	4.27	2786	724	14.27	25.99	6.3	
8	180	4.97	4.19	3343	808	15.81	24.16	6.4	
8	210	4.97	4.32	3900	888	13.11	22.78	6.3	
8	240	4.97	4.28	4458	964	13.88	21.62	6.3	
8	270	4.97	4.38	5015	1036	11.95	20.65	6.5	
8	300	4.97	4.48	5572	1097	10.03	19.68	6.35	
8	30	9.87	6.57	754	503	33.50	66.75	6.1	
8	60	9.87	7.07	1508	736	28.37	48.84	6.4	
8	90	9.87	7.26	2262	943	26.50	41.71	6.35	
8	120	9.87	7.53	3016	1133	23.71	37.56	6.35	
8	150	9.87	7.78	3770	1302	21.22	34.54	6.4	
8	180	9.87	7.78	4524	1462	21.22	32.32	6.4	
8	210	9.87	8.30	5278	1602	15.93	30.36	6.4	
8	240	9.87	7.99	6032	1734	19.04	28.75	6.4	
8	270	9.87	8.42	6786	1861	14.77	27.43	6.45	
8	300	9.87	8.26	7539	1979	16.32	26.24	6.45	
8	30	10.06	6.46	769	522	35.84	67.92	6.2	
8	60	10.06	7.10	1537	773	29.43	50.28	6.4	
8	90	10.06	7.53	2306	983	25.16	42.62	6.4	
8	120	10.06	7.70	3074	1170	23.48	38.04	6.4	
8	150	10.06	7.81	3843	1346	22.42	35.02	6.4	
8	180	10.06	8.12	4612	1507	19.37	32.67	6.4	
8	210	10.06	8.22	5380	1651	18.30	30.69	6.45	
8	240	10.06	8.38	6149	1786	16.77	29.05	6.5	

Table A.4: Continued

Retention Time	Collection Time	Inflow P Concentration	Outflow P concentration	Cumulative P Added	Cumulative P Sorbed	Discrete removal	Cumulative Removal	pH	EC
----- minutes -----		------ ppm ------		------ mg kg^{-1} ------		------ % ------			mS cm^{-1}
8	270	10.06	8.68	6917	1903	13.72	27.51	6.5	
8	300	10.06	8.68	7686	2009	13.72	26.14	6.4	
8	30	14.92	11.02	929	586	26.15	63.07	6.2	
8	60	14.92	8.86	1857	896	40.65	48.23	6.45	
8	90	14.92	9.87	2786	1242	33.86	44.57	6.45	
8	120	14.92	10.26	3715	1544	31.24	41.57	6.45	
8	150	14.92	11.02	4643	1810	26.15	38.99	6.6	
8	180	14.92	11.92	5572	2025	20.13	36.35	6.55	
8	210	14.92	12.51	6501	2194	16.20	33.75	6.6	
8	240	14.92	12.51	7429	2344	16.20	31.56	6.6	
8	270	14.92	12.39	8358	2498	16.97	29.89	6.55	
8	300	14.92	12.56	9287	2651	15.81	28.54	6.55	
8	30	14.98	11.09	932	587	25.97	62.98	6.25	
8	60	14.98	10.29	1864	854	31.35	45.82	6.45	
8	90	14.98	11.30	2797	1115	24.59	39.87	6.45	
8	120	14.98	11.69	3729	1332	21.97	35.72	6.45	
8	150	14.98	11.60	4661	1540	22.59	33.03	6.6	
8	180	14.98	11.05	5593	1768	26.28	31.60	6.6	
8	210	14.98	12.74	6526	1960	14.98	30.03	6.6	
8	240	14.98	11.32	7458	2144	24.43	28.74	6.55	
8	270	14.98	12.62	8390	2331	15.75	27.78	6.55	
8	300	14.98	12.20	9322	2491	18.59	26.72	6.6	
6	30	0.49	0.27	589	429	45.73	72.87	6.6	0.74
6	60	0.49	0.28	1178	690	42.93	58.60	6.4	0.72
6	90	0.49	0.33	1767	915	33.37	51.78	6.4	0.73
6	120	0.49	0.33	2355	1108	32.20	47.03	6.35	0.72
6	150	0.49	0.36	2944	1282	26.83	43.53	6.4	0.73
6	180	0.49	0.37	3533	1436	25.67	40.65	6.55	0.73
6	210	0.49	0.38	4122	1581	23.57	38.36	6.5	0.69
6	240	0.49	0.38	4711	1716	22.17	36.42	6.5	0.71
6	270	0.49	0.38	5300	1846	22.17	34.84	6.5	0.74
6	300	0.49	0.40	5889	1968	19.13	33.42	6.5	0.71
6	30	0.49	0.27	581	417	43.78	71.89	6.5	0.74
6	60	0.49	0.26	1161	681	46.86	58.60	6.45	0.71
6	90	0.49	0.32	1742	914	33.60	52.48	6.4	0.72
6	120	0.49	0.35	2322	1091	27.21	46.96	6.4	0.75
6	150	0.49	0.37	2903	1242	24.85	42.78	6.45	0.73
6	180	0.49	0.39	3484	1373	20.35	39.41	6.55	0.87
6	210	0.49	0.40	4064	1484	17.99	36.52	6.55	0.73
6	240	0.49	0.39	4645	1597	20.83	34.38	6.55	0.73
6	270	0.49	0.40	5226	1710	18.22	32.73	6.5	0.71
6	300	0.49	0.40	5806	1812	16.80	31.21	6.6	0.72
6	30	1.01	0.65	913	620	35.72	67.86	6.45	0.76
6	60	1.01	0.73	1826	907	27.22	49.66	6.3	0.74
6	90	1.01	0.80	2740	1124	20.21	41.01	6.35	0.74
6	120	1.01	0.81	3653	1303	19.06	35.67	6.3	0.72
6	150	1.01	0.85	4566	1459	15.16	31.96	6.35	0.72
6	180	1.01	0.84	5479	1602	16.08	29.23	6.45	0.73
6	210	1.01	0.86	6393	1742	14.70	27.26	6.6	0.75
6	240	1.01	0.85	7306	1881	15.62	25.74	6.4	0.73

Table A.4: Continued

Retention Time	Collection Time	Inflow P Concentration	Outflow P concentration	Cumulative P Added	Cumulative P Sorbed	Discrete removal	Cumulative Removal	pH	EC
----- minutes -----		------ ppm ------		------ mg kg^{-1} ------		------ % ------			$mS\ cm^{-1}$
6	270	1.01	0.85	8219	2025	15.85	24.63	6.4	0.75
6	300	1.01	0.87	9132	2160	13.78	23.65	6.35	0.74
6	30	0.99	0.62	894	615	37.52	68.76	6.45	0.86
6	60	0.99	0.73	1789	899	25.92	50.24	6.3	0.75
6	90	0.99	0.78	2683	1107	20.64	41.25	6.35	0.72
6	120	0.99	0.81	3577	1277	17.36	35.69	6.35	0.73
6	150	0.99	0.82	4472	1430	16.89	31.98	6.35	0.73
6	180	0.99	0.83	5366	1578	16.18	29.40	6.45	0.75
6	210	0.99	0.85	6261	1712	13.84	27.35	6.6	0.71
6	240	0.99	0.84	7155	1842	15.24	25.75	6.5	0.74
6	270	0.99	0.86	8049	1968	12.90	24.45	6.4	0.72
6	300	0.99	0.84	8944	2093	15.01	23.40	6.35	0.74
6	30	4.83	3.92	1369	814	18.87	59.43	6.3	0.78
6	60	4.83	4.14	2739	1041	14.33	38.02	6.3	0.74
6	90	4.83	4.27	4108	1218	11.54	29.66	6.35	0.74
6	120	4.83	4.27	5478	1376	11.54	25.13	6.35	0.74
6	150	4.83	4.43	6847	1513	8.36	22.09	6.3	0.72
6	180	4.83	4.45	8217	1624	7.96	19.77	6.3	0.71
6	210	4.83	4.47	9586	1731	7.56	18.05	6.3	0.7
6	240	4.83	4.29	10956	1859	11.14	16.97	6.3	0.72
6	270	4.83	4.29	12325	2012	11.14	16.32	6.15	0.7
6	300	4.83	4.45	13695	2142	7.96	15.64	6.2	0.7
6	30	4.79	3.72	1359	831	22.39	61.19	6.25	0.77
6	60	4.79	4.18	2717	1071	12.84	39.40	6.3	0.76
6	90	4.79	4.22	4076	1240	12.04	30.42	6.35	0.77
6	120	4.79	4.37	5434	1381	8.83	25.42	6.35	0.76
6	150	4.79	4.25	6793	1518	11.23	22.34	6.25	0.7
6	180	4.79	4.37	8151	1654	8.83	20.29	6.3	0.72
6	210	4.79	4.41	9510	1768	8.02	18.60	6.3	0.72
6	240	4.79	4.35	10869	1886	9.23	17.35	6.3	0.72
6	270	4.79	4.47	12227	1995	6.82	16.31	6.2	0.72
6	300	4.79	4.41	13586	2095	8.02	15.42	6.2	0.73
6	30	9.68	6.18	732	498	36.15	68.07	6.3	0.8
6	60	9.68	6.75	1464	741	30.28	50.64	6.4	0.8
6	90	9.68	7.18	2196	947	25.84	43.12	6.4	0.76
6	120	9.68	7.47	2928	1125	22.83	38.42	6.4	0.75
6	150	9.68	7.62	3660	1286	21.24	35.14	6.4	0.76
6	180	9.68	7.78	4391	1436	19.66	32.69	6.45	0.74
6	210	9.68	7.90	5123	1575	18.39	30.74	6.35	0.74
6	240	9.68	7.90	5855	1710	18.39	29.20	6.35	0.75
6	270	9.68	7.79	6587	1848	19.50	28.06	6.35	0.74
6	300	9.68	8.26	7319	1973	14.66	26.96	6.45	0.75
6	30	9.72	6.72	735	481	30.87	65.44	6.3	0.89
6	60	9.72	7.21	1470	689	25.82	46.89	6.45	0.82
6	90	9.72	7.38	2204	872	24.08	39.58	6.5	0.78
6	120	9.72	7.66	2939	1039	21.24	35.35	6.45	0.82
6	150	9.72	7.76	3674	1191	20.13	32.41	6.45	0.77
6	180	9.72	7.99	4409	1330	17.76	30.17	6.5	0.77
6	210	9.72	7.87	5144	1465	19.03	28.49	6.4	0.76
6	240	9.72	8.12	5878	1596	16.50	27.15	6.4	0.76

Table A.4: Continued

Retention Time	Collection Time	Inflow P Concentration	Outflow P concentration	Cumulative P Added	Cumulative P Sorbed	Discrete removal	Cumulative Removal	pH	EC
----- minutes -----		------ ppm ------		------ mg kg^{-1} ------		------ % ------			mS cm^{-1}
6	270	9.72	8.34	6613	1709	14.21	25.84	6.4	0.75
6	300	9.72	8.49	7348	1807	12.63	24.60	6.5	0.75
6	30	15.04	9.27	1003	694	38.34	69.17	6.25	0.85
6	60	15.04	10.52	2006	1037	30.08	51.69	6.4	0.78
6	90	15.04	10.98	3010	1324	27.02	43.98	6.4	0.79
6	120	15.04	11.67	4013	1572	22.43	39.16	6.4	0.74
6	150	15.04	11.85	5016	1790	21.20	35.69	6.45	0.71
6	180	15.04	12.15	6019	1993	19.21	33.11	6.45	0.74
6	210	15.04	11.53	7023	2207	23.34	31.42	6.45	0.72
6	240	15.04	11.53	8026	2441	23.34	30.41	6.4	0.72
6	270	15.04	12.74	9029	2635	15.31	29.18	6.45	0.74
6	300	15.04	12.51	10032	2796	16.84	27.87	6.5	0.74
6	30	14.87	10.49	992	642	29.42	64.71	6.3	0.85
6	60	14.87	11.51	1983	900	22.61	45.36	6.45	0.76
6	90	14.87	11.11	2975	1137	25.24	38.22	6.45	0.77
6	120	14.87	11.92	3967	1360	19.82	34.30	6.45	0.78
6	150	14.87	11.83	4959	1560	20.44	31.46	6.4	0.77
6	180	14.87	11.83	5950	1763	20.44	29.63	6.45	0.74
6	210	14.87	12.97	6942	1928	12.78	27.77	6.45	0.72
6	240	14.87	12.33	7934	2075	17.03	26.16	6.45	0.77
6	270	14.87	12.74	8926	2231	14.32	24.99	6.5	0.75
6	300	14.87	12.51	9917	2381	15.87	24.00	6.5	0.72
3	30	0.49	0.20	627	495	58.08	79.04	6.4	
3	60	0.49	0.27	1254	815	43.91	65.02	6.55	
3	90	0.49	0.32	1881	1061	34.47	56.41	6.4	
3	120	0.49	0.35	2507	1258	28.33	50.16	6.3	
3	150	0.49	0.37	3134	1424	24.79	45.44	6.35	
3	180	0.49	0.38	3761	1570	21.72	41.74	6.35	
3	210	0.49	0.39	4388	1702	20.30	38.78	6.35	
3	240	0.49	0.39	5015	1827	19.60	36.43	6.35	
3	270	0.49	0.41	5642	1940	16.53	34.39	6.4	
3	300	0.49	0.41	6269	2044	16.53	32.60	6.35	
3	30	0.50	0.18	646	533	65.05	82.53	6.4	
3	60	0.50	0.25	1292	903	49.48	69.90	6.55	
3	90	0.50	0.30	1938	1195	40.77	61.64	6.45	
3	120	0.50	0.33	2584	1438	34.59	55.65	6.4	
3	150	0.50	0.35	3231	1645	29.55	50.93	6.4	
3	180	0.50	0.37	3877	1825	26.11	47.08	6.4	
3	210	0.50	0.38	4523	1990	24.97	44.01	6.4	
3	240	0.50	0.38	5169	2149	24.28	41.58	6.45	
3	270	0.50	0.39	5815	2301	22.68	39.57	6.45	
3	300	0.50	0.40	6461	2442	21.07	37.80	6.4	
3	30	0.99	0.61	989	685	38.51	69.25	6.5	
3	60	0.99	0.68	1979	1031	31.29	52.08	6.45	
3	90	0.99	0.77	2968	1296	22.34	43.66	6.45	
3	120	0.99	0.79	3958	1505	20.01	38.04	6.45	
3	150	0.99	0.83	4947	1686	16.52	34.08	6.45	
3	180	0.99	0.83	5937	1848	16.29	31.14	6.6	
3	210	0.99	0.83	6926	2008	16.05	29.00	6.55	
3	240	0.99	0.83	7916	2168	16.29	27.39	6.55	

Table A.4: Continued

Retention Time	Collection Time	Inflow P Concentration	Outflow P concentration	Cumulative P Added	Cumulative P Sorbed	Discrete removal	Cumulative Removal	pH	EC
----- minutes -----		------ ppm ------		------ mg kg^{-1} ------		------ % ------			mS cm^{-1}
3	270	0.99	0.84	8905	2324	15.12	26.10	6.55	
3	300	0.99	0.85	9894	2467	13.73	24.93	6.55	
3	30	1.01	0.67	1006	672	33.66	66.83	6.45	
3	60	1.01	0.73	2011	980	27.70	48.75	6.45	
3	90	1.01	0.77	3017	1239	23.81	41.09	6.45	
3	120	1.01	0.81	4022	1457	19.46	36.22	6.45	
3	150	1.01	0.83	5028	1645	17.86	32.71	6.5	
3	180	1.01	0.83	6033	1823	17.63	30.22	6.6	
3	210	1.01	0.86	7039	1985	14.65	28.21	6.55	
3	240	1.01	0.86	8044	2133	14.65	26.51	6.5	
3	270	1.01	0.87	9050	2275	13.74	25.14	6.5	
3	300	1.01	0.88	10056	2409	12.82	23.96	6.55	
3	30	4.84	4.06	968	561	16.01	58.00	6.25	
3	60	4.84	4.20	1936	702	13.14	36.29	6.25	
3	90	4.84	4.26	2903	824	11.94	28.37	6.3	
3	120	4.84	4.32	3871	934	10.75	24.12	6.3	
3	150	4.84	4.32	4839	1038	10.75	21.44	6.3	
3	180	4.84	4.34	5807	1140	10.35	19.63	6.35	
3	210	4.84	4.49	6775	1225	7.17	18.08	6.5	
3	240	4.84	4.49	7743	1294	7.17	16.71	6.4	
3	270	4.84	4.22	8710	1390	12.74	15.96	6.3	
3	300	4.84	4.32	9678	1504	10.75	15.54	6.25	
3	30	4.97	4.00	995	595	19.68	59.84	6.2	
3	60	4.97	4.34	1990	757	12.78	38.03	6.25	
3	90	4.97	4.38	2984	880	12.01	29.49	6.3	
3	120	4.97	4.38	3979	1000	12.01	25.12	6.3	
3	150	4.97	4.42	4974	1115	11.23	22.42	6.3	
3	180	4.97	4.34	5969	1235	12.78	20.68	6.35	
3	210	4.97	4.49	6964	1346	9.68	19.33	6.4	
3	240	4.97	4.45	7958	1447	10.46	18.18	6.35	
3	270	4.97	4.38	8953	1558	12.01	17.40	6.3	
3	300	4.97	4.47	9948	1668	10.07	16.77	6.25	
3	30	9.55	8.04	2864	1658	15.79	57.90	6.2	
3	60	9.55	8.78	5728	1999	8.06	34.91	6.4	
3	90	9.55	8.55	8591	2265	10.47	26.36	6.4	
3	120	9.55	9.16	11455	2472	4.03	21.58	6.45	
3	150	9.55	8.93	14319	2622	6.45	18.31	6.35	
3	180	9.55	9.28	17183	2755	2.82	16.03	6.35	
3	210	9.55	9.16	20046	2853	4.03	14.23	6.4	
3	240	9.55	9.08	22910	2980	4.83	13.01	6.35	
3	270	9.55	9.01	25774	3130	5.64	12.14	6.35	
3	300	9.55	9.05	28638	3286	5.24	11.47	6.35	
3	30	9.58	8.39	2875	1616	12.44	56.22	6.2	
3	60	9.58	8.70	5751	1928	9.23	33.53	6.45	
3	90	9.58	9.05	8626	2141	5.62	24.82	6.45	
3	120	9.58	8.66	11501	2361	9.63	20.52	6.45	
3	150	9.58	9.20	14376	2557	4.01	17.78	6.45	
3	180	9.58	9.05	17252	2695	5.62	15.62	6.4	
3	210	9.58	9.20	20127	2834	4.01	14.08	6.45	
3	240	9.58	9.28	23002	2937	3.21	12.77	6.4	

Table A.4: Continued

Retention Time	Collection Time	Inflow P Concentration	Outflow P concentration	Cumulative P Added	Cumulative P Sorbed	Discrete removal	Cumulative Removal	pH	EC
----- minutes -----		------ ppm ------		------ mg kg^{-1} ------		------ % ------			mS cm^{-1}
3	270	9.58	8.78	25878	3105	8.43	12.00	6.35	
3	300	9.58	9.16	28753	3289	4.41	11.44	6.35	
3	30	14.58	9.50	937	632	34.82	67.41	6.35	
3	60	14.58	10.17	1874	937	30.24	49.97	6.5	
3	90	14.58	11.78	2812	1168	19.19	41.55	6.5	
3	120	14.58	12.28	3749	1332	15.79	35.53	6.5	
3	150	14.58	11.55	4686	1504	20.76	32.08	6.45	
3	180	14.58	11.67	5623	1694	19.98	30.13	6.45	
3	210	14.58	12.04	6561	1870	17.45	28.50	6.45	
3	240	14.58	11.48	7498	2051	21.24	27.36	6.4	
3	270	14.58	12.85	8435	2206	11.84	26.15	6.45	
3	300	14.58	12.62	9372	2325	13.42	24.80	6.5	
3	30	14.41	9.66	926	616	32.92	66.46	6.45	
3	60	14.41	10.59	1852	891	26.53	48.09	6.55	
3	90	14.41	12.17	2778	1085	15.50	39.07	6.55	
3	120	14.41	11.64	3705	1246	19.18	33.63	6.5	
3	150	14.41	11.64	4631	1424	19.18	30.74	6.5	
3	180	14.41	11.53	5557	1605	19.98	28.88	6.45	
3	210	14.41	12.68	6483	1753	11.99	27.04	6.45	
3	240	14.41	12.39	7409	1873	13.98	25.28	6.45	
3	270	14.41	13.08	8335	1980	9.19	23.76	6.45	
3	300	14.41	12.51	9261	2084	13.18	22.50	6.5	
0.5	30	0.49	0.35	666	429	28.70	64.35	6.6	
0.5	60	0.49	0.39	1332	594	21.00	44.60	6.5	
0.5	90	0.49	0.40	1998	725	18.20	36.27	6.45	
0.5	120	0.49	0.43	2664	829	13.30	31.14	6.4	
0.5	150	0.49	0.42	3330	921	14.23	27.66	6.4	
0.5	180	0.49	0.43	3996	1013	13.30	25.35	6.4	
0.5	210	0.49	0.43	4662	1100	12.83	23.59	6.35	
0.5	240	0.49	0.43	5328	1187	13.30	22.28	6.35	
0.5	270	0.49	0.43	5994	1277	13.77	21.31	6.4	
0.5	300	0.49	0.44	6660	1358	10.50	20.39	6.45	
0.5	30	0.50	0.37	678	427	25.88	62.94	6.65	
0.5	60	0.50	0.39	1357	589	21.76	43.38	6.55	
0.5	90	0.50	0.41	2035	726	18.78	35.68	6.45	
0.5	120	0.50	0.42	2714	847	16.72	31.20	6.4	
0.5	150	0.50	0.43	3392	955	15.35	28.16	6.4	
0.5	180	0.50	0.43	4070	1053	13.51	25.88	6.4	
0.5	210	0.50	0.42	4749	1155	16.49	24.32	6.35	
0.5	240	0.50	0.43	5427	1260	14.43	23.21	6.35	
0.5	270	0.50	0.43	6106	1359	14.66	22.25	6.45	
0.5	300	0.50	0.43	6784	1457	14.43	21.48	6.5	
0.5	30	1.03	0.73	1108	714	28.83	64.41	6.4	
0.5	60	1.03	0.81	2217	989	20.86	44.63	6.55	
0.5	90	1.03	0.81	3325	1219	20.64	36.67	6.45	
0.5	120	1.03	0.84	4434	1432	17.72	32.30	6.4	
0.5	150	1.03	0.85	5542	1625	17.05	29.31	6.4	
0.5	180	1.03	0.87	6650	1805	15.48	27.14	6.4	
0.5	210	1.03	0.88	7759	1971	14.58	25.41	6.4	
0.5	240	1.03	0.86	8867	2143	16.38	24.17	6.45	

Table A.4: Continued

Retention Time	Collection Time	Inflow P Concentration	Outflow P concentration	Cumulative P Added	Cumulative P Sorbed	Discrete removal	Cumulative Removal	pH	EC
----- minutes -----		------ ppm ------		------ mg kg^{-1} ------		------ % ------			mS cm^{-1}
0.5	270	1.03	0.87	9975	2316	14.81	23.21	6.4	
0.5	300	1.03	0.88	11084	2476	14.13	22.34	6.4	
0.5	30	0.99	0.78	1071	651	21.47	60.74	6.4	
0.5	60	0.99	0.81	2142	861	17.87	40.20	6.55	
0.5	90	0.99	0.86	3213	1029	13.46	32.03	6.45	
0.5	120	0.99	0.87	4284	1167	12.30	27.24	6.4	
0.5	150	0.99	0.87	5355	1298	12.07	24.23	6.4	
0.5	180	0.99	0.85	6427	1441	14.62	22.42	6.4	
0.5	210	0.99	0.89	7498	1576	10.68	21.02	6.4	
0.5	240	0.99	0.89	8569	1690	10.68	19.73	6.4	
0.5	270	0.99	0.88	9640	1809	11.37	18.76	6.4	
0.5	300	0.99	0.89	10711	1927	10.68	17.99	6.4	
0.5	30	4.97	3.58	1033	661	28.00	64.00	6.3	
0.5	60	4.97	4.01	2067	906	19.36	43.84	6.4	
0.5	90	4.97	3.99	3100	1108	19.82	35.76	6.4	
0.5	120	4.97	4.04	4133	1308	18.74	31.64	6.4	
0.5	150	4.97	4.13	5166	1492	16.97	28.88	6.45	
0.5	180	4.97	4.23	6200	1657	15.04	26.73	6.5	
0.5	210	4.97	4.34	7233	1801	12.73	24.90	6.5	
0.5	240	4.97	4.28	8266	1938	13.88	23.45	6.45	
0.5	270	4.97	4.34	9299	2076	12.73	22.32	6.45	
0.5	300	4.97	4.38	10333	2203	11.95	21.32	6.5	
0.5	30	4.99	3.45	1037	679	30.89	65.44	6.3	
0.5	60	4.99	3.87	2074	955	22.43	46.05	6.4	
0.5	90	4.99	4.07	3112	1168	18.59	37.54	6.4	
0.5	120	4.99	4.00	4149	1367	19.82	32.96	6.4	
0.5	150	4.99	4.15	5186	1558	16.90	30.04	6.5	
0.5	180	4.99	4.09	6223	1739	18.06	27.94	6.55	
0.5	210	4.99	4.28	7261	1906	14.21	26.26	6.5	
0.5	240	4.99	4.19	8298	2064	16.13	24.87	6.5	
0.5	270	4.99	4.36	9335	2213	12.68	23.71	6.5	
0.5	300	4.99	4.19	10372	2363	16.13	22.78	6.5	
0.5	30	9.99	8.19	2074	1224	17.98	58.99	6.25	
0.5	60	9.99	8.37	4148	1578	16.21	38.04	6.3	
0.5	90	9.99	8.56	6222	1894	14.28	30.44	6.3	
0.5	120	9.99	8.75	8297	2170	12.35	26.16	6.3	
0.5	150	9.99	8.91	10371	2410	10.80	23.24	6.4	
0.5	180	9.99	8.60	12445	2667	13.89	21.43	6.4	
0.5	210	9.99	8.60	14519	2955	13.89	20.35	6.5	
0.5	240	9.99	8.83	16593	3219	11.58	19.40	6.45	
0.5	270	9.99	9.10	18667	3431	8.87	18.38	6.4	
0.5	300	9.99	8.91	20741	3635	10.80	17.53	6.3	
0.5	30	9.95	8.45	2066	1189	15.11	57.55	6.3	
0.5	60	9.95	8.52	4132	1493	14.33	36.14	6.35	
0.5	90	9.95	8.75	6198	1765	12.01	28.48	6.35	
0.5	120	9.95	8.41	8265	2049	15.49	24.80	6.35	
0.5	150	9.95	8.75	10331	2334	12.01	22.59	6.35	
0.5	180	9.95	8.75	12397	2582	12.01	20.83	6.4	
0.5	210	9.95	8.95	14463	2810	10.07	19.43	6.5	
0.5	240	9.95	8.98	16529	3014	9.68	18.23	6.45	

Table A.4: Continued

Retention Time	Collection Time	Inflow P Concentration	Outflow P concentration	Cumulative P Added	Cumulative P Sorbed	Discrete removal	Cumulative Removal	pH	EC
----- minutes -----		------ ppm ------		------ mg kg^{-1} ------		------ % ------			mS cm^{-1}
0.5	270	9.95	8.95	18595	3218	10.07	17.31	6.45	
0.5	300	9.95	9.10	20661	3410	8.52	16.50	6.35	
0.5	30	14.26	11.43	2407	1442	19.82	59.91	6.3	
0.5	60	14.26	12.36	4813	1841	13.35	38.25	6.45	
0.5	90	14.26	12.70	7220	2133	10.92	29.54	6.45	
0.5	120	14.26	12.03	9626	2452	15.61	25.47	6.45	
0.5	150	14.26	13.17	12033	2732	7.69	22.71	6.45	
0.5	180	14.26	13.22	14439	2913	7.28	20.17	6.45	
0.5	210	14.26	12.70	16846	3132	10.92	18.59	6.45	
0.5	240	14.26	12.82	19252	3385	10.11	17.58	6.4	
0.5	270	14.26	12.82	21659	3628	10.11	16.75	6.35	
0.5	300	14.26	13.97	24066	3774	2.02	15.68	6.4	
0.5	30	14.49	12.42	2445	1398	14.33	57.16	6.35	
0.5	60	14.49	12.99	4891	1700	10.35	34.75	6.45	
0.5	90	14.49	12.88	7336	1963	11.14	26.75	6.5	
0.5	120	14.49	13.45	9782	2186	7.16	22.35	6.45	
0.5	150	14.49	13.68	12227	2342	5.57	19.15	6.45	
0.5	180	14.49	13.28	14673	2512	8.36	17.12	6.45	
0.5	210	14.49	12.99	17118	2741	10.35	16.01	6.45	
0.5	240	14.49	12.82	19564	3009	11.54	15.38	6.4	
0.5	270	14.49	13.22	22009	3257	8.76	14.80	6.35	
0.5	300	14.49	13.91	24455	3413	3.98	13.96	6.4	

Table A.5: Results of Slag fines flow-through experiment.

Retention Time	Collection Time	Inflow P Concentration	Outflow P concentration	Cumulative P Added	Cumulative P Sorbed	Discrete removal	Cumulative Removal	pH	EC
minutes		ppm		mg kg^{-1}		%			mS cm^{-1}
10	60	0.45	0.14	123	103	68.44	84.22	7.4	0.884
10	120	0.45	0.12	245	190	73.36	77.56	8.3	0.84
10	180	0.45	0.17	368	273	62.05	74.27	8.1	0.707
10	240	0.45	0.20	490	345	55.16	70.36	7.28	0.872
10	300	0.45	0.22	613	410	50.74	66.88	7.63	0.899
10	60	0.45	0.03	123	119	94.01	97.01	9.6	0.816
10	120	0.45	0.08	245	226	81.23	92.31	8.8	0.875
10	180	0.45	0.16	368	316	65.00	85.91	7.9	0.869
10	240	0.45	0.21	490	388	52.70	79.15	7.54	0.866
10	300	0.45	0.25	613	447	43.85	72.97	7.49	0.84
10	60	1.11	0.51	302	233	54.31	77.15	8.81	0.748
10	120	1.11	0.50	605	399	55.11	65.93	7.85	0.807
10	180	1.11	0.74	907	533	33.57	58.73	7.326	0.796
10	240	1.11	0.87	1209	616	21.81	50.97	7.475	0.78
10	300	1.11	0.95	1512	672	14.83	44.44	7.23	0.705
10	60	1.11	0.17	302	279	84.42	92.21	10.32	0.721
10	120	1.11	0.38	605	506	65.87	83.68	8.75	0.793
10	180	1.11	0.49	907	690	55.50	76.01	7.75	0.769
10	240	1.11	0.54	1209	851	51.12	70.34	7.72	0.691
10	300	1.11	0.58	1512	1000	47.93	66.17	7.31	0.794
10	30	4.90	0.16	1335	1314	96.84	98.42	10.66	0.844
10	60	4.90	0.04	2670	2622	99.14	98.20	10.09	0.788
10	90	4.90	0.17	4004	3927	96.48	98.07	9.49	0.761
10	120	4.90	0.44	5339	5178	90.99	96.99	9.27	0.747
10	150	4.90	0.80	6674	6344	83.73	95.06	8.89	0.763
10	180	4.90	1.08	8009	7423	77.89	92.69	8.52	0.749
10	210	4.90	1.27	9343	8437	74.00	90.30	8.42	0.754
10	240	4.90	1.59	10678	9382	67.62	87.86	8.3	0.75
10	270	4.90	1.86	12013	10247	61.96	85.30	8.23	0.752
10	300	4.90	2.09	13348	11043	57.36	82.73	8.08	0.75
10	30	4.90	0.29	1335	1295	94.00	97.00	10.63	0.847
10	60	4.90	0.07	2670	2580	98.61	96.65	10.25	0.806
10	90	4.90	0.17	4004	3882	96.48	96.95	9.69	0.767
10	120	4.90	0.42	5339	5137	91.52	96.21	9.46	0.771
10	150	4.90	0.64	6674	6328	86.92	94.82	9.19	0.764
10	180	4.90	0.93	8009	7449	81.08	93.01	8.98	0.762
10	210	4.90	1.19	9343	8496	75.77	90.93	8.7	0.77
10	240	4.90	1.36	10678	9483	72.23	88.81	8.45	0.76
10	270	4.90	1.42	12013	10439	70.99	86.90	8.53	0.754
10	300	4.90	1.69	13348	11350	65.50	85.03	8.41	0.744
10	30	10.56	0.00	2877	2877	100.00	100.00	10.77	0.896
10	60	10.56	0.00	5753	5753	100.00	100.00	10.21	0.77
10	90	10.56	0.27	8630	8593	97.46	99.58	9.62	0.77
10	120	10.56	0.87	11506	11314	91.72	98.33	9.13	0.731
10	150	10.56	1.51	14383	13865	85.66	96.40	8.71	0.75
10	180	10.56	2.21	17259	16235	79.10	94.07	8.41	0.723
10	210	10.56	3.14	20136	18383	70.24	91.29	8	0.751

Table A.5: Continued

Retention Time	Collection Time	Inflow P Concentration	Outflow P concentration	Cumulative P Added	Cumulative P Sorbed	Discrete removal	Cumulative Removal	pH	EC
----- minutes -----		------ ppm ------		------ mg kg^{-1} ------		------ % ------			$mS\ cm^{-1}$
10	240	10.56	3.63	23012	20337	65.65	88.38	8.06	0.732
10	270	10.56	4.58	25889	22096	56.63	85.35	8.04	0.719
10	300	10.56	5.29	28765	23629	49.91	82.14	8.07	0.728
10	30	10.56	0.00	2877	2877	100.00	100.00	10.92	0.907
10	60	10.56	0.00	5753	5753	100.00	100.00	10.28	0.751
10	90	10.56	0.00	8630	8630	100.00	100.00	9.73	0.715
10	120	10.56	0.23	11506	11474	97.79	99.72	9.37	0.709
10	150	10.56	1.13	14383	14165	89.26	98.48	8.87	0.717
10	180	10.56	1.91	17259	16626	81.89	96.33	8.57	0.731
10	210	10.56	2.31	20136	18928	78.11	94.00	8.3	0.713
10	240	10.56	2.90	23012	21094	72.54	91.67	8.26	0.715
10	270	10.56	3.66	25889	23077	65.32	89.14	8.36	0.717
10	300	10.56	4.65	28765	24822	55.98	86.29	8.05	0.724
10	30	15.00	1.77	4086	3845	88.22	94.11	9.55	0.772
10	60	15.00	5.05	8172	7004	66.36	85.70	8.12	0.737
10	90	15.00	9.37	12258	9127	37.56	74.46	7.71	0.773
10	120	15.00	12.07	16344	10293	19.52	62.98	7.57	0.771
10	150	15.00	10.64	20430	11285	29.06	55.24	7.5	0.763
10	180	15.00	11.42	24516	12366	23.85	50.44	7.44	0.77
10	210	15.00	12.02	28602	13260	19.86	46.36	7.45	0.785
10	240	15.00	12.18	32688	14050	18.82	42.98	7.56	0.772
10	270	15.00	11.55	36774	14904	22.99	40.53	7.42	0.758
10	300	15.00	14.73	40860	15411	1.82	37.72	7.33	0.765
10	30	15.00	0.28	4086	4047	98.11	99.06	10.51	0.787
10	60	15.00	0.41	8172	8039	97.25	98.37	10.11	0.777
10	90	15.00	1.45	12258	11870	90.31	96.84	9.29	0.715
10	120	15.00	2.55	16344	15411	83.02	94.29	8.65	0.728
10	150	15.00	5.46	20430	18407	63.59	90.10	8.15	0.758
10	180	15.00	7.34	24516	20750	51.09	84.64	7.92	0.762
10	210	15.00	8.48	28602	22681	43.46	79.30	7.84	0.756
10	240	15.00	9.99	32688	24251	33.40	74.19	7.84	0.766
10	270	15.00	10.85	36774	25499	27.67	69.34	7.76	0.766
10	300	15.00	11.71	40860	26513	21.95	64.89	7.65	0.759
8	42.5	0.45	0.06	107	100	87.06	93.53	10.32	0.803
8	85	0.45	0.09	214	190	80.25	88.59	9.33	0.643
8	127.5	0.45	0.14	321	270	69.43	84.01	8.4	0.684
8	170	0.45	0.19	428	338	57.63	78.89	8.21	0.789
8	212.5	0.45	0.23	536	394	47.79	73.65	7.471	0.866
8	255	0.45	0.29	643	439	35.99	68.36	7.73	0.715
8	297.5	0.45	0.32	750	474	28.12	63.17	7.55	0.857
8	42.5	0.45	0.07	107	99	85.17	92.58	10.2	0.92
8	85	0.45	0.10	214	186	77.79	87.03	9.44	0.734
8	127.5	0.45	0.16	321	262	64.02	81.66	8.82	0.825
8	170	0.45	0.19	428	328	57.63	76.45	8.45	0.897
8	212.5	0.45	0.28	536	379	37.95	70.72	7.71	0.743
8	255	0.45	0.39	643	406	13.85	63.25	7.81	0.921
8	297.5	0.45	0.38	750	422	15.82	56.33	7.62	0.746
8	42.5	1.11	0.61	264	191	44.94	72.47	8.44	0.765
8	85	1.11	0.67	528	304	39.96	57.46	8.97	0.663

Table A.5: Continued

Retention Time	Collection Time	Inflow P Concentration	Outflow P concentration	Cumulative P Added	Cumulative P Sorbed	Discrete removal	Cumulative Removal	pH	EC
----- minutes -----		------ ppm ------		------ mg kg^{-1} ------		------ % ------			mS cm^{-1}
8	127.5	1.11	0.74	793	400	33.18	50.49	7.93	0.744
8	170	1.11	0.83	1057	478	25.40	45.19	7.97	0.669
8	212.5	1.11	0.86	1321	541	22.41	40.94	7.46	0.779
8	255	1.11	0.90	1585	596	19.22	37.58	7.03	0.791
8	297.5	1.11	0.95	1849	640	14.41	34.62	7.429	0.668
8	42.5	1.11	0.25	264	234	77.24	88.62	8.53	0.681
8	85	1.11	0.35	528	426	68.07	80.63	8.3	0.695
8	127.5	1.11	0.51	793	587	53.91	74.09	7.97	0.811
8	170	1.11	0.83	1057	692	25.60	65.50	7.81	0.785
8	212.5	1.11	0.80	1321	763	27.79	57.74	7.44	0.767
8	255	1.11	0.82	1585	834	26.40	52.63	7.13	0.777
8	297.5	1.11	0.94	1849	889	15.32	48.09	7.326	0.646
8	30	4.90	0.00	1646	1646	100.00	100.00	10.99	0.958
8	60	4.90	0.00	3293	3293	100.00	100.00	10.34	0.768
8	90	4.90	0.00	4939	4939	100.00	100.00	9.96	0.728
8	120	4.90	0.08	6586	6572	98.33	99.79	9.53	0.714
8	150	4.90	0.35	8232	8146	92.85	98.95	9.24	0.702
8	180	4.90	0.83	9878	9594	83.13	97.12	8.98	0.706
8	210	4.90	1.04	11525	10927	78.71	94.81	8.63	0.709
8	240	4.90	1.40	13171	12163	71.47	92.34	8.56	0.712
8	270	4.90	1.81	14818	13271	63.16	89.56	8.52	0.714
8	300	4.90	2.06	16464	14267	57.86	86.66	8.2	0.712
8	30	4.90	0.00	1646	1646	100.00	100.00	10.88	0.913
8	60	4.90	0.00	3293	3293	100.00	100.00	10.37	0.768
8	90	4.90	0.09	4939	4924	98.15	99.69	9.93	0.735
8	120	4.90	0.35	6586	6496	92.85	98.64	9.65	0.728
8	150	4.90	0.74	8232	7960	84.90	96.69	9.31	0.719
8	180	4.90	1.17	9878	9285	76.06	93.99	9.04	0.711
8	210	4.90	1.35	11525	10506	72.35	91.16	8.73	0.701
8	240	4.90	1.65	13171	11648	66.34	88.44	8.62	0.707
8	270	4.90	1.87	14818	12703	61.75	85.73	8.55	0.708
8	300	4.90	2.19	16464	13667	55.39	83.01	8.47	0.705
8	30	10.56	0.12	1774	1764	98.87	99.44	11.14	1.06
8	60	10.56	0.03	3548	3525	99.69	99.36	10.42	0.863
8	90	10.56	0.47	5322	5258	95.59	98.79	10.14	0.797
8	120	10.56	1.39	7096	6876	86.88	96.90	9.72	0.767
8	150	10.56	1.80	8870	8382	82.93	94.50	9.42	0.753
8	180	10.56	2.10	10644	9829	80.14	92.34	9.1	0.752
8	210	10.56	2.29	12419	11235	78.33	90.47	8.8	0.77
8	240	10.56	4.14	14193	12468	60.75	87.85	8.45	0.751
8	270	10.56	4.20	15967	13542	60.26	84.81	8.39	0.765
8	300	10.56	4.51	17741	14585	57.30	82.21	8.4	0.765
8	30	10.56	0.05	1774	1770	99.53	99.76	10.95	0.967
8	60	10.56	0.33	3548	3512	96.90	98.99	10.28	0.806
8	90	10.56	0.90	5322	5183	91.48	97.39	9.75	0.78
8	120	10.56	1.37	7096	6767	87.04	95.36	9.24	0.774
8	150	10.56	2.05	8870	8254	80.63	93.05	9.03	0.766
8	180	10.56	2.06	10644	9683	80.47	90.97	8.85	0.76
8	210	10.56	2.41	12419	11082	77.18	89.23	8.58	0.762
8	240	10.56	3.09	14193	12394	70.78	87.33	8.42	0.749

Table A.5: Continued

Retention Time	Collection Time	Inflow P Concentration	Outflow P concentration	Cumulative P Added	Cumulative P Sorbed	Discrete removal	Cumulative Removal	pH	EC
-----	minutes -----	------	ppm ------	------	mg kg^{-1} ------	------	% ------		$mS\ cm^{-1}$
8	270	10.56	3.43	15967	13621	67.49	85.31	8.34	0.754
8	300	10.56	4.18	17741	14755	60.42	83.17	8.18	0.743
8	30	15.78	0.00	2651	2651	100.00	100.00	11.18	1.03
8	60	15.78	0.00	5302	5302	100.00	100.00	10.34	0.76
8	90	15.78	0.32	7953	7926	97.95	99.66	9.7	0.716
8	120	15.78	1.08	10604	10459	93.17	98.63	9.11	0.763
8	150	15.78	2.30	13255	12827	85.44	96.77	8.53	0.718
8	180	15.78	4.53	15906	14904	71.28	93.70	8.21	0.693
8	210	15.78	5.47	18557	16715	65.36	90.07	8.13	0.715
8	240	15.78	6.30	21208	18378	60.09	86.66	8.13	0.71
8	270	15.78	7.39	23859	19879	53.17	83.32	7.95	0.7
8	300	15.78	8.19	26510	21221	48.07	80.05	8.01	0.714
8	30	15.78	0.00	2651	2651	100.00	100.00	11.25	1.19
8	60	15.78	1.75	5302	5155	88.89	97.22	10.5	0.766
8	90	15.78	4.17	7953	7309	73.59	91.90	9.84	0.732
8	120	15.78	2.06	10604	9436	86.92	88.99	9.29	0.708
8	150	15.78	5.44	13255	11457	65.52	86.43	8.74	0.711
8	180	15.78	6.71	15906	13087	57.45	82.27	8.3	0.713
8	210	15.78	3.99	18557	14839	74.74	79.96	8.29	0.691
8	240	15.78	8.79	21208	16417	44.29	77.41	7.89	0.725
8	270	15.78	9.52	23859	17530	39.68	73.47	7.91	0.701
8	300	15.78	9.16	26510	18612	41.98	70.21	7.89	0.714
6	30	0.45	0.00	204	204	100.00	100.00	11.25	1.19
6	60	0.45	0.01	408	407	98.58	99.64	10.5	0.766
6	90	0.45	0.08	612	592	82.41	96.59	9.84	0.732
6	120	0.45	0.13	816	749	71.45	91.68	9.29	0.708
6	150	0.45	0.17	1021	886	62.79	86.77	8.74	0.711
6	180	0.45	0.34	1225	975	25.27	79.64	8.3	0.713
6	210	0.45	0.21	1429	1055	52.40	73.81	8.29	0.691
6	240	0.45	0.23	1633	1158	48.94	70.92	7.89	0.725
6	270	0.45	0.26	1837	1252	42.59	68.13	7.91	0.701
6	300	0.45	0.30	2041	1330	33.93	65.14	7.89	0.714
6	30	0.45	0.00	204	204	100.00	100.00	10.5	1.04
6	60	0.45	0.05	408	396	88.19	97.05	9.75	0.954
6	90	0.45	0.15	612	554	66.83	90.53	9.5	0.927
6	120	0.45	0.20	816	680	55.86	83.24	9.27	0.962
6	150	0.45	0.27	1021	777	39.12	76.09	8.9	0.981
6	180	0.45	0.35	1225	839	21.81	68.48	9.09	0.949
6	210	0.45	0.29	1429	898	36.24	62.85	8.9	0.946
6	240	0.45	0.29	1633	970	34.50	59.41	8.88	0.967
6	270	0.45	0.32	1837	1035	29.31	56.36	8.87	0.963
6	300	0.45	0.35	2041	1089	22.96	53.33	8.85	0.958
6	30	1.11	0.15	503	468	86.10	93.05	10.58	0.83
6	60	1.11	0.21	1007	889	80.83	88.26	9.85	0.785
6	90	1.11	0.30	1510	1276	73.16	84.50	9.45	0.769
6	120	1.11	0.45	2014	1610	59.49	79.96	8.85	0.717
6	150	1.11	0.42	2517	1917	62.37	76.15	9.04	0.73
6	180	1.11	0.48	3021	2216	56.38	73.35	8.88	0.763
6	210	1.11	0.79	3524	2430	28.81	68.96	8.74	0.772
6	240	1.11	0.68	4028	2601	38.88	64.57	8.68	0.77

Table A.5: Continued

Retention Time	Collection Time	Inflow P Concentration	Outflow P concentration	Cumulative P Added	Cumulative P Sorbed	Discrete removal	Cumulative Removal	pH	EC
----- minutes -----		------ ppm ------		------ mg kg^{-1} ------		------ % ------			mS cm^{-1}
6	270	1.11	0.67	4531	2799	39.84	61.77	8.55	0.753
6	300	1.11	0.72	5035	2988	35.04	59.34	8.51	0.757
6	30	1.11	0.50	503	389	54.70	77.35	9.84	0.796
6	60	1.11	0.25	1007	722	77.47	71.72	9.5	0.783
6	90	1.11	0.43	1510	1071	61.17	70.92	9.15	0.762
6	120	1.11	0.68	2014	1322	38.40	65.63	8.94	0.762
6	150	1.11	0.67	2517	1519	40.08	60.36	8.75	0.777
6	180	1.11	0.82	3021	1686	26.17	55.82	8.71	0.747
6	210	1.11	1.13	3524	1748	-1.63	49.60	8.65	0.747
6	240	1.11	1.07	4028	1752	3.40	43.51	8.42	0.764
6	270	1.11	1.01	4531	1783	8.68	39.34	8.46	0.753
6	300	1.11	1.06	5035	1816	4.36	36.06	8.15	0.735
6	33	4.90	0.47	1222	1164	90.49	95.24	10.1	0.775
6	66	4.90	0.97	2445	2208	80.25	90.31	9.1	0.785
6	99	4.90	1.46	3667	3127	70.17	85.27	8.1	0.772
6	132	4.90	1.81	4890	3942	63.09	80.61	7.91	0.777
6	165	4.90	1.90	6112	4701	61.13	76.91	7.6	0.77
6	198	4.90	2.14	7335	5419	56.32	73.88	7.42	0.77
6	231	4.90	2.21	8557	6099	54.96	71.28	7.29	0.759
6	264	4.90	2.55	9780	6728	47.89	68.79	7.51	0.746
6	297	4.90	2.57	11002	7311	47.58	66.45	7.48	0.771
6	33	4.90	1.31	1222	1058	73.18	86.59	9.4	0.776
6	66	4.90	2.32	2445	1827	52.55	74.73	8.65	0.647
6	99	4.90	3.16	3667	2365	35.54	64.50	7.75	0.644
6	132	4.90	3.79	4890	2721	22.59	55.64	7.8	0.635
6	165	4.90	4.03	6112	2968	17.78	48.55	7.64	0.791
6	198	4.90	3.90	7335	3200	20.34	43.63	7.37	0.775
6	231	4.90	3.96	8557	3443	19.28	40.23	7.274	0.636
6	264	4.90	4.08	9780	3663	16.72	37.45	7.385	0.81
6	297	4.90	4.29	11002	3841	12.51	34.91	7.154	0.808
6	15	10.50	1.05	595	566	90.00	95.00	10.2	0.684
6	30	10.50	1.40	1191	1091	86.63	91.66	9.05	0.639
6	60	10.50	3.19	2381	2022	69.62	84.89	8.51	0.656
6	90	10.50	4.80	3572	2759	54.31	77.25	7.79	0.663
6	120	10.50	5.79	4763	3350	44.89	70.34	7.61	0.671
6	150	10.50	6.72	5954	3832	36.04	64.36	7.197	0.672
6	180	10.50	7.44	7144	4220	29.15	59.07	7.5	0.68
6	210	10.50	7.82	8335	4545	25.50	54.53	7.01	0.679
6	240	10.50	7.90	9526	4845	24.80	50.86	7.359	0.663
6	270	10.50	8.25	10716	5120	21.42	47.78	7.19	0.673
6	300	10.50	8.25	11907	5375	21.42	45.14	7.12	0.675
6	15	10.50	0.33	595	586	96.89	98.44	10.15	0.692
6	30	10.50	0.87	1191	1147	91.69	96.37	9.3	0.658
6	60	10.50	2.58	2381	2142	75.39	89.95	8.566	0.639
6	90	10.50	4.50	3572	2931	57.12	82.05	7.825	0.671
6	120	10.50	5.57	4763	3551	47.00	74.55	7.52	0.665
6	150	10.50	6.47	5954	4059	38.43	68.19	7.253	0.661
6	180	10.50	6.52	7144	4514	37.87	63.18	7.53	0.672
6	210	10.50	7.29	8335	4921	30.56	59.04	6.53	0.627
6	240	10.50	7.60	9526	5267	27.61	55.30	7.33	0.652

Table A.5: Continued

Retention Time	Collection Time	Inflow P Concentration	Outflow P concentration	Cumulative P Added	Cumulative P Sorbed	Discrete removal	Cumulative Removal	pH	EC
----- minutes -----		------ ppm ------		------ mg kg^{-1} ------		------ % ------			mS cm^{-1}
6	270	10.50	8.80	10716	5528	16.22	51.59	7.43	0.674
6	300	10.50	7.63	11907	5788	27.33	48.61	7.19	0.65
6	30	15.78	0.00	1789	1789	100.00	100.00	11.22	1.08
6	60	15.78	0.02	3579	3578	99.86	99.96	10.52	0.815
6	90	15.78	0.83	5368	5319	94.74	99.08	9.85	0.782
6	120	15.78	1.69	7158	6965	89.30	97.31	9.24	0.754
6	150	15.78	2.44	8947	8521	84.52	95.23	8.63	0.76
6	180	15.78	3.67	10737	9964	76.77	92.80	8.21	0.765
6	210	15.78	4.47	12526	11292	71.65	90.14	8.26	0.759
6	240	15.78	5.77	14316	12500	63.41	87.32	8.05	0.815
6	270	15.78	6.71	16105	13582	57.47	84.33	8.03	0.746
6	300	15.78	6.45	17895	14625	59.12	81.73	7.99	0.772
6	30	15.78	0.00	1789	1789	100.00	100.00	11.28	1.19
6	60	15.78	0.31	3579	3561	98.04	99.51	10.47	0.822
6	90	15.78	1.14	5368	5269	92.76	98.14	9.86	0.757
6	120	15.78	1.64	7158	6901	89.63	96.41	9.3	0.734
6	150	15.78	2.86	8947	8435	81.88	94.28	8.77	0.743
6	180	15.78	3.41	10737	9869	78.42	91.92	8.52	0.748
6	210	15.78	4.68	12526	11200	70.33	89.41	8.45	0.741
6	240	15.78	6.24	14316	12370	60.44	86.41	8.11	0.745
6	270	15.78	5.51	16105	13493	65.06	83.78	8.12	0.747
6	300	15.78	6.48	17895	14603	58.95	81.60	8.02	0.759
3	30	0.45	0.06	101	94	86.29	93.15	10.61	1.07
3	60	0.45	0.19	203	167	57.96	82.64	10.09	1.01
3	90	0.45	0.23	304	222	49.86	73.06	9.85	1.34
3	120	0.45	0.26	405	269	42.92	66.39	9.58	1.37
3	150	0.45	0.25	506	313	44.08	61.81	9.47	1.37
3	180	0.45	0.26	608	356	41.19	58.62	9.25	1.38
3	210	0.45	0.28	709	396	38.30	55.92	9.12	1.37
3	240	0.45	0.28	810	435	38.30	53.72	9.12	1.37
3	270	0.45	0.29	911	472	35.41	51.84	8.94	1.35
3	300	0.45	0.30	1013	507	32.51	50.06	8.73	1.33
3	30	0.45	0.05	101	95	88.61	94.30	10.88	1.12
3	60	0.45	0.20	203	168	55.07	83.07	9.8	1.01
3	90	0.45	0.26	304	217	41.19	71.42	9.55	1.38
3	120	0.45	0.32	405	252	29.04	62.35	9.26	1.36
3	150	0.45	0.36	506	278	20.37	54.82	9.12	1.38
3	180	0.45	0.37	608	297	17.48	48.84	8.99	1.33
3	210	0.45	0.42	709	309	7.07	43.61	8.86	1.37
3	240	0.45	0.42	810	316	7.07	39.04	8.71	1.34
3	270	0.45	0.45	911	320	0.71	35.14	8.57	1.37
3	300	0.45	0.45	1013	320	-1.03	31.61	8.51	1.32
3	30	1.11	0.05	333	326	95.85	97.92	10.72	1.04
3	60	1.11	0.20	666	623	82.25	93.49	9.98	0.927
3	90	1.11	0.33	999	877	70.30	87.75	9.72	1.19
3	120	1.11	0.39	1332	1102	64.90	82.71	9.38	1.2
3	150	1.11	0.43	1665	1312	61.39	78.80	9.22	1.17
3	180	1.11	0.54	1998	1500	51.31	75.06	9.05	1.24
3	210	1.11	0.60	2331	1662	46.15	71.30	8.94	1.22
3	240	1.11	0.64	2664	1809	41.93	67.89	8.83	1.19

Table A.5: Continued

Retention Time	Collection Time	Inflow P Concentration	Outflow P concentration	Cumulative P Added	Cumulative P Sorbed	Discrete removal	Cumulative Removal	pH	EC
----- minutes -----		------ ppm ------		------ mg kg^{-1} ------		------ % ------			$mS\ cm^{-1}$
3	270	1.11	0.69	2997	1942	37.94	64.78	8.64	1.21
3	300	1.11	0.75	3330	2058	32.08	61.81	8.59	1.26
3	30	1.11	0.01	333	331	98.66	99.33	10.9	1.09
3	60	1.11	0.13	666	642	88.11	96.36	10.04	0.947
3	90	1.11	0.22	999	923	80.61	92.36	9.76	1.2
3	120	1.11	0.29	1332	1181	74.28	88.63	9.51	1.19
3	150	1.11	0.35	1665	1418	68.19	85.15	9.37	1.21
3	180	1.11	0.41	1998	1636	63.03	81.89	9.25	1.22
3	210	1.11	0.45	2331	1840	59.04	78.91	9.15	1.24
3	240	1.11	0.50	2664	2030	55.29	76.20	9.01	1.22
3	270	1.11	0.54	2997	2207	51.31	73.65	8.92	1.2
3	300	1.11	0.60	3330	2370	46.15	71.16	8.87	1.24
3	30	4.91	0.03	1105	1101	99.35	99.67	11.16	1.21
3	60	4.91	0.13	2210	2188	97.40	99.02	10.32	1.27
3	90	4.91	0.31	3314	3243	93.69	97.86	10	1.19
3	120	4.91	0.54	4419	4253	89.10	96.25	9.7	1.18
3	150	4.91	0.73	5524	5215	85.04	94.41	9.41	1.17
3	180	4.91	1.16	6629	6107	76.38	92.13	9.22	1.2
3	210	4.91	1.35	7733	6929	72.49	89.60	9.1	1.15
3	240	4.91	1.68	8838	7693	65.78	87.04	8.84	1.19
3	270	4.91	1.77	9943	8410	64.01	84.58	8.69	1.21
3	300	4.91	2.09	11048	9081	57.48	82.20	8.56	1.22
3	30	4.91	0.04	1105	1100	99.17	99.58	11.15	1.15
3	60	4.91	0.23	2210	2174	95.28	98.41	10.3	1.23
3	90	4.91	0.51	3314	3196	89.63	96.42	9.86	1.18
3	120	4.91	0.81	4419	4152	83.45	93.95	9.47	1.21
3	150	4.91	1.13	5524	5037	76.91	91.20	9.1	1.18
3	180	4.91	1.43	6629	5854	70.90	88.31	8.87	1.21
3	210	4.91	1.71	7733	6606	65.25	85.42	8.75	1.2
3	240	4.91	2.11	8838	7282	57.12	82.39	8.46	1.16
3	270	4.91	2.36	9943	7885	52.00	79.30	8.39	1.18
3	300	4.91	2.74	11048	8416	44.23	76.18	8.2	1.16
3	30	10.56	0.53	2376	2316	94.96	97.48	10.1	0.774
3	60	10.56	1.99	4752	4409	81.19	92.78	8.9	0.706
3	90	10.56	3.94	7128	6118	62.71	85.84	8.05	0.733
3	120	10.56	4.98	9504	7491	52.80	78.82	7.92	0.736
3	150	10.56	6.28	11880	8600	40.54	72.39	7.8	0.646
3	180	10.56	6.67	14256	9519	36.84	66.77	7.72	0.74
3	210	10.56	7.27	16632	10326	31.13	62.09	7.69	0.757
3	240	10.56	7.31	19008	11062	30.80	58.20	7.63	0.728
3	270	10.56	7.75	21384	11744	26.60	54.92	7.62	0.71
3	300	10.56	8.39	23760	12304	20.55	51.79	7.57	0.748
3	30	10.56	0.90	2376	2274	91.43	95.72	10.72	0.816
3	60	10.56	3.39	4752	4167	67.92	87.70	9.85	0.729
3	90	10.56	7.08	7128	5366	32.98	75.28	8.91	0.732
3	120	10.56	6.07	9504	6263	42.55	65.90	8.2	0.702
3	150	10.56	6.58	11880	7217	37.68	60.75	8.05	0.621
3	180	10.56	6.99	14256	8066	33.82	56.58	7.86	0.661
3	210	10.56	7.22	16632	8844	31.64	53.17	7.83	0.716
3	240	10.56	7.36	19008	9580	30.29	50.40	7.72	0.618

Table A.5: Continued

Retention Time	Collection Time	Inflow P Concentration	Outflow P concentration	Cumulative P Added	Cumulative P Sorbed	Discrete removal	Cumulative Removal	pH	EC
----- minutes -----		------ ppm ------		------ mg kg^{-1} ------		------ % ------			mS cm^{-1}
3	270	10.56	7.02	21384	10337	33.48	48.34	7.87	0.729
3	300	10.56	7.63	23760	11065	27.77	46.57	7.73	0.734
3	30	15.78	0.05	1420	1418	99.66	99.83	11.37	1.1
3	60	15.78	0.56	2840	2810	96.46	98.95	10.75	0.824
3	90	15.78	3.22	4261	4061	79.60	95.31	10.28	0.748
3	120	15.78	0.93	5681	5294	94.10	93.19	9.9	0.731
3	150	15.78	8.19	7101	6304	48.07	88.77	9.4	0.715
3	180	15.78	4.12	8521	7170	73.87	84.14	8.99	0.71
3	210	15.78	7.88	9941	8050	50.09	80.97	8.53	0.699
3	240	15.78	6.15	11362	8839	61.05	77.80	8.15	0.706
3	270	15.78	7.02	12782	9667	55.49	75.63	8.02	0.721
3	300	15.78	7.64	14202	10427	51.61	73.42	8.01	0.712
3	30	15.78	0.00	1420	1420	100.00	100.00	11.37	1.25
3	60	15.78	0.08	2840	2837	99.49	99.87	10.72	0.813
3	90	15.78	0.51	4261	4231	96.80	99.30	10.23	0.756
3	120	15.78	0.85	5681	5590	94.61	98.40	9.88	0.649
3	150	15.78	1.38	7101	6909	91.23	97.30	9.5	0.716
3	180	15.78	1.94	8521	8180	87.69	96.00	8.89	0.705
3	210	15.78	2.53	9941	9399	83.98	94.54	8.41	0.707
3	240	15.78	3.51	11362	10548	77.74	92.83	8.11	0.682
3	270	15.78	4.95	12782	11587	68.64	90.65	8.21	0.726
3	300	15.78	5.35	14202	12544	66.11	88.32	8.1	0.717
0.5	30	0.45	0.27	243	170	39.59	69.80	9.81	1.05
0.5	60	0.45	0.35	486	244	21.35	50.13	9.3	1.03
0.5	90	0.45	0.41	729	281	9.54	38.57	9.1	1.07
0.5	120	0.45	0.43	972	298	4.18	30.64	8.8	1.02
0.5	150	0.45	0.44	1215	305	2.03	25.14	8.7	1.03
0.5	180	0.45	0.46	1458	306	-1.19	21.02	8.55	1.05
0.5	210	0.45	0.46	1701	302	-2.26	17.77	8.51	0.926
0.5	240	0.45	0.47	1944	294	-4.40	15.13	8.55	1.02
0.5	270	0.45	0.47	2187	283	-4.41	12.96	8.45	1.03
0.5	300	0.45	0.48	2430	270	-6.56	11.11	8.45	1.06
0.5	30	0.45	0.09	243	218	79.30	89.65	10.37	0.932
0.5	60	0.45	0.17	486	390	62.13	80.18	10.06	1.06
0.5	90	0.45	0.23	729	524	48.18	71.84	9.87	1.01
0.5	120	0.45	0.27	972	632	40.67	64.99	9.73	1.03
0.5	150	0.45	0.29	1215	724	35.30	59.59	9.63	0.909
0.5	180	0.45	0.32	1458	803	29.93	55.09	9.5	1.03
0.5	210	0.45	0.33	1701	871	25.64	51.19	9.45	1.06
0.5	240	0.45	0.35	1944	928	21.35	47.73	9.39	1.02
0.5	270	0.45	0.37	2187	976	18.13	44.62	9.3	1.02
0.5	300	0.45	0.38	2430	1016	14.91	41.81	9.33	1.02
0.5	30	1.11	0.20	599	546	82.02	91.01	10.22	0.807
0.5	60	1.11	0.38	1199	989	65.96	82.50	9.85	0.771
0.5	90	1.11	0.50	1798	1352	55.18	75.19	9.7	0.787
0.5	120	1.11	0.58	2398	1660	47.51	69.23	9.55	0.788
0.5	150	1.11	0.64	2997	1929	42.23	64.36	9.39	0.804
0.5	180	1.11	0.69	3596	2168	37.44	60.27	9.3	0.805
0.5	210	1.11	0.74	4196	2380	33.36	56.72	9.15	0.77
0.5	240	1.11	0.79	4795	2567	29.05	53.53	9.03	0.742

Table A.5: Continued

Retention Time	Collection Time	Inflow P Concentration	Outflow P concentration	Cumulative P Added	Cumulative P Sorbed	Discrete removal	Cumulative Removal	pH	EC
----- minutes -----		------ ppm ------		------ mg kg^{-1} ------		------ % ------			$mS\ cm^{-1}$
0.5	270	1.11	0.84	5395	2727	24.50	50.56	8.91	0.785
0.5	300	1.11	0.88	5994	2863	20.66	47.76	8.87	0.777
0.5	30	1.11	0.28	599	523	74.35	87.18	10.24	0.825
0.5	60	1.11	0.45	1199	922	59.01	76.93	9.76	0.775
0.5	90	1.11	0.60	1798	1237	46.07	68.80	9.61	0.793
0.5	120	1.11	0.65	2398	1500	41.75	62.58	9.48	0.811
0.5	150	1.11	0.68	2997	1741	38.40	58.08	9.33	0.8
0.5	180	1.11	0.72	3596	1962	35.52	54.56	9.32	0.791
0.5	210	1.11	0.76	4196	2162	31.21	51.53	9.13	0.777
0.5	240	1.11	0.80	4795	2341	28.33	48.81	9.12	0.794
0.5	270	1.11	0.84	5395	2499	24.50	46.32	8.98	0.774
0.5	300	1.11	0.89	5994	2633	20.18	43.92	8.97	0.781
0.5	30	4.91	0.47	1326	1262	90.43	95.21	10.31	0.847
0.5	60	4.91	1.04	2651	2384	78.87	89.93	9.62	0.792
0.5	90	4.91	1.58	3977	3357	67.85	84.41	9.21	0.786
0.5	120	4.91	2.19	5303	4174	55.39	78.71	8.99	0.792
0.5	150	4.91	2.55	6629	4860	48.16	73.32	8.89	0.764
0.5	180	4.91	2.63	7954	5487	46.35	68.98	8.71	0.777
0.5	210	4.91	2.73	9280	6088	44.37	65.60	8.61	0.762
0.5	240	4.91	3.11	10606	6625	36.60	62.46	8.54	0.783
0.5	270	4.91	3.25	11931	7092	33.89	59.44	8.41	0.765
0.5	300	4.91	3.24	13257	7542	34.07	56.89	8.37	0.771
0.5	30	4.91	0.58	1326	1248	88.26	94.13	10.81	0.903
0.5	60	4.91	1.06	2651	2353	78.51	88.76	10.43	0.778
0.5	90	4.91	0.88	3977	3418	82.12	85.94	10.07	0.792
0.5	120	4.91	3.02	5303	4218	38.59	79.54	9.53	0.773
0.5	150	4.91	1.74	6629	4902	64.60	73.95	9.11	0.774
0.5	180	4.91	2.23	7954	5693	54.66	71.57	8.91	0.777
0.5	210	4.91	2.73	9280	6349	44.37	68.42	8.77	0.761
0.5	240	4.91	2.84	10606	6923	42.20	65.28	8.59	0.744
0.5	270	4.91	2.96	11931	7465	39.67	62.57	8.59	0.768
0.5	300	4.91	3.18	13257	7963	35.34	60.06	8.43	0.783
0.5	30	10.56	0.73	2851	2753	93.11	96.56	10.92	0.939
0.5	60	10.56	1.37	5702	5322	87.07	93.32	9.5	0.783
0.5	90	10.56	2.64	8554	7632	74.97	89.22	9.06	0.793
0.5	120	10.56	4.12	11405	9571	61.03	83.92	8.38	0.777
0.5	150	10.56	5.73	14256	11093	45.75	77.81	8.21	0.783
0.5	180	10.56	6.17	17107	12337	41.55	72.12	8.14	0.779
0.5	210	10.56	6.79	19958	13438	35.67	67.33	8.17	0.769
0.5	240	10.56	7.41	22810	14371	29.79	63.01	7.98	0.786
0.5	270	10.56	7.56	25661	15202	28.45	59.24	7.97	0.787
0.5	300	10.56	8.00	28512	15953	24.25	55.95	7.85	0.755
0.5	30	10.56	0.30	2851	2811	97.15	98.57	10.38	0.823
0.5	60	10.56	1.42	5702	5429	86.56	95.21	9.2	0.773
0.5	90	10.56	6.01	8554	7277	43.06	85.08	8.55	0.78
0.5	120	10.56	3.92	11405	8788	62.88	77.05	8.19	0.777
0.5	150	10.56	4.77	14256	10465	54.82	73.41	8.15	0.784
0.5	180	10.56	5.80	17107	11890	45.07	69.50	8.15	0.797
0.5	210	10.56	5.96	19958	13153	43.56	65.90	8.1	0.779
0.5	240	10.56	6.65	22810	14302	37.01	62.70	7.9	0.79

Table A.5: Continued

Retention Time	Collection Time	Inflow P Concentration	Outflow P concentration	Cumulative P Added	Cumulative P Sorbed	Discrete removal	Cumulative Removal	pH	EC
----- minutes -----		------ ppm ------		------ mg kg^{-1} ------		------ % ------			mS cm^{-1}
0.5	270	10.56	7.08	25661	15300	32.98	59.62	7.89	0.789
0.5	300	10.56	7.41	28512	16195	29.79	56.80	7.78	0.788
0.5	30	15.78	4.91	2130	1799	68.88	84.44	10.78	0.875
0.5	60	15.78	3.06	4261	3391	80.59	79.59	9.77	0.777
0.5	90	15.78	7.69	6391	4795	51.24	75.03	8.39	0.752
0.5	120	15.78	9.65	8521	5755	38.87	67.54	8.16	0.759
0.5	150	15.78	10.92	10652	6497	30.79	60.99	7.89	0.771
0.5	180	15.78	12.04	12782	7077	23.70	55.37	7.9	0.771
0.5	210	15.78	12.74	14912	7535	19.25	50.53	7.82	0.718
0.5	240	15.78	13.52	17042	7892	14.30	46.31	7.71	0.762
0.5	270	15.78	13.65	19173	8188	13.47	42.71	7.69	0.751
0.5	300	15.78	14.33	21303	8429	9.19	39.57	7.65	0.755

Table A.6: Results of Fly-ash1 flow-through experiment.

Retention Time	Collection Time	Inflow P Concentration	Outflow P concentration	Cumulative P Added	Cumulative P Sorbed	Discrete removal	Cumulative Removal	pH	EC
----- minutes -----		------ ppm ------		------ mg kg^{-1} ------		------ % ------			mS cm^{-1}
10	60	0.51	0.07	689	643	86.52	93.26	8.2	
10	120	0.51	0.12	1379	1205	76.48	87.38	8.1	
10	180	0.51	0.21	2068	1669	58.21	80.70	7.35	
10	240	0.51	0.33	2758	1991	35.16	72.20	7.1	
10	300	0.51	0.37	3447	2207	27.39	64.01	6.95	
10	60	0.50	0.09	680	620	82.40	91.20	8.15	
10	120	0.50	0.18	1360	1120	64.58	82.34	8.05	
10	180	0.50	0.27	2040	1493	45.13	73.18	7.45	
10	240	0.50	0.32	2720	1768	35.88	65.01	7.15	
10	300	0.50	0.45	3400	1927	10.65	56.66	6.9	
10	60	0.96	0.11	1304	1231	88.81	94.40	7.8	
10	120	0.96	0.16	2609	2352	83.01	90.16	7.9	
10	180	0.96	0.29	3913	3351	70.22	85.64	7.55	
10	240	0.96	0.41	5217	4182	57.19	80.16	7	
10	300	0.96	0.47	6521	4887	50.92	74.94	6.9	
10	60	0.99	0.44	1342	1041	55.11	77.56	7.7	
10	120	0.99	0.55	2684	1705	43.86	63.52	7.8	
10	180	0.99	0.71	4026	2186	27.79	54.29	7.5	
10	240	0.99	0.73	5368	2549	26.38	47.49	7	
10	300	0.99	0.72	6710	2910	27.32	43.36	6.9	
10	30	4.82	3.29	2187	1440	31.71	65.85	7.7	
10	60	4.82	3.50	4374	2087	27.43	47.71	7.55	
10	90	4.82	4.01	6561	2571	16.80	39.18	7.3	
10	120	4.82	4.23	8748	2889	12.29	33.02	7.25	
10	150	4.82	4.40	10935	3118	8.72	28.52	7.05	
10	180	4.82	4.40	13122	3309	8.72	25.22	7.1	
10	210	4.82	4.68	15309	3435	2.77	22.44	7.05	
10	240	4.82	4.61	17496	3513	4.36	20.08	6.95	
10	270	4.82	4.61	19684	3608	4.36	18.33	6.85	
10	300	4.82	4.53	21871	3721	5.94	17.01	6.8	
10	30	4.86	3.60	2204	1387	25.79	62.90	7.55	
10	60	4.86	3.63	4409	1950	25.32	44.23	7.45	
10	90	4.86	4.11	6613	2398	15.34	36.26	7.3	
10	120	4.86	4.34	8818	2684	10.62	30.44	7.2	
10	150	4.86	4.53	11022	2875	6.68	26.08	7	
10	180	4.86	4.51	13226	3026	7.08	22.88	7.05	
10	210	4.86	4.65	15431	3152	4.33	20.43	7	
10	240	4.86	4.78	17635	3217	1.57	18.24	6.95	
10	270	4.86	4.74	19840	3261	2.36	16.43	6.85	
10	300	4.86	4.80	22044	3300	1.18	14.97	6.8	
10	30	9.31	2.86	2537	2147	69.27	84.63	7.75	
10	60	9.31	1.79	5073	4050	80.81	79.84	7.8	
10	90	9.31	3.51	7610	5866	62.32	77.08	7.55	
10	120	9.31	5.04	10146	7239	45.93	71.34	7.3	
10	150	9.31	6.16	12683	8251	33.88	65.05	7.15	
10	180	9.31	7.14	15220	8976	23.34	58.98	7	
10	210	9.31	7.20	17756	9560	22.67	53.84	6.9	

Table A.6: Continued

Retention Time	Collection Time	Inflow P Concentration	Outflow P concentration	Cumulative P Added	Cumulative P Sorbed	Discrete removal	Cumulative Removal	pH	EC
----- minutes -----		------ ppm ------		------ mg kg^{-1} ------		------ % ------			mS cm^{-1}
10	240	9.31	6.92	20293	10173	25.68	50.13	6.9	
10	270	9.31	6.87	22829	10831	26.18	47.44	6.85	
10	300	9.31	6.89	25366	11493	26.02	45.31	6.85	
10	30	9.70	3.05	2643	2227	68.57	84.29	7.65	
10	60	9.70	1.30	5285	4278	86.64	80.95	7.8	
10	90	9.70	2.16	7928	6450	77.73	81.36	7.5	
10	120	9.70	3.63	10571	8305	62.63	78.56	7.25	
10	150	9.70	4.79	13214	9801	50.59	74.17	7.1	
10	180	9.70	5.69	15856	11016	41.35	69.47	6.95	
10	210	9.70	6.80	18499	11958	29.95	64.64	6.9	
10	240	9.70	7.70	21142	12626	20.64	59.72	6.9	
10	270	9.70	7.01	23784	13265	27.70	55.77	6.85	
10	300	9.70	6.86	26427	14018	29.31	53.05	6.8	
10	30	15.37	12.61	5233	3086	17.97	58.99	7	
10	60	15.37	13.07	10465	3948	14.98	37.73	6.85	
10	90	15.37	12.38	15698	4850	19.47	30.89	6.75	
10	120	15.37	14.04	20930	5584	8.61	26.68	6.7	
10	150	15.37	14.10	26163	6025	8.24	23.03	6.7	
10	180	15.37	13.87	31395	6495	9.73	20.69	6.75	
10	210	15.37	15.14	36628	6789	1.50	18.53	6.7	
10	240	15.37	13.70	41860	7112	10.86	16.99	6.7	
10	270	15.37	14.33	47093	7572	6.74	16.08	6.65	
10	300	15.37	14.39	52325	7915	6.36	15.13	6.6	
8	42.5	0.50	0.12	594	521	75.66	87.83	7.2	
8	85	0.50	0.27	1187	884	46.36	74.42	6.9	
8	127.5	0.50	0.34	1781	1118	32.76	62.80	6.75	
8	170	0.50	0.41	2374	1268	17.53	53.39	6.8	
8	212.5	0.50	0.45	2968	1348	9.69	45.43	6.75	
8	255	0.50	0.43	3562	1416	13.15	39.76	6.65	
8	297.5	0.50	0.42	4155	1500	15.22	36.11	6.65	
8	42.5	0.44	0.09	522	471	80.47	90.23	7.3	
8	85	0.44	0.20	1045	821	53.47	78.60	7.1	
8	127.5	0.44	0.27	1567	1059	37.74	67.60	6.85	
8	170	0.44	0.32	2090	1229	27.00	58.79	6.9	
8	212.5	0.44	0.37	2612	1343	16.77	51.41	6.8	
8	255	0.44	0.36	3134	1433	17.82	45.73	6.7	
8	297.5	0.44	0.37	3657	1523	16.51	41.65	6.7	
8	42.5	1.02	0.55	1209	884	46.30	73.15	8.3	
8	85	1.02	0.67	2418	1367	33.56	56.54	7.9	
8	127.5	1.02	0.77	3626	1717	24.34	47.34	7.5	
8	170	1.02	0.80	4835	1992	21.16	41.20	7.1	
8	212.5	1.02	0.81	6044	2239	19.79	37.05	7.05	
8	255	1.02	0.84	7253	2461	16.84	33.93	7	
8	297.5	1.02	0.85	8462	2662	16.38	31.46	6.9	
8	42.5	1.02	0.14	1209	1128	86.69	93.34	8.3	
8	85	1.02	0.32	2418	2065	68.26	85.41	8	
8	127.5	1.02	0.63	3626	2706	37.77	74.61	7.5	
8	170	1.02	0.79	4835	3070	22.52	63.49	7.1	
8	212.5	1.02	0.85	6044	3305	16.38	54.69	7.05	

Table A.6: Continued

Retention Time	Collection Time	Inflow P Concentration	Outflow P concentration	Cumulative P Added	Cumulative P Sorbed	Discrete removal	Cumulative Removal	pH	EC
-----	minutes -----	------	ppm ------	------	mg kg^{-1} ------	------	% ------		$mS\ cm^{-1}$
8	255	1.02	0.89	7253	3477	12.06	47.94	7	
8	297.5	1.02	0.92	8462	3608	9.56	42.64	6.95	
8	30	4.99	2.29	2096	1616	54.18	77.09	7.9	
8	60	4.99	2.90	4192	2623	41.91	62.56	7.9	
8	90	4.99	3.46	6288	3383	30.64	53.80	7.6	
8	120	4.99	3.72	8384	3970	25.39	47.35	7.6	
8	150	4.99	4.09	10480	4425	17.98	42.22	7.4	
8	180	4.99	4.30	12577	4759	13.89	37.84	7.4	
8	210	4.99	4.28	14673	5054	14.28	34.45	7.25	
8	240	4.99	4.37	16769	5333	12.35	31.80	7.3	
8	270	4.99	4.37	18865	5592	12.35	29.64	7.2	
8	300	4.99	4.41	20961	5843	11.58	27.87	7.2	
8	30	4.89	1.33	2056	1777	72.87	86.43	7.75	
8	60	4.89	1.82	4111	3171	62.80	77.13	7.8	
8	90	4.89	2.92	6167	4231	40.29	68.60	7.5	
8	120	4.89	3.57	8223	4923	27.07	59.87	7.5	
8	150	4.89	4.14	10278	5359	15.34	52.14	7.3	
8	180	4.89	4.30	12334	5642	12.20	45.74	7.3	
8	210	4.89	4.37	14390	5877	10.62	40.84	7.2	
8	240	4.89	4.37	16445	6095	10.62	37.06	7.2	
8	270	4.89	4.49	18501	6289	8.26	33.99	7.1	
8	300	4.89	4.53	20557	6451	7.48	31.38	7.1	
8	30	9.79	0.90	2349	2241	90.83	95.41	7.6	
8	60	9.79	0.29	4698	4448	97.07	94.68	8	
8	90	9.79	0.36	7047	6720	96.37	95.36	7.6	
8	120	9.79	0.60	9396	8954	93.87	95.30	7.35	
8	150	9.79	1.42	11745	11060	85.44	94.17	7.1	
8	180	9.79	2.68	14094	12917	72.65	91.65	7.1	
8	210	9.79	3.78	16443	14490	61.33	88.13	7.05	
8	240	9.79	4.43	18792	15854	54.78	84.37	6.95	
8	270	9.79	4.80	21141	17096	50.95	80.87	6.85	
8	300	9.79	4.95	23490	18274	49.39	77.80	6.8	
8	30	9.71	0.91	2331	2221	90.60	95.30	7.6	
8	60	9.71	0.26	4661	4411	97.36	94.64	8.15	
8	90	9.71	0.27	6992	6679	97.20	95.52	7.75	
8	120	9.71	0.64	9323	8900	93.43	95.47	7.4	
8	150	9.71	1.32	11653	10996	86.43	94.36	7.1	
8	180	9.71	2.46	13984	12873	74.63	92.06	7.1	
8	210	9.71	3.88	16314	14442	60.00	88.52	7.05	
8	240	9.71	4.62	18645	15751	52.38	84.48	6.95	
8	270	9.71	5.08	20976	16917	47.66	80.65	6.85	
8	300	9.71	5.08	23306	18028	47.66	77.35	6.85	
8	30	14.08	6.48	2958	2278	54.01	77.00	7.55	
8	60	14.08	7.35	5916	3783	47.79	63.95	7.55	
8	90	14.08	10.03	8874	4916	28.79	55.40	7.35	
8	120	14.08	11.29	11831	5635	19.83	47.62	7.15	
8	150	14.08	12.30	14789	6115	12.69	41.35	7.05	
8	180	14.08	12.80	17747	6438	9.13	36.28	6.9	
8	210	14.08	13.85	20705	6598	1.66	31.87	6.85	
8	240	14.08	13.85	23663	6647	1.66	28.09	6.85	

Table A.6: Continued

Retention Time	Collection Time	Inflow P Concentration	Outflow P concentration	Cumulative P Added	Cumulative P Sorbed	Discrete removal	Cumulative Removal	pH	EC
----- minutes -----		------ ppm ------		------ mg kg^{-1} ------		------ % ------			mS cm^{-1}
8	270	14.08	12.80	26621	6806	9.13	25.57	6.85	
8	300	14.08	13.97	29578	6953	0.83	23.51	6.8	
8	30	14.49	6.06	3044	2408	58.21	79.10	7.45	
8	60	14.49	7.19	6087	4060	50.39	66.70	7.5	
8	90	14.49	10.01	9131	5298	30.96	58.02	7.2	
8	120	14.49	11.46	12175	6088	20.96	50.01	7.05	
8	150	14.49	12.39	15219	6628	14.51	43.55	7	
8	180	14.49	13.27	18262	6978	8.47	38.21	6.85	
8	210	14.49	13.73	21306	7187	5.24	33.73	6.85	
8	240	14.49	13.73	24350	7346	5.24	30.17	6.85	
8	270	14.49	14.08	27393	7469	2.82	27.26	6.8	
8	300	14.49	13.68	30437	7598	5.64	24.96	6.8	
6	30	0.50	0.09	564	513	82.04	91.02	8.1	0.882
6	60	0.50	0.12	1127	958	75.70	84.95	8.1	0.85
6	90	0.50	0.19	1691	1345	61.83	79.55	7.8	0.866
6	120	0.50	0.31	2255	1625	37.38	72.06	7.5	0.875
6	150	0.50	0.38	2818	1799	24.45	63.83	7.3	0.743
6	180	0.50	0.40	3382	1924	19.98	56.90	7.05	0.875
6	210	0.50	0.42	3946	2026	15.99	51.34	7	0.794
6	240	0.50	0.43	4509	2111	14.34	46.82	6.95	0.735
6	270	0.50	0.43	5073	2191	13.87	43.18	6.9	0.766
6	300	0.50	0.42	5637	2275	16.22	40.37	6.85	0.917
6	30	0.51	0.18	581	481	65.47	82.73	8.05	0.742
6	60	0.51	0.17	1162	867	67.52	74.61	8.1	0.9
6	90	0.51	0.26	1743	1204	48.59	69.09	7.8	0.877
6	120	0.51	0.40	2324	1409	22.13	60.66	7.5	0.864
6	150	0.51	0.48	2904	1493	6.62	51.40	7.3	0.731
6	180	0.51	0.50	3485	1519	2.51	43.60	7.05	0.842
6	210	0.51	0.51	4066	1529	0.68	37.60	7	0.828
6	240	0.51	0.51	4647	1531	0.23	32.95	6.95	0.816
6	270	0.51	0.52	5228	1530	-0.68	29.27	6.9	0.715
6	300	0.51	0.51	5809	1527	-0.46	26.28	6.85	0.7
6	30	1.01	0.06	1512	1466	93.93	96.96	7.8	
6	60	1.01	0.12	3023	2842	88.13	93.99	7.7	
6	90	1.01	0.19	4535	4119	80.94	90.84	7.5	
6	120	1.01	0.27	6046	5288	73.63	87.45	7.3	
6	150	1.01	0.35	7558	6338	65.40	83.86	7.2	
6	180	1.01	0.44	9069	7262	56.82	80.07	6.95	
6	210	1.01	0.50	10581	8072	50.33	76.29	6.9	
6	240	1.01	0.56	12092	8790	44.64	72.69	6.85	
6	270	1.01	0.59	13604	9441	41.51	69.40	6.8	
6	300	1.01	0.64	15115	10028	36.18	66.34	6.75	
6	30	1.01	0.10	1512	1438	90.33	95.17	8.1	
6	60	1.01	0.20	3023	2730	80.59	90.31	7.9	
6	90	1.01	0.28	4535	3883	71.89	85.62	7.7	
6	120	1.01	0.37	6046	4902	62.96	81.07	7.4	
6	150	1.01	0.43	7558	5812	57.51	76.91	7.3	
6	180	1.01	0.48	9069	6641	52.06	73.22	7	
6	210	1.01	0.53	10581	7395	47.77	69.89	7	
6	240	1.01	0.56	12092	8095	44.76	66.94	6.9	

Table A.6: Continued

Retention Time	Collection Time	Inflow P Concentration	Outflow P concentration	Cumulative P Added	Cumulative P Sorbed	Discrete removal	Cumulative Removal	pH	EC
----- minutes -----		------ ppm ------		------ mg kg^{-1} ------		------ % ------			mS cm^{-1}
6	270	1.01	0.58	13604	8756	42.79	64.37	6.9	
6	300	1.01	0.60	15115	9385	40.35	62.09	6.8	
6	30	5.03	1.34	1902	1649	73.43	86.71	7.45	0.756
6	60	5.03	1.98	3803	2924	60.64	76.87	8.1	0.738
6	90	5.03	2.73	5705	3935	45.71	68.97	7.9	0.724
6	120	5.03	3.55	7607	4650	29.48	61.13	7.7	0.74
6	150	5.03	3.96	9508	5133	21.36	53.99	7.2	0.752
6	180	5.03	4.20	11410	5493	16.46	48.14	7.25	0.733
6	210	5.03	4.53	13312	5744	9.95	43.15	7.05	0.744
6	240	5.03	4.68	15213	5904	6.89	38.81	7.1	0.73
6	270	5.03	4.80	17115	6014	4.59	35.14	6.95	0.73
6	300	5.03	4.84	19017	6094	3.83	32.04	6.95	0.7
6	30	4.93	1.34	1865	1612	72.83	86.42	7.45	0.746
6	60	4.93	2.22	3731	2805	55.11	75.19	8	0.723
6	90	4.93	3.19	5596	3648	35.28	65.20	7.9	0.73
6	120	4.93	3.89	7461	4175	21.23	55.96	7.6	0.734
6	150	4.93	4.14	9326	4523	16.00	48.49	7.2	0.75
6	180	4.93	4.43	11192	4766	10.15	42.59	7.2	0.732
6	210	4.93	4.63	13057	4919	6.24	37.68	7	0.75
6	240	4.93	4.59	14922	5043	7.03	33.80	7.05	0.735
6	270	4.93	4.70	16787	5152	4.68	30.69	6.98	0.73
6	300	4.93	4.76	18653	5229	3.51	28.03	6.9	0.72
6	30	9.94	2.79	2255	1938	71.89	85.95	7.7	0.735
6	60	9.94	3.93	4510	3430	60.43	76.05	7.7	0.72
6	90	9.94	5.64	6765	4599	43.23	67.98	7.4	0.713
6	120	9.94	7.22	9020	5396	27.43	59.82	7.4	0.726
6	150	9.94	7.77	11275	5951	21.85	52.78	7.2	0.7
6	180	9.94	8.25	13530	6390	17.04	47.22	7.2	0.713
6	210	9.94	8.63	15785	6730	13.17	42.64	7.15	0.692
6	240	9.94	8.83	18040	7005	11.23	38.83	7.15	0.704
6	270	9.94	8.63	20295	7281	13.17	35.87	7.05	0.679
6	300	9.94	8.79	22550	7560	11.62	33.53	7	0.68
6	30	9.98	2.14	2264	2021	78.56	89.28	7.75	0.72
6	60	9.98	2.42	4528	3768	75.78	83.23	7.8	0.71
6	90	9.98	3.59	6791	5351	64.05	78.79	7.4	0.717
6	120	9.98	5.44	9055	6591	45.46	72.78	7.35	0.728
6	150	9.98	7.15	11319	7426	28.32	65.60	7.2	0.705
6	180	9.98	7.85	13583	7988	21.38	58.81	7.2	0.711
6	210	9.98	7.86	15846	8470	21.22	53.45	7.1	0.716
6	240	9.98	8.40	18110	8890	15.82	49.09	7.1	0.707
6	270	9.98	8.67	20374	9217	13.12	45.24	7.05	0.732
6	300	9.98	8.52	22638	9532	14.66	42.11	7	0.704
6	30	14.22	7.87	3226	2334	44.70	72.35	7.45	0.71
6	60	14.22	10.97	6451	3424	22.87	53.07	7.7	0.737
6	90	14.22	12.07	9677	4037	15.14	41.72	7.4	0.757
6	120	14.22	12.96	12903	4424	8.86	34.29	7.2	0.714
6	150	14.22	13.31	16129	4671	6.44	28.96	7	0.681
6	180	14.22	13.31	19354	4879	6.44	25.21	7.05	0.719
6	210	14.22	13.99	22580	5009	1.61	22.18	7.05	0.703
6	240	14.22	13.99	25806	5061	1.61	19.61	6.95	0.71

Table A.6: Continued

Retention Time	Collection Time	Inflow P Concentration	Outflow P concentration	Cumulative P Added	Cumulative P Sorbed	Discrete removal	Cumulative Removal	pH	EC
----- minutes -----		------ ppm ------		------ mg kg^{-1} ------		------ % ------			mS cm^{-1}
6	270	14.22	14.17	29032	5093	0.40	17.54	6.9	0.7
6	300	14.22	13.99	32257	5126	1.61	15.89	6.85	0.715
6	30	14.51	9.00	3291	2270	37.98	68.99	7.3	0.71
6	60	14.51	10.49	6581	3351	27.71	50.92	7.55	0.744
6	90	14.51	11.50	9872	4149	20.76	42.02	7.3	0.713
6	120	14.51	11.52	13163	4829	20.61	36.69	7.1	0.744
6	150	14.51	13.36	16453	5298	7.90	32.20	7.1	0.721
6	180	14.51	13.54	19744	5539	6.71	28.05	7	0.719
6	210	14.51	13.71	23035	5740	5.53	24.92	7	0.647
6	240	14.51	13.19	26326	5980	9.08	22.72	6.9	0.73
6	270	14.51	16.63	29616	5889	-14.61	19.89	6.85	0.7
6	300	14.51	13.31	32907	5785	8.29	17.58	6.85	0.711
3	30	0.41	0.09	461	413	79.15	89.57	7.55	
3	60	0.41	0.19	922	716	52.58	77.72	7.5	
3	90	0.41	0.27	1382	913	33.00	66.07	7.4	
3	120	0.41	0.35	1843	1024	15.10	55.57	7.25	
3	150	0.41	0.37	2304	1082	10.07	46.97	7	
3	180	0.41	0.39	2765	1114	3.92	40.31	7.05	
3	210	0.41	0.41	3226	1124	0.28	34.85	7	
3	240	0.41	0.42	3687	1118	-2.80	30.34	6.9	
3	270	0.41	0.42	4147	1106	-2.52	26.67	6.8	
3	300	0.41	0.43	4608	1086	-6.15	23.57	6.75	
3	30	0.49	0.06	556	522	87.59	93.79	8.1	
3	60	0.49	0.15	1112	957	69.05	86.06	7.8	
3	90	0.49	0.28	1669	1271	43.79	76.18	7.55	
3	120	0.49	0.37	2225	1461	24.33	65.65	7.35	
3	150	0.49	0.42	2781	1569	14.60	56.41	7.1	
3	180	0.49	0.47	3337	1624	5.10	48.65	7.15	
3	210	0.49	0.48	3893	1645	2.55	42.25	7.1	
3	240	0.49	0.50	4449	1649	-1.16	37.05	6.95	
3	270	0.49	0.50	5006	1640	-2.09	32.76	6.85	
3	300	0.49	0.51	5562	1627	-2.32	29.26	6.8	
3	30	0.91	0.55	4934	3444	39.62	69.81	7.95	
3	60	0.91	0.62	9868	5207	31.85	52.77	7.8	
3	90	0.91	0.66	14801	6686	28.09	45.17	7.5	
3	120	0.91	0.69	19735	7988	24.70	40.48	7.4	
3	150	0.91	0.72	24669	9108	20.69	36.92	7.15	
3	180	0.91	0.76	29603	10045	17.30	33.93	7.2	
3	210	0.91	0.80	34536	10787	12.79	31.23	7.15	
3	240	0.91	0.81	39470	11381	11.28	28.83	7	
3	270	0.91	0.87	44404	11783	5.02	26.54	6.9	
3	300	0.91	0.89	49338	11962	2.26	24.25	6.85	
3	30	0.88	0.47	4748	3472	46.25	73.12	7.95	
3	60	0.88	0.56	9496	5430	36.22	57.18	7.8	
3	90	0.88	0.59	14245	7066	32.70	49.61	7.5	
3	120	0.88	0.62	18993	8548	29.70	45.01	7.4	
3	150	0.88	0.66	23741	9837	24.62	41.44	7.15	
3	180	0.88	0.70	28489	10911	20.58	38.30	7.2	
3	210	0.88	0.73	33237	11795	16.68	35.49	7.2	
3	240	0.88	0.76	37985	12516	13.68	32.95	7.05	

Table A.6: Continued

Retention Time	Collection Time	Inflow P Concentration	Outflow P concentration	Cumulative P Added	Cumulative P Sorbed	Discrete removal	Cumulative Removal	pH	EC
----- minutes -----		------ ppm ------		------ mg kg^{-1} ------		------ % ------			mS cm^{-1}
3	270	0.88	0.78	42734	13104	11.07	30.66	6.95	
3	300	0.88	0.79	47482	13611	10.29	28.67	6.9	
3	30	4.95	0.44	1591	1520	91.05	95.52	7.7	
3	60	4.95	0.97	3182	2884	80.43	90.63	7.25	
3	90	4.95	2.08	4773	3984	57.88	83.47	7	
3	120	4.95	3.32	6364	4706	32.85	73.95	6.8	
3	150	4.95	3.91	7955	5134	20.92	64.54	6.8	
3	180	4.95	4.24	9546	5414	14.34	56.72	6.9	
3	210	4.95	4.45	11137	5609	10.07	50.36	6.8	
3	240	4.95	4.59	12728	5747	7.36	45.15	6.8	
3	270	4.95	4.72	14319	5843	4.65	40.80	6.7	
3	300	4.95	4.82	15910	5901	2.71	37.09	6.65	
3	30	4.95	1.00	1591	1430	79.74	89.87	7.85	
3	60	4.95	1.82	3182	2568	63.31	80.69	7.25	
3	90	4.95	3.30	4773	3336	33.32	69.90	7	
3	120	4.95	3.96	6364	3760	19.99	59.09	6.8	
3	150	4.95	4.24	7955	4034	14.34	50.70	6.8	
3	180	4.95	4.45	9546	4228	10.07	44.29	6.9	
3	210	4.95	4.47	11137	4385	9.69	39.37	6.8	
3	240	4.95	4.66	12728	4508	5.81	35.42	6.8	
3	270	4.95	4.83	14319	4573	2.32	31.94	6.7	
3	300	4.95	4.82	15910	4613	2.71	28.99	6.65	
3	30	10.10	0.06	1299	1295	99.39	99.69	9.75	
3	60	10.10	0.07	2597	2585	99.31	99.52	9.1	
3	90	10.10	0.10	3896	3872	99.01	99.40	8.85	
3	120	10.10	0.39	5194	5140	96.18	98.95	8.15	
3	150	10.10	2.53	6493	6251	74.98	96.28	7.35	
3	180	10.10	5.00	7792	7066	50.49	90.69	7.2	
3	210	10.10	6.68	9090	7614	33.87	83.76	7.05	
3	240	10.10	7.90	10389	7975	21.81	76.77	7.05	
3	270	10.10	8.56	11687	8216	15.26	70.30	7	
3	300	10.10	9.14	12986	8377	9.53	64.51	6.9	
3	30	9.87	0.06	1269	1265	99.37	99.69	10.2	
3	60	9.87	0.08	2538	2525	99.22	99.49	9.65	
3	90	9.87	0.12	3807	3781	98.75	99.32	9.05	
3	120	9.87	1.20	5076	4964	87.82	97.81	8.2	
3	150	9.87	3.82	6344	5910	61.28	93.16	7.35	
3	180	9.87	5.79	7613	6562	41.37	86.19	7.2	
3	210	9.87	6.94	8882	7012	29.66	78.95	7.05	
3	240	9.87	7.65	10151	7343	22.48	72.34	7.1	
3	270	9.87	8.37	11420	7582	15.22	66.40	7	
3	300	9.87	8.60	12689	7761	12.88	61.16	6.9	
3	30	15.49	8.54	1743	1263	44.90	72.45	7.5	
3	60	15.49	10.36	3486	1943	33.12	55.73	7.5	
3	90	15.49	11.91	5229	2433	23.12	46.52	7.2	
3	120	15.49	12.21	6971	2819	21.18	40.43	7.2	
3	150	15.49	12.72	8714	3159	17.90	36.25	7.1	
3	180	15.49	13.01	10457	3455	16.04	33.04	7.05	
3	210	15.49	13.07	12200	3731	15.66	30.58	7	
3	240	15.49	13.18	13943	3998	14.92	28.67	7	

Table A.6: Continued

Retention Time	Collection Time	Inflow P Concentration	Outflow P concentration	Cumulative P Added	Cumulative P Sorbed	Discrete removal	Cumulative Removal	pH	EC
----- minutes -----		------ ppm ------		------ mg kg^{-1} ------		------ % ------			mS cm^{-1}
3	270	15.49	13.47	15686	4241	13.05	27.04	6.9	
3	300	15.49	13.70	17429	4456	11.56	25.57	6.9	
3	30	14.80	6.86	1665	1279	53.64	76.82	7.5	
3	60	14.80	9.58	3330	2019	35.29	60.64	7.5	
3	90	14.80	11.01	4995	2526	25.61	50.58	7.2	
3	120	14.80	12.05	6659	2894	18.58	43.46	7.2	
3	150	14.80	12.12	8324	3200	18.11	38.44	7.05	
3	180	14.80	12.66	9989	3471	14.44	34.74	7.1	
3	210	14.80	12.78	11654	3705	13.66	31.79	6.95	
3	240	14.80	13.41	13319	3896	9.37	29.25	6.95	
3	270	14.80	13.24	14984	4062	10.54	27.11	6.9	
3	300	14.80	13.30	16649	4234	10.15	25.43	6.9	
0.5	30	0.49	0.14	1668	1425	70.83	85.42	8.25	
0.5	60	0.49	0.17	3336	2567	66.16	76.95	8	
0.5	90	0.49	0.19	5005	3638	62.18	72.69	7.6	
0.5	120	0.49	0.21	6673	4634	57.27	69.45	7.4	
0.5	150	0.49	0.22	8341	5568	54.70	66.76	7.3	
0.5	180	0.49	0.24	10009	6446	50.49	64.40	7.2	
0.5	210	0.49	0.26	11677	7269	48.16	62.24	7.2	
0.5	240	0.49	0.28	13345	8035	43.71	60.21	7.2	
0.5	270	0.49	0.30	15014	8723	38.81	58.10	7.1	
0.5	300	0.49	0.33	16682	9331	34.13	55.94	7	
0.5	30	0.49	0.09	1649	1493	81.13	90.56	8.15	
0.5	60	0.49	0.10	3297	2825	80.42	85.67	8.35	
0.5	90	0.49	0.11	4946	4133	78.29	83.57	7.8	
0.5	120	0.49	0.12	6595	5406	76.16	81.98	7.8	
0.5	150	0.49	0.12	8243	6656	75.45	80.75	7.65	
0.5	180	0.49	0.13	9892	7890	74.27	79.77	7.6	
0.5	210	0.49	0.13	11541	9101	72.61	78.86	7.5	
0.5	240	0.49	0.14	13189	10283	70.72	77.96	7.5	
0.5	270	0.49	0.15	14838	11431	68.59	77.04	7.4	
0.5	300	0.49	0.17	16487	12541	65.99	76.07	7.3	
0.5	30	4.85	2.81	2183	1550	42.00	71.00	8	
0.5	60	4.85	3.67	4366	2274	24.33	52.08	7.95	
0.5	90	4.85	4.19	6549	2688	13.65	41.05	7.75	
0.5	120	4.85	4.11	8731	3003	15.18	34.39	7.45	
0.5	150	4.85	4.54	10914	3239	6.42	29.67	7.25	
0.5	180	4.85	4.62	13097	3361	4.82	25.66	7.05	
0.5	210	4.85	4.54	15280	3484	6.42	22.80	6.95	
0.5	240	4.85	4.69	17463	3589	3.21	20.55	6.95	
0.5	270	4.85	4.75	19646	3646	2.01	18.56	6.9	
0.5	300	4.85	4.81	21828	3677	0.80	16.84	6.85	
0.5	30	4.93	2.72	2218	1606	44.81	72.40	8	
0.5	60	4.93	3.48	4436	2430	29.48	54.77	7.9	
0.5	90	4.93	3.87	6654	2996	21.57	45.02	7.65	
0.5	120	4.93	4.12	8872	3416	16.36	38.51	7.4	
0.5	150	4.93	4.25	11090	3751	13.83	33.83	7.25	
0.5	180	4.93	4.23	13307	4062	14.22	30.53	7.05	
0.5	210	4.93	4.54	15525	4308	7.90	27.75	7	
0.5	240	4.93	4.58	17743	4474	7.11	25.22	6.95	

Table A.6: Continued

Retention Time	Collection Time	Inflow P Concentration	Outflow P concentration	Cumulative P Added	Cumulative P Sorbed	Discrete removal	Cumulative Removal	pH	EC
----- minutes -----		------ ppm ------		------ mg kg^{-1} ------		------ % ------			mS cm^{-1}
0.5	270	4.93	4.68	19961	4610	5.14	23.10	6.9	
0.5	300	4.93	4.50	22179	4763	8.69	21.48	6.85	
0.5	30	10.05	6.39	3878	2646	36.47	68.24	7.65	
0.5	60	10.05	8.44	7755	3664	16.02	47.24	7.2	
0.5	90	10.05	8.33	11633	4307	17.17	37.03	6.95	
0.5	120	10.05	9.06	15510	4833	9.92	31.16	6.8	
0.5	150	10.05	8.90	19388	5247	11.45	27.06	6.8	
0.5	180	10.05	9.21	23266	5631	8.39	24.20	6.9	
0.5	210	10.05	9.02	27143	5994	10.30	22.08	6.8	
0.5	240	10.05	9.25	31021	6349	8.01	20.47	6.8	
0.5	270	10.05	9.63	34898	6586	4.20	18.87	6.75	
0.5	300	10.05	9.75	38776	6726	3.05	17.35	6.7	
0.5	30	9.78	3.98	3774	3007	59.35	79.67	7.65	
0.5	60	9.78	7.17	7548	4631	26.73	61.36	7.15	
0.5	90	9.78	8.44	11322	5395	13.72	47.65	6.9	
0.5	120	9.78	8.63	15096	5875	11.76	38.92	6.85	
0.5	150	9.78	9.13	18870	6223	6.66	32.98	6.9	
0.5	180	9.78	9.25	22644	6452	5.49	28.50	6.9	
0.5	210	9.78	9.06	26418	6697	7.45	25.35	6.8	
0.5	240	9.78	8.98	30192	6992	8.23	23.16	6.85	
0.5	270	9.78	9.48	33966	7207	3.14	21.22	6.8	
0.5	300	9.78	9.59	37740	7303	1.96	19.35	6.75	
0.5	30	15.03	5.50	2030	1658	63.41	81.71	9.3	
0.5	60	15.03	9.93	4059	2647	33.97	65.20	8.7	
0.5	90	15.03	11.68	6089	3218	22.29	52.84	8.3	
0.5	120	15.03	12.32	8119	3627	18.06	44.68	7.7	
0.5	150	15.03	12.78	10148	3963	14.99	39.05	7.2	
0.5	180	15.03	13.36	12178	4228	11.14	34.72	7.2	
0.5	210	15.03	13.47	14208	4446	10.38	31.29	7	
0.5	240	15.03	13.65	16238	4645	9.22	28.61	7	
0.5	270	15.03	13.47	18267	4844	10.38	26.52	6.95	
0.5	300	15.03	13.65	20297	5043	9.22	24.85	6.9	
0.5	30	14.75	4.89	1991	1661	66.85	83.42	9	
0.5	60	14.75	9.49	3981	2681	35.66	67.34	8.5	
0.5	90	14.75	12.38	5972	3196	16.07	53.51	8	
0.5	120	14.75	12.49	7963	3508	15.28	44.05	7.5	
0.5	150	14.75	12.32	9953	3824	16.46	38.42	7.15	
0.5	180	14.75	13.53	11944	4069	8.23	34.07	7.15	
0.5	210	14.75	13.76	13935	4218	6.66	30.27	7	
0.5	240	14.75	14.05	15926	4331	4.70	27.19	7	
0.5	270	14.75	13.94	17916	4432	5.49	24.74	6.95	
0.5	300	14.75	13.01	19907	4604	11.76	23.13	6.9	

Table A.7: Results of Fly-ash2 flow-through experiment.

Retention Time	Collection Time	Inflow P Concentration	Outflow P concentration	Cumulative P Added	Cumulative P Sorbed	Discrete removal	Cumulative Removal	pH	EC
----- minutes -----		------ ppm ------		------ mg kg^{-1} ------		------ % ------			mS cm^{-1}
10	60	0.49	0.22	667	517	54.90	77.45	7.7	
10	120	0.49	0.35	1334	798	29.30	59.77	7.5	
10	180	0.49	0.35	2002	992	29.06	49.58	7.3	
10	240	0.49	0.34	2669	1193	30.96	44.69	6.9	
10	300	0.49	0.34	3336	1399	30.96	41.94	7	
10	60	0.49	0.21	664	522	57.30	78.65	7.8	
10	120	0.49	0.29	1328	845	39.92	63.63	7.5	
10	180	0.49	0.36	1992	1067	26.82	53.54	7.3	
10	240	0.49	0.35	2656	1249	28.01	47.01	6.9	
10	300	0.49	0.38	3320	1413	21.58	42.57	7	
10	60	0.99	0.60	2708	1898	40.14	70.07	7.4	
10	120	0.99	0.81	5416	2690	18.33	49.65	8.7	
10	180	0.99	0.89	8125	3082	10.67	37.94	7.5	
10	240	0.99	0.91	10833	3340	8.35	30.83	7.1	
10	300	0.99	0.92	13541	3550	7.19	26.22	6.9	
10	60	1.06	0.34	2884	2424	68.09	84.05	7.4	
10	120	1.06	0.52	5768	4144	51.20	71.85	8.6	
10	180	1.06	0.66	8653	5426	37.69	62.71	7.5	
10	240	1.06	0.78	11537	6347	26.15	55.02	7.1	
10	300	1.06	0.71	14421	7203	33.23	49.95	6.9	
10	30	4.75	3.09	3233	2182	34.96	67.48	6.8	
10	60	4.75	2.43	6467	3535	48.77	54.67	6.9	
10	90	4.75	2.93	9700	4941	38.19	50.94	6.8	
10	120	4.75	3.16	12933	6100	33.51	47.17	6.7	
10	150	4.75	3.39	16167	7105	28.66	43.95	6.7	
10	180	4.75	3.46	19400	8006	27.05	41.27	6.5	
10	210	4.75	3.71	22633	8797	21.88	38.87	6.5	
10	240	4.75	3.75	25866	9492	21.07	36.69	6.5	
10	270	4.75	3.75	29100	10173	21.07	34.96	6.4	
10	300	4.75	3.94	32333	10789	17.04	33.37	6.4	
10	30	4.98	3.90	3390	2062	21.64	60.82	6.8	
10	60	4.98	3.38	6780	2973	32.11	43.85	6.9	
10	90	4.98	3.85	10170	3900	22.56	38.35	6.8	
10	120	4.98	4.10	13560	4582	17.71	33.79	6.7	
10	150	4.98	4.23	16950	5137	15.02	30.31	6.6	
10	180	4.98	4.25	20340	5640	14.63	27.73	6.55	
10	210	4.98	4.29	23730	6123	13.86	25.80	6.5	
10	240	4.98	4.33	27120	6579	13.09	24.26	6.5	
10	270	4.98	4.23	30509	7056	15.02	23.13	6.3	
10	300	4.98	4.58	33899	7447	8.09	21.97	6.4	
10	30	9.70	4.87	3303	2474	49.79	74.89	7.5	
10	60	9.70	5.18	6606	4066	46.63	61.55	7.9	
10	90	9.70	6.12	9910	5447	36.95	54.96	7.7	
10	120	9.70	7.06	13213	6506	27.18	49.24	7.4	
10	150	9.70	7.55	16516	7320	22.14	44.32	7.1	
10	180	9.70	8.15	19819	7950	15.99	40.11	7.5	
10	210	9.70	8.29	23123	8455	14.57	36.57	7.3	

Table A.7: Continued

Retention Time	Collection Time	Inflow P Concentration	Outflow P concentration	Cumulative P Added	Cumulative P Sorbed	Discrete removal	Cumulative Removal	pH	EC
----- minutes -----		------ ppm ------		------ mg kg^{-1} ------		------ % ------			mS cm^{-1}
10	240	9.70	8.63	26426	8878	11.03	33.59	7.1	
10	270	9.70	8.63	29729	9242	11.03	31.09	7	
10	300	9.70	8.86	33032	9567	8.67	28.96	6.9	
10	30	9.48	5.07	3230	2367	46.58	73.29	7.4	
10	60	9.48	4.91	6459	3897	48.20	60.34	7.8	
10	90	9.48	6.61	9689	5165	30.32	53.31	8.3	
10	120	9.48	7.49	12918	5995	21.05	46.41	7.6	
10	150	9.48	7.90	16148	6604	16.66	40.90	7.6	
10	180	9.48	8.25	19377	7083	13.01	36.55	7.4	
10	210	9.48	9.52	22607	7287	-0.41	32.23	7.2	
10	240	9.48	9.33	25836	7306	1.63	28.28	7.1	
10	270	9.48	9.29	29066	7365	2.03	25.34	6.9	
10	300	9.48	9.29	32296	7431	2.03	23.01	6.9	
10	30	14.96	8.07	5094	3720	46.07	73.03	8.2	
10	60	14.96	10.23	10187	5698	31.61	55.94	8.3	
10	90	14.96	11.17	15281	7148	25.30	46.78	7.8	
10	120	14.96	12.03	20374	8292	19.61	40.70	7.6	
10	150	14.96	12.31	25468	9242	17.69	36.29	7.5	
10	180	14.96	13.12	30561	10006	12.31	32.74	7.5	
10	210	14.96	12.66	35655	10711	15.38	30.04	7.3	
10	240	14.96	13.58	40748	11338	9.23	27.82	7.3	
10	270	14.96	13.52	45842	11817	9.61	25.78	7.2	
10	300	14.96	13.46	50935	12317	10.00	24.18	7	
10	30	14.61	9.24	4976	3403	36.77	68.38	7.4	
10	60	14.61	9.54	9952	5181	34.72	52.06	8.1	
10	90	14.61	11.96	14928	6498	18.19	43.53	7.8	
10	120	14.61	12.12	19904	7375	17.08	37.05	7.6	
10	150	14.61	12.72	24880	8123	12.99	32.65	7.6	
10	180	14.61	12.83	29856	8750	12.20	29.31	7.3	
10	210	14.61	13.29	34832	9279	9.05	26.64	7.3	
10	240	14.61	13.46	39808	9700	7.87	24.37	7.2	
10	270	14.61	13.41	44784	10102	8.27	22.56	7.1	
10	300	14.61	14.38	49760	10346	1.57	20.79	7	
8	42.5	0.50	0.16	593	498	67.99	84.00	7	
8	85	0.50	0.20	1185	875	59.21	73.80	7.6	
8	127.5	0.50	0.31	1778	1163	38.16	65.43	7.3	
8	170	0.50	0.42	2370	1325	16.42	55.89	7.1	
8	212.5	0.50	0.47	2963	1392	6.24	46.98	6.9	
8	255	0.50	0.47	3556	1428	5.78	40.15	6.8	
8	297.5	0.50	0.46	4148	1467	7.63	35.37	6.7	
8	42.5	0.50	0.11	594	527	77.53	88.76	7.1	
8	85	0.50	0.13	1188	977	74.07	82.28	7.8	
8	127.5	0.50	0.20	1782	1378	60.68	77.31	7.5	
8	170	0.50	0.30	2376	1675	39.46	70.50	7.1	
8	212.5	0.50	0.37	2970	1872	26.77	63.02	7	
8	255	0.50	0.42	3564	2001	16.61	56.14	6.8	
8	297.5	0.50	0.45	4158	2079	9.69	49.99	6.7	
8	42.5	0.97	0.18	1156	1048	81.32	90.66	7.3	
8	85	0.97	0.25	2311	1947	74.38	84.25	7.8	

Table A.7: Continued

Retention Time	Collection Time	Inflow P Concentration	Outflow P concentration	Cumulative P Added	Cumulative P Sorbed	Discrete removal	Cumulative Removal	pH	EC
-----	minutes -----	------	ppm ------	------	mg kg^{-1} ------	------	% ------		$mS\ cm^{-1}$
8	127.5	0.97	0.38	3467	2732	61.35	78.79	7.4	
8	170	0.97	0.45	4623	3395	53.34	73.43	7.3	
8	212.5	0.97	0.49	5779	3991	49.88	69.07	7	
8	255	0.97	0.50	6934	4559	48.44	65.75	6.9	
8	297.5	0.97	0.49	8090	5123	49.16	63.33	6.9	
8	42.5	0.92	0.18	1095	986	80.15	90.07	7.4	
8	85	0.92	0.34	2189	1772	63.36	80.92	7.7	
8	127.5	0.92	0.52	3284	2354	43.04	71.68	7.4	
8	170	0.92	0.61	4379	2775	33.83	63.37	7.3	
8	212.5	0.92	0.61	5473	3146	34.08	57.49	7	
8	255	0.92	0.60	6568	3521	34.34	53.61	6.9	
8	297.5	0.92	0.57	7663	3919	38.37	51.14	6.9	
8	30	4.99	0.66	839	783	86.71	93.35	7.2	
8	60	4.99	0.07	1678	1561	98.67	93.02	8	
8	90	4.99	0.06	2516	2389	98.83	94.93	8	
8	120	4.99	0.07	3355	3217	98.67	95.89	8	
8	150	4.99	0.13	4194	4040	97.44	96.32	7.9	
8	180	4.99	0.39	5033	4835	92.11	96.06	7.5	
8	210	4.99	1.09	5872	5549	78.21	94.50	7.3	
8	240	4.99	2.04	6711	6125	59.14	91.28	7.1	
8	270	4.99	2.96	7549	6544	40.77	86.68	6.9	
8	300	4.99	3.73	8388	6821	25.32	81.32	7	
8	30	4.94	0.25	829	808	94.87	97.43	8.4	
8	60	4.94	0.05	1659	1612	98.92	97.16	8.2	
8	90	4.94	0.05	2488	2432	99.00	97.76	7.9	
8	120	4.94	0.06	3317	3252	98.68	98.03	8.8	
8	150	4.94	0.10	4147	4067	97.90	98.08	8	
8	180	4.94	0.31	4976	4861	93.62	97.70	7.5	
8	210	4.94	0.84	5805	5594	82.95	96.35	7.4	
8	240	4.94	1.55	6635	6222	68.62	93.78	7.1	
8	270	4.94	2.37	7464	6722	52.03	90.06	7	
8	300	4.94	2.98	8293	7103	39.72	85.64	6.9	
8	30	9.74	5.41	2046	1478	44.48	72.24	7.5	
8	60	9.74	6.31	4092	2293	35.19	56.04	7.6	
8	90	9.74	5.17	6138	3133	46.92	51.04	7.9	
8	120	9.74	4.65	8184	4148	52.27	50.68	7.7	
8	150	9.74	5.75	10230	5102	41.02	49.88	7.6	
8	180	9.74	6.64	12276	5848	31.88	47.64	7.4	
8	210	9.74	7.10	14322	6452	27.16	45.05	7.4	
8	240	9.74	7.68	16367	6946	21.18	42.44	7.3	
8	270	9.74	8.05	18413	7341	17.40	39.87	7.2	
8	300	9.74	8.15	20459	7686	16.30	37.57	7	
8	30	9.82	3.41	2062	1704	65.30	82.65	7.4	
8	60	9.82	3.25	4124	3067	66.85	74.36	8.2	
8	90	9.82	2.46	6186	4528	74.91	73.20	7.9	
8	120	9.82	4.56	8248	5853	53.58	70.96	7.6	
8	150	9.82	5.42	10310	6867	44.76	66.61	7.7	
8	180	9.82	5.85	12372	7745	40.38	62.60	7.5	
8	210	9.82	6.87	14434	8471	30.07	58.69	7.3	
8	240	9.82	7.65	16496	9009	22.11	54.61	7.3	

Table A.7: Continued

Retention Time	Collection Time	Inflow P Concentration	Outflow P concentration	Cumulative P Added	Cumulative P Sorbed	Discrete removal	Cumulative Removal	pH	EC
----- minutes -----		------ ppm ------		------ mg kg^{-1} ------		------ % ------			mS cm^{-1}
8	270	9.82	7.96	18558	9433	18.98	50.83	7.2	
8	300	9.82	8.17	20620	9802	16.79	47.53	7.1	
8	30	14.90	7.42	3128	2349	50.18	75.09	7.6	
8	60	14.90	8.14	6256	3842	45.33	61.42	7.8	
8	90	14.90	9.54	9384	5113	35.94	54.49	7.4	
8	120	14.90	10.94	12512	6091	26.55	48.68	7.6	
8	150	14.90	12.32	15640	6777	17.32	43.33	7.1	
8	180	14.90	12.66	18768	7282	15.01	38.80	7.4	
8	210	14.90	13.29	21897	7686	10.77	35.10	7.2	
8	240	14.90	12.95	25025	8059	13.08	32.20	7	
8	270	14.90	12.72	28153	8492	14.62	30.16	7	
8	300	14.90	13.98	31281	8817	6.16	28.19	6.9	
8	30	15.04	4.48	3158	2688	70.22	85.11	6.5	
8	60	15.04	7.44	6315	4594	50.53	72.74	7.8	
8	90	15.04	10.01	9473	5920	33.46	62.49	7.6	
8	120	15.04	11.25	12631	6845	25.15	54.20	7.6	
8	150	15.04	12.25	15789	7535	18.54	47.73	7.7	
8	180	15.04	12.90	18946	8052	14.23	42.50	7.4	
8	210	15.04	13.53	22104	8435	10.00	38.16	7.2	
8	240	15.04	13.71	25262	8732	8.84	34.57	7.1	
8	270	15.04	13.65	28419	9018	9.23	31.73	6.9	
8	300	15.04	14.00	31577	9273	6.92	29.37	7	
6	30	0.51	0.20	772	619	60.44	80.22	7.4	
6	60	0.51	0.25	1544	1050	50.97	67.96	7.4	
6	90	0.51	0.32	2316	1389	36.99	59.97	7.2	
6	120	0.51	0.42	3088	1602	18.04	51.86	7.5	
6	150	0.51	0.52	3860	1666	-1.35	43.15	7.2	
6	180	0.51	0.52	4633	1654	-1.80	35.70	7	
6	210	0.51	0.54	5405	1625	-5.64	30.07	6.9	
6	240	0.51	0.56	6177	1563	-10.34	25.31	6.7	
6	270	0.51	0.56	6949	1483	-10.34	21.35	6.7	
6	300	0.51	0.54	7721	1421	-5.86	18.40	6.5	
6	30	0.50	0.16	763	645	68.89	84.44	7.3	
6	60	0.50	0.27	1527	1089	47.45	71.31	7.6	
6	90	0.50	0.32	2290	1406	35.81	61.41	7.7	
6	120	0.50	0.39	3054	1630	22.81	53.39	7.5	
6	150	0.50	0.45	3817	1757	10.26	46.02	7.2	
6	180	0.50	0.47	4580	1824	7.30	39.81	7	
6	210	0.50	0.49	5344	1860	2.28	34.81	6.8	
6	240	0.50	0.50	6107	1874	1.37	30.69	6.8	
6	270	0.50	0.50	6871	1884	1.37	27.43	6.7	
6	300	0.50	0.49	7634	1902	3.19	24.91	6.6	
6	30	1.02	0.71	11614	7606	30.97	65.49	7.6	
6	60	1.02	0.76	23229	10928	26.24	47.05	7.9	
6	90	1.02	0.77	34843	13885	24.66	39.85	7.4	
6	120	1.02	0.76	46457	16841	26.24	36.25	9	
6	150	1.02	0.78	58072	19745	23.76	34.00	7.8	
6	180	1.02	0.79	69686	22472	23.20	32.25	7.5	
6	210	1.02	0.78	81301	25199	23.76	31.00	7.3	
6	240	1.02	0.78	92915	27966	23.88	30.10	7.1	

Table A.7: Continued

Retention Time	Collection Time	Inflow P Concentration	Outflow P concentration	Cumulative P Added	Cumulative P Sorbed	Discrete removal	Cumulative Removal	pH	EC
----- minutes -----		------ ppm ------		------ mg kg^{-1} ------		------ % ------			mS cm^{-1}
6	270	1.02	0.79	104529	30706	23.31	29.38	7	
6	300	1.02	0.77	116144	33486	24.55	28.83	6.9	
6	30	1.05	0.70	11876	7926	33.48	66.74	7.6	
6	60	1.05	0.75	23752	11622	28.75	48.93	7.4	
6	90	1.05	0.77	35628	14879	26.10	41.76	7.4	
6	120	1.05	0.79	47504	17868	24.23	37.61	8	
6	150	1.05	0.84	59380	20484	19.83	34.50	7.8	
6	180	1.05	0.79	71256	23139	24.89	32.47	7.5	
6	210	1.05	0.78	83132	26154	25.88	31.46	7.3	
6	240	1.05	0.77	95008	29248	26.21	30.78	7.1	
6	270	1.05	0.78	106884	32341	25.88	30.26	7	
6	300	1.05	0.75	118760	35546	28.09	29.93	6.9	
6	30	4.59	0.58	1301	1219	87.33	93.66	8	0.654
6	60	4.59	0.75	2602	2331	83.62	89.57	8	0.735
6	90	4.59	1.04	3903	3377	77.29	86.53	7.8	0.705
6	120	4.59	1.36	5204	4339	70.46	83.37	7.5	0.737
6	150	4.59	1.59	6505	5222	65.32	80.27	7.3	0.7
6	180	4.59	1.82	7806	6039	60.34	77.36	7.3	0.747
6	210	4.59	2.06	9107	6790	55.03	74.55	7.1	0.751
6	240	4.59	2.20	10409	7486	51.99	71.92	7	0.659
6	270	4.59	2.37	11710	8140	48.45	69.51	7	0.672
6	300	4.59	2.47	13011	8756	46.26	67.30	7	0.742
6	30	4.90	0.92	1389	1258	81.18	90.59	8	0.715
6	60	4.90	1.43	2778	2315	70.91	83.32	8	0.729
6	90	4.90	2.18	4168	3194	55.59	76.63	7.8	0.705
6	120	4.90	2.70	5557	3892	44.93	70.04	7.5	0.707
6	150	4.90	3.26	6946	4436	33.40	63.86	7.3	0.7
6	180	4.90	3.60	8335	4853	26.61	58.22	7.3	0.68
6	210	4.90	3.94	9724	5173	19.50	53.20	7.1	0.699
6	240	4.90	4.18	11113	5410	14.60	48.68	7	0.63
6	270	4.90	4.26	12503	5602	13.02	44.80	7	0.702
6	300	4.90	4.24	13892	5785	13.42	41.64	7	0.711
6	30	9.84	2.76	1395	1199	71.91	85.96	6.7	0.648
6	60	9.84	3.22	2790	2170	67.24	77.76	6.8	0.655
6	90	9.84	3.89	4185	3060	60.46	73.13	6.9	0.581
6	120	9.84	4.93	5580	3830	49.86	68.63	6.9	0.646
6	150	9.84	5.85	6975	4460	40.51	63.95	6.7	0.598
6	180	9.84	6.25	8370	4997	36.46	59.70	6.5	0.583
6	210	9.84	7.02	9764	5451	28.67	55.83	6.6	0.63
6	240	9.84	7.40	11159	5824	24.78	52.19	6.6	0.659
6	270	9.84	7.62	12554	6154	22.59	49.02	6.6	0.665
6	300	9.84	7.68	13949	6465	21.97	46.35	6.5	0.66
6	30	9.96	2.06	1411	1265	79.32	89.66	6.9	0.681
6	60	9.96	1.81	2822	2403	81.86	85.13	7	0.637
6	90	9.96	2.76	4234	3491	72.31	82.45	7	0.556
6	120	9.96	3.37	5645	4468	66.15	79.14	6.8	0.631
6	150	9.96	3.92	7056	5362	60.61	75.99	6.7	0.641
6	180	9.96	4.80	8467	6155	51.83	72.69	6.7	0.615
6	210	9.96	5.53	9879	6835	44.44	69.19	6.5	0.585
6	240	9.96	6.05	11290	7425	39.20	65.76	6.5	0.63

Table A.7: Continued

Retention Time	Collection Time	Inflow P Concentration	Outflow P concentration	Cumulative P Added	Cumulative P Sorbed	Discrete removal	Cumulative Removal	pH	EC
----- minutes -----		------ ppm ------		------ mg kg^{-1} ------		------ % ------			mS cm^{-1}
6	270	9.96	6.53	12701	7944	34.42	62.55	6.5	0.608
6	300	9.96	6.90	14112	8404	30.73	59.55	6.4	0.65
6	30	14.52	2.88	3294	2967	80.14	90.07	7.4	0.629
6	60	14.52	4.23	6588	5454	70.88	82.79	7.2	0.629
6	90	14.52	6.61	9881	7519	54.48	76.09	7	0.631
6	120	14.52	8.91	13175	9052	38.62	68.70	7.1	0.634
6	150	14.52	10.49	16469	10146	27.79	61.60	6.9	0.644
6	180	14.52	11.47	19763	10950	21.04	55.40	7.1	0.664
6	210	14.52	11.79	23057	11606	18.84	50.34	6.9	0.653
6	240	14.52	12.19	26351	12182	16.09	46.23	6.8	0.662
6	270	14.52	13.55	29644	12557	6.67	42.36	6.7	0.596
6	300	14.52	12.76	32938	12867	12.17	39.06	6.7	0.632
6	30	14.81	4.59	3358	2838	68.98	84.49	7.4	0.634
6	60	14.81	8.60	6717	4700	41.96	69.98	7.1	0.634
6	90	14.81	10.53	10075	5890	28.87	58.46	7	0.634
6	120	14.81	11.65	13434	6733	21.32	50.12	6.9	0.652
6	150	14.81	12.02	16792	7407	18.86	44.11	6.8	0.656
6	180	14.81	12.76	20151	7957	13.86	39.49	7.1	0.652
6	210	14.81	13.21	23509	8371	10.78	35.61	6.9	0.68
6	240	14.81	13.50	26868	8700	8.85	32.38	7	0.66
6	270	14.81	14.41	30226	8894	2.69	29.43	6.8	0.67
6	300	14.81	14.24	33585	9004	3.85	26.81	6.8	0.69
3	30	0.49	0.09	555	504	81.47	90.73	7.7	
3	60	0.49	0.07	1110	967	85.67	87.15	7.9	
3	90	0.49	0.14	1665	1405	71.90	84.36	7.7	
3	120	0.49	0.20	2220	1768	58.83	79.61	7.5	
3	150	0.49	0.26	2775	2063	47.62	74.33	7.2	
3	180	0.49	0.32	3330	2291	34.55	68.79	7.1	
3	210	0.49	0.36	3885	2459	26.14	63.30	6.8	
3	240	0.49	0.39	4440	2588	20.08	58.28	6.7	
3	270	0.49	0.42	4995	2684	14.71	53.73	6.7	
3	300	0.49	0.43	5550	2759	12.14	49.70	6.6	
3	30	0.50	0.11	558	495	77.37	88.69	7.4	
3	60	0.50	0.08	1115	946	84.58	84.83	7.6	
3	90	0.50	0.14	1673	1383	72.03	82.65	7.5	
3	120	0.50	0.23	2231	1734	53.91	77.73	7.4	
3	150	0.50	0.28	2788	2006	43.68	71.94	7.1	
3	180	0.50	0.33	3346	2218	32.53	66.30	7	
3	210	0.50	0.37	3903	2378	24.63	60.92	6.8	
3	240	0.50	0.41	4461	2494	16.96	55.90	6.8	
3	270	0.50	0.44	5019	2571	10.92	51.24	6.7	
3	300	0.50	0.44	5576	2633	11.15	47.22	6.6	
3	30	0.99	0.31	1110	934	68.33	84.17	7.3	
3	60	0.99	0.18	2220	1768	81.81	79.62	8.5	
3	90	0.99	0.45	3330	2521	53.92	75.70	8.2	
3	120	0.99	0.75	4440	2952	23.79	66.49	7.6	
3	150	0.99	0.94	5550	3112	4.92	56.06	7.6	
3	180	0.99	1.05	6660	3104	-6.33	46.60	7.5	
3	210	0.99	1.10	7770	3005	-11.49	38.67	7.2	
3	240	0.99	1.12	8880	2866	-13.60	32.27	7.2	

Table A.7: Continued

Retention Time	Collection Time	Inflow P Concentration	Outflow P concentration	Cumulative P Added	Cumulative P Sorbed	Discrete removal	Cumulative Removal	pH	EC
----- minutes -----		------ ppm ------		------ mg kg^{-1} ------		------ % ------			mS cm^{-1}
3	270	0.99	1.13	9990	2711	-14.30	27.13	7	
3	300	0.99	1.10	11101	2570	-11.02	23.16	7	
3	30	0.98	0.33	1105	919	66.42	83.21	7.7	
3	60	0.98	0.43	2210	1596	56.05	72.22	8.4	
3	90	0.98	0.69	3315	2072	30.15	62.51	8	
3	120	0.98	0.87	4419	2302	11.54	52.10	7.6	
3	150	0.98	0.98	5524	2369	0.47	42.88	7.7	
3	180	0.98	1.02	6629	2348	-4.24	35.42	7.5	
3	210	0.98	1.05	7734	2284	-7.30	29.53	7.2	
3	240	0.98	1.08	8839	2190	-9.66	24.78	7.1	
3	270	0.98	1.03	9944	2108	-5.18	21.20	6.9	
3	300	0.98	0.98	11048	2080	0.00	18.82	7.1	
3	30	4.53	1.05	1358	1201	76.85	88.43	7.6	
3	60	4.53	0.42	2716	2338	90.66	86.09	8.6	
3	90	4.53	1.00	4074	3483	77.95	85.50	8.1	
3	120	4.53	1.59	5431	4452	64.82	81.97	7.7	
3	150	4.53	2.43	6789	5207	46.35	76.69	7.8	
3	180	4.53	2.94	8147	5759	34.99	70.69	7.4	
3	210	4.53	3.30	9505	6181	27.20	65.03	7.4	
3	240	4.53	3.62	10863	6502	20.08	59.86	7.3	
3	270	4.53	3.86	12221	6739	14.83	55.15	7.2	
3	300	4.53	3.99	13578	6920	11.78	50.96	7.2	
3	30	4.91	1.80	1473	1202	63.27	81.64	7.5	
3	60	4.91	1.84	2946	2129	62.49	72.26	8.2	
3	90	4.91	2.42	4419	2963	50.77	67.05	7.9	
3	120	4.91	2.44	5892	3708	50.38	62.93	7.6	
3	150	4.91	3.10	7364	4351	36.95	59.08	7.5	
3	180	4.91	3.38	8837	4852	31.17	54.91	7.4	
3	210	4.91	3.69	10310	5265	24.92	51.07	7.3	
3	240	4.91	3.90	11783	5600	20.54	47.53	7.3	
3	270	4.91	4.03	13256	5883	17.89	44.38	7.2	
3	300	4.91	4.10	14729	6136	16.40	41.66	7.1	
3	30	9.80	1.34	1103	1027	86.34	93.17	9.1	
3	60	9.80	0.95	2205	2001	90.30	90.75	9.7	
3	90	9.80	1.83	3308	2947	81.35	89.11	9.4	
3	120	9.80	2.86	4410	3786	70.80	85.85	9.1	
3	150	9.80	5.10	5513	4441	47.97	80.55	8.9	
3	180	9.80	5.43	6615	4951	44.56	74.84	8.5	
3	210	9.80	5.51	7718	5438	43.76	70.46	8.2	
3	240	9.80	6.02	8820	5891	38.53	66.79	8.2	
3	270	9.80	6.85	9923	6270	30.13	63.19	8.4	
3	300	9.80	7.07	11025	6590	27.91	59.77	8.3	
3	30	9.72	1.96	1094	984	79.84	89.92	9.9	
3	60	9.72	2.93	2188	1802	69.85	82.38	9.7	
3	90	9.72	3.25	3281	2548	66.57	77.66	9.9	
3	120	9.72	6.26	4375	3107	35.64	71.02	9.2	
3	150	9.72	3.86	5469	3632	60.34	66.41	8.9	
3	180	9.72	5.01	6563	4227	48.51	64.42	8.5	
3	210	9.72	6.97	7656	4647	28.29	60.70	8.2	
3	240	9.72	5.64	8750	5032	42.04	57.51	8.2	

Table A.7: Continued

Retention Time	Collection Time	Inflow P Concentration	Outflow P concentration	Cumulative P Added	Cumulative P Sorbed	Discrete removal	Cumulative Removal	pH	EC
----- minutes -----		------ ppm ------		------ mg kg^{-1} ------		------ % ------			mS cm^{-1}
3	270	9.72	5.67	9844	5490	41.72	55.77	8.3	
3	300	9.72	5.78	10938	5940	40.60	54.31	8.3	
3	30	14.67	5.36	3300	2697	63.45	81.73	7.7	
3	60	14.67	8.40	6600	4449	42.72	67.41	7.6	
3	90	14.67	9.74	9899	5708	33.61	57.66	7.7	
3	120	14.67	11.51	13199	6617	21.52	50.14	7.4	
3	150	14.67	11.97	16499	7276	18.38	44.10	7.2	
3	180	14.67	12.65	19799	7806	13.74	39.42	7	
3	210	14.67	12.82	23098	8240	12.56	35.67	6.9	
3	240	14.67	13.11	26398	8622	10.60	32.66	6.8	
3	270	14.67	13.17	29698	8965	10.21	30.19	6.8	
3	300	14.67	13.57	32998	9257	7.46	28.05	6.7	
3	30	15.10	7.36	3397	2569	51.26	75.63	8	
3	60	15.10	7.68	6794	4274	49.13	62.91	7.8	
3	90	15.10	10.15	10191	5666	32.78	55.59	7.8	
3	120	15.10	11.56	13588	6621	23.45	48.72	8.5	
3	150	15.10	11.95	16985	7373	20.86	43.41	7.9	
3	180	15.10	12.73	20383	7994	15.66	39.22	7.5	
3	210	15.10	13.25	23780	8467	12.22	35.61	7.3	
3	240	15.10	13.25	27177	8883	12.22	32.68	7.1	
3	270	15.10	13.48	30574	9272	10.70	30.33	7	
3	300	15.10	13.37	33971	9648	11.46	28.40	6.9	
0.5	30	0.98	0.86	17730	9965	12.41	56.21	8	
0.5	60	0.98	0.89	35459	11938	9.84	33.67	7.5	
0.5	90	0.98	0.92	53189	13391	6.56	25.18	7.4	
0.5	120	0.98	0.94	70918	14367	4.45	20.26	8.5	
0.5	150	0.98	0.95	88648	15094	3.75	17.03	8.1	
0.5	180	0.98	0.97	106377	15571	1.64	14.64	7.6	
0.5	210	0.98	0.98	124107	15717	0.00	12.66	7.4	
0.5	240	0.98	0.99	141836	15675	-0.47	11.05	7.1	
0.5	270	0.98	0.98	159566	15634	0.00	9.80	7	
0.5	300	0.98	0.97	177296	15779	1.64	8.90	6.9	
0.5	30	4.95	1.40	2226	1912	71.77	85.88	7.9	
0.5	60	4.95	2.17	4451	3335	56.16	74.92	7.8	
0.5	90	4.95	3.09	6677	4378	37.54	65.57	7.8	
0.5	120	4.95	2.94	8903	5246	40.48	58.93	7.6	
0.5	150	4.95	3.20	11129	6089	35.23	54.71	7.2	
0.5	180	4.95	3.24	13354	6864	34.45	51.40	7.5	
0.5	210	4.95	3.40	15580	7595	31.21	48.75	7.3	
0.5	240	4.95	3.37	17806	8297	31.83	46.60	7.1	
0.5	270	4.95	3.34	20032	9012	32.45	44.99	7	
0.5	300	4.95	3.56	22257	9684	27.97	43.51	7	
0.5	30	4.97	1.45	2238	1912	70.84	85.42	8.2	
0.5	60	4.97	2.86	4476	3179	42.40	71.02	8.3	
0.5	90	4.97	3.80	6714	3918	23.64	58.35	7.6	
0.5	120	4.97	4.40	8953	4313	11.63	48.17	7.5	
0.5	150	4.97	4.70	11191	4504	5.43	40.24	7.7	
0.5	180	4.97	4.78	13429	4608	3.88	34.31	7.5	
0.5	210	4.97	4.82	15667	4686	3.10	29.91	7.2	
0.5	240	4.97	4.82	17905	4755	3.10	26.56	7.1	

Table A.7: Continued

Retention Time	Collection Time	Inflow P Concentration	Outflow P concentration	Cumulative P Added	Cumulative P Sorbed	Discrete removal	Cumulative Removal	pH	EC
----- minutes -----		------ ppm ------		------ mg kg^{-1} ------		------ % ------			mS cm^{-1}
0.5	270	4.97	4.78	20143	4833	3.88	23.99	6.9	
0.5	300	4.97	4.78	22382	4920	3.88	21.98	6.9	
0.5	30	9.99	2.05	3373	3027	79.46	89.73	8.5	
0.5	60	9.99	5.72	6746	5088	42.75	75.41	8.3	
0.5	90	9.99	7.19	10120	6282	28.03	62.07	7.8	
0.5	120	9.99	8.03	13493	7086	19.67	52.52	7.4	
0.5	150	9.99	8.76	16866	7627	12.39	45.22	7.2	
0.5	180	9.99	8.91	20239	8019	10.84	39.62	7.3	
0.5	210	9.99	9.14	23612	8345	8.52	35.34	7.1	
0.5	240	9.99	9.18	26985	8626	8.13	31.97	7	
0.5	270	9.99	9.26	30359	8887	7.36	29.27	7	
0.5	300	9.99	9.34	33732	9122	6.58	27.04	7	
0.5	30	9.92	4.13	3347	2651	58.38	79.19	8.3	
0.5	60	9.92	7.33	6694	4064	26.07	60.71	8.2	
0.5	90	9.92	7.73	10041	4868	22.01	48.48	7.7	
0.5	120	9.92	7.80	13388	5595	21.38	41.79	7.4	
0.5	150	9.92	8.20	16735	6242	17.33	37.30	7.2	
0.5	180	9.92	8.56	20082	6761	13.66	33.67	7.3	
0.5	210	9.92	8.64	23429	7205	12.88	30.75	7.1	
0.5	240	9.92	8.79	26776	7610	11.32	28.42	7	
0.5	270	9.92	8.68	30123	8008	12.49	26.58	6.9	
0.5	300	9.92	8.72	33471	8420	12.10	25.16	6.9	
0.5	30	14.76	0.75	1992	1942	94.92	97.46	10.4	
0.5	60	14.76	1.48	3985	3784	89.95	94.95	9.8	
0.5	90	14.76	1.89	5977	5548	87.18	92.82	9.6	
0.5	120	14.76	4.12	7970	7135	72.10	89.53	9	
0.5	150	14.76	7.60	9962	8336	48.49	83.68	8.7	
0.5	180	14.76	9.27	11954	9190	37.20	76.87	8.4	
0.5	210	14.76	10.20	13947	9868	30.88	70.75	8	
0.5	240	14.76	11.18	15939	10417	24.24	65.35	8	
0.5	270	14.76	11.67	17932	10867	20.93	60.60	8.1	
0.5	300	14.76	11.86	19924	11271	19.66	56.57	8.2	
0.5	30	15.15	2.29	2046	1891	84.87	92.44	8.3	
0.5	60	15.15	5.89	4091	3384	61.14	82.72	8.3	
0.5	90	15.15	8.53	6137	4457	43.73	72.63	7.6	
0.5	120	15.15	11.37	8182	5159	24.96	63.06	7.9	
0.5	150	15.15	10.98	10228	5696	27.55	55.70	7.6	
0.5	180	15.15	11.97	12273	6193	20.99	50.46	7.5	
0.5	210	15.15	12.18	14319	6608	19.62	46.15	7.3	
0.5	240	15.15	12.43	16365	6992	17.94	42.73	7.1	
0.5	270	15.15	12.72	18410	7340	16.03	39.87	7	
0.5	300	15.15	12.84	20456	7660	15.26	37.45	6.9	

Table A.8: Results of Flue Gas Desulfurization Gypsum flow-through experiment.

Retention Time	Collection Time	Inflow P Concentration	Outflow P concentration	Cumulative P Added	Cumulative P Sorbed	Discrete removal	Cumulative Removal	pH	EC
minutes		ppm		mg kg^{-1}		%			mS cm^{-1}
10	60	0.45	0.06	12.26	11.44	86.64	93.32	6.14	2.423
10	120	0.45	0.13	24.52	21.06	70.41	85.92	7.81	1.97
10	180	0.45	0.22	36.77	28.58	52.21	77.72	7.28	2.58
10	240	0.45	0.26	49.03	34.41	42.87	70.17	6.86	2.28
10	300	0.45	0.30	61.29	39.03	32.54	63.68	6.84	2.27
10	60	0.45	0.05	12.26	11.53	88.11	94.06	6.33	2.05
10	120	0.45	0.12	24.52	21.40	72.87	87.27	7.78	2.45
10	180	0.45	0.19	36.77	29.39	57.62	79.93	7.33	2.18
10	240	0.45	0.24	49.03	35.73	45.82	72.88	7	1.9
10	300	0.45	0.28	61.29	40.90	38.44	66.73	6.81	1.96
10	60	1.11	0.54	30.24	22.88	51.32	75.66	8.53	1.98
10	120	1.11	0.71	60.47	36.04	35.76	59.60	7.39	2.26
10	180	1.11	0.90	90.71	44.26	18.62	48.80	6.975	2.32
10	240	1.11	1.00	120.95	48.60	10.04	40.18	7.267	2.25
10	300	1.11	1.04	151.18	51.03	6.05	33.75	6.94	1.79
10	60	1.11	0.43	30.24	24.44	61.69	80.84	8.32	2.3
10	120	1.11	0.74	60.47	38.88	33.77	64.29	7.428	2.17
10	180	1.11	0.80	90.71	48.21	27.99	53.15	7.027	1.98
10	240	1.11	0.82	120.95	56.37	25.99	46.61	7.307	1.67
10	300	1.11	0.88	151.18	63.45	20.81	41.97	6.94	1.91
10	30	4.90	1.37	16.68	14.35	72.03	86.02	7.18	2.12
10	60	4.90	2.47	33.37	24.50	49.64	73.43	8.21	1.94
10	90	4.90	2.97	50.05	31.92	39.31	63.78	8	1.93
10	120	4.90	3.11	66.74	38.25	36.55	57.31	8.1	1.88
10	150	4.90	3.31	83.42	44.01	32.47	52.75	7.66	1.88
10	180	4.90	3.31	100.11	49.43	32.47	49.37	7.96	1.83
10	210	4.90	3.42	116.79	54.65	30.15	46.79	7.41	1.78
10	240	4.90	3.30	133.48	59.89	32.62	44.87	7.25	1.83
10	270	4.90	3.56	150.16	64.89	27.38	43.21	7.34	1.76
10	300	4.90	3.86	166.85	68.94	21.13	41.32	7.31	1.75
10	30	4.90	1.93	16.68	13.41	60.69	80.34	7.14	2.09
10	60	4.90	2.75	33.37	22.12	43.82	66.30	8.43	1.99
10	90	4.90	3.22	50.05	28.65	34.36	57.23	7.93	1.78
10	120	4.90	3.37	66.74	34.12	31.31	51.13	7.92	1.85
10	150	4.90	3.58	83.42	38.98	26.95	46.73	7.66	1.8
10	180	4.90	3.60	100.11	43.44	26.51	43.40	8.19	1.72
10	210	4.90	3.72	116.79	47.67	24.18	40.82	7.37	1.66
10	240	4.90	4.02	133.48	51.19	17.93	38.35	7.21	1.66
10	270	4.90	3.81	150.16	54.53	22.15	36.31	7.3	1.58
10	300	4.90	4.04	166.85	57.84	17.49	34.66	7.24	1.59
10	30	10.56	5.83	71.91	52.07	44.82	72.41	7.1	2.09
10	60	10.56	4.16	143.83	89.97	60.57	62.55	7.21	2.2
10	90	10.56	6.52	215.74	125.51	38.27	58.17	7.13	2.14
10	120	10.56	7.77	287.65	148.78	26.46	51.72	6.98	2.15
10	150	10.56	8.39	359.57	165.68	20.55	46.08	7	2.07
10	180	10.56	9.67	431.48	176.10	8.42	40.81	6.99	2.12
10	210	10.56	8.82	503.40	185.05	16.46	36.76	6.92	2.13

Table A.8: Continued

Retention Time	Collection Time	Inflow P Concentration	Outflow P concentration	Cumulative P Added	Cumulative P Sorbed	Discrete removal	Cumulative Removal	pH	EC
----- minutes -----		------ ppm ------		------ mg kg^{-1} ------		------ % ------			mS cm^{-1}
10	240	10.56	8.29	575.31	198.71	21.54	34.54	6.99	2.1
10	270	10.56	9.03	647.22	211.66	14.49	32.70	6.98	2.16
10	300	10.56	8.04	719.14	225.44	23.84	31.35	6.96	2.15
10	30	10.56	5.38	71.91	53.61	49.09	74.54	7.18	2.13
10	60	10.56	4.77	143.83	90.97	54.83	63.25	7.21	2.17
10	90	10.56	5.48	215.74	127.98	48.10	59.32	7.16	2.13
10	120	10.56	5.26	287.65	163.34	50.24	56.78	7.21	2.16
10	150	10.56	6.26	359.57	196.05	40.73	54.52	7.16	2.17
10	180	10.56	8.63	431.48	217.26	18.26	50.35	7.07	2.12
10	210	10.56	7.11	503.40	235.58	32.69	46.80	7.13	2.1
10	240	10.56	10.23	575.31	248.47	3.17	43.19	7.08	2.15
10	270	10.56	7.82	647.22	258.95	25.97	40.01	7.11	2.09
10	300	10.56	8.98	719.14	273.67	14.98	38.06	7.05	2.13
10	30	15.00	3.48	51.08	45.15	76.80	88.40	7.12	2.31
10	60	15.00	5.10	102.15	81.62	66.01	79.90	7.1	2.39
10	90	15.00	7.82	153.23	110.70	47.86	72.25	7.2	2.45
10	120	15.00	8.62	204.30	133.79	42.55	65.49	6.94	2.17
10	150	15.00	9.52	255.38	153.99	36.56	60.30	6.85	2.36
10	180	15.00	10.90	306.45	170.30	27.31	55.57	6.86	2.46
10	210	15.00	11.75	357.53	182.81	21.66	51.13	6.86	2.46
10	240	15.00	11.55	408.60	194.22	23.03	47.53	6.92	2.1
10	270	15.00	13.37	459.68	202.88	10.87	44.14	6.89	2.12
10	300	15.00	12.75	510.75	209.48	14.98	41.01	6.82	2.13
10	30	15.00	3.02	51.08	45.94	79.88	89.94	7.17	2.6
10	60	15.00	3.81	102.15	85.38	74.58	83.59	7.18	2.41
10	90	15.00	6.84	153.23	118.31	54.37	77.21	7.09	2.24
10	120	15.00	9.52	204.30	141.53	36.56	69.28	6.97	2.15
10	150	15.00	9.67	255.38	159.94	35.53	62.63	6.94	2.1
10	180	15.00	10.26	306.45	177.08	31.59	57.79	6.93	2.33
10	210	15.00	10.42	357.53	192.96	30.56	53.97	6.92	2.05
10	240	15.00	10.83	408.60	207.87	27.82	50.87	6.94	2.14
10	270	15.00	12.60	459.68	219.06	16.01	47.66	6.86	2.15
10	300	15.00	11.78	510.75	228.64	21.49	44.76	6.95	2.12
8	42.5	0.45	0.18	10.71	8.63	61.07	80.54	9.04	1.95
8	85	0.45	0.29	21.42	13.85	36.48	64.65	7.93	1.8
8	127.5	0.45	0.32	32.13	17.36	29.10	54.03	7.41	1.96
8	170	0.45	0.34	42.84	20.27	25.16	47.31	7.52	1.64
8	212.5	0.45	0.35	53.55	22.75	21.23	42.49	6.728	1.73
8	255	0.45	0.37	64.26	24.84	17.79	38.66	7.05	1.35
8	297.5	0.45	0.39	74.97	26.51	13.36	35.36	7.05	1.59
8	42.5	0.45	0.19	10.71	8.49	58.61	79.31	8.613	2.35
8	85	0.45	0.28	21.42	13.69	38.44	63.92	7.85	2.29
8	127.5	0.45	0.35	32.13	16.97	22.71	52.80	7.39	2.26
8	170	0.45	0.37	42.84	19.19	18.77	44.79	7.445	2.28
8	212.5	0.45	0.39	53.55	20.96	14.34	39.14	6.72	2.03
8	255	0.45	0.41	64.26	22.21	8.93	34.56	7.04	1.91
8	297.5	0.45	0.42	74.97	23.03	6.47	30.72	7.06	1.91
8	42.5	1.11	0.31	26.42	22.75	72.25	86.13	8.61	2.29
8	85	1.11	0.59	52.84	38.50	46.93	72.86	8.3	2.038

Table A.8: Continued

Retention Time	Collection Time	Inflow P Concentration	Outflow P concentration	Cumulative P Added	Cumulative P Sorbed	Discrete removal	Cumulative Removal	pH	EC
-----	minutes -----	------	ppm ------	------	mg kg^{-1} ------	------	% ------		$mS\ cm^{-1}$
8	127.5	1.11	0.74	79.25	49.16	33.77	62.02	7.11	2.37
8	170	1.11	0.87	105.67	56.45	21.41	53.42	7.51	2.07
8	212.5	1.11	0.89	132.09	61.84	19.42	46.82	7.37	1.67
8	255	1.11	0.92	158.51	66.71	17.43	42.08	6.72	1.83
8	297.5	1.11	0.99	184.93	70.44	10.81	38.09	7.032	1.74
8	42.5	1.11	0.28	26.42	23.04	74.45	87.22	8.3	1.98
8	85	1.11	0.59	52.84	39.10	47.13	74.01	8.07	2.22
8	127.5	1.11	0.73	79.25	49.84	34.17	62.89	7.09	1.74
8	170	1.11	0.84	105.67	57.53	24.01	54.44	7.513	2.06
8	212.5	1.11	0.89	132.09	63.32	19.82	47.93	7.344	1.89
8	255	1.11	0.88	158.51	68.66	20.62	43.31	6.81	1.81
8	297.5	1.11	0.98	184.93	72.93	11.71	39.44	7.071	1.77
8	30	4.90	1.80	20.58	16.80	63.22	81.61	8.27	2.58
8	60	4.90	2.84	41.16	27.63	42.08	67.13	7.97	2.17
8	90	4.90	3.22	61.74	35.48	34.21	57.47	7.75	2.15
8	120	4.90	3.64	82.32	41.64	25.65	50.59	7.7	2.12
8	150	4.90	4.19	102.90	45.77	14.47	44.48	7.51	2.15
8	180	4.90	4.64	123.48	47.79	5.21	38.71	7.4	2.11
8	210	4.90	3.59	144.06	51.08	26.70	35.46	7.53	2.11
8	240	4.90	4.50	164.64	54.67	8.18	33.20	7.31	2.1
8	270	4.90	4.09	185.22	57.21	16.57	30.89	7.29	2.1
8	300	4.90	4.81	205.80	59.11	1.89	28.72	7.35	2.17
8	30	4.90	2.71	20.58	14.89	44.70	72.35	7.62	2.31
8	60	4.90	2.88	41.16	23.73	41.20	57.65	7.74	2.18
8	90	4.90	3.08	61.74	31.80	37.18	51.50	7.67	2.2
8	120	4.90	2.79	82.32	40.06	43.13	48.66	7.77	2.1
8	150	4.90	3.99	102.90	46.42	18.66	45.11	7.35	2.08
8	180	4.90	3.50	123.48	51.28	28.62	41.53	7.46	2.01
8	210	4.90	3.93	144.06	56.26	19.71	39.05	7.5	2.01
8	240	4.90	4.17	164.64	59.81	14.82	36.33	7.31	1.99
8	270	4.90	4.85	185.22	61.44	1.01	33.17	7.18	1.92
8	300	4.90	4.73	205.80	61.90	3.46	30.08	7.33	1.95
8	30	10.56	3.38	44.35	37.25	67.97	83.99	8.93	2.1
8	60	10.56	5.55	88.70	62.85	47.46	70.85	8.7	2.08
8	90	10.56	7.22	133.06	80.39	31.66	60.42	8.35	2.29
8	120	10.56	8.06	177.41	92.67	23.70	52.24	8	1.95
8	150	10.56	8.00	221.76	103.30	24.24	46.58	7.8	2.05
8	180	10.56	7.53	266.11	115.04	28.69	43.23	8.1	1.98
8	210	10.56	8.67	310.46	125.37	17.90	40.38	7.98	2.12
8	240	10.56	8.47	354.82	133.73	19.79	37.69	7.8	2.03
8	270	10.56	8.97	399.17	141.46	15.06	35.44	7.74	2.02
8	300	10.56	8.74	443.52	148.62	17.22	33.51	7.6	1.96
8	30	10.56	4.25	44.35	35.42	59.74	79.87	8.41	2.06
8	60	10.56	6.02	88.70	58.21	43.00	65.62	8.3	2.04
8	90	10.56	7.06	133.06	75.10	33.15	56.44	8	2.17
8	120	10.56	7.80	177.41	88.24	26.13	49.74	7.671	1.95
8	150	10.56	8.09	221.76	99.23	23.43	44.75	7.6	1.98
8	180	10.56	8.17	266.11	109.44	22.62	41.13	7.76	2.14
8	210	10.56	8.66	310.46	118.46	18.03	38.16	7.6	1.99
8	240	10.56	8.86	354.82	126.04	16.14	35.52	7.55	1.97

Table A.8: Continued

Retention Time	Collection Time	Inflow P Concentration	Outflow P concentration	Cumulative P Added	Cumulative P Sorbed	Discrete removal	Cumulative Removal	pH	EC
----- minutes -----		------ ppm ------		------ mg kg^{-1} ------		------ % ------			mS cm^{-1}
8	270	10.56	8.29	399.17	134.39	21.54	33.67	7.46	1.94
8	300	10.56	8.31	443.52	143.89	21.27	32.44	7.35	2.06
8	30	15.00	1.93	63.00	58.94	87.11	93.56	8.88	1.95
8	60	15.00	4.39	126.00	108.67	70.75	86.24	8.55	1.93
8	90	15.00	6.01	189.00	149.83	59.93	79.28	8.3	1.89
8	120	15.00	7.44	252.00	184.59	50.40	73.25	8.2	1.95
8	150	15.00	8.44	315.00	214.23	43.71	68.01	7.8	1.91
8	180	15.00	9.06	378.00	240.47	39.58	63.62	7.7	1.89
8	210	15.00	9.21	441.00	265.09	38.59	60.11	7.68	1.88
8	240	15.00	8.64	504.00	290.61	42.43	57.66	7.56	1.94
8	270	15.00	8.21	567.00	318.24	45.28	56.13	7.4	1.94
8	300	15.00	9.04	630.00	345.02	39.73	54.76	7.43	1.92
8	30	15.00	1.85	63.00	59.12	87.68	93.84	8.18	2.02
8	60	15.00	4.77	126.00	108.22	68.19	85.89	7.93	1.92
8	90	15.00	7.31	189.00	145.84	51.25	77.17	7.7	1.94
8	120	15.00	8.61	252.00	175.40	42.57	69.60	7.6	1.93
8	150	15.00	9.04	315.00	201.32	39.73	63.91	7.38	1.94
8	180	15.00	9.60	378.00	225.18	36.03	59.57	7.32	1.98
8	210	15.00	9.87	441.00	247.30	34.18	56.08	7.27	1.93
8	240	15.00	9.87	504.00	268.83	34.18	53.34	7.18	1.86
8	270	15.00	8.06	567.00	294.17	46.27	51.88	7.15	1.87
8	300	15.00	9.87	630.00	319.51	34.18	50.72	7.12	1.85
6	37.5	0.45	0.17	12.76	10.38	62.74	81.37	9.25	2.29
6	75	0.45	0.26	25.52	17.14	43.29	67.19	8.67	2.22
6	112.5	0.45	0.28	38.27	22.27	37.12	58.19	8.22	2.06
6	150	0.45	0.33	51.03	26.40	27.63	51.74	8.25	1.8
6	187.5	0.45	0.34	63.79	29.66	23.37	46.49	7.99	1.71
6	225	0.45	0.36	76.55	32.36	19.10	42.28	7.85	1.61
6	262.5	0.45	0.35	89.30	34.95	21.47	39.14	7.64	1.52
6	300	0.45	0.34	102.06	37.84	23.84	37.08	7.94	1.21
6	37.5	0.45	0.25	12.76	9.23	44.71	72.36	8.87	2.37
6	75	0.45	0.33	25.52	13.72	25.74	53.79	8.57	1.98
6	112.5	0.45	0.35	38.27	16.74	21.47	43.73	8.18	1.69
6	150	0.45	0.35	51.03	19.50	21.94	38.22	8.24	1.53
6	187.5	0.45	0.36	63.79	22.21	20.52	34.82	8	1.5
6	225	0.45	0.36	76.55	24.83	20.52	32.44	7.87	1.43
6	262.5	0.45	0.36	89.30	27.36	19.10	30.64	7.67	1.34
6	300	0.45	0.37	102.06	29.73	18.15	29.13	7.36	1.31
6	30	1.11	0.62	25.17	18.11	43.89	71.94	8.27	2.52
6	60	1.11	0.86	50.35	26.48	22.60	52.59	8.4	2.32
6	90	1.11	0.95	75.52	31.09	14.04	41.17	8.27	2.13
6	120	1.11	1.02	100.70	33.84	7.79	33.60	8.07	1.96
6	150	1.11	1.04	125.87	35.60	6.17	28.28	7.94	1.89
6	180	1.11	1.05	151.05	37.03	5.24	24.52	7.8	1.83
6	210	1.11	1.07	176.22	38.15	3.62	21.65	7.94	1.69
6	240	1.11	1.11	201.40	38.62	0.15	19.18	7.9	1.75
6	270	1.11	1.12	226.57	38.51	-1.01	17.00	7.97	1.7
6	300	1.11	1.12	251.75	38.32	-0.54	15.22	8.13	1.63
6	30	1.11	0.61	25.17	18.26	45.05	72.52	7.95	2.28

Table A.8: Continued

Retention Time	Collection Time	Inflow P Concentration	Outflow P concentration	Cumulative P Added	Cumulative P Sorbed	Discrete removal	Cumulative Removal	pH	EC
----- minutes -----		------ ppm ------		------ mg kg^{-1} ------		------ % ------			mS cm^{-1}
6	60	1.11	0.91	50.35	26.22	18.20	52.07	7.94	2.48
6	90	1.11	1.02	75.52	29.58	8.48	39.16	8.1	2.28
6	120	1.11	1.10	100.70	30.81	1.31	30.60	7.9	2.14
6	150	1.11	1.13	125.87	30.70	-2.16	24.39	7.56	2
6	180	1.11	1.15	151.05	29.95	-3.78	19.83	7.88	1.86
6	210	1.11	1.17	176.22	28.83	-5.17	16.36	7.96	1.81
6	240	1.11	1.16	201.40	27.64	-4.25	13.72	7.73	1.72
6	270	1.11	1.18	226.57	26.31	-6.33	11.61	7.49	1.59
6	300	1.11	1.19	251.75	24.63	-7.02	9.78	7.8	1.66
6	30	4.90	1.50	27.78	23.52	69.35	84.67	8.48	2.21
6	60	4.90	3.05	55.57	38.40	37.72	69.10	8.22	2.16
6	90	4.90	3.88	83.35	46.52	20.76	55.81	7.89	2.2
6	120	4.90	4.16	111.13	51.50	15.10	46.34	7.69	2.12
6	150	4.90	3.76	138.92	56.83	23.23	40.91	7.83	2.15
6	180	4.90	4.77	166.70	60.43	2.73	36.25	7.42	2.14
6	210	4.90	4.52	194.48	61.88	7.68	31.82	7.59	2.16
6	240	4.90	4.37	222.26	64.45	10.86	29.00	7.57	2.13
6	270	4.90	4.97	250.05	65.78	-1.33	26.31	7.41	2.18
6	300	4.90	4.26	277.83	67.40	12.98	24.26	7.55	2.1
6	30	4.90	1.23	27.78	24.29	74.83	87.41	7.76	2.17
6	60	4.90	2.88	55.57	40.41	41.25	72.73	7.72	2.17
6	90	4.90	3.72	83.35	49.49	24.11	59.38	7.7	2.1
6	120	4.90	3.35	111.13	57.22	31.53	51.49	7.69	2.19
6	150	4.90	4.26	138.92	63.41	12.98	45.64	7.42	2.2
6	180	4.90	4.26	166.70	67.04	13.16	40.21	7.43	2.21
6	210	4.90	4.36	194.48	70.40	11.04	36.20	7.42	2.14
6	240	4.90	4.94	222.26	71.82	-0.80	32.31	7.34	2.17
6	270	4.90	4.41	250.05	73.09	9.98	29.23	7.34	2.16
6	300	4.90	5.09	277.83	73.95	-3.81	26.62	7.31	2.17
6	15	10.50	5.00	29.77	22.67	52.34	76.17	6.56	1.98
6	30	10.50	4.84	59.54	38.48	53.89	64.64	8.32	1.99
6	60	10.50	3.32	119.07	74.87	68.36	62.88	8.65	1.99
6	90	10.50	6.13	178.61	107.62	41.66	60.26	7.67	1.42
6	120	10.50	5.49	238.14	134.23	47.70	56.36	7.17	2.03
6	150	10.50	7.20	297.68	157.77	31.40	53.00	6.88	1.996
6	180	10.50	8.13	357.21	173.83	22.55	48.66	7.43	1.967
6	210	10.50	8.75	416.75	185.50	16.65	44.51	6.595	1.89
6	240	10.50	8.97	476.28	194.78	14.54	40.90	7.15	1.87
6	270	10.50	8.66	535.82	204.32	17.49	38.13	6.87	1.86
6	300	10.50	9.14	595.35	213.39	12.99	35.84	6.712	1.87
6	15	10.50	4.80	29.77	22.97	54.31	77.15	6.265	2.09
6	30	10.50	3.94	59.54	40.35	62.46	67.77	7.873	2.01
6	60	10.50	3.72	119.07	78.16	64.57	65.64	8.05	2.03
6	90	10.50	5.15	178.61	112.54	50.93	63.01	7.43	2.02
6	120	10.50	5.54	238.14	141.78	47.28	59.53	7.161	1.97
6	150	10.50	7.34	297.68	164.82	30.14	55.37	6.85	1.97
6	180	10.50	7.47	357.21	182.39	28.87	51.06	7.24	1.97
6	210	10.50	8.69	416.75	196.10	17.21	47.06	6.52	2.01
6	240	10.50	8.58	476.28	206.68	18.33	43.40	6.99	1.85
6	270	10.50	8.13	535.82	218.85	22.55	40.84	6.85	1.96
6	300	10.50	8.66	595.35	230.77	17.49	38.76	6.74	1.95

Table A.8: Continued

Retention Time	Collection Time	Inflow P Concentration	Outflow P concentration	Cumulative P Added	Cumulative P Sorbed	Discrete removal	Cumulative Removal	pH	EC
----- minutes -----		------ ppm ------		------ mg kg^{-1} ------		------ % ------			mS cm^{-1}
6	30	15.78	1.97	59.65	55.92	87.49	93.74	7.5	2.32
6	60	15.78	4.71	119.30	102.94	70.17	86.29	7.29	2.28
6	90	15.78	8.14	178.95	138.30	48.40	77.29	7.15	2.26
6	120	15.78	9.13	238.59	165.30	42.13	69.28	7.13	2.25
6	150	15.78	9.81	298.24	189.15	37.84	63.42	7.1	2.24
6	180	15.78	11.58	357.89	208.38	26.63	58.22	7.06	2.45
6	210	15.78	10.75	417.54	225.84	31.91	54.09	7.1	2.27
6	240	15.78	11.42	477.19	243.59	27.62	51.05	7.07	2.25
6	270	15.78	12.41	536.84	258.19	21.35	48.10	7.01	2.4
6	300	15.78	12.38	596.48	270.98	21.52	45.43	6.99	2.25
6	30	15.78	1.25	59.65	57.29	92.10	96.05	7.53	2.41
6	60	15.78	3.74	119.30	107.51	76.27	90.12	7.27	2.27
6	90	15.78	6.66	178.95	147.50	57.80	82.43	7.16	2.28
6	120	15.78	8.04	238.59	179.37	49.06	75.18	7.12	2.28
6	150	15.78	10.07	298.24	204.79	36.19	68.67	7.03	2.26
6	180	15.78	10.28	357.89	225.99	34.88	63.14	7.07	2.29
6	210	15.78	11.84	417.54	243.84	24.98	58.40	7.05	2.24
6	240	15.78	11.45	477.19	259.48	27.45	54.38	7.03	2.3
6	270	15.78	11.16	536.84	276.39	29.27	51.49	7.05	2.24
6	300	15.78	12.41	596.48	291.49	21.35	48.87	7.02	2.22
3	30	0.45	0.22	10.13	7.61	50.33	75.16	7.2	2.93
3	60	0.45	0.31	20.25	11.78	32.08	58.18	7.1	2.91
3	90	0.45	0.36	30.38	14.43	20.27	47.51	7	2.82
3	120	0.45	0.40	40.50	16.00	10.62	39.50	7	2.76
3	150	0.45	0.43	50.63	16.75	4.18	33.08	6.9	2.68
3	180	0.45	0.45	60.75	17.01	0.96	27.99	7	2.31
3	210	0.45	0.60	70.88	15.42	-32.31	21.75	7	2.66
3	240	0.45	0.46	81.00	13.72	-1.19	16.94	7.05	2.6
3	270	0.45	0.47	91.13	13.49	-3.34	14.81	6.93	2.43
3	300	0.45	0.47	101.25	13.15	-3.34	12.99	7.1	2.36
3	30	0.45	0.23	10.13	7.56	49.25	74.63	7.1	2.9
3	60	0.45	0.32	20.25	11.56	29.93	57.11	7.1	2.84
3	90	0.45	0.44	30.38	13.18	2.03	43.40	7.05	2.82
3	120	0.45	0.47	40.50	13.12	-3.34	32.39	7	2.59
3	150	0.45	0.48	50.63	12.56	-7.63	24.81	6.9	2.06
3	180	0.45	0.49	60.75	11.73	-8.70	19.32	7.04	1.67
3	210	0.45	0.49	70.88	10.85	-8.70	15.31	7.13	1.92
3	240	0.45	0.50	81.00	9.86	-10.85	12.18	7.3	1.83
3	270	0.45	0.50	91.13	8.71	-11.92	9.56	7.1	1.78
3	300	0.45	0.49	101.25	7.61	-9.78	7.52	7.45	1.66
3	30	1.11	0.63	24.98	17.90	43.31	71.66	7.2	2.38
3	60	1.11	0.82	49.95	26.59	26.34	53.24	7.3	2.29
3	90	1.11	0.95	74.93	31.71	14.60	42.32	7.2	2.24
3	120	1.11	1.17	99.90	32.80	-5.85	32.83	7.12	2.36
3	150	1.11	1.19	124.88	31.12	-7.59	24.92	7.05	2.21
3	180	1.11	1.15	149.85	29.71	-3.68	19.83	7.24	1.81
3	210	1.11	1.17	174.83	28.63	-4.98	16.38	7.17	2.01
3	240	1.11	1.17	199.80	27.39	-4.98	13.71	7.56	1.91
3	270	1.11	1.22	224.78	25.55	-9.77	11.36	7.15	1.5
3	300	1.11	1.21	249.75	23.16	-9.33	9.27	7.42	1.62

Table A.8: Continued

Retention Time	Collection Time	Inflow P Concentration	Outflow P concentration	Cumulative P Added	Cumulative P Sorbed	Discrete removal	Cumulative Removal	pH	EC
----- minutes -----		------ ppm ------		------ mg kg^{-1} ------		------ % ------			mS cm^{-1}
3	30	1.11	0.64	24.98	17.79	42.44	71.22	7.1	2.85
3	60	1.11	0.96	49.95	24.80	13.73	49.65	7.32	2.39
3	90	1.11	1.10	74.93	26.65	1.11	35.58	7.15	2.62
3	120	1.11	1.16	99.90	26.28	-4.11	26.31	7.26	2.55
3	150	1.11	1.19	124.88	24.82	-7.59	19.87	7.1	2.68
3	180	1.11	1.22	149.85	22.60	-10.20	15.08	7.17	2.64
3	210	1.11	1.25	174.83	19.78	-12.38	11.31	7.22	2.67
3	240	1.11	1.25	199.80	16.68	-12.38	8.35	7.55	2.51
3	270	1.11	1.22	224.78	13.92	-9.77	6.19	7.24	2.46
3	300	1.11	1.26	249.75	10.99	-13.68	4.40	7.48	2.34
3	30	4.91	1.53	36.83	31.07	68.75	84.38	7.59	2.27
3	60	4.91	3.24	73.65	50.00	34.07	67.89	7.73	2.28
3	90	4.91	3.84	110.48	60.29	21.79	54.57	7.65	2.26
3	120	4.91	4.55	147.30	65.65	7.34	44.57	7.32	2.09
3	150	4.91	4.78	184.13	67.49	2.64	36.65	7.32	2.09
3	180	4.91	4.74	220.95	68.63	3.55	31.06	7.23	1.71
3	210	4.91	4.77	257.78	69.80	2.82	27.08	7.1	2.14
3	240	4.91	4.71	294.60	71.07	4.09	24.13	7.1	2.27
3	270	4.91	5.05	331.43	71.32	-2.78	21.52	7.1	2.22
3	300	4.91	4.74	368.25	71.42	3.37	19.40	7.1	2.2
3	30	4.91	2.47	36.83	27.55	49.61	74.80	7.7	2.36
3	60	4.91	3.52	73.65	41.89	28.29	56.88	7.61	2.23
3	90	4.91	4.25	110.48	49.58	13.48	44.88	7.5	2.21
3	120	4.91	3.98	147.30	55.54	18.90	37.71	7.38	2.21
3	150	4.91	4.66	184.13	59.94	4.99	32.55	7.26	2.22
3	180	4.91	4.71	220.95	61.61	4.09	27.89	7.3	2.22
3	210	4.91	4.87	257.78	62.52	0.84	24.25	7.2	2.14
3	240	4.91	4.50	294.60	64.22	8.42	21.80	7.24	2.18
3	270	4.91	4.82	331.43	66.09	1.74	19.94	7.25	2.2
3	300	4.91	4.46	368.25	68.10	9.15	18.49	7.18	2.26
3	30	10.56	5.08	59.40	45.12	51.91	75.96	7.38	2.18
3	60	10.56	8.06	118.80	67.56	23.66	56.87	7.13	1.61
3	90	10.56	9.66	178.20	77.13	8.54	43.28	7.21	1.96
3	120	10.56	11.01	237.60	78.40	-4.27	33.00	7.1	2.07
3	150	10.56	10.33	297.00	77.76	2.14	26.18	6.99	2.08
3	180	10.56	10.51	356.40	78.55	0.49	22.04	7.05	1.9
3	210	10.56	11.03	415.80	77.38	-4.43	18.61	6.94	2.11
3	240	10.56	10.72	475.20	75.62	-1.48	15.91	6.9	2.01
3	270	10.56	10.96	534.60	74.06	-3.78	13.85	6.9	2.16
3	300	10.56	11.31	594.00	70.84	-7.06	11.93	6.96	2.1
3	30	10.56	4.89	59.40	45.66	53.72	76.86	7.42	2.22
3	60	10.56	8.50	118.80	67.42	19.55	56.75	7.18	2.14
3	90	10.56	9.95	178.20	74.93	5.75	42.05	7.2	2.19
3	120	10.56	10.44	237.60	76.98	1.16	32.40	7.1	2.04
3	150	10.56	10.63	297.00	77.13	-0.65	25.97	7.11	2.07
3	180	10.56	10.77	356.40	76.35	-1.97	21.42	7.08	2.08
3	210	10.56	11.32	415.80	73.62	-7.23	17.71	6.99	2.15
3	240	10.56	11.05	475.20	70.11	-4.60	14.75	6.98	2.11
3	270	10.56	10.79	534.60	68.11	-2.13	12.74	6.98	2.13
3	300	10.56	11.79	594.00	64.02	-11.66	10.78	6.98	2.17

Table A.8: Continued

Retention Time	Collection Time	Inflow P Concentration	Outflow P concentration	Cumulative P Added	Cumulative P Sorbed	Discrete removal	Cumulative Removal	pH	EC
----- minutes -----		------ ppm ------		------ mg kg^{-1} ------		------ % ------			mS cm^{-1}
3	30	15.78	7.07	71.01	55.10	55.19	77.60	7.34	2.1
3	60	15.78	13.81	142.02	79.13	12.48	55.72	7.04	1.99
3	90	15.78	15.06	213.03	85.19	4.57	39.99	7.03	2.14
3	120	15.78	16.62	284.04	84.92	-5.32	29.90	6.99	2.05
3	150	15.78	16.20	355.05	82.08	-2.69	23.12	6.97	1.77
3	180	15.78	16.67	426.06	79.11	-5.66	18.57	6.9	1.75
3	210	15.78	16.67	497.07	75.10	-5.66	15.11	6.9	1.95
3	240	15.78	17.22	568.08	69.85	-9.12	12.30	6.85	2.08
3	270	15.78	17.25	639.09	63.32	-9.29	9.91	6.85	2.13
3	300	15.78	17.14	710.10	56.96	-8.62	8.02	6.8	2.08
3	30	15.78	6.29	71.01	56.86	60.14	80.07	7.42	2.13
3	60	15.78	13.16	142.02	84.11	16.61	59.22	7	2.14
3	90	15.78	15.61	213.03	90.40	1.10	42.43	7.01	2.09
3	120	15.78	15.81	284.04	90.71	-0.21	31.94	7.03	1.11
3	150	15.78	16.41	355.05	89.22	-4.00	25.13	6.96	1.96
3	180	15.78	16.85	426.06	85.38	-6.81	20.04	6.93	1.12
3	210	15.78	16.59	497.07	81.13	-5.16	16.32	6.9	1.72
3	240	15.78	17.25	568.08	76.00	-9.29	13.38	6.86	1.47
3	270	15.78	17.19	639.09	69.53	-8.95	10.88	6.86	2.04
3	300	15.78	18.36	710.10	60.53	-16.38	8.52	6.86	2.09
0.5	30	0.45	0.03	12.15	11.81	94.39	97.19	8.58	2.79
0.5	60	0.45	0.15	24.30	21.59	66.63	88.85	8.28	3.61
0.5	90	0.45	0.33	36.45	27.30	27.31	74.89	8.17	3.76
0.5	120	0.45	0.39	48.60	29.77	13.43	61.26	7.95	3.62
0.5	150	0.45	0.41	60.75	31.16	9.38	51.29	7.73	3.59
0.5	180	0.45	0.44	72.90	31.88	2.44	43.73	7.7	3.46
0.5	210	0.45	0.45	85.05	32.07	0.71	37.71	7.67	3.42
0.5	240	0.45	0.48	97.20	31.73	-6.23	32.65	7.53	3.4
0.5	270	0.45	0.47	109.35	31.05	-5.07	28.39	7.56	3.37
0.5	300	0.45	0.45	121.50	30.68	-1.03	25.25	7.66	3.28
0.5	30	0.45	0.07	12.15	11.14	83.40	91.70	8.13	2.86
0.5	60	0.45	0.24	24.30	19.03	46.39	78.30	8	3.79
0.5	90	0.45	0.37	36.45	22.94	18.06	62.94	7.88	3.7
0.5	120	0.45	0.42	48.60	24.40	5.91	50.20	7.77	3.63
0.5	150	0.45	0.46	60.75	24.66	-1.60	40.59	7.45	3.46
0.5	180	0.45	0.47	72.90	24.29	-4.50	33.32	7.76	3.37
0.5	210	0.45	0.48	85.05	23.60	-6.81	27.75	7.51	3.36
0.5	240	0.45	0.48	97.20	22.78	-6.81	23.43	7.38	3.18
0.5	270	0.45	0.49	109.35	21.77	-9.70	19.91	7.38	3.26
0.5	300	0.45	0.50	121.50	20.56	-10.28	16.92	7.8	3.19
0.5	30	1.11	0.28	29.97	26.22	74.99	87.49	8.02	2.7
0.5	60	1.11	1.03	59.94	38.58	7.47	64.36	8.01	3.63
0.5	90	1.11	1.13	89.91	39.41	-1.91	43.83	7.88	3.65
0.5	120	1.11	1.17	119.88	38.35	-5.19	31.99	7.72	3.43
0.5	150	1.11	1.18	149.85	36.62	-6.36	24.43	7.56	3.52
0.5	180	1.11	1.20	179.82	34.50	-7.77	19.18	7.61	3.39
0.5	210	1.11	1.20	209.79	32.10	-8.24	15.30	7.5	3.29
0.5	240	1.11	1.22	239.76	29.38	-9.88	12.26	7.35	3.31
0.5	270	1.11	1.23	269.73	26.28	-10.82	9.74	7.4	3.22
0.5	300	1.11	1.24	299.70	22.87	-11.99	7.63	7.38	3.21

Table A.8: Continued

Retention Time	Collection Time	Inflow P Concentration	Outflow P concentration	Cumulative P Added	Cumulative P Sorbed	Discrete removal	Cumulative Removal	pH	EC
----- minutes -----		------ ppm ------		------ mg kg^{-1} ------		------ % ------			mS cm^{-1}
0.5	30	1.11	0.14	29.97	28.08	87.41	93.70	7.85	2.71
0.5	60	1.11	0.89	59.94	44.13	19.66	73.62	7.25	3.63
0.5	90	1.11	1.11	89.91	47.03	-0.27	52.31	7.75	3.6
0.5	120	1.11	1.14	119.88	46.64	-2.38	38.90	7.71	3.54
0.5	150	1.11	1.15	149.85	45.78	-3.31	30.55	7.47	3.6
0.5	180	1.11	1.21	179.82	43.91	-9.18	24.42	7.51	3.35
0.5	210	1.11	1.23	209.79	40.92	-10.82	19.50	7.37	3.41
0.5	240	1.11	1.21	239.76	37.92	-9.18	15.82	7.58	3.36
0.5	270	1.11	1.22	269.73	35.10	-9.64	13.01	7.37	3.37
0.5	300	1.11	1.22	299.70	32.10	-10.35	10.71	6.9	3.59

Table A.9: Results of Ca-WTR flow-through experiment.

Retention Time	Collection Time	Inflow P Concentration	Outflow P concentration	Cumulative P Added	Cumulative P Sorbed	Discrete removal	Cumulative Removal	pH	EC
----- minutes -----		------ ppm ------		------ mg kg^{-1} ------		------ % ------			mS cm^{-1}
10	60	0.19	0.15	2607	1582	21.32	60.66	7.3	
10	120	0.19	0.12	5215	2312	34.72	44.34	6.95	
10	180	0.19	0.14	7822	3106	26.19	39.71	7.15	
10	240	0.19	0.15	10429	3710	20.10	35.57	6.75	
10	300	0.19	0.16	13037	4170	15.23	31.99	6.65	
10	60	1.14	0.40	1554	1280	64.78	82.39	7.2	
10	120	1.14	0.50	3108	2219	55.98	71.39	7.4	
10	180	1.14	0.75	4662	2922	34.62	62.69	7.35	
10	240	1.14	0.69	6215	3496	39.28	56.25	7.4	
10	300	1.14	0.59	7769	4174	47.88	53.72	6.85	
10	60	1.16	0.42	1579	1290	63.45	81.73	7.1	
10	120	1.16	0.46	3158	2270	60.56	71.87	7.4	
10	180	1.16	0.58	4737	3140	49.71	66.29	7.3	
10	240	1.16	0.55	6316	3946	52.30	62.47	7.35	
10	300	1.16	0.53	7895	4787	54.29	60.63	6.85	
10	30	4.85	2.96	1320	917	38.87	69.43	6.45	
10	60	4.85	3.02	2641	1422	37.60	53.83	6.75	
10	90	4.85	3.33	3961	1876	31.24	47.36	6.9	
10	120	4.85	3.78	5281	2227	22.02	42.18	6.95	
10	150	4.85	3.95	6601	2495	18.52	37.80	7	
10	180	4.85	3.98	7922	2735	17.88	34.53	7	
10	210	4.85	4.03	9242	2964	16.77	32.07	7.05	
10	240	4.85	3.93	10562	3200	19.00	30.30	7	
10	270	4.85	3.97	11883	3445	18.04	28.99	7	
10	300	4.85	4.03	13203	3675	16.77	27.83	7	
10	30	4.90	2.70	1336	968	44.93	72.46	6.35	
10	60	4.90	2.54	2672	1590	48.23	59.52	6.7	
10	90	4.90	2.99	4008	2173	38.96	54.21	6.8	
10	120	4.90	3.35	5344	2645	31.73	49.50	6.9	
10	150	4.90	3.48	6680	3051	29.06	45.68	6.95	
10	180	4.90	3.83	8016	3391	21.84	42.31	6.95	
10	210	4.90	3.83	9352	3683	21.84	39.38	6.95	
10	240	4.90	3.64	10688	4001	25.76	37.43	6.95	
10	270	4.90	3.73	12024	4333	23.88	36.03	6.9	
10	300	4.90	3.96	13360	4621	19.32	34.59	6.9	
10	30	9.09	3.96	1032	807	56.45	78.22	6.35	
10	60	9.09	3.27	2063	1428	63.99	69.22	6.5	
10	90	9.09	3.83	3095	2057	57.82	66.45	6.6	
10	120	9.09	4.19	4127	2633	53.88	63.80	6.6	
10	150	9.09	4.60	5158	3166	49.42	61.37	6.75	
10	180	9.09	4.87	6190	3660	46.43	59.13	6.7	
10	210	9.09	4.99	7222	4132	45.14	57.22	6.7	
10	240	9.09	5.10	8253	4592	43.86	55.63	6.65	
10	270	9.09	5.53	9285	5020	39.15	54.06	6.6	
10	300	9.09	5.95	10317	5400	34.52	52.34	6.6	
10	30	9.91	3.62	1124	919	63.50	81.75	6.35	
10	60	9.91	2.71	2249	1685	72.69	74.92	6.5	

Table A.9: Continued

Retention Time	Collection Time	Inflow P Concentration	Outflow P concentration	Cumulative P Added	Cumulative P Sorbed	Discrete removal	Cumulative Removal	pH	EC
----- minutes -----		------ ppm ------		------ mg kg^{-1} ------		------ % ------			mS cm^{-1}
10	90	9.91	3.24	3373	2472	67.27	73.28	6.6	
10	120	9.91	3.58	4498	3209	63.81	71.34	6.65	
10	150	9.91	3.76	5622	3917	62.09	69.66	6.75	
10	180	9.91	3.94	6747	4605	60.28	68.25	6.7	
10	210	9.91	4.01	7871	5279	59.57	67.06	6.7	
10	240	9.91	4.18	8996	5939	57.84	66.02	6.65	
10	270	9.91	4.31	10120	6582	56.51	65.03	6.65	
10	300	9.91	4.59	11245	7201	53.68	64.04	6.65	
10	30	15.15	9.28	1376	955	38.77	69.38	6.4	
10	60	15.15	9.07	2752	1498	40.16	54.42	6.4	
10	90	15.15	10.87	4128	1968	28.29	47.69	6.4	
10	120	15.15	11.73	5503	2318	22.58	42.13	6.5	
10	150	15.15	12.58	6879	2590	16.96	37.65	6.55	
10	180	15.15	12.99	8255	2805	14.26	33.98	6.6	
10	210	15.15	13.34	9631	2985	11.95	31.00	6.6	
10	240	15.15	13.23	11007	3155	12.72	28.66	6.6	
10	270	15.15	13.81	12383	3304	8.86	26.68	6.6	
10	300	15.15	13.46	13759	3441	11.18	25.01	6.55	
10	30	15.27	9.28	1386	965	39.24	69.62	6.3	
10	60	15.27	8.60	2773	1540	43.67	55.54	6.4	
10	90	15.27	10.59	4159	2055	30.67	49.42	6.4	
10	120	15.27	11.54	5546	2437	24.40	43.95	6.6	
10	150	15.27	11.38	6932	2783	25.47	40.14	6.55	
10	180	15.27	11.71	8319	3121	23.33	37.52	6.6	
10	210	15.27	12.34	9705	3416	19.20	35.20	6.6	
10	240	15.27	13.75	11092	3618	9.94	32.62	6.65	
10	270	15.27	13.75	12478	3756	9.94	30.10	6.6	
10	300	15.27	13.52	13865	3904	11.47	28.16	6.55	
8	42.5	0.49	0.30	580	404	39.22	69.61	6.5	
8	85	0.49	0.32	1160	618	34.67	53.28	6.4	
8	127.5	0.49	0.38	1741	785	22.96	45.12	6.6	
8	170	0.49	0.37	2321	924	24.87	39.82	6.5	
8	212.5	0.49	0.36	2901	1070	25.35	36.88	6.55	
8	255	0.49	0.36	3481	1219	26.06	35.02	6.55	
8	297.5	0.49	0.37	4062	1367	24.87	33.65	6.6	
8	42.5	0.98	0.36	1549	1264	63.13	81.57	6.55	
8	85	0.98	0.35	3098	2246	63.73	72.50	6.65	
8	127.5	0.98	0.55	4648	3075	43.28	66.17	6.8	
8	170	0.98	0.59	6197	3720	39.95	60.03	6.9	
8	212.5	0.98	0.54	7746	4375	44.70	56.49	7.35	
8	255	0.98	0.52	9295	5085	46.84	54.70	7.2	
8	297.5	0.98	0.50	10844	5825	48.75	53.71	7.55	
8	42.5	0.99	0.39	1568	1258	60.51	80.25	6.5	
8	85	0.99	0.34	3135	2250	66.03	71.76	6.7	
8	127.5	0.99	0.55	4703	3116	44.41	66.25	6.8	
8	170	0.99	0.67	6271	3717	32.31	59.28	6.9	
8	212.5	0.99	0.69	7838	4203	29.73	53.63	7.35	
8	255	0.99	0.53	9406	4798	46.18	51.01	7.2	
8	297.5	0.99	0.48	10973	5560	50.99	50.67	7.55	

Table A.9: Continued

Retention Time	Collection Time	Inflow P Concentration	Outflow P concentration	Cumulative P Added	Cumulative P Sorbed	Discrete removal	Cumulative Removal	pH	EC
----- minutes -----		------ ppm ------		------ mg kg^{-1} ------		------ % ------			mS cm^{-1}
8	30	4.85	2.99	1628	1125	38.21	69.10	6.9	
8	60	4.85	3.44	3257	1672	28.99	51.35	7	
8	90	4.85	3.62	4885	2115	25.34	43.29	6.9	
8	120	4.85	3.80	6513	2498	21.69	38.35	7.15	
8	150	4.85	3.87	8141	2838	20.10	34.86	7.3	
8	180	4.85	4.03	9770	3138	16.76	32.12	7.25	
8	210	4.85	3.93	11398	3429	18.98	30.08	7.3	
8	240	4.85	3.95	13026	3734	18.51	28.67	7.3	
8	270	4.85	4.03	14655	4021	16.76	27.44	7.25	
8	300	4.85	4.00	16283	4299	17.40	26.40	7.1	
8	30	4.79	3.00	1609	1105	37.30	68.65	6.8	
8	60	4.79	3.33	3218	1649	30.39	51.25	6.95	
8	90	4.79	3.67	4827	2081	23.31	43.12	6.85	
8	120	4.79	3.80	6436	2435	20.74	37.84	7.1	
8	150	4.79	3.85	8044	2760	19.62	34.31	7.2	
8	180	4.79	3.96	9653	3056	17.20	31.66	7.15	
8	210	4.79	4.10	11262	3310	14.31	29.39	7.15	
8	240	4.79	4.19	12871	3525	12.46	27.39	7.15	
8	270	4.79	4.15	14480	3732	13.26	25.77	7.1	
8	300	4.79	4.09	16089	3957	14.63	24.59	7	
8	30	9.92	4.75	1516	1153	52.17	76.08	6.4	
8	60	9.92	5.77	3032	1866	41.84	61.55	6.65	
8	90	9.92	6.91	4547	2413	30.35	53.06	6.75	
8	120	9.92	7.19	6063	2852	27.56	47.04	6.85	
8	150	9.92	7.14	7579	3273	28.03	43.19	6.9	
8	180	9.92	7.39	9095	3679	25.54	40.45	6.95	
8	210	9.92	8.05	10611	4016	18.86	37.85	6.9	
8	240	9.92	8.02	12126	4304	19.18	35.49	6.9	
8	270	9.92	8.35	13642	4570	15.91	33.50	6.85	
8	300	9.92	8.35	15158	4811	15.91	31.74	6.9	
8	30	9.96	5.51	1522	1101	44.70	72.35	6.4	
8	60	9.96	5.71	3043	1766	42.69	58.02	6.65	
8	90	9.96	6.63	4565	2345	33.41	51.36	6.65	
8	120	9.96	7.47	6087	2790	25.06	45.83	6.85	
8	150	9.96	7.51	7608	3167	24.59	41.63	6.9	
8	180	9.96	8.13	9130	3494	18.41	38.27	6.9	
8	210	9.96	8.23	10652	3767	17.40	35.36	6.9	
8	240	9.96	7.81	12174	4064	21.65	33.38	6.85	
8	270	9.96	8.01	13695	4378	19.64	31.97	6.85	
8	300	9.96	8.46	15217	4642	15.08	30.51	6.9	
8	30	14.28	8.95	1411	969	37.30	68.65	6.35	
8	60	14.28	10.05	2822	1441	29.61	51.05	6.5	
8	90	14.28	10.66	4233	1828	25.36	43.20	6.6	
8	120	14.28	12.01	5644	2119	15.87	37.55	6.6	
8	150	14.28	12.47	7054	2321	12.68	32.90	6.7	
8	180	14.28	12.93	8465	2477	9.41	29.25	6.7	
8	210	14.28	13.58	9876	2577	4.91	26.10	6.65	
8	240	14.28	13.81	11287	2635	3.27	23.35	6.6	
8	270	14.28	13.98	12698	2673	2.05	21.05	6.65	
8	300	14.28	14.16	14109	2693	0.82	19.09	6.6	

Table A.9: Continued

Retention Time	Collection Time	Inflow P Concentration	Outflow P concentration	Cumulative P Added	Cumulative P Sorbed	Discrete removal	Cumulative Removal	pH	EC
----- minutes -----		------ ppm ------		------ mg kg^{-1} ------		------ % ------			mS cm^{-1}
8	30	14.45	8.74	1428	996	39.52	69.76	6.4	
8	60	14.45	10.14	2856	1491	29.82	52.21	6.55	
8	90	14.45	11.40	4285	1855	21.09	43.29	6.6	
8	120	14.45	12.22	5713	2116	15.44	37.04	6.6	
8	150	14.45	12.38	7141	2328	14.30	32.60	6.75	
8	180	14.45	13.11	8569	2497	9.29	29.14	6.7	
8	210	14.45	13.34	9997	2618	7.68	26.19	6.65	
8	240	14.45	13.63	11426	2713	5.66	23.75	6.6	
8	270	14.45	13.75	12854	2788	4.85	21.69	6.6	
8	300	14.45	13.58	14282	2866	6.06	20.07	6.6	
6	30	0.49	0.19	160	130	62.15	81.07	7.35	
6	60	0.49	0.23	320	222	53.88	69.54	7.2	
6	90	0.49	0.29	480	299	41.83	62.31	6.9	
6	120	0.49	0.44	639	341	10.40	53.26	7.2	
6	150	0.49	0.31	799	379	37.57	47.41	7.05	
6	180	0.49	0.31	959	439	37.81	45.79	7.3	
6	210	0.49	0.36	1119	491	26.70	43.85	7.25	
6	240	0.49	0.39	1279	529	21.03	41.36	7.1	
6	270	0.49	0.35	1439	569	28.59	39.52	6.75	
6	300	0.49	0.33	1599	617	32.37	38.61	6.95	
6	30	0.49	0.26	158	117	47.71	73.86	7.3	
6	60	0.49	0.21	317	199	56.30	62.93	7.2	
6	90	0.49	0.26	475	282	47.71	59.29	7	
6	120	0.49	0.30	633	350	39.12	55.32	7.2	
6	150	0.49	0.32	792	408	33.64	51.53	7.05	
6	180	0.49	0.32	950	463	35.54	48.71	7.25	
6	210	0.49	0.33	1108	517	32.92	46.64	7.25	
6	240	0.49	0.33	1267	568	31.73	44.85	7.15	
6	270	0.49	0.33	1425	618	31.73	43.39	6.8	
6	300	0.49	0.32	1584	670	33.88	42.33	6.9	
6	30	1.17	0.64	379	275	45.09	72.54	6.35	0.913
6	60	1.17	0.75	759	430	36.31	56.62	6.35	0.92
6	90	1.17	0.84	1138	552	28.33	48.52	6.35	0.9
6	120	1.17	0.87	1517	655	25.94	43.18	6.45	0.89
6	150	1.17	0.90	1897	749	23.34	39.47	6.45	0.83
6	180	1.17	0.93	2276	833	20.95	36.58	6.5	0.865
6	210	1.17	0.93	2655	911	20.15	34.29	6.5	0.875
6	240	1.17	0.94	3035	986	19.55	32.49	6.55	0.815
6	270	1.17	0.95	3414	1058	18.55	30.99	6.55	0.85
6	300	1.17	0.94	3793	1131	19.95	29.82	6.45	0.9
6	30	1.17	0.61	379	280	47.48	73.74	6.35	0.93
6	60	1.17	0.46	759	485	60.75	63.93	6.35	0.9
6	90	1.17	0.63	1138	687	45.89	60.39	6.35	0.915
6	120	1.17	0.73	1517	846	37.91	55.77	6.4	0.909
6	150	1.17	0.80	1897	978	31.62	51.57	6.45	0.868
6	180	1.17	0.80	2276	1098	31.82	48.26	6.55	0.72
6	210	1.17	0.81	2655	1217	30.53	45.82	6.45	0.75
6	240	1.17	0.81	3035	1334	31.12	43.95	6.5	0.863
6	270	1.17	0.80	3414	1452	31.52	42.54	6.55	0.888
6	300	1.17	0.81	3793	1571	30.92	41.41	6.5	0.86

Table A.9: Continued

Retention Time	Collection Time	Inflow P Concentration	Outflow P concentration	Cumulative P Added	Cumulative P Sorbed	Discrete removal	Cumulative Removal	pH	EC
----- minutes -----		------ ppm ------		------ mg kg^{-1} ------		------ % ------			mS cm^{-1}
6	30	4.75	0.98	1436	1288	79.28	89.64	6.95	
6	60	4.75	1.19	2873	2396	75.03	83.40	6.8	
6	90	4.75	1.63	4309	3407	65.78	79.07	6.8	
6	120	4.75	1.85	5746	4319	61.12	75.16	6.85	
6	150	4.75	1.91	7182	5187	59.73	72.22	6.8	
6	180	4.75	2.00	8618	6032	57.93	69.99	6.8	
6	210	4.75	2.04	10055	6858	57.11	68.20	6.8	
6	240	4.75	2.13	11491	7664	55.15	66.69	6.75	
6	270	4.75	2.12	12928	8457	55.31	65.42	6.7	
6	300	4.75	2.18	14364	9242	54.00	64.34	6.7	
6	30	4.98	1.09	1507	1342	78.15	89.07	6.8	
6	60	4.98	1.24	3014	2497	75.11	82.85	6.75	
6	90	4.98	1.67	4521	3564	66.53	78.84	6.75	
6	120	4.98	1.93	6028	4527	61.30	75.11	6.75	
6	150	4.98	2.16	7535	5416	56.70	71.89	6.7	
6	180	4.98	2.34	9042	6243	52.96	69.04	6.75	
6	210	4.98	2.42	10548	7029	51.47	66.64	6.7	
6	240	4.98	2.41	12055	7806	51.63	64.75	6.7	
6	270	4.98	2.43	13562	8581	51.24	63.27	6.7	
6	300	4.98	2.44	15069	9352	51.01	62.06	6.65	
6	30	8.27	3.80	1442	1111	54.01	77.00	6.7	1.4
6	60	8.27	4.55	2885	1825	44.98	63.25	6.9	1.2
6	90	8.27	5.00	4327	2434	39.48	56.24	6.8	1.3
6	120	8.27	5.32	5770	2976	35.66	51.57	7.1	1.16
6	150	8.27	5.53	7212	3472	33.15	48.14	7.1	1.25
6	180	8.27	5.79	8655	3927	29.98	45.38	7.1	1.48
6	210	8.27	5.97	10097	4344	27.75	43.02	7.1	1.43
6	240	8.27	6.08	11539	4735	26.45	41.03	7.1	1.5
6	270	8.27	5.93	12982	5130	28.31	39.51	7.1	1.45
6	300	8.27	5.80	14424	5549	29.80	38.47	7.1	1.12
6	30	7.59	4.10	1324	967	46.05	73.02	6.65	1.16
6	60	7.59	4.86	2648	1510	36.01	57.03	6.85	1.337
6	90	7.59	5.42	3973	1938	28.60	48.79	6.8	1.25
6	120	7.59	5.77	5297	2286	23.94	43.16	7.05	1.5
6	150	7.59	6.20	6621	2565	18.26	38.75	7	1.6
6	180	7.59	6.45	7945	2786	15.01	35.06	7	1.2
6	210	7.59	6.68	9270	2964	11.97	31.98	7.05	1.61
6	240	7.59	6.76	10594	3116	10.95	29.41	7.05	1.25
6	270	7.59	6.82	11918	3256	10.14	27.32	7.05	1.36
6	300	7.59	6.73	13242	3398	11.36	25.66	7	1.13
6	30	13.91	6.66	1261	959	52.11	76.06	6.45	0.828
6	60	13.91	8.57	2523	1530	38.40	60.66	6.65	0.775
6	90	13.91	10.00	3784	1950	28.09	51.52	6.7	0.785
6	120	13.91	10.81	5046	2267	22.28	44.94	6.8	0.785
6	150	13.91	11.76	6307	2505	15.46	39.72	6.85	0.77
6	180	13.91	11.36	7569	2718	18.29	35.91	6.85	0.735
6	210	13.91	12.46	8830	2899	10.39	32.83	6.85	0.73
6	240	13.91	12.22	10092	3041	12.14	30.14	6.9	0.735
6	270	13.91	12.34	11353	3189	11.22	28.09	6.8	0.71
6	300	13.91	12.98	12615	3301	6.65	26.17	6.85	0.685

Table A.9: Continued

Retention Time	Collection Time	Inflow P Concentration	Outflow P concentration	Cumulative P Added	Cumulative P Sorbed	Discrete removal	Cumulative Removal	pH	EC
----- minutes -----		------ ppm ------		------ mg kg^{-1} ------		------ % ------			$mS\ cm^{-1}$
6	30	15.00	6.25	1361	1077	58.32	79.16	6.45	0.82
6	60	15.00	8.20	2722	1783	45.37	65.50	6.65	0.795
6	90	15.00	9.65	4083	2335	35.67	57.17	6.75	0.785
6	120	15.00	10.41	5444	2785	30.58	51.16	6.8	0.8
6	150	15.00	11.80	6805	3139	21.34	46.12	6.85	0.735
6	180	15.00	12.46	8166	3399	16.95	41.63	6.9	0.71
6	210	15.00	12.75	9527	3617	15.02	37.96	6.85	0.72
6	240	15.00	13.04	10889	3808	13.10	34.97	6.85	0.735
6	270	15.00	13.33	12250	3973	11.17	32.44	6.85	0.72
6	300	15.00	13.15	13611	4133	12.33	30.37	6.85	0.7
3	30	0.57	0.22	212	171	61.34	80.67	6.15	
3	60	0.57	0.22	424	301	60.93	70.90	6.5	
3	90	0.57	0.24	636	425	56.84	66.89	6.6	
3	120	0.57	0.26	848	543	54.38	64.07	6.65	
3	150	0.57	0.28	1060	655	50.70	61.77	6.75	
3	180	0.57	0.29	1272	759	47.84	59.68	6.8	
3	210	0.57	0.31	1484	859	46.00	57.86	6.8	
3	240	0.57	0.32	1696	954	44.16	56.26	6.8	
3	270	0.57	0.33	1908	1046	42.32	54.82	6.75	
3	300	0.57	0.32	2120	1136	42.53	53.58	6.75	
3	30	0.54	0.22	204	162	59.13	79.57	6.25	
3	60	0.54	0.21	408	285	61.05	69.83	6.55	
3	90	0.54	0.23	611	405	57.43	66.30	6.6	
3	120	0.54	0.25	815	519	54.03	63.66	6.75	
3	150	0.54	0.26	1019	627	52.33	61.56	6.8	
3	180	0.54	0.26	1223	733	51.26	59.93	6.85	
3	210	0.54	0.28	1426	835	49.14	58.54	6.85	
3	240	0.54	0.28	1630	935	48.92	57.35	6.9	
3	270	0.54	0.28	1834	1035	49.14	56.43	6.8	
3	300	0.54	0.29	2038	1133	47.22	55.60	6.85	
3	30	0.99	0.21	494	441	78.60	89.30	6.55	
3	60	0.99	0.33	988	800	66.74	80.99	6.55	
3	90	0.99	0.38	1482	1117	61.57	75.37	6.7	
3	120	0.99	0.36	1976	1426	63.45	72.16	6.65	
3	150	0.99	0.37	2470	1738	62.86	70.36	6.8	
3	180	0.99	0.38	2964	2046	62.04	69.04	6.9	
3	210	0.99	0.38	3458	2351	61.45	68.00	7.1	
3	240	0.99	0.40	3952	2651	59.69	67.07	7.1	
3	270	0.99	0.40	4446	2945	59.33	66.23	7.15	
3	300	0.99	0.41	4940	3236	58.63	65.50	7.2	
3	30	1.01	0.23	504	447	77.21	88.60	6.55	
3	60	1.01	0.32	1009	815	68.69	80.78	6.6	
3	90	1.01	0.35	1513	1154	65.58	76.23	6.7	
3	120	1.01	0.36	2018	1482	64.43	73.43	6.65	
3	150	1.01	0.39	2522	1798	61.10	71.29	6.8	
3	180	1.01	0.38	3027	2109	62.02	69.67	6.9	
3	210	1.01	0.40	3531	2417	60.06	68.44	7.1	
3	240	1.01	0.41	4036	2718	59.60	67.36	7.1	
3	270	1.01	0.42	4540	3015	58.11	66.42	7.15	
3	300	1.01	0.43	5044	3307	57.53	65.56	7.2	

Table A.9: Continued

Retention Time	Collection Time	Inflow P Concentration	Outflow P concentration	Cumulative P Added	Cumulative P Sorbed	Discrete removal	Cumulative Removal	pH	EC
----- minutes -----		------ ppm ------		------ mg kg^{-1} ------		------ % ------			mS cm^{-1}
3	30	4.93	1.62	740	619	67.14	83.57	6.35	
3	60	4.93	2.28	1480	1066	53.81	72.02	6.4	
3	90	4.93	3.20	2220	1395	35.11	62.84	6.35	
3	120	4.93	3.81	2960	1609	22.80	54.37	6.45	
3	150	4.93	4.07	3701	1759	17.59	47.53	6.45	
3	180	4.93	4.35	4441	1868	11.83	42.06	6.55	
3	210	4.93	4.37	5181	1954	11.44	37.72	6.5	
3	240	4.93	4.47	5921	2031	9.47	34.31	6.55	
3	270	4.93	4.58	6661	2093	7.10	31.42	6.5	
3	300	4.93	4.49	7401	2153	9.07	29.08	6.5	
3	30	4.93	1.86	740	601	62.33	81.17	6.35	
3	60	4.93	2.56	1480	1009	48.05	68.18	6.4	
3	90	4.93	3.52	2220	1293	28.64	58.23	6.4	
3	120	4.93	3.94	2960	1473	20.12	49.77	6.45	
3	150	4.93	4.21	3701	1602	14.60	43.29	6.5	
3	180	4.93	4.39	4441	1697	11.05	38.21	6.55	
3	210	4.93	4.47	5181	1773	9.47	34.22	6.5	
3	240	4.93	4.58	5921	1834	7.10	30.98	6.55	
3	270	4.93	4.62	6661	1884	6.31	28.28	6.55	
3	300	4.93	4.70	7401	1925	4.73	26.00	6.5	
3	30	9.93	1.70	1117	1021	82.84	91.42	6.65	
3	60	9.93	3.22	2234	1861	67.57	83.31	6.7	
3	90	9.93	5.02	3351	2514	49.41	75.04	6.65	
3	120	9.93	6.06	4467	3007	38.91	67.32	6.7	
3	150	9.93	6.62	5584	3410	33.28	61.07	6.65	
3	180	9.93	7.25	6701	3747	27.01	55.92	6.65	
3	210	9.93	7.45	7818	4037	24.98	51.64	6.65	
3	240	9.93	7.73	8935	4301	22.16	48.13	6.65	
3	270	9.93	7.84	10052	4542	21.06	45.19	6.65	
3	300	9.93	8.07	11169	4764	18.71	42.66	6.65	
3	30	9.58	2.29	1078	949	76.12	88.06	6.6	
3	60	9.58	3.64	2155	1693	62.00	78.56	6.7	
3	90	9.58	5.54	3233	2254	42.20	69.74	6.6	
3	120	9.58	6.55	4310	2652	31.65	61.54	6.7	
3	150	9.58	7.14	5388	2960	25.48	54.94	6.65	
3	180	9.58	7.37	6465	3222	23.05	49.83	6.7	
3	210	9.58	7.91	7543	3439	17.37	45.60	6.7	
3	240	9.58	8.02	8620	3620	16.23	42.00	6.65	
3	270	9.58	7.87	9698	3804	17.85	39.23	6.65	
3	300	9.58	8.23	10775	3976	14.12	36.90	6.6	
3	30	14.08	5.16	1267	1035	63.34	81.67	6.65	
3	60	14.08	7.77	2534	1720	44.79	67.87	6.8	
3	90	14.08	10.07	3801	2184	28.47	57.45	6.8	
3	120	14.08	12.01	5068	2457	14.69	48.49	7	
3	150	14.08	12.58	6334	2618	10.67	41.32	7	
3	180	14.08	13.38	7601	2716	4.92	35.74	6.95	
3	210	14.08	13.50	8868	2773	4.10	31.27	7	
3	240	14.08	13.15	10135	2841	6.56	28.03	6.95	
3	270	14.08	12.75	11402	2942	9.43	25.81	6.95	
3	300	14.08	12.92	12669	3054	8.20	24.11	6.9	

Table A.9: Continued

Retention Time	Collection Time	Inflow P Concentration	Outflow P concentration	Cumulative P Added	Cumulative P Sorbed	Discrete removal	Cumulative Removal	pH	EC
----- minutes -----		------ ppm ------		------ mg kg^{-1} ------		------ % ------			mS cm^{-1}
3	30	15.29	4.90	1376	1156	67.98	83.99	6.65	
3	60	15.29	7.49	2752	1974	50.99	71.74	6.85	
3	90	15.29	10.92	4128	2521	28.55	61.08	6.8	
3	120	15.29	11.92	5504	2870	22.06	52.14	7	
3	150	15.29	12.98	6880	3125	15.11	45.43	6.95	
3	180	15.29	11.85	8256	3384	22.51	40.99	7	
3	210	15.29	13.96	9632	3599	8.69	37.36	6.9	
3	240	15.29	13.79	11008	3726	9.82	33.85	6.95	
3	270	15.29	13.27	12384	3885	13.22	31.37	6.95	
3	300	15.29	13.33	13760	4064	12.84	29.53	6.9	
0.5	30	0.51	0.10	979	879	79.74	89.87	7.5	
0.5	60	0.51	0.11	1957	1653	78.36	84.46	7.4	
0.5	90	0.51	0.12	2936	2413	76.98	82.19	6.9	
0.5	120	0.51	0.12	3914	3162	76.06	80.78	7.15	
0.5	150	0.51	0.12	4893	3904	75.60	79.79	7.35	
0.5	180	0.51	0.13	5871	4636	73.99	78.95	7.5	
0.5	210	0.51	0.14	6850	5354	72.84	78.16	7.25	
0.5	240	0.51	0.14	7829	6065	72.38	77.47	7.25	
0.5	270	0.51	0.15	8807	6760	69.63	76.75	7.1	
0.5	300	0.51	0.16	9786	7436	68.71	75.99	6.9	
0.5	30	0.49	0.12	945	832	76.16	88.08	7.55	
0.5	60	0.49	0.11	1890	1557	77.35	82.41	7.45	
0.5	90	0.49	0.12	2835	2281	75.92	80.49	7.05	
0.5	120	0.49	0.12	3779	2998	75.68	79.32	7.35	
0.5	150	0.49	0.13	4724	3704	73.78	78.40	7.55	
0.5	180	0.49	0.13	5669	4401	73.78	77.63	7.25	
0.5	210	0.49	0.13	6614	5094	73.06	77.03	7.45	
0.5	240	0.49	0.13	7559	5783	72.59	76.50	7.1	
0.5	270	0.49	0.14	8504	6462	71.16	75.99	7.2	
0.5	300	0.49	0.16	9448	7120	68.30	75.36	7.1	
0.5	30	1.15	0.11	1546	1475	90.82	95.41	6.9	
0.5	60	1.15	0.12	3092	2867	89.29	92.73	6.8	
0.5	90	1.15	0.13	4638	4241	88.48	91.45	6.75	
0.5	120	1.15	0.14	6184	5607	88.17	90.67	6.8	
0.5	150	1.15	0.14	7730	6964	87.46	90.10	6.7	
0.5	180	1.15	0.15	9276	8313	86.95	89.61	6.75	
0.5	210	1.15	0.16	10822	9651	86.13	89.18	6.7	
0.5	240	1.15	0.17	12368	10974	85.12	88.73	6.7	
0.5	270	1.15	0.18	13914	12282	84.10	88.27	6.7	
0.5	300	1.15	0.20	15460	13569	82.37	87.77	6.65	
0.5	30	0.98	0.09	1329	1271	91.33	95.67	7	
0.5	60	0.98	0.10	2658	2473	89.55	93.05	6.95	
0.5	90	0.98	0.10	3986	3662	89.44	91.87	6.9	
0.5	120	0.98	0.11	5315	4846	88.72	91.17	7	
0.5	150	0.98	0.12	6644	6020	88.01	90.61	6.95	
0.5	180	0.98	0.12	7973	7186	87.42	90.13	6.95	
0.5	210	0.98	0.12	9301	8346	87.30	89.73	6.9	
0.5	240	0.98	0.14	10630	9498	86.00	89.35	6.85	
0.5	270	0.98	0.15	11959	10634	85.05	88.92	6.85	
0.5	300	0.98	0.16	13288	11755	83.63	88.46	6.8	

Table A.9: Continued

Retention Time	Collection Time	Inflow P Concentration	Outflow P concentration	Cumulative P Added	Cumulative P Sorbed	Discrete removal	Cumulative Removal	pH	EC
----- minutes -----		------ ppm ------		------ mg kg^{-1} ------		------ % ------			mS cm^{-1}
0.5	30	4.88	2.18	1097	852	55.25	77.63	6.3	
0.5	60	4.88	3.18	2194	1346	34.81	61.33	6.5	
0.5	90	4.88	3.57	3291	1684	26.83	51.16	6.6	
0.5	120	4.88	4.06	4388	1923	16.77	43.82	6.6	
0.5	150	4.88	4.23	5485	2087	13.17	38.05	6.7	
0.5	180	4.88	4.37	6582	2216	10.38	33.67	6.7	
0.5	210	4.88	4.39	7679	2328	9.98	30.31	6.65	
0.5	240	4.88	4.54	8776	2420	6.79	27.57	6.65	
0.5	270	4.88	4.62	9873	2486	5.19	25.18	6.6	
0.5	300	4.88	4.58	10970	2547	5.99	23.22	6.6	
0.5	30	5.09	2.26	1145	891	55.60	77.80	6.35	
0.5	60	5.09	3.13	2290	1430	38.47	62.42	6.5	
0.5	90	5.09	3.71	3436	1805	27.15	52.55	6.6	
0.5	120	5.09	4.11	4581	2071	19.20	45.21	6.6	
0.5	150	5.09	4.29	5726	2271	15.68	39.65	6.7	
0.5	180	5.09	4.45	6871	2433	12.62	35.40	6.7	
0.5	210	5.09	4.35	8017	2588	14.53	32.28	6.65	
0.5	240	5.09	4.58	9162	2728	9.94	29.78	6.65	
0.5	270	5.09	4.70	10307	2829	7.65	27.45	6.6	
0.5	300	5.09	4.64	11452	2923	8.80	25.52	6.6	
0.5	30	9.52	0.71	1028	989	92.52	96.26	6.45	
0.5	60	9.52	2.64	2056	1836	72.23	89.32	6.4	
0.5	90	9.52	4.22	3084	2494	55.71	80.87	6.4	
0.5	120	9.52	5.12	4112	3018	46.22	73.39	6.5	
0.5	150	9.52	5.75	5140	3459	39.59	67.30	6.55	
0.5	180	9.52	6.20	6168	3841	34.85	62.28	6.6	
0.5	210	9.52	6.48	7196	4184	31.90	58.15	6.6	
0.5	240	9.52	6.70	8223	4501	29.61	54.73	6.6	
0.5	270	9.52	6.98	9251	4790	26.67	51.77	6.6	
0.5	300	9.52	6.68	10279	5080	29.78	49.42	6.65	
0.5	30	9.56	1.07	1032	974	88.80	94.40	6.5	
0.5	60	9.56	3.36	2064	1767	64.85	85.61	6.45	
0.5	90	9.56	5.10	3096	2343	46.68	75.66	6.45	
0.5	120	9.56	5.97	4129	2778	37.56	67.28	6.55	
0.5	150	9.56	6.59	5161	3132	31.04	60.68	6.6	
0.5	180	9.56	6.96	6193	3432	27.13	55.42	6.65	
0.5	210	9.56	7.43	7225	3687	22.24	51.03	6.65	
0.5	240	9.56	7.62	8257	3906	20.29	47.31	6.65	
0.5	270	9.56	7.71	9289	4110	19.31	44.25	6.6	
0.5	300	9.56	7.03	10321	4347	26.48	42.11	6.6	
0.5	30	14.15	3.51	764	669	75.16	87.58	6.7	
0.5	60	14.15	5.92	1529	1179	58.14	77.12	7.1	
0.5	90	14.15	7.36	2293	1584	48.02	69.11	7.4	
0.5	120	14.15	8.44	3057	1922	40.39	62.88	7.5	
0.5	150	14.15	9.14	3821	2212	35.41	57.89	7.5	
0.5	180	14.15	10.05	4586	2458	28.99	53.60	7.15	
0.5	210	14.15	10.82	5350	2659	23.53	49.70	7.3	
0.5	240	14.15	11.10	6114	2831	21.60	46.31	7.4	
0.5	270	14.15	11.32	6878	2990	20.00	43.47	7.3	
0.5	300	14.15	11.66	7643	3134	17.59	41.00	7.2	

Table A.9: Continued

Retention Time	Collection Time	Inflow P Concentration	Outflow P concentration	Cumulative P Added	Cumulative P Sorbed	Discrete removal	Cumulative Removal	pH	EC
----- minutes -----		------ ppm ------		------ mg kg^{-1} ------		------ % ------			mS cm^{-1}
0.5	30	14.15	3.50	764	670	75.25	87.62	6.7	
0.5	60	14.15	5.38	1529	1194	61.99	78.12	7.05	
0.5	90	14.15	6.95	2293	1626	50.91	70.90	7.35	
0.5	120	14.15	8.19	3057	1981	42.16	64.81	7.4	
0.5	150	14.15	8.94	3821	2283	36.86	59.75	7.4	
0.5	180	14.15	10.19	4586	2531	28.03	55.20	7.1	
0.5	210	14.15	10.64	5350	2733	24.81	51.09	7.2	
0.5	240	14.15	11.19	6114	2908	20.96	47.56	7.35	
0.5	270	14.15	11.39	6878	3063	19.51	44.53	7.25	
0.5	300	14.15	11.60	7643	3206	18.07	41.95	7.15	

Table A.10: Results of Al-WTR1 flow-through experiment.

Retention Time	Collection Time	Inflow P Concentration	Outflow P concentration	Cumulative P Added	Cumulative P Sorbed	Discrete removal	Cumulative Removal	pH	EC
----- minutes -----		------ ppm ------		------ mg kg^{-1} ------		------ % ------			mS cm^{-1}
10	60	0.51	0.30	925	652	40.93	70.47	6.3	
10	120	0.51	0.34	1851	998	33.77	53.91	6.3	
10	180	0.51	0.36	2776	1289	29.08	46.42	6.3	
10	240	0.51	0.38	3702	1540	25.28	41.61	6.15	
10	300	0.51	0.40	4627	1761	22.37	38.05	6.3	
10	60	0.52	0.33	950	650	36.81	68.41	6.25	
10	120	0.52	0.32	1901	1010	38.99	53.15	6.3	
10	180	0.52	0.34	2851	1361	34.85	47.74	6.3	
10	240	0.52	0.35	3801	1682	32.67	44.25	6.15	
10	300	0.52	0.36	4751	1987	31.58	41.82	6.3	
10	60	1.03	0.48	799	613	53.34	76.67	6.25	
10	120	1.03	0.48	1598	1040	53.56	65.06	6.45	
10	180	1.03	0.50	2397	1460	51.65	60.91	6.35	
10	240	1.03	0.51	3197	1868	50.30	58.43	6.35	
10	300	1.03	0.51	3996	2268	49.85	56.76	6.25	
10	60	1.15	0.51	898	699	55.57	77.79	6.3	
10	120	1.15	0.50	1796	1204	57.08	67.06	6.45	
10	180	1.15	0.52	2694	1708	54.97	63.38	6.35	
10	240	1.15	0.54	3592	2191	52.77	61.00	6.35	
10	300	1.15	0.59	4490	2648	48.86	58.96	6.3	
10	30	4.93	3.91	2237	1350	20.68	60.34	6.4	
10	60	4.93	3.84	4475	1828	22.08	40.86	6.4	
10	90	4.93	3.89	6712	2310	20.99	34.42	6.3	
10	120	4.93	4.02	8949	2752	18.51	30.75	6.5	
10	150	4.93	4.16	11187	3133	15.49	28.00	6.45	
10	180	4.93	4.11	13424	3492	16.66	26.01	6.4	
10	210	4.93	4.13	15661	3860	16.27	24.65	6.4	
10	240	4.93	4.22	17898	4203	14.33	23.48	6.3	
10	270	4.93	4.28	20136	4510	13.17	22.40	6.45	
10	300	4.93	4.32	22373	4796	12.39	21.44	6.4	
10	30	5.02	3.84	2281	1409	23.56	61.78	6.65	
10	60	5.02	3.71	4561	1976	26.14	43.31	6.35	
10	90	5.02	3.95	6842	2518	21.43	36.81	6.35	
10	120	5.02	3.97	9123	3002	20.97	32.90	6.5	
10	150	5.02	4.15	11403	3440	17.48	30.17	6.5	
10	180	5.02	4.18	13684	3830	16.72	27.99	6.5	
10	210	5.02	4.24	15964	4198	15.58	26.30	6.4	
10	240	5.02	4.28	18245	4545	14.82	24.91	6.4	
10	270	5.02	4.36	20526	4866	13.30	23.71	6.45	
10	300	5.02	4.13	22806	5221	17.86	22.89	6.45	
10	30	9.33	6.74	2541	1623	27.75	63.87	6.05	
10	60	9.33	6.86	5082	2311	26.44	45.48	6.1	
10	90	9.33	6.71	7622	3004	28.07	39.41	6.3	
10	120	9.33	7.70	10163	3582	17.43	35.24	6.3	
10	150	9.33	7.81	12704	4010	16.29	31.57	6.45	
10	180	9.33	7.88	15245	4414	15.47	28.95	6.4	
10	210	9.33	7.95	17785	4798	14.81	26.98	6.4	

Table A.10: Continued

Retention Time	Collection Time	Inflow P Concentration	Outflow P concentration	Cumulative P Added	Cumulative P Sorbed	Discrete removal	Cumulative Removal	pH	EC
----- minutes -----		------ ppm ------		------ mg kg^{-1} ------		------ % ------			mS cm^{-1}
10	240	9.33	8.07	20326	5158	13.50	25.38	6.6	
10	270	9.33	7.67	22867	5555	17.76	24.29	6.45	
10	300	9.33	8.07	25408	5952	13.50	23.43	6.4	
10	30	9.79	7.53	2666	1639	23.01	61.51	6.05	
10	60	9.79	7.72	5331	2228	21.14	41.79	6.2	
10	90	9.79	8.33	7997	2707	14.82	33.86	6.35	
10	120	9.79	8.41	10662	3092	14.04	29.00	6.3	
10	150	9.79	8.41	13328	3466	14.04	26.01	6.25	
10	180	9.79	8.60	15993	3815	12.09	23.85	6.45	
10	210	9.79	8.72	18659	4121	10.92	22.09	6.45	
10	240	9.79	8.87	21324	4392	9.36	20.59	6.6	
10	270	9.79	8.98	23990	4626	8.19	19.28	6.45	
10	300	9.79	8.98	26655	4844	8.19	18.17	6.45	
10	30	14.61	11.50	3980	2414	21.28	60.64	6.1	
10	60	14.61	10.50	7961	3398	28.15	42.68	6.3	
10	90	14.61	11.73	11941	4350	19.72	36.43	6.45	
10	120	14.61	12.62	15922	5014	13.64	31.49	6.4	
10	150	14.61	11.53	19902	5706	21.13	28.67	6.4	
10	180	14.61	13.47	23883	6282	7.80	26.30	6.45	
10	210	14.61	12.79	27863	6686	12.47	23.99	6.45	
10	240	14.61	13.64	31843	7066	6.63	22.19	6.25	
10	270	14.61	13.59	35824	7337	7.02	20.48	6.45	
10	300	14.61	13.93	39804	7570	4.68	19.02	6.4	
10	30	14.61	10.50	3980	2550	28.15	64.07	6.2	
10	60	14.61	11.30	7961	3562	22.69	44.74	6.4	
10	90	14.61	11.96	11941	4375	18.17	36.64	6.45	
10	120	14.61	12.22	15922	5062	16.37	31.80	6.4	
10	150	14.61	12.56	19902	5668	14.03	28.48	6.45	
10	180	14.61	11.64	23883	6352	20.35	26.60	6.45	
10	210	14.61	12.79	27863	7005	12.47	25.14	6.35	
10	240	14.61	12.73	31843	7509	12.86	23.58	6.3	
10	270	14.61	13.42	35824	7928	8.19	22.13	6.5	
10	300	14.61	13.02	39804	8309	10.92	20.87	6.45	
8	42.5	0.42	0.23	397	288	45.08	72.54	6.25	
8	85	0.42	0.19	794	484	53.60	60.94	6.15	
8	127.5	0.42	0.20	1190	691	51.13	58.08	6.15	
8	170	0.42	0.21	1587	889	48.65	56.03	6.15	
8	212.5	0.42	0.22	1984	1081	47.83	54.47	6.2	
8	255	0.42	0.22	2381	1268	46.73	53.27	6.15	
8	297.5	0.42	0.23	2777	1450	44.80	52.20	6.2	
8	42.5	0.43	0.24	410	297	44.97	72.48	6.25	
8	85	0.43	0.23	820	483	45.77	58.93	6.15	
8	127.5	0.43	0.24	1230	666	43.37	54.14	6.15	
8	170	0.43	0.27	1639	831	37.52	50.72	6.15	
8	212.5	0.43	0.26	2049	990	39.91	48.32	6.2	
8	255	0.43	0.25	2459	1158	41.78	47.07	6.15	
8	297.5	0.43	0.26	2869	1327	40.71	46.24	6.2	
8	42.5	1.01	0.79	2393	1454	21.49	60.75	6.5	
8	85	1.01	0.82	4786	1934	18.62	40.40	6.5	

Table A.10: Continued

Retention Time	Collection Time	Inflow P Concentration	Outflow P concentration	Cumulative P Added	Cumulative P Sorbed	Discrete removal	Cumulative Removal	pH	EC
----- minutes -----		------ ppm ------		------ mg kg^{-1} ------		------ % ------			mS cm^{-1}
8	127.5	1.01	0.85	7179	2338	15.17	32.57	6.5	
8	170	1.01	0.86	9572	2687	14.02	28.07	6.5	
8	212.5	1.01	0.87	11965	3014	13.33	25.19	7.2	
8	255	1.01	0.88	14358	3320	12.18	23.12	6.95	
8	297.5	1.01	0.89	16751	3600	11.26	21.49	7.1	
8	30	4.93	3.15	1656	1128	36.18	68.09	6.2	
8	60	4.93	3.21	3312	1716	34.93	51.82	6.25	
8	90	4.93	3.45	4968	2255	30.09	45.38	6.35	
8	120	4.93	3.65	6624	2718	25.87	41.03	6.35	
8	150	4.93	3.72	8280	3136	24.62	37.87	6.4	
8	180	4.93	3.82	9936	3526	22.43	35.48	6.4	
8	210	4.93	3.94	11592	3878	20.08	33.45	6.35	
8	240	4.93	3.99	13248	4201	18.99	31.71	6.35	
8	270	4.93	4.12	14904	4494	16.41	30.15	6.3	
8	300	4.93	4.18	16560	4756	15.24	28.72	6.15	
8	30	5.12	3.26	1721	1173	36.32	68.16	6.2	
8	60	5.12	3.48	3441	1762	32.11	51.19	6.25	
8	90	5.12	3.71	5162	2275	27.60	44.08	6.35	
8	120	5.12	3.82	6883	2731	25.34	39.68	6.4	
8	150	5.12	3.91	8604	3153	23.69	36.65	6.4	
8	180	5.12	3.97	10324	3550	22.49	34.39	6.4	
8	210	5.12	4.12	12045	3912	19.55	32.48	6.4	
8	240	5.12	4.14	13766	4245	19.18	30.84	6.35	
8	270	5.12	4.14	15487	4575	19.18	29.54	6.4	
8	300	5.12	4.20	17207	4895	18.05	28.45	6.3	
8	30	9.70	6.28	2038	1379	35.33	67.66	6.45	
8	60	9.70	6.41	4075	2084	33.91	51.14	6.35	
8	90	9.70	7.01	6113	2713	27.78	44.38	6.35	
8	120	9.70	7.27	8151	3252	25.10	39.89	6.45	
8	150	9.70	7.50	10188	3739	22.74	36.70	6.45	
8	180	9.70	7.63	12226	4188	21.32	34.25	6.45	
8	210	9.70	7.89	14264	4595	18.65	32.22	6.45	
8	240	9.70	8.05	16302	4959	17.07	30.42	6.45	
8	270	9.70	8.33	18339	5277	14.16	28.78	6.5	
8	300	9.70	8.21	20377	5578	15.34	27.37	6.4	
8	30	9.93	6.44	2086	1409	35.13	67.56	6.5	
8	60	9.93	6.79	4172	2105	31.59	50.46	6.35	
8	90	9.93	7.27	6257	2714	26.83	43.38	6.3	
8	120	9.93	7.36	8343	3264	25.91	39.13	6.45	
8	150	9.93	7.68	10429	3771	22.68	36.16	6.45	
8	180	9.93	7.94	12515	4217	20.06	33.69	6.4	
8	210	9.93	8.09	14601	4619	18.53	31.64	6.4	
8	240	9.93	8.21	16686	4993	17.30	29.92	6.3	
8	270	9.93	8.21	18772	5354	17.30	28.52	6.45	
8	300	9.93	8.29	20858	5706	16.53	27.36	6.4	
8	30	14.85	9.15	2495	1726	38.40	69.20	6.05	
8	60	14.85	10.18	4990	2598	31.46	52.07	6.15	
8	90	14.85	11.12	7484	3304	25.14	44.14	6.15	
8	120	14.85	11.37	9979	3910	23.44	39.18	6.3	
8	150	14.85	11.12	12474	4516	25.14	36.20	6.4	

Table A.10: Continued

Retention Time	Collection Time	Inflow P Concentration	Outflow P concentration	Cumulative P Added	Cumulative P Sorbed	Discrete removal	Cumulative Removal	pH	EC
----- minutes -----		------ ppm ------		------ mg kg^{-1} ------		------ % ------			mS cm^{-1}
8	180	14.85	11.80	14969	5085	20.51	33.97	6.4	
8	210	14.85	12.06	17463	5576	18.82	31.93	6.45	
8	240	14.85	12.45	19958	6013	16.19	30.13	6.5	
8	270	14.85	12.62	22453	6402	15.04	28.51	6.4	
8	300	14.85	11.99	24948	6830	19.28	27.38	6.45	
8	30	14.56	9.65	2447	1636	33.73	66.87	6.05	
8	60	14.56	10.41	4893	2398	28.54	49.00	6.1	
8	90	14.56	10.91	7340	3054	25.08	41.60	6.35	
8	120	14.56	12.01	9787	3575	17.53	36.53	6.3	
8	150	14.56	12.12	12233	3995	16.75	32.65	6.35	
8	180	14.56	12.45	14680	4377	14.55	29.82	6.4	
8	210	14.56	12.56	17127	4724	13.76	27.58	6.4	
8	240	14.56	12.62	19573	5055	13.37	25.83	6.5	
8	270	14.56	13.48	22020	5310	7.47	24.12	6.45	
8	300	14.56	12.67	24467	5560	12.97	22.73	6.45	
6	30	0.52	0.28	469	342	46.13	73.06	6.3	
6	60	0.52	0.28	937	556	45.25	59.38	6.3	
6	90	0.52	0.28	1406	771	46.35	54.85	6.3	
6	120	0.52	0.27	1874	989	46.79	52.78	6.3	
6	150	0.52	0.28	2343	1207	46.13	51.52	6.2	
6	180	0.52	0.28	2811	1421	45.25	50.54	6.25	
6	210	0.52	0.30	3280	1627	42.60	49.60	6.3	
6	240	0.52	0.30	3748	1826	42.60	48.72	6.2	
6	270	0.52	0.30	4217	2022	41.05	47.96	6.2	
6	300	0.52	0.31	4685	2213	40.61	47.24	6.25	
6	30	0.51	0.31	465	325	39.77	69.89	6.3	
6	60	0.51	0.33	931	499	34.88	53.61	6.3	
6	90	0.51	0.35	1396	654	31.77	46.85	6.3	
6	120	0.51	0.36	1862	797	29.77	42.83	6.3	
6	150	0.51	0.37	2327	931	27.55	39.99	6.25	
6	180	0.51	0.39	2792	1049	23.11	37.55	6.3	
6	210	0.51	0.39	3258	1156	23.11	35.49	6.3	
6	240	0.51	0.40	3723	1263	22.88	33.93	6.15	
6	270	0.51	0.40	4189	1368	22.22	32.66	6.15	
6	300	0.51	0.40	4654	1469	21.11	31.56	6.25	
6	30	1.00	0.62	451	312	38.00	69.00	6.2	0.67
6	60	1.00	0.65	903	476	34.80	52.70	6.3	0.726
6	90	1.00	0.71	1354	620	29.07	45.78	6.55	0.683
6	120	1.00	0.71	1806	751	28.73	41.56	6.35	0.69
6	150	1.00	0.72	2257	878	27.93	38.91	6.5	0.69
6	180	1.00	0.74	2709	1000	25.98	36.92	6.5	0.675
6	210	1.00	0.75	3160	1115	25.07	35.29	6.4	0.667
6	240	1.00	0.77	3612	1224	23.01	33.89	6.4	0.703
6	270	1.00	0.74	4063	1334	25.87	32.84	6.6	0.69
6	300	1.00	0.78	4515	1442	21.75	31.93	6.6	0.658
6	30	4.97	3.67	2820	1780	26.26	63.13	6.4	0.685
6	60	4.97	4.05	5640	2411	18.51	42.76	6.2	0.717
6	90	4.97	4.24	8460	2880	14.72	34.04	6.4	0.675
6	120	4.97	4.15	11279	3322	16.65	29.45	6.4	1.413
6	150	4.97	4.32	14099	3743	13.17	26.54	6.45	0.705

Table A.10: Continued

Retention Time	Collection Time	Inflow P Concentration	Outflow P concentration	Cumulative P Added	Cumulative P Sorbed	Discrete removal	Cumulative Removal	pH	EC
----- minutes -----		------ ppm ------		------ mg kg^{-1} ------		------ % ------			mS cm^{-1}
6	180	4.97	4.32	16919	4114	13.17	24.31	6.45	0.675
6	210	4.97	4.30	19739	4491	13.55	22.75	7.05	0.69
6	240	4.97	4.40	22559	4846	11.62	21.48	7	0.693
6	270	4.97	4.43	25379	5162	10.84	20.34	6.75	0.709
6	300	4.97	4.36	28199	5490	12.39	19.47	6.8	0.658
6	30	5.01	3.41	2842	1876	32.05	66.02	6.3	0.681
6	60	5.01	3.85	5683	2660	23.13	46.81	6.2	0.707
6	90	5.01	4.10	8525	3248	18.22	38.10	6.45	0.708
6	120	5.01	4.16	11367	3747	16.91	32.96	6.5	0.711
6	150	5.01	4.16	14209	4227	16.91	29.75	6.45	0.692
6	180	5.01	4.28	17050	4675	14.60	27.42	6.35	0.712
6	210	5.01	4.24	19892	5101	15.37	25.64	6.9	0.683
6	240	5.01	4.34	22734	5511	13.45	24.24	6.9	0.702
6	270	5.01	4.20	25575	5931	16.14	23.19	6.7	0.725
6	300	5.01	4.43	28417	6324	11.53	22.25	6.85	0.67
6	30	9.86	4.28	1481	1159	56.58	78.29	6.3	0.684
6	60	9.86	5.35	2961	1916	45.71	64.72	6.25	0.681
6	90	9.86	6.01	4442	2543	38.99	57.26	6.3	0.658
6	120	9.86	6.28	5922	3101	36.34	52.36	6.4	0.667
6	150	9.86	6.55	7403	3618	33.52	48.88	6.35	0.685
6	180	9.86	6.57	8883	4113	33.37	46.31	6.35	0.711
6	210	9.86	7.20	10364	4560	26.96	44.00	6.4	0.698
6	240	9.86	7.26	11844	4955	26.33	41.83	6.35	0.694
6	270	9.86	7.58	13325	5320	23.05	39.93	6.35	0.682
6	300	9.86	7.42	14806	5674	24.77	38.32	6.25	0.682
6	30	10.01	5.20	1504	1113	48.09	74.04	6.25	0.71
6	60	10.01	6.11	3007	1768	39.01	58.80	6.25	0.686
6	90	10.01	6.51	4511	2325	35.01	51.53	6.35	0.648
6	120	10.01	6.98	6015	2815	30.24	46.81	6.4	0.672
6	150	10.01	7.31	7518	3246	27.01	43.17	6.4	0.682
6	180	10.01	7.57	9022	3632	24.39	40.26	6.35	0.694
6	210	10.01	7.71	10526	3989	23.01	37.89	6.4	0.667
6	240	10.01	7.91	12030	4319	21.01	35.91	6.4	0.627
6	270	10.01	7.77	13533	4646	22.39	34.33	6.35	0.652
6	300	10.01	8.05	15037	4962	19.62	33.00	6.2	0.688
6	30	14.84	7.16	1683	1277	51.78	75.89	6.4	0.695
6	60	14.84	7.72	3366	2117	48.00	62.89	6.4	0.675
6	90	14.84	8.43	5049	2884	43.21	57.13	6.3	0.698
6	120	14.84	9.14	6732	3571	38.43	53.05	6.5	0.682
6	150	14.84	9.78	8415	4182	34.11	49.69	6.5	0.716
6	180	14.84	10.19	10098	4732	31.33	46.87	6.45	0.665
6	210	14.84	10.70	11781	5231	27.93	44.40	6.3	0.58
6	240	14.84	10.97	13464	5686	26.08	42.23	6.3	0.697
6	270	14.84	11.36	15147	6103	23.46	40.29	6.5	0.669
6	300	14.84	11.11	16830	6512	25.16	38.69	6.4	0.675
6	30	14.61	4.20	1657	1419	71.24	85.62	6.4	0.685
6	60	14.61	6.02	3314	2496	58.78	75.32	6.35	0.689
6	90	14.61	7.43	4971	3390	49.14	68.20	6.3	0.68
6	120	14.61	7.59	6628	4195	48.04	63.30	6.45	0.632
6	150	14.61	8.86	8285	4919	39.34	59.38	6.5	0.623

Table A.10: Continued

Retention Time	Collection Time	Inflow P Concentration	Outflow P concentration	Cumulative P Added	Cumulative P Sorbed	Discrete removal	Cumulative Removal	pH	EC
----- minutes -----		------ ppm ------		------ mg kg^{-1} ------		------ % ------			mS cm^{-1}
6	180	14.61	9.21	9942	5552	36.99	55.84	6.4	0.652
6	210	14.61	10.19	11599	6109	30.25	52.67	6.35	0.661
6	240	14.61	10.63	13256	6586	27.27	49.68	6.35	0.685
6	270	14.61	10.97	14913	7018	24.92	47.06	6.45	0.682
6	300	14.61	10.76	16570	7443	26.33	44.92	6.35	0.65
3	30	0.52	0.35	582	385	32.37	66.19	6.3	
3	60	0.52	0.36	1165	567	30.17	48.73	6.25	
3	90	0.52	0.38	1747	730	25.77	41.81	6.3	
3	120	0.52	0.39	2329	876	24.22	37.61	6.25	
3	150	0.52	0.39	2911	1018	24.45	34.95	6.2	
3	180	0.52	0.40	3494	1154	22.24	33.02	6.25	
3	210	0.52	0.40	4076	1282	21.80	31.45	6.3	
3	240	0.52	0.41	4658	1406	20.92	30.19	6.2	
3	270	0.52	0.41	5241	1528	20.92	29.16	6.15	
3	300	0.52	0.41	5823	1648	20.48	28.31	6.2	
3	30	0.53	0.34	600	408	35.89	67.95	6.15	
3	60	0.53	0.36	1200	612	32.26	51.01	6.2	
3	90	0.53	0.42	1801	774	21.58	42.98	6.3	
3	120	0.53	0.44	2401	890	17.09	37.07	6.3	
3	150	0.53	0.45	3001	991	16.45	33.01	6.25	
3	180	0.53	0.47	3601	1073	11.11	29.80	6.25	
3	210	0.53	0.49	4202	1132	8.33	26.93	6.3	
3	240	0.53	0.49	4802	1183	8.76	24.64	6.2	
3	270	0.53	0.50	5402	1227	5.98	22.72	6.2	
3	300	0.53	0.50	6002	1263	5.98	21.04	6.25	
3	30	0.98	0.40	294	234	59.31	79.66	6.15	
3	60	0.98	0.49	587	395	50.07	67.17	6.4	
3	90	0.98	0.54	881	535	45.27	60.67	6.45	
3	120	0.98	0.57	1175	663	42.00	56.41	6.4	
3	150	0.98	0.59	1468	782	39.42	53.27	6.5	
3	180	0.98	0.61	1762	895	37.32	50.79	6.35	
3	210	0.98	0.64	2056	1001	34.74	48.68	6.65	
3	240	0.98	0.64	2349	1102	34.28	46.91	6.55	
3	270	0.98	0.66	2643	1200	32.76	45.42	6.55	
3	300	0.98	0.67	2937	1296	32.05	44.12	6.5	
3	30	0.98	0.30	295	250	69.28	84.64	6.15	
3	60	0.98	0.33	590	450	66.49	76.26	6.4	
3	90	0.98	0.35	885	643	64.39	72.65	6.45	
3	120	0.98	0.36	1180	831	62.99	70.41	6.35	
3	150	0.98	0.38	1475	1015	61.60	68.79	6.45	
3	180	0.98	0.38	1770	1195	60.90	67.53	6.45	
3	210	0.98	0.39	2065	1374	60.32	66.54	6.65	
3	240	0.98	0.39	2360	1552	59.97	65.74	6.6	
3	270	0.98	0.40	2655	1727	58.92	65.04	6.5	
3	300	0.98	0.41	2950	1900	58.45	64.41	6.5	
3	30	4.93	1.98	1109	885	59.72	79.86	6.35	
3	60	4.93	2.69	2217	1469	45.47	66.23	6.4	
3	90	4.93	3.06	3326	1931	37.92	58.05	6.5	
3	120	4.93	3.20	4435	2336	35.14	52.67	6.5	
3	150	4.93	3.43	5544	2699	30.36	48.69	6.5	

Table A.10: Continued

Retention Time	Collection Time	Inflow P Concentration	Outflow P concentration	Cumulative P Added	Cumulative P Sorbed	Discrete removal	Cumulative Removal	pH	EC
----- minutes -----		------ ppm ------		------ mg kg^{-1} ------		------ % ------			mS cm^{-1}
3	180	4.93	3.52	6652	3025	28.51	45.48	6.45	
3	210	4.93	3.64	7761	3328	26.05	42.88	6.35	
3	240	4.93	3.66	8870	3615	25.74	40.76	6.5	
3	270	4.93	3.70	9979	3895	24.81	39.04	6.55	
3	300	4.93	3.74	11087	4167	24.20	37.58	6.4	
3	30	4.95	2.24	1113	862	54.81	77.41	6.1	
3	60	4.95	2.78	2226	1411	43.83	63.36	6.4	
3	90	4.95	3.07	3339	1865	37.85	55.86	6.5	
3	120	4.95	3.26	4452	2266	34.16	50.89	6.5	
3	150	4.95	3.45	5565	2625	30.32	47.16	6.5	
3	180	4.95	3.48	6678	2958	29.56	44.29	6.45	
3	210	4.95	3.62	7791	3271	26.79	41.99	6.3	
3	240	4.95	3.74	8904	3556	24.34	39.94	6.45	
3	270	4.95	3.79	10017	3822	23.41	38.15	6.6	
3	300	4.95	3.75	11130	4087	24.18	36.72	6.55	
3	30	10.22	7.80	5747	3554	23.68	61.84	6.3	
3	60	10.22	8.44	11493	4732	17.34	41.18	6.2	
3	90	10.22	8.71	17240	5653	14.70	32.79	6.45	
3	120	10.22	8.87	22987	6455	13.20	28.08	6.5	
3	150	10.22	9.10	28733	7148	10.93	24.88	6.5	
3	180	10.22	9.10	34480	7777	10.93	22.55	6.5	
3	210	10.22	8.79	40227	8492	13.95	21.11	7.15	
3	240	10.22	9.10	45973	9207	10.93	20.03	6.9	
3	270	10.22	8.48	51720	10008	16.97	19.35	6.8	
3	300	10.22	9.10	57467	10810	10.93	18.81	6.8	
3	30	9.99	7.61	5617	3476	23.76	61.88	6.2	
3	60	9.99	8.37	11233	4598	16.20	40.93	6.3	
3	90	9.99	8.60	16850	5443	13.89	32.30	6.4	
3	120	9.99	9.06	22467	6093	9.26	27.12	6.55	
3	150	9.99	9.02	28083	6624	9.64	23.59	6.5	
3	180	9.99	9.14	33700	7133	8.49	21.17	6.35	
3	210	9.99	9.06	39317	7632	9.26	19.41	6.85	
3	240	9.99	8.79	44933	8227	11.96	18.31	6.85	
3	270	9.99	9.14	50550	8802	8.49	17.41	6.85	
3	300	9.99	8.83	56167	9365	11.57	16.67	6.75	
3	30	15.13	4.03	1362	1181	73.38	86.69	6.3	
3	60	15.13	6.20	2724	2082	59.02	76.44	6.25	
3	90	15.13	7.53	4086	2826	50.24	69.17	6.35	
3	120	15.13	7.80	5448	3499	48.49	64.22	6.35	
3	150	15.13	9.16	6810	4098	39.48	60.17	6.3	
3	180	15.13	9.60	8172	4615	36.57	56.48	6.35	
3	210	15.13	10.13	9534	5090	33.06	53.39	6.35	
3	240	15.13	10.73	10895	5513	29.09	50.60	6.4	
3	270	15.13	11.31	12257	5883	25.27	48.00	6.3	
3	300	15.13	10.71	13619	6254	29.24	45.92	6.2	
3	30	15.07	6.00	1357	1087	60.17	80.08	6.25	
3	60	15.07	7.81	2713	1822	48.21	67.14	6.25	
3	90	15.07	8.81	4070	2431	41.54	59.72	6.3	
3	120	15.07	9.78	5427	2951	35.10	54.37	6.35	
3	150	15.07	10.36	6784	3401	31.27	50.13	6.35	

Table A.10: Continued

Retention Time	Collection Time	Inflow P Concentration	Outflow P concentration	Cumulative P Added	Cumulative P Sorbed	Discrete removal	Cumulative Removal	pH	EC
----- minutes -----		------ ppm ------		------ mg kg^{-1} ------		------ % ------			mS cm^{-1}
3	180	15.07	10.45	8140	3821	30.66	46.94	6.35	
3	210	15.07	11.28	9497	4199	25.14	44.22	6.4	
3	240	15.07	11.01	10854	4553	26.98	41.95	6.35	
3	270	15.07	11.75	12211	4886	22.07	40.01	6.4	
3	300	15.07	12.12	13567	5169	19.62	38.10	6.2	
0.5	30	0.51	0.34	556	375	34.78	67.39	6.4	
0.5	60	0.51	0.36	1112	553	29.39	49.74	6.35	
0.5	90	0.51	0.38	1668	710	27.15	42.58	6.35	
0.5	120	0.51	0.38	2225	858	26.03	38.58	6.5	
0.5	150	0.51	0.39	2781	999	24.68	35.94	6.45	
0.5	180	0.51	0.40	3337	1129	21.99	33.84	6.35	
0.5	210	0.51	0.40	3893	1252	22.21	32.16	6.45	
0.5	240	0.51	0.40	4449	1376	22.21	30.92	6.45	
0.5	270	0.51	0.40	5005	1500	22.66	29.98	6.4	
0.5	300	0.51	0.40	5561	1623	21.54	29.19	6.3	
0.5	30	0.51	0.27	551	405	46.87	73.43	6.45	
0.5	60	0.51	0.26	1102	668	48.68	60.60	6.35	
0.5	90	0.51	0.28	1653	928	45.74	56.14	6.45	
0.5	120	0.51	0.27	2205	1184	47.09	53.71	6.55	
0.5	150	0.51	0.27	2756	1445	47.55	52.43	6.45	
0.5	180	0.51	0.28	3307	1701	45.28	51.43	6.5	
0.5	210	0.51	0.30	3858	1941	41.89	50.31	6.45	
0.5	240	0.51	0.30	4409	2169	40.75	49.18	6.45	
0.5	270	0.51	0.31	4960	2388	38.94	48.15	6.45	
0.5	300	0.51	0.33	5512	2594	35.55	47.06	6.3	
0.5	30	0.99	0.33	537	446	66.37	83.18	6.8	
0.5	60	0.99	0.39	1073	788	60.95	73.42	6.45	
0.5	90	0.99	0.41	1610	1109	58.76	68.90	6.4	
0.5	120	0.99	0.42	2147	1422	57.73	66.24	6.55	
0.5	150	0.99	0.44	2684	1728	56.23	64.38	6.6	
0.5	180	0.99	0.45	3220	2025	54.38	62.87	6.55	
0.5	210	0.99	0.48	3757	2308	51.27	61.44	6.5	
0.5	240	0.99	0.49	4294	2581	50.24	60.10	6.45	
0.5	270	0.99	0.51	4831	2847	48.97	58.94	6.55	
0.5	300	0.99	0.53	5367	3105	47.13	57.85	6.45	
0.5	30	0.98	0.36	531	433	63.06	81.53	6.75	
0.5	60	0.98	0.39	1061	759	60.15	71.57	6.5	
0.5	90	0.98	0.41	1592	1073	58.05	67.41	6.35	
0.5	120	0.98	0.42	2122	1378	56.88	64.92	6.55	
0.5	150	0.98	0.44	2653	1677	55.72	63.20	6.65	
0.5	180	0.98	0.45	3183	1968	53.97	61.81	6.55	
0.5	210	0.98	0.47	3714	2250	52.34	60.57	6.45	
0.5	240	0.98	0.48	4244	2523	50.94	59.45	6.45	
0.5	270	0.98	0.49	4775	2792	50.12	58.46	6.55	
0.5	300	0.98	0.50	5306	3055	49.07	57.58	6.45	
0.5	30	5.01	3.01	1352	945	39.87	69.93	6.1	
0.5	60	5.01	3.44	2704	1427	31.33	52.77	6.4	
0.5	90	5.01	3.68	4056	1818	26.60	44.83	6.35	
0.5	120	5.01	3.79	5408	2163	24.32	39.99	6.25	
0.5	150	5.01	3.82	6760	2487	23.71	36.80	6.3	

Table A.10: Continued

Retention Time	Collection Time	Inflow P Concentration	Outflow P concentration	Cumulative P Added	Cumulative P Sorbed	Discrete removal	Cumulative Removal	pH	EC
----- minutes -----		------ ppm ------		------ mg kg^{-1} ------		------ % ------			mS cm^{-1}
0.5	180	5.01	3.94	8112	2791	21.27	34.41	6.5	
0.5	210	5.01	4.09	9464	3059	18.30	32.32	6.6	
0.5	240	5.01	3.95	10816	3325	21.12	30.74	6.6	
0.5	270	5.01	4.17	12167	3581	16.77	29.43	6.45	
0.5	300	5.01	4.09	13519	3818	18.30	28.24	6.4	
0.5	30	4.85	2.55	1311	967	47.49	73.75	6.1	
0.5	60	4.85	2.93	2621	1537	39.55	58.63	6.4	
0.5	90	4.85	3.25	3932	2013	33.10	51.20	6.3	
0.5	120	4.85	3.38	5243	2428	30.27	46.32	6.3	
0.5	150	4.85	3.56	6554	2802	26.65	42.75	6.35	
0.5	180	4.85	3.60	7864	3146	25.87	40.00	6.55	
0.5	210	4.85	3.74	9175	3465	22.88	37.77	6.4	
0.5	240	4.85	3.72	10486	3768	23.35	35.94	6.65	
0.5	270	4.85	3.80	11796	4063	21.62	34.44	6.6	
0.5	300	4.85	3.84	13107	4341	20.84	33.12	6.5	
0.5	30	9.67	6.60	2610	1718	31.67	65.83	6.25	
0.5	60	9.67	7.39	5219	2438	23.49	46.71	6.35	
0.5	90	9.67	7.53	7829	3033	22.08	38.73	6.4	
0.5	120	9.67	7.90	10439	3560	18.31	34.10	6.45	
0.5	150	9.67	8.15	13049	4004	15.72	30.68	6.45	
0.5	180	9.67	8.26	15658	4398	14.54	28.09	6.45	
0.5	210	9.67	8.41	18268	4757	12.97	26.04	6.5	
0.5	240	9.67	8.60	20878	5070	11.00	24.28	6.5	
0.5	270	9.67	8.56	23488	5362	11.39	22.83	6.5	
0.5	300	9.67	8.56	26097	5659	11.39	21.69	6.5	
0.5	30	9.86	6.12	2661	1835	37.92	68.96	6.3	
0.5	60	9.86	7.14	5322	2706	27.59	50.85	6.4	
0.5	90	9.86	7.61	7983	3377	22.81	42.30	6.5	
0.5	120	9.86	7.88	10644	3947	20.04	37.08	6.4	
0.5	150	9.86	7.99	13305	4466	18.96	33.57	6.35	
0.5	180	9.86	8.26	15966	4933	16.18	30.90	6.4	
0.5	210	9.86	8.22	18627	5369	16.57	28.83	6.45	
0.5	240	9.86	8.34	21288	5795	15.41	27.22	6.4	
0.5	270	9.86	8.41	23949	6195	14.64	25.87	6.5	
0.5	300	9.86	8.41	26610	6584	14.64	24.74	6.45	
0.5	30	14.97	11.92	4042	2432	20.35	60.18	6.3	
0.5	60	14.97	12.91	8084	3122	13.77	38.62	6.15	
0.5	90	14.97	12.28	12126	3764	17.98	31.04	6.1	
0.5	120	14.97	12.74	16168	4429	14.92	27.39	6.15	
0.5	150	14.97	14.00	20210	4862	6.50	24.06	6.1	
0.5	180	14.97	14.00	24252	5125	6.50	21.13	6.15	
0.5	210	14.97	14.57	28294	5310	2.68	18.77	6.15	
0.5	240	14.97	13.42	32336	5573	10.33	17.24	6.1	
0.5	270	14.97	12.62	36377	6099	15.69	16.77	6.1	
0.5	300	14.97	13.88	40419	6563	7.27	16.24	6.1	
0.5	30	15.14	11.10	4088	2590	26.71	63.35	6.1	
0.5	60	15.14	11.72	8177	3598	22.62	44.01	6.1	
0.5	90	15.14	12.51	12265	4416	17.40	36.01	6.1	
0.5	120	15.14	13.14	16353	5043	13.24	30.84	6.1	
0.5	150	15.14	13.19	20442	5576	12.86	27.28	6.1	

Table A.10: Continued

Retention Time	Collection Time	Inflow P Concentration	Outflow P concentration	Cumulative P Added	Cumulative P Sorbed	Discrete removal	Cumulative Removal	pH	EC
----- minutes -----		------ ppm ------		------ mg kg^{-1} ------		------ % ------			mS cm^{-1}
0.5	180	15.14	13.77	24530	6025	9.08	24.56	6.15	
0.5	210	15.14	13.88	28618	6381	8.32	22.30	6.15	
0.5	240	15.14	14.45	32707	6643	4.54	20.31	6.1	
0.5	270	15.14	13.19	36795	6999	12.86	19.02	6.1	
0.5	300	15.14	13.42	40883	7494	11.35	18.33	6	

Table A.11: Results of Al-WTR2 flow-through experiment.

Retention Time	Collection Time	Inflow P Concentration	Outflow P concentration	Cumulative P Added	Cumulative P Sorbed	Discrete removal	Cumulative Removal	pH	EC
----- minutes -----		------ ppm ------		------ mg kg^{-1} ------		------ % ------			$mS\ cm^{-1}$
10	60	0.49	0.39	332	200	20.32	60.16	6.15	
10	120	0.49	0.34	665	286	31.19	42.96	5.9	
10	180	0.49	0.35	997	385	28.83	38.64	6.05	
10	240	0.49	0.36	1330	477	26.23	35.87	5.95	
10	300	0.49	0.37	1662	561	24.10	33.73	5.9	
10	60	0.49	0.37	331	204	23.03	61.52	6.1	
10	120	0.49	0.33	662	295	32.29	44.59	5.9	
10	180	0.49	0.34	993	398	30.15	40.13	6.05	
10	240	0.49	0.36	1324	493	26.83	37.22	5.95	
10	300	0.49	0.36	1654	579	25.17	34.98	5.9	
10	60	0.99	0.78	672	405	20.52	60.26	7	
10	120	0.99	0.76	1344	550	22.62	40.92	6.3	
10	180	0.99	0.80	2017	690	18.89	34.20	6.2	
10	240	0.99	0.84	2689	805	15.39	29.93	6.35	
10	300	0.99	0.84	3361	908	15.16	27.00	6.2	
10	60	0.99	0.78	674	408	21.17	60.59	6.9	
10	120	0.99	0.76	1348	559	23.62	41.49	6.3	
10	180	0.99	0.79	2021	705	19.78	34.89	6.2	
10	240	0.99	0.83	2695	828	16.52	30.71	6.3	
10	300	0.99	0.85	3369	931	14.19	27.64	6.2	
10	30	4.95	4.33	104	58	12.44	56.22	5.9	
10	60	4.95	3.85	207	76	22.16	36.76	5.75	
10	90	4.95	3.57	311	102	27.76	32.83	5.75	
10	120	4.95	3.70	415	129	25.11	31.23	5.8	
10	150	4.95	3.77	518	155	23.87	29.88	5.85	
10	180	4.95	3.93	622	178	20.60	28.61	5.9	
10	210	4.95	3.87	725	200	21.69	27.54	5.85	
10	240	4.95	3.87	829	222	21.85	26.82	5.8	
10	270	4.95	3.93	933	244	20.60	26.20	5.9	
10	300	4.95	3.84	1036	267	22.31	25.72	5.8	
10	30	4.77	4.45	100	53	6.85	53.42	5.85	
10	60	4.77	3.95	200	65	17.24	32.73	5.8	
10	90	4.77	3.55	300	87	25.62	28.97	5.8	
10	120	4.77	3.66	400	111	23.37	27.85	5.85	
10	150	4.77	3.62	500	135	24.17	27.03	5.9	
10	180	4.77	3.66	600	159	23.37	26.49	5.9	
10	210	4.77	3.77	700	181	20.95	25.87	5.9	
10	240	4.77	3.70	800	203	22.40	25.34	5.85	
10	270	4.77	3.77	900	224	20.95	24.94	5.9	
10	300	4.77	3.85	1000	245	19.34	24.46	5.85	
10	30	9.55	8.02	130	75	15.95	57.98	6.05	
10	60	9.55	5.84	260	111	38.83	42.68	6.1	
10	90	9.55	3.67	390	176	61.55	45.19	6.1	
10	120	9.55	3.71	520	256	61.15	49.23	6.35	
10	150	9.55	3.89	650	334	59.22	51.42	6.25	
10	180	9.55	4.29	780	409	55.11	52.38	6.25	
10	210	9.55	4.59	910	478	51.97	52.54	6.35	

Table A.11: Continued

Retention Time	Collection Time	Inflow P Concentration	Outflow P concentration	Cumulative P Added	Cumulative P Sorbed	Discrete removal	Cumulative Removal	pH	EC
----- minutes -----		------ ppm ------		------ mg kg^{-1} ------		------ % ------			mS cm^{-1}
10	240	9.55	4.83	1040	544	49.39	52.31	6.3	
10	270	9.55	4.95	1170	608	48.18	51.92	6.25	
10	300	9.55	5.29	1300	668	44.64	51.37	6.2	
10	30	9.58	8.66	131	72	9.63	54.81	6.05	
10	60	9.58	5.30	261	107	44.70	40.99	6.1	
10	90	9.58	4.80	392	169	49.91	43.09	6.15	
10	120	9.58	5.12	522	232	46.62	44.39	6.35	
10	150	9.58	5.44	653	290	43.25	44.50	6.3	
10	180	9.58	5.76	783	345	39.88	44.01	6.3	
10	210	9.58	5.90	914	396	38.44	43.32	6.4	
10	240	9.58	6.12	1044	445	36.19	42.57	6.35	
10	270	9.58	6.22	1175	491	35.07	41.80	6.3	
10	300	9.58	6.30	1305	536	34.26	41.08	6.25	
10	30	14.92	13.08	185	104	12.34	56.17	5.9	
10	60	14.92	11.46	370	137	23.22	36.97	5.9	
10	90	14.92	10.22	554	187	31.54	33.78	6	
10	120	14.92	10.93	739	241	26.76	32.62	6.1	
10	150	14.92	9.85	924	297	34.01	32.17	6.1	
10	180	14.92	12.10	1109	346	18.90	31.22	6.2	
10	210	14.92	11.83	1294	383	20.75	29.59	6.2	
10	240	14.92	10.77	1478	428	27.84	28.93	6.15	
10	270	14.92	10.95	1663	478	26.61	28.74	6.15	
10	300	14.92	11.25	1848	525	24.60	28.43	6.15	
10	30	14.98	13.54	186	102	9.60	54.80	5.95	
10	60	14.98	10.86	371	136	27.51	36.68	5.95	
10	90	14.98	9.16	557	198	38.88	35.52	6.05	
10	120	14.98	9.94	742	265	33.65	35.70	6.1	
10	150	14.98	10.26	928	325	31.50	35.08	6.15	
10	180	14.98	10.17	1113	384	32.12	34.53	6.25	
10	210	14.98	9.92	1299	446	33.81	34.31	6.25	
10	240	14.98	10.93	1484	502	27.04	33.82	6.2	
10	270	14.98	10.63	1670	554	29.04	33.18	6.2	
10	300	14.98	10.93	1855	606	27.04	32.67	6.2	
8	42.5	0.49	0.35	234	151	28.65	64.32	6.15	
8	85	0.49	0.39	468	209	20.96	44.56	6.2	
8	127.5	0.49	0.40	703	255	18.63	36.31	6.1	
8	170	0.49	0.40	937	299	18.87	31.92	6.05	
8	212.5	0.49	0.40	1171	343	18.40	29.26	6.1	
8	255	0.49	0.40	1405	386	18.87	27.49	6.2	
8	297.5	0.49	0.42	1640	426	14.67	25.96	6.3	
8	42.5	0.51	0.40	241	146	21.52	60.76	6.1	
8	85	0.51	0.42	482	193	17.45	40.12	6.2	
8	127.5	0.51	0.41	722	237	19.26	32.87	6.1	
8	170	0.51	0.42	963	281	17.22	29.21	6.1	
8	212.5	0.51	0.43	1204	321	15.41	26.63	6.1	
8	255	0.51	0.43	1445	358	15.41	24.76	6.25	
8	297.5	0.51	0.43	1686	395	15.18	23.41	6.25	
8	42.5	1.00	0.70	474	307	29.66	64.83	6.4	
8	85	1.00	0.84	948	415	15.99	43.83	6.1	

Table A.11: Continued

Retention Time	Collection Time	Inflow P Concentration	Outflow P concentration	Cumulative P Added	Cumulative P Sorbed	Discrete removal	Cumulative Removal	pH	EC
----- minutes -----		------ ppm ------		------ mg kg^{-1} ------		------ % ------			mS cm^{-1}
8	127.5	1.00	0.87	1422	484	12.74	34.01	5.95	
8	170	1.00	0.87	1896	543	12.51	28.66	6	
8	212.5	1.00	0.87	2370	603	12.51	25.43	5.95	
8	255	1.00	0.88	2844	659	11.35	23.18	5.95	
8	297.5	1.00	0.88	3318	715	12.05	21.54	5.9	
8	42.5	0.99	0.58	471	334	41.77	70.88	6.4	
8	85	0.99	0.74	941	492	25.67	52.30	6.1	
8	127.5	0.99	0.84	1412	587	14.70	41.59	5.95	
8	170	0.99	0.86	1883	654	13.53	34.72	6	
8	212.5	0.99	0.87	2354	714	11.90	30.32	5.95	
8	255	0.99	0.87	2824	770	11.90	27.25	5.95	
8	297.5	0.99	0.90	3295	818	8.63	24.83	5.9	
8	30	4.99	2.68	105	77	46.25	73.13	6.6	
8	60	4.99	2.85	210	123	42.87	58.84	6.6	
8	90	4.99	3.04	315	166	39.18	52.91	6.45	
8	120	4.99	3.14	420	207	37.19	49.23	6.2	
8	150	4.99	3.31	524	244	33.81	46.48	6.2	
8	180	4.99	3.42	629	278	31.50	44.17	6.15	
8	210	4.99	3.54	734	310	29.20	42.20	6.2	
8	240	4.99	3.26	839	343	34.73	40.92	6.2	
8	270	4.99	3.53	944	377	29.35	39.93	6.15	
8	300	4.99	3.49	1049	408	30.12	38.91	6.1	
8	30	4.90	2.43	103	77	50.37	75.18	6.6	
8	60	4.90	2.39	206	130	51.15	62.97	6.6	
8	90	4.90	2.48	309	181	49.27	58.72	6.45	
8	120	4.90	2.72	411	229	44.42	55.75	6.25	
8	150	4.90	2.88	514	273	41.13	53.15	6.2	
8	180	4.90	3.04	617	314	37.99	50.89	6.25	
8	210	4.90	3.04	720	353	37.99	49.05	6.25	
8	240	4.90	3.14	823	391	35.80	47.53	6.25	
8	270	4.90	3.20	926	427	34.70	46.16	6.2	
8	300	4.90	3.25	1029	462	33.61	44.96	6.1	
8	30	9.60	6.95	161	103	27.65	63.82	5.95	
8	60	9.60	6.72	323	150	30.04	46.33	5.95	
8	90	9.60	7.01	484	196	27.01	40.40	5.95	
8	120	9.60	7.29	645	237	24.13	36.69	6.05	
8	150	9.60	7.15	807	277	25.57	34.32	6.05	
8	180	9.60	7.27	968	317	24.29	32.76	6.05	
8	210	9.60	7.64	1129	353	20.45	31.27	6.15	
8	240	9.60	6.87	1291	393	28.44	30.42	6.1	
8	270	9.60	7.78	1452	431	19.02	29.68	6.1	
8	300	9.60	7.58	1614	463	21.09	28.71	6.1	
8	30	9.60	6.06	161	110	36.91	68.46	5.95	
8	60	9.60	6.40	323	167	33.40	51.81	6	
8	90	9.60	6.40	484	221	33.40	45.67	6	
8	120	9.60	6.38	645	275	33.56	42.62	6.1	
8	150	9.60	6.57	807	328	31.64	40.62	6.1	
8	180	9.60	6.86	968	376	28.60	38.87	6.1	
8	210	9.60	7.16	1129	420	25.41	37.17	6.2	
8	240	9.60	6.61	1291	466	31.16	36.06	6.15	

Table A.11: Continued

Retention Time	Collection Time	Inflow P Concentration	Outflow P concentration	Cumulative P Added	Cumulative P Sorbed	Discrete removal	Cumulative Removal	pH	EC
----- minutes -----		------ ppm ------		------ mg kg^{-1} ------		------ % ------			mS cm^{-1}
8	270	9.60	7.58	1452	508	21.09	34.96	6.15	
8	300	9.60	7.50	1614	542	21.89	33.61	6.15	
8	30	14.09	7.88	158	114	44.06	72.03	6.05	
8	60	14.09	7.71	316	184	45.28	58.35	6.15	
8	90	14.09	8.32	473	252	40.94	53.27	6.15	
8	120	14.09	8.60	631	315	38.98	49.94	6.3	
8	150	14.09	8.78	789	376	37.67	47.62	6.3	
8	180	14.09	9.36	947	432	33.57	45.62	6.3	
8	210	14.09	9.84	1105	482	30.14	43.65	6.4	
8	240	14.09	10.44	1262	526	25.88	41.70	6.35	
8	270	14.09	10.07	1420	569	28.50	40.09	6.3	
8	300	14.09	11.23	1578	608	20.31	38.52	6.25	
8	30	14.84	6.39	166	130	56.91	78.46	6.15	
8	60	14.84	6.91	332	222	53.41	66.81	6.2	
8	90	14.84	7.52	499	307	49.29	61.66	6.25	
8	120	14.84	8.14	665	386	45.17	58.05	6.3	
8	150	14.84	8.99	831	456	39.42	54.90	6.35	
8	180	14.84	9.47	997	519	36.15	52.05	6.35	
8	210	14.84	9.75	1163	578	34.29	49.64	6.4	
8	240	14.84	9.89	1329	634	33.35	47.67	6.35	
8	270	14.84	10.28	1496	687	30.71	45.93	6.3	
8	300	14.84	10.49	1662	737	29.31	44.34	6.3	
6	30	0.49	0.36	139	89	27.45	63.73	6.5	0.85
6	60	0.49	0.39	279	122	20.65	43.89	6.1	0.71
6	90	0.49	0.41	418	148	16.43	35.44	6	0.72
6	120	0.49	0.41	558	171	15.96	30.63	6.4	0.69
6	150	0.49	0.41	697	193	15.96	27.69	6.25	0.71
6	180	0.49	0.42	836	214	14.78	25.64	6.2	0.76
6	210	0.49	0.41	976	236	15.72	24.15	6.25	0.71
6	240	0.49	0.42	1115	257	15.49	23.09	6.25	0.7
6	270	0.49	0.41	1254	279	15.96	22.27	6.2	0.7
6	300	0.49	0.42	1394	301	15.02	21.59	6.15	0.71
6	30	0.50	0.35	140	91	29.36	64.68	6.4	0.74
6	60	0.50	0.39	281	126	20.50	44.81	6.1	0.72
6	90	0.50	0.41	421	153	17.94	36.28	6.05	0.71
6	120	0.50	0.42	561	176	15.15	31.34	6.45	0.71
6	150	0.50	0.41	702	199	17.24	28.31	6.25	0.71
6	180	0.50	0.43	842	220	12.82	26.10	6.2	0.71
6	210	0.50	0.43	983	238	13.05	24.22	6.3	0.75
6	240	0.50	0.43	1123	256	13.05	22.82	6.3	0.71
6	270	0.50	0.42	1263	276	15.38	21.87	6.25	0.71
6	300	0.50	0.44	1404	296	12.12	21.05	6.2	0.71
6	30	0.99	0.77	374	229	22.33	61.16	6.1	0.85
6	60	0.99	0.85	749	298	14.58	39.81	6.15	0.74
6	90	0.99	0.86	1123	351	13.42	31.21	6.05	0.71
6	120	0.99	0.88	1498	396	11.11	26.47	6.05	0.72
6	150	0.99	0.89	1872	437	10.41	23.33	6.1	0.76
6	180	0.99	0.88	2247	478	11.57	21.27	6.1	0.79
6	210	0.99	0.90	2621	517	9.26	19.72	6.1	0.7
6	240	0.99	0.89	2996	553	10.18	18.47	6.2	0.72

Table A.11: Continued

Retention Time	Collection Time	Inflow P Concentration	Outflow P concentration	Cumulative P Added	Cumulative P Sorbed	Discrete removal	Cumulative Removal	pH	EC
----- minutes -----		------ ppm ------		------ mg kg^{-1} ------		------ % ------			mS cm^{-1}
6	270	0.99	0.89	3370	591	10.18	17.55	6.15	0.67
6	300	0.99	0.88	3745	631	10.88	16.85	6.15	0.7
6	30	1.00	0.74	379	238	25.85	62.92	6.1	0.72
6	60	1.00	0.81	758	323	18.99	42.67	6.2	0.73
6	90	1.00	0.86	1136	386	13.95	33.94	6.05	0.84
6	120	1.00	0.88	1515	435	12.35	28.74	6.05	0.81
6	150	1.00	0.88	1894	482	12.35	25.46	6.15	0.79
6	180	1.00	0.89	2273	528	11.67	23.22	6.15	0.72
6	210	1.00	0.88	2652	573	12.35	21.62	6.1	0.7
6	240	1.00	0.86	3030	624	14.18	20.57	6.2	0.71
6	270	1.00	0.89	3409	672	11.44	19.71	6.15	0.72
6	300	1.00	0.88	3788	717	12.35	18.93	6.1	0.71
6	30	4.98	3.14	141	97	36.96	68.48	6.2	
6	60	4.98	3.30	283	147	33.87	51.94	6.1	
6	90	4.98	3.52	424	192	29.39	45.17	5.9	
6	120	4.98	3.67	565	231	26.46	40.86	5.95	
6	150	4.98	3.63	707	269	27.23	38.06	5.95	
6	180	4.98	3.77	848	305	24.46	36.02	5.95	
6	210	4.98	3.80	989	340	23.84	34.33	5.95	
6	240	4.98	3.87	1130	372	22.30	32.92	5.9	
6	270	4.98	3.82	1272	404	23.38	31.80	5.9	
6	300	4.98	3.87	1413	437	22.45	30.91	5.9	
6	30	4.77	3.50	135	86	26.59	63.29	6.15	
6	60	4.77	3.60	271	120	24.65	44.46	6.1	
6	90	4.77	3.83	406	150	19.82	37.05	5.9	
6	120	4.77	3.76	541	178	21.27	32.92	6	
6	150	4.77	3.92	677	205	17.89	30.26	5.95	
6	180	4.77	3.93	812	229	17.56	28.17	5.95	
6	210	4.77	4.10	947	250	14.10	26.40	5.95	
6	240	4.77	4.02	1082	270	15.79	24.97	5.9	
6	270	4.77	4.10	1218	291	14.10	23.86	5.9	
6	300	4.77	4.14	1353	309	13.29	22.84	5.9	
6	30	9.68	4.48	146	113	53.74	76.87	6.5	1.1
6	60	9.68	5.23	293	186	45.97	63.37	6.55	0.85
6	90	9.68	5.57	439	250	42.49	56.99	6.45	0.74
6	120	9.68	6.01	586	309	37.89	52.79	6.25	0.76
6	150	9.68	6.50	732	361	32.82	49.30	6.25	0.71
6	180	9.68	6.78	878	407	29.96	46.32	6.25	0.74
6	210	9.68	6.92	1025	450	28.54	43.88	6.25	0.71
6	240	9.68	7.04	1171	490	27.27	41.88	6.25	0.72
6	270	9.68	6.98	1317	531	27.90	40.29	6.2	0.71
6	300	9.68	7.15	1464	570	26.16	38.97	6.2	0.7
6	30	9.64	5.35	146	105	44.49	72.24	6.55	1.1
6	60	9.64	5.66	292	168	41.30	57.57	6.6	0.83
6	90	9.64	5.91	437	226	38.76	51.72	6.5	0.75
6	120	9.64	6.20	583	281	35.73	48.10	6.3	0.76
6	150	9.64	6.57	729	330	31.91	45.25	6.3	0.73
6	180	9.64	7.04	875	373	26.98	42.61	6.4	0.71
6	210	9.64	6.93	1021	413	28.09	40.46	6.35	0.73
6	240	9.64	7.03	1166	453	27.14	38.85	6.35	0.73

Table A.11: Continued

Retention Time	Collection Time	Inflow P Concentration	Outflow P concentration	Cumulative P Added	Cumulative P Sorbed	Discrete removal	Cumulative Removal	pH	EC
----- minutes -----		------ ppm ------		------ mg kg^{-1} ------		------ % ------			mS cm^{-1}
6	270	9.64	6.96	1312	493	27.77	37.59	6.3	0.72
6	300	9.64	7.07	1458	533	26.66	36.55	6.3	0.72
6	30	15.04	6.51	190	148	56.71	78.36	6.15	1.06
6	60	15.04	7.58	379	249	49.60	65.76	6.35	0.83
6	90	15.04	7.91	569	341	47.38	60.00	6.4	0.79
6	120	15.04	8.58	758	427	42.94	56.29	6.3	0.7
6	150	15.04	9.43	948	503	37.27	53.05	6.3	0.7
6	180	15.04	10.10	1137	569	32.83	50.05	6.3	0.7
6	210	15.04	10.12	1327	631	32.68	47.58	6.35	0.71
6	240	15.04	8.95	1516	701	40.49	46.21	6.3	0.69
6	270	15.04	10.15	1706	770	32.53	45.13	6.3	0.69
6	300	15.04	11.16	1895	825	25.79	43.53	6.35	0.69
6	30	15.10	6.88	190	147	54.44	77.22	6.2	1.06
6	60	15.10	7.60	380	246	49.64	64.63	6.4	0.8
6	90	15.10	8.54	571	334	43.46	58.60	6.4	0.79
6	120	15.10	9.25	761	413	38.73	54.23	6.35	0.7
6	150	15.10	9.64	951	484	36.14	50.87	6.35	0.7
6	180	15.10	9.99	1141	550	33.85	48.22	6.35	0.7
6	210	15.10	10.06	1332	614	33.40	46.14	6.35	0.69
6	240	15.10	10.47	1522	675	30.65	44.37	6.35	0.7
6	270	15.10	10.15	1712	736	32.79	42.97	6.3	0.68
6	300	15.10	9.73	1902	801	35.53	42.09	6.3	0.69
3	30	0.49	0.27	137	100	45.46	72.73	6.15	
3	60	0.49	0.30	275	157	37.92	57.21	6.45	
3	90	0.49	0.32	412	207	33.92	50.11	6.45	
3	120	0.49	0.34	550	251	30.38	45.62	6.25	
3	150	0.49	0.35	687	292	28.97	42.43	6.2	
3	180	0.49	0.35	825	330	27.56	40.07	6.2	
3	210	0.49	0.36	962	368	26.85	38.23	6.2	
3	240	0.49	0.37	1100	404	25.20	36.71	6.2	
3	270	0.49	0.37	1237	438	24.50	35.39	6.2	
3	300	0.49	0.37	1375	471	23.32	34.24	6.2	
3	30	0.49	0.27	138	101	45.61	72.80	6.2	
3	60	0.49	0.32	277	156	34.61	56.46	6.45	
3	90	0.49	0.33	415	203	32.74	48.86	6.45	
3	120	0.49	0.35	554	246	29.70	44.45	6.25	
3	150	0.49	0.35	692	287	29.70	41.50	6.2	
3	180	0.49	0.36	831	326	26.90	39.30	6.25	
3	210	0.49	0.36	969	363	26.43	37.50	6.25	
3	240	0.49	0.37	1107	399	25.73	36.07	6.25	
3	270	0.49	0.37	1246	434	24.32	34.84	6.2	
3	300	0.49	0.38	1384	467	22.69	33.71	6.2	
3	30	1.00	0.75	225	140	24.79	62.40	6.15	
3	60	1.00	0.79	450	192	20.87	42.61	5.9	
3	90	1.00	0.82	675	236	18.45	34.96	5.8	
3	120	1.00	0.85	900	274	14.99	30.40	5.8	
3	150	1.00	0.87	1125	305	13.15	27.14	5.8	
3	180	1.00	0.87	1351	334	12.68	24.77	5.9	
3	210	1.00	0.88	1576	362	11.99	22.99	5.85	
3	240	1.00	0.90	1801	387	10.15	21.50	5.8	

Table A.11: Continued

Retention Time	Collection Time	Inflow P Concentration	Outflow P concentration	Cumulative P Added	Cumulative P Sorbed	Discrete removal	Cumulative Removal	pH	EC
----- minutes -----		------ ppm ------		------ mg kg^{-1} ------		------ % ------			mS cm^{-1}
3	270	1.00	0.88	2026	412	11.99	20.34	5.85	
3	300	1.00	0.91	2251	435	8.76	19.35	5.85	
3	30	0.99	0.82	222	130	17.03	58.52	6.05	
3	60	0.99	0.87	445	162	11.90	36.49	5.9	
3	90	0.99	0.88	667	188	10.73	28.10	5.8	
3	120	0.99	0.88	890	211	10.73	23.76	5.8	
3	150	0.99	0.88	1112	236	11.43	21.22	5.8	
3	180	0.99	0.90	1335	258	8.63	19.36	5.9	
3	210	0.99	0.92	1557	276	7.47	17.74	5.85	
3	240	0.99	0.92	1780	292	7.00	16.43	5.8	
3	270	0.99	0.92	2002	308	7.00	15.38	5.85	
3	300	0.99	0.89	2225	327	9.80	14.68	5.85	
3	30	4.90	3.19	138	93	34.86	67.43	5.95	
3	60	4.90	3.37	276	138	31.10	50.20	5.85	
3	90	4.90	3.51	413	179	28.28	43.37	5.85	
3	120	4.90	3.64	551	216	25.62	39.26	5.95	
3	150	4.90	3.70	689	251	24.36	36.41	5.95	
3	180	4.90	3.93	827	281	19.82	34.02	5.95	
3	210	4.90	3.87	964	309	20.92	32.07	6	
3	240	4.90	3.90	1102	338	20.45	30.65	6	
3	270	4.90	3.91	1240	366	20.13	29.50	6	
3	300	4.90	3.98	1378	392	18.72	28.49	6	
3	30	4.90	3.36	138	91	31.41	65.71	5.95	
3	60	4.90	3.39	276	133	30.79	48.40	5.9	
3	90	4.90	3.61	413	173	26.24	41.77	5.9	
3	120	4.90	3.64	551	208	25.62	37.81	6	
3	150	4.90	3.90	689	240	20.29	34.84	6	
3	180	4.90	3.97	827	267	18.88	32.30	6	
3	210	4.90	4.02	964	292	17.94	30.31	6.05	
3	240	4.90	4.04	1102	317	17.47	28.74	6.05	
3	270	4.90	3.94	1240	342	19.51	27.60	6	
3	300	4.90	4.13	1378	366	15.67	26.60	6	
3	30	9.58	5.68	180	126	40.68	70.34	6.05	
3	60	9.58	6.45	359	192	32.66	53.51	6.1	
3	90	9.58	6.64	539	249	30.73	46.24	6.05	
3	120	9.58	6.95	719	302	27.52	41.96	6.15	
3	150	9.58	7.27	899	348	24.15	38.74	6.05	
3	180	9.58	7.41	1078	390	22.71	36.19	6.05	
3	210	9.58	7.64	1258	429	20.30	34.09	6.05	
3	240	9.58	7.41	1438	467	22.71	32.52	6	
3	270	9.58	7.52	1617	507	21.59	31.36	6	
3	300	9.58	7.73	1797	544	19.34	30.27	6	
3	30	9.74	5.93	183	127	39.09	69.55	6.1	
3	60	9.74	6.53	365	193	32.93	52.78	6.2	
3	90	9.74	6.96	548	249	28.51	45.43	6.2	
3	120	9.74	6.93	730	301	28.83	41.24	6.25	
3	150	9.74	7.21	913	351	25.98	38.47	6.15	
3	180	9.74	7.41	1096	397	23.93	36.22	6.15	
3	210	9.74	7.93	1278	436	18.56	34.08	6.15	
3	240	9.74	7.82	1461	470	19.67	32.21	6.1	

Table A.11: Continued

Retention Time	Collection Time	Inflow P Concentration	Outflow P concentration	Cumulative P Added	Cumulative P Sorbed	Discrete removal	Cumulative Removal	pH	EC
----- minutes -----		------ ppm ------		------ mg kg^{-1} ------		------ % ------			mS cm^{-1}
3	270	9.74	7.93	1643	505	18.56	30.75	6.1	
3	300	9.74	7.75	1826	541	20.46	29.63	6.1	
3	30	14.69	6.97	207	158	52.56	76.28	6.5	
3	60	14.69	8.70	413	254	40.81	61.48	6.5	
3	90	14.69	9.94	620	330	32.35	53.18	6.45	
3	120	14.69	9.62	827	399	34.55	48.25	6.4	
3	150	14.69	10.42	1033	465	29.06	44.96	6.3	
3	180	14.69	9.87	1240	528	32.82	42.62	6.4	
3	210	14.69	11.44	1446	585	22.17	40.46	6.35	
3	240	14.69	11.16	1653	633	24.05	38.29	6.3	
3	270	14.69	10.91	1860	685	25.77	36.81	6.25	
3	300	14.69	10.82	2066	738	26.40	35.73	6.3	
3	30	15.04	7.18	211	161	52.27	76.14	6.5	
3	60	15.04	8.72	423	261	42.02	61.64	6.45	
3	90	15.04	9.66	634	343	35.74	54.05	6.4	
3	120	15.04	9.39	846	421	37.58	49.71	6.4	
3	150	15.04	10.52	1057	492	30.08	46.53	6.3	
3	180	15.04	11.11	1269	551	26.10	43.46	6.4	
3	210	15.04	9.85	1480	616	34.52	41.58	6.35	
3	240	15.04	11.21	1692	679	25.49	40.13	6.35	
3	270	15.04	10.98	1903	735	27.02	38.59	6.3	
3	300	15.04	11.34	2115	789	24.57	37.31	6.25	
0.5	30	0.49	0.41	165	96	16.53	58.26	7.2	
0.5	60	0.49	0.42	329	122	14.64	36.92	6.8	
0.5	90	0.49	0.43	494	143	12.04	29.06	6.6	
0.5	120	0.49	0.42	658	164	13.22	24.95	6.35	
0.5	150	0.49	0.43	823	185	12.28	22.51	6.25	
0.5	180	0.49	0.43	987	206	12.51	20.83	6.2	
0.5	210	0.49	0.43	1152	226	12.28	19.62	6.2	
0.5	240	0.49	0.43	1316	246	11.80	18.67	6.25	
0.5	270	0.49	0.43	1481	265	12.04	17.92	6.25	
0.5	300	0.49	0.43	1646	285	11.33	17.30	6.15	
0.5	30	0.48	0.41	162	92	13.68	56.84	7.2	
0.5	60	0.48	0.43	324	112	11.04	34.60	6.8	
0.5	90	0.48	0.43	486	129	10.56	26.67	6.6	
0.5	120	0.48	0.43	647	146	10.08	22.58	6.35	
0.5	150	0.48	0.42	809	164	12.48	20.32	6.25	
0.5	180	0.48	0.43	971	182	9.60	18.78	6.2	
0.5	210	0.48	0.43	1133	199	10.56	17.53	6.25	
0.5	240	0.48	0.43	1295	215	9.84	16.62	6.25	
0.5	270	0.48	0.43	1457	231	9.36	15.84	6.2	
0.5	300	0.48	0.43	1618	246	9.36	15.19	6.15	
0.5	30	0.99	0.87	298	167	12.54	56.27	6.2	
0.5	60	0.99	0.87	595	205	12.54	34.40	6.4	
0.5	90	0.99	0.88	893	240	11.37	26.92	6.45	
0.5	120	0.99	0.89	1190	272	9.98	22.86	6.25	
0.5	150	0.99	0.90	1488	301	9.75	20.26	6.2	
0.5	180	0.99	0.90	1785	330	9.52	18.49	6.2	
0.5	210	0.99	0.91	2083	356	7.89	17.09	6.2	
0.5	240	0.99	0.90	2380	382	9.29	16.03	6.2	

Table A.11: Continued

Retention Time	Collection Time	Inflow P Concentration	Outflow P concentration	Cumulative P Added	Cumulative P Sorbed	Discrete removal	Cumulative Removal	pH	EC
----- minutes -----		------ ppm ------		------ mg kg^{-1} ------		------ % ------			mS cm^{-1}
0.5	270	0.99	0.91	2678	408	8.36	15.23	6.2	
0.5	300	0.99	0.91	2975	433	8.36	14.54	6.2	
0.5	30	0.99	0.81	298	177	18.53	59.26	6.15	
0.5	60	0.99	0.83	596	229	16.21	38.32	6.4	
0.5	90	0.99	0.85	895	274	14.59	30.68	6.4	
0.5	120	0.99	0.85	1193	318	14.82	26.69	6.2	
0.5	150	0.99	0.86	1491	360	13.43	24.17	6.2	
0.5	180	0.99	0.88	1789	398	11.58	22.23	6.2	
0.5	210	0.99	0.89	2088	431	10.65	20.64	6.2	
0.5	240	0.99	0.87	2386	465	12.04	19.48	6.2	
0.5	270	0.99	0.89	2684	499	10.89	18.59	6.2	
0.5	300	0.99	0.88	2982	532	11.12	17.83	6.2	
0.5	30	4.91	4.10	442	257	16.46	58.23	6.1	
0.5	60	4.91	4.27	883	322	12.93	36.46	6	
0.5	90	4.91	4.27	1325	379	12.93	28.62	6	
0.5	120	4.91	4.25	1767	437	13.32	24.74	6.25	
0.5	150	4.91	4.31	2208	493	12.15	22.34	6.15	
0.5	180	4.91	4.48	2650	539	8.62	20.35	6.1	
0.5	210	4.91	4.47	3092	578	9.01	18.70	6.2	
0.5	240	4.91	4.41	3533	621	10.19	17.56	6.15	
0.5	270	4.91	4.45	3975	664	9.40	16.70	6.15	
0.5	300	4.91	4.37	4417	709	10.97	16.05	6.1	
0.5	30	4.95	4.12	445	260	16.72	58.36	6.05	
0.5	60	4.95	4.31	890	326	12.83	36.57	6	
0.5	90	4.95	4.45	1335	377	10.11	28.20	6	
0.5	120	4.95	4.31	1781	428	12.83	24.02	6.2	
0.5	150	4.95	4.43	2226	480	10.50	21.55	6.15	
0.5	180	4.95	4.56	2671	520	7.78	19.48	6.1	
0.5	210	4.95	4.48	3116	558	9.33	17.92	6.2	
0.5	240	4.95	4.56	3561	596	7.78	16.75	6.2	
0.5	270	4.95	4.60	4006	629	7.00	15.71	6.15	
0.5	300	4.95	4.70	4451	656	5.05	14.74	6.1	
0.5	30	9.80	8.46	1323	752	13.65	56.82	6	
0.5	60	9.80	8.73	2646	914	10.92	34.55	6.1	
0.5	90	9.80	8.61	3968	1066	12.09	26.87	6.1	
0.5	120	9.80	8.96	5291	1203	8.58	22.74	6.15	
0.5	150	9.80	8.88	6614	1322	9.36	19.98	6.2	
0.5	180	9.80	9.07	7937	1432	7.41	18.05	6.15	
0.5	210	9.80	8.84	9260	1546	9.75	16.70	6.15	
0.5	240	9.80	8.96	10582	1667	8.58	15.75	6.2	
0.5	270	9.80	9.15	11905	1768	6.63	14.85	6.25	
0.5	300	9.80	8.92	13228	1871	8.97	14.14	6.2	
0.5	30	9.30	7.93	1256	720	14.70	57.35	6.05	
0.5	60	9.30	8.69	2511	854	6.57	33.99	6.2	
0.5	90	9.30	8.42	3767	954	9.45	25.33	6.2	
0.5	120	9.30	8.38	5023	1076	9.86	21.41	6.25	
0.5	150	9.30	8.96	6279	1161	3.70	18.49	6.3	
0.5	180	9.30	8.61	7534	1230	7.39	16.33	6.25	
0.5	210	9.30	8.92	8790	1302	4.11	14.82	6.25	
0.5	240	9.30	8.69	10046	1370	6.57	13.63	6.3	

Table A.11: Continued

Retention Time	Collection Time	Inflow P Concentration	Outflow P concentration	Cumulative P Added	Cumulative P Sorbed	Discrete removal	Cumulative Removal	pH	EC
----- minutes -----		------ ppm ------		------ mg kg^{-1} ------		------ % ------			mS cm^{-1}
0.5	270	9.30	8.58	11302	1460	7.80	12.92	6.35	
0.5	300	9.30	8.88	12557	1537	4.52	12.24	6.3	
0.5	30	14.95	13.91	3106	1661	6.94	53.47	6.35	
0.5	60	14.95	14.15	6211	1852	5.40	29.82	6.5	
0.5	90	14.95	13.34	9317	2104	10.80	22.58	6.35	
0.5	120	14.95	13.91	12423	2379	6.94	19.15	6.5	
0.5	150	14.95	13.57	15528	2631	9.26	16.94	6.5	
0.5	180	14.95	13.68	18634	2907	8.49	15.60	6.45	
0.5	210	14.95	13.28	21740	3212	11.19	14.78	6.45	
0.5	240	14.95	13.86	24845	3500	7.33	14.09	6.5	
0.5	270	14.95	13.11	27951	3805	12.34	13.61	6.45	
0.5	300	14.95	13.97	31057	4099	6.56	13.20	6.5	
0.5	30	14.95	12.88	3106	1768	13.89	56.94	6.4	
0.5	60	14.95	13.97	6211	2086	6.56	33.58	6.5	
0.5	90	14.95	12.59	9317	2433	15.82	26.12	6.45	
0.5	120	14.95	13.40	12423	2841	10.42	22.87	6.55	
0.5	150	14.95	14.15	15528	3086	5.40	19.88	6.5	
0.5	180	14.95	13.74	18634	3296	8.10	17.69	6.5	
0.5	210	14.95	13.34	21740	3589	10.80	16.51	6.5	
0.5	240	14.95	13.68	24845	3889	8.49	15.65	6.5	
0.5	270	14.95	14.38	27951	4081	3.86	14.60	6.5	
0.5	300	14.95	14.03	31057	4236	6.17	13.64	6.5	

Table A.12: Results of Excell Minerals flow-through experiment.

Retention Time	Collection Time	Inflow P Concentration	Outflow P concentration	Cumulative P Added	Cumulative P Sorbed	Discrete removal	Cumulative Removal	pH	EC
----- minutes -----		------ ppm ------		------ mg kg^{-1} ------		------ % ------			$mS\ cm^{-1}$
10	60	0.49	0.33	331	219	32.46	66.23	7	
10	120	0.49	0.36	664	317	25.57	47.69	6.9	
10	180	0.49	0.40	998	389	17.82	39.00	6.9	
10	240	0.49	0.43	1331	440	12.65	33.04	6.5	
10	300	0.49	0.42	1665	484	14.06	29.10	6.7	
10	60	0.49	0.38	332	204	22.88	61.44	7	
10	120	0.49	0.39	664	276	20.52	41.57	6.9	
10	180	0.49	0.41	996	336	15.80	33.77	6.9	
10	240	0.49	0.43	1328	383	12.50	28.86	6.7	
10	300	0.49	0.40	1661	433	17.22	26.06	6.8	
10	60	1.05	0.27	2856	2487	74.11	87.06	7	
10	120	1.05	0.31	5713	4550	70.38	79.65	6.8	
10	180	1.05	0.51	8569	6291	51.53	73.42	6.95	
10	240	1.05	0.77	11425	7400	26.09	64.77	6.95	
10	300	1.05	1.12	14282	7672	-7.02	53.72	6.7	
10	60	0.96	0.41	2612	2059	57.66	78.83	7	
10	120	0.96	0.29	5224	3727	70.01	71.34	6.85	
10	180	0.96	0.41	7836	5391	57.42	68.80	6.75	
10	240	0.96	0.56	10448	6689	41.96	64.02	6.95	
10	300	0.96	0.78	13060	7480	18.58	57.27	6.7	
10	30	4.92	1.63	2232	1861	66.78	83.39	6.55	
10	60	4.92	0.80	4463	3540	83.66	79.31	7	
10	90	4.92	0.96	6695	5371	80.44	80.22	6.8	
10	120	4.92	1.24	8927	7102	74.71	79.56	6.8	
10	150	4.92	1.49	11158	8714	69.77	78.09	7	
10	180	4.92	1.89	13390	10179	61.53	76.02	7	
10	210	4.92	2.13	15622	11497	56.58	73.60	7.1	
10	240	4.92	2.22	17853	12741	54.93	71.37	7	
10	270	4.92	2.40	20085	13924	51.09	69.33	6.85	
10	300	4.92	2.38	22316	15069	51.56	67.53	6.8	
10	30	4.93	2.35	2240	1707	52.37	76.19	6.6	
10	60	4.93	1.52	4481	3069	69.26	68.50	7	
10	90	4.93	1.69	6721	4581	65.66	68.15	6.9	
10	120	4.93	2.11	8962	5958	57.30	66.49	6.8	
10	150	4.93	2.90	11202	7062	41.20	63.04	7	
10	180	4.93	2.98	13442	7967	39.63	59.27	7	
10	210	4.93	2.89	15683	8874	41.35	56.58	7	
10	240	4.93	2.99	17923	9778	39.32	54.55	7.05	
10	270	4.93	3.01	20164	10655	39.01	52.84	6.85	
10	300	4.93	3.04	22404	11522	38.38	51.43	6.8	
10	30	8.85	5.93	2010	1336	32.97	66.49	7.1	
10	60	8.85	3.61	4020	2263	59.24	56.30	7.3	
10	90	8.85	3.66	6029	3448	58.71	57.19	7.6	
10	120	8.85	4.24	8039	4562	52.10	56.74	7.4	
10	150	8.85	4.73	10049	5553	46.55	55.26	7.35	
10	180	8.85	5.19	12059	6436	41.35	53.37	7.35	
10	210	8.85	5.22	14068	7264	40.99	51.63	7.35	

Table A.12: Continued

Retention Time	Collection Time	Inflow P Concentration	Outflow P concentration	Cumulative P Added	Cumulative P Sorbed	Discrete removal	Cumulative Removal	pH	EC
----- minutes -----		------ ppm ------		------ mg kg^{-1} ------		------ % ------			mS cm^{-1}
10	240	8.85	5.50	16078	8056	37.91	50.11	7.3	
10	270	8.85	6.01	18088	8760	32.09	48.43	7.15	
10	300	8.85	6.06	20098	9399	31.56	46.77	7.15	
10	30	9.87	7.18	2240	1425	27.21	63.60	7.1	
10	60	9.87	4.76	4480	2310	51.81	51.56	6.9	
10	90	9.87	4.71	6720	3476	52.28	51.72	7.5	
10	120	9.87	5.12	8960	4600	48.09	51.33	7.5	
10	150	9.87	5.50	11201	5634	44.29	50.31	7.3	
10	180	9.87	6.17	13441	6550	37.49	48.74	7.3	
10	210	9.87	6.09	15681	7399	38.28	47.19	7.35	
10	240	9.87	6.68	17921	8189	32.27	45.70	7.3	
10	270	9.87	7.07	20161	8868	28.31	43.99	7	
10	300	9.87	7.09	22401	9500	28.16	42.41	7.1	
10	30	14.74	10.08	3346	2202	31.60	65.80	7.2	
10	60	14.74	8.61	6692	3426	41.56	51.19	7.4	
10	90	14.74	9.42	10038	4725	36.11	47.07	7.3	
10	120	14.74	10.15	13384	5850	31.13	43.71	7.3	
10	150	14.74	10.54	16730	6847	28.49	40.93	7.4	
10	180	14.74	11.30	20075	7715	23.35	38.43	7.4	
10	210	14.74	10.66	23421	8569	27.71	36.59	7.4	
10	240	14.74	11.67	26767	9381	20.86	35.05	7.25	
10	270	14.74	11.67	30113	10079	20.86	33.47	7.3	
10	300	14.74	11.41	33459	10806	22.57	32.30	7.3	
10	30	14.62	9.42	3320	2251	35.61	67.81	7.3	
10	60	14.62	8.20	6640	3571	43.93	53.79	7.25	
10	90	14.62	8.84	9960	4957	39.53	49.77	7.4	
10	120	14.62	9.78	13279	6162	33.10	46.41	7.35	
10	150	14.62	10.24	16599	7209	29.96	43.43	7.45	
10	180	14.62	10.52	19919	8173	28.08	41.03	7.3	
10	210	14.62	10.86	23239	9066	25.73	39.01	7.8	
10	240	14.62	11.16	26559	9886	23.69	37.22	7.2	
10	270	14.62	11.28	29879	10660	22.90	35.68	7.2	
10	300	14.62	11.00	33199	11452	24.79	34.49	7.2	
8	42.5	0.51	0.48	306	163	6.75	53.38	6.8	
8	85	0.51	0.24	612	255	53.35	41.71	7.2	
8	127.5	0.51	0.29	918	403	43.44	43.94	7.1	
8	170	0.51	0.33	1224	523	34.89	42.75	7	
8	212.5	0.51	0.38	1530	617	26.79	40.36	6.95	
8	255	0.51	0.35	1835	706	31.06	38.46	6.95	
8	297.5	0.51	0.34	2141	805	33.99	37.61	6.7	
8	42.5	0.52	0.33	309	209	35.69	67.85	6.8	
8	85	0.52	0.21	617	357	60.01	57.85	7	
8	127.5	0.52	0.24	926	531	52.87	57.38	7.05	
8	170	0.52	0.31	1235	675	40.38	54.69	6.95	
8	212.5	0.52	0.34	1543	790	33.68	51.16	7.05	
8	255	0.52	0.33	1852	898	36.36	48.47	6.9	
8	297.5	0.52	0.34	2161	1007	34.58	46.61	6.7	
8	42.5	1.00	0.23	1580	1399	77.14	88.57	6.95	
8	85	1.00	0.21	3160	2632	78.87	83.29	6.95	

Table A.12: Continued

Retention Time	Collection Time	Inflow P Concentration	Outflow P concentration	Cumulative P Added	Cumulative P Sorbed	Discrete removal	Cumulative Removal	pH	EC
----- minutes -----		------ ppm ------		------ mg kg^{-1} ------		------ % ------			mS cm^{-1}
8	127.5	1.00	0.24	4740	3853	75.75	81.29	6.95	
8	170	1.00	0.27	6320	5027	72.75	79.53	6.85	
8	212.5	1.00	0.29	7900	6162	71.02	78.00	6.75	
8	255	1.00	0.28	9480	7292	71.94	76.91	6.7	
8	297.5	1.00	0.26	11060	8444	73.90	76.34	6.55	
8	42.5	0.98	0.30	1562	1326	69.74	84.87	7	
8	85	0.98	0.25	3124	2454	74.77	78.56	6.95	
8	127.5	0.98	0.29	4685	3588	70.44	76.58	7	
8	170	0.98	0.33	6247	4654	66.12	74.50	6.85	
8	212.5	0.98	0.37	7809	5661	62.73	72.49	6.82	
8	255	0.98	0.35	9371	6651	64.14	70.98	6.7	
8	297.5	0.98	0.33	10932	7673	66.71	70.19	6.55	
8	30	4.82	1.12	1012	894	76.68	88.34	7.2	
8	60	4.82	0.50	2023	1735	89.54	85.72	7.5	
8	90	4.82	0.63	3035	2627	86.92	86.56	7.45	
8	120	4.82	0.81	4047	3487	83.11	86.17	8	
8	150	4.82	1.05	5059	4303	78.26	85.07	7.55	
8	180	4.82	1.16	6070	5084	75.96	83.75	7.9	
8	210	4.82	1.28	7082	5840	73.50	82.46	7.65	
8	240	4.82	1.33	8094	6577	72.31	81.26	7.3	
8	270	4.82	1.41	9105	7300	70.64	80.18	7.4	
8	300	4.82	1.44	10117	8012	70.01	79.19	7.3	
8	30	4.59	1.44	964	812	68.51	84.25	7.5	
8	60	4.59	0.83	1927	1537	81.93	79.74	7.4	
8	90	4.59	1.14	2891	2293	75.18	79.34	7.4	
8	120	4.59	1.46	3854	2984	68.26	77.44	7.5	
8	150	4.59	1.70	4818	3616	62.84	75.06	7.55	
8	180	4.59	1.88	5781	4203	59.01	72.70	7.8	
8	210	4.59	2.13	6745	4746	53.67	70.37	7.55	
8	240	4.59	2.24	7708	5251	51.17	68.12	7.2	
8	270	4.59	2.30	8672	5738	49.84	66.17	7.35	
8	300	4.59	2.30	9635	6218	49.84	64.53	7.3	
8	30	9.59	5.61	2301	1628	41.48	70.74	7.2	
8	60	9.59	5.30	4603	2620	44.76	56.93	7	
8	90	9.59	6.15	6904	3548	35.89	51.40	6.95	
8	120	9.59	6.39	9205	4345	33.33	47.20	6.75	
8	150	9.59	6.55	11506	5093	31.73	44.26	6.65	
8	180	9.59	6.65	13808	5811	30.61	42.08	6.85	
8	210	9.59	6.84	16109	6493	28.69	40.31	6.75	
8	240	9.59	6.81	18410	7157	29.01	38.88	6.75	
8	270	9.59	6.93	20712	7810	27.73	37.71	6.75	
8	300	9.59	6.88	23013	8454	28.21	36.74	6.7	
8	30	9.28	2.50	2228	1928	73.08	86.54	7.15	
8	60	9.28	1.79	4456	3642	80.76	81.73	7.2	
8	90	9.28	2.81	6684	5318	69.69	79.56	7.2	
8	120	9.28	4.11	8912	6715	55.74	75.35	7.05	
8	150	9.28	4.53	11140	7907	51.20	70.97	6.95	
8	180	9.28	5.04	13368	8987	45.75	67.22	6.95	
8	210	9.28	5.18	15596	9988	44.18	64.04	6.8	
8	240	9.28	5.73	17824	10907	38.23	61.19	6.8	

Table A.12: Continued

Retention Time	Collection Time	Inflow P Concentration	Outflow P concentration	Cumulative P Added	Cumulative P Sorbed	Discrete removal	Cumulative Removal	pH	EC
----- minutes -----		------ ppm ------		------ mg kg^{-1} ------		------ % ------			mS cm^{-1}
8	270	9.28	5.81	20052	11749	37.41	58.59	6.7	
8	300	9.28	5.86	22280	12577	36.91	56.45	6.5	
8	30	14.45	6.33	2428	1896	56.22	78.11	7.1	
8	60	14.45	4.31	4856	3431	70.16	70.65	7.3	
8	90	14.45	5.73	7283	5015	60.36	68.85	7.6	
8	120	14.45	6.72	9711	6397	53.47	65.87	7.4	
8	150	14.45	7.27	12139	7648	49.66	63.01	7.3	
8	180	14.45	8.55	14567	8747	40.83	60.05	7.4	
8	210	14.45	9.49	16995	9660	34.35	56.84	7.4	
8	240	14.45	9.58	19422	10486	33.70	53.99	7.2	
8	270	14.45	9.93	21850	11274	31.27	51.60	7.1	
8	300	14.45	10.14	24278	12016	29.81	49.49	7.1	
8	30	15.33	8.86	2575	1831	42.23	71.12	6.75	
8	60	15.33	6.96	5151	3078	54.61	59.77	6.9	
8	90	15.33	7.67	7726	4425	49.95	57.27	7.6	
8	120	15.33	8.36	10301	5653	45.44	54.88	7.6	
8	150	15.33	9.00	12877	6770	41.32	52.58	7.3	
8	180	15.33	9.11	15452	7825	40.55	50.64	7.2	
8	210	15.33	9.98	18027	8796	34.90	48.79	7.45	
8	240	15.33	10.12	20603	9683	33.99	47.00	7.4	
8	270	15.33	10.38	23178	10537	32.31	45.46	7	
8	300	15.33	10.87	25753	11327	29.10	43.98	7.1	
6	30	0.49	0.28	222	159	43.26	71.63	6.8	0.518
6	60	0.49	0.24	444	263	50.67	59.30	7.1	0.523
6	90	0.49	0.26	667	372	46.85	55.79	7.5	0.507
6	120	0.49	0.31	889	464	36.09	52.21	7.6	0.59
6	150	0.49	0.36	1111	534	26.77	48.05	7.3	0.52
6	180	0.49	0.43	1333	577	12.19	43.29	7.1	0.515
6	210	0.49	0.34	1555	624	30.36	40.15	7.5	0.522
6	240	0.49	0.39	1777	682	21.27	38.35	7.5	0.492
6	270	0.49	0.38	2000	730	21.99	36.50	7.5	0.51
6	300	0.49	0.38	2222	778	21.51	35.02	7.5	0.519
6	30	0.49	0.26	223	164	47.10	73.55	6.7	0.529
6	60	0.49	0.21	446	281	57.81	63.00	7.2	0.66
6	90	0.49	0.23	670	406	53.76	60.60	7.6	0.528
6	120	0.49	0.33	893	503	33.07	56.30	7.5	0.6
6	150	0.49	0.30	1116	583	38.54	52.20	7.3	0.5
6	180	0.49	0.35	1339	658	29.02	49.13	7.3	0.505
6	210	0.49	0.30	1563	733	38.06	46.91	7.5	0.524
6	240	0.49	0.33	1786	811	32.12	45.43	7.65	0.528
6	270	0.49	0.33	2009	883	32.35	43.96	7.15	0.502
6	300	0.49	0.32	2232	958	34.97	42.93	7.55	0.516
6	30	0.99	0.39	1495	1196	60.05	80.03	6.5	0.88
6	60	0.99	0.27	2990	2188	72.69	73.20	6.95	0.697
6	90	0.99	0.37	4484	3200	62.63	71.35	6.9	0.661
6	120	0.99	0.47	5979	4057	52.09	67.85	7	0.689
6	150	0.99	0.60	7474	4741	39.45	63.44	7	0.71
6	180	0.99	0.53	8969	5386	46.82	60.05	6.8	0.692
6	210	0.99	0.48	10463	6119	51.27	58.48	7	0.73
6	240	0.99	0.47	11958	6891	51.97	57.62	6.9	0.695

Table A.12: Continued

Retention Time	Collection Time	Inflow P Concentration	Outflow P concentration	Cumulative P Added	Cumulative P Sorbed	Discrete removal	Cumulative Removal	pH	EC
----- minutes -----		------ ppm ------		------ mg kg^{-1} ------		------ % ------			mS cm^{-1}
6	270	0.99	0.46	13453	7682	53.85	57.10	7	0.735
6	300	0.99	0.47	14948	8480	52.91	56.73	6.9	0.732
6	30	4.95	3.20	1403	950	35.40	67.70	7	0.515
6	60	4.95	2.76	2806	1509	44.23	53.76	7	0.515
6	90	4.95	3.32	4210	2050	32.92	48.70	6.9	0.488
6	120	4.95	3.53	5613	2483	28.74	44.23	6.9	0.51
6	150	4.95	4.04	7016	2813	18.36	40.09	6.9	0.496
6	180	4.95	3.81	8419	3103	23.01	36.86	6.8	0.49
6	210	4.95	3.67	9823	3447	25.95	35.09	6.8	0.501
6	240	4.95	3.80	11226	3791	23.16	33.77	6.6	0.466
6	270	4.95	3.89	12629	4104	21.46	32.50	6.8	0.506
6	300	4.95	3.90	14032	4403	21.15	31.38	6.8	0.512
6	30	5.16	2.29	1463	1139	55.65	77.82	7	0.56
6	60	5.16	2.12	2926	1977	58.92	67.55	7	0.51
6	90	5.16	2.27	4389	2818	56.09	64.20	6.9	0.516
6	120	5.16	2.50	5852	3605	51.49	61.60	6.9	0.515
6	150	5.16	2.69	7315	4331	47.85	59.21	6.8	0.51
6	180	5.16	2.70	8778	5030	47.70	57.31	6.8	0.492
6	210	5.16	2.72	10241	5725	47.25	55.90	6.8	0.513
6	240	5.16	2.85	11704	6398	44.73	54.66	6.8	0.503
6	270	5.16	2.83	13167	7055	45.17	53.58	6.9	0.51
6	300	5.16	2.88	14630	7710	44.28	52.70	6.9	0.511
6	30	9.48	0.67	1344	1297	92.92	96.46	7.55	0.51
6	60	9.48	0.74	2688	2541	92.19	94.51	7.45	0.472
6	90	9.48	0.87	4032	3770	90.82	93.50	7.5	0.495
6	120	9.48	1.01	5376	4981	89.37	92.65	7.5	0.45
6	150	9.48	1.21	6721	6168	87.19	91.78	7.6	0.477
6	180	9.48	1.42	8065	7325	85.01	90.83	7.6	0.476
6	210	9.48	1.60	9409	8455	83.08	89.86	7.55	0.478
6	240	9.48	1.77	10753	9560	81.30	88.90	7.45	0.522
6	270	9.48	1.93	12097	10641	79.69	87.97	7.6	0.49
6	300	9.48	2.05	13441	11704	78.40	87.08	7.3	0.474
6	30	9.86	0.16	1397	1386	98.37	99.18	7.3	
6	60	9.86	0.17	2795	2760	98.29	98.76	7.3	
6	90	9.86	0.25	4192	4128	97.43	98.46	7.3	
6	120	9.86	0.40	5590	5479	95.96	98.02	7.15	
6	150	9.86	0.84	6987	6788	91.45	97.15	7.05	
6	180	9.86	0.80	8385	8069	91.84	96.24	7.05	
6	210	9.86	0.85	9782	9349	91.37	95.57	6.9	
6	240	9.86	1.02	11180	10614	89.66	94.94	6.9	
6	270	9.86	1.15	12577	11858	88.34	94.28	6.75	
6	300	9.86	1.29	13974	13082	86.94	93.62	6.65	
6	30	14.67	8.44	3025	2155	42.47	71.24	7.1	0.47
6	60	14.67	8.67	6050	3416	40.90	56.46	6.95	0.47
6	90	14.67	9.20	9074	4598	37.30	50.68	6.8	0.462
6	120	14.67	9.91	12099	5653	32.44	46.72	6.7	0.478
6	150	14.67	10.14	15124	6611	30.87	43.71	6.75	0.478
6	180	14.67	10.83	18149	7474	26.17	41.18	6.6	0.518
6	210	14.67	10.83	21173	8265	26.17	39.04	6.7	0.469
6	240	14.67	11.29	24198	9010	23.04	37.23	6.75	0.485

Table A.12: Continued

Retention Time	Collection Time	Inflow P Concentration	Outflow P concentration	Cumulative P Added	Cumulative P Sorbed	Discrete removal	Cumulative Removal	pH	EC
----- minutes -----		------ ppm ------		------ mg kg^{-1} ------		------ % ------			$mS\ cm^{-1}$
6	270	14.67	11.41	27223	9695	22.25	35.61	6.8	0.436
6	300	14.67	11.50	30248	10358	21.63	34.24	6.6	0.466
6	30	15.19	7.72	3131	2336	49.20	74.60	7.15	0.471
6	60	15.19	7.97	6263	3851	47.53	61.48	6.9	0.477
6	90	15.19	8.95	9394	5238	41.10	55.76	6.9	0.466
6	120	15.19	9.70	12526	6447	36.11	51.47	6.7	0.475
6	150	15.19	10.46	15657	7500	31.11	47.90	6.75	0.48
6	180	15.19	10.85	18789	8434	28.54	44.89	6.65	0.467
6	210	15.19	11.18	21920	9294	26.42	42.40	6.7	0.49
6	240	15.19	10.90	25051	10150	28.23	40.52	6.85	0.475
6	270	15.19	11.13	28183	11010	26.72	39.07	6.8	0.387
6	300	15.19	10.74	31314	11887	29.29	37.96	6.7	0.482
3	30	0.52	0.42	787	474	20.61	60.31	6.95	
3	60	0.52	0.38	1573	666	28.07	42.32	7.3	
3	90	0.52	0.40	2360	868	23.46	36.81	7.15	
3	120	0.52	0.42	3146	1042	20.61	33.11	6.95	
3	150	0.52	0.44	3933	1188	16.45	30.20	6.85	
3	180	0.52	0.45	4719	1309	14.47	27.74	6.85	
3	210	0.52	0.44	5506	1430	16.23	25.97	6.73	
3	240	0.52	0.45	6292	1546	13.38	24.58	6.9	
3	270	0.52	0.44	7079	1663	16.23	23.49	6.75	
3	300	0.52	0.45	7865	1785	14.91	22.70	6.55	
3	30	0.52	0.37	776	498	28.44	64.22	7.1	
3	60	0.52	0.38	1552	712	26.44	45.83	7.1	
3	90	0.52	0.41	2329	893	20.22	38.33	7.1	
3	120	0.52	0.42	3105	1044	18.67	33.61	7	
3	150	0.52	0.44	3881	1173	14.67	30.22	6.9	
3	180	0.52	0.45	4657	1279	12.67	27.46	6.9	
3	210	0.52	0.45	5433	1381	13.56	25.41	6.72	
3	240	0.52	0.45	6209	1483	12.67	23.87	6.85	
3	270	0.52	0.45	6986	1586	14.00	22.70	6.7	
3	300	0.52	0.45	7762	1688	12.22	21.74	6.55	
3	30	0.97	0.25	2193	1915	74.68	87.34	6.6	
3	60	0.97	0.32	4386	3470	67.08	79.11	6.9	
3	90	0.97	0.30	6579	4966	69.34	75.48	6.8	
3	120	0.97	0.31	8773	6479	68.62	73.85	7.15	
3	150	0.97	0.33	10966	7956	66.13	72.56	7	
3	180	0.97	0.34	13159	9396	65.18	71.41	7	
3	210	0.97	0.36	15352	10806	63.40	70.39	7.1	
3	240	0.97	0.38	17545	12167	60.67	69.35	7.1	
3	270	0.97	0.40	19738	13483	59.36	68.31	7	
3	300	0.97	0.40	21931	14776	58.53	67.37	6.7	
3	30	0.99	0.22	2235	1986	77.71	88.86	6.6	
3	60	0.99	0.35	4470	3582	65.13	80.14	7	
3	90	0.99	0.43	6704	4949	57.21	73.82	7.1	
3	120	0.99	0.22	8939	6462	78.18	72.29	7.1	
3	150	0.99	0.26	11174	8159	73.75	73.02	7	
3	180	0.99	0.38	13409	9672	61.64	72.13	7.05	
3	210	0.99	0.43	15644	10995	56.74	70.28	7.1	
3	240	0.99	0.40	17878	12297	59.77	68.78	7.15	

Table A.12: Continued

Retention Time	Collection Time	Inflow P Concentration	Outflow P concentration	Cumulative P Added	Cumulative P Sorbed	Discrete removal	Cumulative Removal	pH	EC
----- minutes -----		------ ppm ------		------ mg kg^{-1} ------		------ % ------			mS cm^{-1}
3	270	0.99	0.40	20113	13637	60.12	67.80	6.9	
3	300	0.99	0.40	22348	14977	59.89	67.02	6.8	
3	30	4.95	0.13	743	733	97.37	98.69	7.3	
3	60	4.95	0.20	1486	1452	95.95	97.67	7.4	
3	90	4.95	0.39	2229	2150	92.17	96.47	7.7	
3	120	4.95	0.55	2972	2823	88.86	94.98	7.8	
3	150	4.95	0.70	3715	3472	85.79	93.45	7.45	
3	180	4.95	0.93	4458	4093	81.30	91.80	7.4	
3	210	4.95	1.00	5201	4691	79.80	90.19	7.3	
3	240	4.95	1.18	5944	5271	76.26	88.67	7.35	
3	270	4.95	1.33	6687	5826	73.19	87.12	7.2	
3	300	4.95	1.41	7430	6364	71.53	85.65	7.3	
3	30	5.09	0.20	764	749	96.06	98.03	7.1	
3	60	5.09	0.28	1527	1476	94.45	96.64	7.7	
3	90	5.09	0.39	2291	2189	92.38	95.57	7.7	
3	120	5.09	0.48	3054	2888	90.62	94.55	7.8	
3	150	5.09	0.61	3818	3570	88.09	93.51	7.45	
3	180	5.09	0.70	4581	4236	86.25	92.46	7.5	
3	210	5.09	0.75	5345	4890	85.25	91.50	7.6	
3	240	5.09	0.84	6108	5535	83.57	90.61	7.6	
3	270	5.09	0.88	6872	6169	82.65	89.78	7.3	
3	300	5.09	1.07	7635	6786	78.89	88.88	7.4	
3	30	9.59	2.07	1079	963	78.42	89.21	7	
3	60	9.59	5.08	2158	1639	47.00	75.96	7.1	
3	90	9.59	3.70	3238	2225	61.47	68.72	7	
3	120	9.59	4.23	4317	2858	55.96	66.22	7	
3	150	9.59	4.83	5396	3428	49.64	63.53	6.9	
3	180	9.59	4.96	6475	3957	48.28	61.10	6.9	
3	210	9.59	5.08	7554	4471	47.00	59.18	6.9	
3	240	9.59	5.49	8633	4955	42.77	57.39	6.7	
3	270	9.59	5.44	9713	5419	43.25	55.80	6.9	
3	300	9.59	5.61	10792	5876	41.49	54.45	7	
3	30	7.32	0.63	823	788	91.40	95.70	6.9	
3	60	7.32	0.87	1646	1526	88.05	92.71	7.1	
3	90	7.32	1.25	2469	2230	82.91	90.30	7	
3	120	7.32	1.55	3292	2895	78.83	87.95	7.1	
3	150	7.32	1.71	4115	3535	76.62	85.90	6.9	
3	180	7.32	1.88	4938	4156	74.32	84.16	6.9	
3	210	7.32	1.94	5761	4764	73.48	82.70	6.7	
3	240	7.32	2.18	6584	5355	70.23	81.34	6.7	
3	270	7.32	2.25	7407	5929	69.29	80.05	6.8	
3	300	7.32	2.29	8230	6497	68.66	78.95	6.8	
3	30	15.29	7.21	3439	2627	52.80	76.40	6.7	
3	60	15.29	8.59	6878	4288	43.80	62.35	6.6	
3	90	15.29	9.58	10317	5683	37.29	55.08	6.5	
3	120	15.29	10.28	13757	6887	32.75	50.07	6.35	
3	150	15.29	10.58	17196	7980	30.79	46.41	6.55	
3	180	15.29	10.49	20635	9049	31.39	43.85	6.5	
3	210	15.29	10.88	24074	10085	28.82	41.89	6.5	
3	240	15.29	10.97	27513	11065	28.21	40.22	6.6	

Table A.12: Continued

Retention Time	Collection Time	Inflow P Concentration	Outflow P concentration	Cumulative P Added	Cumulative P Sorbed	Discrete removal	Cumulative Removal	pH	EC
----- minutes -----		------ ppm ------		------ mg kg^{-1} ------		------ % ------			mS cm^{-1}
3	270	15.29	11.18	30952	12012	26.85	38.81	6.6	
3	300	15.29	11.64	34391	12884	23.83	37.46	6.7	
3	30	14.88	7.97	3348	2452	46.46	73.23	6.5	
3	60	14.88	9.65	6696	3818	35.12	57.01	6.5	
3	90	14.88	10.21	10044	4931	31.39	49.09	6.4	
3	120	14.88	11.06	13392	5886	25.64	43.95	6.4	
3	150	14.88	11.37	16740	6710	23.62	40.09	6.5	
3	180	14.88	11.41	20088	7496	23.31	37.32	6.4	
3	210	14.88	11.41	23437	8277	23.31	35.31	6.45	
3	240	14.88	11.92	26785	9000	19.89	33.60	6.5	
3	270	14.88	12.17	30133	9637	18.18	31.98	6.65	
3	300	14.88	12.24	33481	10238	17.72	30.58	6.45	
0.5	30	0.51	0.25	1961	1480	50.99	75.50	6.8	
0.5	60	0.51	0.27	3922	2436	46.44	62.11	6.95	
0.5	90	0.51	0.29	5882	3319	43.71	56.43	7.2	
0.5	120	0.51	0.29	7843	4170	43.03	53.16	6.9	
0.5	150	0.51	0.31	9804	4971	38.70	50.70	7	
0.5	180	0.51	0.33	11765	5703	35.97	48.48	7.2	
0.5	210	0.51	0.34	13726	6373	32.33	46.43	7	
0.5	240	0.51	0.35	15686	6989	30.50	44.55	7.1	
0.5	270	0.51	0.38	17647	7544	26.18	42.75	7.1	
0.5	300	0.51	0.41	19608	8000	20.26	40.80	7	
0.5	30	0.50	0.27	1947	1429	46.76	73.38	6.7	
0.5	60	0.50	0.29	3895	2304	43.09	59.15	7	
0.5	90	0.50	0.29	5842	3130	41.72	53.57	7.1	
0.5	120	0.50	0.31	7790	3906	38.05	50.15	7	
0.5	150	0.50	0.32	9737	4629	36.22	47.54	6.95	
0.5	180	0.50	0.34	11684	5299	32.55	45.35	7.1	
0.5	210	0.50	0.35	13632	5908	30.03	43.34	7.1	
0.5	240	0.50	0.37	15579	6466	27.28	41.51	7.15	
0.5	270	0.50	0.40	17527	6939	21.32	39.59	6.9	
0.5	300	0.50	0.43	19474	7292	14.90	37.44	6.9	
0.5	30	1.00	0.14	2701	2509	85.80	92.90	6.8	
0.5	60	1.00	0.16	5401	4804	84.16	88.94	7.8	
0.5	90	1.00	0.17	8102	7067	83.45	87.23	7.4	
0.5	120	1.00	0.17	10803	9311	82.75	86.20	7.4	
0.5	150	1.00	0.18	13503	11537	82.05	85.44	7.45	
0.5	180	1.00	0.19	16204	13740	81.11	84.79	7.4	
0.5	210	1.00	0.20	18904	15913	79.83	84.18	7.4	
0.5	240	1.00	0.21	21605	18055	78.77	83.57	7.4	
0.5	270	1.00	0.22	24306	20166	77.60	82.97	7.45	
0.5	300	1.00	0.23	27006	22256	77.13	82.41	7.5	
0.5	30	0.98	0.18	2658	2411	81.43	90.71	7.15	
0.5	60	0.98	0.20	5315	4555	79.91	85.69	7.1	
0.5	90	0.98	0.21	7973	6657	78.27	83.49	7.2	
0.5	120	0.98	0.22	10631	8723	77.22	82.05	7.15	
0.5	150	0.98	0.24	13288	10756	75.82	80.95	7.05	
0.5	180	0.98	0.25	15946	12760	75.00	80.02	7	
0.5	210	0.98	0.26	18604	14738	73.83	79.22	6.9	
0.5	240	0.98	0.27	21261	16679	72.20	78.45	6.9	

Table A.12: Continued

Retention Time	Collection Time	Inflow P Concentration	Outflow P concentration	Cumulative P Added	Cumulative P Sorbed	Discrete removal	Cumulative Removal	pH	EC
----- minutes -----		------ ppm ------		------ mg kg^{-1} ------		------ % ------			mS cm^{-1}
0.5	270	0.98	0.29	23919	18579	70.79	77.67	6.8	
0.5	300	0.98	0.31	26577	20426	68.22	76.86	6.65	
0.5	30	4.97	0.63	2235	2093	87.26	93.63	7.35	
0.5	60	4.97	0.90	4470	3983	81.86	89.09	7.1	
0.5	90	4.97	1.10	6705	5767	77.85	86.01	7.1	
0.5	120	4.97	1.23	8940	7478	75.22	83.64	6.8	
0.5	150	4.97	1.41	11175	9118	71.52	81.59	6.8	
0.5	180	4.97	1.51	13410	10694	69.51	79.74	6.8	
0.5	210	4.97	1.70	15645	12206	65.81	78.02	7	
0.5	240	4.97	1.82	17880	13650	63.34	76.34	6.95	
0.5	270	4.97	1.99	20115	15027	59.87	74.70	6.95	
0.5	300	4.97	2.13	22351	16334	57.09	73.08	6.85	
0.5	30	4.60	0.83	2071	1885	82.01	91.00	7.35	
0.5	60	4.60	1.24	4142	3490	73.01	84.26	7.2	
0.5	90	4.60	1.52	6214	4940	66.94	79.50	7	
0.5	120	4.60	1.75	8285	6274	61.94	75.73	6.9	
0.5	150	4.60	1.94	10356	7516	57.95	72.57	6.8	
0.5	180	4.60	2.18	12427	8662	52.70	69.70	6.9	
0.5	210	4.60	2.30	14499	9727	50.12	67.09	6.85	
0.5	240	4.60	2.54	16570	10709	44.71	64.63	6.8	
0.5	270	4.60	2.74	18641	11590	40.38	62.17	6.85	
0.5	300	4.60	2.90	20712	12392	37.05	59.83	6.8	
0.5	30	9.42	3.78	3179	2540	59.82	79.91	6.6	
0.5	60	9.42	4.08	6358	4393	56.71	69.09	6.6	
0.5	90	9.42	4.46	9537	6130	52.62	64.28	6.5	
0.5	120	9.42	4.84	12716	7739	48.61	60.86	6.7	
0.5	150	9.42	5.20	15895	9225	44.84	58.04	6.5	
0.5	180	9.42	5.59	19074	10584	40.67	55.49	6.5	
0.5	210	9.42	5.70	22253	11859	39.53	53.29	6.5	
0.5	240	9.42	6.14	25432	13040	34.78	51.27	6.55	
0.5	270	9.42	6.19	28611	14138	34.29	49.41	6.7	
0.5	300	9.42	6.87	31790	15113	27.09	47.54	6.7	
0.5	30	9.88	3.38	3335	2764	65.76	82.88	6.7	
0.5	60	9.88	4.99	6670	4685	49.45	70.24	6.6	
0.5	90	9.88	5.70	10005	6216	42.36	62.13	6.6	
0.5	120	9.88	5.94	13340	7587	39.86	56.87	6.5	
0.5	150	9.88	5.96	16675	8914	39.70	53.46	6.4	
0.5	180	9.88	6.50	20010	10147	34.24	50.71	6.6	
0.5	210	9.88	6.28	23346	11325	36.43	48.51	6.5	
0.5	240	9.88	6.44	26681	12514	34.87	46.90	6.4	
0.5	270	9.88	6.65	30016	13641	32.68	45.45	6.55	
0.5	300	9.88	7.05	33351	14663	28.63	43.97	6.6	
0.5	30	14.73	5.76	1989	1600	60.89	80.44	7	
0.5	60	14.73	8.37	3978	2635	43.17	66.24	7.1	
0.5	90	14.73	9.20	5967	3438	37.55	57.61	6.9	
0.5	120	14.73	9.34	7956	4175	36.61	52.48	6.9	
0.5	150	14.73	9.43	9945	4897	35.99	49.24	6.8	
0.5	180	14.73	9.62	11935	5601	34.74	46.93	6.8	
0.5	210	14.73	9.43	13924	6304	35.99	45.28	6.8	
0.5	240	14.73	10.08	15913	6977	31.62	43.84	6.8	

Table A.12: Continued

Retention Time	Collection Time	Inflow P Concentration	Outflow P concentration	Cumulative P Added	Cumulative P Sorbed	Discrete removal	Cumulative Removal	pH	EC
----- minutes -----		------ ppm ------		------ mg kg^{-1} ------		------ % ------			mS cm^{-1}
0.5	270	14.73	9.80	17902	7624	33.49	42.59	6.8	
0.5	300	14.73	9.80	19891	8290	33.49	41.68	6.9	
0.5	30	14.45	5.00	1950	1613	65.37	82.68	7.15	
0.5	60	14.45	6.50	3901	2786	55.02	71.44	7.1	
0.5	90	14.45	7.14	5851	3816	50.56	65.22	7	
0.5	120	14.45	7.12	7801	4803	50.72	61.57	6.9	
0.5	150	14.45	7.04	9751	5798	51.27	59.46	6.8	
0.5	180	14.45	7.15	11702	6790	50.48	58.03	6.8	
0.5	210	14.45	7.21	13652	7771	50.08	56.92	6.8	
0.5	240	14.45	7.51	15602	8727	48.01	55.94	6.7	
0.5	270	14.45	7.64	17552	9655	47.13	55.01	6.7	
0.5	300	14.45	7.63	19503	10575	47.21	54.22	6.9	

APPENDIX B

Chemical and physical characterization data of industrial by-product materials. Materials analyzed by Agro-Environmental Chemistry Laboratory, Oklahoma State University, Stillwater, OK and Soil, Water and Forage Analytical Laboratory, Oklahoma State University, OK.

Table B.1: Results of water extraction

Material	Ca	Mg	Fe	Al	Na	K	P	Mn	Ni	Cu	Zn	As	Cr	Cd
	mg kg^{-1}													
AMDR1	97.3	24.7	1.28	13.4	9.94	43.4	0.27	71.7	0.00	0.00	0.95	0.00	0.00	0.00
AMDR2	6705	437	0.35	0.64	260	948	0.30	3.45	0.09	0.24	0.03	0.03	0.04	0.00
AMDR3	3727	237	0.34	0.48	186	56.3	0.20	3.41	0.05	0.04	0.02	0.04	0.03	0.01
AMDR4	709	2123	0.33	0.80	866	119	0.20	0.06	0.16	0.07	0.20	0.07	0.04	0.00
Fly-ash1	1136	0.84	0.29	536	195	37.8	0.19	0.00	0.01	0.02	0.00	0.03	1.60	0.00
Fly-ash2	1042	0.93	0.31	733	296	54.3	0.17	0.00	0.00	0.06	0.00	0.00	1.02	0.00
Fly-ash3	23.6	0.74	0.27	348	815	153	0.20	0.00	0.01	0.03	0.00	0.06	0.37	0.00
Al-WTR1	424	20.2	0.23	0.81	87.8	37.6	0.56	53.0	0.04	0.23	0.00	0.04	0.03	0.00
Al-WTR2	2179	25.6	0.22	0.59	96.6	64.7	0.39	1.80	0.04	0.13	0.00	0.17	0.04	0.01
Ca-WTR1	751	2181	0.22	0.28	3698	304	0.30	0.24	0.05	0.10	0.23	0.10	0.04	0.00
Ca-WTR2	3490	0.78	0.27	6.93	41.7	30.3	0.16	0.00	0.02	0.04	0.00	0.01	0.11	0.00
FGD gypsum1	6520	37.1	0.31	0.83	37.2	16.7	0.18	0.16	0.06	0.03	0.01	0.03	0.04	0.01
FGD gypsum2	6670	2.39	0.10	0.42	14.2	8.76	0.19	0.05	0.06	0.00	0.01	0.04	0.04	0.00
Slag fines	611	1.22	0.31	87.8	23.2	11.4	0.12	0.00	0.00	0.02	0.00	0.08	0.15	0.00
Slag1	339	1.02	0.25	26.9	117	85.4	0.20	0.00	0.00	0.32	0.00	0.03	0.40	0.00
Slag2	168	2.09	0.29	8.47	28.4	14.7	0.13	0.00	0.03	0.02	0.00	0.02	0.37	0.00
Slag3	253	1.72	0.25	19.3	20.3	7.75	0.15	0.00	0.01	0.00	0.00	0.03	0.14	0.00
Slag4	261	1.11	0.25	57.1	22.1	7.38	0.16	0.00	0.00	0.00	0.00	0.00	0.15	0.00
Slag coated	6511	41.4	0.29	2.27	55.4	8.36	0.17	0.72	0.06	0.00	0.00	0.06	0.05	0.00
Excell Minerals	203	1.88	0.22	2.34	42.5	18.1	0.20	0.00	0.00	0.06	0.00	0.01	1.61	0.00
LA Ash	12252	0.19	0.12	0.26	39.4	84.4	0.17	0.00	0.08	0.00	0.00	0.07	1.31	0.00
Foundry Sand1	65.9	2.79	1.26	6.20	13.7	3.43	0.17	0.00	0.01	0.00	0.00	0.04	0.04	0.00
Foundry Sand2	0.53	0.41	0.78	3.94	527	292	0.18	0.00	0.03	0.04	0.00	0.04	0.04	0.00

Table B.1: Continued

Material	Ca	Mg	Fe	Al	Na	K	P	Mn	Ni	Cu	Zn	As	Cr	Cd
	mg kg^{-1}													
Foundry Sand3	6.31	1.59	3.25	10.84	1343	16.8	0.67	0.00	0.03	0.02	0.05	0.05	0.05	0.01
Green Sand	133	119	126	285	448	39.0	0.93	0.61	0.74	1.72	1.55	0.06	0.15	0.01
Haydite	356	12.1	0.37	1.63	20.6	22.0	0.25	0.00	0.00	0.05	0.00	0.37	0.04	0.00
Ultra-Phos	4437	275	1.31	0.31	497	1306	0.70	2.53	0.08	0.14	0.05	0.03	0.04	0.00
Bauxite	34.35	9.26	25.5	89.3	3000	78.4	3.13	0.08	0.10	0.00	0.00	0.45	0.22	0.01
Leonardite	867	226	0.86	7.91	317	48.3	0.18	1.01	0.03	0.04	0.23	0.10	0.03	0.01
Paper mill pulp	590	98.5	2.48	15.2	540	107	4.69	0.05	0.14	2.99	0.11	0.08	0.06	0.00

Table B.2: Results of Toxicity Characteristic Leaching Procedure (TCLP) extraction

Material	Ca	Mg	Fe	Al	Na	K	P	Mn	Ni	Cu	Zn	As	Cr	Cd
	mg kg^{-1}													
AMDR1	102	25.5	0.14	0.70	0.59	4.16	0.54	49.4	6.25	0.00	0.18	0.07	0.00	0.00
AMDR2	22311	1049	8.93	107	93.1	1027	0.47	112	3.11	2.22	22.4	0.17	0.00	0.21
AMDR3	11575	14699	0.44	0.00	6.80	78.2	0.60	26.9	0.91	0.00	0.06	0.21	0.00	0.00
AMDR4	6550	342	0.32	0.05	3.42	60.6	0.60	80.8	0.11	0.00	0.04	0.14	0.00	0.02
Fly-ash1	22133	2357	0.61	22.1	8.36	45.2	107	2.13	3.80	1.81	2.68	3.48	7.25	0.34
Fly-ash2	26277	3535	0.11	7.82	3.37	68.0	4.79	0.13	3.21	0.00	0.01	0.96	6.50	0.04
Fly-ash3	31646	1680	0.00	0.00	2.25	124	0.69	0.16	0.00	0.00	0.00	2.01	3.92	0.00
Al-WTR1	2395	73.0	12.8	2028	131	85.7	1.77	972	0.17	0.38	0.02	0.44	0.92	0.02
Al-WTR2	14015	126	0.04	18.7	5.19	79.8	0.00	1632	0.17	0.07	0.33	0.35	0.00	0.04
Ca-WTR1	26701	6850	0.16	3.03	3.65	177	0.00	20.2	0.00	0.00	0.00	0.47	0.00	0.04
Ca-WTR2	28882	2199	0.03	1.85	3.79	61.4	0.00	11.8	0.00	0.00	0.00	1.62	0.00	0.04
FGD gypsum1	28792	722	7.84	31.8	80.3	2.59	0.69	9.21	0.38	0.42	1.15	0.24	0.00	0.01
FGD gypsum2	24321	223	3.32	14.1	35.6	13.3	0.08	3.96	0.15	3.42	1.87	0.62	0.00	0.04
Slag fines	32854	0.09	0.00	4.46	1.37	54.7	0.50	0.14	0.00	0.00	0.00	0.17	0.21	0.00
Slag1	25577	2296	0.00	0.00	1.01	112	0.54	0.23	0.00	0.47	0.00	0.14	0.07	0.00
Slag2	25805	2578	1.07	0.70	13.3	40.3	0.58	239	0.72	0.00	6.22	0.11	0.00	0.02
Slag3	23881	3053	0.00	0.00	1.99	21.7	0.67	121	0.13	0.00	1.26	0.18	0.00	0.00
Slag4	21959	3201	0.21	0.00	4.59	6.74	0.48	203	2.89	0.00	1.19	0.18	0.00	0.00
Slag coated	25081	3613	32.5	38.7	329	0.00	0.57	522	2.23	0.04	4.86	0.18	0.06	0.00
Excell Minerals	29324	681	0.37	4.38	7.87	94.2	0.00	0.06	0.00	0.00	0.00	0.04	2.07	0.04
LA Ash	66110	0.00	0.00	4.29	0.87	228	0.00	0.00	0.00	0.00	0.00	0.00	1.63	0.03
Foundry Sand1	1279	113	36.5	84.5	372	31.7	0.00	3.07	0.53	0.63	0.93	0.00	0.00	0.04
Foundry Sand2	52.6	5.39	9.44	4.54	95.1	303	0.00	0.57	1.16	3.92	4.49	0.00	0.00	0.03
Foundry Sand3	465	2.98	5.48	4.00	55.5	15.9	1.89	0.65	0.06	0.16	2.29	0.00	0.00	0.04
Green Sand	8087	439	9.39	17.4	96.4	132	0.00	10.9	1.33	0.40	0.45	0.24	0.00	0.04
Haydite	1384	64.2	13.7	101	140	79.5	0.15	8.87	0.16	0.45	0.14	0.94	0.00	0.04

Table B.2: Continued

Material	Ca	Mg	Fe	Al	Na	K	P	Mn	Ni	Cu	Zn	As	Cr	Cd
	mg kg^{-1}													
Ultra-Phos	7966	438	415	41.0	4301	1414	11.1	17.0	0.00	1.05	0.28	0.00	0.00	0.04
Bauxite	9680	389	0.02	119	1.28	224	0.00	0.00	0.00	0.00	0.00	0.84	0.00	0.04
Leonardite	1144	332	28.1	165	281	43.9	0.64	1.41	0.00	0.00	0.13	0.13	0.00	0.00
Paper mill pulp	32930	334	8.71	54.2	90.5	76.8	19.2	4.31	0.00	4.36	1.87	0.45	0.00	0.00

Table B.3: Results of EPA 3051 Total Digestion

Material	Ca	Mg	Fe	Al	Na	K	P	Mn	Ni	Cu	Zn	As	Cr	Cd	B	S
								mg kg^{-1}								
AMDR1	220	123	455681	2033	45.6	174	1417	373	59.3	0.00	0.00	56.9	12.0	20.2	1628	9356
AMDR2	23006	1555	189871	98282	403	1479	6219	301	113	271	803	108	60.9	21.0	687	27273
AMDR3	8342	1167	338805	9292	260	1670	533	457	36.6	0.00	24.0	267	16.5	17.4	1088	6311
AMDR4	204779	34853	118259	16651	1015	463	78.7	10005	334	2.75	444	40.2	6.80	7.08	291	17082
Fly-ash1	150941	25961	41821	86898	7030	2326	3430	0.00	51.7	115	148	93.5	53.7	11.9	815	6507
Fly-ash2	153547	28469	36637	64934	8090	2173	3562	0.00	36.3	109	106	81.7	48.7	10.6	699	6661
Fly-ash3	175907	40352	38877	79079	10274	1753	3174	0.00	35.7	119	50.0	93.8	42.7	11.8	559	7596
Al-WTR1	3277	1644	16824	157325	153	2017	1394	2034	17.3	71.9	33.3	262	102	20.2	48.9	5316
Al-WTR2	18661	1857	14487	81375	233	2799	2375	12635	29.7	125	44.7	212	22.7	10.4	58.4	3705
Ca-WTR1	286629	19060	7177	14166	4549	1757	428	154	6.23	2.68	19.1	30.4	6.53	1.98	7.53	8495
Ca-WTR2	314668	9462	4836	16367	283	1391	784	78.3	5.43	0.00	16.6	33.0	17.4	2.10	0.88	5678
FGD gypsum1	209000	1501	1791	782	46.5	317	41.2	10.4	1.48	2.10	6.98	12.4	0.40	0.35	14.6	156992
FGD gypsum2	147053	466	1101	427	11.4	121	27.0	4.88	0.20	9.40	4.35	11.9	0.93	0.38	3.88	111939
Slag fines	272452	90142	155062	36843	343	87.3	838	31417	105	139	404	64.9	4628	8.80	411	8346
Slag1	176318	58075	235602	32195	512	313	412	15012	150	387	1175	65.4	2536	13.2	899	5584
Slag2	199741	41531	221292	17163	233	120	958	27425	56.6	184	86.6	62.1	4539	11.4	405	3851
Slag3	236484	63703	139330	26697	254	21.7	1152	39615	49.9	47.0	94.8	55.6	4071	8.03	417	4756
Slag4	237616	68374	146654	27462	390	63.1	1022	34699	89.1	127	511	63.1	4673	8.70	433	6479
Excell Minerals	268523	62408	70475	20723	327	250	190	10374	501	52.7	70.7	43.2	3514	4.63	239	4734
LA Ash	242130	1826	14618	32506	805	3190	166	0.00	29.1	35.9	19.0	58.0	35.0	5.18	76.0	30949
Foundry Sand1	669	3283	889	721	48.1	66.0	2.78	7.43	31.0	2.10	17.5	0.73	1.30	0.13	0.00	24.9
Foundry Sand2	13.7	37.8	118	139	584	355	4.30	1.30	3.15	17.3	5.85	0.33	0.35	0.60	0.00	0.58
Foundry Sand3	483	157	200	273	1923	22.3	15.2	5.33	0.90	0.00	6.88	0.10	0.60	0.03	4.30	16.4
Green Sand	9434	75787	19977	7571	746	276	34.8	185	573	59.9	67.7	12.5	28.5	2.45	33.6	359
Haydite	3500	1918	22310	18090	696	3396	166	384	14.9	3.13	26.6	22.5	17.1	3.08	73.5	414
Ultra-Phos	16643	610	168740	4709	413	1528	2634	238	19.7	72.3	0.15	34.2	16.1	8.18	500	5225

Table B.3: Continued

Material	Ca	Mg	Fe	Al	Na	K	P	Mn	Ni	Cu	Zn	As	Cr	Cd	B	S
	mg kg^{-1}															
Bauxite	15000	1663	213217	98493	48244	565	248	0.00	40.4	0.00	0.00	110	513	19.4	753	848
Leonardite	8251	1073	4368	13413	479	360	15.7	0.00	7.25	1.58	14.5	19.4	4.00	2.43	50.8	4937
Paper mill pulp	162998	1804	933	18430	815	158	238	0.00	2.98	68.9	60.6	24.3	6.25	2.28	3.48	3037

Table B.4: Various extraction data and properties of by-products

Material	Exchangeable Al	Oxalate Al	Oxalate Fe	Oxalate Mg	Oxalate P	Total N	Total C	pH	EC	Crystalline minerals
	---------- mg kg^{-1} ----------					----- % -----			$mS\ cm^{-1}$	
AMDR1	17.2	136	25951	32.3	58.9	0.08	1.26	3.24	0.51	Goethite
AMDR2	0.00	46784	30415	1369	261	0.26	2.80	7.09	2.79	Hematite,Gypsum
AMDR3	0.00	353	39809	392	53.1	0.17	2.70	6.35	1.98	Goethite
AMDR4	0.00	5389	32818	16594	23.3	0.09	6.32	8.39	2.97	Calcite
Fly-ash1	689	27090	8619	8124	1720	0.02	0.31	11.44	1.35	Quartz
Fly-ash2	978	29281	10001	12728	2451	0.01	0.35	11.40	1.32	Quartz
Fly-ash3	334	26505	7078	20282	1384	0.01	0.49	11.16	1.82	-
Al-WTR1	0.00	57739	2515	111	331	0.79	10.14	7.26	0.45	Quartz
Al-WTR2	0.00	37420	2108	147	960	1.59	18.11	7.32	2.14	Quartz
Ca-WTR1	0.00	5210	998	19497	178	0.12	5.47	8.89	6.30	Calcite
Ca-WTR2	0.00	-	-	-	-	0.09	4.00	8.79	0.28	-
FGD gypsum1	0.00	56.3	610	1120	36.6	0.03	0.95	8.12	2.15	Gypsum
FGD gypsum2	0.00	55.4	432	569	33.5	0.02	0.76	9.00	2.21	-
Slag fines	14.4	931	4402	8103	29.5	0.02	1.74	11.30	0.66	Portlandite
Slag1	103	2718	15011	6166	40.3	0.04	3.10	10.91	0.37	-
Slag2	0.00	188	2223	671	14.2	0.01	1.04	9.64	0.08	-
Slag3	938	1360	15974	9302	49.0	0.01	0.73	-	-	-
Slag4	77.1	842	4707	8690	53.3	0.02	1.24	12.09	4.84	-
Slag coated	525	2344	10929	6044	47.7	0.01	0.49	-	-	-
Excell Minerals	0.00	2301	19183	15763	42.4	0.02	1.54	10.99	0.40	Tri-calcium magnesium orthosilicate
LA Ash	0.00	9703	1967	648	104	0.06	3.03	12.51	10.85	-
Foundry Sand1	0.00	35.8	132	97.1	10.2	0.03	1.47	8.97	0.09	-

Table B.4: Continued

Material	Exchangeable Al	Oxalate Al	Oxalate Fe	Oxalate Mg	Oxalate P	Total N	Total C	pH	EC	Crystalline minerals
	---------- mg kg^{-1} ----------					----- % -----			$mS\ cm^{-1}$	
Foundry Sand2	0.00	11.0	31.5	24.5	10.5	0.02	0.86	9.12	0.52	-
Foundry Sand3	0.00	8.04	20.9	10.8	12.3	0.01	0.39	10.38	1.45	-
Green Sand	0.00	928	3695	1660	35.6	0.05	1.25	9.15	0.46	-
Haydite	0.69	441	564	121	42.3	0.02	0.36	9.24	0.22	-
Ultra-Phos	0.00	932	51922	449	991	0.52	10.12	6.19	3.75	-
Bauxite	1.31	35089	272	1157	292	0.04	0.96	10.02	2.40	-
Leonardite	153	3934	1963	865	12.0	0.85	8.02	4.10	1.16	-
Paper mill pulp	8.22	948	140	704	90.4	0.01	0.32	8.07	0.59	-

VITA

Dustin James Stoner

Candidate for the Degree of

Master of Science

Thesis: INDUSTRIAL BY-PRODUCT CHARACTERIZATION FOR PHOSPHORUS REMOVAL IN ENVIRONMENTAL CONTAMINANT FILTERS

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Graduated from Fairfax High School, Fairfax, Missouri in May, 2004.

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Institution: Oklahoma State University Location: Stillwater, Oklahoma

Title of Study: INDUSTRIAL BY-PRODUCT CHARACTERIZATION FOR PHOSPHORUS REMOVAL IN ENVIRONMENTAL CONTAMINANT FILTERS

Pages in Study: 236 Candidate for the Degree of Master of Science

Major Field: Plant and Soil Science

Scope and Method of Study: The objectives of this study were to characterize industrial by-products for chemical properties and phosphorus sorption characteristics for potential use in environmental contaminant filters. Laboratory experiments were conducted on various by-products to examine the chemical composition of the materials. Twelve materials ranging from fly-ash to drinking water treatment residuals to acid mine drainage residuals were selected for flow-through analysis where five different flow rates and phosphorus concentrations were used to evaluate the effectiveness of the materials in a flow-through setting. Information was also provided on how to properly construct a contaminant filter.

Findings and Conclusions: Industrial by-product chemical characteristics that were found to be important for phosphorus sorption were pH and high quantities of calcium, iron, and aluminum. Flow-through data also helped produce an empirical model that can help predict the performance of a by-product in an environmental contaminant filter. The model also provides information on how much material will be needed in a filter to allow for proper construction. A filter must be built to accommodate the site location and material used in order to maximize efficiency.

ADVISER'S APPROVAL: Dr. Chad Penn