Modelling the loss of nitrogen and phosphorus from a turfed slope

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**Modelling the Loss of Nitrogen and Phosphorus
from a Turfed Slope**

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2014

Modelling the Loss of Nitrogen and Phosphorous from a Turfed Slope

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LIST OF SYMBOLS

A	catchment area
A_x	cross-sectional area
Ab	absorbance
b	empirical parameter in two-layer model
C	chemical concentration
C_0	initial chemical concentration
C_t	chemical concentration at t
c	mass balance in IHACRES
D	catchment drainage density
DA	drainage area
D_m	active soil surface layer depth
D_x	diffusion coefficient
d	transport coefficient
EG	catchment elongation
F_w	fraction wash-off
f	infiltration rate
f	temperature modulation
g	gravity acceleration
H_0	depth of the mixing layer
h	overland flow depth
I	light intensity
i	rainfall intensity
K	runoff coefficient
K_r	soil surface roughness parameter
k	decay coefficient
k_m	exchange rate
k_s	loss coefficient of soil adsorption
k_t	natural loss coefficient
k_{wn}	wash-off coefficient for nitrogen

k_{wp}	wash-off coefficient for phosphorus
L	soil moisture index
l	light pass length
M	chemical mass
M_0	Initial chemical mass
M_w	mass wash-off
m	empirical exponent
n	Manning's coefficient
p	non-linear response term in IHACRES
Q	runoff discharge
q	unit discharge
q_p	peak runoff rate
$R(t)$	runoff volume
Re	Reynold's number
r_k	observed rainfall
S	sources and sinks
SL	catchment slope
SY_e	event sediment yield
s	soil surface gradient
T	temperature
t	time
t_k	observed temperature
t_p	time from initiation of rainfall to the formation of runoff
t_r	reference temperature
u	advection velocity
V	volume of the water quality cell
V_s	the relative volume of slow flow
v	surface wind speed
ν	kinematic viscosity
x	distance
x_k^q	quick flow discharge
x_k^s	slow flow discharge

Z	longitudinal dispersion coefficient
ρ_b	dry bulk density of soil
θ	soil moisture
α	kinematic-wave resistance parameter
Γ	dispersion coefficient
τ_k	drying rate
τ_w	drying rate at reference temperature
τ_q	recession time constant for quick flow
τ_s	recession time constant for slow flow
ε	molar absorptivity

SUMMARY

The domain of nutrient loss model embraces a number of physic-chemical, hydrological and hydraulic processes acting on chemical fertiliser left on the soil surface and these processes include raindrop splash and impact, attachment of the chemical on soil particles, and detachment of the compounds from soil surface and subsequent wash-off and transport via surface runoff. Different types of nutrient loss and transport models have been developed in recent decades. However, there is a dearth of study involving the time-variable source, where the nutrient mass is temporally variable and is influenced by the environment. This Ph.D study presents the development of an integrated nutrient loss model that describes the N and P loss and transport process from soil surface, taking into account environmental losses.

Three series of laboratory experiment were carried out to investigate the physical and chemical mechanisms of the environmental loss, including the N and P loss brought forth through natural loss, infiltration and soil adsorption, and plant up-take. Four indices were investigated, including ammonia nitrogen (NH_4^+), nitrate nitrogen (NO_3^-), total nitrogen (TN) and total phosphorus (TP). The loss of N and P compounds, when exposed to the elements was found to fit a first order kinetic equation, while the loss of N and P due to soil adsorption and infiltration was approximated using a second order kinetic equation.

A 17-month outdoor experimental programme was conducted to calibrate the integrated nutrient loss model. A comparative study was carried out on the full nutrient loss model and partial model without the temporally variable source term. The aim was to assess the significance of including environmental losses into the nutrient loss model. It was found that in the case of Singapore, the temporal loss of the nutrient, which was generally neglected in nutrient loss studies by others, was important. The partial model without considering environmental loss would over estimate the loss of nutrient in the surface runoff, and the error could be as high as 100% in some cases.

Published results by others, where relevant, were extracted and reformatted for use in the comparative study in this Ph.D study. The findings from the simulation and comparative study showed that by adjusting the environmental loss rate, which was strongly influenced by the climate (especially temperature and humidity), the integrated nutrient loss model could indeed satisfactorily reproduce nutrient loss patterns that closely matched the measured nutrient loss by others.

CHAPTER 1 INTRODUCTION

1.1 Background

Water is the origin of life – a very apt statement on the importance of water resources to all living on Earth. However, the modern history witnesses the deterioration of water resources as the wheel of modernisation and industrial revolution advances. Since the recent decades, we as human beings recognize the importance of sustainable utilisation and management of water resources and modern conservation tools have been developed to help policy makers understand and manage water resources, among which water quality modelling is an important one. Water quality models have been developed and studied to predict the presence, transport and deterioration of water by pollutants using mathematical simulation techniques. In general, pollutants in a water body can be divided into three categories: biotic pollutants, such as *E.coli*, and bacteria; physical pollutants, such as suspended solids, and thermal pollution; and chemical pollutants, such as nitrogen and phosphorous.

Nitrogen (N) and Phosphorous (P) are two very important elements in water quality modelling. Their presence in excess, among others, has a significant negative impact on water quality, such as result in the occurrence of eutrophication, lead to algal blooms, *etc.* Recent surveys (ILEC 1988-1993) reported that 54% of lakes in Asia are eutrophic; 53% in Europe; 48% in North America; 41% in South America, and in Africa, 28%. Growing anthropogenic N and P pollution has been discharged into water bodies in recent decades. Agricultural activity is one of the reasons that lead to nitrogen and phosphorus pollution. It has been reported (Changyu *et al.* 2010) that the world-wide nitrogen fertiliser utilization ratio is 50%, while phosphorus usage ratio is only 25%. This means that considerable amount nitrogen and phosphorus fertilisers are “lost” as far as the original objective is concerned (Mingfang *et al.* 2010; Tian *et al.* 2010). It has been shown (Sharpley *et al.* 1996) that the amount of phosphorus lost to surface waters increases linearly with the

amount of phosphorus in the soil, and most of the phosphorus is derived from commercial fertiliser. Clearly, agricultural activities, or more specifically, the application of fertiliser is a very essential source when one model soil N and P loss.

Soil N and P loss process is generally very similar to soil erosion process. In most cases, the fertiliser is an integral part of the soil clumps and pore water. Soil erosion process by water and transport of the eroded particles includes detachment, entrainment, transport and deposition of soil particles at various parts of the slope. The major driving force of these processes is shear stresses generated by raindrop impact and surface runoff. Most published studies adopt the same strategy where soil nutrient loss was estimated by drawing an analogy between nutrient loss and soil erosion and followed by transport of the entrained materials in a channel (Leinard *et al.* 1987; Young *et al.* 1987; Bouraoui and Dillaha 1996; Arnold *et al.* 1998; Kinnell 2000; Shaw *et al.* 2006).

Note that there is a distinct difference in the source term in the N and P loss process from that of soil erosion. In soil erosion modelling, it is generally assumed that the soil particle available on the land surface is inexhaustible and in constant supply. In the case of N and P loss process, the amount available on the land surface is finite and decreases over time. Only a handful of reported studies had taken into consideration the temporal-influenced nutrient source and loss of the chemical compounds (Zhang *et al.* 2007; Vadas *et al.* 2008). In some studies about the chemical wash-off from impervious surfaces such as roofs and roads, a simple first-order kinetic decay of pollutants on surface was applied. And it is believed that the decay of pollutants is due to wash-off (Egodawatta *et al.* 2007; Soonthornnonda *et al.* 2008; Egodawatta *et al.* 2009). The loss of pollutants was not mentioned.

It was reported in Vadas *et al.* (2008) 's study that large concentrations of dissolved P in runoff can occur shortly after a surface fertiliser application, while similar result were obtained by Kleinman and Sharpley (2002). It was also found that most of the N and P applied on soil surface had adsorbed to soil within the first 2 days after fertiliser application (Williams 1969). There is a dearth of study that

investigating the characteristics of pollutant losses, in terms of N and P, due to exposure of elements to the surrounding environment, such as soil particles, plant coverage could be found in literature. The physical mechanisms describing the N and P loss remains unclear.

The preceding brief review of the current studied on nutrient loss models indicates that an integrated nutrient loss model involving time-variable source, where the nutrient mass is temporally variable and is influenced by the environment, is needed to overcome the missing links in existing nutrient loss models. This model should be able to simulate the environment losses of the source, and physically consider the interaction between nutrient compounds and various environmental components, including climate, topography, and soil property, *etc.*

1.2 Objectives of study

Knowing the complexity of nutrient loss modelling, and the in-depth knowledge required to conduct a comprehensive model study, this study aims to develop an integrated nutrient loss model that can describe comprehensively pollutants wash-off and transport from agricultural land by rain or other environmental factors.

The objectives of this study include the followings:

1. To investigate and quantitatively model the fertiliser degradation on soil surface, including the natural fertiliser degradation, soil adsorption and infiltration introduced fertiliser degradation, and N and P plant-uptake;
2. To develop an integrated nutrient loss model that describes the N and P transport process from soil surface, considering the raindrop splashing effects, runoff entrainment and wash-off, attached to soil particles and soil erosion, surface runoff and sediment transport and loss of N and P;
3. To calibrate and validate the integrated model using outdoor experimental data;

1.3 Scope of study

This study includes the following tasks:

1. To understand the loss mechanism of N and P exposed to the elements, including the natural loss of N and P when exposed to environment, soil adsorption with the presence of rainwater and plant coverage;
2. To develop a model that describes the N and P transport processes, and includes time-influenced source;
3. To set up laboratory experiments that could provide reliable data and could be used to test, verify and calibrate the model;
4. To develop and refine the integrated nutrient loss model, and calibrated the model using data obtained from laboratory experiments and controlled outdoor experiments;
5. To assess the significance of involving the environment loss into the nutrient loss model, and test the model applicability using outdoor experimental data and published data;

1.4 Organization of the thesis report

In the ensuing chapters, literature review of the current state of the art of water quality modelling and nutrient loss is present in chapter 2. The chemical properties of typical chemical fertilisers are also reviewed and presented. Chapter 3 covers detailed description of the experimental design, including three series of laboratory experiments which were conducted to elucidate the characteristics of fertiliser loss, and a controlled outdoor experiment for model calibration and verification. In chapter 4, the theoretical background of the model development is presented. Five important modules are developed and introduced in detail. The integrated model structure is also presented in this chapter. Chapter 5 presents the results obtained from the three series of laboratory experiment. The physical mechanisms of environmental loss of N and P, such as natural loss, soil adsorption in the presence of rainwater and plant coverage are investigated and corresponding coefficients are calibrated. The data obtained from the controlled outdoor experiments are presented in chapter 6. The rainfall-runoff model is calibrated and the nutrient loss model is

verified using the data obtained. The wash-off coefficients are calibrated herein. Chapter 7 covers the data processing of relevant reported studies by others. Those data are later used to demonstrate the validity of the integrated nutrient loss model. Also presented is the assessment of the significance of introducing the temporal-variable source pollutant. Finally, chapter 8 concludes the findings of the study, and recommendations for future studies are made.

CHAPTER 2 LITERATURE REVIEW

2.1 Nutrient loss from land surface

The focus of this study is on nutrient loss from land surface. The source of nutrient is in the form of chemical fertiliser available commercially.

There are various forms and types of fertilisers. Certain fertilisers are applied in crystal form while others are applied in liquid state. Those in crystal form are either dissolved in soil water or chemically fixed by soil particle in particulate form or ionic form. Those in liquid form are usually present as ions. The soil zone where fertiliser is applied also varies depending on the type of compounds in the fertiliser. Where it includes volatile compounds, the fertiliser is generally applied 5-10 cm below soil surface. In that case, the fertiliser is generally not washed off by surface runoff.

Soil nutrients loss is also influenced by geographical factors, climate, soil properties and anthropological activities. As a result, soil nutrients loss is characteristically random, spatially and temporally variable and the relationships among them non-universal. There are great difficulties controlling soil nutrients loss, and not to mention modelling the process. The temporal variability of soil nutrients loss is the result of spatial non-homogeneity of the soil media and hydrological conditions.

N and P loss from soil media is generally higher during rainy seasons when precipitation and runoff is large (Kleinman and Sharpley 2002; Donohue *et al.* 2005). Wu *et al.* (1996) studied the characteristics of N and P losses from soil slope, and showed that discharge of total nitrogen, dissolved nitrogen, total phosphorus and dissolved phosphorus decrease as rainfall-runoff process progresses. To add to the complexity, hydrological processes such as rainfall are also temporally and spatially variable.

In section 2.2, general information of commercial inorganic fertilisers is introduced.

Soil N and P compounds and constituents of typically commercial fertilisers are reviewed in section 2.3. Also included in this section are the transformations of the N and P compounds in soil. The mode of the processes involved in nitrogen and phosphorus detachment and transport from soil surface by rain, including raindrop splashing and induced chemical detachment, runoff wash-off process and transport process are presented in section 2.4. Models available in describing above mentioned processes are introduced in section 2.5. In section 2.6, existing water quality models are reviewed, and two typical water quality models: water quality transport module in HEC-RAS and US EPA Storm Water Management Model (SWMM) are introduced. Other relevant information of N and P loss from soil, such as land use classification, soil properties including soil texture is given in Appendixes A and B.

2.2 Constituent compounds in commercially available inorganic fertilisers

2.2.1 Nitrogen fertiliser

Nitrogen is a very important element for growth of plants. It is one of the main elements in amino acid, and also an indispensable element in protein. More importantly, it is also a component of chlorophyllous, which is a crucial part of photosynthesis. Application of nitrogen fertiliser generally increases agricultural yields, while enhance the quality of the crop and harvest.

Various nitrogen compounds that can be found in a typical commercial fertiliser could be found in Table 2-1.

Table 2- 1 Nitrogen compounds in commercial fertilisers (cyclopedia 2010)

Fertiliser name	Formula of the active compound	Activity	Description
Ammonium sulfate	$(\text{NH}_4)_2\text{SO}_4$	contains 20-21% nitrogen	high solubility, white particle
Ammonium hydrogen carbonate	NH_4HCO_3	contains 17% nitrogen	pH 8.2-8.4, white crystal
Urea	$\text{CH}_4\text{N}_2\text{O}$	contains 46% nitrogen	white crystal
Ammonium chloride	NH_4Cl	contains 17% nitrogen	white crystal
Ammonium nitrate	NH_4NO_3	contains 33-35% nitrogen	white crystal
Aqueous ammonia	$\text{NH}_3 \text{ H}_2\text{O}$	contains 20% nitrogen	liquid

2.2.2 Phosphorus fertiliser

Phosphorus is another essential element for plants growth. Commonly applied phosphorus fertilisers are:

1. Calcium superphosphate $[\text{Ca}(\text{H}_2\text{PO}_4)_2 \text{ H}_2\text{O}]$: contains 12%-18% P_2O_5 , soluble;
2. Double superphosphate: contains 45% P_2O_5 ;
3. Calcium Magnesium phosphate: the main constituents are $\text{Mg}_3(\text{PO}_4)_2$ and $\text{Ca}_3(\text{PO}_4)_2$, insoluble;

2.2.3 Multiple compounds fertiliser

Generally most fertiliser products contains multiple plant supplements, which contain more than one type of active compound including the followings (cyclopedia 2010):

1. Ammonium phosphate: contains 12-18% nitrogen and 46-56% P_2O_5
2. N-P-K fertiliser: consist of nitrogen, phosphorus and potassium, each 10%.
3. Compound and potassium compound is soluble and part of the phosphate is soluble.
4. Monopotassium phosphate $[\text{KH}_2\text{PO}_4]$: contains 24% P_2O_5 , 21% K_2O
5. Potassium nitrate $[\text{KNO}_3]$: contains 13.5% nitrogen

2.2.4 Summary

Table 2-2 includes a list of compounds that could be found in a typical commercial fertiliser.

Table 2- 2 A list of compounds in a typical commercial fertiliser (Zhang *et al.* 2009; cyclopedia 2010; Wikipedia 2010)

	Fertiliser	Active constituent	Phase	Apply position	Solubility
Nitrogen	$(\text{NH}_4)_2\text{SO}_4$	20-21% N	grainy	In soil	soluble
	NH_4HCO_3	17% N	crystal	In soil (10cm)	soluble
	NH_4Cl	17% N	crystal	Soil surface	soluble
	NH_4NO_3	33-35% N	crystal	Soil surface	soluble
	$\text{CH}_4\text{N}_2\text{O}$	46% N	crystal	In soil or on leaf surface	soluble
	$\text{NH}_3 \text{ H}_2\text{O}$	20% N	liquid	In soil (5-10cm)	
	NaNO_3	15-16% N	crystal	Soil surface	soluble
Phosphorus	$\text{Ca}(\text{H}_2\text{PO}_4)_2 \text{ H}_2\text{O}$	12-18% P_2O_5	powder or grainy	In soil or on leaf surface	soluble
	Double superphosphate	45% P_2O_5	powder or grainy	In soil or on leaf surface	soluble
	$\text{Ca}_3(\text{PO}_4)_2$	12-20% P_2O_5	powder	In soil	insoluble
	CaHPO_4	27-40% P_2O_5	powder	In soil	insoluble
Compound fertiliser	Ammonium phosphate	12-18% N and 46-56% P_2O_5	grainy	In soil (4-5cm)	soluble
	N-P-K fertiliser	10% N and 10% P	grainy	In soil	Soluble N, part soluble P
	KH_2PO_4	24% P_2O_5	crystal	Leaf surface	soluble
	KNO_3	13.5% N	crystal	In soil	soluble

2.3 Forms of inorganic nitrogen and phosphorus compounds in soil

2.3.1 Nitrogen compounds in soil

2.3.1.1 Ammonia nitrogen: NH_4^+

Ammonium nitrogen in soil is generally present in three forms: (a) free ions, (b) exchangeable form and (c) fixed form. The ionic form of ammonium nitrogen exists in soil solution and the dominant ammonia form is determined by the pH of soil pore water. In a neutral environment, the predominant form of ammonia is NH_4^+ . With higher alkalinity, the concentration of NH_3 increases while the concentration of NH_4^+ decreases. The exchangeable ammonium nitrogen is adsorbed on soil particle surface. Under certain condition, this part of nitrogen can be released. Ammonium nitrogen in fixed form is fixed by soil particle and is unlikely to be removed readily.

2.3.1.2 Nitrate nitrogen: NO_3^-

Generally, nitrate nitrogen is rarely fixed by soil particle, and is present as free ions in soil pore water. It can be easily washed off by rainfall or irrigation process, which results in nitrogen leaching.

2.3.1.3 Nitrite nitrogen: NO_2^-

In soil, nitrite nitrogen is generally present in the form of free ions. It is readily taken up by plants, and also readily transformed into other nitrogen compounds.

2.3.2 Phosphorus compounds in soil

Most of the phosphorus compounds in soil are insoluble. In neutral and alkaline soil, the phosphorus compounds are: $\text{Ca}_3(\text{PO}_4)_2$, $\text{Mg}_3(\text{PO}_4)_2$, octacalcium phosphate [$\text{Ca}_8\text{H}_2(\text{PO}_4)_6$], apatite. In acidic soil, the phosphorus compounds are FePO_4 , AlPO_4 , phosphorus iron ore, and amblygonite.

The amount of soluble phosphorus or phosphate is dependent on pH (Figure 2-1 and

Table 2-3). H_2PO_4^- and HPO_4^{2-} are the main forms of soluble phosphorus, in soil. When $\text{pH}=7.22$, the concentrations of H_2PO_4^- and HPO_4^{2-} are equal. When $\text{pH}<7.22$, H_2PO_4^- is dominant in soil and when $\text{pH}>7.22$, the dominant ion is HPO_4^{2-} (Busman *et al.* 2009).

Table 2- 3 Dominant phosphate ion under different pH (Busman *et al.* 2009)

Phosphorus	pH			
	5	6	7	8
H_3PO_4	0.10	0.01	-	-
H_2PO_4^-	97.99	83.68	33.90	4.88
HPO_4^{2-}	1.91	16.32	66.10	95.11
PO_4^{3-}	-	-	-	0.01

Figure 2- 1 Phosphorus availability in relation with soil pH (Busman *et al.* 2009)

Apart from that, in acidic soil, 80% of the phosphate is besieged by Ferrum or Aluminium colloid. This part of phosphate is termed as occlude phosphorus (Oc-P), and it is difficult to be taken by plants.

2.3.3 Transformation of inorganic nutrients in soil

After the fertiliser is applied, only 30-50% of the nitrogen is generally taken up by plants. The rest of the nitrogen either remains in soil or undergoes certain

transformations. Table 2- 4 lists the transformation of the fertiliser compounds.

Table 2- 4 Transformations of active compounds after being fertilized (Canada 2010; University 2010)

Compound	Transformation
NH_4^+	$(\text{NH}_4)_2\text{CO}_3 \rightarrow 2\text{NH}_3 \uparrow + \text{CO}_2 \uparrow + \text{H}_2\text{O}$, with presence of water
	Be transformed into NH_3 with increase of pH
	Be transformed into NO_3^- or NO_2^- by nitrification with a soil pH ranges from 5.6 to 10.0
	Be adsorbed or fixed by soil particle
NO_3^-	Be washed off from soil
	$2\text{HNO}_3 \xrightarrow{+4\text{H}-\text{H}_2\text{O}} \text{aHNO}_2 \xrightarrow{+2\text{H}-\text{H}_2\text{O}} 2\text{NO} \uparrow \xrightarrow{+2\text{H}-\text{H}_2\text{O}} \text{N}_2 \uparrow$ <p>The process is termed as denitrification, and it is influenced by soil pH and moisture.</p>
NO_2^-	Be transformed into NO_3^-
Soluble P	React with Fe^{3+} or Al^{3+} under acid condition, result in precipitation
	React with Ca^{2+} under alkaline condition, result in precipitation
	Be adsorbed by soil particle in ion forms
Insoluble P	Be transformed into H_2PO_4^- or HPO_4^{2-} by microorganisms

2.4 Pollutant entrainment and transport models

After it has been applied, a significant amount of fertilisers are left on the soil surface or mulch area, in the form of crystal or particle, or being dissolved in soil water and “fixed” by surface soil particles. When it rains, the residual fertiliser found on soil surface could be washed-off under the impact of rainwater. The mode of N and P wash-off and transport from soil into surface runoff involves several processes. With the presence of rainwater, soluble nitrogen and phosphorus compounds will dissolve in the rainwater, some of which will infiltrate deeper into the soil, while the some of the remaining portion may be washed off the soil by surface runoff, transported with the runoff water and ended up in the receipt water. The insoluble compounds of the fertiliser may be attached to sediment particles and enter surface runoff as suspended sediment/particles. The wash off process of the

insoluble compounds is similar to soil erosion process by surface runoff.

The N and P entrainment is schematically shown in Figure 2-2. The processes involved in are rainfall-runoff process, raindrop impacted splash of chemicals, runoff wash-off process and runoff transport process.

Figure 2- 2 Schematic of N and P transport on soil surface

The physical mechanisms describing those processes could be found in the literature to help us understand the entrainment of pollutants into the receipt water.

2.4.1 Rainfall-runoff model

Rainfall-Runoff model is used to describe various hydrological phenomena within a watershed. Both sediment and pollutant yields from a watershed are strongly related to the overland flow (Carpenter *et al.* 1998; Aksoy and Kavvas 2005). A rainfall-runoff model simulates the runoff production according to corresponding hydrological information such as precipitation, infiltration, evaporation *etc.* and it is the foundation of a water quality model not only because runoff is the media of pollutants transport, but also is the driving force of pollutants detachment from land surface.

The history of rainfall-runoff modelling dated from 150 years ago when the first widely used model was born: the rational method (Eq.2-1). The talent Irish engineer Thomas James Mulvaney (1822-1892) illustrated most of the problems that

hydrological modellers ever met, although only the peak discharge can be calculated using the rational method (Beven 2011).

$$Q = KiA \quad \text{Eq.2- 1}$$

where,

Q = peak discharge (m³/s);

K = runoff coefficient;

i = average rainfall intensity (mm/h)

A = catchment area (m²).

A further development of rainfall-runoff model started with the time-area concept, based on which, the unit hydrograph method was developed (Figure 2-3). Being simple to understand and easy to apply, the technique of unit hydrograph is well accepted and widely applied in hydrology engineering (Beven 2011). Commonly used variations of unit hydrograph are: histogram from historical data, triangle unit hydrograph and Nash cascade of N linear stores method. However, the technique of unit hydrograph has its own limitations. First is the effective rainfall determination. This is definitely a nonlinear problem that involves complex hydrological processes such as rainfall intensity, soil conditions, while the unit hydrograph remains a linear routing technique. Effective rainfall determination methods were then developed. Commonly used ones are infiltration capacity method (e.g. Horton's infiltration curve), ϕ index method (Bedient and Huber 1992) and constant percentage method. The second problem is numerical difficulties in calculating and calibrating the unit hydrograph.

Figure 2- 3 Example of unit hydrograph

The development of computer science leads to a remarkable leap of rainfall-runoff modelling. A number of digital computer rainfall-runoff models were developed. Examples that are still current in use include the HSPF model from the USA (Bicknell *et al.* 1997), the HBV from Sweden (Bergström 1995), the Tank model from Japan (Sugawara 1974) and the Xinanjiang model from China (Zhao 1992).

Existing rainfall-runoff model can be divided into two categories: deterministic model and statistic model. The former one can be further categorized into conceptual model, based on the physical conceptualization of the hydrological phenomenon, and physically based model, applying hydraulic equations. A summary of existing rainfall-runoff models are shown in Table 2-5.

Table 2- 5 Brief descriptions of representative rainfall-runoff models

Model	Description
IHACRES	<ul style="list-style-type: none"> • $u_t = R_t(S_t + S_{t-1})/2$; • $S_t = R_t + \left[1 - \frac{1}{\tau(T_i)}\right] S_{t-1}$; • $\tau(T_i) = \tau_\omega \exp(10f - T_i f)$; • Apply generalised linear transfer function to relate effective rainfall to total discharge.
HBV	<ul style="list-style-type: none"> • Semi-distributed conceptual model; • Sub-basin divided based on DEM; • Input data include rainfall observed, temperature, evaporation estimated, <i>etc.</i>; • Suitable for large river basin.
SWM	<ul style="list-style-type: none"> • Deterministic model; • Input data include precipitation, evaporation estimated, evaporation ability, <i>etc.</i>; • Suitable for both small-scale and large-scale watershed.
HSPF	<ul style="list-style-type: none"> • Continuous simulation model; • Input data include precipitation, temperature, soil properties, channel properties, <i>etc.</i>; • Suitable for both natural and developed watersheds; • Include nonpoint load simulation and instream simulation.
Xinanjia	<ul style="list-style-type: none"> • Conceptual model; • Input data include precipitation, evapotranspiration, <i>etc.</i>; • Model include VIC-2L (two-layer) and VIC-3L (three-layer) structure; • Suitable for large-scale hydrological modelling.
Tank model	<ul style="list-style-type: none"> • Conceptual model; • Rainfall-runoff process is conceptualized to several cascade or parallel tank; • Suitable for both small-scale and large-scale watershed.
TOPMODEL	<ul style="list-style-type: none"> • Distributed conceptual model; • Distribution of downslope transmissivity with depth is assumed as an exponential function of storage deficit or water table depth; • Suitable for small catchment.
HEC-1	<ul style="list-style-type: none"> • Lumped conceptual model; • River Basin is represented as an interconnected group of subareas; • Input data include precipitation, basin area, soil type, lag time, <i>etc.</i>; • Suitable for single storm.
SCS	<ul style="list-style-type: none"> • Input data include lag time, length of further point of overland flow from the outlet. Average slope of the basin, Curve Number (CN); • Suitable for small catchment.

2.4.2 Nutrient entrainment into surface water by raindrop impact

Surface runoff is the major pathway for fertilisers to be entrained and flow into surface water bodies (Tong and Yang 2008; Vadas *et al.* 2008). Water flow and chemical transport on soil surface takes place both in the vertical and lateral directions (Wallach *et al.* 2001). It has been demonstrated that chemicals near soil surface are most likely to be entrained into run off as a result of raindrop impact, (Gao *et al.* 2004; Gao *et al.* 2005; Dong *et al.* 2013).

There are reported studies on soluble chemical transfer due to raindrop driven process and models had been developed to describe the chemical exchange process between soil surface and overland flow. Among the many models the two-layer model is a commonly used model (Steenhuis and Walter 1980; Ahuja 1990; Wallach *et al.* 2001; Gao *et al.* 2004; Gao *et al.* 2005; Tong and Yang 2008). In a two layer model, it is suggested that there is a certain region under soil surface where the surface water, soil solution and infiltrated water completely and instantaneously mix with each other and there is no chemical transfer to this layer from the soil below (Ahuja and Lehman 1983; Ahuja 1990; Tong and Yang 2008). This layer is called the mixing layer or exchange layer and the depth of this layer is constant (Steenhuis and Walter 1980; Ahuja *et al.* 1981; Emmerich *et al.* 1989). According to Zhang *et al.* (1997), the effective mixing layer depth is less than 3-4 mm (Zhang *et al.* 1997) on the water-soil interface. The two-layer model was developed after the Rose model, in which soil erosion under the raindrop impact with absence of overland flow was modelled (Rose *et al.* 1983; Hairsine and Rose 1991; Rose *et al.* 1994; Gao *et al.* 2004; Gao *et al.* 2005).

Several assumptions were made in the development of the conservation equation in the two layer model (Steenhuis and Walter 1980; Tong and Yang 2008), and they include the followings:

1. Chemicals are only considered to transfer in a columnar fashion only;
2. Infiltration and diffusion processes at the bottom of soil mixing layer are considered as vectors and downward positive;

3. Infiltration and diffusion processes are represented by the incomplete mixing parameter γ (infiltration water interacts with water of soil mixing layer incompletely and the diffusion process is neglected).
4. Ejection of soil water by rainfall impact at the interface of ponded overland flow and soil mixing layer is represented by the incomplete mixing parameter α (ponding water mixed with soil mixing layer incompletely and other factors are neglected).

The model can be expressed as (Wang *et al.* 1998; Dong *et al.* 2013):

$$C(t) = k_m \frac{C_0 \rho_b H_0}{R(t)(it_p + \rho_b \theta_0 H_0)} t^b \quad \text{Eq.2- 2}$$

where,

$C(t)$ = chemical concentration in runoff (mg/L);

k_m = exchange rate;

c_0 = initial chemical concentration in surface soil (g/g);

ρ_b = dry bulk density of soil (g/cm³);

H_0 = depth of the mixing layer (Colon and McMahon);

$R(t)$ = runoff volume (l);

i = rainfall intensity (cm/min);

t_p = time from initiation of rainfall to the formation of runoff (min);

θ_0 = initial soil moisture (%); and

b = empirical parameter.

This physically based two-layer model could describe the loss of soluble component of chemical fertiliser under the impact of raindrop in runoff water. Dong *et al.* (2013) reported that the predictions agree well with the experimental results obtained in their study and the model could be used to model the movement of solutes in the overland flow under different soil moisture contents. However, it was also noted in their study that the model did not perform well when there was severe soil erosion during the rainfall.

2.4.3 Nutrient wash-off model

The nutrient wash-off model consists of two parts. The first part describes the mechanism of the washing off of soluble chemical. During this process, soluble chemicals are dissolved and form part of the runoff directly. The physical mechanism is relatively simple and determined by the hydraulic conditions and solubility of the chemical in water. The other part describes the sediment wash-off. It was known that certain chemicals, e.g. phosphorus is not chemically stable in the soluble form and is readily absorbed by soil constituents, such as clays, aluminium and iron compound coated soil particles (Bolland *et al.* 2003). It was also known that phosphorus attached to the surface of sediment particles and is hence transported when soil erosion take place (Aksoy and Kavvas 2005). Therefore, the soil erosion does not only introduce sediment into surface runoff, but also entrains chemicals that are attached on the sediment particles.

2.4.3.1 Soluble chemical wash-off model

The transport of chemical from soil surface to overland flow induced by runoff wash-off can be modelled by considering the pollutant mass remaining on the surface. This model is based on the assumption that the rate of chemical wash-off rate is proportional to the remaining chemical mass (Sartor *et al.* 1974; Alley 1981; Alley and Smith 1981; Soonthornnonda *et al.* 2008) and the wash-off process is not influenced by the change in of surface during rainfall (Egodawatta *et al.* 2009) . As noted by Sator *et al.* (1974), the wash-off process can be best represented using a first order equation:

$$\frac{dM}{dt} = -diM \quad \text{Eq.2- 3}$$

where, M is nutrient mass (kg); d is transport coefficient (cm^{-1}); i is average effective rainfall intensity (cm/hr). Eq. 2-3 and similar equations have been used by Sartor *et al.* (1974), Alley (1981) and Alley and Smith (1981).

2.4.3.2 Sediment transport model

Most hillslope and watershed scale erosion and sediment transport models can be

divided into two categories, similar to that in rainfall-runoff models: models could either be constructed based on a conceptual framework or based on mass conservation equation. The former ones are generally named as conceptual or empirical models (e.g. USLE) and the later ones are called physical models (e.g. USDA-WEPP model).

Most of the conceptual soil loss models were developed based on the Universal Soil Loss Equation (USLE). The USLE “predicts” the long term average annual rate of soil erosion from a field slope based on the factors that influence soil erosion namely, rainfall pattern, soil type, topography, crop system and management practices (Wischmeier and Smith 1978). However, it can only be applied to “predict” soil loss due to sheet or rill erosion but not gully, wind or tillage erosion. Five factors are used to calculate the soil loss for a given site. Soil Loss is expressed as:

$$A = R \times K \times LS \times C \times P \quad \text{Eq.2- 4}$$

“A” represents the potential long term average annual soil loss in tons per acre per year.

“R” is the rainfall factor, which is a numerical value that expresses the capacity of a rainfall to erode soil from an unprotected field. The greater the intensity and duration of the rain storm, the higher the erosion potential. The erosion potential of a rain storm is proportional to the product value of two rainfall characters: total kinetic energy of the storm (E) and its maximum 30 minute intensity (I_{30}).

“K” is the soil erodibility factor. It can be expressed in M tons of soil loss per hectare per unit of rainfall index for a slope of 9% and length of 22.13 meters. Texture is the principal factor affecting K, but structure, organic matter and permeability also contribute.

“LS” is the length and steepness of slope factor. It represents a ratio of soil loss under given conditions to that at a site with the “standard” slope steepness of 9% and slope length of 22.13 m.

“C” is the cropping and management factor. It is the ratio of the soil loss from land

under a specific crop and management system to the corresponding loss from continuously fallow and tilled land. C factor is affected by crop type, quality of cover and root growth, water use by the growing plants *etc.*

“P” is the support practice factor. It reflects the effects of practices that will reduce the amount and rate of the water runoff and thus reduce the amount of erosion.

Physically-based models not only represent essential mechanisms that influence soil erosion, but also take into consideration of physical characters such as plant growth and climate (Zhang *et al.* 1996). Zhang *et al.* (1996) and Aksoy *et al.* (2005) reviewed and categorized existing hillslope and watershed scale erosion and sediment transport models. Based on their study, some of the models are summarized below in Table 2-6.

Table 2- 6 Summary of representative soil erosion models

Model	Category	Author	Description
USLE	Conceptual	Wischmeier and Smith (1978)	<ul style="list-style-type: none"> • $A = R \times K \times LS \times C \times P$
RUSLE	Conceptual	Renard <i>et al.</i> (1991)	<ul style="list-style-type: none"> • Revised USLE.
SEDD	Conceptual	Biesemans <i>et al.</i> (2000)	<ul style="list-style-type: none"> • Based on USLE; • Monte Carlo technique was used to test the model parameters.
AGNPS	Conceptual	Pekarova <i>et al.</i> (1999); Rode and Fredo (1999)	<ul style="list-style-type: none"> • Event based model; • Erosion estimated by USLE and routed by Steady-state continuity equation.
LASCAM	Conceptual	Viney and Sivapalan (1999)	<ul style="list-style-type: none"> • Daily time interval.
Kinematic mathematic models	Physical	Foster and Mayer (1972)	<ul style="list-style-type: none"> • $\frac{dq_s}{dx} = D_r - D_i$
ANSWERS	Physical	Beasley <i>et al.</i> (1980)	<ul style="list-style-type: none"> • Sediment is detached by rainfall and runoff; • Sediment is transported by runoff; • Runoff and erosion was modelled use independent functions
USDA-WEPP	Physical	Nearing <i>et al.</i> (1989)	<ul style="list-style-type: none"> • Daily continuous model; • Calculate erosion in the rills and interrill areas separately; • Steady-state sediment continuity equation is adopted.
WESP	Physical	Lopes (1987)	<ul style="list-style-type: none"> • 1-D continuity equation for sediment transport; • Suitable for small watershed; • Assume that erosion and deposition occur simultaneously.

2.4.4 Runoff transport model

Lateral chemical transport along a uniform slope can be mathematically modelled by solving the mass balance equation of surface runoff (Eq. 2-5) and the conservation equation of dissolved chemicals in surface runoff (Eq.2-6) (Wallach *et al.* 2001; Deng *et al.* 2005).

$$\frac{\partial h}{\partial t} + \frac{\partial q}{\partial x} = i(t) - f(t) \quad \text{Eq.2- 5 (a)}$$

$$\text{with } q = \alpha h^m \quad \text{Eq. 2-5 (b)}$$

$$\frac{\partial (Ch)}{\partial t} + \frac{\partial (Cq)}{\partial x} = \frac{\partial}{\partial x} \left(Zh \frac{\partial C}{\partial x} \right) + k_m D_m (C_s - C) \quad \text{Eq.2- 6}$$

where,

x = distance along the slope;

h = overland flow depth;

t = time;

q = unit discharge on the slope direction;

i = rainfall intensity;

f = infiltration rate;

α = kinematic-wave resistance parameter;

m = empirical exponent;

C = chemical concentration;

C_s = chemical concentration in active soil surface layer;

Z = longitudinal dispersion coefficient;

k_m = chemical exchange rate; and

D_m = active soil surface layer depth.

In Eq. 2-6, overland flow can be either laminar or turbulent (De Lima 1992; Wallach *et al.* 2001; Myers 2002), and corresponding α and m can be determined based on Reynolds' number (Table 2-7).

Table 2- 7 α and m values based on Reynolds' number

Flow Regime	Reynold's number ($Re = \frac{\rho v D}{\mu}$)	m	α	Remarks
Laminar	$Re < 500$	3	$8gs/K_r v$	s = soil surface gradient g = gravity acceleration v = kinematic viscosity K_r = soil surface roughness parameter n = Manning's coefficient
Turbulent	$Re > 500$ and $n^6(hs)^{1/2} > 1.1 \times 10^{-13}$	5/3	$s^{1/2}/n$	

In addition to the one-dimensional advection-dispersion equation, Yan and Kahawita (2000) developed a two dimensional numerical model for the transport of pollutant under unsteady flow conditions based on the St. Venant equation, the Green-Ampt infiltration equation, the pollutant transport equation and a solubility rate equation.

2.5 Water quality models

2.5.1 Overview

There are a large number of water quality and transport models in the literature. It is only recently that physical model becomes the main stream in water quality and transport modelling, among which SWMM, STORM (modelling urban storm pollution), ARM (modelling agricultural pollution), ANSWERS, CREAMS (modelling catchment pollution) are the favourites. A typical integrated water quality model involves four sub-models (as shown in Figure 2-4):

Figure 2- 4 A typical Integrated Water Quality Model

Rainfall-Runoff model is used to solve various hydrological problems of a watershed, and is the foundation of the transport model because the rainfall-runoff process is the driving force and transport medium of the whole process.

Soil erosion and sediment transport model simulates the transport of sediment in surface flow. Sediment is not only an important pollutant in the aquatic environment, but also an essential agent or carrier of other pollutants, such as N, P and heavy metals. As a result, soil erosion and sediment transport model plays an important role in integrated water quality modelling.

The core of a water quality model is pollutant transport and transformation model, which simulates the transport and transformation of pollutants during runoff formation and concentration. Water quality model for receiving water, at the tail end of the pollutant transport is perhaps an equally if not more important part of water quality modelling, as it is at the receiving water body that the pollutants accumulates and exemplify all kinds of negative effects of contaminant.

There is added complexity to water quality model as the source of pollutants could be diffuse, i.e. non-point source. Such water quality model is an essential part of modern water quality modelling. Commonly used non-point source water quality models are summarized in Table 2-8.

Table 2- 8 Commonly used non-point source water quality models (Li 1996; Li and Shen 1996; Hu *et al.* 2002)

Name	Time of Publication	Format of Parameters	Spatial Scale	Temporal Scale	Time Interval	Model Description
ANSWERS	1977	Distributional	Catchment	Single event----Long term continuous	For storm events: 60s For non-storm events: 1d	Initial loss of precipitation, infiltration, overland flow and evaporation are considered in the hydrological sub-model and splash erosion, scouring and deposition are considered in the erosion sub-model. Contaminants transport model is added later on, including N-P sub-model and complex equilibrium of contaminants.
CREAMS	1979	Lumped	Cropland and small scale	Long term continuous	1 day	SCS hydrological sub-model and Green-Ampt infiltration model are applied. Evaporation is considered and splash erosion, scouring and deposition are considered in the erosion sub-model. Sub-models also include deposition and scouring of river channel, N-P loads and simple equilibrium of contaminants.
AGNP	1987	Distributional	Catchment	Single event----Long term continuous	1 day	SCS hydrological sub-model; Universal Soil Loss Equation; N-P-COD load sub-model; No contaminants equilibrium is considered.
SWAP	1996	Lumped	Catchment	Long term continuous	1 day	SCS hydrological sub-model, infiltration, evaporation and snow melt; Revised USLE; N-P load and complex equilibrium of contaminants.
LAOD	1996	Distributional	Catchment	Long term continuous	1 day	Runoff Coefficient method for the calculation of runoff; no erosion sub-model; the TN, TP and BOD loads are calculated by statistical model.
HSPF	1976	Lumped	Catchment	Long term continuous	From 1 min to 1 day	Stanford hydrological sub-model; splash erosion, scouring and deposition are considered in the erosion sub-model, contaminant sub-model including N, P and fertilisers loads, and complex equilibrium of contaminants is considered.

Apart from those non-point sources water quality models, models with other functional objectives had also been developed. Cox (2003) reviewed the currently available in-stream water quality models, such as SIMCAT, TOMCAT, QUAL2E. For in-stream water quality models, hydrodynamics and contaminant diffusion mechanisms are the key contents in the approaches of model development. SIMCAT (SIMulation of CATchments) and TOMCAT (Temporal/Overall Model for CATchments) are two popular models developed by the EA (National Environment Agency) in England and Wales. However, they rarely appear in the literature (Jamieson and Fedra 1996) because they are not widely used outside UK. Both of these softwares are stochastic, one-dimensional deterministic steady state models. The QUAL2E model (Brown and Barnwell 1987) was developed by USEPA (US Environmental Protection Agency). It can simulate steady and unsteady transport of pollutants and can simulate interaction of up to 15 water quality parameters, including ammonia-N, nitrate-N, Nitrite-N and DP (Dissolved Phosphorus). The basic equation that is used to describe the behaviour of pollutant in-stream transport is the one-dimensional conservative advective-diffusion equation:

$$A_x \frac{\partial C_x}{\partial t} + \frac{\partial}{\partial x} (u A_x C_x) = \frac{\partial}{\partial x} \left(A_x D_c \frac{\partial C_x}{\partial x} \right) + \frac{dC_x}{dt} \pm S(C_x, x, t) \quad \text{Eq.2- 7}$$

in which C_x is the constituent concentration, t is time, x is distance, u is advection velocity, A_x is cross-sectional area, D_x is diffusion coefficient, and $S(C, x, t)$ are all sources and sinks.

C. Zoppou (2001) reviewed water quality models for urban storm events (Zoppou 2001). Among the many models he reviewed, SWMM and STORM were found to be the most widely used models. SWMM (Huber and Dickinson 1988; Roesner *et al.* 1988) simulates both water quality and quantity of urban storm water runoff and combined sewer overflow. Surface runoff simulation is based on rainfall intensities and antecedent soil moisture conditions, land use and topography and the rainfall-runoff process including infiltration depression, evaporation and surface runoff, is simulated by simple nonlinear reservoir storage. Surface pollutant allows either linear or nonlinear accumulation with time and the wash off process is treated as a simple function of runoff or as a first-order decay relationship. The pollutants parameters in SWMM are: SS, settleable solids, BOD, COD, TN, TP, oil/grease,

total coliforms. STORM was developed to simulate runoff and pollutant loads from urban and rural watersheds in response to precipitation. It is an hourly interval model. For the calculation of hourly runoff, three methods can be used in STORM, namely: coefficient method, soil-complex-cover method and the unit hydrograph method. Erosion is estimated using an empirical relationship and the pollutant accumulation is treated as either proportional to the dust and dirt accumulated or a simpler linear function of time. Washoff is proportional to the amount of pollutant accumulated. Suspended and settleable solids, BOD, TN and orthophosphates are modelled. Table 2-9 shows the Characteristics of representative models reviewed in Zoppou's study.

Table 2- 9 Characteristics of representative models (C. Zoppou, 2001, adapted from Nix, 1991)

Model	Model characteristics													
	Routing level			Time modelling scale		Pollutant predictive method			Pollutant transport			Optimisation		
	Simple storage	Hydrologic	Hydraulic	Continuous	Event	Empirical	Buildup and washoff	Soil loss	Advective diffusion equation	Completely mixed reactor	Plug flow	Analytical	Linear programming	Non-linear programming
DR3M-QUAL	√	√	√		√	√	√	√			√			√
HSPF	√	√		√	√	√	√	√		√	√			
MIKE-SWMM	√	√	√	√	√	√	√	√	√	√	√			
QSS	√	√	√	√	√	√	√				√	√		
STORM	√				√		√	√		√				
SWMM	1	√	2		√	√	√	√		√	√			
SWMM Level 1				√		√						√		
Wallingford Model	√	√	√	√	√	√	√		3					

1, flow balance only; 2, with EXTRAN module; 3, advection only.

2.5.2 Review of selected water quality models

2.5.2.1 Water quality module in HEC-RAS

HEC-RAS (The U.S. Army Corps of Engineers' River Analysis System) allows the users to perform a one-dimensional steady and unsteady flow river hydraulics calculations for a full network of natural and constructed channels (USACE 2010), and is based on the steady or unsteady flow calculations. A water quality analysis module has been included to perform riverine water quality analyses, and the parameters include Water Temperature, Algae, Dissolved Oxygen (DO), Carbonaceous Biological Oxygen Demand (CBOD), Dissolved Orthophosphate, Dissolved Organic Phosphorus, Dissolved Ammonium Nitrate, Dissolved Nitrite Nitrogen, Dissolved Nitrate Nitrogen and Dissolved Organic Nitrogen. Also included in this model is a sediment transport computation module. A key element is that all four components (steady flow simulation, unsteady flow simulation, movable boundary sediment transport calculation and water quality analysis) use a common geometric data representation and common geometric and hydraulic computation routines.

An extension tools set, HEC-GeoRAS is specifically designed and developed to allow users create HEC-RAS importable geometric file using AcrGIS (a general purpose Geographic Information System software) and enable viewing of exported results from RAS. This extension filled the gap between RAS geometric data and GIS data.

The HEC-RAS water quality module uses the QUICKEST-ULTIMATE explicit numerical scheme (Leonard 1979; Leonard 1991) to solve the one-dimensional advection dispersion equation (Eq. 2-8).

$$\frac{\partial}{\partial t}(V\phi) = -\frac{\partial}{\partial x}(Q\phi)\Delta x - \frac{\partial}{\partial x}\left(\Gamma A \frac{\partial \phi}{\partial x}\right)\Delta x \quad \text{Eq.2- 8}$$

where,

V = volume of the water quality cell (m^3);

ϕ = water temperature ($^{\circ}\text{C}$) or concentration (kg/m^3);

Q = discharge (m^3/s);

A = cross section area (m^2);

Γ = dispersion coefficient (m^2/s); and

S = source or sink (kg/s).

Individual sources, sinks and computed concentrations are the outputs of the HEC-RAS water quality module. The model simulates fate and transport of water temperature, arbitrary conservative and non-conservative constituents dissolved nitrogen, dissolved phosphorus, algae, CBOD and DO (USACE 2010).

Figure 2- 5 Schematic of water quality parameters

In the water quality module, pathways between the variables (DO, Nitrogen, etc.)

and the corresponding coefficients are considered (see Figure 2-5). All the parameters shown in Figure 2-5 are user defined and are allowed for in HEC-RAS.

2.5.2.2 U.S. EPA Storm Water Management Model (SWMM)

Storm Water Management Model (SWMM), first developed by U.S. Environmental Protection Agency (EPA) in 1971, is a dynamic rainfall-runoff simulation model for single event or long term simulation of water quantity and quality from urban areas. The latest version of SWMM (SWMM 5.0) accounts for various hydrological processes such as time-varying rainfall, evaporation of standing surface water, rainfall interception from depression storage, infiltration into unsaturated soil, percolation of infiltrated water into groundwater, interflow and nonlinear reservoir routing of overland flow (Rossman 2010).

The water quality module in SWMM consists of various processes to estimate the production of pollutant loads associated with the runoff generated by the water quantity model. Those processes are:

- Dry weather Pollutant build-up over different land uses;
- Pollutant wash-off from specific land uses during storm events;
- Direct contribution of rainfall deposition;
- Reduction in dry weather build-up due to street cleaning;
- Reduction in wash-off load due to BMPs;
- Entry of dry weather sanitary flows and user-specified external inflows at any point in the drainage system;
- Routing of water quality constituents through drainage system;
- Reduction in constituent concentration through treatment in storage units or by natural processes in pipes and channels

2.5.3 Summary

Present water quality models seek to describe the spatial and temporal changes of certain constituents. It is only during the past decades and following the emerging water quality issues that components of state variables have been gradually

incorporated into water quality models. In fact water quality model is complex and covers a wide range of issues ranging from the simple Street-Phelps equation (Raucch *et al.* 1998), describing the relationship between the dissolved oxygen concentration and the biological oxygen demand to models that describe comprehensive O, N and P cycles (Shanahan *et al.* 1998). However, there appear to be a number of common deficiencies among most of these models.

First of all, the building-up and washing-off processes of pollutants are not very well understood. The simple exponential relationship that is generally used may not be reliable (Carpenter *et al.* 1998; Zoppou 2001), especially for the pollutants placed on pervious surfaces (e.g. soil surface). There are very few data sets available to verify or establish new empirical relationships. Non-constant nutrient sources from soil, that is, the nutrient sources are temporally variable, including the effects of loss of fertilisers on soil surface due to exposure to the environment is generally not considered.

Secondly, adsorption of chemicals to sediments is a major component in the transport of pollutants (Zoppou 2001; Aksoy and Kavvas 2005). Most of the existing water quality models do not include the effects of dissolution and entrainment as attachment of chemicals to soil particles. Furthermore the sediment transport equations are solved simultaneously with the shallow water wave equations (Aksoy and Kavvas 2005) without due consideration of other related processes.

Finally, pollutants leaching and chemical reactions with soil materials are also not very well understood. While it may be a slow process, plant uptake of fertiliser is a major consumptive loss of fertiliser. Very few nutrient loss models include the potential loss of chemicals due to plant uptake.

CHAPTER 3 EXPERIMENTAL METHODS

3.1 Introduction

In nutrient loss modelling, it is essential to understand the underlying physical processes and the availability of reliable and accurate mathematical equations that are used to describe the pollutant transport process. In order to obtain the necessary information to develop the model, three series of laboratory experiments were carried out for this study. The first series of laboratory experiment was carried out to investigate the loss of nitrogen (N) and phosphorus (P) compounds in a typical commercial fertiliser. The second series of laboratory experiment was designed to elucidate the loss of N and P compounds due to infiltration and adsorption to soil particles using a soil column. The last series was designed to investigate the N and P loss due to plant up-take.

A controlled outdoor experiments campaign was conducted to obtain the necessary data for model calibration and verification. In the controlled outdoor experiments, agricultural garden fertiliser was applied to the outdoor plot selected. The day when the fertiliser was applied was set as time zero, i.e. the initial condition. During the subsequent days, temperature and rainfall amount, where applicable, was recorded and surface runoff was collected for chemical analysis. The measured results were later compared with the modelling results, and the pertinent model parameters were optimized accordingly.

In this chapter, the theoretical basis of the pertinent N and P compounds and the corresponding chemical laboratory analysis are introduced and the equipment and methods used to determine N and P concentrations in the samples are described. The laboratory experimental setups are presented in section 3.2. Also presented in this chapter are the experimental setup of the outdoor experimental plot and the data collection method.

3.2 Nitrogen and phosphorous - chemical analysis

The method used to detect N and P concentrations (NO_3^- -N, NH_4^+ -N, TN and TP) was based on spectrophotometry, and can be applied to qualitatively and quantitatively analyze the presence of a particular substance in the test sample. This method is based on Lambert-Beer Law. By measuring the absorption spectrum, the concentration of a particular substance can be determined. The instrument used in this study was spectrophotometer DR3800 from Hach (Figure 3- 1).

Figure 3- 1 Spectrophotometer DR 3800

The DR 3800 spectrophotometer is a VIS spectrophotometer with a wavelength range of 320 to 1100 nm. The instrument comes with a complete set of application programs and multi-language support. The DR 3800 spectrophotometer contains the following application modes: Stored Programs (pre-installed tests), Barcode Programs, User Programs, Favourite Programs, Single Wavelength Mode, Multi-Wavelength Mode, Wavelength Scan and Time Course Mode. The DR 3800 Spectrophotometer provides digital readouts in direct concentration units, absorbance or percent transmittance (HachCompany 2007). The spectrophotometer was calibrated by the professionals from Hach company annually to make sure that the chemical test result is reliable. Disposable test reagent vials were also provided by the company.

The methods used in this study were: Cadmium Reduction Method for NO_3^- -N analysis (concentration detection range: 0.3-3 mg/L NO_3^- -N); Salicylate Method for NH_4^+ -N analysis (concentration detection range: 0.4-50 mg/L NH_4^+ -N); Persulfate Digestion Method for TN analysis (concentration detection range: 2-150 mg/L N);

PhosVer 3 with Acid Persulfate Digestion Method for TP (concentration detection range: 0.02-1.1 mg/L P) analysis, and Molybdovanadate Method with Acid Persulfate Digestion for TP (concentration detection range: 1.0-100 mg/L PO_4^{3-}) analysis (HachCompany 2007).

Figure 3- 2 Experiments for analyzing N and P concentrations (test tubes at the far left served as control - blank contrasts)

The concentrations of test samples were characterized by different darkness of the water sample after been treated with the appropriate reagents. The darker the treated sample was, the higher was the concentration. For different parameter, the representative colour was different: NH_4^+ -N was colour coded by green, LR TP was colour coded by blue, while the others were colour coded by yellow (Figure 3- 2).

3.3 Experimental setup

An agriculture-grade N-P-K fertiliser was used the source of N and P both the laboratory experiments and the controlled outdoor experiment, of which the major nutrients were nitrogen phosphorus and potassium and 6 minor nutrients were calcium, magnesium, sulphur, iron, manganese, and zinc. The fertiliser was tested for the nitrogen and phosphorus constituents before the experiments were conducted, and the NH_4^+ , NO_3^- and TP content was 3%, 10% and 13% by weight, respectively.

3.3.1 Laboratory experiments

3.3.1.1 N and P loss over time

The N and P compounds degrade when they are left to the elements. The loss process can be investigated by leaving N and P samples (e.g. fertilisers) exposed to the environment and measure the N and P content at pre-determined intervals. In the experiments, the inorganic fertiliser were pre-packed in 0.1g/package and several packages were left exposed in a fume cupboard and in the open (but sheltered). Two to three fertiliser packages were removed and tested at pre-determined intervals (0, 1, 3, 7, 9, 11, 15, 18, 22, 29, 37, 46, 56, and 67 days after exposure). The fertilisers were dissolved in 500ml deionised (DI) water and the concentrations of N and P were measured using the standard method.

3.3.1.2 N and P loss due to infiltration and soil adsorption

In this study, loss and loss of fertiliser (nutrient load) in the soil due to infiltration (leaching) was investigated using the soil column method as described following. A 80cm high acrylic cylinder 20 cm in diameter with a side outlet 50 cm from the base was used. The cylinder was filled with clean quartz sand from the base to the side outlet, i.e. the soil column was 50 cm in length. A funnel at the base of the cylinder to collect the water percolated through the soil column. The use of quartz sand as the soil medium instead of natural loam since clean quartz sand particles do not contain N and P.

Figure 3- 3 Soil column experimental setup. (a) photo of the soil column apparatus;
(b) Schematic of the dimensions of the soil column apparatus.

Three series of experiments with different fertiliser application rates were conducted. In these experiments, selected quantities of inorganic fertiliser were blended into pre-saturated sand and placed in the top 20 cm of the soil column. The quantity used corresponded to the amount equivalent to a fertiliser application rates of (a) 225kg of Nitrogen per ha (N/ha) and 135kg of Phosphorous per ha (P/ha); (b) 500kg N/ha and 300kg P/ha; and (c) 1000kg N/ha and 600kg P/ha. Rainfall rate with an equivalent intensity of 50 mm/hr, lasting for 0.2 hour, i.e rainfall depth of 10 mm was used for each leaching experiment. Samples of the infiltrated water were collected at selected time intervals; every 24 hours at the beginning of experiment and less frequent (e.g. 2-3 days interval) during the later part of the experiments.

As the N and P concentrations (NH_4^+ , NO_3^- , TN and TP) of the sample collected from the water-soil column was too high to be tested directly using the standard method, the samples were diluted before the chemical test and in order to minimize the error brought forth by the dilution, the tests were carried out in replicate

3.3.1.3 N and P loss due to plants uptake

Five boxes were filled with either soil only or soil with plant (Figure 3- 4). Box 1 was treated with water only and to serve as the background baseline control. Boxes 2 and 3 were treated with water and fertiliser at a rate of 225kg/ha. Box 2 was without plant. The fertiliser application rate in Boxes 4 and 5 was based on 100kg/ha. At each sample collection day, 200ml DI water was injected into each box. Water samples were collected and analyzed for N and P.

(a) Schematic of the experiment setup

(b) Photo of the control experiment

Figure 3- 4 Plant uptake experiment setup

3.3.2 Controlled outdoor experiments

Controlled outdoor experiments was also carried out to investigate and verify the combined effects of time, infiltration, runoff and plants on N and P concentrations in surface runoff following the use of fertiliser on the plot.

3.3.2.1 Site information

3.3.2.1.1 Climate

Singapore is located in the equatorial region, and the local climate is classified as “Tropical Rainforest Climate” based on the Koppen climate classification (McKnight and Tom L. *et al.*, 2000). Although the “Tropical Rainforest Climate” is characterized by one without distinct seasons, uniform temperature and pressure, high humidity and abundant rainfall, the rainfall distribution in Singapore is not uniform and is influenced by the monsoon seasons which are observed twice each year. The first season is the Northeast Monsoon which occurs from December to early March. The second is the Southwest Monsoon season which occurs from June to September. The periods between monsoon seasons receive less rain. During the Northeast Monsoon, there are cloudy conditions in December and January with frequent afternoon showers. It is relatively dry in February till early March although monthly rainfall still exceeds 120mm. During the Southwest Monsoon season, southeast winds prevail. Isolated to scattered showers occur in the late morning and early afternoon. The mean annual temperature was 28.3°C; average annual rainfall was 2345 mm, and the average annual humidity was 84.2% (NEA, Singapore, 2007). The distribution of the monthly mean rainfall and temperature is shown in Figure 3- 5.

Figure 3- 5 Singapore climate chart

Table 3-1 shows the monthly statistical climate data, recorded by National Environmental Agency (NEA), Singapore, from 1869-2011.

Table 3- 1 Statistical data of Singapore weather (National Environment Agency 2012)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
24-hr mean temperature (°C)	25.9	26.5	26.9	27.4	27.7	27.7	27.4	27.3	27.2	27.0	26.5	26.0
Mean monthly total rainfall (mm)	243.2	159.9	185.7	178.9	171.3	162.1	158.7	175.4	169.2	193.8	256.9	287.4
Mean raindays	15	11	14	15	15	13	13	14	14	16	19	19
24-hr mean relative humidity (%)	84.7	82.8	83.8	84.8	84.4	83.0	82.8	83.0	83.4	84.1	86.4	86.9
Mean daily surface wind speed (m/s)	2.5	2.4	1.8	1.3	1.4	1.6	1.9	1.9	1.7	1.3	1.3	1.9

3.3.2.1.2 Topography

A rectangular outdoor experimental plot (1x15 m) located at Nanyang Technological University, Singapore was selected and used as the test plot to carry out the controlled outdoor experiments. The topographical information of the plot, including elevation, was collected using electronic total station to generate the Digital Elevation Model (DEM) by ARCGIS. The slope and contour of the experiment plot is shown in Figure 3- 6, the boundary of the rectangular plot is highlighted in red frame. The average slope of the test plot was 1 in 4.24.

Figure 3- 6 Slope and contour map of the experimental plot

3.3.2.1.3 Soil property

Soil is a complex, living, changing and dynamic component of the agroecosystem. In nutrient loss modelling, soil serves as both the background (source or sink) and one of the pathways of the pollutant transport. Therefore, in designing the controlled outdoor experiments, it is important to investigate the soil property first. The test locations were selected at 2 meters interval from the top of the plot.

(1) Soil moisture

Soil moisture can be measured by using a drying oven. Certain amount of soil samples (e.g. 20g) were collected from the plot at each test location, and placed in the oven. The weight of the samples was monitored until no change, which meant the sample was dry. The gravimetric soil moisture is then determined as:

$$\text{Soil moisture (weight \%)} = \frac{\text{weight of soil sample} - \text{weight of dry soil}}{\text{weight of dry soil}} \quad \text{Eq.3- 1}$$

(2) Soil temperature

Soil temperature was measured at noon during a sunny day. At each of the temperature measuring location, a temperature probe was used to measure the temperature at the soil surface, 5cm below the surface and 15 cm below the surface.

(3) Soil texture

Texture is one of the most stable attributes of the soil and it refers to the percentage by weight of sand (particle size between 0.05 to 2.0mm), silt (0.002 to 0.05mm), and clay (<0.002) in the soil sample. The soil samples collected at the sampling point were air dried and then pounded to break up the large aggregates. For each sample, 100g of soil was weighed and put in the top of a set of sieves. The sieves were set to shake for 15 minutes. Soil particles in each sieve was collected and weighed, and particle size distribution obtained. And finally, the soil texture was determined using the soil texture triangle as shown in Appendix B.

3.3.2.1.4 Plot design

Typically investigation of pollutant wash-off from watershed and enter into the recipient water involves outdoor experiments and to obtain the necessary data. The plot area might be designed to be either as small as several centimetres in length and width (Shaw *et al.* 2006; Egodawatta *et al.* 2007), where the experiment conditions (e.g. rainfall intensity, initial mass on surface, *etc.*) was easy to control but the results were less representative; or as large as a whole catchment (Gerke *et al.* 2001; Ng Kee Kwong *et al.* 2002), where the data was more realistic and without

the need to consider physical processes taking place within the catchment. In this study, the author designed a small outdoor plot on a rectangular grass slope. The plot measured 15m x 1m.

3.3.2.2 Outdoor plot overview

Figure 3- 7 shows a schematic sketch and Figure 3- 8 shows the photograph of the outdoor plot (the boundary is highlighted in red lines: grass slope with clay loam soil; dimensions: 15m x 1m; steepness: 1 in 4.24). Also indicated in the sketch were the locations of the rain gauge and channels used to intercept the surface runoff. The dimension of the plot was also indicated.

Figure 3- 7 Sketch of the outdoor plot

Figure 3- 8 Photo of the outdoor plot

Runoff samples were collected by the channels installed. The sampling locations were numbered (Table 3- 2) from the top to the bottom for convenience of later analysis.

Table 3- 2 Named sample collection location

Sampling ID	Location
WS 1	5 meters from the slop top
WS 2	9meters from the slope top
WS 3	11 meters from the slope top

3.3.2.3 Meteorological data collection

Meteorological data, include rainfall, temperature were measured at the top of the outdoor plot. Rain gauge is widely used for meteorologists and hydrologists to measure the amount of liquid precipitation (e.g. rainfall) over a set period of time. Early rain gauges like graduated cylinders are manually operated and the precision is around 0.5mm (National Weather Service 2010). Another type of rain gauge is the tipping bucket rain gauge, consisting of a funnel that collects and channels the precipitation into a small seesaw-like container. After a pre-set amount of precipitation falls, the lever tips, dumping the collected water and sending an

electrical signal. In this study, a tipping bucket rain gauge (Figure 3- 9) attached with a thermometer and a data logger, which can record precipitation and temperature automatically was used to collect rainfall information.

Figure 3- 9 Tipping bucket rain gauge

3.3.2.4 Runoff calculation

Runoff calculation of the outdoor plot is difficult in this study because of the limitation of data and the ephemeral runoff generated. IHACRES model was chosen to simulate the rainfall-runoff process because it has been carried out in both humid and arid catchment and was proved to be successful. Moreover, IHACRES was proved to be effective to simulating ephemeral stream flow in its application on a low-yielding catchment in Australia (Ye *et al.* 1998), and only requires a few parameters in its calibration (Sriwongsitanon and Taesonbat 2011). After weighing the various options, pro and con of various models, IHACRES was finally adopted in this study. The feasibility study and validation of applying IHACRES model in this study was shown in later part of the report in Chapter 6.

The IHACRES model is a conceptual rainfall-runoff model consisting of two modules: a non-linear loss module to transform the measured rainfall to effective rainfall, and a linear routing module compute a linear combination of antecedent streamflow values and effective rainfall (Figure 3- 10).

Figure 3- 10 Model structure of IHACRES (Sriwongsitanon and Taesonbat 2011)

In IHACRES model, the non-linear representation of the effective rainfall (Mati *et al.*) proposed by Ye *et al.* (1998) is:

$$u_i = [c(\phi_i - L)]^p r_k \quad \text{Eq.3- 2}$$

where, r_k is the observed rainfall (mm) on day k , c is the mass balance, L is the soil moisture index threshold for producing flows and p is the non-linear response term (Ye *et al.* 1998). In this equation, the parameters L and p are typically only necessary for ephemeral catchments (Carcano *et al.* 2008). Soil moisture (ϕ_i) is determined by:

$$\phi_k = r_k + \left(1 - \frac{1}{\tau_k}\right) \phi_{k-1} \quad \text{Eq.3- 3}$$

where, τ_k is the drying rate as determined by:

$$\tau_k = \tau_w e^{[0.062f(t_r - T_k)]} \quad \text{Eq.3- 4}$$

where, T_k is the observed temperature ($^{\circ}\text{C}$), τ_w is the drying rate at reference temperature ($^{\circ}\text{C}$), f is the temperature modulation ($^{\circ}\text{C}^{-1}$) and t_r is the reference temperature ($^{\circ}\text{C}$).

In the linear module, the effective rainfall was converted into runoff using a linear relationship. There are two components in the flow routing—quick flow and slow flow. For ephemeral streams, one component is usually sufficient (Ye *et al.* 1998). Eq. 3-9 shows the equations for calculating runoff.

$$x_k = x_k^q + x_k^s \quad \text{Eq. 3- 5 (a)}$$

$$x_k^q = -\alpha_q x_{k-1}^q + \beta_q u_k \quad \text{Eq. 3-9 (b)}$$

$$x_k^s = -\alpha_s x_{k-1}^s + \beta_s u_k \quad \text{Eq. 3-9 (c)}$$

where, x_k^q is the quick flow at time step k and x_k^s is the slow flow. Those two components are combined to yield the runoff x_k . Parameters α_q and β_q are time constants for the quick flow, α_s and β_s are the time constants for the slow flow.

3.3.2.5 Surface runoff sample collection

Selected quantities of inorganic fertiliser were applied uniformly on the test plot. The quantity used corresponded to the amount equivalent to a fertiliser application rate of 225kg of Nitrogen per ha (N/ha) and 100kg of Phosphorous per ha (P/ha); and 300kg N/ha and 130kg P/ha. Three small channels, made of halved PVC tube, were installed to intercept and collect the surface runoff (Figure 3- 11). The width of the channels was 10cm and the length was 1m. Beakers were placed at the end of each channels (left side in Figure 3- 11) to collect the runoff sample for laboratory analysis later. In order to minimize the influence of the chemical substance in the direct rainfall, the channels were covered.

Figure 3- 11 Channel installed to collect surface runoff sample

During a rainfall event, surface runoff on the test plot was collected in the small channel and the runoff sample was collected in the beaker. The runoff sample was analyzed to obtain the corresponding N and P concentrations.

CHAPTER 4 MODEL DEVELOPMENT

4.1 Introduction

4.1.1 Problem definition

Nitrogen (N) and Phosphorous (P) are the two targets in this study. Sharpley *et al.* (1996) reported a preliminary relationship which stated that the amount of P that enter surface water is proportional to the amount of P in the soil. One major pathway for fertilisers to enter surface waterbodies is through the rainfall-runoff process. Wu and Li (1996); Kleinman and Sharpley (2002) suggested that the loss amount of N or P from the soil media generally increased during rainy seasons when high precipitation and runoff were observed.

There are reported studies on the modelling of nutrient leaching from the soil surface (Kalita and Kanwar 1993; Zhang *et al.* 2007), and spatial distribution of nutrient (N and P) in the soil (He *et al.* 2000; Paramasivam *et al.* 2002; Zhang *et al.* 2007). Transport of nutrient from a nutrient source in a watershed has also been reported (Leinard *et al.* 1987; Bouraoui and Dillaha 1996; Arnold *et al.* 1998). Other models including the Two-Layer Model have been reported by Gao *et al.*, (2004), Tong and Yang (2008), Vadas *et al.* (2008) and Wallach *et al.* (2001).

There are still gaps in the knowledge of modelling nutrient loss from soil surface, and they include: (1) N and P loss on pervious surface during the wash-off process; and (2) variable nutrient concentration on the soil surface. This study aims to develop a model that could address, among other nutrient loss phenomena, these two issues.

4.1.2 Theoretical background

Soil N and P loss process is generally very similar to soil erosion process. In most cases, the fertiliser is an integral part of the soil clumps and pore water. Soil erosion

process by water and transport of the eroded particles includes detachment, entrainment, transport and deposition of soil particles at various parts of the slope. The major driving force of these processes is shear stresses generated by raindrop impact and surface runoff. Most published studies adopt the same strategy that soil N and P loss may be estimated by drawing an analogy between nutrient loss and soil erosion and followed by transport of the entrained materials in a channel (Shaw *et al.*, 2006). Raindrop impact on land surface and the ensuing particle detachment have been reported (Rose *et al.* 1994; Deletic *et al.* 1997). However, rainfall impact or entrainment of nutrient into the flow by rainfall had always been neglected in the model description of particle wash-off process. Only bed shear stress had been considered (Akan 1988). This is still the case in current stormwater quality models.

Note that there is a distinct difference in the source term in the N and P loss process from that of soil erosion. In soil erosion modelling, it is generally assumed that the soil particle available on the land surface is inexhaustible and in constant supply. In the case of N and P loss process, the amount available on the land surface is finite and decreases over time. Sartor *et al.* (1974) introduced the first particulate pollutant wash-off model by assuming a proportional relationship between the particle loss rate and the spatial density of particles available on the surface (Sartor *et al.* 1974; Alley and Smith 1981; Egodawatta *et al.* 2009), and the wash-off process can be best represented using a first order kinetic equation:

$$\frac{dM}{dt} = -diM \quad \text{Eq. 4- 1}$$

where, M is nutrient mass (kg); d is transport coefficient (cm^{-1}); i is average effective rainfall intensity (cm/hr).

Mathematical models have been developed to describe the transport of pore-water-dissolved chemicals by surface runoff. The physically based models are generally developed based on mass-balance equations (Eq.4-2) and are used to investigate the dependence of surface runoff pollution and its extent on the system hydrological parameters (Wallach *et al.* 2001).

$$\frac{\partial(ch)}{\partial t} + \frac{\partial(cq)}{\partial x} = \frac{\partial}{\partial x} \left(Zh \frac{\partial C}{\partial x} \right) + k_m D_m (C_s - C) \quad \text{Eq. 4- 2}$$

where,

x = distance along the slope;
 h = overland flow depth;
 t = time;
 q = unit discharge on the slope direction;
 i = rainfall intensity;
 f = infiltration rate;
 α = kinematic-wave resistance parameter;
 m = empirical exponent;
 C = chemical concentration;
 C_s = chemical concentration in active soil surface layer;
 Z = longitudinal dispersion coefficient;
 k_m = chemical exchange rate; and
 D_m = active soil surface layer depth.

4.1.3 Modelling approaches

4.1.3.1 Approaches to quantitative estimation

Nix (1994) categorized water quantitative models into simple, simple routing and complex routing model according to details of parameters and data requirement and computing resources. For a simple model, little data is required and no routing is performed. Hence very little details of the flow and pollutant behaviour were simulated (National Weather Service 2010). Table 4- 1 contains a list of some of the commonly used approaches to water quantitative estimation. Brief evaluations of those approaches are also provided. It can be seen that simple storm water models, such as empirical models do not simulate certain important processes, such as the decay of pollutants, temporal and spatial variability of the system, *etc.* The more complex models generally overcome these short comings, but at a cost.

Table 4- 1 Approaches to water quantity estimation

Models	Example(s)	Advantages	Disadvantages	Sources
Statistical models	Regression models	Measurable physical parameters that are considered important in particular process are used	The statistical relationship developed from a given set of data reflects only a particular spatial arrangement.	Zoppou (2001)
Empirical models	The rational method	Involve a functional relationship between a dependent variable and variables that are considered germane to the process.		Beven (2011)
Hydraulic models	Shallow water wave equations	Hyperbolic equations allow information propagate both upstream and downstream; Provide detailed information of a watershed; Produce satisfy accuracy in representing the interaction of flow and water depth;	The computational efforts required to solved a complicated network of channels could be resource intensive	Zoppou and Roberts (1999)
	Kinematic wave model	Numerical schemes can be used in solving complicated problems; Detailed catchment information is not required and only one boundary condition.	No attenuation; Assumption made in this model is generally valid for overland flow only; Truncation errors are introduced by finite difference approximations	Zoppou (2001)
	Diffusion wave model	Capable to simulate flow attenuation;		Zoppou (2001)
Hydrological model	Unit Hydrograph	Can be obtained by either catchments measurement or analytical techniques; Easy to apply;		Beven (2011)
	Lumped continuity model	Instantaneous catchment response; Only two curves is required; Applicable for non-uniform spatial and temporal precipitation distributions	Satisfy the mass conservation equation only; Errors are significant for some circumstances;	Colon and McMahon (1987)
	Muskingum method	Storage in a river or a reservoir depend on both inflow and outflow;		Beven (2011)

4.1.3.2 Pollutant transport modelling

Advective-diffusion equation is typically the one single equation used in a deterministic pollutant transport model. Generally, the advection brought forth by flowing water dominates the pollutant transport process. Pollutants are assumed not to cause any effect on the flow field and are calculated independently of the

pollutants transformations although it is not so physically. The advective-diffusion equation used to describe the behaviour of a pollutant in a flow stream is the one-dimensional conservative advective-diffusion equation (Eq.4-3)

$$A_x \frac{\partial C_x}{\partial t} + \frac{\partial}{\partial x}(uA_x C_x) = \frac{\partial}{\partial x}\left(A_x D_c \frac{\partial C_x}{\partial x}\right) + \frac{dC_x}{dt} \pm S(C_x, x, t) \quad \text{Eq. 4- 3}$$

in which C_x is the constituent concentration, t is time, x is distance, u is advection velocity, A_x is cross-sectional area, D_x is diffusion coefficient, and $S(C,x,t)$ are all sources and sinks.

For non-conservative pollutants, one can also include a production or loss of pollutant in the source term in Eq.4-3 (National Weather Service 2010). Generally this process can be described by a first order relationship. The advantage of a first-order process is that the overall first-order rate coefficient is the sum of that for all the individual pollutants.

Other reported approaches include (i) completely mix flow and (ii) plug flow. The former, is generally based on the continuity equation only, while the later generally includes travel temporal description of the concentration changes enroute.

4.1.4 Framework of model development

Fertilisers load in the soil decreases with loss over time regardless there is rainfall or not after the fertilisers have been applied. There is very little published information on this phenomenon. This study will include the effect of fertiliser loss in the nutrient loss model. However, one may be able to establish a preliminary relationship between soil N and P loss with time using published data. An attempt to develop this preliminary relationship is also described herein - see section 4.2.

Rainfall-runoff process is the main driver behind soil nutrient loss. So the second consideration in the development of a nutrient loss model is to understand N and P leaching process with respect to precipitation. Generally, the wash-off process can be divided into wash-off process on an impervious surface and wash-off process on a pervious surface (according to landuse). The wash-off process on an impervious

surface is relatively simple, and the physical mechanism of this process is well documented in the literature. Therefore, one could readily adopt the findings and experience of modelling the nutrient wash-off process on an impervious surface in the literature. The nutrient wash-off process on a pervious surface is more complex and involves several indeterminate factors apart from rainfall-runoff process, including the type of plants, and chemical/physical interactions of the fertiliser with soil particles (e.g. adsorption) *etc.*

Reported studies in the literature suggested that the use of a first-order kinetic in nitrogen and phosphorus loss as adsorbate may be appropriate (Saeed and Sun 2011). The loss can be described using a first order kinetic equation as follow:

$$\frac{dC_t}{dt} = -kC_t \quad \text{Eq. 4- 4}$$

where, t is time after fertiliser been applied (days), C_t is the nutrient concentration (mg/L) at t , and k is the decay coefficient.

On the other hand, there were some other studies which indicated that a second-order rate equation may be applied to describe the kinetics of adsorption of NH_4^+ and phosphate into certain adsorbent (Blanchard *et al.* 1984; Ho and McKay 1998; Shin *et al.* 2004; Ho 2006), as follow:

$$\frac{dC_t}{dt} = -kC_t^2 \quad \text{Eq. 4- 5}$$

where, t is time after the fertiliser has been applied (days), C_t is the nutrient concentration (mg/L), k is the decay coefficient.

The first order kinetic equation is generally accepted in the studies of constructed wetland, when considering nitrogen and phosphorus removal efficiency, while the application of a second order kinetic could be found in the literature regarding waste treatment. The physical mechanisms of the environmental loss of fertiliser on soil surface after application remains unclear. In order to develop proper models to describe the environmental loss, a series of physical laboratory experiments has been designed to obtain the necessary data. The data is also used to calibrate the models.

Field observation is often necessary for this type of study. In the present study, a

small scale controlled outdoor experiments was carried out to obtain data that are necessary to calibrate and verify the integrated nutrient loss model.

In the ensuing sections, 5 modules considered in the model development were introduced. These modules include: N and P loss model, raindrop splash model, pollutant entrainment model, runoff transport model and catchment integration model. The general model structure was also presented. The laboratory experiment and controlled outdoor experiments results that were used in model calibration, integration and verification were presented in chapter 5 and 6.

4.2 Model development

In this study, 5 modules were developed based on the physical processes of N and P wash-off. In module 1, the author develops loss model to describe N and P deterioration on the soil surface and provides the necessary input parameter for the source term in the integrated nutrient loss model. Module 2 is the raindrop splash model, and is used to simulate the detachment of pollutants from the soil surface, followed by a pollutant entrainment model (module 3), to simulate pollutant entrainment into overland flow during the wash-off process. Module 4 is the runoff transport model that describes transport of the pollutant entrained into the runoff from the top of the slope to the outlet. The last module, catchment integration model strings the sub-plot outlets to the integrated catchment.

4.2.1 Module 1: N and P Loss Model

Reported studies showed that after it was being applied on the ground, only 30-50% of the nitrogen in the fertiliser was generally taken by plants. The rest was either being fixed by soil particles through adsorption or was lost in a number of ways including emission and transformations (Scholefield and Stone 1995; Zöbisch *et al.* 1995; Brian and Steve 1999). Although there are various factors that influencing degradation of fertiliser in the outdoor experiments, this thesis writer believes that it is still possible to establish certain preliminary relationship between soil N loss with time base on published data. An attempt to develop this relationship is elaborated

herein.

In this study, the nitrogen concentrations in soil presented in previous studies were extracted for re-plot (Figure 4- 1), aiming in establishing preliminary relationship between soil N concentration and time. It can be seen from Figure 4- 1 that the re-plotted data could be fitted using a straight line under logarithm scale, where N_0 refers to the N concentration on the initial day.

Figure 4- 1 Analysis of published data on Nitrogen deterioration (Choi *et al.* 2003; Ju *et al.* 2004; Ma *et al.* 2006; Yin and Mao 2007)

4.2.1.1 N and P loss during dry weather

It has been reported that the emission of N is determined by the chemical concentration gradient (influenced by soil water pH and surface temperature) and surface wind speed (Fillery *et al.* 1984; Brian and Steve 1999; Smith *et al.* 2007). Therefore, the N and P deterioration during the dry weather could be expressed by Eq. 4-6 as follow:

$$M_t = f(t, T, pH, v)M_0 \quad \text{Eq. 4- 6}$$

where, T is the surface temperature (°C), pH is the soil water pH, and v is the surface wind speed (m/s).

Sommer and Ersboll (1996) captured the linear regression of ammonia emission from agricultural land. The relationship of the accumulated ammonia emission could be expressed by (solid line in Figure 4- 2) as:

$$F = 6.12pH - 19.7 \quad \text{Eq. 4- 7}$$

where, F is the cumulated percentage of ammonia volatilization. This relationship may provide explanation for the 70% variation in three different studies (Sommer *et al.* 2004). In the current thesis study, experiment results from various reported studies were collected and plotted on the same graph and the best fitted line of the dataset is shown in Figure 4- 2, too (dash line). Figure 4-2 confirmed the linear relationship between ammonia emission and pH concluded from previous studies.

Figure 4- 2 Correlation between ammonia volatilization rate and pH
(Izaurrealde *et al.* 1987; Sommer and Ersboll 1996; Sommer *et al.* 2004; Jumei *et al.* 2008)

A linear relationship between ammonia volatilization rate and the temperature was also found in previous studies, see Figure 4- 3(a). In this thesis study, the author tried a different best fitted function for the dataset using the logarithmic scale, and obtained a far better correlation coefficient (R^2), see Figure 4- 3(b).

Therefore, one may conclude that the ammonia emission is linearly dependent on pH of soil water as what is commonly accepted. However, an exponential equation was found to be better in representing the relationship between ammonia emission and surface temperature than a linear equation developed in previous studies (Anderson *et al.* 2003; Sommer *et al.* 2004)

(a) normal scale fitting (Anderson *et al.* 2003; Sommer *et al.* 2004; Jumei *et al.* 2008)

(b) logarithmic scale fitting (Anderson *et al.* 2003; Sommer *et al.* 2004; Jumei *et al.* 2008)

Figure 4- 3 Correlation between ammonia volatilization rate and temperature

Although it is commonly accepted in studies related to fertiliser emission that there is a linear relationship of NH_4^+ emission with pH and temperature, respectively, the

mechanism of the temporal loss of fertiliser is still not clear. In order to further develop the temporal distribution of N and P concentrations, a laboratory experiment was carried out to establish the necessary relationship, see Chapter 3, section 3.3

4.2.1.2 N and P loss during wet weather

N and P deterioration during the period of wet weather is more complex than that during the period of dry weather since the presence of rain water adds to the complexity of the physic-chemical interactions among pollutants, soil particles and rain water. The major processes in the N and P deterioration in the presence of rain water are adsorption, plant uptake and infiltration.

In the studies of constructed wetlands, researchers often apply kinetic equations to represent the N and P loss under the combined effects of adsorption and infiltration. A first-order equation was most commonly accepted (Rousseau *et al.* 2004; Mayo and Bigambo 2005). There were other studies which indicated that a second-order rate might be applied to describe the kinetics of adsorption of NH_4^+ and phosphate by certain adsorbent (Blanchard *et al.* 1984; Ho and McKay, 1998; Shin *et al.*, 2004 and Ho, 2006). In this study, both first-order and second-order kinetic equation were proposed to simulate the N and P loss due to infiltration and soil adsorption. A series of laboratory experiments was designed to evaluate and calibrate both equations, see Chapter 3.

Development of the proposed N & P loss model follows the approach described herein.

A first order kinetic may be expressed as follow,

$$\frac{dM}{dt} = -kC \quad \text{Eq. 4- 8}$$

so that

$$\frac{C_t}{C_0} = e^{-kt} \quad \text{Eq. 4- 9}$$

where C is the chemical concentration (mg/L) and k is the decay coefficient.

A second-order kinetic equation may be expressed as in Eq. 4-10

$$\frac{dC}{dt} = -kC^2 \quad \text{Eq. 4- 10}$$

By integrating Eq.4-10, one obtains an equation that describes temporal distribution of N/N_0 (or P/P_0).

$$\frac{C_t}{C_0} = \frac{1}{kC_0t+1} \quad \text{Eq. 4- 11}$$

where, t is time after fertiliser been applied (days), C_t is the chemical concentration at t (mg/L), C_0 is the initial chemical concentration at $t=0$ (mg/L) and k is the decay coefficient related to fertiliser application rate. Noted that since C_0 is determined by and only by fertiliser application rate, Eq.4-11 may be simplified and expressed as:

$$\frac{C_t}{C_0} = \frac{1}{k_2t+1} \quad \text{Eq. 4- 12}$$

where k_2 is defined as fertiliser coefficient.

4.2.2 Module 2: Raindrop Splash Model

Pollutants and sediments on a soil surface may be detached by splashing induced by raindrop impact. In the splash model, rainfall information and fertiliser application rate are used as the input parameters. Certain amount of soil particles, sometimes with fertiliser attached on the particles, and chemical particulates are detached in the raindrop splash. The splashed up amount ends up in the surface water and are then transported by the surface runoff.

There are reported studies on soluble chemical transfer due to raindrop driven process and a number of models had been developed to simulate the chemical exchange process between soil surface and overland flow. The two-layer model is commonly used to describe this process (Steenhuis and Walter 1980; Ahuja 1990; Wallach *et al.* 2001; Gao *et al.* 2004; Gao *et al.* 2005; Tong and Yang 2008).

The two-layer model was developed after the Rose model, in which soil erosion under the raindrop impact with absence of overland flow was modelled (Rose *et al.* 1983; Hairsine and Rose 1991; Rose *et al.* 1994; Gao *et al.* 2004; Gao *et al.* 2005). The two-layer model can be expressed as (Dong *et al.* 2013):

$$C(t) = k_m \frac{C_0 \rho_b H_0}{R(t)(P t_p + \rho_b \theta_0 H_0)} t^b \quad \text{Eq. 4- 13}$$

where,

$C(t)$ = solute concentration in runoff (mg/L);

k_m = exchange rate;

C_0 = initial solute concentration in surface soil (g/g);

ρ_b = dry bulk density of soil (g/cm³);

H_0 = depth of the mixing layer (Colon and McMahon);

$R(t)$ = runoff volume (l);

p = rainfall intensity (cm/min);

t_p = time from initiation of rainfall to the formation of runoff (min);

θ_0 = initial soil moisture (%); and

b = empirical parameter.

This two-layer model contains the premise that there is a certain region under the soil surface where the surface water, soil solution and infiltrated water completely and instantaneously mixed. It is also assumed that there is no chemical transfer to this layer from the soil below (Ahuja and Lehman 1983; Ahuja 1990; Tong and Yang 2008). This layer is called the mixing layer or exchange layer and the depth of this layer is constant (Steenhuis and Walter 1980; Ahuja *et al.* 1981; Emmerich *et al.* 1989). According to the study by Zhang *et al.* (1997), the effective mixing layer thickness is less than 3-4 mm.

4.2.3 Module 3: Pollutant Entrainment Model

The runoff wash-off model consists of two parts. The first describes the mechanism of the soluble chemical wash-off and the second deals with the particulate chemical, e.g. phosphorus compounds.

4.2.3.1 Entrainment of Soluble pollutants

During this process, soluble chemicals are washed-off and entrained into the runoff directly. The physical mechanism is relatively simple and is determined by the hydraulic conditions and dilution after mixing. Generally, the transport of chemical

from soil surface to overland flow induced by runoff can be modelled indirectly by considering the pollutant mass that remains on the soil surface. The wash-off process can be best represented using a first order equation:

$$\frac{dM}{dt} = -k_{wn} i M \quad \text{Eq. 4- 14}$$

where, M is nutrient mass (kg); k_{wn} is wash-off coefficient for nitrogen (cm^{-1}); i is average effective rainfall intensity (cm/hr).

By integrating Eq. 4-14, Eq.4-15 can be obtained as follow.

$$\frac{M_t}{M_0} = e^{-k_{wn} i t} \quad \text{Eq. 4- 15}$$

where, M_0 is the initial mass on the surface at $t=0$; and M_t is the remaining nutrient mass on the surface at time t after the onset of a rainfall event.

Defining a capacity factor C_f as the ability of a certain rainfall intensity to mobilize available particles, the resulting mathematical equation can be expressed as:

$$F_w = C_f (1 - e^{-k_{wn} i t}) \quad \text{Eq. 4- 16}$$

where, F_w is the fraction wash-off.

4.2.3.2 Particulate pollutant entrainment

The second component is sediment wash-off. It was known that certain chemicals, e.g. phosphorus is not chemically stable in the soluble form and is readily absorbed by soil constituents, such as clays, aluminium and iron compound present in the soil particles (Bolland *et al.* 2003). It was also known that phosphorus is generally attached to the surface of sediment particles and moves with sediment particles. (Aksoy and Kavvas 2005). Therefore, one could readily draw an analogy between soil erosion and particulate pollutants wash-off. As a pragmatic approach to model particulate pollutant loss after the commonly used soil loss model: USLE (Universal Soil Loss Equation).

$$A = R \times K \times LS \times C \times P \quad \text{Eq. 4- 17}$$

where,

“ A ” represents the potential long term average annual soil loss in tons per acre per year.

- “R” is the rainfall factor, which is a numerical value that expresses the capacity of a rainfall to erode soil from an unprotected field. The greater the intensity and duration of the rain storm, the higher the erosion potential. The erosion potential of a rain storm is proportional to the product value of two rainfall characters: total kinetic energy of the storm (E) and its maximum 30 minute intensity (I_{30}).
- “K” is the soil erodibility factor. It can be expressed in M tons of soil loss per hectare per unit of rainfall index for a slope of 9% and length of 22.13 meters. Texture is the principal factor affecting K, but structure, organic matter and permeability also contribute.
- “LS” is the length and steepness of slope factor. It represents a ratio of soil loss under given conditions to that at a site with the “standard” slope steepness of 9% and slope length of 22.13 m.
- “C” is the cropping and management factor. It is the ratio of the soil loss from land under a specific crop and management system to the corresponding loss from continuously fallow and tilled land. C factor is affected by crop type, quality of cover and root growth, water use by the growing plants *etc.*
- “P” is the support practice factor. It reflects the effects of practices that will reduce the amount and rate of the water runoff and thus reduce the amount of erosion.

Originally developed in the USA to predict long term average annual erosion under a variety of crop management systems, the USLE has been widely used all over the world for small watersheds or catchments (Williams *et al.* 1971). Unfortunately, the original USLE is not designed to predict event erosion well. Event based version USLE has been developed in 1975, known as the Modified Universal Soil Loss Equation (MUSLE) (Kinnell 2000), in which a runoff index was included in the expression (Eq. 4-18).

$$SY_e = X_e KLSCP \quad \text{Eq. 4- 18}$$

where SY_e is the event sediment yield, and X_e could be estimated by the following equation:

$$X_e = 1.586(Q_e q_p)^{0.56} DA^{0.12} \quad \text{Eq. 4- 19}$$

where Q_e is runoff amount (mm) and q_p is the peak runoff rate (mm/h) obtained during the erosion event, DA is drainage area expressed in ha, and other symbols are as defined in the USLE.

The advantage of including the runoff term is the elimination of large overestimates of soil loss when runoff is negligible and rainfall amounts are great (Foster *et al.* 1982). The Agricultural Non-Point Source Pollution (AGNPS) model is an example of the application of MUSLE based on a grid-cell modelling approach (Young *et al.* 1987). It has been applied in various studies (Donoso *et al.* 1999; Grunwald and Norton 2000), and proved to be successful (Kinnell 2000).

As stated in chapter 2, the non-constant particle pollutant (e.g. phosphorus) sources from soil were generally not considered when applying USLE oriented nutrient loss models. In this study, the entrainment of particulate pollutant, such as phosphorus is modelled indirectly by considering the pollutant mass attached on the sediment particles. Defining a coefficient k_a , representing the proportion of phosphorus attached on the sediment, phosphorus washed off from the soil surface could be represented as a function of sediment yield:

$$M_w = k_a SY_e \quad \text{Eq. 4- 20}$$

with

$$k_a = f(M_t) \quad \text{Eq. 4- 21}$$

where, M_w is the mass wash-off by surface runoff; M_t is the pollutant mass on soil surface at time t ; and other parameters remain as defined for the USLE.

4.2.4 Module 4: Runoff Transport Model

Sediment and pollutant detached by both raindrop impact and runoff wash-off is finally routed into the recipient water using the runoff transport model. Lateral chemical transport along a uniform slope can be mathematically modelled by solving the mass balance equation of surface runoff (Eq. 4-20) and the conservation equation of dissolved chemicals in surface runoff (Eq.4-21) (Wallach *et al.* 2001; Deng *et al.* 2005).

$$\frac{\partial h}{\partial t} + \frac{\partial q}{\partial x} = I(t) - f(t) \quad \text{Eq. 4- 22(a)}$$

With

$$q = \alpha h^m \quad \text{Eq. 4- 22(b)}$$

$$\frac{\partial(ch)}{\partial t} + \frac{\partial(cq)}{\partial x} = \frac{\partial}{\partial x} \left(Zh \frac{\partial c}{\partial x} \right) + k_m D_m (C_s - C) \quad \text{Eq. 4- 23}$$

where,

x = distance along the slope;

h = overland flow depth;

t = time;

q = unit discharge on the slope direction;

i = rainfall intensity;

f = infiltration rate;

α = kinematic-wave resistance parameter;

m = empirical exponent;

C = chemical concentration;

C_s = chemical concentration in active soil surface layer;

Z = longitudinal dispersion coefficient;

k_m = chemical exchange rate; and

D_m = active soil surface layer depth.

This model is proved to be able to simulate realistic changes in pollutant transfer rates and concentrations applying kinematic-wave approximation (Deng *et al.* 2005). The parameters were estimated by data collected from laboratory experiment and the comparison between simulated and measured results (solute transport rates and pollutographs) shown that the simulated results agrees well with the measured results, despite the 5.1% uncertainty brought by unintended variation in rainfall intensity generated under the laboratory experiment condition.

4.3 Model structure

A brief illustration of the model structure of this study has been shown earlier in Figure 4- 4. The model includes 2 sub-processes. Process 1 simulates the N and P wash-off process when it rains, where 5 sub-models are included in this module (see

section 4.2). Process 2 simulates the loss of fertilisers in the soil over time when there is no rainfall (dry weather). The initial condition is the quantity of fertiliser applied at the beginning. During the days that follow, and depending on the wet or dry weather condition (rain or dry), the following corresponding considerations are made (see Figure 4- 4).

Figure 4- 4 General model structure

4.3.1 N and P wash-off during the wet weather

The left part of the flow chart (Figure 4- 4) caters to the process when it rains. The fertiliser (N and P) is washed-off and infiltrated into the soil, leading to decrease of nutrient mass on the soil surface. In the mean time, certain amount of the nutrient is washed off and entrained into the overland flow or surface runoff, and transported down the slope.

Rainfall- runoff model

From the start of the rain, the rainfall information is recorded as the input to the rainfall-runoff model and the corresponding runoff is generated. The output of the rainfall-runoff model, the discharge, is used as input information for the soil erosion model and chemical wash-off model.

Raindrop splash model

Pollutants and sediments on the soil surface are detached by raindrop impact. Rainfall information and fertiliser application rate are used as input for the raindrop splash model. Certain amount of soil particles, sometimes with fertiliser attached on the particles, and chemical particulates are detached by splashing. This part of the contaminants ended up in the recipient water.

Soil erosion model

The runoff discharge generated from the rainfall-runoff model is used as input for the soil erosion model. The corresponding rate of soil erosion from the field slope is simulated and the amount of pollutants attached on the sediment is calculated. The entrained sediment and pollutants transported by the surface runoff and also ended up in recipient water.

Chemical wash-off model

As the rainfall progresses, soil water storage is gradually filled up with infiltrated rain water. Pondered rain water accumulates and further develops to form overland flow, and with the overland flow, the N & P are washed off the soil surface and

entrained transported downslope. In the chemical wash-off model, runoff discharge generated from the rainfall-runoff model is one of the input parameters. Other input parameters include chemical mass available on soil surface, and wash-off rate, *etc.*

Runoff transport model

Sediment and N and P compounds detached by both raindrop impact and runoff / wash-off are finally routed into the recipient water through the runoff transport model.

At the end of a loop, after all the wash-off processes have ceased, the mass of pollutants remaining on soil surface is generated and used as input information for the next cycle. If another rainfall event occurred in the same day, steps 1-5 are repeated to generate another contaminant wash-off results. The sediment and chemical detached during the day and the total runoff discharged generated are recorded for the computation of daily pollutant concentration.

4.3.2 N and P loss during the dry weather

Temporal loss or natural loss of fertiliser takes place during the dry weather (no rainfall). The main pathway for the loss of inorganic fertiliser material (in terms of ammonia) during dry weather was through volatilization. The characteristics of loss follow the relationship established from the laboratory experiments.

4.4 Model integration

An integrated nutrient loss model was developed to investigate the N and P loss process by coupling the N and P loss model, raindrop splash model, pollutant entrainment model and the runoff transport model. There are two major considerations in integrating the models. The first deals with the integration processes of different sub-models and the corresponding time scale while the second deals with the integration over space, i.e. the spatial scale.

4.4.1 Model integration - time scale

In a raindrop splash model, one often investigates the impact brought forth by raindrop to the particulate soil and chemical on the soil surface. The starting point of most of these models is the ponding level when soil is saturated some times after the rainfall has started. The end point is when the rain has stopped. Tong and Yang's study (2008) divided a storm into four different processes from the starts of the rainfall: soil saturation process, ponding process, runoff process and runoff recession process. And in each process, a set of equations were developed to describe the chemical loss process under the raindrop impact.

A rainfall-runoff model is also event based. Rainfall-runoff models are developed to relate the hyetograph to the runoff hydrograph (see Figure 4- 5). The typical inputs of a rainfall-runoff model are: soil water storage, infiltration, evaporation, precipitation and related coefficients, such as storage capacity curve number in Xinanjiang Model (Zhao 1992), outflow coefficient in Tank model (Sugawara 1974). The input precipitation information is the rainfall amount during a particular time interval, normally measured in an hour or several hours (e.g. 6hr unit hydrograph).

Figure 4- 5 Example of hyetograph and hydrograph (Egodawatta *et al.* 2007).

As to the soil erosion model, most researchers do not focus on the sediment amount that is washed-off by a certain rainfall events, but are more interested in studying

the monthly or annual erosion rate. The Universal Soil Loss Equation (USLE) is a good example. The USLE “predicts” the long term average annual rate of soil erosion from a field slope based on the factors that govern soil erosion namely, rainfall patterns, soil type, topography, crop system and management practices (Wischmeier and Smith 1978). Those different processes are bases on different time scale and may be problematic in the integration of the proposed model.

4.4.2 Model integration – the spatial scale

The model is developed and calibrated based on the controlled outdoor experiments described in chapter 3. Noted that the dimension of the plot (15m (L)×1m(W)) is smaller than an actual catchment, it is important to recognize the spatial different between the controlled outdoor experiments condition and the actual catchment condition when integrating the model. The runoff transport model links the nutrient loss modelling result of each sub-plot into a catchment as a whole.

CHAPTER 5 LABORATORY EXPERIMENT RESULTS AND DISCUSSIONS

5.1 Introduction

One of the objectives of this study as identified in Chapter 1 was to investigate and quantitatively model the leaching process of nitrogen and phosphorous from the soil surface. Results from published studies were investigated and analyzed to format the data into a suitable form for use in this study. The extracted data and the corresponding results obtained from the re-processed data were presented in this chapter.

The experiments carried out in this study include three series of laboratory experiments and controlled outdoor experiments. The objective of the laboratory experiments was to investigate the characteristics of environmental loss of nitrogen (N) and phosphorus (P) on soil surface over time, due to plant induced reactions, infiltration and soil adsorption, respectively. The results were presented and discussed in conjunction with the results of reported studies. The sub-models simulating the N and P deterioration processes induced by these three factors were also developed. Comparison of reported results and those obtained in this study were made and the findings were discussed.

5.2 N and P loss over time

Figure 5-1 shows the experimental results of the N and P deterioration over time. The fertiliser sample was kept in a fuming cupboard under a constant temperature (20°C), so that the deterioration of component was only dependent on time.

Figure 5- 1 Fertiliser loss over time

It can be seen from Figure 5- 1 that the loss of the constituent components fits either a linear regression equation or a first-order kinetic equation. In order to find which equation could better represent the component loss patterns, a comparison of both equations was carried out. The result is shown in Table 5- 1. Considering a first order kinetic equation:

$$\frac{dM}{dt} = -k_t M \quad \text{Eq. 5- 1}$$

then

$$\frac{M_t}{M_0} = e^{-k_t t} \quad \text{Eq. 5- 2}$$

where M is the chemical mass remaining (mg) and k_t is the natural loss coefficient and is determined by air temperature.

Table 5- 1 Comparison of correlation of two fitting method for N and P loss over time

	Linear equation		First-order kinetic equation	
	Best fitting equation	Correlation (R^2)	Best fitting equation	Correlation (R^2)
NO_3^-	$M_t = -0.0049t + 1$	0.53	$\frac{M_t}{M_0} = e^{-0.0055t}$	0.56
NH_4^+	$M_t = -0.0028t + 1$	0.63	$\frac{M_t}{M_0} = e^{-0.0030t}$	0.65
TN	$M_t = -0.0040t + 1$	0.94	$\frac{M_t}{M_0} = e^{-0.0045t}$	0.94
TP	$M_t = -0.0008t + 1$	0.64	$\frac{M_t}{M_0} = e^{-0.0008t}$	0.65

The goodness of fit of 0.56-0.94 was considered good. However, one can readily deduced from inspecting Figure 5-1 that the difference was actually very small. As such one could deduce that the model and the experimental results were indeed similar. The correlation between the measured results and first order kinetic equation modelled results, together with the line of perfect agreement are shown in Figure 5- 2 to Figure 5- 5.

Figure 5- 2 Correlation of measured and modelled results of NO_3^- loss over time

Figure 5- 3 Correlation of measured and modelled results of NH_4^+ loss over time

Figure 5- 4 Correlation between measured and modelled results of TN loss over time

Figure 5- 5 Correlation between measured and modelled results of TP loss over time

It was established readily in chapter 4 that based on the data extracted from

previous studies, the ammonia emission is linearly dependent on pH and exponentially dependent on surface temperature. The results of this laboratory study further developed the Eq. 4-6 by establishing the equation describing nitrogen loss over time. It can be seen from Table 5- 1 that the loss rates could be ranked in the order $\text{NO}_3^- > \text{TN} > \text{NH}_4^+ > \text{TP}$. This order indicated that the likelihood of the chemicals to be lost when they are exposed to the environment. Although it was generally accepted that nitrate does not volatilize or loss under natural condition. The experimental results indicated that being left to exposure to the air, nitrate content in the fertiliser decreased. Similar findings were reported in Chang, M.C. (2000), Louro, A. et al. (2013) and Fischer, R. (2002). The experimental results also indicated that the loss of nitrate content in the fertiliser could be approximated by using a first-order kinetic equation (Eq. 5-1).

Noted that the decrease in concentration of TP over the 70 days investigation is 4%, indicated that phosphorus is stable and unlikely to volatilize or react with surround elements under the experiment condition (natural condition).

5.3 N and P loss due to infiltration and soil adsorption

Figure 5- 6 to Figure 5- 9 show the results obtained using the soil column experiments. The upper and lower ends of each connecting lines in these four figures indicate the highest and lowest concentration of the replicated test results on each sampling day. The average values of the chemical concentrations were calculated to minimize the experimental error and were used in the model calibration (points in Figure 5- 6 to Figure 5- 9).

Figure 5- 6 NO_3^- loss due to infiltration and soil adsorption (R refers to fertiliser application rate in kg N/ha)

Figure 5- 7 NH_4^+ loss due to infiltration and soil adsorption (R refers to fertiliser application rate in kg N/ha)

Figure 5- 8 TN loss due to infiltration and soil adsorption (R refers to fertiliser application rate in kg N/ha)

Figure 5- 9 TP loss due to infiltration and soil adsorption (R refers to fertiliser application rate in kg P/ha)

In this study, the author attempts to approximate the nitrogen and phosphorus loss in both the first-order and second-order kinetic equations, and the multiple correlation coefficients are shown in Table 5- 2. For a first-order equation:

$$\frac{dM}{dt} = -kM \quad \text{Eq. 5 - 3}$$

For a second-order kinetic equation:

$$\frac{dM}{dt} = -kM^2 \quad \text{Eq. 5 - 4}$$

As is evident in Table 5- 2, the data fitted using the first-order kinetic produces a reasonably good correlation, with the average R^2 equals to 0.83 for NO_3^- -N, 0.91 for NH_4^+ -N, 0.91 for TN and 0.64 for TP, respectively. However, it can be observed also that the fitting by applying the second-order kinetic performs even better for three of the four indices, NH_4^+ , TN (except for the case that fertiliser application rate is 225 kg N/ha) and TP. Especially for TP, the correlation coefficient can be as high as 0.99 (fertiliser application rate at 300kg P/ha).

Table 5- 2 Comparison of first-order and second-order kinetics on soil adsorption of nitrogen and phosphorus

	Fertiliser applied Rate (kg N/ha)	First-order simulation	Second order simulation
NO ₃ ⁻	500	R ² =0.64	R ² =0.69
	1000	R ² =0.56	R ² =0.58
NH ₄ ⁺	225	R ² =0.87	R ² =0.94
	500	R ² =0.92	R ² =0.97
	1000	R ² =0.82	R ² =0.86
TN	225	R ² =0.65	R ² =0.73
	500	R ² =0.82	R ² =0.88
	1000	R ² =0.89	R ² =0.92
TP	135	R ² =0.88	R ² =0.99
	300	R ² =0.84	R ² =0.95

Another attempt to examine the reliability of using the second-order kinetic equation is carried out using the published data. The statistical analysis of the replotted data adapted from published work related to soil nutrient loads was plotted against the second-order kinetic equation (Eq. 5-4), regardless data obtained conditions. It can be seen that the agreement between the mean curve and the modelled curves are satisfactory with R^2 equals to 0.66 (Figure 5- 10).

Figure 5- 10 Analysis of published data using second order kinetic equation (Choi *et al.* 2003; Ju *et al.* 2004; Ma *et al.* 2006; Yin and Mao 2007)

After gaining confidence with the second-order equation to approximate the nitrogen and phosphorus loss due to soil adsorption, the amount of nutrient remaining on the soil surface after the onset of a rainfall event due to soil adsorption and infiltration can be estimated similarly and developed as follow (by integrating Eq. 5-4):

$$\frac{M_t}{M_0} = \frac{1}{kM_0t+1} \quad \text{Eq. 5 - 5}$$

where, M_t is the nutrient mass at t (mg), M_0 is the initial nutrient mass at $t = 0$ (mg)

and k is the decay coefficient related to the initial chemical mass amount. Moreover, since M_0 is determined by and only by fertiliser application rate, Eq. 5-5 could be simplified to:

$$\frac{M_t}{M_0} = \frac{1}{k_s t + 1} \quad \text{Eq. 5 - 6}$$

where k_s is defined as the loss coefficient introduced by soil adsorption and infiltration, and it is determined by fertiliser application rate. The parameter k_s was introduced as a lumped parameter to account for loss of N. Adsorption is but one of the contribution

Eq. 5-6 was used to estimate the corresponding k_s values for different fertiliser application rates, and the results are presented in Table 5- 3.

Table 5- 3 k_s values of studied compounds under different fertiliser application rates

Compound	Fertiliser applied rate (kg/ha)	Soil adsorption coefficient (k_s)	Multiple correlation coefficient(R^2)
NO_3^-	500	0.021	0.69
	1000	0.013	0.58
NH_4^+	225	0.045	0.94
	500	0.040	0.97
	1000	0.015	0.87
TN	225	0.042	0.73
	500	0.038	0.88
	1000	0.016	0.92
TP	135	0.124	0.99
	300	0.067	0.95

A comparison of the model and experimental results was presented in 错误!未找到引用源。 . The correlation between measured and second order kinetic equation modelled results, together with the line of perfect agreement were shown in Figure 5- 12. It can be seen from Figure 5- 12 that the correlations between the second

order kinetic equation modelled results and the experiment measured result are satisfactory in most cases (all NH_4^+ , TN and TP cases). In the NO_3^- cases, the modelled results agree well with the measure results at both ends of the perfect agreement line, but have some derivation (up to 20% of the measured concentration) in the middle. In the TP cases, the modelled results agree well with the measured result in both cases of fertiliser application rate at 135kg P/ha and 300kg P/ha.

Figure 5- 11 Comparison of experiment and modelled results of N and P loss due to infiltration and soil adsorption
((a) NO_3^- ; (b) NH_4^+ ; (c) TN; (d) TP)

Figure 5- 12 Correlation between measured and second order kinetic equation modelled results

5.4 N and P loss due to plant uptake

The consensus in the literatures on the nitrogen and phosphorus removal brought forth by plant uptake in the wetland are consistently of the belief that the performance of nitrogen and phosphorus under the impact of vegetation would be different. Lucas and Greenway (2011) concluded in their study that the presence of vegetation significantly increases NO_x and total nitrogen retention, hence promotes the nitrogen loss, while the phosphorus retention had been demonstrated to be high (86-88%) with proper media, no matter vegetated or not (Lucas and Greenway 2011). The followings contain the results on plant uptake obtained in this study.

5.4.1 Nitrogen deterioration due to plant uptake

The concentrations of the three nitrogen indices investigated in this study are presented in Figure 5- 13 and Figure 5- 14. The solid lines in Figure 5- 13 and Figure 5- 14 represent the deterioration of nitrogen with time in the unplanted experimental boxes and the dash lines represent those with plants. It can be seen from Figure 5- 13 and Figure 5- 14 that the difference in ammonia nitrogen ($\text{NH}_4^+\text{-N}$) concentration induced by plant is more significant than that in nitrite nitrogen ($\text{NO}_3^-\text{-N}$). It was observed that the concentration differences in the early days (e.g. 0-15 days) were typically more significant than that in later days (Figure 5- 13 and Figure 5- 14, NH_4^+ and TN).

Figure 5- 13 Result of the plant uptake control experiment-Nitrogen (Fertiliser application rate at 100kg N/ha; --Δ--: box with covering plants; —□—: box without covering plants)

Figure 5- 14 Result of the plant uptake control experiment-Nitrogen (Fertiliser application rate at 225kg N/ha; -Δ- -: box with covering plants; —□—: box without covering plants)

The uptake rate calculated based on the data got from the control experiment is presented in Figure 5- 15.

Figure 5- 15 Uptake rate of nitrogen (□: fertiliser application rate at 225kg N/ha; ○: fertiliser application rate at 100kg N/ha)

5.4.2 Phosphorus deterioration due to plant uptake

Similar analysis was done on the TP investigation. Figure 5- 16 and Figure 5- 17 present the experiment result of the TP loss due to plant uptake under two different fertiliser application rate: 60 kg P/ha and 135kg P/ha. The solid line in these two figures indicates the TP concentration in the box with no covering plants and the dash line indicated the one in the box with covering plants. The soil prosperities and plant from all the boxes were obtained from the same source. Same amount of water was used for all the boxes during the experiment and the same fertiliser was used as well (fertiliser application rate were also the same for the two boxes within one group). It can be seen in Figures 5-16 and 5-17 that the differences between the dash-line (data obtained from the box with plant) and solid-line (data obtained from the box without plant) are very small. Thus one may conclude that reduction is independent of plant coverage. It is reasonable to neglect the impact brought by covering plant on the TP loss, which confirmed the conclusion from previous study that the loss of phosphorus is independent on the plant coverage.

Figure 5- 16 Result of the plant uptake control experiment-phosphorus (Fertiliser application rate at 60kg P/ha; - - Δ - -: box with covering plants; — $\square$ —: box without covering plants)

Figure 5- 17 Result of the plant uptake control experiment-phosphorus (Fertiliser application rate at 135kg P/ha; - - Δ - -: box with covering plants; — $\square$ —: box without covering plants)

5.5 Summary

The laboratory experiment results also confirmed previous conclusion that the presence of vegetation promotes the nitrogen loss, but has little impact on the phosphorus loss. Therefore, in this study, the plant-uptake impacted phosphorus loss was neglected, and was not taken into consideration in the N and P deterioration model.

A comparative study was conducted to further investigate the environmental loss of nitrogen. The loss potential (% of the total applied nitrogen that had been degraded during experiment) brought forth through several potential factors investigated are computed and presented in Table 5- 4. This loss potential indicates the likelihood to loss of compounds when they are exposed under the natural condition, soil adsorption and infiltration and plant up-take, respectively.

Table 5- 4 Comparison of loss rates (% of nitrogen applied)

	Natural loss (%)	Soil adsorption and infiltration (%)	Plant up-take (%)
NO ₃ ⁻	30	45	0.002
NH ₄ ⁺	13	63	0.019
TN	26	69	0.076

As evidenced in Table 5- 4, the observed nitrogen plant up-take is a very small proportion compared to the loss attributed to the other two factors. The difference could be as high as 10³ in magnitudes. Therefore it is reasonable to neglect the environmental loss of nitrogen due to plant up-take when considering the nitrogen loss model.

CHAPTER 6 CONTROLLED OUTDOOR EXPERIMENTS

The controlled outdoor experiments were designed to investigate the N and P wash-off from a turfed slope. The experiments were conducted from September 2011 to January 2013. Air temperature and rainfalls were recorded. During this period a total of 275 rainfall events were observed and 7 series (covered 37 rainfall events) of surface runoff were successfully sampled and analyzed. The parameters measured in the sample analyses include: ammonia nitrogen (NH_4^+), nitrate nitrogen (NO_3^-), total nitrogen (TN) and total phosphorus (TP).

The air temperature and rainfall recorded for the controlled outdoor experiments are presented in section 6.1. Also included are the sampling dates. The runoff discharge on each sampling date was simulated by using the software package IHACRES model and the results are presented in section 6.2. In section 6.3, preliminary findings of the outdoor experiments were described. The N and P wash-off coefficients were optimized based on the N and P concentrations measured. Validation of the N and P loss model is presented in section 6.4.

6.1 Air temperature and rainfall

The controlled outdoor experiments were conducted during the period from September 2011 to January 2013. Air temperature and rainfall data collected are included in Appendixes C and D, respectively. The rainfall information is summarized in Table 6- 1. In Table 6- 1, rainfall data collected during the experiments were classified into six groups, based on the rainfall classification standard of American Meteorological Society.

Table 6- 1 Rainfall information

Total rainfall events recorded	275	
* Classification of rainfall	Average rainfall intensity (mm/hr)	No. of events during investigation
Very light	<0.25	4
Light	0.25-1	13
Moderate	1-4	97
Heavy	4-16	110
Very heavy	16-50	46
Extreme	>50	5

* classification based on American Meteorological Society (GLICKMAN 2000)

The day when the fertiliser was applied was defined as the start date of investigation, and the day when the N and P concentration reaching or approaching the baseline concentration was defined as the end date of the experimental test run. During the 17-month of controlled outdoor experiments, 7 series of runoff in total were successfully accomplished, and they are listed in Table 6- 2. Because of the limitation of sample collecting device, the author was unable to collect runoff sample when the rainfall amount (intensity, duration) was too small. The successful sampling dates during the sampling period are also listed in Table 6- 2.

Table 6- 2 Summary of sampling information

Start date	End date	Number of rainfall events during the period	Successful sampling date (MM-DD)
2011-12-15	2011-12-23	11	12-15;12-16;12-17;12-18;12-19;12-20
2012-03-02	2012-03-13	5	03-02;03-05;03-08;03-09;03-13
2012-04-29	2012-05-13	8	04-30;05-02;05-05;05-07;05-09
2012-07-21	2012-07-28	5	07-24;07-26;07-28
2012-08-14	2012-08-23	5	08-17;08-19;08-21;08-23
2012-10-13	2012-10-22	9	10-14;10-16;10-17;10-18;10-19;10-20; 10-21;10-22
2012-11-21	2012-11-20	10	11-22;11-23;11-25;11-26;11-28;11-29

6.2 Runoff estimation

Typically, the rates of runoff could be measured using volumetric method or velocity method (Hudson 1993). The simplest way to estimate small flows is by direct measurement of the time to fill a container of known volume. By using this method, the flow needs to be diverted into a channel or pipe which in turn discharges into a suitably sized container, and the time to fill it is measured by using a stopwatch. It is difficult to apply this method in the present study for runoff measurement since for various administrative reasons, it is impractical and almost impossible to isolate and divert the flow from the outdoor plot.

Another method of flow measurement is by using the velocity-area method. This method depends on measuring the average velocity of flow and the cross-sectional area of the channel and hence calculating the flow by multiplying the average velocity with cross-sectional area. A simple way to estimate the velocity is to measure the time taken for a floating object to travel a measured distance downstream. Since the velocity is not the same at all places in the stream, being slower at the sides and bottom, and faster on the surface, 0.8 of the surface velocity as measured by the float gives an approximate value for the average velocity

(Hudson 1993).

The runoff of the outdoor experimental plot was measured successfully several times during the observation period using the velocity-area method. However, due to the rather rapid response of the surface runoff to rainfall and the uncertainty of the time of occurrence of, it is difficult to measure the runoff accurately every time. In that case, simulated runoff based on the rainfall measurements was used in this study.

6.2.1 IHACRES model - calibration

6.2.1.1 Feasibility investigation

In all the reported work on using IHACRES in rainfall-runoff studies, a 1 day time step was generally adopted. In this present study, and considering the dimension of the outdoor experimental plot (15m (L)×1m(W)), the time step was set to 10 minutes instead of 1 day. In order to check the feasibility of using this proposed time interval (time resolution) in IHACRES for the runoff calculation in this study, the shorter time interval of 10-minute was tested using the rainfall-runoff measurement conducted in a separate study in the Kranji catchment which is located at the northern part of Singapore (Chua, Lo *et al.* 2009).

The observed stream flow data was collected from Kranji catchment (Figure 6- 1) at runoff station KC07 and the rainfall and temperature data were recorded at 2 stations, Sungei Kadut (downstream, coordinator: N1.4172 E103.74855) and Bukit Timah Dairy Farm (upstream, coordinator: N1.364 E103.777) of the catchment(Chua *et al.* 2009).

Figure 6- 1 Kranji catchment and the monitors' location

The effective rainfall was calculated by using the non-linear module in IHACRES, and the results are presented in Figure 6- 2. A comparison of the modelled and observed stream flow is shown in Figure 6- 3. The R^2 of the comparison was calculated to evaluate the model performance. According to the published studies, R^2 –value of the order of 0.7 can be considered as “good” for this type of work, see Franceschini and Tsai (2010) and Wan, Ji et al. (2012). In the present study, R^2 was found to be 0.652, which was good for this type of work.

Figure 6- 2 Observed rainfall (mm) and modelled effective rainfall (mm) by using

IHACRES

Figure 6- 3 Modelled and observed stream flow (m³/s) by using IHACRES

6.2.1.2 Calibration of IHACRES model

Sriwongsitanon and Taesonbat (2011) proposed a set of relationship that might be used to estimate the pertinent parameters in IHACRES model (Table 6-3).

Table 6-3 Equations derived for estimating IHACRES parameters (Sriwongsitanon and Taesonbat 2011)

Relationship equation	c=mass balance; τ_w =drying rate at reference temperature; f=temperature modulation; τ_q =recession time constant for quick flow; τ_s =recession time constant for slow flow; V_s =the relative volume of slow flow; A=catchment area; D=catchment drainage density; SL=catchment slope; EG=catchment elongation.
$\frac{1}{c} = 14.628 \times A^{0.236} EG^{-0.733}$	
$f = 5.256 \times A^{1.515} D^{2.908} SL^{0.684} EG^{3.52}$	
$\tau_w = 5.047 \times A^{3.703} D^{7.133} SL^{-0.503} EG^{6.458}$	
$\tau_q = 0.078 \times A^{3.505} D^{6.518} SL^{0.615} EG^{6.685}$	
$\tau_s = 6.729 \times A^{0.208} D^{0.717} SL^{0.813} EG^{0.173}$	
$\frac{1}{V_s} = 2.043 \times A^{-0.207} D^{-0.667} SL^{-0.242} EG^{-0.418}$	

Together with the IHACRES linear module and equation presented in chapter 3, the coefficients for the controlled outdoor experiments were estimated and listed in

Table 6- 4.

Table 6- 4 IHACRES model calibration

Non-linear module	
mass balance term (c)	0.0038
drying rate at reference temperature (τ_w)	1.00
temperature modulation (f)	1.00
reference temperature (t_{ref})	20.00
moisture threshold for producing flow (L)	0.00
power on soil moisture (p)	0.90
Linear Module	
Recession rate ($\alpha(s)$)	-0.799
Peak response ($\beta(s)$)	0.013
Time constant ($\tau(s)$)	0.489
Volume proportion (v(s))	0.064

The runoff of the outdoor experimental plot was measured several times on 13th, March, 2012. The measured runoff is plotted in Figure 6- 4. Also included in the plot is the runoff simulated using IHACRES. It can be seen from Figure 6- 4 that the agreement of the measured runoff and the simulated runoff using IHACRES is satisfactory.

(a) Comparison of simulated and measured runoff - Time in HH:MM

(b) Agreement of the simulated and measured runoff

Figure 6- 4 Validation of the application of IHACRES model

6.2.2 Runoff simulation by using IHACRES

With the confidence gained in using IHACRES model as a tool for rainfall-runoff

simulation. The coefficients that had been calibrated were applied to generate the runoff. A typical example of the generated runoff on the sampling date of 2nd, March, 2012 is shown in Figure 6- 5. The corresponding rainfall information is listed in Table 6- 5.

Table 6- 5 Rainfall information on 2nd, March, 2012

Time	Rainfall (mm)
3/2/2012 12:50	5.2
3/2/2012 13:00	3.2
3/2/2012 13:10	4.4
3/2/2012 13:20	2
3/2/2012 13:30	0.2
3/2/2012 13:40	0.2
3/2/2012 13:50	0
3/2/2012 14:00	0
3/2/2012 14:10	0
3/2/2012 14:20	0
3/2/2012 14:30	0
3/2/2012 14:40	0
3/2/2012 14:50	0
3/2/2012 15:00	0
3/2/2012 15:10	0
3/2/2012 15:20	0.2
3/2/2012 15:30	1
3/2/2012 15:40	0.6
3/2/2012 15:50	0.2
3/2/2012 16:00	0
3/2/2012 16:10	0.4
3/2/2012 16:20	0.4
3/2/2012 16:30	0
3/2/2012 16:40	0.2
3/2/2012 16:50	0
3/2/2012 17:00	0.4
3/2/2012 17:10	0
3/2/2012 17:20	0.2

Figure 6- 5 A typical example for the runoff generated by using the IHACRES model (Date: 2nd, March, 2012, time in HH:MM)

It can be seen from Table 6- 5 and Figure 6- 5 that there is a quick response for the runoff to rainfall at the outdoor experimental plot, and the recession time is short. Similar characteristic was observed in the other runoff plot, shown in Appendix E. The full runoff data during the sampling period are presented in Appendix E.

6.3 Preliminary findings of the controlled outdoor experiments

The results of the water sample analyses collected from the controlled outdoor experiments are plotted and included in Appendix F¹. A typical example of the plots is shown in Figure 6- 6. It can be seen that the highest nitrogen and phosphorus concentrations in the surface runoff were generally observed after the first rainfall event which took place immediately after the application of the fertiliser, the so-called first flush phenomena (Van and Mahler, 2003; Egodawatta *et al.*, 2007). After the first event, NH_4^+ concentration is 8.85 times higher than that during the second event. The ratio of the first and second event concentration for other parameters are correspondingly, 1.3 for TN, 1.74 for NO_3^- and 3.57 for TP.

Base on the findings of the experiments, the author also deduced that the first two rainfall events following the application of fertiliser accounted for most of the N and P losses of the fertiliser application cycle (test series). Take the outdoor experimental results as shown in Figure 6- 6 for example, the first two rainfall events accounted for 89.9% of the total observed NH_4^+ loss for the test series. The percentages of the other three parameters are correspondingly: 80.7% for NO_3^- , 92.1% for TN and 77.9% for TP. Similar results can be observed in other plots as shown in Appendix F.

¹ Data presented in Appendix F, section F.1 and F.2, were not used in calibration or validation of the model, because the sampling points at those two locations were designed to investigate how slope length impacts the N and P concentrations, but no significant regularity was found in the present study.

(a) Observed N (P) concentrations (mg/L)

(b) Observed N (P) concentrations (C/C_0)

Figure 6- 6 A typical example of the controlled outdoor experimental results (Data collected from 2nd MAR to 13th MAR, 2012)

The above preliminary findings of the controlled outdoor experiments indicate that the first two rainfall events following the application of fertiliser played significantly important role in the N and P losses within a cycle.

6.4 N and P wash-off coefficient

6.4.1 N wash-off coefficient

The entrainment and wash off of nitrogen into surface runoff is in the form of N soluble in water. Therefore, the soluble pollutants entrainment model introduced in chapter 4 is applicable here. According to Egodawatta *et al.* (2009), the fraction of pollutant wash-off F_w is:

$$F_w = C_f(1 - e^{-k_{wn}it}) \quad \text{Eq. 4- 24}$$

Physically, C_f denote the maximum F_w if a particular rainfall intensity were to continue for a long period of time, and k_{wn} denotes the rate at which the particulate matter is washed-off from a surface.

Egodawatta *et al.* (2009) established the k_{wn} and C_f value based on his field investigation. It was suggested in their study that C_f was related to rainfall intensity, and varied linearly from 0.75 to 0.91 for 20 to 40 mm/h rainfall intensity, respectively and then increased linearly from 0.91 to 1 for rainfall intensity ranging from 90 to 115 mm/h, respectively. It was also suggested that C_f remained constant at 0.91 for rainfall intensity ranging from 40 to 90 mm/h, and equals 1 for rainfall intensity greater than 115mm/h, see Figure 6- 7.

Figure 6- 7 Distribution of C_f value as a function of rainfall intensity according to Egodawatta *et al.* (2009)

The wash-off coefficient k_{wn} varies with the type of surface according to Egodawatta *et al.* (2009)'s study. A higher k_{wn} value indicates smoother surfaces and lower k_{wn} value indicates rougher surfaces. The k_{wn} for roofs and roads surface have been suggested as 9.33×10^{-3} , and 8.0×10^{-4} , respectively.

In the present study, k_{wn} is not only a function of the characteristic of the surface (e.g. surface roughness), but also the mobility of chemicals. A typical set of the results of the chemical analysis of the water sample (sampling period: 2nd MAR to 13th MAR, 2012) collected from the outdoor experiments was used to calibrate the k_{wn} to reflect the characteristic of the turfed slope. The optimum k_{wn} obtained for wash-off nitrogen from grass land surface was found to be 7.3×10^{-4} . This is a reasonable value and in the same magnitude of order to that suggested by Egodawatta *et al.* (2009).

To verified the values of k_{wn} and C_f , base on the water quality analyses, in terms of concentration of nitrogen, carried out during the period April 2012 to November 2012 (5 series of tests) for samples collected at location WS 3 were used. These test series included various different experimental conditions: fertiliser was applied at two different rates (225kg/ha and 300 kg/ha); rainfall characteristics (rainfall intensity, duration) varied with months and antecedent conditions. The modelled results were plotted together with the measured results. A typical sample (sampling period: 29th April to 13th May) was shown in Table 6- 6 and Figure 6- 8. In order to present the results clearly, the null points are not shown. The full dataset and plot of all series of tests are presented in Appendix G.

Table 6- 6 Measured and simulated N concentrations of the controlled outdoor experiments (mg/L)

Time	NH ₄ ⁺		NO ₃ ⁻		TN		Remarks
	Simulated	Measured	Simulated	Measured	Simulated	Measured	
4/30/2012 7:00	0.00		0.00		0.00		
4/30/2012 7:10	0.00		0.00		0.00		
4/30/2012 7:20	9.93	9.7	2.98	4.8	24.89	23	
4/30/2012 7:30	6.06		1.82		14.96		
4/30/2012 7:40	1.72		0.52		4.18		
4/30/2012 7:50	0.16		0.05		0.39		
...							No runoff
4/30/2012 12:40	7.24		2.17		11.06		
...							No runoff
5/2/2012 8:30	5.32	5.1	1.62	2.8	5.80	5	
5/2/2012 8:40	4.52		1.38		4.85		
5/2/2012 8:50	1.18		0.36		1.25		
5/2/2012 9:00	0.86		0.26		0.90		
5/2/2012 9:10	0.55		0.17		0.57		
5/2/2012 9:20	0.34		0.10		0.34		
5/2/2012 9:30	0.73		0.22		0.73		
5/2/2012 9:40	0.45		0.14		0.44		
5/2/2012 9:50	0.00		0.00		0.00		
5/2/2012 17:00	0.00		0.00		0.00		
5/2/2012 17:10	0.00		0.00		0.00		
5/2/2012 17:20	0.00		0.00		0.00		
5/2/2012 17:30	0.18		0.05		0.08		
5/2/2012 17:40	0.14		0.04		0.07		
5/2/2012 17:50	0.01		0.00		0.01		
5/2/2012 18:00	0.00		0.00		0.00		
5/2/2012 18:10	0.00		0.00		0.00		
5/2/2012 18:20	0.03		0.01		0.01		
...							No runoff
5/5/2012 1:10	1.25	1.5	0.40	0.4	2.71	3	
5/5/2012 1:20	0.42		0.13		0.90		
5/5/2012 1:30	0.22		0.07		0.46		
5/5/2012 1:40	0.31		0.10		0.64		
5/5/2012 1:50	0.12		0.04		0.24		
5/5/2012 2:00	0.21		0.07		0.42		
5/5/2012 2:10	0.04		0.01		0.07		
5/5/2012 2:20	0.04		0.01		0.07		
5/5/2012 2:30	0.03		0.01		0.06		
5/5/2012 2:40	0.02		0.01		0.04		

Time	NH ₄ ⁺		NO ₃ ⁻		TN		Remarks
	Simulated	Measured	Simulated	Measured	Simulated	Measured	
5/5/2012 2:50	0.04		0.01		0.07		
5/5/2012 3:00	0.02		0.00		0.03		
5/5/2012 3:10	0.02		0.01		0.03		
5/5/2012 3:20	0.00		0.00		0.00		
5/5/2012 3:30	0.00		0.00		0.00		
5/5/2012 3:40	0.03		0.01		0.06		
5/5/2012 3:50	0.04		0.01		0.07		
5/5/2012 4:00	0.14		0.04		0.23		
5/5/2012 4:10	0.06		0.02		0.09		
5/5/2012 4:20	0.07		0.02		0.11		
5/5/2012 4:30	0.08		0.03		0.13		
5/5/2012 4:40	0.10		0.03		0.16		
5/5/2012 4:50	0.12		0.04		0.18		
5/5/2012 5:00	0.14		0.05		0.22		
5/5/2012 5:10	0.31		0.10		0.47		
...							No runoff
5/7/2012 5:40	0.72	1.3	0.24	0.9	1.03	2	
5/7/2012 5:50	0.44		0.15		0.62		
5/7/2012 6:00	0.38		0.13		0.52		
5/7/2012 6:10	0.45		0.15		0.62		
5/7/2012 6:20	0.24		0.08		0.32		
5/7/2012 6:30	0.14		0.05		0.19		
5/7/2012 6:40	0.00		0.00		0.00		
5/7/2012 6:50	0.07		0.02		0.08		
5/7/2012 7:00	0.00		0.00		0.00		
5/7/2012 7:10	0.00		0.00		0.00		
5/7/2012 7:20	0.00		0.00		0.00		
5/7/2012 7:30	0.00		0.00		0.00		
5/7/2012 7:40	0.15		0.05		0.18		
5/7/2012 7:50	0.00		0.00		0.00		
5/7/2012 8:00	0.18		0.06		0.21		
5/7/2012 8:10	0.19		0.06		0.22		
...							No runoff
5/9/2012 2:10	0.26	0.1	0.09	0.5	0.52	1	
5/9/2012 2:20	0.24		0.08		0.47		
5/9/2012 2:30	0.14		0.05		0.27		
5/9/2012 2:40	0.06		0.02		0.11		
5/9/2012 2:50	0.10		0.04		0.20		
5/9/2012 3:00	0.03		0.01		0.06		
5/9/2012 3:10	0.04		0.01		0.07		
5/9/2012 3:20	0.05		0.02		0.08		

Time	NH ₄ ⁺		NO ₃ ⁻		TN		Remarks
	Simulated	Measured	Simulated	Measured	Simulated	Measured	
5/9/2012 3:30	0.00		0.00		0.00		
5/9/2012 3:40	0.07		0.02		0.11		
5/9/2012 3:50	0.00		0.00		0.00		
5/9/2012 4:00	0.09		0.03		0.15		
5/9/2012 4:10	0.21		0.07		0.35		
5/9/2012 4:20	0.00		0.00		0.00		
5/9/2012 4:30	0.10		0.03		0.15		
5/9/2012 4:40	0.00		0.00		0.00		
5/9/2012 4:50	0.00		0.00		0.00		
5/9/2012 5:00	0.00		0.00		0.00		
5/9/2012 9:00	0.00		0.00		0.00		
5/9/2012 9:10	0.00		0.00		0.00		
5/9/2012 9:20	0.00		0.00		0.00		
5/9/2012 9:30	0.00		0.00		0.00		
5/9/2012 9:40	0.00		0.00		0.00		
5/9/2012 9:50	0.00		0.00		0.00		
5/9/2012 10:00	0.00		0.00		0.00		
5/9/2012 10:10	0.52		0.18		0.49		
...							No runoff
5/13/2012 1:10	0.11	0	0.04	0.1	0.23	0	
5/13/2012 1:20	0.07		0.02		0.14		
5/13/2012 1:30	0.03		0.01		0.07		
5/13/2012 1:40	0.03		0.01		0.05		
5/13/2012 1:50	0.04		0.02		0.09		
5/13/2012 2:00	0.02		0.01		0.03		
5/13/2012 2:10	0.02		0.01		0.04		
5/13/2012 2:20	0.02		0.01		0.05		
5/13/2012 2:30	0.03		0.01		0.06		
5/13/2012 2:40	0.08		0.03		0.16		
5/13/2012 2:50	0.09		0.03		0.17		
5/13/2012 3:00	0.11		0.04		0.20		
5/13/2012 3:10	0.09		0.03		0.17		
5/13/2012 3:20	0.06		0.02		0.11		
5/13/2012 3:30	0.05		0.02		0.08		
5/13/2012 3:40	0.05		0.02		0.09		
5/13/2012 3:50	0.03		0.01		0.05		
5/13/2012 4:00	0.04		0.01		0.06		
5/13/2012 4:10	0.00		0.00		0.00		
5/13/2012 4:20	0.08		0.03		0.14		
...							No runoff
5/13/2012 6:50	0.31		0.11		0.40		

Time	NH ₄ ⁺		NO ₃ ⁻		TN		Remarks
	Simulated	Measured	Simulated	Measured	Simulated	Measured	
5/13/2012 7:00	0.00		0.00		0.00		
5/13/2012 7:10	0.00		0.00		0.00

Figure 6- 8 A typical example of comparison of measured and simulated N concentrations (Test period: 29th April-13th May)

The modelled results together with the best-fitted curve are shown in Figure 6- 9. It can be seen that the simulated concentrations based on the k_{wn} obtained and the C_f extracted from Egodawatta *et al.* (2009)’s study show satisfactory agreement with the outdoor experimental results. The agreement was especially good for the first two rainfall events of the test series.

Figure 6- 9 Validation of k_w and C_f

6.4.2 P wash-off coefficient

The pathway of phosphorus entrainment into surface runoff is different from that of nitrogen. Nitrogen is generally transported by runoff in soluble form. Whereas phosphorus is transported together with sediment particulates entrained by runoff. The parameters of the particulate pollutant entrainment model proposed in chapter 4

were estimated using the data obtained from the controlled outdoor experiments.

$$M_w = k_a SY_e \quad \text{Eq. 4- 25}$$

with

$$k_a = f(M_t) \quad \text{Eq. 4- 26}$$

SY_e is represented by:

$$SY_e = X_e KLSCP \quad \text{Eq. 4- 27}$$

where, SY_e is the event sediment yield, and X_e is estimated using the following equation:

$$X_e = 1.586(Q_e q_p)^{0.56} DA^{0.12} \quad \text{Eq. 4- 28}$$

Since the K, LS, C and P factors in USLE are determined by and only by landuse and topography, those factors are reduced to a lumped constant in order to simplify the model. A new coefficient k_r is defined to include the constant K, LS, C and P factors in the phosphorus attachment coefficient k_a . k_{wp} is defined as the wash-off coefficient for phosphorus. Thus Eq. 4-26 may be written as:

$$M_w = k_{wp} X_e \quad \text{Eq. 6- 1}$$

with

$$k_{wp} = f(M_t) \quad \text{Eq. 6- 2}$$

Water quality sampling results from the outdoor experiments were used to establish the k_{wp} in equation 6-2. The k_{wp} expression obtained for wash-off phosphorus from grass land surface is found to be:

$$k_{wp} = 0.625e^{0.0641M_t} \quad \text{Eq. 6- 3}$$

This equation (Eq. 6-3) was then used in the evaluation of the TP concentrations measured from the 5 series of tests during the period April 2012 to November 2012 collected at location WS 3. The modelled results were then plotted together with the measured results for comparison. A typical example is presented in Table 6- 7 and Figure 6- 10. The full dataset and plots are presented in Appendix H.

Table 6- 7 Measured and simulated N concentrations of the controlled outdoor experiments

Time	TP concentration (mg/L)		Time	TP concentration (mg/L)	
	Simulated	Measured		Simulated	Measured
4/30/2012 0:00	0.00		5/7/2012 0:00	0.00	
4/30/2012 0:10	0.00		5/7/2012 0:10	0.88	
4/30/2012 0:20	0.00		5/7/2012 0:20	0.75	
4/30/2012 0:30	0.00		5/7/2012 0:30	0.65	
4/30/2012 0:40	0.00		5/7/2012 0:40	0.56	
4/30/2012 0:50	0.00		5/7/2012 0:50	0.49	
4/30/2012 1:00	0.00		5/7/2012 1:00	0.43	
4/30/2012 1:10	0.00		5/7/2012 1:10	0.38	
4/30/2012 1:20	0.00		5/7/2012 1:20	0.34	
4/30/2012 1:30	0.00		5/7/2012 1:30	0.31	
4/30/2012 1:40	0.00		5/7/2012 1:40	0.28	
4/30/2012 1:50	0.00		5/7/2012 1:50	0.25	
4/30/2012 2:00	0.00		5/7/2012 2:00	0.23	
4/30/2012 2:10	0.00		5/7/2012 2:10	0.21	
4/30/2012 2:20	0.00		5/7/2012 2:20	0.19	
4/30/2012 2:30	0.00		5/7/2012 2:30	0.18	
4/30/2012 2:40	0.00		5/7/2012 2:40	0.16	
4/30/2012 2:50	0.00		5/7/2012 2:50	0.15	
4/30/2012 3:00	0.00		5/7/2012 3:00	0.14	
4/30/2012 3:10	0.00		5/7/2012 3:10	0.13	
4/30/2012 3:20	0.00		5/7/2012 3:20	0.12	
4/30/2012 3:30	0.00		5/7/2012 3:30	0.11	
4/30/2012 3:40	0.00		5/7/2012 3:40	0.11	
4/30/2012 3:50	0.00		5/7/2012 3:50	0.10	
4/30/2012 4:00	0.00		5/7/2012 4:00	0.10	
4/30/2012 4:10	0.00		5/7/2012 4:10	0.09	
4/30/2012 4:20	0.00		5/7/2012 4:20	0.09	
4/30/2012 4:30	0.00		5/7/2012 4:30	0.08	
4/30/2012 4:40	0.00		5/7/2012 4:40	0.08	
4/30/2012 4:50	0.00		5/7/2012 4:50	0.07	
4/30/2012 5:00	0.00		5/7/2012 5:00	0.07	
4/30/2012 5:10	0.00		5/7/2012 5:10	0.07	
4/30/2012 5:20	0.00		5/7/2012 5:20	0.06	
4/30/2012 5:30	0.00		5/7/2012 5:30	0.06	
4/30/2012 5:40	0.00		5/7/2012 5:40	0.75	
4/30/2012 5:50	0.00		5/7/2012 5:50	0.72	
4/30/2012 6:00	0.00		5/7/2012 6:00	0.72	

Time	TP concentration (mg/L)		Time	TP concentration (mg/L)	
	Simulated	Measured		Simulated	Measured
4/30/2012 6:10	0.00		5/7/2012 6:10	0.75	
4/30/2012 6:20	0.00		5/7/2012 6:20	0.91	
4/30/2012 6:30	0.00		5/7/2012 6:30	0.87	
4/30/2012 6:40	0.00		5/7/2012 6:40	0.84	
4/30/2012 6:50	0.00		5/7/2012 6:50	0.81	
4/30/2012 7:00	0.00		5/7/2012 7:00	0.78	
4/30/2012 7:10	0.00		5/7/2012 7:10	0.75	
4/30/2012 7:20	7.36	7.56	5/7/2012 7:20	0.72	
4/30/2012 7:30	4.89		5/7/2012 7:30	0.70	
4/30/2012 7:40	5.59		5/7/2012 7:40	0.69	
4/30/2012 7:50	0.48		5/7/2012 7:50	0.67	
4/30/2012 8:00	0.36		5/7/2012 8:00	0.66	
4/30/2012 8:10	0.29		5/7/2012 8:10	0.65	
4/30/2012 8:20	0.25		5/7/2012 8:20	0.63	
4/30/2012 8:30	0.22		5/7/2012 8:30	0.61	
4/30/2012 8:40	0.19		5/7/2012 8:40	0.59	
4/30/2012 8:50	0.17		5/7/2012 8:50	0.57	
4/30/2012 9:00	0.16		5/7/2012 9:00	0.56	
4/30/2012 9:10	0.15		5/7/2012 9:10	0.54	
4/30/2012 9:20	0.13		5/7/2012 9:20	0.53	
4/30/2012 9:30	0.12		5/7/2012 9:30	0.51	
4/30/2012 9:40	0.12		5/7/2012 9:40	0.49	
4/30/2012 9:50	0.11		5/7/2012 9:50	0.48	
4/30/2012 10:00	0.10		5/7/2012 10:00	0.47	
4/30/2012 10:10	0.10		5/7/2012 10:10	0.45	
4/30/2012 10:20	0.09		5/7/2012 10:20	0.44	
4/30/2012 10:30	0.09		5/7/2012 10:30	0.43	
4/30/2012 10:40	0.08		5/7/2012 10:40	0.42	
4/30/2012 10:50	0.08		5/7/2012 10:50	0.40	
4/30/2012 11:00	0.07		5/7/2012 11:00	0.39	0.41
4/30/2012 11:10	0.07		5/7/2012 11:10	0.38	
4/30/2012 11:20	0.07		5/7/2012 11:20	0.37	
4/30/2012 11:30	0.06		5/7/2012 11:30	0.36	
4/30/2012 11:40	0.06		5/7/2012 11:40	0.35	
4/30/2012 11:50	0.06		5/7/2012 11:50	0.34	
4/30/2012 12:00	0.06		5/7/2012 12:00	0.33	
4/30/2012 12:10	0.05		5/7/2012 12:10	0.32	
4/30/2012 12:20	0.05		5/7/2012 12:20	0.31	
4/30/2012 12:30	0.05		5/7/2012 12:30	0.31	
4/30/2012 12:40	0.06		5/7/2012 12:40	0.30	

Time	TP concentration (mg/L)		Time	TP concentration (mg/L)	
	Simulated	Measured		Simulated	Measured
4/30/2012 12:50	0.06		5/7/2012 12:50	0.29	
4/30/2012 13:00	0.06		5/7/2012 13:00	0.28	
4/30/2012 13:10	0.05		5/7/2012 13:10	0.27	
4/30/2012 13:20	0.05		5/7/2012 13:20	0.27	
4/30/2012 13:30	0.05		5/7/2012 13:30	0.26	
4/30/2012 13:40	0.05		5/7/2012 13:40	0.25	
4/30/2012 13:50	0.05		5/7/2012 13:50	0.25	
4/30/2012 14:00	0.05		5/7/2012 14:00	0.24	
4/30/2012 14:10	0.04		5/7/2012 14:10	0.23	
4/30/2012 14:20	0.04		5/7/2012 14:20	0.23	
4/30/2012 14:30	0.04		5/7/2012 14:30	0.22	
4/30/2012 14:40	0.04		5/7/2012 14:40	0.21	
4/30/2012 14:50	0.04		5/7/2012 14:50	0.21	
4/30/2012 15:00	0.04		5/7/2012 15:00	0.20	
4/30/2012 15:10	0.04		5/7/2012 15:10	0.20	
4/30/2012 15:20	0.04		5/7/2012 15:20	0.19	
4/30/2012 15:30	0.03		5/7/2012 15:30	0.19	
4/30/2012 15:40	0.03		5/7/2012 15:40	0.18	
4/30/2012 15:50	0.03		5/7/2012 15:50	0.18	
4/30/2012 16:00	0.03		5/7/2012 16:00	0.17	
4/30/2012 16:10	0.03		5/7/2012 16:10	0.17	
4/30/2012 16:20	0.03		5/7/2012 16:20	0.16	
4/30/2012 16:30	0.03		5/7/2012 16:30	0.16	
4/30/2012 16:40	0.03		5/7/2012 16:40	0.15	
4/30/2012 16:50	0.03		5/7/2012 16:50	0.15	
4/30/2012 17:00	0.03		5/7/2012 17:00	0.15	
4/30/2012 17:10	0.03		5/7/2012 17:10	0.14	
4/30/2012 17:20	0.02		5/7/2012 17:20	0.14	
4/30/2012 17:30	0.02		5/7/2012 17:30	0.14	
4/30/2012 17:40	0.02		5/7/2012 17:40	0.13	
4/30/2012 17:50	0.02		5/7/2012 17:50	0.13	
4/30/2012 18:00	0.02		5/7/2012 18:00	0.12	
4/30/2012 18:10	0.02		5/7/2012 18:10	0.12	
4/30/2012 18:20	0.02		5/7/2012 18:20	0.12	
4/30/2012 18:30	0.02		5/7/2012 18:30	0.11	
4/30/2012 18:40	0.02		5/7/2012 18:40	0.11	
4/30/2012 18:50	0.02		5/7/2012 18:50	0.11	
4/30/2012 19:00	0.02		5/7/2012 19:00	0.11	
4/30/2012 19:10	0.02		5/7/2012 19:10	0.10	
4/30/2012 19:20	0.02		5/7/2012 19:20	0.10	

Time	TP concentration (mg/L)		Time	TP concentration (mg/L)	
	Simulated	Measured		Simulated	Measured
4/30/2012 19:30	0.02		5/7/2012 19:30	0.10	
4/30/2012 19:40	0.02		5/7/2012 19:40	0.10	
4/30/2012 19:50	0.02		5/7/2012 19:50	0.09	
4/30/2012 20:00	0.02		5/7/2012 20:00	0.09	
4/30/2012 20:10	0.02		5/7/2012 20:10	0.09	
4/30/2012 20:20	0.01		5/7/2012 20:20	0.09	
4/30/2012 20:30	0.01		5/7/2012 20:30	0.08	
4/30/2012 20:40	0.01		5/7/2012 20:40	0.08	
4/30/2012 20:50	0.01		5/7/2012 20:50	0.08	
4/30/2012 21:00	0.01		5/7/2012 21:00	0.08	
4/30/2012 21:10	0.01		5/7/2012 21:10	0.07	
4/30/2012 21:20	0.01		5/7/2012 21:20	0.07	
4/30/2012 21:30	0.01		5/7/2012 21:30	0.07	
4/30/2012 21:40	0.01		5/7/2012 21:40	0.07	
4/30/2012 21:50	0.01		5/7/2012 21:50	0.07	
4/30/2012 22:00	0.01		5/7/2012 22:00	0.07	
4/30/2012 22:10	0.01		5/7/2012 22:10	0.06	
4/30/2012 22:20	0.01		5/7/2012 22:20	0.06	
4/30/2012 22:30	0.01		5/7/2012 22:30	0.06	
4/30/2012 22:40	0.01		5/7/2012 22:40	0.06	
4/30/2012 22:50	0.01		5/7/2012 22:50	0.06	
4/30/2012 23:00	0.01		5/7/2012 23:00	0.06	
4/30/2012 23:10	0.01		5/7/2012 23:10	0.05	
4/30/2012 23:20	0.01		5/7/2012 23:20	0.05	
4/30/2012 23:30	0.01		5/7/2012 23:30	0.05	
4/30/2012 23:40	0.01		5/7/2012 23:40	0.05	
4/30/2012 23:50	0.01		5/7/2012 23:50	0.05	
5/2/2012 0:00	0.00		5/9/2012 0:00	0.00	
5/2/2012 0:10	0.18		5/9/2012 0:10	0.00	
5/2/2012 0:20	0.13		5/9/2012 0:20	0.00	
5/2/2012 0:30	0.10		5/9/2012 0:30	0.00	
5/2/2012 0:40	0.08		5/9/2012 0:40	0.00	
5/2/2012 0:50	0.06		5/9/2012 0:50	0.00	
5/2/2012 1:00	0.05		5/9/2012 1:00	0.00	
5/2/2012 1:10	0.04		5/9/2012 1:10	0.00	
5/2/2012 1:20	0.03		5/9/2012 1:20	0.00	
5/2/2012 1:30	0.03		5/9/2012 1:30	0.00	
5/2/2012 1:40	0.02		5/9/2012 1:40	0.00	
5/2/2012 1:50	0.02		5/9/2012 1:50	0.00	
5/2/2012 2:00	0.02		5/9/2012 2:00	0.00	

Time	TP concentration (mg/L)		Time	TP concentration (mg/L)	
	Simulated	Measured		Simulated	Measured
5/2/2012 2:10	0.01		5/9/2012 2:10	0.18	0.37
5/2/2012 2:20	0.01		5/9/2012 2:20	0.17	
5/2/2012 2:30	0.01		5/9/2012 2:30	0.16	
5/2/2012 2:40	0.01		5/9/2012 2:40	0.15	
5/2/2012 2:50	0.01		5/9/2012 2:50	0.14	
5/2/2012 3:00	0.01		5/9/2012 3:00	0.13	
5/2/2012 3:10	0.01		5/9/2012 3:10	0.12	
5/2/2012 3:20	0.01		5/9/2012 3:20	0.11	
5/2/2012 3:30	0.01		5/9/2012 3:30	0.11	
5/2/2012 3:40	0.01		5/9/2012 3:40	0.10	
5/2/2012 3:50	0.00		5/9/2012 3:50	0.09	
5/2/2012 4:00	0.00		5/9/2012 4:00	0.09	
5/2/2012 4:10	0.00		5/9/2012 4:10	0.09	
5/2/2012 4:20	0.00		5/9/2012 4:20	0.09	
5/2/2012 4:30	0.00		5/9/2012 4:30	0.08	
5/2/2012 4:40	0.00		5/9/2012 4:40	0.08	
5/2/2012 4:50	0.00		5/9/2012 4:50	0.08	
5/2/2012 5:00	0.00		5/9/2012 5:00	0.07	
5/2/2012 5:10	0.00		5/9/2012 5:10	0.07	
5/2/2012 5:20	0.00		5/9/2012 5:20	0.07	
5/2/2012 5:30	0.00		5/9/2012 5:30	0.07	
5/2/2012 5:40	0.00		5/9/2012 5:40	0.06	
5/2/2012 5:50	0.00		5/9/2012 5:50	0.06	
5/2/2012 6:00	0.00		5/9/2012 6:00	0.06	
5/2/2012 6:10	0.00		5/9/2012 6:10	0.06	
5/2/2012 6:20	0.00		5/9/2012 6:20	0.06	
5/2/2012 6:30	0.00		5/9/2012 6:30	0.05	
5/2/2012 6:40	0.00		5/9/2012 6:40	0.05	
5/2/2012 6:50	0.00		5/9/2012 6:50	0.05	
5/2/2012 7:00	0.00		5/9/2012 7:00	0.05	
5/2/2012 7:10	0.00		5/9/2012 7:10	0.05	
5/2/2012 7:20	0.00		5/9/2012 7:20	0.05	
5/2/2012 7:30	0.00		5/9/2012 7:30	0.04	
5/2/2012 7:40	0.00		5/9/2012 7:40	0.04	
5/2/2012 7:50	0.00		5/9/2012 7:50	0.04	
5/2/2012 8:00	0.00		5/9/2012 8:00	0.04	
5/2/2012 8:10	0.00		5/9/2012 8:10	0.04	
5/2/2012 8:20	0.00		5/9/2012 8:20	0.04	
5/2/2012 8:30	1.18		5/9/2012 8:30	0.04	
5/2/2012 8:40	1.18		5/9/2012 8:40	0.04	

Time	TP concentration (mg/L)		Time	TP concentration (mg/L)	
	Simulated	Measured		Simulated	Measured
5/2/2012 8:50	1.67		5/9/2012 8:50	0.04	
5/2/2012 9:00	1.60		5/9/2012 9:00	0.03	
5/2/2012 9:10	1.59		5/9/2012 9:10	0.03	
5/2/2012 9:20	1.53		5/9/2012 9:20	0.03	
5/2/2012 9:30	1.62		5/9/2012 9:30	0.03	
5/2/2012 9:40	1.56		5/9/2012 9:40	0.03	
5/2/2012 9:50	1.51		5/9/2012 9:50	0.03	
5/2/2012 10:00	1.45		5/9/2012 10:00	0.03	
5/2/2012 10:10	1.41		5/9/2012 10:10	0.05	
5/2/2012 10:20	1.36		5/9/2012 10:20	0.05	
5/2/2012 10:30	1.32		5/9/2012 10:30	0.05	
5/2/2012 10:40	1.28		5/9/2012 10:40	0.05	
5/2/2012 10:50	1.24		5/9/2012 10:50	0.05	
5/2/2012 11:00	1.20		5/9/2012 11:00	0.04	
5/2/2012 11:10	1.17		5/9/2012 11:10	0.04	
5/2/2012 11:20	1.13		5/9/2012 11:20	0.04	
5/2/2012 11:30	1.10		5/9/2012 11:30	0.04	
5/2/2012 11:40	1.07		5/9/2012 11:40	0.04	
5/2/2012 11:50	1.04		5/9/2012 11:50	0.04	
5/2/2012 12:00	1.01		5/9/2012 12:00	0.04	
5/2/2012 12:10	0.98		5/9/2012 12:10	0.04	
5/2/2012 12:20	0.96		5/9/2012 12:20	0.04	
5/2/2012 12:30	0.93		5/9/2012 12:30	0.03	
5/2/2012 12:40	0.90		5/9/2012 12:40	0.03	
5/2/2012 12:50	0.88		5/9/2012 12:50	0.03	
5/2/2012 13:00	0.85		5/9/2012 13:00	0.03	
5/2/2012 13:10	0.83		5/9/2012 13:10	0.03	
5/2/2012 13:20	0.81		5/9/2012 13:20	0.03	
5/2/2012 13:30	0.79		5/9/2012 13:30	0.03	
5/2/2012 13:40	0.76		5/9/2012 13:40	0.03	
5/2/2012 13:50	0.74		5/9/2012 13:50	0.03	
5/2/2012 14:00	0.72		5/9/2012 14:00	0.03	
5/2/2012 14:10	0.70		5/9/2012 14:10	0.03	
5/2/2012 14:20	0.68		5/9/2012 14:20	0.03	
5/2/2012 14:30	0.67		5/9/2012 14:30	0.03	
5/2/2012 14:40	0.65		5/9/2012 14:40	0.02	
5/2/2012 14:50	0.63		5/9/2012 14:50	0.02	
5/2/2012 15:00	0.61		5/9/2012 15:00	0.02	
5/2/2012 15:10	0.60		5/9/2012 15:10	0.02	
5/2/2012 15:20	0.58		5/9/2012 15:20	0.02	

Time	TP concentration (mg/L)		Time	TP concentration (mg/L)	
	Simulated	Measured		Simulated	Measured
5/2/2012 15:30	0.57		5/9/2012 15:30	0.02	
5/2/2012 15:40	0.55		5/9/2012 15:40	0.02	
5/2/2012 15:50	0.54		5/9/2012 15:50	0.02	
5/2/2012 16:00	0.52		5/9/2012 16:00	0.02	
5/2/2012 16:10	0.51		5/9/2012 16:10	0.02	
5/2/2012 16:20	0.49		5/9/2012 16:20	0.02	
5/2/2012 16:30	0.48		5/9/2012 16:30	0.02	
5/2/2012 16:40	0.47		5/9/2012 16:40	0.02	
5/2/2012 16:50	0.45		5/9/2012 16:50	0.02	
5/2/2012 17:00	0.44		5/9/2012 17:00	0.02	
5/2/2012 17:10	0.43		5/9/2012 17:10	0.02	
5/2/2012 17:20	0.42		5/9/2012 17:20	0.02	
5/2/2012 17:30	1.71		5/9/2012 17:30	0.02	
5/2/2012 17:40	1.75	4.12	5/9/2012 17:40	0.02	
5/2/2012 17:50	1.65		5/9/2012 17:50	0.01	
5/2/2012 18:00	1.58		5/9/2012 18:00	0.01	
5/2/2012 18:10	1.52		5/9/2012 18:10	0.01	
5/2/2012 18:20	1.47		5/9/2012 18:20	0.01	
5/2/2012 18:30	1.42		5/9/2012 18:30	0.01	
5/2/2012 18:40	1.38		5/9/2012 18:40	0.01	
5/2/2012 18:50	1.35		5/9/2012 18:50	0.01	
5/2/2012 19:00	1.31		5/9/2012 19:00	0.01	
5/2/2012 19:10	1.28		5/9/2012 19:10	0.01	
5/2/2012 19:20	1.25		5/9/2012 19:20	0.01	
5/2/2012 19:30	1.22		5/9/2012 19:30	0.01	
5/2/2012 19:40	1.19		5/9/2012 19:40	0.01	
5/2/2012 19:50	1.16		5/9/2012 19:50	0.01	
5/2/2012 20:00	1.14		5/9/2012 20:00	0.01	
5/2/2012 20:10	1.11		5/9/2012 20:10	0.01	
5/2/2012 20:20	1.09		5/9/2012 20:20	0.01	
5/2/2012 20:30	1.06		5/9/2012 20:30	0.01	
5/2/2012 20:40	1.04		5/9/2012 20:40	0.01	
5/2/2012 20:50	1.01		5/9/2012 20:50	0.01	
5/2/2012 21:00	0.99		5/9/2012 21:00	0.01	
5/2/2012 21:10	0.97		5/9/2012 21:10	0.01	
5/2/2012 21:20	0.94		5/9/2012 21:20	0.01	
5/2/2012 21:30	0.92		5/9/2012 21:30	0.01	
5/2/2012 21:40	0.90		5/9/2012 21:40	0.01	
5/2/2012 21:50	0.88		5/9/2012 21:50	0.01	
5/2/2012 22:00	0.85		5/9/2012 22:00	0.01	

Time	TP concentration (mg/L)		Time	TP concentration (mg/L)	
	Simulated	Measured		Simulated	Measured
5/2/2012 22:10	0.83		5/9/2012 22:10	0.01	
5/2/2012 22:20	0.81		5/9/2012 22:20	0.01	
5/2/2012 22:30	0.79		5/9/2012 22:30	0.01	
5/2/2012 22:40	0.77		5/9/2012 22:40	0.01	
5/2/2012 22:50	0.75		5/9/2012 22:50	0.01	
5/2/2012 23:00	0.74		5/9/2012 23:00	0.01	
5/2/2012 23:10	0.72		5/9/2012 23:10	0.01	
5/2/2012 23:20	0.70		5/9/2012 23:20	0.01	
5/2/2012 23:30	0.68		5/9/2012 23:30	0.01	
5/2/2012 23:40	0.66		5/9/2012 23:40	0.01	
5/2/2012 23:50	0.65		5/9/2012 23:50	0.01	
5/5/2012 0:00	0.00		5/13/2012 0:00	0.00	
5/5/2012 0:10	0.00		5/13/2012 0:10	0.00	
5/5/2012 0:20	0.00		5/13/2012 0:20	0.00	
5/5/2012 0:30	0.00		5/13/2012 0:30	0.00	
5/5/2012 0:40	0.00		5/13/2012 0:40	0.00	
5/5/2012 0:50	0.00		5/13/2012 0:50	0.00	
5/5/2012 1:00	0.00		5/13/2012 1:00	0.00	
5/5/2012 1:10	0.64	0.83	5/13/2012 1:10	0.23	
5/5/2012 1:20	0.63		5/13/2012 1:20	0.19	
5/5/2012 1:30	0.24		5/13/2012 1:30	0.17	
5/5/2012 1:40	0.20		5/13/2012 1:40	0.15	
5/5/2012 1:50	0.10		5/13/2012 1:50	0.14	
5/5/2012 2:00	0.08		5/13/2012 2:00	0.13	0.13
5/5/2012 2:10	0.06		5/13/2012 2:10	0.12	
5/5/2012 2:20	0.05		5/13/2012 2:20	0.11	
5/5/2012 2:30	0.04		5/13/2012 2:30	0.10	
5/5/2012 2:40	0.04		5/13/2012 2:40	0.10	
5/5/2012 2:50	0.04		5/13/2012 2:50	0.10	
5/5/2012 3:00	0.04		5/13/2012 3:00	0.10	
5/5/2012 3:10	0.04		5/13/2012 3:10	0.10	
5/5/2012 3:20	0.04		5/13/2012 3:20	0.09	
5/5/2012 3:30	0.04		5/13/2012 3:30	0.09	
5/5/2012 3:40	0.04		5/13/2012 3:40	0.09	
5/5/2012 3:50	0.04		5/13/2012 3:50	0.08	
5/5/2012 4:00	0.04		5/13/2012 4:00	0.08	
5/5/2012 4:10	0.04		5/13/2012 4:10	0.08	
5/5/2012 4:20	0.04		5/13/2012 4:20	0.08	
5/5/2012 4:30	0.04		5/13/2012 4:30	0.07	
5/5/2012 4:40	0.04		5/13/2012 4:40	0.07	

Time	TP concentration (mg/L)		Time	TP concentration (mg/L)	
	Simulated	Measured		Simulated	Measured
5/5/2012 4:50	0.04		5/13/2012 4:50	0.07	
5/5/2012 5:00	0.04		5/13/2012 5:00	0.07	
5/5/2012 5:10	0.04		5/13/2012 5:10	0.07	
5/5/2012 5:20	0.04		5/13/2012 5:20	0.06	
5/5/2012 5:30	0.04		5/13/2012 5:30	0.06	
5/5/2012 5:40	0.04		5/13/2012 5:40	0.06	
5/5/2012 5:50	0.04		5/13/2012 5:50	0.06	
5/5/2012 6:00	0.04		5/13/2012 6:00	0.06	
5/5/2012 6:10	0.04		5/13/2012 6:10	0.05	
5/5/2012 6:20	0.04		5/13/2012 6:20	0.05	
5/5/2012 6:30	0.04		5/13/2012 6:30	0.05	
5/5/2012 6:40	0.04		5/13/2012 6:40	0.05	
5/5/2012 6:50	0.04		5/13/2012 6:50	0.05	
5/5/2012 7:00	0.04		5/13/2012 7:00	0.05	
5/5/2012 7:10	0.04		5/13/2012 7:10	0.05	
5/5/2012 7:20	0.04		5/13/2012 7:20	0.05	
5/5/2012 7:30	0.04		5/13/2012 7:30	0.05	
5/5/2012 7:40	0.04		5/13/2012 7:40	0.05	
5/5/2012 7:50	0.04		5/13/2012 7:50	0.05	
5/5/2012 8:00	0.04		5/13/2012 8:00	0.04	
5/5/2012 8:10	0.04		5/13/2012 8:10	0.04	
5/5/2012 8:20	0.04		5/13/2012 8:20	0.04	
5/5/2012 8:30	0.04		5/13/2012 8:30	0.04	
5/5/2012 8:40	0.04		5/13/2012 8:40	0.04	
5/5/2012 8:50	0.04		5/13/2012 8:50	0.04	
5/5/2012 9:00	0.04		5/13/2012 9:00	0.04	
5/5/2012 9:10	0.03		5/13/2012 9:10	0.04	
5/5/2012 9:20	0.03		5/13/2012 9:20	0.04	
5/5/2012 9:30	0.03		5/13/2012 9:30	0.03	
5/5/2012 9:40	0.03		5/13/2012 9:40	0.03	
5/5/2012 9:50	0.03		5/13/2012 9:50	0.03	
5/5/2012 10:00	0.03		5/13/2012 10:00	0.03	
5/5/2012 10:10	0.03		5/13/2012 10:10	0.03	
5/5/2012 10:20	0.03		5/13/2012 10:20	0.03	
5/5/2012 10:30	0.03		5/13/2012 10:30	0.03	
5/5/2012 10:40	0.03		5/13/2012 10:40	0.03	
5/5/2012 10:50	0.03		5/13/2012 10:50	0.03	
5/5/2012 11:00	0.03		5/13/2012 11:00	0.03	
5/5/2012 11:10	0.03		5/13/2012 11:10	0.03	
5/5/2012 11:20	0.03		5/13/2012 11:20	0.03	

Time	TP concentration (mg/L)		Time	TP concentration (mg/L)	
	Simulated	Measured		Simulated	Measured
5/5/2012 11:30	0.03		5/13/2012 11:30	0.03	
5/5/2012 11:40	0.03		5/13/2012 11:40	0.02	
5/5/2012 11:50	0.02		5/13/2012 11:50	0.02	
5/5/2012 12:00	0.02		5/13/2012 12:00	0.02	
5/5/2012 12:10	0.02		5/13/2012 12:10	0.02	
5/5/2012 12:20	0.02		5/13/2012 12:20	0.02	
5/5/2012 12:30	0.02		5/13/2012 12:30	0.02	
5/5/2012 12:40	0.02		5/13/2012 12:40	0.02	
5/5/2012 12:50	0.02		5/13/2012 12:50	0.02	
5/5/2012 13:00	0.02		5/13/2012 13:00	0.02	
5/5/2012 13:10	0.02		5/13/2012 13:10	0.02	
5/5/2012 13:20	0.02		5/13/2012 13:20	0.02	
5/5/2012 13:30	0.02		5/13/2012 13:30	0.02	
5/5/2012 13:40	0.02		5/13/2012 13:40	0.02	
5/5/2012 13:50	0.02		5/13/2012 13:50	0.02	
5/5/2012 14:00	0.02		5/13/2012 14:00	0.02	
5/5/2012 14:10	0.02		5/13/2012 14:10	0.02	
5/5/2012 14:20	0.02		5/13/2012 14:20	0.02	
5/5/2012 14:30	0.02		5/13/2012 14:30	0.02	
5/5/2012 14:40	0.02		5/13/2012 14:40	0.02	
5/5/2012 14:50	0.02		5/13/2012 14:50	0.01	
5/5/2012 15:00	0.02		5/13/2012 15:00	0.01	
5/5/2012 15:10	0.01		5/13/2012 15:10	0.01	
5/5/2012 15:20	0.01		5/13/2012 15:20	0.01	
5/5/2012 15:30	0.01		5/13/2012 15:30	0.01	
5/5/2012 15:40	0.01		5/13/2012 15:40	0.01	
5/5/2012 15:50	0.01		5/13/2012 15:50	0.01	
5/5/2012 16:00	0.01		5/13/2012 16:00	0.01	
5/5/2012 16:10	0.01		5/13/2012 16:10	0.01	
5/5/2012 16:20	0.01		5/13/2012 16:20	0.01	
5/5/2012 16:30	0.01		5/13/2012 16:30	0.01	
5/5/2012 16:40	0.01		5/13/2012 16:40	0.01	
5/5/2012 16:50	0.01		5/13/2012 16:50	0.01	
5/5/2012 17:00	0.01		5/13/2012 17:00	0.01	
5/5/2012 17:10	0.01		5/13/2012 17:10	0.01	
5/5/2012 17:20	0.01		5/13/2012 17:20	0.01	
5/5/2012 17:30	0.01		5/13/2012 17:30	0.01	
5/5/2012 17:40	0.01		5/13/2012 17:40	0.01	
5/5/2012 17:50	0.01		5/13/2012 17:50	0.01	
5/5/2012 18:00	0.01		5/13/2012 18:00	0.01	

Time	TP concentration (mg/L)		Time	TP concentration (mg/L)	
	Simulated	Measured		Simulated	Measured
5/5/2012 18:10	0.01		5/13/2012 18:10	0.01	
5/5/2012 18:20	0.01		5/13/2012 18:20	0.01	
5/5/2012 18:30	0.01		5/13/2012 18:30	0.01	
5/5/2012 18:40	0.01		5/13/2012 18:40	0.01	
5/5/2012 18:50	0.01		5/13/2012 18:50	0.01	
5/5/2012 19:00	0.01		5/13/2012 19:00	0.01	
5/5/2012 19:10	0.01		5/13/2012 19:10	0.01	
5/5/2012 19:20	0.01		5/13/2012 19:20	0.01	
5/5/2012 19:30	0.01		5/13/2012 19:30	0.01	
5/5/2012 19:40	0.01		5/13/2012 19:40	0.01	
5/5/2012 19:50	0.01		5/13/2012 19:50	0.01	
5/5/2012 20:00	0.01		5/13/2012 20:00	0.01	
5/5/2012 20:10	0.01		5/13/2012 20:10	0.01	
5/5/2012 20:20	0.01		5/13/2012 20:20	0.01	
5/5/2012 20:30	0.01		5/13/2012 20:30	0.01	
5/5/2012 20:40	0.01		5/13/2012 20:40	0.01	
5/5/2012 20:50	0.01		5/13/2012 20:50	0.01	
5/5/2012 21:00	0.01		5/13/2012 21:00	0.01	
5/5/2012 21:10	0.01		5/13/2012 21:10	0.01	
5/5/2012 21:20	0.01		5/13/2012 21:20	0.01	
5/5/2012 21:30	0.01		5/13/2012 21:30	0.00	
5/5/2012 21:40	0.01		5/13/2012 21:40	0.00	
5/5/2012 21:50	0.01		5/13/2012 21:50	0.00	
5/5/2012 22:00	0.01		5/13/2012 22:00	0.00	
5/5/2012 22:10	0.00		5/13/2012 22:10	0.00	
5/5/2012 22:20	0.00		5/13/2012 22:20	0.00	
5/5/2012 22:30	0.00		5/13/2012 22:30	0.00	
5/5/2012 22:40	0.00		5/13/2012 22:40	0.00	
5/5/2012 22:50	0.00		5/13/2012 22:50	0.00	
5/5/2012 23:00	0.00		5/13/2012 23:00	0.00	
5/5/2012 23:10	0.00		5/13/2012 23:10	0.00	
5/5/2012 23:20	0.00		5/13/2012 23:20	0.00	
5/5/2012 23:30	0.00		5/13/2012 23:30	0.00	
5/5/2012 23:40	0.00		5/13/2012 23:40	0.00	
5/5/2012 23:50	0.00		5/13/2012 23:50	0.00

Figure 6- 10 A typical example of comparison of simulated and measured TP concentration (Test period: 29th April-13th May)

The modelled results together with the best-fitted curve are shown in Figure 6- 11 for validation of k_{wp} equation.

Figure 6- 11 Validation of k_{wp}

CHAPTER 7 NUTRIENT LOSS MODEL

7.1 Layout of Chapter 7

In this chapter, validation of the nutrient loss model and the integrated nutrient loss model are presented. There are many published studies that had been conducted to investigate nitrogen (N) or phosphorus (P) loss under various conditions. Some of the studies focused on the transformation of N or P (Mangimbulude *et al.* 2012) while some considered the leaching of N or P under the impact of different runoff volume or depth (Smith *et al.* 2001b; Udawatta *et al.* 2006). The observations and modelled results of some of these studies are very valuable for the studies in investigating the N and P loss.

The published results, in the forms of either laboratory observations, or field/catchment measurements, where relevant, have been extracted and reformatted for comparative study in this study. The model developed in the present study was applied to model the nutrient loss under the reported experimental conditions of these studies. The modelled results were plotted together with the tabulated datasets and the performance of the present model examined.

In section 7.2, the author presents the calibrated coefficients of the current model. Comparison of the modelled results by using the present model with and without temporal variation of the nutrient was also presented in section 7.2. The objective is to assess the significance of the temporal influence of the source N and P. In section 7.3, the published dataset was described briefly. The methodology used to reformat the datasets is also described. The reformatted data are tabulated (see appendix I) for later analyses. The experimental schemes (rainfall generation schemes, fertiliser application schemes, *etc.*) of the published studies were also modelled using the present model and the simulated results are presented herein. The model results were plotted together with the measured data obtained from other studies to test the validity and performance of the present model. A summary is presented in section 7.4.

7.2 Integrated nutrient loss model

In the present study, the author developed an integrated nutrient loss model, which includes consideration of time-variable source of N and P. The parameters required for the model have been calibrated as described in the chapters 5 and 6, and the pertinent parameters are summarized in Table 7- 1.

Table 7- 1 Summary of model coefficients

	Fertiliser rate (FR, kg/ha)	Natural loss coefficient (k_t)	Soil adsorption coefficient (k_s)	Wash-off coefficient
NO_3^-	500 1000	0.0055	0.021 0.013	$k_{wn}=7.3 \times 10^{-4}$
NH_4^+	225 500 1000	0.0030	0.045 0.040 0.015	
TN	225 500 1000	0.0045	0.042 0.038 0.016	
TP	135 300	0.0008	0.124 0.067	$k_{wp} = 0.625e^{0.0641M_t}$

7.2.1 The proposed nutrient loss model

The integrated model was used to model the nutrient loss under the experimental conditions recorded at the controlled outdoor plot. In order to examine the significance of the temporal influence on the pollutant source, simulation of N and P losses with and without time-variable influent of pollutant under the controlled outdoor experiments condition (e.g. rainfall, temperature, surface condition, soil moisture, *etc.*), the simulation was carried out in two modes: (1) full nutrient loss model, and (2) partial loss model without environmental loss by neglecting the N and P loss component in the present model.

The measured concentrations of the samples collected from the outdoor plot, together with the corresponding simulated results are shown in Table 7- 2 and Table 7- 3 and presented in chronological order. The results are presented in two forms: the absolute concentration (C , in mg/L) and relative concentration, C/C_0 , where C_0 is the initial N or P concentration.

Table 7- 2 Measured and simulated N concentration

Date (DD/MM/ YYYY)	Days after fertiliser applied	Rain time (HH:MM)		NH ₄ ⁺				NO ₃ ⁻				TN			
				Simulated		Measured		Simulated		Measured		Simulated		Measured	
		Start	Finish	C(mg/L)	C/C ₀	C(mg/L)	C/C ₀	C(mg/L)	C/C ₀	C(mg/L)	C/C ₀	C(mg/L)	C/C ₀	C(mg/L)	C/C ₀
30/04/2012	1	07:20	07:50	9.93	1.00	9.7	1.00	2.98	1.00	4.8	1.00	24.89	1.00	23	1.00
02/05/2012	3	17:20	18:20	5.32	0.54	5.1	0.53	1.62	0.54	2.8	0.58	5.80	0.23	5	0.22
05/05/2012	6	01:10	05:10	1.25	0.13	1.5	0.15	0.40	0.13	0.4	0.08	2.71	0.11	3	0.13
07/05/2012	8	07:20	10:00	0.72	0.07	1.3	0.13	0.24	0.08	0.9	0.19	1.03	0.04	2	0.09
09/05/2012	10	04:00	06:30	0.26	0.03	0.1	0.01	0.09	0.03	0.5	0.10	0.52	0.02	1	0.04
13/05/2012	14	03:10	06:30	0.11	0.01	0.0	0.00	0.04	0.01	0.1	0.02	0.23	0.01	0	0.00
24/07/2012	3	06:50	07:20	12.81	1.00	9.7	1.00	3.45	1.00	2.7	1.00	28.82	1.00	23	1.00
26/07/2012	5	18:30	19:00	0.71	0.06	0.6	0.06	1.48	0.43	1.4	0.52	2.34	0.08	8	0.35
28/07/2012	7	19:40	22:00	0.17	0.01	0.4	0.04	0.42	0.12	0.2	0.07	0.59	0.02	2	0.09
17/08/2012	3	08:30	10:20	14.05	1.00	16.4	1.00	4.36	1.00	5.3	1.00	32.45	1.00	39	1.00
19/08/2012	5	14:10	14:30	0.29	0.02	4.4	0.27	0.87	0.20	1.7	0.32	7.49	0.23	10	0.26
21/08/2012	7	10:40	19:00	1.10	0.08	1.2	0.07	0.36	0.08	0.3	0.06	0.99	0.03	0	0.00
23/08/2012	9	10:10	10:50	1.05	0.07	0.5	0.03	0.36	0.08	0.3	0.06	1.01	0.03	1	0.03
14/10/2012	1	19:00	19:50	17.96	1.00	12.7	1.00	4.05	1.00	4.9	1.00	36.33	1.00	37	1.00
16/10/2012	3	14:00	14:20	0.45	0.03	0.7	0.06	0.30	0.08	0.4	0.08	2.14	0.06	4	0.11
17/10/2012	4	15:10	16:40	0.74	0.04	2.7	0.21	1.14	0.28	1.9	0.39	1.07	0.03	3	0.08
18/10/2012	5	12:50	15:10	0.95	0.05	1.3	0.10	1.93	0.48	1.4	0.29	2.61	0.07	7	0.19
19/10/2012	6	16:00	17:10	0.46	0.03	0.8	0.06	0.95	0.23	1.1	0.22	1.26	0.03	1	0.03
20/10/2012	7	18:10	18:50	0.02	0.00	0.2	0.02	0.04	0.01	0.4	0.08	0.05	0.00	1	0.03
21/10/2012	8	10:40	14:10	0.55	0.03	0.4	0.03	0.49	0.12	0.4	0.08	2.74	0.08	1	0.03
22/11/2012	1	09:40	10:00	15.26	1.00	15.1	1.00	4.82	1.00	4.7	1.00	36.83	1.00	36	1.00
23/11/2012	2	01:42	18:52	7.00	0.46	9.1	0.60	2.54	0.53	2.1	0.45	17.16	0.47	17	0.47
25/11/2012	4	04:40	09:50	2.46	0.16	0.7	0.05	1.29	0.27	0.5	0.11	6.30	0.17	2	0.06
26/11/2012	5	09:40	11:50	0.53	0.03	0.6	0.04	0.30	0.06	0.3	0.06	1.37	0.04	1	0.03
28/11/2012	7	03:40	15:10	0.13	0.01	0.2	0.01	0.06	0.01	0.1	0.02	0.32	0.01	0	0.00
29/11/2012	8	00:10	02:30	0.04	0.00	0.1	0.01	0.01	0.00	0	0.00	0.10	0.00	0	0.00

Table 7- 3 Measured and simulated P concentration

Date (DD/MM/ YYYY)	Days after fertiliser applied	Rain time (HH:MM)		TP			
				Simulated		Measured	
		Start	Finish	Concentration (mg/L)	C/C ₀	Concentration (mg/L)	C/C ₀
30/04/2012	1	07:20	07:50	7.36	1.00	7.56	1.00
02/05/2012	3	17:20	18:20	0.64	0.09	0.83	0.11
05/05/2012	6	01:10	05:10	0.64	0.09	0.83	0.11
07/05/2012	8	07:20	10:00	0.39	0.05	0.41	0.05
09/05/2012	10	04:00	06:30	0.18	0.03	0.37	0.05
13/05/2012	14	03:10	06:30	0.13	0.02	0.13	0.02
24/07/2012	3	06:50	07:20	3.77	1.00	3.51	1.00
26/07/2012	5	18:30	19:00	0.54	0.14	0.85	0.24
28/07/2012	7	19:40	22:00	0.12	0.03	0.13	0.04
17/08/2012	3	08:30	10:20	8.47	1.00	4.57	1.00
19/08/2012	5	14:10	14:30	0.66	0.08	0.71	0.16
21/08/2012	7	10:40	19:00	0.16	0.02	0.12	0.03
23/08/2012	9	10:10	10:50	0.05	0.01	0.1	0.02
14/10/2012	1	19:00	19:50	5.66	1.00	6.34	1.00
16/10/2012	3	14:00	14:20	0.15	0.03	0.13	0.02
17/10/2012	4	15:10	16:40	0.31	0.05	0.82	0.13
18/10/2012	5	12:50	15:10	0.30	0.05	0.68	0.11
19/10/2012	6	16:00	17:10	0.15	0.03	0.45	0.07
20/10/2012	7	18:10	18:50	0.16	0.03	0.31	0.05
21/10/2012	8	10:40	14:10	0.22	0.04	0.07	0.01
22/11/2012	1	09:40	10:00	4.42	1.00	4.77	1.00
23/11/2012	2	01:42	18:52	1.15	0.26	1.92	0.40
25/11/2012	4	04:40	09:50	0.21	0.05	0.25	0.05
26/11/2012	5	09:40	11:50	0.42	0.09	0.15	0.03
28/11/2012	7	03:40	15:10	0.11	0.03	0.12	0.03
29/11/2012	8	00:10	02:30	0.10	0.02	0.09	0.02

The measured and simulated results obtained using the model developed in this study are plotted together with the simulated results obtained using the model with and without N and P loss component. The modelled results without temporal loss are shown in Table 7- 4. “Nitrogen” refers to all nitrogen compounds and “Phosphorus” refers to all phosphorus compounds.

Table 7- 4 Simulated results without considering time-variable influent

Rain Date (YYYYMMDD)	Days after first rain day	Rain time (HH:MM)		C/C ₀	
		Start	Finish	Nitrogen	Phosphorus
20120302	0	06:00	07:30	1.00	1.00
20120305	3	09:00	10:00	0.94	0.97
20120308	6	00:20	04:30	0.89	0.95
20120309	7	03:40	06:20	0.81	0.88
20120311	9	14:10	15:00	0.78	0.73
20120312	10	0:00	04:00	0.78	0.38
20120313	11	17:00	17:50	0.66	0.07
20120430	0	07:20	07:50	1.00	1.00
20120502	2	17:20	18:20	0.85	0.95
20120505	5	01:10	05:10	0.76	0.77
20120507	7	07:20	10:00	0.76	0.63
20120509	9	04:00	06:30	0.44	0.63
20120513	13	03:10	06:30	0.44	0.63
20120724	0	06:50	07:20	1.00	1.00
20120726	2	18:30	19:00	0.84	0.74
20120728	4	19:40	22:00	0.79	0.51
20120817	0	08:30	10:20	1.00	1.00
20120819	2	14:10	14:30	0.82	0.80
20120821	4	10:40	19:00	0.80	0.53
20120823	6	10:10	10:50	0.75	0.36
20121014	0	19:00	19:50	1.00	1.00
20121016	2	14:00	14:20	0.97	0.90
20121017	3	15:10	16:40	0.82	0.90
20121018	4	12:50	15:10	0.77	0.90
20121019	5	16:00	17:10	0.73	0.84
20121020	6	18:10	18:50	0.73	0.84
20121021	7	10:40	14:10	0.73	0.84
20121122	0	09:40	10:00	1.00	1.00
20121123	1	01:42	18:52	0.94	0.89
20121125	3	04:40	09:50	0.41	0.76
20121126	4	09:40	11:50	0.31	0.76
20121128	6	03:40	15:10	0.20	0.74
20121129	7	00:10	02:30	0.20	0.74

The results of the simulation with and without temporal loss and measured results are shown in Figure 7- 1 to Figure 7- 6, in the form of C/C₀ over time (days after the first rain day). Also shown in the figures are the rain days (indicated by arrows) during the investigation period.

It was noted that the concentrations simulated and measured were different after each application even when the application rates the same during the experiment. The

reason is that the simulated and measured concentration (C) is not only influenced by the fertiliser application rate, but also the rainfall characteristics (intensity, duration, depth etc.)

It can be seen from Figure 7- 1 to Figure 7- 6 that the full model fits the measured data fairly well in most cases, whereas the partial model (without loss) appears not to fit the measured data at all. This observation indicates that the model developed is fully capable of simulating the nutrient loss in the turfed slope of the controlled outdoor plot. Temporal loss of the nutrient, particularly during the non rainy day and in tropical climate like Singapore is significant. Modelling nutrient loss without considering environmental loss would over-estimate the loss of nutrient in the surface runoff by a big margin.

○ Measured concentration — Simulated concentration with time variable source - - - Simulated concentration without time variable source
 Figure 7- 1 Comparison of the nutrient loss model (with and without loss) and measured N and P (2nd MAR-13th MAR)

Figure 7- 2 Comparison of the nutrient loss model (with and without loss) and measured N and P (30th APR-13th MAY)

○ Measured concentration — Simulated concentration with time variable source - - - Simulated concentration without time variable source

Figure 7- 3 Comparison of the nutrient loss model (with and without loss) and measured N and P (24th JUL-28th JUL)

○ Measured concentration — Simulated concentration with time variable source - - - Simulated concentration without time variable source

Figure 7- 4 Comparison of the nutrient loss model (with and without loss) and measured N and P (17th AUG-23rd AUG)

○ Measured concentration — Simulated concentration with time variable source - - - - Simulated concentration without time variable source

Figure 7- 5 Comparison of the nutrient loss model (with and without loss) and measured N and P (14th OCT-21st OCT)

Figure 7- 6 Comparison of the nutrient loss model (with and without loss) and measured N and P (22nd NOV-29th NOV)

7.2.2 Discussion

The model simulated nutrient loss was calculated included natural loss of N and P, and N and P loss due to soil adsorption and infiltration, as well as loss of N and P brought in the runoff. It is noted that chemical compounds react differently to the surrounding environment during the wash-off and entrainment process as a result of the various inherent physical and chemical properties. For example, NH_4^+ is more likely to be absorbed by soil particle than NO_3^- , which means that the mobility of NO_3^- by runoff is higher than that for NH_4^+ . Whereas the detachment of NH_4^+ from soil surface to surface runoff is a physical process through the raindrop splash impact. It could be assumed that NO_3^- is more sensitive to runoff than to rainfall. Whereas NH_4^+ would be expected to be more sensitive to rainfall splash impact than being washed off. As can be seen in Figure 7- 1 to Figure 7- 6, although the patterns of the solid lines (full model) of simulated concentration of NH_4^+ and NO_3^- are similar, one can still observe the difference between the two compounds on the rain day (e.g. different range and magnitude from day 2 to day 4 in Figure 7- 5). Such characteristics are not found in the simulated results without considering the time-variable influent (dash lines in Figure 7- 1 to Figure 7- 6). The above observation indicated that by including the soil adsorption equation, the model developed in the present study successfully simulated the different characteristics and reactions of NH_4^+ and NO_3^- to the rainfall (splash) and runoff.

7.3 Comparison of nutrient model with studies by others

7.3.1 Dataset of Smith K.A *et al.* (2001)

The study was conducted on N and P losses in the surface runoff following organic manure and inorganic fertiliser application on the plot. The study area was located at ADAS Rosemaund, Herefordshire and covers an area of 2×15 m, and on a uniform slope of approximately 5° (Smith *et al.* 2001a; Smith *et al.* 2001b). Only the

experimental results following the application of inorganic fertiliser were extracted. The inorganic fertiliser application rates were 40 kg N/ha and 33kg P/ha, 60 kg N/ha, 120 kg N/ha, respectively. The original plot of their field investigation results was N or P losses (g/ha) against surface runoff depth (mm). The N and P concentrations were extracted and expressed in mg/L. The reformatted data are tabulated in Tables I-1 and I-2 of Appendix I.

7.3.2 Dataset from Udawatta *et al.* (2006)

Udawatta *et al.* (2006) studied nitrogen loss in runoff from three agricultural watersheds, located at Knox County, MO, USA (40°01'N, 92°11'W) (Udawatta *et al.* 2006). The catchment area investigated was 1.65 ha with a slope steepness of 2.1%. Three different fertiliser application schemes were used and they were: (1) 160 kg N/ha and 50kg P/ha in 1993; (2) 40 kg P/ha in 1995; (3) 60kg N/ha in 1996. The original plot of their field investigation results was TN concentration (mg/L) and NO_3^- concentration (mg/L) as a function of runoff volume (m^3/ha). The data extracted are tabulated in Table I-3 of Appendix I. The original unit of the runoff volume (m^3/ha) was converted to cubic meter. The corresponding TN and NO_3^- concentration were estimated and extracted from the original plot.

7.3.3 Dataset from Smith D.R *et al.* (2007)

Smith D.R *et al.* (2007) investigated the nutrient (N and P) loss to surface water following fertiliser application. The impacts of different fertiliser (inorganic, swine manure and poultry litter) on runoff water quality were reported. Only the experimental results following the application of inorganic fertiliser were extracted. The dimension of the plot was 0.75m in width and 2m in length. The fertiliser application rate in the study was 36 kg P/ha and 100kg N/ha. The rainfall were generated artificially at an intensity of 100mm/h at 1, 4, 8, 15 and 29 days after the fertiliser was applied. The original data were plotted as flow weight mean concentrations (soluble P, NH_4^+ and NO_3^-) over time (days) after fertiliser application

(Smith *et al.* 2007). The extracted results are shown in Table I-4 of Appendix I.

7.3.4 Dataset from McDowell *et al.* (2003, 2005)

McDowell *et al.* (2005)'s study was carried out in New Zealand in a 0.2 ha turfed plot. Phosphorus fertilisers were applied on the surface at a rate of 30 kg P/ha. Artificial rainfall was generated and over land flow samples were collected at 1, 7, 14, 28, 112 and 192 days after application of the fertiliser (McDowell and Catto 2005). The experiments reported in McDowell *et al.* (2003) were conducted under similar conditions to that of McDowell (2005), but the researchers were looking for a different target in the 2003 study (McDowell, Monaghan *et al.* 2003). The results of both the 2003 and 2005 studies were tabulated in Tables I-5 and I-6 of Appendix I.

7.3.5 Dataset from Scholefield *et al.* (1995)

The study of Scholefield *et al.* (1995) was conducted to assess the losses of nutrient in runoff from pastures (Scholefield and Stone 1995). Field investigation was carried out on a 2 ha plot located at southwest England in 1982. N-P-K fertiliser was applied on the plot at a rate of 45 kg N/ha with 70% of the N as NH_4^+ , and 24 kg P/ha with all soluble P compounds. Rainfall and runoff were recorded for one month after the fertiliser was applied and N and P concentrations were analyzed on the rain days. The rainfall, runoff, N and P concentrations were extracted and tabulated in Table I-7 of Appendix I.

7.3.6 Study of Vadas *et al.* (2008)

Vadas *et al.* (2008) developed a simple model to calculate the dissolved P concentration in the runoff (mg/L) as follow:

$$\text{Runoff dissolved P} = [\text{available fertiliser P (mg)}] \times [\% \text{fertiliser released}] \times \frac{[\text{P distribution factor}]}{[\text{total rain during the event (L)}]}$$

The P distribution factor is calculated by using the following equation:

$$P \text{ distribution factor} = 0.034e^{3.4 \times [\text{runoff to rain ratio}]}$$

According to Vadas *et al.* (2008), the fertiliser released into the runoff was 75% of the initial P applied for the first rainfall event, 40% of the remaining P for the second rainfall and 7.5% of the remaining P for the third rainfall event (Vadas *et al.* 2008).

Vadas *et al.* (2008)'s equations and distribution was used to estimate the data otherwise not reported in the studies by others.

7.3.7 Modelling others' studies using the proposed nutrient model

The experimental conditions of the laboratory experiments and outdoor experiments tests of the cited studies are summarized in Table 7- 5.

Table 7- 5 Summary of experiment designs of the published studies

Author	Study area	Slope	Fertiliser applied	Rain	Runoff	Original plot	
						X axis	Y axis
Smith K.A (2001)	30m ²	5°	40,60,120 kg N/ha	N.A.	1-6 mm	Runoff (mm)	N loss (g/ha)
Udawatta R.P (2006)	1.65ha	2.1%	160 kg N/ha & 50 kg P/ha; 40 kg P / ha; 60 kg N / ha	Monthly mean available Range: 6mm-296mm	Monthly mean available Range:1-237mm	Runoff volume (m ³ /ha)	N concentration (mg/L)
Smith D.R (2007)	1.5 m ²	N.A.	35kg P/ha 100 kg N/ha	Intensity: 100 mm/hr	N.A.	Days after fertiliser applied	N, P concentration (mg/L)
Vadas P.A (2008)	44 cm ²	0	2.5, 5.0,10,20 g P	75 mm/hr for 45 mins (56.25 mm) 48 mm/hr for 45 mins (36 mm)	N.A.	Equations for prediction of TP concentration (mg/L) for first 3 events	
McDowell (2005)	0.2 ha	N.A.	30 kg P/ha	Intensity: 17mm/hr	N.A.	Days after fertiliser applied	P concentration (mg/L)
Scholefield <i>et al.</i> (1995)	2 ha	5-9°	45 kg N/ha 24 kg P/ha	Daily rainfall depth available	Daily runoff depth available	Investigation date	N, P concentration (mg/L)
Present study	15 m ²	7%	225, 300 kg/ha with TN:24% TP:13%	Natural rainfall, recorded every 10 minutes Range: 0.2mm-190mm	IHACRES computed	Days after first rain	N, P concentration (mg/L)

Three schemes were proposed as model inputs for the verification of the present model, and they are listed in Table 7- 6.

Table 7- 6 Simulation schemes for model verification

Scheme	Mass of fertiliser applied		Rain			Available literatures
	Nitrogen (g)	Phosphorus (g)	Intensity (mm/hr)	Duration (hr)	Depth (mm)	
A	150	52.5	100	0.56	56.25	Smith K.A (2001) Udawatta R.P (2006) Smith D.R (2007) Vadas P.A (2008)
B	1800	600	17	2.12	36	Smith K.A (2001) Udawatta R.P (2006) McDowell (2005) Vadas P.A (2008)
C	90	48	As recorded by Scholefield <i>et al.</i> (1995)			Scholefield <i>et al.</i> (1995)

Scheme A

Scheme A was set up based on the experiment design of Smith D.R *et al.* (2006) and Vadas P.A *et al.* (2008), and the rain days were set to 1, 4, 8, 15, 29 days after the fertiliser was applied as was designed in the study by Smith D.R *et al.* (2006). Runoff was read from the study of Udawatta R.P *et al.* (2006) and corresponding N and P concentrations were read from Smith K.A *et al.* (2001) and Udawatta R.P *et al.* (2006).

Scheme B

Scheme B was set up based on the studies of McDowell *et al.* (2005) and Vadas P.A *et al.* (2008). N and P concentrations adopted from Smith K.A *et al.* (2001) and Udawatta R.P *et al.* (2006) were read at the same manner as in Scheme A. The rain day were set to 1, 7, 14, 28 days after fertiliser applied as designed by McDowell *et al.* (2005).

Scheme C

Scheme C was set up under the same experiment conditions of Scholefield *et al.* (1995). All the computed concentrations in absolute values were then converted to C/C_0 for validation of the model, where C_0 is the concentration of the first rain events (initial concentration).

All the schemes proposed were simulated using the integrated nutrient loss model developed in the present study. The modelled results (C/C_0) together with the datasets obtained from the studies cited were plotted in Figure 7- 7 to Figure 7- 16. “Singapore degradation rate” in Figure 7-7 to Figure 7-16 refers to the rate of degradation of the fertiliser under the environmental condition of Singapore, and was established experimentally. By “Singapore environmental condition”, the author referred to the typical outdoor condition in Singapore, which had the following characteristics: mean annual temperature of 28.3°C; average annual rainfall of 2345 mm; and average annual humidity of 84.2%. The 25%, 50%, 100%, 200% and 300% of the “Singapore degradation rate” were “assigned” to represent the probable degradation rate of the studies cited. Note that only (TN and TP) were modelled in Scheme C.

Figure 7- 7 Comparison of model and results by others (NH_4^+ , Scheme A)

Figure 7- 8 Comparison of model and results by others (NO₃⁻, Scheme A)

Figure 7- 9 Comparison of model and results by others (TN, Scheme A)

Figure 7- 10 Comparison of model and results by others (TP, Scheme A)

Figure 7- 11 Comparison of model and results by others (NH_4^+ , Scheme B)

Figure 7- 12 Comparison of model and results by others (NO₃⁻, Scheme B)

Figure 7- 13 Comparison of model and results by others (TN, Scheme B)

Figure 7- 14 Comparison of model and results by others (TP, Scheme B)

Figure 7- 15 Comparison of model and results by others (TN, Scheme C)

Figure 7- 16 Comparison of model and results by others (TP, Scheme C)

Although there are obvious wide scatter of the data points obtained from the studies cited, one may observe from Figure 7- 7 to Figure 7- 16 that the proposed model not only reproduces the trend correctly, and the magnitude of the concentration is of the right magnitude of order. As to be expected, the environmental conditions of these studies were different and detailed information was not published. The simulated results produced using the present model would be reasonable considering the different humidity or rainfall intensity of the cited studies. Granted that the model could not fully simulate the experimental conditions used by the studies cited because of the diverse conditions and gross estimation of the parameters, one can still conclude that the present model provides a reasonably good simulation of nutrient loss in these schemes.

7.4 Summary

The integrated nutrient loss model was able to simulate and fit the data very well. Despite the gross estimation made of the experimental conditions and pertinent parameters, the model also reproduced reasonably good fir with the reported data

obtained from studies cited. The objective of including these comparisons was to illustrate that the model developed in this study is applicable for Singapore condition and other environmental conditions.

CHAPTER 8 CONCLUSIONS AND RECOMMENDATIONS

8.1 Conclusions

Runoff water quality from a watershed depends on many factors, including pollutant sources and characteristics, weather and hydrological conditions, topography and soil properties. Although the complex hydrological conditions remain a challenge to modelling soil nutrient loss process, certain preliminary findings have led to the conclusions that fertiliser phosphorous and nitrogen are the nutrients that generally end up in the recipient water bodies. There are reported studies on investigations performed on a watershed scale of km^2 and down to small plots measured in m^2 . Most of these studies did not consider time-variable source pollutants. In any case, the temporal effects are generally averaged out because of the spatial and temporal scale used in the study, see for example, Leinard *et al.* (1987); Young *et al.* (1987); Bouraoui and Dillaha (1996); Arnold *et al.* (1998); Kinnell (2000); Shaw *et al.* (2006).

Only a handful of reported studies could be found that had taken into consideration the temporal-variability of nutrient source and loss of the chemical compounds (Zhang *et al.* 2007; Vadas *et al.* 2008). It was found that most of the N and P applied on soil surface had adsorbed to the soil particles within the first 2 days after the fertiliser had been applied (Williams 1969). The impact of the environment loss appeared to have diminished and was generally neglected in these reported studies. However, in the case of N and P loss model in Singapore, environmental loss cannot be neglected because of the hot and humid climate, and also due to the relatively small catchment area and short concentrate time.

In this PhD study, the author considered the relevant physical mechanisms of N and P loss when the fertiliser was left exposed to the elements, including the N and P loss brought forth through natural loss, infiltration and soil adsorption, and plant up-take.

Three series of laboratory experiment and a controlled outdoor study were conducted. It was found from the laboratory experiments that the natural N and P loss due to the exposure to the elements fitted a first order kinetic equation, while the loss of N and P in the soil-water column experiment fitted a second order kinetic equation.

An integrated nutrient loss model describing the wash-off process of agricultural inorganic nitrogen and phosphorus on the soil surface, considering environmental loss of N and P was developed in this study. The model was calibrated and verified using the data obtained from the controlled outdoor experiments.

The impact of environmental loss was evaluated by considering the nutrient loss model with and without the temporally variable–influence of the source pollutants. The findings of the comparative study with partial (without environmental loss) showed that the impact of environmental loss was indeed significant. While the full integrated nutrient loss model fitted the outdoor experimental data very well in most cases, the partial model appeared to grossly underestimate the nutrient loss by a wide margin, and was more than 100% in some cases. This observation indicates that the temporal loss of the nutrient, particularly during the non-rain day in tropical climate like Singapore, is an important consideration.

The integrated nutrient loss with time-variable source pollutant was also applied to simulate nutrient loss in experiments by other researchers. Knowing that climate (especially temperature and humidity) governs the rate of loss, and such rate is lower in temperate and less humid region, the author elected to set the loss rate at a fraction (or multiple) of the loss rate in Singapore. The findings of the simulation study showed that the integrated nutrient loss model could indeed satisfactorily reproduce nutrient loss patterns that matched the measured nutrient loss by others.

8.2 Recommendations

In this study, the integrated model of N and P wash-off from grassland soil surface has been developed and tested. While the methodology proposed in this study is universal, the application might be limited because of the need to make gross estimate of the

environmental conditions which are site specific. First of all, due to the time limitation, both the laboratory experiment and the controlled outdoor experiment were conducted under 2-3 proposed schemes (in terms of fertiliser application rates). Available data were still scarce to allow the model to be fully developed and to estimate the fertiliser degradation coefficients. Secondly, the controlled outdoor experiment in the present study was carried out on a small area and the characteristics of the N and P losses from a larger area had not been carried out. In the case of an integrated model for a multi-landuse watershed, there is still room for further research and investigation.

The present study has focused on the N and P loss from a small plot. A multi-landuse watershed is a collection of a number of plots. There is a need to develop a transport model to channel and link the nutrient losses from various sub-catchments. Such study would require geographical information and use of watershed and transport models, and an integrated framework to link the various processes together.

Environmental loss of fertiliser, especially N and P, has been investigated but only as a lumped loss term in this study. In fact, environmental loss may be the results of various factors, including climate (temperature, air moisture, wind speed, rainfall *etc.*), topography (slope length and steepness, land-use *etc.*), soil property (soil water, pH, soil texture, porosity, micro-organism content *etc.*). Due to the complexity of the physical and chemical interactions between pollutants and the environment, one may need to conduct comprehensive study with strictly controlled environment and relaxing the relevant parameters one at a time, to establish the influence of each and every parameter. It is only after establishing the physical and chemical parameters then one would be able to establish a robust, truly physically-based nutrient loss model.

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APPENDIX

Appendix A. Land Use

Land use refers to the total arrangements, activities and inputs people undertake in a certain land cover type to produce, change or maintain it (FAO 1997a; FAO/UNEP 1999). FAO (Food and Agriculture Organization of the United Nations) provides a detailed categories of land use types, reproduced here in Table A-1 (Watson *et al.* 2001)

According to this definition, a rough classification of land use types in and around urban area can be extracted as follows.

1. Residential Land Use - where people live (houses, apartment buildings)
2. Institutional Land Use - government related (schools, town hall, police station)
3. Recreational Land Use - for fun, entertainment purposes (parks, bowling place)
4. Open / Vacant Space Land Use - empty land
5. Commercial Land Use - places to do with [making] money (stores, banks)
6. Industrial Land Use - working places that help industry (factories)
7. Agricultural Land Use - land used to grow food *etc.* (farmland)

Table A - 1: Land-use categories recognized in FAO's World Census of Agriculture

In Sequence of Increasing Intensity of Use	Equivalents
(a) Deserts (barren land and waste land)	-
(b) Non-Forest Wooded Lands (scrubland; may include national parks and wilderness recreational areas)	-
(c) Wetlands, Non-Forest (marshes)	Wetlands
(d) Land under Forest (natural forests and most non-managed woodlands)	Forest Land
(e) Land under Forestry / Silviculture	Forest Land
(f) Land under Shifting Cultivation (temporarily abandoned land that is not part of a holding)	Agro-forestry Land
(g) Land under Agroforestry (permanent use of land at holding level, but with mixed crop growing, animal herding, and tree utilization)	Agro-forestry Land
(h) Land with Temporary Fallow (resting for a period of time, less than 5 years, before it is planted again with annual crops)	Cropland
(i) Land under Permanent Meadows and Pastures [used for herbaceous forage crops that are either managed/cultivated (pastures) or growing wild (grazing land); trees and shrubs may be present or grown purposely, but foraging is the most important use of the area; grazed woodlands]	Rangeland/Gra sslands
(j) Land under Temporary Meadows and Pastures (cultivated temporarily, for less than 5 years, for herbaceous forage crops, mowing, or pasturing, in alternation with arable cropping)	Rangeland/Gra sslands
(k) Land under Permanent Crops (perennials; cultivated with long-term crops that do not have to be replanted for several years after each harvest; harvested components are not timber but fruits, latex, and other products that do not significantly harm the growth of the planted trees or shrubs: orchards, vineyards, rubber and oil palm plantations, coffee, tea, sisal, <i>etc.</i>)	Agro-forestry Land
(l) Land under Temporary Crops (annuals; cultivated with crops	Cropland

with a growing cycle of under 1 year, which must be newly sown or planted for further production after harvesting; not only small grain crops such as beets, wheat, and soy bean but also bi-annuals that are destroyed at harvesting, such as cassava, yams, and sugarcane; bananas are transitional to the permanent crops category)	
(m) Land under Temporary Crops Requiring Wetland Conditions [wet-foot crops such as irrigated rice and jute (dry-foot crops with intermittent irrigation included in other categories)]	Wetlands
(n) Land under Protective Cover (greenhouses and other urban or peri-urban intensive use, formal or informal; vegetable growing, home gardening, residential parks, golf courses, <i>etc.</i>)	Peri-Urban Land
(o) Land under Residential / Industrial / Transportation Facilities	Peri-Urban Land

Land use plays an important role in water quality modelling, since it influences all activities from initial presence through the pollutant build-up, wash-off and transportation processes as sources, sinks, passageways and so on. In this study, land use types have been summarized into two macro-categories: relatively impervious surfaces and pervious surfaces according to soil type and permeability (Figure A-1).

Figure A - 1 Impervious and pervious surfaces

1. Impervious surfaces

Impervious surface refers to the artificial structures that are covered by water impenetrable materials such as asphalt, concrete, brick and stone. Impervious surfaces in urban areas include rooftops, pavements, parking lots and harden ground in

residential and industrial areas, *etc.*

As urbanization progresses, more and more impervious surfaces are formed, becoming more impervious to rainfall and leading to higher surface runoff volume, overland flow velocity and shorter time of concentration. Hence higher pollutant wash-off rate will be expected. A number of studies have shown that while urban areas cover only 3 percent of the U.S. land surface, the runoff from these areas is the primary source of pollution in 13 percent of rivers, 18 percent of lakes and 32 percent of estuaries (Dina 2008). Large number of studies had also been conducted to investigate pollutants build-up and wash-off processes on rooftops and pavements (Sartor *et al.* 1974; Alley 1981; Paramasivam *et al.* 2002; Egodawatta and Goonetilleke 2008; Wang *et al.* 2010). The physical mechanisms of the pollutants transfer from impermeable surfaces into surface runoff are well understood.

2. Pervious surfaces

Pervious surfaces, also known as permeable or porous surfaces refer to the surfaces that allow water to percolate into the soil and recharge the ground water table (Kelly 2007). Pervious surface in urban areas include turf areas, permeable pavements, green rooftops, parks, artificial and natural wetlands and forests, *etc.*

Today, more and more environmental researchers and relevant departments focus their attentions on pervious surfaces in urban area. Various types of artificial pervious surface, such as rain garden, green roof, have been developed and constructed to avoid the environmental hazards brought forth by urban stormwater.

3. Land Use in Singapore

Singapore is a highly urbanized country. According to the information provided by Wikipedia (http://en.wikipedia.org/wiki/Geography_of_Singapore, 2012), in year 1993, 87% of Singapore was developed. The land use distribution is shown in Figure A-2.

Figure A - 2 Singapore land use distribution

Appendix B. Soil Characteristics

Soil properties include physical and chemical properties. Physical properties refer to soil texture, soil structure, compaction and organic matter. In hydrological researches, soil permeability is an important element and permeability is directly affected by those physical properties. Soil texture can be decided by the well-know soil texture triangle.

Figure B - 1 USDA texture triangle

Appendix C. Rainfall information

Date	Rainfall Depth (mm)	Duration (hrs)	Average Intensity(mm/hr)
2011-9-2	1.8	1.6	1.1
2011-9-8	3.2	0.2	19.2
2011-9-10	7.4	5.0	1.5
2011-9-11	40.4	1.9	20.9
2011-9-12	1.4	0.0	42.0
2011-9-13	13	1.9	6.8
2011-9-14	17	9.8	1.7
2011-9-18	13.4	0.6	23.6
2011-9-19	1.8	3.0	0.6
2011-9-20	35	4.0	8.7
2011-9-22	12.8	4.6	2.8
2011-9-26	29	3.9	7.4
2011-9-27	12.4	0.1	93.0
2011-9-28	11.2	5.2	2.1
2011-9-30	21.8	2.5	8.7
2011-10-1	0.8	0.6	1.3
2011-10-2	23.2	4.8	4.8
2011-10-4	44.2	6.1	7.2
2011-10-6	9.6	2.9	3.3
2011-10-8	1.4	0.1	21.0
2011-10-9	19.4	2.9	6.6
2011-10-10	2.6	0.3	7.8
2011-10-11	12.6	3.7	3.4
2011-10-17	3.6	3.5	1.0
2011-10-18	12.4	3.5	3.6
2011-10-19	10	4.1	2.5
2011-10-20	2	1.3	1.6
2011-10-21	11	1.2	9.4
2011-10-22	1.6	0.3	6.0
2011-10-24	3.6	0.2	15.4
2011-10-25	27.8	6.2	4.5
2011-10-26	11.4	2.6	4.3
2011-10-27	32.6	12.6	2.6

Date	Rainfall Depth (mm)	Duration (hrs)	Average Intensity(mm/hr)
2011-10-28	45	5.3	8.5
2011-10-29	8	2.1	3.9
2011-10-31	32	4.4	7.2
2011-11-1	15.4	4.0	3.8
2011-11-3	5.8	1.5	4.0
2011-11-4	3	0.4	7.5
2011-11-6	10.8	4.2	2.6
2011-11-8	14.6	2.5	5.8
2011-11-12	14	4.9	2.9
2011-11-13	10.6	10.1	1.0
2011-11-14	22.6	1.0	21.9
2011-11-14	36.2	2.0	17.8
2011-11-15	6.2	1.0	6.4
2011-11-20	63	6.7	9.4
2011-11-21	2.8	2.4	1.2
2011-11-23	3	4.8	0.6
2011-11-24	21.4	4.8	4.4
2011-11-25	6.6	1.0	6.8
2011-11-26	8.4	3.5	2.4
2011-11-27	1.8	1.9	1.0
2011-11-28	16.4	2.1	7.9
2011-11-30	2.4	1.2	2.1
2011-12-1	2.2	4.0	0.6
2011-12-2	4.2	5.6	0.8
2011-12-3	7.4	7.2	1.0
2011-12-4	6.8	2.7	2.5
2011-12-7	49	1.9	26.3
2011-12-8	7.8	0.8	9.4
2011-12-11	1.4	1.7	0.8
2011-12-14	6.2	2.7	2.3
2011-12-15	4	0.3	15.0
2011-12-16	25.4	4.3	6.0
2011-12-17	23.8	4.1	5.8

Date	Rainfall Depth (mm)	Duration (hrs)	Average Intensity(mm/hr)
2011-12-18	48.6	9.8	5.0
2011-12-19	66.2	19.0	3.5
2011-12-20	4.4	3.0	1.5
2011-12-23	58.6	5.7	10.3
2011-12-24	33.6	13.4	2.5
2011-12-25	24	9.9	2.4
2012-1-2	4.6	1.7	2.7
2012-1-8	9	3.4	2.7
2012-1-9	2.2	0.9	2.5
2012-1-10	0.8	0.8	1.0
2012-1-15	17.6	2.3	7.8
2012-1-19	6.4	0.7	9.6
2012-1-20	5.6	1.7	3.4
2012-1-21	15	5.3	2.8
2012-1-22	17.2	8.0	2.1
2012-1-23	6.6	5.1	1.3
2012-1-27	29.6	3.0	9.9
2012-1-31	17	1.8	9.4
2012-2-2	25.6	3.0	8.6
2012-2-7	6.4	0.3	19.2
2012-2-11	1	2.4	0.4
2012-2-19	1.4	0.2	6.0
2012-2-20	5	0.4	13.6
2012-2-25	4.8	0.3	16.0
2012-2-26	44.8	1.9	23.6
2012-2-27	18.4	4.7	3.9
2012-2-28	4.2	0.3	12.6
2012-2-29	4.4	1.0	4.4
2012-3-1	3.4	1.2	2.8
2012-3-2	2	1.4	1.4
2012-3-2	20.8	2.4	8.7
2012-3-5	40.8	0.9	43.7
2012-3-8	32.6	4.1	8.0

Date	Rainfall Depth (mm)	Duration (hrs)	Average Intensity(mm/hr)
2012-3-9	25.4	2.6	9.6
2012-3-10	2.6	0.7	3.7
2012-3-11	2.6	0.7	3.9
2012-3-12	3.6	3.9	0.9
2012-3-13	33.2	0.8	39.8
2012-3-14	14.8	6.8	2.2
2012-3-18	10	2.6	3.8
2012-3-25	93.2	3.3	28.0
2012-3-30	4.4	0.2	26.4
2012-3-31	80.4	7.6	10.5
2012-4-2	38.4	3.8	10.2
2012-4-4	103	4.6	22.2
2012-4-6	0.6	0.2	3.6
2012-4-7	28.4	3.4	8.3
2012-4-8	20.2	1.0	19.5
2012-4-9	19.6	1.1	17.8
2012-4-9	30	2.1	14.3
2012-4-10	1.6	1.1	1.5
2012-4-12	45.2	0.6	75.3
2012-4-14	6.8	3.7	1.9
2012-4-16	5.4	0.4	12.5
2012-4-19	6.2	5.0	1.2
2012-4-21	61.4	6.1	10.1
2012-4-28	1.6	0.2	8.0
2012-4-30	3.6	0.5	7.2
2012-5-2	3.8	1.2	3.3
2012-5-2	4.8	0.8	6.0
2012-5-5	32.6	3.8	8.7
2012-5-7	3.8	2.5	1.5
2012-5-9	7.8	2.4	3.3
2012-5-13	12.2	3.2	3.8
2012-5-15	2	0.2	12.0
2012-5-16	28	4.9	5.7

Date	Rainfall Depth (mm)	Duration (hrs)	Average Intensity(mm/hr)
2012-5-17	7.6	3.9	1.9
2012-5-20	8.2	1.5	5.3
2012-5-21	11	0.7	16.5
2012-5-22	26.4	0.8	31.7
2012-5-23	46.4	5.2	8.9
2012-5-24	11.8	1.3	9.1
2012-5-25	1.2	1.1	1.1
2012-5-27	9.6	3.3	2.9
2012-5-30	16.4	2.9	5.7
2012-5-31	1	0.8	1.2
2012-6-1	10	2.8	3.6
2012-6-6	9.4	0.4	23.5
2012-6-8	60.4	7.6	8.0
2012-6-26	9.2	0.6	14.5
2012-6-27	10.6	1.0	11.0
2012-6-28	1	0.1	10.0
2012-6-30	70.8	3.0	23.3
2012-7-1	7.4	1.6	4.6
2012-7-2	10.8	2.2	4.9
2012-7-3	6	0.8	7.5
2012-7-3	9	0.9	10.0
2012-7-4	6	1.4	4.2
2012-7-7	11.8	1.4	8.6
2012-7-14	3	0.5	5.6
2012-7-14	20.8	6.5	3.2
2012-7-16	3.8	1.0	3.8
2012-7-17	2.4	0.1	18.0
2012-7-17	2	0.7	3.0
2012-7-19	3.8	0.3	14.3
2012-7-19	17	1.5	11.3
2012-7-20	0.8	0.2	3.4
2012-7-24	1.4	0.5	2.8
2012-7-25	0.4	0.0	12.0

Date	Rainfall Depth (mm)	Duration (hrs)	Average Intensity(mm/hr)
2012-7-26	7.2	0.5	14.4
2012-7-28	5.6	2.2	2.5
2012-8-3	7.8	2.8	2.8
2012-8-4	96.9	9.7	10.0
2012-8-17	24.2	1.7	14.5
2012-8-19	1.2	0.2	7.2
2012-8-23	2.8	0.6	4.9
2012-8-26	3.8	0.3	12.7
2012-8-26	35.8	1.3	27.5
2012-8-27	76.6	7.6	10.1
2012-8-28	1.4	0.7	2.1
2012-8-30	18.6	0.9	20.7
2012-8-30	19.8	1.1	18.6
2012-8-31	7.8	2.6	3.0
2012-9-4	1	0.3	3.3
2012-9-5	0.8	10.6	0.1
2012-9-8	0.8	2.6	0.3
2012-9-9	0.6	4.2	0.1
2012-9-11	3.2	0.5	6.0
2012-9-17	11.8	0.3	35.4
2012-9-19	2	0.2	12.0
2012-9-20	40	1.6	24.5
2012-9-25	15.2	0.4	41.5
2012-9-26	3.4	1.7	2.0
2012-9-27	12.8	1.2	11.0
2012-9-27	9	3.2	2.8
2012-9-28	1	0.9	1.1
2012-9-28	2.2	22.7	0.1
2012-9-29	86.4	2.5	35.0
2012-9-30	103.8	4.1	25.1
2012-9-30	3.6	2.0	1.8
2012-9-30	63.4	3.7	17.3
2012-9-30	10.2	1.0	10.6

Date	Rainfall Depth (mm)	Duration (hrs)	Average Intensity(mm/hr)
2012-10-1	14	11.9	1.2
2012-10-2	5.6	4.1	1.4
2012-10-2	6.4	3.3	1.9
2012-10-2	45.4	12.1	3.8
2012-10-3	66.6	2.8	24.1
2012-10-3	4.8	1.6	3.1
2012-10-3	121.2	4.9	24.6
2012-10-4	3.6	1.3	2.8
2012-10-5	3	0.2	15.0
2012-10-5	62.2	12.1	5.2
2012-10-6	30.4	12.0	2.5
2012-10-7	91	13.6	6.7
2012-10-8	12.2	3.6	3.4
2012-10-8	3	2.2	1.4
2012-10-9	9.6	1.5	6.5
2012-10-9	7	7.0	1.0
2012-10-9	4	2.6	1.5
2012-10-10	8	1.8	4.4
2012-10-10	3.8	2.5	1.5
2012-10-10	8	0.6	13.3
2012-10-10	6	0.5	12.0
2012-10-11	20.6	0.8	26.9
2012-10-14	5	0.7	6.8
2012-10-16	1.4	0.2	7.0
2012-10-17	13.4	1.4	9.8
2012-10-18	15.2	2.2	6.9
2012-10-19	4.8	1.1	4.5
2012-10-20	19	0.5	35.6
2012-10-21	0.8	0.2	4.8
2012-10-21	10.4	3.3	3.2
2012-10-27	10.8	0.7	16.2
2012-10-29	1	0.1	7.5
2012-10-30	5.4	0.3	18.0

Date	Rainfall Depth (mm)	Duration (hrs)	Average Intensity(mm/hr)
2012-10-31	70	4.5	15.4
2012-11-1	17.6	7.8	2.2
2012-11-2	52.2	1.8	29.0
2012-11-2	30.2	3.9	7.8
2012-11-3	12.2	5.8	2.1
2012-11-3	3.6	2.6	1.4
2012-11-4	8.2	0.3	30.8
2012-11-5	6.2	0.9	6.9
2012-11-5	1.6	0.2	9.6
2012-11-5	1.8	0.3	5.4
2012-11-5	3.8	2.5	1.5
2012-11-5	3.4	0.7	4.6
2012-11-5	15.2	1.1	14.3
2012-11-6	5	3.5	1.4
2012-11-7	2	0.4	5.0
2012-11-8	4.4	1.6	2.8
2012-11-9	4.8	1.3	3.8
2012-11-11	20	1.0	19.4
2012-11-13	29.2	0.4	67.4
2012-11-13	3.8	2.4	1.6
2012-11-13	3.4	0.5	6.8
2012-11-14	3.6	2.6	1.4
2012-11-14	198	13.3	14.9
2012-11-16	12	1.2	10.3
2012-11-16	22.6	2.9	7.7
2012-11-16	43.4	8.3	5.2
2012-11-17	3	1.0	2.9
2012-11-22	4.6	0.1	34.5
2012-11-22	5	1.1	4.4
2012-11-23	2.4	17.2	0.1
2012-11-24	0.6	2.2	0.3
2012-11-25	134.2	5.0	27.0
2012-11-25	5.2	1.6	3.2

Date	Rainfall Depth (mm)	Duration (hrs)	Average Intensity(mm/hr)
2012-11-25	4.2	5.2	0.8
2012-11-26	4.4	2.1	2.1
2012-11-26	98.8	10.1	9.8
2012-11-27	3.4	2.7	1.3
2012-11-28	61.2	11.5	5.3
2012-11-29	4.4	2.1	2.1
2012-11-30	150.4	6.6	22.7

Appendix D. Air Temperature

2011.SEP.01-2011.DEC.01

2011.DEC.01-2012.MAR.01

2012.MAR.01-2012.JUN.01

2012.JUN.01-2012.SEP.01

2012.SEP.01-2012.DEC.01

Appendix E. Runoff simulated using IHACRES based on recorded rainfall (vertical axis: runoff [$\times 10^{-3} \text{ m}^3/\text{s}$]; rainfall depth [mm]; horizontal axis [Hours from Midnight HH:MM])

2012-03-02

2012-03-05

2012-03-08

2012-03-09

2012-03-13

2012-04-30

2012-05-02

2012-05-05

2012-05-07

2012-05-09

2012-07-24

2012-07-26

2012-07-27

2012-07-28

2012-08-17

2012-08-19

2012-08-21

2012-08-23

2012-10-14

2012-10-16

2012-10-17

2012-10-18

2012-10-19

2012-10-20

2012-10-21

2012-11-22

2011-11-23

2012-11-25

2012-11-26

2012-11-28

Appendix F. N and P concentrations—controlled outdoor experiments

F.1 Sample Collection Location: WS 1

Table F- 1 Investigation period: 30th APR-9th MAY, 2012

Date (MMDD)	Time (Days)	NH ₄ ⁺		TN		NO ₃ ⁻		TP	
		C (mg/L)	C/C ₀	C (mg/L)	C/C ₀	C (mg/L)	C/C ₀	C (mg/L)	C/C ₀
0429	0	Fertiliser applied							
0430	1	10.7	1.00	31	1.00	4.1	1.00	7.01	1.00
0501	2								
0502	3	7.4	0.69	18	0.58	2.7	0.66	3.45	0.49
0503	4								
0504	5								
0505	6	0.9	0.08	3	0.10	0.3	0.07	0.79	0.11
0506	7								
0507	8	1.1	0.10	2	0.06	0.3	0.07	0.33	0.05
0508	9								
0509	10	0.5	0.05	1	0.03	0.2	0.05	0.17	0.02
0510	11								
0511	12								
0512	13								
0513	14	0.2	0.02	1	0.03	0	0.00	0.04	0.01

Figure F-1(a) Observed N (P) concentrations (mg/L)

Figure F- 1(b) Observed N (P) concentrations (C/C_0)

Table F- 2 Investigation period: 22nd JUL-28th JUL, 2012

Date (MMDD)	Time (Days)	NH ₄ ⁺		TN		NO ₃ ⁻		TP	
		C(mg/L)	C/C ₀	C(mg/L)	C/C ₀	C(mg/L)	C/C ₀	C(mg/L)	C/C ₀
0721	0	Fertiliser applied							
0722	1								
0723	2								
0724	3	7.9	1.00	18	1.00	1.9	1.00	3.12	1.00
0725	4								
0726	5	1.1	0.14	4	0.22	0.9	0.47	1.21	0.39
0727	6								
0728	7	0.1	0.01	1	0.06	0.2	0.11	0.61	0.20

Figure F- 2 (a) Observed N (P) concentrations (mg/L)

Figure F- 2 (b) Observed N (P) concentrations (C/C₀)

Table F- 3 Investigation period: 15th AUG-23th AUG, 2012

Date (MMDD)	Time (Days)	NH ₄ ⁺		TN		NO ₃ ⁻		TP	
		C(mg/L)	C/C ₀	C(mg/L)	C/C ₀	C(mg/L)	C/C ₀	C(mg/L)	C/C ₀
0814	0	Fertiliser applied							
0815	1								
0816	2								
0817	3	14.6	1.00	35	1.00	4.9	1.00	4.28	1.00
0818	4								
0819	5	4.8	0.33	9	0.26	2.1	0.43	0.64	0.15
0820	6								
0821	7	0.9	0.06	3	0.09	0.5	0.10	0.15	0.04
0822	8								
0823	9	0.4	0.03	0	0.00	0.1	0.02	0.07	0.02

Figure F- 3(a) Observed N (P) concentrations (mg/L)

Figure F- 3(b) Observed N (P) concentrations (C/C₀)

Table F- 4 Investigation period: 14th OCT-22th OCT, 2012

Date (MMDD)	Time (Days)	NH ₄ ⁺		TN		NO ₃ ⁻		TP	
		C (mg/L)	C/C ₀	C (mg/L)	C/C ₀	C(mg/L)	C/C ₀	C(mg/L)	C/C ₀
1013	0	Fertiliser applied							
1014	1	14.1	1.00	33	1.00	5.1	1.00	5.93	1.00
1015	2								
1016	3	3.4	0.24	7	0.21	0.6	0.12	1.12	0.19
1017	4	1.5	0.11	3	0.09	0.4	0.08	0.77	0.13
1018	5	0.9	0.06	5	0.15	1.1	0.22	0.58	0.10
1019	6	0.4	0.03	2	0.06	0.6	0.12	0.43	0.07
1020	7	0.2	0.01	1	0.03	0.3	0.06	0.28	0.05
1021	8	0.1	0.01	3	0.09	0.1	0.02	0.11	0.02
1022	9	0	0.00	0	0.00	0.1	0.02	0.08	0.01

Figure F- 4 (a) Observed N (P) concentrations (mg/L)

Figure F- 4 (b) Observed N (P) concentrations (C/C₀)

Table F- 5 Investigation period: 22nd NOV-29th NOV, 2012

Date (MMDD)	Time (Days)	NH ₄ ⁺		TN		NO ₃ ⁻		TP	
		C(mg/L)	C/C ₀	C(mg/L)	C/C ₀	C(mg/L)	C/C ₀	C(mg/L)	C/C ₀
1121	0	Fertiliser applied							
1122	1	13.3	1.00	36	1.00	4.4	1.00	3.88	1.00
1123	2	9.3	0.70	22	0.61	2.9	0.66	1.87	0.48
1124	3								
1125	4	0.6	0.05	3	0.08	0.5	0.11	0.94	0.24
1126	5	0.4	0.03	1	0.03	0.1	0.02	0.24	0.06
1127	6								
1128	7	0.1	0.01	1	0.03	0.1	0.02	0.09	0.02
1129	8	0.1	0.01	0	0.00	0	0.00	0.11	0.03
1130	9	0	0.00	1	0.03	0	0.00	0.02	0.01

Figure F- 5 (a) Observed N (P) concentrations (mg/L)

Figure F- 5 (b) Observed N (P) concentrations (C/C₀)

F.2 Sample Collection Location: WS 2

Table F- 6 Investigation period: 30th APR-9th MAY, 2012

Date (MMDD)	Time (Days)	NH ₄ ⁺		TN		NO ₃ ⁻		TP	
		C(mg/L)	C/C0	C(mg/L)	C/C0	C(mg/L)	C/C0	C(mg/L)	C/C0
0429	0	Fertiliser applied							
0430	1	9.9	1.00	29	1.00	0.3		1.13	
0501	2								
0502	3	6.8	0.69	11	0.38	3.1	1.00	3.96	1.00
0503	4								
0504	5								
0505	6	1.3	0.13	5	0.17	1.3	0.42	2.43	0.61
0506	7								
0507	8	1.1	0.11	3	0.10	0.8	0.26	1.36	0.34
0508	9								
0509	10	0.7	0.07	1	0.03	0.6	0.19	0.96	0.24
0510	11								
0511	12								
0512	13								
0513	14	0.1	0.01	2	0.07	0.5	0.16	0.62	0.16

Figure F- 6 (a) Observed N (P) concentrations (mg/L)

Figure F- 6 (b) Observed N (P) concentrations (C/C₀)

Table F- 7 Investigation period: 22nd JUL-28th JUL, 2012

Date (MMDD)	Time (Days)	NH ₄ ⁺		TN		NO ₃ ⁻		TP	
		C(mg/L)	C/C ₀	C(mg/L)	C/C ₀	C(mg/L)	C/C ₀	C(mg/L)	C/C ₀
0721	0	Fertiliser applied							
0722	1								
0723	2								
0724	3	8.4	1.00	21	1.00	2.1	1.00	2.97	1.00
0725	4								
0726	5	1.9	0.23	7	0.33	0.4	0.19	0.89	0.30
0727	6								
0728	7	0.3	0.04	3	0.14	0.1	0.05	0.44	0.15
0729	8

Figure F- 7 (a) Observed N (P) concentrations (mg/L)

Figure F- 7 (b) Observed N (P) concentrations (C/C₀)

Table F- 8 Investigation period: 15th AUG-23th AUG, 2012

Date (MMDD)	Time (Days)	NH ₄ ⁺		TN		NO ₃ ⁻		TP	
		C(mg/L)	C/C ₀	C(mg/L)	C/C ₀	C(mg/L)	C/C ₀	C(mg/L)	C/C ₀
0814	0	Fertiliser applied							
0815	1								
0816	2								
0817	3	15.1	1.00	25	1.00	4.4	1.00	3.97	1.00
0818	4		0.00		0.00		0.00		0.00
0819	5	3.4	0.23	11	0.44	1.7	0.39	1.11	0.28
0820	6		0.00		0.00		0.00		0.00
0821	7	0.7	0.05	5	0.20	0.7	0.16	0.75	0.19
0822	8		0.00		0.00		0.00		0.00
0823	9	0.2	0.01	2	0.08	0.3	0.07	0.28	0.07

Figure F- 8(a) Observed N (P) concentrations (mg/L)

Figure F- 8(b) Observed N (P) concentrations (C/C₀)

Table F- 9 Investigation period: 14th OCT-22th OCT, 2012

Date (MMDD)	Time (Days)	NH ₄ ⁺		TN		NO ₃ ⁻		TP	
		C(mg/L)	C/C ₀	C(mg/L)	C/C ₀	C(mg/L)	C/C ₀	C(mg/L)	C/C ₀
1013	0	Fertiliser applied							
1014	1	13.7	1.00	33	1.00	4.7	1.00	5.47	1.00
1015	2								
1016	3	3.7	0.27	11	0.33	1.1	0.23	1.31	0.24
1017	4	2.1	0.15	6	0.18	0.9	0.19	0.84	0.15
1018	5	1.2	0.09	1	0.03	0.7	0.15	0.46	0.08
1019	6	0.7	0.05	4	0.12	0.9	0.19	0.33	0.06
1020	7	0.1	0.01	2	0.06	0.4	0.09	0.19	0.03
1021	8	0	0.00	1	0.03	0.2	0.04	0.07	0.01
1022	9	0	0.00	1	0.03	0	0.00	0.01	0.00

Figure F- 9(a) Observed N (P) concentrations (mg/L)

Figure F- 9(b) Observed N (P) concentrations (C/C₀)

Table F- 10 Investigation period: 22nd NOV-29th NOV, 2012

Date (MMDD)	Time (Days)	NH ₄ ⁺		TN		NO ₃ ⁻		TP	
		C(mg/L)	C/C ₀	C(mg/L)	C/C ₀	C(mg/L)	C/C ₀	C(mg/L)	C/C ₀
1121	0	Fertiliser applied							
1122	1	14.1	1.00	34	1.00	3.9	1.00	3.24	1.00
1123	2	8.1	0.57	19	0.56	2.4	0.62	1.61	0.50
1124	3								
1125	4	0.7	0.05	5	0.15	0.7	0.18	1.02	0.31
1126	5	0.5	0.04	3	0.09	0.2	0.05	0.45	0.14
1127	6								
1128	7	0.2	0.01	2	0.06	0.2	0.05	0.13	0.04
1129	8	0.1	0.01	1	0.03	0.1	0.03	0.18	0.06
1130	9	0.1	0.01	1	0.03	0.1	0.03	0.04	0.01

Figure F- 10 (a) Observed N (P) concentrations (mg/L)

Figure F- 10 (b) Observed N (P) concentrations (C/C₀)

F.3 Sample Collection Location: WS 3

Table F- 11 Investigation period: 30th APR-9th MAY, 2012

Date (MMDD)	Time (Days)	NH ₄ ⁺		TN		NO ₃ ⁻		TP	
		C(mg/L)	C/C ₀	C(mg/L)	C/C ₀	C(mg/L)	C/C ₀	C(mg/L)	C/C ₀
0429	0	Fertiliser applied							
0430	1	9.7	1.00			4.8	1.00	7.56	1.00
0501	2								
0502	3	9.1	0.94	23	1.00	2.8	0.58	4.12	0.54
0503	4								
0504	5								
0505	6	1.5	0.15	5	0.22	0.4	0.08	0.83	0.11
0506	7								
0507	8	1.3	0.13	3	0.13	0.9	0.19	0.41	0.05
0508	9								
0509	10	0.1	0.01	2	0.09	0.5	0.10	0.37	0.05
0510	11								
0511	12								
0512	13								
0513	14	0	0.00	1	0.04	0.1	0.02	0.13	0.02

Figure F- 11(a) Observed N (P) concentrations (mg/L)

Figure F- 11(b) Observed N (P) concentrations (C/C₀)

Table F- 12 Investigation period: 22nd JUL-28th JUL, 2012

Date (MMDD)	Time (Days)	NH ₄ ⁺		TN		NO ₃ ⁻		TP	
		C(mg/L)	C/C ₀	C(mg/L)	C/C ₀	C(mg/L)	C/C ₀	C(mg/L)	C/C ₀
0721	0	Fertiliser applied							
0722	1								
0723	2								
0724	3	9.7	1.00	23	1.00	2.7	1.00	3.51	1.00
0725	4								
0726	5	0.6	0.06	8	0.35	1.4	0.52	0.85	0.24
0727	6								
0728	7	0.4	0.04	2	0.09	0.2	0.07	0.13	0.04

Figure F- 12(a) Observed N (P) concentrations (mg/L)

Figure F- 12(b) Observed N (P) concentrations (C/C₀)

Table F- 13 Investigation period: 15th AUG-23th AUG, 2012

Date (MMDD)	Time (Days)	NH ₄ ⁺		TN		NO ₃ ⁻		TP	
		C(mg/L)	C/C ₀	C(mg/L)	C/C ₀	C(mg/L)	C/C ₀	C(mg/L)	C/C ₀
0814	0	Fertiliser applied							
0815	1								
0816	2								
0817	3	16.4	1.00	39	1.00	5.3	1.00	4.57	1.00
0818	4								
0819	5	4.4	0.27	10	0.26	1.7	0.32	0.71	0.16
0820	6								
0821	7	1.2	0.07	0	0.00	0.3	0.06	0.12	0.03
0822	8								
0823	9	0.5	0.03	1	0.03	0.2	0.04	0.1	0.02

Figure F- 13(a) Observed N (P) concentrations (mg/L)

Figure F- 13(b) Observed N (P) concentrations (C/C₀)

Table F- 14 Investigation period: 14th OCT-22th OCT, 2012

Date (MMDD)	Time (Days)	NH ₄ ⁺		TN		NO ₃ ⁻		TP	
		C(mg/L)	C/C ₀	C(mg/L)	C/C ₀	C(mg/L)	C/C ₀	C(mg/L)	C/C ₀
1013	0	Fertiliser applied							
1014	1	12.7	1.00	37	1.00	4.9	1.00	6.34	1.00
1015	2								
1016	3	0.7	0.06	4	0.11	0.4	0.08	0.13	0.02
1017	4	2.7	0.21	3	0.08	1.9	0.39	0.82	0.13
1018	5	1.3	0.10	7	0.19	1.4	0.29	0.68	0.11
1019	6	0.8	0.06	1	0.03	1.1	0.22	0.45	0.07
1020	7	0.2	0.02	1	0.03	0.4	0.08	0.31	0.05
1021	8	0.4	0.03	1	0.03	0.4	0.08	0.07	0.01
1022	9	0	0.00	0	0.00	0	0.00	0	0.00

Figure F- 14(a) Observed N (P) concentrations (mg/L)

Figure F- 14(b) Observed N (P) concentrations (C/C₀)

Table F- 15 Investigation period: 22nd NOV-29th NOV, 2012

Date (MMDD)	Time (Days)	NH ₄ ⁺		TN		NO ₃ ⁻		TP	
		C(mg/L)	C/C ₀	C(mg/L)	C/C ₀	C(mg/L)	C/C ₀	C(mg/L)	C/C ₀
1121	0	Fertiliser applied							
1122	1	15.1	1.00	36	1.00	4.7	1.00	4.77	1.00
1123	2	9.1	0.60	17	0.47	2.1	0.45	1.92	0.40
1124	3								
1125	4	0.7	0.05	2	0.06	0.5	0.11	0.25	0.05
1126	5	0.6	0.04	1	0.03	0.3	0.06	0.15	0.03
1127	6								
1128	7	0.2	0.01	0	0.00	0.1	0.02	0.12	0.03
1129	8	0.1	0.01	0	0.00	0	0.00	0.09	0.02
1130	9	0	0.00	0	0.00	0.1	0.02	0.06	0.01

Figure F- 15 (a) Observed N (P) concentrations (mg/L)

Figure F- 15 (b) Observed N (P) concentrations (C/C₀)

F.4 Investigation on March, 2012

Table F- 16 Sample collected at location WS 1

Date (MMDD)	Time (Days)	NH ₄ ⁺		TN		NO ₃ ⁻		TP	
		C(mg/L)	C/C ₀	C(mg/L)	C/C ₀	C(mg/L)	C/C ₀	C(mg/L)	C/C ₀
0301	0	Fertiliser applied							
0302	1	4.9	1.00	15	1.00	2.5	1.00	1.77	1.00
0303	2								
0304	3								
0305	4	1.3	0.27	13	0.87	1.5	0.60	0.78	0.44
0306	5								
0307	6								
0308	7	0.8	0.16	6	0.40	0.5	0.20	0.58	0.33
0309	8	0.6	0.12	4	0.27	0.4	0.16	0.51	0.29
0310	9								
0311	10								
0312	11								
0313	12	0	0.00	1	0.07	0.6	0.24	0.43	0.24

Figure F- 16(a) Observed N (P) concentrations (mg/L)

Figure F- 17(b) Observed N (P) concentrations (C/C_0)

Table F- 17 Sample collected at location WS 2

Date (MMDD)	Time (Days)	NH ₄ ⁺		TN		NO ₃ ⁻		TP	
		C(mg/L)	C/C ₀	C(mg/L)	C/C ₀	C(mg/L)	C/C ₀	C(mg/L)	C/C ₀
0301	0	Fertiliser applied							
0302	1	9.3	1.00	22	1.00	2.8	1.00	3.28	1.00
0303	2								
0304	3								
0305	4	0.6	0.06	17	0.77	1.4	0.50	0.91	0.28
0306	5								
0307	6								
0308	7	1	0.11	9	0.41	1	0.36	0.61	0.19
0309	8	0.6	0.06	7	0.32	0.7	0.25	0.55	0.17
0310	9								
0311	10								
0312	11								
0313	12	0.2	0.02	3	0.14	0.4	0.14	0.43	0.13

Figure F- 17(a) Observed N (P) concentrations (mg/L)

Figure F- 18(b) Observed N (P) concentrations (C/C_0)

Table F- 18 Sample collected at location WS 3

Date (MMDD)	Time (Days)	NH ₄ ⁺		TN		NO ₃ ⁻		TP	
		C(mg/L)	C/C ₀	C(mg/L)	C/C ₀	C(mg/L)	C/C ₀	C(mg/L)	C/C ₀
0301	0								
0302	1	12.4	1.00	33	1.00	4	1.00	4.92	1.00
0303	2								
0304	3								
0305	4	2	0.16	25	0.76	2.3	0.58	1.38	0.28
0306	5								
0307	6								
0308	7	1.4	0.11	9	0.27	2	0.50	0.98	0.20
0309	8	0.7	0.06	8	0.24	1.2	0.30	1	0.20
0310	9								
0311	10								
0312	11								
0313	12	0.3	0.02	14	0.42	0.9	0.23	0.65	0.13

Figure F- 18 (a) Observed N (P) concentrations (mg/L)

Figure F- 19 (b) Observed N (P) concentrations (C/C_0)

**Appendix G. Comparison of the simulated and measured N
concentrations in the controlled outdoor experiments**

29th, April, 2012~13th, May, 2012							
Time	NH ₄ ⁺ concentration		NO ₃ ⁻ concentration		TN concentration		Remarks
	Simulated	Measured	Simulated	Measured	Simulated	Measured	
4/30/2012 7:00	0.00		0.00		0.00		
4/30/2012 7:10	0.00		0.00		0.00		
4/30/2012 7:20	9.93	9.7	2.98	4.8	24.89	23	
4/30/2012 7:30	6.06		1.82		14.96		
4/30/2012 7:40	1.72		0.52		4.18		
4/30/2012 7:50	0.16		0.05		0.39		
4/30/2012 8:00	0.00		0.00		0.00		
...							No rain
5/2/2012 8:00	0.00		0.00		0.00		
5/2/2012 8:10	0.00		0.00		0.00		
5/2/2012 8:20	0.00		0.00		0.00		
5/2/2012 8:30	5.32	5.1	1.62	2.8	5.80	5	
5/2/2012 8:40	4.52		1.38		4.85		
5/2/2012 8:50	1.18		0.36		1.25		
5/2/2012 9:00	0.86		0.26		0.90		
5/2/2012 9:10	0.55		0.17		0.57		
5/2/2012 9:20	0.34		0.10		0.34		
5/2/2012 9:30	0.73		0.22		0.73		
5/2/2012 9:40	0.45		0.14		0.44		
5/2/2012 9:50	0.00		0.00		0.00		
5/2/2012 17:00	0.00		0.00		0.00		
5/2/2012 17:10	0.00		0.00		0.00		
5/2/2012 17:20	0.00		0.00		0.00		
5/2/2012 17:30	0.18		0.05		0.08		
5/2/2012 17:40	0.14		0.04		0.07		
5/2/2012 17:50	0.01		0.00		0.01		
5/2/2012 18:00	0.00		0.00		0.00		
5/2/2012 18:10	0.00		0.00		0.00		
5/2/2012 18:20	0.03		0.01		0.01		
5/2/2012 18:30	0.00		0.00		0.00		
...							No rain
5/5/2012 1:00	0.00		0.00		0.00		
5/5/2012 1:10	1.25	1.5	0.40	0.4	2.71	3	
5/5/2012 1:20	0.42		0.13		0.90		
5/5/2012 1:30	0.22		0.07		0.46		
5/5/2012 1:40	0.31		0.10		0.64		
5/5/2012 1:50	0.12		0.04		0.24		

29th, April, 2012~13th, May, 2012							
Time	NH ₄ ⁺ concentration		NO ₃ ⁻ concentration		TN concentration		Remarks
	Simulated	Measured	Simulated	Measured	Simulated	Measured	
5/5/2012 2:00	0.21		0.07		0.42		
5/5/2012 2:10	0.04		0.01		0.07		
5/5/2012 2:20	0.04		0.01		0.07		
5/5/2012 2:30	0.03		0.01		0.06		
5/5/2012 2:40	0.02		0.01		0.04		
5/5/2012 2:50	0.04		0.01		0.07		
5/5/2012 3:00	0.02		0.00		0.03		
5/5/2012 3:10	0.02		0.01		0.03		
5/5/2012 3:20	0.00		0.00		0.00		
5/5/2012 3:30	0.00		0.00		0.00		
5/5/2012 3:40	0.03		0.01		0.06		
5/5/2012 3:50	0.04		0.01		0.07		
5/5/2012 4:00	0.14		0.04		0.23		
5/5/2012 4:10	0.06		0.02		0.09		
5/5/2012 4:20	0.07		0.02		0.11		
5/5/2012 4:30	0.08		0.03		0.13		
5/5/2012 4:40	0.10		0.03		0.16		
5/5/2012 4:50	0.12		0.04		0.18		
5/5/2012 5:00	0.14		0.05		0.22		
5/5/2012 5:10	0.31		0.10		0.47		
5/5/2012 5:20	0.00		0.00		0.00		
...							No rain
5/7/2012 5:40	0.72	1.3	0.24	0.9	1.03	2	
5/7/2012 5:50	0.44		0.15		0.62		
5/7/2012 6:00	0.38		0.13		0.52		
5/7/2012 6:10	0.45		0.15		0.62		
5/7/2012 6:20	0.24		0.08		0.32		
5/7/2012 6:30	0.14		0.05		0.19		
5/7/2012 6:40	0.00		0.00		0.00		
5/7/2012 6:50	0.07		0.02		0.08		
5/7/2012 7:00	0.00		0.00		0.00		
5/7/2012 7:10	0.00		0.00		0.00		
5/7/2012 7:20	0.00		0.00		0.00		
5/7/2012 7:30	0.00		0.00		0.00		
5/7/2012 7:40	0.15		0.05		0.18		
5/7/2012 7:50	0.00		0.00		0.00		
5/7/2012 8:00	0.18		0.06		0.21		

29th, April, 2012~13th, May, 2012							
Time	NH ₄ ⁺ concentration		NO ₃ ⁻ concentration		TN concentration		Remarks
	Simulated	Measured	Simulated	Measured	Simulated	Measured	
5/7/2012 8:10	0.19		0.06		0.22		
5/7/2012 8:20	0.00		0.00		0.00		
5/7/2012 8:30	0.00		0.00		0.00		
...							No rain
5/9/2012 2:10	0.26	0.1	0.09	0.5	0.52	1	
5/9/2012 2:20	0.24		0.08		0.47		
5/9/2012 2:30	0.14		0.05		0.27		
5/9/2012 2:40	0.06		0.02		0.11		
5/9/2012 2:50	0.10		0.04		0.20		
5/9/2012 3:00	0.03		0.01		0.06		
5/9/2012 3:10	0.04		0.01		0.07		
5/9/2012 3:20	0.05		0.02		0.08		
5/9/2012 3:30	0.00		0.00		0.00		
5/9/2012 3:40	0.07		0.02		0.11		
5/9/2012 3:50	0.00		0.00		0.00		
5/9/2012 4:00	0.09		0.03		0.15		
5/9/2012 4:10	0.21		0.07		0.35		
5/9/2012 4:20	0.00		0.00		0.00		
5/9/2012 4:30	0.10		0.03		0.15		
5/9/2012 4:40	0.00		0.00		0.00		
5/9/2012 4:50	0.00		0.00		0.00		
5/9/2012 5:00	0.00		0.00		0.00		
5/9/2012 9:00	0.00		0.00		0.00		
5/9/2012 9:10	0.00		0.00		0.00		
5/9/2012 9:20	0.00		0.00		0.00		
5/9/2012 9:30	0.00		0.00		0.00		
5/9/2012 9:40	0.00		0.00		0.00		
5/9/2012 9:50	0.00		0.00		0.00		
5/9/2012 10:00	0.00		0.00		0.00		
5/9/2012 10:10	0.52		0.18		0.49		
5/9/2012 10:20	0.00		0.00		0.00		
5/9/2012 10:30	0.00		0.00		0.00		
5/9/2012 10:40	0.00		0.00		0.00		
5/9/2012 10:50	0.00		0.00		0.00		
5/9/2012 11:00	0.00		0.00		0.00		
5/9/2012 11:10	0.00		0.00		0.00		
5/9/2012 11:20	0.00		0.00		0.00		

29th, April, 2012~13th, May, 2012							
Time	NH ₄ ⁺ concentration		NO ₃ ⁻ concentration		TN concentration		Remarks
	Simulated	Measured	Simulated	Measured	Simulated	Measured	
5/13/2012 0:40	0.00		0.00		0.00		
5/13/2012 0:50	0.00		0.00		0.00		
5/13/2012 1:00	0.00		0.00		0.00		
5/13/2012 1:10	0.11	0	0.04	0.1	0.23	0	
5/13/2012 1:20	0.07		0.02		0.14		
5/13/2012 1:30	0.03		0.01		0.07		
5/13/2012 1:40	0.03		0.01		0.05		
5/13/2012 1:50	0.04		0.02		0.09		
5/13/2012 2:00	0.02		0.01		0.03		
5/13/2012 2:10	0.02		0.01		0.04		
5/13/2012 2:20	0.02		0.01		0.05		
5/13/2012 2:30	0.03		0.01		0.06		
5/13/2012 2:40	0.08		0.03		0.16		
5/13/2012 2:50	0.09		0.03		0.17		
5/13/2012 3:00	0.11		0.04		0.20		
5/13/2012 3:10	0.09		0.03		0.17		
5/13/2012 3:20	0.06		0.02		0.11		
5/13/2012 3:30	0.05		0.02		0.08		
5/13/2012 3:40	0.05		0.02		0.09		
5/13/2012 3:50	0.03		0.01		0.05		
5/13/2012 4:00	0.04		0.01		0.06		
5/13/2012 4:10	0.00		0.00		0.00		
5/13/2012 4:20	0.08		0.03		0.14		
5/13/2012 4:30	0.00		0.00		0.00		
5/13/2012 4:40	0.00		0.00		0.00		
5/13/2012 4:50	0.00		0.00		0.00		
5/13/2012 5:00	0.00		0.00		0.00		
5/13/2012 5:10	0.00		0.00		0.00		
5/13/2012 5:20	0.00		0.00		0.00		
5/13/2012 5:30	0.00		0.00		0.00		
5/13/2012 5:40	0.00		0.00		0.00		
5/13/2012 5:50	0.00		0.00		0.00		
5/13/2012 6:00	0.00		0.00		0.00		
5/13/2012 6:10	0.00		0.00		0.00		
5/13/2012 6:20	0.00		0.00		0.00		
5/13/2012 6:30	0.00		0.00		0.00		
5/13/2012 6:40	0.00		0.00		0.00		

29th, April, 2012~13th, May, 2012							
Time	NH ₄ ⁺ concentration		NO ₃ ⁻ concentration		TN concentration		Remarks
	Simulated	Measured	Simulated	Measured	Simulated	Measured	
5/13/2012 6:50	0.31		0.11		0.40		
5/13/2012 7:00	0.00		0.00		0.00		
5/13/2012 7:10	0.00		0.00		0.00

21 st , July, 2012~29 th , July, 2012							
Time	NH ₄ ⁺ concentration		NO ₃ ⁻ concentration		TN concentration		Remarks
	Simulated	Measured	Simulated	Measured	Simulated	Measured	
7/24/2012 5:40	0.00		0.00		0.00		
7/24/2012 5:50	0.00		0.00		0.00		
7/24/2012 6:00	0.00		0.00		0.00		
7/24/2012 6:10	0.00		0.00		0.00		
7/24/2012 6:20	0.00		0.00		0.00		
7/24/2012 6:30	0.00		0.00		0.00		
7/24/2012 6:40	0.00		0.00		0.00		
7/24/2012 6:50	12.81	9.7	3.45	2.7	28.82	23	
7/24/2012 7:00	5.20		1.43		11.75		
7/24/2012 7:10	0.00		0.00		0.00		
7/24/2012 7:20	2.04		0.58		4.62		
7/24/2012 7:30	0.00		0.00		0.00		
7/24/2012 7:40	0.00		0.00		0.00		
7/24/2012 7:50	0.00		0.00		0.00		
...							No rain
7/26/2012 17:40	0.00		0.00		0.00		
7/26/2012 17:50	0.00		0.00		0.00		
7/26/2012 18:00	0.00		0.00		0.00		
7/26/2012 18:10	0.00		0.00		0.00		
7/26/2012 18:20	0.00		0.00		0.00		
7/26/2012 18:30	0.71	0.6	1.48	1.4	2.34	8	
7/26/2012 18:40	0.00		0.00		0.00		
7/26/2012 18:50	0.04		0.08		0.13		
7/26/2012 19:00	0.01		0.03		0.04		
7/26/2012 19:10	0.00		0.00		0.00		
7/26/2012 19:20	0.00		0.00		0.00		
7/26/2012 19:30	0.00		0.00		0.00		
7/26/2012 19:40	0.00		0.00		0.00		
...							No rain
7/28/2012 19:30	0.00		0.00		0.00		
7/28/2012 19:40	0.17	0.4	0.42	0.2	0.59	2	
7/28/2012 19:50	0.00		0.00		0.00		
7/28/2012 20:00	0.10		0.24		0.33		
7/28/2012 20:10	0.05		0.12		0.16		
7/28/2012 20:20	0.03		0.08		0.10		
7/28/2012 20:30	0.01		0.04		0.05		
7/28/2012 20:40	0.01		0.02		0.03		
7/28/2012 20:50	0.00		0.00		0.00		
7/28/2012 21:00	0.00		0.00		0.00		
7/28/2012 21:10	0.00		0.00		0.00		
7/28/2012 21:20	0.00		0.00		0.00		
7/28/2012 21:30	0.03		0.09		0.10

14 th , August, 2012~23 rd , August, 2012							
Time	NH ₄ ⁺ concentration		NO ₃ ⁻ concentration		TN concentration		Remarks
	Simulated	Measured	Simulated	Measured	Simulated	Measured	
8/17/2012 8:00	0.00		0.00		0.00		
8/17/2012 8:10	0.00		0.00		0.00		
8/17/2012 8:20	0.00		0.00		0.00		
8/17/2012 8:30	1.93		0.60		8.17		
8/17/2012 8:40	0.76		0.24		3.16		
8/17/2012 8:50	0.05		0.01		0.19		
8/17/2012 9:00	0.00		0.00		0.00		
8/17/2012 9:10	0.21		0.06		0.83		
8/17/2012 9:20	0.63		0.20		2.46		
8/17/2012 9:30	0.38		0.12		1.47		
8/17/2012 9:40	0.90		0.28		3.42		
8/17/2012 9:50	1.21		0.38		4.51		
8/17/2012 10:00	0.91		0.28		3.34		
8/17/2012 10:10	0.14		0.04		0.50		
8/17/2012 10:20	0.00		0.00		0.00		
8/17/2012 10:30	0.00		0.00		0.00		
...							No rain
8/17/2012 14:50	0.00		0.00		0.00		
8/17/2012 15:00	14.05	16.4	4.36	5.3	32.45	39	
...							No rain
8/19/2012 14:10	0.29	4.4	0.87	1.7	7.49	10	
8/19/2012 14:20	0.24		0.70		5.99		
8/19/2012 14:30	0.00		0.00		0.00		
8/19/2012 17:30	0.00		0.00		0.00		
8/19/2012 17:40	4.32		1.29		8.04		
8/19/2012 17:50	0.00		0.00		0.00		
8/19/2012 18:00	0.00		0.00		0.00		
8/19/2012 18:10	0.00		0.00		0.00		
...							No rain
8/21/2012 10:00	0.00		0.00		0.00		
8/21/2012 10:10	0.00		0.00		0.00		
8/21/2012 10:20	0.00		0.00		0.00		
8/21/2012 10:30	0.00		0.00		0.00		
8/21/2012 10:40	1.10	1.2	0.36	0.3	0.99	0	
8/21/2012 10:50	0.00		0.00		0.00		
8/21/2012 11:00	0.00		0.00		0.00		
...							No rain

14 th , August, 2012~23 rd , August, 2012							
Time	NH ₄ ⁺ concentration		NO ₃ ⁻ concentration		TN concentration		Remarks
	Simulated	Measured	Simulated	Measured	Simulated	Measured	
8/21/2012 15:20	0.55		0.18		0.32		
8/21/2012 15:30	0.00		0.00		0.00		
8/21/2012 15:40	0.32		0.11		0.18		
...							No rain
8/23/2012 9:40	0.00		0.00		0.00		
8/23/2012 9:50	0.00		0.00		0.00		
8/23/2012 10:00	1.05	0.5	0.36	0.3	1.01	1	
8/23/2012 10:10	0.16		0.06		0.16		
8/23/2012 10:20	0.08		0.03		0.07		
8/23/2012 10:30	0.05		0.02		0.05		
8/23/2012 10:40	0.00		0.00		0.00		
8/23/2012 10:50	0.00		0.00		0.00		
8/23/2012 11:00	0.00		0.00		0.00		
8/23/2012 11:10	0.00		0.00		0.00		
8/23/2012 11:20	0.00		0.00		0.00		
8/23/2012 11:30	0.00		0.00		0.00		
8/23/2012 11:40	0.00		0.00		0.00		
8/23/2012 11:50	0.00		0.00		0.00		
8/23/2012 12:00	0.00		0.00		0.00		
8/23/2012 12:10	0.00		0.00		0.00		
8/23/2012 12:20	0.00		0.00		0.00		
8/23/2012 12:30	0.00		0.00		0.00

13 th October, 2012~22 nd October, 2012							
Time	NH ₄ ⁺ concentration		NO ₃ ⁻ concentration		TN concentration		Remarks
	Simulated	Measured	Simulated	Measured	Simulated	Measured	
10/14/2012 18:00	0.00		0.00		0.00		
10/14/2012 18:10	0.00		0.00		0.00		
10/14/2012 18:20	0.00		0.00		0.00		
10/14/2012 18:30	0.00		0.00		0.00		
10/14/2012 18:40	0.00		0.00		0.00		
10/14/2012 18:50	0.00		0.00		0.00		
10/14/2012 19:00	17.96	12.7	4.05	4.9	36.33	37	
10/14/2012 19:10	10.78		2.47		21.84		
10/14/2012 19:20	3.22		0.75		6.54		
10/14/2012 19:30	2.25		0.54		4.58		
10/14/2012 19:40	0.73		0.18		1.50		
10/14/2012 19:50	0.00		0.00		0.00		
10/14/2012 20:00	0.00		0.00		0.00		
10/14/2012 20:10	0.00		0.00		0.00		
10/14/2012 20:20	0.00		0.00		0.00		
10/14/2012 20:30	0.00		0.00		0.00		
10/14/2012 20:40	0.00		0.00		0.00		
10/14/2012 20:50	0.00		0.00		0.00		
10/14/2012 21:00	0.00		0.00		0.00		
10/14/2012 21:10	0.00		0.00		0.00		
10/14/2012 21:20	0.00		0.00		0.00		
10/14/2012 21:30	0.00		0.00		0.00		
10/14/2012 21:40	0.00		0.00		0.00		
10/14/2012 21:50	0.00		0.00		0.00		
10/14/2012 22:00	0.00		0.00		0.00		
10/14/2012 22:10	0.00		0.00		0.00		
10/14/2012 22:20	0.00		0.00		0.00		
10/14/2012 22:30	5.12		1.66		10.78		
10/14/2012 22:40	0.00		0.00		0.00		
...							No rain
10/16/2012 13:20	0.00		0.00		0.00		
10/16/2012 13:30	0.00		0.00		0.00		
10/16/2012 13:40	0.00		0.00		0.00		
10/16/2012 13:50	0.00		0.00		0.00		
10/16/2012 14:00	0.45	0.7	0.30	0.4	2.14	4	
10/16/2012 14:10	0.22		0.15		1.03		
10/16/2012 14:20	0.00		0.00		0.00		
10/16/2012 14:30	0.00		0.00		0.00		
10/16/2012 14:40	0.00		0.00		0.00		

13 th October, 2012~22 nd October, 2012							
Time	NH ₄ ⁺ concentration		NO ₃ ⁻ concentration		TN concentration		Remarks
	Simulated	Measured	Simulated	Measured	Simulated	Measured	
10/16/2012 14:50	0.00		0.00		0.00		
10/16/2012 15:00	0.00		0.00		0.00		
...							No rain
10/17/2012 14:00	0.00		0.00		0.00		
10/17/2012 14:10	0.00		0.00		0.00		
10/17/2012 14:20	0.00		0.00		0.00		
10/17/2012 14:30	0.00		0.00		0.00		
10/17/2012 14:40	0.00		0.00		0.00		
10/17/2012 14:50	0.00		0.00		0.00		
10/17/2012 15:00	0.00		0.00		0.00		
10/17/2012 15:10	0.74	2.7	1.14	1.9	1.07	3	
10/17/2012 15:20	0.67		1.05		0.97		
10/17/2012 15:30	0.37		0.59		0.53		
10/17/2012 15:40	0.29		0.47		0.42		
10/17/2012 15:50	0.21		0.35		0.30		
10/17/2012 16:00	0.26		0.44		0.38		
10/17/2012 16:10	0.23		0.40		0.34		
10/17/2012 16:20	0.12		0.21		0.18		
10/17/2012 16:30	0.03		0.05		0.04		
10/17/2012 16:40	0.00		0.00		0.00		
10/17/2012 16:50	0.00		0.00		0.00		
10/17/2012 17:00	0.00		0.00		0.00		
...							No rain
10/18/2012 10:30	0.00		0.00		0.00		
10/18/2012 10:40	0.00		0.00		0.00		
10/18/2012 10:50	0.00		0.00		0.00		
10/18/2012 11:00	0.95	1.3	1.93	1.4	2.61	7	
10/18/2012 11:10	0.00		0.00		0.00		
10/18/2012 11:20	0.00		0.00		0.00		
10/18/2012 11:30	0.00		0.00		0.00		
10/18/2012 11:40	0.00		0.00		0.00		
10/18/2012 11:50	0.00		0.00		0.00		
10/18/2012 12:00	0.00		0.00		0.00		
10/18/2012 12:10	0.00		0.00		0.00		
10/18/2012 12:20	0.00		0.00		0.00		
10/18/2012 12:30	0.00		0.00		0.00		
10/18/2012 12:40	0.00		0.00		0.00		
10/18/2012 12:50	0.08		0.18		0.21		
10/18/2012 13:00	0.05		0.13		0.15		

13 th October, 2012~22 nd October, 2012							
Time	NH ₄ ⁺ concentration		NO ₃ ⁻ concentration		TN concentration		Remarks
	Simulated	Measured	Simulated	Measured	Simulated	Measured	
10/18/2012 13:10	0.03		0.07		0.08		
10/18/2012 13:20	0.01		0.01		0.02		
10/18/2012 13:30	0.00		0.00		0.00		
10/18/2012 13:40	0.00		0.00		0.00		
10/18/2012 13:50	0.00		0.00		0.00		
10/18/2012 14:00	0.00		0.00		0.00		
10/18/2012 14:10	0.00		0.01		0.01		
10/18/2012 14:20	0.00		0.00		0.00		
10/18/2012 14:30	0.00		0.00		0.00		
10/18/2012 14:40	0.01		0.04		0.03		
10/18/2012 14:50	0.00		0.00		0.00		
10/18/2012 15:00	0.00		0.01		0.01		
10/18/2012 15:10	0.00		0.00		0.00		
...							No rain
10/19/2012 10:00	0.00		0.00		0.00		
10/19/2012 10:10	0.00		0.00		0.00		
10/19/2012 10:20	0.00		0.00		0.00		
10/19/2012 10:30	0.00		0.00		0.00		
10/19/2012 10:40	0.00		0.00		0.00		
10/19/2012 10:50	0.00		0.00		0.00		
10/19/2012 11:00	0.46	0.8	0.95	1.1	1.26	1	
10/19/2012 11:10	0.00		0.00		0.00		
10/19/2012 11:20	0.00		0.00		0.00		
10/19/2012 11:30	0.00		0.00		0.00		
10/19/2012 11:40	0.00		0.00		0.00		
10/19/2012 11:50	0.00		0.00		0.00		
10/19/2012 15:30	0.00		0.00		0.00		
10/19/2012 15:40	0.00		0.00		0.00		
10/19/2012 15:50	0.00		0.00		0.00		
10/19/2012 16:00	0.07		0.24		0.20		
10/19/2012 16:10	0.04		0.14		0.12		
10/19/2012 16:20	0.00		0.00		0.00		
10/19/2012 16:30	0.00		0.00		0.00		
10/19/2012 16:40	0.00		0.00		0.00		
10/19/2012 16:50	0.01		0.05		0.04		
10/19/2012 17:00	0.01		0.05		0.04		
10/19/2012 17:10	0.00		0.01		0.01		
10/19/2012 17:20	0.00		0.00		0.00		
10/19/2012 17:30	0.00		0.00		0.00		

13 th October, 2012~22 nd October, 2012							
Time	NH ₄ ⁺ concentration		NO ₃ ⁻ concentration		TN concentration		Remarks
	Simulated	Measured	Simulated	Measured	Simulated	Measured	
10/19/2012 17:40	0.00		0.00		0.00		
10/19/2012 17:50	0.00		0.00		0.00		
10/19/2012 18:00	0.01		0.02		0.02		
10/19/2012 18:10	0.00		0.00		0.00		
10/19/2012 18:20	0.00		0.00		0.00		
...							No rain
10/20/2012 17:00	0.00		0.00		0.00		
10/20/2012 17:10	0.00		0.00		0.00		
10/20/2012 17:20	0.00		0.00		0.00		
10/20/2012 17:30	0.00		0.00		0.00		
10/20/2012 17:40	0.00		0.00		0.00		
10/20/2012 17:50	0.00		0.00		0.00		
10/20/2012 18:00	0.00		0.00		0.00		
10/20/2012 18:10	0.02	0.2	0.04	0.4	0.05	1	
10/20/2012 18:20	0.02		0.03		0.04		
10/20/2012 18:30	0.01		0.01		0.01		
10/20/2012 18:40	0.00		0.00		0.00		
10/20/2012 18:50	0.00		0.00		0.00		
...							No rain
10/21/2012 2:20	0.00		0.00		0.00		
10/21/2012 2:30	0.00		0.00		0.00		
10/21/2012 2:40	0.55	0.4	0.49	0.4	2.74	1	
10/21/2012 2:50	0.22		0.20		1.10		
10/21/2012 3:00	0.00		0.00		0.00		
10/21/2012 10:00	0.00		0.00		0.00		
10/21/2012 10:10	0.00		0.00		0.00		
10/21/2012 10:20	0.00		0.00		0.00		
10/21/2012 10:30	0.20		0.41		1.12		
10/21/2012 10:40	0.00		0.00		0.00		
10/21/2012 10:50	0.00		0.00		0.00		
10/21/2012 11:00	0.00		0.00		0.00		
10/21/2012 11:10	0.00		0.00		0.00		
10/21/2012 11:20	0.00		0.00		0.00		
10/21/2012 11:30	0.00		0.00		0.00		
10/21/2012 11:40	0.13		0.29		0.70		
10/21/2012 11:50	0.15		0.35		0.84		
10/21/2012 12:00	0.08		0.19		0.44		
10/21/2012 12:10	0.01		0.02		0.04		
10/21/2012 12:20	0.00		0.01		0.02		

13 th October, 2012~22 nd October, 2012							
Time	NH ₄ ⁺ concentration		NO ₃ ⁻ concentration		TN concentration		Remarks
	Simulated	Measured	Simulated	Measured	Simulated	Measured	
10/21/2012 12:30	0.00		0.00		0.00		
10/21/2012 12:40	0.00		0.00		0.00		
10/21/2012 12:50	0.00		0.00		0.00		
10/21/2012 13:00	0.00		0.00		0.00		
10/21/2012 13:10	0.00		0.00		0.01		
10/21/2012 13:20	0.00		0.01		0.02		
10/21/2012 13:30	0.00		0.01		0.01		
10/21/2012 13:40	0.00		0.00		0.01		
10/21/2012 13:50	0.00		0.01		0.01		
10/21/2012 14:00	0.01		0.02		0.03

21 st November, 2012~25 th November, 2012							
Time	NH ₄ ⁺ concentration		NO ₃ ⁻ concentration		TN concentration		Remarks
	Simulated	Measured	Simulated	Measured	Simulated	Measured	
11/22/2012 0:00	0.00		0.00		0.00		
11/22/2012 0:10	0.00		0.00		0.00		
11/22/2012 0:20	0.00		0.00		0.00		
11/22/2012 0:30	15.26	15.1	4.82	4.7	36.83	36	
11/22/2012 0:40	0.00		0.00		0.00		
11/22/2012 0:50	0.00		0.00		0.00		
11/22/2012 8:00	0.00		0.00		0.00		
11/22/2012 8:10	2.25		1.58		5.93		
11/22/2012 8:20	0.00		0.00		0.00		
11/22/2012 8:30	0.00		0.00		0.00		
11/22/2012 8:40	0.00		0.00		0.00		
11/22/2012 8:50	0.00		0.00		0.00		
11/22/2012 9:00	0.00		0.00		0.00		
11/22/2012 9:10	0.00		0.00		0.00		
11/22/2012 9:20	0.00		0.00		0.00		
11/22/2012 9:30	0.00		0.00		0.00		
11/22/2012 9:40	0.21		0.17		0.57		
11/22/2012 9:50	0.19		0.16		0.52		
11/22/2012 11:00	0.00		0.00		0.00		
11/22/2012 11:10	0.00		0.00		0.00		
11/22/2012 11:20	0.00		0.00		0.00		
11/22/2012 11:30	0.00		0.00		0.00		
11/22/2012 11:40	0.18		0.18		0.48		
11/22/2012 11:50	0.00		0.00		0.00		
11/22/2012 12:00	0.00		0.00		0.00		
11/22/2012 12:10	0.00		0.00		0.00		
11/22/2012 12:20	0.00		0.00		0.00		
11/22/2012 12:30	0.00		0.00		0.00		
11/22/2012 12:40	0.18		0.20		0.49		
11/22/2012 12:50	0.00		0.00		0.00		
11/22/2012 13:00	0.06		0.07		0.17		
11/22/2012 13:10	0.00		0.00		0.00		
11/22/2012 13:20	0.00		0.00		0.00		
11/22/2012 13:30	0.00		0.00		0.00		
11/22/2012 13:40	0.00		0.00		0.00		
11/22/2012 13:50	0.00		0.00		0.00		
11/22/2012 14:00	0.00		0.00		0.00		

21 st November, 2012~25 th November, 2012							
Time	NH ₄ ⁺ concentration		NO ₃ ⁻ concentration		TN concentration		Remarks
	Simulated	Measured	Simulated	Measured	Simulated	Measured	
11/22/2012 14:10	0.00		0.00		0.00		
11/22/2012 14:20	0.00		0.00		0.00		
11/22/2012 14:30	0.02		0.03		0.07		
11/22/2012 14:40	0.00		0.00		0.00		
11/22/2012 14:50	0.00		0.00		0.00		
11/22/2012 15:00	0.00		0.00		0.00		
11/22/2012 15:10	0.04		0.06		0.12		
11/22/2012 15:20	0.00		0.00		0.00		
11/22/2012 15:30	0.00		0.00		0.00		
11/22/2012 15:40	0.00		0.00		0.00		
11/22/2012 15:50	0.00		0.00		0.00		
11/22/2012 16:00	0.00		0.00		0.00		
11/22/2012 16:10	0.00		0.00		0.00		
11/22/2012 16:20	0.00		0.00		0.00		
11/22/2012 16:30	0.00		0.00		0.00		
11/22/2012 16:40	0.00		0.00		0.00		
11/22/2012 16:50	0.00		0.00		0.00		
11/22/2012 17:00	0.14		0.24		0.40		
11/22/2012 17:10	0.16		0.30		0.48		
11/22/2012 17:20	0.00		0.00		0.00		
11/22/2012 17:30	0.00		0.00		0.00		
11/22/2012 17:40	0.12		0.22		0.35		
11/22/2012 17:50	0.14		0.27		0.42		
...							No rain
11/23/2012 1:00	0.00		0.00		0.00		
11/23/2012 1:10	0.00		0.00		0.00		
11/23/2012 1:20	0.00		0.00		0.00		
11/23/2012 1:30	0.00		0.00		0.00		
11/23/2012 1:40	7.00	9.1	2.54	2.1	17.16	17	
11/23/2012 1:50	0.00		0.00		0.00		
11/23/2012 2:00	0.00		0.00		0.00		
11/23/2012 2:10	0.00		0.00		0.00		
11/23/2012 2:20	4.20		1.64		10.38		
11/23/2012 2:30	4.02		1.59		9.95		
11/23/2012 2:40	0.00		0.00		0.00		
11/23/2012 2:50	0.00		0.00		0.00		
11/23/2012 8:00	0.00		0.00		0.00		

21 st November, 2012~25 th November, 2012							
Time	NH ₄ ⁺ concentration		NO ₃ ⁻ concentration		TN concentration		Remarks
	Simulated	Measured	Simulated	Measured	Simulated	Measured	
11/23/2012 8:10	0.00		0.00		0.00		
11/23/2012 8:20	0.00		0.00		0.00		
11/23/2012 8:30	0.00		0.00		0.00		
11/23/2012 8:40	0.00		0.00		0.00		
11/23/2012 8:50	0.00		0.00		0.00		
11/23/2012 9:00	0.00		0.00		0.00		
11/23/2012 9:10	0.00		0.00		0.00		
11/23/2012 9:20	0.00		0.00		0.00		
11/23/2012 9:30	0.00		0.00		0.00		
11/23/2012 9:40	0.00		0.00		0.00		
11/23/2012 9:50	0.00		0.00		0.00		
11/23/2012 10:00	0.00		0.00		0.00		
11/23/2012 10:10	0.82		0.72		2.21		
11/23/2012 10:20	0.00		0.00		0.00		
11/23/2012 10:30	0.00		0.00		0.00		
11/23/2012 10:40	0.00		0.00		0.00		
11/23/2012 10:50	0.00		0.00		0.00		
11/23/2012 11:00	0.50		0.48		1.36		
11/23/2012 11:10	0.00		0.00		0.00		
11/23/2012 11:20	0.00		0.00		0.00		
11/23/2012 11:30	0.00		0.00		0.00		
11/23/2012 11:40	0.00		0.00		0.00		
11/23/2012 11:50	0.00		0.00		0.00		
11/23/2012 12:00	0.00		0.00		0.00		
11/23/2012 12:10	0.00		0.00		0.00		
11/23/2012 12:20	0.00		0.00		0.00		
11/23/2012 12:30	0.00		0.00		0.00		
11/23/2012 12:40	0.00		0.00		0.00		
11/23/2012 12:50	0.37		0.44		1.04		
11/23/2012 13:00	0.45		0.53		1.26		
11/23/2012 13:10	0.00		0.00		0.00		
11/23/2012 13:20	0.23		0.29		0.66		
11/23/2012 13:30	0.28		0.35		0.79		
11/23/2012 13:40	0.17		0.21		0.47		
11/23/2012 13:50	0.00		0.00		0.00		
11/23/2012 14:00	0.00		0.00		0.00		
...							No rain

21 st November, 2012~25 th November, 2012							
Time	NH ₄ ⁺ concentration		NO ₃ ⁻ concentration		TN concentration		Remarks
	Simulated	Measured	Simulated	Measured	Simulated	Measured	
11/25/2012 4:00	0.00		0.00		0.00		
11/25/2012 4:10	0.00		0.00		0.00		
11/25/2012 4:20	0.00		0.00		0.00		
11/25/2012 4:30	0.00		0.00		0.00		
11/25/2012 4:40	0.00		0.00		0.00		
11/25/2012 4:50	2.46	0.7	1.29	0.5	6.30	2	
11/25/2012 5:00	2.35		1.25		6.03		
11/25/2012 5:10	0.00		0.00		0.00		
11/25/2012 5:20	0.00		0.00		0.00		
11/25/2012 5:30	0.00		0.00		0.00		
11/25/2012 5:40	0.00		0.00		0.00		
11/25/2012 5:50	0.09		0.05		0.22		
11/25/2012 6:00	0.05		0.03		0.12		
11/25/2012 6:10	0.01		0.01		0.02		
11/25/2012 6:20	0.02		0.01		0.05		
11/25/2012 6:30	0.01		0.01		0.03		
11/25/2012 6:40	0.01		0.00		0.02		
11/25/2012 6:50	0.01		0.01		0.02		
11/25/2012 7:00	0.02		0.01		0.06		
11/25/2012 7:10	0.02		0.01		0.05		
11/25/2012 7:20	0.01		0.01		0.03		
11/25/2012 7:30	0.00		0.00		0.00		
11/25/2012 7:40	0.01		0.00		0.01		
11/25/2012 7:50	0.01		0.00		0.01		
...							No rain
11/25/2012 14:00	0.00		0.00		0.00		
11/25/2012 14:10	0.00		0.00		0.00		
11/25/2012 14:20	0.00		0.00		0.00		
11/25/2012 14:30	0.00		0.00		0.00		
11/25/2012 14:40	0.00		0.00		0.00		
11/25/2012 14:50	0.02		0.02		0.05		
11/25/2012 15:00	0.00		0.01		0.01		
11/25/2012 15:10	0.01		0.01		0.02		
11/25/2012 15:20	0.01		0.01		0.02		
11/25/2012 15:30	0.01		0.02		0.03		
11/25/2012 15:40	0.00		0.00		0.01		
11/25/2012 15:50	0.00		0.00		0.01		

21 st November, 2012~25 th November, 2012							
Time	NH ₄ ⁺ concentration		NO ₃ ⁻ concentration		TN concentration		Remarks
	Simulated	Measured	Simulated	Measured	Simulated	Measured	
11/25/2012 16:00	0.00		0.00		0.00		
11/25/2012 16:10	0.00		0.00		0.00		
11/25/2012 16:20	0.01		0.01		0.02		
11/25/2012 16:30	0.00		0.00		0.00		
11/25/2012 16:40	0.00		0.00		0.00		
11/25/2012 16:50	0.00		0.00		0.00		
11/25/2012 17:00	0.00		0.00		0.00		
11/25/2012 17:10	0.00		0.00		0.00		
11/25/2012 17:20	0.01		0.02		0.03		
11/25/2012 17:30	0.00		0.00		0.00		
11/25/2012 17:40	0.00		0.00		0.00		
11/25/2012 17:50	0.01		0.03		0.04		
11/25/2012 18:00	0.00		0.00		0.00		
11/25/2012 18:10	0.00		0.00		0.00		
11/25/2012 18:20	0.00		0.00		0.00		
11/25/2012 18:30	0.00		0.00		0.00		
11/25/2012 18:40	0.02		0.04		0.06		
11/25/2012 18:50	0.00		0.00		0.00		
11/25/2012 19:00	0.01		0.03		0.03		
11/25/2012 19:10	0.01		0.03		0.04		
11/25/2012 19:20	0.00		0.00		0.00		
11/25/2012 19:30	0.01		0.03		0.04		
11/25/2012 19:40	0.01		0.02		0.03		
11/25/2012 19:50	0.01		0.02		0.02		
11/25/2012 20:00	0.01		0.02		0.03		
11/25/2012 20:10	0.00		0.00		0.00		
11/25/2012 20:20	0.00		0.00		0.00		
11/25/2012 20:30	0.00		0.00		0.00		
11/25/2012 20:40	0.00		0.00		0.00		
11/25/2012 20:50	0.01		0.03		0.03		
11/25/2012 21:00	0.00		0.00		0.00		
11/25/2012 21:10	0.00		0.00		0.00		
11/25/2012 21:20	0.00		0.01		0.01		
11/25/2012 21:30	0.00		0.00		0.00		
11/25/2012 21:40	0.01		0.02		0.02		
11/25/2012 21:50	0.00		0.00		0.00		
11/25/2012 22:00	0.00		0.01		0.01		

21st November, 2012~25th November, 2012							
Time	NH ₄ ⁺ concentration		NO ₃ ⁻ concentration		TN concentration		Remarks
	Simulated	Measured	Simulated	Measured	Simulated	Measured	
11/25/2012 22:10	0.00		0.00		0.00		
11/25/2012 22:20	0.00		0.00		0.00		
11/25/2012 22:30	0.00		0.00		0.00		
11/25/2012 22:40	0.00		0.00		0.00		
11/25/2012 22:50	0.00		0.00		0.00		
11/25/2012 23:00	0.01		0.02		0.02		
11/25/2012 23:10	0.01		0.03		0.02		
11/25/2012 23:20	0.00		0.00		0.00		
11/25/2012 23:30	0.00		0.00		0.00		
11/25/2012 23:40	0.00		0.00		0.00		
11/25/2012 23:50	0.01		0.03		0.02

26 th , November, 2012~29 th , November, 2012							
Time	NH ₄ ⁺ concentration		NO ₃ ⁻ concentration		TN concentration		Remarks
	Simulated	Measured	Simulated	Measured	Simulated	Measured	
11/26/2012 0:00	0.00		0.00		0.00		
11/26/2012 0:10	0.00		0.00		0.00		
11/26/2012 0:20	0.00		0.00		0.00		
11/26/2012 0:30	1.54		0.52		3.77		
11/26/2012 0:40	0.00		0.00		0.00		
11/26/2012 0:50	1.18		0.41		2.89		
...							No rain
11/26/2012 4:00	0.00		0.00		0.00		
11/26/2012 4:10	0.00		0.00		0.00		
11/26/2012 4:20	0.00		0.00		0.00		
11/26/2012 4:30	0.00		0.00		0.00		
11/26/2012 4:40	0.00		0.00		0.00		
11/26/2012 4:50	0.90		0.48		2.32		
11/26/2012 5:00	0.00		0.00		0.00		
11/26/2012 5:10	0.00		0.00		0.00		
11/26/2012 5:20	0.53	0.6	0.30	0.3	1.37	1	
11/26/2012 5:30	0.00		0.00		0.00		
11/26/2012 5:40	0.00		0.00		0.00		
11/26/2012 5:50	0.00		0.00		0.00		
11/26/2012 6:00	0.00		0.00		0.00		
11/26/2012 6:10	0.00		0.00		0.00		
11/26/2012 6:20	0.00		0.00		0.00		
11/26/2012 6:30	0.00		0.00		0.00		
11/26/2012 6:40	0.46		0.30		1.20		
11/26/2012 6:50	0.00		0.00		0.00		
11/26/2012 7:00	0.00		0.00		0.00		
11/26/2012 7:10	0.00		0.00		0.00		
11/26/2012 7:20	0.00		0.00		0.00		
11/26/2012 7:30	0.00		0.00		0.00		
11/26/2012 7:40	0.00		0.00		0.00		
11/26/2012 7:50	0.00		0.00		0.00		
11/26/2012 8:00	0.00		0.00		0.00		
11/26/2012 8:10	0.00		0.00		0.00		
11/26/2012 8:20	0.00		0.00		0.00		
11/26/2012 8:30	0.00		0.00		0.00		
11/26/2012 8:40	0.00		0.00		0.00		
11/26/2012 8:50	0.00		0.00		0.00		
11/26/2012 9:00	0.00		0.00		0.00		
11/26/2012 9:10	0.29		0.25		0.79		
11/26/2012 9:20	0.00		0.00		0.00		

26 th , November, 2012~29 th , November, 2012							
Time	NH ₄ ⁺ concentration		NO ₃ ⁻ concentration		TN concentration		Remarks
	Simulated	Measured	Simulated	Measured	Simulated	Measured	
11/26/2012 9:30	0.00		0.00		0.00		
11/26/2012 9:40	0.18		0.15		0.48		
11/26/2012 9:50	0.00		0.00		0.00		
11/26/2012 10:00	0.13		0.11		0.34		
11/26/2012 10:10	0.15		0.14		0.41		
11/26/2012 10:20	0.10		0.10		0.27		
11/26/2012 10:30	0.00		0.00		0.00		
11/26/2012 10:40	0.09		0.08		0.23		
11/26/2012 10:50	0.10		0.10		0.28		
11/26/2012 11:00	0.05		0.05		0.14		
11/26/2012 11:10	0.01		0.02		0.04		
11/26/2012 11:20	0.03		0.03		0.08		
11/26/2012 11:30	0.00		0.00		0.00		
11/26/2012 11:40	0.01		0.01		0.03		
11/26/2012 11:50	0.00		0.00		0.00		
11/26/2012 12:00	0.00		0.00		0.00		
11/26/2012 12:10	0.00		0.00		0.00		
11/26/2012 12:20	0.00		0.00		0.00		
11/26/2012 12:30	0.00		0.00		0.00		
11/26/2012 12:40	0.00		0.00		0.00		
11/26/2012 12:50	0.00		0.00		0.00		
11/26/2012 13:00	0.00		0.00		0.00		
11/26/2012 13:10	0.00		0.00		0.00		
11/26/2012 13:20	0.00		0.00		0.00		
11/26/2012 13:30	0.02		0.02		0.04		
11/26/2012 13:40	0.00		0.00		0.00		
11/26/2012 13:50	0.00		0.00		0.00		
11/26/2012 14:00	0.00		0.00		0.00		
11/26/2012 14:10	0.00		0.00		0.00		
11/26/2012 14:20	0.01		0.01		0.03		
11/26/2012 14:30	0.02		0.03		0.07		
11/26/2012 14:40	0.01		0.01		0.02		
11/26/2012 14:50	0.01		0.01		0.02		
11/26/2012 15:00	0.00		0.00		0.01		
11/26/2012 15:10	0.01		0.01		0.01		
...							No rain
11/28/2012 2:10	0.00		0.00		0.00		
11/28/2012 2:20	0.00		0.00		0.00		
11/28/2012 2:30	0.00		0.00		0.00		
11/28/2012 2:40	0.00		0.00		0.00		

26th, November, 2012~29th, November, 2012							
Time	NH ₄ ⁺ concentration		NO ₃ ⁻ concentration		TN concentration		Remarks
	Simulated	Measured	Simulated	Measured	Simulated	Measured	
11/28/2012 2:50	0.00		0.00		0.00		
11/28/2012 3:00	0.00		0.00		0.00		
11/28/2012 3:10	0.00		0.00		0.00		
11/28/2012 3:20	0.00		0.00		0.00		
11/28/2012 3:30	0.00		0.00		0.00		
11/28/2012 3:40	0.13	0.2	0.06	0.1	0.32	0	
11/28/2012 3:50	0.08		0.04		0.19		
11/28/2012 4:00	0.06		0.03		0.16		
11/28/2012 4:10	0.07		0.04		0.18		
11/28/2012 4:20	0.01		0.00		0.02		
11/28/2012 4:30	0.00		0.00		0.00		
11/28/2012 4:40	0.00		0.00		0.00		
11/28/2012 4:50	0.00		0.00		0.01		
11/28/2012 5:00	0.00		0.00		0.00		
11/28/2012 5:10	0.00		0.00		0.01		
11/28/2012 5:20	0.00		0.00		0.00		
...							No rain
11/28/2012 10:20	0.00		0.00		0.01		
11/28/2012 10:30	0.00		0.00		0.01		
11/28/2012 10:40	0.00		0.00		0.01		
11/28/2012 10:50	0.00		0.00		0.00		
11/28/2012 11:00	0.01		0.01		0.01		
11/28/2012 11:10	0.01		0.01		0.02		
11/28/2012 11:20	0.00		0.00		0.00		
11/28/2012 11:30	0.01		0.01		0.02		
11/28/2012 11:40	0.01		0.01		0.02		
11/28/2012 11:50	0.01		0.01		0.02		
11/28/2012 12:00	0.00		0.00		0.00		
11/28/2012 12:10	0.00		0.00		0.00		
11/28/2012 12:20	0.01		0.01		0.02		
11/28/2012 12:30	0.00		0.00		0.00		
11/28/2012 12:40	0.01		0.01		0.02		
11/28/2012 12:50	0.00		0.00		0.00		
11/28/2012 13:00	0.01		0.01		0.02		
11/28/2012 13:10	0.02		0.02		0.05		
11/28/2012 13:20	0.00		0.00		0.00		
11/28/2012 13:30	0.01		0.01		0.02		
11/28/2012 13:40	0.02		0.03		0.05		
11/28/2012 13:50	0.01		0.01		0.02		
11/28/2012 14:00	0.01		0.01		0.02		

26th, November, 2012~29th, November, 2012							
Time	NH ₄ ⁺ concentration		NO ₃ ⁻ concentration		TN concentration		Remarks
	Simulated	Measured	Simulated	Measured	Simulated	Measured	
11/28/2012 14:10	0.01		0.01		0.02		
11/28/2012 14:20	0.01		0.01		0.02		
11/28/2012 14:30	0.00		0.00		0.00		
11/28/2012 14:40	0.01		0.01		0.02		
11/28/2012 14:50	0.01		0.01		0.02		
11/28/2012 15:00	0.01		0.01		0.01		
11/28/2012 15:10	0.01		0.01		0.02		
11/28/2012 15:20	0.00		0.00		0.00		
11/28/2012 15:30	0.00		0.00		0.00		
...							No rain
11/28/2012 18:10	0.00		0.00		0.00		
11/28/2012 18:20	0.00		0.00		0.00		
11/28/2012 18:30	0.00		0.00		0.00		
11/28/2012 18:40	0.00		0.01		0.01		
11/28/2012 18:50	0.00		0.00		0.00		
11/28/2012 19:00	0.00		0.00		0.00		
11/28/2012 19:10	0.00		0.00		0.00		
11/28/2012 19:20	0.00		0.00		0.01		
11/28/2012 19:30	0.00		0.00		0.00		
...							No rain
11/29/2012 0:00	0.00		0.00		0.00		
11/29/2012 0:10	0.04	0.1	0.01	0	0.10	0	
11/29/2012 0:20	0.00		0.00		0.00		
11/29/2012 0:30	0.00		0.00		0.00		
11/29/2012 0:40	0.00		0.00		0.00		
11/29/2012 0:50	0.02		0.01		0.04		
11/29/2012 1:00	0.02		0.01		0.05		
11/29/2012 1:10	0.02		0.01		0.05		
11/29/2012 1:20	0.00		0.00		0.00		
11/29/2012 1:30	0.00		0.00		0.00		
11/29/2012 1:40	0.00		0.00		0.00		
11/29/2012 1:50	0.02		0.01		0.04		
11/29/2012 2:00	0.01		0.00		0.02		
11/29/2012 2:10	0.00		0.00		0.00		
11/29/2012 2:20	0.00		0.00		0.01		
11/29/2012 2:30	0.00		0.00		0.00		
...							No rain
11/29/2012 4:50	0.00		0.00		0.00		
11/29/2012 5:00	0.00		0.00		0.00		
11/29/2012 5:10	0.00		0.00		0.00		

26th, November, 2012~29th, November, 2012							
Time	NH ₄ ⁺ concentration		NO ₃ ⁻ concentration		TN concentration		Remarks
	Simulated	Measured	Simulated	Measured	Simulated	Measured	
11/29/2012 5:20	0.00		0.00		0.00		
11/29/2012 5:30	0.03		0.02		0.08		
11/29/2012 5:40	0.00		0.00		0.00		
11/29/2012 5:50	0.00		0.00		0.00		
11/29/2012 6:00	0.00		0.00		0.00		
...							No rain
11/29/2012 8:00	0.00		0.00		0.00		
11/29/2012 8:10	0.02		0.01		0.05		
11/29/2012 8:20	0.00		0.00		0.00		
11/29/2012 8:30	0.00		0.00		0.00		
11/29/2012 8:40	0.00		0.00		0.00		
11/29/2012 8:50	0.00		0.00		0.00		
...							No rain
11/29/2012 12:00	0.00		0.00		0.00		
11/29/2012 12:10	0.00		0.00		0.00		
11/29/2012 12:20	0.00		0.00		0.00		
11/29/2012 12:30	0.00		0.00		0.00		
11/29/2012 12:40	0.01		0.01		0.02		
11/29/2012 12:50	0.00		0.00		0.00		
11/29/2012 13:00	0.00		0.00		0.00		
11/29/2012 13:10	0.00		0.00		0.00		
11/29/2012 13:20	0.00		0.00		0.00		
11/29/2012 13:30	0.00		0.00		0.00		
11/29/2012 13:40	0.00		0.00		0.00		
11/29/2012 13:50	0.00		0.00		0.00		
11/29/2012 14:00	0.00		0.00		0.00		
11/29/2012 14:10	0.00		0.01		0.01		
11/29/2012 14:20	0.00		0.00		0.00		
11/29/2012 14:30	0.00		0.00		0.00		
11/29/2012 14:40	0.00		0.00		0.00		
11/29/2012 14:50	0.00		0.00		0.00		
11/29/2012 15:00	0.00		0.00		0.00		
11/29/2012 15:10	0.00		0.00		0.00		
11/29/2012 15:20	0.00		0.00		0.00		
11/29/2012 15:30	0.00		0.00		0.00		
11/29/2012 15:40	0.00		0.00		0.00		
11/29/2012 15:50	0.00		0.00		0.00		
11/29/2012 16:00	0.00		0.00		0.00		
11/29/2012 16:10	0.00		0.00		0.00		
11/29/2012 16:20	0.00		0.00		0.00		

26th, November, 2012~29th, November, 2012							
Time	NH ₄ ⁺ concentration		NO ₃ ⁻ concentration		TN concentration		Remarks
	Simulated	Measured	Simulated	Measured	Simulated	Measured	
11/29/2012 16:30	0.00		0.00		0.00		
11/29/2012 16:40	0.00		0.00		0.00		
11/29/2012 16:50	0.00		0.00		0.01		
11/29/2012 17:00	0.00		0.00		0.00		
11/29/2012 17:10	0.00		0.00		0.00		
11/29/2012 17:20	0.00		0.00		0.00		
11/29/2012 17:30	0.00		0.00		0.00		
11/29/2012 17:40	0.00		0.00		0.00		
11/29/2012 17:50	0.00		0.00		0.00		
11/29/2012 18:00	0.00		0.00		0.00		
11/29/2012 18:10	0.00		0.00		0.00		
11/29/2012 18:20	0.00		0.00		0.00

NO_3^-

TN

Appendix H. Comparison of the simulated and measured TP concentrations in the controlled outdoor experiments

30 th , April,2012~13 th , May,2012					
Time	TP concentration		Time	TP concentration	
	Simulated	Measured		Simulated	Measured
4/30/2012 0:00	0.00		5/7/2012 0:00	0.00	
4/30/2012 0:10	0.00		5/7/2012 0:10	0.88	
4/30/2012 0:20	0.00		5/7/2012 0:20	0.75	
4/30/2012 0:30	0.00		5/7/2012 0:30	0.65	
4/30/2012 0:40	0.00		5/7/2012 0:40	0.56	
4/30/2012 0:50	0.00		5/7/2012 0:50	0.49	
4/30/2012 1:00	0.00		5/7/2012 1:00	0.43	
4/30/2012 1:10	0.00		5/7/2012 1:10	0.38	
4/30/2012 1:20	0.00		5/7/2012 1:20	0.34	
4/30/2012 1:30	0.00		5/7/2012 1:30	0.31	
4/30/2012 1:40	0.00		5/7/2012 1:40	0.28	
4/30/2012 1:50	0.00		5/7/2012 1:50	0.25	
4/30/2012 2:00	0.00		5/7/2012 2:00	0.23	
4/30/2012 2:10	0.00		5/7/2012 2:10	0.21	
4/30/2012 2:20	0.00		5/7/2012 2:20	0.19	
4/30/2012 2:30	0.00		5/7/2012 2:30	0.18	
4/30/2012 2:40	0.00		5/7/2012 2:40	0.16	
4/30/2012 2:50	0.00		5/7/2012 2:50	0.15	
4/30/2012 3:00	0.00		5/7/2012 3:00	0.14	
4/30/2012 3:10	0.00		5/7/2012 3:10	0.13	
4/30/2012 3:20	0.00		5/7/2012 3:20	0.12	
4/30/2012 3:30	0.00		5/7/2012 3:30	0.11	
4/30/2012 3:40	0.00		5/7/2012 3:40	0.11	
4/30/2012 3:50	0.00		5/7/2012 3:50	0.10	
4/30/2012 4:00	0.00		5/7/2012 4:00	0.10	
4/30/2012 4:10	0.00		5/7/2012 4:10	0.09	
4/30/2012 4:20	0.00		5/7/2012 4:20	0.09	
4/30/2012 4:30	0.00		5/7/2012 4:30	0.08	
4/30/2012 4:40	0.00		5/7/2012 4:40	0.08	
4/30/2012 4:50	0.00		5/7/2012 4:50	0.07	
4/30/2012 5:00	0.00		5/7/2012 5:00	0.07	
4/30/2012 5:10	0.00		5/7/2012 5:10	0.07	
4/30/2012 5:20	0.00		5/7/2012 5:20	0.06	
4/30/2012 5:30	0.00		5/7/2012 5:30	0.06	
4/30/2012 5:40	0.00		5/7/2012 5:40	0.75	

30 th , April,2012~13 th , May,2012					
Time	TP concentration		Time	TP concentration	
	Simulated	Measured		Simulated	Measured
4/30/2012 5:50	0.00		5/7/2012 5:50	0.72	
4/30/2012 6:00	0.00		5/7/2012 6:00	0.72	
4/30/2012 6:10	0.00		5/7/2012 6:10	0.75	
4/30/2012 6:20	0.00		5/7/2012 6:20	0.91	
4/30/2012 6:30	0.00		5/7/2012 6:30	0.87	
4/30/2012 6:40	0.00		5/7/2012 6:40	0.84	
4/30/2012 6:50	0.00		5/7/2012 6:50	0.81	
4/30/2012 7:00	0.00		5/7/2012 7:00	0.78	
4/30/2012 7:10	0.00		5/7/2012 7:10	0.75	
4/30/2012 7:20	7.36	7.56	5/7/2012 7:20	0.72	
4/30/2012 7:30	4.89		5/7/2012 7:30	0.70	
4/30/2012 7:40	5.59		5/7/2012 7:40	0.69	
4/30/2012 7:50	0.48		5/7/2012 7:50	0.67	
4/30/2012 8:00	0.36		5/7/2012 8:00	0.66	
4/30/2012 8:10	0.29		5/7/2012 8:10	0.65	
4/30/2012 8:20	0.25		5/7/2012 8:20	0.63	
4/30/2012 8:30	0.22		5/7/2012 8:30	0.61	
4/30/2012 8:40	0.19		5/7/2012 8:40	0.59	
4/30/2012 8:50	0.17		5/7/2012 8:50	0.57	
4/30/2012 9:00	0.16		5/7/2012 9:00	0.56	
4/30/2012 9:10	0.15		5/7/2012 9:10	0.54	
4/30/2012 9:20	0.13		5/7/2012 9:20	0.53	
4/30/2012 9:30	0.12		5/7/2012 9:30	0.51	
4/30/2012 9:40	0.12		5/7/2012 9:40	0.49	
4/30/2012 9:50	0.11		5/7/2012 9:50	0.48	
4/30/2012 10:00	0.10		5/7/2012 10:00	0.47	
4/30/2012 10:10	0.10		5/7/2012 10:10	0.45	
4/30/2012 10:20	0.09		5/7/2012 10:20	0.44	
4/30/2012 10:30	0.09		5/7/2012 10:30	0.43	
4/30/2012 10:40	0.08		5/7/2012 10:40	0.42	
4/30/2012 10:50	0.08		5/7/2012 10:50	0.40	
4/30/2012 11:00	0.07		5/7/2012 11:00	0.39	0.41
4/30/2012 11:10	0.07		5/7/2012 11:10	0.38	
4/30/2012 11:20	0.07		5/7/2012 11:20	0.37	
4/30/2012 11:30	0.06		5/7/2012 11:30	0.36	

30 th , April,2012~13 th , May,2012					
Time	TP concentration		Time	TP concentration	
	Simulated	Measured		Simulated	Measured
4/30/2012 11:40	0.06		5/7/2012 11:40	0.35	
4/30/2012 11:50	0.06		5/7/2012 11:50	0.34	
4/30/2012 12:00	0.06		5/7/2012 12:00	0.33	
4/30/2012 12:10	0.05		5/7/2012 12:10	0.32	
4/30/2012 12:20	0.05		5/7/2012 12:20	0.31	
4/30/2012 12:30	0.05		5/7/2012 12:30	0.31	
4/30/2012 12:40	0.06		5/7/2012 12:40	0.30	
4/30/2012 12:50	0.06		5/7/2012 12:50	0.29	
4/30/2012 13:00	0.06		5/7/2012 13:00	0.28	
4/30/2012 13:10	0.05		5/7/2012 13:10	0.27	
4/30/2012 13:20	0.05		5/7/2012 13:20	0.27	
4/30/2012 13:30	0.05		5/7/2012 13:30	0.26	
4/30/2012 13:40	0.05		5/7/2012 13:40	0.25	
4/30/2012 13:50	0.05		5/7/2012 13:50	0.25	
4/30/2012 14:00	0.05		5/7/2012 14:00	0.24	
4/30/2012 14:10	0.04		5/7/2012 14:10	0.23	
4/30/2012 14:20	0.04		5/7/2012 14:20	0.23	
4/30/2012 14:30	0.04		5/7/2012 14:30	0.22	
4/30/2012 14:40	0.04		5/7/2012 14:40	0.21	
4/30/2012 14:50	0.04		5/7/2012 14:50	0.21	
4/30/2012 15:00	0.04		5/7/2012 15:00	0.20	
4/30/2012 15:10	0.04		5/7/2012 15:10	0.20	
4/30/2012 15:20	0.04		5/7/2012 15:20	0.19	
4/30/2012 15:30	0.03		5/7/2012 15:30	0.19	
4/30/2012 15:40	0.03		5/7/2012 15:40	0.18	
4/30/2012 15:50	0.03		5/7/2012 15:50	0.18	
4/30/2012 16:00	0.03		5/7/2012 16:00	0.17	
4/30/2012 16:10	0.03		5/7/2012 16:10	0.17	
4/30/2012 16:20	0.03		5/7/2012 16:20	0.16	
4/30/2012 16:30	0.03		5/7/2012 16:30	0.16	
4/30/2012 16:40	0.03		5/7/2012 16:40	0.15	
4/30/2012 16:50	0.03		5/7/2012 16:50	0.15	
4/30/2012 17:00	0.03		5/7/2012 17:00	0.15	
4/30/2012 17:10	0.03		5/7/2012 17:10	0.14	
4/30/2012 17:20	0.02		5/7/2012 17:20	0.14	

30 th , April,2012~13 th , May,2012					
Time	TP concentration		Time	TP concentration	
	Simulated	Measured		Simulated	Measured
4/30/2012 17:30	0.02		5/7/2012 17:30	0.14	
4/30/2012 17:40	0.02		5/7/2012 17:40	0.13	
4/30/2012 17:50	0.02		5/7/2012 17:50	0.13	
4/30/2012 18:00	0.02		5/7/2012 18:00	0.12	
4/30/2012 18:10	0.02		5/7/2012 18:10	0.12	
4/30/2012 18:20	0.02		5/7/2012 18:20	0.12	
4/30/2012 18:30	0.02		5/7/2012 18:30	0.11	
4/30/2012 18:40	0.02		5/7/2012 18:40	0.11	
4/30/2012 18:50	0.02		5/7/2012 18:50	0.11	
4/30/2012 19:00	0.02		5/7/2012 19:00	0.11	
4/30/2012 19:10	0.02		5/7/2012 19:10	0.10	
4/30/2012 19:20	0.02		5/7/2012 19:20	0.10	
4/30/2012 19:30	0.02		5/7/2012 19:30	0.10	
4/30/2012 19:40	0.02		5/7/2012 19:40	0.10	
4/30/2012 19:50	0.02		5/7/2012 19:50	0.09	
4/30/2012 20:00	0.02		5/7/2012 20:00	0.09	
4/30/2012 20:10	0.02		5/7/2012 20:10	0.09	
4/30/2012 20:20	0.01		5/7/2012 20:20	0.09	
4/30/2012 20:30	0.01		5/7/2012 20:30	0.08	
4/30/2012 20:40	0.01		5/7/2012 20:40	0.08	
4/30/2012 20:50	0.01		5/7/2012 20:50	0.08	
4/30/2012 21:00	0.01		5/7/2012 21:00	0.08	
4/30/2012 21:10	0.01		5/7/2012 21:10	0.07	
4/30/2012 21:20	0.01		5/7/2012 21:20	0.07	
4/30/2012 21:30	0.01		5/7/2012 21:30	0.07	
4/30/2012 21:40	0.01		5/7/2012 21:40	0.07	
4/30/2012 21:50	0.01		5/7/2012 21:50	0.07	
4/30/2012 22:00	0.01		5/7/2012 22:00	0.07	
4/30/2012 22:10	0.01		5/7/2012 22:10	0.06	
4/30/2012 22:20	0.01		5/7/2012 22:20	0.06	
4/30/2012 22:30	0.01		5/7/2012 22:30	0.06	
4/30/2012 22:40	0.01		5/7/2012 22:40	0.06	
4/30/2012 22:50	0.01		5/7/2012 22:50	0.06	
4/30/2012 23:00	0.01		5/7/2012 23:00	0.06	
4/30/2012 23:10	0.01		5/7/2012 23:10	0.05	

30 th , April,2012~13 th , May,2012					
Time	TP concentration		Time	TP concentration	
	Simulated	Measured		Simulated	Measured
4/30/2012 23:20	0.01		5/7/2012 23:20	0.05	
4/30/2012 23:30	0.01		5/7/2012 23:30	0.05	
4/30/2012 23:40	0.01		5/7/2012 23:40	0.05	
4/30/2012 23:50	0.01		5/7/2012 23:50	0.05	
5/2/2012 0:00	0.00		5/9/2012 0:00	0.00	
5/2/2012 0:10	0.18		5/9/2012 0:10	0.00	
5/2/2012 0:20	0.13		5/9/2012 0:20	0.00	
5/2/2012 0:30	0.10		5/9/2012 0:30	0.00	
5/2/2012 0:40	0.08		5/9/2012 0:40	0.00	
5/2/2012 0:50	0.06		5/9/2012 0:50	0.00	
5/2/2012 1:00	0.05		5/9/2012 1:00	0.00	
5/2/2012 1:10	0.04		5/9/2012 1:10	0.00	
5/2/2012 1:20	0.03		5/9/2012 1:20	0.00	
5/2/2012 1:30	0.03		5/9/2012 1:30	0.00	
5/2/2012 1:40	0.02		5/9/2012 1:40	0.00	
5/2/2012 1:50	0.02		5/9/2012 1:50	0.00	
5/2/2012 2:00	0.02		5/9/2012 2:00	0.00	
5/2/2012 2:10	0.01		5/9/2012 2:10	0.18	0.37
5/2/2012 2:20	0.01		5/9/2012 2:20	0.17	
5/2/2012 2:30	0.01		5/9/2012 2:30	0.16	
5/2/2012 2:40	0.01		5/9/2012 2:40	0.15	
5/2/2012 2:50	0.01		5/9/2012 2:50	0.14	
5/2/2012 3:00	0.01		5/9/2012 3:00	0.13	
5/2/2012 3:10	0.01		5/9/2012 3:10	0.12	
5/2/2012 3:20	0.01		5/9/2012 3:20	0.11	
5/2/2012 3:30	0.01		5/9/2012 3:30	0.11	
5/2/2012 3:40	0.01		5/9/2012 3:40	0.10	
5/2/2012 3:50	0.00		5/9/2012 3:50	0.09	
5/2/2012 4:00	0.00		5/9/2012 4:00	0.09	
5/2/2012 4:10	0.00		5/9/2012 4:10	0.09	
5/2/2012 4:20	0.00		5/9/2012 4:20	0.09	
5/2/2012 4:30	0.00		5/9/2012 4:30	0.08	
5/2/2012 4:40	0.00		5/9/2012 4:40	0.08	
5/2/2012 4:50	0.00		5/9/2012 4:50	0.08	
5/2/2012 5:00	0.00		5/9/2012 5:00	0.07	

30 th , April,2012~13 th , May,2012					
Time	TP concentration		Time	TP concentration	
	Simulated	Measured		Simulated	Measured
5/2/2012 5:10	0.00		5/9/2012 5:10	0.07	
5/2/2012 5:20	0.00		5/9/2012 5:20	0.07	
5/2/2012 5:30	0.00		5/9/2012 5:30	0.07	
5/2/2012 5:40	0.00		5/9/2012 5:40	0.06	
5/2/2012 5:50	0.00		5/9/2012 5:50	0.06	
5/2/2012 6:00	0.00		5/9/2012 6:00	0.06	
5/2/2012 6:10	0.00		5/9/2012 6:10	0.06	
5/2/2012 6:20	0.00		5/9/2012 6:20	0.06	
5/2/2012 6:30	0.00		5/9/2012 6:30	0.05	
5/2/2012 6:40	0.00		5/9/2012 6:40	0.05	
5/2/2012 6:50	0.00		5/9/2012 6:50	0.05	
5/2/2012 7:00	0.00		5/9/2012 7:00	0.05	
5/2/2012 7:10	0.00		5/9/2012 7:10	0.05	
5/2/2012 7:20	0.00		5/9/2012 7:20	0.05	
5/2/2012 7:30	0.00		5/9/2012 7:30	0.04	
5/2/2012 7:40	0.00		5/9/2012 7:40	0.04	
5/2/2012 7:50	0.00		5/9/2012 7:50	0.04	
5/2/2012 8:00	0.00		5/9/2012 8:00	0.04	
5/2/2012 8:10	0.00		5/9/2012 8:10	0.04	
5/2/2012 8:20	0.00		5/9/2012 8:20	0.04	
5/2/2012 8:30	1.18		5/9/2012 8:30	0.04	
5/2/2012 8:40	1.18		5/9/2012 8:40	0.04	
5/2/2012 8:50	1.67		5/9/2012 8:50	0.04	
5/2/2012 9:00	1.60		5/9/2012 9:00	0.03	
5/2/2012 9:10	1.59		5/9/2012 9:10	0.03	
5/2/2012 9:20	1.53		5/9/2012 9:20	0.03	
5/2/2012 9:30	1.62		5/9/2012 9:30	0.03	
5/2/2012 9:40	1.56		5/9/2012 9:40	0.03	
5/2/2012 9:50	1.51		5/9/2012 9:50	0.03	
5/2/2012 10:00	1.45		5/9/2012 10:00	0.03	
5/2/2012 10:10	1.41		5/9/2012 10:10	0.05	
5/2/2012 10:20	1.36		5/9/2012 10:20	0.05	
5/2/2012 10:30	1.32		5/9/2012 10:30	0.05	
5/2/2012 10:40	1.28		5/9/2012 10:40	0.05	
5/2/2012 10:50	1.24		5/9/2012 10:50	0.05	

30 th , April,2012~13 th , May,2012					
Time	TP concentration		Time	TP concentration	
	Simulated	Measured		Simulated	Measured
5/2/2012 11:00	1.20		5/9/2012 11:00	0.04	
5/2/2012 11:10	1.17		5/9/2012 11:10	0.04	
5/2/2012 11:20	1.13		5/9/2012 11:20	0.04	
5/2/2012 11:30	1.10		5/9/2012 11:30	0.04	
5/2/2012 11:40	1.07		5/9/2012 11:40	0.04	
5/2/2012 11:50	1.04		5/9/2012 11:50	0.04	
5/2/2012 12:00	1.01		5/9/2012 12:00	0.04	
5/2/2012 12:10	0.98		5/9/2012 12:10	0.04	
5/2/2012 12:20	0.96		5/9/2012 12:20	0.04	
5/2/2012 12:30	0.93		5/9/2012 12:30	0.03	
5/2/2012 12:40	0.90		5/9/2012 12:40	0.03	
5/2/2012 12:50	0.88		5/9/2012 12:50	0.03	
5/2/2012 13:00	0.85		5/9/2012 13:00	0.03	
5/2/2012 13:10	0.83		5/9/2012 13:10	0.03	
5/2/2012 13:20	0.81		5/9/2012 13:20	0.03	
5/2/2012 13:30	0.79		5/9/2012 13:30	0.03	
5/2/2012 13:40	0.76		5/9/2012 13:40	0.03	
5/2/2012 13:50	0.74		5/9/2012 13:50	0.03	
5/2/2012 14:00	0.72		5/9/2012 14:00	0.03	
5/2/2012 14:10	0.70		5/9/2012 14:10	0.03	
5/2/2012 14:20	0.68		5/9/2012 14:20	0.03	
5/2/2012 14:30	0.67		5/9/2012 14:30	0.03	
5/2/2012 14:40	0.65		5/9/2012 14:40	0.02	
5/2/2012 14:50	0.63		5/9/2012 14:50	0.02	
5/2/2012 15:00	0.61		5/9/2012 15:00	0.02	
5/2/2012 15:10	0.60		5/9/2012 15:10	0.02	
5/2/2012 15:20	0.58		5/9/2012 15:20	0.02	
5/2/2012 15:30	0.57		5/9/2012 15:30	0.02	
5/2/2012 15:40	0.55		5/9/2012 15:40	0.02	
5/2/2012 15:50	0.54		5/9/2012 15:50	0.02	
5/2/2012 16:00	0.52		5/9/2012 16:00	0.02	
5/2/2012 16:10	0.51		5/9/2012 16:10	0.02	
5/2/2012 16:20	0.49		5/9/2012 16:20	0.02	
5/2/2012 16:30	0.48		5/9/2012 16:30	0.02	
5/2/2012 16:40	0.47		5/9/2012 16:40	0.02	

30 th , April,2012~13 th , May,2012					
Time	TP concentration		Time	TP concentration	
	Simulated	Measured		Simulated	Measured
5/2/2012 16:50	0.45		5/9/2012 16:50	0.02	
5/2/2012 17:00	0.44		5/9/2012 17:00	0.02	
5/2/2012 17:10	0.43		5/9/2012 17:10	0.02	
5/2/2012 17:20	0.42		5/9/2012 17:20	0.02	
5/2/2012 17:30	1.71		5/9/2012 17:30	0.02	
5/2/2012 17:40	1.75	4.12	5/9/2012 17:40	0.02	
5/2/2012 17:50	1.65		5/9/2012 17:50	0.01	
5/2/2012 18:00	1.58		5/9/2012 18:00	0.01	
5/2/2012 18:10	1.52		5/9/2012 18:10	0.01	
5/2/2012 18:20	1.47		5/9/2012 18:20	0.01	
5/2/2012 18:30	1.42		5/9/2012 18:30	0.01	
5/2/2012 18:40	1.38		5/9/2012 18:40	0.01	
5/2/2012 18:50	1.35		5/9/2012 18:50	0.01	
5/2/2012 19:00	1.31		5/9/2012 19:00	0.01	
5/2/2012 19:10	1.28		5/9/2012 19:10	0.01	
5/2/2012 19:20	1.25		5/9/2012 19:20	0.01	
5/2/2012 19:30	1.22		5/9/2012 19:30	0.01	
5/2/2012 19:40	1.19		5/9/2012 19:40	0.01	
5/2/2012 19:50	1.16		5/9/2012 19:50	0.01	
5/2/2012 20:00	1.14		5/9/2012 20:00	0.01	
5/2/2012 20:10	1.11		5/9/2012 20:10	0.01	
5/2/2012 20:20	1.09		5/9/2012 20:20	0.01	
5/2/2012 20:30	1.06		5/9/2012 20:30	0.01	
5/2/2012 20:40	1.04		5/9/2012 20:40	0.01	
5/2/2012 20:50	1.01		5/9/2012 20:50	0.01	
5/2/2012 21:00	0.99		5/9/2012 21:00	0.01	
5/2/2012 21:10	0.97		5/9/2012 21:10	0.01	
5/2/2012 21:20	0.94		5/9/2012 21:20	0.01	
5/2/2012 21:30	0.92		5/9/2012 21:30	0.01	
5/2/2012 21:40	0.90		5/9/2012 21:40	0.01	
5/2/2012 21:50	0.88		5/9/2012 21:50	0.01	
5/2/2012 22:00	0.85		5/9/2012 22:00	0.01	
5/2/2012 22:10	0.83		5/9/2012 22:10	0.01	
5/2/2012 22:20	0.81		5/9/2012 22:20	0.01	
5/2/2012 22:30	0.79		5/9/2012 22:30	0.01	

30 th , April,2012~13 th , May,2012					
Time	TP concentration		Time	TP concentration	
	Simulated	Measured		Simulated	Measured
5/2/2012 22:40	0.77		5/9/2012 22:40	0.01	
5/2/2012 22:50	0.75		5/9/2012 22:50	0.01	
5/2/2012 23:00	0.74		5/9/2012 23:00	0.01	
5/2/2012 23:10	0.72		5/9/2012 23:10	0.01	
5/2/2012 23:20	0.70		5/9/2012 23:20	0.01	
5/2/2012 23:30	0.68		5/9/2012 23:30	0.01	
5/2/2012 23:40	0.66		5/9/2012 23:40	0.01	
5/2/2012 23:50	0.65		5/9/2012 23:50	0.01	
5/5/2012 0:00	0.00		5/13/2012 0:00	0.00	
5/5/2012 0:10	0.00		5/13/2012 0:10	0.00	
5/5/2012 0:20	0.00		5/13/2012 0:20	0.00	
5/5/2012 0:30	0.00		5/13/2012 0:30	0.00	
5/5/2012 0:40	0.00		5/13/2012 0:40	0.00	
5/5/2012 0:50	0.00		5/13/2012 0:50	0.00	
5/5/2012 1:00	0.00		5/13/2012 1:00	0.00	
5/5/2012 1:10	0.64	0.83	5/13/2012 1:10	0.23	
5/5/2012 1:20	0.63		5/13/2012 1:20	0.19	
5/5/2012 1:30	0.24		5/13/2012 1:30	0.17	
5/5/2012 1:40	0.20		5/13/2012 1:40	0.15	
5/5/2012 1:50	0.10		5/13/2012 1:50	0.14	
5/5/2012 2:00	0.08		5/13/2012 2:00	0.13	0.13
5/5/2012 2:10	0.06		5/13/2012 2:10	0.12	
5/5/2012 2:20	0.05		5/13/2012 2:20	0.11	
5/5/2012 2:30	0.04		5/13/2012 2:30	0.10	
5/5/2012 2:40	0.04		5/13/2012 2:40	0.10	
5/5/2012 2:50	0.04		5/13/2012 2:50	0.10	
5/5/2012 3:00	0.04		5/13/2012 3:00	0.10	
5/5/2012 3:10	0.04		5/13/2012 3:10	0.10	
5/5/2012 3:20	0.04		5/13/2012 3:20	0.09	
5/5/2012 3:30	0.04		5/13/2012 3:30	0.09	
5/5/2012 3:40	0.04		5/13/2012 3:40	0.09	
5/5/2012 3:50	0.04		5/13/2012 3:50	0.08	
5/5/2012 4:00	0.04		5/13/2012 4:00	0.08	
5/5/2012 4:10	0.04		5/13/2012 4:10	0.08	
5/5/2012 4:20	0.04		5/13/2012 4:20	0.08	

30 th , April,2012~13 th , May,2012					
Time	TP concentration		Time	TP concentration	
	Simulated	Measured		Simulated	Measured
5/5/2012 4:30	0.04		5/13/2012 4:30	0.07	
5/5/2012 4:40	0.04		5/13/2012 4:40	0.07	
5/5/2012 4:50	0.04		5/13/2012 4:50	0.07	
5/5/2012 5:00	0.04		5/13/2012 5:00	0.07	
5/5/2012 5:10	0.04		5/13/2012 5:10	0.07	
5/5/2012 5:20	0.04		5/13/2012 5:20	0.06	
5/5/2012 5:30	0.04		5/13/2012 5:30	0.06	
5/5/2012 5:40	0.04		5/13/2012 5:40	0.06	
5/5/2012 5:50	0.04		5/13/2012 5:50	0.06	
5/5/2012 6:00	0.04		5/13/2012 6:00	0.06	
5/5/2012 6:10	0.04		5/13/2012 6:10	0.05	
5/5/2012 6:20	0.04		5/13/2012 6:20	0.05	
5/5/2012 6:30	0.04		5/13/2012 6:30	0.05	
5/5/2012 6:40	0.04		5/13/2012 6:40	0.05	
5/5/2012 6:50	0.04		5/13/2012 6:50	0.05	
5/5/2012 7:00	0.04		5/13/2012 7:00	0.05	
5/5/2012 7:10	0.04		5/13/2012 7:10	0.05	
5/5/2012 7:20	0.04		5/13/2012 7:20	0.05	
5/5/2012 7:30	0.04		5/13/2012 7:30	0.05	
5/5/2012 7:40	0.04		5/13/2012 7:40	0.05	
5/5/2012 7:50	0.04		5/13/2012 7:50	0.05	
5/5/2012 8:00	0.04		5/13/2012 8:00	0.04	
5/5/2012 8:10	0.04		5/13/2012 8:10	0.04	
5/5/2012 8:20	0.04		5/13/2012 8:20	0.04	
5/5/2012 8:30	0.04		5/13/2012 8:30	0.04	
5/5/2012 8:40	0.04		5/13/2012 8:40	0.04	
5/5/2012 8:50	0.04		5/13/2012 8:50	0.04	
5/5/2012 9:00	0.04		5/13/2012 9:00	0.04	
5/5/2012 9:10	0.03		5/13/2012 9:10	0.04	
5/5/2012 9:20	0.03		5/13/2012 9:20	0.04	
5/5/2012 9:30	0.03		5/13/2012 9:30	0.03	
5/5/2012 9:40	0.03		5/13/2012 9:40	0.03	
5/5/2012 9:50	0.03		5/13/2012 9:50	0.03	
5/5/2012 10:00	0.03		5/13/2012 10:00	0.03	
5/5/2012 10:10	0.03		5/13/2012 10:10	0.03	

30 th , April,2012~13 th , May,2012					
Time	TP concentration		Time	TP concentration	
	Simulated	Measured		Simulated	Measured
5/5/2012 10:20	0.03		5/13/2012 10:20	0.03	
5/5/2012 10:30	0.03		5/13/2012 10:30	0.03	
5/5/2012 10:40	0.03		5/13/2012 10:40	0.03	
5/5/2012 10:50	0.03		5/13/2012 10:50	0.03	
5/5/2012 11:00	0.03		5/13/2012 11:00	0.03	
5/5/2012 11:10	0.03		5/13/2012 11:10	0.03	
5/5/2012 11:20	0.03		5/13/2012 11:20	0.03	
5/5/2012 11:30	0.03		5/13/2012 11:30	0.03	
5/5/2012 11:40	0.03		5/13/2012 11:40	0.02	
5/5/2012 11:50	0.02		5/13/2012 11:50	0.02	
5/5/2012 12:00	0.02		5/13/2012 12:00	0.02	
5/5/2012 12:10	0.02		5/13/2012 12:10	0.02	
5/5/2012 12:20	0.02		5/13/2012 12:20	0.02	
5/5/2012 12:30	0.02		5/13/2012 12:30	0.02	
5/5/2012 12:40	0.02		5/13/2012 12:40	0.02	
5/5/2012 12:50	0.02		5/13/2012 12:50	0.02	
5/5/2012 13:00	0.02		5/13/2012 13:00	0.02	
5/5/2012 13:10	0.02		5/13/2012 13:10	0.02	
5/5/2012 13:20	0.02		5/13/2012 13:20	0.02	
5/5/2012 13:30	0.02		5/13/2012 13:30	0.02	
5/5/2012 13:40	0.02		5/13/2012 13:40	0.02	
5/5/2012 13:50	0.02		5/13/2012 13:50	0.02	
5/5/2012 14:00	0.02		5/13/2012 14:00	0.02	
5/5/2012 14:10	0.02		5/13/2012 14:10	0.02	
5/5/2012 14:20	0.02		5/13/2012 14:20	0.02	
5/5/2012 14:30	0.02		5/13/2012 14:30	0.02	
5/5/2012 14:40	0.02		5/13/2012 14:40	0.02	
5/5/2012 14:50	0.02		5/13/2012 14:50	0.01	
5/5/2012 15:00	0.02		5/13/2012 15:00	0.01	
5/5/2012 15:10	0.01		5/13/2012 15:10	0.01	
5/5/2012 15:20	0.01		5/13/2012 15:20	0.01	
5/5/2012 15:30	0.01		5/13/2012 15:30	0.01	
5/5/2012 15:40	0.01		5/13/2012 15:40	0.01	
5/5/2012 15:50	0.01		5/13/2012 15:50	0.01	
5/5/2012 16:00	0.01		5/13/2012 16:00	0.01	

30 th , April,2012~13 th , May,2012					
Time	TP concentration		Time	TP concentration	
	Simulated	Measured		Simulated	Measured
5/5/2012 16:10	0.01		5/13/2012 16:10	0.01	
5/5/2012 16:20	0.01		5/13/2012 16:20	0.01	
5/5/2012 16:30	0.01		5/13/2012 16:30	0.01	
5/5/2012 16:40	0.01		5/13/2012 16:40	0.01	
5/5/2012 16:50	0.01		5/13/2012 16:50	0.01	
5/5/2012 17:00	0.01		5/13/2012 17:00	0.01	
5/5/2012 17:10	0.01		5/13/2012 17:10	0.01	
5/5/2012 17:20	0.01		5/13/2012 17:20	0.01	
5/5/2012 17:30	0.01		5/13/2012 17:30	0.01	
5/5/2012 17:40	0.01		5/13/2012 17:40	0.01	
5/5/2012 17:50	0.01		5/13/2012 17:50	0.01	
5/5/2012 18:00	0.01		5/13/2012 18:00	0.01	
5/5/2012 18:10	0.01		5/13/2012 18:10	0.01	
5/5/2012 18:20	0.01		5/13/2012 18:20	0.01	
5/5/2012 18:30	0.01		5/13/2012 18:30	0.01	
5/5/2012 18:40	0.01		5/13/2012 18:40	0.01	
5/5/2012 18:50	0.01		5/13/2012 18:50	0.01	
5/5/2012 19:00	0.01		5/13/2012 19:00	0.01	
5/5/2012 19:10	0.01		5/13/2012 19:10	0.01	
5/5/2012 19:20	0.01		5/13/2012 19:20	0.01	
5/5/2012 19:30	0.01		5/13/2012 19:30	0.01	
5/5/2012 19:40	0.01		5/13/2012 19:40	0.01	
5/5/2012 19:50	0.01		5/13/2012 19:50	0.01	
5/5/2012 20:00	0.01		5/13/2012 20:00	0.01	
5/5/2012 20:10	0.01		5/13/2012 20:10	0.01	
5/5/2012 20:20	0.01		5/13/2012 20:20	0.01	
5/5/2012 20:30	0.01		5/13/2012 20:30	0.01	
5/5/2012 20:40	0.01		5/13/2012 20:40	0.01	
5/5/2012 20:50	0.01		5/13/2012 20:50	0.01	
5/5/2012 21:00	0.01		5/13/2012 21:00	0.01	
5/5/2012 21:10	0.01		5/13/2012 21:10	0.01	
5/5/2012 21:20	0.01		5/13/2012 21:20	0.01	
5/5/2012 21:30	0.01		5/13/2012 21:30	0.00	
5/5/2012 21:40	0.01		5/13/2012 21:40	0.00	
5/5/2012 21:50	0.01		5/13/2012 21:50	0.00	

30th, April,2012~13th, May,2012					
Time	TP concentration		Time	TP concentration	
	Simulated	Measured		Simulated	Measured
5/5/2012 22:00	0.01		5/13/2012 22:00	0.00	
5/5/2012 22:10	0.00		5/13/2012 22:10	0.00	
5/5/2012 22:20	0.00		5/13/2012 22:20	0.00	
5/5/2012 22:30	0.00		5/13/2012 22:30	0.00	
5/5/2012 22:40	0.00		5/13/2012 22:40	0.00	
5/5/2012 22:50	0.00		5/13/2012 22:50	0.00	
5/5/2012 23:00	0.00		5/13/2012 23:00	0.00	
5/5/2012 23:10	0.00		5/13/2012 23:10	0.00	
5/5/2012 23:20	0.00		5/13/2012 23:20	0.00	
5/5/2012 23:30	0.00		5/13/2012 23:30	0.00	
5/5/2012 23:40	0.00		5/13/2012 23:40	0.00	
5/5/2012 23:50	0.00		5/13/2012 23:50	0.00	

2012-04-30~2012-05-13

21 st , July, 2012~28 th , July, 2012					
Time	TP concentration		Time	TP concentration	
	Simulated	Measured		Simulated	Measured
7/24/2012 0:00	0.00		7/26/2012 12:00	0.00	
7/24/2012 0:10	0.00		7/26/2012 12:10	0.00	
7/24/2012 0:20	0.00		7/26/2012 12:20	0.00	
7/24/2012 0:30	0.00		7/26/2012 12:30	0.00	
7/24/2012 0:40	0.00		7/26/2012 12:40	0.00	
7/24/2012 0:50	0.00		7/26/2012 12:50	0.00	
7/24/2012 1:00	0.00		7/26/2012 13:00	0.00	
7/24/2012 1:10	0.00		7/26/2012 13:10	0.00	
7/24/2012 1:20	0.00		7/26/2012 13:20	0.00	
7/24/2012 1:30	0.00		7/26/2012 13:30	0.00	
7/24/2012 1:40	0.00		7/26/2012 13:40	0.00	
7/24/2012 1:50	0.00		7/26/2012 13:50	0.00	
7/24/2012 2:00	0.00		7/26/2012 14:00	0.00	
7/24/2012 2:10	0.00		7/26/2012 14:10	0.00	
7/24/2012 2:20	0.00		7/26/2012 14:20	0.00	
7/24/2012 2:30	0.00		7/26/2012 14:30	0.00	
7/24/2012 2:40	0.00		7/26/2012 14:40	0.00	
7/24/2012 2:50	0.00		7/26/2012 14:50	0.00	
7/24/2012 3:00	0.00		7/26/2012 15:00	0.00	
7/24/2012 3:10	0.00		7/26/2012 15:10	0.00	
7/24/2012 3:20	0.00		7/26/2012 15:20	0.00	
7/24/2012 3:30	0.00		7/26/2012 15:30	0.00	
7/24/2012 3:40	0.00		7/26/2012 15:40	0.00	
7/24/2012 3:50	0.00		7/26/2012 15:50	0.00	
7/24/2012 4:00	0.00		7/26/2012 16:00	0.00	
7/24/2012 4:10	0.00		7/26/2012 16:10	0.00	
7/24/2012 4:20	0.00		7/26/2012 16:20	0.00	
7/24/2012 4:30	0.00		7/26/2012 16:30	0.00	
7/24/2012 4:40	0.00		7/26/2012 16:40	0.00	
7/24/2012 4:50	0.00		7/26/2012 16:50	0.00	
7/24/2012 5:00	0.00		7/26/2012 17:00	0.00	
7/24/2012 5:10	0.00		7/26/2012 17:10	0.00	
7/24/2012 5:20	0.00		7/26/2012 17:20	0.00	
7/24/2012 5:30	0.00		7/26/2012 17:30	0.00	
7/24/2012 5:40	0.00		7/26/2012 17:40	0.00	
7/24/2012 5:50	0.00		7/26/2012 17:50	0.00	
7/24/2012 6:00	0.00		7/26/2012 18:00	0.00	
7/24/2012 6:10	0.00		7/26/2012 18:10	0.00	
7/24/2012 6:20	0.00		7/26/2012 18:20	0.00	
7/24/2012 6:30	0.00		7/26/2012 18:30	0.10	

21 st , July, 2012~28 th , July, 2012					
Time	TP concentration		Time	TP concentration	
	Simulated	Measured		Simulated	Measured
7/24/2012 6:40	0.00		7/26/2012 18:40	0.10	
7/24/2012 6:50	3.77	3.51	7/26/2012 18:50	0.20	
7/24/2012 7:00	3.78		7/26/2012 19:00	0.18	
7/24/2012 7:10	2.86		7/26/2012 19:10	0.16	
7/24/2012 7:20	2.29		7/26/2012 19:20	0.16	
7/24/2012 7:30	1.82		7/26/2012 19:30	0.15	
7/24/2012 7:40	1.48		7/26/2012 19:40	0.14	
7/24/2012 7:50	1.22		7/26/2012 19:50	0.14	
7/24/2012 8:00	1.02		7/26/2012 20:00	0.13	
7/24/2012 8:10	0.86		7/26/2012 20:10	0.13	
7/24/2012 8:20	0.73		7/26/2012 20:20	0.13	
7/24/2012 8:30	0.63		7/26/2012 20:30	0.13	
7/24/2012 8:40	0.55		7/26/2012 20:40	0.12	
7/24/2012 8:50	0.48		7/26/2012 20:50	0.12	
7/24/2012 9:00	0.42		7/26/2012 21:00	0.12	
7/24/2012 9:10	0.37		7/26/2012 21:10	0.12	
7/24/2012 9:20	0.33		7/26/2012 21:20	0.11	
7/24/2012 9:30	0.30		7/26/2012 21:30	0.11	
7/24/2012 9:40	0.27		7/26/2012 21:40	0.11	
7/24/2012 9:50	0.24		7/26/2012 21:50	0.11	
7/24/2012 10:00	0.22		7/26/2012 22:00	0.10	
7/24/2012 10:10	0.20		7/26/2012 22:10	0.10	
7/24/2012 10:20	0.18		7/26/2012 22:20	0.16	
7/24/2012 10:30	0.17		7/26/2012 22:30	0.15	
7/24/2012 10:40	0.16		7/26/2012 22:40	0.15	
7/24/2012 10:50	0.15		7/26/2012 22:50	0.14	
7/24/2012 11:00	0.14		7/26/2012 23:00	0.14	
7/24/2012 11:10	0.13		7/26/2012 23:10	0.13	
7/24/2012 11:20	0.12		7/26/2012 23:20	0.13	
7/24/2012 11:30	0.11		7/26/2012 23:30	0.13	
7/24/2012 11:40	0.10		7/26/2012 23:40	0.13	
7/24/2012 11:50	0.10		7/26/2012 23:50	0.12	
7/24/2012 12:00	0.09		7/28/2012 0:00	0.00	
7/24/2012 12:10	0.09		7/28/2012 0:10	0.67	
7/24/2012 12:20	0.08		7/28/2012 0:20	0.55	
7/24/2012 12:30	0.08		7/28/2012 0:30	0.45	
7/24/2012 12:40	0.07		7/28/2012 0:40	0.38	
7/24/2012 12:50	0.07		7/28/2012 0:50	0.32	
7/24/2012 13:00	0.07		7/28/2012 1:00	0.27	
7/24/2012 13:10	0.06		7/28/2012 1:10	0.23	

21 st , July, 2012~28 th , July, 2012					
Time	TP concentration		Time	TP concentration	
	Simulated	Measured		Simulated	Measured
7/24/2012 13:20	0.06		7/28/2012 1:20	0.20	
7/24/2012 13:30	0.06		7/28/2012 1:30	0.18	
7/24/2012 13:40	0.06		7/28/2012 1:40	0.16	
7/24/2012 13:50	0.05		7/28/2012 1:50	0.14	
7/24/2012 14:00	0.05		7/28/2012 2:00	0.12	0.13
7/24/2012 14:10	0.05		7/28/2012 2:10	0.11	
7/24/2012 14:20	0.05		7/28/2012 2:20	0.10	
7/24/2012 14:30	0.05		7/28/2012 2:30	0.09	
7/24/2012 14:40	0.04		7/28/2012 2:40	0.08	
7/24/2012 14:50	0.04		7/28/2012 2:50	0.07	
7/24/2012 15:00	0.04		7/28/2012 3:00	0.07	
7/24/2012 15:10	0.04		7/28/2012 3:10	0.06	
7/24/2012 15:20	0.04		7/28/2012 3:20	0.06	
7/24/2012 15:30	0.04		7/28/2012 3:30	0.05	
7/24/2012 15:40	0.04		7/28/2012 3:40	0.05	
7/24/2012 15:50	0.03		7/28/2012 3:50	0.05	
7/24/2012 16:00	0.03		7/28/2012 4:00	0.04	
7/24/2012 16:10	0.03		7/28/2012 4:10	0.04	
7/24/2012 16:20	0.03		7/28/2012 4:20	0.04	
7/24/2012 16:30	0.03		7/28/2012 4:30	0.04	
7/24/2012 16:40	0.03		7/28/2012 4:40	0.03	
7/24/2012 16:50	0.03		7/28/2012 4:50	0.03	
7/24/2012 17:00	0.03		7/28/2012 5:00	0.03	
7/24/2012 17:10	0.03		7/28/2012 5:10	0.03	
7/24/2012 17:20	0.03		7/28/2012 5:20	0.03	
7/24/2012 17:30	0.03		7/28/2012 5:30	0.03	
7/24/2012 17:40	0.02		7/28/2012 5:40	0.02	
7/24/2012 17:50	0.02		7/28/2012 5:50	0.02	
7/24/2012 18:00	0.02		7/28/2012 6:00	0.02	
7/24/2012 18:10	0.02		7/28/2012 6:10	0.02	
7/24/2012 18:20	0.02		7/28/2012 6:20	0.02	
7/24/2012 18:30	0.02		7/28/2012 6:30	0.02	
7/24/2012 18:40	0.02		7/28/2012 6:40	0.02	
7/24/2012 18:50	0.02		7/28/2012 6:50	0.02	
7/24/2012 19:00	0.02		7/28/2012 7:00	0.02	
7/24/2012 19:10	0.02		7/28/2012 7:10	0.02	
7/24/2012 19:20	0.02		7/28/2012 7:20	0.02	
7/24/2012 19:30	0.02		7/28/2012 7:30	0.02	
7/24/2012 19:40	0.02		7/28/2012 7:40	0.01	
7/24/2012 19:50	0.02		7/28/2012 7:50	0.01	

21 st , July, 2012~28 th , July, 2012					
Time	TP concentration		Time	TP concentration	
	Simulated	Measured		Simulated	Measured
7/24/2012 20:00	0.02		7/28/2012 8:00	0.01	
7/24/2012 20:10	0.02		7/28/2012 8:10	0.01	
7/24/2012 20:20	0.10		7/28/2012 8:20	0.01	
7/24/2012 20:30	0.10		7/28/2012 8:30	0.01	
7/24/2012 20:40	0.10		7/28/2012 8:40	0.01	
7/24/2012 20:50	0.09		7/28/2012 8:50	0.01	
7/24/2012 21:00	0.09		7/28/2012 9:00	0.01	
7/24/2012 21:10	0.09		7/28/2012 9:10	0.01	
7/24/2012 21:20	0.10		7/28/2012 9:20	0.01	
7/24/2012 21:30	0.10		7/28/2012 9:30	0.01	
7/24/2012 21:40	0.10		7/28/2012 9:40	0.01	
7/24/2012 21:50	0.10		7/28/2012 9:50	0.01	
7/24/2012 22:00	0.09		7/28/2012 10:00	0.01	
7/24/2012 22:10	0.09		7/28/2012 10:10	0.01	
7/24/2012 22:20	0.09		7/28/2012 10:20	0.01	
7/24/2012 22:30	0.09		7/28/2012 10:30	0.01	
7/24/2012 22:40	0.08		7/28/2012 10:40	0.01	
7/24/2012 22:50	0.08		7/28/2012 10:50	0.01	
7/24/2012 23:00	0.08		7/28/2012 11:00	0.01	
7/24/2012 23:10	0.08		7/28/2012 11:10	0.01	
7/24/2012 23:20	0.08		7/28/2012 11:20	0.01	
7/24/2012 23:30	0.07		7/28/2012 11:30	0.01	
7/24/2012 23:40	0.07		7/28/2012 11:40	0.01	
7/24/2012 23:50	0.07		7/28/2012 11:50	0.01	
7/26/2012 0:00	0.00		7/28/2012 12:00	0.01	
7/26/2012 0:10	0.54	0.85	7/28/2012 12:10	0.01	
7/26/2012 0:20	0.43		7/28/2012 12:20	0.01	
7/26/2012 0:30	0.35		7/28/2012 12:30	0.01	
7/26/2012 0:40	0.28		7/28/2012 12:40	0.01	
7/26/2012 0:50	0.23		7/28/2012 12:50	0.01	
7/26/2012 1:00	0.19		7/28/2012 13:00	0.01	
7/26/2012 1:10	0.16		7/28/2012 13:10	0.01	
7/26/2012 1:20	0.14		7/28/2012 13:20	0.01	
7/26/2012 1:30	0.12		7/28/2012 13:30	0.01	
7/26/2012 1:40	0.10		7/28/2012 13:40	0.00	
7/26/2012 1:50	0.09		7/28/2012 13:50	0.00	
7/26/2012 2:00	0.08		7/28/2012 14:00	0.00	
7/26/2012 2:10	0.07		7/28/2012 14:10	0.00	
7/26/2012 2:20	0.06		7/28/2012 14:20	0.00	
7/26/2012 2:30	0.06		7/28/2012 14:30	0.00	

21 st , July, 2012~28 th , July, 2012					
Time	TP concentration		Time	TP concentration	
	Simulated	Measured		Simulated	Measured
7/26/2012 2:40	0.05		7/28/2012 14:40	0.00	
7/26/2012 2:50	0.04		7/28/2012 14:50	0.00	
7/26/2012 3:00	0.04		7/28/2012 15:00	0.00	
7/26/2012 3:10	0.04		7/28/2012 15:10	0.00	
7/26/2012 3:20	0.03		7/28/2012 15:20	0.00	
7/26/2012 3:30	0.03		7/28/2012 15:30	0.00	
7/26/2012 3:40	0.03		7/28/2012 15:40	0.00	
7/26/2012 3:50	0.03		7/28/2012 15:50	0.00	
7/26/2012 4:00	0.02		7/28/2012 16:00	0.00	
7/26/2012 4:10	0.02		7/28/2012 16:10	0.00	
7/26/2012 4:20	0.02		7/28/2012 16:20	0.00	
7/26/2012 4:30	0.02		7/28/2012 16:30	0.00	
7/26/2012 4:40	0.02		7/28/2012 16:40	0.00	
7/26/2012 4:50	0.02		7/28/2012 16:50	0.00	
7/26/2012 5:00	0.02		7/28/2012 17:00	0.00	
7/26/2012 5:10	0.02		7/28/2012 17:10	0.00	
7/26/2012 5:20	0.01		7/28/2012 17:20	0.00	
7/26/2012 5:30	0.01		7/28/2012 17:30	0.00	
7/26/2012 5:40	0.01		7/28/2012 17:40	0.00	
7/26/2012 5:50	0.01		7/28/2012 17:50	0.00	
7/26/2012 6:00	0.01		7/28/2012 18:00	0.00	
7/26/2012 6:10	0.01		7/28/2012 18:10	0.00	
7/26/2012 6:20	0.01		7/28/2012 18:20	0.00	
7/26/2012 6:30	0.01		7/28/2012 18:30	0.00	
7/26/2012 6:40	0.01		7/28/2012 18:40	0.00	
7/26/2012 6:50	0.01		7/28/2012 18:50	0.00	
7/26/2012 7:00	0.01		7/28/2012 19:00	0.00	
7/26/2012 7:10	0.01		7/28/2012 19:10	0.00	
7/26/2012 7:20	0.01		7/28/2012 19:20	0.00	
7/26/2012 7:30	0.01		7/28/2012 19:30	0.00	
7/26/2012 7:40	0.01		7/28/2012 19:40	0.06	
7/26/2012 7:50	0.01		7/28/2012 19:50	0.06	
7/26/2012 8:00	0.01		7/28/2012 20:00	0.06	
7/26/2012 8:10	0.01		7/28/2012 20:10	0.08	
7/26/2012 8:20	0.01		7/28/2012 20:20	0.08	
7/26/2012 8:30	0.01		7/28/2012 20:30	0.08	
7/26/2012 8:40	0.01		7/28/2012 20:40	0.07	
7/26/2012 8:50	0.01		7/28/2012 20:50	0.07	
7/26/2012 9:00	0.01		7/28/2012 21:00	0.07	
7/26/2012 9:10	0.01		7/28/2012 21:10	0.07	

21 st , July, 2012~28 th , July, 2012					
Time	TP concentration		Time	TP concentration	
	Simulated	Measured		Simulated	Measured
7/26/2012 9:20	0.01		7/28/2012 21:20	0.07	
7/26/2012 9:30	0.01		7/28/2012 21:30	0.07	
7/26/2012 9:40	0.01		7/28/2012 21:40	0.07	
7/26/2012 9:50	0.01		7/28/2012 21:50	0.07	
7/26/2012 10:00	0.00		7/28/2012 22:00	0.07	
7/26/2012 10:10	0.00		7/28/2012 22:10	0.07	
7/26/2012 10:20	0.00		7/28/2012 22:20	0.06	
7/26/2012 10:30	0.00		7/28/2012 22:30	0.06	
7/26/2012 10:40	0.00		7/28/2012 22:40	0.06	
7/26/2012 10:50	0.00		7/28/2012 22:50	0.06	
7/26/2012 11:00	0.00		7/28/2012 23:00	0.06	
7/26/2012 11:10	0.00		7/28/2012 23:10	0.06	
7/26/2012 11:20	0.00		7/28/2012 23:20	0.05	
7/26/2012 11:30	0.00		7/28/2012 23:30	0.05	
7/26/2012 11:40	0.00		7/28/2012 23:40	0.05	
7/26/2012 11:50	0.00		7/28/2012 23:50	0.05	

2012-07-21~2012-07-29

15 th , August, 2012~23 rd , August, 2012					
Time	TP concentration		Time	TP concentration	
	Simulated	Measured		Simulated	Measured
8/17/2012 0:00	0.00		8/21/2012 0:00	0.00	
8/17/2012 0:10	0.00		8/21/2012 0:10	0.39	
8/17/2012 0:20	0.00		8/21/2012 0:20	0.32	
8/17/2012 0:30	0.00		8/21/2012 0:30	0.26	
8/17/2012 0:40	0.00		8/21/2012 0:40	0.22	
8/17/2012 0:50	0.00		8/21/2012 0:50	0.19	
8/17/2012 1:00	0.00		8/21/2012 1:00	0.16	0.12
8/17/2012 1:10	0.00		8/21/2012 1:10	0.14	
8/17/2012 1:20	0.00		8/21/2012 1:20	0.12	
8/17/2012 1:30	0.00		8/21/2012 1:30	0.10	
8/17/2012 1:40	0.00		8/21/2012 1:40	0.09	
8/17/2012 1:50	0.00		8/21/2012 1:50	0.08	
8/17/2012 2:00	0.00		8/21/2012 2:00	0.07	
8/17/2012 2:10	0.00		8/21/2012 2:10	0.06	
8/17/2012 2:20	0.00		8/21/2012 2:20	0.06	
8/17/2012 2:30	0.00		8/21/2012 2:30	0.05	
8/17/2012 2:40	0.00		8/21/2012 2:40	0.05	
8/17/2012 2:50	0.00		8/21/2012 2:50	0.04	
8/17/2012 3:00	0.00		8/21/2012 3:00	0.04	
8/17/2012 3:10	0.00		8/21/2012 3:10	0.04	
8/17/2012 3:20	0.00		8/21/2012 3:20	0.03	
8/17/2012 3:30	0.00		8/21/2012 3:30	0.03	
8/17/2012 3:40	0.00		8/21/2012 3:40	0.03	
8/17/2012 3:50	0.00		8/21/2012 3:50	0.03	
8/17/2012 4:00	0.00		8/21/2012 4:00	0.03	
8/17/2012 4:10	0.00		8/21/2012 4:10	0.02	
8/17/2012 4:20	0.00		8/21/2012 4:20	0.02	
8/17/2012 4:30	0.00		8/21/2012 4:30	0.02	
8/17/2012 4:40	0.00		8/21/2012 4:40	0.02	
8/17/2012 4:50	0.00		8/21/2012 4:50	0.02	
8/17/2012 5:00	0.00		8/21/2012 5:00	0.02	
8/17/2012 5:10	0.00		8/21/2012 5:10	0.02	
8/17/2012 5:20	0.00		8/21/2012 5:20	0.02	
8/17/2012 5:30	0.00		8/21/2012 5:30	0.02	
8/17/2012 5:40	0.00		8/21/2012 5:40	0.01	
8/17/2012 5:50	0.00		8/21/2012 5:50	0.01	
8/17/2012 6:00	0.00		8/21/2012 6:00	0.01	
8/17/2012 6:10	0.00		8/21/2012 6:10	0.01	
8/17/2012 6:20	0.00		8/21/2012 6:20	0.01	
8/17/2012 6:30	0.00		8/21/2012 6:30	0.01	

15 th , August, 2012~23 rd , August, 2012					
Time	TP concentration		Time	TP concentration	
	Simulated	Measured		Simulated	Measured
8/17/2012 6:40	0.00		8/21/2012 6:40	0.01	
8/17/2012 6:50	0.00		8/21/2012 6:50	0.01	
8/17/2012 7:00	0.00		8/21/2012 7:00	0.01	
8/17/2012 7:10	0.00		8/21/2012 7:10	0.01	
8/17/2012 7:20	0.00		8/21/2012 7:20	0.01	
8/17/2012 7:30	0.00		8/21/2012 7:30	0.01	
8/17/2012 7:40	0.00		8/21/2012 7:40	0.01	
8/17/2012 7:50	0.00		8/21/2012 7:50	0.01	
8/17/2012 8:00	0.00		8/21/2012 8:00	0.01	
8/17/2012 8:10	0.00		8/21/2012 8:10	0.01	
8/17/2012 8:20	0.00		8/21/2012 8:20	0.01	
8/17/2012 8:30	8.47	4.57	8/21/2012 8:30	0.01	
8/17/2012 8:40	0.00		8/21/2012 8:40	0.01	
8/17/2012 8:50	0.00		8/21/2012 8:50	0.01	
8/17/2012 9:00	0.00		8/21/2012 9:00	0.01	
8/17/2012 9:10	0.00		8/21/2012 9:10	0.01	
8/17/2012 9:20	0.00		8/21/2012 9:20	0.01	
8/17/2012 9:30	0.00		8/21/2012 9:30	0.01	
8/17/2012 9:40	0.00		8/21/2012 9:40	0.01	
8/17/2012 9:50	0.00		8/21/2012 9:50	0.01	
8/17/2012 10:00	0.00		8/21/2012 10:00	0.01	
8/17/2012 10:10	0.00		8/21/2012 10:10	0.01	
8/17/2012 10:20	0.00		8/21/2012 10:20	0.01	
8/17/2012 10:30	0.00		8/21/2012 10:30	0.01	
8/17/2012 10:40	0.00		8/21/2012 10:40	0.05	
8/17/2012 10:50	0.00		8/21/2012 10:50	0.05	
8/17/2012 11:00	0.00		8/21/2012 11:00	0.05	
8/17/2012 11:10	0.00		8/21/2012 11:10	0.05	
8/17/2012 11:20	0.00		8/21/2012 11:20	0.05	
8/17/2012 11:30	0.00		8/21/2012 11:30	0.05	
8/17/2012 11:40	0.00		8/21/2012 11:40	0.04	
8/17/2012 11:50	0.00		8/21/2012 11:50	0.04	
8/17/2012 12:00	0.00		8/21/2012 12:00	0.04	
8/17/2012 12:10	0.00		8/21/2012 12:10	0.04	
8/17/2012 12:20	0.00		8/21/2012 12:20	0.04	
8/17/2012 12:30	0.00		8/21/2012 12:30	0.04	
8/17/2012 12:40	0.00		8/21/2012 12:40	0.04	
8/17/2012 12:50	0.00		8/21/2012 12:50	0.04	
8/17/2012 13:00	0.00		8/21/2012 13:00	0.04	
8/17/2012 13:10	0.00		8/21/2012 13:10	0.03	

15 th , August, 2012~23 rd , August, 2012					
Time	TP concentration		Time	TP concentration	
	Simulated	Measured		Simulated	Measured
8/17/2012 13:20	0.00		8/21/2012 13:20	0.03	
8/17/2012 13:30	0.00		8/21/2012 13:30	0.03	
8/17/2012 13:40	0.00		8/21/2012 13:40	0.03	
8/17/2012 13:50	0.00		8/21/2012 13:50	0.03	
8/17/2012 14:00	0.00		8/21/2012 14:00	0.03	
8/17/2012 14:10	0.00		8/21/2012 14:10	0.03	
8/17/2012 14:20	0.00		8/21/2012 14:20	0.03	
8/17/2012 14:30	0.00		8/21/2012 14:30	0.03	
8/17/2012 14:40	0.00		8/21/2012 14:40	0.03	
8/17/2012 14:50	0.00		8/21/2012 14:50	0.03	
8/17/2012 15:00	0.00		8/21/2012 15:00	0.03	
8/17/2012 15:10	0.00		8/21/2012 15:10	0.02	
8/17/2012 15:20	0.00		8/21/2012 15:20	0.05	
8/17/2012 15:30	0.00		8/21/2012 15:30	0.05	
8/17/2012 15:40	0.00		8/21/2012 15:40	0.05	
8/17/2012 15:50	0.00		8/21/2012 15:50	0.05	
8/17/2012 16:00	0.01		8/21/2012 16:00	0.05	
8/17/2012 16:10	0.01		8/21/2012 16:10	0.05	
8/17/2012 16:20	0.01		8/21/2012 16:20	0.05	
8/17/2012 16:30	0.01		8/21/2012 16:30	0.05	
8/17/2012 16:40	0.01		8/21/2012 16:40	0.05	
8/17/2012 16:50	0.01		8/21/2012 16:50	0.04	
8/17/2012 17:00	0.01		8/21/2012 17:00	0.04	
8/17/2012 17:10	0.01		8/21/2012 17:10	0.04	
8/17/2012 17:20	0.01		8/21/2012 17:20	0.04	
8/17/2012 17:30	0.01		8/21/2012 17:30	0.04	
8/17/2012 17:40	0.01		8/21/2012 17:40	0.04	
8/17/2012 17:50	0.01		8/21/2012 17:50	0.04	
8/17/2012 18:00	0.01		8/21/2012 18:00	0.04	
8/17/2012 18:10	0.01		8/21/2012 18:10	0.04	
8/17/2012 18:20	0.01		8/21/2012 18:20	0.03	
8/17/2012 18:30	0.01		8/21/2012 18:30	0.03	
8/17/2012 18:40	0.01		8/21/2012 18:40	0.03	
8/17/2012 18:50	0.01		8/21/2012 18:50	0.03	
8/17/2012 19:00	0.01		8/21/2012 19:00	0.05	
8/17/2012 19:10	0.01		8/21/2012 19:10	0.05	
8/17/2012 19:20	0.01		8/21/2012 19:20	0.05	
8/17/2012 19:30	0.01		8/21/2012 19:30	0.05	
8/17/2012 19:40	0.01		8/21/2012 19:40	0.05	
8/17/2012 19:50	0.01		8/21/2012 19:50	0.04	

15 th , August, 2012~23 rd , August, 2012					
Time	TP concentration		Time	TP concentration	
	Simulated	Measured		Simulated	Measured
8/17/2012 20:00	0.01		8/21/2012 20:00	0.04	
8/17/2012 20:10	0.01		8/21/2012 20:10	0.04	
8/17/2012 20:20	0.01		8/21/2012 20:20	0.04	
8/17/2012 20:30	0.01		8/21/2012 20:30	0.04	
8/17/2012 20:40	0.01		8/21/2012 20:40	0.04	
8/17/2012 20:50	0.01		8/21/2012 20:50	0.04	
8/17/2012 21:00	0.01		8/21/2012 21:00	0.04	
8/17/2012 21:10	0.01		8/21/2012 21:10	0.04	
8/17/2012 21:20	0.01		8/21/2012 21:20	0.03	
8/17/2012 21:30	0.01		8/21/2012 21:30	0.03	
8/17/2012 21:40	0.01		8/21/2012 21:40	0.03	
8/17/2012 21:50	0.01		8/21/2012 21:50	0.03	
8/17/2012 22:00	0.01		8/21/2012 22:00	0.03	
8/17/2012 22:10	0.01		8/21/2012 22:10	0.03	
8/17/2012 22:20	0.01		8/21/2012 22:20	0.03	
8/17/2012 22:30	0.01		8/21/2012 22:30	0.03	
8/17/2012 22:40	0.01		8/21/2012 22:40	0.03	
8/17/2012 22:50	0.01		8/21/2012 22:50	0.03	
8/17/2012 23:00	0.01		8/21/2012 23:00	0.03	
8/17/2012 23:10	0.01		8/21/2012 23:10	0.03	
8/17/2012 23:20	0.01		8/21/2012 23:20	0.03	
8/17/2012 23:30	0.01		8/21/2012 23:30	0.02	
8/17/2012 23:40	0.01		8/21/2012 23:40	0.02	
8/17/2012 23:50	0.01		8/21/2012 23:50	0.02	
8/19/2012 0:00	0.00		8/23/2012 0:00	0.00	
8/19/2012 0:10	0.06		8/23/2012 0:10	0.00	
8/19/2012 0:20	0.04		8/23/2012 0:20	0.00	
8/19/2012 0:30	0.04		8/23/2012 0:30	0.00	
8/19/2012 0:40	0.03		8/23/2012 0:40	0.00	
8/19/2012 0:50	0.02		8/23/2012 0:50	0.00	
8/19/2012 1:00	0.02		8/23/2012 1:00	0.00	
8/19/2012 1:10	0.02		8/23/2012 1:10	0.00	
8/19/2012 1:20	0.01		8/23/2012 1:20	0.00	
8/19/2012 1:30	0.01		8/23/2012 1:30	0.00	
8/19/2012 1:40	0.01		8/23/2012 1:40	0.00	
8/19/2012 1:50	0.01		8/23/2012 1:50	0.00	
8/19/2012 2:00	0.01		8/23/2012 2:00	0.00	
8/19/2012 2:10	0.01		8/23/2012 2:10	0.00	
8/19/2012 2:20	0.01		8/23/2012 2:20	0.00	
8/19/2012 2:30	0.01		8/23/2012 2:30	0.00	

15 th , August, 2012~23 rd , August, 2012					
Time	TP concentration		Time	TP concentration	
	Simulated	Measured		Simulated	Measured
8/19/2012 2:40	0.01		8/23/2012 2:40	0.00	
8/19/2012 2:50	0.00		8/23/2012 2:50	0.00	
8/19/2012 3:00	0.00		8/23/2012 3:00	0.00	
8/19/2012 3:10	0.00		8/23/2012 3:10	0.00	
8/19/2012 3:20	0.00		8/23/2012 3:20	0.00	
8/19/2012 3:30	0.00		8/23/2012 3:30	0.00	
8/19/2012 3:40	0.00		8/23/2012 3:40	0.00	
8/19/2012 3:50	0.00		8/23/2012 3:50	0.00	
8/19/2012 4:00	0.00		8/23/2012 4:00	0.00	
8/19/2012 4:10	0.00		8/23/2012 4:10	0.00	
8/19/2012 4:20	0.00		8/23/2012 4:20	0.00	
8/19/2012 4:30	0.00		8/23/2012 4:30	0.00	
8/19/2012 4:40	0.00		8/23/2012 4:40	0.00	
8/19/2012 4:50	0.00		8/23/2012 4:50	0.00	
8/19/2012 5:00	0.00		8/23/2012 5:00	0.00	
8/19/2012 5:10	0.00		8/23/2012 5:10	0.00	
8/19/2012 5:20	0.00		8/23/2012 5:20	0.00	
8/19/2012 5:30	0.00		8/23/2012 5:30	0.00	
8/19/2012 5:40	0.00		8/23/2012 5:40	0.00	
8/19/2012 5:50	0.00		8/23/2012 5:50	0.00	
8/19/2012 6:00	0.00		8/23/2012 6:00	0.00	
8/19/2012 6:10	0.00		8/23/2012 6:10	0.00	
8/19/2012 6:20	0.00		8/23/2012 6:20	0.00	
8/19/2012 6:30	0.00		8/23/2012 6:30	0.00	
8/19/2012 6:40	0.00		8/23/2012 6:40	0.00	
8/19/2012 6:50	0.00		8/23/2012 6:50	0.00	
8/19/2012 7:00	0.00		8/23/2012 7:00	0.00	
8/19/2012 7:10	0.00		8/23/2012 7:10	0.00	
8/19/2012 7:20	0.00		8/23/2012 7:20	0.00	
8/19/2012 7:30	0.00		8/23/2012 7:30	0.00	
8/19/2012 7:40	0.00		8/23/2012 7:40	0.00	
8/19/2012 7:50	0.00		8/23/2012 7:50	0.00	
8/19/2012 8:00	0.00		8/23/2012 8:00	0.00	
8/19/2012 8:10	0.00		8/23/2012 8:10	0.00	
8/19/2012 8:20	0.00		8/23/2012 8:20	0.00	
8/19/2012 8:30	0.00		8/23/2012 8:30	0.00	
8/19/2012 8:40	0.00		8/23/2012 8:40	0.00	
8/19/2012 8:50	0.00		8/23/2012 8:50	0.00	
8/19/2012 9:00	0.00		8/23/2012 9:00	0.00	
8/19/2012 9:10	0.00		8/23/2012 9:10	0.00	

15 th , August, 2012~23 rd , August, 2012					
Time	TP concentration		Time	TP concentration	
	Simulated	Measured		Simulated	Measured
8/19/2012 9:20	0.00		8/23/2012 9:20	0.00	
8/19/2012 9:30	0.00		8/23/2012 9:30	0.00	
8/19/2012 9:40	0.00		8/23/2012 9:40	0.00	
8/19/2012 9:50	0.00		8/23/2012 9:50	0.00	
8/19/2012 10:00	0.00		8/23/2012 10:00	0.05	0.1
8/19/2012 10:10	0.00		8/23/2012 10:10	0.08	
8/19/2012 10:20	0.00		8/23/2012 10:20	0.08	
8/19/2012 10:30	0.00		8/23/2012 10:30	0.08	
8/19/2012 10:40	0.00		8/23/2012 10:40	0.08	
8/19/2012 10:50	0.00		8/23/2012 10:50	0.07	
8/19/2012 11:00	0.00		8/23/2012 11:00	0.07	
8/19/2012 11:10	0.00		8/23/2012 11:10	0.07	
8/19/2012 11:20	0.00		8/23/2012 11:20	0.07	
8/19/2012 11:30	0.00		8/23/2012 11:30	0.07	
8/19/2012 11:40	0.00		8/23/2012 11:40	0.06	
8/19/2012 11:50	0.00		8/23/2012 11:50	0.06	
8/19/2012 12:00	0.00		8/23/2012 12:00	0.06	
8/19/2012 12:10	0.00		8/23/2012 12:10	0.06	
8/19/2012 12:20	0.00		8/23/2012 12:20	0.06	
8/19/2012 12:30	0.00		8/23/2012 12:30	0.06	
8/19/2012 12:40	0.00		8/23/2012 12:40	0.05	
8/19/2012 12:50	0.00		8/23/2012 12:50	0.05	
8/19/2012 13:00	0.00		8/23/2012 13:00	0.05	
8/19/2012 13:10	0.00		8/23/2012 13:10	0.05	
8/19/2012 13:20	0.00		8/23/2012 13:20	0.05	
8/19/2012 13:30	0.00		8/23/2012 13:30	0.05	
8/19/2012 13:40	0.00		8/23/2012 13:40	0.05	
8/19/2012 13:50	0.00		8/23/2012 13:50	0.04	
8/19/2012 14:00	0.00		8/23/2012 14:00	0.04	
8/19/2012 14:10	0.66	0.71	8/23/2012 14:10	0.04	
8/19/2012 14:20	0.64		8/23/2012 14:20	0.04	
8/19/2012 14:30	0.62		8/23/2012 14:30	0.04	
8/19/2012 14:40	0.60		8/23/2012 14:40	0.04	
8/19/2012 14:50	0.58		8/23/2012 14:50	0.04	
8/19/2012 15:00	0.57		8/23/2012 15:00	0.04	
8/19/2012 15:10	0.55		8/23/2012 15:10	0.04	
8/19/2012 15:20	0.54		8/23/2012 15:20	0.04	
8/19/2012 15:30	0.52		8/23/2012 15:30	0.03	
8/19/2012 15:40	0.51		8/23/2012 15:40	0.03	
8/19/2012 15:50	0.50		8/23/2012 15:50	0.03	

15 th , August, 2012~23 rd , August, 2012					
Time	TP concentration		Time	TP concentration	
	Simulated	Measured		Simulated	Measured
8/19/2012 16:00	0.48		8/23/2012 16:00	0.03	
8/19/2012 16:10	0.47		8/23/2012 16:10	0.03	
8/19/2012 16:20	0.46		8/23/2012 16:20	0.03	
8/19/2012 16:30	0.44		8/23/2012 16:30	0.03	
8/19/2012 16:40	0.43		8/23/2012 16:40	0.03	
8/19/2012 16:50	0.42		8/23/2012 16:50	0.03	
8/19/2012 17:00	0.41		8/23/2012 17:00	0.03	
8/19/2012 17:10	0.40		8/23/2012 17:10	0.03	
8/19/2012 17:20	0.39		8/23/2012 17:20	0.03	
8/19/2012 17:30	0.38		8/23/2012 17:30	0.02	
8/19/2012 17:40	0.51		8/23/2012 17:40	0.02	
8/19/2012 17:50	0.49		8/23/2012 17:50	0.02	
8/19/2012 18:00	0.48		8/23/2012 18:00	0.02	
8/19/2012 18:10	0.47		8/23/2012 18:10	0.02	
8/19/2012 18:20	0.46		8/23/2012 18:20	0.02	
8/19/2012 18:30	0.44		8/23/2012 18:30	0.02	
8/19/2012 18:40	0.43		8/23/2012 18:40	0.02	
8/19/2012 18:50	0.42		8/23/2012 18:50	0.02	
8/19/2012 19:00	0.41		8/23/2012 19:00	0.02	
8/19/2012 19:10	0.40		8/23/2012 19:10	0.02	
8/19/2012 19:20	0.39		8/23/2012 19:20	0.02	
8/19/2012 19:30	0.38		8/23/2012 19:30	0.02	
8/19/2012 19:40	0.37		8/23/2012 19:40	0.02	
8/19/2012 19:50	0.36		8/23/2012 19:50	0.02	
8/19/2012 20:00	0.35		8/23/2012 20:00	0.02	
8/19/2012 20:10	0.34		8/23/2012 20:10	0.02	
8/19/2012 20:20	0.33		8/23/2012 20:20	0.02	
8/19/2012 20:30	0.32		8/23/2012 20:30	0.02	
8/19/2012 20:40	0.31		8/23/2012 20:40	0.01	
8/19/2012 20:50	0.30		8/23/2012 20:50	0.01	
8/19/2012 21:00	0.30		8/23/2012 21:00	0.01	
8/19/2012 21:10	0.29		8/23/2012 21:10	0.01	
8/19/2012 21:20	0.28		8/23/2012 21:20	0.01	
8/19/2012 21:30	0.27		8/23/2012 21:30	0.01	
8/19/2012 21:40	0.27		8/23/2012 21:40	0.01	
8/19/2012 21:50	0.26		8/23/2012 21:50	0.01	
8/19/2012 22:00	0.25		8/23/2012 22:00	0.01	
8/19/2012 22:10	0.25		8/23/2012 22:10	0.01	
8/19/2012 22:20	0.24		8/23/2012 22:20	0.01	
8/19/2012 22:30	0.23		8/23/2012 22:30	0.01	

15 th , August, 2012~23 rd , August, 2012					
Time	TP concentration		Time	TP concentration	
	Simulated	Measured		Simulated	Measured
8/19/2012 22:40	0.23		8/23/2012 22:40	0.01	
8/19/2012 22:50	0.22		8/23/2012 22:50	0.01	
8/19/2012 23:00	0.21		8/23/2012 23:00	0.01	
8/19/2012 23:10	0.21		8/23/2012 23:10	0.01	
8/19/2012 23:20	0.20		8/23/2012 23:20	0.01	
8/19/2012 23:30	0.20		8/23/2012 23:30	0.01	
8/19/2012 23:40	0.19		8/23/2012 23:40	0.01	
8/19/2012 23:50	0.19		8/23/2012 23:50	0.01	

2012-08-15~2012-08-23

14 th , October, 2012~22 nd , October, 2012					
Time	TP concentration		Time	TP concentration	
	Simulated	Measured		Simulated	Measured
10/14/2012 0:00	0.00		10/18/2012 12:00	0.04	
10/14/2012 0:10	0.00		10/18/2012 12:10	0.04	
10/14/2012 0:20	0.00		10/18/2012 12:20	0.04	
10/14/2012 0:30	0.00		10/18/2012 12:30	0.04	
10/14/2012 0:40	0.00		10/18/2012 12:40	0.04	
10/14/2012 0:50	0.00		10/18/2012 12:50	0.09	
10/14/2012 1:00	0.00		10/18/2012 13:00	0.09	
10/14/2012 1:10	0.00		10/18/2012 13:10	0.11	
10/14/2012 1:20	0.00		10/18/2012 13:20	0.08	
10/14/2012 1:30	0.00		10/18/2012 13:30	0.07	
10/14/2012 1:40	0.00		10/18/2012 13:40	0.06	
10/14/2012 1:50	0.00		10/18/2012 13:50	0.06	
10/14/2012 2:00	0.00		10/18/2012 14:00	0.06	
10/14/2012 2:10	0.00		10/18/2012 14:10	0.05	
10/14/2012 2:20	0.00		10/18/2012 14:20	0.05	
10/14/2012 2:30	0.00		10/18/2012 14:30	0.05	
10/14/2012 2:40	0.00		10/18/2012 14:40	0.05	
10/14/2012 2:50	0.00		10/18/2012 14:50	0.05	
10/14/2012 3:00	0.00		10/18/2012 15:00	0.05	
10/14/2012 3:10	0.00		10/18/2012 15:10	0.05	
10/14/2012 3:20	0.00		10/18/2012 15:20	0.05	
10/14/2012 3:30	0.00		10/18/2012 15:30	0.05	
10/14/2012 3:40	0.00		10/18/2012 15:40	0.05	
10/14/2012 3:50	0.00		10/18/2012 15:50	0.05	
10/14/2012 4:00	0.00		10/18/2012 16:00	0.05	
10/14/2012 4:10	0.00		10/18/2012 16:10	0.05	
10/14/2012 4:20	0.00		10/18/2012 16:20	0.05	
10/14/2012 4:30	0.00		10/18/2012 16:30	0.05	
10/14/2012 4:40	0.00		10/18/2012 16:40	0.05	
10/14/2012 4:50	0.00		10/18/2012 16:50	0.05	
10/14/2012 5:00	0.00		10/18/2012 17:00	0.05	
10/14/2012 5:10	0.00		10/18/2012 17:10	0.05	
10/14/2012 5:20	0.00		10/18/2012 17:20	0.05	
10/14/2012 5:30	0.00		10/18/2012 17:30	0.05	
10/14/2012 5:40	0.00		10/18/2012 17:40	0.04	
10/14/2012 5:50	0.00		10/18/2012 17:50	0.04	
10/14/2012 6:00	0.00		10/18/2012 18:00	0.04	
10/14/2012 6:10	0.00		10/18/2012 18:10	0.04	
10/14/2012 6:20	0.00		10/18/2012 18:20	0.04	
10/14/2012 6:30	0.00		10/18/2012 18:30	0.04	

14 th , October, 2012~22 nd , October, 2012					
Time	TP concentration		Time	TP concentration	
	Simulated	Measured		Simulated	Measured
10/14/2012 6:40	0.00		10/18/2012 18:40	0.04	
10/14/2012 6:50	0.00		10/18/2012 18:50	0.04	
10/14/2012 7:00	0.00		10/18/2012 19:00	0.04	
10/14/2012 7:10	0.00		10/18/2012 19:10	0.04	
10/14/2012 7:20	0.00		10/18/2012 19:20	0.04	
10/14/2012 7:30	0.00		10/18/2012 19:30	0.04	
10/14/2012 7:40	0.00		10/18/2012 19:40	0.04	
10/14/2012 7:50	0.00		10/18/2012 19:50	0.04	
10/14/2012 8:00	0.00		10/18/2012 20:00	0.03	
10/14/2012 8:10	0.00		10/18/2012 20:10	0.03	
10/14/2012 8:20	0.00		10/18/2012 20:20	0.03	
10/14/2012 8:30	0.00		10/18/2012 20:30	0.03	
10/14/2012 8:40	0.00		10/18/2012 20:40	0.03	
10/14/2012 8:50	0.00		10/18/2012 20:50	0.03	
10/14/2012 9:00	0.00		10/18/2012 21:00	0.03	
10/14/2012 9:10	0.00		10/18/2012 21:10	0.03	
10/14/2012 9:20	0.00		10/18/2012 21:20	0.03	
10/14/2012 9:30	0.00		10/18/2012 21:30	0.03	
10/14/2012 9:40	0.00		10/18/2012 21:40	0.03	
10/14/2012 9:50	0.00		10/18/2012 21:50	0.03	
10/14/2012 10:00	0.00		10/18/2012 22:00	0.03	
10/14/2012 10:10	0.00		10/18/2012 22:10	0.03	
10/14/2012 10:20	0.00		10/18/2012 22:20	0.03	
10/14/2012 10:30	0.00		10/18/2012 22:30	0.02	
10/14/2012 10:40	0.00		10/18/2012 22:40	0.02	
10/14/2012 10:50	0.00		10/18/2012 22:50	0.02	
10/14/2012 11:00	0.00		10/18/2012 23:00	0.02	
10/14/2012 11:10	0.00		10/18/2012 23:10	0.02	
10/14/2012 11:20	0.00		10/18/2012 23:20	0.02	
10/14/2012 11:30	0.00		10/18/2012 23:30	0.02	
10/14/2012 11:40	0.00		10/18/2012 23:40	0.02	
10/14/2012 11:50	0.00		10/18/2012 23:50	0.02	
10/14/2012 12:00	0.00		10/19/2012 0:00	0.00	
10/14/2012 12:10	0.00		10/19/2012 0:10	0.15	0.45
10/14/2012 12:20	0.00		10/19/2012 0:20	0.13	
10/14/2012 12:30	0.00		10/19/2012 0:30	0.11	
10/14/2012 12:40	0.00		10/19/2012 0:40	0.09	
10/14/2012 12:50	0.00		10/19/2012 0:50	0.08	
10/14/2012 13:00	0.00		10/19/2012 1:00	0.07	
10/14/2012 13:10	0.00		10/19/2012 1:10	0.06	

14 th , October, 2012~22 nd , October, 2012					
Time	TP concentration		Time	TP concentration	
	Simulated	Measured		Simulated	Measured
10/14/2012 13:20	0.00		10/19/2012 1:20	0.06	
10/14/2012 13:30	0.00		10/19/2012 1:30	0.05	
10/14/2012 13:40	0.00		10/19/2012 1:40	0.05	
10/14/2012 13:50	0.00		10/19/2012 1:50	0.04	
10/14/2012 14:00	0.00		10/19/2012 2:00	0.04	
10/14/2012 14:10	0.00		10/19/2012 2:10	0.04	
10/14/2012 14:20	0.00		10/19/2012 2:20	0.03	
10/14/2012 14:30	0.00		10/19/2012 2:30	0.03	
10/14/2012 14:40	0.00		10/19/2012 2:40	0.03	
10/14/2012 14:50	0.00		10/19/2012 2:50	0.03	
10/14/2012 15:00	0.00		10/19/2012 3:00	0.02	
10/14/2012 15:10	0.00		10/19/2012 3:10	0.02	
10/14/2012 15:20	0.00		10/19/2012 3:20	0.02	
10/14/2012 15:30	0.00		10/19/2012 3:30	0.02	
10/14/2012 15:40	0.00		10/19/2012 3:40	0.02	
10/14/2012 15:50	0.00		10/19/2012 3:50	0.02	
10/14/2012 16:00	0.00		10/19/2012 4:00	0.02	
10/14/2012 16:10	0.00		10/19/2012 4:10	0.02	
10/14/2012 16:20	0.00		10/19/2012 4:20	0.01	
10/14/2012 16:30	0.00		10/19/2012 4:30	0.01	
10/14/2012 16:40	0.00		10/19/2012 4:40	0.01	
10/14/2012 16:50	0.00		10/19/2012 4:50	0.01	
10/14/2012 17:00	0.00		10/19/2012 5:00	0.01	
10/14/2012 17:10	0.00		10/19/2012 5:10	0.01	
10/14/2012 17:20	0.00		10/19/2012 5:20	0.01	
10/14/2012 17:30	0.00		10/19/2012 5:30	0.01	
10/14/2012 17:40	0.00		10/19/2012 5:40	0.01	
10/14/2012 17:50	0.00		10/19/2012 5:50	0.01	
10/14/2012 18:00	0.00		10/19/2012 6:00	0.01	
10/14/2012 18:10	0.00		10/19/2012 6:10	0.01	
10/14/2012 18:20	0.00		10/19/2012 6:20	0.01	
10/14/2012 18:30	0.00		10/19/2012 6:30	0.01	
10/14/2012 18:40	0.00		10/19/2012 6:40	0.01	
10/14/2012 18:50	0.00		10/19/2012 6:50	0.01	
10/14/2012 19:00	5.66	6.34	10/19/2012 7:00	0.01	
10/14/2012 19:10	3.89		10/19/2012 7:10	0.01	
10/14/2012 19:20	4.47		10/19/2012 7:20	0.01	
10/14/2012 19:30	0.76		10/19/2012 7:30	0.01	
10/14/2012 19:40	0.53		10/19/2012 7:40	0.01	
10/14/2012 19:50	0.41		10/19/2012 7:50	0.01	

14 th , October, 2012~22 nd , October, 2012					
Time	TP concentration		Time	TP concentration	
	Simulated	Measured		Simulated	Measured
10/14/2012 20:00	0.33		10/19/2012 8:00	0.01	
10/14/2012 20:10	0.28		10/19/2012 8:10	0.01	
10/14/2012 20:20	0.25		10/19/2012 8:20	0.01	
10/14/2012 20:30	0.22		10/19/2012 8:30	0.01	
10/14/2012 20:40	0.20		10/19/2012 8:40	0.01	
10/14/2012 20:50	0.18		10/19/2012 8:50	0.01	
10/14/2012 21:00	0.16		10/19/2012 9:00	0.00	
10/14/2012 21:10	0.15		10/19/2012 9:10	0.00	
10/14/2012 21:20	0.14		10/19/2012 9:20	0.00	
10/14/2012 21:30	0.13		10/19/2012 9:30	0.00	
10/14/2012 21:40	0.12		10/19/2012 9:40	0.00	
10/14/2012 21:50	0.11		10/19/2012 9:50	0.00	
10/14/2012 22:00	0.10		10/19/2012 10:00	0.00	
10/14/2012 22:10	0.10		10/19/2012 10:10	0.00	
10/14/2012 22:20	0.09		10/19/2012 10:20	0.00	
10/14/2012 22:30	0.09		10/19/2012 10:30	0.00	
10/14/2012 22:40	0.09		10/19/2012 10:40	0.00	
10/14/2012 22:50	0.08		10/19/2012 10:50	0.00	
10/14/2012 23:00	0.08		10/19/2012 11:00	0.05	
10/14/2012 23:10	0.07		10/19/2012 11:10	0.05	
10/14/2012 23:20	0.07		10/19/2012 11:20	0.05	
10/14/2012 23:30	0.07		10/19/2012 11:30	0.05	
10/14/2012 23:40	0.06		10/19/2012 11:40	0.05	
10/14/2012 23:50	0.06		10/19/2012 11:50	0.04	
10/16/2012 0:00	0.00		10/19/2012 12:00	0.04	
10/16/2012 0:10	0.15	0.13	10/19/2012 12:10	0.04	
10/16/2012 0:20	0.12		10/19/2012 12:20	0.04	
10/16/2012 0:30	0.09		10/19/2012 12:30	0.04	
10/16/2012 0:40	0.08		10/19/2012 12:40	0.04	
10/16/2012 0:50	0.06		10/19/2012 12:50	0.04	
10/16/2012 1:00	0.05		10/19/2012 13:00	0.04	
10/16/2012 1:10	0.04		10/19/2012 13:10	0.04	
10/16/2012 1:20	0.04		10/19/2012 13:20	0.03	
10/16/2012 1:30	0.03		10/19/2012 13:30	0.03	
10/16/2012 1:40	0.03		10/19/2012 13:40	0.03	
10/16/2012 1:50	0.02		10/19/2012 13:50	0.03	
10/16/2012 2:00	0.02		10/19/2012 14:00	0.03	
10/16/2012 2:10	0.02		10/19/2012 14:10	0.03	
10/16/2012 2:20	0.02		10/19/2012 14:20	0.03	
10/16/2012 2:30	0.01		10/19/2012 14:30	0.03	

14 th , October, 2012~22 nd , October, 2012					
Time	TP concentration		Time	TP concentration	
	Simulated	Measured		Simulated	Measured
10/16/2012 2:40	0.01		10/19/2012 14:40	0.03	
10/16/2012 2:50	0.01		10/19/2012 14:50	0.03	
10/16/2012 3:00	0.01		10/19/2012 15:00	0.03	
10/16/2012 3:10	0.01		10/19/2012 15:10	0.03	
10/16/2012 3:20	0.01		10/19/2012 15:20	0.03	
10/16/2012 3:30	0.01		10/19/2012 15:30	0.02	
10/16/2012 3:40	0.01		10/19/2012 15:40	0.02	
10/16/2012 3:50	0.01		10/19/2012 15:50	0.02	
10/16/2012 4:00	0.01		10/19/2012 16:00	0.06	
10/16/2012 4:10	0.01		10/19/2012 16:10	0.07	
10/16/2012 4:20	0.01		10/19/2012 16:20	0.07	
10/16/2012 4:30	0.00		10/19/2012 16:30	0.07	
10/16/2012 4:40	0.00		10/19/2012 16:40	0.06	
10/16/2012 4:50	0.00		10/19/2012 16:50	0.08	
10/16/2012 5:00	0.00		10/19/2012 17:00	0.08	
10/16/2012 5:10	0.00		10/19/2012 17:10	0.08	
10/16/2012 5:20	0.00		10/19/2012 17:20	0.07	
10/16/2012 5:30	0.00		10/19/2012 17:30	0.07	
10/16/2012 5:40	0.00		10/19/2012 17:40	0.07	
10/16/2012 5:50	0.00		10/19/2012 17:50	0.07	
10/16/2012 6:00	0.00		10/19/2012 18:00	0.07	
10/16/2012 6:10	0.00		10/19/2012 18:10	0.06	
10/16/2012 6:20	0.00		10/19/2012 18:20	0.06	
10/16/2012 6:30	0.00		10/19/2012 18:30	0.06	
10/16/2012 6:40	0.00		10/19/2012 18:40	0.06	
10/16/2012 6:50	0.00		10/19/2012 18:50	0.06	
10/16/2012 7:00	0.00		10/19/2012 19:00	0.06	
10/16/2012 7:10	0.00		10/19/2012 19:10	0.06	
10/16/2012 7:20	0.00		10/19/2012 19:20	0.05	
10/16/2012 7:30	0.00		10/19/2012 19:30	0.05	
10/16/2012 7:40	0.00		10/19/2012 19:40	0.05	
10/16/2012 7:50	0.00		10/19/2012 19:50	0.05	
10/16/2012 8:00	0.00		10/19/2012 20:00	0.05	
10/16/2012 8:10	0.00		10/19/2012 20:10	0.05	
10/16/2012 8:20	0.00		10/19/2012 20:20	0.05	
10/16/2012 8:30	0.00		10/19/2012 20:30	0.04	
10/16/2012 8:40	0.00		10/19/2012 20:40	0.04	
10/16/2012 8:50	0.00		10/19/2012 20:50	0.04	
10/16/2012 9:00	0.00		10/19/2012 21:00	0.04	
10/16/2012 9:10	0.00		10/19/2012 21:10	0.04	

14 th , October, 2012~22 nd , October, 2012					
Time	TP concentration		Time	TP concentration	
	Simulated	Measured		Simulated	Measured
10/16/2012 9:20	0.00		10/19/2012 21:20	0.04	
10/16/2012 9:30	0.00		10/19/2012 21:30	0.04	
10/16/2012 9:40	0.00		10/19/2012 21:40	0.04	
10/16/2012 9:50	0.00		10/19/2012 21:50	0.04	
10/16/2012 10:00	0.00		10/19/2012 22:00	0.04	
10/16/2012 10:10	0.00		10/19/2012 22:10	0.03	
10/16/2012 10:20	0.00		10/19/2012 22:20	0.03	
10/16/2012 10:30	0.00		10/19/2012 22:30	0.03	
10/16/2012 10:40	0.00		10/19/2012 22:40	0.03	
10/16/2012 10:50	0.00		10/19/2012 22:50	0.03	
10/16/2012 11:00	0.00		10/19/2012 23:00	0.03	
10/16/2012 11:10	0.00		10/19/2012 23:10	0.03	
10/16/2012 11:20	0.00		10/19/2012 23:20	0.03	
10/16/2012 11:30	0.00		10/19/2012 23:30	0.03	
10/16/2012 11:40	0.00		10/19/2012 23:40	0.03	
10/16/2012 11:50	0.00		10/19/2012 23:50	0.03	
10/16/2012 12:00	0.00		10/20/2012 0:00	0.00	
10/16/2012 12:10	0.00		10/20/2012 0:10	0.16	0.31
10/16/2012 12:20	0.00		10/20/2012 0:20	0.14	
10/16/2012 12:30	0.00		10/20/2012 0:30	0.12	
10/16/2012 12:40	0.00		10/20/2012 0:40	0.11	
10/16/2012 12:50	0.00		10/20/2012 0:50	0.09	
10/16/2012 13:00	0.00		10/20/2012 1:00	0.08	
10/16/2012 13:10	0.00		10/20/2012 1:10	0.08	
10/16/2012 13:20	0.00		10/20/2012 1:20	0.07	
10/16/2012 13:30	0.00		10/20/2012 1:30	0.06	
10/16/2012 13:40	0.00		10/20/2012 1:40	0.06	
10/16/2012 13:50	0.00		10/20/2012 1:50	0.05	
10/16/2012 14:00	0.07		10/20/2012 2:00	0.05	
10/16/2012 14:10	0.07		10/20/2012 2:10	0.04	
10/16/2012 14:20	0.07		10/20/2012 2:20	0.04	
10/16/2012 14:30	0.07		10/20/2012 2:30	0.04	
10/16/2012 14:40	0.07		10/20/2012 2:40	0.03	
10/16/2012 14:50	0.06		10/20/2012 2:50	0.03	
10/16/2012 15:00	0.06		10/20/2012 3:00	0.03	
10/16/2012 15:10	0.06		10/20/2012 3:10	0.03	
10/16/2012 15:20	0.06		10/20/2012 3:20	0.03	
10/16/2012 15:30	0.06		10/20/2012 3:30	0.02	
10/16/2012 15:40	0.06		10/20/2012 3:40	0.02	
10/16/2012 15:50	0.05		10/20/2012 3:50	0.02	

14 th , October, 2012~22 nd , October, 2012					
Time	TP concentration		Time	TP concentration	
	Simulated	Measured		Simulated	Measured
10/16/2012 16:00	0.05		10/20/2012 4:00	0.02	
10/16/2012 16:10	0.05		10/20/2012 4:10	0.02	
10/16/2012 16:20	0.05		10/20/2012 4:20	0.02	
10/16/2012 16:30	0.05		10/20/2012 4:30	0.02	
10/16/2012 16:40	0.05		10/20/2012 4:40	0.02	
10/16/2012 16:50	0.05		10/20/2012 4:50	0.02	
10/16/2012 17:00	0.04		10/20/2012 5:00	0.02	
10/16/2012 17:10	0.04		10/20/2012 5:10	0.01	
10/16/2012 17:20	0.04		10/20/2012 5:20	0.01	
10/16/2012 17:30	0.04		10/20/2012 5:30	0.01	
10/16/2012 17:40	0.04		10/20/2012 5:40	0.01	
10/16/2012 17:50	0.04		10/20/2012 5:50	0.01	
10/16/2012 18:00	0.04		10/20/2012 6:00	0.01	
10/16/2012 18:10	0.04		10/20/2012 6:10	0.01	
10/16/2012 18:20	0.04		10/20/2012 6:20	0.01	
10/16/2012 18:30	0.04		10/20/2012 6:30	0.01	
10/16/2012 18:40	0.03		10/20/2012 6:40	0.01	
10/16/2012 18:50	0.03		10/20/2012 6:50	0.01	
10/16/2012 19:00	0.03		10/20/2012 7:00	0.01	
10/16/2012 19:10	0.03		10/20/2012 7:10	0.01	
10/16/2012 19:20	0.03		10/20/2012 7:20	0.01	
10/16/2012 19:30	0.03		10/20/2012 7:30	0.01	
10/16/2012 19:40	0.03		10/20/2012 7:40	0.01	
10/16/2012 19:50	0.03		10/20/2012 7:50	0.01	
10/16/2012 20:00	0.03		10/20/2012 8:00	0.01	
10/16/2012 20:10	0.03		10/20/2012 8:10	0.01	
10/16/2012 20:20	0.03		10/20/2012 8:20	0.01	
10/16/2012 20:30	0.03		10/20/2012 8:30	0.01	
10/16/2012 20:40	0.02		10/20/2012 8:40	0.01	
10/16/2012 20:50	0.02		10/20/2012 8:50	0.01	
10/16/2012 21:00	0.02		10/20/2012 9:00	0.01	
10/16/2012 21:10	0.02		10/20/2012 9:10	0.01	
10/16/2012 21:20	0.02		10/20/2012 9:20	0.01	
10/16/2012 21:30	0.02		10/20/2012 9:30	0.01	
10/16/2012 21:40	0.02		10/20/2012 9:40	0.01	
10/16/2012 21:50	0.02		10/20/2012 9:50	0.01	
10/16/2012 22:00	0.02		10/20/2012 10:00	0.01	
10/16/2012 22:10	0.02		10/20/2012 10:10	0.01	
10/16/2012 22:20	0.02		10/20/2012 10:20	0.01	
10/16/2012 22:30	0.02		10/20/2012 10:30	0.00	

14 th , October, 2012~22 nd , October, 2012					
Time	TP concentration		Time	TP concentration	
	Simulated	Measured		Simulated	Measured
10/16/2012 22:40	0.02		10/20/2012 10:40	0.00	
10/16/2012 22:50	0.02		10/20/2012 10:50	0.00	
10/16/2012 23:00	0.02		10/20/2012 11:00	0.00	
10/16/2012 23:10	0.02		10/20/2012 11:10	0.00	
10/16/2012 23:20	0.02		10/20/2012 11:20	0.00	
10/16/2012 23:30	0.02		10/20/2012 11:30	0.00	
10/16/2012 23:40	0.02		10/20/2012 11:40	0.00	
10/16/2012 23:50	0.01		10/20/2012 11:50	0.00	
10/17/2012 0:00	0.00		10/20/2012 12:00	0.00	
10/17/2012 0:10	0.31	0.82	10/20/2012 12:10	0.00	
10/17/2012 0:20	0.25		10/20/2012 12:20	0.00	
10/17/2012 0:30	0.20		10/20/2012 12:30	0.00	
10/17/2012 0:40	0.16		10/20/2012 12:40	0.00	
10/17/2012 0:50	0.14		10/20/2012 12:50	0.00	
10/17/2012 1:00	0.11		10/20/2012 13:00	0.00	
10/17/2012 1:10	0.10		10/20/2012 13:10	0.00	
10/17/2012 1:20	0.08		10/20/2012 13:20	0.00	
10/17/2012 1:30	0.07		10/20/2012 13:30	0.00	
10/17/2012 1:40	0.06		10/20/2012 13:40	0.00	
10/17/2012 1:50	0.05		10/20/2012 13:50	0.00	
10/17/2012 2:00	0.05		10/20/2012 14:00	0.00	
10/17/2012 2:10	0.04		10/20/2012 14:10	0.00	
10/17/2012 2:20	0.04		10/20/2012 14:20	0.00	
10/17/2012 2:30	0.03		10/20/2012 14:30	0.00	
10/17/2012 2:40	0.03		10/20/2012 14:40	0.00	
10/17/2012 2:50	0.03		10/20/2012 14:50	0.00	
10/17/2012 3:00	0.02		10/20/2012 15:00	0.00	
10/17/2012 3:10	0.02		10/20/2012 15:10	0.00	
10/17/2012 3:20	0.02		10/20/2012 15:20	0.00	
10/17/2012 3:30	0.02		10/20/2012 15:30	0.00	
10/17/2012 3:40	0.02		10/20/2012 15:40	0.00	
10/17/2012 3:50	0.02		10/20/2012 15:50	0.00	
10/17/2012 4:00	0.02		10/20/2012 16:00	0.00	
10/17/2012 4:10	0.01		10/20/2012 16:10	0.00	
10/17/2012 4:20	0.01		10/20/2012 16:20	0.00	
10/17/2012 4:30	0.01		10/20/2012 16:30	0.00	
10/17/2012 4:40	0.01		10/20/2012 16:40	0.00	
10/17/2012 4:50	0.01		10/20/2012 16:50	0.00	
10/17/2012 5:00	0.01		10/20/2012 17:00	0.00	
10/17/2012 5:10	0.01		10/20/2012 17:10	0.00	

14 th , October, 2012~22 nd , October, 2012					
Time	TP concentration		Time	TP concentration	
	Simulated	Measured		Simulated	Measured
10/17/2012 5:20	0.01		10/20/2012 17:20	0.00	
10/17/2012 5:30	0.01		10/20/2012 17:30	0.00	
10/17/2012 5:40	0.01		10/20/2012 17:40	0.00	
10/17/2012 5:50	0.01		10/20/2012 17:50	0.00	
10/17/2012 6:00	0.01		10/20/2012 18:00	0.00	
10/17/2012 6:10	0.01		10/20/2012 18:10	0.11	
10/17/2012 6:20	0.01		10/20/2012 18:20	0.11	
10/17/2012 6:30	0.01		10/20/2012 18:30	0.06	
10/17/2012 6:40	0.01		10/20/2012 18:40	0.05	
10/17/2012 6:50	0.01		10/20/2012 18:50	0.04	
10/17/2012 7:00	0.01		10/20/2012 19:00	0.04	
10/17/2012 7:10	0.01		10/20/2012 19:10	0.04	
10/17/2012 7:20	0.01		10/20/2012 19:20	0.04	
10/17/2012 7:30	0.01		10/20/2012 19:30	0.04	
10/17/2012 7:40	0.00		10/20/2012 19:40	0.04	
10/17/2012 7:50	0.00		10/20/2012 19:50	0.04	
10/17/2012 8:00	0.00		10/20/2012 20:00	0.04	
10/17/2012 8:10	0.00		10/20/2012 20:10	0.04	
10/17/2012 8:20	0.00		10/20/2012 20:20	0.04	
10/17/2012 8:30	0.00		10/20/2012 20:30	0.04	
10/17/2012 8:40	0.00		10/20/2012 20:40	0.04	
10/17/2012 8:50	0.00		10/20/2012 20:50	0.04	
10/17/2012 9:00	0.00		10/20/2012 21:00	0.04	
10/17/2012 9:10	0.00		10/20/2012 21:10	0.04	
10/17/2012 9:20	0.00		10/20/2012 21:20	0.04	
10/17/2012 9:30	0.00		10/20/2012 21:30	0.04	
10/17/2012 9:40	0.00		10/20/2012 21:40	0.04	
10/17/2012 9:50	0.00		10/20/2012 21:50	0.04	
10/17/2012 10:00	0.00		10/20/2012 22:00	0.04	
10/17/2012 10:10	0.00		10/20/2012 22:10	0.04	
10/17/2012 10:20	0.00		10/20/2012 22:20	0.04	
10/17/2012 10:30	0.00		10/20/2012 22:30	0.04	
10/17/2012 10:40	0.00		10/20/2012 22:40	0.04	
10/17/2012 10:50	0.00		10/20/2012 22:50	0.04	
10/17/2012 11:00	0.00		10/20/2012 23:00	0.04	
10/17/2012 11:10	0.00		10/20/2012 23:10	0.04	
10/17/2012 11:20	0.00		10/20/2012 23:20	0.04	
10/17/2012 11:30	0.00		10/20/2012 23:30	0.04	
10/17/2012 11:40	0.00		10/20/2012 23:40	0.04	
10/17/2012 11:50	0.00		10/20/2012 23:50	0.04	

14 th , October, 2012~22 nd , October, 2012					
Time	TP concentration		Time	TP concentration	
	Simulated	Measured		Simulated	Measured
10/17/2012 12:00	0.00		10/21/2012 0:00	0.00	
10/17/2012 12:10	0.00		10/21/2012 0:10	0.22	0.07
10/17/2012 12:20	0.00		10/21/2012 0:20	0.19	
10/17/2012 12:30	0.00		10/21/2012 0:30	0.17	
10/17/2012 12:40	0.00		10/21/2012 0:40	0.15	
10/17/2012 12:50	0.00		10/21/2012 0:50	0.14	
10/17/2012 13:00	0.00		10/21/2012 1:00	0.13	
10/17/2012 13:10	0.00		10/21/2012 1:10	0.11	
10/17/2012 13:20	0.00		10/21/2012 1:20	0.10	
10/17/2012 13:30	0.00		10/21/2012 1:30	0.10	
10/17/2012 13:40	0.00		10/21/2012 1:40	0.09	
10/17/2012 13:50	0.00		10/21/2012 1:50	0.08	
10/17/2012 14:00	0.00		10/21/2012 2:00	0.07	
10/17/2012 14:10	0.00		10/21/2012 2:10	0.07	
10/17/2012 14:20	0.00		10/21/2012 2:20	0.06	
10/17/2012 14:30	0.00		10/21/2012 2:30	0.06	
10/17/2012 14:40	0.00		10/21/2012 2:40	0.12	
10/17/2012 14:50	0.00		10/21/2012 2:50	0.11	
10/17/2012 15:00	0.00		10/21/2012 3:00	0.10	
10/17/2012 15:10	0.08		10/21/2012 3:10	0.10	
10/17/2012 15:20	0.08		10/21/2012 3:20	0.09	
10/17/2012 15:30	0.09		10/21/2012 3:30	0.09	
10/17/2012 15:40	0.08		10/21/2012 3:40	0.08	
10/17/2012 15:50	0.08		10/21/2012 3:50	0.08	
10/17/2012 16:00	0.08		10/21/2012 4:00	0.07	
10/17/2012 16:10	0.08		10/21/2012 4:10	0.07	
10/17/2012 16:20	0.08		10/21/2012 4:20	0.07	
10/17/2012 16:30	0.08		10/21/2012 4:30	0.06	
10/17/2012 16:40	0.07		10/21/2012 4:40	0.06	
10/17/2012 16:50	0.07		10/21/2012 4:50	0.06	
10/17/2012 17:00	0.07		10/21/2012 5:00	0.06	
10/17/2012 17:10	0.07		10/21/2012 5:10	0.05	
10/17/2012 17:20	0.06		10/21/2012 5:20	0.05	
10/17/2012 17:30	0.06		10/21/2012 5:30	0.05	
10/17/2012 17:40	0.06		10/21/2012 5:40	0.05	
10/17/2012 17:50	0.06		10/21/2012 5:50	0.05	
10/17/2012 18:00	0.06		10/21/2012 6:00	0.04	
10/17/2012 18:10	0.06		10/21/2012 6:10	0.04	
10/17/2012 18:20	0.06		10/21/2012 6:20	0.04	
10/17/2012 18:30	0.06		10/21/2012 6:30	0.04	

14 th , October, 2012~22 nd , October, 2012					
Time	TP concentration		Time	TP concentration	
	Simulated	Measured		Simulated	Measured
10/17/2012 18:40	0.05		10/21/2012 6:40	0.04	
10/17/2012 18:50	0.05		10/21/2012 6:50	0.04	
10/17/2012 19:00	0.05		10/21/2012 7:00	0.04	
10/17/2012 19:10	0.05		10/21/2012 7:10	0.03	
10/17/2012 19:20	0.05		10/21/2012 7:20	0.03	
10/17/2012 19:30	0.05		10/21/2012 7:30	0.03	
10/17/2012 19:40	0.05		10/21/2012 7:40	0.03	
10/17/2012 19:50	0.05		10/21/2012 7:50	0.03	
10/17/2012 20:00	0.05		10/21/2012 8:00	0.03	
10/17/2012 20:10	0.05		10/21/2012 8:10	0.03	
10/17/2012 20:20	0.04		10/21/2012 8:20	0.03	
10/17/2012 20:30	0.04		10/21/2012 8:30	0.03	
10/17/2012 20:40	0.04		10/21/2012 8:40	0.03	
10/17/2012 20:50	0.04		10/21/2012 8:50	0.03	
10/17/2012 21:00	0.04		10/21/2012 9:00	0.02	
10/17/2012 21:10	0.04		10/21/2012 9:10	0.02	
10/17/2012 21:20	0.04		10/21/2012 9:20	0.02	
10/17/2012 21:30	0.04		10/21/2012 9:30	0.02	
10/17/2012 21:40	0.04		10/21/2012 9:40	0.02	
10/17/2012 21:50	0.04		10/21/2012 9:50	0.02	
10/17/2012 22:00	0.03		10/21/2012 10:00	0.02	
10/17/2012 22:10	0.03		10/21/2012 10:10	0.02	
10/17/2012 22:20	0.03		10/21/2012 10:20	0.02	
10/17/2012 22:30	0.03		10/21/2012 10:30	0.05	
10/17/2012 22:40	0.03		10/21/2012 10:40	0.05	
10/17/2012 22:50	0.03		10/21/2012 10:50	0.05	
10/17/2012 23:00	0.03		10/21/2012 11:00	0.05	
10/17/2012 23:10	0.03		10/21/2012 11:10	0.05	
10/17/2012 23:20	0.03		10/21/2012 11:20	0.04	
10/17/2012 23:30	0.03		10/21/2012 11:30	0.04	
10/17/2012 23:40	0.03		10/21/2012 11:40	0.05	
10/17/2012 23:50	0.03		10/21/2012 11:50	0.05	
10/18/2012 0:00	0.00		10/21/2012 12:00	0.05	
10/18/2012 0:10	0.30	0.68	10/21/2012 12:10	0.10	
10/18/2012 0:20	0.25		10/21/2012 12:20	0.09	
10/18/2012 0:30	0.21		10/21/2012 12:30	0.08	
10/18/2012 0:40	0.18		10/21/2012 12:40	0.08	
10/18/2012 0:50	0.15		10/21/2012 12:50	0.07	
10/18/2012 1:00	0.13		10/21/2012 13:00	0.07	
10/18/2012 1:10	0.12		10/21/2012 13:10	0.07	

14 th , October, 2012~22 nd , October, 2012					
Time	TP concentration		Time	TP concentration	
	Simulated	Measured		Simulated	Measured
10/18/2012 1:20	0.10		10/21/2012 13:20	0.06	
10/18/2012 1:30	0.09		10/21/2012 13:30	0.06	
10/18/2012 1:40	0.08		10/21/2012 13:40	0.06	
10/18/2012 1:50	0.07		10/21/2012 13:50	0.06	
10/18/2012 2:00	0.06		10/21/2012 14:00	0.06	
10/18/2012 2:10	0.06		10/21/2012 14:10	0.06	
10/18/2012 2:20	0.05		10/21/2012 14:20	0.06	
10/18/2012 2:30	0.05		10/21/2012 14:30	0.06	
10/18/2012 2:40	0.04		10/21/2012 14:40	0.06	
10/18/2012 2:50	0.04		10/21/2012 14:50	0.06	
10/18/2012 3:00	0.04		10/21/2012 15:00	0.05	
10/18/2012 3:10	0.03		10/21/2012 15:10	0.05	
10/18/2012 3:20	0.03		10/21/2012 15:20	0.05	
10/18/2012 3:30	0.03		10/21/2012 15:30	0.05	
10/18/2012 3:40	0.03		10/21/2012 15:40	0.05	
10/18/2012 3:50	0.03		10/21/2012 15:50	0.05	
10/18/2012 4:00	0.02		10/21/2012 16:00	0.05	
10/18/2012 4:10	0.02		10/21/2012 16:10	0.05	
10/18/2012 4:20	0.02		10/21/2012 16:20	0.05	
10/18/2012 4:30	0.02		10/21/2012 16:30	0.05	
10/18/2012 4:40	0.02		10/21/2012 16:40	0.05	
10/18/2012 4:50	0.02		10/21/2012 16:50	0.05	
10/18/2012 5:00	0.02		10/21/2012 17:00	0.04	
10/18/2012 5:10	0.02		10/21/2012 17:10	0.04	
10/18/2012 5:20	0.02		10/21/2012 17:20	0.04	
10/18/2012 5:30	0.01		10/21/2012 17:30	0.04	
10/18/2012 5:40	0.01		10/21/2012 17:40	0.04	
10/18/2012 5:50	0.01		10/21/2012 17:50	0.04	
10/18/2012 6:00	0.01		10/21/2012 18:00	0.04	
10/18/2012 6:10	0.01		10/21/2012 18:10	0.04	
10/18/2012 6:20	0.01		10/21/2012 18:20	0.04	
10/18/2012 6:30	0.01		10/21/2012 18:30	0.04	
10/18/2012 6:40	0.01		10/21/2012 18:40	0.04	
10/18/2012 6:50	0.01		10/21/2012 18:50	0.03	
10/18/2012 7:00	0.01		10/21/2012 19:00	0.03	
10/18/2012 7:10	0.01		10/21/2012 19:10	0.03	
10/18/2012 7:20	0.01		10/21/2012 19:20	0.03	
10/18/2012 7:30	0.01		10/21/2012 19:30	0.03	
10/18/2012 7:40	0.01		10/21/2012 19:40	0.03	
10/18/2012 7:50	0.01		10/21/2012 19:50	0.03	

14 th , October, 2012~22 nd , October, 2012					
Time	TP concentration		Time	TP concentration	
	Simulated	Measured		Simulated	Measured
10/18/2012 8:00	0.01		10/21/2012 20:00	0.03	
10/18/2012 8:10	0.01		10/21/2012 20:10	0.03	
10/18/2012 8:20	0.01		10/21/2012 20:20	0.03	
10/18/2012 8:30	0.01		10/21/2012 20:30	0.03	
10/18/2012 8:40	0.01		10/21/2012 20:40	0.03	
10/18/2012 8:50	0.01		10/21/2012 20:50	0.03	
10/18/2012 9:00	0.01		10/21/2012 21:00	0.03	
10/18/2012 9:10	0.01		10/21/2012 21:10	0.02	
10/18/2012 9:20	0.01		10/21/2012 21:20	0.02	
10/18/2012 9:30	0.01		10/21/2012 21:30	0.02	
10/18/2012 9:40	0.01		10/21/2012 21:40	0.02	
10/18/2012 9:50	0.01		10/21/2012 21:50	0.02	
10/18/2012 10:00	0.01		10/21/2012 22:00	0.02	
10/18/2012 10:10	0.01		10/21/2012 22:10	0.02	
10/18/2012 10:20	0.01		10/21/2012 22:20	0.02	
10/18/2012 10:30	0.01		10/21/2012 22:30	0.02	
10/18/2012 10:40	0.00		10/21/2012 22:40	0.02	
10/18/2012 10:50	0.00		10/21/2012 22:50	0.02	
10/18/2012 11:00	0.05		10/21/2012 23:00	0.02	
10/18/2012 11:10	0.05		10/21/2012 23:10	0.02	
10/18/2012 11:20	0.05		10/21/2012 23:20	0.02	
10/18/2012 11:30	0.05		10/21/2012 23:30	0.02	
10/18/2012 11:40	0.05		10/21/2012 23:40	0.02	
10/18/2012 11:50	0.05		10/21/2012 23:50	0.02	

2012-10-14~2012-10-22

22 nd , November, 2012~29 th , November, 2012					
Time	TP concentration		Time	TP concentration	
	Simulated	Measured		Simulated	Measured
11/22/2012 0:00	0.00		11/26/2012 0:00	0.00	
11/22/2012 0:10	4.53		11/26/2012 0:10	0.77	
11/22/2012 0:20	3.53		11/26/2012 0:20	0.69	
11/22/2012 0:30	4.42	4.77	11/26/2012 0:30	0.69	
11/22/2012 0:40	3.54		11/26/2012 0:40	0.62	
11/22/2012 0:50	2.87		11/26/2012 0:50	0.61	
11/22/2012 1:00	2.35		11/26/2012 1:00	0.56	
11/22/2012 1:10	1.95		11/26/2012 1:10	0.51	
11/22/2012 1:20	1.63		11/26/2012 1:20	0.47	
11/22/2012 1:30	1.38		11/26/2012 1:30	0.43	
11/22/2012 1:40	1.18		11/26/2012 1:40	0.40	
11/22/2012 1:50	1.02		11/26/2012 1:50	0.37	
11/22/2012 2:00	0.88		11/26/2012 2:00	0.35	
11/22/2012 2:10	0.77		11/26/2012 2:10	0.32	
11/22/2012 2:20	0.68		11/26/2012 2:20	0.30	
11/22/2012 2:30	0.60		11/26/2012 2:30	0.29	
11/22/2012 2:40	0.53		11/26/2012 2:40	0.27	
11/22/2012 2:50	0.48		11/26/2012 2:50	0.25	
11/22/2012 3:00	0.43		11/26/2012 3:00	0.24	
11/22/2012 3:10	0.39		11/26/2012 3:10	0.23	
11/22/2012 3:20	0.35		11/26/2012 3:20	0.22	
11/22/2012 3:30	0.32		11/26/2012 3:30	0.21	
11/22/2012 3:40	0.30		11/26/2012 3:40	0.20	
11/22/2012 3:50	0.27		11/26/2012 3:50	0.19	
11/22/2012 4:00	0.25		11/26/2012 4:00	0.18	
11/22/2012 4:10	0.23		11/26/2012 4:10	0.17	
11/22/2012 4:20	0.22		11/26/2012 4:20	0.16	
11/22/2012 4:30	0.20		11/26/2012 4:30	0.16	
11/22/2012 4:40	0.19		11/26/2012 4:40	0.15	
11/22/2012 4:50	0.18		11/26/2012 4:50	0.25	
11/22/2012 5:00	0.17		11/26/2012 5:00	0.24	
11/22/2012 5:10	0.16		11/26/2012 5:10	0.23	
11/22/2012 5:20	0.15		11/26/2012 5:20	0.25	
11/22/2012 5:30	0.14		11/26/2012 5:30	0.24	
11/22/2012 5:40	0.13		11/26/2012 5:40	0.23	
11/22/2012 5:50	0.13		11/26/2012 5:50	0.23	
11/22/2012 6:00	0.12		11/26/2012 6:00	0.22	
11/22/2012 6:10	0.11		11/26/2012 6:10	0.21	
11/22/2012 6:20	0.11		11/26/2012 6:20	0.20	
11/22/2012 6:30	0.10		11/26/2012 6:30	0.20	

22 nd , November, 2012~29 th , November, 2012					
Time	TP concentration		Time	TP concentration	
	Simulated	Measured		Simulated	Measured
11/22/2012 6:40	0.10		11/26/2012 6:40	0.23	
11/22/2012 6:50	0.09		11/26/2012 6:50	0.22	
11/22/2012 7:00	0.09		11/26/2012 7:00	0.21	
11/22/2012 7:10	0.09		11/26/2012 7:10	0.21	
11/22/2012 7:20	0.08		11/26/2012 7:20	0.20	
11/22/2012 7:30	0.08		11/26/2012 7:30	0.19	
11/22/2012 7:40	0.08		11/26/2012 7:40	0.19	
11/22/2012 7:50	0.07		11/26/2012 7:50	0.18	
11/22/2012 8:00	0.07		11/26/2012 8:00	0.18	
11/22/2012 8:10	0.24		11/26/2012 8:10	0.17	
11/22/2012 8:20	0.23		11/26/2012 8:20	0.17	
11/22/2012 8:30	0.22		11/26/2012 8:30	0.16	
11/22/2012 8:40	0.21		11/26/2012 8:40	0.16	
11/22/2012 8:50	0.20		11/26/2012 8:50	0.15	
11/22/2012 9:00	0.20		11/26/2012 9:00	0.15	
11/22/2012 9:10	0.19		11/26/2012 9:10	0.21	
11/22/2012 9:20	0.18		11/26/2012 9:20	0.20	
11/22/2012 9:30	0.18		11/26/2012 9:30	0.20	
11/22/2012 9:40	0.36		11/26/2012 9:40	0.22	
11/22/2012 9:50	0.37		11/26/2012 9:50	0.21	
11/22/2012 10:00	0.35		11/26/2012 10:00	0.22	
11/22/2012 10:10	0.33		11/26/2012 10:10	0.22	
11/22/2012 10:20	0.32		11/26/2012 10:20	0.23	
11/22/2012 10:30	0.31		11/26/2012 10:30	0.22	
11/22/2012 10:40	0.30		11/26/2012 10:40	0.23	
11/22/2012 10:50	0.29		11/26/2012 10:50	0.22	
11/22/2012 11:00	0.28		11/26/2012 11:00	0.28	
11/22/2012 11:10	0.27		11/26/2012 11:10	0.28	
11/22/2012 11:20	0.26		11/26/2012 11:20	0.30	
11/22/2012 11:30	0.26		11/26/2012 11:30	0.29	
11/22/2012 11:40	0.27		11/26/2012 11:40	0.28	
11/22/2012 11:50	0.26		11/26/2012 11:50	0.27	
11/22/2012 12:00	0.26		11/26/2012 12:00	0.26	
11/22/2012 12:10	0.25		11/26/2012 12:10	0.26	
11/22/2012 12:20	0.24		11/26/2012 12:20	0.25	
11/22/2012 12:30	0.24		11/26/2012 12:30	0.24	
11/22/2012 12:40	0.26		11/26/2012 12:40	0.24	
11/22/2012 12:50	0.26		11/26/2012 12:50	0.23	
11/22/2012 13:00	0.35		11/26/2012 13:00	0.22	
11/22/2012 13:10	0.33		11/26/2012 13:10	0.22	

22 nd , November, 2012~29 th , November, 2012					
Time	TP concentration		Time	TP concentration	
	Simulated	Measured		Simulated	Measured
11/22/2012 13:20	0.32		11/26/2012 13:20	0.21	
11/22/2012 13:30	0.30		11/26/2012 13:30	0.32	
11/22/2012 13:40	0.29		11/26/2012 13:40	0.31	
11/22/2012 13:50	0.28		11/26/2012 13:50	0.30	
11/22/2012 14:00	0.28		11/26/2012 14:00	0.29	
11/22/2012 14:10	0.27		11/26/2012 14:10	0.28	
11/22/2012 14:20	0.26		11/26/2012 14:20	0.31	
11/22/2012 14:30	0.26		11/26/2012 14:30	0.30	
11/22/2012 14:40	0.25		11/26/2012 14:40	0.32	
11/22/2012 14:50	0.25		11/26/2012 14:50	0.31	
11/22/2012 15:00	0.24		11/26/2012 15:00	0.42	0.15
11/22/2012 15:10	0.24		11/26/2012 15:10	0.32	
11/22/2012 15:20	0.23		11/26/2012 15:20	0.27	
11/22/2012 15:30	0.23		11/26/2012 15:30	0.25	
11/22/2012 15:40	0.22		11/26/2012 15:40	0.23	
11/22/2012 15:50	0.22		11/26/2012 15:50	0.21	
11/22/2012 16:00	0.21		11/26/2012 16:00	0.20	
11/22/2012 16:10	0.21		11/26/2012 16:10	0.20	
11/22/2012 16:20	0.20		11/26/2012 16:20	0.19	
11/22/2012 16:30	0.20		11/26/2012 16:30	0.20	
11/22/2012 16:40	0.19		11/26/2012 16:40	0.20	
11/22/2012 16:50	0.19		11/26/2012 16:50	0.20	
11/22/2012 17:00	0.20		11/26/2012 17:00	0.31	
11/22/2012 17:10	0.20		11/26/2012 17:10	0.07	
11/22/2012 17:20	0.20		11/26/2012 17:20	0.09	
11/22/2012 17:30	0.19		11/26/2012 17:30	0.00	
11/22/2012 17:40	0.21		11/26/2012 17:40	0.00	
11/22/2012 17:50	0.20		11/26/2012 17:50	0.00	
11/22/2012 18:00	0.20		11/26/2012 18:00	0.00	
11/22/2012 18:10	0.19		11/26/2012 18:10	0.00	
11/22/2012 18:20	0.19		11/26/2012 18:20	0.01	
11/22/2012 18:30	0.18		11/26/2012 18:30	0.01	
11/22/2012 18:40	0.18		11/26/2012 18:40	0.01	
11/22/2012 18:50	0.17		11/26/2012 18:50	0.01	
11/22/2012 19:00	0.17		11/26/2012 19:00	0.01	
11/22/2012 19:10	0.16		11/26/2012 19:10	0.01	
11/22/2012 19:20	0.16		11/26/2012 19:20	0.01	
11/22/2012 19:30	0.16		11/26/2012 19:30	0.02	
11/22/2012 19:40	0.15		11/26/2012 19:40	0.02	
11/22/2012 19:50	0.15		11/26/2012 19:50	0.02	

22 nd , November, 2012~29 th , November, 2012					
Time	TP concentration		Time	TP concentration	
	Simulated	Measured		Simulated	Measured
11/22/2012 20:00	0.14		11/26/2012 20:00	0.02	
11/22/2012 20:10	0.14		11/26/2012 20:10	0.03	
11/22/2012 20:20	0.14		11/26/2012 20:20	0.03	
11/22/2012 20:30	0.13		11/26/2012 20:30	0.04	
11/22/2012 20:40	0.13		11/26/2012 20:40	0.04	
11/22/2012 20:50	0.13		11/26/2012 20:50	0.04	
11/22/2012 21:00	0.12		11/26/2012 21:00	0.05	
11/22/2012 21:10	0.12		11/26/2012 21:10	0.05	
11/22/2012 21:20	0.12		11/26/2012 21:20	0.06	
11/22/2012 21:30	0.11		11/26/2012 21:30	0.06	
11/22/2012 21:40	0.11		11/26/2012 21:40	0.07	
11/22/2012 21:50	0.11		11/26/2012 21:50	0.07	
11/22/2012 22:00	0.11		11/26/2012 22:00	0.08	
11/22/2012 22:10	0.10		11/26/2012 22:10	0.08	
11/22/2012 22:20	0.10		11/26/2012 22:20	0.09	
11/22/2012 22:30	0.10		11/26/2012 22:30	0.09	
11/22/2012 22:40	0.10		11/26/2012 22:40	0.10	
11/22/2012 22:50	0.09		11/26/2012 22:50	0.10	
11/22/2012 23:00	0.09		11/26/2012 23:00	0.11	
11/22/2012 23:10	0.09		11/26/2012 23:10	0.11	
11/22/2012 23:20	0.09		11/26/2012 23:20	0.11	
11/22/2012 23:30	0.08		11/26/2012 23:30	0.12	
11/22/2012 23:40	0.08		11/26/2012 23:40	0.12	
11/22/2012 23:50	0.08		11/26/2012 23:50	0.13	
11/23/2012 0:00	0.00		11/28/2012 0:00	0.00	
11/23/2012 0:10	1.71		11/28/2012 0:10	0.46	
11/23/2012 0:20	1.37		11/28/2012 0:20	0.42	
11/23/2012 0:30	1.11		11/28/2012 0:30	0.39	
11/23/2012 0:40	0.91		11/28/2012 0:40	0.36	
11/23/2012 0:50	0.75		11/28/2012 0:50	0.33	
11/23/2012 1:00	0.63		11/28/2012 1:00	0.31	
11/23/2012 1:10	0.53		11/28/2012 1:10	0.29	
11/23/2012 1:20	0.45		11/28/2012 1:20	0.27	
11/23/2012 1:30	0.39		11/28/2012 1:30	0.25	
11/23/2012 1:40	1.15	1.92	11/28/2012 1:40	0.24	
11/23/2012 1:50	1.00		11/28/2012 1:50	0.22	
11/23/2012 2:00	0.88		11/28/2012 2:00	0.21	
11/23/2012 2:10	0.78		11/28/2012 2:10	0.20	
11/23/2012 2:20	0.80		11/28/2012 2:20	0.19	
11/23/2012 2:30	0.74		11/28/2012 2:30	0.18	

22 nd , November, 2012~29 th , November, 2012					
Time	TP concentration		Time	TP concentration	
	Simulated	Measured		Simulated	Measured
11/23/2012 2:40	0.66		11/28/2012 2:40	0.17	
11/23/2012 2:50	0.60		11/28/2012 2:50	0.16	
11/23/2012 3:00	0.54		11/28/2012 3:00	0.16	
11/23/2012 3:10	0.50		11/28/2012 3:10	0.15	
11/23/2012 3:20	0.45		11/28/2012 3:20	0.14	
11/23/2012 3:30	0.42		11/28/2012 3:30	0.14	
11/23/2012 3:40	0.39		11/28/2012 3:40	0.30	
11/23/2012 3:50	0.36		11/28/2012 3:50	0.29	
11/23/2012 4:00	0.33		11/28/2012 4:00	0.29	
11/23/2012 4:10	0.31		11/28/2012 4:10	0.28	
11/23/2012 4:20	0.29		11/28/2012 4:20	0.61	
11/23/2012 4:30	0.27		11/28/2012 4:30	0.22	
11/23/2012 4:40	0.25		11/28/2012 4:40	0.17	
11/23/2012 4:50	0.24		11/28/2012 4:50	0.18	
11/23/2012 5:00	0.23		11/28/2012 5:00	0.10	
11/23/2012 5:10	0.21		11/28/2012 5:10	0.09	
11/23/2012 5:20	0.20		11/28/2012 5:20	0.07	
11/23/2012 5:30	0.19		11/28/2012 5:30	0.06	
11/23/2012 5:40	0.18		11/28/2012 5:40	0.06	
11/23/2012 5:50	0.17		11/28/2012 5:50	0.06	
11/23/2012 6:00	0.16		11/28/2012 6:00	0.06	
11/23/2012 6:10	0.16		11/28/2012 6:10	0.06	
11/23/2012 6:20	0.15		11/28/2012 6:20	0.06	
11/23/2012 6:30	0.14		11/28/2012 6:30	0.06	
11/23/2012 6:40	0.14		11/28/2012 6:40	0.07	
11/23/2012 6:50	0.13		11/28/2012 6:50	0.07	
11/23/2012 7:00	0.13		11/28/2012 7:00	0.08	
11/23/2012 7:10	0.12		11/28/2012 7:10	0.08	
11/23/2012 7:20	0.12		11/28/2012 7:20	0.08	
11/23/2012 7:30	0.11		11/28/2012 7:30	0.09	
11/23/2012 7:40	0.11		11/28/2012 7:40	0.09	
11/23/2012 7:50	0.10		11/28/2012 7:50	0.10	
11/23/2012 8:00	0.10		11/28/2012 8:00	0.11	0.12
11/23/2012 8:10	0.10		11/28/2012 8:10	0.11	
11/23/2012 8:20	0.09		11/28/2012 8:20	0.12	
11/23/2012 8:30	0.09		11/28/2012 8:30	0.12	
11/23/2012 8:40	0.09		11/28/2012 8:40	0.13	
11/23/2012 8:50	0.08		11/28/2012 8:50	0.13	
11/23/2012 9:00	0.08		11/28/2012 9:00	0.13	
11/23/2012 9:10	0.08		11/28/2012 9:10	0.14	

22 nd , November, 2012~29 th , November, 2012					
Time	TP concentration		Time	TP concentration	
	Simulated	Measured		Simulated	Measured
11/23/2012 9:20	0.08		11/28/2012 9:20	0.14	
11/23/2012 9:30	0.07		11/28/2012 9:30	0.14	
11/23/2012 9:40	0.07		11/28/2012 9:40	0.15	
11/23/2012 9:50	0.07		11/28/2012 9:50	0.15	
11/23/2012 10:00	0.07		11/28/2012 10:00	0.15	
11/23/2012 10:10	0.21		11/28/2012 10:10	0.15	
11/23/2012 10:20	0.21		11/28/2012 10:20	0.15	
11/23/2012 10:30	0.20		11/28/2012 10:30	0.16	
11/23/2012 10:40	0.20		11/28/2012 10:40	0.16	
11/23/2012 10:50	0.19		11/28/2012 10:50	0.16	
11/23/2012 11:00	0.22		11/28/2012 11:00	0.16	
11/23/2012 11:10	0.21		11/28/2012 11:10	0.16	
11/23/2012 11:20	0.21		11/28/2012 11:20	0.16	
11/23/2012 11:30	0.20		11/28/2012 11:30	0.17	
11/23/2012 11:40	0.19		11/28/2012 11:40	0.17	
11/23/2012 11:50	0.19		11/28/2012 11:50	0.17	
11/23/2012 12:00	0.18		11/28/2012 12:00	0.17	
11/23/2012 12:10	0.18		11/28/2012 12:10	0.17	
11/23/2012 12:20	0.17		11/28/2012 12:20	0.18	
11/23/2012 12:30	0.17		11/28/2012 12:30	0.17	
11/23/2012 12:40	0.16		11/28/2012 12:40	0.18	
11/23/2012 12:50	0.21		11/28/2012 12:50	0.18	
11/23/2012 13:00	0.20		11/28/2012 13:00	0.19	
11/23/2012 13:10	0.20		11/28/2012 13:10	0.18	
11/23/2012 13:20	0.22		11/28/2012 13:20	0.18	
11/23/2012 13:30	0.21		11/28/2012 13:30	0.19	
11/23/2012 13:40	0.22		11/28/2012 13:40	0.19	
11/23/2012 13:50	0.22		11/28/2012 13:50	0.19	
11/23/2012 14:00	0.21		11/28/2012 14:00	0.19	
11/23/2012 14:10	0.20		11/28/2012 14:10	0.20	
11/23/2012 14:20	0.20		11/28/2012 14:20	0.19	
11/23/2012 14:30	0.19		11/28/2012 14:30	0.19	
11/23/2012 14:40	0.19		11/28/2012 14:40	0.20	
11/23/2012 14:50	0.18		11/28/2012 14:50	0.20	
11/23/2012 15:00	0.18		11/28/2012 15:00	0.20	
11/23/2012 15:10	0.17		11/28/2012 15:10	0.20	
11/23/2012 15:20	0.17		11/28/2012 15:20	0.20	
11/23/2012 15:30	0.16		11/28/2012 15:30	0.19	
11/23/2012 15:40	0.16		11/28/2012 15:40	0.19	
11/23/2012 15:50	0.16		11/28/2012 15:50	0.18	

22 nd , November, 2012~29 th , November, 2012					
Time	TP concentration		Time	TP concentration	
	Simulated	Measured		Simulated	Measured
11/23/2012 16:00	0.15		11/28/2012 16:00	0.18	
11/23/2012 16:10	0.15		11/28/2012 16:10	0.17	
11/23/2012 16:20	0.14		11/28/2012 16:20	0.17	
11/23/2012 16:30	0.14		11/28/2012 16:30	0.17	
11/23/2012 16:40	0.14		11/28/2012 16:40	0.16	
11/23/2012 16:50	0.13		11/28/2012 16:50	0.16	
11/23/2012 17:00	0.13		11/28/2012 17:00	0.16	
11/23/2012 17:10	0.12		11/28/2012 17:10	0.15	
11/23/2012 17:20	0.12		11/28/2012 17:20	0.15	
11/23/2012 17:30	0.12		11/28/2012 17:30	0.14	
11/23/2012 17:40	0.12		11/28/2012 17:40	0.14	
11/23/2012 17:50	0.11		11/28/2012 17:50	0.14	
11/23/2012 18:00	0.11		11/28/2012 18:00	0.13	
11/23/2012 18:10	0.11		11/28/2012 18:10	0.13	
11/23/2012 18:20	0.10		11/28/2012 18:20	0.13	
11/23/2012 18:30	0.10		11/28/2012 18:30	0.12	
11/23/2012 18:40	0.10		11/28/2012 18:40	0.23	
11/23/2012 18:50	0.20		11/28/2012 18:50	0.22	
11/23/2012 19:00	0.20		11/28/2012 19:00	0.22	
11/23/2012 19:10	0.19		11/28/2012 19:10	0.21	
11/23/2012 19:20	0.19		11/28/2012 19:20	0.22	
11/23/2012 19:30	0.18		11/28/2012 19:30	0.21	
11/23/2012 19:40	0.18		11/28/2012 19:40	0.21	
11/23/2012 19:50	0.17		11/28/2012 19:50	0.20	
11/23/2012 20:00	0.17		11/28/2012 20:00	0.20	
11/23/2012 20:10	0.16		11/28/2012 20:10	0.19	
11/23/2012 20:20	0.16		11/28/2012 20:20	0.19	
11/23/2012 20:30	0.15		11/28/2012 20:30	0.18	
11/23/2012 20:40	0.15		11/28/2012 20:40	0.18	
11/23/2012 20:50	0.15		11/28/2012 20:50	0.17	
11/23/2012 21:00	0.14		11/28/2012 21:00	0.17	
11/23/2012 21:10	0.14		11/28/2012 21:10	0.17	
11/23/2012 21:20	0.13		11/28/2012 21:20	0.16	
11/23/2012 21:30	0.13		11/28/2012 21:30	0.16	
11/23/2012 21:40	0.13		11/28/2012 21:40	0.15	
11/23/2012 21:50	0.12		11/28/2012 21:50	0.15	
11/23/2012 22:00	0.12		11/28/2012 22:00	0.15	
11/23/2012 22:10	0.12		11/28/2012 22:10	0.14	
11/23/2012 22:20	0.11		11/28/2012 22:20	0.14	
11/23/2012 22:30	0.11		11/28/2012 22:30	0.13	

22 nd , November, 2012~29 th , November, 2012					
Time	TP concentration		Time	TP concentration	
	Simulated	Measured		Simulated	Measured
11/23/2012 22:40	0.11		11/28/2012 22:40	0.13	
11/23/2012 22:50	0.11		11/28/2012 22:50	0.13	
11/23/2012 23:00	0.10		11/28/2012 23:00	0.12	
11/23/2012 23:10	0.10		11/28/2012 23:10	0.12	
11/23/2012 23:20	0.20		11/28/2012 23:20	0.12	
11/23/2012 23:30	0.20		11/28/2012 23:30	0.11	
11/23/2012 23:40	0.19		11/28/2012 23:40	0.11	
11/23/2012 23:50	0.19		11/28/2012 23:50	0.11	
11/25/2012 0:00	0.00		11/29/2012 0:00	0.00	
11/25/2012 0:10	1.89		11/29/2012 0:10	0.60	
11/25/2012 0:20	1.55		11/29/2012 0:20	0.55	
11/25/2012 0:30	1.29		11/29/2012 0:30	0.51	
11/25/2012 0:40	1.08		11/29/2012 0:40	0.47	
11/25/2012 0:50	0.91		11/29/2012 0:50	0.45	
11/25/2012 1:00	0.78		11/29/2012 1:00	0.43	
11/25/2012 1:10	0.67		11/29/2012 1:10	0.41	
11/25/2012 1:20	0.58		11/29/2012 1:20	0.38	
11/25/2012 1:30	0.51		11/29/2012 1:30	0.36	
11/25/2012 1:40	0.45		11/29/2012 1:40	0.34	
11/25/2012 1:50	0.39		11/29/2012 1:50	0.45	
11/25/2012 2:00	0.35		11/29/2012 2:00	0.42	
11/25/2012 2:10	0.31		11/29/2012 2:10	0.40	
11/25/2012 2:20	0.28		11/29/2012 2:20	0.38	
11/25/2012 2:30	0.26		11/29/2012 2:30	0.36	
11/25/2012 2:40	0.23		11/29/2012 2:40	0.35	
11/25/2012 2:50	0.21		11/29/2012 2:50	0.33	
11/25/2012 3:00	0.19		11/29/2012 3:00	0.32	
11/25/2012 3:10	0.18		11/29/2012 3:10	0.30	
11/25/2012 3:20	0.17		11/29/2012 3:20	0.29	
11/25/2012 3:30	0.15		11/29/2012 3:30	0.28	
11/25/2012 3:40	0.14		11/29/2012 3:40	0.27	
11/25/2012 3:50	0.13		11/29/2012 3:50	0.26	
11/25/2012 4:00	0.12		11/29/2012 4:00	0.25	
11/25/2012 4:10	0.12		11/29/2012 4:10	0.24	
11/25/2012 4:20	0.11		11/29/2012 4:20	0.23	
11/25/2012 4:30	0.10		11/29/2012 4:30	0.22	
11/25/2012 4:40	0.10		11/29/2012 4:40	0.22	
11/25/2012 4:50	0.31		11/29/2012 4:50	0.21	
11/25/2012 5:00	0.30		11/29/2012 5:00	0.20	
11/25/2012 5:10	0.29		11/29/2012 5:10	0.20	

22 nd , November, 2012~29 th , November, 2012					
Time	TP concentration		Time	TP concentration	
	Simulated	Measured		Simulated	Measured
11/25/2012 5:20	0.27		11/29/2012 5:20	0.19	
11/25/2012 5:30	0.26		11/29/2012 5:30	0.22	
11/25/2012 5:40	0.25		11/29/2012 5:40	0.22	
11/25/2012 5:50	0.63		11/29/2012 5:50	0.21	
11/25/2012 6:00	0.46		11/29/2012 6:00	0.20	
11/25/2012 6:10	0.08		11/29/2012 6:10	0.20	
11/25/2012 6:20	0.07		11/29/2012 6:20	0.19	
11/25/2012 6:30	0.06		11/29/2012 6:30	0.19	
11/25/2012 6:40	0.06		11/29/2012 6:40	0.18	
11/25/2012 6:50	0.06		11/29/2012 6:50	0.17	
11/25/2012 7:00	0.06		11/29/2012 7:00	0.17	
11/25/2012 7:10	0.07		11/29/2012 7:10	0.16	
11/25/2012 7:20	0.04		11/29/2012 7:20	0.16	
11/25/2012 7:30	0.02		11/29/2012 7:30	0.16	
11/25/2012 7:40	0.01		11/29/2012 7:40	0.15	
11/25/2012 7:50	0.01		11/29/2012 7:50	0.15	
11/25/2012 8:00	0.01		11/29/2012 8:00	0.14	
11/25/2012 8:10	0.01		11/29/2012 8:10	0.21	
11/25/2012 8:20	0.01		11/29/2012 8:20	0.20	
11/25/2012 8:30	0.01		11/29/2012 8:30	0.20	
11/25/2012 8:40	0.01		11/29/2012 8:40	0.19	
11/25/2012 8:50	0.01		11/29/2012 8:50	0.19	
11/25/2012 9:00	0.01		11/29/2012 9:00	0.18	
11/25/2012 9:10	0.01		11/29/2012 9:10	0.18	
11/25/2012 9:20	0.01		11/29/2012 9:20	0.17	
11/25/2012 9:30	0.01		11/29/2012 9:30	0.17	
11/25/2012 9:40	0.01		11/29/2012 9:40	0.16	
11/25/2012 9:50	0.01		11/29/2012 9:50	0.16	
11/25/2012 10:00	0.02		11/29/2012 10:00	0.15	
11/25/2012 10:10	0.02		11/29/2012 10:10	0.15	
11/25/2012 10:20	0.02		11/29/2012 10:20	0.14	
11/25/2012 10:30	0.02		11/29/2012 10:30	0.14	
11/25/2012 10:40	0.02		11/29/2012 10:40	0.14	
11/25/2012 10:50	0.03		11/29/2012 10:50	0.13	
11/25/2012 11:00	0.03		11/29/2012 11:00	0.13	
11/25/2012 11:10	0.03		11/29/2012 11:10	0.13	
11/25/2012 11:20	0.03		11/29/2012 11:20	0.12	
11/25/2012 11:30	0.04		11/29/2012 11:30	0.12	
11/25/2012 11:40	0.04		11/29/2012 11:40	0.12	
11/25/2012 11:50	0.05		11/29/2012 11:50	0.11	

22 nd , November, 2012~29 th , November, 2012					
Time	TP concentration		Time	TP concentration	
	Simulated	Measured		Simulated	Measured
11/25/2012 12:00	0.05		11/29/2012 12:00	0.11	
11/25/2012 12:10	0.05		11/29/2012 12:10	0.11	
11/25/2012 12:20	0.06		11/29/2012 12:20	0.10	
11/25/2012 12:30	0.06		11/29/2012 12:30	0.10	0.09
11/25/2012 12:40	0.07		11/29/2012 12:40	0.20	
11/25/2012 12:50	0.07		11/29/2012 12:50	0.20	
11/25/2012 13:00	0.08		11/29/2012 13:00	0.19	
11/25/2012 13:10	0.08		11/29/2012 13:10	0.19	
11/25/2012 13:20	0.09		11/29/2012 13:20	0.18	
11/25/2012 13:30	0.09		11/29/2012 13:30	0.18	
11/25/2012 13:40	0.10		11/29/2012 13:40	0.17	
11/25/2012 13:50	0.10		11/29/2012 13:50	0.17	
11/25/2012 14:00	0.11		11/29/2012 14:00	0.16	
11/25/2012 14:10	0.11		11/29/2012 14:10	0.20	
11/25/2012 14:20	0.11		11/29/2012 14:20	0.20	
11/25/2012 14:30	0.12		11/29/2012 14:30	0.19	
11/25/2012 14:40	0.12		11/29/2012 14:40	0.19	
11/25/2012 14:50	0.15		11/29/2012 14:50	0.18	
11/25/2012 15:00	0.15		11/29/2012 15:00	0.18	
11/25/2012 15:10	0.16		11/29/2012 15:10	0.17	
11/25/2012 15:20	0.16		11/29/2012 15:20	0.17	
11/25/2012 15:30	0.17		11/29/2012 15:30	0.17	
11/25/2012 15:40	0.18		11/29/2012 15:40	0.16	
11/25/2012 15:50	0.18		11/29/2012 15:50	0.16	
11/25/2012 16:00	0.18		11/29/2012 16:00	0.15	
11/25/2012 16:10	0.18		11/29/2012 16:10	0.15	
11/25/2012 16:20	0.18		11/29/2012 16:20	0.14	
11/25/2012 16:30	0.18		11/29/2012 16:30	0.14	
11/25/2012 16:40	0.18		11/29/2012 16:40	0.14	
11/25/2012 16:50	0.18		11/29/2012 16:50	0.20	
11/25/2012 17:00	0.18		11/29/2012 17:00	0.20	
11/25/2012 17:10	0.18		11/29/2012 17:10	0.19	
11/25/2012 17:20	0.18		11/29/2012 17:20	0.21	
11/25/2012 17:30	0.18		11/29/2012 17:30	0.21	
11/25/2012 17:40	0.18		11/29/2012 17:40	0.20	
11/25/2012 17:50	0.18		11/29/2012 17:50	0.20	
11/25/2012 18:00	0.18		11/29/2012 18:00	0.19	
11/25/2012 18:10	0.18		11/29/2012 18:10	0.19	
11/25/2012 18:20	0.18		11/29/2012 18:20	0.18	
11/25/2012 18:30	0.18		11/29/2012 18:30	0.18	

22 nd , November, 2012~29 th , November, 2012					
Time	TP concentration		Time	TP concentration	
	Simulated	Measured		Simulated	Measured
11/25/2012 18:40	0.20		11/29/2012 18:40	0.17	
11/25/2012 18:50	0.20		11/29/2012 18:50	0.17	
11/25/2012 19:00	0.20		11/29/2012 19:00	0.16	
11/25/2012 19:10	0.20		11/29/2012 19:10	0.16	
11/25/2012 19:20	0.19		11/29/2012 19:20	0.15	
11/25/2012 19:30	0.21	0.25	11/29/2012 19:30	0.15	
11/25/2012 19:40	0.21		11/29/2012 19:40	0.15	
11/25/2012 19:50	0.21		11/29/2012 19:50	0.14	
11/25/2012 20:00	0.21		11/29/2012 20:00	0.14	
11/25/2012 20:10	0.20		11/29/2012 20:10	0.13	
11/25/2012 20:20	0.20		11/29/2012 20:20	0.13	
11/25/2012 20:30	0.20		11/29/2012 20:30	0.13	
11/25/2012 20:40	0.19		11/29/2012 20:40	0.12	
11/25/2012 20:50	0.24		11/29/2012 20:50	0.12	
11/25/2012 21:00	0.23		11/29/2012 21:00	0.12	
11/25/2012 21:10	0.23		11/29/2012 21:10	0.11	
11/25/2012 21:20	0.23		11/29/2012 21:20	0.11	
11/25/2012 21:30	0.22		11/29/2012 21:30	0.11	
11/25/2012 21:40	0.24		11/29/2012 21:40	0.11	
11/25/2012 21:50	0.23		11/29/2012 21:50	0.10	
11/25/2012 22:00	0.23		11/29/2012 22:00	0.10	
11/25/2012 22:10	0.23		11/29/2012 22:10	0.10	
11/25/2012 22:20	0.22		11/29/2012 22:20	0.09	
11/25/2012 22:30	0.22		11/29/2012 22:30	0.09	
11/25/2012 22:40	0.21		11/29/2012 22:40	0.09	
11/25/2012 22:50	0.21		11/29/2012 22:50	0.09	
11/25/2012 23:00	0.21		11/29/2012 23:00	0.08	
11/25/2012 23:10	0.21		11/29/2012 23:10	0.08	
11/25/2012 23:20	0.21		11/29/2012 23:20	0.08	
11/25/2012 23:30	0.20		11/29/2012 23:30	0.08	
11/25/2012 23:40	0.20		11/29/2012 23:40	0.08	
11/25/2012 23:50	0.21		11/29/2012 23:50	0.07	

2012-11-21~2012-11-30

Appendix I. Reformatted data extracted from studies by others including Smith K.A (2001), Udawatta *et al.* (2006), Smith D.R *et al.* (2007), McDowell *et al.* (2003, 2005) and Scholefield *et al.* (1995).

Table I- 1 Reformatted data extracted from Smith K.A (2001)-Nitrogen

Surface runoff (mm)	NH ₄ ⁺ Loss (g/ha)	NH ₄ ⁺ concentration (mg/L)	Surface runoff (mm)	NO ₃ ⁻ Loss (g/ha)	NO ₃ ⁻ concentration (mg/L)
0.79	5.49	1.39	0.83	15.80	3.81
1.00	8.54	1.71	1.03	22.72	4.39
1.27	17.68	2.78	1.29	35.06	5.44
1.82	23.98	2.63	1.80	70.12	7.81
2.46	23.98	1.95	2.49	81.48	6.54
2.65	29.07	2.20	2.68	89.38	6.68
3.01	31.91	2.12	3.07	92.35	6.02
3.49	37.20	2.13	3.51	92.84	5.29
3.83	40.65	2.12	3.81	95.31	5.00
3.99	40.85	2.05	4.19	107.65	5.14
4.19	40.85	1.95	4.63	112.59	4.87
4.59	44.11	1.92	4.86	115.56	4.75
4.81	45.73	1.90	5.42	116.54	4.30
5.45	48.37	1.78			

Table I- 2 Reformatted data extracted from Smith K.A (2001)-Phosphorus

Surface runoff (mm)	TP Loss (g/ha)	TP concentration (mg/L)
0.54	1.37	0.50
1.21	2.89	0.48
1.39	2.97	0.43
1.82	3.45	0.38
2.06	4.02	0.39
2.18	4.10	0.38
2.48	5.46	0.44
3.01	6.18	0.41
3.37	6.83	0.41
3.55	7.07	0.40
4.23	8.67	0.41
4.71	9.40	0.40
4.98	10.52	0.42
5.20	11.33	0.44

Table I- 3 Reformatted data extracted from Udawatta *et al.* (2006)

Runoff Volume (m ³ /ha)	Runoff Volume (m ³)	TN concentration (mg/L)	Runoff Volume (m ³ /ha)	Runoff Volume (m ³)	NO ₃ ⁻ concentration (mg/L)
18.40	0.03	1.53	24.46	0.04	2.93
49.08	0.07	19.16	30.58	0.05	53.48
49.08	0.07	24.52	42.81	0.06	5.86
55.21	0.08	9.20	48.93	0.07	12.82
55.21	0.08	32.95	55.05	0.08	27.11
55.21	0.08	38.31	55.05	0.08	15.02
61.35	0.09	3.07	61.16	0.09	19.41
79.75	0.12	42.15	61.16	0.09	46.52
79.75	0.12	45.21	61.16	0.09	1.47
85.89	0.13	13.41	73.39	0.11	24.91
85.89	0.13	66.67	73.39	0.11	34.43
85.89	0.13	75.86	79.51	0.12	45.42
104.29	0.16	5.36	85.63	0.13	73.99
104.29	0.16	61.69	97.86	0.15	64.84
116.56	0.17	45.21	103.98	0.16	8.42
116.56	0.17	69.35	103.98	0.16	2.93
122.70	0.18	12.64	110.09	0.17	53.11
141.10	0.21	9.20	116.21	0.17	45.05
165.64	0.25	6.51	116.21	0.17	68.50
165.64	0.25	1.53	128.44	0.19	10.26

Runoff Volume (m ³ /ha)	Runoff Volume (m ³)	TN concentration (mg/L)	Runoff Volume (m ³ /ha)	Runoff Volume (m ³)	NO ₃ ⁻ concentration (mg/L)
177.91	0.27	23.37	146.79	0.22	6.23
233.13	0.35	6.90	165.14	0.25	1.10
263.80	0.40	3.07	177.37	0.27	5.13
276.07	0.41	11.11	183.49	0.28	10.62
306.75	0.46	8.05	220.18	0.33	4.03
312.88	0.47	5.36	275.23	0.41	9.16
355.83	0.53	8.43	281.35	0.42	2.93
368.10	0.55	3.45	318.04	0.48	6.23
417.18	0.63	6.90	360.86	0.54	5.49
441.72	0.66	9.96	409.79	0.61	4.76
472.39	0.71	2.68	440.37	0.66	6.23
607.36	0.91	1.92	470.95	0.71	2.93
613.50	0.92	20.31	611.62	0.92	11.36
736.20	1.10	20.69	733.95	1.10	17.58
736.20	1.10	1.92	1015.29	1.52	8.79
858.90	1.29	1.53	1051.99	1.58	15.75
901.84	1.35	2.68	1064.22	1.60	19.41
938.65	1.41	1.53	1070.34	1.61	16.85
1018.41	1.53	15.71	1314.99	1.97	5.49
1030.68	1.55	1.92	1577.98	2.37	14.29
1042.95	1.56	21.07	1669.73	2.50	5.86
1055.22	1.58	21.07		0.04	
1073.62	1.61	18.01		0.05	
1312.88	1.97	8.43		0.06	
1570.55	2.36	16.86		0.07	
1680.98	2.52	11.49		0.08	

Table I- 4 Reformatted data extracted from Smith D.R *et al.* (2007)

Days after fertiliser apply	Concentration (mg/L)		
	Soluble P	NH ₄ ⁺	NO ₃ ⁻
1	4.86	6.11	0.07
4	3.79	6.29	0.20
8	1.35	1.61	0.46
15	2.34	1.71	0.46
29	2.61	0.75	1.50

Table I- 5 TP concentration investigate by McDowell *et al.* (2005)

Days	TP (mg/L)
1	2.44
1	1.32
1	0.49
7	1.29
7	0.49
7	1.68
7	1.03
14	1.04
14	0.39
14	0.93
14	1.24
28	0.47
28	0.30
28	0.34

Table I- 6 TP concentration investigate by McDowell *et al.* (2003)

Day	TP mg/L
7	7.049505
7	3.287129
7	0.29703
7	3.623762
7	1.168317
34	1.306931
34	0.673267
34	0.316832
34	0.831683
34	0.455446
84	0.49505
84	0.257426
84	0.673267

Table I- 7 Reformatted data extracted from Scholefield *et al.* (1995)

Date (MMDD)	Days after fertiliser applied	Rainfall (mm)	Runoff (mm)	N (mg/L)	P (mg/L)
0222	0	31.63	37.15	0.29	0.00
0225	3	30.96	32.13	8.30	1.09
0226	4	27.11	37.15	2.71	0.53
0228	6	33.97	35.98	1.79	0.29
0301	7	30.96	32.97	0.58	0.00
0303	9	23.10	28.28	0.46	0.00
0309	15	18.08	18.24	0.17	0.00
0313	19	35.98	36.32	0.23	0.00
0316	22	34.14	37.15	0.12	0.00
0317	23	27.78	29.96	0.29	0.00
0321	27	16.74	22.09	0.52	0.00
0326	32	25.94	37.82	0.23	0.00