MULTI-METHOD APPROACH TO QUANTIFYING NUTRIENT RETENTION IN A WASTEWATER IRRIGATED WATERSHED

by

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Abstract

As water is becoming more scarce, the application of wastewater onto land is becoming increasingly common. It is of particular interest in places where the otherwise receiving water body is considered too sensitive to handle the increased load of nutrients, and other wastewater constituents. This study utilized three methods to determine the extent to which phosphorus and nitrogen are being retained within a wastewater irrigated watershed in southern B.C., Canada. The methods include; Mass Balance, an End Member Mixing Analysis (EMMA) to determine real time and seasonal retention, and a soil analysis to determine long term retention within the soil profile. Retention estimates of P and N using the mass balance method were found to be between 53-93% and 48-77% respectively. Using the End Member Mixing Analysis, retention rates of P and N were found to be between 72-91% and 64-81% respectively. Seasonally, summer and winter had the highest retention rates, while the lowest retention was found during spring freshet. The soil analysis results found a 32% increase in phosphorus storage in irrigated soil over non-irrigated soils. This increase translated to a 40% retention rate (11,300 kg) of phosphorus in the irrigated soils during the course of the 35-year irrigation program.

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Abbreviations

CEC = cation exchange capacity

Cl = Chloride

^oC = Degrees Celsius

EPA = Environmental Protection Agency

ET_o = Reference Evapotranspiration

EMMA = end member mixing analysis

GW = groundwater

ha = hectare

I = inputs

ICP-OES = Ion Coupled Plasma Optic Emissions Spectrometer

kg = kilogram

L = liters

m = meters

mg = milligrams

N = nitrogen

Na = sodium

O = outputs

P = phosphorus

Q = discharge

R = retention

SW = sub-watershed

ΔS = change in storage

T_w = residence time in units of time.

TP = Total phosphorus

TN = Total nitrogen

VPD = vapor pressure deficit [kPa]

WWTP = waste water treatment plant

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Dedication

To my family. By now I have spent over half of a 13-year marriage in Academia and I am DONE!! Time to get back to life!! And to Mary who was crucial in making this possible.

Chapter 1: Literature Review

The combination of a growing population and increasing global mean temperatures is resulting in global and regional water scarcity. It is projected that by 2025, 48% of the world's population will be living in river basins that are considered to be water stressed (World Resources Institute, 2014). As a consequence, there has been an increase in water re-use. One of the most beneficial ways to re-use large quantities of water is to use wastewater to irrigate plants. In addition to saving water and providing nutrients for crops, wastewater irrigation has great potential to divert wastewater away from receiving surface water that might be degraded from excess nutrients (eutrophication). Using a watershed approach is one of the best ways to determine the effectiveness of wastewater irrigation for protecting surface waters from eutrophication.

Watersheds are defined as an area of land, bound by topographical high points, such as ridges or hills, where all the surface and groundwater are ideally well-contained, easily measured and gravity drained down gradient to the lowest point. Watersheds contain uplands and aquatic systems. Uplands include all areas of land within a watershed that are above the level of where water flows. Aquatic systems include streams, wetlands, ponds and lakes. Aquatic systems and the underlying groundwater act as water stores within the watershed. Watersheds are an open system, where both the uplands and aquatic systems within a watershed are subject to various environmental fluxes (Moldan and Cerny, 1994). Fluxes can be described as inputs (flux of material into a system) and outputs (the flux of material out of the system). Some of the most prominent materials included in these fluxes are water and nutrients. Within the watershed, both water and nutrients are subject to a host of biogeochemical processes which result in varying amounts of internal cycling. The inputs and outputs and internal processes of either water or nutrients within a watershed are governed by climate, topography, geology, soil type, biota and hydrology (Atol *et al.*, 2011). In a natural watershed, these governing factors are generally not subject to significant changes over a time-scale of years to decades and are considered to be at steady-state, where inputs = outputs (Liken *et al.*, 1977; Molden and Cerny, 1994). However, in some cases there can be a 'disturbance' that can result in significant changes to the system. These disturbances can be of natural origin, or due to human activities. Natural disturbances can include flood events, fire and pest outbreaks. Some anthropogenic disturbances include land-use changes, deforestation and the effect of climate change such as changes in temperature. A major environmental concern associated with any disturbance to a watershed, is the potential release of excess nutrients into downstream aquatic environments (Vitousek *et al.*, 1976).

In the event of a disturbance, different elements will respond differently with time. Generally, materials within a watershed can be categorized into two classes based on how they behave with their surroundings. Materials that are non-reactive (conservative), and those that are reactive (non-conservative). A conservative material is a solute that does not change form, and is not subject to geochemical reactions in the system of interest (Moldan and Cerny, 1976). A non-conservative material does react with it's surrounding and is subject to chemical and biological changes within a watershed (Moldan and Cerny, 1976). Water and conservative elements, such as chloride, tend to respond relatively quickly to changes, reaching a new steady-state within years or decades (Liken *et al*,. 1970), while non-conservative elements, such as phosphorus and nitrogen, can take a very long time (100's of years) to return to a new steady-state (Liken *et al*,. 1970). Often times, between the time of disturbance and the 'new' steady-state the inputs of non-conservative materials are greater than the outputs resulting in an accumulation of material within the watershed, this accumulation can be seen as a form of retention. This retention of a given material results in pools, or reservoirs. Pools and reservoirs are defined as stores of a given material. One way to study the potential impacts of a disturbance to the nutrient balance, is establishing a sound understanding of the water budget and the fluxes of nutrients in water.

Non-agricultural watersheds receive water primarily through precipitation. In watersheds subject to agricultural practices, this is sometimes supplemented with irrigation of imported water, and potentially nutrients in the case of wastewater irrigation. Much of the water that reaches the surface of the watershed is either evaporated directly, or transpired though vegetation back to the atmosphere (together 'evapotranspiration'). In the case where inputs are greater than evapotranspiration (ET), water infiltrates into the ground and contributes to sub-surface flows as groundwater. From there, water moves down gradient through the soil either toward a stream channel, pond or continues on as groundwater. The water that reaches the stream channel becomes surface water. In this case, where a stream is being fed by groundwater it is called a 'gaining stream'. In some cases, where conditions permit, streams can also lose water back to groundwater, and are referred to as 'losing streams'. In some cases, depending on the hydrologic, topographic and geological characteristics of the watershed, water can exchange between the surface and groundwater multiple times during its flow path (Winter *et al.,* 1998; Sophocleous, 2002; Jackson *et al.*, 2009). All these processes within the watershed either contribute water into the watershed as inputs (precipitation and irrigation), store water within the watershed (reservoirs), or export water out of the watershed as outputs (evaporation, surface and sub-surface flows). If these fluxes of inputs and outputs are measured, a water mass balance can be determined.

Mass Balance

A mass balance is an accounting of a given material within a specific system boundary. In the case of a 'watershed approach', this boundary is the topographical divide for gravitational flow. The water mass balance of a watershed can be described by equation 1.

$$I - O = \Delta S, \qquad (1)$$

where

I =inputs in mass time^{-1},

O = outputs in mass time^{-1},

and

ΔS = change in storage in mass time^{-1}.

This mass balance equation has application for both dynamic systems, and steady-state systems. In a dynamic system, the fluxes of both inputs and outputs can change with time, resulting in ΔS also changing. In cases where inputs are greater than outputs, ΔS is positive, and when outputs are greater than inputs, ΔS is negative. In a steady-state system the rate of inputs and the output are stable over time resulting in ΔS being constant over time. In both cases the volume of storage, and either the rate of inputs or outputs can be used to determine the residence time of water within a given watershed (Equation 2).

$$S / I = T_w \qquad (2)$$

where:

S = storage in m^3,

I = inputs in m^3 time^{-1},

and

T_w = residence time in units of time.

The mass balance approach can also be useful when examining the behavior of materials in a watershed. The reason for this is because water is the primary driver behind the movement of most materials within a watershed. Dissolved materials in water are extremely mobile, allowing them to travel with the same velocity and direction as the water (Moldan and Cerny, 1976). In cases where the material is conservative, it can be used as a tracer to track water as it moves through the watershed. One of the most common materials used as a conservative tracer in water is chloride (Moldan and Cerny, 1976).

Chloride has been widely used as an environmental tracer in the hydrologic cycle because it is conservative during passage in both surface and subsurface environments (Claassen and Halm, 1992; Kass *et al.*, 2005; Kirchner *et al.*, 2010; Moldan and Cerny, 1976). Primary inputs of Cl into a watershed include wet and dry deposition of Cl present in the atmosphere and in some cases wastewater irrigation. Once introduced into the watershed, chloride moves through the watershed following the same surface and sub-surface hydrologic pathways as the water in which it is dissolved. Unlike water, chloride does not evaporate, resulting in surface water or groundwater discharge as the only two export pathways of chloride from the watershed. Therefore, at steady state, the mass balance equation for chloride can also be described by equation 1. The absence of evaporation in the chloride mass balance, also makes it useful by modifying equation 1 to determine exports through groundwater that are otherwise hard to estimate (equation 3),

$$I - O_{surface} = O_{sub\text{-}surface}, \quad (3),$$

where:

$O_{surface}$ = chloride exports through surface water discharge, in units mass time^{-1},

and

$O_{sub\text{-}surface}$ = chloride exports through sub-surface discharge, in units mass time^{-1}.

In addition, chloride can also be useful in refining the evaporation portion of the water budget (Claassen and Halm, 1992). The conservative nature of chloride and the distilling effects of evaporation result in an increase in the concentrations of chloride in the non-evaporated water remaining in the watershed (evapoconcentration). Using the initial chloride concentration in precipitation and the Cl concentrations in discharge water the amount of evapoconcentration can be determined. This evapoconcentration can then be used to estimate the proportion of initial water that is needed to evaporate in order to justify the Cl concentration of discharge waters.

In contrast to conservative tracers like chloride, non-conservative materials change form over time depending on their environment. Some of the most common non-conservative materials within a watershed are nutrients, primarily phosphorus and nitrogen. As with water and chloride, there are a variety of sources of P and N that contribute nutrients to the watershed. Inputs of P and N are subject to a variety of processes within the watershed, some of which result in nutrient retention. Factors that can influence retention can include; climate, topography, soil type, biota, hydrology and nutrient loading (Atol et al., 2011). The nutrients that are not retained are subject to further transport mechanisms and ultimately make their way to downstream water bodies. Exports of nutrients are primarily through surface and sub-surface discharge. Similar to water and chloride, accounting for the inputs and outputs of nutrients within a watershed gives rise to the nutrient mass balance (equation 1). Generally, in cases where ΔS is positive there is a positive retention occurring within the watershed, and in cases where ΔS is negative, more material is leaving then entering the system.

End Member Mixing Analysis

There are orthogonal methods to validate the mass balance approach to determine nutrient retention. Fundamentally, the chemistry of each stream within a watershed is a representation of the different sources that contribute to a given stream (Christopherson and Hooper, 1992). In some cases, a stream may have multiple sources. In the case where sources exhibit their own unique chemistry, they can be referred to as End-Members. In the case where end-members containing distinctly different concentrations of conservative materials, and exhibit linear mixing, the proportions of the end-members making up the mixed water can be determined by an end member mixing analysis (EMMA) (Equation 4).

$$[T]_{mixture} = x\,[T]_A + (1-x)\,[T]_B \quad (4)$$

Where:

$[T]_{mixture}$ = concentration of a given tracer within the mixed water sample in mg L^{-1},

$[T]_A$ = concentration of given tracer in end-member ‘A’, in mg L^{-1},

$[T]_B$ = concentration of given tracer in end-member 'B', in mg L^{-1},

and

x = the fraction of water A and 1-x is the fraction of water B.

In some cases, the effects of evaporation can differ between end-members, resulting in incorrect representation of each end-member within the mixed stream. To compensate for this difference, the use of a ratio of two different conservative elements present in both end-members can be used instead of a single tracer. The use of two tracers is useful because the ratio between two conservative elements remains constant, regardless of evapoconcentration (Davis *et al*., 1998). The relationship between the ratio of two tracers in each end-member and the portion in the mixing water sample can be modeled by a curve (Figure 1). A detailed account of the calculations of the mixing curve can be found in Appendix F.

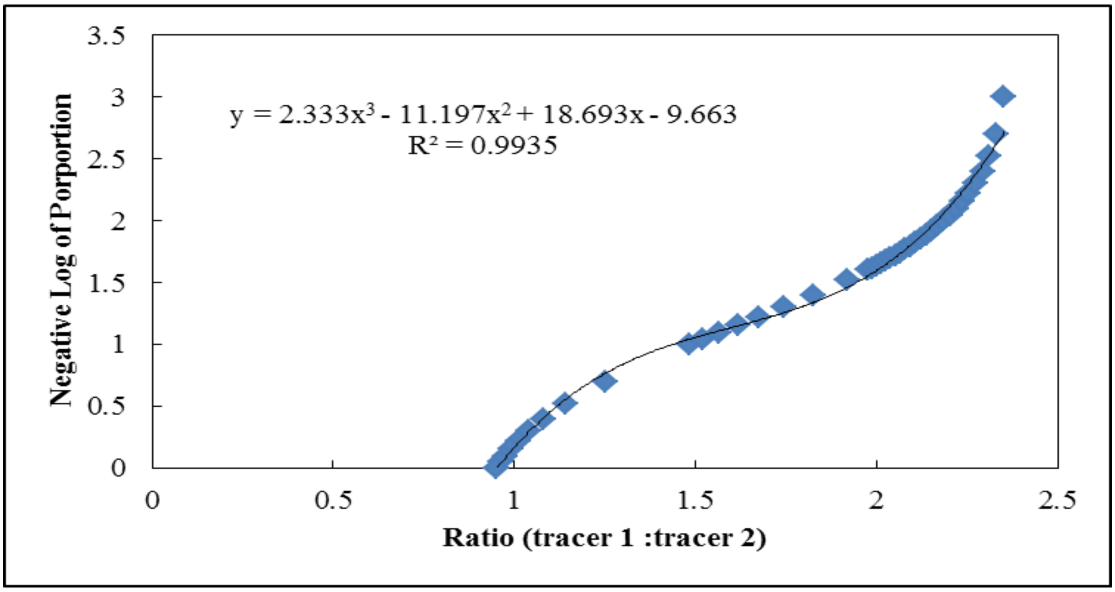

Figure 1: Plot of the ratio of two conservative tracers vs portion of each end-member in mixing sample.

Upon determination of the proportion of each End-member present in the mixed stream sample the theoretical concentrations of non-conservative elements within the mixed sample can be calculated based on the initial ratio within a given end-member. The difference between the theoretical concentrations of the non-conservative material and the measured concentration in the stream gives an estimate of the proportion of material that is being retained (Equation 6).

$$\%retention = \frac{N\ measured}{N\ expected} * 100 \qquad (6)$$

where:

$N_{measured}$ = the measured concentration (mg L^{-1}) of nutrient in the water sample,

and

$N_{expected}$ = the expected concentration (mg L^{-1}) of nutrient base on previous equation.

To determine retention over time, the results given in the EMMA approach and input estimates determined using the mass balance approach, can be used to determine the change in storage within the watershed (ΔS) using equation 7

$$\Delta S = I\ R \qquad (7)$$

where;

I= inputs of material in (mass $time^{-1}$),

and

R = measured / expected material

Both the mass balance approach and the EMMA approach are useful in the determination of nutrient retention within a watershed that is either in an undisturbed natural state or where there has been a disturbance to the nutrients cycle. However, there is a third watershed approach that relies on the differences in response time between conservative and non-conservative elements within the watershed to determine long term retention in the cases where there has been a known disturbance and the time of the disturbance is known.

Soils Analysis

The third watershed approach evaluates retention of nutrients in watershed by sample nutrient concentrations within the reservoirs themselves. Both the mass balance approach and the EMMA are useful in determining the retention of nutrient on a yearly or even seasonal timescale, while the third watershed approach is useful in determining nutrient retention over long periods of time. The non-conservative characteristics of nutrients within the watershed lead to complex interactions between the nutrients and their surroundings. Some of these interactions lead to long term storage of nutrients within the watershed. One of the largest stores of nutrients within a watershed is within the soils. Retention processes of nutrient within soils include assimilation, adsorption, precipitation. With the exception of some aquatic systems, in an undisturbed watershed these processes generally occur at a rate that is at steady-state, resulting in little change in nutrient concentration over time (Liken *et al.*,1970; Moldan and Cerny, 1976). In some aquatic systems, ongoing long-term retention has been noted to occur through the process of particulate phosphorus settling to the bottom of the water column. This process is sometimes referred to as sedimentation. However, in some cases, watersheds are subject to a change in land-use which can result in a disturbance to the nutrient balance of the watershed. In the case of a disturbance, the rate of nutrient inputs into the watershed changes, which in-turn changes the nutrient concentration and overall storage of nutrients in soils over time. If the concentrations of nutrients within the disturbed soils can be compared to nutrient concentration in soils of an undisturbed portion of the watershed the following equation can be used to determine retention as ΔS,

$$\Delta S = (N_D - N_N) / T_D, \quad (8)$$

where:

ΔS= change in storage over time (mass m^{-2} $time^{-1}$),

N_D=mass of nutrients in disturbed soils (mass kg),

N_N= mass of nutrients in non-disturbed soils (mass kg),

and

T_D= time since disturbance occurred (time).

Each of the methods discussed has different errors and assumptions. As a result, the use of any one of these methods independently is subject to having more error then using a combination of all three. Therefore, a watershed study using all three methods combined is a more robust way to determine nutrient retention at a watershed scale.

The mass balance and EMMA approach can estimate nutrient retention on a seasonal or year timescale, but require extensive data collection over a longer period of time. A draw-back to these approaches is that they do not give an indication of where retention may be occurring within the watershed. In contrast, soil analysis does not provide seasonal or yearly retention, but gives an integrated estimate of how much the soil is retaining nutrient over a long time-period using one sampling event. Regardless of the method used to estimate nutrient retention within a watershed, the findings are dependent on the biogeochemistry of the nutrients and their interaction with their surroundings.

Phosphorus and Nitrogen

P and N exist within our environment in many forms and are prone to change readily within the many environments where they are present. Within a watershed, pools of P and N can be found in the lithosphere, hydrosphere, biosphere and the atmosphere. The movements of both P and N between these pools are referred to as fluxes and are dependent on a host of complex processes.

Within watersheds, both phosphorus and nitrogen can occur in either organic or inorganic forms and can be either in the dissolved or particulate form, with only the dissolved inorganic forms of P and N being bio-available. The sum of the dissolved and particulate forms of P and N are referred to as total P (TP) and total N (TN). Much of the inorganic phosphorus in particulate form occurs as aluminum, iron or calcium compounds while the organic phosphorus compounds include phosphate esters, nucleic acids and phospholipids (Riemersma *et al*, 2006). Organic nitrogen occurs as proteins, amino acids, amino sugars and many other complex compounds. The inorganic forms include ammonium, nitrite, nitrate, nitrous oxide, nitrogen dioxide and finally di-nitrogen gas (Havlin, 2013). In solution, phosphorus is present as phosphate ($H_2PO_4^-$, HPO_4^{-2}) and organic P (Brady, 2010). The distribution of the dissolved species of P is pH dependent. In acidic conditions $H_2PO_4^-$ dominates while above a pH of 7.2 HPO_4^{-2} dominates (Havlin, 2013). With respect to nitrogen, nitrate is found to dominate over ammonium within the soil water (Havlin, 2013).

Nutrient Inputs

Natural sources of phosphorus include rock weathering and atmospheric deposition. *In situ* rock weathering serves as one of the largest natural inputs of P into a watershed. Almost all the phosphorus that is derived from rock originates from the mineral apatite ($Ca_{10}(PO_4)_6X_2$) with estimates ranging from 0 to 0.048 kg P ha^{-1} yr^{-1} (Dillion and Kirschner, 1977). Atmospheric deposition is primarily derived from burned biomass, and wind-eroded particles. P from burned biomass is considered to be insignificant due to the small fraction of P that actually becomes airborne. Particulate P within the atmosphere either settles out by gravity or is scavenged by precipitation, contributing over 90% of total atmospheric P deposition. Precipitation has an average content of 0.01-0.06 mg TP L^{-1}, with total deposition estimated to be 0.05-0.7 Kg TP ha^{-1} (Anderson, 2006; Smil, 2000).

Natural inputs of nitrogen within a watershed include biological fixation via, leguminous plants and bacteria, and wet and dry atmospheric deposition. In some case, fixation of N_2 by plants as well as from some specialized bacteria are the primary drivers behind atmospheric inputs of N. Legumes such as beans or alfalfa can form a symbiotic relationship with specific bacteria to convert atmospheric N_2 to a form that plants can use. Biological fixation in non-agricultural grasslands is estimated at 0-2.5 Kg N $ha^{-1}y^{-1}$ (Vlassek et al., 1973). Nitrogen within dust particles can also contribute N to a watershed. Rates of fixed-N deposition from the atmosphere have been estimated to range from 0 - 7.7 Kg N $ha^{-1}y^{-1}$ representing an average of 28% of total atmospheric deposition and play an important role in the N cycle (Anderson, 2006). N deposition associated with lightning is often deposited on the earth as nitric acid (HNO_3) due to the fixation of N_2 to NO and NO_x.

Nutrient Within a Watershed

A portion of the nutrients that enter a watershed is taken up by vegetation and incorporated into biomass. The overall pool of nutrient within biomass varies widely and is largely dependent on nutrient availability, species present, and climate. Generally, P and N make up approximately 0.2-0.4% and 1-6% of plant dry matter, respectively (Brady, 2010). The nutrient that is available to plants must be in the dissolved form either as phosphate ions, organic P, nitrate or ammonium (Halvin, 2013). The retention associated with plant uptake is variable and often depends on land use. For instance, in cases where the plants are left to complete the life cycle the phosphorus and nitrogen stay within the plant until it dies and contribute to the accumulation of organic matter, which is then rapidly mineralized back to their respective inorganic forms.

The abundance of nutrient within soils is a function of soil type, geology, loading rates as well as hydrology, and climate. Generally, phosphorus and nitrogen make up about 0.005-0.15 and 0.02-2.5% of soil by weight, respectively (Havlin, 2013). Two common reactions that result in an accumulation of P and N in soils are chemical precipitation and adsorbtion which both result in highly insoluble P- and N-compounds (Havlin, 2013). With respect to phosphorus, precipitation of Fe/Al-P secondary minerals dominate in acidic soils due to interaction with the –OH and H groups on mineral surfaces. In basic (high pH) soils, phosphate tends to interact with CO_3^{-2} and Ca to produce secondary minerals (Havlin, 2013).

Nitrogen retention/accumulation within the soils is dependent on loading rates and soil type and structure. The primary mechanisms for retention in soils is the adsorption of ammonium onto the surfaces of clay and humic particles within the soil and the formation of Organic N (Havlin, 2013). The degree to which N is adsorbed is dependent on the Cation Exchange Capacity (CEC) of the soil. (Havlin, 2013). Two additional processes that result in attenuation of nitrogen specifically, are volatilization, and nitrification/denitrification. Volatilization of ammonia gas (NH_3) is dependent on several factors including pH, wind speed, soil temperature and organic matter content and can be extremely variable (Halvin, 2014; Schreffler, 2005). Gaseous loss of nitrogen via denitrification can occur through microbial processes when soil conditions are anaerobic (Brady 2010). Denitrification is the process of nitrogen oxides being reduced to di-nitrogen gas by micro-organisms. Reported rates of denitrification in grass land soils range widely, ranging from 0-239 kg N ha^{-1}, with irrigated soils showing generally higher rates. However, most studies report on average approximately 1.9 kg N ha^{-1} (Barton *et al*., 1999).

Aquatic Environments

The retention of phosphorus and nitrogen within wetlands, ponds and streams is largely a function of the available time they have to react with their surroundings. Streams are often fast flowing with limited vegetation resulting in a shorter residence time for nutrients limiting sedimentation and uptake by vegetation (Reddy, 1999). In wetlands and ponds, the residence time of nutrients is much longer then in streams resulting in an increase in biological, physical and chemical processes. Nutrient retention mechanisms in wetlands are dominated by biotic uptake, and sedimentation for both P and N, and denitrification of nitrogen. Biotic processes resulting in retention within wetlands include the uptake of P and N by vegetation, plankton, periphyton and microbial transformations (Saunders and Kalff, 2001; Reddy *et al.*, 2010). Sedimentation is the settling out of materials from the water column. Among these materials are nutrients, either associated with detritus from dead biomass or soil particles. Once the nutrients are within the sediments they are subject to both adsorption and precipitation resulting in a long-term sink for both P and N. Sedimentation is important because it can occur indefinitely retaining a portion of the incoming nutrient on an on-going basis year after year. Furthermore, the wetland sediments can often be anaerobic resulting in increased rates of denitrification. The anaerobic conditions present in many wetlands allow for the production of N_2 or N_2O gas from nitrate or nitrite by bacteria resulting in removal of N from the watershed entirely.

In some cases, the inputs of nutrients are greater than nutrient retention. The nutrients that are not retained by the watershed and enter down gradient systems are seen as outputs.

Outputs of Phosphorus and Nitrogen

The primary pathways by which both P and N leave a watershed include dissolved and particulate nutrients in surface and sub-surface water flows. Factors that influence nutrient losses include; loading, topography, soil type, climate and hydrology (McDowell, 2001). Precipitation and snowmelt have been shown to be a dominant force behind nutrient loss within a watershed (Sharpley, 1980). In undisturbed watersheds erosion is often negligible resulting in low particulate losses, making solutes the dominant form of nutrient transport through the soil profile (Smil, 2000). Although surface runoff and erosion are important pathways for P and N loss, they are spatially limited and temporarily confined to high magnitude and high intensity rainfall events. As a result, infiltration capacity of the soil and preferential flow paths through the soil resulting in leaching to groundwater are also important contributors to the overall movement of dissolved P and N through a watershed (Heathwaite, 2000). The magnitude of transport of P and N through the soil matrix is controlled by factors such as void size, number of fissures and degree of aggregation. In unsaturated soil conditions water has been shown to flow very quickly through large pores and fissures in the soil allowing for the transport of both dissolved and particulate P and N resulting in little interaction with their surroundings, and lead to significant exports (Heathwaite, 2000). One example showed that at 20 cm depth over 80% of P was in the dissolved fraction, of which 60% was inorganic (Heathwaite, 2000).

Within a natural watershed, the rate of inputs, outputs, and retention processes remain relatively stable over time, resulting in stable concentrations of nutrients within the different pools of nutrients. However, there are times when watersheds are subject to natural or anthropogenic changes resulting in a disturbance to the watershed. This study focuses on wastewater irrigation as a disturbance within a watershed, and the impacts to the nutrient balance as a result of wastewater irrigation.

Wastewater Irrigation

Wastewater as a Disturbance

Traditionally, treated wastewater is discharged to surface water bodies. However, wastewater is increasingly being discharged to land, primarily by way of irrigation (Hamiltion *et al*., 2007; Toze, 2006). The introduction of municipal wastewater to land within a watershed can vary widely in quality and quantity resulting in a variety of changes within the watershed dynamics.

Municipal Wastewater

Globally, wastewater effluent is sanitary waste from residential, commercial and industrial establishments. As a consequence, wastewater typically consists primarily of organic and inorganic waste, nutrients, suspended solids, microorganisms and residential/commercial chemicals (Toze, 2006). Typically, treatment of wastewater in developed countries includes primary, secondary and often tertiary treatments. Different degrees of treatment result in varying levels of contaminant removal prior to discharge into the environment (CCME, 2006). Primary treatment is the most basic form and strictly involves the removal of a portion of solids within the wastewater. Secondary treatment removes much of the dissolved and suspended organic compounds, resulting in a decrease in the biological oxygen demand and nutrient content. In common tertiary treatment, the wastewater is subject to further biological nutrient removal, removal of micro pollutants, and chemicals as well as disinfection.

Phosphorus in treated municipal wastewater is a combination of orthophosphate (40-50%), organic phosphates and polyphosphates (EPA, 2006). The concentration of P in treated wastewater can vary greatly. Phosphorus levels in very basic treatment facilities can be as high as 6.7 mg L^{-1}, and as low as 0.01 mg L^{-1} in more advanced treatment facilities (Barton etal,.2005, Ragsdale, 2007).

Total nitrogen in wastewater is made up of ammonia (NH_3), ammonium (NH_4), nitrate (NO_2), nitrite (NO_3), organic N, with organic N accounting for approximately 40% and ammonia and ammonium accounting for the remainder (USEPA, 2006). Nitrogen concentrations in treated wastewater can range anywhere from 1.0 to 17 mg L^{-1} (Barton *et al*., 2005; Laurenson *et al*., 2007).

Why Wastewater Irrigation

Irrigation of municipal wastewater can have both agricultural and environmental benefits. The agricultural benefits include the return of valuable water to agricultural land resulting in a decrease in demand on local fresh water resources, as well as supplying much needed nutrients to facilitate more intensive agricultural land use, especially in areas that would otherwise not be able to sustain certain crops (Hamilton *et al*., 2006). P and N uptake by crops has been shown to be close to 3 times greater in wastewater irrigated soil then in non-irrigated soils (Barton et al, 2005).

As well as being an important source of water for agricultural use wastewater irrigation also helps to keep water from being discharged directly to surface water. Research has shown that the discharge of both treated and non-treated wastewater can result in degradation of the receiving environment (Anderson *et al.,* 1998; Correll, 1999; Schreffler, 2005; likens *et al.,* 1970). This degradation is often linked to the presence of nutrients found in wastewater. Phosphorus and nitrogen have been found to be the nutrients that are most often limiting in freshwater ecosystems (Correll, 1999). A very small increase in either phosphorus or nitrogen concentrations in receiving surface waters can degrade aquatic water systems and compromise water used for drinking, industry, and recreation (Barton, 2004). The USEPA reports that 64% of lakes and 44% of the streams surveyed in the USA were found to be in poor health (USEPA, 2009). In this assessment, it suggests that 1/3 of poor stream health is due to excess nutrients in the water (USEPA, 2009).

Applying nutrient rich wastewater to land rather than directly to surface water often results in additional retention of nutrients by both vegetation and soil which ultimately decreases the amount of nutrients that are able to reach streams and lakes. Generally, total retention of both P and N shows a range between 2-98%, with sandy soils having lower retention rates then silt loams. (Barton *et al*, 2005; Kardos and Hook, 1976; Laurenson *et al*, 2007). Plant growth was also found to play a factor in nutrient retention with large increases in productivity seen in most cases. In a silt loam that did not receive any supplemental nutrients, P uptake by plants was on average 54 kg P ha^{-1}. When the fields were irrigated with wastewater P uptake by plants rose to an average of 158 kg P $ha^{-1}yr^{-1}$. In the same study, nitrogen uptake in a non-irrigated field was measured at 215 kg N $ha^{-1}yr^{-1}$ and rose to 638 kg N ha^{-1} yr^{-1} in irrigated fields (Barton et al, 2005). This equates to an estimated 300% increase due to wastewater irrigation. Longer term studies (13 and 24 years) show lower retention results, estimating an increase in P retention of 27 to 55% (Ishkandar and Syers, 1980; Lin and Banin, 2005). When wastewater irrigation was applied at 5 cm/week close to 96.5% of P was retained with the soil. In the same study, when irrigation rates were doubled retention of P was reduced to 66% (Burton and Hook, 1979).

Globally, Israel is a leader with respect to wastewater irrigation, reclaiming more than 60% of its effluent (Hamilton, 2007). Other countries such as Australia, New Zealand and the United States (mainly California) also report using large amounts of wastewater as irrigation (Hamilton, 2007). In Canada, wastewater irrigation is uncommon, with possible reasons being high availability of freshwater and lack of education and social acceptance around the subject of wastewater irrigation.

Chapter 2: Introduction to Study

This study assesses the extent to which phosphorus and nitrogen are being retained at a watershed scale, using all three methods discussed in chapter 1. These methods include; mass balance, an end member mixing analysis (EMMA), and a soil analysis.

The first approach uses a mass balance method to determine retention as the difference between inputs and outputs of nutrient within the system. The second method incorporates an EMMA, calculating retention as the difference between the expected flux of nutrients and the measured flux of nutrients out of the watershed. The final approach applies to only phosphorus and compares the difference in P content between irrigated and non-irrigated soils within the watershed. The calculated mass difference in P storage within the sampled soil will give an estimate of the long-term retention of P over the course of the irrigation program.

Background and Site Description

City of Vernon Wastewater Irrigation Program

Currently, the City of Vernon (British Columbia, Canada) is using an irrigation system to dispose of 100% of its wastewater effluent and has been doing so for approximately 35 years. Each year 970 ha of land are irrigated with between 3.2 to 5.5 million m^3 of wastewater. The wastewater undergoes tertiary treatment and is then pumped 7 km up to a large storage reservoir (McKay Reservoir). McKay Reservoir has approximately 10 million m^3 storage capacity. The treated wastewater has a residence time within the reservoir of approximately 2 years. From the reservoir, the reclaimed water is then chlorinated and subsequently spray irrigated on to receiving lands from May till early October. The irrigation water has average P and N concentrations of 0.7 and 4.0 mg l^{-1}, respectively. Cl and Na concentrations are 105 and 100 mg l^{-1}, respectively. The current irrigated land-use includes; golf courses, recreational fields, seed orchards, seedling nurseries, a tree research center, hay production and pasture grazing livestock.

Location

The study was conducted in the north Okanagan Valley in the southern interior of British Columbia (Latitude = 50°14‘N, Longitude = 119°17’W) (Figure 2). The City of

Vernon lies just to the north with Okanagan Lake to the west and Kalamalka Lake to the east (Figure 2). The subject watershed was 332 ha in size with an elevation ranging from 500 to 740 masl. The predominant aspect of the catchment is south with an average slope of 0.065 m/m. The primary vegetation within the study site consisted of grasslands dominated by bluebunch wheatgrass (*Pseudoroegneria spicata*) and kentucky bluegrass (*Poa pratensis*). Tree species present include widely spaced ponderosa pine (*Pinus ponderosa*) and small clusters of trembling aspen (*Populus tremuloides*) in the upper dyer reaches of the watershed. The wetland portions of the watershed are dominated by bulrushes (*Scirpus Cyperaceae*) and various other wetland sedges. The predominant land-use for the entire watershed is cattle grazing with approximately 220 head of cattle year around, and additional 100 head of cattle during the summer months. During the winter months, an estimated 151,000 kg of alfalfa hay are imported to feed the cattle.

Figure 2: General Site Location (Google Earth, 2017)

Geology

Geological mapping of the area indicates that the underlying bedrock of the study site is composed primarily of granodiorite, diorite, quartz diorite, and quartz monazite dating back to the Middle Jurassic period (Moe, 2015; Glombick *et al*, 2000). The Surficial geology in the area is glacial-fluvial deposits ranging from zero to several meters thick. The soils within the study site are primarily brunisolic. Pockets of Chernozems were found beneath the grassland portions and to a lesser extent regosols in the upper regions of the catchment where the soils are shallow and less developed (Haney, 2006).

Climate

The study area is located in a region with a dry continental climate resulting in hot summers and mild winters. Summertime daytime averages are 25ºC with highs of 38ºC, average winters time temperatures are -4ºC with lows of -30ºC. The Coast and Cascade Mountains to the west create a rain shadow effect limiting precipitation throughout the year. Average precipitation is 428 mm yr^{-1} with 337 mm coming as rain (Environment Canada, 2016). Evapotranspiration is quite high in the North Okanagan accounting for up to 85% of precipitation throughout the year (Cohen and Kulkarni 2001).

General Watershed Description

The Subject Watershed is known as the Bailey Creek watershed and is made up of 4 Sub-watersheds (SW-X) (Figure 3). Each Sub-watershed is characterized by a small stream that was monitored at the outlet of the watershed for discharge, and sampled throughout the study. There are several ponds throughout the irrigated portion of the study site with the largest one approximately 700 m^2 in size, located in the lower reaches of the watershed. Some ponds and wetlands likely are a result of the irrigation program because very few ponds and wetlands are present outside of the irrigated area. Wetlands/ponds within the study site take up approximately 65,000 m^2 (2%) of the study area.

Bailey Creek Watershed

Bailey Creek Watershed represents the whole watershed and is 332 ha in size (Fig.3). It is made up of the 4 Sub-watersheds. Of the 332 ha, 112 ha (33%) are irrigated. The discharge station is located in Bailey Creek at the bottom of the watershed, and represents the exit point for surface water for this study. Bailey Creek is fed by each of the streams from the sub-watersheds, as well as a small stream that originates from seepage from a reservoir dam.

Sub-Watershed 2

Sub-watershed 2 (SW-2, Figure 3) is a west facing 18 ha portion of pasture on the east side of the Bailey Creek watershed, of which is 89% irrigated (16 ha). The catchment area is moderately steep, with very little wetland storage area within it (0.07%). Sub-watershed 2 is permanently grazed by 12 head of cattle which are fed with imported Alfalfa hay in the winter.

Sub-Watershed 3

Sub-watershed 3 (SW-3, Fig. 3) is 69.5 ha in size with close to 42 ha (60%) of it irrigated. SW-3 has an South facing aspect and overall only gently sloped. Within the SW- 3 area there are several small ponds, wetland areas and two homesteads. SW-3 has the highest percentage of wetlands and ponds at 2% of the area (14,865 m^2).

Sub-Watershed 4

Sub-watershed 4 (SW-4, Fig. 3) is the largest within with study site at 82 ha. Twenty-two ha (27%) of SW-4 is irrigated and consists of predominantly pasture land with approximately 200 head of cattle that graze all year long. It is primarily south facing, and contains several small ponds and wetlands (1.4% of the area). The upper regions of SW-4 are quite steep, while the lower irrigated portion has the lowest grade of the study site. The north portion of SW-4 has never been irrigated and is the location of the background reference sampling site.

Sub-Watershed 5

Sub-watershed 5 (SW-5, Fig. 3) is 99 ha in size and is drained by a small ephemeral stream that flows only during the spring freshet. There is no irrigation and limited cattle grazing, which only occurs during the late summer months. SW-5 is south facing with a similar gentle grade to SW-4.

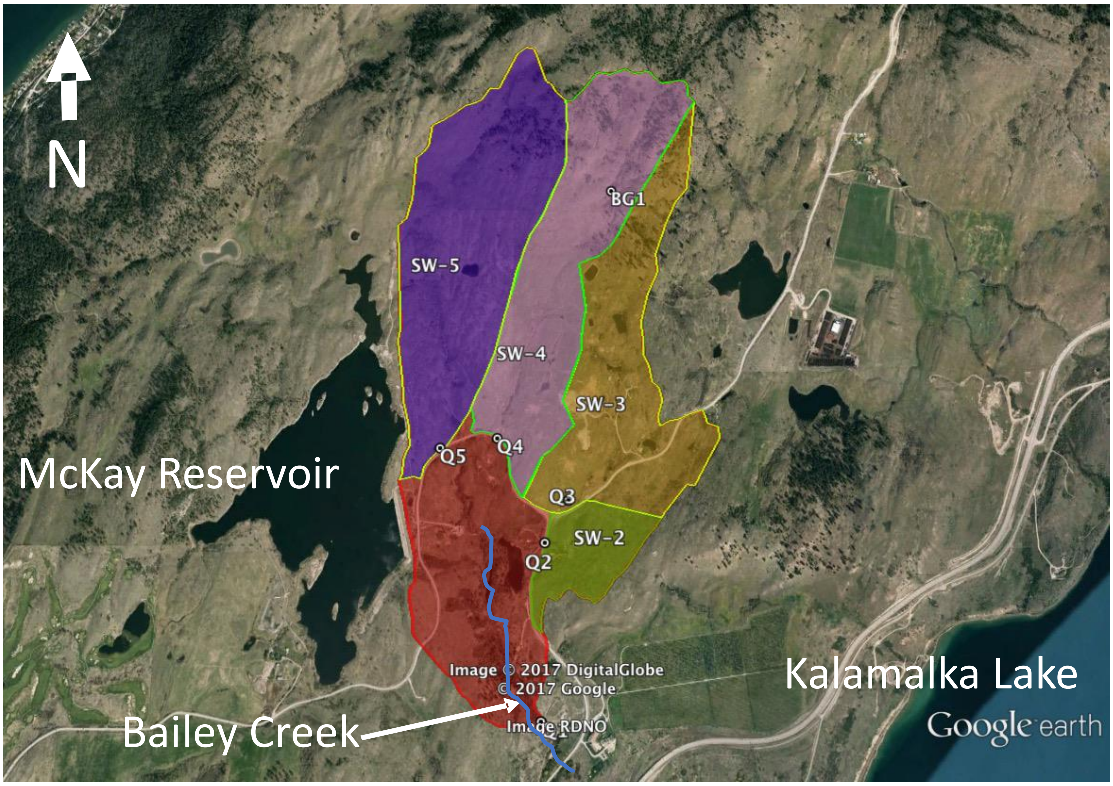

Figure 3: Image of Study site, showing boundaries of Sub-watersheds and primary sampling sites for each Sub-watershed (Google Earth, 2016)

Irrigation within Study Basin

The City of Vernon wastewater irrigation program has been ongoing for approximately 35 years. In 2015 the irrigation program ran from May 3, 2015 to Oct 16, 2015, totaling 167 days. During that time, approximately 671,000 m^3 of treated wastewater was irrigated over 112 ha of the Study Basin (Figure 4). The average yearly depth of irrigation was approximately 600 mm, which is close to average irrigation depth for a silt loam in the region (Gough *et al*.,1994).

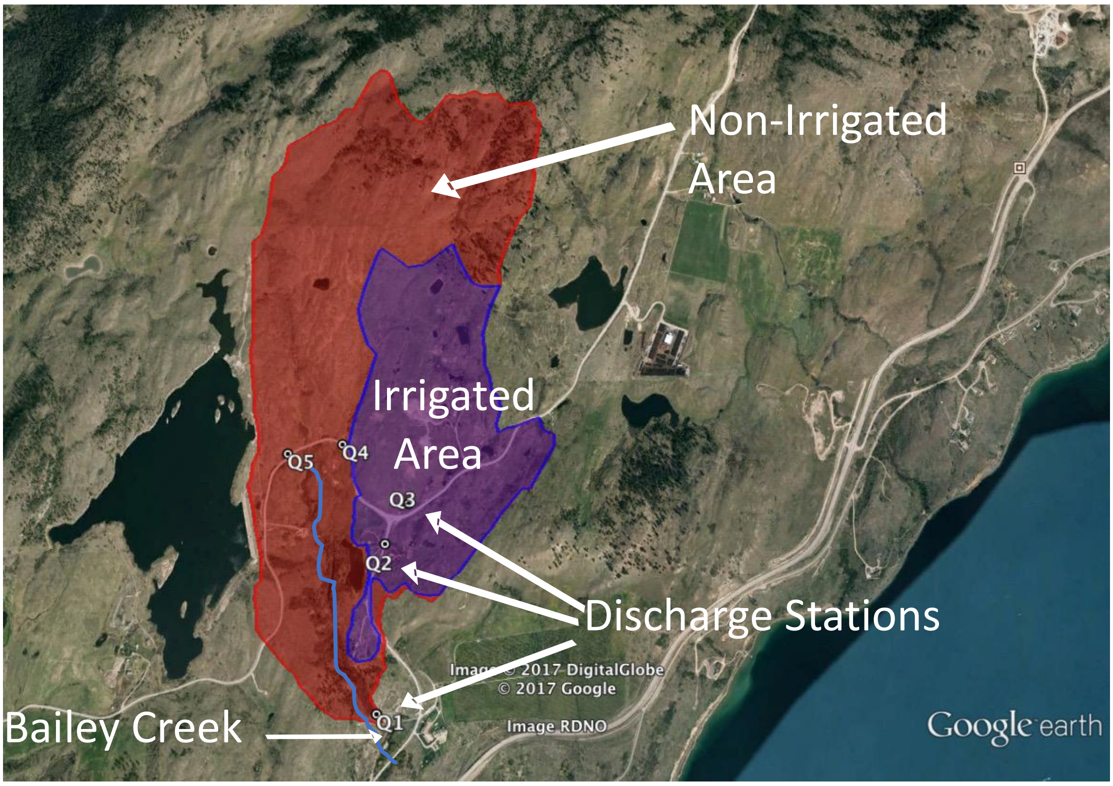

Figure 4: Image showing the unirrigated and irrigated portions of the watershed as wells as Bailey Creek and discharge stations (Google Earth, 2016).

Chapter 3: Methods

The Hydrometric data for the water mass balance included precipitation measurements, evaporation calculations and irrigation inputs. Stream discharge measurements were made to quantify surface water outputs.

Climate

Climate data for this study was collected using two weather stations. The primary weather station was a HOBO© U30 weather station (Onset Computer Corporation, Bourne, MA, USA) installed centrally within the study watershed and was used to measure precipitation (mm), temperature (^{0}C), relative humidity (%), barometric pressure (kPa), radiation (Wm^{-2}), and wind speed (m s^{-1}).

Precipitation was determined using a tipping bucket with a 0.2 mm resolution (S-RGB-M002). Temperature and relative humidity were record using a 12-bit smart HOBO smart sensor (S-TMB-M002). Solar radiation was measured using a silicon pyranometer (S-LIB-M003), with a range of 0 to 1280 Wm^{-2} over a spectral range of 300 to 1100 nm covering all the visible spectrum and a small portion of infrared. Barometric pressure was recorded using a HOBO pressure transducer (U20-001-04-Ti) with a + - 0.15% error. A HOBO wind speed smart sensor was used to record wind speeds ranging from 0-76 m s^{-1}, with an error of + - 1.1 m s^{-1}.

The second weather station was located 3.6 km north northeast of the study site and was operated by Ministry of Transport (MOT). The second weather station was used for verification of precipitation data and wind speed.

Evaporation and Evapotranspiration

In the case where spray irrigation is being used, a portion of the irrigated water is often subject to direct evaporation and never makes to the ground surface (Montero et al., 2009). The evaporation rates directly from irrigation were calculated using an empirical method based on calculated vapour pressure deficit and wind speed (Equation 12) (Montero et al., 2009).

$$Wedl = 7.63(e_s - e_a)^{0.5} + 1.65U \qquad (12),$$

where:

Wedl = proportion of irrigated volume that is evaporated

e_s-e_a= Vapour pressure deficit

e_s= saturation vapour pressure (kPa)

e_a= actual vapour pressure (kPa),

and

U= Wind speed in meters/second.

In many cases, it is not feasible to estimate evapotranspiration rates directly using methods such as the Eddy Covariance or lysimeters. One way to compensate for this, is to use available climate data to determine a reference evapotranspiration (ET_o) (An, 2010; Allen *et al.*, 1998; FOA, 2014; Monteith, 1981; Penman, 1948)). For this study, calculations of daily ET_o were determined using data collected from the weather stations and a physically-based analytical method based on a Modified Penman-Monteith equation intended for irrigated grassland (Shahidian *et al.*, 2008; Smith *et al.*, 1991; Zotarelli *et al.*, 2010) (Equation 13). Some assumptions included in the FOA method are that the grassland is adequately supplied with water, an assumed height of grass of 0.12 m tall, an albedo of 0.23 and a surface resistance of 70 s m^{-1} (Allen, 2000). Evaporation rates for the non-irrigated portions of the study site were estimated also using a modified Penman-Monteith using many of the same variables as equation 13, but with some changes in some of the constants to account for greater saturation from irrigation in dry summer weather (Equation 14) (See A

ppendix A for details).

Equation 13:

$$ET_o = \frac{0.408\Delta\,(R_n - G)\; + \;\gamma \frac{900}{T + 273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34\, u_2)} \qquad (13)$$

Equation 14:

$$E = \frac{\Delta \frac{R_N - G}{\lambda} + (\rho C_\rho \frac{(e_s - e_a)}{r_a})}{\Delta + \gamma(1 + \frac{r_c}{r_a})} \qquad (14)$$

Where;

ET_o = daily ET (mm/d),

E = Non-irrigated ET (mm/d)

T = air temperature at 2 m high (°C),

u_2 = wind speed at 2 m high [m/s] = 2 m s^{-1},

R_n = net radiation at the crop surface (MJ $m^{-2}d^{-1}$),

Δ = slope vapour pressure curve (kPa °C^{-1}),

λ = Latent heat of Vaporization (kj kg^{-1}),

ρ=Air density (kPa),

$C\rho$=Specific Heat of Air (KJ kg^{-1}),

r_a=Aerodynamic resistance,

r_c= Canopy resistance for Grass (20 m s^{-1}),

γ = psychometric constant (kPa °C^{-1}),

e_s= saturation vapour pressure (kPa),

e_a= actual vapour pressure (kPa),

and

G = soil heat flux density MJ $m^{-2}d^{-1}$.

For both equations 13 and 14 necessary local information included altitude and latitude to determine the local psychrometric constant (γ) and extraterrestrial radiation (R_a). Solar radiation was based on a radiation balance model and measured as W m^{-2} and converted to MJ m^{-2} d^{-1} to calculate R_n (1Wm^{-2} = 0.0864 MJ m^{-2}). Estimates of ET_o in this study are likely somewhat underestimated because the sensor did not measure irradiance at wavelengths above 1300 nm. Thus, calculated ET_o estimates are conservative.

Surface Water Hydrology

Surface drainage for the sub-watersheds, and Bailey Creek was monitored for discharge throughout the study with 6 discharge stations. Each discharge station was located at the upstream end of an existing culvert within the study area (Figure 5 and 6). Each station consisted of a stilling pond that was dug at the upstream end of a culvert and a rigid PVC piezometer into which a pressure transducer was installed to measure the height of water in the each of the stilling ponds (Figure 5). Pressure transducers were programmed to record water height at 15-minute intervals. A barometric pressure transducer was also located at a central location within the watershed and used to compensate for the differences in barometric pressure throughout the study. Using a calibrated bucket and a stopwatch where possible, and a Mini Price flow meter for high flows, the discharge at each location was measured at intervals to represent the range of discharge for each stream. The discharge values were then plotted against the corresponding height of the stilling pond using Excel to develop rating curves (Appendix B).

Figure 5: Photo showing stilling pond with piezometer installed.

Atmospheric Deposition Sampling

Six atmospheric samplers were installed at three different locations in the upper, middle and lower portions of the study watershed to measure both wet and dry atmospheric deposition of chloride, phosphorus and nitrogen. Atmospheric samplers consisted of a funnel fastened to a post that was 2.5 meters above ground and a tube was attached to the funnel and led to a sampling bottle below (Figure 6). The sampling bottles were replaced when nearly full or monthly if little precipitation occurred. Each sampler was also rinsed periodically with a known amount of deionized water to collect dry deposition of analytes which had accumulated within it. To prevent contamination from birds, sharp screws were installed on the rim of the sampler to inhibit birds from landing on the funnel and defecating into the funnel resulting in contamination. In the case of contamination, the data were discard and sampler was cleaned thoroughly.

Figure 6: Photo of atmospheric sampler in upper regions of watershed.

Irrigation, Surface and Groundwater Samples

All water samples were collected at a range of intervals from 1 to 3 weeks, inversely proportional to the magnitude of flow. Samples were collected in 500 ml High-Density Polyethylene (HDP) bottles and rinsed twice with sample water before sample collection. Regular sampling locations included irrigation samples (Irr1), all five discharge stations, the dam seepage, and 3 groundwater locations. Irrigation samples were taken weekly from the main irrigation line servicing the primary sprinklers. Water samples representing ambient background conditions were taken from two seasonal springs located in the upper non-irrigated portion of the watershed, which flowed only during the freshet. Several other background samples were taken from groundwater seeps found in exposed bedrock outcrops located nearby to the study site. Regular samples were also taken from a dug surface well centrally located within the watershed.

Sample Analysis

All samples were refrigerated within 4 hours and kept dark until they were processed for analysis to inhibit chemical and biological changes within the sample. One hundred ml of each water sample taken was filtered using a Whatman GF/C glass microfiber filter. The filtrates were analyzed for chloride, sodium and dissolved phosphorus. Particulate matter on filters was analyzed for particulate phosphorus. A portion of non-filtered sample was analyzed for total nitrogen. Analytical techniques used were all in accordance to Environmental Protection Agency (EPA) standards, using appropriate calibration and quality assurances. Minimum R^2 values of 0.998 were used for all calibration curves.

Chloride

The determination of dissolved chloride was conducted using an approved ASTM method for chloride in wastewater, using a Thermo Scientific ISE (ion specific electrode). The meter was calibrated in accordance with the Thermo Scientific Orion Star user manual. Chloride calibration standards were prepared ranging from 0 mg L^{-1} to 1000 mg L^{-1}. The detection limit of the ISE probe is >1.8 ppm with + - 2% reproducibility. The potential for interference associated with the chloride analysis using the ISE probe include very high ratios of OH^-, Br, I^-, S_2O_3, NH_3, and CN^- to chloride. A standard addition method was used to determine if interference was occurring within the samples. Quality control measures included; 50 ppm spikes, blanks and a water standard to account for drift between samples.

Dissolved Phosphorus Analysis

Dissolved phosphorus water samples were first filtered and then digested using potassium persulfate to convert all forms of P to PO_4. The P analysis was done using an ascorbic acid colorimetric method described by Murphy (1962) using a Cary 50 Spectrophotometer.

Particulate Phosphorus Analysis

The particulate matter collected on the glass fiber filter was muffled at 450 C^o to oxidize the organic matter within the sample. The muffled filter was then extracted and heated in HCl (Jarvie et al., 2002). The sample was diluted and analyzed by the same method as the dissolved P described above. The mass of P calculated in the extract was divided by the volume of filtered water to determine the particulate P concentration in mg L^{-1}.

Nitrogen Analysis

Water samples analyzed for total nitrogen were digested using potassium persulfate to convert all forms of N to nitrate. Nitrate in samples was converted to nitrite by Vanadium reduction. Nitrite was measured colorimetrically with a Cary 50 spectrophotometer using methods originally described by Doane and Horwath, (2003), and Miranda *et al*., (2001).

Sodium Analysis

The elemental concentrations of sodium, were measured using inductively coupled plasma optical emission spectroscopy (ICP-OES), with a Thermo Scientific iCAP 600 series spectrometer. Procedural methods used adhered to ASTM approved methods provided in the Thermo Scientific user manual. Briefly, the system was calibrated for each analyte through a series of six standard solutions over a concentration range of 0 to 10 ppm prepared from stock solutions. Emission lines for analytes were chosen to minimize the interference with other substances within the samples. All samples were diluted with 1% HNO_3 and ultra-pure deionized water to fall within the range of the prepared standards. One ppm indium was used as an internal standard in all calibration solutions and samples. Each sample was analyzed three times to get an average concentration. Spikes and blanks were run every 20 samples to correct for instrument drift.

Soil Sampling

The determination of phosphorus retention within the soil included a total of 24 soil samples taken from randomly selected locations throughout the watershed (Figure 7). Of the 24 samples, 11 samples were taken in irrigated soils and 13 in unirrigated soil. All soil was sampled using a 3.81 cm diameter coring pipe pounded into the soil to a depth of 45 cm. The pipe was then excavated from the ground and the total contents of the pipe were placed into a clean zip lock bag. The pipe was cleaned with a rag between sampling locations. A pair of scissors were used to cut all above ground vegetation away prior to sampling. All below ground biota were included in the sample.

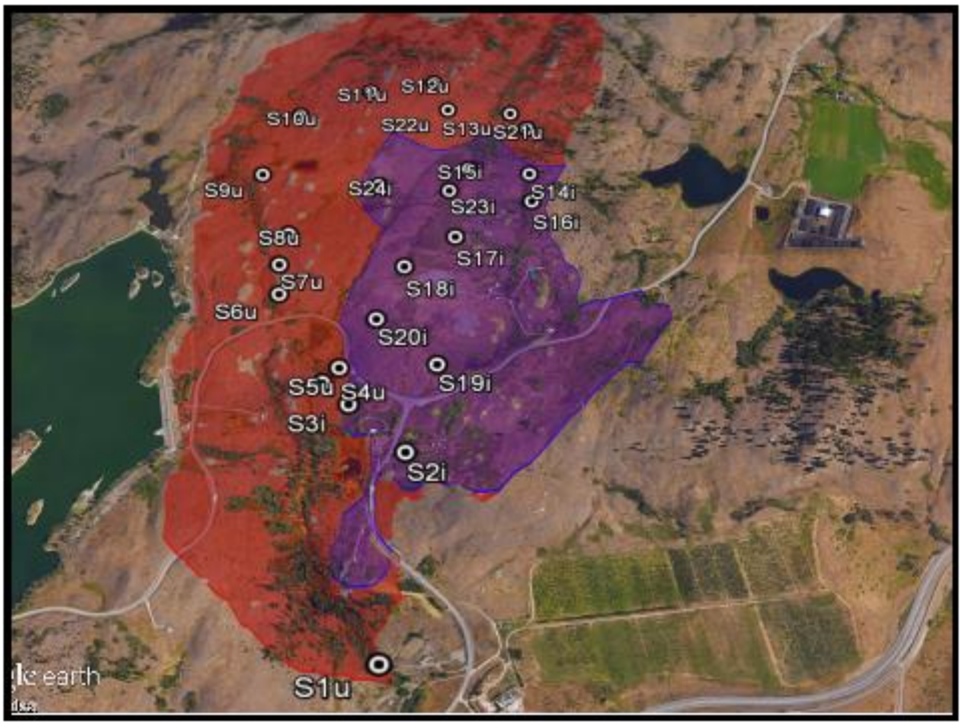

Figure 7: Satellite image showing soil sampling locations (Image: Google earth 2016).

Soil Sample Preparation

Soil samples were weighed and dried at 60 ^{0}C for 26 hours. Moisture content within the soil was determined as the difference between the wet and dried weight of the samples. Once dried, samples were mixed with mortar and pestle to ensure homogeneity. A sub-sample (approx. 1 gram) was weighed and muffled at 550 ^{0}C for 120 minutes. Organic content was determined by weighing the samples before and after oxidation in a muffle furnace at 550 ^{0}C for 2 hours.

Soil Phosphorus Analysis

The muffled sample was then extracted in 50 ml of 0.1 N HCl for 90 minutes to ensure all forms of P were converted to PO_4. Once digested a sub-sample for each soil sample was extracted in HCl, diluted and analyzed following a colorimetric method originally described by AP Rowland (1997). The spectrophotometer used was a Cary 50. Spike, blanks and water standard were used throughout the analysis to correct for potential instrument drift.

The concentrations of phosphorus in soils were used to calculate the grams of P m^{-2} to a depth of 0.45 m. Phosphorus retention was calculated as the difference in mass of P between the irrigated and non-irrigated portions of the watershed after correction for changes in bulk density from 35 years of irrigation. A detailed account of the P retention calculation can be found in Appendix D.

Chapter 4: Results

Hydrologic Mass Balance

The results for the hydrologic components of the mass balance method included precipitation, irrigation and the groundwater seep as inputs. Measured outputs included evapotranspiration and stream discharge. Outputs as groundwater flows were calculated as the difference between inputs and outputs.

Precipitation

Yearly Precipitation was measured to be 332 mm which is average for Vernon B.C. (Environment Canada, 2016). Over the entire watershed, this amounts to 1,100,240 m^3 (3,320 m^3 ha^{-1}). The majority of the precipitation occurred during the winter and springs months with 71% of the precipitation occurring from October to March. January had the highest amount of precipitation with 50 mm. April was found to have only 4 mm of rain which is unusually low when compared with local climate normal (28.7 mm, Environment Canada, 2016) (Figure 8).

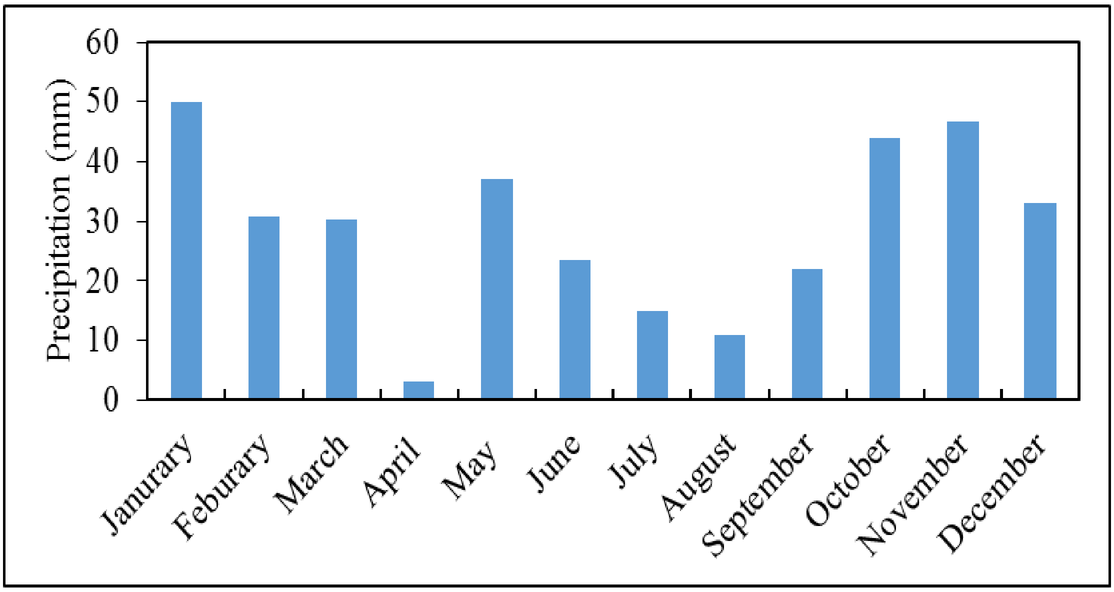

Figure 8: Monthly precipitation for study basin in mm.

Irrigation

An average of 610 mm of wastewater was irrigated onto the Bailey Creek watershed, totaling to yearly irrigation inputs of 671,000 m^3. SW-2, 3 and 4 received an estimated 109,800, 256,000 and 134,000 m^3, respectively. SW-5 did not receive any irrigation during the study. In the case of broadcast/impact irrigation, a portion of the irrigated water evaporates directly into the air. In this study an estimated 6.5% of the irrigation water was lost directly to the atmosphere (Equation 5). The total input of water into the entire watershed from irrigation water was 627,000 m^3. Irrigation inputs for the Sub-watersheds were 91,300, 230,000 and 125,000 m^3 of wastewater, respectively (Table 1).

A further 34,400 m^3 of water entered the Bailey Creek watershed downstream of the sub-watersheds through seepage in the reservoir dam. The average discharge from the seepage was 0.0011 $m^3 s^{-1}$. Total water inputs were 1,764,000 m^3, with precipitation and irrigation accounting for 62% and 35%, respectively. Within the Sub-watersheds, SW-2 received 60.5% of water inputs through irrigation which was the highest portion of the sub-watersheds. In SW-3 and 4 an estimated 51 and 31.5% of water was from irrigation.

Table 1: Summary of inputs of water for Bailey Creek watershed and Sub-watersheds

Water Inputs in m^3			
Watershed	Precipitation (% of total)	Irrigation Volume (% of Total)	Total Inputs (Depth mm)
Bailey Creek	1,102,000 (62.5)	627,000 (37.5)	1,764,000 (530)
SW-2	59,700 (39.5)	91,300 (60.5)	151,000 (839)
SW-3	230,700 (49)	239, 000 (51)	470,000 (676)
SW-4	272,200 (68.5)	125,000 (31.5)	398,000 (785)
SW-5	328,680 (100)	0 (0)	328,680 (332)

Evapotranspiration

Evapotranspiration (ET) rates were calculated using the modified Penman-Monteith equation to be approximately 250 mm yr^{-1} for the non-irrigated portions of the watershed and 418 mm yr^{-1} for the irrigated portion of the study site (Appendix A). The estimates for non-irrigated grasslands in this study are very close to the estimates of 287 mm yr^{-1} given by Cohen and Kulkarni (2001). The dominating factors influencing ET rates are temperature, relative humidity, wind-speed and moisture availability. Using the average wind speeds of the 2 meteorological stations, the total outputs via ET were calculated to be 1,015,000 m^3 of water. Rates of evapotranspiration in the non-irrigated portion were highest during the late spring and were low during the dry summer months. ET in the irrigated portion was highest during late spring and summer months (Figure 9 and 10).

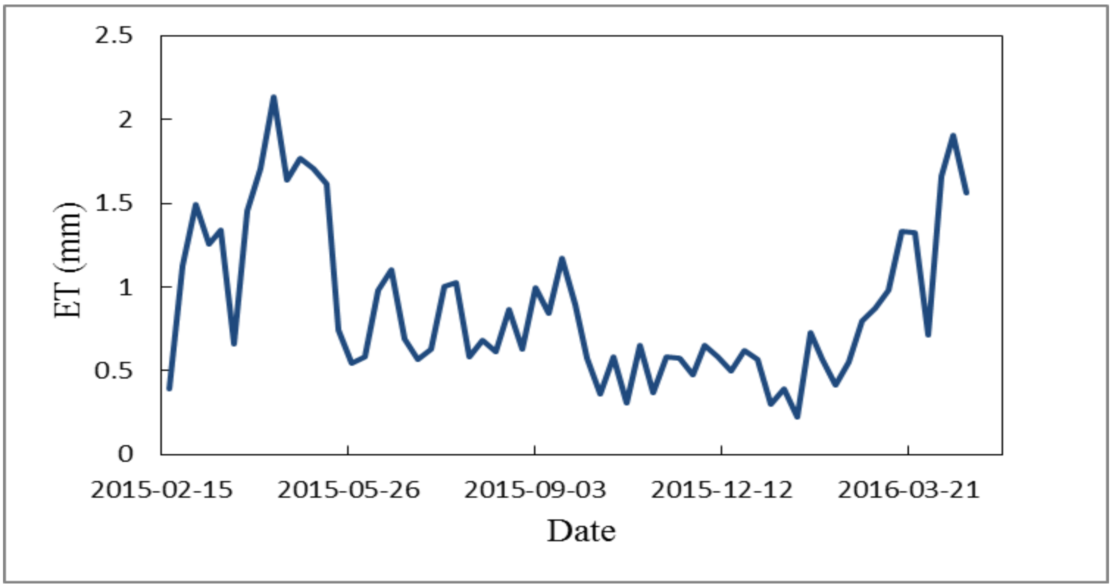

Figure 9: Weekly averages showing estimated seasonal evapotranspiration for non-irrigated land (mm day^{-1}).

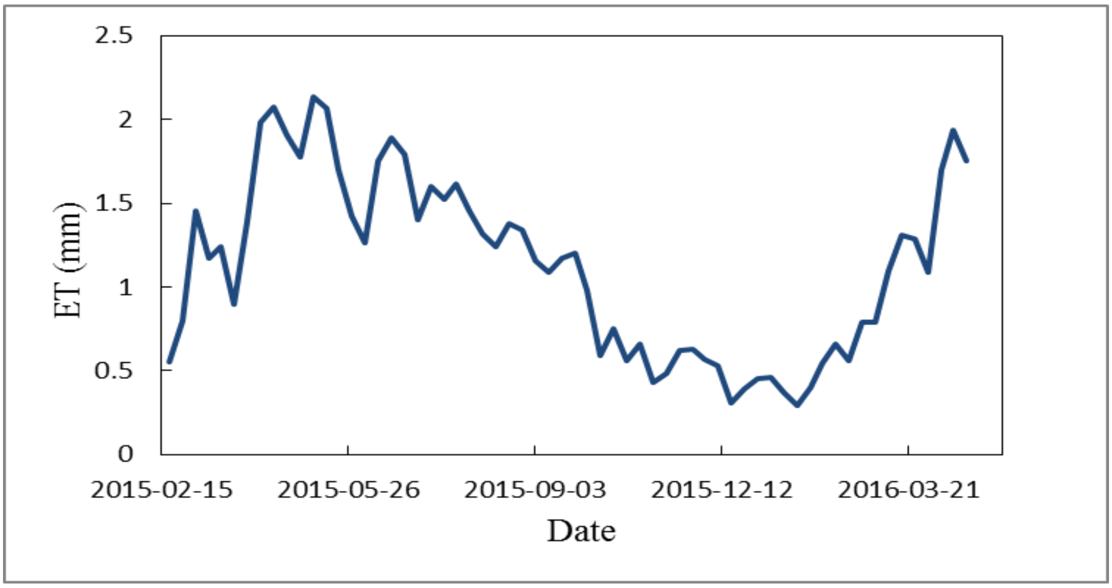

Figure 10: Weekly averages showing estimated seasonal evapotranspiration for irrigated land (mm day^{-1}).

Surface water outputs

Surface water outputs were measured as the sum of the daily discharge from Bailey Creek which represented the sole surface water outlet for the study watershed. The discharge of the smaller streams representing the surface water outputs of each of the sub-watershed was also measured. The rating curves used to determine daily discharge and hydrographs for the sub-watersheds are shown in Appendix B.

Discharge for Bailey Creek was highest during spring freshet followed by a drop in discharge until the start of irrigation season. During the irrigation season stream discharge remained stable followed by a drop in flows in the fall and winter months. The yearly discharge from Bailey Creek was 481,000 $m^{3.}$ Bailey Creek had an average measured discharge of 0.015 $m^3 s^{-1}$ ranging from 0.006 $m^3 s^{-1}$ during the winter to 0.03 $m^3 s^{-1}$ during freshet.

The yearly yield of water from the study site was 481,000 $m^3 yr^{-1}$ (1,450 $m^3 ha^{-1}$), with an average daily yield of 4.1 $m^3 ha^{-1}$ (Table 2, Figure 11). The total yearly discharge from SW-2 was 77,500 $m^3 yr^{-1}$ (16% of the total watershed flows). Seasonally, the discharge generated from SW-2 was represented by large increases during freshet and the start of the irrigation season, followed by sharp decreases following the end of the irrigation season. SW-2 had the highest yearly and average daily yield of 4,300 $m^3 ha^{-1}$ and 10.7 $m^3 ha^{-1}$, respectively. The high yield from SW-2 is directly related to SW-2 also having the highest intensity of irrigation. SW-3 had a recorded discharge of 120,500 $m^3 yr^{-1}$ making it the highest yearly discharge of the sub-watersheds. (25% of the Bailey Creek discharge). The season trend of discharge from SW-3 was similar to that of SW-2 with the majority of flows occurring during freshet and irrigation season. SW-3 had a yearly water yield of 1,730 $m^3 ha^{-1}$. SW-4 had a recorded discharge of 44,000 $m^3 yr^{-1}$ (9% of the Bailey Creek discharge). Seasonally, flows from SW-4 were high during spring freshet like that of SW-2 and 3 but showed only small increases during the irrigation season. SW-4 had a yearly yield of 1,150 $m^3 ha^{-1}$ ranging from 0.9 to 8.5 $m^3 ha^{-1}$. SW-5 had a recorded discharge of 50,000 m^3 (10% of the Bailey Creek discharge), with almost all the flow occurring during the spring freshet. Near the beginning of May surface flows from SW-5 had ceased. SW-5 had an annual yield of 501 $m^3 ha^{-1}$ which was the lowest recorded yield among the sub-watersheds.

Table 2: Discharge and yield data for Bailey Creek and each Sub-watershed in m^3 ha^{-1}.

Station	Total Discharge	Yield (m^3 ha^{-1})			
		Yearly	Average Daily	Min daily	Max daily
Bailey Creek	481,000	1,450	4.1	1.8	8.1
Sub-watershed 2	77,500	4,300	10.7	0.03	25.9
Sub-watershed 3	121,000	1,700	4.7	2.7	9.8
Sub-watershed 4	44,000	1,150	1.6	0.9	8.5
Sub-watershed 5	50,000	500	3.1	0	39.1

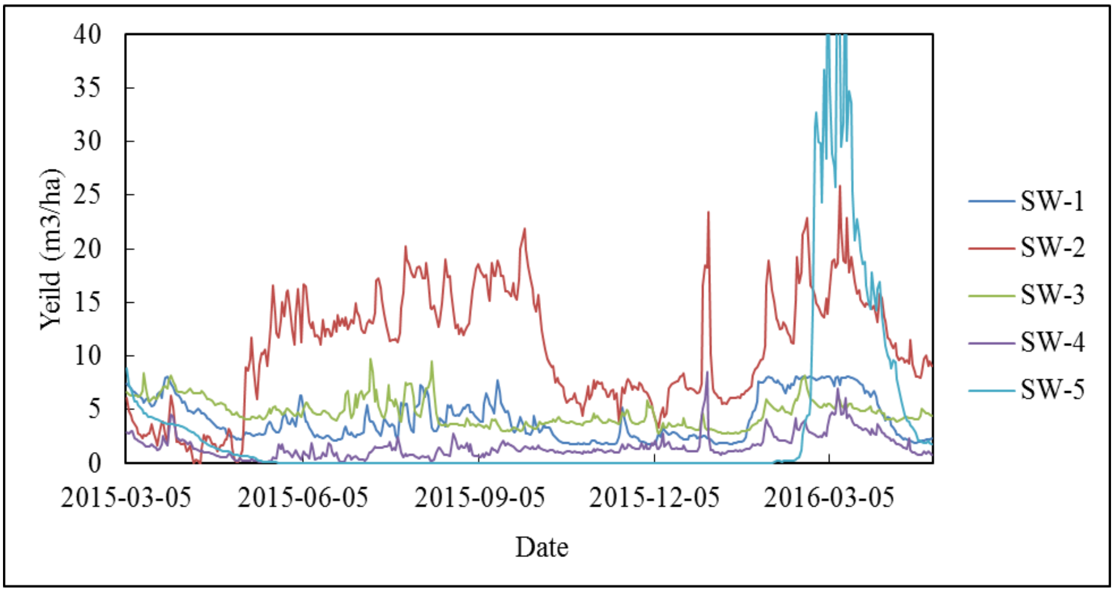

Figure 11: Plot showing yield of water per ha in each Sub-watershed and Bailey creek (SW-1).

Comparing the yield of water to the proportion of the sub-watersheds irrigated, we see that the watersheds with the highest and lowest proportion of land irrigated were also found to have the highest and lowest water yields per hectare (Figure 12). The relationship between land irrigated and water yield was found to be linear with an R^2 value of 0.87 (Figure 12).

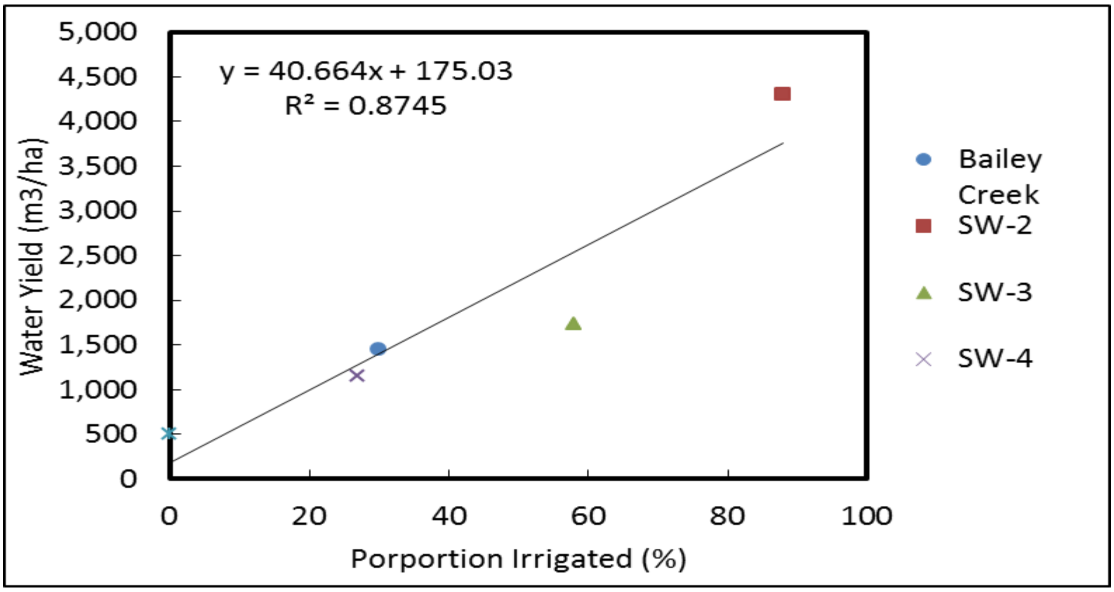

Figure 12: Plot showing % of watershed irrigated vs. yield of water per ha.

Within the irrigated watersheds, inputs and outputs were both higher during spring and irrigation season and lowest during the winter months (Figures 13 - 17). In SW-5 with no irrigation the inputs were highest during the fall and winter, while outputs were highest during spring freshet and tapered off through the summer months.

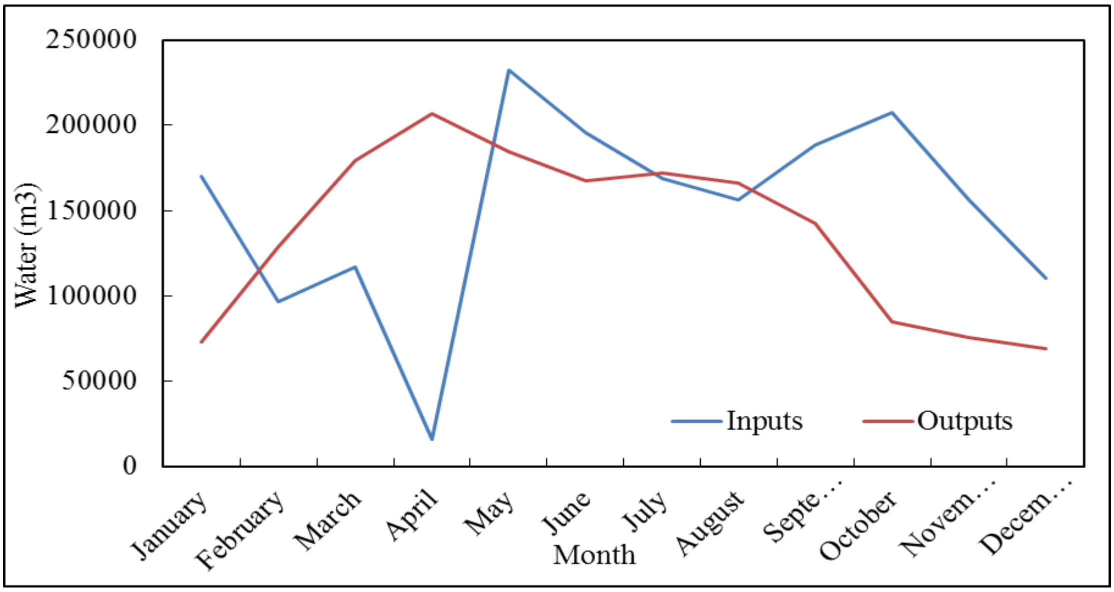

Figure 13: Monthly inputs and outputs of water from the Bailey Creek watershed in m^3.

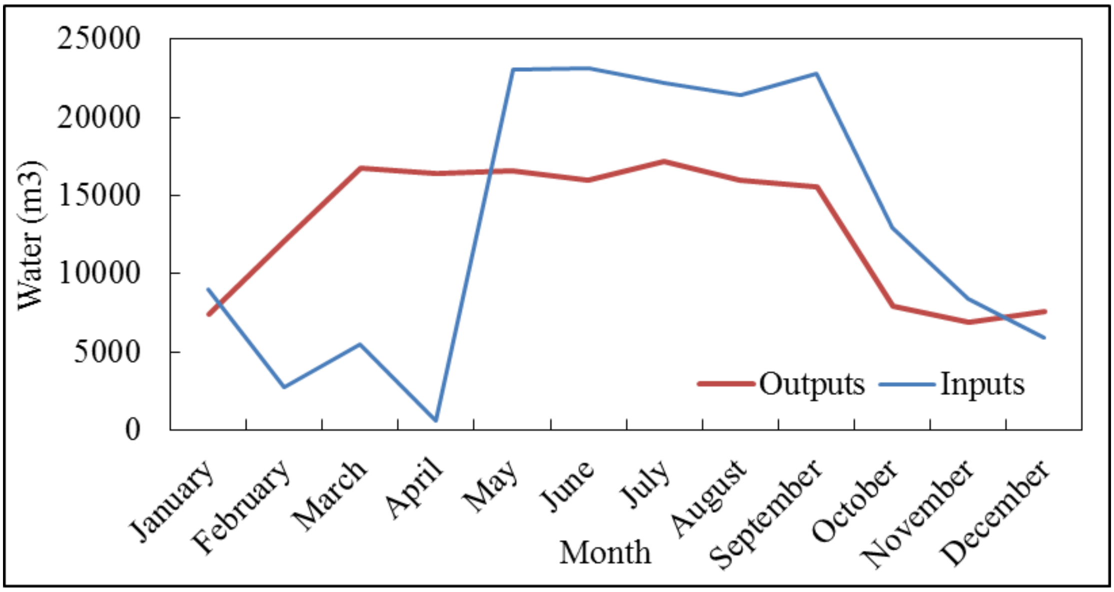

Figure 14: Monthly inputs and outputs of water from the SW-2 in m^3.

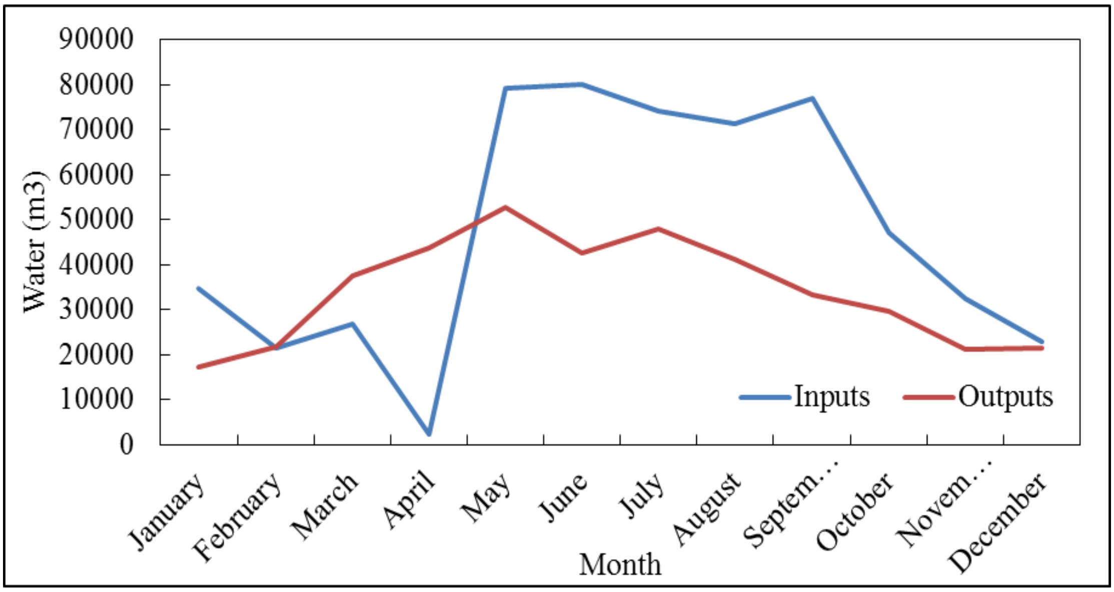

Figure 15: Monthly inputs and outputs of water from the SW-3 in m^3.

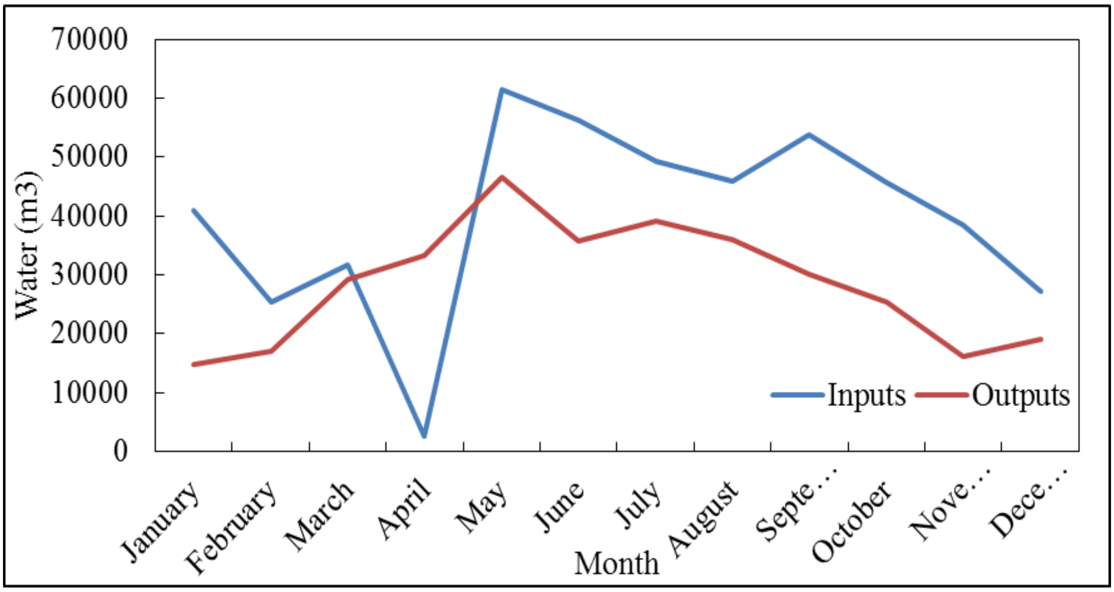

Figure 16: Monthly inputs and outputs of water from the SW-4 in m^3.

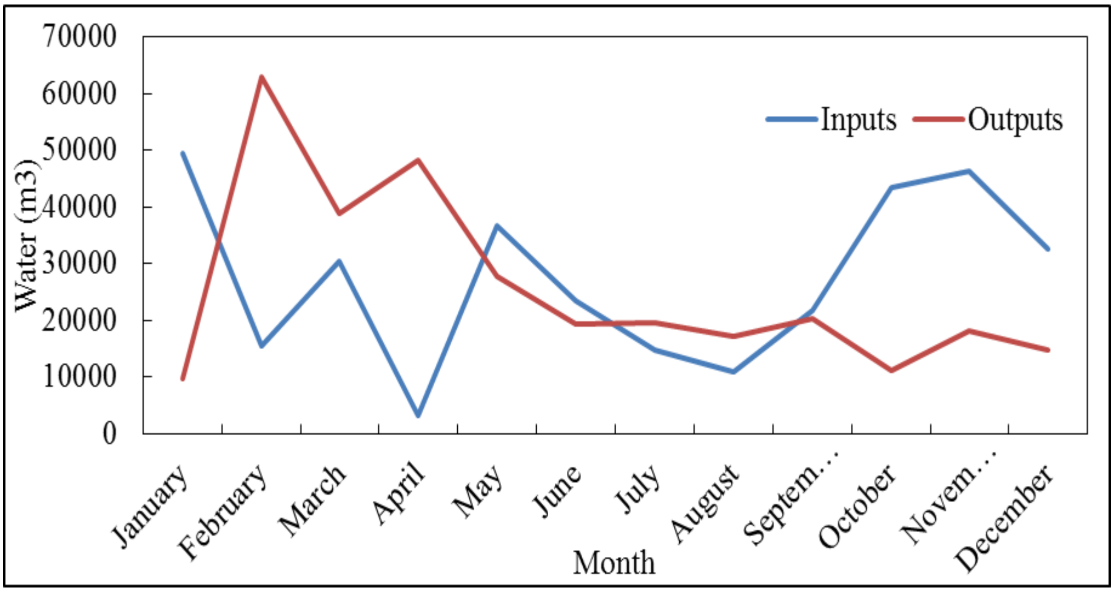

Figure 17: Monthly inputs and outputs of water from the SW-5 in m^3.

Groundwater outputs were calculated as the difference between inputs and outputs of water. Within the Bailey Creek watershed, evapotranspiration and surface water discharge accounted for approximately 85% of the total inputs. Groundwater exiting the study watershed was an estimated 269,000 m^3 accounting for 15% of total inputs of water (Table 3). Of the Sub-Watersheds, SW-2 has the lowest proportion of outputs through groundwater totalling only 1%. Groundwater exports from SW-3, 4 and 5 accounted for 21, 28 and 10%, respectively. Some reasons for the higher losses of water through groundwater flows in the SW-3,4 and 5 may be the longer transit times of water within the watershed due to size and or steepness as well as potential differences in the underlying geology. Watersheds with shallower soils and with more bedrock present are less likely to lose water through groundwater flows then those with thicker overburden.

Table 3: Summary table of inputs and outputs of water in Bailey Creek and each sub-watershed.

Watershed	Inputs (m3)				Outputs (m3)				
	Precip (0.332m)	Irrigation (0.61m)	GW Seep	Total Inputs	ETn (0.25m)	ETi (0.418m)	Discharge (m3)	Total Outputs	Groundwater (% of Total inputs)
Bailey Creek	1,102,000	627385	34403	1,764,000	555,000	460,000	481,000	1,495,000	269,000 (15)
SW-2	597,00	91,300	0	151,000	5,000	66,900	77,00	149,000	1,650 (1)
SW-3	231,000	240,000	0	470,000	68,800	176,000	121,000	365,000	105,000 (21)
SW-4	272,000	126,000	0	398,000	150,000	92,000	44,000	286,000	112,000 (28)
SW-5	329,000	0	0	329,000	248,000	0	50,000	297,000	31,000 (10)

Chloride Mass Balance

The chloride mass balance was comprised of inputs from atmospheric deposition and irrigation water, and outputs from surface and groundwater discharge. Chloride data are found in Appendix C.

In total 22 atmospheric samples were collected over the 14-month study period. The average chloride concentration in the precipitation was 2.9 mg L^{-1} ranging from 0.5 to 10 mg L^{-1} with highest concentrations being found in the summer months during the irrigation season (Figure 18). Yearly atmospheric inputs of chloride were estimated to be 2,690 kg (8.1 kg Cl ha^{-1}).

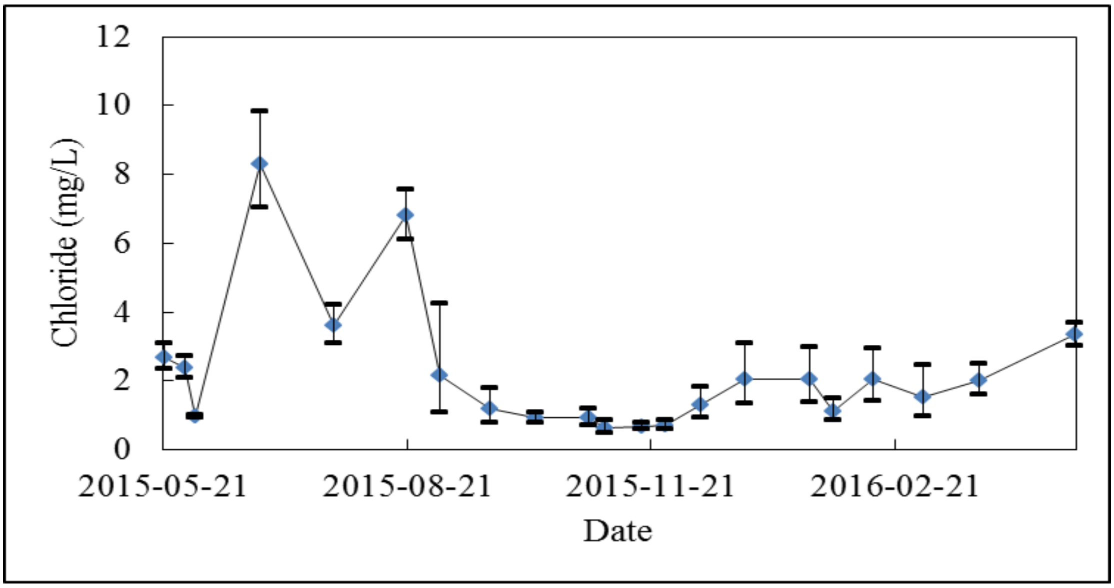

Figure 18: Average chloride concentrations in atmospheric samples with + - standard deviations.

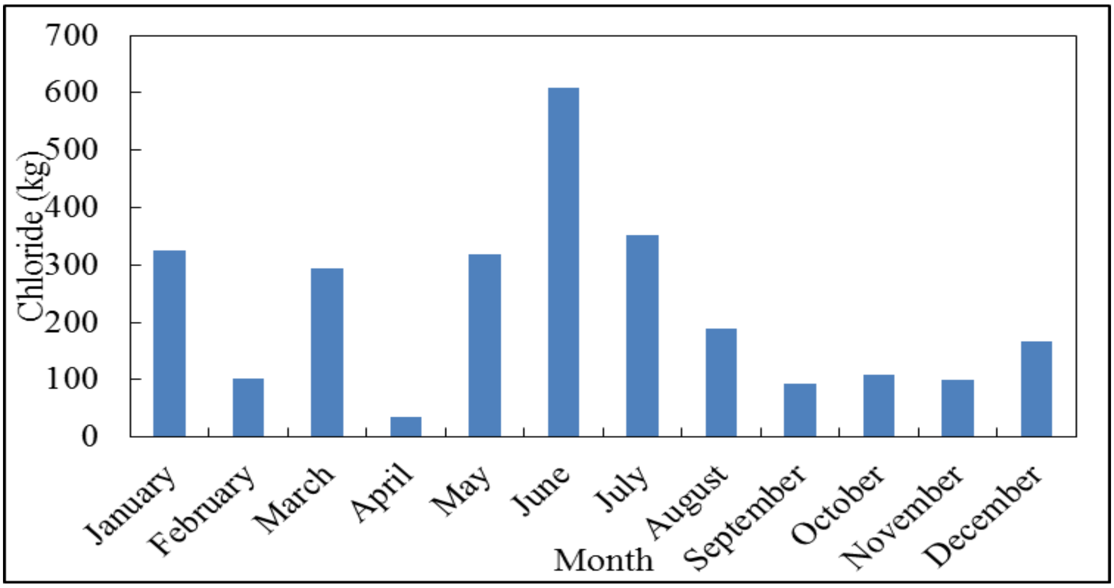

Figure 19: Watershed inputs of chloride through atmospheric deposition in kg.

The wastewater used for irrigation in the study site had an average concentration of 105 mg L^{-1} Cl with a minimum, maximum of 80.5, 139 mg L^{-1} respectively (Figure 18). Total chloride inputs through irrigation were an estimated 70,500 kg which accounts for 91.7% of total inputs of chloride (Figure 19). Chloride from wastewater irrigation accounted for 98.6% of Cl in SW-2, 97.9% in SW-3 and 95.5% in SW-4 (Table 4).

The seep feeding into Bailey Creek had an average chloride concentration of 107 mg L^{-1}, and contributed 3,710 kg of Cl to Bailey creek accounting for approximately 4.8% of the total Cl. The Cl concentration within the groundwater seep was very similar to that of the irrigation water, suggesting the spring originates from the McKay reservoir seepage through the earthen dam.

Table 4: Summary of chloride inputs in kilograms and % of total inputs.

Inputs				
Watershed	Atmospheric (kg) /% of total	Irrigation (kg) / % of total	Dam Leak (kg) / % of total	Total (kg)
Bailey Creek	2,690 / 3.5%	70,000 / 91.7%	3,710 / 4.8%	77,000
2	150 / 1.4%	10,000 / 98.6%	0	10,000
3	560 / 2.04%	27,000 / 97.9%	0	27,000
4	660 / 4.48%	14,000 / 95.5%	0	15,000
5	800 / 100%	0	0	803

Chloride exports from the study site were either through surface or groundwater flows. Surface water exports of chloride were calculated using chloride concentrations and surface water discharge. Chloride concentrations within Bailey Creek were on average 163 mg L^{-1} with a max and min of 184 and 131 mg L^{-1}, respectively, with the lowest concentrations found during spring freshet indicating dilution from increased precipitation and runoff. Total annual outputs of chloride through Bailey Creek were 81,700 kg, an average yield of 247 kg Cl ha^{-1} (Table 5).

Discharge waters from SW-2 had the lowest average concentration of Cl at 129 mg L^{-1} ranging from 101 mg L^{-1} during irrigation season to 151 mg L^{-1} in October. SW-2 had an annual loss of 8,400 kg (490 kg $ha^{-1}yr^{-1}$) through surface water.

SW-3 discharge waters had an average record concentration of 173 mg L^{-1} ranging from 142 during irrigation season to 197 mg L^{-1} in the fall. In total SW-3 lost 21,000 kg (301 kg $ha^{-1}yr^{-1}$) through surface water flows annually.

SW-4 chloride outputs through surface water were an estimated to be 8,000 kg (98 kg $ha^{-1}yr^{-1}$). Average Cl concentrations in SW-4 discharge water were 187 mg L^{-1}, which was the highest average concentration of chloride of the watersheds. Cl concentrations ranged from 120 to 228 mg L^{-1}, with the lowest concentrations found during freshet and irrigation season.

SW-5 having received no irrigation had an average chloride concentration in its discharge waters of 60 mg L^{-1} with a range from 42 to 81 mg L^{-1} respectively. Total annual losses of Cl from SW-5 surface discharge were 3,500 kg, an annual yield of 35 kg ha^{-1} yr^{-1}.

Table 5: Summary table of chloride losses through Bailey Creek and each Sub-watershed.

Station	Total Chloride (kg)	Yield (kg ha^{-1})	
		Yearly	Average Daily
Bailey Creek	82,000	247	0.7
Sub-watershed 2	8,400	490	1.3
Sub-watershed 3	21,000	301	0.8
Sub-watershed 4	8,000	98	0.3
Sub-watershed 5	3,500	35	0.1

The seasonal outputs of chloride are very similar to that of water. Increases in yields are seen during both freshet and the start of the irrigation season (Figure 20). Again, Sub-watershed 2 has the most dramatic increases with the larger irrigated sub-watersheds displaying more muted changes. Sub-watershed 5 showed high yields during a very short period of time in the late winter and early spring with no yield at all in the summer and fall months. As with the water balance, chloride yields were found to depend directly on % irrigated area (Figure 21).

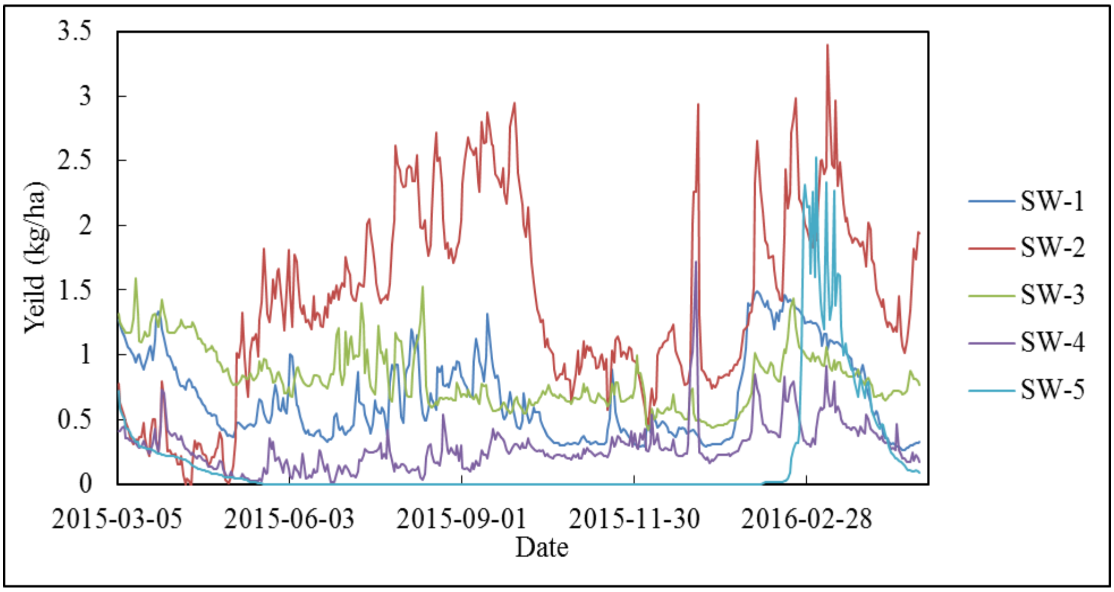

Figure 20: Yield of chloride from Bailey Creek watershed and Sub-watersheds in kg ha^{-1}

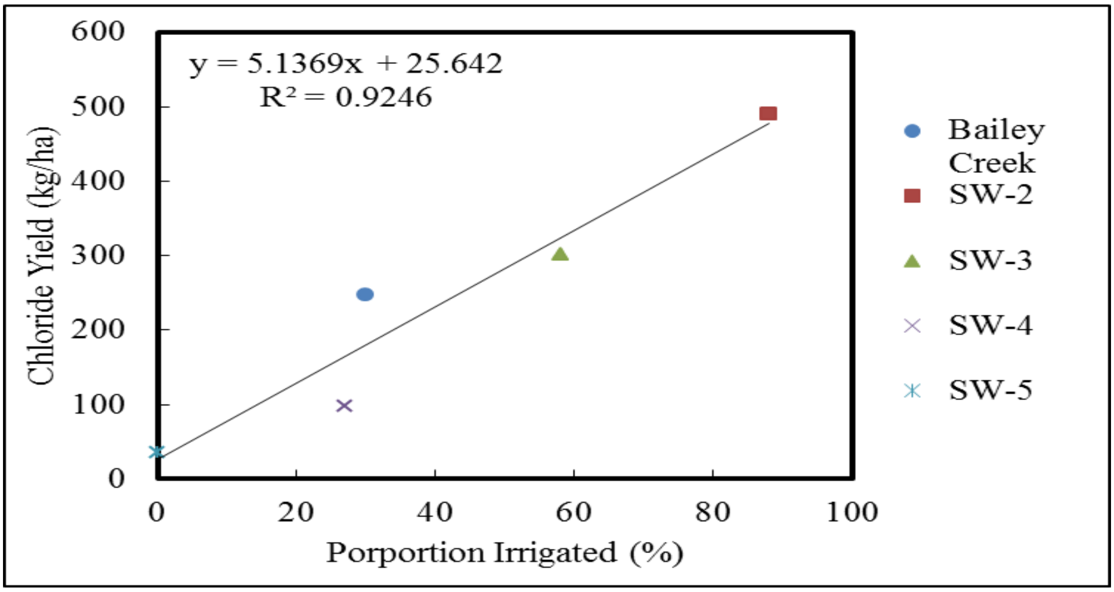

Figure 21: Plot showing % of watershed irrigated vs yield of chloride per ha.

Within the irrigated watersheds the inputs of chloride are dominated by irrigation while the outputs of chloride are driven by surface water discharge (Figures 22 – 26). In the Bailey Creek watershed and SW-3, 4 outputs of chloride were more attenuated, with outputs of chloride spread out more evenly throughout the year. In SW-2 the outputs are less attenuated with spikes during irrigation season and freshet. The result from SW-2-4 indicate that attenuation is a function of storage. In SW-5 with no irrigation the inputs are all atmospheric, and are highest during the months with the greatest rain fall. Outputs of chloride for SW-5 occur almost solely in February and March with the spring freshet flows.

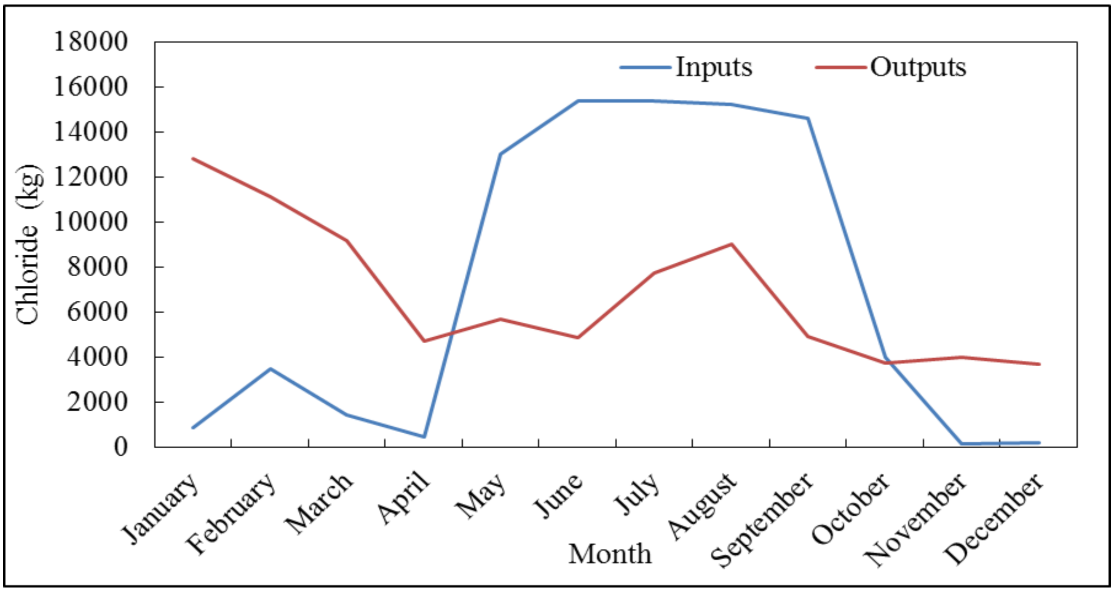

Figure 22: Monthly inputs and outputs of chloride from the Bailey Creek Watershed.

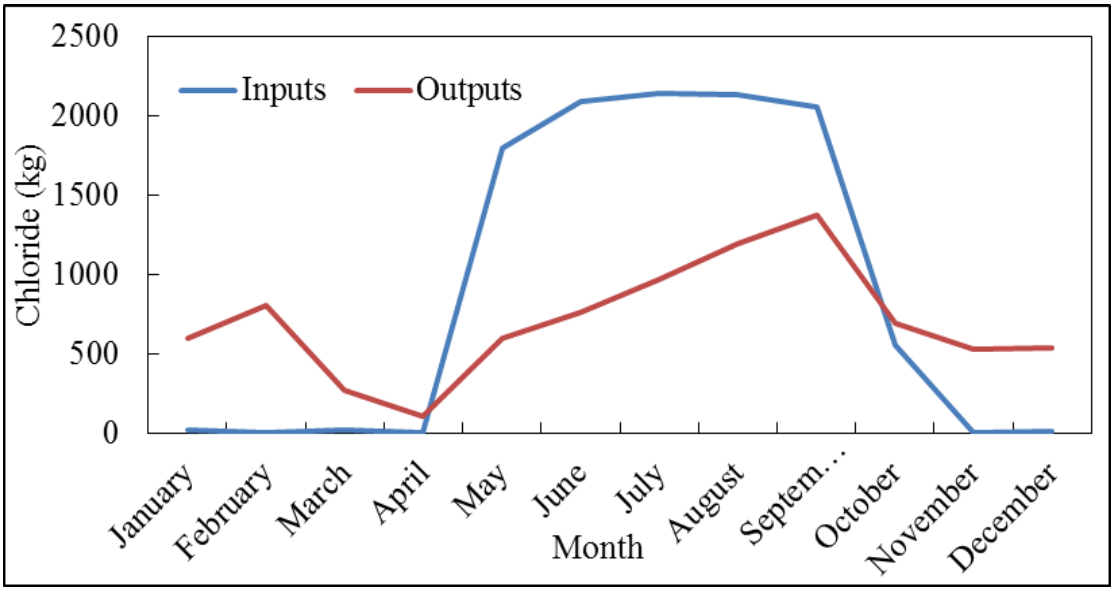

Figure 23: Monthly inputs and outputs of chloride from the SW-2

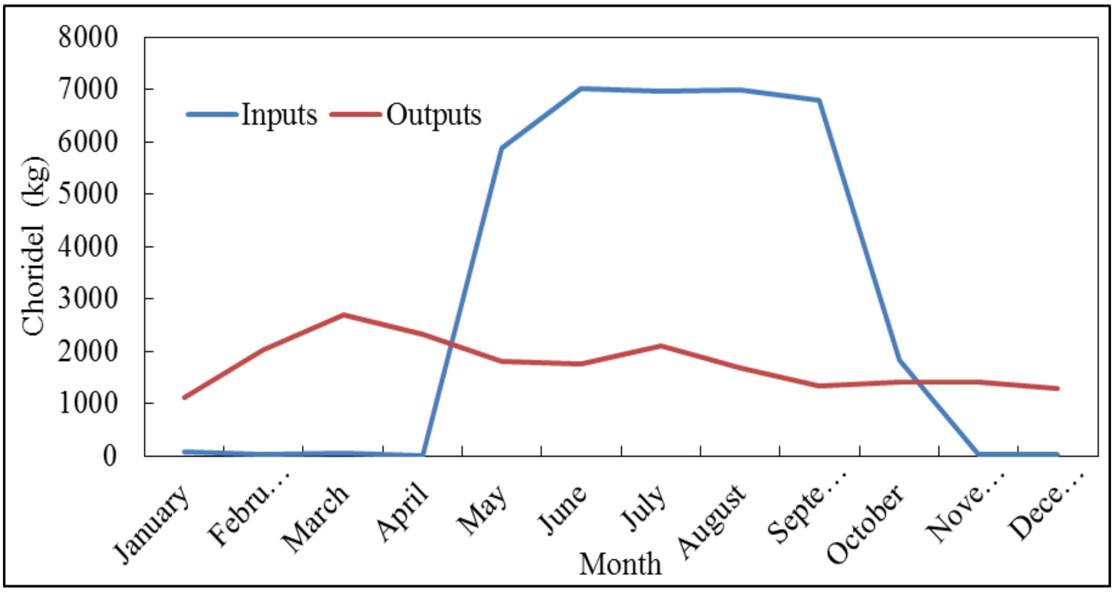

Figure 24: Monthly inputs and outputs of chloride from the SW-3 in kg.

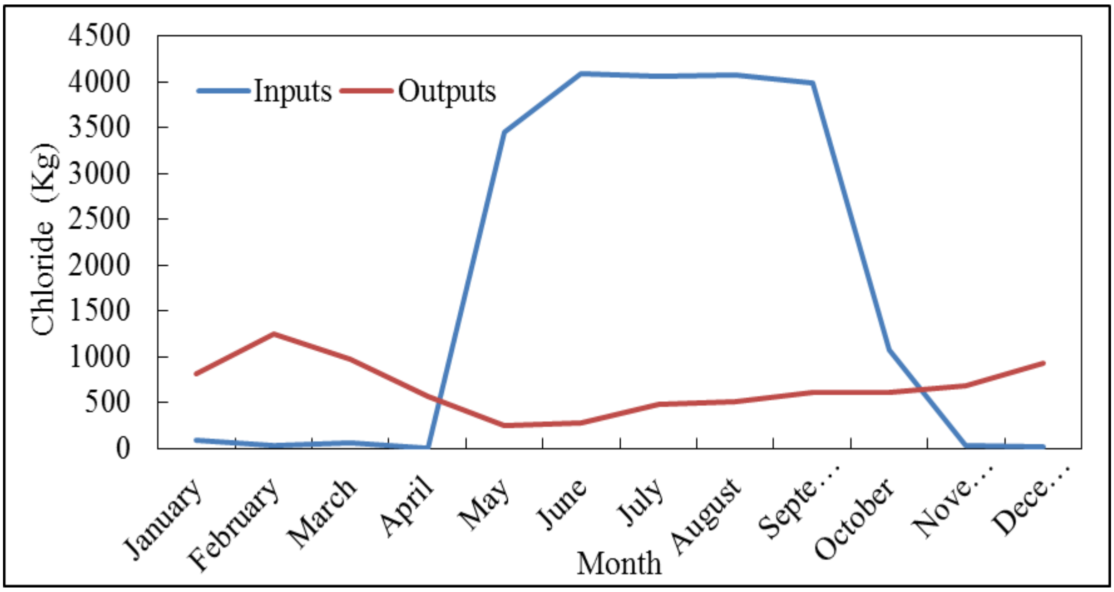

Figure 25: Monthly inputs and outputs of chloride from the SW-4 in kg.

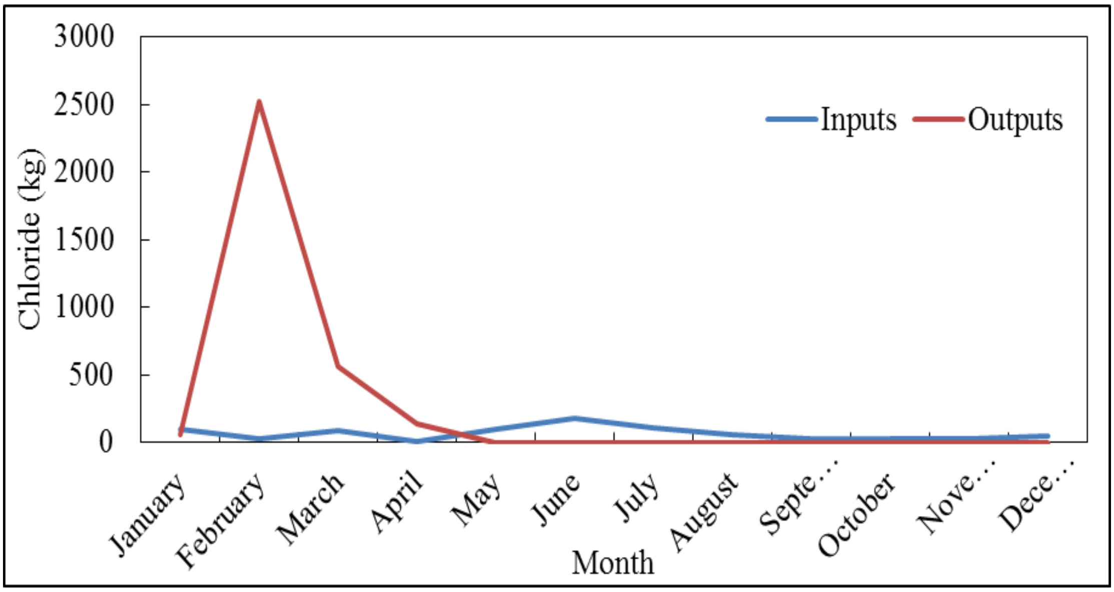

Figure 26: Monthly inputs and outputs of chloride from the SW-5 in kg.

Groundwater losses of Chloride from the study site were calculated as the difference between inputs from the atmosphere and irrigation and surface water outputs (Table 6). Overall, the chloride budget balances to within 6%. The estimated % of chloride exports from SW-2 through groundwater was 19% of total inputs. SW-3 groundwater losses of chloride accounted for 23.6% of inputs. SW-4 lost the most through groundwater flows making up an estimated 45% of total inputs. SW-5 lost 4 times as much chloride through surface water then the estimated inputs for that same year. The much higher outputs of Cl then estimated inputs indicate that the hydrology and geochemistry of SW-5 is likely being affected by the McKay Reservoir to the west and possibly the wastewater irrigation in the adjacent Sub-watershed (SW-4).

Table 6: Summary table of chloride balance for Bailey Creek and Sub-watersheds in kg and % of total inputs.

Watershed	Inputs				Outputs	
	Atmospheric (% of total)	Irrigation (% of total)	Dam Leak (% of total)	Total Inputs	Cl in Discharge (% of inputs)	Cl lost thru Groundwater (% of inputs)
Bailey Creek	2,690 (3.5)	70,500 (91.7)	3,710 (4.8)	77,000	81,700 (106)	0 (0)
2	146 (1.4)	10,250 (98.6)	0	10,4000	8,420 (81)	1,970 (19)
3	562 (2.04)	26,900 (97.9)	0	27,000	21,000 (76)	6,500 (23.6)
4	661 (4.48)	14,100 (95.5)	0	14,800	8,00 (54)	6,750 (45.7)
5	803 (100)	0	0	803	3,480 (433)	0

Based on the chloride balance, 92% of all the chloride within the discharge waters of Bailey Creek is from irrigation. The concentrations of chloride in the irrigation water were on average 105 mg L^{-1}, and the average concentration of Cl within groundwater leaving the study watershed was on average 162 mg L^{-1}. In order to evapoconcentrate the chloride from 105 to 162 mg L^{-1}, approximately 35% of the original water needed to be evaporated. This is close to the estimates in the water balance which estimated 44% of total inputs of water were lost from the watershed though evaporation.

Based on the mass flux of chloride from Bailey Creek, an estimate of how much irrigation is needed to supply that amount of chloride was calculated. Starting with the total chloride flux of 81,700 kg and subtracting chloride from the Groundwater seep and atmospheric inputs of chloride, we are left with 75,100 kg of chloride. Dividing this total by the average concentration of chloride in the irrigation water (105 mg L^{-1}), a total of 716,000 m^3 is derived. Estimates of irrigation inputs in the water budget were an estimated 671,000 m^3 of water. This is within 5% of the chloride based estimate.

Nutrient Mass Balance

Inputs of both phosphorus and nitrogen that were included in this study are inputs through wet and dry atmospheric deposition, irrigation water and imported alfalfa hay. Primary exports of P and N included in this study were losses through surface and groundwater flows.

Atmospheric Inputs

Concentrations of total phosphorus in precipitation ranged from 0.01 to 1.9 mg L^{-1}. This is a little bit higher then the global averages of between0.01 and 0.05 mg L^{-1} (Anderson, 2006; Smil, 2000). Seasonally, concentrations were found to be the highest during the spring and irrigation season (Figure 27). Annual atmospheric inputs of P were measured to be an average of 174 kg (0.52 Kg P ha^{-1}) with the highest rates of deposition occurring during the summer months and the lowest during February, April and December (Figure 28).

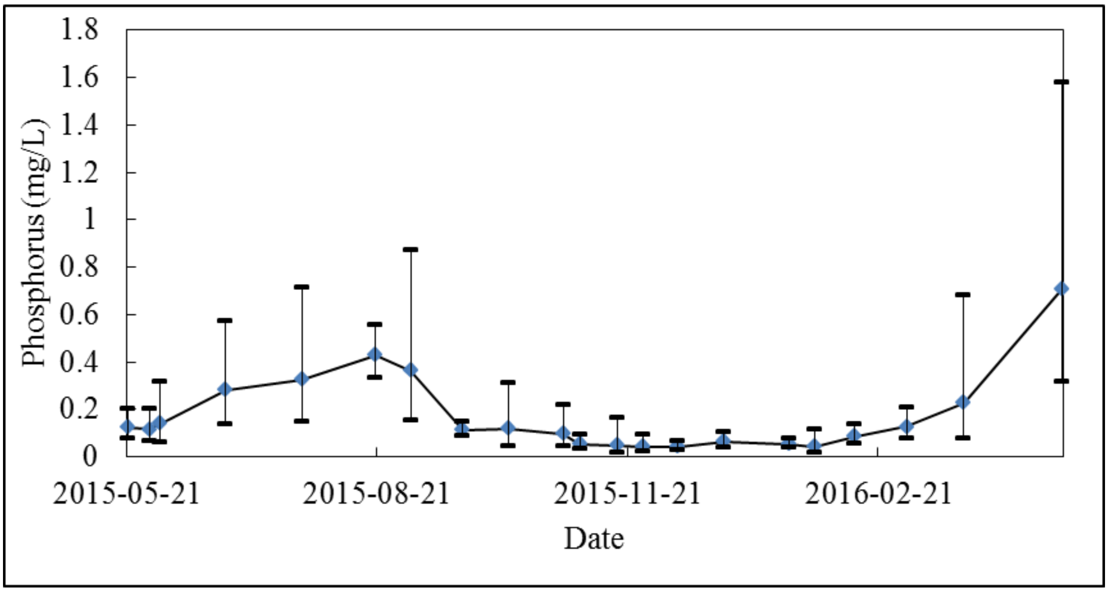

Figure 27: Seasonal phosphorus concentrations in atmospheric samples in mg L^{-1}.

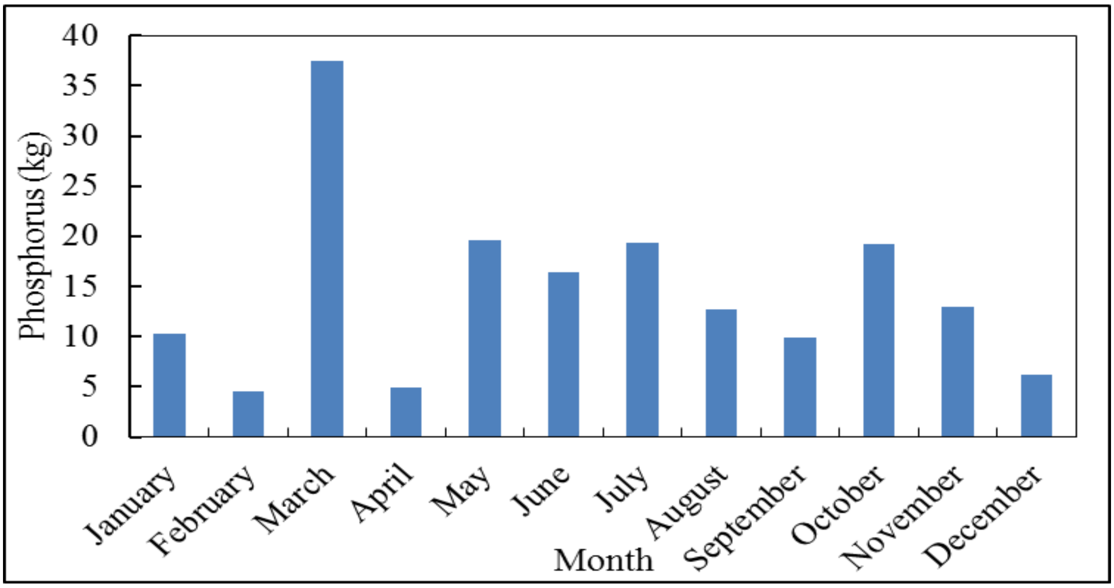

Figure 28: Study Basin monthly atmospheric input of phosphorus in kilograms.

Concentrations of total nitrogen in precipitation ranged from 0.01 to 11.9 mg L^{-1}. Seasonally, concentration trends were similar to that of P with the highest concentrations found during the spring and irrigation season (Figure 29). Yearly atmospheric inputs of N were measured to be 1,760 kg (5.3 Kg N ha^{-1}) with the highest rates of deposition occurring during March, May, June and November. The months with the lowest deposition were February, April, September and December (Figure 30).

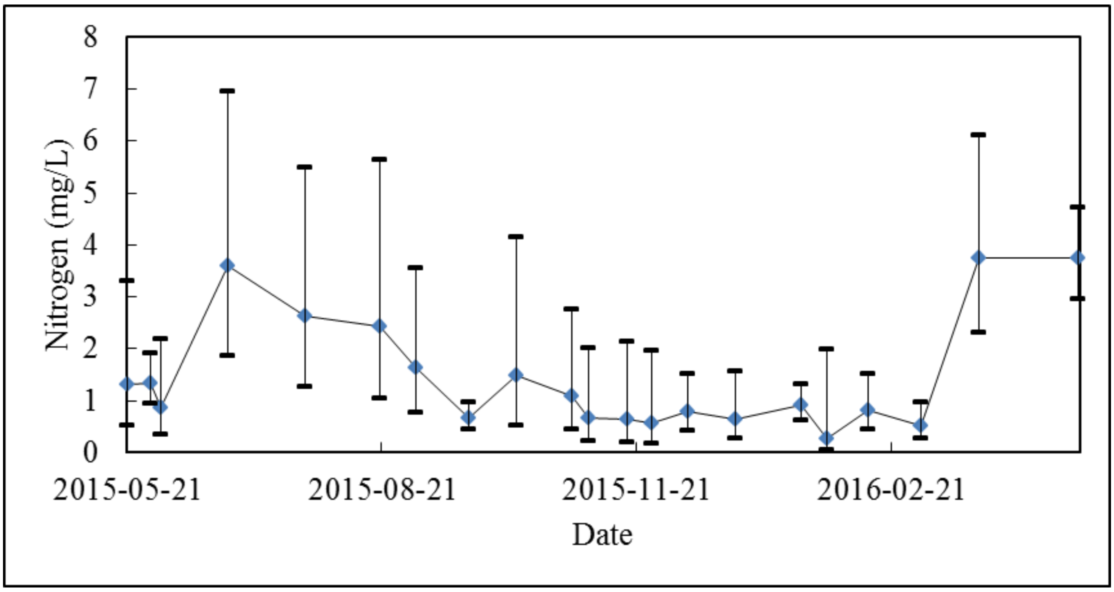

Figure 29: Seasonal nitrogen concentrations in atmospheric samples in mg L^{-1}.

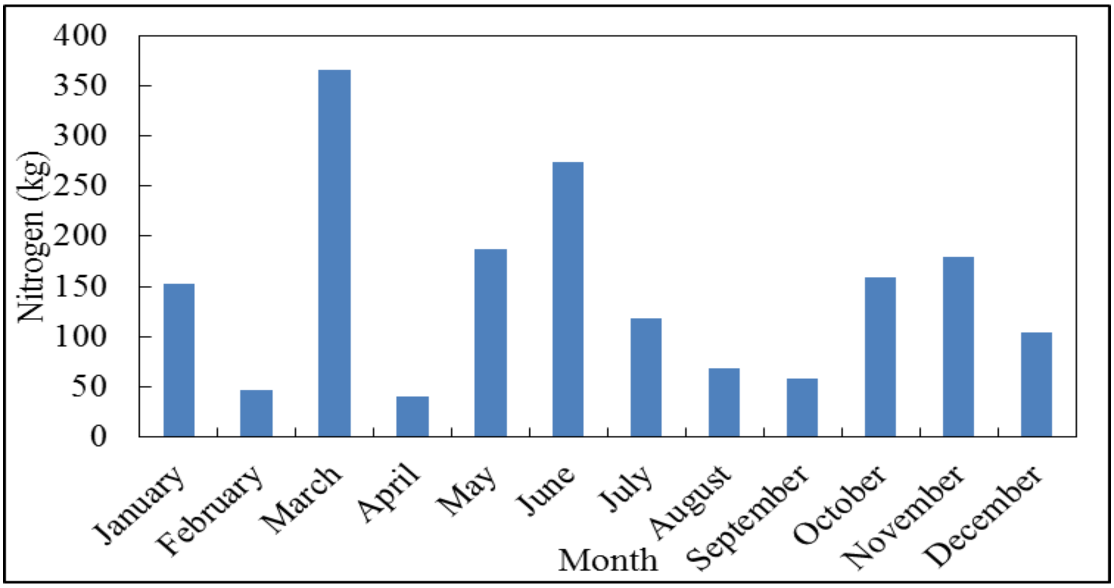

Figure 30: Study basin monthly atmospheric input of nitrogen.

The wastewater irrigation water in the study site had an average TP concentration of 0.71 mg L^{-1} with a min and max of 0.55 and 1.17 mg L^{-1} respectively. Phosphorus found within the irrigation water was 92% in the dissolved form. Total irrigation inputs of TP were calculated to be 487 kg (1.46 Kg ha^{-1}) over the course of the irrigation season (Table 7).

Concentrations of TN in irrigation water were an average of 4.03 mg L^{-1} with a min and max of 1.99 and 6.1 mg L^{-1} respectively. Total irrigation inputs of TN were estimated at 2,780 kg (8.34 kg ha^{-1}) over the course of the irrigation season. The Sub-watershed with the irrigation loading of both P and N was SW-2 with an estimated input of 3.86 Kg P ha^{-1} and 20.8 Kg N ha^{-1}. Sub-watersheds 3 and 4 received an annual input of P through irrigation of 3.28 and 1.6 Kg P ha^{-1} and N input from irrigation was 18.7 and 9.2 Kg N ha^{-1}, respectively (Table 8).

Sub-watersheds 2, 3 and 4 all received inputs of nutrient from alfalfa hay being imported for cattle feed during the winter months. Estimates of nutrient imports from Alfalfa hay were based on reported mass of hay imported reported by the relevant landowners and a value of 0.22% P and 1.375% N by weight within Alfalfa. Total inputs through alfalfa hay were an estimated 334 kg of P and 2090 kg of N during the winter months (Table 7 and 8). Of the Sub-watersheds receiving alfalfa hay, SW-3 received the most P and N with 185 and 1,223 kg respectively. Sub-watersheds 2 and 4 received 24 and 125 kg P and 150 and 775 kg N, respectively.

The Bailey Creek watershed received additional 7 kg of phosphorus and 85 Kg of Nitrogen from the groundwater seep, accounting for approximately 1% of total inputs.

Inputs of both P and N show similar trends. Proportionally, wastewater irrigation contributed the majority of both P and N in watersheds that were subject to irrigation. The next largest contributor of nutrients to the study watershed was nutrients within imported hay (Tables 7 and 8).

Table 7: Inputs of phosphorus into Bailey Creek watershed and Sub-watersheds in kg and % of total inputs.

Inputs of Phosphorus (kg)					
Watershed	Atmospheric / % of total	Irrigation / % of total	Dam Seep / % of total	Hay / % of total	Total (kg)
Bailey Creek	174 / 17%	487 / 49%	7 / 1%	334 / 33%	1002
2	9 / 9%	69 / 68%	0 / 0%	24 / 23%	103
3	36 / 8%	228 / 51%	0 / 0%	185 / 41%	450
4	43 / 14%	132 / 44%	0 / 0%	125 / 42%	300
5	52 / 100%	0 / 0%	0 / 0%	0 / 0%	52

Table 8: Inputs of nitrogen into Bailey Creek watershed and Sub-watersheds in kg and % of total inputs.

Inputs of Nitrogen (kg)					
Watershed	Atmospheric / % of total	Irrigation / % of total	Dam Seep / % of total	Hay / % of total	Total (kg)
Bailey Creek	1760 / 26%	2780 / 41%	85 / 1%	2090 / 31%	6706
2	95 / 15%	375 / 60%	0 / 0%	150 / 24%	620
3	370 / 13%	1300 / 45%	0 / 0%	1220 / 42%	2892
4	434 / 22%	754 / 38%	0 / 0%	775 / 39%	1963
5	475 / 100%	0 / 0%	0 / 0%	0 / 0%	475

Nutrient Exports

Nutrient exports from the study watershed included nutrient in surface water discharge and groundwater flows. Generally, the concentrations of both P and N were found to be highest during the irrigation season and lowest during the winter months in each of watersheds.

Concentrations of total phosphorus in the discharge water of Bailey Creek were on average 0.15mg L^{-1} and ranged from 0.068 to 0.23 mg L^{-1} s (Table 9, Figure 31). Annual output of Total Phosphorus from Bailey Creek was 71 kg, an average yield of 0.21 kg $ha^{-1}yr^{-1}$ (Table 10). Discharge waters from SW-2 had the highest average concentration of TP at 0.25 mg L^{-1}. SW-2 had an annual loss of 17.9 kg (0.99 kg $ha^{-1}yr^{-1}$) through surface water. SW-3 discharge waters had an average concentration of 0.11 mg L^{-1}. In total SW-3 has an annual phosphorus loss of 13 kg (0.189 kg $ha^{-1}yr^{-1}$) through surface water flows. Average TP concentrations in SW-4 discharge water were 0.17 mg L^{-1}, with the lowest concentrations found during freshet and irrigation season. SW-4 phosphorus outputs through surface water were an estimated to be 6.95 kg (0.08 kg $ha^{-1}yr^{-1}$). SW-5 having received no irrigation had an average phosphorus concentration in its discharge waters of 0.06 mg L^{-1}.

Concentrations of Nitrogen within Bailey Creek were on average 2.4 mg L^{-1} and ranged from 0.84 to 3.85 mg L^{-1} (Table 9 and Figure 32). Annual output of Total Nitrogen from Bailey Creek was 1170 kg, an average yield of 3.5 kg $ha^{-1}yr^{-1}$ (Table 10). Discharge waters from SW-2 had the highest average concentration of 3.8 mg N L^{-1}. Annually, SW-2 lost 226 kg (8.77 kg $ha^{-1}yr^{-1}$) of nitrogen through surface water. SW-3 discharge waters had an average measured TN concentration of 3.01 mg L^{-1}. In total SW-3 has an annual phosphorus loss of 383 kg (7.78 kg $ha^{-1}yr^{-1}$) through surface water flows. Average TN concentrations in SW-4 discharge water were 2.9 mg L^{-1}. SW-4 nitrogen outputs through surface water were an estimated to be 122 kg (2.07 kg $ha^{-1}yr^{-1}$). SW-5 having received no irrigation had an average nitrogen concentration in its discharge waters of 1.9 mg L^{-1}. Total annual losses of Cl from SW-5 surface discharge were 81.6 kg, with an annual yield of 0.82 kg ha^{-1} yr^{-1}.

Table 9: Summary table of average phosphorus concentrations Bailey Creek and Sub-watersheds in mg L^{-1}.

Nutrient Concentrations in Discharge water (mg L^{-1})						
Watershed	Phosphorus (mg L^{-1})			Nitrogen (mg L^{-1})		
	Average	Min	Max	Average	Min	Max
Bailey Creek	0.15	0.68	0.23	2.4	0.84	3.85
SW-2	0.25	0.07	0.96	3.8	1.31	7.34
SW-3	0.11	0.03	0.27	3.01	0.81	5.83
SW-4	0.17	0.025	0.51	2.9	1.03	7.35
SW-5	0.06	0.016	0.31	1.9	0.9	3.1

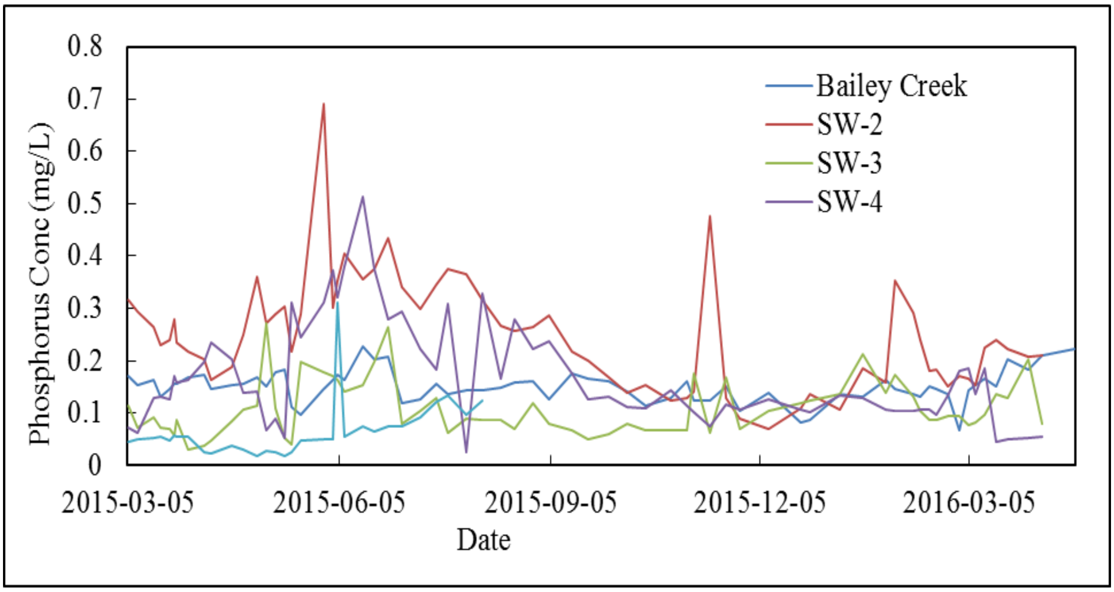

Figure 31: Seasonal phosphorus concentrations in discharge waters in mg L^{-1}.

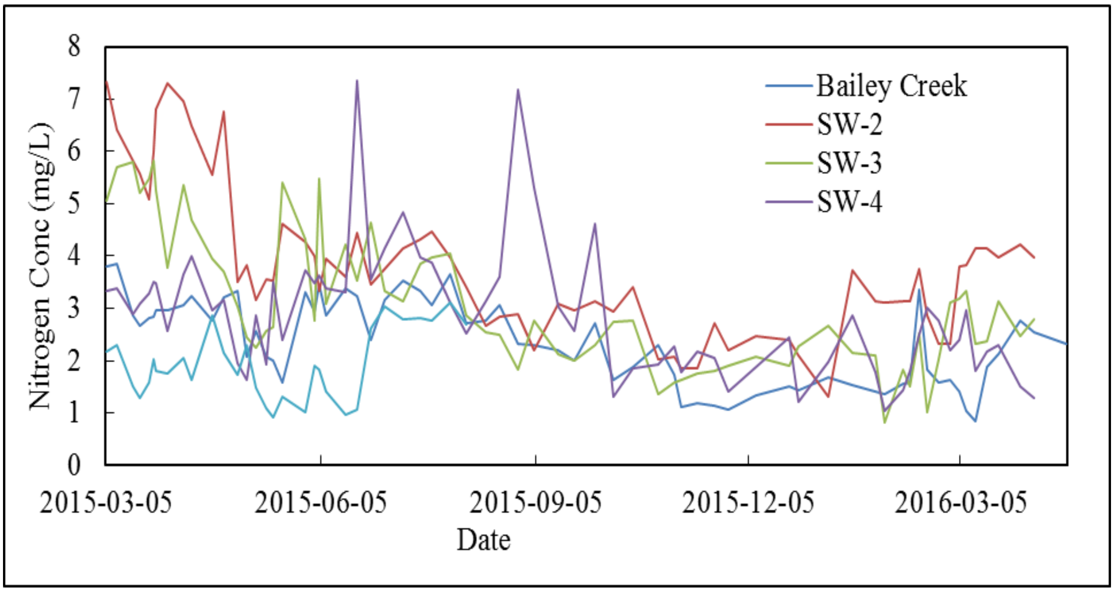

Figure 32: Seasonal nitrogen concentrations in discharge waters in mg L^{-1}.

Table 10: Summary table of phosphorus losses through Bailey Creek and each Sub-watershed in kg.

Station	Phosphorus		Nitrogen	
	Total Surface water Outputs (kg)	Yield (kg/ha)	Total Surface water Outputs (kg)	Yield (kg/ha)
Bailey Creek	71.0	0.2	1170	3.5
Sub-watershed 2	18.0	1.0	226	8.8
Sub-watershed 3	13.0	0.19	383	7.0
Sub-watershed 4	7.0	0.08	122	2.1
Sub-watershed 5	4.60	0.05	82	0.8

Nutrient yields of both phosphorus and nitrogen were found to be highest during the irrigation season and freshet with the exception of the non-irrigated watershed (SW-5), which had no nutrient yield during the irrigation season (Figure 33 and 34). SW-2 had the most dramatic increases in nutrient yield during both irrigation and the freshet season. Nutrient yields in the larger watersheds were similar to SW-2 with the highest yields during the freshet season but showed more muted increases during irrigation season. The relationship between yield of nutrients and the proportion of land irrigated (Figures 35 and 36) are similar to that of water and chloride. The relationship between phosphorus and proportion of irrigated land was $r^2 = 0.74$. Nitrogen yields have a significantly higher degree of correlation (r^2=0.922) to % of irrigated land than phosphorus (Figure 36).

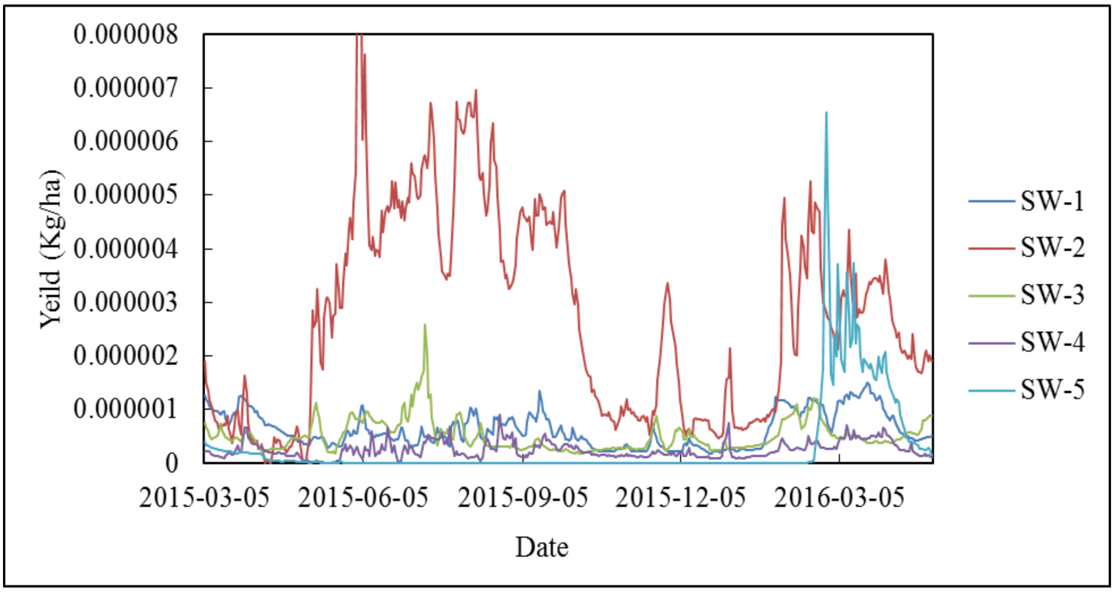

Figure 33: Yield of phosphorus in discharge waters in kg ha^{-1}.

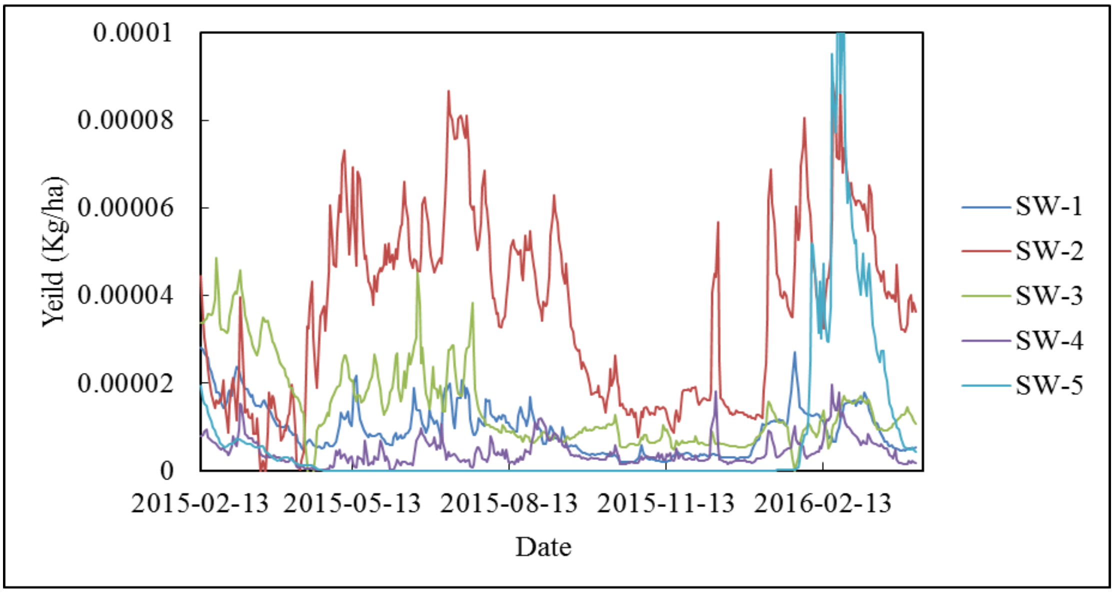

Figure 34: Yield of nitrogen in discharge waters in kg ha^{-1}.

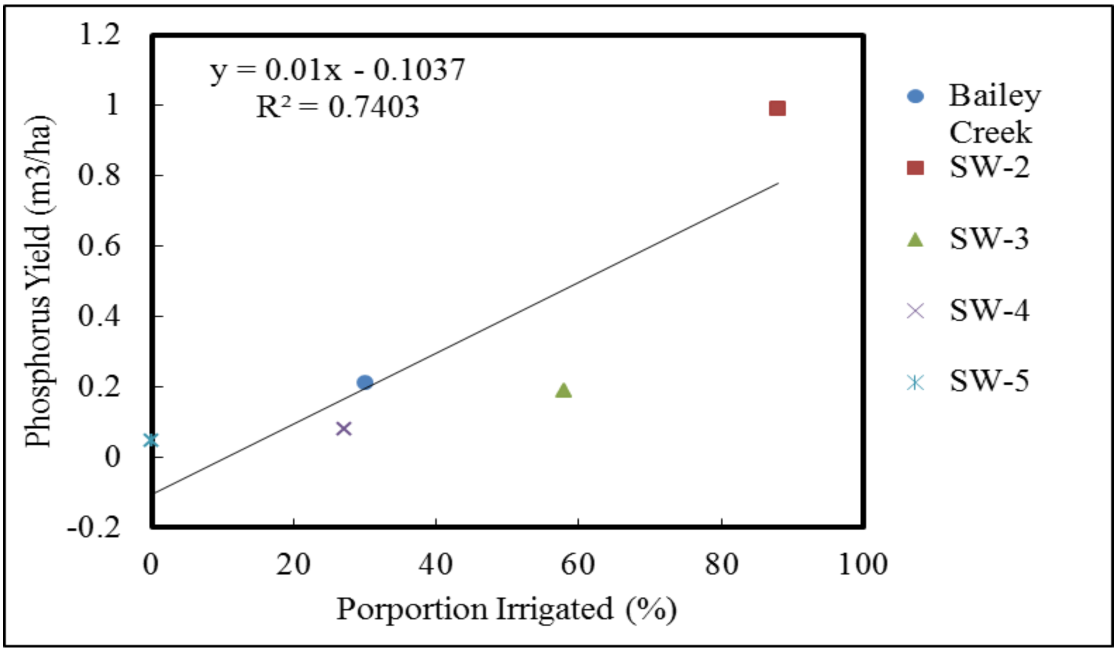

Figure 35: % of watershed irrigated vs yield of phosphorus per ha

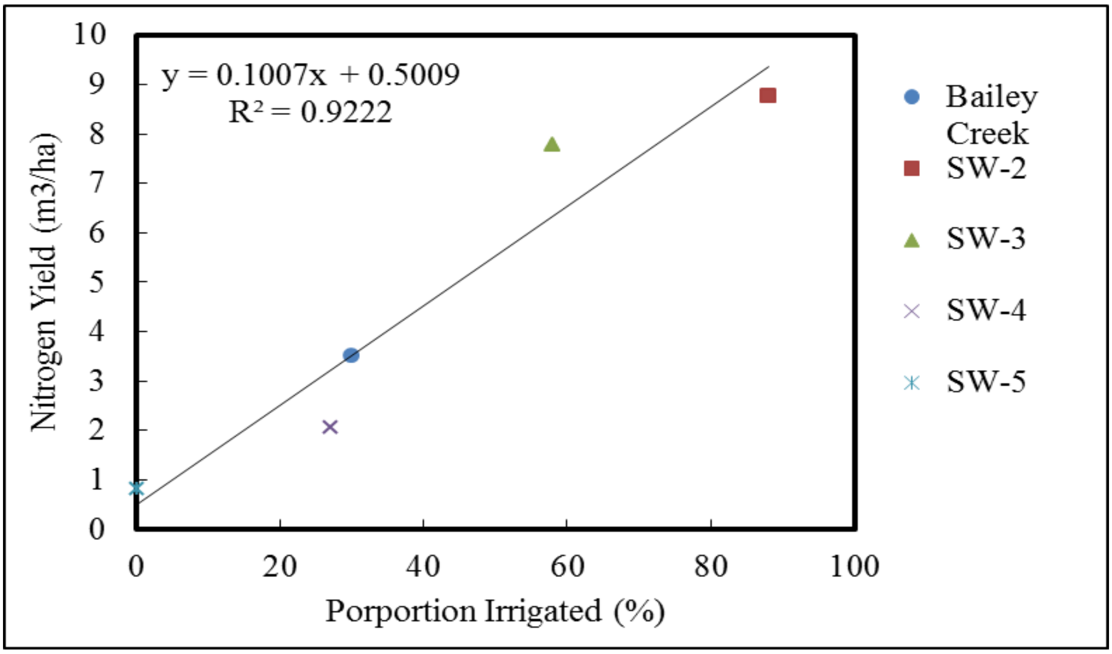

Figure 36: % of watershed irrigated vs. yield of nitrogen per ha.

Within the irrigated watersheds the inputs of both phosphorus and nitrogen are dominated by irrigation while the outputs of nutrients remain minimal throughout the year (Figures 37-46). The Sub-watershed with the highest outputs compared to inputs was SW-2. In SW-2 the outputs are less attenuated with spikes during irrigation season. In SW-5 with no irrigation the inputs were driven by atmospheric inputs and are highest during the months with the greatest rain fall. Outputs of nutrient for SW-5 occur almost solely in February and March with the spring freshet flows.

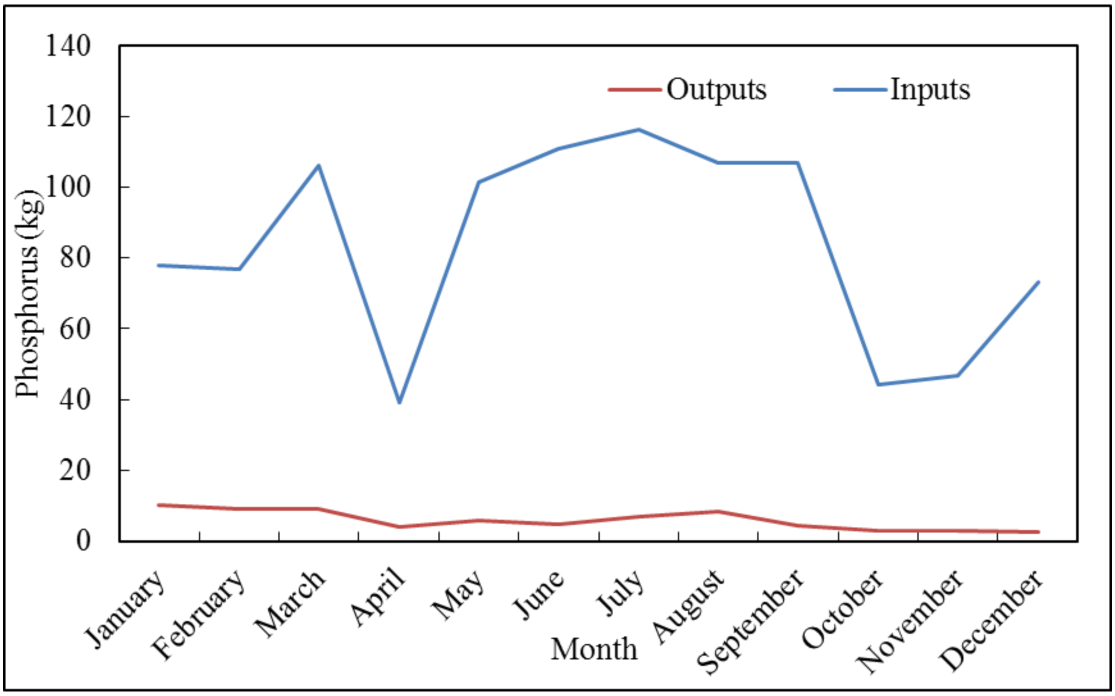

Figure 37: Monthly inputs and outputs of phosphorus from the Bailey Creek watershed.

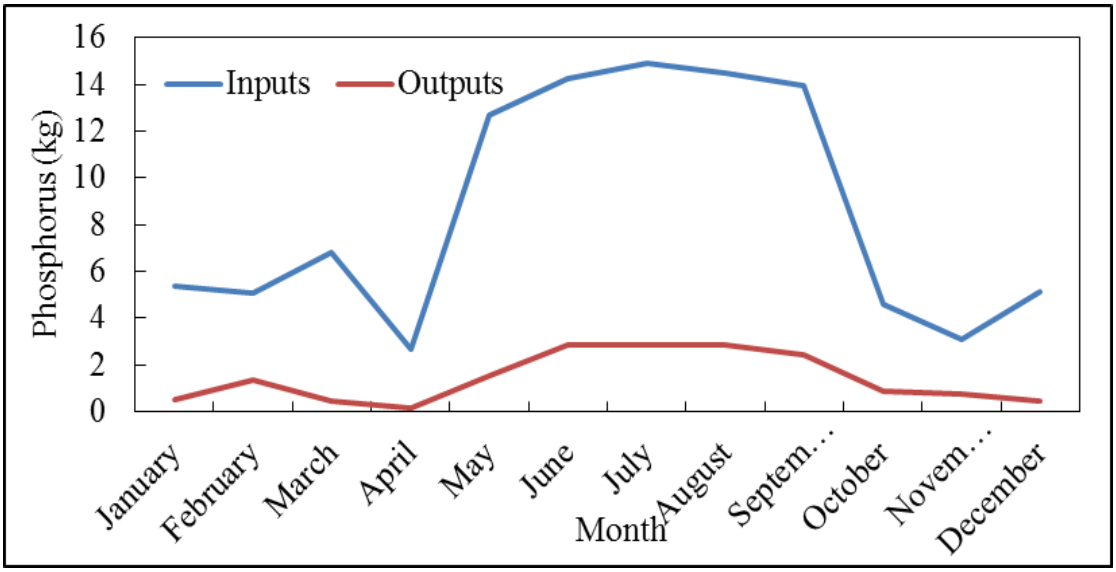

Figure 38: Monthly inputs and outputs of phosphorus from the SW-2.

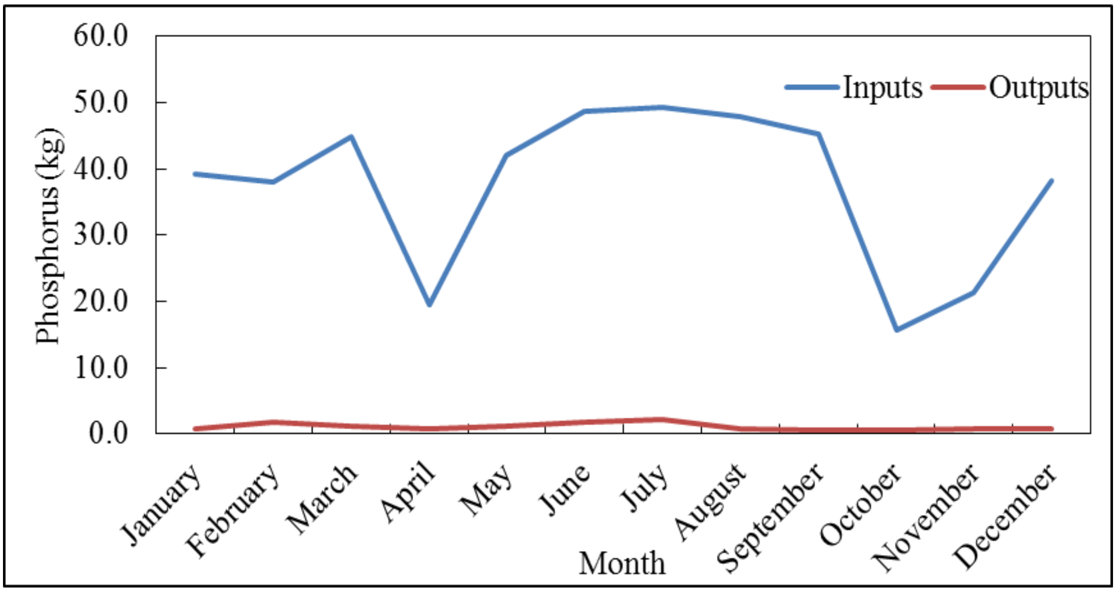

Figure 39: Monthly inputs and outputs of phosphorus from the SW-3.

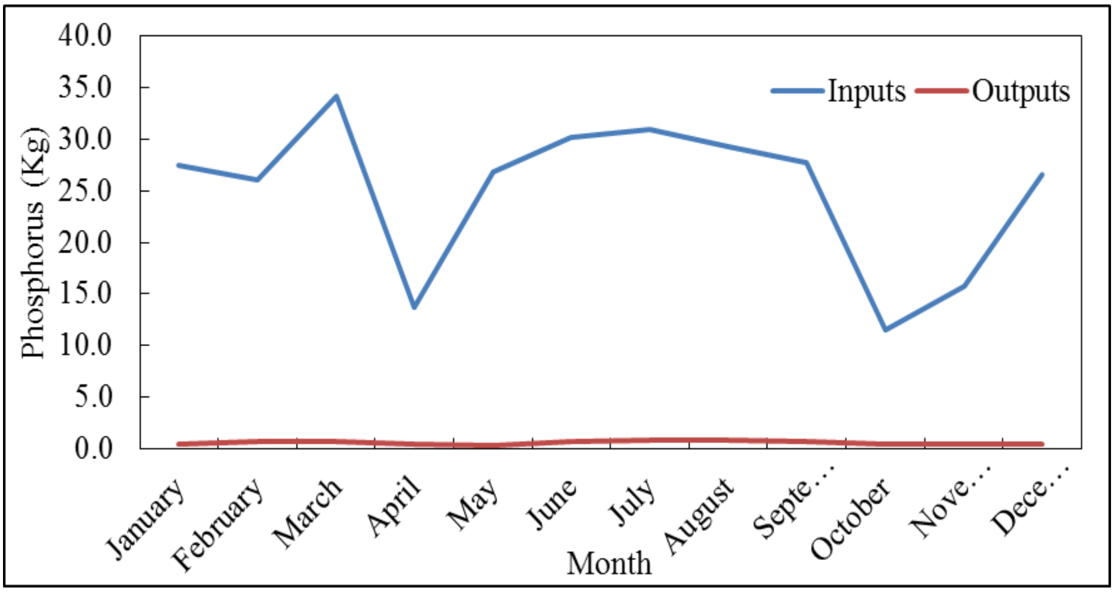

Figure 40: Monthly inputs and outputs of phosphorus from the SW-4.

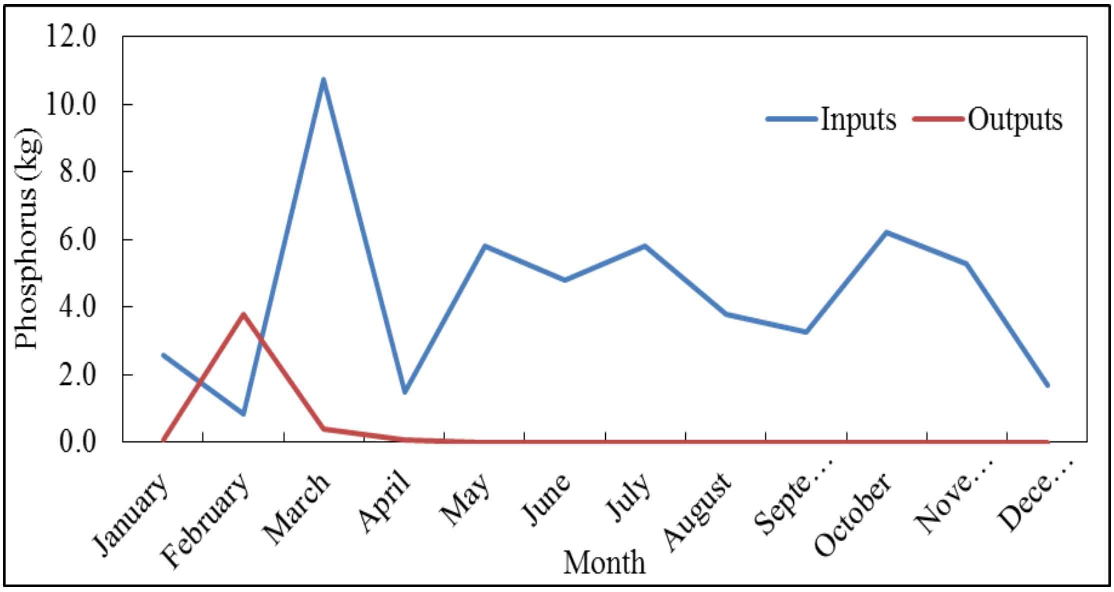

Figure 41: Monthly inputs and outputs of phosphorus from the SW-5.

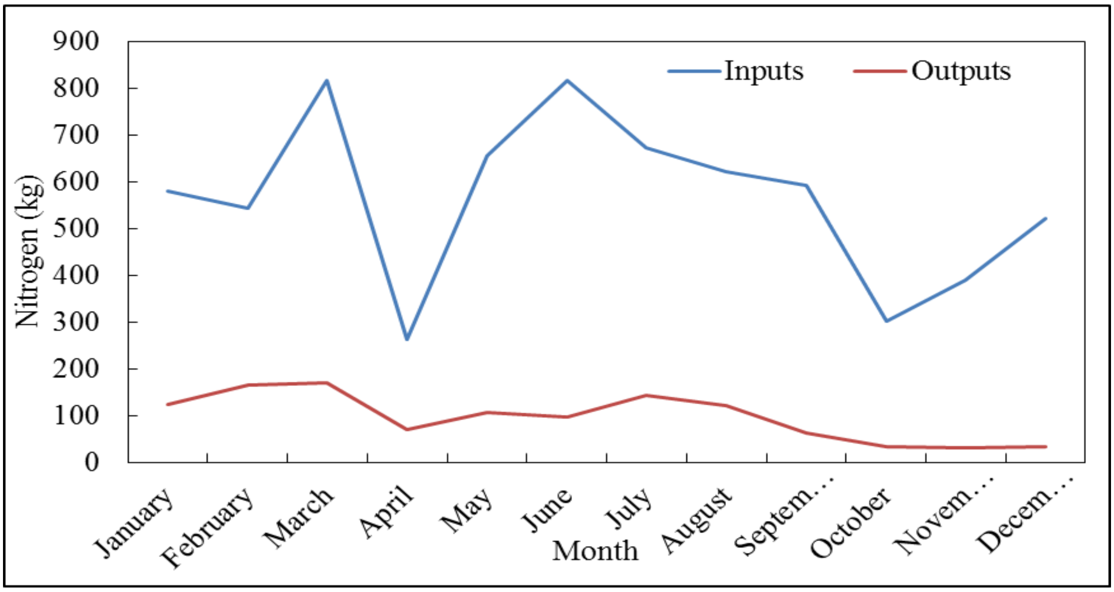

Figure 42: Monthly inputs and outputs of nitrogen from the Bailey Creek watershed.

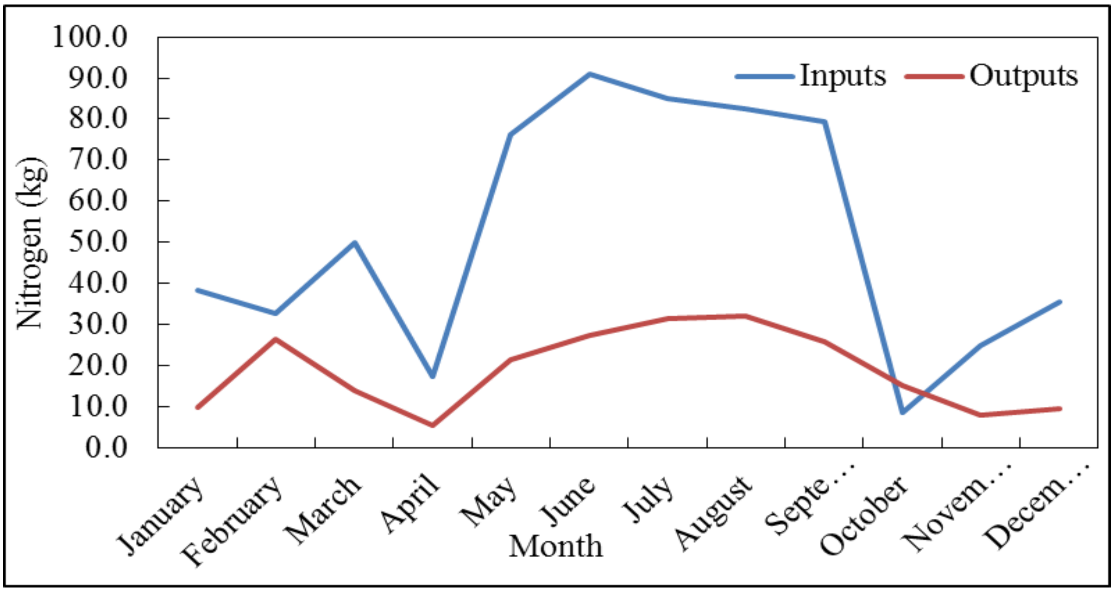

Figure 43: Monthly inputs and outputs of nitrogen from the SW-2

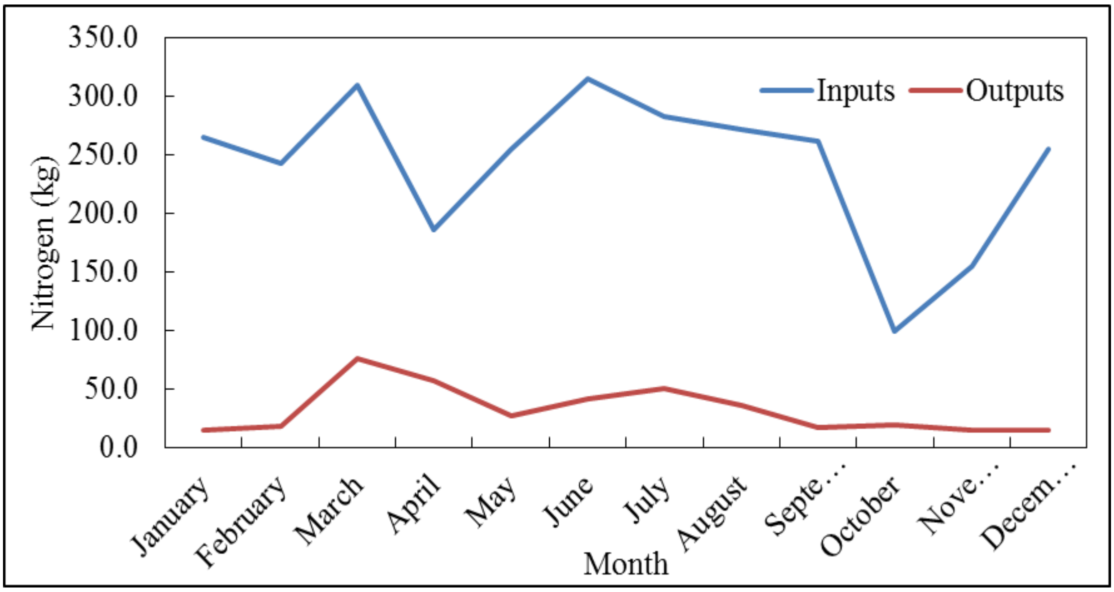

Figure 44: Monthly inputs and outputs of nitrogen from the SW-3.

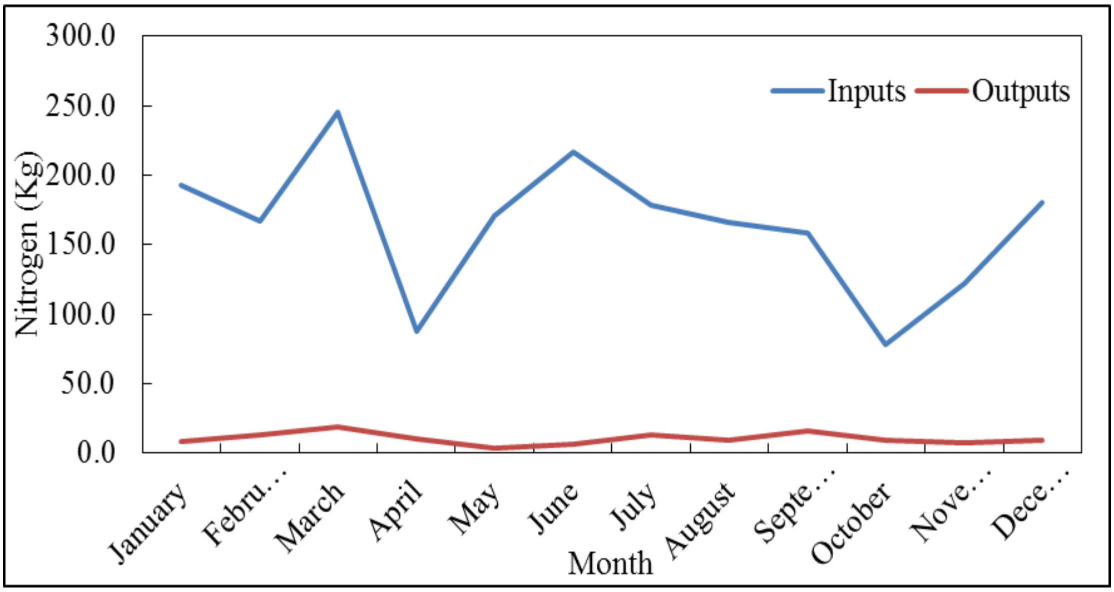

Figure 45: Monthly inputs and outputs of nitrogen from the SW-4.

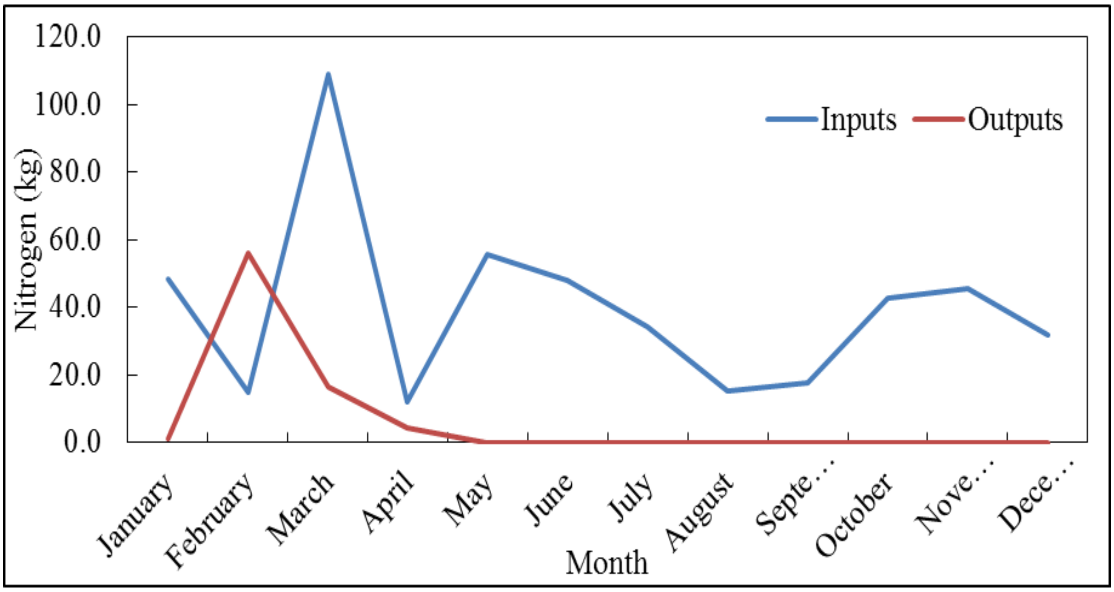

Figure 46: Monthly inputs and outputs of nitrogen from the SW-5.

P and N Retention estimates were calculated by difference of inputs and outputs, where outputs equal surface and groundwater estimated based on the water and the chloride budgets (Table 11 and 12). Retention estimate of P ranged from 53% in SW-4 to 93% for the entire Bailey Creek watershed. N Retention ranged from 45% in SW-2 to 83% in SW-5. On average, there was a 12 and 13% difference in calculated P and N retention between retention based on the water budget and retention based on the chloride budget. For the entire Bailey Creek watershed and SW-5 the chloride budget indicated a higher degree of retention for both P and N and lower for SW-2, 3 and 4. Retention of both P and N was highest in the Bailey

Creek watershed and SW-5. The lowest retention rates were in SW-2 and 4 where groundwater losses were also the highest. Comparing retention estimates based on the water and chloride budgets, we see that the chloride budget estimated higher retention rates in Bailey Creek and SW-5. For the remaining Sub-watersheds, the estimates of retention were higher using the water budget data. When comparing P and N retention estimates, P retention was on average 10% higher than N for all watersheds.

Table 11: Summary table of phosphorus inputs and outputs and retention through Bailey Creek and each.

Watershed	Phosphorus Inputs in kg					Phosphorus Outputs in kg			Retention in kg
	Atmospheric (% of total)	Irrigation (% of total)	Groundwater Seep (% of total)	Alfalfa (% of inputs)	Total Inputs	P in Surface water discharge (% of inputs)	Groundwater losses water balance (% of total inputs) / Groundwater losses chloride balance (% of total inputs)	Total outputs water balance / Total outputs Chloride balance	Water balance (% retention) / Chloride balance (% retention)
Bailey Creek	174 (17%)	490 (49%)	7 (1%)	330 (33%)	1002	71.0 (7%)	150 (14.8%)	219	780 (78%)
							0 (0%)	71	930 (93%)
2	9 (9%)	70 (68%)	NA	24 (23%)	103	18.0 (17%)	1 (1%)	19	84 (81.6)
							19 (19%)	37	66 (64%)
3	36 (8%)	230 (51%)	NA	190 (41%)	450	13.0 (2%)	94 (21%)	108	340 (76%)
							110 (24%)	119	330 (74%)
4	43 (14%)	130 (44%)	NA	125 (42%)	300	67.0 (2%)	84 (28%)	91	210 (70%)
							140 (45%)	142	160 (53%)
5	52 (100%)	0 (0%)	NA	0 (0%)	52	5.0 (9%)	5 (10%)	10	42 (81%)
							0 (0%)	5	47 (91%)

Table 12: Summary table of nitrogen inputs and outputs through Bailey Creek and each Sub-watershed.

Watershed	Nitrogen Inputs (kg)					Nitrogen Outputs (kg)			Retention (kg)
	Atmospheric (% of total)	Irrigation (% of total)	Groundwater Seep (% of total)	Alfalfa (% of inputs)	Total Inputs	In Surface water discharge (% of inputs)	Groundwater losses water balance (% of total inputs)	Total outputs water balance	Water balance (% retention)
							Groundwater losses chloride balance (% of total inputs)	Total outputs Chloride balance	Chloride balance (% retention)
Bailey Creek	1760 (26%)	2775 (41%)	85 (1%)	2090 (31%)	6706	1170 (17%)	990 (15%)	2,160	4,550 (68%)
							402 (6%)	1,570	5,140 (77%)
2	95 (15%)	375 (60%)	0 (0%)	150 (24%)	620	226 (36%)	6.2 (21%)	232	390 (62%)
							118 (24%)	344	280 (45%)
3	368 (13%)	1300 (45%)	0 (0%)	1220 (42%)	2892	383 (13%)	607 (28%)	990	1,900 (66%)
							683 (24%)	1,066	1,830 (63%)
4	434 (22%)	754 (38%)	0 (0%)	775 (39%)	1963	122 (6%)	550 (28%)	672	1,290 (66%)
							897 (45%)	1,019	940 (48%)
5	475 (100%)	0 (0%)	0 (0%)	0 (0%)	475	82.0 (17%)	47.5 (10%)	129	350 (73%)
							0 (0%)	81.6	390 (83%)

End Member Mixing Analysis

Primary contributors (end-members) to surface water discharge within the study site were groundwater flows derived from precipitation and irrigation water. The average concentrations of Cl and Na in ambient background water within the study watershed were 6.95 and 15.99 mg L^{-1}, respectively. Average concentrations of Cl and Na within irrigation water were 105 and 100 mg L^{-1}, respectively. To account for possible differences in evapoconcentration of each end-member the ratio (R) of Cl to Na was used to determine the proportion each end-member contributed to the stream discharge (Equation 5). Ratios of Na to Cl concentrations within the background water and irrigation water were 2.37 and 0.95 respectively and exhibited a 3rd order polynomial relationship with an $r^2 = 0.99$ (Appendix F). The chemistry of each end-member was analyzed to determine whether they satisfied the underlying assumptions of an EMMA. It was found that the concentrations of Cl and Na were stable over time, exhibited linear mixing within their flow-paths and the ratio of Na:Cl were distinctly different between the two end-members (Figure 47).

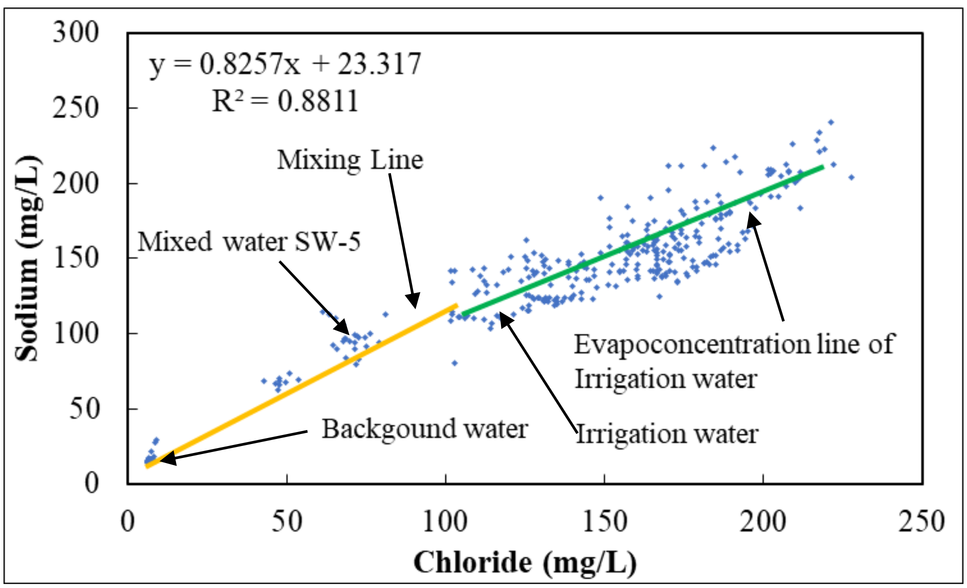

Figure 47: Plot of chloride vs sodium exhibiting a linear mixing relationship.

Average concentrations of Cl and Na in Bailey Creek were 162 and 150 mg L^{-1}, respectively. The Sub-basin concentration of Cl and Na ranged from 25 to 186 mg L^{-1} and 34 to 187 mg L^{-1}, respectively. The lowest concentrations were in SW-5 discharge water and highest in SW-4 (Table 13).

Table 13: Chloride and sodium concentrations within the study watershed.

Location	Chloride (mg/l)	Sodium (mg/l)	Ratio
	Average	Average	Na/Cl
Bailey Creek	162	150	0.93
Sub-basin 2	131	135	1.03
Sub-basin 3	173	155	0.90
Sub-basin 4	186	187	1.01
Sub-basin 5	25	34	1.36

Un-mixing the discharge waters from Bailey Creek produced on average 91% irrigation water and 9% background flow, with seasonal highs of 100% and lows of 46% irrigation water. SW-3 was on average the most dominated by irrigation water with an average of 92%, a high of 100% and a low of 41%. Sub-basins 2 and 4 showed similar composition throughout the study with averages of 62 and 68% respectively. Sub-basin 2 had a low of 11% irrigation and a high of 100%. SB-4 had a high of 100% and low 14%. Seasonally for all basins, during freshet, snowmelt runoff and higher rates of precipitation contribute more to outputs. In all cases, the proportion of irrigation in surface water discharge is highest during late summer and winter.

Background concentrations of TP were 0.05 mg L^{-1}, and 1.58 mg L^{-1} for N. Average P and N concentrations in the irrigation water averaged 0.71 and 4.04 mg L^{-1}, respectively. Based on the proportions of each end member and concentrations of Cl found in the discharge samples, potential concentrations of phosphorus and nitrogen were calculated using Equation 5 assuming conservative behavior. Average potential P concentrations in Bailey Creek were 1.11 mg L^{-1} with seasonal highs of 1.25 mg L^{-1} during the irrigation season and lows of 0.9 mg L^{-1} during the late winter (Table 14). Potential N concentrations in Bailey Creek had an average, minimum and maximum of 8.9, 5.9 and 22.5 mg L^{-1}, respectively (Table 15). Sub-Watershed 4 had the highest average potential concentrations of P and N at 1.3 and 17.8 mg L^{-1} respectively. The Sub-basin to have the lowest potential concentration of P and N was SW-5 (Table 14 and 15). Seasonally, potential concentrations of P and N were highest in the in the winter and summer months respectively.

Table 14: Potential and measured concentration of P in discharge water.

Location	Potential P (mg L^{-1})			Measured P (mg L^{-1})		
	Average	Min	Max	Average	Min	Max
Bailey Creek	1.1	0.9	1.3	0.15	0.07	0.2
SW-2	0.9	0.7	1.5	0.25	0.07	0.7
SW-3	1.2	1.0	1.3	0.11	0.03	0.3
SW-4	1.3	0.8	1.6	0.18	0.05	0.5
SW-5	0.2	0	0.6	0.03	0.0	0.5

Table 15: Potential and measured concentration of N in discharge water.

Location	Potential N (mg L^{-1})			Measured N (mg L^{-1})		
	Average	Min	Max	Average	Min	Max
Bailey Creek	8.9	5.1	22.5	3.2	0.7	9.4
SW-2	13.5	4.7	23.1	2.3	0.8	3.9
SW-3	9.2	5.8	22.6	3.0	0	5.8
SW-4	17.8	4.7	34.3	2.9	1.0	7.4
SW-5	6.0	3.2	10.3	0.8	0	3.1

Retention estimates were calculated based on the difference between the potential concentration of nutrients and the measured nutrients in the surface water flows (Table 16). To compensate for the variation in discharge rates at different times of the year, retention results were daily weighted for discharge. On average for the entire watershed, P retention was an estimated 87.5%. The highest and lowest average P retention was SW-3 with 91% and SW- 2 with 73%, respectively. Retention estimates for SW-4 and SW-5 were 86 and 89 %, respectively. June had the lowest P retention rates for all Sub-watersheds with the winter months having the highest estimated P retention. SW-2 had the largest degree of changes in retention seasonally, with much lower retention during the irrigation season.

Nitrogen retention rates were generally lower than phosphorus retention throughout the year. The average yearly retention of nitrogen for the study site was 73% (Table 16). SW-3 had the lowest N retention average of 65%, occurring during spring freshet flows. SW-2 and SW-4 both had calculated retention rates of 81%. Monthly retention rates of N were found to be highest in the winter months at all discharge locations and lowest during the late spring and summer months (Figure 48 and 49). Bailey Creek retention estimates ranged from 60% in April to 85% in November. Sub-basin 5, having no irrigation had an average N retention of 90.6%.

Table 16: Daily discharge weighted phosphorus and nitrogen retention of Bailey Creek watershed and Sub-watersheds.

Location	Retention P (%)			Retention N (%)		
	Average	Min	Max	Average	Min	Max
Bailey Creek	88	77	94	73	40	92
SW-2	7	13	91	81	40	92
SW-3	91	73	98	65	13	99
SW-4	86	56	97	81	29	93
SW-5	89	34	100	91	68	100

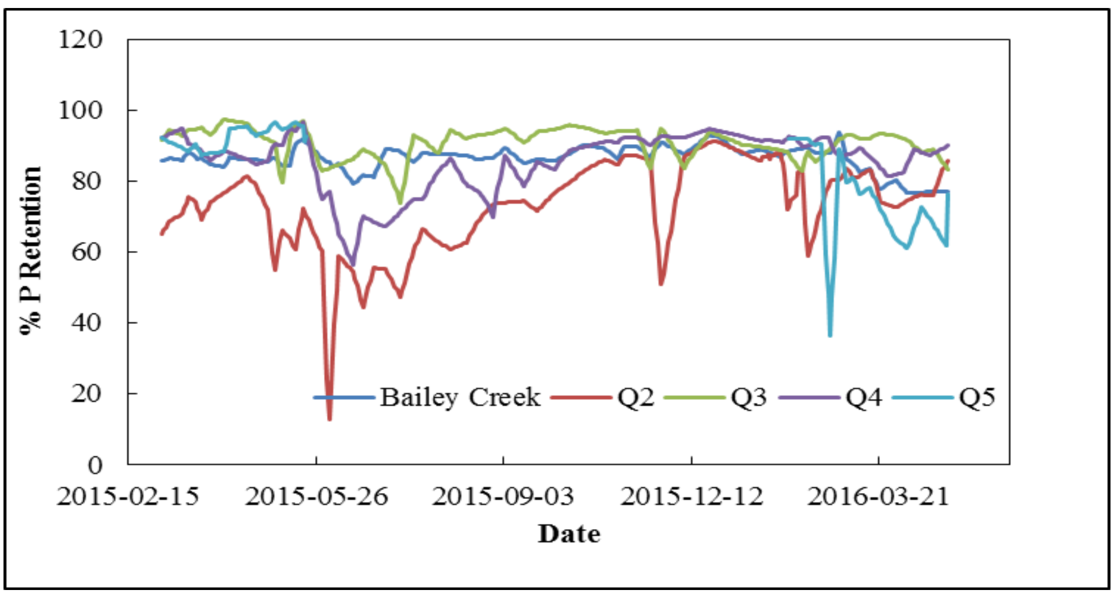

Figure 48: Plot of seasonal phosphorus retention.

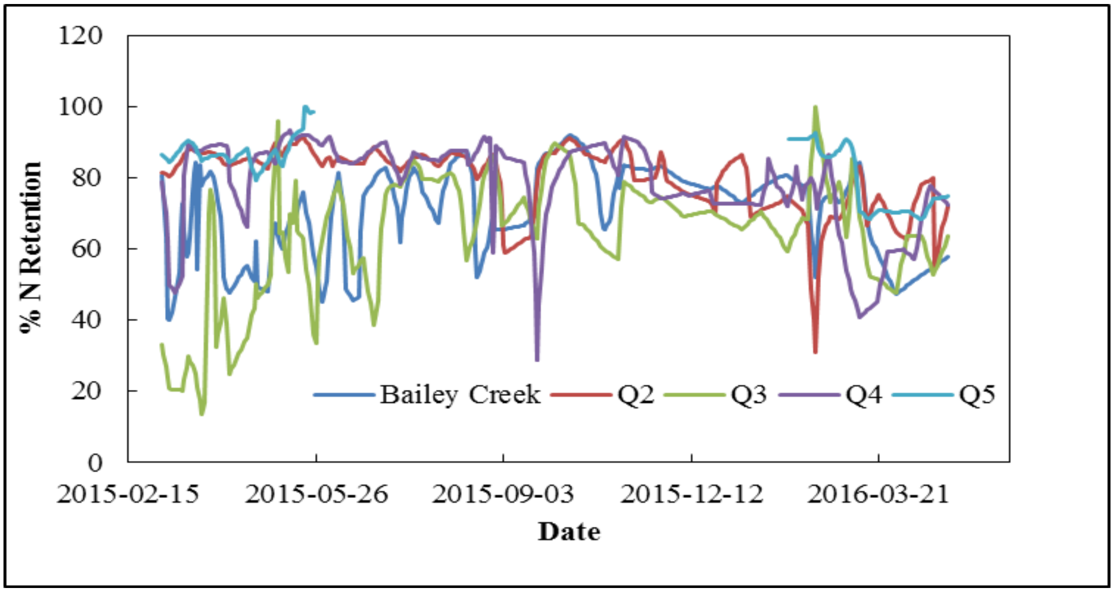

Figure 49: Plot of seasonal nitrogen retention.

Retention estimates from EMMA results were very similar to the result of the mass balance approach (Table 17). On average, the mass balance approach estimated 9% lower rates of retention than the EMMA for P and 2.8% higher for N. Seasonally, the mass balance approach calculated lower rates of P retention in the spring and most of the summer in SW-2, whereas the EMMA approach showed the same lower retention in the spring but then showed retention increasing steadily throughout the summer (Figure 48). The EMMA method indicated low retention rates of N during spring freshet in SW-3 whereas the mass balance approach did not (Figure 49). Furthermore, the mass balance method calculated large exports of both P and N in the spring in SW-5, whereas with the EMMA method the reported exports during the same time were much smaller. A possible reason for the seasonal difference between the two methods is the time lag associated with subsurface flows paths.

Table 17: Retention estimates using EMMA.

Watershed	P retention (%)		N retention (%)	
	Mass Balance	EMMA	Mass Balance	EMMA
Bailey Creek	86	88	73	71
SW-2	73	73	81	80
SW-3	75	91	65	65
SW-4	61	86	81	78
SW-5	86	89	91	83

Soil Analysis

The soils samples were analyzed for organic content, moisture content, bulk density (Appendix D) and total P concentrations (Tables 18 and 19). Soil characteristics were found to differ significantly between irrigated and non-irrigated portions of the study watershed. Moisture content and organic matter content were found to be 100% and 50% higher in irrigated soils then in non-irrigated soils, respectively, and the bulk density of irrigated soils was determined to be 33% lower than that of non-irrigated soils.

Table 18: Summary of soil characteristics.

Parameter	Location	
	Irrigated	Non-irrigated
Moisture Content (g/g)	0.1762	0.087
Organic Content (%)	3.254	2.198
Bulk Density (g/cm3)	0.751	1.129

The average phosphorus content within irrigated and non-irrigated soils was significantly different, with concentrations of 0.56 and 0.36 mg P g^{-1} of soil, respectively (Appendix D). Per ha, mass storage of phosphorus to an average depth of 0.45 m was estimated at 1920 kg ha^{-1} in irrigated soils and 1810 kg ha^{-1} in non-irrigated soils, a difference of 104 kg/ha over the course of the past 35 years of irrigation. In total, the irrigated portion of the Bailey Creek watershed had retained an additional 11,600 kg over the last 35 years. Total inputs of P over this same time period are 28,700 kg. Therefore, an estimated 40% of Phosphorus inputs for the Bailey Creek watershed have been retained within the soils over the course of the 35-year irrigation program. Of the sub-watersheds, the soil in SW-2 had the highest amount retained with an estimated 51% retention rate. SW-3 and 4 data indicated that 30 and 25% of P, respectively has been retained within the soils (Table 20). The differences in retention rate between the sub-watersheds could be the result of differences in soil characteristics and land use practices.

Table 19: Summary phosphorus data and retention within soil.

Parameter	Location	
	Irrigated	Non-irrigated
Phosphorus Concentration (mg/g)	0.566	0.364
Mass Storage of Phosphorus in top 0.45 m of soil (kg/ha)	1918	1814
Retention (kg/ irrigated ha)	104	

Table 20: Summary of phosphorus retention over the course of the irrigation program

Watershed	TP from Irrigation (kg/yr)	Alfalfa TP (kg/yr)	Total inputs (kg).	TP retention (kg/ha/yr)	TP Retention over 35 years (kg)	% retention
Bailey Creek	487	334	28735	104	11648	40.5
SW-2	69	24	3255	104	1664	51.1
SW-3	228	184	14420	104	4368	30.3
SW-4	132	125	8995	104	2288	25.4

The result of the soil analysis compared to the mass balance and EMMA results range from 20 to 60% lower. The reason for this is that the soil analysis only looks at retention occurring within the top 0.45 m of soil and does not account for retention that may take place further along the watershed flowpath, for example deeper down in the soil profile or other retention mechanisms such as retention within wetlands. Another reason for the difference in retention is the soil analysis does not take into account the differences in bulk density as a result of the irrigation program.

Chapter 5: Discussion

The objective of this study was to use a watershed approach to determine the degree to which phosphorus and nitrogen are being retained in a watershed that has been subject to wastewater irrigation for over 35 years. Retention of phosphorus and nitrogen within the Bailey Creek watershed and sub-watersheds was determined using a mass balance and an end member mixing analysis. The mass balance approach and EMMA allowed for better understanding of the seasonality of nutrient retention for each sub-watershed and how the differences between the sub-watersheds affected retention rates throughout the year. Both the mass balance and the EMMA approaches showed that SW-2 had the lowest retention rates and much of the losses of nutrients were during spring freshet and irrigation season. The larger sub-watersheds exhibited higher rates of retention and more attenuated yields of nutrient throughout the year. This suggests that smaller steeper watersheds are less suitable for wastewater irrigation from a nutrient perspective. A soil analysis was used to determine long term P retention within the irrigated soils. Although there have been several studies of nutrient retention with respect to wastewater irrigation (Barton *et al.*, 2005; Bond, 1998; Hamilton *et al*., 2007; Kardos and Hook, 1976; Schreffler, 2005), to the author's knowledge no other studies have used multiple methods within one study to determine both P and N retention, nor is there any record of chloride being used as a tracer to determine nutrient retention. The use of three different approaches to look at nutrient retention has increased the robustness of the study and shed a unique perspective on the topic. Also, unique to this study is the length of time the subject irrigation program had been in operation. Research on nutrient retention and wastewater irrigation has generally been focused on the early stages of wastewater irrigation programs, many of which have been set up specifically for a given study (i.e. months to years) (Barton et al, 2005; Kardos and Hook, 1976; Laurenson et al, 2007).

The degree to which nutrients are being retained within a watershed can be influenced by a variety of climactic variables including precipitation, temperature, vegetation, soil type and the hydrologic regime (Barton et al, 2005; Kardos and Hook, 1976; Laurenson et al, 2007). This is important when looking at the subject of wastewater irrigation primarily because a large majority of well-established wastewater irrigation programs are in hot and dry climates where water scarcity has long been a major issue (Hamilton et al., 2003, Duran-Alverez and Jimenez-

Cisneros, 2014). Consequently, many studies of nutrient retention from wastewater irrigation have also been in places where the climate is hot and dry. These study sites are often characterized by long hot summers and mild winters where growing seasons are long and irrigation can occur throughout the year (Duran-Alverez and Jimenez-Cisneros, 2014; Hamilton *et al*., 2003; Toze, 2005). This study was carried out in the interior of British Columbia, Canada where summers are often short and hot and the winters are long and cold. This difference in climate is important because of the influence that it can have on the hydrologic regime of watersheds.

The hydrological regime in the reference watershed was typical for low elevations of the BC interior (J.M Buttle *et al*., 2013; Kass, 2005). The winter was cold and much of the precipitation was in the form of snow resulting in no surface water discharge. The spring consisted of an increase in rain and warmer temperatures resulting in high freshet discharge rates as the snow was melting. The summer was hot with little precipitation, high potential evapotranspiration and no surface water discharge in the non-irrigated parts of the watershed.

Outputs of water for the Bailey Creek watershed as a whole and the reference watershed (SW-5) through groundwater flows were found to be negligible. Within the irrigated watersheds, yields of water through surface water discharge continued throughout the year and were on average 300-800% higher than the reference watershed (Table 2). A mass balance study in Chester County, Pennsylvania with very similar irrigation loadings, but double the precipitation rates, reported a 250-600% increase in streamflow which is very similar to the results in my study (Schreffler, 2005). The difference between inputs and surface water outputs in this study was explained by a 70% increase in groundwater recharge and close to double the ET (0.88 m).

The estimates of groundwater recharge in the Schreffler (2005) study were determined using a water mass balance approach. Another common approach to estimating groundwater is to use chloride as a conservative tracer (Allison and Hughes; 1978; Ator *et al*., 2011; Buttle *et al*., 2012; Cleave *et al.*, 1974; Mullaney, 1999; Wood, 1999). Using chloride to determine exports through groundwater flow involves determining the fluxes of chloride into and out of a watershed and determines groundwater losses by difference. In cases where wastewater irrigation is not occurring, and weathering sources of chloride are negligible, the primary input of chloride into a watershed is from the atmosphere (Moldan and Cerny, 1994). Research on chloride deposition indicates that chloride deposition is largely related to proximity to the ocean, nearby industrial activity and annual precipitation rates (Gustafsson, 1999). Annually, bulk atmospheric deposition within the Bailey Creek watershed was determined to be 8.1 Kg Cl ha^{-1} with the majority of the deposition occurring during the summer months (Figure 19). Similar inland deposition rates of chloride were found in Sweden (Gustafsson, 1999). However seasonally, the trends are reversed, with the highest rates of deposition recorded in the winter and fall when precipitation was greatest. One reason for the seasonal difference in Cl deposition between the Bailey Creek watershed and the result from Sweden may be an increase in aerosols containing Cl as a result of the wastewater irrigation. Alternatively, an increase in sea spray aerosols in Sweden in the winter could also be a factor. In the case where wastewater irrigation is present within a watershed, chloride loading from wastewater can easily dominate the chloride cycle because the total chloride deposition from the atmosphere is often minimal compared to inputs from the irrigation program. In my study, atmospheric deposition was found to make up 3.5%, of total Cl inputs (Table 4). Irrigation water within the Bailey Creek watershed and irrigated sub-watershed accounted for between 92 and 98% of the chloride inputs, and had chloride concentrations typical of treated wastewater in North America (EPA, 2009, Hamilton, 2007, Schreffler, 2005).

Due to the conservative nature of chloride, the outputs of chloride from a watershed are surface water discharge and groundwater flows. In watersheds that are not subject to wastewater irrigation, chloride concentrations are usually quite low. Globally, reported averages of chloride concentration in streams are between 0 - 15 mg L^{-1} (Billett and Cresser, 1994, Likens, 1977). In the US, average yields of chloride from an undisturbed watershed reported by the USGS are approximately 22 kg ha^{-1} (USGS, 2010). In cases where chloride concentrations are higher, it is most often due to sources of pollution, such as road salting, wastewater inputs, water softeners and potash based fertilizers. The chloride concentration in the surface water discharge of the reference watershed for this study, was on average 60 mg L^{-1} (Table 5), suggesting that there is some form of pollution occurring. The most likely source of pollution is groundwater originating from the wastewater reservoir. Two pieces of evidence for this are the differences between total inputs (803 kg) and outputs (3480 kg) (Table 5), and the similarity in the chloride concentration of the perennial groundwater seep down gradient (107 mg L^{-1}) and the irrigation water (105 mg L^{-1}).

Nutrient Inputs and Outputs

The natural inputs of phosphorus into the study watershed include atmospheric deposition and weathering. Atmospheric inputs were found to be on average 0.52 kg P ha $^{-1}$ (Table 6), well within the range of typical reported global averages of 0 - 1.7 Kg P ha^{-1} (Newmann 1995, Anderson, 2006., Smil, 2000; Riemersma *et al.*, 2006). As with chloride, the concentrations of P within the atmospheric samples were significantly higher during the irrigation season. The most plausible reason for this may be due to an increase in P associated with dust and some degree of localized drift from the nearby spray irrigation.

Groundwater samples in the upper reaches of the Bailey Creek watershed, representing ambient conditions, indicated natural inputs of P were negligible. Phosphorus concentrations in the wastewater irrigation for this study were found to be on average 0.71 mg L^{-1}. When compared to wastewater irrigation studies worldwide, the P levels in this study are much lower (Bond, 1998; EPA, 2009; Hamilton, 2006; Kardos, 1976). The most likely reason for this is the lower level of wastewater treatment that occurs in many of the countries that practice wastewater irrigation when compared to the tertiary treatment present in the City of Vernon.

Outputs of phosphorus from a watershed include surface water discharge and exports through groundwater. Phosphorus concentrations in surface water from non-irrigated grasslands range from 0.02-9.2 mg L^{-1} and 0.02-11.4 mg L^{-1} in irrigated watersheds, and often account for approximately 1% of inputs (Riemersma *et al*., 2006). In my study, the average yield in the non-irrigated portion was 0.046 kg ha^{-1} yr^{-1} accounting for 9% of inputs. Although the yield is within the range expected based on other research, 9% of inputs is much higher than expected. A possible reason for this is similar to the higher than normal chloride yields within the same sub-watershed originating from influences from the reservoir and nearby irrigation. Output yields in the irrigated sub-watershed ranged from 0.08 to 1 kg ha^{-1} yr^{-1} (Table 9) which is 2 to 4 times lower then reported in a similar study carried out in New Zealand (Barton, 2005). The likely reason for this is similar levels of retention but lower levels of nutrients in the wastewater in this study relative to others.

In cases where increased amounts of phosphorus is found to leave the watershed, it is often strongly associated with increased rates of erosion during freshet (Baker, 2005; Carpenter, 1998; McClain, 1998; McDowell, 2005). In my study, only the concentrations of dissolved phosphorus and not particulate P in the discharge water were seen to increase during times of higher discharge, suggesting that erosion is not a significant loss mechanism from the Bailey Creek watershed. The lowest concentrations were found during the winter when the stream discharge was also at its lowest levels.

Yearly atmospheric deposition of nitrogen into the study site (5.3 Kg N ha^{-1}) (Table 7) was found to be slightly higher than other available records for Interior BC (2-5 Kg N $ha^{-1}y^{-1}$ (Eickhout et al. 2006), but well within the range of global estimates (Bessy, 2006). Similar to chloride and phosphorus, the concentration of nitrogen within the atmospheric samples was four times higher during irrigation season then during the winter months, indicating possible influence from irrigation. Atmospheric inputs of N accounted for an estimated 26% of total inputs to the study Bailey Creek watershed.

The nitrogen concentrations measured within the wastewater irrigation for this study were found to be well within the range of reported averages of wastewater in developed countries (Barton et al., 2005; Laurenson et al., 2007).

Concentrations of N within the discharge waters of the sub-watersheds and Bailey Creek were highest during spring freshet and remain higher throughout the irrigation season. Similarly, to P, the lowest N concentrations were recorded through the winter months. As with P, yields of N through surface water were seen to increase with irrigation (Figure 35). In soils that are subject to both irrigation and fertilizer application (Carpenter, 1998, Mueller *et al*., 2012).

Retention

Based on the mass balance data the retention of P within the non-irrigated watershed ranged from 81-91%. Nitrogen retention in this same sub-watershed ranged from 73-83%. These estimates of retention are lower than what would be expected based on other research which suggests that retention rates are often as high as 99% (Likens, 2010; Moldan and Cerny, 1994; Riemersma *et al*., 2006). These lower than expected retention rates in the non-irrigated watershed could be the result of influences from the adjacent McKay reservoir and potentially the nearby irrigation program in the other sub-watershed. The chloride budget of SW-5 indicate that there is a certain amount of sub-surface seepage coming from the reservoir entering SW-5. It is plausible that nutrient is also entering the SW-5 in the same way and find its way to the surface water discharge of SW-5 resulting in an increase in output, and therefore lowering the retention estimates.

Retention estimates using the mass balance approach in the irrigated watersheds ranged from 78-93% and 68-77% of P and N, respectively (Table 10 and 11). These results are comparable to a mass balance study that was completed in a watershed in Michigan with similar wastewater irrigation rates (5cm/week) (Barton and Hook, 1976), where 96.5% of P was retained within the watershed. In the same study, when irrigation rates were doubled, retention of P was reduced to 66%, suggesting that rate of irrigation is an important variable influencing retention. Another factor influencing P retention is soil type (Barton *et al*., 2005). In similar soils to the current study, P retention was also similar, estimated at over 90% (Barton *et al*., 2005), even though the effluent had approximately 3 times higher concentrations of both P and N. This suggests that if the irrigation rates remained the same, the watershed in my study could potentially continue to retain a high percentage of nutrients even if there was an increase in nutrient concentration. Overall, the mass balance approach for determining nutrient retention allowed for the use of seasonal weather and discharge data to determine monthly inputs and outputs of water, chloride, phosphorus, and nitrogen as they moved through the watershed. It also allows for supplemental nutrients, such as the nutrients from imported feed to be included in the overall watershed budget.

In contrast to the mass balance approach the EMMA approach uses exclusively the chemical composition of the water to determine nutrient retention based on the concentration of chloride as a conservative tracer and the relative concentrations of nutrients in different portions of the stream water. Traditionally, an EMMA has been used as a technique to identify the main source components of stream runoff (Mulholland, 1993). In this study, an EMMA (equation 5) was useful to determine the portion of the mixed stream that was from irrigation and what proportion was a result of background flows. As a result of this analysis, it was determined that an average of 94% (Figure 46) of stream flow in the Bailey Creek watershed and the irrigated sub-watersheds is derived from wastewater irrigation, which agrees with the results from the mass balance approach.

The original version of the EMMA suggests that linear mixing of two elements within a watershed indicates that both elements are acting conservatively (Hooper and Christopherson, 1990). This principle has been well established and is most often used as a way to characterize stormflow events, effluent flows and groundwater recharge (Burns *et al*., 2001; Kirchner *et al*., 2010; Vulava *et al*., 2008). In the case of my study it was a useful tool to determine retention of non-conservative substances (Jarvie *et al.,* 2011).

Based on the difference between the potential and measured concentrations of P and N principles, it was determined that the retention rates of P and N were 86 and 71% (Table 15), respectively. These results are on average very close to the mass balance results (Table 16) with the exception of SW-4. For SW-4 the EMMA indicated on average of 20% more retention for P and N than from the mass balance approach. One reason for this may be the high percentage of groundwater exports from the sub-watershed. Seasonally, the results of the EMMA agreed with the mass balance results which show the lowest retention during the irrigation season and highest retention during the winter months.

Using both the results of the mass balance and the EMMA, SW-2 has on average 10 – 15 % lower retention then the other sub-watersheds within the study. There are a number of factors that may be resulting in the lower retention. One reason is that, SW-2 is most intensively irrigated sub-watershed with the steepest grade, resulting in the shortest potential transit time for the water to get from the irrigation outlet to the discharge point and retention is a function of residence time. Another likely reason is that fact that SW-2 is subject to the highest rate nutrient loading from both irrigation inputs and the importing of nutrient from feed.

Unlike the mass balance and the EMMA approaches, the soil analysis was not used to determine seasonal or real-time retention, but rather used to determine long term accumulation of P within the soil to estimate long term retention. Retention estimates were based on the comparison between irrigated and non-irrigated regions of the watershed. Like the mass balance method, inputs of nutrient from feed were included in the final retention estimates. However, with the soil analysis it was assumed that the current year's nutrient input estimates are representative of the average year over the past 35 years. Due to unknown rates of denitrification, the long-term accumulation of N within the soil was not included in this study.

The inclusion of the soil analysis in this study gave insight into some of the changes in the soil structure and composition from irrigation that may have contributed to the overall retention of P over time. The inputs of wastewater led to an apparent increase in productivity, soil organic matter and a decrease in soil bulk density. The soil analysis for this study determined an increase in P storage of 32% in irrigated soils over non-irrigated soils, less than half of the 68% increases of P concentration at similar depths in silty sand soils in Israel (Lin *et al*,. 2005). Likely reasons for this difference could include different P concentration within the wastewater due to different levels of treatment and much higher loading rate of wastewater to the study site (6 meters per year for 82 months).

Another factor found to influence P concentrations in wastewater irrigated soils is soil type. Four different soils within a New Zealand watershed with some land use and climate similarities to my study were irrigated with wastewater. It was found that the silt and clay soils retained higher levels of P then course sandy soils. In the soils most closely comparable to this study, similar increases were reported (38%) (Barton, 2005). Retention of P in soils generally occurs in the first few years then ultimately reaches equilibrium resulting in a decrease in retention in the later years (Ishkandar and Syers, 1980; Lin and Banin, 2005; Quin and Woods, 1978). It is speculated that the reason for this is due to the finite locations within the soil that permit absorption and precipitation.

From the results in this study, it is estimated that 11,650 kg P has been retained over the course of the 35-year irrigation program. This is equivalent to 40% of total phosphorus inputs during this same period. Although the soil data do not allow us to speculate on the degree to which the soils are retaining the yearly inputs of nutrient, we do know based on the result of the mass balance approach and the EMMA, that retention is still occurring after 35 years of irrigation. This ongoing retention is most likely as a result of the continued retention in soils and alternative sinks for the nutrients within a watershed such as wetlands and deeper sub-surface processes (Saunders, 2001; Reddy, 1999; Quin and Forsythe, 1978).

Chapter 6: Conclusion and Potential Future Work.

As water becomes increasingly scarce, understanding the value of wastewater and nutrient management will become more important. I set out to use three different approaches to quantify nutrient retention in a wastewater-irrigated watershed. The results show that a large proportion of the nutrients introduced into the watershed by wastewater irrigation are being retained after 35 years of wastewater irrigation. If managed properly, wastewater irrigation can enhance agricultural production as well as potentially protecting receiving surface water bodies from excess nutrient loading. In the case of the City of Vernon, an estimated 99.7% of phosphorus and 97.8% of the nitrogen that enters the wastewater treatment plant is retained, while irrigating over 970 ha. Of the Sub-watersheds, the flatter sub-watersheds with increased storage via wetlands and or ponds will potentially have higher retention rates then smaller steeper watersheds with less storage.

Understanding retention of nutrients in watersheds irrigated with wastewater is important in developing effective wastewater irrigation programs in to the future. Each of the three methods used in this study, has its merits. The mass balance is straight forward, but requires extensive site-specific field work and data to establish a tight water balance and subsequent nutrient balance. EMMA has potential to be a useful inexpensive tool to improve the understanding of a wastewater irrigation program without an extensive research program. The introduction of wastewater into a watershed, results in a new distinct end member that allows for estimates of retention on a sample by sample basis. Finally, the soil analysis approach can be useful in determining where some of the retention is occurring within the watershed.

Although this study and many other studies indicate that wastewater irrigation can be an integral part of water reuse and help solve the problem of nutrient loading to aquatic environments, there are still gaps in our understand regarding sustainable wastewater irrigation. In order to design sustainable wastewater irrigation programs there needs to be more research carried out that seeks to understand the influences the wastewater irrigation has on small catchment hydrology. My results indicate the hydrologic regime within the study watershed has been completely altered by irrigation. There are wetlands now present that would not be present naturally. Stream flow that is naturally confined to spring is extended throughout the year by irrigation. These changes to a watershed could result in both positive and negative impacts to stakeholders within and downstream of the proposed irrigation program. Positive impact could include increased land value, while negative impact may include water management issues associated with increases in water flows. Currently there is little research focused on these long-term effects.

Another gap in scientific understanding is around the use of conservative tracers as a way to determine nutrient retention. The use of conservative tracers proved to be a useful tool in this study and has the potential to further improve our understanding of nutrient retention by helping to better understand potential losses through different hydrologic flow paths.

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Appendices

Appendix A: Weather Data

Table A1: Weather station data

Date	Daily Precipitation (mm)	Daily Average wind U30 station (m/s)	MOT Wind speed m/s	T min	T max	T ave	Daily RH %	VPD	SR net (Rns-Rnl)	Slope Vapour Press	Daily ET Calculation (Saturated Soil) (mm)	Daily ET Calculation (Non-Saturated) (mm)
2015-02-13	0	0.15	1.40	4.61	6.10	5.36	88.34	0.10	2.01	0.06	0.41	0.21
2015-02-14	0	0.48	1.42	0.66	13.31	6.98	76.41	0.19	1.64	0.05	0.51	0.42
2015-02-15	0	0.32	1.70	-2.57	8.59	3.01	79.84	0.19	2.16	0.06	0.61	0.47
2015-02-16	0	0.32	1.97	-4.11	5.44	0.67	87.05	0.13	2.53	0.07	0.60	0.31
2015-02-17	0	0.23	1.63	-5.67	4.30	-0.68	87.54	0.13	2.63	0.08	0.61	0.29
2015-02-18	0	0.31	1.64	-4.65	3.67	-0.49	87.60	0.13	2.43	0.07	0.58	0.42
2015-02-19	0	0.17	1.52	-3.57	4.69	0.56	85.50	0.14	2.29	0.07	0.56	0.64
2015-02-20	0.4	0.78	1.40	0.14	9.46	4.80	73.98	0.22	1.85	0.06	0.64	0.87
2015-02-21	0	1.12	2.76	-4.23	8.79	2.28	57.88	0.40	1.80	0.07	1.28	0.78
2015-02-22	0	0.19	1.40	-5.51	5.31	-0.10	69.01	0.32	2.31	0.07	0.77	0.55
2015-02-23	0	0.29	0.90	-4.65	7.67	1.51	71.55	0.28	2.20	0.07	0.63	0.68
2015-02-24	0	0.35	1.48	-1.67	8.42	3.37	68.93	0.28	1.98	0.06	0.70	0.63
2015-02-25	0	0.39	1.56	-3.45	9.51	3.03	66.83	0.31	1.85	0.06	0.74	1.95
2015-02-26	0	0.28	2.03	-2.86	5.28	1.21	69.59	0.29	2.19	0.07	0.84	2.42
2015-02-27	0	2.17	2.86	0.66	8.32	4.49	68.91	0.27	1.87	0.06	1.06	1.04
2015-02-28	0	1.66	2.07	-4.05	6.46	1.21	53.91	0.45	1.71	0.07	1.36	2.04
2015-03-01	0	0.25	1.53	-4.02	4.30	0.14	64.25	0.36	4.27	0.07	1.18	1.83
2015-03-02	0	1.38	1.75	-2.74	6.15	1.71	63.72	0.35	3.84	0.07	1.30	1.31
2015-03-03	0	0.93	2.02	-7.16	3.12	-2.02	43.87	0.62	5.82	0.08	2.15	1.90
2015-03-04	0	0.46	2.09	-7.58	4.45	-1.56	49.82	0.55	5.53	0.08	1.86	1.20
2015-03-05	0	0.22	1.27	-4.83	7.32	1.24	59.52	0.40	5.01	0.07	1.28	1.12

Date	Daily Precipitation (mm)	Daily Average wind U30 station (m/s)	MOT Wind speed m/s	T min	T max	T ave	Daily RH %	VPD	SR net (Rns-Rnl)	Slope Vapour Press	Daily ET Calculation (Saturated Soil) (mm)	Daily ET Calculation (Non-Saturated) (mm)
2015-03-06	0	0.38	1.86	-0.51	11.78	5.64	62.68	0.31	4.62	0.06	1.17	0.68
2015-03-07	0	0.35	1.42	-0.42	14.22	6.90	68.14	0.26	4.54	0.05	0.99	0.86
2015-03-08	0	0.38	1.61	-2.02	13.91	5.95	72.47	0.23	5.40	0.06	1.11	0.81
2015-03-09	0	0.93	1.80	-0.73	17.11	8.19	62.25	0.30	4.99	0.05	1.23	0.93
2015-03-10	0	0.59	1.84	0.77	14.46	7.61	62.91	0.29	5.14	0.05	1.21	1.82
2015-03-11	0	0.67	2.26	5.28	16.70	10.99	61.10	0.27	4.01	0.05	1.06	1.53
2015-03-12	0	2.17	3.58	4.97	14.48	9.73	56.87	0.31	3.54	0.05	1.45	2.18
2015-03-13	0	0.74	2.24	3.04	16.03	9.54	63.49	0.27	4.72	0.05	1.15	1.56
2015-03-14	0	2.84	3.15	8.79	17.46	13.13	52.84	0.31	3.94	0.04	1.46	0.88
2015-03-15	2	0.56	1.79	3.35	9.46	6.41	66.88	0.27	3.30	0.06	0.92	1.08
2015-03-16	0	0.83	1.67	0.66	11.25	5.95	56.84	0.36	5.20	0.06	1.36	2.09
2015-03-17	0	1.06	1.87	1.10	12.07	6.59	67.04	0.27	5.33	0.05	1.25	1.75
2015-03-18	0	1.81	3.20	3.17	14.79	8.98	53.93	0.35	5.04	0.05	1.63	1.26
2015-03-19	0	1.23	2.86	5.49	11.57	8.53	73.79	0.20	3.51	0.05	0.93	0.78
2015-03-20	2.2	0.18	1.87	4.87	9.56	7.21	88.17	0.09	3.26	0.05	0.58	0.49
2015-03-21	6	1.37	2.81	4.14	12.73	8.43	76.41	0.18	4.12	0.05	0.95	0.76
2015-03-22	0	0.96	2.36	0.47	12.34	6.40	68.24	0.26	5.52	0.06	1.29	0.99
2015-03-23	0	0.90	1.77	2.29	14.36	8.33	66.67	0.26	5.22	0.05	1.16	0.85
2015-03-24	6.6	0.84	1.93	3.20	10.61	6.90	77.73	0.18	4.82	0.05	0.97	0.41
2015-03-25	12.8	0.62	1.97	1.81	6.38	4.09	85.36	0.13	3.15	0.06	0.68	0.42
2015-03-26	0.6	0.11	2.72	3.59	8.72	6.15	88.84	0.09	3.40	0.06	0.62	0.69
2015-03-27	0	0.40	2.21	5.95	16.03	10.99	84.71	0.11	5.00	0.05	0.78	0.90
2015-03-28	0	3.05	4.36	8.62	16.77	12.70	51.77	0.32	4.02	0.04	1.64	1.44
2015-03-29	0	1.82	3.26	5.59	13.95	9.77	62.06	0.27	3.89	0.05	1.28	1.78

Date	Daily Precipitation (mm)	Daily Average wind U30 station (m/s)	MOT Wind speed m/s	T min	T max	T ave	Daily RH %	VPD	SR net (Rns-Rnl)	Slope Vapour Press	Daily ET Calculation (Saturated Soil) (mm)	Daily ET Calculation (Non-Saturated) (mm)
2015-03-30	0	0.52	2.69	7.37	18.68	13.02	72.99	0.18	4.78	0.04	0.91	1.00
2015-03-31	0.2	2.43	2.95	1.70	13.31	7.50	67.04	0.26	5.55	0.05	1.44	1.52
2015-04-01	0.4	1.16	2.81	1.13	10.76	5.94	63.82	0.30	7.98	0.06	1.75	1.69
2015-04-02	0	1.45	2.49	-1.07	11.78	5.36	58.88	0.35	8.33	0.06	1.94	1.84
2015-04-03	0.8	1.20	2.71	0.50	12.22	6.36	60.66	0.32	7.97	0.06	1.80	1.37
2015-04-04	0.2	0.94	1.91	0.27	11.08	5.68	64.86	0.29	8.12	0.06	1.66	1.72
2015-04-05	0	0.98	2.83	-2.57	13.19	5.31	56.32	0.38	9.87	0.06	2.19	2.12
2015-04-06	0	1.35	2.73	1.02	14.29	7.65	49.10	0.40	9.48	0.05	2.18	1.59
2015-04-07	0	1.05	2.12	-0.09	12.97	6.44	64.12	0.30	9.17	0.06	1.81	1.34
2015-04-08	0	0.75	2.22	-1.67	16.49	7.41	57.69	0.35	10.23	0.05	2.01	2.00
2015-04-09	0	1.10	2.72	-1.24	17.84	8.30	48.53	0.41	10.10	0.05	2.22	1.79
2015-04-10	0	1.46	2.59	2.82	14.39	8.60	60.52	0.30	7.48	0.05	1.65	1.68
2015-04-11	0	3.90	2.47	4.69	11.93	8.31	42.63	0.43	9.15	0.05	2.49	2.14
2015-04-12	0	3.00	2.35	3.41	11.35	7.38	40.95	0.46	9.26	0.05	2.50	3.31
2015-04-13	0	1.47	2.38	3.83	13.02	8.42	58.87	0.31	6.64	0.05	1.58	2.38
2015-04-14	0.2	2.29	3.47	3.93	12.63	8.28	48.86	0.39	8.08	0.05	2.16	1.99
2015-04-15	0	1.76	3.01	0.16	14.94	7.55	50.06	0.40	10.1	0.05	2.31	1.80
2015-04-16	0	0.65	1.84	0.47	17.77	9.12	60.01	0.31	10.2	0.05	1.82	1.66
2015-04-17	0	1.38	2.25	1.24	21.32	11.28	59.73	0.29	8.32	0.05	1.63	1.08
2015-04-18	0	1.47	1.87	4.38	17.53	10.96	38.01	0.44	10.0	0.05	2.15	1.47
2015-04-19	0	0.71	2.31	2.66	19.98	11.32	51.07	0.35	10.2	0.05	1.91	1.49
2015-04-20	0	0.64	2.22	2.96	23.11	13.03	53.72	0.32	10.0	0.04	1.76	2.06
2015-04-21	0	1.32	3.03	6.20	24.46	15.33	52.17	0.30	9.43	0.04	1.73	1.76
2015-04-22	0	2.27	3.50	3.12	13.76	8.44	51.52	0.37	9.17	0.05	2.19	2.05

Date	Daily Precipitation (mm)	Daily Average wind U30 station (m/s)	MOT Wind speed m/s	T min	T max	T ave	Daily RH %	VPD	SR net (Rns-Rnl)	Slope Vapour Press	Daily ET Calculation (Saturated Soil) (mm)	Daily ET Calculation (Non-Saturated) (mm)
2015-04-23	0.4	1.40	2.38	0.33	14.24	7.29	57.55	0.34	9.42	0.05	1.98	1.55
2015-04-24	1	1.44	2.49	2.58	10.27	6.43	75.53	0.20	9.23	0.06	1.61	0.78
2015-04-25	0.2	0.68	1.79	1.56	9.81	5.68	79.19	0.17	7.67	0.06	1.34	0.91
2015-04-26	0	1.03	2.15	1.75	16.44	9.10	62.56	0.28	10.5	0.05	1.86	1.79
2015-04-27	0	1.34	2.37	4.40	17.70	11.05	53.57	0.33	8.16	0.05	1.71	1.83
2015-04-28	0	1.99	3.11	4.19	23.71	13.95	56.32	0.29	9.13	0.04	1.75	1.65
2015-04-29	0	3.13	2.15	6.74	16.77	11.76	41.80	0.40	9.50	0.04	2.21	2.83
2015-04-30	0	3.09	2.37	7.87	16.39	12.13	45.80	0.36	7.66	0.04	1.94	2.56
2015-05-01	0	3.11	3.11	8.87	19.25	14.06	45.20	0.35	10.6	0.04	2.16	1.37
2015-05-02	0	1.60	2.58	2.53	15.72	9.13	43.64	0.42	10.5	0.05	2.33	2.06
2015-05-03	0	0.67	2.24	0.33	19.41	9.87	45.35	0.41	12.6	0.05	2.35	3.14
2015-05-04	0.6	1.50	3.06	3.35	23.04	13.20	48.13	0.35	11.5	0.04	2.14	1.97
2015-05-05	2	3.03	3.08	5.90	16.27	11.09	56.12	0.31	11.9	0.05	2.17	0.98
2015-05-06	1.4	0.77	1.65	4.56	14.36	9.46	67.31	0.24	8.95	0.05	1.53	1.03
2015-05-07	0	0.87	2.14	-0.06	19.32	9.63	57.64	0.32	13.7	0.05	2.28	1.40
2015-05-08	0	1.14	2.53	2.88	21.32	12.10	42.22	0.40	13.5	0.04	2.43	1.71
2015-05-09	0	0.84	2.53	2.85	23.88	13.37	38.70	0.42	12.5	0.04	2.29	1.89
2015-05-10	0	1.11	2.28	7.95	25.50	16.72	38.89	0.37	12.40	0.04	2.05	2.02
2015-05-11	0	1.40	3.09	8.72	25.09	16.90	34.70	0.39	12.18	0.04	2.20	2.13
2015-05-12	0	1.95	3.78	6.74	22.13	14.43	43.89	0.36	11.82	0.04	2.25	1.81
2015-05-13	0	1.37	3.27	7.32	20.41	13.87	59.13	0.26	8.28	0.04	1.56	0.98
2015-05-14	0	1.28	2.36	8.22	20.08	14.15	64.11	0.23	11.56	0.04	1.70	0.78
2015-05-15	0	0.79	2.11	5.39	24.05	14.72	57.20	0.27	13.56	0.04	1.96	0.80
2015-05-16	0	0.97	2.07	7.42	26.11	16.76	51.55	0.29	13.28	0.04	1.91	0.86

Date	Daily Precipitation (mm)	Daily Average wind U30 station (m/s)	MOT Wind speed m/s	T min	T max	T ave	Daily RH %	VPD	SR net (Rns-Rnl)	Slope Vapour Press	Daily ET Calculation (Saturated Soil) (mm)	Daily ET Calculation (Non-Saturated) (mm)
2015-05-17	9.6	0.60	2.33	11.20	17.61	14.40	83.22	0.10	7.12	0.04	0.94	0.30
2015-05-18	0	0.80	1.92	10.35	25.28	17.81	65.73	0.20	12.60	0.03	1.57	0.61
2015-05-19	0	0.68	2.29	7.72	27.75	17.74	54.66	0.27	13.64	0.03	1.84	0.79
2015-05-20	0	0.98	2.39	10.03	28.52	19.27	42.68	0.32	12.85	0.03	1.89	0.93
2015-05-21	0	0.66	2.12	10.35	29.82	20.08	43.62	0.31	12.66	0.03	1.77	0.92
2015-05-22	0	1.03	2.08	10.49	30.47	20.48	44.33	0.30	11.86	0.03	1.70	0.95
2015-05-23	0	1.01	2.38	13.23	28.47	20.85	47.33	0.27	10.47	0.03	1.54	0.78
2015-05-24	9.6	1.04	2.88	10.88	17.72	14.30	79.03	0.13	6.18	0.04	0.93	0.24
2015-05-25	2.8	0.52	1.61	9.49	21.89	15.69	72.39	0.17	13.54	0.04	1.68	0.25
2015-05-26	2.4	0.29	1.39	12.10	22.49	17.29	78.86	0.12	9.23	0.04	1.12	0.24
2015-05-27	0	0.33	1.56	9.83	26.45	18.14	68.60	0.18	12.37	0.03	1.50	0.55
2015-05-28	0	0.63	1.89	10.03	27.63	18.83	63.29	0.21	12.19	0.03	1.52	0.80
2015-05-29	8.8	1.21	2.99	11.90	26.01	18.96	71.00	0.16	10.27	0.03	1.27	0.47
2015-05-30	0	1.06	2.90	10.83	25.77	18.30	69.27	0.17	12.23	0.03	1.49	0.48
2015-05-31	0	0.42	1.56	7.62	26.33	16.97	54.25	0.27	12.51	0.04	1.72	1.18
2015-06-01	0	1.26	2.97	14.07	28.05	21.06	58.95	0.21	11.20	0.03	1.46	0.99
2015-06-02	12	1.19	2.49	12.05	16.23	14.14	86.38	0.08	5.83	0.04	0.77	0.50
2015-06-03	3.2	2.26	4.02	11.20	14.72	12.96	82.95	0.11	7.71	0.04	1.04	0.28
2015-06-04	1.2	0.98	1.85	11.05	21.60	16.33	84.12	0.09	9.26	0.04	1.08	0.19
2015-06-05	0	0.37	1.95	9.11	27.36	18.24	69.48	0.17	14.92	0.03	1.72	0.35
2015-06-06	0	0.42	2.09	10.42	30.37	20.39	62.07	0.20	14.07	0.03	1.63	0.73
2015-06-07	0	0.36	1.92	12.46	32.59	22.52	59.42	0.21	14.15	0.03	1.56	0.74
2015-06-08	0	1.90	2.88	17.94	34.52	26.23	35.82	0.29	13.25	0.03	1.74	0.66
2015-06-09	0	0.91	2.23	15.44	31.15	23.30	41.03	0.29	13.70	0.03	1.73	1.51

Date	Daily Precipitation (mm)	Daily Average wind U30 station (m/s)	MOT Wind speed m/s	T min	T max	T ave	Daily RH %	VPD	SR net (Rns-Rnl)	Slope Vapour Press	Daily ET Calculation (Saturated Soil) (mm)	Daily ET Calculation (Non-Saturated) (mm)
2015-06-10	0	0.84	2.12	11.66	31.64	21.65	44.54	0.29	13.81	0.03	1.79	1.66
2015-06-11	0	3.52	3.15	16.84	27.09	21.97	33.24	0.33	12.39	0.03	2.07	1.22
2015-06-12	1.4	1.84	3.29	9.66	16.89	13.27	58.85	0.26	7.92	0.04	1.58	0.86
2015-06-13	0	0.76	2.00	5.26	23.02	14.14	56.17	0.29	14.44	0.04	2.08	0.97
2015-06-14	0	0.86	2.57	6.05	25.26	15.65	54.78	0.28	14.97	0.04	2.10	0.92
2015-06-15	0	0.68	2.17	7.24	28.74	17.99	49.93	0.29	15.23	0.03	2.03	0.99
2015-06-16	0	0.97	1.98	9.49	30.57	20.03	42.89	0.31	13.90	0.03	1.90	1.17
2015-06-17	0	1.17	2.34	14.98	29.72	22.35	33.08	0.33	12.17	0.03	1.80	1.56
2015-06-18	0	1.38	2.87	13.43	26.89	20.16	48.18	0.27	12.02	0.03	1.73	1.25
2015-06-19	0	2.15	3.79	11.35	24.24	17.79	42.78	0.32	14.04	0.03	2.21	0.91
2015-06-20	0.2	0.90	1.96	8.92	23.76	16.34	61.97	0.23	12.64	0.04	1.70	0.69
2015-06-21	0	0.79	2.15	6.56	25.04	15.80	59.45	0.25	15.10	0.04	2.01	0.75
2015-06-22	0	0.81	2.61	7.04	29.24	18.14	50.74	0.29	14.04	0.03	1.95	0.88
2015-06-23	0.4	0.50	2.16	13.45	27.58	20.51	58.45	0.22	12.59	0.03	1.53	0.65
2015-06-24	0	1.10	2.65	13.55	29.14	21.34	47.47	0.27	11.66	0.03	1.63	0.51
2015-06-25	0	0.68	1.83	13.69	32.46	23.07	45.60	0.27	12.04	0.03	1.52	0.41
2015-06-26	0	0.47	1.60	15.63	35.56	25.59	44.44	0.26	13.61	0.03	1.51	0.51
2015-06-27	0	0.46	2.24	14.53	39.52	27.02	41.65	0.27	12.85	0.02	1.49	0.59
2015-06-28	0	0.69	2.55	17.37	39.77	28.57	36.93	0.27	11.67	0.02	1.43	0.60
2015-06-29	5.2	0.78	2.41	16.37	28.07	22.22	71.66	0.14	8.07	0.03	0.97	0.46
2015-06-30	0	0.91	2.81	14.55	32.12	23.34	62.46	0.18	12.57	0.03	1.40	0.51
2015-07-01	0	1.10	2.63	16.63	31.10	23.87	56.37	0.21	13.48	0.03	1.51	0.53
2015-07-02	0	0.76	2.45	14.86	35.85	25.36	51.62	0.23	13.07	0.03	1.48	0.80
2015-07-03	0	0.88	2.59	15.84	35.82	25.83	42.05	0.26	12.16	0.03	1.53	0.81

Date	Daily Precipitation (mm)	Daily Average wind U30 station (m/s)	MOT Wind speed m/s	T min	T max	T ave	Daily RH %	VPD	SR net (Rns-Rnl)	Slope Vapour Press	Daily ET Calculation (Saturated Soil) (mm)	Daily ET Calculation (Non-Saturated) (mm)
2015-07-04	0	1.83	2.67	14.98	32.07	23.53	29.92	0.34	12.47	0.03	1.91	0.66
2015-07-05	0	0.87	2.22	13.55	31.74	22.64	32.48	0.34	12.99	0.03	1.82	0.70
2015-07-06	0	0.35	2.00	13.19	33.08	23.13	40.95	0.29	11.23	0.03	1.49	0.65
2015-07-07	0	0.77	2.49	14.77	34.81	24.79	39.15	0.29	12.29	0.03	1.61	0.44
2015-07-08	0	0.48	1.95	14.82	36.61	25.71	38.02	0.29	12.22	0.03	1.50	0.50
2015-07-09	0	0.36	1.81	16.51	38.31	27.41	40.17	0.26	11.12	0.02	1.31	0.64
2015-07-10	0	0.75	1.87	17.89	34.05	25.97	44.58	0.25	8.46	0.03	1.16	0.95
2015-07-11	0	1.35	2.85	16.89	28.74	22.82	61.43	0.19	8.81	0.03	1.18	0.75
2015-07-12	0.4	1.87	3.10	15.46	26.87	21.16	56.50	0.22	11.32	0.03	1.52	0.63
2015-07-13	0	1.25	2.48	17.11	28.12	22.61	47.81	0.25	11.64	0.03	1.55	0.98
2015-07-14	0	0.65	1.90	14.75	29.99	22.37	47.24	0.26	12.32	0.03	1.55	1.54
2015-07-15	0	2.27	3.80	14.53	28.47	21.50	44.48	0.28	10.66	0.03	1.75	1.28
2015-07-16	0	2.34	2.99	12.73	24.36	18.55	41.07	0.32	10.69	0.03	1.92	0.91
2015-07-17	0	1.34	2.09	9.71	29.69	19.70	42.33	0.32	12.68	0.03	1.86	0.56
2015-07-18	0	0.55	1.69	12.78	31.00	21.89	47.07	0.27	11.52	0.03	1.49	1.09
2015-07-19	0.2	0.41	1.85	14.65	35.80	25.22	50.45	0.23	11.46	0.03	1.33	1.33
2015-07-20	0	2.46	4.52	16.42	35.29	25.85	44.54	0.25	11.46	0.03	1.64	1.03
2015-07-21	0	2.31	3.91	16.42	27.43	21.92	34.32	0.33	10.35	0.03	1.90	0.96
2015-07-22	0	1.06	2.70	13.86	27.01	20.44	47.74	0.27	10.99	0.03	1.62	0.98
2015-07-23	0	0.78	2.10	12.97	28.84	20.90	48.97	0.27	10.47	0.03	1.48	1.23
2015-07-24	0.4	1.62	3.85	15.94	23.04	19.49	58.17	0.22	7.89	0.03	1.34	0.80
2015-07-25	13	1.28	3.00	13.33	23.95	18.64	68.83	0.17	9.25	0.03	1.24	0.43
2015-07-26	1	0.86	2.14	10.88	21.13	16.01	67.60	0.19	8.87	0.04	1.28	0.61
2015-07-27	0	0.57	1.54	10.17	24.94	17.56	59.24	0.23	12.60	0.04	1.64	0.76

Date	Daily Precipitation (mm)	Daily Average wind U30 station (m/s)	MOT Wind speed m/s	T min	T max	T ave	Daily RH %	VPD	SR net (Rns-Rnl)	Slope Vapour Press	Daily ET Calculation (Saturated Soil) (mm)	Daily ET Calculation (Non-Saturated) (mm)
2015-07-28	0	1.32	2.66	15.32	27.33	21.33	52.15	0.24	11.11	0.03	1.52	0.49
2015-07-29	0	0.55	2.28	11.37	31.10	21.24	53.61	0.24	12.78	0.03	1.59	0.51
2015-07-30	0	0.39	2.49	13.52	34.33	23.93	45.74	0.26	12.37	0.03	1.54	0.49
2015-07-31	0	0.42	2.31	12.46	36.66	24.56	39.42	0.30	12.19	0.03	1.57	0.39
2015-08-01	0	0.45	1.56	13.76	34.55	24.15	34.10	0.32	9.44	0.03	1.33	0.73
2015-08-02	0	0.35	1.77	15.37	34.55	24.96	40.51	0.28	8.72	0.03	1.20	0.71
2015-08-03	0	1.19	2.15	15.18	30.62	22.90	31.02	0.34	7.13	0.03	1.42	0.92
2015-08-04	0	0.88	2.39	14.82	30.67	22.74	41.17	0.29	9.18	0.03	1.44	0.89
2015-08-05	1.4	0.93	2.09	11.66	22.35	17.00	64.10	0.21	6.23	0.04	1.06	0.69
2015-08-06	0	1.32	2.82	12.34	23.83	18.09	69.73	0.17	8.83	0.03	1.21	0.47
2015-08-07	0	0.49	2.00	9.26	30.32	19.79	59.93	0.22	10.78	0.03	1.41	0.66
2015-08-08	0	0.99	2.37	11.95	32.74	22.35	51.34	0.25	9.83	0.03	1.39	0.52
2015-08-09	0.2	0.81	2.31	14.15	31.41	22.78	54.52	0.22	9.83	0.03	1.30	0.41
2015-08-10	0	0.40	2.36	16.25	33.34	24.79	53.38	0.22	8.11	0.03	1.10	0.40
2015-08-11	0.2	0.34	2.00	16.89	34.86	25.88	49.65	0.23	8.09	0.03	1.06	0.52
2015-08-12	0	0.69	2.53	14.86	35.88	25.37	42.69	0.27	8.38	0.03	1.27	0.70
2015-08-13	0	0.76	1.74	16.99	38.14	27.57	36.90	0.28	8.27	0.02	1.17	1.12
2015-08-14	3.2	1.39	3.12	15.06	29.77	22.41	48.66	0.25	7.15	0.03	1.31	0.93
2015-08-15	0	2.14	3.55	12.65	23.64	18.15	59.71	0.22	6.90	0.03	1.31	0.52
2015-08-16	1	0.51	2.41	8.49	27.24	17.86	59.97	0.23	10.50	0.03	1.47	0.54
2015-08-17	0	0.42	1.93	13.50	28.37	20.93	52.40	0.25	9.46	0.03	1.30	0.54
2015-08-18	0	0.68	1.69	14.41	30.09	22.25	47.33	0.26	9.10	0.03	1.28	1.12
2015-08-19	0	0.74	2.61	10.83	33.63	22.23	47.27	0.27	9.47	0.03	1.43	1.54
2015-08-20	0	2.16	4.01	17.75	31.08	24.41	42.40	0.27	8.80	0.03	1.54	0.87

Date	Daily Precipitation (mm)	Daily Average wind U30 station (m/s)	MOT Wind speed m/s	T min	T max	T ave	Daily RH %	VPD	SR net (Rns-Rnl)	Slope Vapour Press	Daily ET Calculation (Saturated Soil) (mm)	Daily ET Calculation (Non-Saturated) (mm)
2015-08-21	0	2.04	2.90	8.97	19.63	14.30	53.57	0.29	6.19	0.04	1.49	0.72
2015-08-22	0	0.71	2.69	7.17	27.36	17.26	54.44	0.27	10.48	0.04	1.62	0.38
2015-08-23	0	0.08	1.47	8.74	24.20	16.47	61.08	0.23	6.77	0.04	1.04	0.45
2015-08-24	0	0.39	1.91	10.08	28.92	19.50	44.96	0.30	8.29	0.03	1.34	0.52
2015-08-25	0	0.36	2.05	10.44	28.72	19.58	46.55	0.29	8.70	0.03	1.37	0.81
2015-08-26	0	0.28	1.97	12.44	28.62	20.53	52.47	0.25	7.74	0.03	1.16	0.62
2015-08-27	0	1.20	2.25	12.07	30.34	21.21	45.03	0.29	7.59	0.03	1.35	0.91
2015-08-28	0	0.43	2.70	15.94	25.26	20.60	52.29	0.24	5.92	0.03	1.09	1.28
2015-08-29	2.2	1.23	3.11	13.11	21.29	17.20	75.40	0.14	6.77	0.04	0.98	0.86
2015-08-30	1.2	2.35	4.00	11.81	21.96	16.89	60.94	0.23	8.25	0.04	1.46	1.01
2015-08-31	1.6	1.63	3.42	12.70	17.11	14.90	66.27	0.20	4.51	0.04	1.06	1.07
2015-09-01	1.2	0.91	2.74	12.00	18.06	15.03	79.58	0.12	4.81	0.04	0.78	0.59
2015-09-02	0.4	1.95	3.22	10.05	20.44	15.24	54.94	0.27	5.94	0.04	1.42	1.02
2015-09-03	1.4	0.85	2.34	6.69	19.03	12.86	63.20	0.24	6.92	0.04	1.29	1.13
2015-09-04	0	1.12	2.84	5.77	19.72	12.75	65.68	0.23	6.48	0.04	1.27	1.28
2015-09-05	0	1.15	2.60	6.38	16.84	11.61	66.31	0.23	5.05	0.04	1.13	1.56
2015-09-06	0	1.89	2.95	7.17	20.60	13.89	49.63	0.32	5.78	0.04	1.56	1.60
2015-09-07	0	2.03	3.37	12.78	20.79	16.78	51.72	0.28	5.20	0.04	1.38	0.54
2015-09-08	11	0.74	2.05	10.03	15.58	12.80	83.61	0.11	4.18	0.04	0.67	0.24
2015-09-09	0.2	0.15	1.94	11.69	21.15	16.42	81.42	0.11	5.06	0.04	0.70	0.24
2015-09-10	0	0.51	2.30	9.56	26.62	18.09	71.95	0.16	6.17	0.03	0.91	0.41
2015-09-11	0	0.27	1.97	10.57	28.25	19.41	70.43	0.16	5.91	0.03	0.85	0.76
2015-09-12	0	0.94	2.49	10.86	30.47	20.66	58.24	0.22	5.39	0.03	1.02	0.81
2015-09-13	0	2.12	3.36	11.25	22.39	16.82	50.02	0.29	5.76	0.04	1.47	1.14

Date	Daily Precipitation (mm)	Daily Average wind U30 station (m/s)	MOT Wind speed m/s	T min	T max	T ave	Daily RH %	VPD	SR net (Rns-Rnl)	Slope Vapour Press	Daily ET Calculation (Saturated Soil) (mm)	Daily ET Calculation (Non-Saturated) (mm)
2015-09-14	0	0.39	1.52	5.46	15.72	10.59	65.88	0.24	5.69	0.05	1.08	1.34
2015-09-15	1.2	2.06	3.76	7.44	17.68	12.56	57.85	0.28	5.96	0.04	1.52	0.96
2015-09-16	0	0.63	2.39	4.43	17.61	11.02	68.23	0.22	6.36	0.05	1.21	1.46
2015-09-17	0.2	0.82	2.32	6.03	17.03	11.53	69.11	0.21	5.17	0.04	1.05	1.73
2015-09-18	0	2.64	3.95	11.30	19.75	15.52	56.84	0.26	5.11	0.04	1.40	2.10
2015-09-19	0.8	2.11	3.52	12.03	16.89	14.46	69.84	0.19	3.63	0.04	0.96	1.15
2015-09-20	0	3.24	4.17	10.17	25.74	17.96	63.51	0.21	4.62	0.03	1.18	0.53
2015-09-21	0	0.72	2.26	5.54	18.58	12.06	56.08	0.30	6.50	0.04	1.38	0.93
2015-09-22	0	0.55	2.51	0.77	19.67	10.22	64.46	0.27	6.82	0.05	1.37	0.68
2015-09-23	0	0.54	2.40	2.16	21.44	11.80	64.77	0.25	6.25	0.04	1.24	0.43
2015-09-24	0	0.18	1.82	5.64	22.56	14.10	66.97	0.21	4.80	0.04	0.89	0.48
2015-09-25	5.6	0.22	2.08	9.68	14.96	12.32	80.71	0.13	3.34	0.04	0.61	0.28
2015-09-26	0	0.46	1.82	3.78	17.27	10.52	73.56	0.19	6.29	0.05	1.08	0.62
2015-09-27	0	0.39	2.89	1.18	17.84	9.51	70.18	0.23	6.72	0.05	1.29	0.64
2015-09-28	0	0.44	2.60	1.83	19.41	10.62	72.44	0.20	6.56	0.05	1.18	0.49
2015-09-29	0	0.26	2.18	2.85	20.56	11.70	72.04	0.20	6.36	0.04	1.10	0.51
2015-09-30	0	0.37	2.23	4.51	22.90	13.70	70.95	0.19	6.08	0.04	1.03	0.60
2015-10-01	0	0.43	2.42	4.61	22.82	13.72	71.59	0.19	1.60	0.04	0.59	0.88
2015-10-02	10.4	0.75	1.89	5.02	12.56	8.79	83.89	0.12	2.58	0.05	0.55	0.48
2015-10-03	0	1.90	1.88	3.88	15.51	9.69	69.86	0.22	2.38	0.05	0.85	0.55
2015-10-04	0	0.50	2.10	2.05	15.61	8.83	76.18	0.18	2.66	0.05	0.69	0.38
2015-10-05	0	0.28	1.96	1.34	15.77	8.56	81.63	0.14	2.83	0.05	0.61	0.32
2015-10-06	0	0.21	1.58	2.82	13.81	8.32	84.47	0.12	2.67	0.05	0.52	0.29
2015-10-07	0.8	0.51	1.77	5.95	15.03	10.49	83.65	0.12	2.56	0.05	0.51	0.15

Date	Daily Precipitation (mm)	Daily Average wind U30 station (m/s)	MOT Wind speed m/s	T min	T max	T ave	Daily RH %	VPD	SR net (Rns-Rnl)	Slope Vapour Press	Daily ET Calculation (Saturated Soil) (mm)	Daily ET Calculation (Non-Saturated) (mm)
2015-10-08	0.2	0.36	1.23	10.86	15.53	13.20	86.55	0.09	2.54	0.04	0.41	0.36
2015-10-09	0	0.13	1.40	8.99	17.70	13.35	86.63	0.09	2.53	0.04	0.41	0.72
2015-10-10	4	2.09	3.72	10.42	18.32	14.37	79.27	0.13	2.57	0.04	0.68	0.81
2015-10-11	0	2.93	4.57	8.37	17.39	12.88	50.62	0.32	1.36	0.04	1.47	0.92
2015-10-12	0	0.72	2.48	6.00	14.39	10.19	74.98	0.18	2.55	0.05	0.71	0.46
2015-10-13	0	0.36	2.22	3.46	18.70	11.08	76.85	0.16	2.34	0.05	0.60	0.42
2015-10-14	0	0.37	2.38	0.25	16.49	8.37	76.27	0.19	2.73	0.05	0.72	0.41
2015-10-15	0	0.30	1.85	0.38	15.13	7.76	76.88	0.18	2.82	0.05	0.68	0.35
2015-10-16	0	0.31	1.56	1.53	17.37	9.45	73.24	0.20	2.51	0.05	0.63	0.38
2015-10-17	0	0.27	1.37	2.24	17.84	10.04	71.24	0.21	2.40	0.05	0.60	0.51
2015-10-18	1.4	0.41	1.82	8.47	15.20	11.83	80.07	0.13	2.51	0.04	0.53	0.23
2015-10-19	1.2	0.44	1.36	9.78	18.22	14.00	82.88	0.11	2.19	0.04	0.41	0.18
2015-10-20	0	0.30	1.89	3.75	16.18	9.96	75.07	0.18	2.47	0.05	0.62	0.30
2015-10-21	0.2	0.18	1.53	2.02	10.52	6.27	84.00	0.13	2.71	0.06	0.56	0.20
2015-10-22	0	0.26	1.28	1.45	16.65	9.05	78.82	0.16	2.65	0.05	0.56	0.35
2015-10-23	0	0.19	1.87	-0.34	13.16	6.41	78.97	0.17	2.95	0.06	0.68	0.45
2015-10-24	0	0.36	2.14	-1.02	9.46	4.22	84.39	0.14	3.04	0.06	0.68	0.66
2015-10-25	0.4	0.28	1.74	-0.51	10.91	5.20	79.94	0.17	2.85	0.06	0.67	0.64
2015-10-26	6.2	1.59	1.93	5.72	13.86	9.79	81.27	0.14	2.58	0.05	0.63	0.22
2015-10-27	0	0.30	1.70	2.93	8.17	5.55	75.82	0.20	2.52	0.06	0.67	1.07
2015-10-28	4	0.11	1.57	0.16	6.05	3.11	88.85	0.10	2.50	0.06	0.51	0.67
2015-10-29	0.2	2.13	3.00	5.69	13.98	9.84	76.56	0.17	2.53	0.05	0.81	0.87
2015-10-30	5.2	0.94	3.02	4.14	11.90	8.02	85.46	0.11	2.60	0.05	0.60	0.65
2015-10-31	9.8	1.22	2.40	3.78	12.12	7.95	81.41	0.14	2.53	0.05	0.66	0.65

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2015-11-01	6.8	1.66	3.62	3.25	10.25	6.75	77.34	0.18	0.64	0.05	0.67	0.28
2015-11-02	0.8	0.06	1.21	0.91	9.76	5.33	86.31	0.12	0.58	0.06	0.21	0.14
2015-11-03	0	0.36	1.15	-1.50	7.95	3.22	80.79	0.17	0.97	0.06	0.36	0.29
2015-11-04	0	0.02	1.42	-3.63	6.69	1.53	86.21	0.13	0.63	0.07	0.26	0.38
2015-11-05	0.6	0.24	1.56	-1.87	8.64	3.39	86.16	0.13	0.72	0.06	0.29	0.22
2015-11-06	0	0.59	1.37	-1.79	5.57	1.89	84.22	0.15	1.46	0.07	0.45	0.52
2015-11-07	3.8	0.05	2.98	4.09	6.81	5.45	87.94	0.10	1.82	0.06	0.45	0.33
2015-11-08	4	0.29	2.37	3.96	12.00	7.98	86.47	0.10	-0.60	0.05	0.14	0.25
2015-11-09	0	0.55	2.34	-1.33	6.26	2.46	79.27	0.19	1.41	0.07	0.60	0.97
2015-11-10	0	0.05	1.20	-4.59	4.71	0.06	83.10	0.17	0.56	0.07	0.27	0.46
2015-11-11	0	1.99	3.97	-2.83	9.41	3.29	73.01	0.25	0.52	0.06	0.93	0.49
2015-11-12	0	0.35	1.82	-3.75	4.61	0.43	80.25	0.20	1.70	0.07	0.58	1.03
2015-11-13	0	2.10	3.47	4.09	12.63	8.36	70.61	0.22	0.99	0.05	0.87	0.44
2015-11-14	7.4	1.09	2.99	2.61	10.35	6.48	79.83	0.16	1.71	0.06	0.65	0.53
2015-11-15	8.4	0.49	1.65	-0.06	4.69	2.31	87.49	0.12	1.89	0.07	0.47	0.77
2015-11-16	0	0.80	1.56	-4.62	3.70	-0.46	79.53	0.21	1.18	0.07	0.55	0.54
2015-11-17	14.8	2.26	4.12	2.02	7.57	4.80	83.48	0.14	1.98	0.06	0.73	0.40
2015-11-18	0	0.63	2.11	-2.48	5.54	1.53	70.18	0.29	0.68	0.07	0.66	0.80
2015-11-19	0	0.25	1.91	-4.74	4.38	-0.18	79.41	0.21	0.66	0.07	0.44	0.55
2015-11-20	0	0.40	1.89	-3.84	5.21	0.68	69.54	0.30	0.12	0.07	0.53	0.52
2015-11-21	0	0.19	1.64	-6.20	2.13	-2.04	82.89	0.19	1.00	0.08	0.42	0.33
2015-11-22	0	0.03	1.06	-3.51	1.48	-1.01	85.21	0.15	1.44	0.08	0.39	0.41
2015-11-23	0.2	0.39	1.11	-1.33	2.29	0.48	86.57	0.13	1.70	0.07	0.44	0.84
2015-11-24	0	3.71	1.58	-6.48	-0.23	-3.36	72.86	0.31	1.72	0.08	1.18	0.18

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2015-11-25	0	0.51	2.24	-10.41	-2.13	-6.27	75.06	0.32	1.11	0.10	0.77	0.24
2015-11-26	0	0.40	2.43	-12.16	-2.16	-7.16	82.09	0.24	1.32	0.10	0.67	0.82
2015-11-27	0	0.29	1.72	-7.35	-6.14	-6.74	85.14	0.19	1.58	0.10	0.56	0.80
2015-11-28	0	0.51	1.94	-8.00	-6.74	-7.37	87.13	0.17	1.56	0.10	0.56	1.32
2015-11-29	0	0.61	1.99	-8.43	-5.26	-6.85	88.74	0.15	1.58	0.10	0.53	1.83
2015-11-30	0	2.07	3.32	-6.07	-5.23	-5.65	86.31	0.17	1.61	0.09	0.75	1.82
2015-12-01	0	3.04	3.92	-5.76	-3.09	-4.43	79.82	0.24	-0.50	0.09	0.79	1.13
2015-12-02	0.4	1.44	2.28	-3.75	0.72	-1.52	84.16	0.17	0.55	0.08	0.49	1.50
2015-12-03	1.8	0.28	1.52	-0.48	4.19	1.86	88.49	0.11	1.10	0.07	0.32	0.92
2015-12-04	0.2	3.43	4.33	2.50	5.46	3.98	84.04	0.14	-0.11	0.06	0.56	0.28
2015-12-05	12	0.52	1.65	0.44	2.69	1.56	86.45	0.13	1.57	0.07	0.45	0.22
2015-12-06	3	0.07	1.38	0.93	3.99	2.46	89.70	0.09	0.81	0.07	0.24	0.62
2015-12-07	0	0.26	1.76	1.32	5.80	3.56	88.08	0.11	1.65	0.06	0.41	1.11
2015-12-08	3.2	2.37	3.98	2.93	11.37	7.15	81.28	0.15	1.55	0.05	0.70	0.94
2015-12-09	6	2.66	3.62	0.85	10.15	5.50	70.15	0.25	-1.47	0.06	0.77	0.61
2015-12-10	0.6	0.57	2.22	-1.24	4.51	1.63	78.60	0.20	1.32	0.07	0.60	0.29
2015-12-11	0.2	0.02	1.50	-1.53	4.04	1.26	89.70	0.10	0.63	0.07	0.22	0.13
2015-12-12	0.8	0.09	1.31	-0.34	2.02	0.84	88.86	0.11	0.93	0.07	0.27	0.17
2015-12-13	2.6	0.07	0.97	-0.40	2.05	0.83	90.06	0.10	1.55	0.07	0.35	0.15
2015-12-14	0.2	0.37	1.40	-1.96	2.96	0.50	81.52	0.18	0.85	0.07	0.38	0.15
2015-12-15	0	0.02	0.86	-3.90	0.41	-1.74	86.71	0.14	0.91	0.08	0.26	0.24
2015-12-16	1	0.11	1.30	-8.36	1.83	-3.27	85.53	0.17	0.39	0.08	0.25	1.01
2015-12-17	0	0.19	1.69	-8.60	-3.27	-5.93	86.84	0.16	0.96	0.10	0.39	1.66
2015-12-18	0.6	1.85	3.09	-3.75	1.21	-1.27	87.03	0.14	0.17	0.08	0.43	1.36

Date	Daily Precipitation (mm)	Daily Average wind U30 station (m/s)	MOT Wind speed m/s	T min	T max	T ave	Daily RH %	VPD	SR net (Rns-Rnl)	Slope Vapour Press	Daily ET Calculation (Saturated Soil) (mm)	Daily ET Calculation (Non-Saturated) (mm)
2015-12-19	0.2	2.09	3.41	-2.33	0.30	-1.02	83.71	0.17	-0.89	0.08	0.42	1.15
2015-12-20	0	2.16	3.13	-1.93	0.58	-0.68	84.46	0.16	0.82	0.08	0.60	0.48
2015-12-21	0	0.65	2.01	-4.93	-1.07	-3.00	87.18	0.14	0.86	0.08	0.40	0.35
2015-12-22	0.2	0.17	1.71	-4.02	-0.14	-2.08	89.16	0.12	0.80	0.08	0.30	0.22
2015-12-23	0	0.26	1.55	-4.96	-1.50	-3.23	89.24	0.12	0.87	0.08	0.31	0.25
2015-12-24	0	0.06	1.48	-5.57	-0.76	-3.17	89.09	0.12	0.86	0.08	0.29	0.55
2015-12-25	0	0.27	2.28	-13.73	-2.51	-8.12	84.58	0.21	0.77	0.11	0.49	0.65
2015-12-26	0	0.79	1.87	-13.77	-4.74	-9.26	88.93	0.16	1.12	0.11	0.48	0.08
2015-12-27	0	0.00	0.74	-4.96	-2.57	-3.76	89.74	0.12	1.48	0.09	0.35	-0.05
2015-12-28	0	0.00	0.00	-6.90	-1.04	-3.97	89.65	0.12	1.29	0.09	0.27	0.47
2015-12-29	0	0.03	1.70	-4.83	-2.39	-3.61	88.80	0.13	1.49	0.09	0.43	0.50
2015-12-30	0	0.92	1.78	-7.45	-4.35	-5.90	80.46	0.24	0.85	0.10	0.58	0.90
2015-12-31	0	0.45	1.94	-15.91	-4.38	-10.15	82.17	0.27	0.81	0.12	0.56	1.45
2016-01-01	0	0.46	3.20	-12.90	-6.71	-9.80	85.54	0.21	1.29	0.11	0.68	1.02
2016-01-02	0	0.38	3.15	-12.34	-9.03	-10.69	87.63	0.19	1.33	0.12	0.63	0.53
2016-01-03	0	0.24	2.12	-12.01	-9.95	-10.98	88.34	0.18	1.32	0.12	0.52	0.17
2016-01-04	0	0.04	1.00	-9.92	-4.93	-7.42	88.55	0.15	1.49	0.10	0.42	0.10
2016-01-05	0	0.00	0.90	-5.05	-0.76	-2.90	89.01	0.12	1.64	0.08	0.40	0.05
2016-01-06	0.2	0.00	0.70	-1.90	2.32	0.21	89.80	0.10	1.20	0.07	0.27	0.08
2016-01-07	2.8	0.00	1.02	-0.40	2.07	0.84	89.92	0.10	1.41	0.07	0.32	0.18
2016-01-08	1.6	0.01	1.91	-1.99	2.02	0.02	87.67	0.12	0.96	0.07	0.33	0.23
2016-01-09	0.8	0.05	1.92	-5.54	2.40	-1.57	88.19	0.13	0.88	0.08	0.33	0.31
2016-01-10	0	0.03	1.37	-3.12	-0.34	-1.73	88.83	0.12	1.38	0.08	0.37	0.47
2016-01-11	0	0.51	2.26	-2.31	-0.23	-1.27	83.53	0.17	1.37	0.08	0.55	0.49

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2016-01-12	0	0.49	2.28	-2.07	-0.14	-1.11	85.53	0.15	1.23	0.08	0.48	0.19
2016-01-13	4.8	0.02	1.03	-1.93	2.13	0.10	90.18	0.10	1.42	0.07	0.33	0.40
2016-01-14	8	0.21	1.46	-4.68	6.48	0.90	83.71	0.16	-0.22	0.07	0.17	0.63
2016-01-15	1.4	1.18	2.73	-6.58	2.61	-1.98	87.91	0.13	0.62	0.08	0.42	0.14
2016-01-16	0	0.02	1.15	-5.57	-0.40	-2.98	89.48	0.12	1.60	0.08	0.40	0.21
2016-01-17	0.4	0.06	1.08	-3.09	1.07	-1.01	89.82	0.11	1.37	0.08	0.34	0.22
2016-01-18	10.6	0.36	1.57	-1.38	4.12	1.37	88.01	0.11	0.02	0.07	0.17	0.18
2016-01-19	0	0.10	1.55	-3.33	5.15	0.91	88.46	0.11	0.17	0.07	0.17	0.16
2016-01-20	2.2	0.05	1.00	-0.06	2.72	1.33	90.51	0.09	0.88	0.07	0.23	0.33
2016-01-21	5	0.29	1.13	0.52	3.27	1.90	89.38	0.10	1.15	0.07	0.30	0.34
2016-01-22	1.2	1.13	2.37	0.83	5.62	3.22	87.86	0.11	1.05	0.06	0.40	0.14
2016-01-23	0	0.04	1.45	-2.42	2.32	-0.05	90.60	0.09	1.19	0.07	0.31	0.28
2016-01-24	4.4	0.04	1.41	-0.68	1.81	0.56	91.70	0.08	0.85	0.07	0.23	0.41
2016-01-25	0	0.76	1.79	-3.69	1.97	-0.86	86.93	0.14	0.05	0.08	0.25	0.76
2016-01-26	0.2	1.22	2.14	-0.96	3.46	1.25	88.39	0.11	1.19	0.07	0.42	1.04
2016-01-27	0.2	1.03	2.13	1.21	4.25	2.73	87.95	0.11	0.61	0.06	0.33	0.87
2016-01-28	0	3.21	5.55	2.82	7.77	5.30	77.65	0.19	0.08	0.06	0.84	1.58
2016-01-29	2.2	1.44	3.01	-0.17	5.44	2.63	83.42	0.15	1.25	0.06	0.59	0.82
2016-01-30	0.6	2.56	2.47	-1.73	2.26	0.27	86.10	0.14	0.60	0.07	0.50	0.41
2016-01-31	3.4	0.30	1.60	-2.65	0.93	-0.86	90.81	0.10	0.68	0.08	0.25	0.46
2016-02-01	1.2	0.55	2.04	-1.96	0.85	-0.55	90.16	0.10	2.19	0.07	0.53	0.42
2016-02-02	0	1.04	1.81	-8.56	5.31	-1.63	85.86	0.16	2.68	0.08	0.72	0.73
2016-02-03	0	0.61	1.27	-7.25	-1.33	-4.29	88.63	0.13	2.40	0.09	0.61	0.67
2016-02-04	5	1.28	1.69	-2.63	3.46	0.42	87.28	0.13	2.44	0.07	0.62	0.46

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2016-02-05	0	0.76	1.89	0.38	4.92	2.65	85.96	0.13	2.19	0.06	0.56	0.76
2016-02-06	0	2.97	3.00	-2.04	7.59	2.78	60.05	0.37	1.91	0.06	1.51	0.45
2016-02-07	0	0.08	1.26	-4.38	2.56	-0.91	84.81	0.16	2.27	0.08	0.55	0.15
2016-02-08	0	0.09	0.90	-3.66	3.25	-0.20	87.50	0.13	2.34	0.07	0.51	0.10
2016-02-09	0	0.09	0.71	-5.08	4.04	-0.52	89.40	0.11	2.44	0.07	0.51	0.16
2016-02-10	0	0.12	1.26	-3.48	2.61	-0.43	89.50	0.11	2.14	0.07	0.48	0.29
2016-02-11	3	0.11	1.51	-2.13	3.35	0.61	89.50	0.10	2.25	0.07	0.49	0.99
2016-02-12	5.4	0.55	1.59	0.74	5.13	2.94	90.38	0.09	2.18	0.06	0.46	0.88
2016-02-13	0.2	3.78	4.02	3.01	7.82	5.41	82.22	0.15	2.06	0.06	0.81	0.69
2016-02-14	0.4	1.55	3.00	0.05	5.59	2.82	85.67	0.13	2.19	0.06	0.65	0.26
2016-02-15	4.6	0.31	1.56	1.59	8.52	5.05	87.53	0.11	2.10	0.06	0.46	0.25
2016-02-16	0.2	0.19	2.48	0.91	11.27	6.09	85.73	0.12	2.01	0.06	0.50	0.47
2016-02-17	2	0.04	1.00	0.55	4.01	2.28	89.99	0.09	2.18	0.07	0.44	0.52
2016-02-18	3.6	1.75	3.17	2.24	6.79	4.51	86.09	0.12	2.19	0.06	0.62	0.81
2016-02-19	0.6	0.44	1.37	1.04	5.59	3.32	86.54	0.12	2.20	0.06	0.50	0.69
2016-02-20	0.2	2.81	2.40	-1.41	8.87	3.73	60.20	0.36	1.55	0.06	1.33	2.08
2016-02-21	0	0.42	2.46	-1.93	5.90	1.98	78.06	0.21	2.24	0.07	0.74	1.00
2016-02-22	0	1.65	2.64	-2.36	9.21	3.43	69.80	0.27	1.95	0.06	1.02	0.76
2016-02-23	0	0.33	2.19	-4.38	7.07	1.34	80.39	0.19	2.44	0.07	0.71	0.38
2016-02-24	0	0.25	1.46	-2.65	8.10	2.72	76.86	0.21	2.14	0.06	0.62	0.38
2016-02-25	0	0.22	1.44	-3.57	9.14	2.79	78.62	0.20	2.17	0.06	0.60	0.30
2016-02-26	0.2	0.18	0.97	-2.51	7.85	2.67	81.34	0.17	2.22	0.06	0.52	0.78
2016-02-27	0	0.32	1.46	0.27	12.32	6.29	82.12	0.15	1.83	0.06	0.47	1.08
2016-02-28	4.2	1.46	3.74	-0.28	6.97	3.34	81.83	0.16	2.18	0.06	0.78	0.92

Date	Daily Precipitation (mm)	Daily Average wind U30 station (m/s)	MOT Wind speed m/s	T min	T max	T ave	Daily RH %	VPD	SR net (Rns-Rnl)	Slope Vapour Press	Daily ET Calculation (Saturated Soil) (mm)	Daily ET Calculation (Non-Saturated) (mm)
2016-02-29	0	1.61	3.67	2.29	10.57	6.43	59.77	0.33	1.50	0.06	1.24	1.31
2016-03-01	6.4	0.36	2.57	0.50	2.74	1.62	85.83	0.13	2.59	0.07	0.65	0.80
2016-03-02	1	0.83	1.70	0.74	7.80	4.27	84.52	0.13	4.16	0.06	0.83	0.51
2016-03-03	0.2	1.79	2.02	1.97	11.71	6.84	75.58	0.20	4.68	0.05	1.06	0.68
2016-03-04	0.2	0.18	1.57	-0.99	11.03	5.02	79.55	0.18	4.26	0.06	0.86	0.87
2016-03-05	0.8	1.15	2.75	4.51	16.11	10.31	73.76	0.19	4.58	0.05	1.00	0.82
2016-03-06	7.8	0.77	2.19	1.64	12.53	7.09	80.47	0.16	4.44	0.05	0.89	1.07
2016-03-07	0.6	1.29	2.89	-0.06	8.67	4.30	85.69	0.12	3.85	0.06	0.82	0.79
2016-03-08	0	1.95	3.13	0.63	10.17	5.40	64.86	0.30	5.49	0.06	1.56	1.17
2016-03-09	6.4	0.90	1.64	-2.10	7.62	2.76	77.23	0.21	4.37	0.06	1.02	1.35
2016-03-10	0.8	2.84	3.01	1.72	14.22	7.97	61.79	0.30	4.61	0.05	1.51	0.76
2016-03-11	0	0.43	1.42	-1.24	12.32	5.54	61.76	0.33	5.16	0.06	1.21	1.29
2016-03-12	0.6	0.65	2.08	0.50	10.39	5.44	83.19	0.14	3.60	0.06	0.76	1.26
2016-03-13	0	0.85	2.24	-1.87	6.91	2.52	82.40	0.16	4.05	0.07	0.92	1.70
2016-03-14	0	3.56	4.02	3.33	9.41	6.37	60.32	0.32	4.80	0.06	1.76	1.41
2016-03-15	0	1.84	2.96	2.72	10.42	6.57	54.38	0.37	4.74	0.05	1.66	1.31
2016-03-16	0	0.83	1.71	-0.96	8.52	3.78	71.40	0.25	5.12	0.06	1.19	1.03
2016-03-17	0	0.78	2.21	-3.39	9.51	3.06	60.27	0.37	6.45	0.06	1.67	1.34
2016-03-18	0	0.67	2.13	-4.05	9.78	2.87	59.69	0.38	6.34	0.06	1.65	1.23
2016-03-19	0	0.53	2.62	0.05	12.00	6.03	53.77	0.38	4.88	0.06	1.49	1.31
2016-03-20	0.6	0.15	1.11	0.93	9.78	5.36	70.09	0.25	3.75	0.06	0.82	1.40
2016-03-21	0	1.30	2.47	1.56	12.90	7.23	76.97	0.18	5.93	0.05	1.17	1.23
2016-03-22	0	1.20	3.01	3.56	12.73	8.15	73.47	0.20	4.55	0.05	1.08	1.66
2016-03-23	1.2	1.84	3.50	4.61	10.98	7.80	66.97	0.25	4.17	0.05	1.28	1.57

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2016-03-24	2.4	2.28	3.72	3.72	11.71	7.72	61.23	0.30	4.45	0.05	1.52	0.88
2016-03-25	0	0.65	1.88	-0.85	9.83	4.49	71.82	0.25	4.77	0.06	1.12	0.74
2016-03-26	0	0.49	1.67	-1.99	12.82	5.42	67.75	0.28	6.29	0.06	1.33	0.82
2016-03-27	5.6	0.58	1.85	3.62	6.54	5.08	82.73	0.14	3.61	0.06	0.76	0.33
2016-03-28	0.2	0.46	0.97	2.13	10.10	6.11	77.86	0.18	3.98	0.06	0.78	0.60
2016-03-29	0	0.60	2.25	-1.73	14.55	6.41	67.48	0.27	6.37	0.06	1.38	0.89
2016-03-30	0	0.47	2.23	0.99	19.03	10.01	69.70	0.23	5.95	0.05	1.16	0.61
2016-03-31	0	0.52	2.17	2.53	20.51	11.52	68.18	0.23	5.60	0.04	1.09	1.03
2016-04-01	0	0.38	1.93	2.21	22.20	12.21	67.81	0.23	9.40	0.04	1.47	1.03
2016-04-02	0	1.80	3.39	4.01	21.18	12.59	58.04	0.29	8.83	0.04	1.75	1.45
2016-04-03	0	0.40	1.83	3.46	18.94	11.20	59.98	0.28	8.58	0.05	1.51	1.78
2016-04-04	0.2	2.28	4.12	5.59	13.31	9.45	68.44	0.23	4.91	0.05	1.31	1.82
2016-04-05	1.4	4.36	4.02	5.13	10.32	7.72	51.07	0.38	9.51	0.05	2.45	2.69
2016-04-06	0	5.78	4.94	16.31	8.83	12.57	69.47	0.20	8.59	0.04	1.55	1.33
2016-04-07	0	1.87	1.90	19.36	3.58	11.47	52.30	0.34	9.54	0.04	1.87	1.49
2016-04-08	0	2.58	2.47	22.94	7.11	15.02	32.06	0.43	8.66	0.04	2.15	1.74
2016-04-09	0.6	2.35	2.45	22.94	8.98	15.96	44.37	0.34	6.77	0.04	1.65	2.13
2016-04-10	0.1	2.29	2.14	19.51	3.22	11.36	44.32	0.39	8.82	0.04	2.05	1.84
2016-04-11	0.1	2.54	2.51	19.42	5.44	12.43	44.64	0.37	8.73	0.04	2.03	1.58
2016-04-12	0.0	2.20	2.27	18.87	4.89	11.88	43.97	0.39	6.35	0.04	1.79	1.73
2016-04-13	0.3	2.42	2.58	15.80	6.69	11.24	51.89	0.33	7.86	0.05	1.82	2.35
2016-04-14	0.7	3.55	3.62	16.20	5.28	10.74	57.61	0.30	9.85	0.05	2.03	1.97
2016-04-15	0.0	4.26	4.18	17.04	4.31	10.68	49.85	0.36	9.73	0.05	2.33	1.05
2016-04-16	0.0	3.82	2.60	17.18	4.30	10.74	50.44	0.35	8.22	0.05	2.05	1.41

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2016-04-17	0.3	1.94	2.13	21.08	7.12	14.10	45.48	0.35	9.77	0.04	1.90	1.91
2016-04-18	0.0	2.32	2.25	25.02	8.05	16.54	42.11	0.35	9.15	0.04	1.85	1.72
2016-04-19	0.0	1.54	1.56	25.73	10.28	18.01	47.49	0.30	9.06	0.03	1.52	1.84
2016-04-20	0.0	2.16	2.29	27.31	10.13	18.72	48.67	0.29	8.78	0.03	1.58	2.19
2016-04-21	0.0	2.68	2.93	27.31	11.50	19.41	76.27	0.13	8.27	0.03	1.04	0.82
2016-04-22	0.0	3.48	2.94	23.55	10.67	17.11	63.14	0.21	8.33	0.04	1.42	1.37
2016-04-23	0.1	2.09	2.27	20.08	8.36	14.22	53.56	0.29	8.08	0.04	1.61	1.97
2016-04-24	0.0	2.84	2.77	17.57	8.32	12.95	48.88	0.33	6.90	0.04	1.78	1.74
2016-04-25	0.0	1.98	1.95	16.05	7.83	11.94	45.60	0.37	9.66	0.04	1.98	2.34
2016-04-26		1.57	1.75	14.37	4.62	9.49	45.55	0.40	7.09	0.05	1.76	

Appendix B: Stream Discharge Data

Q1		Q2		GW Seep		Q3		Q4		Q5	
Discharge (L/sec)	Water Level (cm)	Discharge (L/sec)	Water Level (cm)	Discharge (L/sec)	Water Level (cm)	Discharge (L/sec)	Water Level (cm)	Discharge (L/sec)	Water Level (cm)	Discharge (L/sec)	Water Level (cm)
26.5	29.4	0.8	9.5	3.2	18.9	5.5	16.6	3.2	15.4	4.8	16.9
25.3	28.7	0.7	9.7	2.5	17.6	25.3	28.7	2.9	14.1	4.7	16.2
23.5	27.9	0.5	9.7	2.9	19.0	23.5	27.9	1.8	12.1	4.8	16.4
22.9	27.7	0.4	9.1	2.1	17.1	31.6	31.6	1.7	12.1	6.0	17.2
31.6	31.6	0.7	9.8	1.5	15.4	17.4	26.6	1.8	11.8	3.1	15.5
17.4	26.6	0.3	9.0	0.3	10.3	10.6	24.6	0.7	10.4	1.7	14.6
10.6	24.6	1.4	10.6	0.3	8.4	3.3	12.8	0.6	11.0	0.1	10.9
9.3	22.9	1.2	10.8	0.1	8.0	2.8	12.5	0.3	10.6		
6.8	21.2	2.3	11.0			2.9	12.5	0.3	11.2		
		4.3	13.7					0.0	8.6		
		0.5	9.8					0.2	10.6		
		3.2	12.6					0.2	9.4		
		2.5	11.9					0.4	10.2		
								0.2	9.0		
								0.1	8.9		
								1.3	12.0		
								1.7	12.9		
								2.4	14.0		
								0.1	6.8		

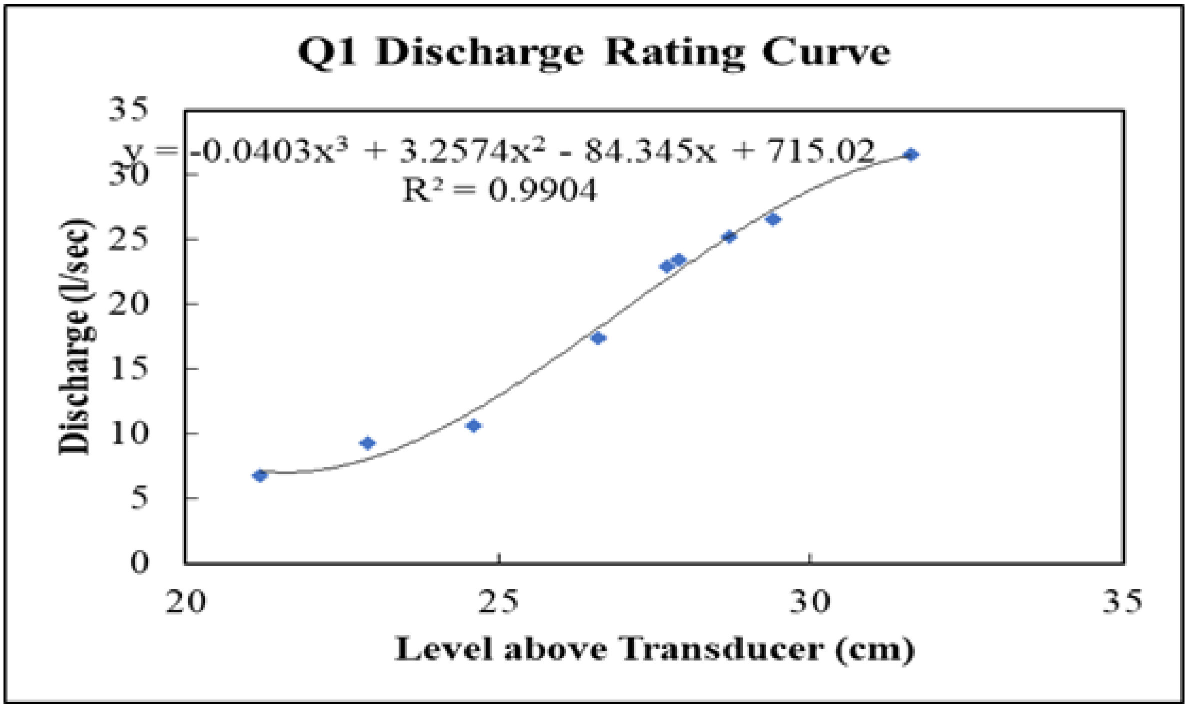

Figure B1: Discharge rating curve for Q1 discharge station on Bailey Creek

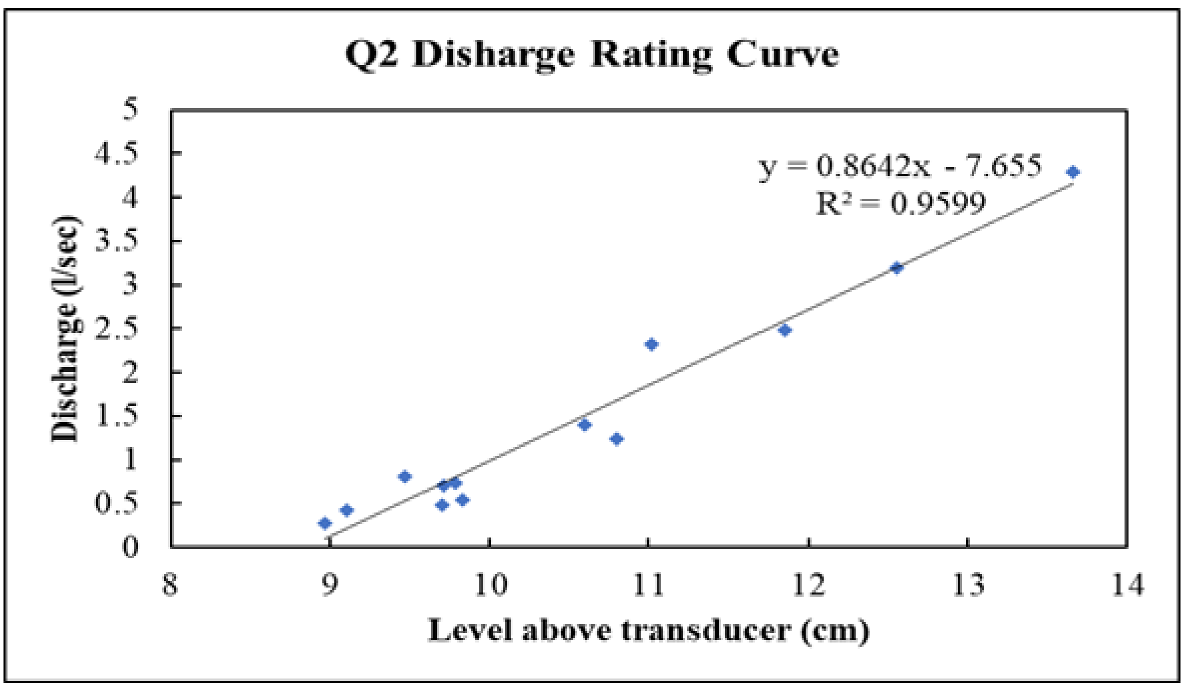

Figure B2: Discharge rating curve for Q2 discharge station.

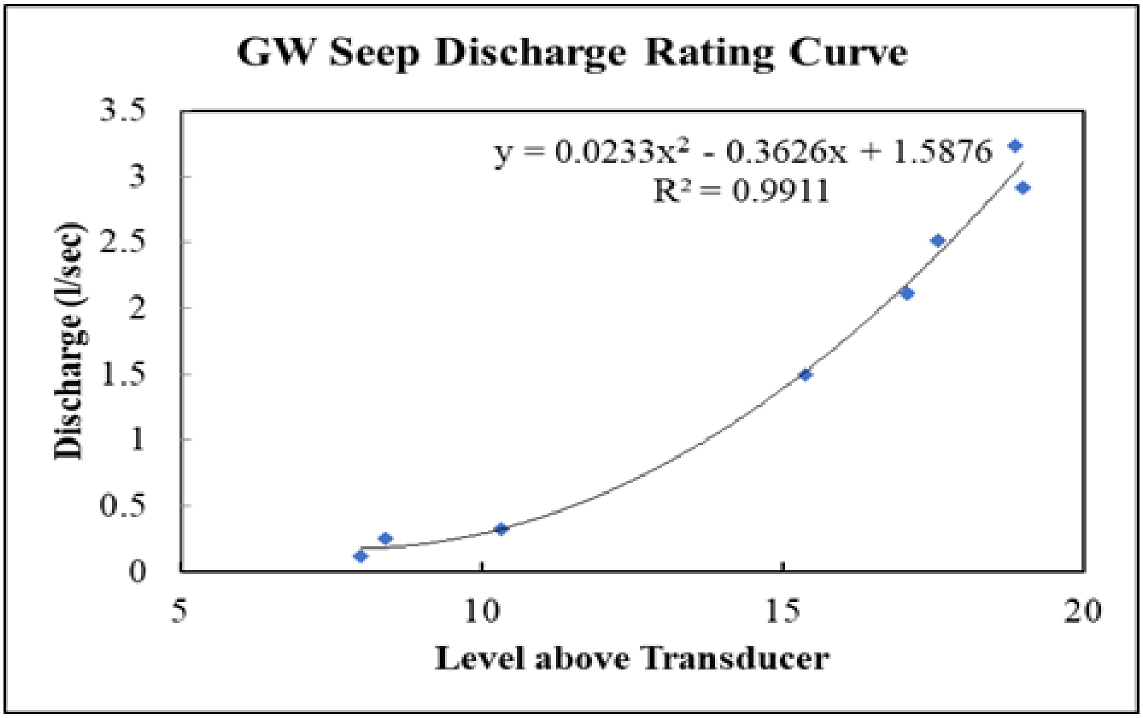

Figure B3: Discharge rating curve for the Groundwater seep discharge station.

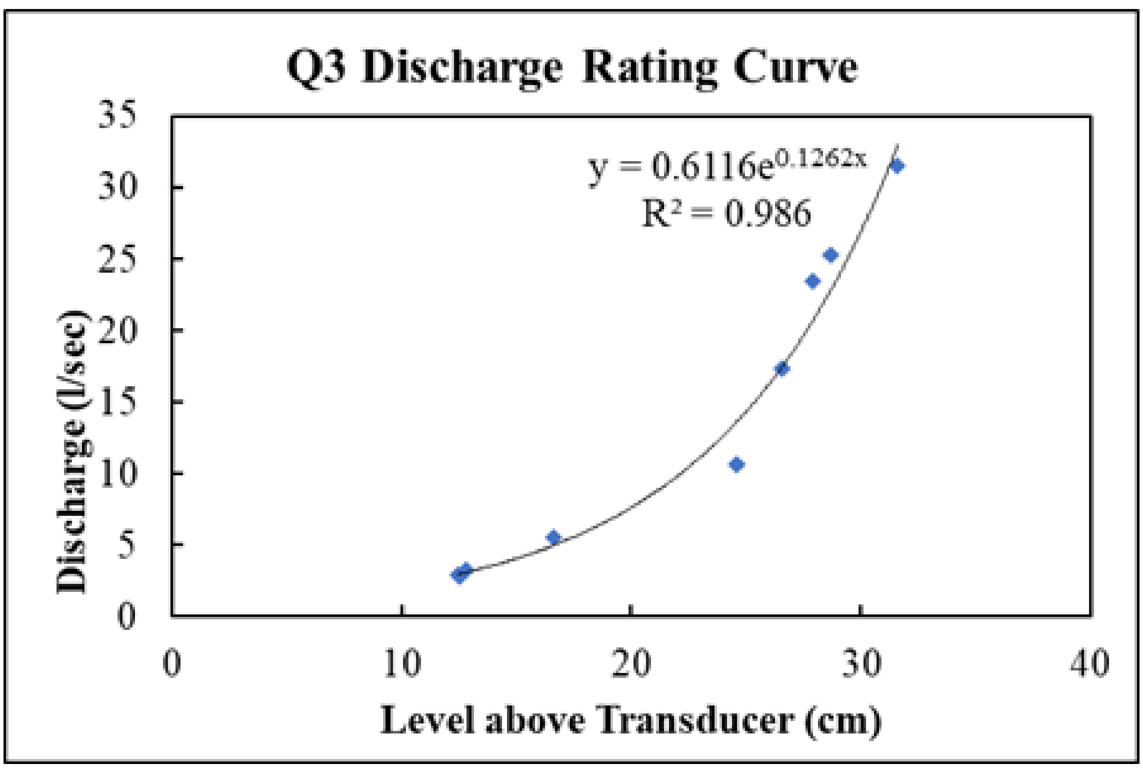

Figure B4: Discharge rating curve for Q3 discharge station.

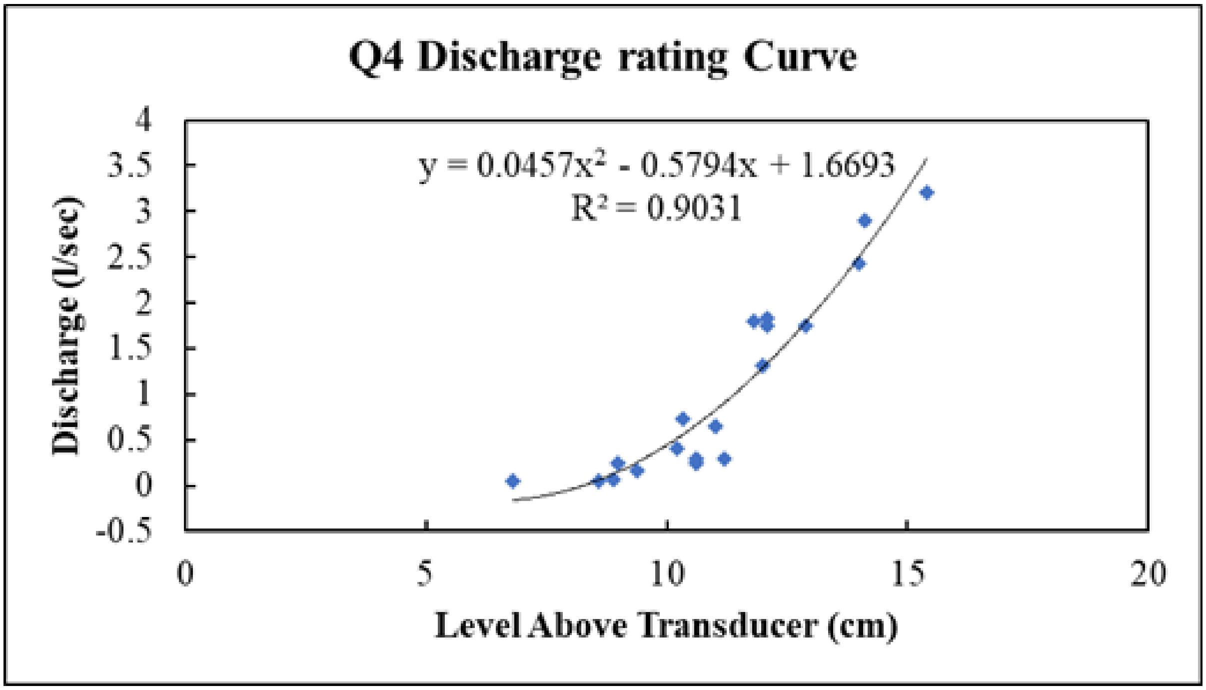

Figure B5: Discharge rating curve for Q4 discharge station.

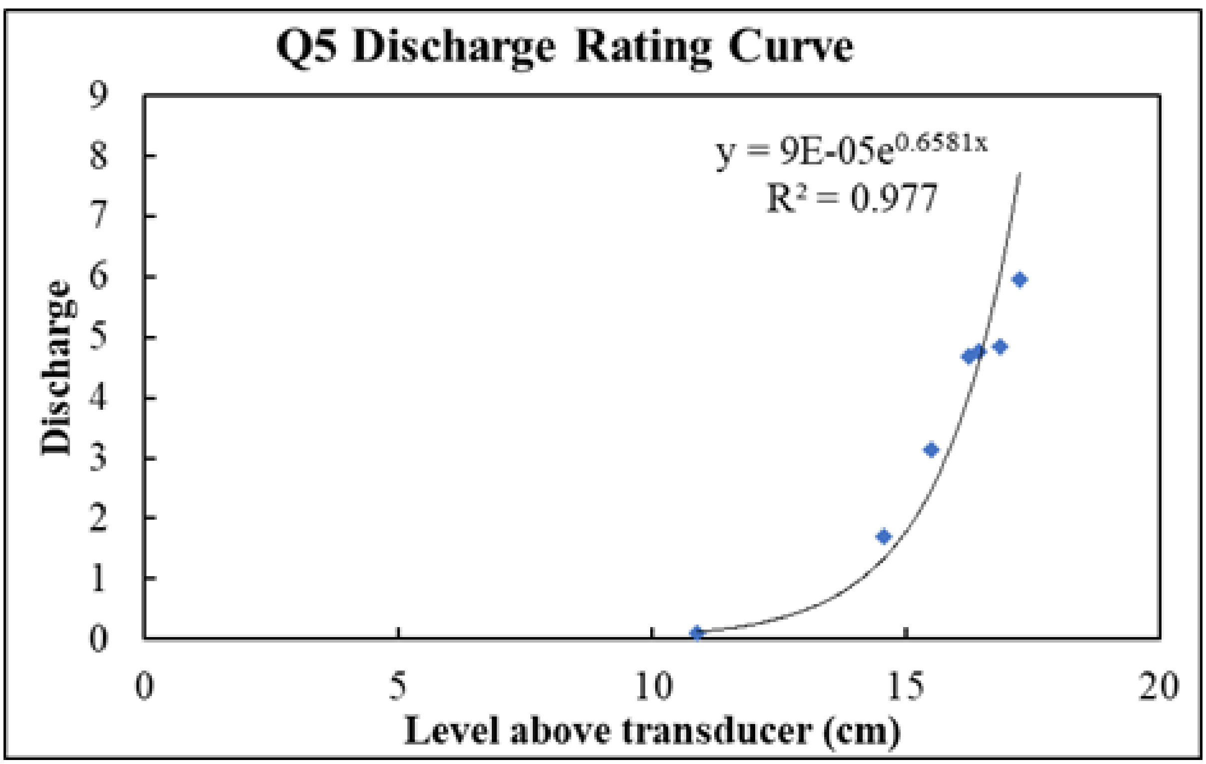

Figure B6: Discharge rating curve for Q5 discharge station

Appendix C: Chemistry Data Base

Date yy/mm/dd	Sample Location	Dissolved P (mg/l)	Particulate P (mg/l)	Total P (mg/l)	TN (mg/l	Sodium (mg/l)	Chloride Conc (mg/l)
2015-03-05	Q1	0.164	0.006	0.170	3.789	174.528	170.718
2015-03-09	Q1	0.153	0.000	0.154	3.856	152.345	166.617
2015-03-16	Q1	0.159	0.003	0.162	2.870	160.977	165.943
2015-03-19	Q1	0.131	0.001	0.132	2.678	158.664	169.340
2015-03-23	Q1	0.143	0.003	0.146	2.803	160.521	157.427
2015-03-25	Q1	0.155	0.001	0.155	2.847	107.166	163.938
2015-03-26	Q1	0.149	0.006	0.155	2.959	162.801	165.272
2015-03-31	Q1	0.162	0.005	0.168	2.955	157.492	156.156
2015-04-07	Q1	0.161	0.011	0.172	3.053	149.577	156.791
2015-04-10	Q1	0.134	0.012	0.146	3.240	136.482	160.650
2015-04-19	Q1	0.143	0.011	0.154	2.761	145.765	160.650
2015-04-24	Q1	0.154	0.002	0.156	3.204	158.860	165.272
2015-04-30	Q1	0.159	0.008	0.168	3.343	142.704	167.294
2015-05-04	Q1	0.146	0.004	0.150	2.070	141.922	164.604
2015-05-08	Q1	0.170	0.008	0.178	2.574	145.961	166.617
2015-05-12	Q1	0.177	0.006	0.183	2.074	147.883	170.718
2015-05-15	Q1	0.108	0.003	0.111	2.009	147.720	170.028
2015-05-19	Q1	0.064	0.031	0.095	1.579	152.899	170.718
2015-05-29	Q1	0.139	0.007	0.145	3.316	145.700	156.791
2015-06-02	Q1	0.154	0.009	0.164	2.940	155.505	161.957
2015-06-04	Q1	0.160	0.014	0.173	3.467	154.723	157.427
2015-06-07	Q1	0.154	0.008	0.163	2.869	157.296	156.791
2015-06-15	Q1	0.222	0.004	0.227	3.369	142.899	160.000
2015-06-20	Q1	0.197	0.005	0.202	3.228	157.003	159.353
2015-06-26	Q1	0.199	0.007	0.206	2.405	155.277	158.708
2015-07-02	Q1	0.108	0.010	0.119	3.152	160.717	156.791
2015-07-10	Q1	0.110	0.017	0.126	3.542	152.834	158.067
2015-07-17	Q1	0.147	0.010	0.157	3.321	157.752	151.789
2015-07-22	Q1	0.126	0.009	0.135	3.059	159.837	162.615
2015-07-30	Q1	0.127	0.016	0.143	3.657	162.117	166.617
2015-08-06	Q1	0.130	0.012	0.143	2.706	164.984	163.938
2015-08-14	Q1	0.143	0.006	0.149	2.763	175.081	165.943
2015-08-20	Q1	0.142	0.016	0.157	3.056	155.472	165.943
2015-08-28	Q1	0.149	0.011	0.161	2.331	166.547	174.213
2015-09-04	Q1	0.121	0.005	0.126	2.298	155.765	173.508
2015-09-14	Q1	0.154	0.022	0.177	2.197	151.726	170.718
2015-09-21	Q1	0.158	0.007	0.165	1.998	169.349	174.213
2015-09-30	Q1	0.142	0.017	0.160	2.704	165.961	157.427
2015-10-08	Q1	0.132	0.008	0.140	1.625	169.479	163.275

Date yy/mm/dd	Sample Location	Dissolved P (mg/l)	Particulate P (mg/l)	Total P (mg/l)	TN (mg/l	Sodium (mg/l)	Chloride Conc (mg/l)
2015-10-16	Q1	0.093	0.021	0.114	1.881	169.805	169.340
2015-10-27	Q1	0.121	0.007	0.128	2.302	162.769	172.108
2015-11-03	Q1	0.159	0.002	0.162	1.727	164.853	171.412
2015-11-06	Q1	0.122	0.002	0.123	1.104	159.302	173.508
2015-11-13	Q1	0.121	0.003	0.123	1.186	158.114	175.631
2015-11-20	Q1	0.145	0.004	0.150	1.141	156.354	166.617
2015-11-26	Q1	0.065	0.039	0.103	1.066	145.442	166.617
2015-12-08	Q1	0.134	0.004	0.138	1.327	154.836	163.275
2015-12-22	Q1	0.051	0.031	0.082	1.509	149.424	168.655
2015-12-26	Q1	0.041	0.044	0.085	1.426	149.468	166.617
2016-01-08	Q1	0.134	0.003	0.137	1.686	153.054	160.650
2016-01-18	Q1	0.123	0.008	0.131	1.542	155.034	174.213
2016-01-28	Q1	0.131	0.031	0.163	1.402	151.228	183.637
2016-02-01	Q1	0.146	0.001	0.147	1.368	151.844	184.383
2016-02-09	Q1	0.135	0.000	0.135	1.565	146.388	182.894
2016-02-12	Q1	0.130	0.000	0.130	1.579	146.960	181.418
2016-02-16	Q1	0.142	0.010	0.151	3.359	147.070	181.418
2016-02-19	Q1	0.143	0.003	0.146	1.838	144.166	177.779
2016-02-24	Q1	0.130	0.005	0.135	1.584	140.008	166.617
2016-02-29	Q1	0.068	0.000	0.068	1.637	135.740	157.427
2016-03-04	Q1	0.143	0.001	0.144	1.411	131.648	153.646
2016-03-07	Q1	0.140	0.013	0.152	1.047	130.614	147.543
2016-03-11	Q1	0.158	0.007	0.165	0.845	123.398	139.406
2016-03-16	Q1	0.144	0.007	0.151	1.881	121.154	134.958
2016-03-21	Q1	0.122	0.080	0.202	2.131	121.528	132.251
2016-03-30	Q1	0.153	0.030	0.183	2.769	121.660	136.609
2016-04-05	Q1	0.151	0.059	0.210	2.553	121.814	131.716
2016-04-19	Q1	0.156	0.066	0.223	2.328	122.782	142.837
2015-03-05	Q2	0.306	0.009	0.315	7.339	142.215	127.515
2015-03-09	Q2	0.287	0.005	0.293	6.419	143.322	132.788
2015-03-16	Q2	0.262	0.002	0.265	5.834	140.651	128.552
2015-03-19	Q2	0.221	0.008	0.230	5.566	149.316	131.716
2015-03-23	Q2	0.235	0.004	0.239	5.075	151.987	130.125
2015-03-26	Q2	0.271	0.007	0.278	6.004	148.958	125.974
2015-03-31	Q2	0.217	0.018	0.235	6.803	153.518	128.032
2015-04-07	Q2	0.200	0.016	0.217	7.303	140.489	131.184
2015-04-10	Q2	0.180	0.023	0.202	6.968	139.609	128.032
2015-04-19	Q2	0.153	0.010	0.163	6.491	135.114	123.948

Date yy/mm/dd	Sample Location	Dissolved P (mg/l)	Particulate P (mg/l)	Total P (mg/l)	TN (mg/l	Sodium (mg/l)	Chloride Conc (mg/l)
2015-04-24	Q2	0.181	0.006	0.187	5.556	143.648	125.464
2015-04-30	Q2	0.226	0.023	0.249	6.769	137.362	126.485
2015-05-04	Q2	0.298	0.063	0.361	3.504	132.638	112.917
2015-05-08	Q2	0.247	0.025	0.272	3.835	127.524	112.917
2015-05-12	Q2	0.244	0.045	0.289	3.152	135.179	112.006
2015-05-15	Q2	0.174	0.130	0.304	3.561	126.482	109.315
2015-05-19	Q2	0.176	0.041	0.217	3.535	128.339	110.205
2015-05-29	Q2	0.262	0.028	0.290	4.626	133.876	102.038
2015-06-02	Q2	0.569	0.121	0.690	4.259	138.502	111.102
2015-06-07	Q2	0.267	0.035	0.302	3.993	141.759	102.868
2015-06-15	Q2	0.309	0.044	0.353	3.334	142.248	108.433
2015-06-20	Q2	0.303	0.101	0.404	3.953	141.792	101.625
2015-06-26	Q2	0.296	0.060	0.356	3.595	143.518	112.006
2015-07-02	Q2	0.315	0.061	0.375	4.436	141.010	118.065
2015-07-10	Q2	0.332	0.102	0.435	3.449	132.638	116.166
2015-07-17	Q2	0.275	0.066	0.340	3.741	150.977	120.481
2015-07-22	Q2	0.235	0.063	0.298	4.157	151.238	124.957
2015-07-30	Q2	0.292	0.053	0.345	4.321	147.785	130.653
2015-08-06	Q2	0.268	0.107	0.375	4.462	148.534	135.506
2015-08-14	Q2	0.296	0.069	0.365	3.980	147.524	138.842
2015-08-20	Q2	0.282	0.035	0.317	3.413	145.798	144.584
2015-08-28	Q2	0.235	0.031	0.266	2.675	147.622	143.417
2015-09-04	Q2	0.235	0.022	0.257	2.837	136.156	144.584
2015-09-14	Q2	0.249	0.016	0.265	2.890	140.554	151.789
2015-09-21	Q2	0.253	0.033	0.286	2.197	142.606	146.947
2015-09-30	Q2	0.205	0.012	0.217	3.081	145.244	131.184
2015-10-08	Q2	0.190	0.011	0.200	2.951	146.189	138.842
2015-10-16	Q2	0.151	0.017	0.167	3.137	141.954	141.111
2015-10-27	Q2	0.131	0.007	0.138	2.947	144.495	143.417
2015-11-03	Q2	0.153	0.001	0.153	3.397	145.993	142.259
2015-11-06	Q2	0.122	0.002	0.124	2.013	137.632	138.842
2015-11-13	Q2	0.126	0.003	0.129	2.083	138.468	146.947
2015-11-20	Q2	0.138	0.003	0.141	1.864	135.762	145.171
2015-11-26	Q2	0.442	0.033	0.475	1.856	136.444	141.111
2015-12-08	Q2	0.123	0.006	0.129	2.719	127.380	142.837
2015-12-22	Q2	0.066	0.024	0.090	2.207	122.782	146.352
2015-12-26	Q2	0.040	0.030	0.070	2.476	112.200	116.166
2016-01-08	Q2	0.103	0.007	0.110	2.385	132.858	133.328
2016-01-18	Q2	0.125	0.009	0.135	2.104	124.080	137.721

Date yy/mm/dd	Sample Location	Dissolved P (mg/l)	Particulate P (mg/l)	Total P (mg/l)	TN (mg/l	Sodium (mg/l)	Chloride Conc (mg/l)
2016-01-28	Q2	0.102	0.003	0.105	1.315	122.210	134.413
2016-02-01	Q2	0.181	0.006	0.186	3.724	125.840	140.540
2016-02-09	Q2	0.158	0.000	0.158	3.129	123.970	139.406
2016-02-12	Q2	0.338	0.015	0.353	3.100	116.842	124.451
2016-02-16	Q2	0.281	0.009	0.290	3.143	115.192	126.485
2016-02-19	Q2	0.233	0.008	0.240	3.138	118.646	126.485
2016-02-24	Q2	0.174	0.006	0.180	3.762	123.728	132.788
2016-02-29	Q2	0.174	0.008	0.182	2.860	124.212	134.958
2016-03-04	Q2	0.148	0.002	0.151	2.328	119.878	134.958
2016-03-07	Q2	0.165	0.006	0.171	2.323	122.144	131.716
2016-03-11	Q2	0.166	0.000	0.166	3.791	121.220	131.184
2016-03-16	Q2	0.139	0.013	0.152	3.820	123.728	129.074
2016-03-21	Q2	0.139	0.087	0.226	4.141	124.146	127.515
2016-03-30	Q2	0.155	0.085	0.240	4.155	123.552	127.515
2016-04-05	Q2	0.154	0.069	0.223	3.968	123.244	128.032
2016-04-13	Q2	0.141	0.068	0.209	4.222	125.598	126.485
2016-04-19	Q2	0.146	0.064	0.210	3.973	125.400	125.464
2015-03-05	GW seep	0.234	0.021	0.255	3.097	122.801	113.376
2015-03-09	GW seep	0.226	0.001	0.227	3.289	128.306	105.400
2015-03-16	GW seep	0.210	-0.002	0.208	2.830	114.072	99.991
2015-03-19	GW seep	0.214	-0.002	0.212	2.338	123.094	94.094
2015-03-23	GW seep	0.210	0.000	0.209	2.624	112.410	88.544
2015-03-26	GW seep	0.213	0.007	0.220	2.874	124.202	86.417
2015-03-31	GW seep	0.210	0.001	0.212	2.584	112.117	86.768
2015-04-07	GW seep	0.163	0.007	0.170	2.240	105.603	85.720
2015-04-10	GW seep	0.231	0.004	0.234	2.727	102.476	90.724
2015-04-19	GW seep	0.233	0.002	0.235	2.374	108.990	89.991
2015-04-24	GW seep	0.237	0.003	0.240	3.091	109.121	87.829
2015-04-30	GW seep	0.247	0.006	0.254	3.039	108.925	90.724
2015-05-04	GW seep	0.244	0.007	0.251	2.270	108.208	92.206
2015-05-08	GW seep	0.256	0.003	0.259	2.552	105.896	95.245
2015-05-12	GW seep	0.236	0.003	0.239	2.378	112.052	99.184
2015-05-15	GW seep	0.116	-0.001	0.116	1.905	119.870	98.383
2015-05-19	GW seep	0.146	0.000	0.146	1.796	113.257	99.991
2015-05-29	GW seep	0.210	0.001	0.211	3.259	132.248	102.452
2015-06-02	GW seep	0.258	0.002	0.260	2.657	117.622	100.805
2015-06-07	GW seep	0.275	0.001	0.277	2.201	120.065	96.020
2015-06-15	GW seep	0.270	0.012	0.282	2.210	124.951	99.586
2015-06-20	GW seep	0.278	0.003	0.281	2.285	122.378	107.557

Date yy/mm/dd	Sample Location	Dissolved P (mg/l)	Particulate P (mg/l)	Total P (mg/l)	TN (mg/l	Sodium (mg/l)	Chloride Conc (mg/l)
2015-06-26	GW seep	0.305	0.005	0.310	2.586	123.844	104.974
2015-07-02	GW seep	0.084	0.014	0.098	2.776	119.414	113.836
2015-07-10	GW seep	0.156	0.003	0.159	3.378	123.257	109.315
2015-07-22	GW seep	0.212	0.005	0.217	2.564	129.088	118.544
2015-07-30	GW seep	0.181	0.006	0.187	2.175	127.134	121.462
2015-08-06	GW seep	0.195	0.003	0.198	2.714	126.059	121.462
2015-08-14	GW seep	0.196	0.006	0.201	3.108	123.355	123.948
2015-08-20	GW seep		NA	NA	NA	126.000	126.485
2015-08-28	GW seep	0.175	0.013	0.188	1.767	124.658	128.032
2015-09-04	GW seep	0.221	0.008	0.229	2.266	127.883	130.125
2015-09-14	GW seep	0.218	0.006	0.224	1.565	120.782	126.485
2015-09-21	GW seep	0.194	0.003	0.197	1.232	121.987	125.464
2015-09-30	GW seep	0.224	0.005	0.229	1.394	119.153	118.065
2015-10-08	GW seep	0.220	0.004	0.224	1.179	120.684	116.638
2015-10-16	GW seep	0.148	0.015	0.162	2.059	122.052	122.450
2015-10-27	GW seep	0.112	0.006	0.118	1.686	118.990	122.948
2015-11-03	GW seep	0.162	0.000	0.162	1.836	123.290	128.032
2015-11-06	GW seep	0.167	0.001	0.168	1.257	123.024	133.869
2015-11-13	GW seep	0.158	0.001	0.159	1.228	120.736	137.164
2015-11-20	GW seep	0.222	0.001	0.224	1.414	120.296	138.842
2015-11-26	GW seep	0.198	0.004	0.203	1.405	121.748	142.837
2015-12-08	GW seep	0.247	0.001	0.248	1.901	117.942	140.540
2015-12-22	GW seep	0.161	0.014	0.175	1.331	77.946	103.286
2016-01-08	GW seep	0.253	0.049	0.302	1.662	112.662	129.074
2016-01-18	GW seep	0.219	0.003	0.222	2.199	114.202	134.958
2016-01-28	GW seep	0.249	0.000	0.249	2.659	103.884	122.948
2016-02-01	GW seep	0.241	0.000	0.241	3.110	103.114	122.450
2016-02-09	GW seep	0.107	NA	NA	1.853	108.812	160.000
2016-02-12	GW seep	0.207	0.000	0.207	2.946	110.946	168.655
2016-02-16	GW seep	0.206	0.001	0.206	2.083	109.890	161.302
2016-02-24	GW seep	0.230	0.000	0.230	2.788	106.942	116.638
2016-02-29	GW seep	0.197	0.000	0.197	2.313	99.154	91.833
2016-03-04	GW seep	0.181	0.000	0.181	1.066	89.518	74.384
2016-03-07	GW seep	0.182	0.002	0.184	1.354	87.956	73.784
2016-03-11	GW seep	0.179	0.002	0.181	2.395	84.370	68.872
2016-03-16	GW seep	0.165	0.001	0.166	2.898	81.026	64.287
2016-03-21	GW seep	0.080	0.004	0.083	3.359	79.750	62.488
2016-03-30	GW seep	0.172	0.001	0.173	3.239	79.508	63.510

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2016-04-05	GW seep	0.175	0.000	0.175	2.841	77.880	62.236
2016-04-13	GW seep	0.102	0.047	0.149	3.373	79.442	65.073
2016-04-19	GW seep	0.178	0.003	0.181	2.942	83.028	72.597
2015-03-05	Q3	0.070	0.044	0.114	5.071	171.336	196.734
2015-03-09	Q3	0.068	0.003	0.071	5.705	155.700	186.638
2015-03-16	Q3	0.092	0.000	0.093	5.803	159.577	188.921
2015-03-19	Q3	0.072	-0.001	0.071	5.196	155.700	192.008
2015-03-23	Q3	0.070	0.001	0.070	5.490	154.756	189.688
2015-03-26	Q3	0.055	0.003	0.058	5.834	150.293	174.920
2015-03-31	Q3	0.081	0.006	0.087	5.258	182.085	174.213
2015-04-07	Q3	0.024	0.007	0.031	3.776	147.394	182.155
2015-04-10	Q3	0.031	0.007	0.038	5.352	152.150	185.131
2015-04-19	Q3	0.044	0.003	0.047	4.682	156.743	187.396
2015-04-24	Q3	0.074	0.009	0.084	3.948	179.674	188.157
2015-04-30	Q3	0.102	0.006	0.107	3.709	158.469	192.008
2015-05-04	Q3	0.101	0.012	0.113	3.044	183.713	179.226
2015-05-08	Q3	0.235	0.035	0.271	-2.447	167.980	195.146
2015-05-12	Q3	0.098	0.011	0.109	2.248	163.518	194.357
2015-05-15	Q3	0.048	0.005	0.053	2.578	189.316	195.146
2015-05-19	Q3	0.037	0.003	0.040	2.652	162.997	185.883
2015-05-29	Q3	0.139	0.059	0.197	5.396	164.984	166.617
2015-06-02	Q3	0.174	0.003	0.177	4.321	155.147	154.896
2015-06-07	Q3	0.164	0.007	0.171	2.767	158.404	160.650
2015-06-15	Q3	0.153	0.011	0.164	5.471	166.971	171.412
2015-06-20	Q3	0.135	0.005	0.140	3.086	176.417	185.131
2015-06-26	Q3	0.150	0.004	0.154	4.228	168.371	179.226
2015-07-02	Q3	0.167	0.030	0.197	3.542	179.674	182.894
2015-07-10	Q3	0.234	0.032	0.265	4.644	152.932	142.837
2015-07-17	Q3	0.072	0.008	0.080	3.343	172.704	163.938
2015-07-22	Q3	0.091	0.013	0.104	3.144	174.723	176.344
2015-07-30	Q3	0.125	0.002	0.128	3.856	153.941	148.744
2015-08-06	Q3	0.057	0.004	0.061	3.967	164.625	155.525
2015-08-14	Q3	0.079	0.010	0.089	4.059	158.274	163.938
2015-08-20	Q3	0.078	0.010	0.088	2.874	173.453	180.684
2015-08-28	Q3	0.076	0.010	0.086	2.537	187.101	186.638
2015-09-04	Q3	0.065	0.004	0.070	2.497	183.909	197.533
2015-09-14	Q3	0.097	0.021	0.118	1.824	169.805	186.638
2015-09-21	Q3	0.065	0.014	0.079	2.769	180.814	189.688
2015-09-30	Q3	0.056	0.011	0.067	2.128	179.381	174.920

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2015-10-08	Q3	0.042	0.007	0.049	2.011	166.124	167.294
2015-10-16	Q3	0.052	0.008	0.060	2.302	164.593	178.501
2015-10-27	Q3	0.071	0.008	0.079	2.740	163.583	175.631
2015-11-03	Q3	0.064	0.004	0.068	2.777	154.430	168.655
2015-11-06	Q3	0.067	0.000	0.068	1.356	153.648	166.617
2015-11-13	Q3	0.066	0.001	0.067	1.587	157.344	172.108
2015-11-20	Q3	0.169	0.006	0.176	1.628	141.790	156.156
2015-11-26	Q3	0.040	0.023	0.063	1.765	160.292	179.953
2015-12-08	Q3	0.167	0.001	0.168	1.802	132.352	151.175
2015-12-22	Q3	0.045	0.025	0.070	1.893	125.136	167.294
2016-01-08	Q3	0.101	0.002	0.103	2.067	140.602	154.896
2016-01-18	Q3	0.115	0.003	0.118	1.897	141.966	166.617
2016-01-28	Q3	0.120	0.003	0.123	2.280	138.534	160.650
2016-02-01	Q3	0.136	0.000	0.136	2.659	138.490	169.340
2016-02-09	Q3	0.212	0.000	0.212	2.160	144.254	179.226
2016-02-12	Q3	0.135	0.003	0.138	2.107	135.366	172.806
2016-02-16	Q3	0.169	0.005	0.174	0.006	133.760	172.806
2016-02-19	Q3	0.129	0.002	0.130	1.819	138.182	176.344
2016-02-24	Q3	0.103	0.001	0.103	1.498	146.080	185.131
2016-02-29	Q3	0.086	0.000	0.086	2.519	149.028	177.779
2016-03-04	Q3	0.081	0.006	0.087	1.008	141.460	179.226
2016-03-07	Q3	0.089	0.005	0.093	2.035	137.632	167.973
2016-03-11	Q3	0.082	0.011	0.093	3.110	140.206	169.340
2016-03-16	Q3	0.075	0.002	0.076	3.196	141.922	170.718
2016-03-21	Q3	0.070	0.011	0.081	3.340	142.054	165.272
2016-03-30	Q3	0.086	0.009	0.095	2.332	136.972	165.943
2016-04-05	Q3	0.108	0.029	0.137	2.361	138.248	167.973
2016-04-13	Q3	0.089	0.040	0.130	3.143	140.844	172.108
2016-04-19	Q3	0.116	0.086	0.202	2.472	139.898	175.631
2015-03-05	Q4	0.076	0.003	0.078	2.794	143.876	144.584
2015-03-09	Q4	0.071	0.000	0.071	3.338	145.700	152.405
2015-03-16	Q4	0.064	0.000	0.064	3.388	175.700	185.131
2015-03-19	Q4	0.129	0.000	0.129	2.879	207.166	192.788
2015-03-23	Q4	0.129	0.002	0.131	3.075	187.427	178.501
2015-03-26	Q4	0.113	0.012	0.125	3.294	176.840	151.789
2015-03-31	Q4	0.161	0.010	0.171	3.495	211.401	170.028
2015-04-07	Q4	0.153	0.006	0.159	3.486	217.883	191.232
2015-04-10	Q4	0.155	0.009	0.164	2.557	192.834	199.141

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2015-04-19	Q4	0.187	0.011	0.198	3.652	202.573	210.766
2015-04-24	Q4	0.224	0.011	0.235	3.987	228.860	216.830
2015-04-30	Q4	0.194	0.008	0.202	2.965	206.710	202.395
2015-05-04	Q4	0.134	0.003	0.137	3.170	208.111	208.219
2015-05-08	Q4	0.134	0.008	0.141	1.944	205.928	201.577
2015-05-12	Q4	0.061	0.005	0.066	1.622	208.534	203.217
2015-05-15	Q4	0.084	0.006	0.090	2.865	233.681	217.711
2015-05-19	Q4	0.052	0.001	0.053	1.926	221.466	217.711
2015-05-29	Q4	0.307	0.004	0.311	3.498	211.270	174.213
2015-06-02	Q4	0.236	0.009	0.246	2.400	190.358	148.744
2015-06-07	Q4	0.305	0.006	0.312	3.728	162.052	125.464
2015-06-15	Q4	0.351	0.022	0.373	3.480	142.834	119.994
2015-06-20	Q4	0.316	0.005	0.321	3.617	171.010	151.789
2015-06-26	Q4	0.371	0.009	0.380	3.387	195.277	170.028
2015-07-02	Q4	0.488	0.025	0.513	3.307	240.293	221.269
2015-07-10	Q4	0.243	0.133	0.376	7.356	223.648	184.383
2015-07-17	Q4	0.271	0.009	0.280	3.546	184.365	157.427
2015-07-22	Q4	0.284	0.009	0.293	4.139	190.717	164.604
2015-07-30	Q4	0.216	0.006	0.222	4.829	212.085	181.418
2015-08-06	Q4	0.180	0.003	0.183	3.975	214.625	188.157
2015-08-14	Q4	0.302	0.006	0.308	3.874	225.896	209.064
2015-08-20	Q4	0.250	0.025	0.275	3.105	107.166	208.219
2015-08-28	Q4	0.317	0.011	0.329	2.521	174.886	158.708
2015-09-04	Q4	0.162	0.003	0.165	3.129	187.557	182.155
2015-09-14	Q4	0.261	0.018	0.279	3.591	192.248	185.883
2015-09-21	Q4	0.213	0.009	0.222	7.171	212.638	222.167
2015-09-30	Q4	0.216	0.022	0.238	5.294	209.349	201.577
2015-10-08	Q4	0.165	0.009	0.174	3.044	222.704	219.483
2015-10-27	Q4	0.115	0.011	0.126	2.566	209.316	202.395
2015-11-03	Q4	0.121	0.010	0.131	4.621	212.378	207.377
2015-11-06	Q4	0.108	0.002	0.110	1.306	207.020	211.622
2015-11-13	Q4	0.105	0.003	0.108	1.852	204.952	205.703
2015-11-20	Q4	0.137	0.005	0.143	1.926	204.006	211.622
2015-11-26	Q4	0.106	0.009	0.115	2.273	204.248	227.636
2015-12-08	Q4	0.100	0.001	0.101	1.785	180.466	189.688
2015-12-22	Q4	0.044	0.030	0.075	2.166	198.352	207.377
2016-01-18	Q4	0.112	0.003	0.116	2.054	167.024	193.571
2016-01-28	Q4	0.106	0.000	0.106	1.411	179.432	186.638
2016-02-01	Q4	0.127	0.000	0.127	1.886	191.356	202.395

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2016-02-09	Q4	0.107	0.000	0.107	2.452	200.794	209.913
2016-02-12	Q4	0.101	0.001	0.102	1.219	176.902	186.638
2016-02-16	Q4	0.133	0.001	0.134	1.968	180.796	189.688
2016-02-19	Q4	0.126	0.002	0.128	2.874	187.330	191.232
2016-02-24	Q4	0.105	0.001	0.106	1.781	191.400	204.871
2016-02-29	Q4	0.103	0.000	0.103	1.032	186.714	195.939
2016-03-04	Q4	0.094	0.010	0.104	1.435	124.168	129.599
2016-03-07	Q4	0.099	0.009	0.107	1.795	112.706	121.462
2016-03-11	Q4	0.095	0.011	0.106	2.486	115.390	125.974
2016-03-16	Q4	0.091	0.004	0.095	2.999	123.750	131.716
2016-03-21	Q4	0.097	0.036	0.133	2.759	122.056	130.653
2016-03-30	Q4	0.087	0.092	0.179	2.203	131.868	139.972
2016-04-05	Q4	0.129	0.057	0.186	2.395	142.054	154.896
2016-04-13	Q4	0.090	0.045	0.135	2.966	163.900	179.953
2016-04-19	Q4	0.150	0.034	0.184	1.800	183.766	211.622
2015-03-05	Q5	0.046	0.000	0.046	2.182	113.257	80.992
2015-03-09	Q5	0.049	0.001	0.050	2.307	100.228	76.215
2015-03-16	Q5	0.051	0.000	0.051	1.499	95.147	68.039
2015-03-19	Q5	0.054	0.000	0.054	1.280	110.065	65.602
2015-03-23	Q5	0.046	0.000	0.046	1.593	105.733	68.039
2015-03-26	Q5	0.052	0.005	0.058	2.021	112.899	63.510
2015-03-31	Q5	0.048	0.005	0.053	1.812	114.756	61.484
2015-04-07	Q5	0.052	0.002	0.055	1.763	92.769	64.810
2015-04-10	Q5	0.013	0.012	0.025	2.057	90.033	65.869
2015-04-19	Q5	0.019	0.003	0.022	1.622	96.515	68.593
2015-04-24	Q5	0.027	0.010	0.037	2.861	94.072	71.430
2015-04-30	Q5	0.021	0.009	0.029	2.157	95.081	69.714
2015-05-04	Q5	0.014	0.002	0.017	1.722	99.153	71.430
2015-05-08	Q5	0.021	0.006	0.027	2.292	96.775	68.316
2015-05-12	Q5	0.022	0.002	0.024	1.479	97.590	72.892
2015-05-15	Q5	0.018	0.000	0.018	1.083	98.567	72.304
2015-05-19	Q5	0.024	0.000	0.024	0.905	97.622	74.686
2016-02-12	Q5	0.045	0.002	0.046	1.315	94.270	79.046
2016-02-16	Q5	0.050	0.000	0.050	1.013	90.134	71.430
2016-02-19	Q5	0.050	0.000	0.050	1.891	91.894	75.294
2016-02-24	Q5	0.309	0.001	0.310	1.829	84.282	68.593
2016-02-29	Q5	0.055	0.000	0.055	1.402	79.728	72.011
2016-03-04	Q5	0.062	0.013	0.075	0.956	73.634	51.027

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2016-03-07	Q5	0.062	0.002	0.064	1.066	62.700	47.437
2016-03-11	Q5	0.071	0.003	0.073	2.615	68.948	42.867
2016-03-16	Q5	0.059	0.015	0.075	3.042	69.982	47.823
2016-03-21	Q5	0.069	0.023	0.092	2.788	68.882	47.823
2016-03-30	Q5	0.073	0.049	0.121	2.803	66.660	46.675
2016-04-05	Q5	0.068	0.065	0.132	2.769	65.736	47.630
2016-04-13	Q5	0.078	0.020	0.097	3.110	67.474	49.600
2016-04-19	Q5	0.075	0.048	0.124	2.683	69.410	53.787
2015-02-28	Backgrou nd	0.068	0.006	0.074	0.941	15.678	6.356
2015-03-12	Backgrou nd	0.045	0.000	0.045	3.276	13.798	6.279
2015-03-17	Backgrou nd	0.036	0.000	0.036	1.374	15.739	6.565
2015-03-23	Backgrou nd	0.042	0.001	0.043	1.173	16.256	6.645
2015-03-31	Backgrou nd	0.048	0.009	0.056	1.280	16.485	6.837
2015-04-10	Backgrou nd	0.008	0.006	0.014	1.575	16.528	7.658
2015-04-19	Backgrou nd	0.008	0.000	0.008	1.557	18.463	8.338
2015-04-24	Backgrou nd	0.014	0.004	0.018	1.813	16.925	7.119
2015-05-04	Backgrou nd	0.010	0.006	0.017	1.205	16.883	6.565
2015-05-12	Backgrou nd	0.004	0.003	0.007	0.622	17.772	6.512
2015-05-19	Backgrou nd	0.018	0.000	0.018	1.396	21.658	7.689
2016-02-16	Backgrou nd	0.051	0.000	0.051	2.059	16.636	7.783
2016-02-19	Backgrou nd	0.088	0.000	0.088	1.431	15.552	6.864
2016-02-19	Backgrou nd	0.077	0.000	0.077	1.239	15.442	6.699
2016-02-24	Backgrou nd	0.065	0.000	0.065	0.404	14.960	6.781
2016-02-29	Backgrou nd	0.062	0.000	0.062	0.639	15.112	6.381
2016-03-04	Backgrou nd	0.069	0.006	0.074	0.682	14.516	6.672
2016-03-07	Backgrou	0.077	0.005	0.082	0.749	14.106	7.062

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	nd						
2016-03-11	Background	0.077	0.001	0.078	3.028	14.870	6.892
2016-03-16	Background	0.063	0.000	0.063	2.543	14.557	6.781
2016-03-21	Background	0.069	0.017	0.086	3.086	14.874	7.783
2016-03-30	Background	0.065	0.000	0.065	2.798	15.046	6.645
2015-05-04	Background	0.023	0.003	0.026	0.892	27.752	8.648
2015-05-12	Background	0.038	0.008	0.047	1.470	29.492	9.042
2015-05-12	Irr1	1.167	0.008	1.175	3.509	108.893	101.625
2015-05-15	Irr1	0.610	0.005	0.615	3.704	112.834	102.038
2015-05-29	Irr 1	0.811	0.006	0.816	5.130	117.655	94.859
2015-06-07	Irr 1	0.803	0.005	0.808	4.878	139.544	94.859
2015-06-15	Irr 1	0.846	0.007	0.853	4.887	110.130	96.801
2015-06-26	Irr 1	0.661	0.005	0.666	4.913	114.951	102.038
2015-07-02	Irr 1	0.636	0.007	0.643	5.444	110.228	106.258
2015-07-10	Irr 1	0.690	0.016	0.705	6.068	110.847	104.126
2015-07-22	Irr 1	0.804	0.006	0.810	5.179	111.433	104.549
2015-08-14	Irr 1	0.686	0.014	0.700	4.316	109.837	112.006
2015-08-20	Irr 1	0.604		0.604	NA	80.586	102.868
2015-09-04	Irr 1	0.571	0.030	0.601	2.578	112.182	117.587
2015-09-14	Irr 1	0.591	0.019	0.609	2.359	110.554	117.587
2015-09-21	Irr 1	0.603	0.031	0.634	2.987	112.020	107.122
2015-09-30	Irr 1	0.526	0.024	0.550	1.994	117.003	114.762
2015-10-08	Irr 1	0.640	0.023	0.663	2.627	103.160	114.298
2015-05-29	Jeff Well	0.342	0.000	0.342	8.117	187.199	124.451
2015-07-02	Jeff Well	0.263	0.003	0.266	7.502	169.674	130.125
2015-07-10	Jeff Well	0.312	0.004	0.316	6.440	158.990	122.948
2015-07-22	Jeff Well	0.337	0.000	0.337	6.542	157.818	133.328
2015-08-14	Jeff Well	0.408	0.001	0.408	6.732	194.984	178.501
2015-09-14	Jeff Well	0.395	0.016	0.412	3.798	162.834	162.615
2015-10-16	Jeff Well	0.358	0.005	0.363	4.536	178.860	138.842
2015-11-03	Jeff Well	0.310	0.001	0.312	5.939	173.811	152.405
2015-11-20	Jeff Well	0.277	0.000	0.277	3.885	163.174	152.405
2015-12-22	Jeff Well	0.281	0.010	0.291	3.645	173.602	199.141
2016-01-18	Jeff Well	0.223	0.007	0.231	3.600	183.700	273.174

Date yy/mm/dd	Sample Location	Dissolved P (mg/l)	Particulate P (mg/l)	Total P (mg/l)	TN (mg/l	Sodium (mg/l)	Chloride Conc (mg/l)
2016-02-24	Jeff Well	0.043	0.000	0.043	4.793	180.730	200.761
2016-03-11	Jeff Well	0.312	0.005	0.316	4.573	170.830	162.615
2016-03-21	Jeff Well	0.306	0.003	0.309	6.146	162.074	155.525
2016-04-05	Jeff Well	0.285	0.009	0.294	6.899	158.114	162.615
2016-04-13	Jeff Well	0.272	0.013	0.285	5.863	152.328	162.615

Appendix D: Soil Data

Table D1: Soil Data

Sample ID	Location	Irrigated	dried sample (g)	Organics by %	Bulk density (g/cm3)	Total P (mg/g ash)	Total P mg/soil sample	Total P mg/m2 of soil to depth of 0.45 meters	kg/ha to a depth of 45cm
2	Fitchits	I	276.7	5.24	0.54	0.70	194.47	172105	1721.1
3	Jeffs	I	350.1	3.87	0.68	0.65	227.69	201502	2015.0
14	Central North	I	294.8	3.55	0.57	0.53	155.03	137205	1372.1
15	Central North	I	345.3	3.18	0.67	0.54	186.04	164644	1646.4
16	East Central	I	493.4	2.65	0.96	0.57	280.72	248435	2484.3
17	East Central	I	382.5	1.98	0.75	0.37	142.51	126126	1261.3
18	Middle of Daves	I	360.0	4.02	0.70	0.67	241.07	213349	2133.5
19	South Daves	I	467.7	2.23	0.91	0.60	279.26	247147	2471.5
20	South Daves	I	618.7	2.53	1.21	0.56	346.38	306542	3065.4
23	Middle of Daves	I	372.0	3.10	0.73	0.48	179.14	158541	1585.4
24	Middle of Daves	I	274.6	3.45	0.54	0.56	152.76	135191	1351.9
1	By Atm 1	U	622.9	1.20	1.21	0.29	179.16	158556	1585.6
4	By Weather station	U	573.2	1.88	1.12	0.48	274.76	243160	2431.6
5	By Q3	U	462.8	4.03	0.90	0.38	173.84	153852	1538.5
7	West side up on ridge	U	629.4	1.96	1.23	0.43	270.81	239671	2396.7
8	West side	U	510.0	2.08	0.99	0.45	227.76	201564	2015.6
9	West side	U	740.4	1.13	1.44	0.47	351.16	310780	3107.8
13	North by BG1	U	244.8	5.58	0.48	0.06	14.89	13175	131.8
11	North	U	609.8	1.76	1.19	0.45	274.25	242711	2427.1
12	North	U	485.4	1.40	0.95	0.43	208.57	184582	1845.8
21	North Daves	U	522.3	1.30	1.02	0.35	182.80	161775	1617.7
22	North Daves	U	433.0	1.83	0.84	0.22	97.11	85946	859.5

Appendix E: Atmospheric Data

Table E1: Atmospheric Data for phosphorus

Sampling Date	Atm 1	Atm 2	Atm 3	Atm 4	Atm 5	Atm 6	Average	Standard Deviation
2015-05-21	0.197	0.056	0.110		0.157	0.155	0.135	0.054
2015-05-29	0.082	0.071	0.129	0.326	0.085	0.110	0.134	0.096
2015-06-02	0.076	0.057	0.534	0.229	0.098	0.140	0.189	0.180
2015-06-26	0.161	0.213	NA	0.262	0.200	0.969	0.361	0.342
2015-07-24	0.234	0.191	0.180	0.368	0.265	1.493	0.455	0.513
2015-08-20	0.467	0.458	0.284	0.577	0.346	0.502	0.439	0.106
2015-09-02	0.233	0.205	0.199	0.479	0.263	1.925	0.551	0.681
2015-09-21	0.107	0.126	0.125	0.166	0.082	0.093	0.116	0.030
2015-10-08	0.049	0.134	0.106	0.037	0.502	0.214	0.174	0.173
2015-10-28	0.047	0.081	0.083	0.045	0.122	0.428	0.134	0.147
2015-11-03	0.042	0.052	0.041	0.040	0.038	0.159	0.062	0.048
2015-11-17	0.023	0.026	0.015	0.026	0.375	0.119	0.097	0.142
2015-11-26	0.024	0.024	0.054	0.165	0.026	0.045	0.056	0.055
2015-12-09	0.030	0.030	0.032	0.042	0.072	0.078	0.047	0.022
2015-12-26	0.043	0.043	0.039	0.076	0.082	0.138	0.070	0.038
2016-01-19	0.045	0.041	0.035	0.046	0.071	0.097	0.056	0.024
2016-01-28	0.017	0.029	0.028	0.017	0.195	0.114	0.067	0.073
2016-02-12	0.068	0.050	0.136	0.065	0.156	0.086	0.093	0.043
2016-03-02	0.089	0.070	0.287	0.096	0.143	0.160	0.141	0.079
2016-03-23	0.113	0.119	0.179	0.121	0.241	1.961	0.455	0.739
2016-04-28	0.371	0.639	1.278	0.602	0.274		0.633	0.392

Table E2: Atmospheric Data for nitrogen

Date	Atm 1	Atm 2	Atm 3	Atm 4	Atm 5	Atm 6	Average	Standard Deviation
2015-05-21	0.334	0.501	1.671	2.465	2.459	2.919	1.725	1.091
2015-05-29	1.307	0.969	0.859	1.623	2.343	1.369	1.411	0.534
2015-06-02	0.329	0.887	3.871	0.824	1.338	0.317	1.261	1.335
2015-06-26	2.571	2.273		2.488	9.897	6.908	4.827	3.432
2015-07-24	1.603	1.791	1.615	2.902	2.225	11.024	3.527	3.706
2015-08-20	2.602	1.772	0.648	4.588	1.998		2.321	1.451
2015-09-02	1.548	1.299	0.499	2.320	1.558		1.445	0.653
2015-09-21	0.495	0.504	0.432	0.962	0.693	1.109	0.699	0.279
2015-10-08	0.777	0.970	0.916	1.127	1.113	11.963	2.811	4.485
2015-10-28	0.481	0.918	0.799	0.781	0.919	6.781	1.780	2.455
2015-11-03	0.348	0.633	0.401	0.418	0.403	6.069	1.379	2.300
2015-11-17	0.405	0.889	0.134	0.280	1.352	3.859	1.153	1.399
2015-11-26	0.058	0.687	1.047	0.574	0.669	2.283	0.886	0.754
2015-12-09	0.723		0.459	0.490	0.893	2.257	0.964	0.744
2015-12-26	0.491	0.295	0.315	0.520	1.032	3.057	0.952	1.065
2016-01-19	0.708	0.649	0.731	0.889	1.119	1.727	0.970	0.408
2016-01-28	0.419	0.236	0.011	0.111	1.080	3.343	0.867	1.271
2016-02-12	0.729	0.331	0.570	0.930	1.284	1.843	0.948	0.545
2016-03-02	0.270	0.191	0.634	0.742	0.747	0.946	0.588	0.296
2016-03-23	2.053	2.778	3.594	3.609	4.382	8.665	4.180	2.337
2016-04-28	3.349	4.177	4.688	4.261	2.628		3.821	0.824

Table E3: Atmospheric Data for chloride

Date	Atm 1	Atm 2	Atm 3	Atm 4	Atm 5	Atm 6	Average	Standard Deviation
2015-05-21	3.28	2.62	2.39	3.06	2.54	2.31	2.7	0.39
2015-05-29	2.62	2.03	2.70	2.52	1.99	2.58	2.4	0.31
2015-06-02	0.96	0.96		1.02	0.90	0.99	1.0	0.04
2015-06-26	9.87	7.58	10.04	7.06	7.48		8.4	1.43
2015-07-24	3.12	3.79	3.04	3.99	3.32	4.53	3.6	0.58
2015-08-20	6.61	7.89	5.95	6.57	7.13		6.8	0.72
2015-09-02	1.52	1.51	1.33	2.11	1.83	8.35	2.8	2.75
2015-09-21	1.10	0.94	0.78	0.90	2.21	1.70	1.3	0.56
2015-10-08	1.15	0.86	0.72	0.83	0.99	1.00	0.9	0.15
2015-10-28	1.47	0.76	1.03	0.91	0.83	0.68	0.9	0.28
2015-11-03	1.16	0.61	0.52	0.52	0.57	0.56	0.7	0.25
2015-11-17	0.70	0.69	0.62	0.79	0.72	0.52	0.7	0.09
2015-11-26	0.97	0.63	0.64	0.68	0.75	0.60	0.7	0.13
2015-12-09	1.48	1.16	1.07	1.28	2.37	0.85	1.4	0.53
2015-12-26	2.12	1.09	1.96	2.03	1.94	4.07	2.2	0.99
2016-01-19	1.64	1.95	2.02	2.40	3.80	1.22	2.2	0.89
2016-01-28	0.99	1.00	0.90	1.08	1.97	1.11	1.2	0.40
2016-02-12	2.73	2.30	2.49	2.11	2.19	0.99	2.1	0.61
2016-03-02	1.99	1.67	2.21	1.73	1.63	0.60	1.6	0.56
2016-03-23	2.09	1.70	2.14	1.75	1.66	2.94	2.0	0.48
2016-04-28	3.54	3.10	3.84	3.28	3.02		3.4	0.34

Appendix F: EMMA Mixing

EMMA mixing step wise process

End Member Mixing Analysis (EMMA)

EMMA is a hydro-chemical-mixing model, which is used to separate different geographical source components that make up a mixed sample using conservative tracers (Hooper and Christopherson, 1992). The use of EMMA is predicated on the following assumptions; 1) The end member concentration are temporally constant or their variations are known, 2) the mixing process is driven by hydrodynamic mixing and is linear, 3) The chosen tracers act conservatively throughout their respective flow paths, 4) and the source solutions have concentrations that are distinctly different from each other (Barthold et al., 2011).

EMMA is based on the linear process of conservative mixing of end-members with a constant concentration. In principle, it allows one to determine the relative contributions of the two different sources at a given point within the study area. In cases where there is suspected evapoconcentration of either of the End-members a mass ratio of two conservative tracers can be used.

The following steps describe the general process of an EMMA using a ratio of two tracers and subsequent determination of nutrient retention:

1. Determine the average yearly concentrations of chloride, sodium, phosphorus and nitrogen concentration in both the irrigation water and the background water.

2. Determine the average ratio of Cl/Na in both end members.

3. Determine Ratios of P/Cl and N/Cl for both end members

4. Using the ratios determined in step 2 and the negative log of a range of proportions from 0.1 to 0.99 to plot the relationship between the end members and the proportion of each within a mixed sample.

5. Determine an equation describing the plotted relationship.

6. Substitute the ratio of the two tracers in the mixed water in for X in the equation determined in steps 4 and 5, and Antilog the results to determine the predicted portions of End-member one. End-member 2 is equal to 100- End-member one.

7. Use the equation below to determine the expected concentration of the nutrient in the mixed sample.

Equation A:

$$N_{\exp ected} = ((R_{irr} * P_{irr}) + (R_{BG} * P_{BG})) * Cl_{mixed}$$

$$R_{irr} = (\frac{N_{irr}}{Cl_{irr}})$$

$$R_{BG} = (\frac{N_{BG}}{Cl_{BG}})$$

Where:

$N_{expected}$=Expected concentration (mg L^{-1}) of the chosen nutrient,

Cl_{irr}=the initial concentration (mg L^{-1}) of Chloride in irrigation water,

N_{irr}= the initial concentration (mg L^{-1}) of phosphorus in irrigation water,

P_{irr}= proportion on Irrigation water determined in previous step,

Cl_{BG} =the initial concentration (mg L^{-1}) of Chloride in Background water,

N_{BG}= the initial concentration of phosphorus in Background water,

Cl_{sample}= Chloride concentration (mg L^{-1}) in discharge sample,

and

P_{BG}= proportion on Background water determined in previous step

8. Determine the % retention of the given nutrient using the equation below.

Equation B:

$$\%retention = \frac{Nmeasured}{N \exp ected} * 100$$

Where:

$N_{measured}$= the measured concentration (mg L^{-1}) of Nutrient in the water sample,

and

$N_{expected}$=the expected concentration (mg L^{-1}) of Nutrient base on previous equation.

9. Calculate the average monthly retention and the average monthly discharge.

10. Divide the average monthly discharge by the total yearly discharge to determine the relative contribution each makes to the yearly discharge of that station.

11. Use the Equation 4 below to determine the weighted monthly retention based on daily discharge.

Equation 5:

$$WR_{monthly} = \sum Rd * (\frac{Qd}{Qm})$$

Where:

$WR_{monthly}$= Flow weighted monthly retention

Rd = Daily % retention

Qd = Daily Discharge,

and

Qy = Monthly discharge.