ABSTRACT

EFFECTIVENESS OF WATER QUALITY BENEFITS PROVIDED BY STORMWATER MANAGEMENT FACILITIES/INFILTRATION BASINS

by
Vinicius Rodrigues de Mattos Barreto

Stormwater Best Management Practices (BMP) and devices are systems frequently built under assumed design performances, but rarely verified after construction. Their effectiveness in protecting the environment against pollutants carried by stormwater runoff has been extensively questioned and investigated. This research presents a case study of an infiltration basin in Medford, NJ to verify if the 80% expected Total Suspended Solids (TSS) removal as stated in the New Jersey Stormwater BMP Manual is actually achieved. A sampling pit was installed on the site and infiltrated water samples were collected during three rain events and TSS measurements were compared with the inflow. In addition, part of the samples also had Total Phosphate (TP) and Total Nitrogen (TN) measured to verify compliance with their respective expected reduction. Results from this study show that pollutant removal vary from one event to the other and within the event itself. Greater rainfall depths yield higher pollutant concentration and only during peak pollutant wash, expected reduction was actually achieved. But for the majority of time it did not meet expected removal rates.

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For those who always believed and never doubted me:
my mother, my father, my grandparents and the love of my life.

Para aqueles que sempre acreditaram e nunca duvidaram de mim:
minha mãe, meu pai, meus avós e o amor da minha vida.

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TABLE OF CONTENTS

Chapter **Page**

0

LIST OF TABLES

Table **Page**

LIST OF FIGURES

Figure **Page**

LIST OF ABREVIATIONS

BMP	Best Management Practices
NJ	New Jersey
NPDES	National Pollutant Discharge Elimination System
TMDL	Total Maximum Daily Load
TN	Total Nitrogen
TP	Total Phosphorus / Total Phosphate
TSS	Total Suspended Solids

LIST OF DEFINITIONS

Basin	A natural depression on the earth's surface
Runoff	Water from rain or snow that flows over the surface of the earth
Weir	A dam or wall to raise the water level or divert its flow

CHAPTER 1

INTRODUCTION

Stormwater Management has been a concern in constructed areas for at least 35 years (Tixier *et al.*, 2011). Although historical stormwater management targeted flood control, current approaches focus on smaller and more frequent rain events (NJDEP, 2004; Gilbert Jenkins *et al.*, 2010).

Where there is human activity the generation of waste and pollutants occurs (USDA, 1986; Barbosa *et al.*, 2012; Lynch *et al.*, 2015). Historically wastewater has been the main focus when it comes to the subject of environmental regulations, but recent trends show a growing concern about the quality of stormwater (NJDEP, 2004; Barbosa *et al.*, 2012).

Fine particles are often carried as suspended materials by stormwater runoff and it is now well known that stormwater runoff is capable of carrying large quantities of pollutants from urban environments, and usually discharges directly into a water body (Shammaa and Zhu, 2001; NJDEP, 2004; Barbosa *et al.*, 2012; Daly *et al.*, 2014). These pollutants may vary from pavement wear, fuel combustion byproducts, salt for deicing, nutrients from fertilizer, sediment and organic matter (NJDEP, 2004; Lynch *et al.*, 2015). Sediment is one of the most significant pollutants carried by runoff and is a key constituent of Total Suspended Solids (TSS), a major parameter utilized in determining the stormwater quality (NJDEP, 2004; Pinelands Commission, 2005). Total Suspended Solids is frequently used in many stormwater studies with this purpose, since stormwater is the main source of TSS released into the environment (Erickson *et al.*, 2007; Flint and Davis, 2007; Jenkins *et al.*, 2010; Horst *et al.*, 2011; Trowsdale and Simcock, 2011; Fassman, 2012; Kayhanian *et al.*, 2012; Falbo *et al.*, 2013; Carpenter *et al.*, 2014; Maniquiz-Redillas *et al.*, 2014).

Many researchers have documented that the pollutants in urban stormwater runoff contributions are linked to the degradation of their receiving waters (Booth and Jackson, 1997; Stanfield and Kilgour, 2006; Wenger *et al.*, 2008; Clark and Pitt, 2012; Daly *et al.*, 2014; Loperfido *et al.*, 2014). Stormwater runoff from urban areas is one of the leading causes of surface waters degradation (Gilbert Jenkins *et al.*, 2010; Daly *et al.*, 2014). Therefore, controlling the pollutants discharge of the runoff, before it reaches receiving bodies and contaminates them, becomes a major goal in stormwater management projects (Clark and Pitt, 2012).

The increase of urban development over recent decades results in the increase of stormwater runoff and pollution carried to receiving waters. Urbanization usually is accompanied by vegetation clearing, soil compaction and increased imperviousness conditions. This condition has turned stormwater management into a priority concern for planning, construction and maintenance of existing stormwater infrastructure (Lucke and Nichols, 2015).

1.1 Objectives

The objective of this research is to assess and discuss the stormwater quality benefits provided by Infiltration Basins, in particular the effectiveness of filtration in the reduction of Total Suspended Solids (TSS) through field experiments, and then compare the results with the observations described in the New Jersey Best Management Practices Manual.

1.2 Best Management Practices

Stormwater Best Management Practices (BMP) are a set of strategies, techniques and structural controls that focus both on management of quantity and quality of stormwater runoff to the maximum extent practicable (NJDEP, 2004; Loperfido *et al.*, 2014). These measures have been developed and applied extensively for the past 35 years (Tixier *et al.*, 2011). Stormwater BMP devices have been traditionally used in a centralized manner with the implementation of large scale projects aiming to solve runoff issues in comprehensive areas. But since problems associated with urban hydrology remain, they have recently been implemented in a more distributed approach with multiple smaller scale stormwater treatment units widely distributed across the landscape (Loperfido *et al.*, 2014). Stormwater Best Management Practices may be structural, like facilities or devices constructed to deal with stormwater issues, or non-structural, like street cleaning or minimizing impervious areas (NJDEP, 2004).

Limiting the pollutants in stormwater becomes a vital measure to reduce their impact and prevent future degradation (NJDEP, 2004; Clark and Pitt, 2012). In the United States, measures to control contamination rely on the National Pollutant Discharge Elimination System (NPDES) permits and Total Maximum Daily Load (TMDL) regulations. Documented technologies guide the selection of treatment measures and techniques and list expected pollutant percentage removal regarding the best available technology and practices (Clark and Pitt, 2012). Table 1.1 presents expected pollutants removal adapted from the New Jersey Stormwater Best Management Practices (BMP) Manual.

The characterization of the pollutants by size is important, since it affects its treatability with different techniques being used to remove different size particles. Larger particles, like sand, can be removed by filtration, while some of the smaller particles, like metal ions, may need reverse osmosis. It has been established that substantial fractions of the pollutants at the drainage systems outfall are particulate-associated. Some pollutants may react or are associated with other solids, requiring a controlled removal of the associated solids (Clark and Pitt, 2012; Kandra *et al.*, 2014). Sedimentation and filtration have been widely used as best management practices for the removal of such particulates. The combined application of both technologies have also been utilized and demonstrated reduction of these pollutants (Walker, 2001; Reddy *et al.*, 2014).

Table 1.1 TSS, TP and TN Removal Rates for BMPs

Best Management Practice (BMP)	**Adopted TSS Removal Rate** (%)	**Total Phosphorus Removal Rate** (%)	**Total Nitrogen Removal Rate** (%)
Bioretention Basin	90	60	30
Constructed Stormwater Wetland	90	50	30
Extended Detention Basin	40 to 60 [a]	20	20
Infiltration Basin	80	60	50
Manufactured Treatment Devices	Varies from device to device	Varies from device to device	Varies from device to device
Pervious Paving System	Volume Reduction or 80 [b]	60	50
Sand Filter	80	50	35
Vegetative Filter	60 to 80	30	30
Wet Pond	50 to 90 [c]	50	30

Source: Adapted from NJDEP , "Chapter 4: Stormwater Pollutant Removal Criteria," New Jersey Stormwater Best Management Practices Manual, (New Jersey: Trenton, 2004).

Notes:

a) Final rate based upon detention time.
b) If system includes a runoff storage bed that functions as an infiltration basin.
c) Final rate based upon pool volume and detention time.

1.2.1 Stormwater as a Resource

Current visions on stormwater are changing, and it is regarded as a strategical resource (NJDEP, 2004; Kuster *et al.*, 2010; Petit-Boix *et al.*, 2015). The use of devices that capture stormwater and store it for future use is now largely encouraged. Still, in some countries, like India, groundwater is the basic resource and may provide up to 60% of irrigation and 80% of drinking water necessities (Kumar *et al.*, 2012). Over exploitation of this resource is a growing concern in many countries, in which groundwater table measurements are falling at an alarming pace (Wang *et al.*, 2012). The artificial recharge of aquifers became a valuable tool to increase water resources for drinking water production in many countries (Kuster *et al.*, 2010).

With the growth of impervious surfaces, especially in developing countries, infiltration rates are significantly reduced (Petit-Boix *et al.*, 2015). To correct this, it is possible to employ systems that are capable of increasing or restoring a site's infiltration capacity in order to allow stormwater to infiltrate the soil and recharge aquifers. This also enables storage of large volumes of water for future use (Kuster *et al.*, 2010). Aquifers may be recharged through a number of methods, including infiltration basins, dry wells or even injected through a well for deeper or confined aquifers (Kuster *et al.*, 2010). Infiltration basins achieve this goal by conducting a fraction of the stormwater runoff to a basin with a highly permeable soil where it remains until it can be completely absorbed.

The NJ Stormwater BMP Manual asserts that infiltration structures also provide filtration of stormwater runoff for removal of TSS and other pollutants, including toxic substances. Provided that strict rules and regulations are followed in the design of the basins the filtrated water can be safely used to recharge the aquifers (NJDEP, 2004). But some authors still argue that it is still not fully understood whether artificial recharge could bring negative impacts to groundwater quality and how this can be mitigated (Zhang *et al.*, 2015).

1.2.2 Low Impact Development Practices

Development of a site usually results in the removal of vegetation and replacement of pervious areas with impervious surfaces (USDA, 1986; NJDEP, 2004; Barbosa *et al.*, 2012; Lucke and Nichols, 2015). The extensive adoption of impervious pavements in urban environments increases the peak flow rates and volumes of stormwater, reduces the time of concentration and reduces the base flow on streams (NJDEP, 2004; Fletcher *et al.*, 2013; Lynch *et al.*, 2015). The lack of vegetation and the imperviousness of roads, sidewalks and buildings increases the occurrence of floods while the water quality decreases because of excess sediment, nutrients and heavy metals carried by the stormwater runoff (Lucke and Nichols, 2015; Lynch *et al.*, 2015; Petit-Boix *et al.*, 2015).

For this reason, Low Impact Development Practices have been documented and allows engineers to design sites with improved hydrological performance, reducing and discontinuing impervious surfaces and giving stormwater a second chance to infiltrate. Compaction of the soil by heavy machinery during construction can considerably reduce soil infiltration rates. The New Jersey Stormwater Best Management Manual emphasizes the importance of ensuring that, during the period of the clearing, grading and construction of the site, heavy machinery must be kept away from areas expected to receive infiltration devices (NJDEP, 2004; Bean and Dukes, 2016).

The incorporation of plants in Stormwater treatment systems for runoff is a strategy outlined to allow the capture of sediments and provide aesthetic benefits. These solutions not only improve conditions for natural life, but the expansion of the roots of the plants reduce clogging and improve infiltration rates (Clark and Pitt, 2012).

1.2.3 Focus on Stormwater Quality Assessment

First BMP designs aimed to control runoff peak flow rates, but their functions were expanded to incorporate stormwater quality issues (NJDEP, 2004; Tixier *et al.*, 2011). Documented technologies guide the selection of treatment measures and techniques and list pollutant percent removal regarding the best available technology and practices (CLARK e PITT, 2012).

Studying and understanding of the site in question is very important when assessing stormwater management. Determining specific discharge goals depends entirely on the pollutant production potential of the environment. Certain pollutants can be anticipated and their concentrations estimated based on the history and location of the site (Clark and Pitt, 2012). It is only after pollutants have been identified that decision towards selection of suitable measures and technologies can be made and the systems designed (Clark and Pitt, 2012).

The decision process involving Stormwater Management must be mindful of characteristics and properties of the site, its current and future use, and its economic and legal situations, not to mention other uncertainties (USDA, 1986; NJDEP, 2004; Barbosa *et al.*, 2012). Stormwater management designs focus on reducing volumes and pollutants concentrations, usually based on the first-flush assumption, a phenomenon in which the pollutants are expected to be washed on the initial moments of runoff (Daly *et al.*, 2014; Loperfido *et al.*, 2014).

1.2.4 Maintenance

Broad employment of best management practices represents an important progress in prevention of pollution from urban environments, but once these devices are built maintenance is often neglected (Arias *et al.*, 2013). Experience has revealed that regular maintenance is essential to ensure that stormwater management infrastructure will perform reliably and effectively. Failure to properly maintain these facilities results in problems such as clogging of infiltration devices, floods, aesthetic decline, mosquito breading, public safety hazard and degradation of receiving water bodies (NJDEP, 2004; Kandra *et al.*, 2014; Bean and Dukes, 2016). It’s been observed that basins may lose hydrological performance due to clogging of upper layers (NJDEP, 2004; Kumar *et al.*, 2012; Kandra *et al.*, 2014; Lucke and Nichols, 2015).

The New Jersey Stormwater BMP Manual requires that a maintenance plan must be developed for every stormwater management project clearly identifying the responsible parties, schedule of activities and cost estimates. It is recommended that design and construction of stormwater BMP systems take this into account and incorporate details to facilitate, minimize and allow efficient and effective maintenance of the facilities, like the inclusion of forebays, trash racks and access control (NJDEP, 2004).

Most BMP devices are built under the assumption that they will function as expected, but their pollutant load and effectiveness are rarely verified after construction (Arias *et al.*, 2013). Therefore, some researchers question the real effectiveness of BMP strategies and if pollution removal is actually being achieved or if the pollutants are simply being redistributed and accumulated. (Bäckström *et al.*, 2002; Snodgrass *et al.*, 2008; Tixier *et al.*, 2011).

1.3 Characterization of Stormwater Runoff

The quality of the runoff is largely affected by the type of development and the use of the site. Evidence of degradation due to runoff contributions have been found in streams that receive urban waters (Booth and Jackson, 1997; Stanfield and Kilgour, 2006; Wenger *et al.*, 2008). Limiting pollutants discharge becomes vital to reduce current harm and prevent future degradation (Clark and Pitt, 2012).

The New Jersey Stormwater Best Management Practices Manual lists values of common pollutants found in stormwater runoff that are presented in Table 1.2. Particles of tires, asphalt, dust and heavy metals released by automobiles, suspended solids, hydrocarbons, pathogens and nutrients are examples of impurities and pollutants that can be washed up by stormwater runoff and become a hazard to public health (NJDEP, 2004; Han *et al.*, 2006; Kandra *et al.*, 2014; Reddy *et al.*, 2014).

Sediments in stormwater runoff usually start off as soil materials eroded from uplands as a result of natural processes and human activity. Some of the impurities mentioned in Table 1.2 can then be sorbed by the sediment and be deposited as the stormwater flows through irregularities and obstacles in its path. Once deposited, the pollutant enriched sediment can be remobilized by favorable environmental conditions and be carried forward causing even more harm further downstream (NJDEP, 2004).

Among the nutrients that can be present in stormwater runoff, inorganic phosphorus and inorganic nitrogen are of major importance in the state of New Jersey, since they can over-stimulate plant growth when in excessive amounts causing eutrophication in slower moving water bodies (NJDEP, 2004; Stagge *et al.*, 2012).

In regular concentrations nitrogen and phosphorus are not considered harmful, but both can be transported by groundwater. Nitrates remain soluble in the soil and may reach the aquifer below the root zone and this may pose public health hazard for communities that rely on groundwater for regular water supply, since high concentrations of nitrate in drinking water can cause infant methemoglobinemia. Phosphorus on the other hand often combines with fine soil particles and remains inert in the soil until it is either utilized by plants or eroded away with the soil (NJDEP, 2004; Meinikmann *et al.*, 2015).

Table 1.2 Typical Stormwater Pollutants

Pollutant	Typical Concentration
Total suspended solids [a]	80 mg/L
Total phosphorus [b]	0.30 mg/L
Total nitrogen [a]	2.0 mg/L
Total organic carbon [d]	12.7 mg/L
Fecal coliform bacteria [c]	3600 MPN/100mL
E. Coli bacteria [c]	1450 MPN/100mL
Petroleum hydrocarbons [d]	3.5 mg/L
Cadmium [e]	2 µg/L
Copper [a]	10 µg/L
Lead [a]	18 µg/L
Zinc [e]	150 µg/L
Chlorides [f] (winter only)	230 mg/L
Insecticides [g]	0.1 to 2.0 µg/L
Herbicides [g]	To 5.0 µg/L

Source: NJDEP , "Chapter 1: Impacts of development on runoff," New Jersey Stormwater Best Management Practices Manual, (New Jersey: Trenton,2004).

Notes:

- Data Sources [a] Schueler (1987), [b] Schueler (1995), [c] Schueler (1997), [d] Rabanal and Grizzard (1996), [e] USEPA (1983), [f] Oberts (1995), [g] Schueler (1996).
- Concentrations represent mean or median storm concentrations measured at typical sites and may be greater during individual storms. Mean or median runoff concentrations from stormwater hotspots are higher than those shown.
- Units: mg/L = milligrams/L µg/L = micrograms/liter MPN = Most Probable Number

1.3.1 Environmental Variability

The assessment of runoff pollutants in stormwater management is very complex and is largely affected by environmental variability (Daly *et al.*, 2014). Typical stormwater systems operate based on rain events that vary broadly in intensity, duration and reoccurrence. Not only the quantity and quality of the discharges vary, but also characteristics of the surrounding environment. This variation depends on the particularities of the communities, available economic resources, and available research and technology. There are many older cities that still operate without a separate stormwater sewer system. Overflows due to rain events in these systems have the potential to cause severe impacts on receiving waters (Barbosa *et al.*, 2012).

The devices designed to mitigate problems caused by stormwater must take into account hydric potential of the site, volume of stormwater to be treated, pollutant removal capacity, budget and time constrains, and future type of occupation and use of site. Considering the aforementioned factors is crucial for good stormwater management, since bad decisions may cause floods, loss of money and time (Barbosa *et al.*, 2012).

The composition of the pollutant load may also vary depending on the level of development of the surroundings. In the urban environment, tire, asphalt, dust and heavy metal particles released by automobiles are examples of impurities and pollutants that can be washed up by stormwater runoff and promote hazard to public health. Cadmiun, copper, lead, nickel, chromium and zinc are some of the most common heavy metal contaminants found in urban environments (Han *et al.*, 2006; Kandra *et al.*, 2014; Reddy *et al.*, 2014).

Contamination variability within a single rain event is also possible. It has been observed that in certain circumstances pollutant load may present higher concentrations in the initial moments of the discharge. As mentioned before, this phenomenon in known as first flush and even though it is not an universal or constant occurrence, it may be influenced by variations in precipitation characteristics and length, conditions of anteceding dry period and land use (Barbosa *et al.*, 2012; Arias *et al.*, 2013).

1.4 Infiltration Basins

An infiltration basin is a device designed and built to temporarily store a volume of stormwater and allow it to infiltrate into the soil. This volume is defined by the New Jersey Stormwater BMP Manual as the Water Quality Design Storm Volume and is calculated as the volume of runoff generated by a rainfall with 1.25 inch of depth and duration of 2 hours over the basin's drainage area. These devices are built in areas with highly permeable soil, usually with the intent to address the Strategy #2 of the NJ Stormwater BMP Manual, "The minimization of impervious surfaces and breaking up or disconnection of the flow of runoff over impervious surfaces" (NJDEP, 2004; 2016).

Basins are stormwater management structures that have been widely used for many years to control the volume of the runoff and experience has shown that these devices could also provide some water quality benefits if certain measures were incorporated to the design. The construction of basins may occur by damming a channel or by constructing a pond by cut and fill. Low Impact Development techniques recommend that natural drainage patterns should not be significantly altered (NJDEP, 2004; 2016).

Detention basins were originally used to reduce peak runoff flowrates by temporarily storing a volume of water and slowly releasing it through a control outlet structure. Some basins may be designed to retain a certain volume of water that could be used it the future for certain activities like irrigation. Retention ponds are an interesting solution to certain areas, especially rural areas, since it may hold and provide water during the entire year. Available storage volume provides means not only to reduce peak flowrates of runoff, but allows some treatability through sedimentation, although dissolved pollutants will remain in place (Lynch *et al.*, 2015).

In addition to addressing water quality issues the basins can also be used as infiltration devices; addressing the groundwater recharge deficit created by the growth of impervious surfaces as a consequence of development. These devices treat pollutants through settling, filtration of the runoff through the soil, and chemical and biological activity within the soil. The NJ Stormwater BMP Manual requires that infiltration basins must be equipped with a highly permeable sand layer at the bottom with a minimum thickness of 6 inches. This layer acts as a media filter capturing most of the sediment, preventing them from clogging the subsoil and maintaining the hydrological performance over time (Kumar *et al.*, 2012; Kandra *et al.*, 2014; Lucke and Nichols, 2015). Simple maintenance measures like tiling are capable of reorganizing the disposition of the media filter, recreating the capillary arteries that allows the water to percolate. When a basin begins to present signs of failure, the sand layer can be replaced and this may extend the life-span of the device. Infiltration flowrates must be high enough to ensure that no standing water remains in an infiltration basin 72 hours after a rain event. Older basins may fail due to clogging and not comply with this requirement and this may cause anaerobic condition, odor and mosquito breeding issues (NJDEP, 2004; 2016).

CHAPTER 2

METHODS

To fulfill the proposed objectives, the research was divided in three steps. Initially a literature review was conducted on recent journal articles and follow-up studies on infiltration basins and other BMP devices. Next, information on existing infiltration basins in the state of New Jersey was requested from several state and municipal departments and based on this data, a site was selected to install a sampling pit. Third, water samples from the input, intermediate (pond formed by accumulated stormwater) and output (infiltrated) of the chosen infiltration basin were then collected during three different rain events and then analyzed. To verify the effectiveness of the filtration process as described by the NJ stormwater BMP Manual, TSS measurements were conducted on all samples. Total Nitrogen (TN) and Total Phosphate (TP) were also measured in a fraction of the samples. Results were then plotted along rain volumes measured by a weather station in the Southern Jersey Regional airport, situated approximately 1.8 miles from the site.

Samples from an additional site with similar characteristics were also collected for TSS background comparison, sample size and detection limits verification. Figure 1.1 shows the location of the site, the weather station, and the distance between them; Figure 1.2 presents an orthoaerialphotograph of the site and a point indicating the location of the basin and Figure 1.3 is a photograph taken of the site facing NW.

2.1 Literature Review

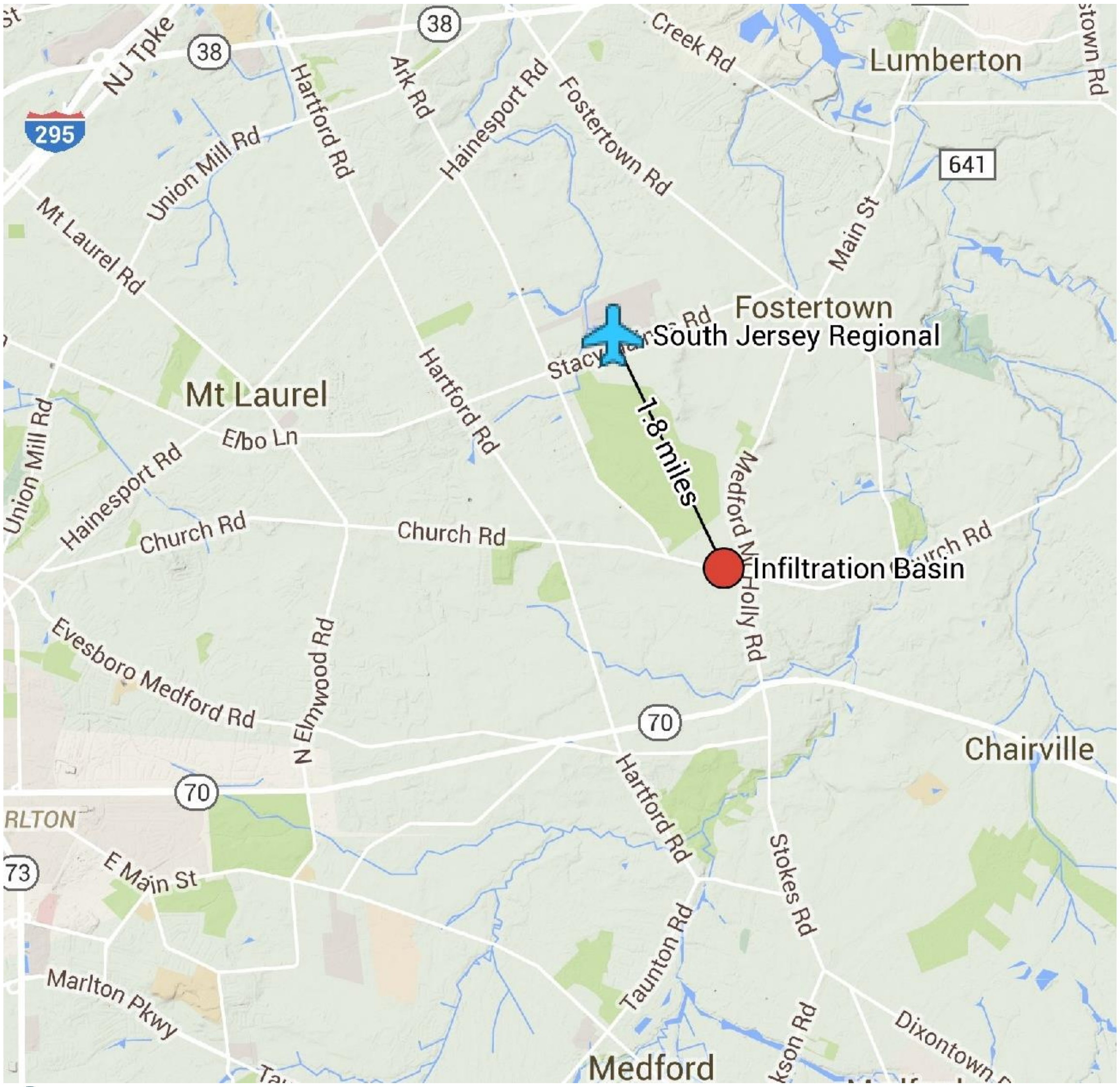
Literature review was conducted to identify data on current practices in stormwater quality assessment and recent investigations or follow-up studies of infiltration basins and other BMP devices regarding their water quality capacities to theoretically and statistically fundament the project. Journal articles, government documents, reports, regulations and online Geographic Information Systems (GIS) databases were reviewed to establish a base of comparison for field investigation and methodology on further steps.

2.2 Site Selection

Information regarding existing infiltration basins was requested from several state and municipal departments to identify possible sites for field investigations. The following criteria were used to select the site: a non-subsurface basin, with infiltration and water quality components, that was built after the year 2006. Sub-surface infiltration basins were discarded because they are equipped with a pre-treatment device, that reduces TSS in 80%, therefore not compatible with the objectives of this research

The decision to exclude basins built before 2006 was made to minimize chances of older basins potentially failing due to clogging and to ensure that they were built according to the revision of the New Jersey Stormwater Best Management Practices Manual that occurred in 2004. This investigation did not focus on the infiltration capacity of the basin, instead it analyzed if the expected pollutant removal is actually achieved. The literature review did not yield studies describing such analysis in a real life setting. Data from the New Jersey Hydrologic Modeling Database were also used to identify potential sites. Final decision was made based on *in situ* inspections and assessment of overall maintenance status.

The selected site was an infiltration basin adjacent to a parking lot and County Road 616 in the Township of Medford. The area is composed of mixed light residential and light commercial development. County Road 616 is a major Burlington County corridor. Figure 2.1 presents a map situating the site, the South Jersey Regional airport, and presents the distance between the two; Figure 2.2 presents an orthoaerialphotograph of the site and a point indicating the location of the infiltration basin; Figure 2.3 depicts the selected site, facing NW and Figure 2.4 is a photograph taken of the basin, where the inlet structure that conveys runoff from the road into the basin can be seen. The site, the parking lot and CR 616 presented good signs of maintenance during all visits to the site and street cleaning appears to be performed regularly.



Southern Jersey Regional Airport
Infiltration Basin
1.8 miles

Figure 2.1 Site of Infiltration Basin, Southern Jersey Regional Airport and distance.

Source: Google "MyMaps Webapp" GOOGLE MAPS March 2016. http://mymaps.google.com/ accessed March 11, 2016.

● Infiltration Basin

Figure 2.2 Othoaerialphotograph of site.

Source: Google "MyMaps Webapp" GOOGLE MAPS March 2016. http://mymaps.google.com/ accessed March 11, 2016.

Figure 2.3 Photograph of site.

Source: Photograph of the site facing NW taken on January 9th 2016.

Figure 2.4 Photograph of site detailing inlet.

Source: Photograph of the site taken on March 15th 2016.

2.3 Sampling and Lab Analysis

A sampling pit was installed on the site to collect the infiltrated stormwater representing the output of the infiltration basin. Figure 2.5 is a schematic representation of the sampling pit design. All samples were assessed for TSS and a fraction of them had their Total Nitrogen and Total Phosphate measured. To represent the input, samples were collected at the concrete inlet, that functions as a weir, conveying excess runoff from the gutter into the infiltration basin. Figure 2.4 is a photograph of the site facing west, detailing the inlet. Samples from the water that accumulated in the basin and formed a pond were also collected representing the intermediate step of the treatment train. Figure 2.6 is a photograph of the site with the sampling pit.

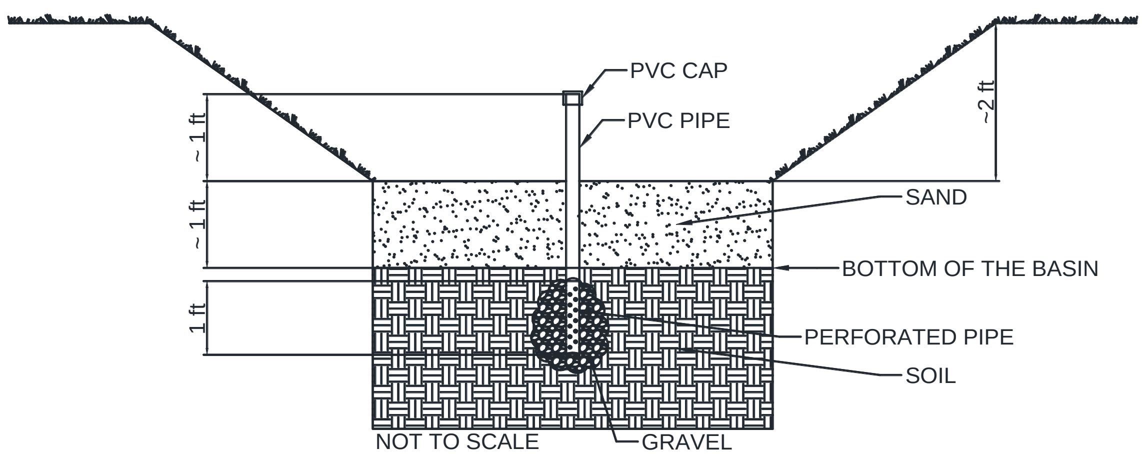


Figure 2.5 Scheme of Sampling Pit design.

Figure 2.6 Photograph of Sampling Station.

Source: Photograph of the site taken on February 15th 2016.

All samples were collected in triplicates in volumes ranging from 140 to 400 ml. Sampling of the input and output were taken in 10 minute intervals, while samples from the pond were collected every 30 min. Samples were collected as soon as runoff began to flow through the concrete inlet or whenever there was accumulated water in the sampling pit.

TSS analysis followed the Standard Methods procedure 2540D that determines that samples must be filtered through a weighted standard glass fiber filter. After this the filters are dried at temperatures between 103°C and 105°C for at least one hour. Filters are then dessicated, weighed and returned to the oven. The process of drying, dessicating and weighing is repeated until weight is constant or within a 5% or 0.5 mg difference to the last weighing, whichever is less. Total Nitrogen (TN) and Total Phosphate (TP) were measured using standard test kits manufactured by Hach. For TN, the reagent sets used were 2672145 and 2671745and for TP, 2742645.

CHAPTER 3

RESULTS

Total Suspended Solids concentration on the first rain event for the input ranged from 12.8 mg/l to 44.9 mg/l (mean concentration 27.1 mg/l). The TSS concentration of the output for the same rain event ranged from 8.5 mg/l to 19.2 mg/l (mean concentration 14.1 mg/l). The measured concentrations of TSS of the ponded water (intermediate) ranged between 12.0 mg/l and 23.4 mg/l (mean concentration 17.4 mg/l). Figure 3.1 is a chart presenting all TSS measurements on the first rain event along with the rainfall depths recorded by the weather station and Figure 3.2 presents the average TSS measurements from triplicates at each instant of the aforementioned rain event for input, intermediate and output, and recorded rainfall depths.

Total Suspended Solids concentration for the input during the second rain event ranged from 11.5 mg/l to 35.1 mg/l (mean concentration 23.4 mg/l). The output concentrations varied from 7.2 mg/l to 19.0 mg/l (mean concentration 13.3 mg/l). and the intermediate presented TSS concentrations ranging from 19.1 mg/l to 30.1 mg/l (mean concentration 24.3 mg/l). Figure 3.3 presents all TSS measurements from the second rain event and the rain records, while Figure 3.4 presents the averages of these measurements.

On the third and last rain event TSS concentrations measured from the infiltration basin inflow ranged between 7.1 mg/l and 108.3 mg/l (mean concentration 30.7mg/l). The outflow for the same rain event presented TSS concentrations varying from 8.2 mg/l to 18.3 mg/l (mean concentration 13.1 mg/l) and the intermediate TSS measurements ranged from 11.5 mg/l to 27.6 mg/l (mean concentration 18.4 mg/l). Figure 3.5 depicts all TSS measurements from the third rain event plotted alongside the rain records. Figure 3.6 shows the average of the aforesaid TSS measurements and the rain records for the same rain event, while Table 3.1 presents maximum, minimum and mean TSS measurements and total rainfall depths for all three rain events.

Table 3.1 Maximum, minimum and mean TSS measurements

		First Rain Event (02/03/2016) mg/l	**Second Rain Event** (03/02/2016) mg/l	**Third Rain Event** (03/14/2016) mg/l
Input	Max	44.9	35.1	108.3
	Mean	27.1	23.4	30.7
	Min	12.8	11.5	7.1
Output	Max	19.2	19.0	18.3
	Mean	14.1	13.3	13.1
	Min	8.5	7.2	8.2
Intermediate	Max	23.4	30.1	27.6
	Mean	17.4	24.3	18.4
	Min	12.0	19.1	11.5
Total Rainfall Depth		0.78 inch	0.16 inch	3.16 inches

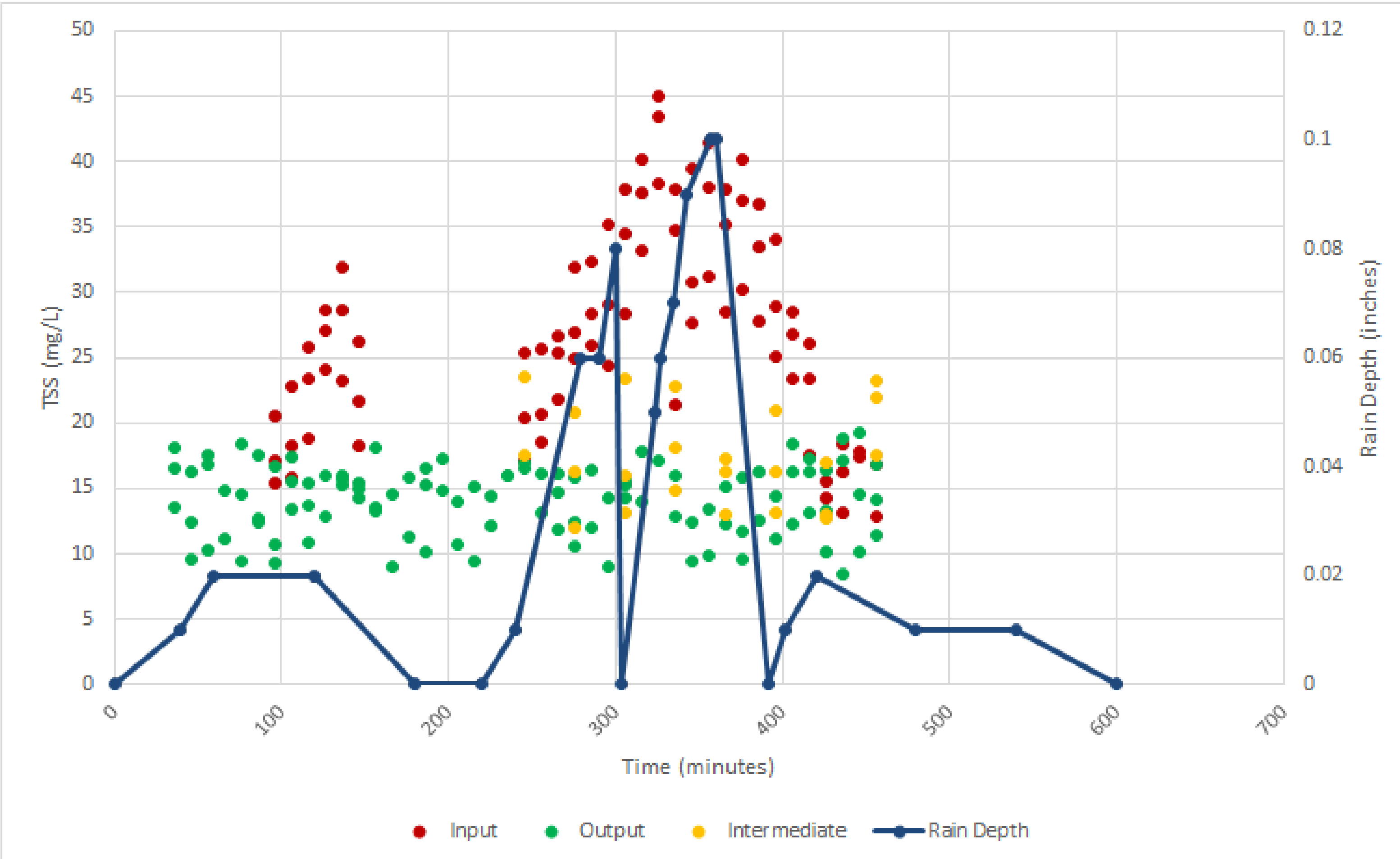


Figure 3.1 TSS measurements – First rain event (02/03/2016).

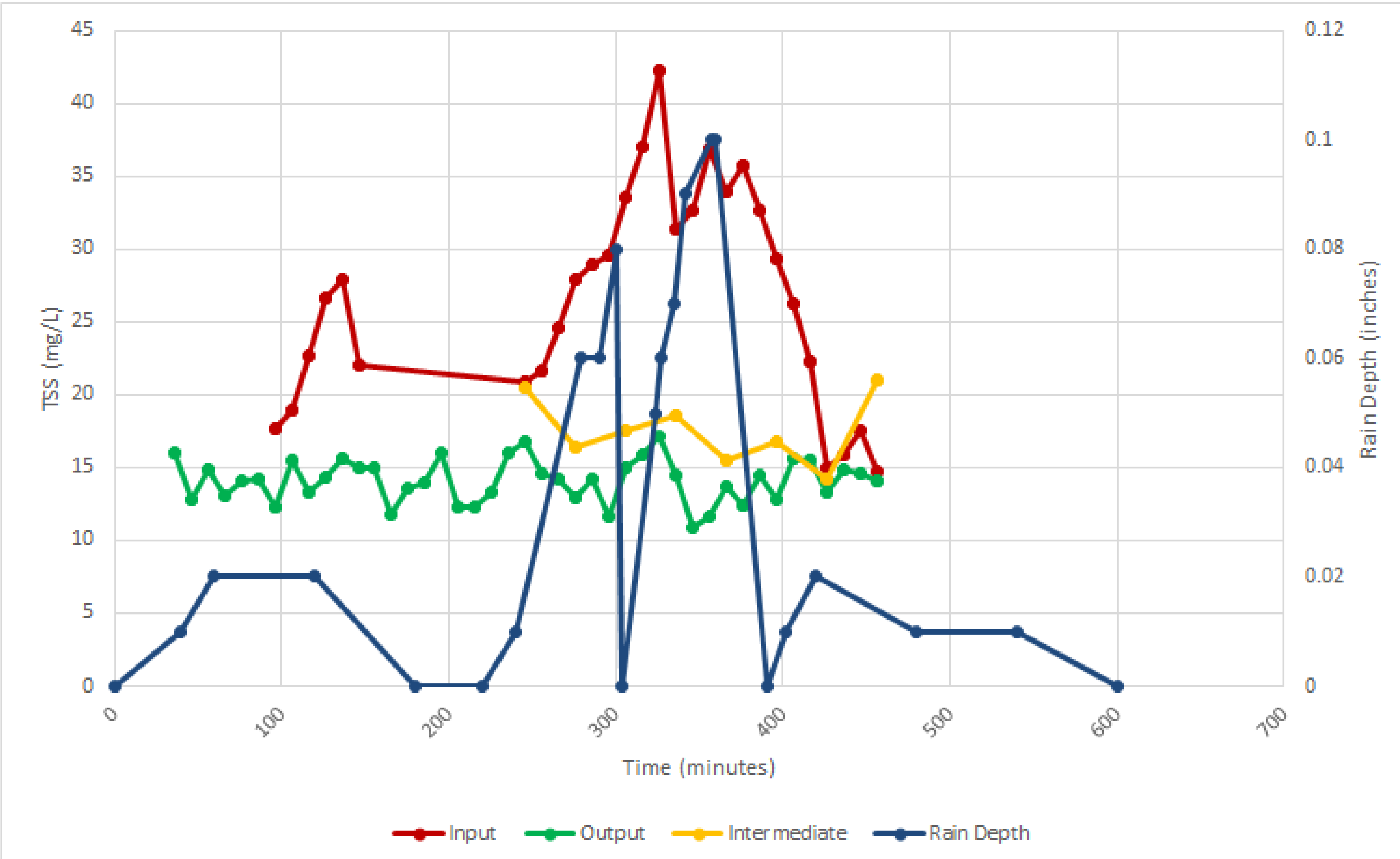


Figure 3.2 Average TSS measurements – First rain event (02/03/2016).

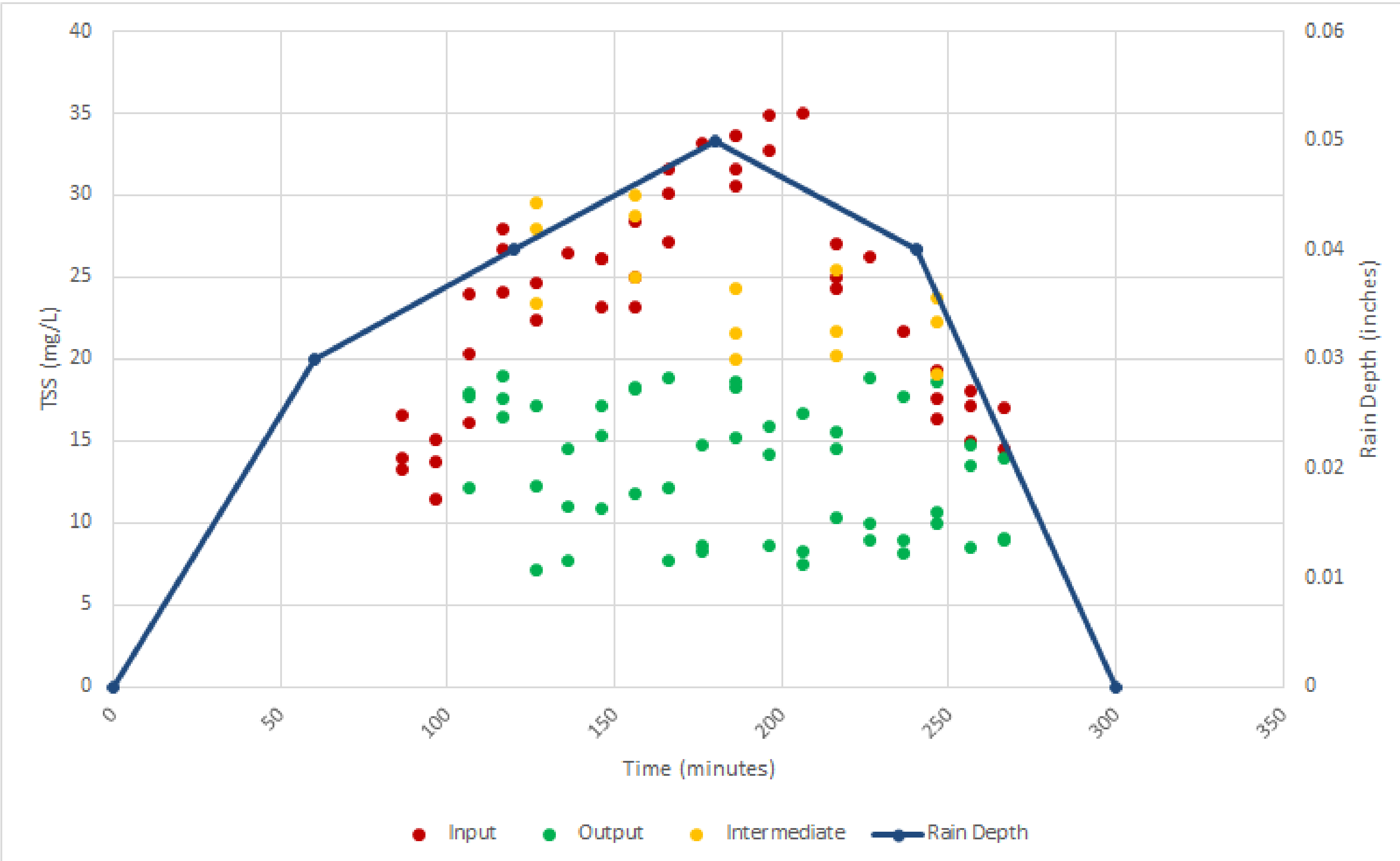


Figure 3.3 TSS measurements – Second rain event (03/02/2016).

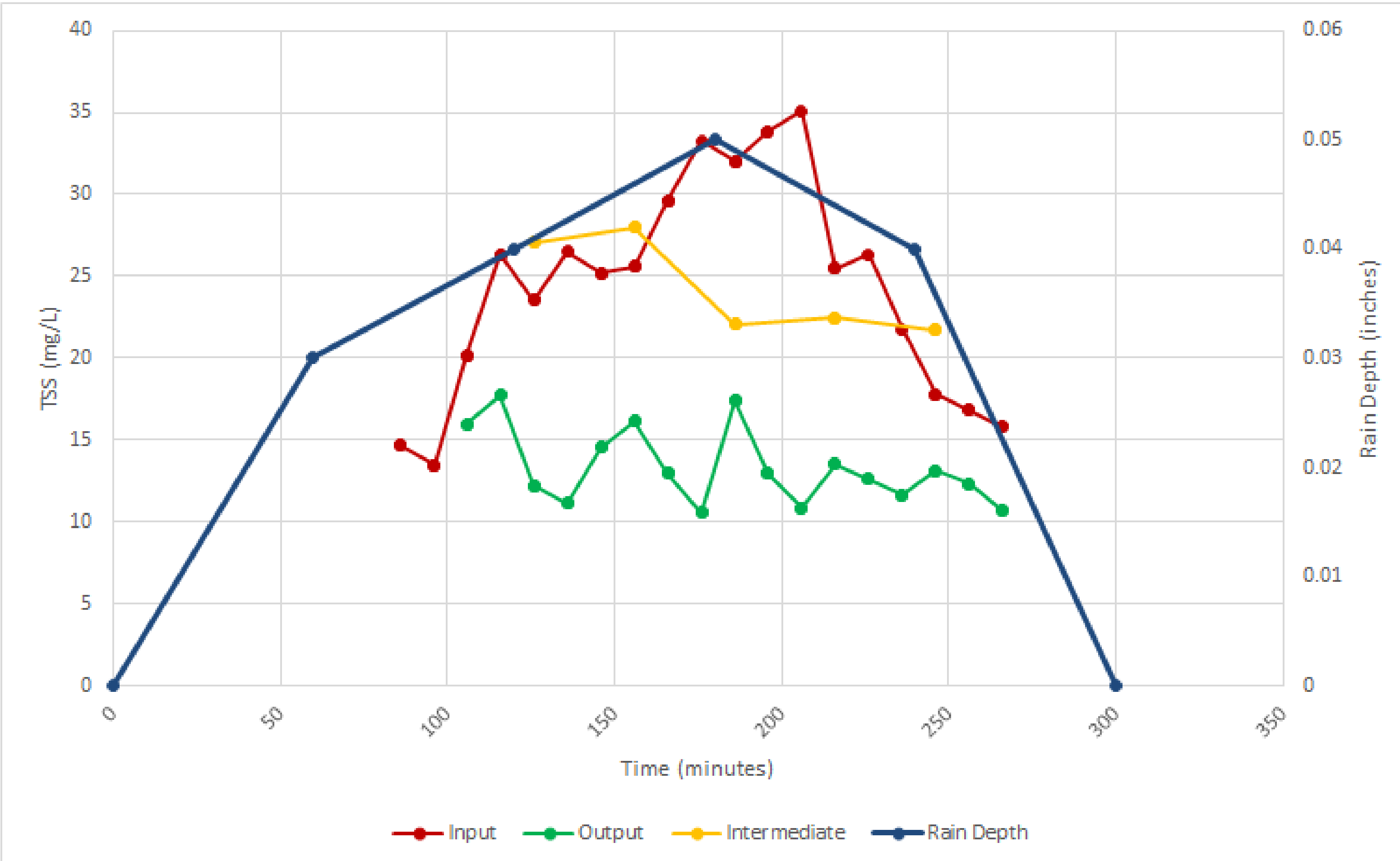


Figure 3.4 Average TSS measurements – Second rain event (03/02/2016).

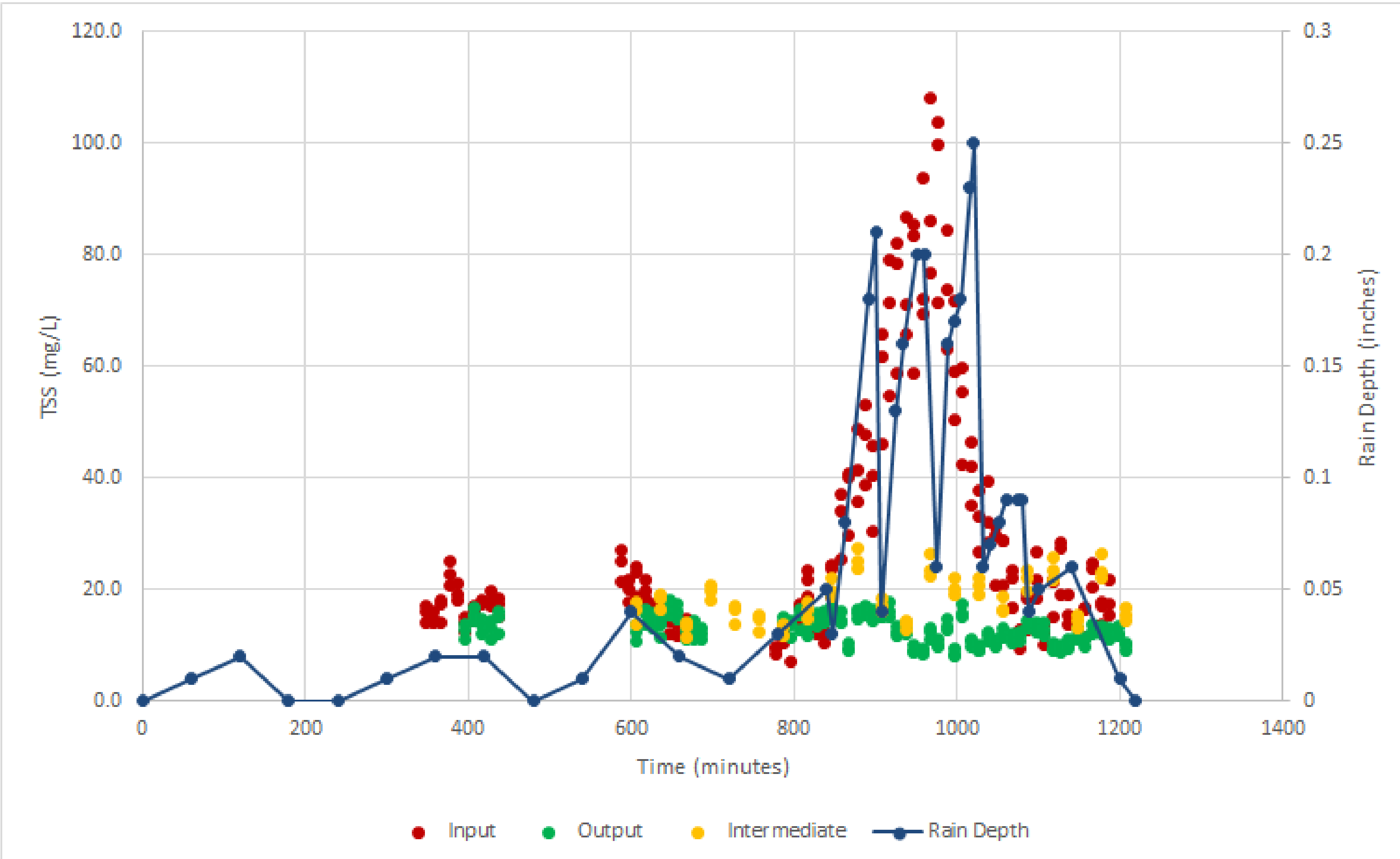


Figure 3.5 TSS measurements – Third rain event (03/14/2016).

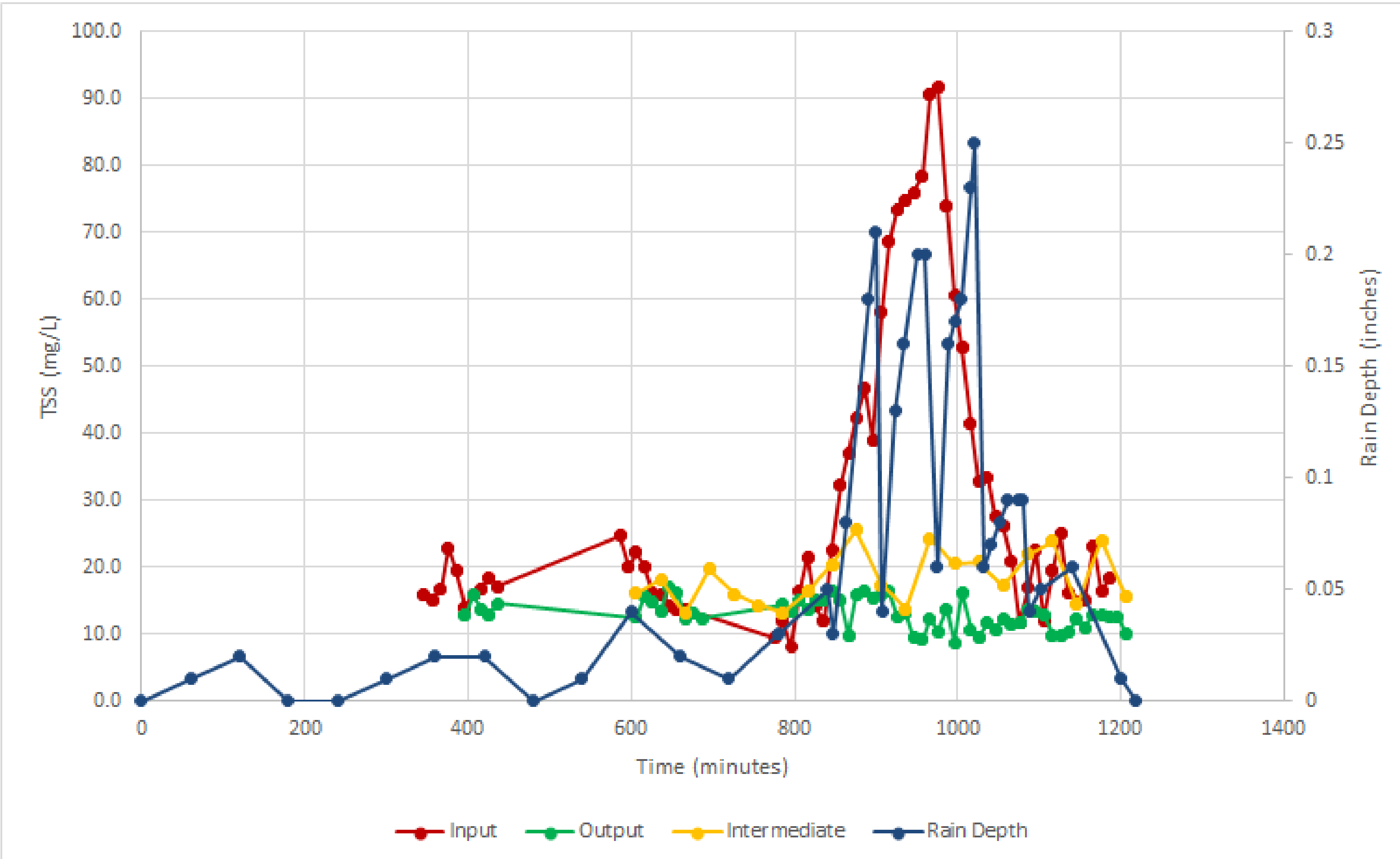


Figure 3.6 Average TSS measurements – Third rain event (03/14/2016).

Fifteen samples from the first rain event were selected to have Total Phosphate measured. The TP measurements from the six samples chosen from input ranged from 0.08 mg/l to 0.31 mg/l (mean concentration 0.20 mg/l). Concentrations from the six samples selected from the output ranged from 0.07 mg/l to 0.19 mg/l (mean concentration 0.13 mg/l). The three samples selected from the intermediate ranged between 0.54 mg/l and 0.58 (mean concentration 0.56 mg/l). Figure 3.7 depicts the TP measurements for the first rain event over time.

Only six samples from the second rain event had their TP measured. The measurements for the two samples from the input ranged from 0.23 mg/l to 0.26 mg/l (mean concentration 0.25 mg/l). Three samples were selected from the output and TP measurements were between 0.29 mg/l and 0.40 mg/l (mean concentration 0.36 mg/l). One sample from the intermediate was selected to have TP measured and the result was 0.46 mg/l. Figure 3.8 presents the TP measurements for the second rain event.

Seven samples from the third rain event had TP measured. The three samples from the input ranged from 0.31 to 0.73 mg/l (mean concentration 0.51 mg/l), while the three samples from the output were between 0.12 mg/l and 0.20 mg/l (mean concentration 0.16 mg/l). One sample from the intermediate was selected to have the TP quantified and the measurement was 0.22 mg/l. Figure 3.9 shows the TP measurements for the third rain event and Table 3.2 presents the maximum, minimum and mean concentrations of all TP measurements.

Table 3.2 Maximum, minimum and mean TP measurements

		First Rain Event (02/03/2016) mg/l	**Second Rain Event** (03/02/2016) mg/l	**Third Rain Event** (03/14/2016) mg/l
Input	Max	0.31	0.26	0.73
	Mean	0.20	0.25	0.51
	Min	0.08	0.23	0.31
	n	6	2	3
Output	Max	0.19	0.40	0.20
	Mean	0.13	0.36	0.16
	Min	0.07	0.29	0.12
	n	6	3	3
Intermediate	Max	0.58		
	Mean	0.56	0.46	0.22
	Min	0.54		
	n	3	1	1

Note: n = number of samples

For the assessment of Total Nitrogen, fifteen samples were selected from the first rain event. For the six samples chosen from the input, the results were between 0.56 mg/l and 3.43 mg/l (mean concentration 1.72 mg/l), while the output measurements ranged from below detection limits and up to 0.56 mg/l (mean concentration 0.54 mg/l excluding measurements below detection limits). The three samples selected from the intermediate from the same rain event for TN assessment ranged from 3.25 mg/l to 3.87 mg/l (mean concentration 3.58 mg/l). Figure 3.10 presents all TN measurements for the first rain event.

For the second rain event six samples were selected for TN measurements and the two measurements from the input were 1.00 mg/l and 2.81 mg/l (mean concentration 1.90 mg/l). Three samples were selected from the output of the second rain even and their TN measurements were between 0.63 and 1.56 mg/l (mean concentration 1.12 mg/l) while the intermediate, that had one sample assessed, measured 1.37 mg/l. Figure 3.11 presents all TN measurements for the second rain event.

On the third rain event six samples were selected for TN measurements. The three samples selected from the input ranged from 0.69 mg/l to 4.37 mg/l (mean concentration 2.43 mg/l, while the two samples from the output were 0.50 mg/l and 0.88 mg/l (mean concentration 0.69 mg/l). The intermediate of the third rain event had only one sample assessed for TN and the result was 1.25 mg/l. Figure 3.12 depicts the results of all TN measurements for the third rain event and Table 3.3 lists maximum, minimum and mean values for all TN measurements.

Table 3.3 Maximum, minimum and mean TN measurements

		First Rain Event (02/03/2016) mg/l	**Second Rain Event** (03/02/2016) mg/l	**Third Rain Event** (03/14/2016) mg/l
Input	Max	3.43	2.81	4.37
	Mean	1.72	1.90	2.43
	Min	0.56	1.00	0.69
	n	6	2	3
Output	Max	0.56	1.56	0.88
	Mean	0.54	1.12	0.69
	Min	BDL	0.63	0.50
	n	6	3	2
Intermediate	Max	3.87		
	Mean	3.58	1.37	1.25
	Min	3.25		
	n	3	1	1

Notes:

- n = number of samples
- BDL = Below Detection Limits

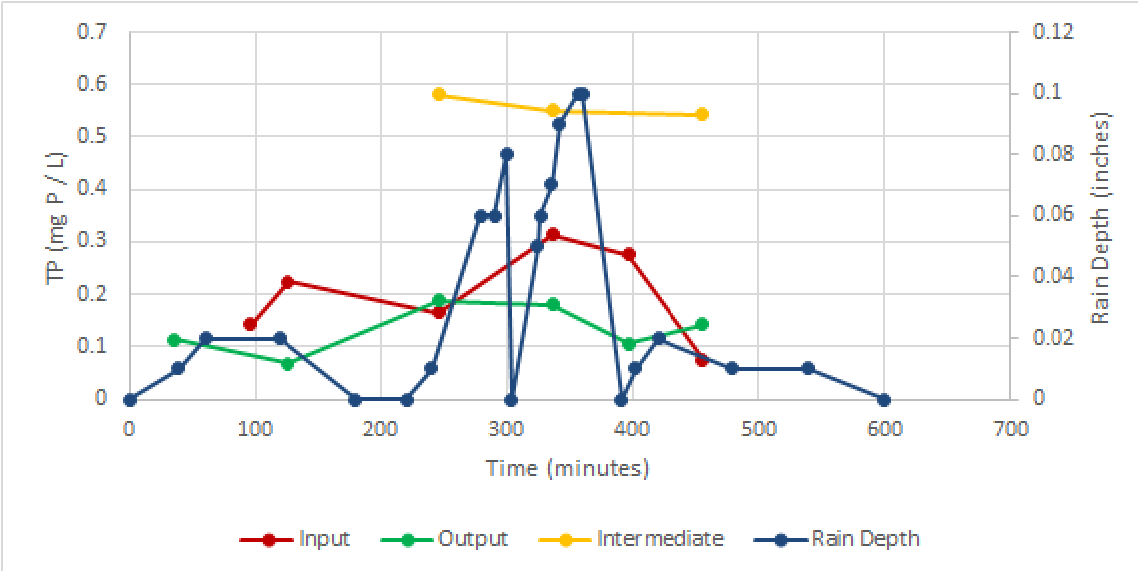


Figure 3.7 Total Phosphate – First rain event (02/03/2016).

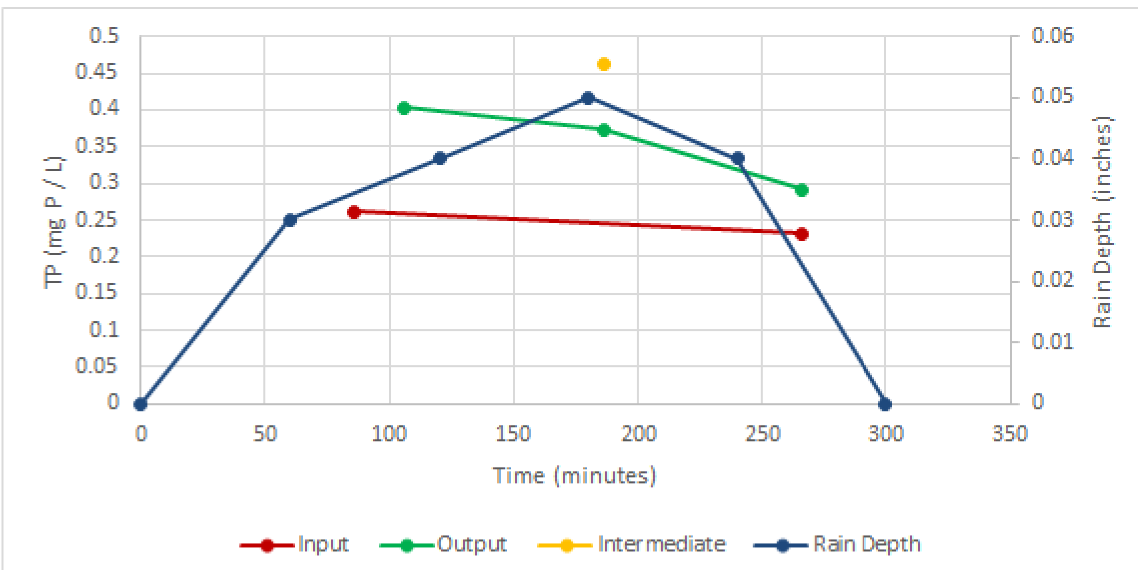


Figure 3.8 Total Phosphate – Second rain event (03/02/2016).

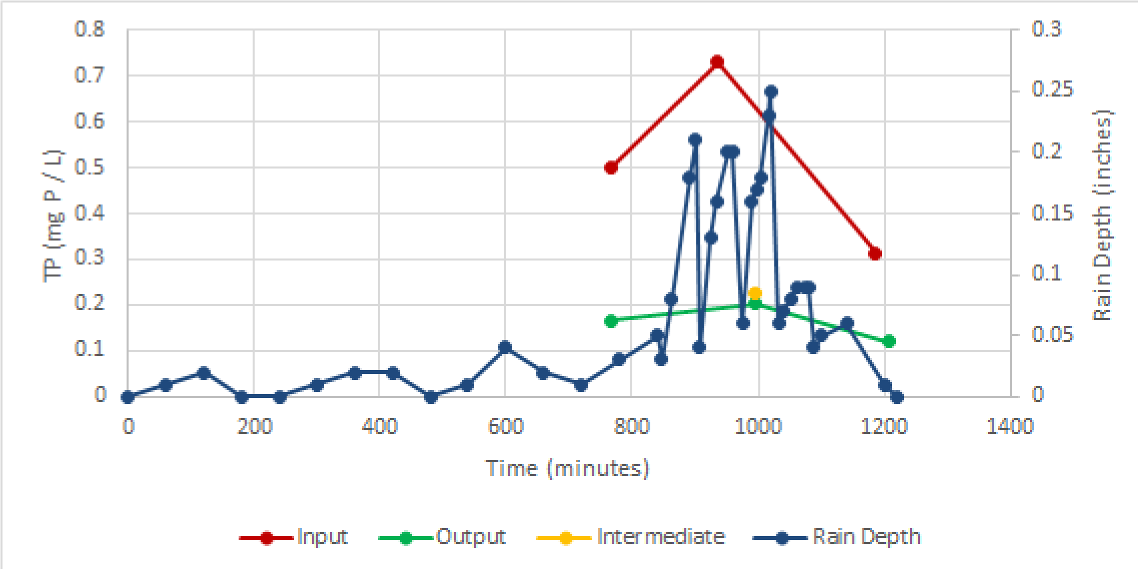


Figure 3.9 Total Phosphate – Third rain event (03/14/2016).

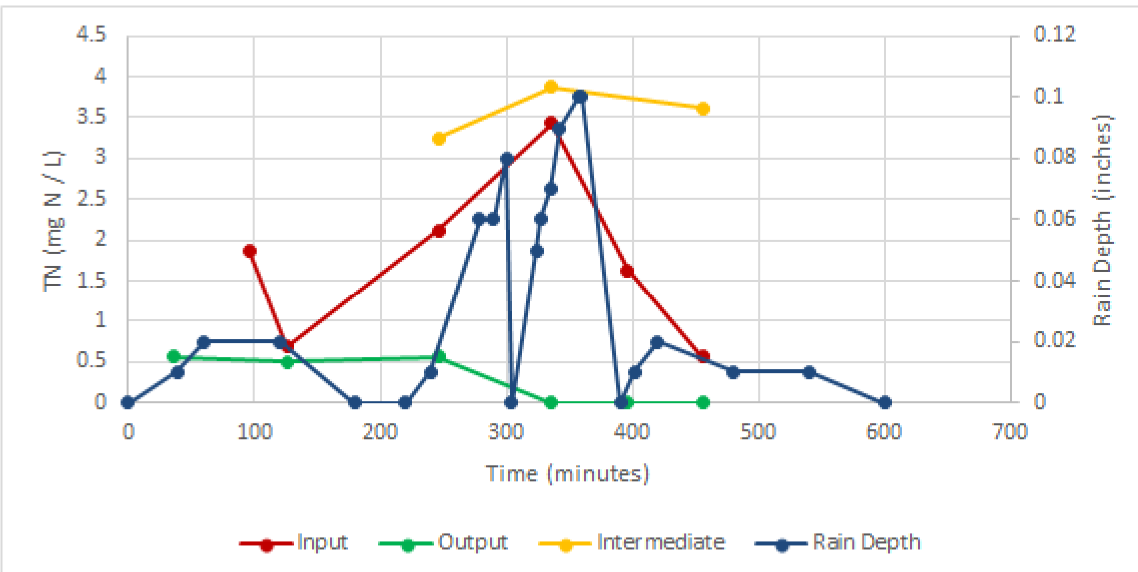


Figure 3.10 Total Nitrogen – First rain event (02/03/2016).

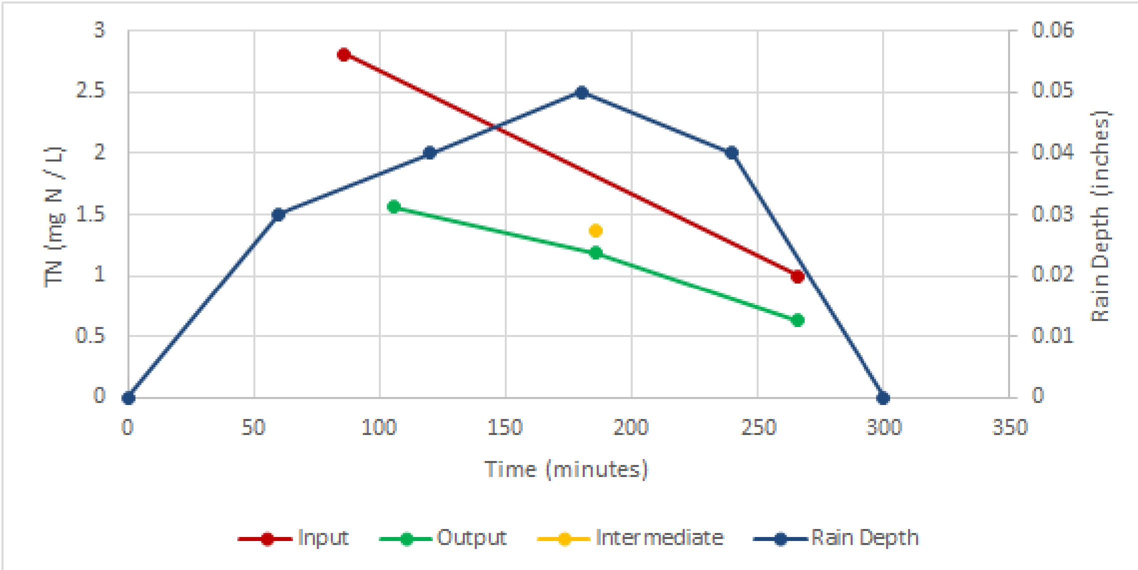


Figure 3.11 Total Nitrogen – Second rain event (03/02/2016).

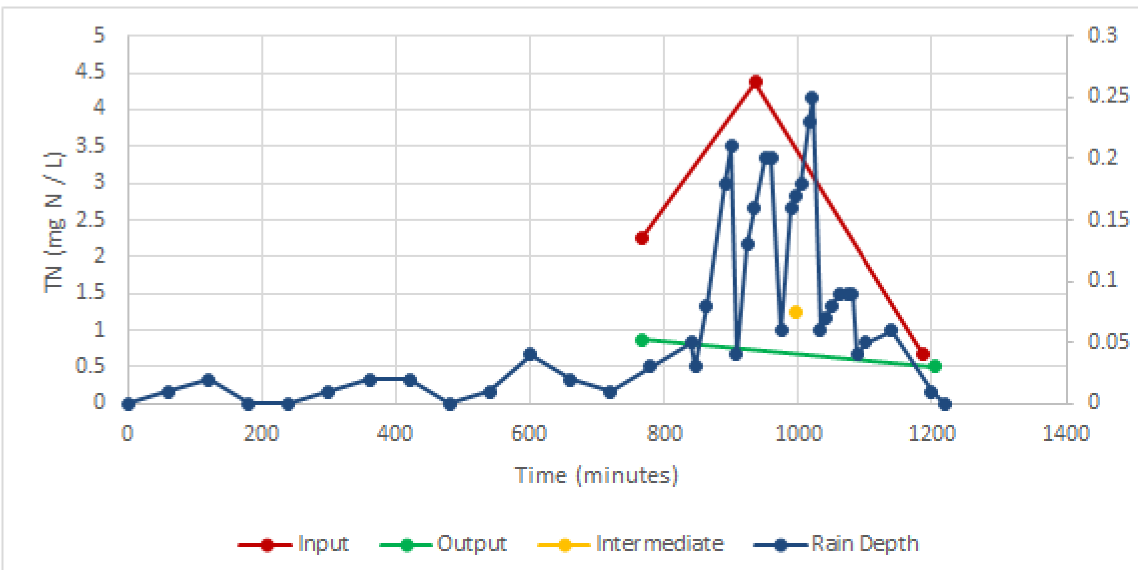


Figure 3.12 Total Nitrogen – Third rain event (03/14/2016).

CHAPTER 4

DISCUSSION AND CONCLUSIONS

Reduction in TP and TN was also observed, however the limited number of samples is not enough to assert the significance of these results. Arias *et al.* (2013) studied the pollutant load in stormwater runoff in a 40 ha residential area and verified Total Phosphorus concentration ranged from 0.162 mg/l to 0.834 mg/l. All samples in this study that were submitted to TP measurements presented results below the values presented by Arias *et al.* (2013). Although the Chapter 4 "Stormwater Pollutant Removal Criteria" of the NJ Stormwater BMP Manual states that infiltration basins are capable of reducing TP in 60% and TN in 50% , the Chapter 9.5 "Standard for Infiltration Basins" does not mention the removal of TP or TN, only adopting TSS percentage removal rate. Chapter 9.5 was revised in February 2016, during the writing of this paper and there is still no mention of TP and TN stormwater quality benefits. Both editions actually mention treatment provided by biological and chemical activity, which could be attributed to these nutrients, but the manual does not provide details of which pollutants are affected by this treatment and how. Recently researchers have been combining efforts to correlate TSS and other pollutants in stormwater runoff, like TSS, TP and particulate-bound metals (Kandra *et al.*, 2014). This reinforces the idea that control of the sediments is the first step to reduce concentration of other pollutants (Clark and Pitt, 2012; Kandra *et al.*, 2014).

Overall reduction in TSS has been observed in all three rain events, however the magnitude of the reduction varied not only from one event to the other, but also within each event. Expected 80% TSS removal was only achieved at one moment and only in one rain event. Reductions in TSS concentrations were superior when inflow concentrations were also greater. Higher input TSS concentrations appear to be linked to greater rainfall depths and intensity, while output concentrations seem to remain somewhat constant.

Since most BMPs are designed as input/output devices, studies that evaluate effectiveness of the treatment provided by such devices are also usually conducted following the same concept. Measurements from the output are expected to present a reduced pollutant load, in comparison to the input. As seen before in Table 1.1, adapted from the NJ Stormwater BMP Manual, the expected reduction for TSS is 80%, 60% for TP and 50% for TN. During the first rain event, the difference between input and output indicate that the maximum TSS reduction achieved was 59%. Table 4.1 presents the TSS reductions at initial, peak and final instants of the first rain event.

Table 4.1 Average TSS reductions – First Rain Event

T minutes	Average Input mg/l	Average Output mg/l	Reduction
96	17.7	12.2	31%
136	27.9	15.7	44%
246	20.9	16.7	20%
326	42.2	17.1	59%
416	22.3	15.5	31%
456	14.8	14.1	5%

On the second rain event, a higher reduction was achieved during peak inflow concentrations as the difference between the average input and average output reached 69%. Table 4.2 presents TSS reductions during the peak pollutant inflow on the second rain event.

Table 4.2 Average TSS reductions – Second Rain Event

T minutes	Average Input mg/l	Average Output mg/l	Reduction
106	20.2	16.0	21%
156	25.6	16.2	37%
206	35.1	10.9	69%
236	21.8	11.7	46%
2666	15.8	10.7	32%

The third rain event had the largest rainfall depth and duration of all events. It also produced the highest inflow concentration of all three rain events, exceeding the typical concentration for TSS listed by the NJ Stormwater BMP Manual, as seen in Tables 1.2 and 3.1. Only during peak inflow concentrations of the third rain event the 80% expected TSS removal was achieved. Table 4.3 presents TSS reductions at several instants of the third rain event. On the same table it can be observed that at a certain moment reduction appears to be negative, due to very low inflow TSS concentration in comparison with the output TSS concentration. This is related to the fact that output TSS concentrations remained somewhat constant during all three rain events, while the inflow of TSS varied significantly. The time it takes for the water and the solids to percolate the bottom of the basin, the soil and enter the sampling chamber is not known. Therefore, these comparisons of averages of the input and output at the same instant permit only a rough assessment of the order of magnitude of pollutant reduction, but it seems that during the majority of time the differences between inflow and outflow concentrations of TSS did not achieve the 80% removal goal.

Table 4.3 Average TSS reductions – Third Rain Event

T Minutes	**Average Input** mg/l	**Average Output** mg/l	**Reduction**
396	14.1	12.7	10%
436	17.2	14.5	15%
606	22.2	15.5	30%
666	13.8	12.4	10%
786	12.0	14.4	-20%
876	42.2	15.9	62%
966	90.5	12.4	86%
1016	41.4	10.7	74%
1066	20.8	11.4	45%
1176	16.4	13.0	21%

Some authors question that protection of aquatic ecosystems is not guaranteed by simply complying with the guidelines and standards for stormwater best management practices and that no studies have comprehensively demonstrated that these objectives have been achieved (Roy *et al.*, 2008; Tixier *et al.*, 2011).

This study has methodological limitations that are worth mentioning. It is possible that soil particles may have dislodged from the sub-soil and entered the sampling pit, affecting the measurements. Due to elevated financial costs and limited budget to monitor each event, only three rain events were recorded. To improve the statistical strength of the results, all samples were collected in triplicates and input and output had 10 minute intervals. Even taking these limitations into account, the fact that the observed reductions in TSS were under the expected 80% for most of the time raises questions about the effectiveness of filtration in infiltration basins in properly reducing the pollutants in stormwater management.

In conclusion, although from a strategical point of view it is crucial to address the groundwater recharge deficit, there is insufficient understading of the actual filtration capacity of infiltration basins in a real life setting. The results observed in this study indicate the need for further evaluation of the topic before recommending the indiscriminate use of infiltration basins with the purpose of stormwater management.

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