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Inlet Protection Devices and Their Effectiveness

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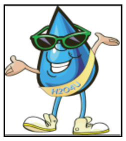

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The opinions, findings, and conclusions expressed in this publication are those of the authors and not necessarily those of the State of Florida Department of Transportation. Furthermore, the authors are not responsible for the actual effectiveness of these control options or drainage problems that might occur due to their improper use. This does not promote the specific use of any of these particular systems.

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Thirteen (13) Inlet Protection Devices are evaluated for flooding and pollution removal potential. Each inlet protection device (IPD) reflects a common product for control of sediment in the State of Florida. The IPD were installed and evaluated for both curb (Type 5) and drop (Type C) inlets. At least three runoff events were conducted for each product type. Water Quality measurements for turbidity, total solids, pH, alkalinity, and nutrients are done before and after passing through the IPD. Removal effectiveness under the conditions during each runoff event is calculated. The evaluations are performed using runoff from ½ inch rainfall events.

Recommendations based on the field evaluations include:

- All IPDs performed at a level that reduced the amount of sediment and nutrients entering the storm sewer or water body.
- Each IPD evaluated has its own unique data set for pollution control.
- All IPDs will perform the best with regular and proper maintenance. A regularly scheduled inspection and/or cleaning of an IPD should be required. The scheduled maintenance will increase the effectiveness and product life, while decreasing the risk of ponding on a roadway.
- Turbidity, total solids, and nutrient reduction are estimated. These estimates can eventually become part of a mass loading reduction program in a watershed. The estimates presented in this work should be considered.
- For both the curb and drop IPD, ease of installation and maintenance is a factor in achieving desired performance. Thus, regular inspections should be part of a maintenance program.
- For drop inlets, IPDs in series consisting of a product upstream of the inlet to attenuate flow rate and a product beneath the grate that can filter the water is a more efficient system. The grate capture product will have to be maintained.

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Eight manufactures of inlet protection devices provided product for evaluation. Their contribution is acknowledged as this work takes on real world application using an Inlet Protection Device (IPD) for sediment control. Also, the authors appreciate a review of the draft final report conducted by John Goolsby, Eddie Snell, and Patricia Tierney who practice erosion and sediment control. In addition, many professionals attending educational courses at the University of Central Florida have offered suggestions that have made this research more suitable for application.

EXECUTIVE SUMMARY

The purpose of this research project is to evaluate the use of various inlet protection devices (IPDs) during soil disturbing activities. The evaluating measurements include flooding potential and the reduction in sediment and other pollutants present in roadways and swales from entering the storm drainage system. Curb (Type 5) and ground level drop (Type C) inlets were used as typical for FDOT applications.

Uncontrolled erosion and sediment from land development activities can result in costly damage to aquatic areas and to both private and public lands (Livingston et al. 1988). The transport of sediment during runoff events can lead to blocked stormwater conveyance systems, plugged culverts, filled navigable channels, impacted wetlands, impaired fish spawning, clogged gills of fish and invertebrates, and suppressed aquatic life.

Inlet protection is considered to be one part of a Stormwater Pollution Prevention Plan (SWPPP) used to control sediment entering into a stormwater conveyance system and into water bodies. Inlet protection is often necessary around stormwater inlets and culverts that accept runoff from disturbed areas (State of Florida, 2007). Sediment and nutrients generated and transported during construction activities must be controlled to meet effluent discharge standards. The effluent concentration leaving at the point of discharge must not exceed the turbidity value of 29 Nephelometric Turbidity Units (NTUs) above background levels in most Florida water bodies, and must not exceed existing background turbidity in the Keys or in impaired water bodies (Florida Department of Environmental Protection, 1995). Ponding is an issue that may occur with IPDs, as sediments accumulate during use of the device. Many IPDs are commercially

available and should be evaluated to determine pollutant removal effectiveness and the potential of localized flooding, or ponding.

Various product types were evaluated in order to determine what types of measures and standards can reasonably be used to set minimum requirements for product removal efficiencies and flooding potential. Seven curb inlet and six drop inlet protection devices were evaluated and the products listed randomly and generically as follows:

Curb Inlets

1. Product A is a plastic corrugated pipe wrapped in a geofiber fabric acting as a sock with two sand bags holding it in place.
2. Product B consists of recycled synthetic fibers and other material designed with multiple 2 inch orifice (holes) for water bypass to minimize ponding. The product is held in place by its own weight.
3. Product C is a woven, polypropylene material wrapped around PVC and Styrofoam, and consists of an overflow weir to minimize ponding. The product is held in place by wedges between the pavement and inlet top.
4. Product W is made of wood chips held together by a mesh net, with no overflow prevention. The product is held in place by its own weight.
5. Product S contains a lightweight plastic material wrapped with a non-woven geotextile and sand bags attached to each end to hold it down.
6. Product E contains tire chips wrapped in a woven geotextile and consists of an overflow weir to minimize ponding. It is held in place by its own weight.
7. Product G is a woven geotextile with an internal rigid plastic frame. It is held in place by weights on the backside.

Drop Inlets

1. Product DM is a non-woven geotextile that wraps round and secured to the grate.
2. Product DH is a non-woven geotextile that is secured under the grate. An overflow opening is included in the design.
3. Product DW is a wood chip wattle that goes around the perimeter of the inlet.
4. Product DB is a recycled synthetic fiber staked around the outside perimeter of the inlet.
5. Product DE is a log of wood chunks wrapped in a woven geotextile. It encircles the drop inlet.
6. Product DU is a non-woven geotextile that is placed over the grate. The product is secured by magnets located at each corner.

Three experimental rain events were performed at the UCF Stormwater Management Research and Testing (SMART) laboratory on each product. The third rain event was considered a clog test, since heavy loading of sediment would have accumulated in front of the product over time. Water quality samples were analyzed and performance observations were recorded.

The testing performed on the curb and drop inlets were full scale rainfall simulations. A watershed runoff sheet flow replication was created. The simulated rain device positioned approximately 300 gallons of water onto the watershed area over 3.5-minute duration to simulate a 0.5 inch rain event, producing a peak discharge of about 0.20 cubic feet per second (cfs). The average intensity of rainfall was 8.7 inches per hour to produce the peak discharge.

The experimental 30 by 30 feet watershed had a consistent amount and type of sediment placed on it prior to each test. A-3 fine-sand existing at the SMART laboratory was used during testing. The generated runoff for the curb inlet transported the sediment and other particles towards the inlet with pavement slopes of 1:1 and 60:1. The drop inlet had a gradual estimated 20:1 slope. Water samples were collected upstream and downstream of the inlet, to measure water quality parameters before and after the IPD. The change in water level in the inlet over time was measured to estimate the flow rate through the product. The watershed conditions for the drop inlet test were prepared similarly to the curb inlet test.

From the field evaluation, the following are general recommendations.

Turbidity, sediment, and nutrients before and after an IPD can be measured accurately.

- All the IPDs performed to reduce the amount of sediment and nutrients entering the storm sewer or water body, although to differing degrees.
- Each IPD evaluated has its own unique set of removal rates under the loading and runoff evaluation conditions.
- Turbidity, total solids, and nutrient reduction can be part of a mass loading reduction program in a watershed.
- A regularly scheduled inspection and/or cleaning of an IPD is required in order to increase the effectiveness and product life, while also decreasing the risk of ponding on roadways.
- For drop inlets, a treatment system consisting of a product upstream of the inlet to attenuate flow and a product beneath the grate that can filter the water is a more efficient pollutant removal system and lasts longer. The grate capture unit will have to be maintained more frequently than the upstream one.

- Caution should always be taken in the deployment of these systems so that upstream flooding does not cause unsafe high water conditions.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1 INTRODUCTION

1.1 PURPOSE

The purpose of this work is to report on the effectiveness of an inlet protection device (IPD) to reduce sediment and other pollutants present in roadways and swales before runoff waters enter the storm drainage system. Curb (Type 5) and ground level drop (Type C) inlets were used as typical of FDOT applications.

1.2 BACKGROUND

1.2.1 Stormwater Pollution Prevention Plan (SWPPP)

Uncontrolled erosion and sediment from land development activities can result in costly damage to aquatic areas and to both private and public lands (Livingston et al., 1988). The transport of large volumes of sediment during rain events leads to blocked stormwater conveyance systems, plugged culverts, filled navigable channels, impaired fish spawning, clogged gills of fish and invertebrates, and suppressed aquatic life. The sources of stormwater discharges regulated under the National Pollutant Discharge Elimination System (NPDES) Stormwater Program are construction activities, industrial activities, and municipal separate storm sewer systems (MS4).

Stormwater runoff from construction activities can have a significant impact on surface water quality by contributing sediment and other pollutants to water bodies and wetlands. The NPDES Stormwater Program regulates construction activities that disturb one or more acres of land and discharge stormwater to surface waters of the State of Florida or into a municipal separate storm sewer system (MS4). The regulatory definition of a MS4 is "a conveyance or system of conveyances like roads with stormwater systems, municipal streets, catch basins, curbs, gutters, ditches, constructed channels, or storm drains" (State of Florida, 2007).

A proper Stormwater Pollution Prevention Plan (SWPPP) must identify the location, relative timing, and specifications for all erosion control, sediment control, and stabilization measures that are required as part of the project construction. The plan must provide for compliance with the terms and schedule of implementing the proposed project, beginning with the initiation of construction activities. The plan may be submitted as a separate document, or may be contained as part of the plans and specifications of the construction documents.

A key component of the SWPPP is an effective sediment and erosion control plan which is essential for controlling stormwater pollution during construction. Erosion and sediment control plans range from very simple for small, single-phase projects to complex for large, multiple-phase projects. When unforeseen circumstances such as extreme rainfall events or construction delays occur, existing erosion and sedimentation controls may no longer provide reasonable collection of solids and associated pollutants. Thus they may need to be replaced so as to provide protection of receiving waters. The SWPPP should be updated as needed to reflect the additional erosion and sediment control measures implemented on site (Florida Department of Environmental Protection, 2009).

Inlet protection is considered to be one part of a SWPPP used to control the releasing of sediment into a stormwater system or a water body. Inlet protection should be considered around stormwater intakes and culverts that accept runoff from disturbed areas (State of Iowa, 2008; State of Florida, 2007). Sediment and nutrients generated and transported during construction activities are required to be controlled to meet effluent discharge standards. The effluent concentration leaving a discharge point must not exceed 29 Nephelometric Turbidity Units (NTU) above background levels and must not exceed background levels in the Florida Keys or in impaired water bodies (Florida Department of Environmental Protection, 1995). Various types of IPDs are on the market and were tested to determine effectiveness in sediment and nutrient removal along with the IPD clogging potential.

Storm sewers which are placed in service before the contributing drainage area is stabilized can convey large amounts of sediment to natural drainage ways, storm sewers, and surface water bodies. In case of extreme sediment loading, a storm sewer may clog or lose a major portion of its capacity. To avoid these problems, it is necessary to prevent sediment from entering the system at the inlets. There are several types of inlet filters and traps which have different applications depending upon site conditions and type of inlet.

1.2.2 The National Pollutant Discharge Elimination System (NPDES)

The following provides information from NPDES used to guide the conduct of the research relative to regulations currently being used.

> Title 40--Protection of Environment
> CHAPTER I--ENVIRONMENTAL PROTECTION AGENCY
> PART 122--EPA ADMINISTERED PERMIT PROGRAMS:
> THE NATIONAL POLLUTANT DISCHARGE ELIMINATION SYSTEM
>
> 122.26 Storm water discharges (applicable to State NPDES programs, see 123.25).
> E) *Characterization plan*. Information and a proposed program to meet the requirements of paragraph (d)(2)(iii) of this section. Such description shall

include: the location of outfalls or field screening points appropriate for representative data collection under paragraph (d)(2)(iii)(A) of this section, a description of why the outfall or field screening point is representative, the seasons during which sampling is intended, a description of the sampling equipment. The proposed location of outfalls or field screening points for such sampling should reflect water quality concerns (see paragraph (d)(1)(iv)(C) of this section) to the extent practicable.

(v) Management programs. (A) A description of the existing management programs to control pollutants from the municipal separate storm sewer system. The description shall provide information on existing structural and source controls, including operation and maintenance measures for structural controls that are currently being implemented. Such controls may include, but are not limited to: Procedures to control pollution resulting from construction activities; floodplain management controls; wetland protection measures; best management practices for new subdivisions; and emergency spill response programs. The description may address controls established under State rules and regulations.

Characterization data. When “quantitative data’’ for a pollutant are required under paragraph (d)(a)(iii)(A)(3) of this paragraph, the applicant must collect a sample of effluent in accordance with 40 CFR 122.21(g)(7) and analyze it for the pollutant in accordance with analytical methods approved under 40 CFR part 136. When no analytical method is approved the applicant may use any suitable method but must provide a description of the method. The applicant must provide information characterizing the quality and quantity of discharges covered in the permit application, including:

(A) Quantitative data from representative outfalls designated by the Director (based on information received in part 1 of the application, the Director shall designate between five and ten outfalls or field screening points as representative of the commercial, residential and industrial land use activities of the drainage area contributing to the system or, where there

> are less than five outfalls covered in the application, the Director shall designate all outfalls) developed as follows:
>
> (1) For each outfall or field screening point designated under this subparagraph, samples shall be collected of storm water discharges from three storm events occurring at least one month apart in accordance with the requirements at § 122.21(g)(7) (the Director may allow exemptions to sampling three storm events when climatic conditions create good cause for such exemptions);
>
> (2) A narrative description shall be provided of the date and duration of the storm event(s) sampled, rainfall estimates of the storm event which generated the sampled discharge and the duration between the storm event sampled and the end of the previous measurable (greater than 0.1 inch rainfall) storm event.

These regulations help guide this research, as the research team sampled at least three storm events to collect data on the effectiveness of each IPD. The dates and storm duration with rainfall volumes used for evaluation were noted. All runoff events were from rainfall greater than 0.1 inch of rainfall. In addition, the location of the inlets and IPDs were noted.

The trade names of the IPDs were deliberately not mentioned so as to minimize comparison of materials. There have not been significant uniform standards for IPD evaluation; therefore, it was more important to develop techniques for measurement and to offer methods for evaluation and testing. The results of the evaluations show that the IPD products have their unique levels of solids capture, pollutant removal, flow rate, installation procedures, and maintenance requirements. The user will have to determine which IPD is appropriate for a particular inlet protection location.

1.2.3 Inlet Protection Practices

The absence of an IPD leads to the plugging and clogging of inlets and inlet throats. Figure 1 shows an impaired curb inlet. Inlet protection devices protect inlets from large debris and small sediment particles alike.

(M. Goolsby, 2009)

Figure 1: Lack of inlet protection

The curb inlet in Figure 2 has a serious risk of discharging polluted runoff. Any contribution from the portable toilet could contain high amounts of nutrients and other biological pollutants. The overfilled dumpster on site also contains sediments and other pollutants that could plug the inlet or impact the ecosystem when entering the stormwater conveyance system.

(M. Goolsby, 2009)

Figure 2: Absence of inlet protection on residential construction

The image in Figure 3 demonstrates incorrect drop inlet protection. If one looks closely through the grate, there is a collapsed non-woven geotextile. The system is not secured to the inlet; therefore it quickly failed with an open area and does not provide any sediment control protection for the inlet.

(M. Goolsby, 2010)

Figure 3: Improper drop inlet protection

Figure 4 shows an improper use of a curb IPD. The turbid runoff flows directly into the inlet because the device was not installed correctly to reduce the amount of sediment reaching the storm sewer.

(M. Goolsby, 2010)

Figure 4: Improper curb inlet protection practice

Heavy sediment loading that has no erosion or sediment control around it, as shown in Figure 5, can result in large volumes of sediment particles reaching the inlet. IPDs are not designed to retain or contain such large amounts of sediment. Therefore, it is essential to prevent this erosion and sediment transport from occurring prior to reaching the IPD.

(M. Goolsby, 2010)

Figure 5: Improper aggregate storage

The implementation of an IPD alone cannot effectively handle the amount of sediment being transported in Figure 6. A Proper erosion and sediment control plan in a SWPPP can significantly limit the amount of sediment and pollution reaching the inlet.

(M. Goolsby, 2010)

Figure 6: No source control adjacent to inlet

1.3 WATER QUALITY IMPACTS

1.3.1 Sediment Loading Impact to Water Bodies

Once suspended in water, soil particles may become a major water pollutant. When increases in total solids occur in water, plant and animal life changes may occur and sometimes elimination of a species occurs in the area affected by total solids. Necessary life functions such as photosynthesis, respiration, growth, and reproduction are impacted by the presence of suspended particles. Since construction projects can be one source of soil particles that contribute sediment to Florida's streams, lakes, canals, and shorelines, it is important to understand how to control sediment both during and following land disturbance activities. As construction activities disturb land, erosion occurs during rainfall or wind events. For example, "Construction areas can produce 10 to 20 times more soil particles lost than from lands where vegetation exists. Reservoirs, harbors, and canals can clog with silt. Loss of recreational areas and wildlife habitat reduces the beneficial water uses for humans and can harm plants and animals" (State of Florida Erosion & Sediment Control, 2007).

1.3.2 Nutrients, Pesticides, and Heavy Metals

Sediment loading from construction areas may also increase the amount of nutrients in water. Nutrients, more specifically phosphorus and nitrates, can often come from fertilizers used at construction sites to aid in the establishment of vegetation. When runoff waters carry sediment downstream into water, plants that live in water use the nutrients to increase the biomass, which robs the water of oxygen and can kill aquatic organisms, including fish. In addition to nutrients, herbicides and pesticides may also exist in construction site soils or upstream drainage basins. When runoff events occur, these harmful chemicals are also carried with the sediments. Additionally, improper application of pesticides can also result in the direct contamination of water. It is estimated that over half of the trace metals carried in runoff waters are attached to sediments (Caltrans, 1996). Sources of these metals found at construction sites include galvanized metal, paint, and wood preservatives. Nearly all metals can be toxic to plants, animals, and fish in certain concentrations. In addition, metals can accumulate in the tissues of plants, animals, and fish and have the potential to contaminate drinking water.

1.3.3 Hydrocarbons and Other Wastes Found in Runoff Waters

Other pollutants found in runoff from construction sites include hydrocarbon compounds caused by leaks from heavy equipment, hydraulic line failures, hydrocarbon spills during refueling, inappropriate disposal of drained fluids, and so forth. When runoff occurs, these hydrocarbons can wash into the water, harming plant and animal life. Other wastes from construction sites that can lead to unsightly and polluted water include: wash water from concrete mixers; paints and painting equipment; wastes from cleaning of vehicles and equipment; wastes from trees and shrubs removed during land clearing; wood and paper from building product packaging; food containers, such as paper, aluminum, and metal cans; and sanitary wastes. All of these can each add to the sediment in runoff waters (State of Florida Erosion & Sediment Control, 2007).

1.4 IPD PROCESS OF EVALUATION

In a SWPPP, the primary role of the IPD is to prevent large objects and sediment from entering and impairing the stormwater systems. Every IPD in the market is designed to effectively remove large objects; therefore, other performance parameters must be used to evaluate and separate effective products from ineffective or less effective products.

An ideal IPD requires documentation of its practicality and effectiveness. Practicality may be defined as the product's convenience in all areas of application. A user needs a product that has a simple and relatively easy installation. Along with the ease of installation, preference goes to an IPD that is relatively light in weight pre and post use since it is more economical for companies to use less manpower to install the products. A reduction in time and labor put into installation equals more capital saved by the company. Ideally, proper maintenance for the product should be at a minimum and the product longevity should out-last the project construction duration or until the product is no longer needed (e.g. vegetation is established).

An essential product evaluation criterion is safety. The product should be easily visible to bikers, pedestrians, and cars. Also, the product should be somehow secured to the site to prevent dislodging which could cause potential hazards on roadways or sidewalks, or clog the stormwater system. An emergency bypass is an effective measure applied to products that will prevent the possibility of ponding which can also be a major road hazard. The summation of simple installation and maintenance, light in weight, and public safety meet the requirements for the practicality of an effective IPD. The utilization of recycled material as part of an IPD is inherently desirable from an environmental stewardship perspective, but only if the product also does what it is installed to do.

In summary, an effective IPD should pass water while also capturing total solids and associated pollutants. High water flow through the device requires large opening size in the product; however, capturing fine sediment requires small opening size. Since particle retention is inversely proportional to water flow, the more fine particles captured, the lower the flow through the device. Ideal effectiveness occurs where the maximum amount of particles is retained while the water flow is just high enough to prevent hazards such as ponding.

1.4.1 Method for Measuring Product Effectiveness

To quantify the effectiveness of the product, runoff experiments were performed to simulate the real field application of the inlet protection products. Water from a cistern was pumped through a network of 2-inch PVC piping onto the test asphalt pavement field to simulate sheet flow with turbidity values in excess of 500 NTU. The volume of water was 0.5 inch or 8.57 inches per hour across the watershed producing a maximum flow rate into the inlet of 0.18 cfs. This volume is sufficient on most impervious areas to cause runoff. The runoff that passes through the curb or drop inlets is channeled to the back of the inlet and discharged into a 500 gallon tub. Samples were collected upstream and downstream of an IPD and then tested in the chemistry laboratory. Volume measurements were also taken as a direct measure of runoff rate and to assess the potential of flood protection. Flow capacities of the products were also measured.

Laboratory tests were conducted on the water samples collected from the experimental runoff conditions. Water quality analyses are necessary to investigate how the product actually alters the quality of the water. Turbidity is a measure of water clarity, or a measure of how the material suspended in water decreases the passage of light through the water in terms of Nephelometric Turbidity Units (NTU's). High turbidity reduces dissolved oxygen (DO) in water by reducing the amount of light penetrating the water, which inhibits photosynthesis and the production of dissolved oxygen (Environmental Protection Agency, 2006). The pH and alkalinity of the water were also measured as a reference statistic, even though significant change was not expected when using any IPD. Tests for nitrogen and phosphorus were performed to measure the removal of nutrients. Phosphorus is the common limiting nutrient for growth organisms in freshwater systems. When excess nitrogen and phosphorous are present in water, eutrophication can occur, which may devastate an ecosystem through severe reductions in water quality, fish, and other animal populations. The total nitrogen and total phosphorus tests were used to represent or approximate the percent removal for nutrients. As a whole, the water quality test analyses were used to measure the concentration changes from upstream to downstream by each IPD.

1.4.2 Clogging and Flow Rates

The clogging of an IPD occurs when an excessive amount of sediment collects inside and in front of the device while in use. The method to evaluate the clogging potential of the products was conducted during field testing. At each minute interval, the water level of the runoff on the product and the distance from the product that the ponding occurs is measured and recorded. The degree of ponding that occurs in front of the device represents the severity of clogging.

The clogging potential was tested to ensure the material can perform its task even after heavy loading of sediment. A sieve analysis was conducted to evaluate removal efficiencies for the product in relation to the particle size. Additionally, a soil sample was collected from the sediment that was deposited in front of the product, labeled as upstream sample. A downstream soil sample was also collected from the soil that settled in the inlet storage tank after it passes through the product, labeled as downstream sample. The difference in grain sizes that appear before and after passing the IPD will help for the determination of the removal efficiency of an IPD.

1.5 PRODUCTS TO BE EVALUATED

The field simulations were performed on each IPD to establish a uniform set of standards in an effort to evaluate product effectiveness for pollution control and flooding potential. The grate was wrapped with a thick black non-woven geotextile during all evaluations to remove any influence the grate may have on the performance of each IPD.

1.5.1 Curb Inlet Products

Product A is a plastic corrugated pipe wrapped in a thin black 6 ounce geofiber fabric acting as a sock with two sand bags holding it in place (Figure 7).

Figure 7: Product A

Product B is a rolled up recycled synthetic fibers and recycled material (Figure 8). This product is designed with 2 inch orifices, one foot on center as overflow measures to help minimize ponding. The product is held down by its self-weight.

Figure 8: Product B

Product C is a modular device made up of woven, polypropylene material wrapped around PVC and Styrofoam (Figure 9). This product consists of an overflow weir for the prevention of ponding. The product is held in place by Styrofoam wedges.

Figure 9: Product C

Product W is made of wood chips held together by a mesh net, as seen in Figure 10. There is no overflow prevention. The product is held down by its self-weight.

Figure 10: Product W

Product S is a product that contains a lightweight plastic internal frame wrapped with a non-woven geotextile (Figure 11). This product is box shaped, with sand bags attached to each end to hold it down.

Figure 11: Product S

Product E is tire chips wrapped in a woven geotextile (Figure 12). The design consists of an overflow weir for safety. It is held down by its self-weight.

Figure 12: Product E

Product G is a woven geotextile with a rigid plastic frame internally, shown in Figure 13. It is held together by weights on the backside.

Figure 13: Product G

1.5.2 Drop Inlet Products

Product DM is a non-woven geotextile that wraps around and is secured to the grate, as shown in Figure 14.

Figure 14: Product DM

Product DH is a non-woven geotextile that is secured under the grate and is designed to attenuate and filter runoff. An overflow opening is included in the design, see Figure 15.

Figure 15: Product DH

Product DW is a wood chip wattle that goes around the perimeter of the inlet, as shown in Figure 16.

Figure 16: Product DW

Product DB is made of recycled synthetic fibers and is staked around the outside perimeter of the inlet with about 2.25 inch orifices on one foot spacing, see Figure 17.

Figure 17: Product DB

Product DE is a log of wood chunks wrapped in a woven geotextile. It encompasses the drop inlet, see Figure 18.

Figure 18: Product DE

Product DU is a non-woven geotextile that is placed over the grate, as shown in Figure 19. The product is secured by magnets located at each corner.

Figure 19: Product DU

Product DE+DH**:** describes products DE and DH combined in series, see Figure 20.

Figure 20: Product DE + DH

Three experimental rain events are performed with each product. The last rain event is considered an obstruction test since heavy loading of sediment will have accumulated in front of the product. Water quality samples and flooding performance observations are recorded.

CHAPTER 2 METHODOLOGY

This chapter presents the experimental set up, equipment and the methods for the evaluation. In addition, each product used as an IPD is discussed in general terms to provide information on a general type and installation rather than a specific design and installation.

2.1 CURB INLET TEST

2.1.1 Equipment

1. Twelve one liter water sample bottles
2. One stop watch
3. Data sheet with clipboard
4. Camera
5. Upstream sampling device (Figure 2a)
6. Measuring tape
7. 500 gallon tub
8. Inlet protection device

2.1.2 Setup Procedure

1. Clean the 500 gallons tub.
2. Install the grate with the geotextile cover attached over the inlet.
3. Install the curb inlet protection product according to manufacturer’s instructions.
4. Run 2” PVC piping system for the sheet flow simulator from the cistern to the test field (See Figure 21) and check each joint to make sure they are tightened.
5. Evenly pour approximately 2 cubic feet of soil on the 900 square foot watershed/pavement.
6. Water sampling bottles are brought out with the recording sheet.

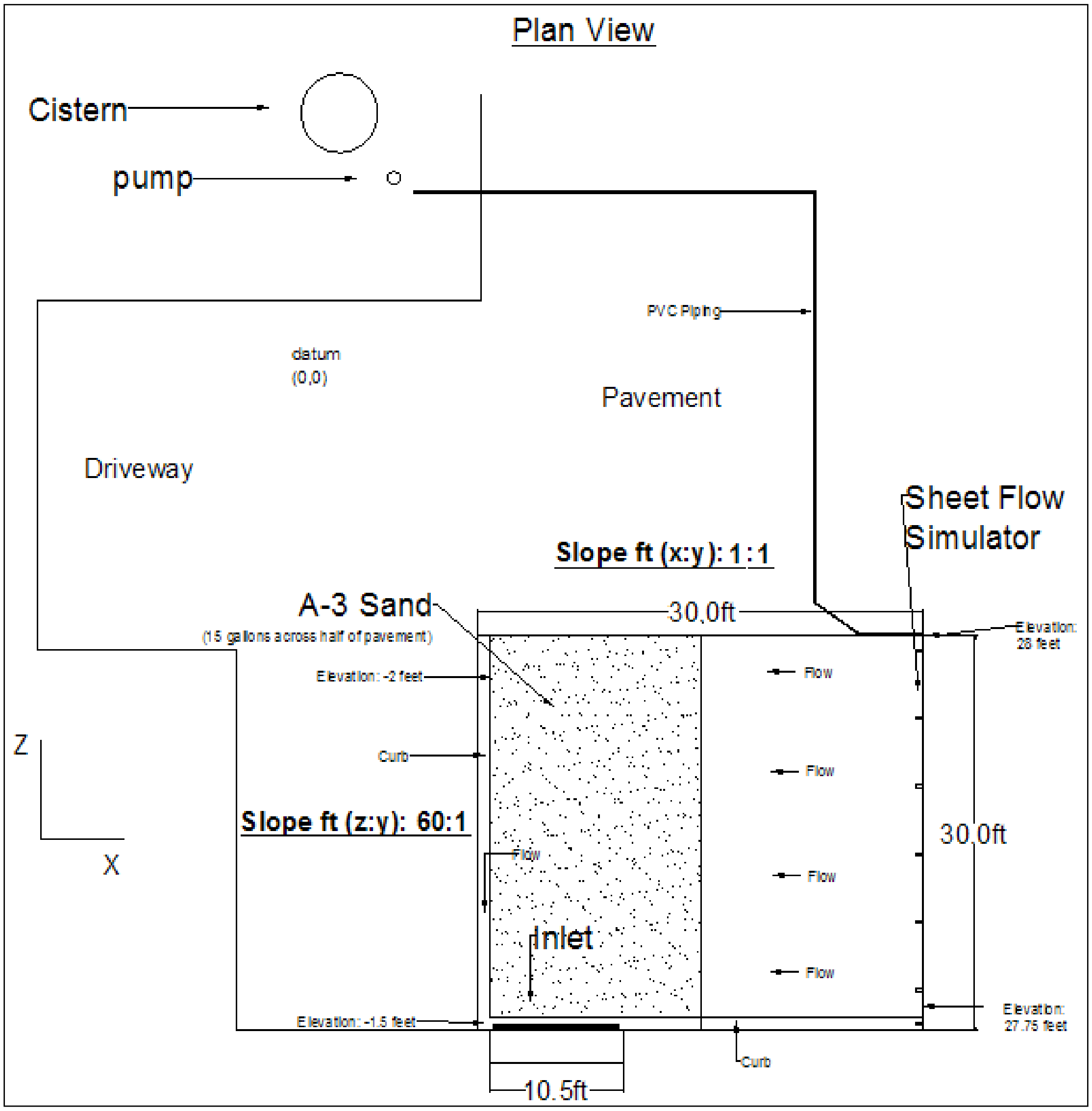

Figure 21: Plan view of curb inlet watershed and test

2.1.3 Product Installation & Maintenance Instructions:

Product A

- Place product in front of opening; make sure the entire opening is covered by the product.
- Place sand/rock bags on top of the product at each end.

Product B

- Place product in front of opening; make sure the entire opening is covered by the product.
- Angle the overflow holes so that the runoff will not pond.

Product C

- Place one anchoring wedge on the ends of each 3 foot section.
- Connect together two sections of the Product C by inserting the Male Pipe Connector into the open end of the Female Pipe Fitting. (glue the sections together, use of PVC cement is optional).
- Once the two sections are connected together, slide the anchoring.
- Anchoring wedge to cover and seal off the seam area between the two sections.
- Align the Product C section with the sediment flap facing down (to touch the pavement). This will form a barrier against water flowing underneath the unit and will prevent water/sediment bypass.
- Install the assembled unit into the “throat” of the curb inlet by pushing each anchoring wedge down into proper position (Note: The black corrugated plastic covered part of the wedge should face down—toward the ground). At the ends of the curb inlet, position the anchoring wedges to seal off the corners.

Note: The top of each anchoring wedge is perforated. If the wedge is too large for the inlet, simply tear off the top section and reinstall (a second perforation is available if needed). The front of the anchoring wedges should be flush with the face of the inlet.

Product W

- Place product in front of opening, make sure the entire opening is covered by the product.

Product S

- Identify opening dimensions to determine the number of Product S sections required.
- Completely fill the stabilizations chamber on each end of each Product S section with sand bags or crushed stone bags.
- Secure ends of the stabilization pockets with ties to be provided by others.
- Place Product S in front of the curb inlet or opening to prevent the migration of slit into the storm drain system.

User should not assume all flow rates, site conditions and safety measures are considered. Installation procedures and safety considerations can vary upon site conditions.

Product E

- Place product in front of opening; make sure the entire opening is covered by the product.

Product G

- Place unit in curb inlet so weighted flap hangs down in curb inlet holding Product G firmly in place.
- Center so that one foot of Product G extends beyond each end of curb inlet.

- Inspection after each wet weather event is recommended.
- Remove all sediment and debris from surface after each wet weather event.
- Remove Product G, clean out and replace.

2.1.4 Evaluation Conditions for Curb IPD

The evaluations require three people, each having a specific task. Person 1 runs the centrifugal pump system, Person 2 collects the downstream samples, measures the volume of flow, and runs the timer, and Person 3 collects upstream samples and takes photos. The water is transported from a cistern via centrifugal pump, through a series of 2-inch PVC piping that conveys the water to the evaluation watershed using PVC pipes with perforated holes to simulate "sheet flow" (Appendix: Figure 55 and Figure 56). The time for delivery is 3.5 minutes which is equivalent to 0.5 inches of rainfall over the watershed. After the centrifugal pump is started, it takes approximately one minute for the sheet flow to reach the sampling location at the inlet. Once the runoff reaches the sampling location, samples are collected upstream and downstream at one minute intervals until the evaluation event is completed. The evaluation duration lasts approximately 7 minutes for a 0.5 inch simulated rainfall on the watershed. The maximum water depth on the upstream end of the product is measured.

2.2 DROP INLET TEST

2.2.1 Equipment

1. Ten one Liter water sample bottles
2. One stop watch
3. Data sheet with clipboard
4. Camera

5. Upstream sampling device (Figure 2a)
6. Measuring tape
7. 500 gallon tub

2.2.2 Setup Procedure

1. Clean the 500 gallons tub.
2. Install the product around the grate following manufacturer's instructions.
3. Run 2" PVC piping system for the sheet flow simulator from the cistern to the test field (See Figure 22) and check each joint to make sure they are tightened.
4. The watershed was bare soil so no additional soil was added.
5. Water sampling bottles are brought out with the recording sheet.

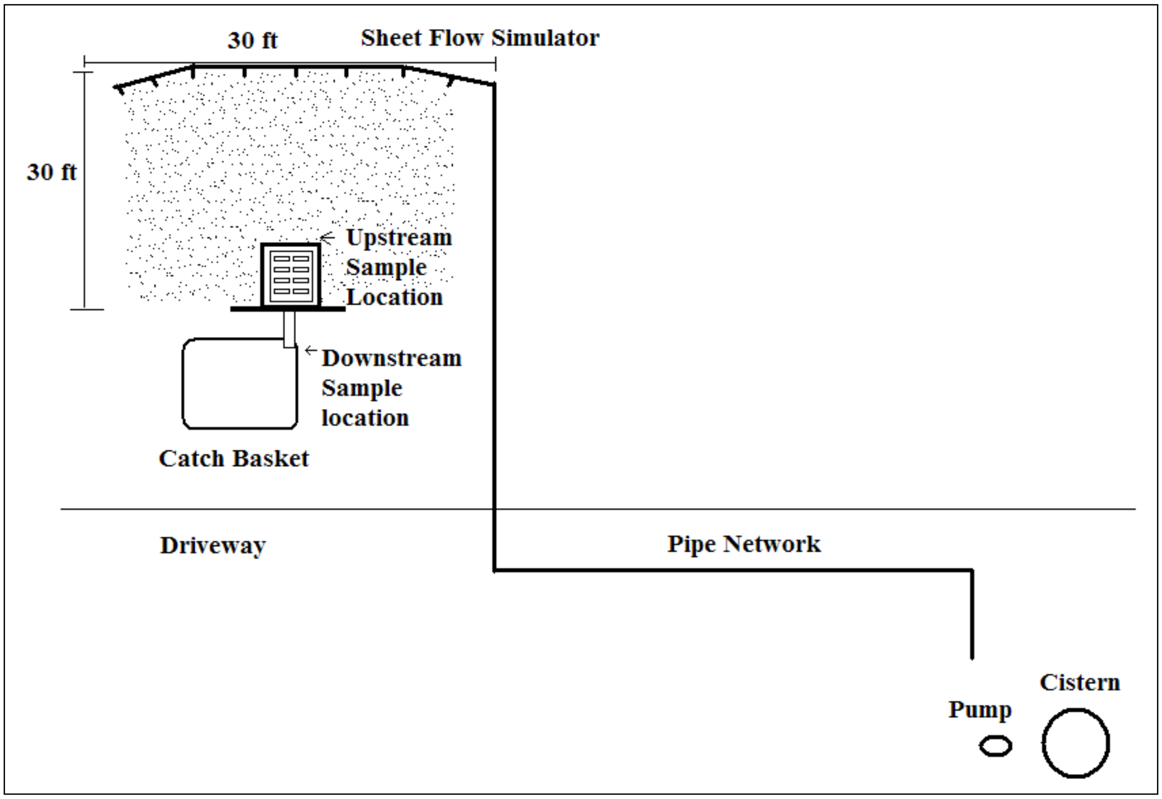

Figure 22: Plan view of drop inlet watershed and test

2.2.3 Product Installation & Maintenance Instructions:

Product DM:

- Wrap product around grate and secured by puncturing holes in the geotextile and securing it with zip ties to the grate.

Product DH:

- Place product below the grate and around the lip of the inlet. Set grate on top of the product.

Product DW:

- Set product around the outside perimeter of the inlet.

Product DB:

- Stake the product around the outside perimeter of the inlet.

Product DE:

- Set the product around the outside perimeter of the inlet.

Product DE+DH:

- Combination of product DE and DH installed.

2.2.4 Evaluation Conditions for Drop IPD

The evaluations require three people, each having a specific task. Person 1 runs the centrifugal pump system. Person 2 collects the downstream samples, measures the volume of flow, and operates the timer. Person 3 collects upstream samples and takes photos. The water is transported from a cistern via centrifugal pump, through a series of 2-inch PVC piping that conveys the water to the testing field having PVC pipes with perforated holes to simulate “sheet flow” similar to the curb inlet evaluations. The rainfall duration is 3.5 minutes for 0.5 inches of rainfall over the watershed. After the centrifugal pump is started, it takes approximately one minute for the sheet flow to reach the sampling location at the inlet. Once the runoff reaches the sampling location, samples are collected upstream and downstream at one minute intervals until the test is completed. The height of the water in the collection chamber after the IPD (downstream) is measured at minute intervals to determine the change in volume over time, or flow rate. Each evaluation test takes approximately 7 minutes. The maximum water level that is reached on the product is measured.

CHAPTER 3 RESULTS

3.1 CURB INLET RESULTS

Flow rate and water quality data were collected for each IPD. Figure 23 shows the results of the flow measurements presented as hydrographs. The rates are average for three tests and as measured after the IPD. The maximum or peak flow rate values are presented in Table 1. The water quality results are compiled and plotted in a graph shown in Figure 24. Each IPD has one graph per water quality parameter and contains the data for the three rainfall experiments performed, and are shown in the Appendix. The concentration is plotted against time at which the sampling was done. The difference in the measured concentration between the upstream and downstream sample is calculated. For the conditions of the evaluations, the average percent removal for each water quality parameter over the three tests is used as the performance measure.

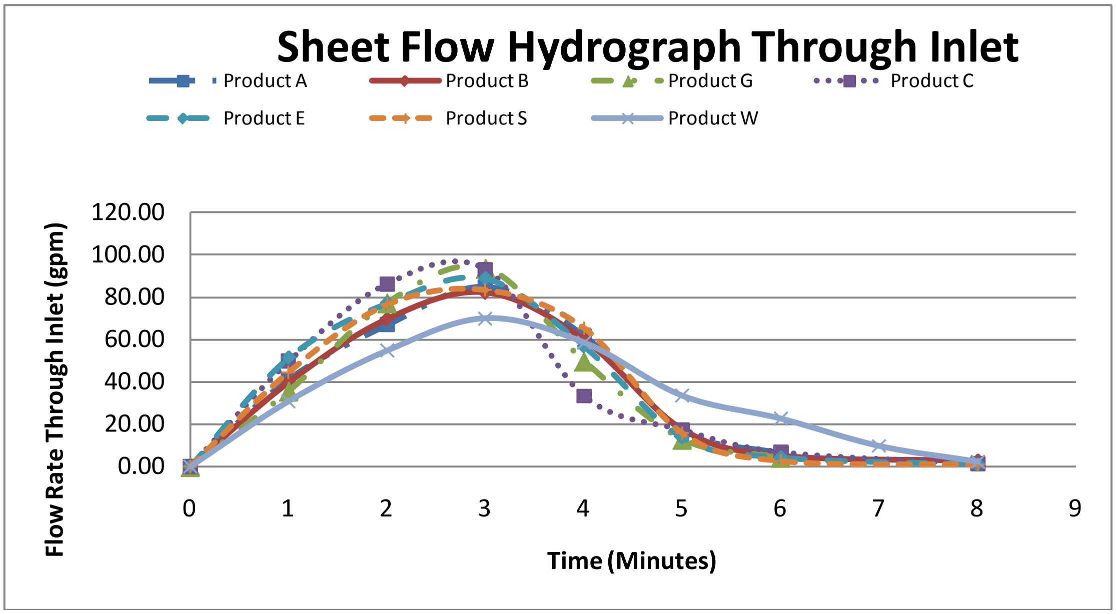

Figure 23: Hydrograph for each IPDs

Table 1: Peak flows through IPDs

Product	Peak Flow throug1.34h IPD (gpm)	Peak Flow through IPD (gpm/ft)	Peak Flow through IPD (cfs)	Peak Flow through IPD (cfs/ft)
Product A	83.50	8.35	0.19	0.019
Product B	82.20	8.22	0.18	0.018
Product C	93.15	9.32	0.21	0.021
Product E	88.86	8.89	0.20	0.020
Product G	93.70	9.37	0.21	0.021
Product S	83.32	8.33	0.19	0.019
Product W	70.01	7.00	0.16	0.016

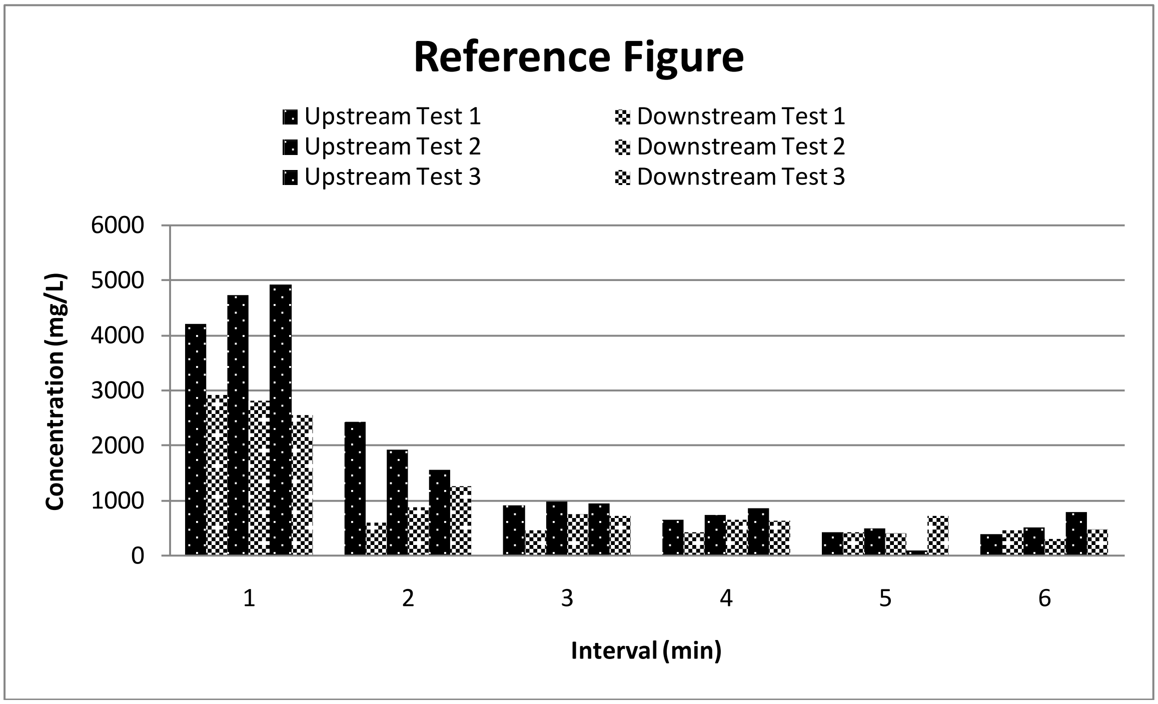

Figure 24: Reference sample graph of average total solids concentrations for 3 rainfall events over time

3.1.1 Turbidity

The results from the turbidity test confirm that the products reduced turbidity. There were differences as shown in Figure 25. There was an initial high value for turbidity that is most likely caused by the initial flush of the soils. After the initial measurement there was a linear decrease in turbidity over time. A reason for this decrease in turbidity is as a result of a decrease in the amount of sediment transported over time. What was also found in all product evaluations is the percent change for later sampling events were lower, sometimes even negative, implying clogging and overflow. All results of the sampling are shown for each IPD and for each evaluation procedure in the Appendix.

Table 2: Average turbidity values and percent removal for curb inlet

Product	Average Upstream (NTU)	Average Downstream (NTU)	Average Percent Removal
Product A	1131	736	34.92%
Product B	1230	811	34.07%
Product C	1410	880	37.59%
Product W	1040	973	6.44%
Product S	973	689	29.19%
Product E	990	702	29.09%
Product G	924	703	23.92%

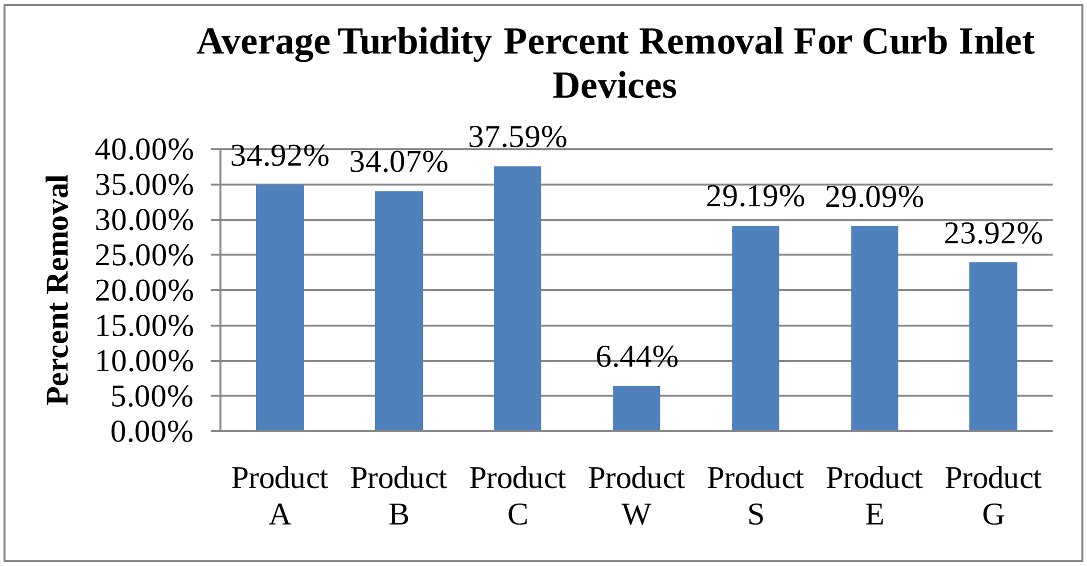

Figure 25: Average turbidity percent removal for curb IPDs

3.1.2 pH and Alkalinity

The pH values remained relatively constant with time and for all experiments and for each IPD. The average results are shown in Table 3 with the difference in pH from before to after the IPD shown in Figure 26.

Table 3: Average pH values and percent difference for curb inlet

Product	Average Upstream	Average Downstream	Average Percent Removal
Product A	7.87	7.87	0.00%
Product B	7.87	7.58	3.68%
Product C	7.77	7.64	1.67%
Product W	7.74	7.75	-0.13%
Product S	7.85	7.9	-0.64%
Product E	7.81	7.73	1.02%
Product G	7.51	7.48	0.40%

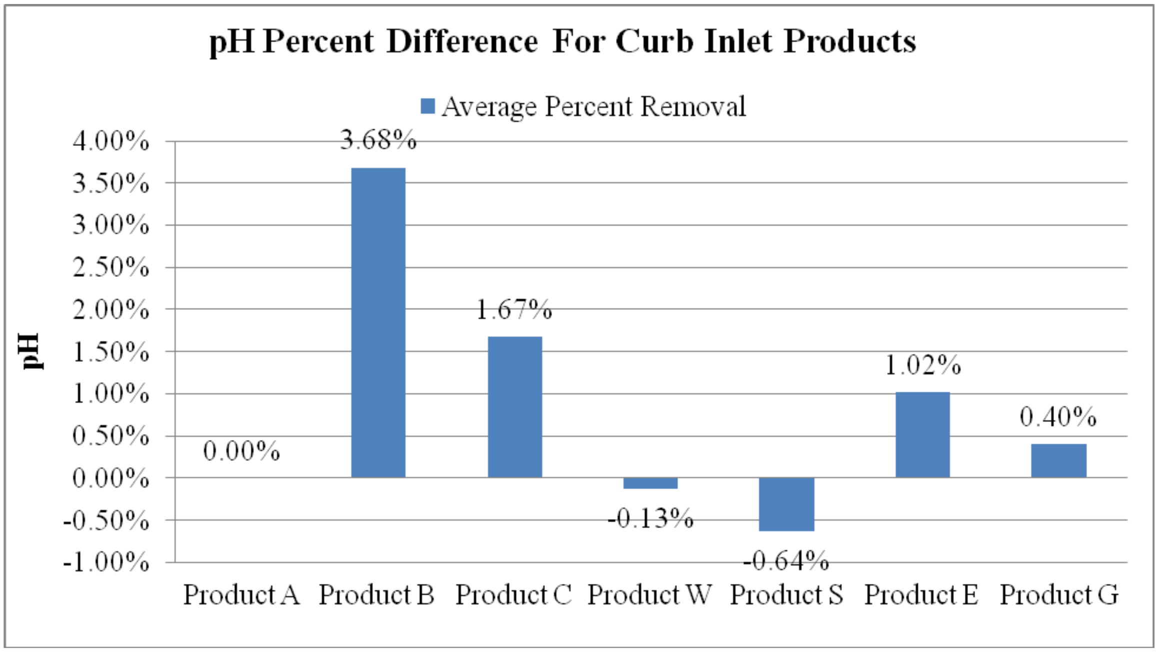

Figure 26: Average percent pH difference for curb IPDs

As expected, the change in pH from upstream to downstream is and should be almost negligible for the products test (Figure 27). For all the Products evaluated, the pH and alkalinity changes are not considered significant, as expected with the materials used in each of the IPD. As an example using Product A, there is no change in average pH between upstream and downstream samples, while the change in alkalinity for Product A is 5.81%, which is not considered significant, see Table 4. Since nitrate and dissolved ammonia are natural components that contribute to alkalinity, the removal of these can also lower the buffering capacity of the water.

Table 4: Average alkalinity values and percent difference for curb inlet

Product	Average Upstream (mg/LCaCO$_3$)	Average Downstream (mg/LCaCO$_3$)	Average Percent Removal
Product A	172	162	5.81%
Product B	187	170	9.09%
Product C	170	153	10.00%
Product W	128	118	7.81%
Product S	146	133	8.90%
Product E	134	125	6.72%
Product G	137	137	0.00%

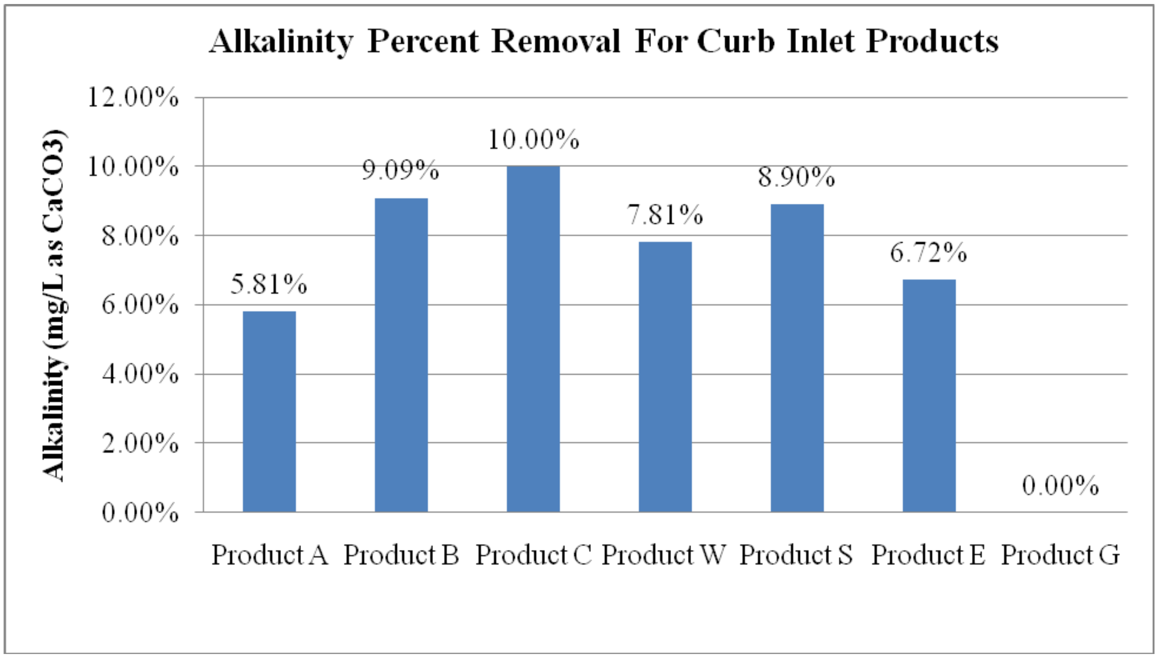

Figure 27: Average alkalinity percent difference for curb IPDs

3.1.3 Total Nitrogen & Total Phosphorous

Total nitrogen and total phosphorus were measured and the averages for each product tested are shown in Table 5 and Table 6, respectively. The average nutrient removal is shown in Figure 28. There were no significant differences in removal percentages among each of the three tests. As shown in the tables, all IPDs except product W remove nitrogen. That product contains wood products and there may be some residual nitrogen in the wood.

Table 5: Average Curb Inlet Total Nitrogen Values and Percent Removal

Product	Average Upstream (mg/L)	Average Downstream (mg/L)	Average Nitrogen Percent Removal
Product A	3.06	1.98	35.29%
Product B	4.30	3.08	28.37%
Product C	3.97	2.40	39.55%
Product W	2.40	2.33	2.92%
Product S	4.01	3.40	15.21%
Product E	3.27	2.32	29.05%
Product G	4.01	3.46	13.72%

Table 6: Average Curb Inlet Total Phosphorous Values and Percent Removal

Product	Average Upstream (mg/L)	Average Downstream (mg/L)	Average Phosphorous Percent Removal
Product A	2.35	1.73	26.38%
Product B	2.11	1.60	24.17%
Product C	2.17	1.53	29.49%
Product W	1.09	0.85	22.02%
Product S	0.59	0.50	15.25%
Product E	0.42	0.34	19.05%
Product G	0.93	0.69	25.81%

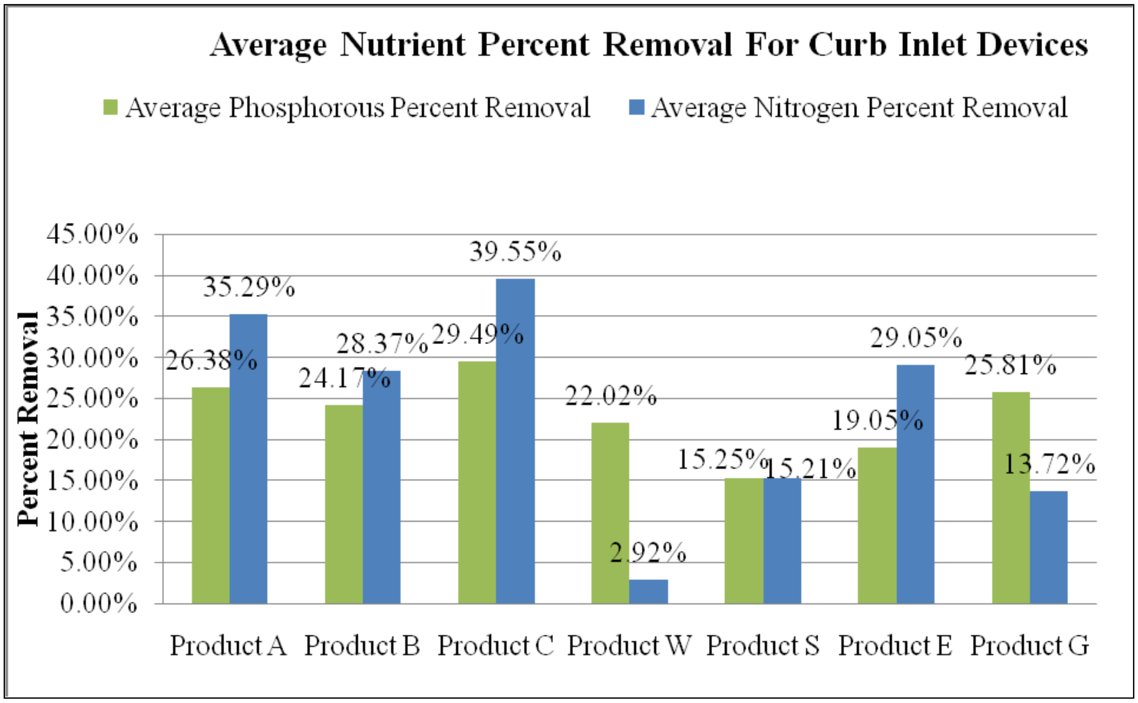

Figure 28: Average TN and TP percent difference for curb IPDs

3.1.4 Total Solids

Table 7: Average total solids values and percent removal for curb inlet

Product	Average Upstream (mg/L)	Average Downstream (mg/L)	Average Percent Removal
Product A	1679	1219	27.40%
Product B	2528	1969	22.11%
Product C	2609	1579	39.48%
Product W	1972	1556	21.10%
Product S	1609	1203	25.23%
Product E	1608	1021	36.50%
Product G	1623	1100	32.22%

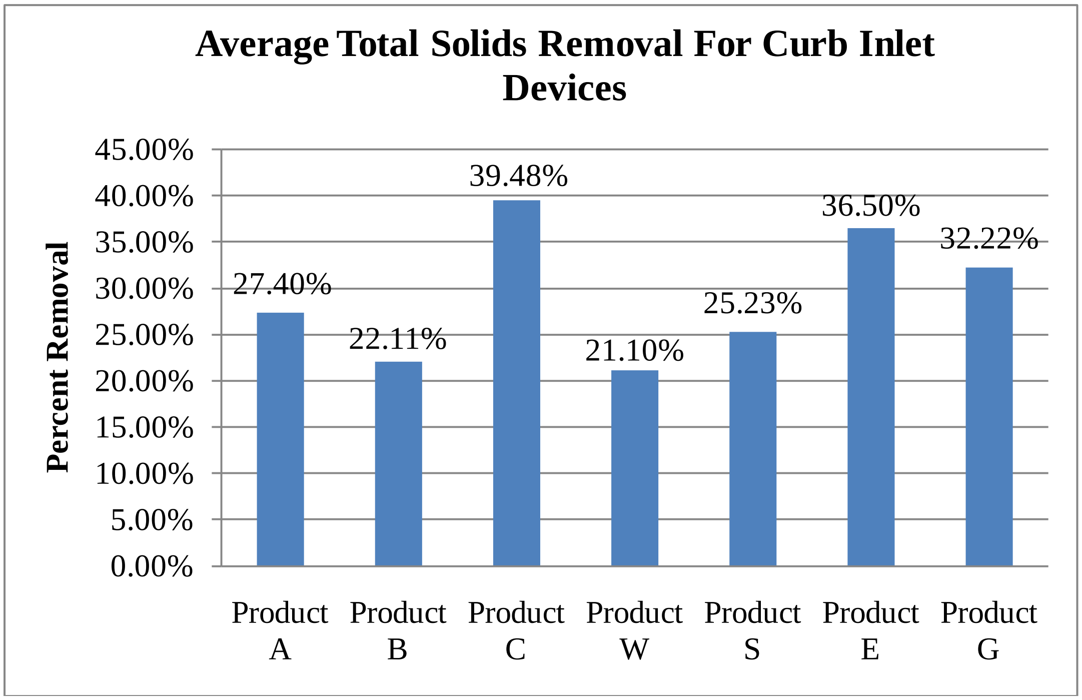

Figure 29: Average TS percent removal for curb IPDs

3.1.5 Sieve Analysis

After a runoff event, soil samples are collected on that captured by the IPD and also from the sediment that passed through the IPD. After the samples are dried, a sieve analysis is performed and analysis is made of the difference between the upstream and downstream samples (Appendix: Table 5 to

Table 17 and Figure 43 to Figure 49). The purpose is to quantify the capacity of the IPD to remove particles.

Figure 30 shows the percent removal of particles greater than 0.25 mm between the upstream and downstream soil samples. This difference shows that some particles greater than or equal to 0.25 mm are being prevented from entering the inlet. This difference is consistent for all IPDs and at all particle sizes. The 0.25 mm size is used to illustrate the retention of particles.

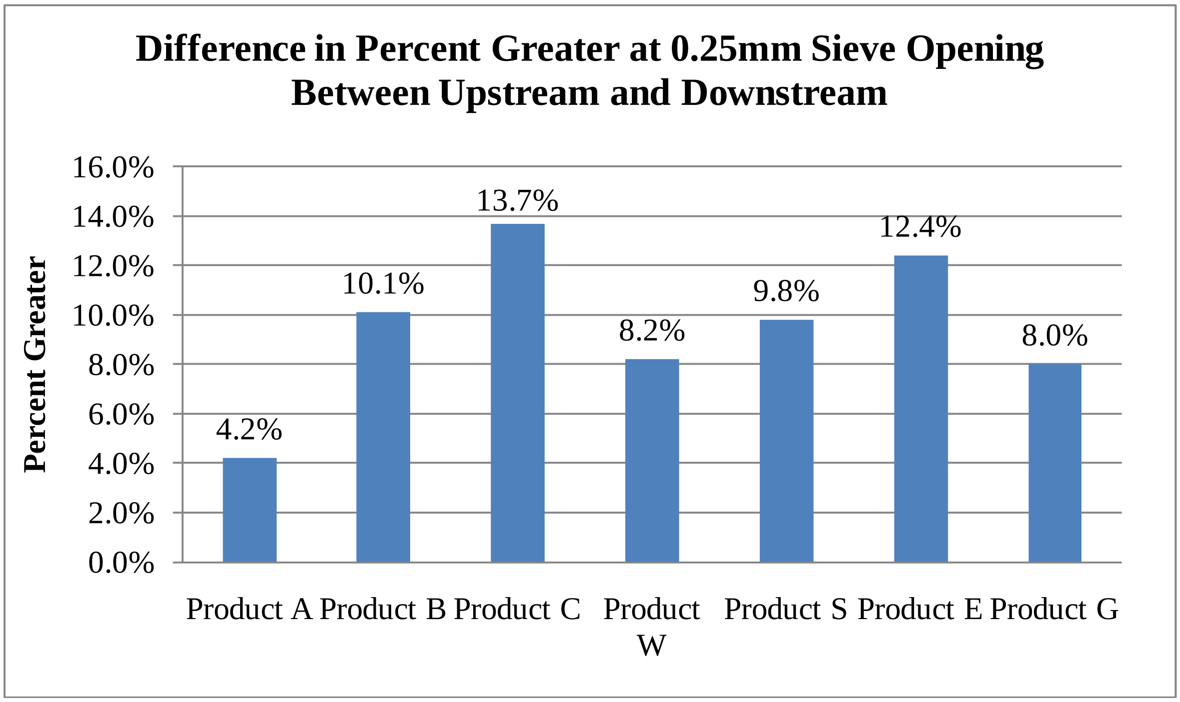

Figure 30: Percent greater than 0.25mm upstream vs. downstream curb IPDs

The upstream sieve analysis for Product A (Figure 43) produces a curvilinear plot that illustrates 29.1% of the grain size of 0.25 mm is found in the sediment. The soil for the upstream sample is considered poorly graded sand. The downstream sieve analysis plotted a relatively similar curvilinear plot. The percentage of the sediment for the grain size of 0.25 mm and larger is 24.9%. The percent difference between the two samples is 4.2%, which represents the difference in the amount of particles greater than 0.25mm entering the storm sewer system. The soil classification for the downstream sample is labeled as well graded sand. The plot of upstream and downstream sediment on the percent finer versus grain size graph shows the distribution of grain sizes in each sample.

3.1.6 Flow Rates

The flow rates are measured by the change in volume of the inlet tank over the change in time. This value is then divided by the linear footage of the inlet opening in order to normalize it per linear foot. All peak flow values are determined by averaging the peak flow rate for 3 simulated rainfall events. All the IPDs had approximately the same peak flow rate, and there was no significant difference between each individual flow rate and the overall average flow rate of 8.5 gpm/foot of product from all measured values.

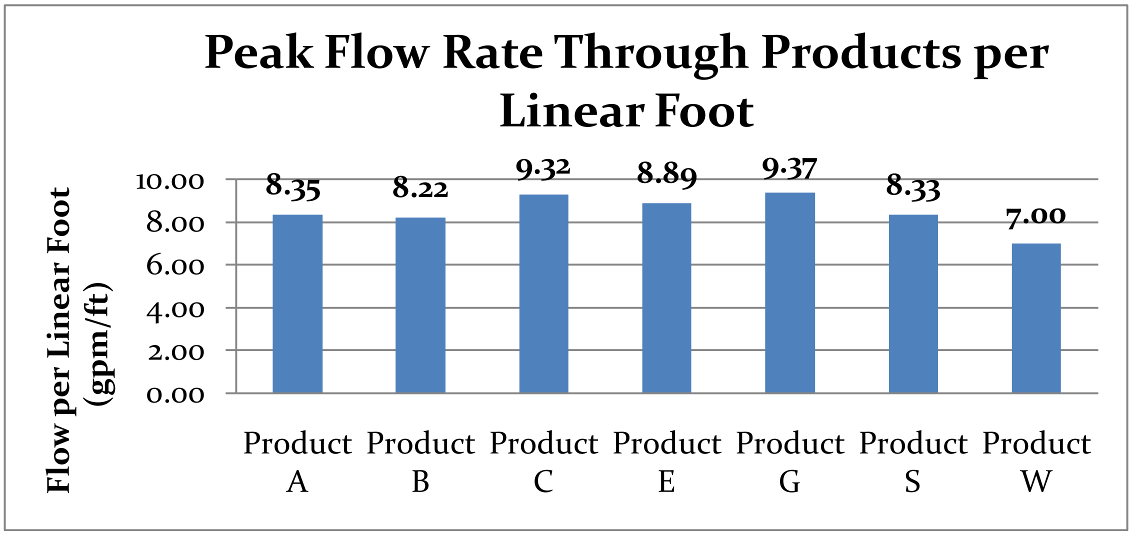

Figure 31: Flow rates per linear foot

3.2 DROP INLET RESULTS

3.2.1 Turbidity

Average turbidity values for each IPD used with a drop inlet are shown in Table 8. The average turbidity removal for all three tests performed is shown in Figure 32 for each IPD.

Table 8: Average turbidity values and percent removal for drop inlet

Product	Average Upstream (NTU)	Average Downstream (NTU)	Average Percent Removal
Product DM	484	468	3.31%
Product DH	495	444	10.30%
Product DB	330	327	0.91%
Product DE	257	243	5.45%
Product DU	355	332	6.48%
Product DW	368	363	1.36%
Product DE+DH	294	179	39.12%

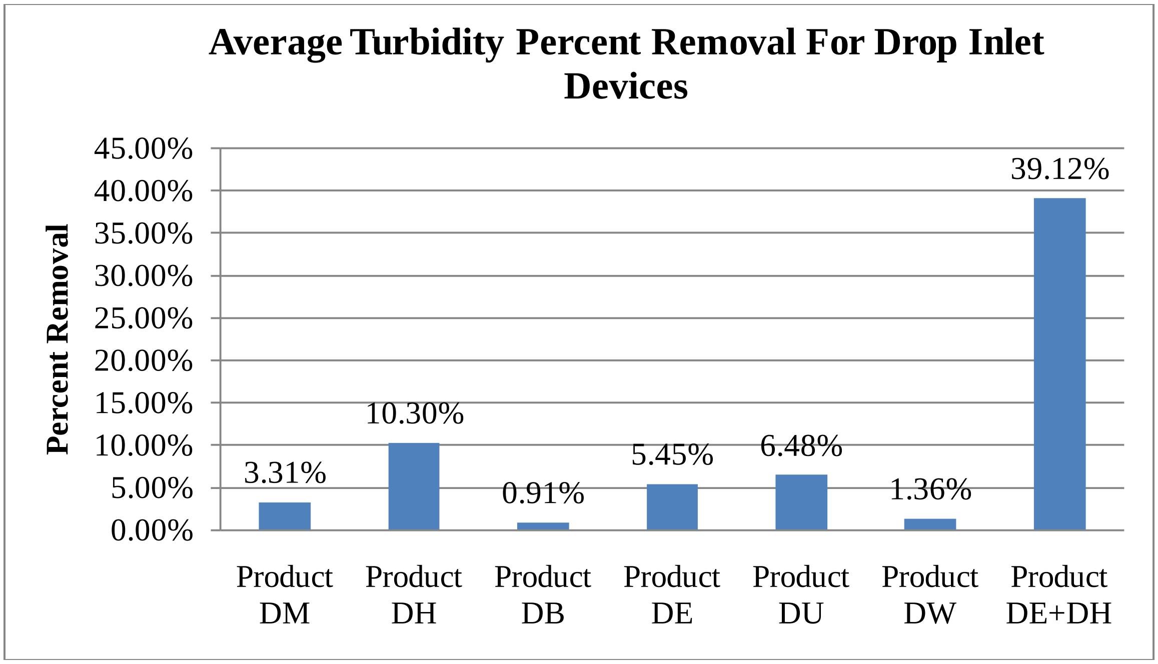

Figure 32: Average percent turbidity removal for drop IPDs

3.2.2 pH and Alkalinity

Table 9: Average drop inlet pH values and percent difference

Product	Average Upstream	Average Downstream	Average Percent Removal
Product DM	7.55	7.39	2.12%
Product DH	8.1	7.9	2.47%
Product DB	7.99	7.81	2.25%
Product DE	7.85	7.79	1.40%
Product DU	8.04	7.93	1.37%
Product DW	8.08	7.74	4.21%
Product DE+DH	7.91	7.82	1.14%

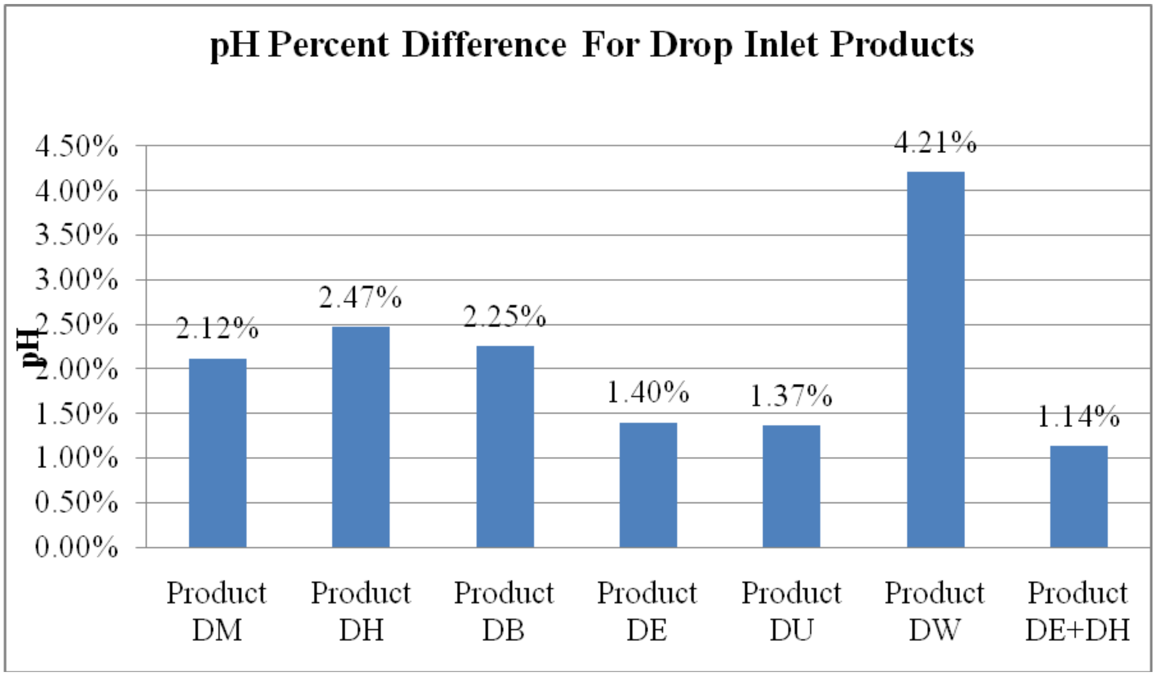

Figure 33: pH percent difference for drop IPDs

Table 10: Average alkalinity values and percent difference for drop inlet

Product	Average Upstream (mg/L as $CaCO_3$)	Average Downstream (mg/L as $CaCO_3$)	Average Percent Removal
Product DM	161	158	1.86%
Product DH	186	178	4.30%
Product DB	211	206	2.37%
Product DE	204	190	6.86%
Product DU	213	209	1.88%
Product DW	195	188	3.59%
Product DE+DH	183	164	8.74%

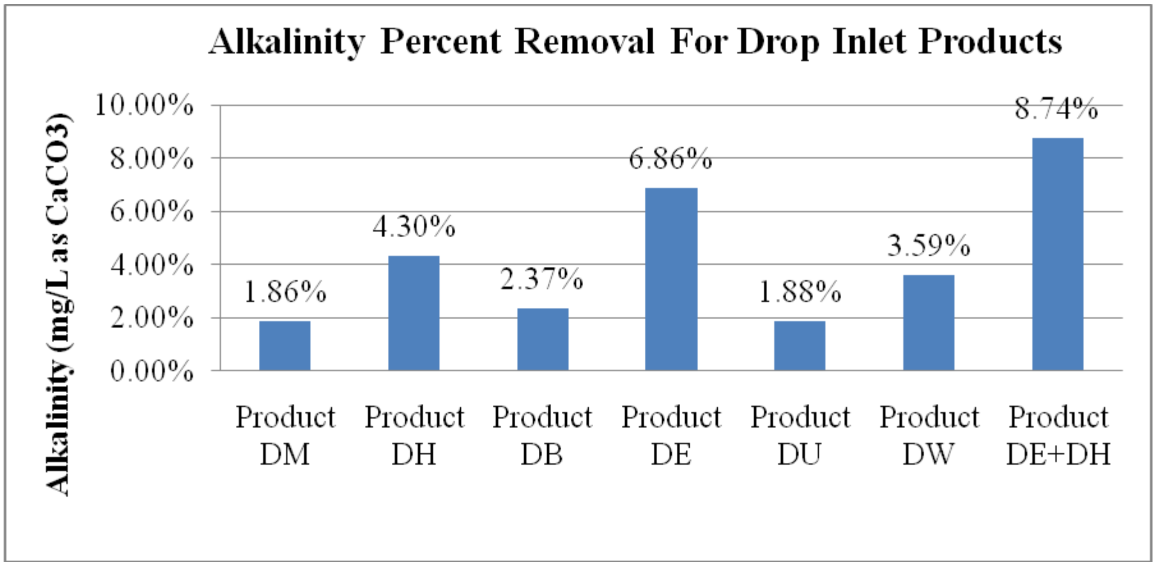

Figure 34: Alkalinity percent removal for drop IPDs

The change in pH from upstream to downstream is and should be almost negligible for the products tested (Figure 33). The alkalinity decreased over the evaluation time period, showing a minor change in alkalinity during all events and with all products (Figure 34). Since nitrate and dissolved ammonia are natural components that contribute to alkalinity, the removal of these can also lower the buffering capacity of the water.

3.2.3 Total Nitrogen & Total Phosphorous

Total nitrogen and total phosphorous removals results are shown in Figure 35 and Tables 11 and 12. As with solids and turbidity, the treatment train performed the best.

Table 11: Average total nitrogen values and percent removal for drop inlet

Product	Average Upstream (mg/L)	Average Downstream (mg/L)	Average Nitrogen Percent Removal
Product DM	0.64	0.62	3.13%
Product DH	0.67	0.64	4.48%
Product DB	0.40	0.39	2.50%
Product DE	0 .40	0.34	15.37%
Product DU	0.59	0.58	1.69%
Product DW	0.43	0.39	9.30%
Product DE+DH	1.51	1.08	28.25%

Table 12: Average total phosphorus values and percent removal for drop inlet

Product	Average Upstream (mg/L)	Average Downstream (mg/L)	Average Phosphorous Percent Removal
Product DM	0.40	0.373	6.75%
Product DH	0.52	0.49	5.77%
Product DB	0.34	0.31	8.82%
Product DE	0.67	0.58	13.43%
Product DU	0.50	0.49	2.00%
Product DW	0.58	0.53	8.62%
Product DE+DH	0.97	0.73	24.74%

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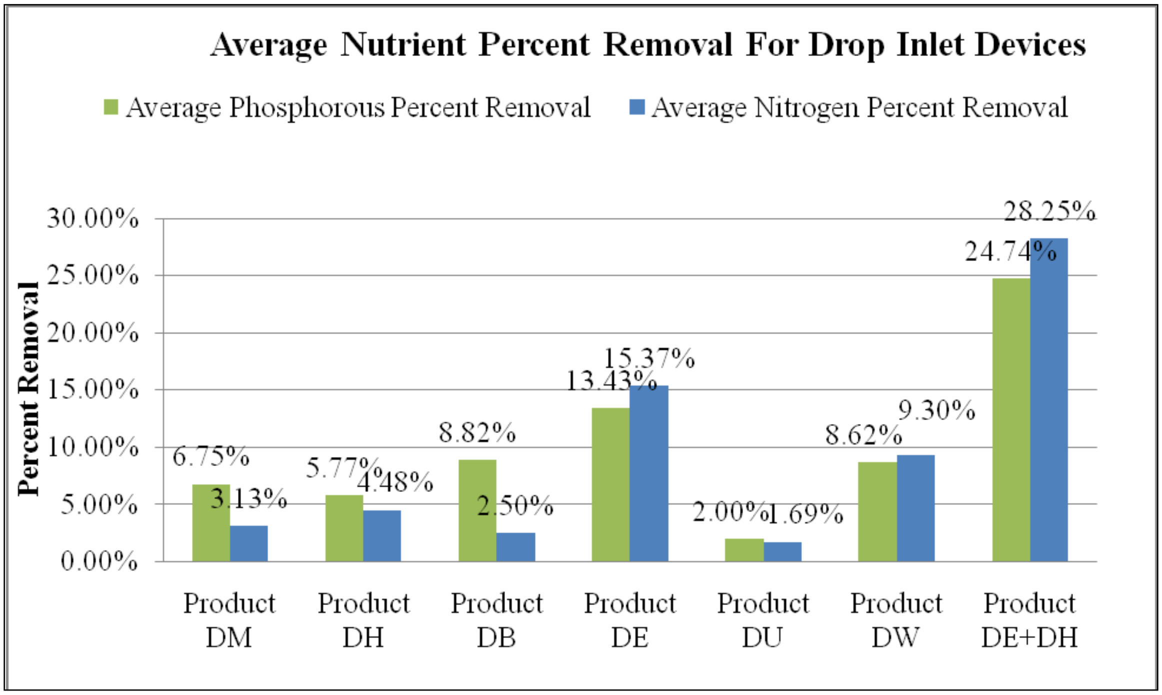

Figure 35: Average percent TN & TP removal for drop IPDs

3.2.4 Total Solids

Total solids results are shown in Figure 36 and Table 13. Again the treatment train approach showed the highest removals.

Table 13: Average total solids values and percent removal for drop inlet

Product	Average Upstream (mg/L)	Average Downstream (mg/L)	Average Percent Removal
Product DM	1181	1166	1.27%
Product DH	1200	1150	4.17%
Product DB	889	792	10.95%
Product DE	728	647	11.23%
Product DU	871	834	4.25%
Product DW	1104	941	14.76%
Product DE+DH	654	437	33.18%

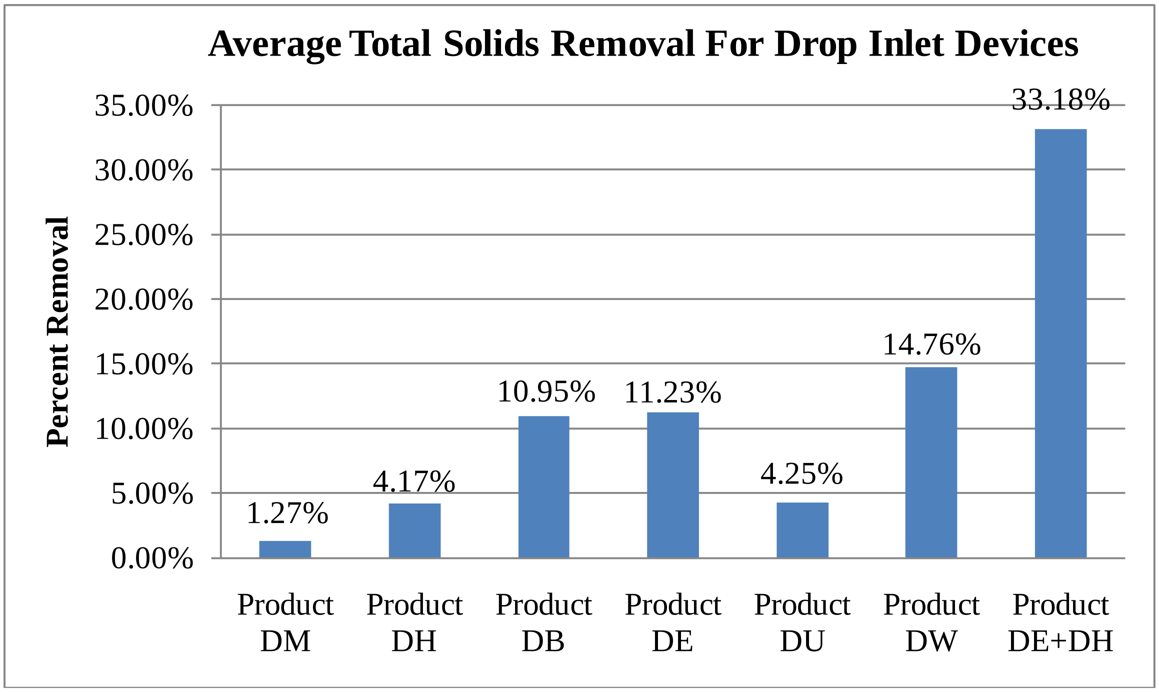

Figure 36: Average percent total solids removal for drop IPDs

There was significant short circuiting of water under the drop inlet products. Installation must be done very carefully. To reduce the installation difficulties, the use of two products as a treatment train preformed much better.

CHAPTER 4 CONCLUSIONS

Using installation and experimental observation during runoff, researchers recorded sufficient information to form an analysis of the product types. This information is presented in this chapter.

4.1 CURB INLET CONCLUSIONS

When there is a grate in front of the inlet, a grate type cover is used to prevent flow from passing through the grate as recommended by the manufacturers. The use of a non-woven geotextile to wrap over the grate is simple in appearance but difficult to install because of the weight of the grate and perforations for zip tie support can be considered very difficult to install.

4.1.1 Product A

Referring to the design of Product A (Appendix: Figure 57), it is light-weight, and also very simple in design and installation. The material is hollow plastic tubing wrapped in thin stretch fabric. Through observation of the three field experiments, Product A can pass water at an acceptable rate initially, but over time it experiences significant clogging that may increase the chances of roadway flooding, if not maintained. This product has no overflow weir or any other process to prevent excessive ponding during high intensity rain events. For public safety concerns, there should be an overflow weir to prevent flooding on roadways during extreme rain events. Turbidity and nutrient removal are in the highest group of the products tested. The average turbidity removal for all products is 27.9%, while Product A has a removal of 34.92%. The total nitrogen and total phosphorous removal are higher than the overall average. Total solids removal is below the overall average. The average total solids percent removal is 29.2%, while Product A removed 27.4% of total solids. The total nitrogen and total phosphorous average removal for all products are 23.4% and 23.2%, while Product A removed 35.29% and 26.38% for total nitrogen and total phosphorus respectively.

The installation and maintenance directions are very simple and easy to reproduce. However, the product is easily damaged by wear and handling. There is no proper way to keep the product secure to the curb site, which can significantly affect its ability to perform as designed. Sand bags are used to hold the product down, and if they become damaged can contribute to the pollution of the stormwater conveyance system. Without sandbags, the product is susceptible to openings where the water can short circuit the product. The product is structurally susceptible to damage from heavy loads (i.e. cars, construction vehicles) which may permanently damage the product.

4.1.2 Product B

Product B (Appendix: Figure 58) is made of recycled material, but lacked effectiveness in many of the categories measured. The product was moderate in weight, consisting of rolled up recycled material wrapped in a net with orifices (about 2 inch in diameter) openings. The flow of water through the product was reduced significantly between the first and last tests due to clogging and ponding became an issue. Overflow weirs were constructed on the product, which requires the installer to be aware of what angle to install the product so that the weirs will overflow before severe ponding occurs. The removal efficiency of nutrients, turbidity, and alkalinity was higher than the average of all the products tested. The average turbidity percent removal for all products is

27.9%, whereas the Product B turbidity removal is 34.07%. The total solids average removal is below the overall product average, having 22.11% whereas the overall product average is 29.2%. The product is not secured to the site, so vandalism and theft can occur.

The product cannot be permanently damaged by cars or other vehicles, but it is capable of being compressed and pushed into the inlet with enough lateral force which may cause a reduction in performance, especially related to flow. Also, if the product is turned, the orifices will not be at the correct angle for overflow protection and the product will cause ponding in high intensity rain events.

4.1.3 Product C

Product C (Appendix: Figure 59) is a unique, modular, design. The product is extremely light weight. The percent removals for Product C are higher than the overall product averages for every water quality category tested. The product has a gap at the top to permit overflow at a specific flow rate. The bright color of the product helps with safety by increasing the awareness of drivers, bikers, and pedestrians, and the fact that the product is not protruding from the curb opening, and rather it is inside the curb also helps with safety. The product is reusable, except for the Styrofoam joints, which will need to be replaced. However, the product is difficult and timely to install properly if instructions are not provided. There are strict methods to follow to ensure high removal efficiency. The product is wedged into the site, which provides a level of security.

4.1.4 Product W

Product W (Appendix: Figure 60) is heavy relative to the other products tested and may be difficult to carry by one person. The material consists of recycled waste wood products from tree trimmings. The material components leached during initial testing, but leaching decreased over time. This could result in the low turbidity removal rates while achieving total solids removal rates in line with other products tested. Sediment builds up rapidly relative to other products tested, which decreased the products permeability and added to the potential for flooding, if not properly maintained. The product leaching contributed to the turbidity and nutrients, which is a concern. The fact that the product resembles yard waste could confuse people that are unaware of its intended purpose; which could result in public tampering, vandalism, or theft. The percent removal for Product W was below the average in all categories. The turbidity percent removal is 6.44%, while the average of all products is 27.9%. The use of organic materials leached color thus contributing to the turbidity measurements. The total solids removal is 21.1%, with the average of all products being 29.2%. Product W is simple to install, though the weight and shape of the IPD makes it difficult for one person to carry.

4.1.5 Product S

Product S (Appendix: Figure 61) is light in weight relative to the other products tested, except for the sand bags that are attached on each end. For the 12-foot inlet section used in this evaluation, two devices are needed to cover the opening. An overflow section is located where the devices meet. During one test, problems were noted with flow going underneath the product, but the other device had no trouble stopping the sediment. Product S is easily deformed if stepped on. The product takes up a large space in front of curb, which could present hazards to bicyclists. Product S has a turbidity percent removal of 20.19% which is slightly above the average for all products, this is 27.9%, but is below the average for all other tests.

4.1.6 Product E

Product E (Appendix: Figure 62) is a heavy product relative to all the products tested, but there are handles to help ease the process of carrying it. The product consists of a woven geotextile with tire chunks that give it weight which is one of the filter components. The product is only made in sections of up to 10 feet in length, so a 3-foot product extension was added. Relative to the other products evaluated, this product has a high initial removal, but clogs quickly, if not maintained. The average turbidity removal is 29.09%, which is higher than the average turbidity removal for all products, 27.9%. The total nitrogen removal for Product E is 29.05% which is higher than the average for all products at 23.4%. The total phosphorus average removal is 19.05% which is lower than the average for all products at 23.2%. The total solids removal is 36.5% compared to 29.2% overall product average.

4.1.7 Product G

Product G (Appendix: Figure 63) is light weight relative to the other products evaluated and is rigid with handles to carry it. The product is made of woven geotextile and is secured to the site by weights that pull it flush against the curb inlet opening. The design of the product is for high flow rates, as it passed runoff at the fastest rate at 9.37gpm/ft with the average for all products being 8.5gpm/ft. The removal rates for the product are below average compared to all products evaluated in every category except for total solids and total phosphorous. This is likely due to the fact that the flow rate is higher than the other products evaluated. The average for total phosphorous removal for Product G is 25.81%, while the overall average for all products is 23.2%. The total solids percent removal is 32.22% for Product G, while the overall average for all products is 29.2%.

4.2 DROP INLET CONCLUSIONS

There are four possible design approaches when it comes to drop inlet protection. The first approach is to wrap or cover the grate with a geotextile or some other semi-permeable material. The second approach is to install some filtering fabric below the grate. The third approach is to encircle the inlet with a product to treat the water prior to reaching the inlet. The fourth approach is to use a combination of the first three. Different products from each of these categories were evaluated; and from the results conclusions are drawn below.

4.2.1 Grate Cover Approach

The first product, Product DM, is a non-woven geotextile wrapped around the grate and attached by zip ties. Product DU is non-woven geotextile that is attached to the grate by magnets. An overflow weir is installed in the middle of Product DU, but not Product DM. The grates did not flush with the inlet opening, so short circuiting or product "bypass" occurred. During high flow rates the products achieved minimal removal, because the majority of the water flows through the edges and gaps around the grate perimeter. In order for a product of this design to improve in performance the gaps need to be plugged or covered. This would require more effort, material, and time.

4.2.2 Beneath Inlet Grate Approach

Product DH is a non-woven geotextile material that is funnel shaped and designed to go inside the inlet. This increases the likelihood that the product will capture most of the runoff that enters the drop inlet. The design has emergency overflow orifices for high intensity rain events that exceed design capacity. Due to the products ability to retain particles, regular maintenance is required to minimize bypass.

4.2.3 Inlet Perimeter Approach

The products that encompass the inlet work well in dissipating the flow, which settles out total solids, and also performs some filtration. Products DW and DE are heavy enough to prevent the water from quickly flowing underneath. Product DB is not heavy enough to attenuate all flow rates and thus some flow rates will result in an underflow short circuit.

4.2.4 Combined Treatment Approach

Based on the analysis of each individual treatment method, it is concluded that the recommended method for drop inlet protection is to implement a combined treatment system in series. The best combination is a product around the perimeter of the inlet to attenuate the flow rate, then a product beneath the grate to capture the slowed runoff and filter it into the stormwater conveyance system. This can be seen with the results of products DE+DH which outperformed all of the individual drop inlet products.

CHAPTER 5 RECOMMENDATIONS

5.1 GENERAL RECOMMENDATIONS

All products will achieve suggestive performance with routine and proper maintenance. Without properly designed, installed, and maintained IPDs the risk of ponding and increased quantities of sediment entering the stormwater conveyance systems are greatly increased.

The authors recommend that products used for sediment and erosion control should be required to meet specific standards before being permitted for applications. Though IPDs are designed to partition sediment from runoff, they also attenuate flow rates through the inlet. These inlet openings are altered by IPDs during construction activities; thus, runoff entering stormwater conveyance systems during rain events is restricted causing potential safety concerns due to roadway flooding. Therefore, flow rates through the products per linear foot should be established. Products selected should be assessed on a site specific basis. For example, if there are no vehicles using the road, then flow rates might not matter much. High traffic areas would be more of a concern.

From the observations during runoff testing, water passing through an IPD became inhibited to a certain degree by the third test on all products tested. A schedule of routine inspection and/or cleaning of an IPD should be required and enforced. The scheduled maintenance will increase the effectiveness and product life, while also decreasing the risk of ponding on roadways and improve pollutant removal effectiveness.

Turbidity and total solids removal benchmarks should be established. By setting minimum standards, the technology of the IPD design and effectiveness should improve. The minimum standards would also remove the cheap and ineffective products from entering the market and being purchased and implemented by construction companies. Additionally, having standards of sediment removal would facilitate more emphasis on turbidity and total solids removal in highly sensitive areas like Outstanding Florida Waters, public parks, fishing or shellfish harvesting areas, and wetlands.

Pollution removal is documented within this report. With these numbers, it is possible to estimate mass loading reduction for the pollution parameters measured. This should be done considering the annual rainfall and the associated runoff.

5.2 CURB INLET RECOMMENDATIONS

All the products tested functioned to remove pollutants to a certain extent. All have unique abilities that are documented within this work. The curb inlet throats have a specific design capacity which should be considered to prevent roadway flooding hazards. This design capacity becomes altered when IPDs are installed in front of the inlet throat. Thus, routine inspection and maintenance as well as an overflow capability for curb inlet IPDs in high traffic areas is essential for ensuring public safety.

5.3 DROP INLET RECOMMENDATIONS

For drop inlets, a treatment system consisting of a product upstream of the inlet to attenuated flow rate and a product beneath the grate that can capture and filter the water is recommended. Improved filtration and less flooding potential can be achieved by combining the IPDs.

Most of the products tested that encompassed the perimeter of the inlet, with the noted exceptions being product DW and DE, allowed the water to travel beneath the products, but still attenuated the flow to settle out total solids to some extent. The other product types that wrapped around the grate or went below the grate attenuated the entire flow and filtered it, which resulted in significant bypass and overflow.

It is possible to install products around the perimeter of the inlet with a grate cover product and a below grate catchment product to increase removal. The author's recommendation is that when using a drop inlet, IPDs include, at a minimum, the use of a perimeter IPD and another for the grate. This will attenuate flow rates, settle out some particles, and then filter the runoff that reaches the storm sewer. The use of a perimeter barrier also promotes a higher infiltration potential into the ground surrounding the drop inlet, resulting in a decreased volume of turbid runoff into the storm sewer.

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APPENDIX

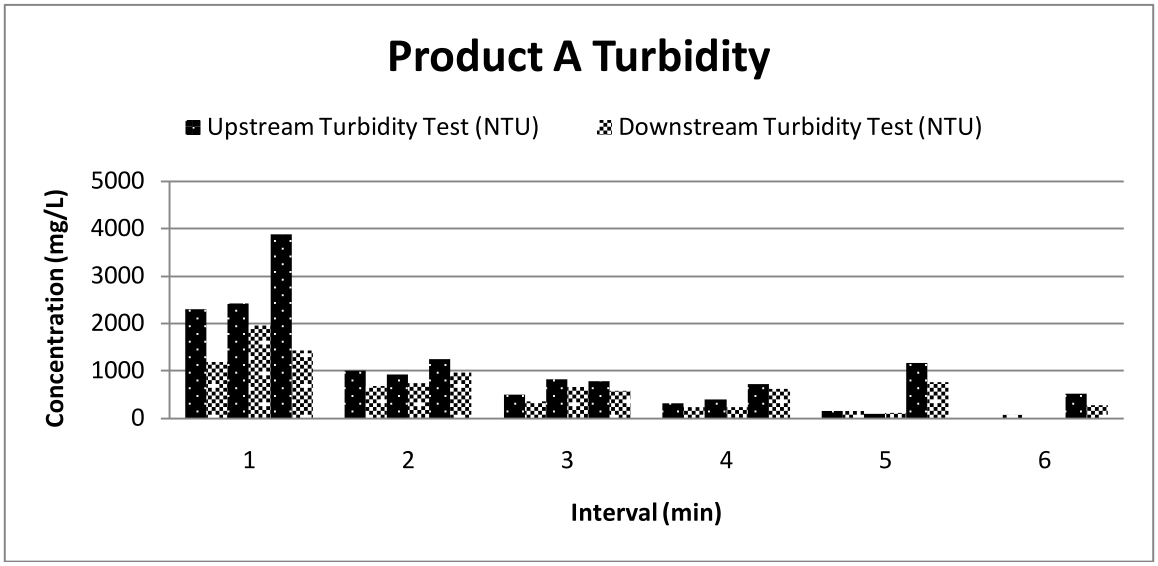

Figure 37: Sample water turbidity for 3 rainfall events on Product A over time

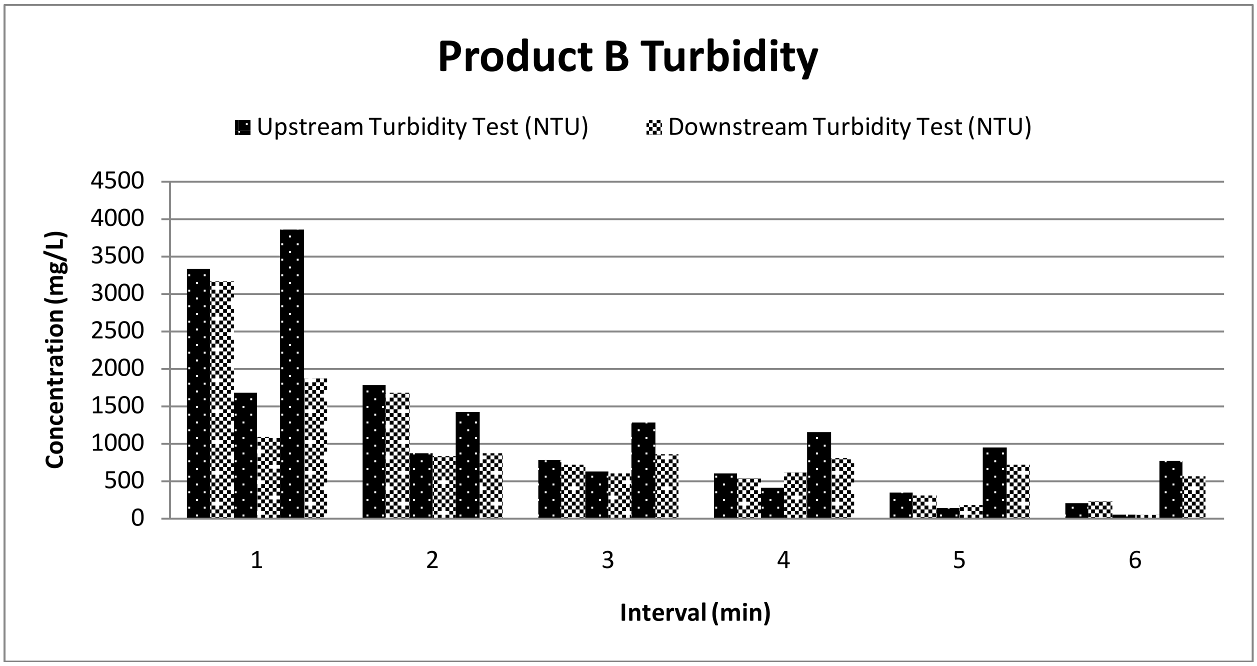

Figure 38: Sample water turbidity for 3 rainfall events on Product B over time

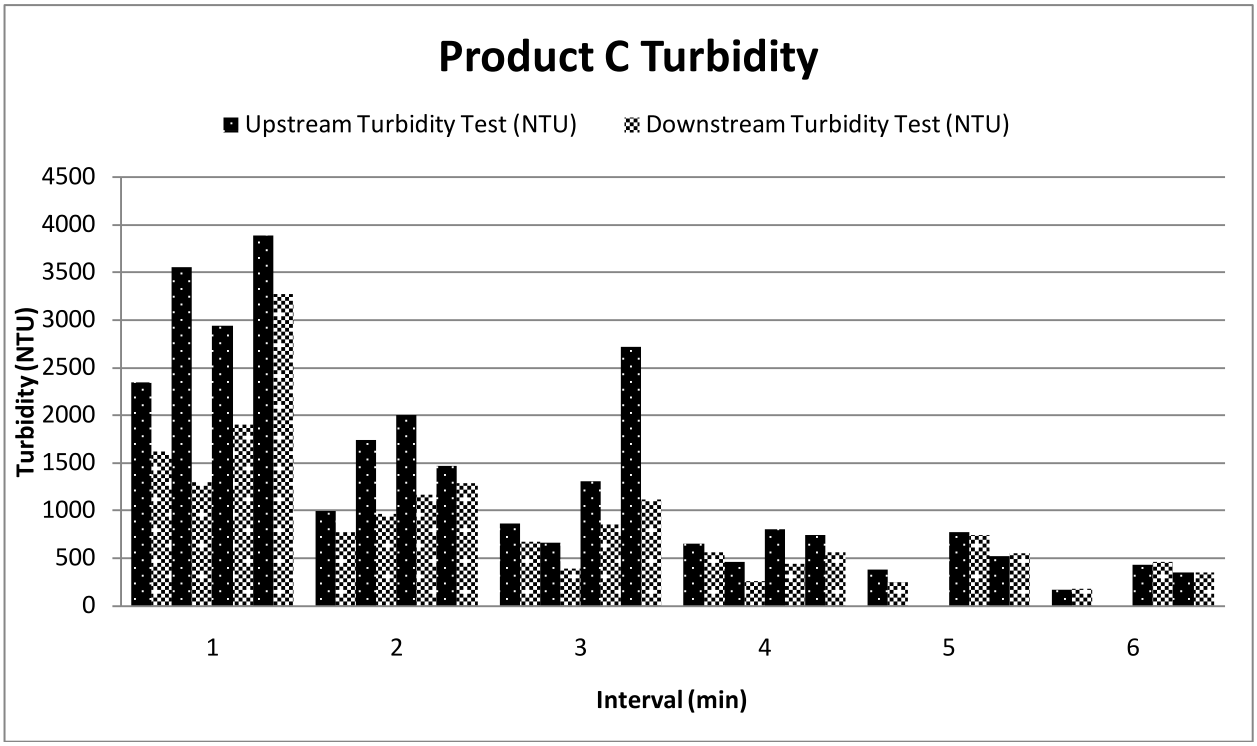

Figure 39: Sample water turbidity for 4 rainfall events on Product C over time

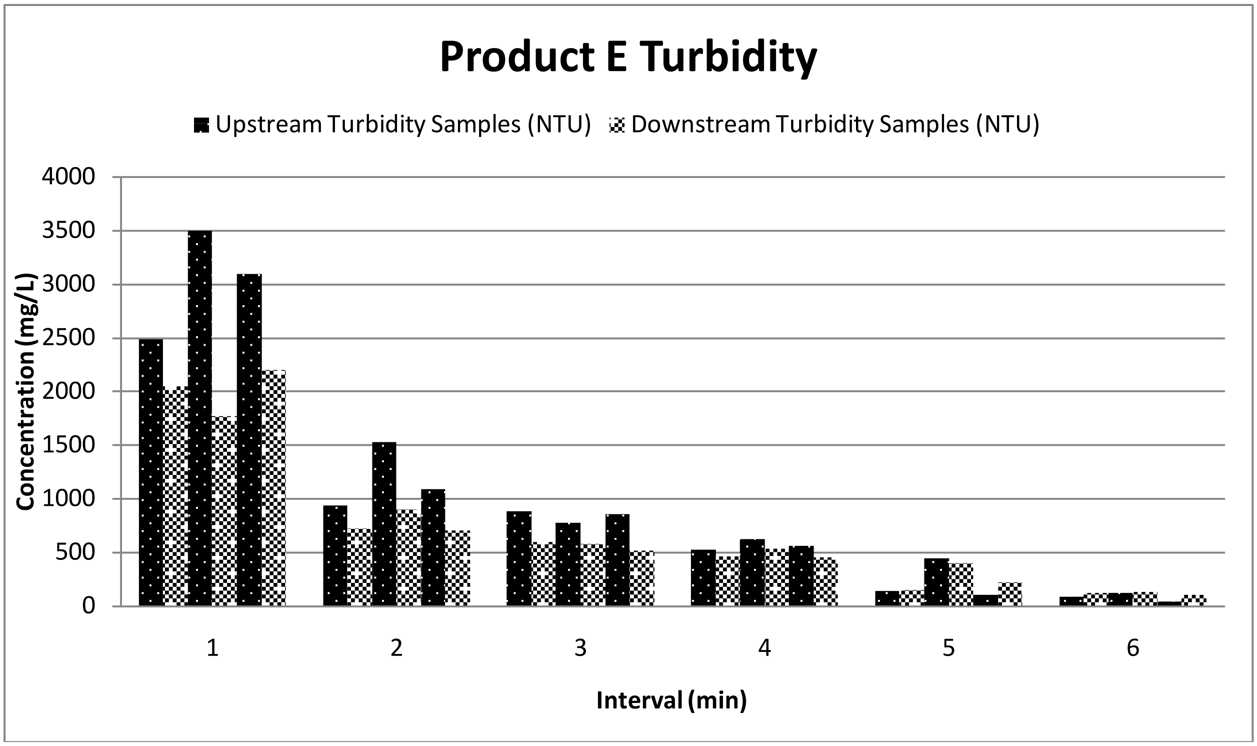

Figure 40: Sample water turbidity for 3 rainfall events on Product E over time

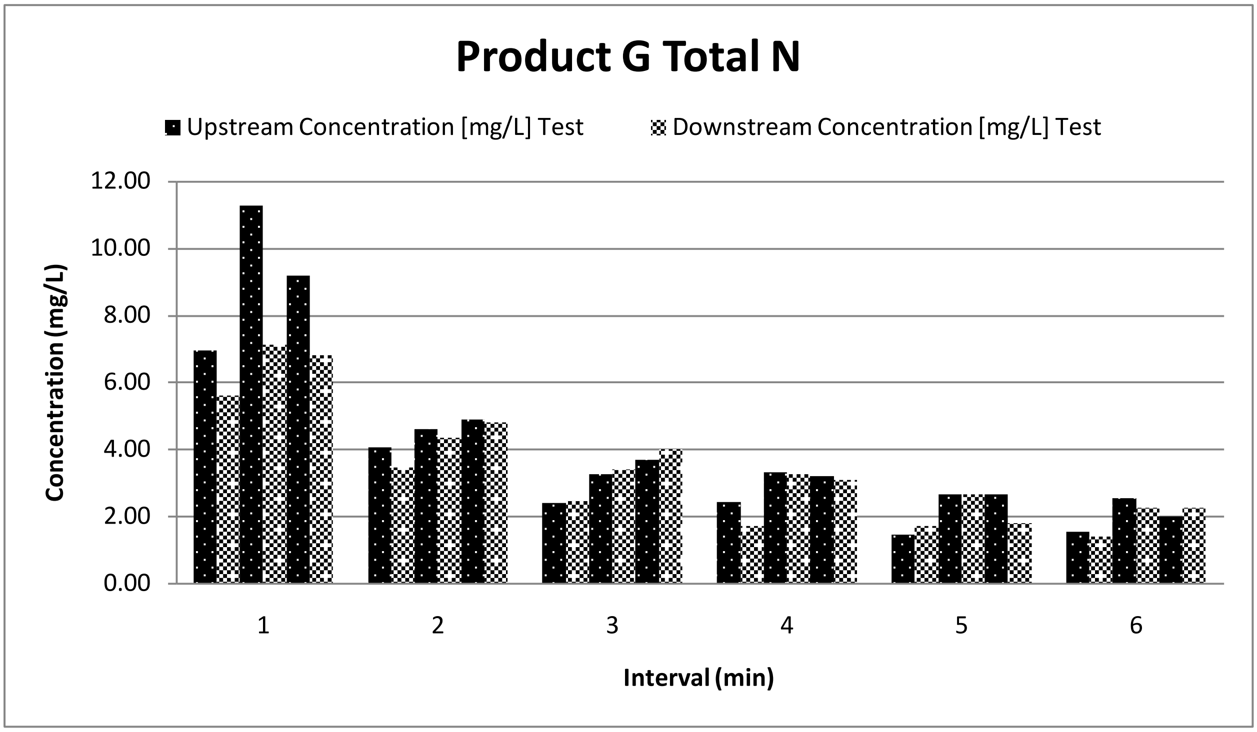

Figure 41: Sample water turbidity for 3 rainfall events on Product G over time

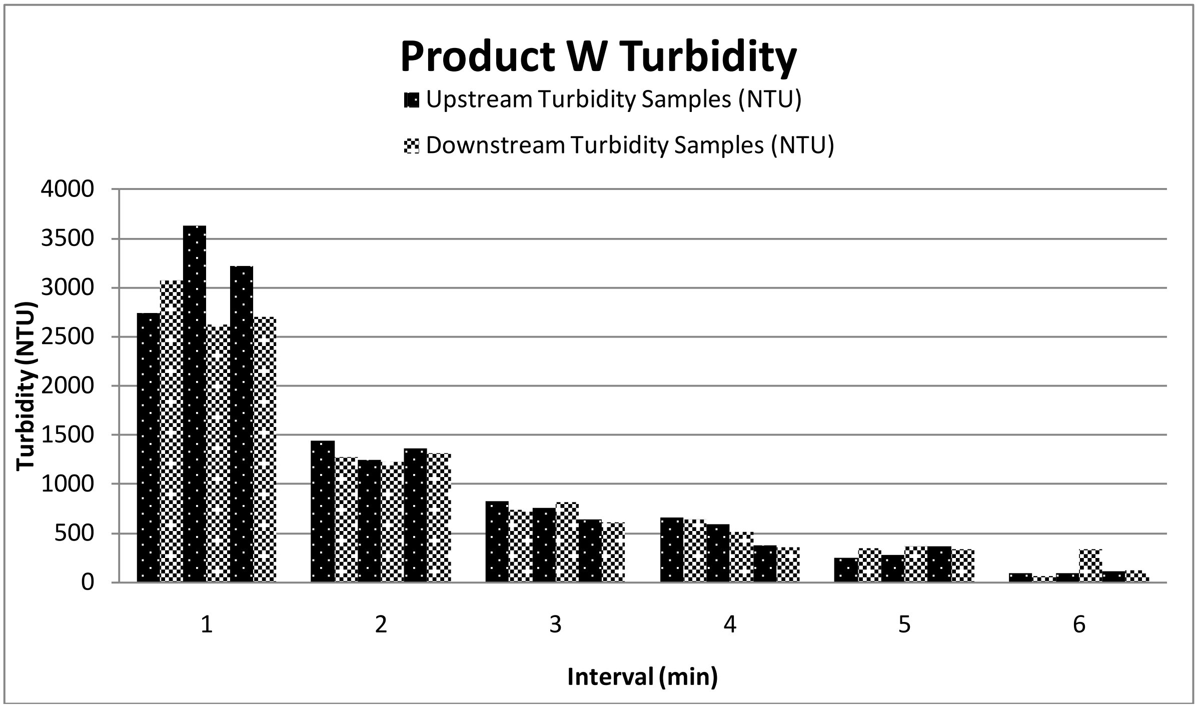

Figure 42: Sample water turbidity for 3 rainfall events on Product W over time

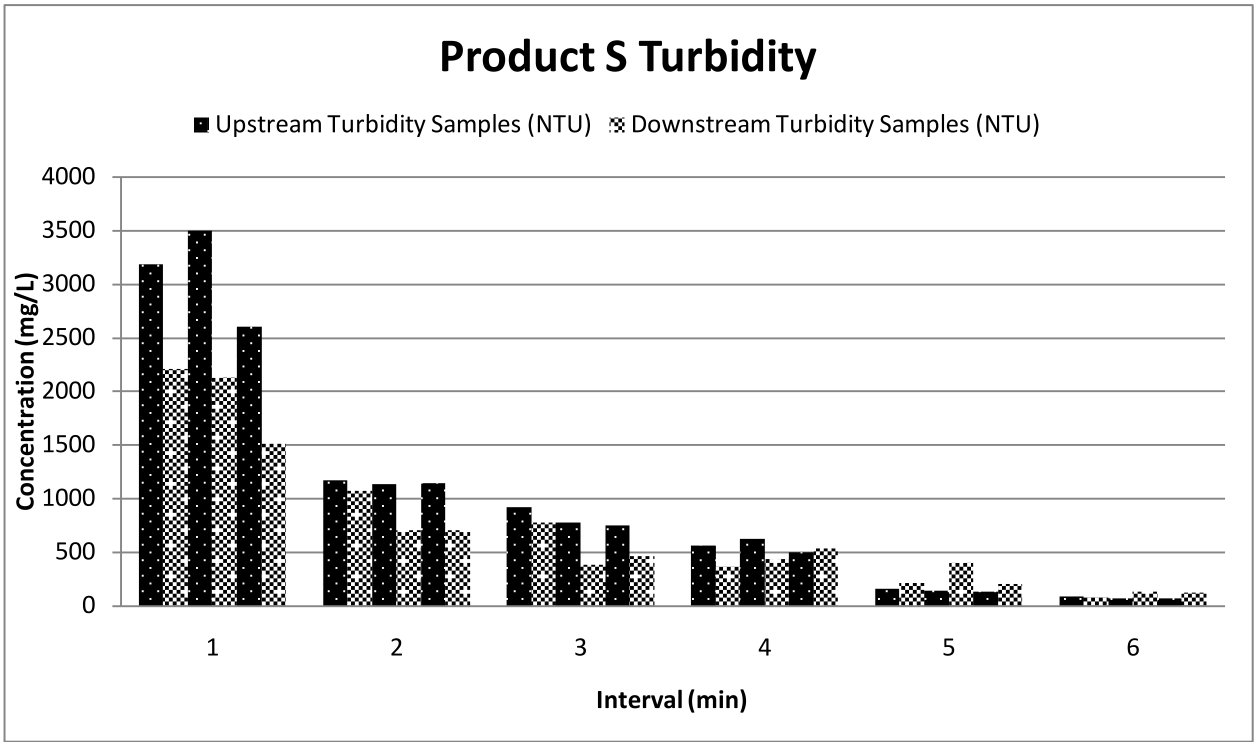

Figure 43: Sample water turbidity for 3 rainfall events on Product S over time

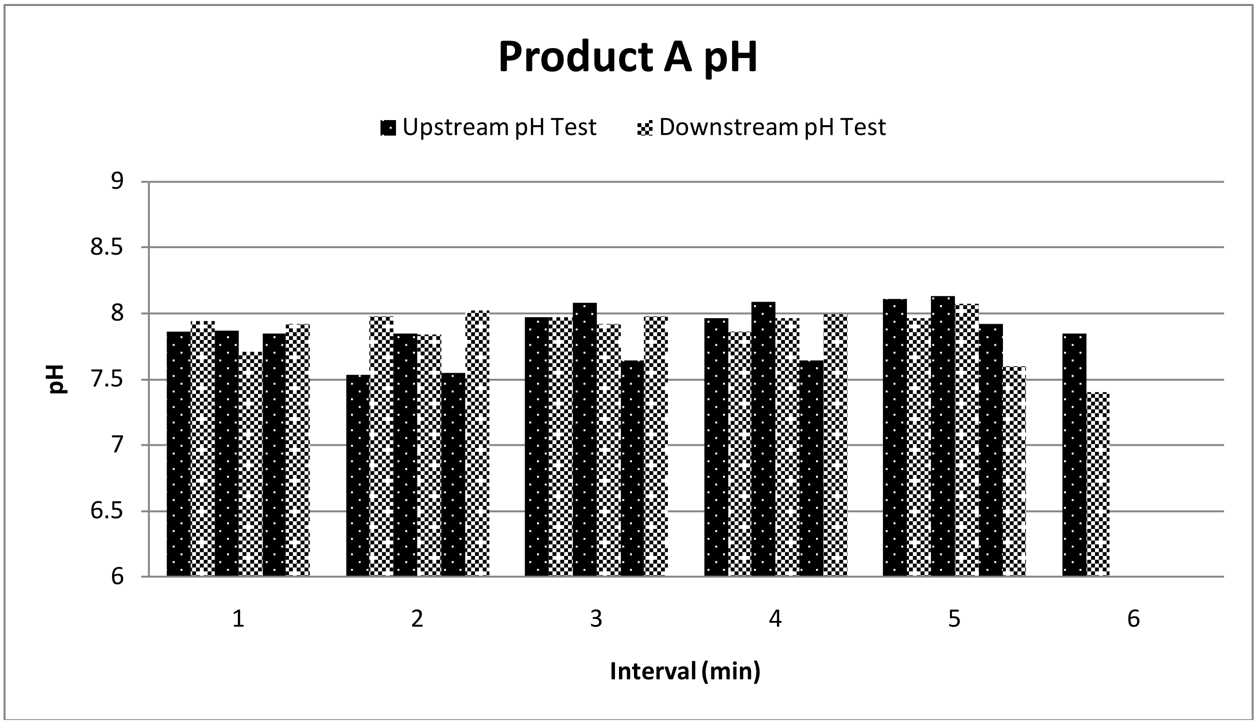

Figure 44: Sample water pH for 3 rainfall events on Product A over time

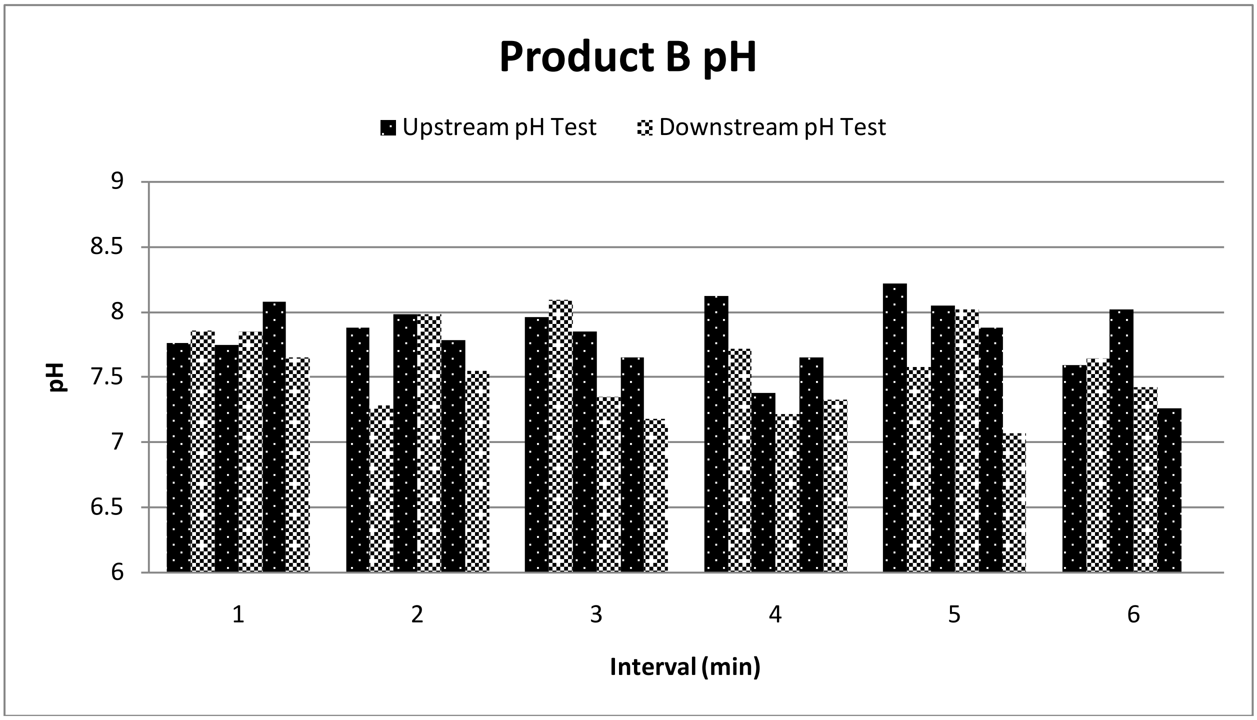

Figure 45: Sample water pH for 3 rainfall events on Product B over time

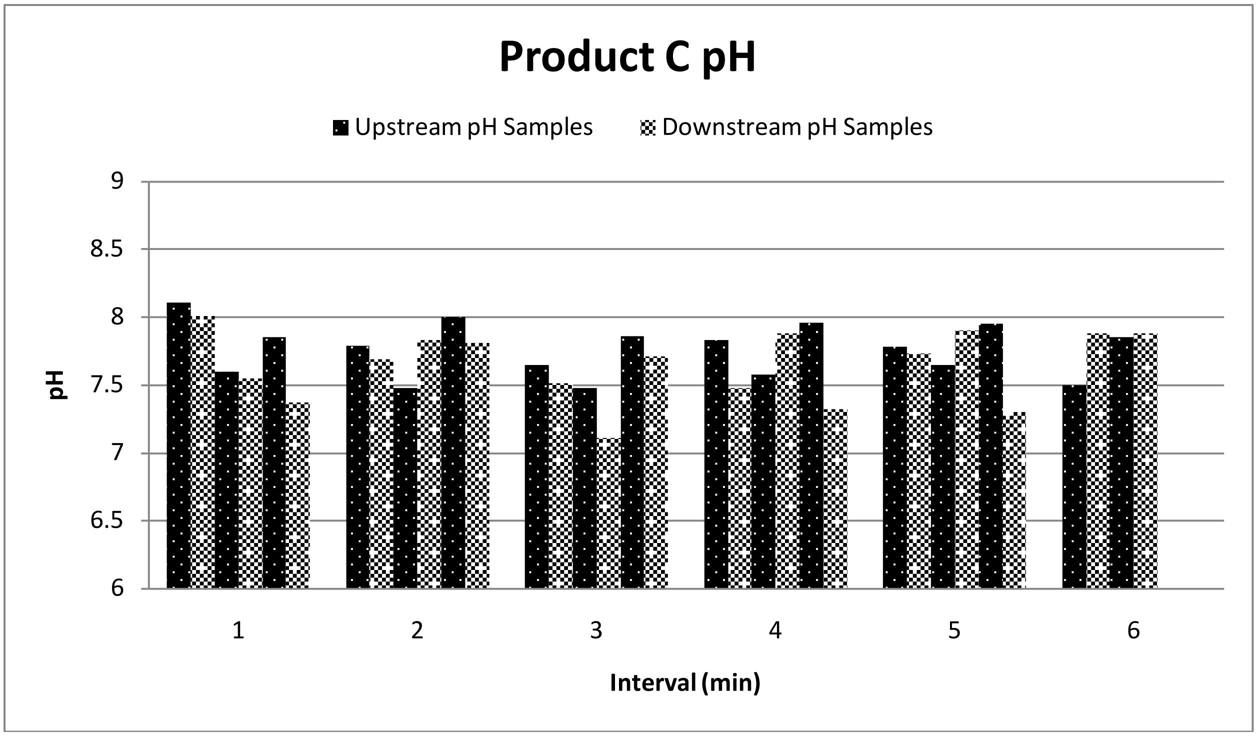

Figure 46: Sample water pH for 3 rainfall events on Product C over time

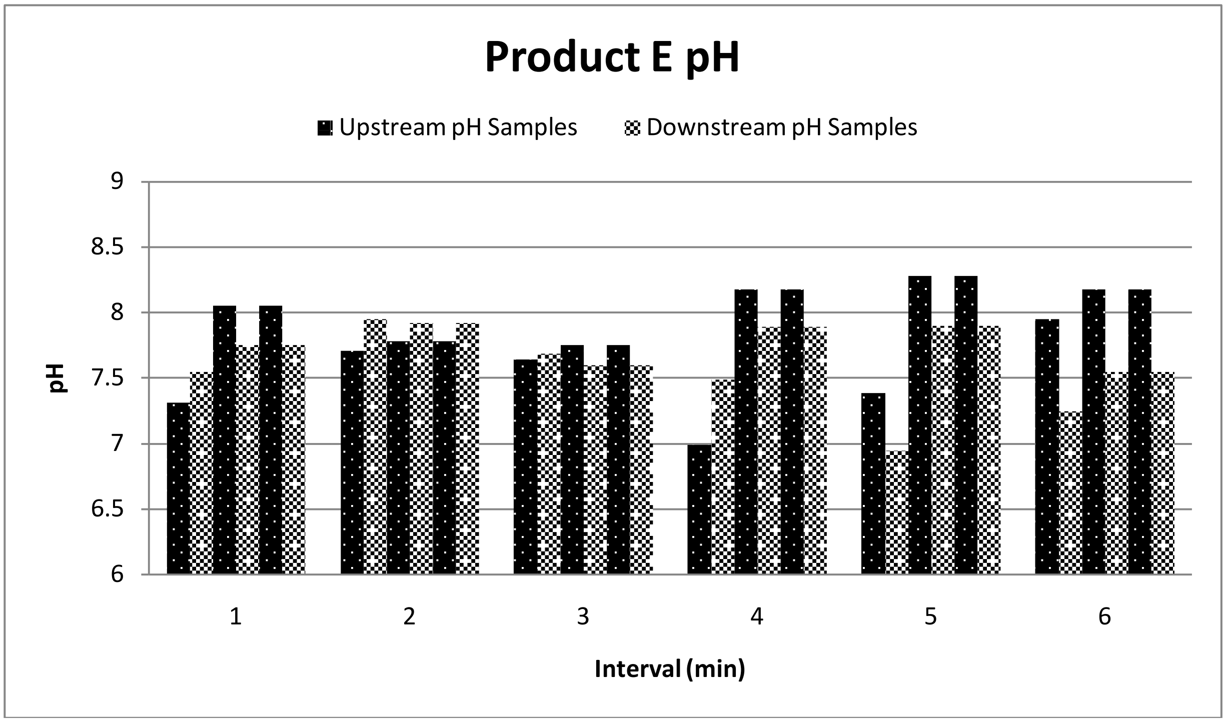

Figure 47: Sample water pH for 3 rainfall events on Product E over time

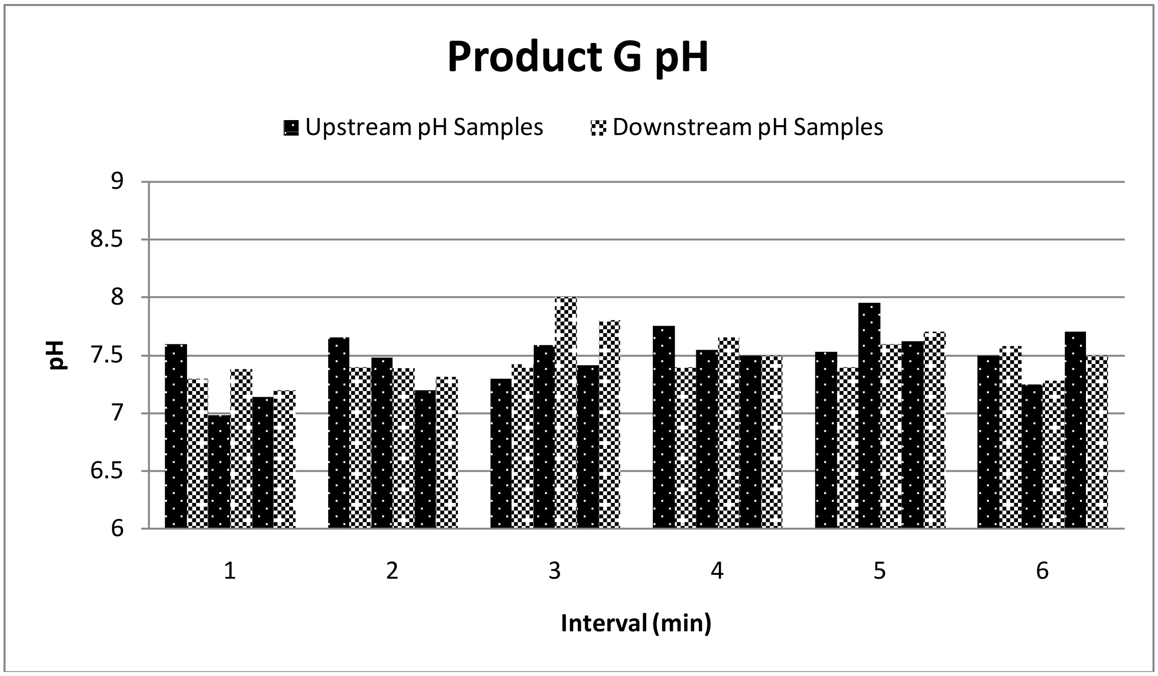

Figure 48: Sample water pH for 3 rainfall events on Product G over time

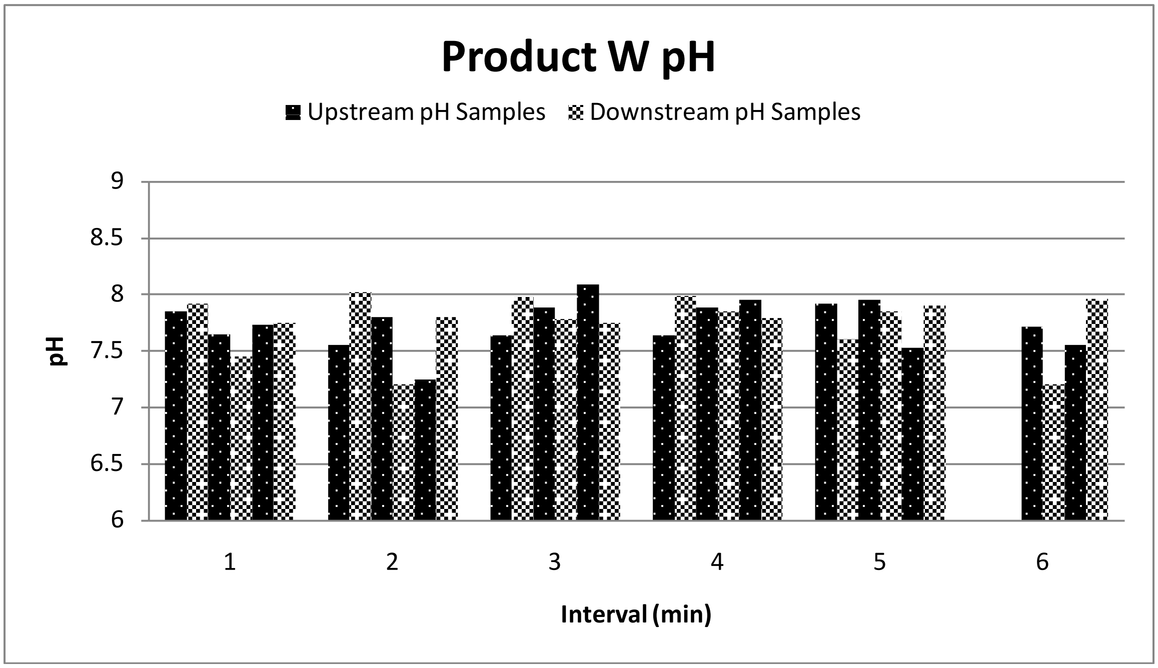

Figure 49: Sample water pH for 3 rainfall events on Product W over time

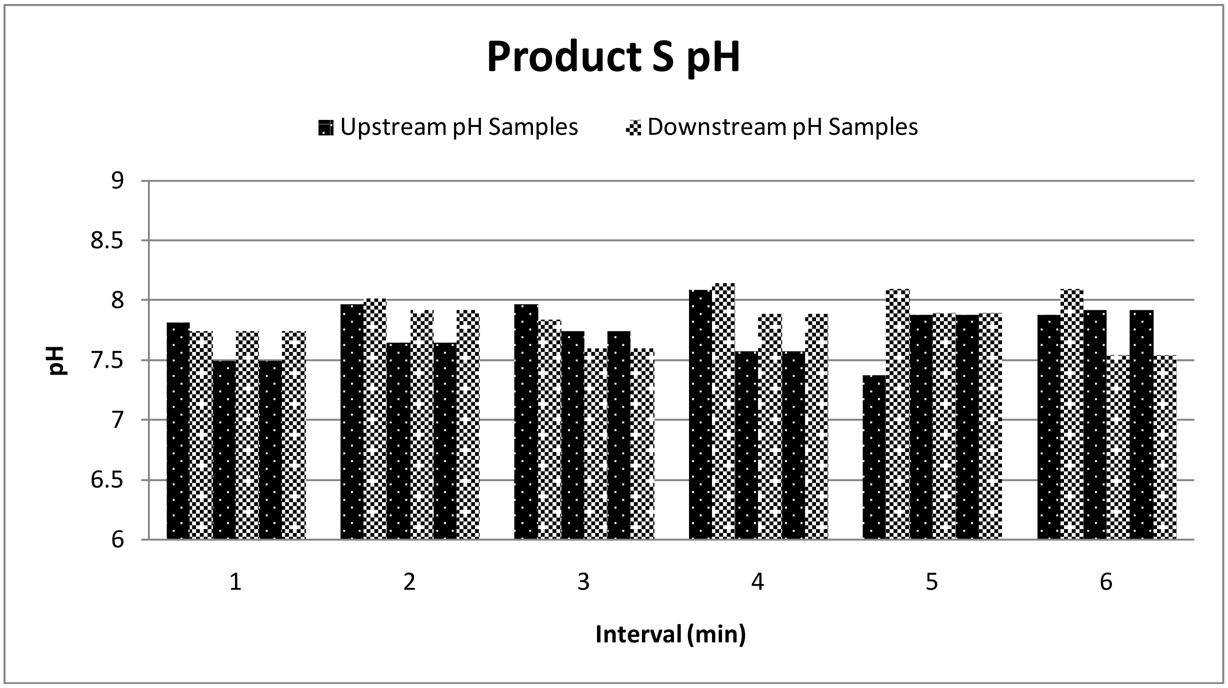

Figure 50: Sample water pH for 3 rainfall events on Product S over time

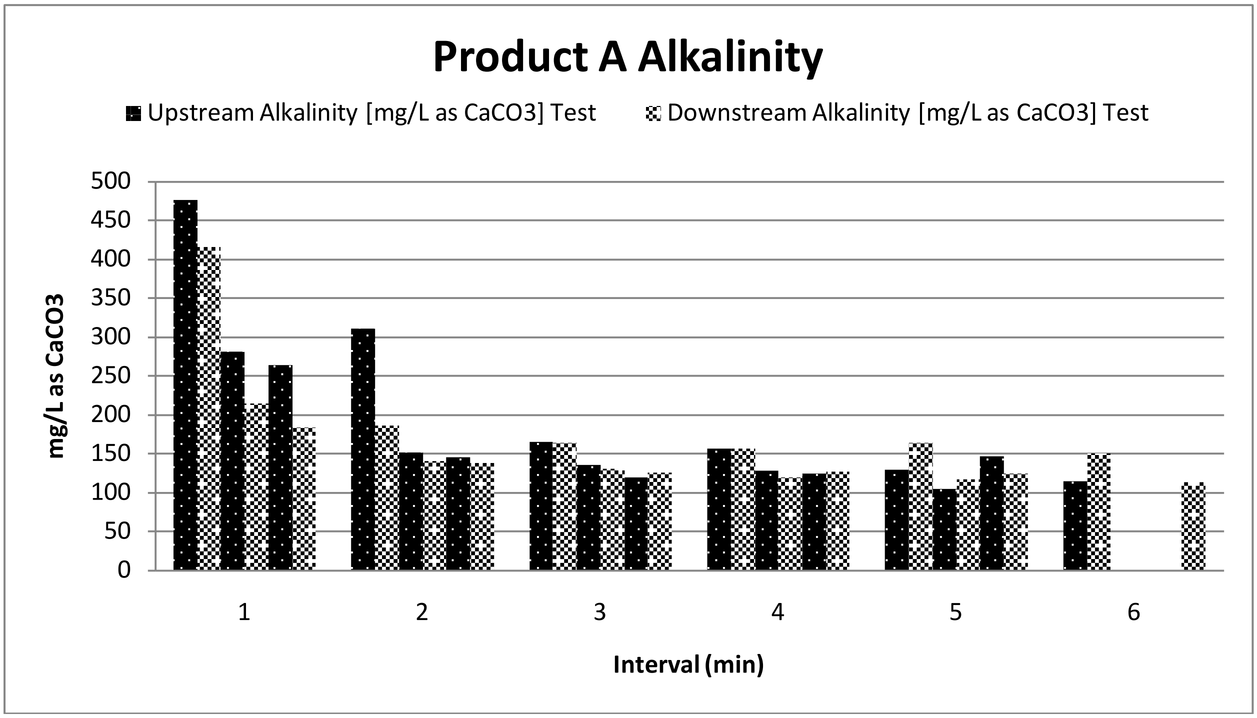

Figure 51: Sample water alkalinity for 3 rainfall events on Product A over time

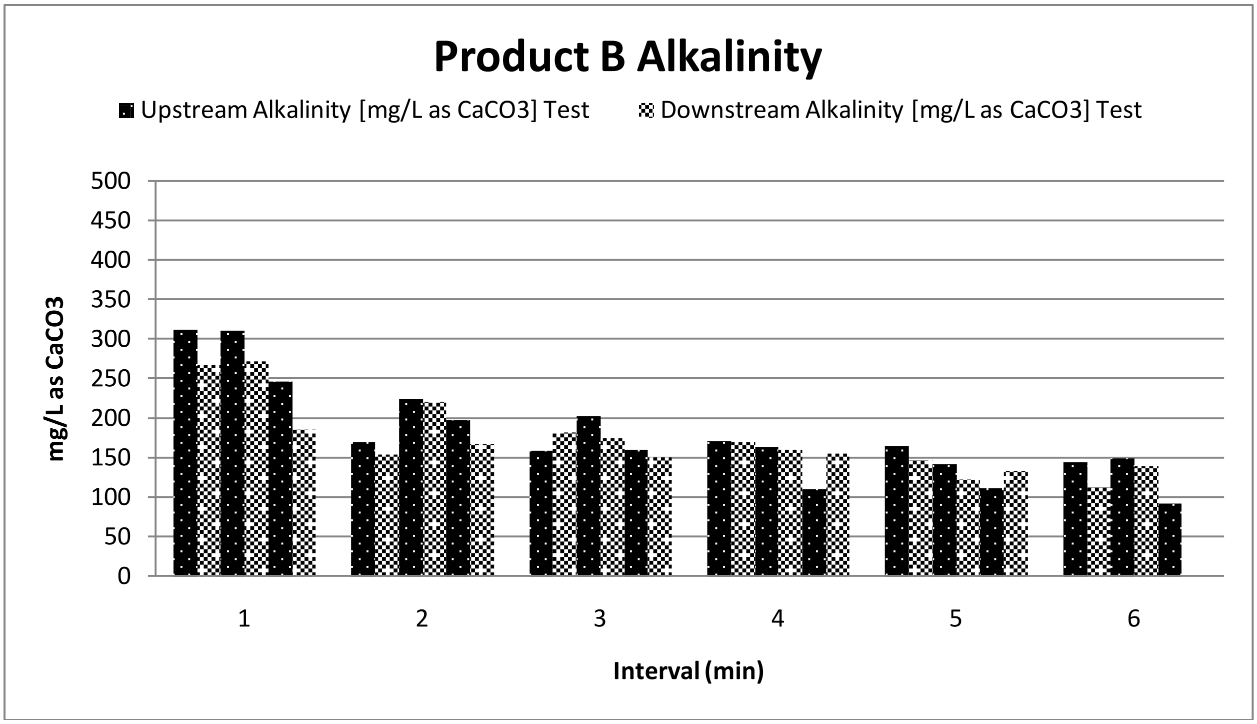

Figure 52: Sample water alkalinity for 3 rainfall events on Product B over time

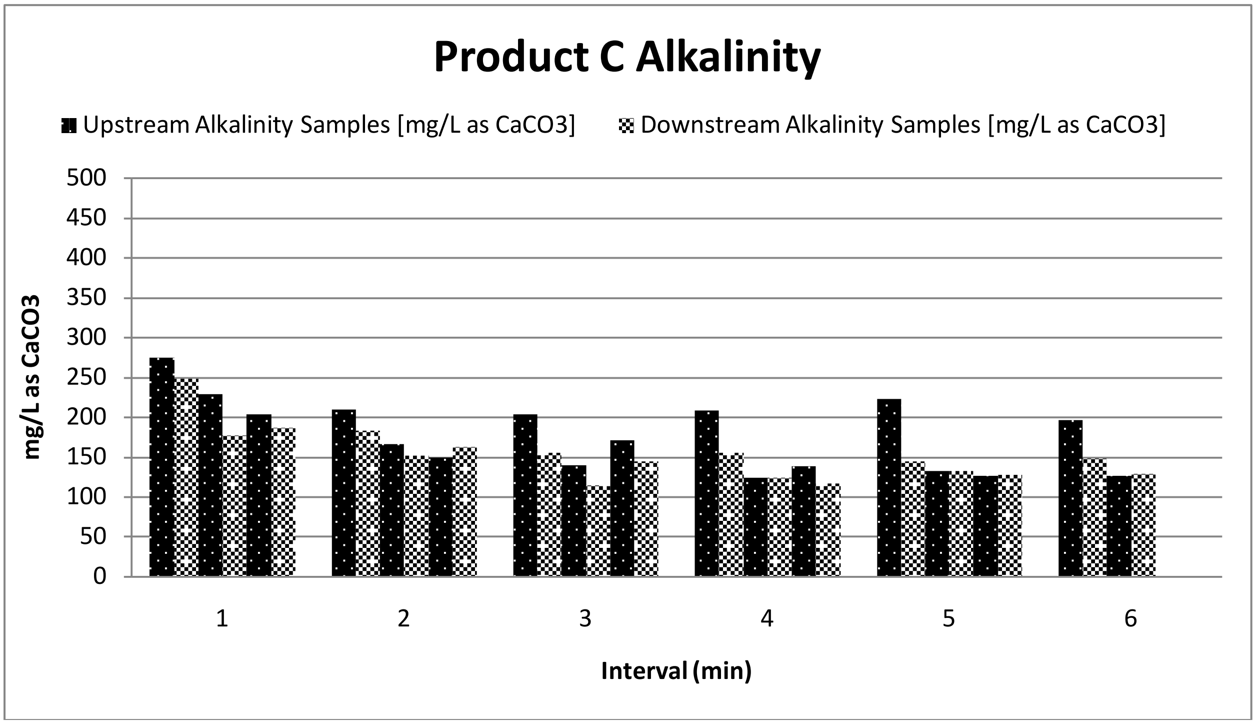

Figure 53: Sample water alkalinity for 3 rainfall events on Product C over time

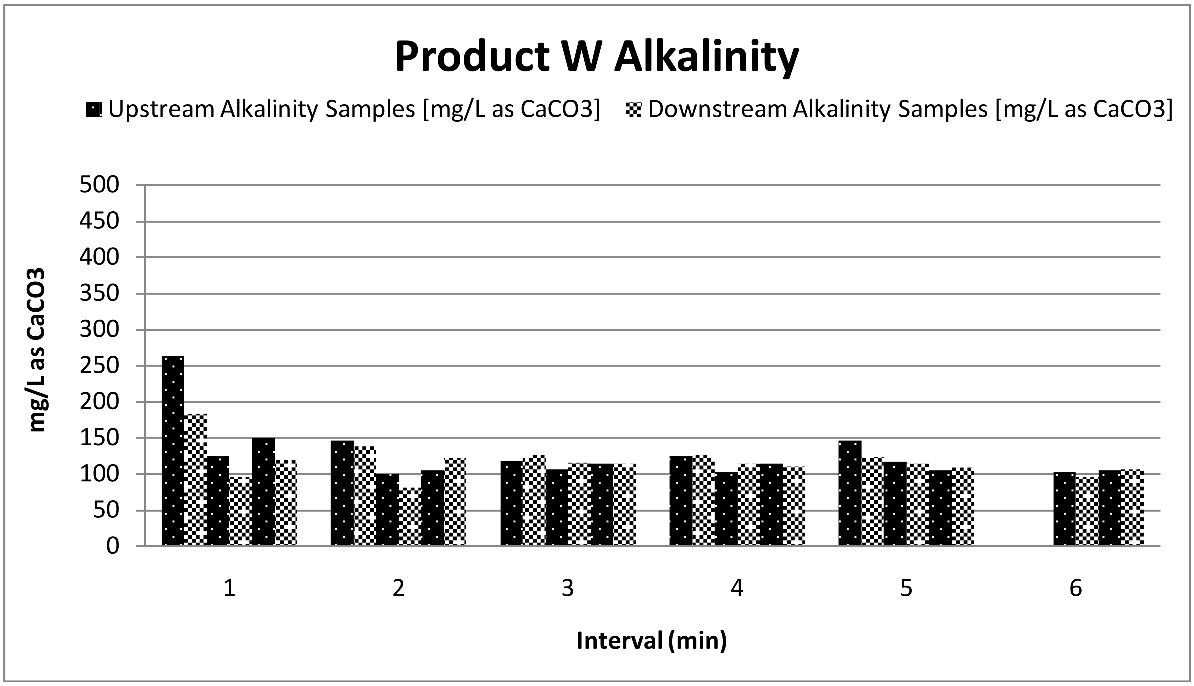

Figure 54: Sample water alkalinity for 3 rainfall events on Product W over time

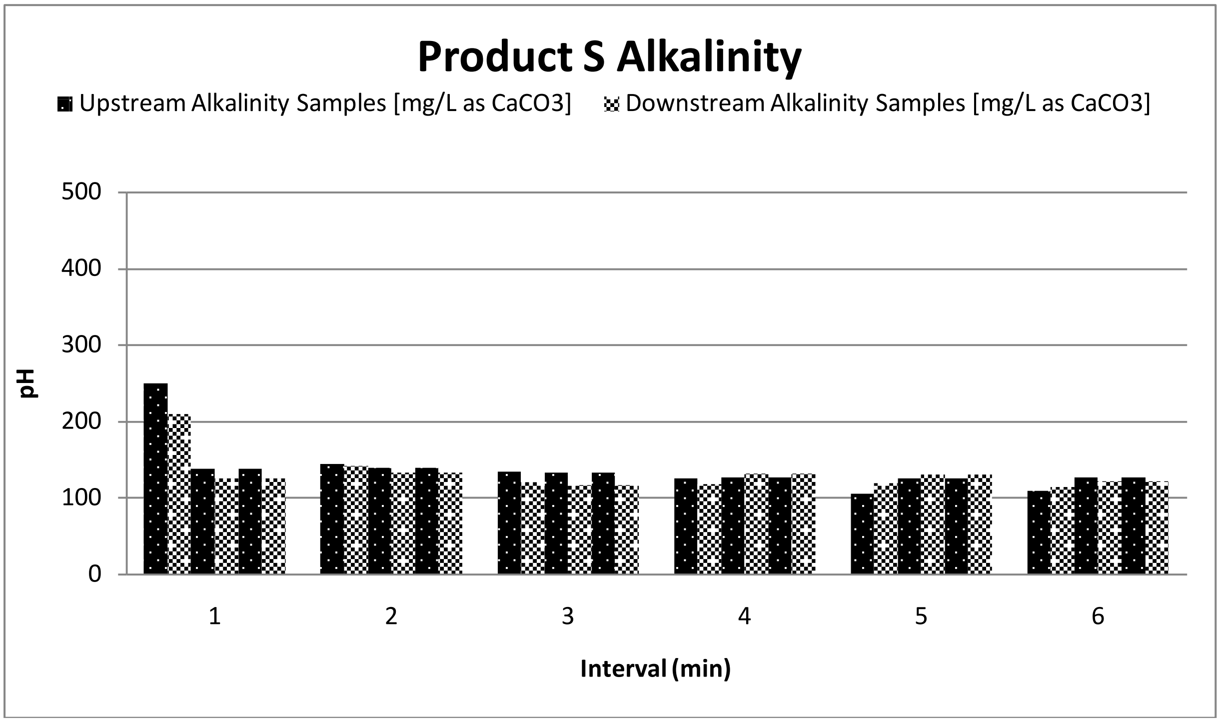

Figure 55: Sample water alkalinity for 3 rainfall events on Product S over time

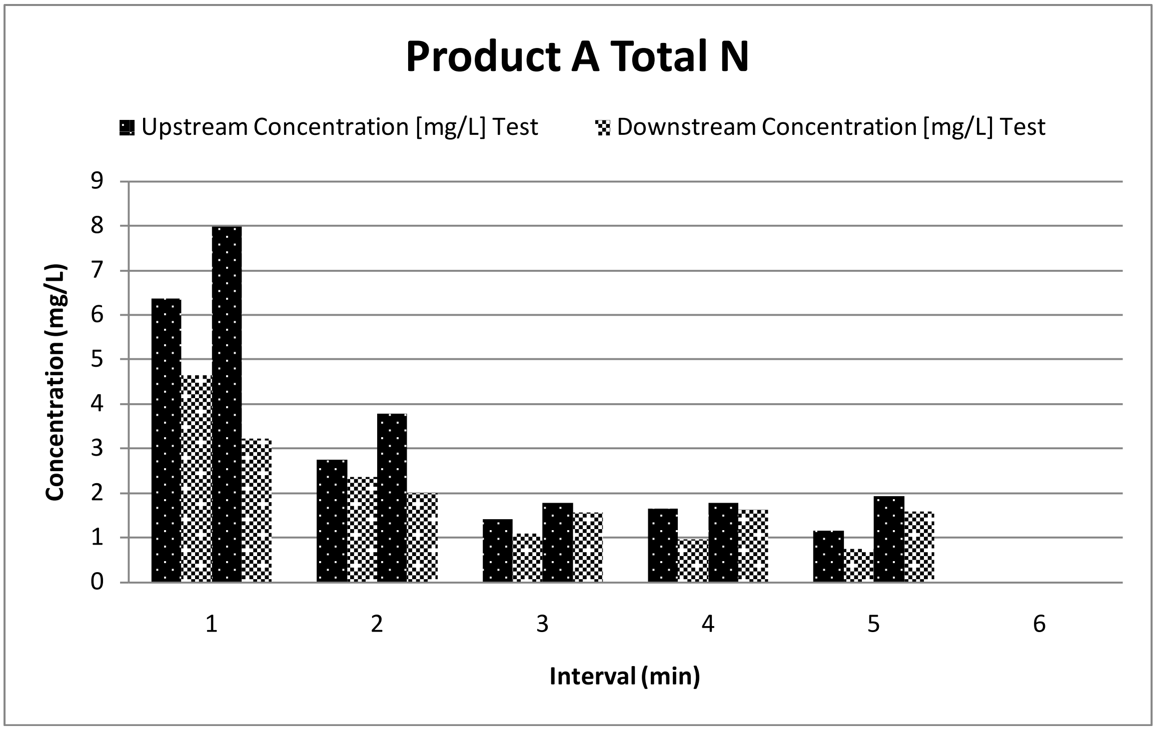

Figure 56: Sample water TN concentration for 2 rainfall events on Product A over time

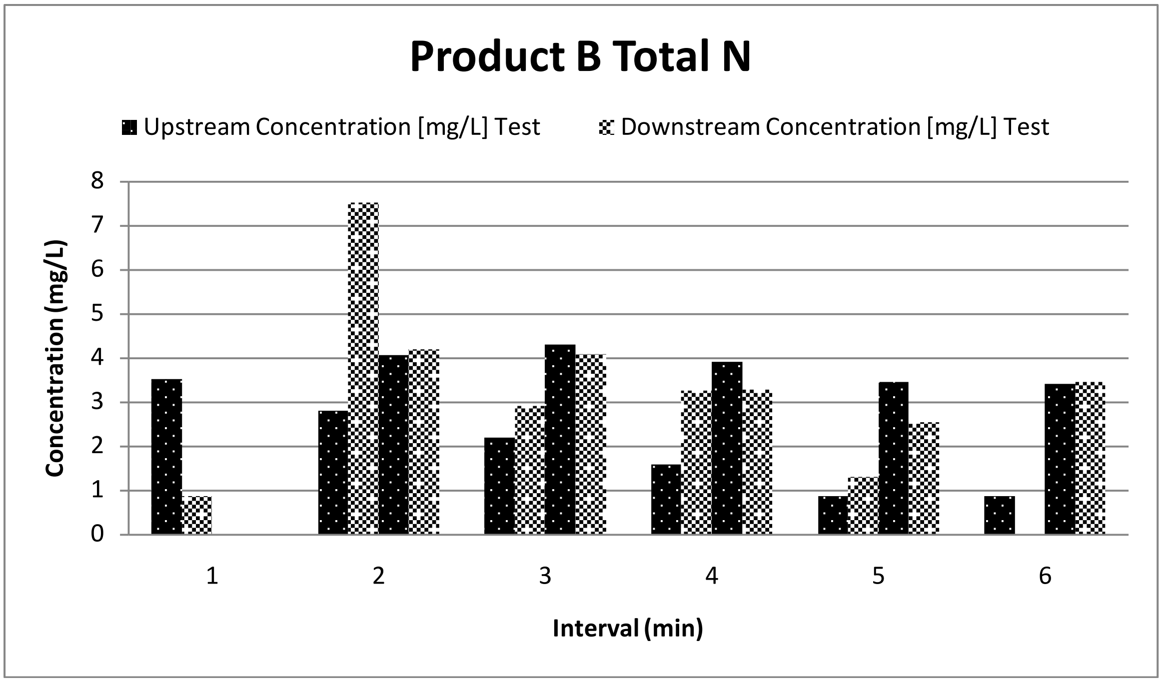

Figure 57: Sample water TN concentration for 2 rainfall events on Product B over time

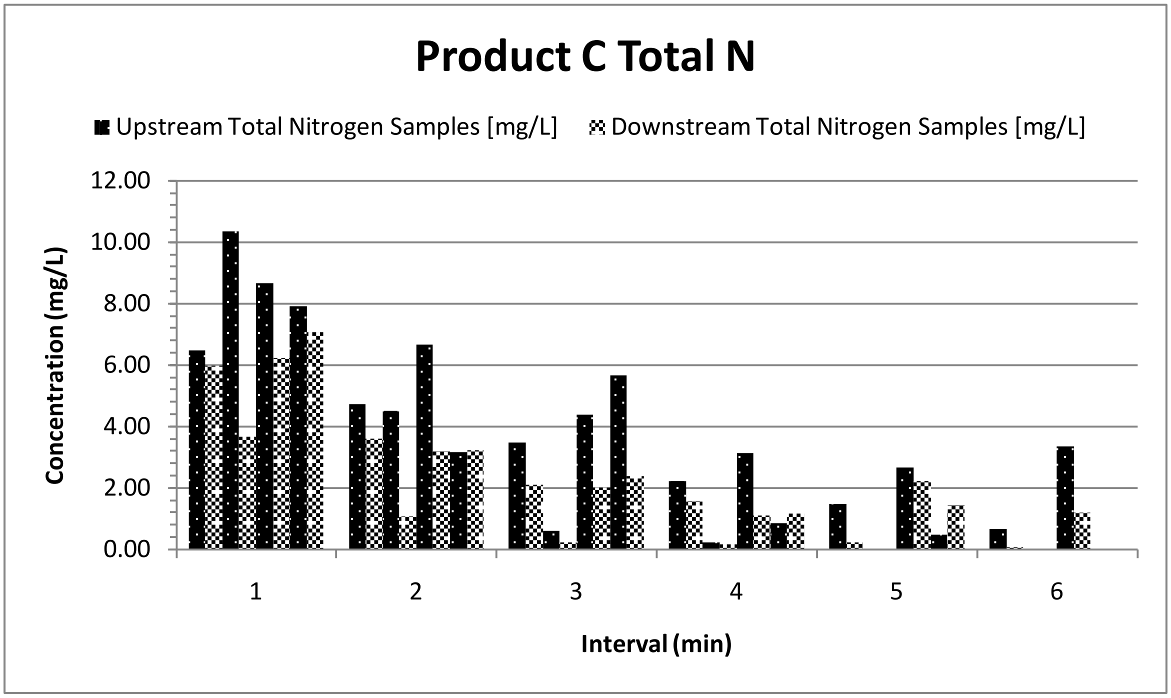

Figure 58: Sample water TN concentration for 4 rainfall events on Product C over time

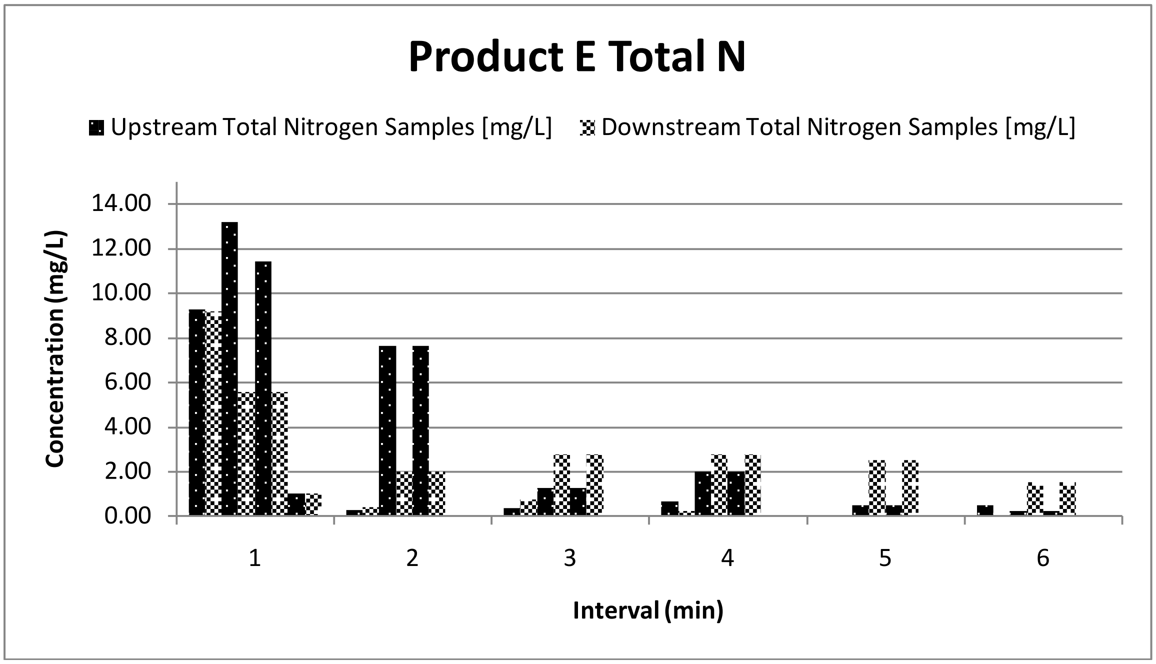

Figure 59: Sample water TN concentration for 3 rainfall events on Product E over time

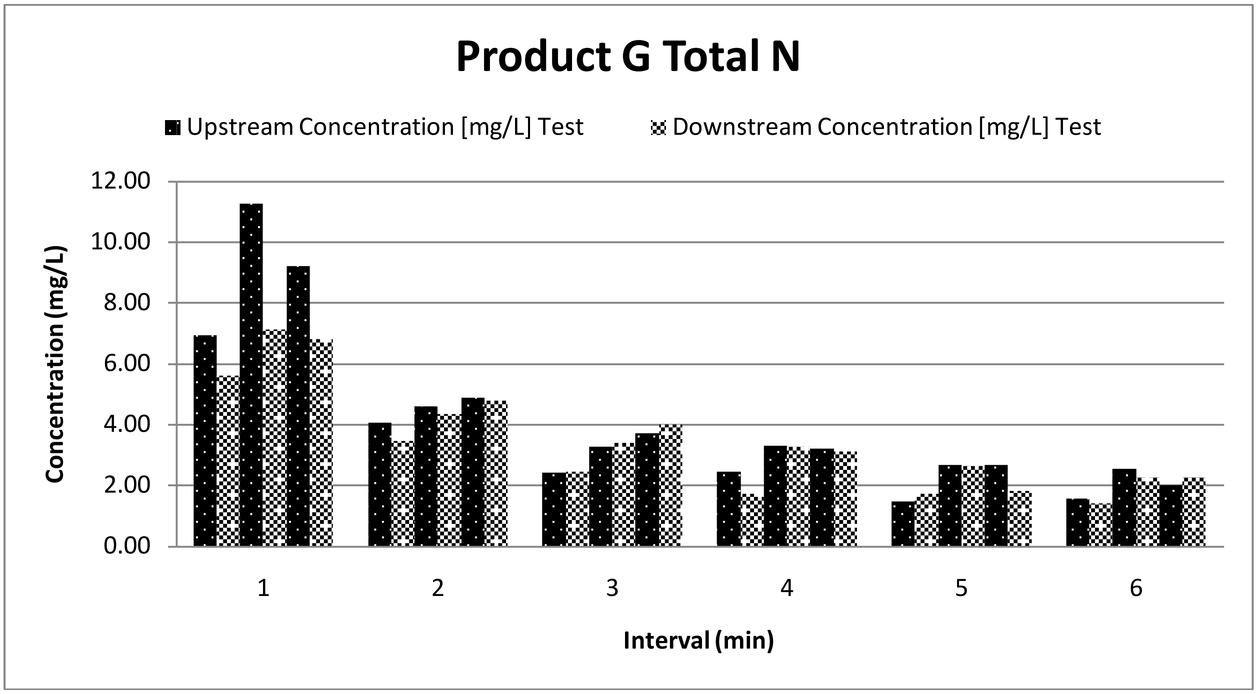

Figure 60: Sample water TN concentration for 3 rainfall events on Product G over time

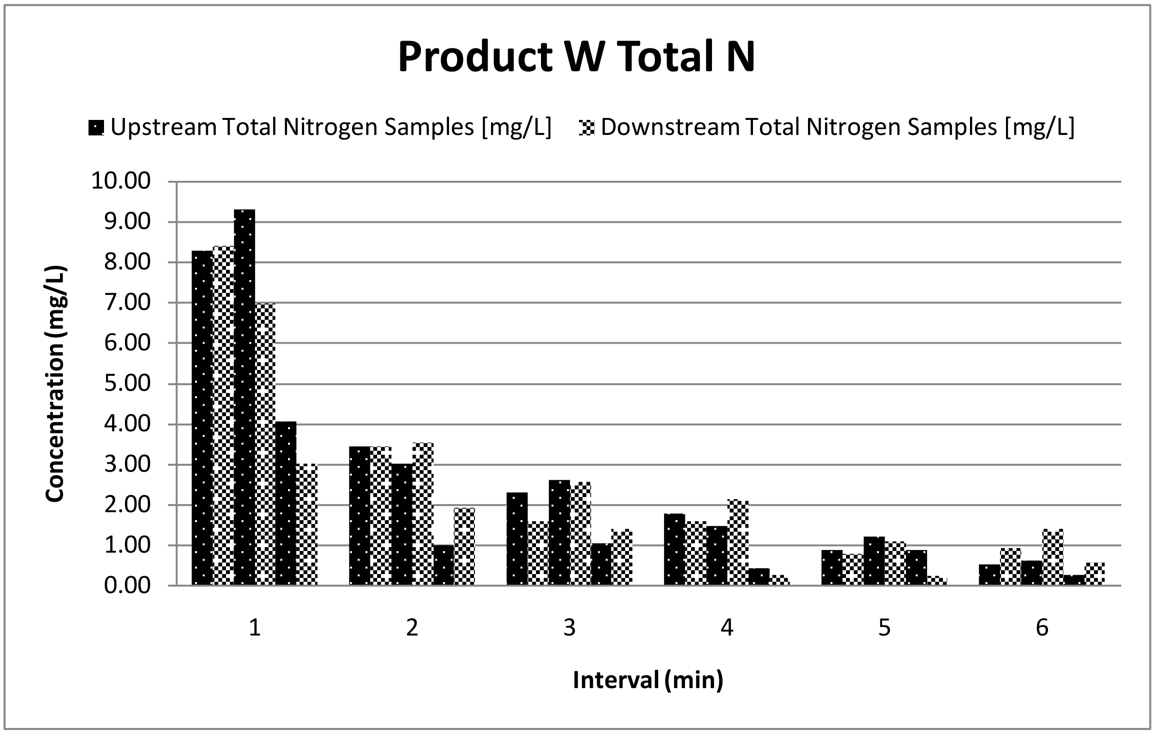

Figure 61: Sample water TN concentration for 3 rainfall events on Product W over time

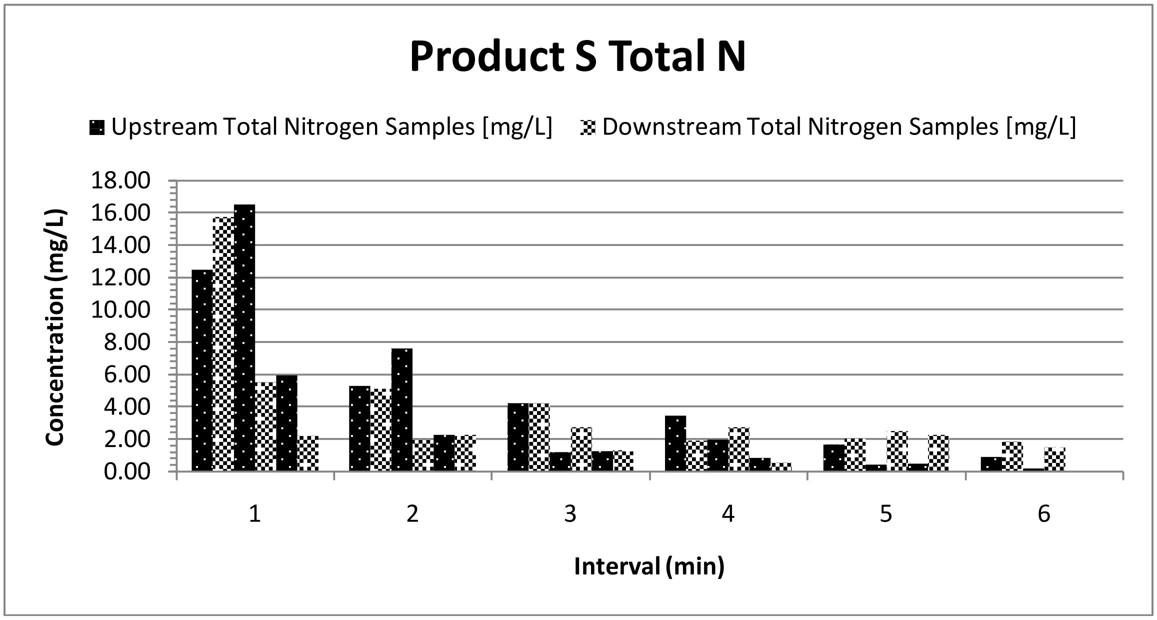

Figure 62: Sample water TN concentration for 3 rainfall events on Product S over time

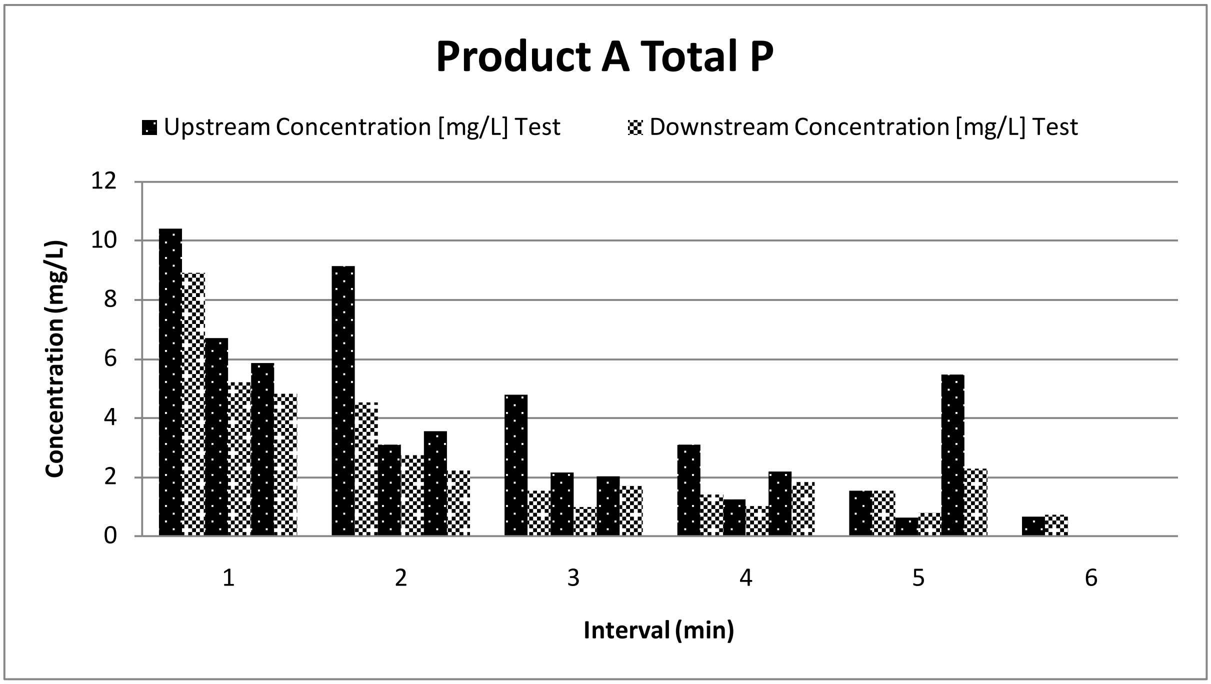

Figure 63: Sample water TP concentration for 3 rainfall events on Product A over time

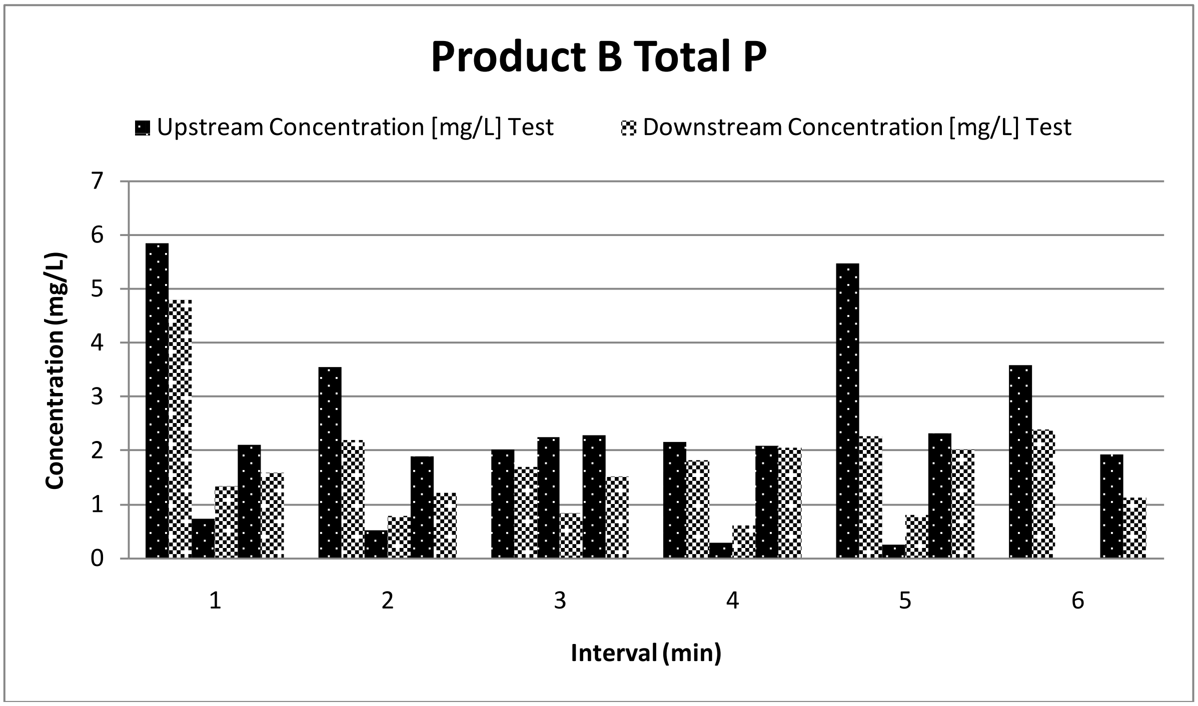

Figure 64: Sample water TP concentration for 3 rainfall events on Product B over time

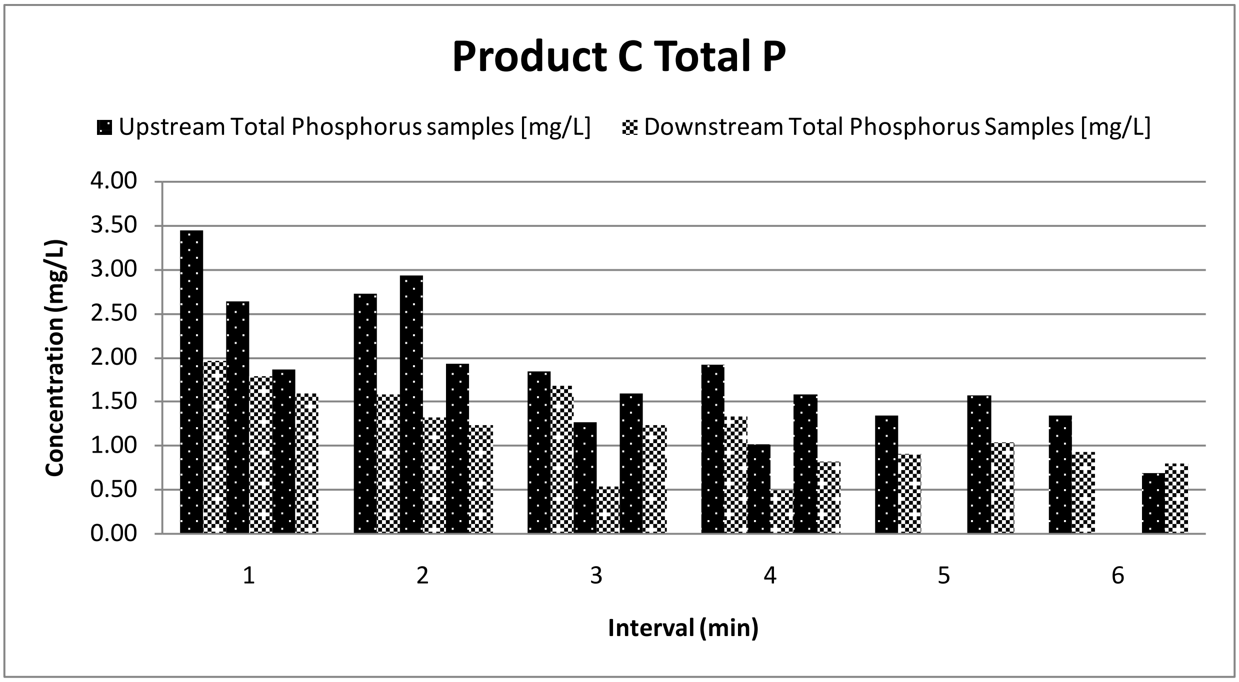

Figure 65: Sample water TP concentration for 3 rainfall events on Product C over time

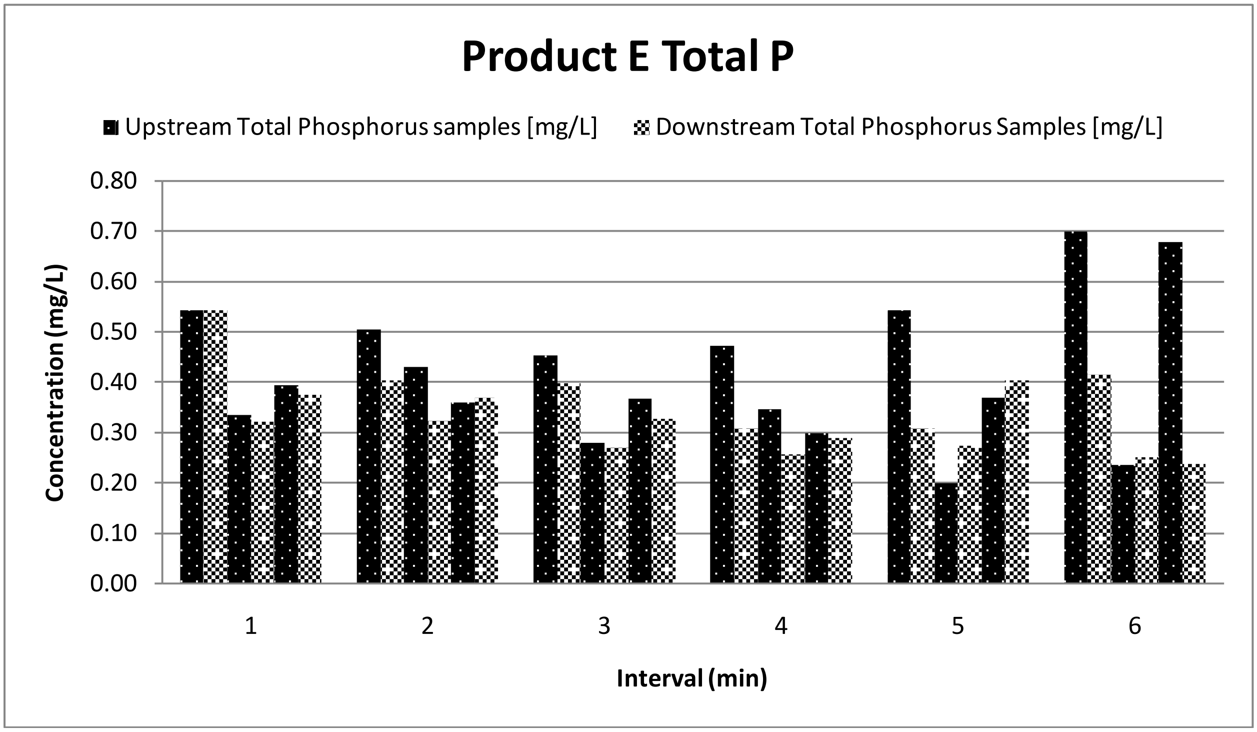

Figure 66: Sample water TP concentration for 3 rainfall events on Product E over time

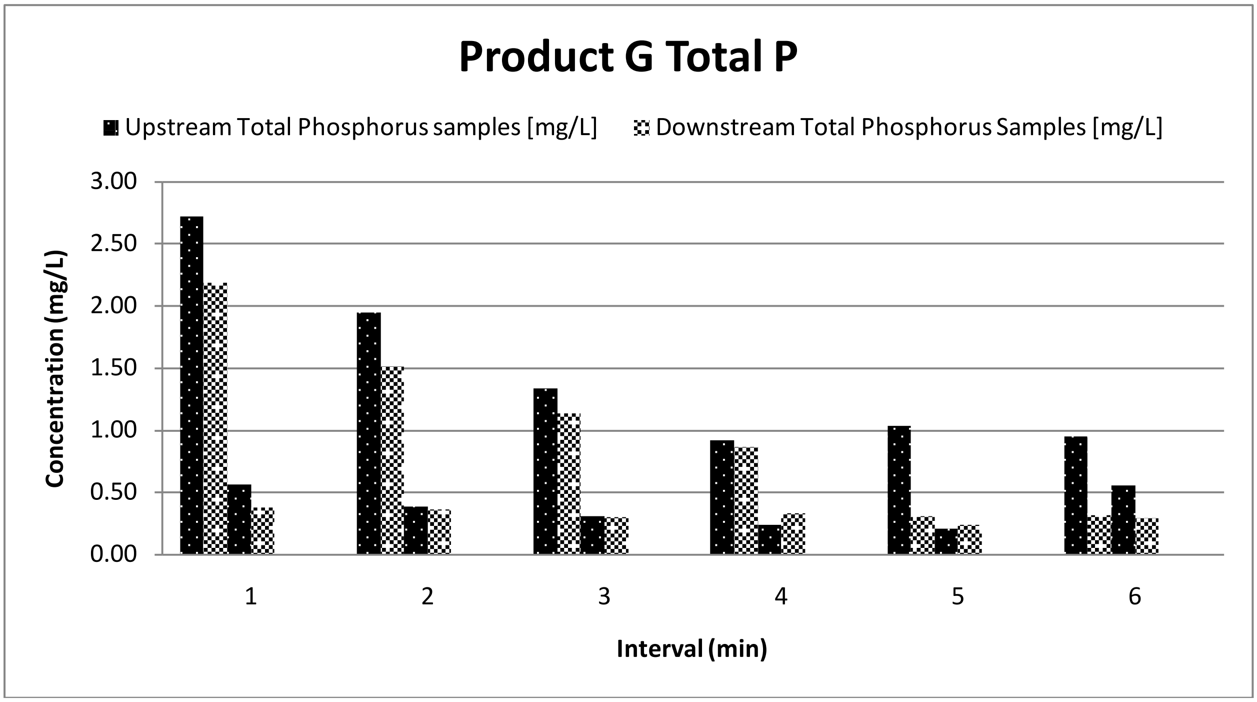

Figure 67: Sample water TP concentration for 3 rainfall events on Product G over time

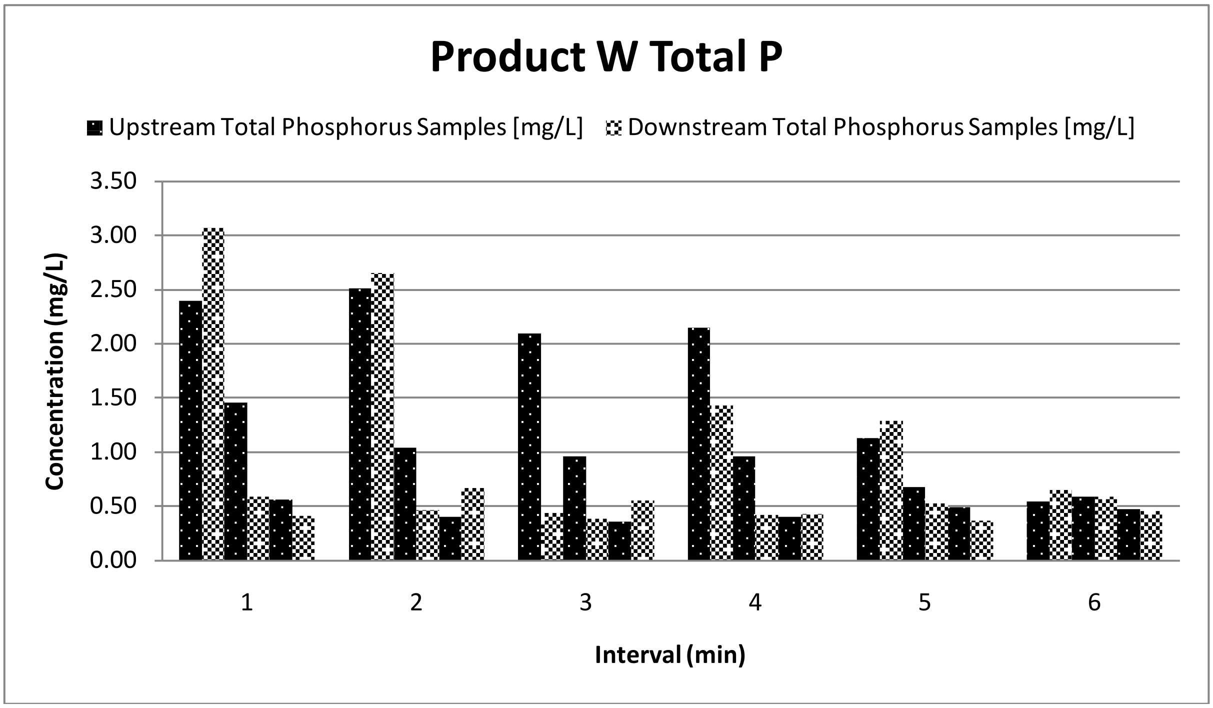

Figure 68: Sample water TP concentration for 3 rainfall events on Product W over time

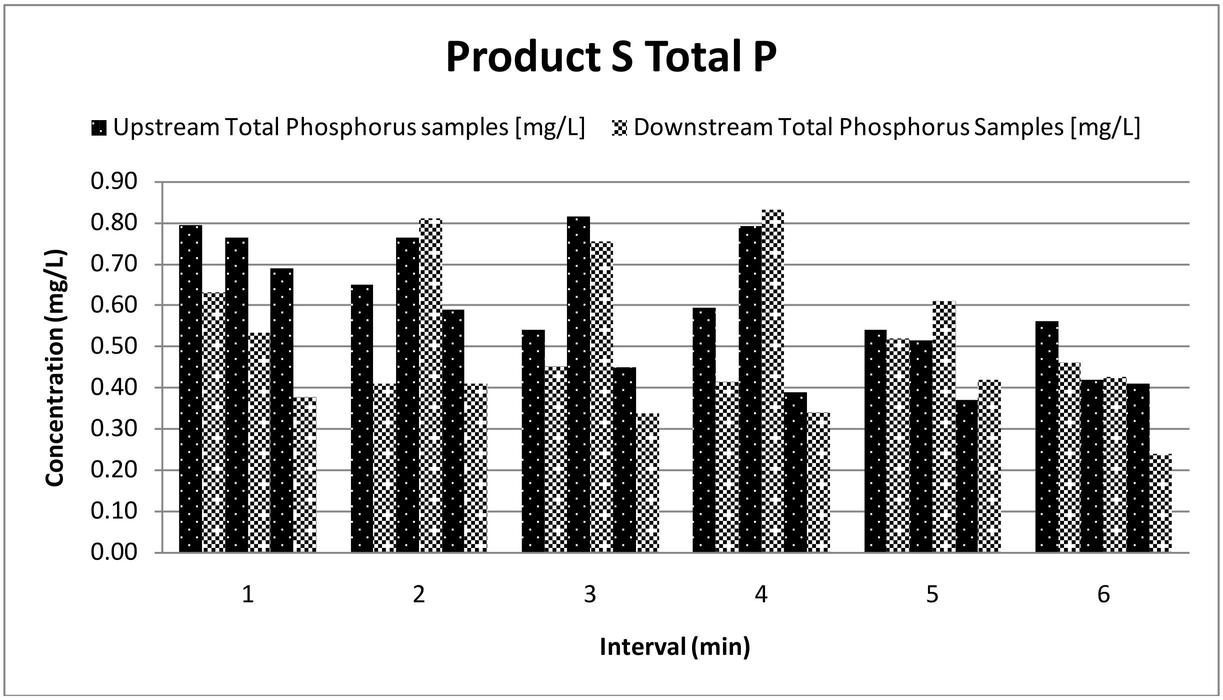

Figure 69: Sample water TP concentration for 3 rainfall events on Product S over time

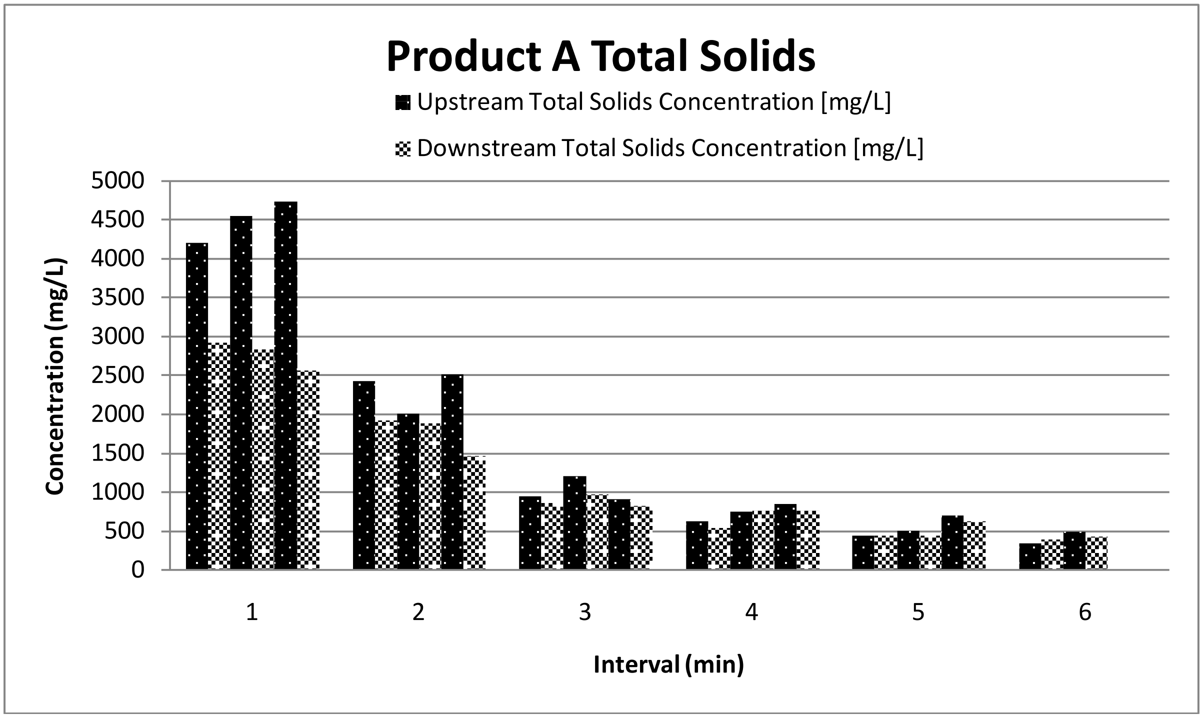

Figure 70: Sample water TS concentration for 3 rainfall events on Product A over time

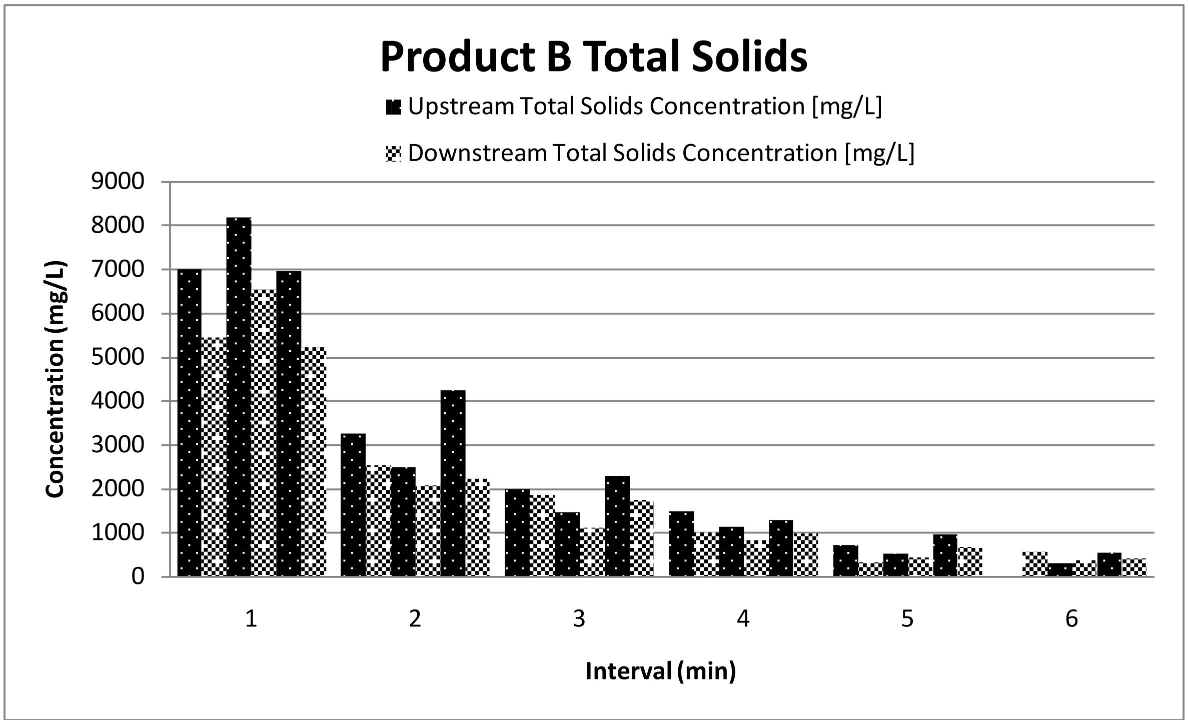

Figure 71: Sample water TS concentration for 3 rainfall events on Product B over time

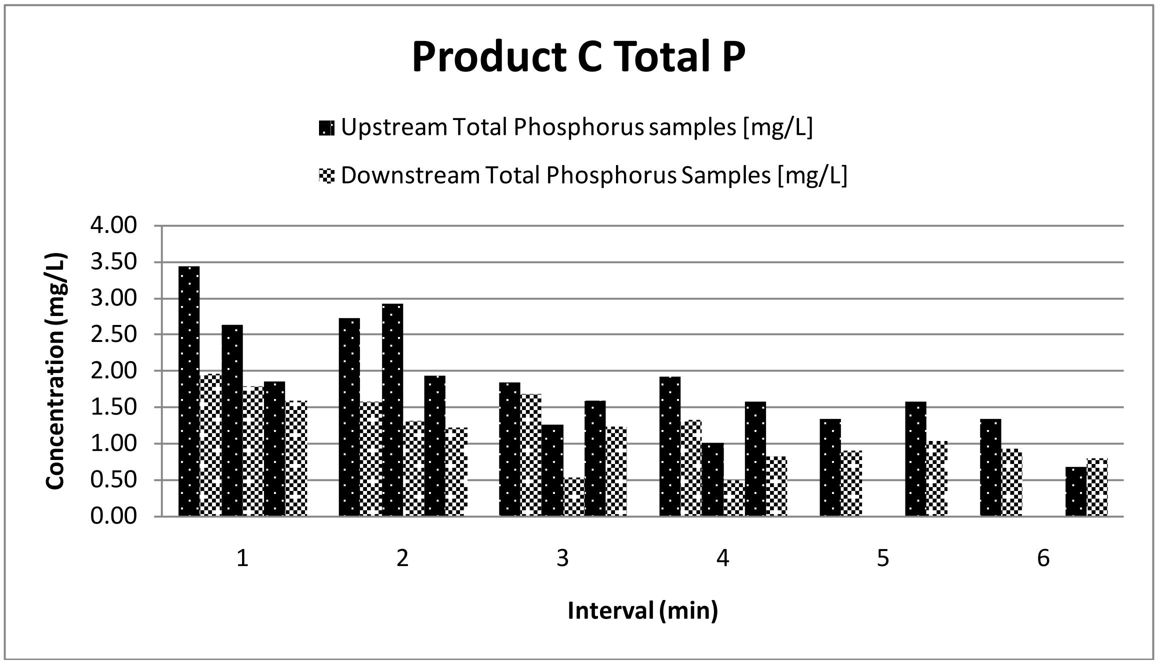

Figure 72: Sample water TS concentration for 3 rainfall events on Product C over time

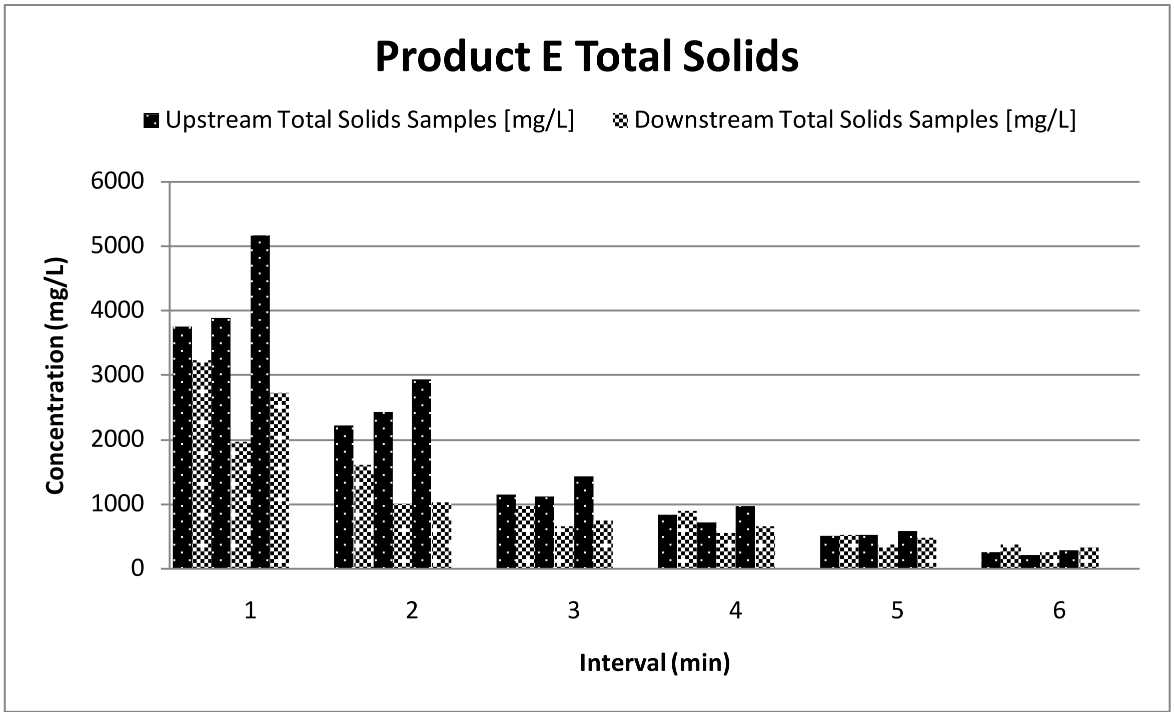

Figure 73: Sample water TS concentration for 3 rainfall events on Product E over time

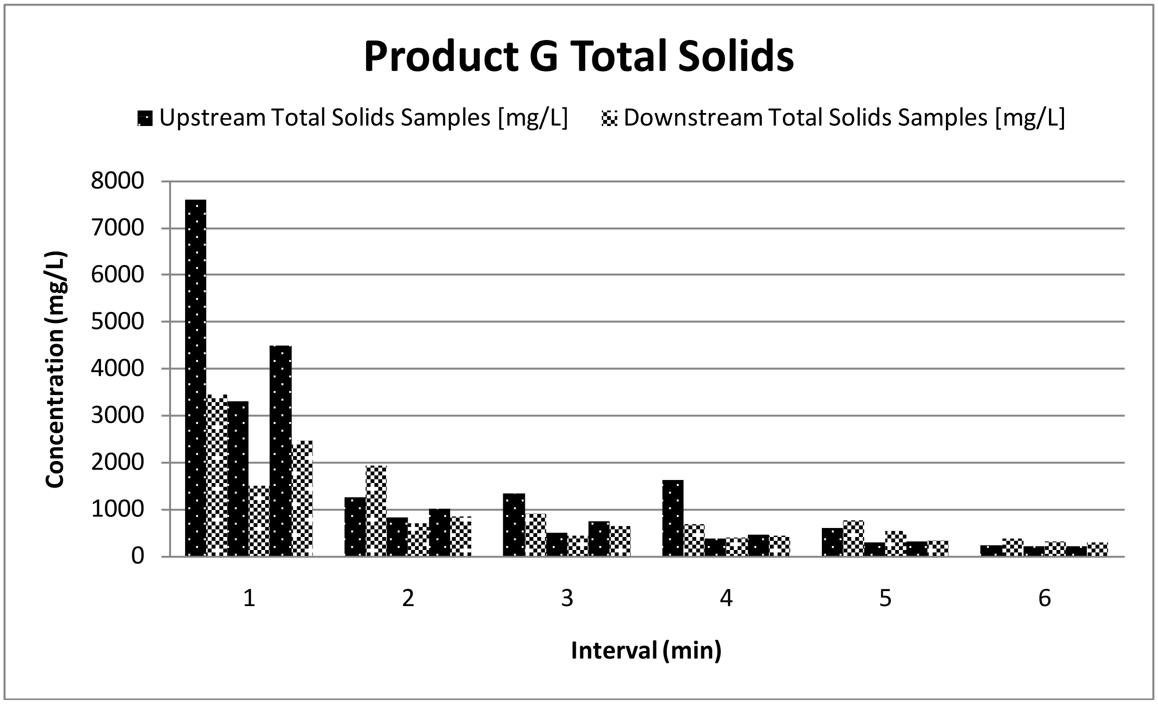

Figure 74: Sample water TS concentration for 3 rainfall events on Product G over time

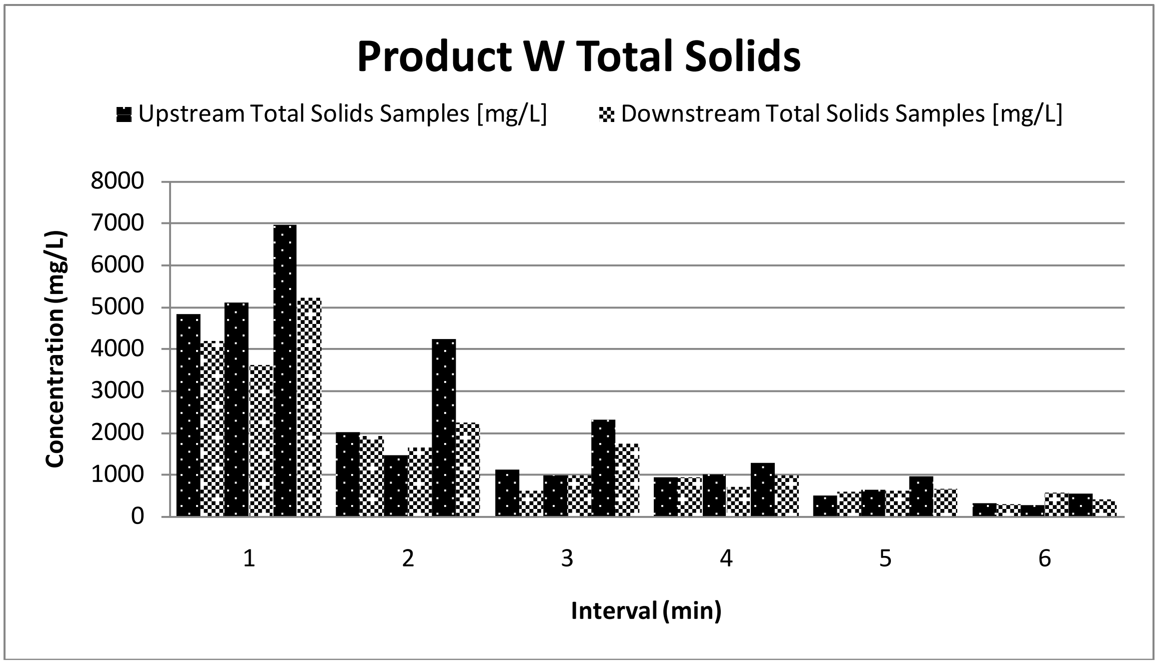

Figure 75: Sample water TS concentration for 3 rainfall events on Product W over time

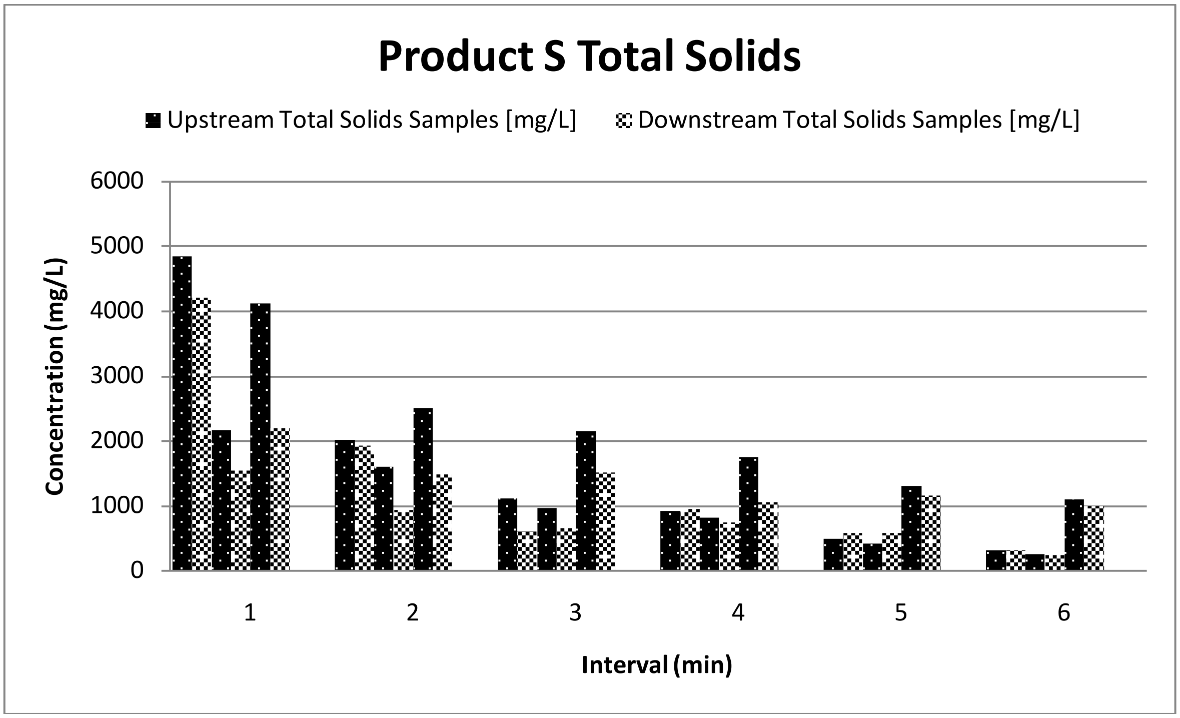

Figure 76: Sample water TS concentration for 3 rainfall events on Product S over time

Table 14: Product A upstream sieve analysis

Sieve Analysis

Description of soil A-2-4 Fine Sand

Sample No. 1

Mass of oven dry sample, W 622.8 g

Location UCF Stormwater Lab - Curb Inlet

Tested by Matthew Goolsby

Date November 11, 2009

Sieve No.	Sieve opening (mm)	Mass of soil retained on each sieve, W_n (g)	Percent of mass retained on each sieve, R_n	Cumulative percent retained, $\sum R_n$	Percent finer, 100 - $\sum R_n$
4	4.750	0.1	0.0	0.0	100.0
10	2.000	0.8	0.1	0.1	99.9
20	0.850	4.6	0.7	0.9	99.1
40	0.425	12.5	2.0	2.9	97.1
60	0.250	163.0	26.2	29.1	70.9
140	0.106	418.8	67.3	96.4	3.6
200	0.075	12.3	2.0	98.4	1.6
Pan	--	9.6	1.5	99.9	0.1

$W_1 = \sum$ 622.3 G

Mass loss during sieve analysis = $[(W - W_1) \div W] \times 100 =$ 0.08 % (OK if less than 2%)

$D_{60} =$ 0.34

$D_{30} =$ 0.27

$D_{10} =$ 0.16

(Determined from graph, corresponding to percents finer of 60%, 30%, and 10%)

Uniformity coefficient, $C_u = (D_{60} / D_{10}) =$ 2.13

Coefficient of gradation, $C_c = [D^2_{30} \div (D_{60} \times D_{10})] =$ 1.34

Effective size of soil sample, $D_{10} =$ **0.15 *mm***

AASHTO Classification System:-

Unified Classification System:- **Poorly Graded Sand [*SP*]**

Table 15: Product A downstream sieve analysis

Sieve Analysis

Description of soil A-3 Fine Sand Sample No. 1

Mass of oven dry sample, W 354.8 g

Location UCF Stormwater Lab - Curb Inlet

Tested by Matthew Goolsby Date November 11, 2009

Sieve No.	Sieve opening (mm)	Mass of soil retained on each sieve, W_n (g)	Percent of mass retained on each sieve, R_n	Cumulative percent retained, $\sum R_n$	Percent finer, 100 - $\sum R_n$
4	4.750	0.0	0.0	0.0	100.0
10	2.000	0.5	0.1	0.1	99.9
20	0.850	1.8	0.5	0.6	99.4
40	0.425	11.6	3.3	3.9	96.1
60	0.250	74.6	21.0	24.9	75.1
140	0.106	238.6	67.2	92.2	7.8
200	0.075	12.0	3.4	95.6	4.4
Pan	--	15.1	4.3	99.8	0.2

$W_1 = \sum$ 354.2 G

Mass loss during sieve analysis = $[(W - W_1) \div W] \times 100 =$ 0.17 % (OK if less than 2%)

$D_{60} =$ 0.34

$D_{30} =$ 0.27

$D_{10} =$ 0.16

(Determined from graph, corresponding to percents finer of 60%, 30%, and 10%)

Uniformity coefficient, $C_u = (D_{60} / D_{10}) =$ 2.13

Coefficient of gradation, $C_c = [D^2_{30} \div (D_{60} \times D_{10})] =$ 1.34

Effective size of soil sample, D_{10} = **0.15 *mm***

AASHTO Classification System:-

Unified Classification System:- **Poorly Graded Sand [*SP*]**

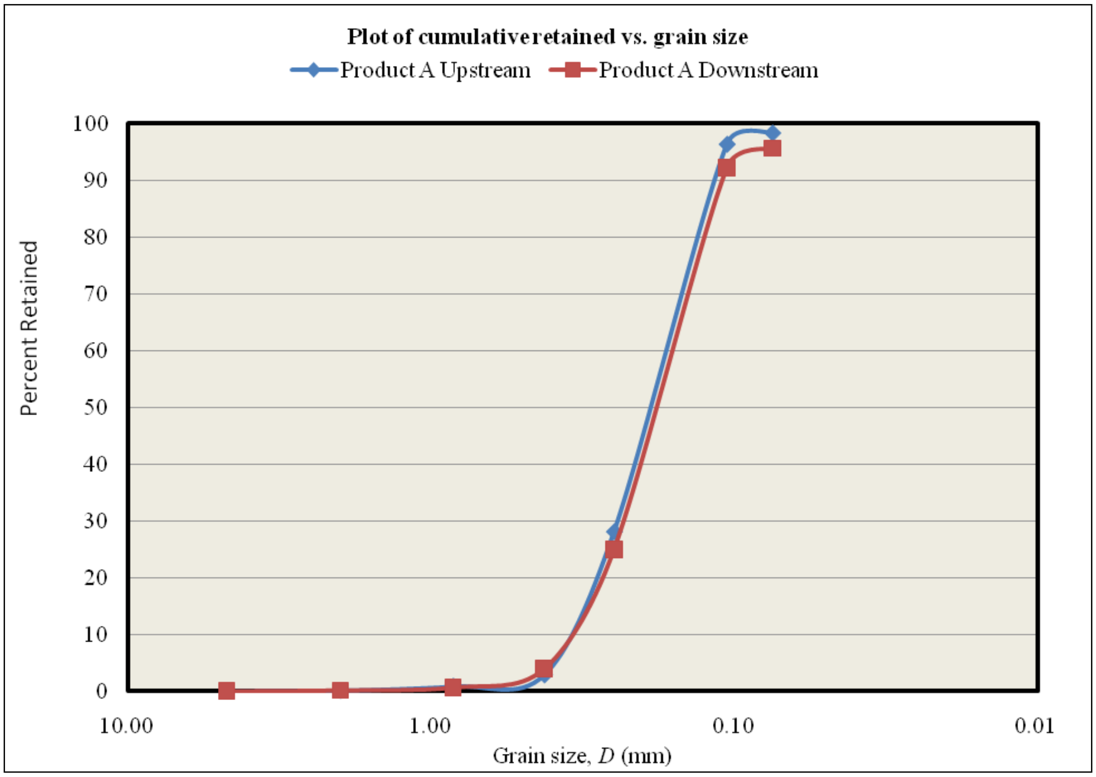

Figure 77: Product A sieve analysis retained plot

Table 16: Product B upstream sieve analysis

Sieve Analysis

Description of soil A-3 Fine Sand Sample No. 1

Mass of oven dry sample, W 534.12 g

Location UCF Stormwater Lab - Curb Inlet

Tested by Matthew Goolsby Date November 9, 2009

Sieve No.	Sieve opening (mm)	Mass of soil retained on each sieve, W_n (g)	Percent of mass retained on each sieve, R_n	Cumulative percent retained, $\sum R_n$	Percent finer, 100 - $\sum R_n$
4	4.750	0.4	0.1	0.1	99.9
10	2.000	2.0	0.4	0.4	99.6
20	0.850	3.6	0.7	1.1	98.9
40	0.425	10.9	2.0	3.2	96.8
60	0.250	152.9	28.7	31.8	68.2
140	0.106	343.6	64.5	96.4	3.6
200	0.075	10.1	1.9	98.3	1.7
Pan	--	7.9			

$W_1 = \sum$ 532.7 g

Mass loss during sieve analysis = $[(W - W_1) \div W] \times 100 =$ 0.27 % (OK if less than 2%)

$D_{60} =$ 0.24

$D_{30} =$ 0.17

$D_{10} =$ 0.125

(Determined from graph, corresponding to percents finer of 60%, 30%, and 10%)

Uniformity coefficient, $C_u = (D_{60} / D_{10}) =$ 1.92

Coefficient of gradation, $C_c = [D^2_{30} \div (D_{60} \times D_{10})] =$ 0.91

Effective size of soil sample, $D_{10} =$ **0.125 *mm***

AASHTO Classification System:- **A-3 Fine Sand**

Unified Classification System:- **Poorly Graded Sand [SP]**

Table 17: Product B downstream sieve analysis

Mass of oven dry sample, W 173.8 g

Location UCF Stormwater Lab - Curb Inlet
Tested by Matthew Goolsby Date June 9, 2009

Sieve No.	Sieve opening (mm)	Mass of soil retained on each sieve, W_n (g)	Percent of mass retained on each sieve, R_n	Cumulative percent retained, $\sum R_n$	Percent finer, 100 - $\sum R_n$
4	4.750	0.0	0.0	0.0	100.0
10	2.000	0.5	0.3	0.3	99.7
20	0.850	2.0	1.2	1.4	98.6
40	0.425	5.7	3.3	4.7	95.3
60	0.250	29.5	17.0	21.7	78.3
140	0.106	107.6	61.9	83.6	16.4
200	0.075	10.5	6.0	89.6	10.4
Pan	--	16.8			

$W_1 = \sum$ 172.6 g

Mass loss during sieve analysis = $[(W - W_1) \div W] \times 100$ = 0.69 % (OK if less than 2%)

D_{60} = 0.2
D_{30} = 0.15
D_{10} = 0.085
(Determined from graph, corresponding to percents finer of 60%, 30%, and 10%)

Uniformity coefficient, $C_u = (D_{60} / D_{10})$ = 2.35

Coefficient of gradation, $C_c = [D^2_{30} \div (D_{60} \times D_{10})]$ = 1.24

Effective size of soil sample, D_{10} = **0.085 *mm***

AASHTO Classification System:- **A-3 Fine Sand**

Unified Classification System:- **Poorly Graded Sand [SP]**

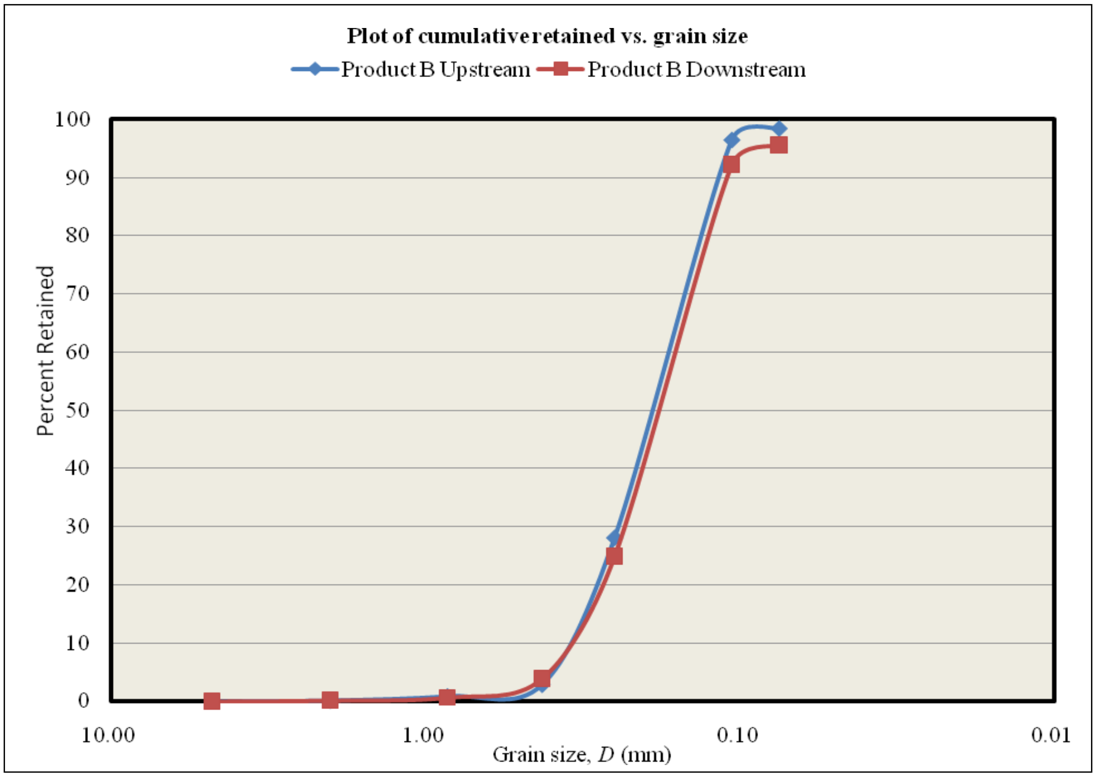

Figure 78: Product B sieve analysis retained plot

Table 18: Product C upstream sieve analysis

Sieve Analysis

Description of soil A-3 Fine Sand Sample No. 1

Mass of oven dry sample, W 397.85 g

Location UCF Stormwater Lab - Curb Inlet

Tested by Matthew Goolsby Date January 15, 2010

Sieve No.	Sieve opening (mm)	Mass of soil retained on each sieve, W_n (g)	Percent of mass retained on each sieve, R_n	Cumulative percent retained, $\sum R_n$	Percent finer, 100 - $\sum R_n$
4	4.750	0.0	0.0	0.0	100.0
10	2.000	1.1	0.3	0.3	99.7
20	0.850	2.2	0.5	0.8	99.2
40	0.425	7.0	1.8	2.6	97.4
60	0.250	99.9	25.2	27.8	72.2
140	0.106	272.2	68.8	96.6	3.4
200	0.075	7.7	1.9	98.5	1.5
Pan	0.005	4.5			

$W_1 = \sum$ 396.6 g

Mass loss during sieve analysis = $[(W - W_1) \div W] \times 100$ = 0.32 % (OK if less than 2%)

D_{60} = 0.22

D_{30} = 0.18

D_{10} = 0.12

(Determined from graph, corresponding to percents finer of 60%, 30%, and 10%)

Uniformity coefficient, $C_u = (D_{60} / D_{10})$ = 1.83

Coefficient of gradation, $C_c = [D^2_{30} \div (D_{60} \times D_{10})]$ = 1.23

Effective size of soil sample, D_{10} = **0.15 *mm***

AASHTO Classification System:-

Unified Classification System:- **Poor Graded Sand [SP]**

Table 19: Product C downstream sieve analysis

Sieve Analysis

Description of soil A-3 Fine Sand Sample No. 1

Mass of oven dry sample, W 100.18 g

Location UCF Stormwater Lab - Curb Inlet

Tested by Matthew Goolsby Date January 15, 2010

Sieve No.	Sieve opening (mm)	Mass of soil retained on each sieve, W_n (g)	Percent of mass retained on each sieve, R_n	Cumulative percent retained, $\sum R_n$	Percent finer, 100 - $\sum R_n$
4	4.750	0.0	0.0	0.0	100.0
10	2.000	0.5	0.5	0.5	99.5
20	0.850	3.3	3.3	3.8	96.2
40	0.425	1.2	1.2	5.0	95.0
60	0.250	9.1	9.1	14.1	85.9
140	0.106	49.4	49.3	63.3	36.7
200	0.075	5.7	5.7	69.0	31.0
Pan	0.005	30.9	30.8	99.9	0.1

$W_1 = \sum$ 100.0 g

Mass loss during sieve analysis = $[(W - W_1) \div W] \times 100$ = 0.15 % (OK if less than 2%)

D_{60} = 1.2

D_{30} = 0.39

D_{10} = 0.16

(Determined from graph, corresponding to percents finer of 60%, 30%, and 10%)

Uniformity coefficient, $C_u = (D_{60} / D_{10})$ = 7.50

Coefficient of gradation, $C_c = [D^2_{30} \div (D_{60} \times D_{10})]$ = 0.79

Effective size of soil sample, D_{10} = **0.15 *mm***

AASHTO Classification System:-

Unified Classification System:- **Well Graded Sand [SW]**

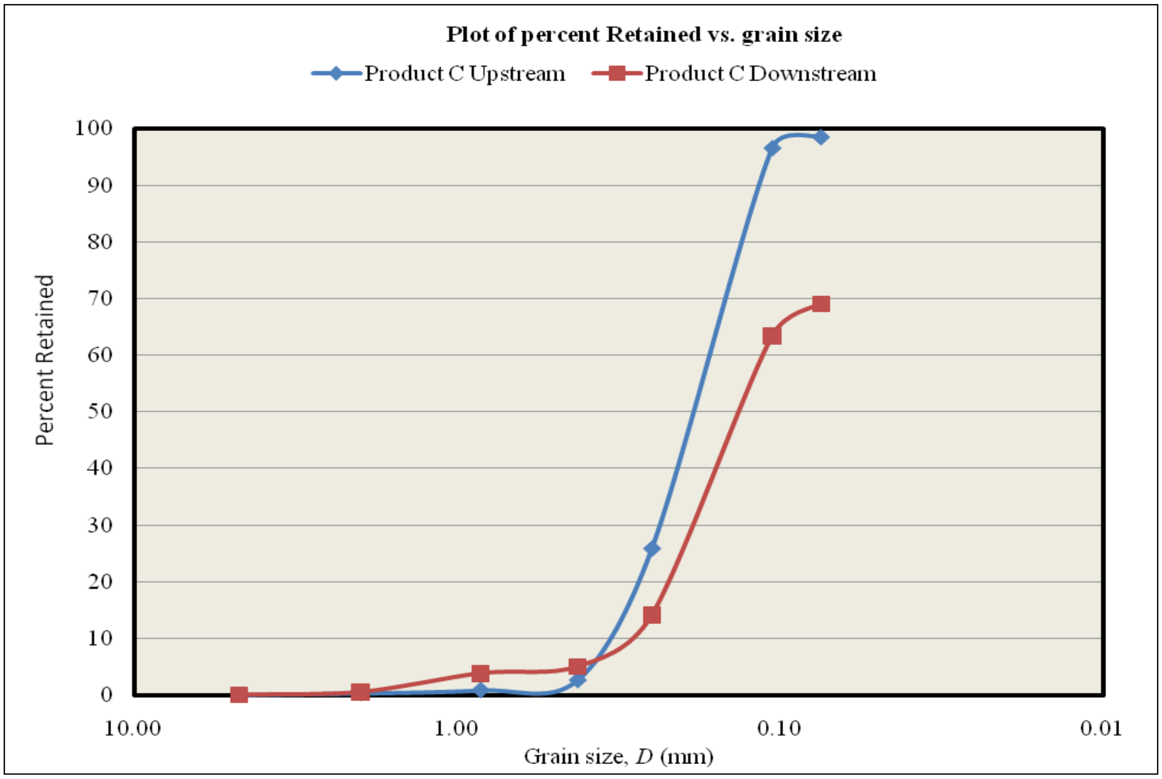

Figure 79: Product C sieve analysis retained plot

Table 20: Product E upstream sieve analysis

Sieve Analysis

Description of soil A-3 Fine Sand Sample No. 1

Mass of oven dry sample, W 569.2 g

Location UCF Stormwater Lab - Curb Inlet

Tested by Matthew Goolsby Date November 23, 2009

Sieve No.	Sieve opening (mm)	Mass of soil retained on each sieve, W_n (g)	Percent of mass retained on each sieve, R_n	Cumulative percent retained, $\sum R_n$	Percent finer, 100 - $\sum R_n$
4	4.750	1.8	0.3	0.3	99.7
10	2.000	2.0	0.4	0.7	99.3
20	0.850	3.0	0.5	1.2	98.8
40	0.425	11.2	2.0	3.2	96.8
60	0.250	192.3	33.8	36.9	63.1
140	0.106	339.1	59.6	96.5	3.5
200	0.075	10.5	1.8	98.4	1.6
Pan	--	9.2	1.6		

$W_1 = \sum$ 569.1 G

Mass loss during sieve analysis = $[(W - W_1) \div W] \times 100$ = 0.02 % (OK if less than 2%)

D_{60} = 0.29

D_{30} = 0.19

D_{10} = 0.135

(Determined from graph, corresponding to percents finer of 60%, 30%, and 10%)

Uniformity coefficient, $C_u = (D_{60} / D_{10})$ = 2.15

Coefficient of gradation, $C_c = [D^2_{30} \div (D_{60} \times D_{10})]$ = 0.92

Effective size of soil sample, D_{10} = **0.135 *mm***

AASHTO Classification System:- **A-3 Fine Sand**

Unified Classification System:- **Poorly Graded Sand [SP]**

Table 21: Product E downstream sieve analysis

Sieve Analysis

Description of soil A-3 Fine Sand Sample No. 1

Mass of oven dry sample, W 107 g

Location UCF Stormwater Lab - Curb Inlet

Tested by Matthew Goolsby Date November 23, 2009

Sieve No.	Sieve opening (mm)	Mass of soil retained on each sieve, W_n (g)	Percent of mass retained on each sieve, R_n	Cumulative percent retained, $\sum R_n$	Percent finer, 100 - $\sum R_n$
4	4.750	0.1	0.1	0.1	99.9
10	2.000	0.3	0.3	0.4	99.6
20	0.850	2.0	1.9	2.2	97.8
40	0.425	4.1	3.8	6.1	93.9
60	0.250	19.6	18.4	24.5	75.5
140	0.106	65.3	61.6	86.1	13.9
200	0.075	4.8	4.5	90.6	9.4
Pan	--	9.5			

$W_1 = \sum$ 106.4 G

Mass loss during sieve analysis = $[(W - W_1) \div W] \times 100 =$ 0.56 % (OK if less than 2%)

$D_{60} =$ 0.2

$D_{30} =$ 0.15

$D_{10} =$ 0.11

(Determined from graph, corresponding to percents finer of 60%, 30%, and 10%)

Uniformity coefficient, $C_u = (D_{60} / D_{10}) =$ 1.82

Coefficient of gradation, $C_c = [D^2_{30} \div (D_{60} \times D_{10})] =$ 0.96

Effective size of soil sample, $D_{10} =$ **0.11 *mm***

AASHTO Classification System:- **A-3 Fine Sand**

Unified Classification System:- **Poorly Graded**

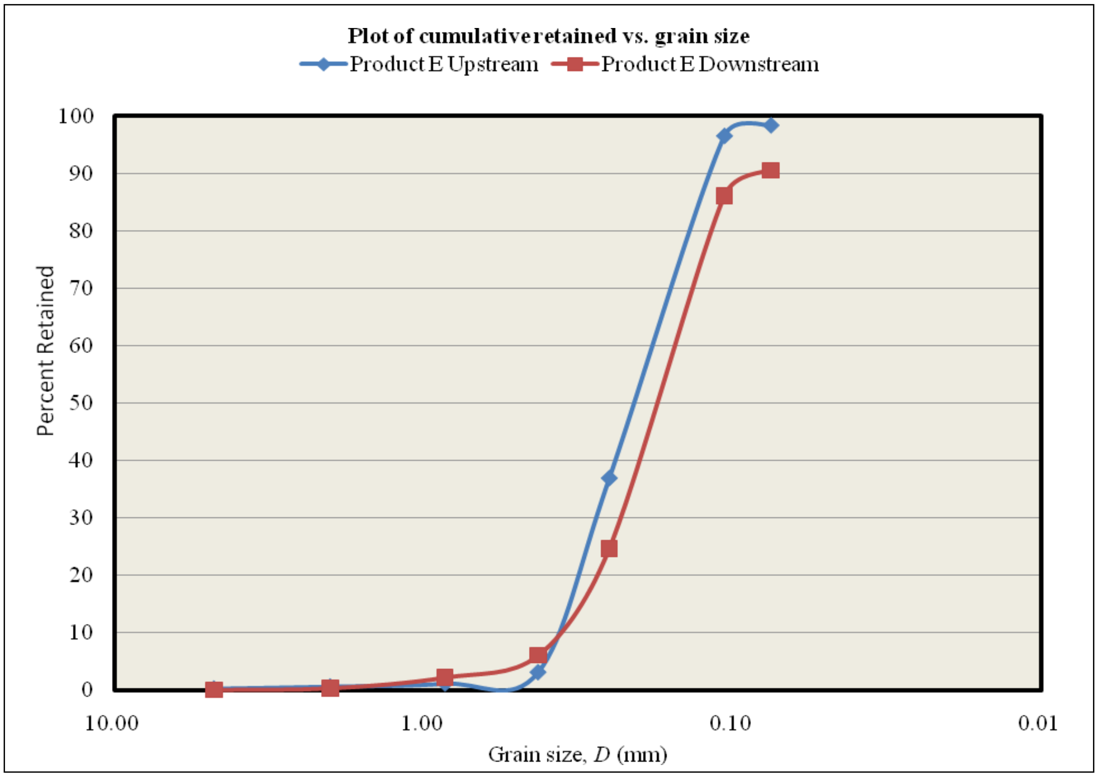

Figure 80: Product E sieve analysis retained plot

Table 22: Product G upstream sieve analysis

Sieve Analysis

Description of soil A-3 Fine Sand Sample No. 1

Mass of oven dry sample, W 582.7 g

Location UCF Stormwater Lab - Curb Inlet

Tested by Matthew Goolsby Date December 9, 2009

Sieve No.	Sieve opening (mm)	Mass of soil retained on each sieve, W_n (g)	Percent of mass retained on each sieve, R_n	Cumulative percent retained, $\sum R_n$	Percent finer, 100 - $\sum R_n$
4	4.750	2.0	0.3	0.3	99.7
10	2.000	2.8	0.5	0.8	99.2
20	0.850	3.6	0.6	1.4	98.6
40	0.425	13.6	2.3	3.8	96.2
60	0.250	133.9	23.0	26.8	73.2
140	0.106	414.8	71.2	98.0	2.0
200	0.075	7.8	1.3	99.3	0.7
Pan	--	3.4	0.6		

$W_1 = \sum$ 582.1 G

Mass loss during sieve analysis = $[(W - W_1) \div W] \times 100$ = 0.10 % (OK if less than 2%)

D_{60} = 0.29

D_{30} = 0.19

D_{10} = 0.135

(Determined from graph, corresponding to percents finer of 60%, 30%, and 10%)

Uniformity coefficient, $C_u = (D_{60} / D_{10})$ = 2.15

Coefficient of gradation, $C_c = [D^2_{30} \div (D_{60} \times D_{10})]$ = 0.92

Effective size of soil sample, D_{10} = **0.135 *mm***

AASHTO Classification System:- **A-3 Fine Sand**

Unified Classification System:- **Poorly Graded Sand [SP]**

Table 23: Product G downstream sieve analysis

Sieve Analysis

Description of soil A-3 Fine Sand Sample No. 1

Mass of oven dry sample, W 133.2 g

Location UCF Stormwater Lab - Curb Inlet

Tested by Matthew Goolsby Date December 9, 2009

Sieve No.	Sieve opening (*mm*)	Mass of soil retained on each sieve, W_n (g)	Percent of mass retained on each sieve, R_n	Cumulative percent retained, $\sum R_n$	Percent finer, 100 - $\sum R_n$
4	4.750	0.0	0.0	0.0	100.0
10	2.000	0.0	0.0	0.0	100.0
20	0.850	0.1	0.1	0.1	99.9
40	0.425	2.0	1.5	1.6	98.4
60	0.250	23.0	17.3	18.8	81.2
140	0.106	97.1	72.9	91.7	8.3
200	0.075	3.9	2.9	94.7	5.3
Pan	--	6.5			

$W_1 = \sum$ 132.6 G

Mass loss during sieve analysis = $[(W - W_1) \div W] \times 100 =$ 0.45 % (OK if less than 2%)

$D_{60} =$ 0.2

$D_{30} =$ 0.15

$D_{10} =$ 0.11

(Determined from graph, corresponding to percents finer of 60%, 30%, and 10%)

Uniformity coefficient, $C_u = (D_{60} / D_{10}) =$ 1.82

Coefficient of gradation, $C_c = [D^2_{30} \div (D_{60} \times D_{10})] =$ 0.96

Effective size of soil sample, $D_{10} =$ **0.11 *mm***

AASHTO Classification System:- **A-3 Fine Sand**

Unified Classification System:- **Poorly Graded**

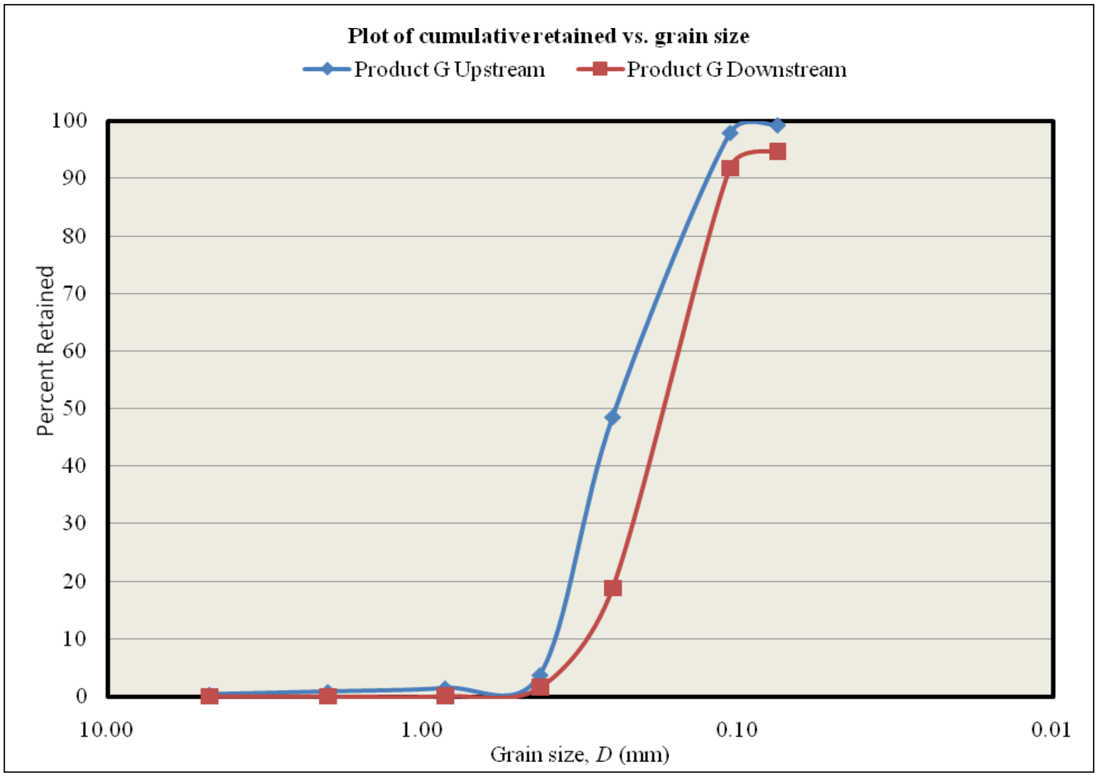

Figure 81: Product G sieve analysis retained plot

Table 24: Product W upstream sieve analysis

Sieve Analysis

Description of soil A-2-4 Fine Sand Sample No. 1

Mass of oven dry sample, *W* 544.4 g

Location UCF Stormwater Lab - Curb Inlet

Tested by Matthew Goolsby Date November 10, 2009

Sieve No.	Sieve opening (*mm*)	Mass of soil retained on each sieve, W_n (g)	Percent of mass retained on each sieve, R_n	Cumulative percent retained, $\sum R_n$	Percent finer, 100 - $\sum R_n$
4	4.750	0.2	0.0	0.0	100.0
10	2.000	4.7	0.9	0.9	99.1
20	0.850	6.9	1.3	2.2	97.8
40	0.425	13.6	2.5	4.7	95.3
60	0.250	153.1	28.2	32.9	76.1
140	0.106	349.0	64.2	97.1	2.9
200	0.075	9.3	1.7	98.8	1.2
Pan	--	6.0			

$W_1 = \sum$ 543.7 G

Mass loss during sieve analysis = $[(W - W_1) \div W] \times 100 =$ 0.13 % (OK if less than 2%)

$D_{60} =$ 0.22

$D_{30} =$ 0.18

$D_{10} =$ 0.12

(Determined from graph, corresponding to percents finer of 60%, 30%, and 10%)

Uniformity coefficient, $C_u = (D_{60} / D_{10}) =$ 1.83

Coefficient of gradation, $C_c = [D^2_{30} \div (D_{60} \times D_{10})] =$ 1.23

Effective size of soil sample, $D_{10} =$ **0.15 *mm***

AASHTO Classification System:-

Unified Classification System:- **Poorly Graded Sand [*SP*]**

Table 25: Product W downstream sieve analysis

Sieve Analysis

Description of soil: A-3 Fine Sand

Sample No.: 1

Mass of oven dry sample, W: 88.8 g

Location: UCF Stormwater Lab - Curb Inlet

Tested by: Matthew Goolsby

Date: November 23, 2009

Sieve No.	Sieve opening (mm)	Mass of soil retained on each sieve, W_n (g)	Percent of mass retained on each sieve, R_n	Cumulative percent retained, $\sum R_n$	Percent finer, 100 - $\sum R_n$
4	4.750	0.0	0.0	0.0	100.0
10	2.000	0.3	0.3	0.3	99.7
20	0.850	0.5	0.6	0.9	99.1
40	0.425	1.7	1.9	2.8	97.2
60	0.250	19.4	21.9	24.7	75.3
140	0.106	50.0	56.3	81.0	19.0
200	0.075	5.1	5.7	86.7	13.3
Pan	-	11.8			

$W_1 = \sum$ 88.8 G

Mass loss during sieve analysis = $[(W - W_1) \div W] \times 100 =$ 0.00 % (OK if less than 2%)

$D_{60} =$ 1.2

$D_{30} =$ 0.39

$D_{10} =$ 0.16

(Determined from graph, corresponding to percents finer of 60%, 30%, and 10%)

Uniformity coefficient, $C_u = (D_{60} / D_{10}) =$ 7.50

Coefficient of gradation, $C_c = [D^2_{30} \div (D_{60} \times D_{10})] =$ 0.79

Effective size of soil sample, $D_{10} =$ **0.15 *mm***

AASHTO Classification System:-

Unified Classification System:- **Well Graded Sand [SW]**

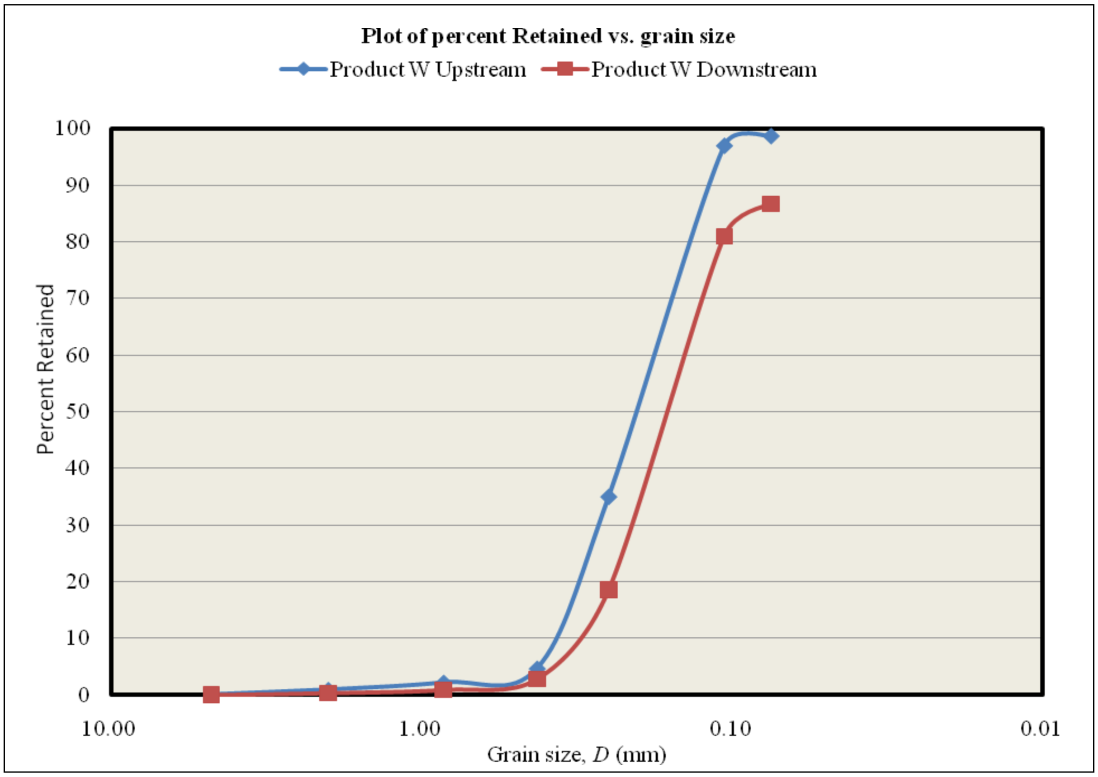

Figure 82: Product W sieve analysis retained plot

Table 26: Product S upstream sieve analysis

Sieve Analysis

Description of soil A-2-4 Fine Sand

Sample No. 1

Mass of oven dry sample, W 354.2 g

Location UCF Stormwater Lab - Curb Inlet

Tested by Matthew Goolsby

Date December 15, 2009

Sieve No.	Sieve opening (mm)	Mass of soil retained on each sieve, W_n (g)	Percent of mass retained on each sieve, R_n	Cumulative percent retained, $\sum R_n$	Percent finer, 100 - $\sum R_n$
4	4.750	1.3	0.4	0.4	99.6
10	2.000	1.8	0.5	0.9	99.1
20	0.850	2.7	0.8	1.6	98.4
40	0.425	7.4	2.1	3.7	96.3
60	0.250	87.9	24.9	28.6	72.4
140	0.106	237.6	67.3	95.9	4.1
200	0.075	6.9	1.9	97.9	2.1
Pan	--	6.6			

$W_1 = \sum$ 353.2 G

Mass loss during sieve analysis = $[(W - W_1) \div W] \times 100 =$ 0.28 % (OK if less than 2%)

$D_{60} =$ 0.22

$D_{30} =$ 0.18

$D_{10} =$ 0.12

(Determined from graph, corresponding to percents finer of 60%, 30%, and 10%)

Uniformity coefficient, $C_u = (D_{60} / D_{10}) =$ 1.83

Coefficient of gradation, $C_c = [D^2_{30} \div (D_{60} \times D_{10})] =$ 1.23

Effective size of soil sample, $D_{10} =$ **0.15 *mm***

AASHTO Classification System:-

Unified Classification System:- **Poorly Graded Sand [*SP*]**

Table 27: Product S downstream sieve analysis

Sieve Analysis

Description of soil A-3 Fine Sand Sample No. 1
Mass of oven dry sample, W 184.5 g

Location UCF Stormwater Lab - Curb Inlet

Tested by Matthew Goolsby Date December 15, 2009

Sieve No.	Sieve opening (mm)	Mass of soil retained on each sieve, W_n (g)	Percent of mass retained on each sieve, R_n	Cumulative percent retained, $\sum R_n$	Percent finer, 100 - $\sum R_n$
4	4.750	0.0	0.0	0.0	100.0
10	2.000	0.2	0.1	0.1	99.9
20	0.850	2.0	1.1	1.2	98.8
40	0.425	3.6	2.0	3.1	96.9
60	0.250	28.9	15.7	18.8	81.8
140	0.106	122.7	66.6	85.4	14.6
200	0.075	9.2	5.0	90.4	9.6
Pan	0.005	17.5	9.5	99.8	0.2

$W_1 = \sum$ 184.2 G

Mass loss during sieve analysis = [(W - W_1) ÷ W] × 100 = 0.16 % (OK if less than 2%)

D_{60} = 1.2
D_{30} = 0.39
D_{10} = 0.16
(Determined from graph, corresponding to percents finer of 60%, 30%, and 10%)

Uniformity coefficient, $C_u = (D_{60} / D_{10})$ = 7.50

Coefficient of gradation, $C_c = [D^2_{30} \div (D_{60} \times D_{10})]$ = 0.79

Effective size of soil sample, D_{10} = **0.15 *mm***

AASHTO Classification System:-

Unified Classification System:- **Well Graded Sand [SW]**

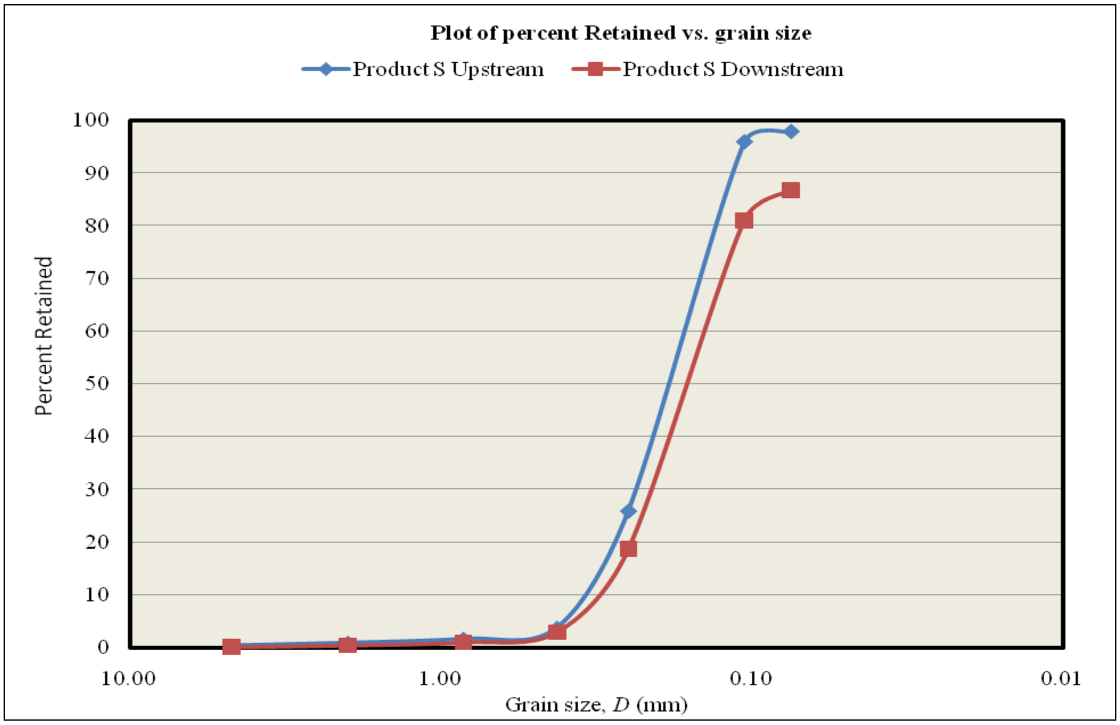

Figure 83: Product S sieve analysis retained plot

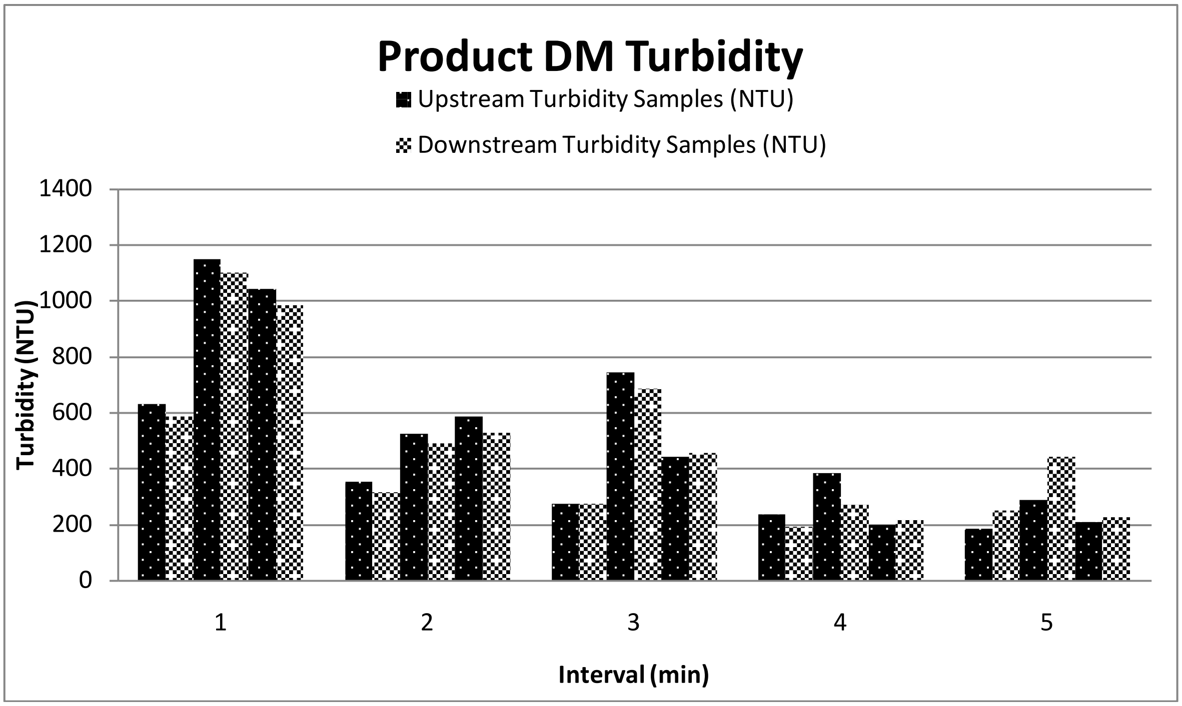

Figure 84: Sample water turbidity for 3 rainfall events on Product DM over time

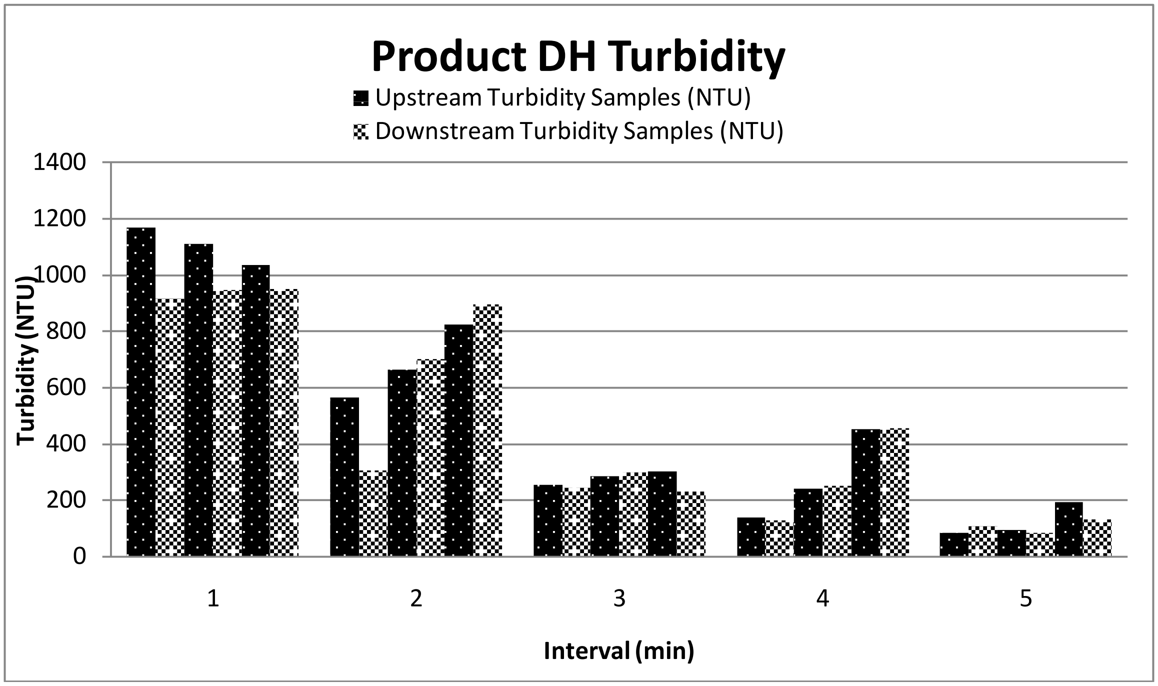

Figure 85: Sample water turbidity for 3 rainfall events on Product DH over time

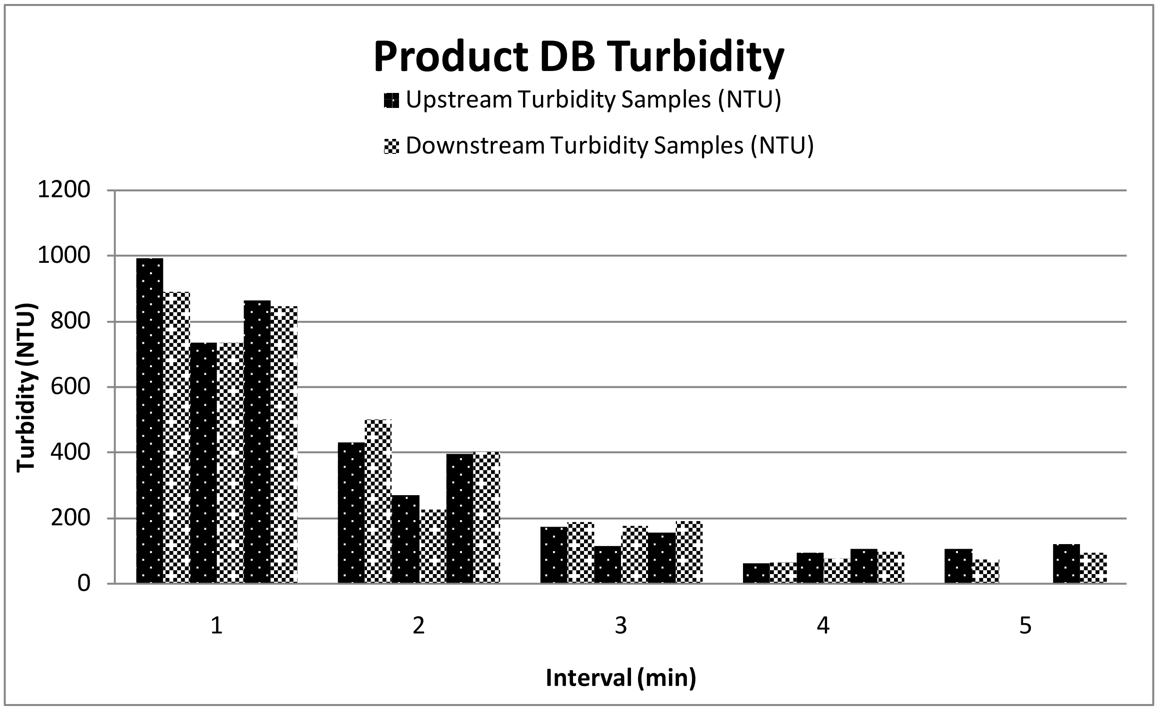

Figure 86: Sample water turbidity for 3 rainfall events on Product DB over time

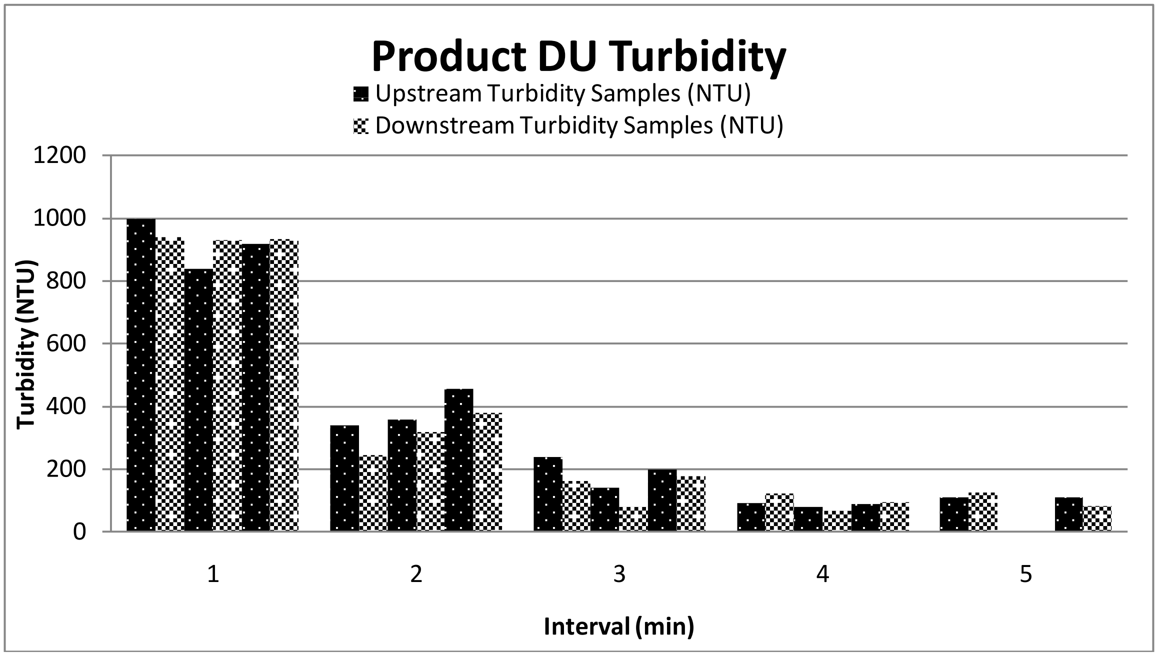

Figure 87: Sample water turbidity for 3 rainfall events on Product DU over time

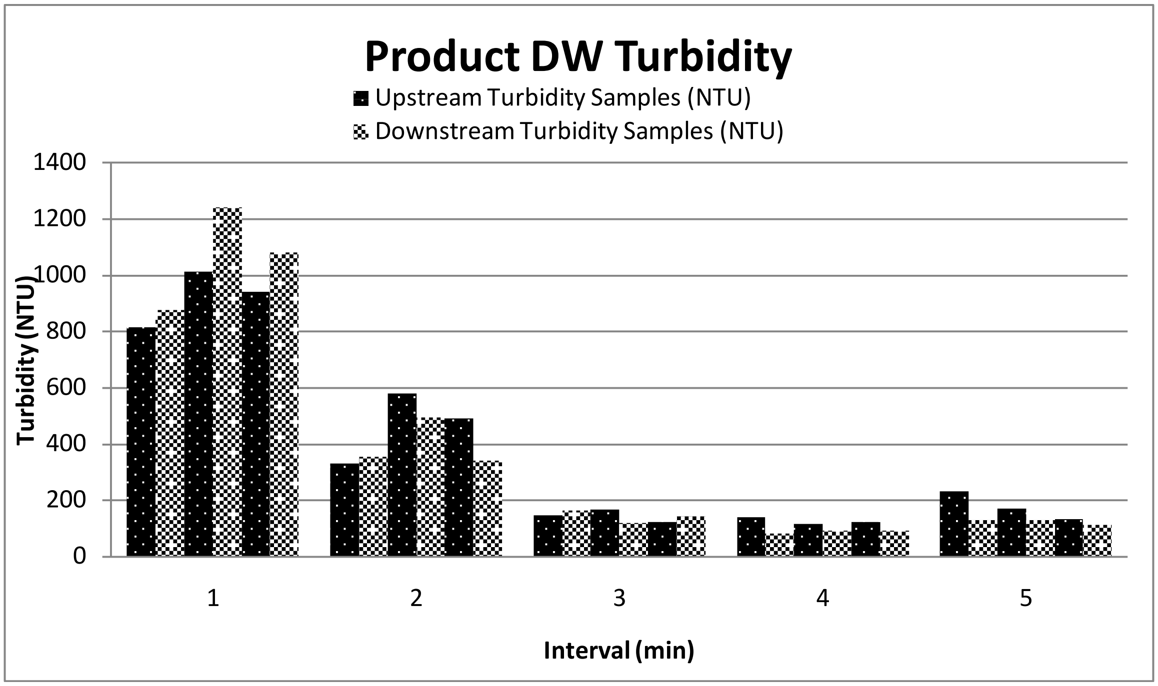

Figure 88: Sample water turbidity for 3 rainfall events on Product DW over time

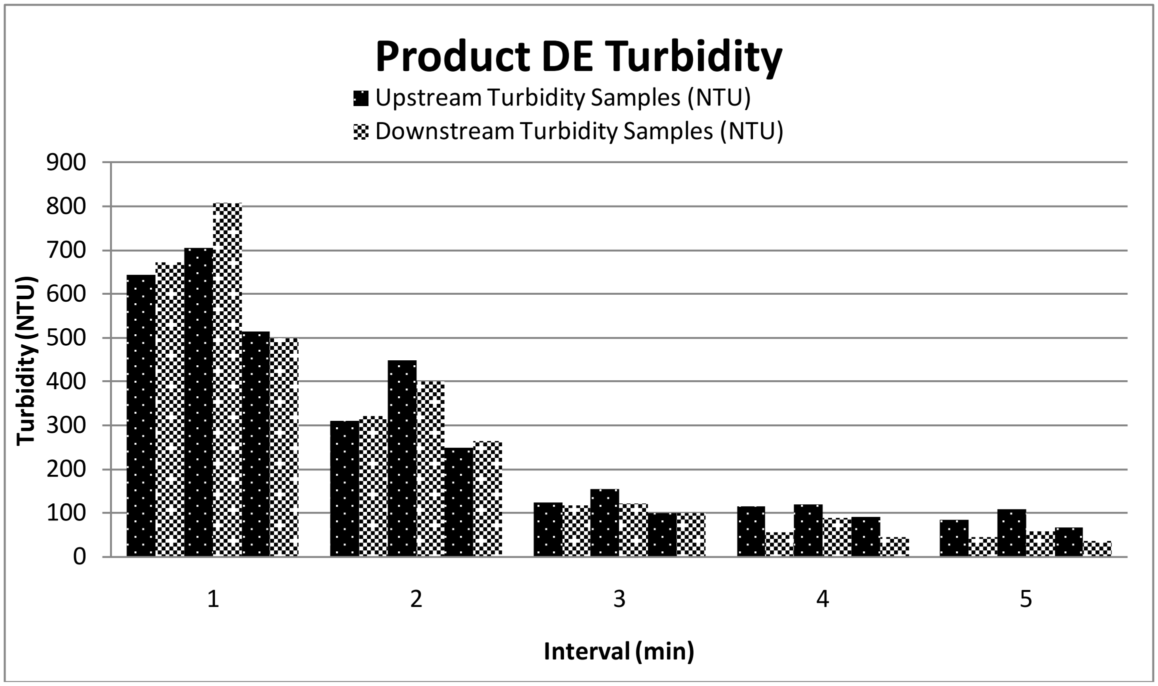

Figure 89: Sample water turbidity for 3 rainfall events on Product DE over time

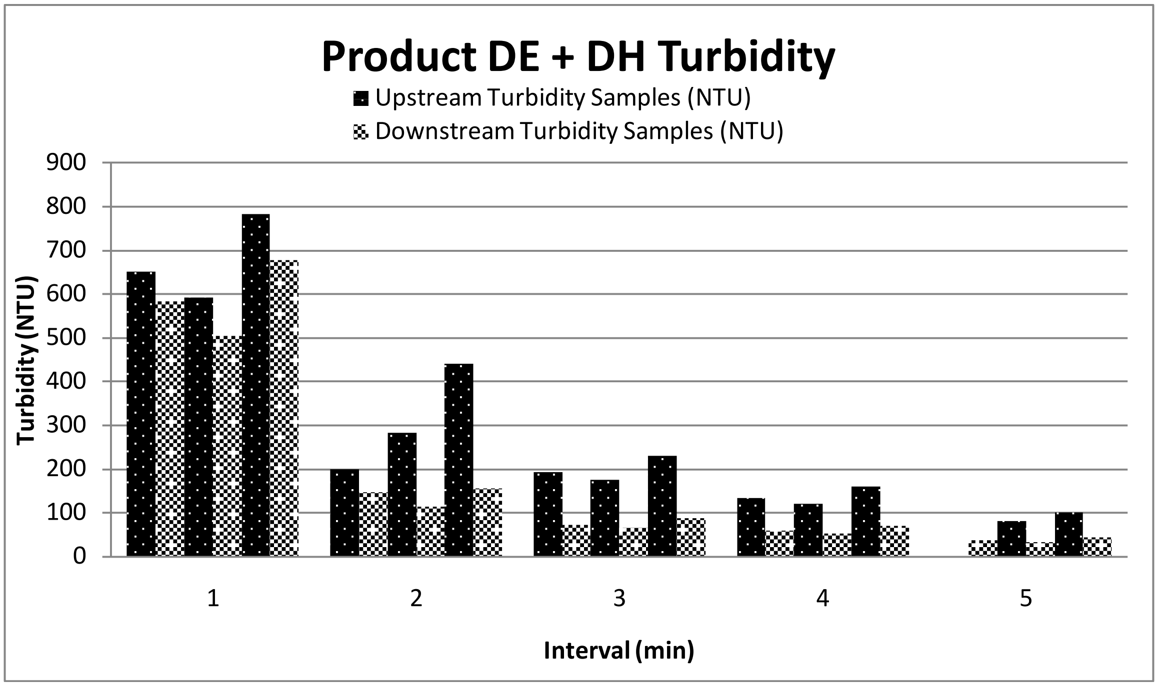

Figure 90: Sample water turbidity for 3 rainfall events on Product DE + DH over time

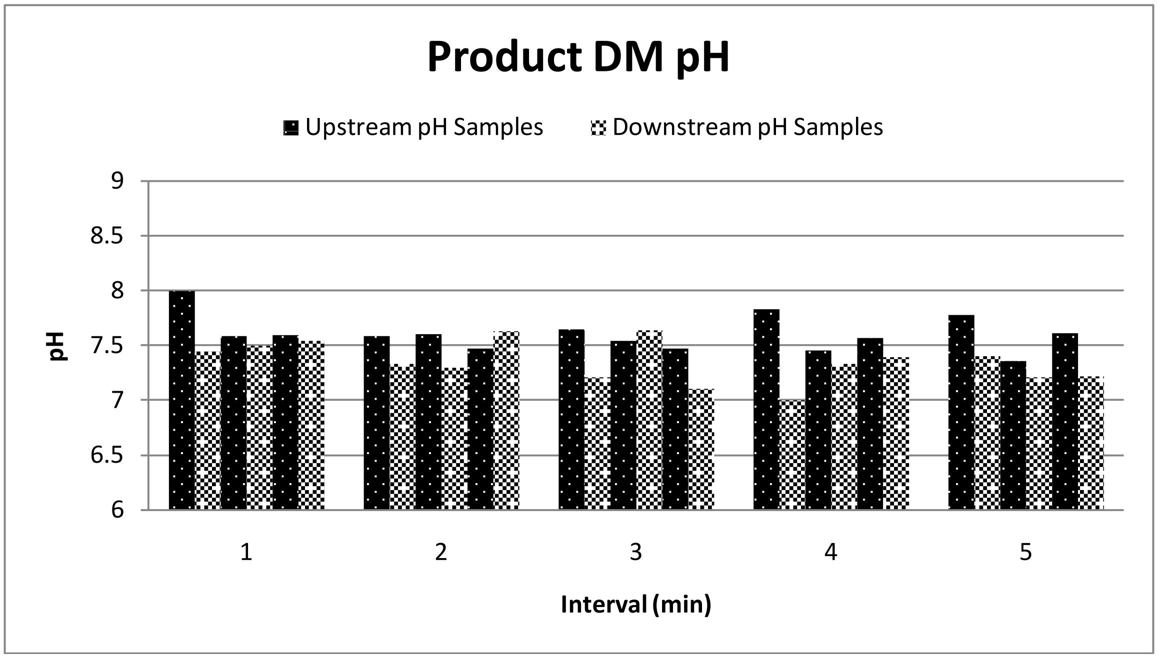

Figure 91: Sample water pH for 3 rainfall events on Product DM over time

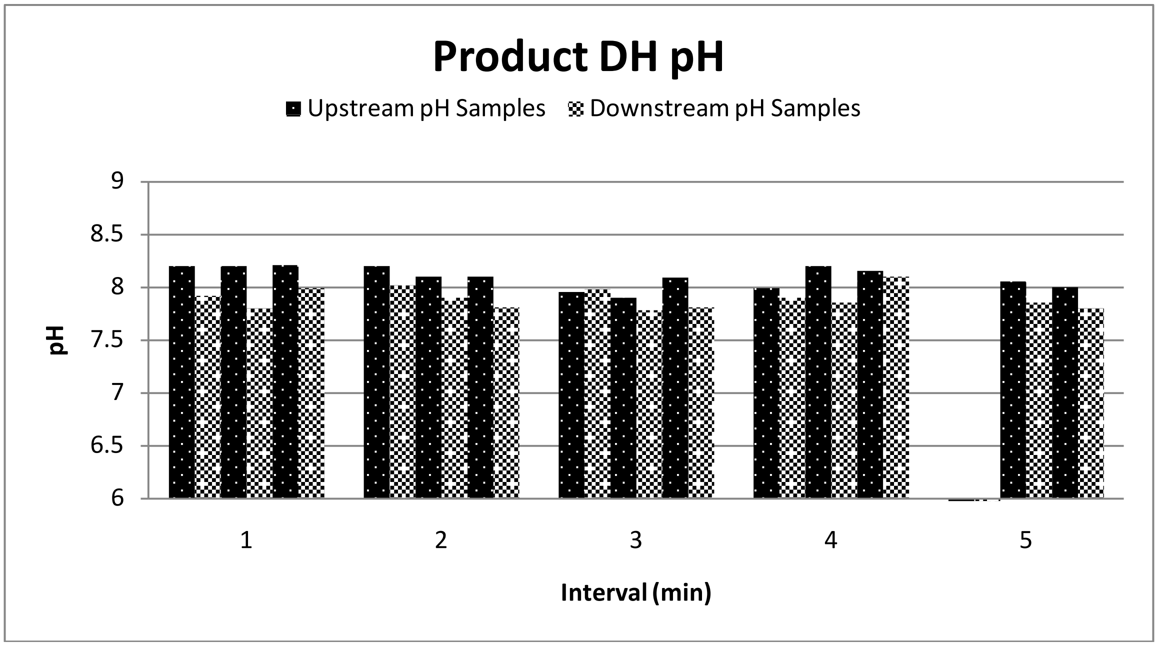

Figure 92: Sample water pH for 3 rainfall events on Product DH over time

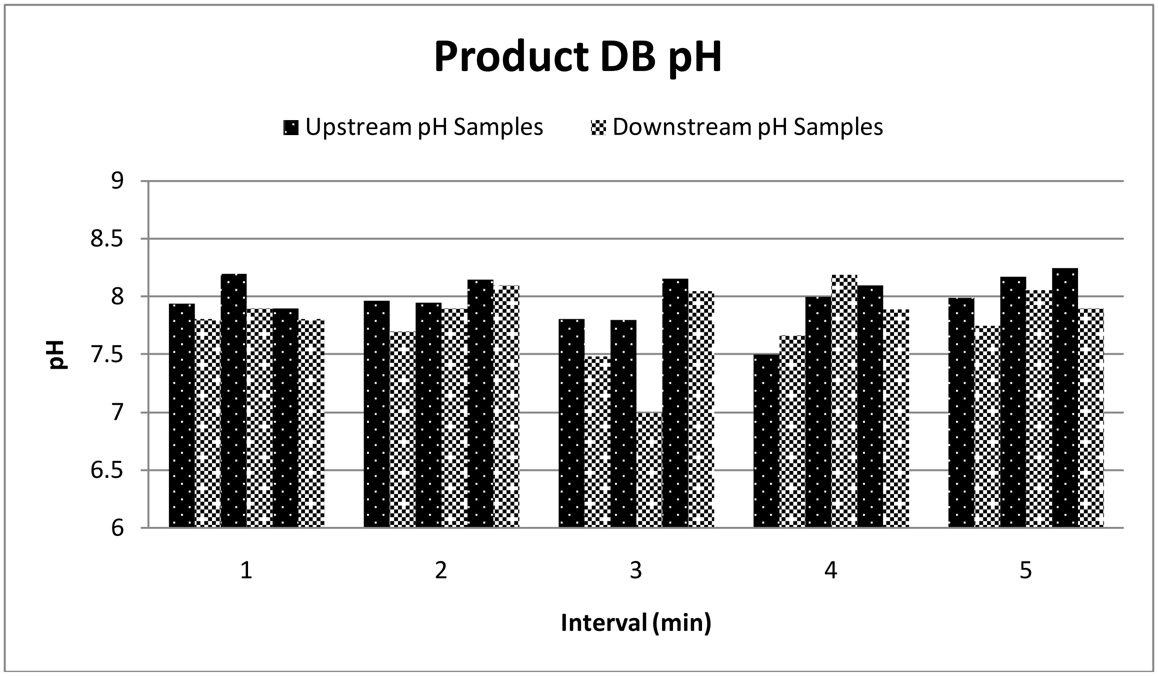

Figure 93: Sample water pH for 3 rainfall events on Product DB over time

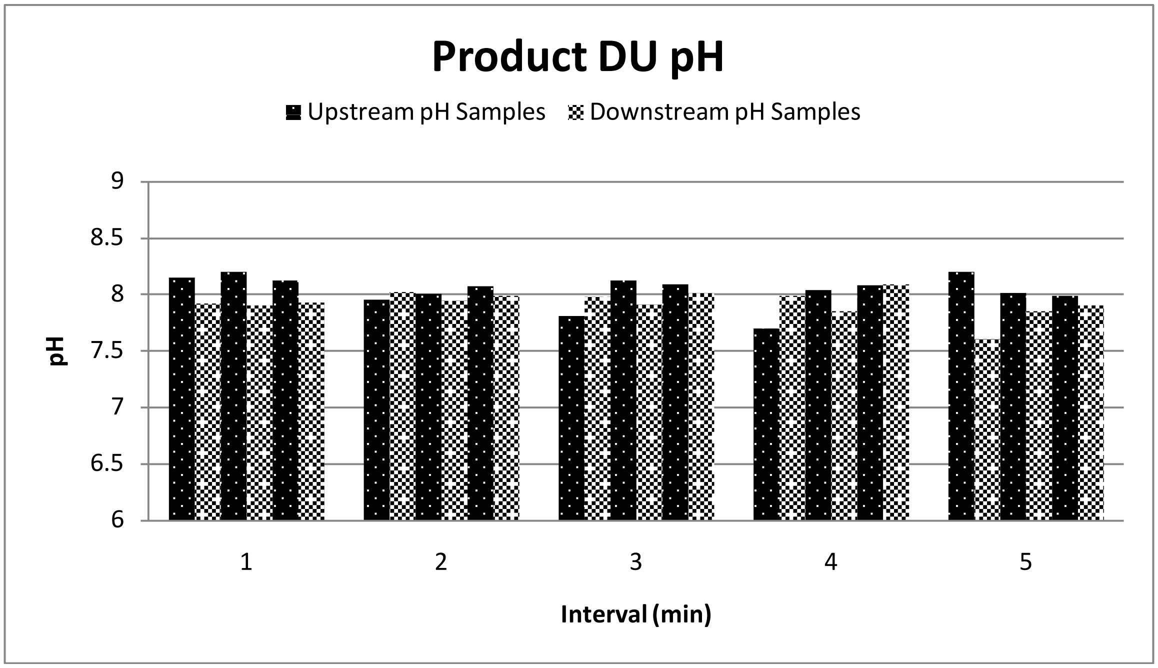

Figure 94: Sample water pH for 3 rainfall events on Product DU over time

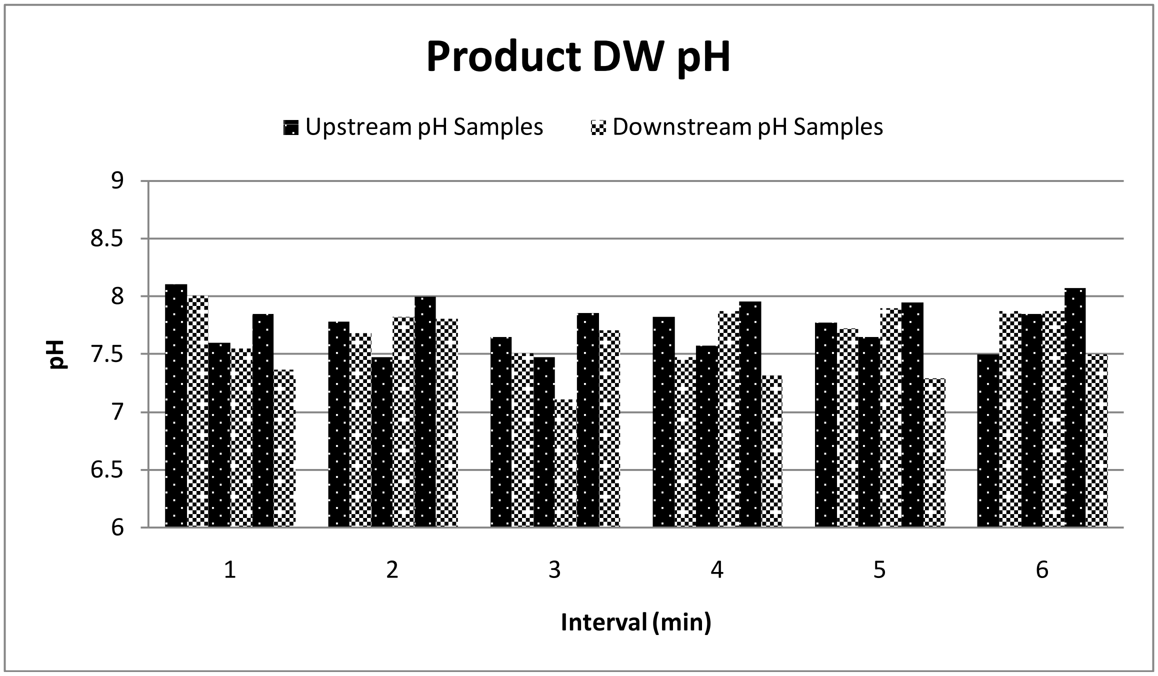

Figure 95: Sample water pH for 3 rainfall events on Product DW over time

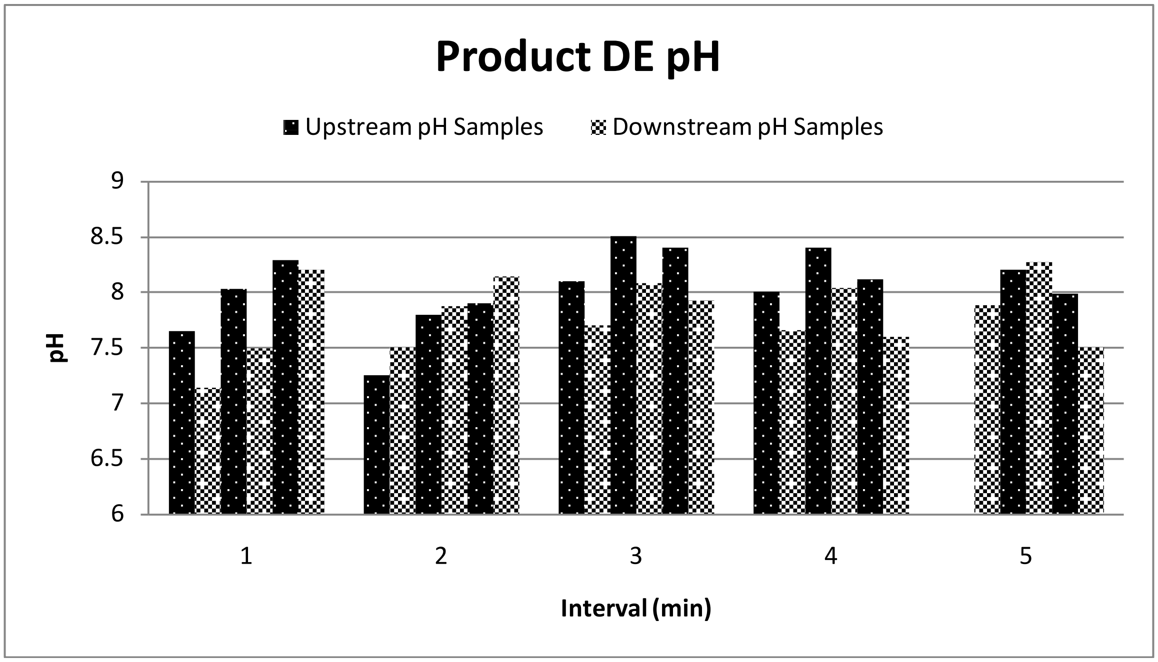

Figure 96: Sample water pH for 3 rainfall events on Product DE over time

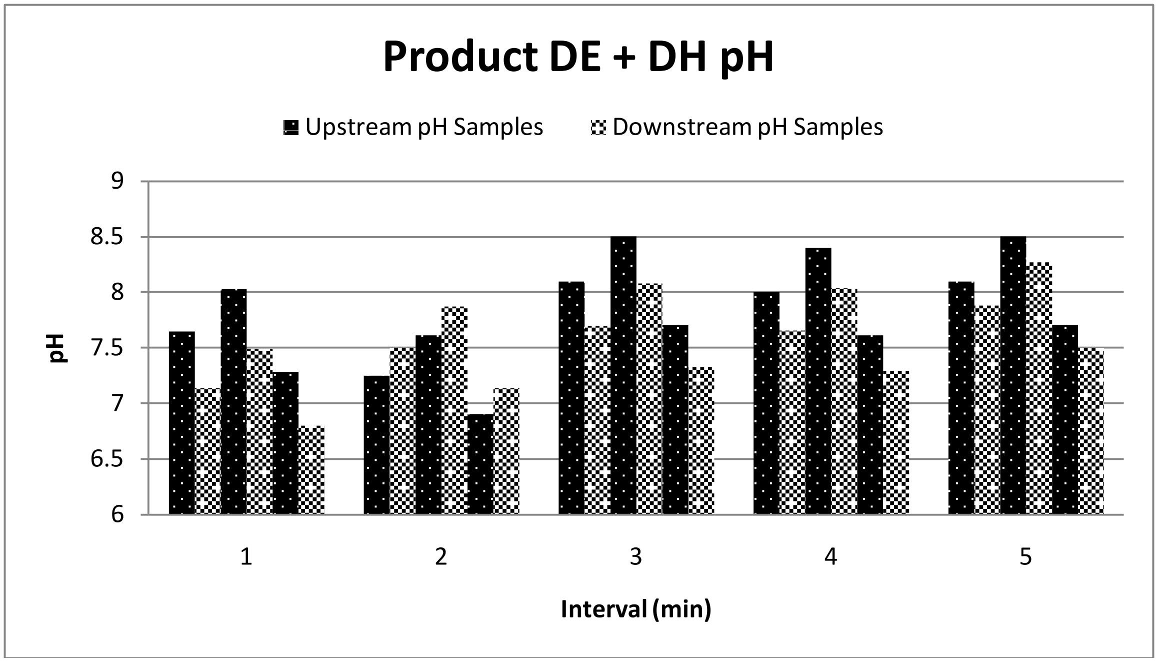

Figure 97: Sample water pH for 3 rainfall events on Product DE + DH over time

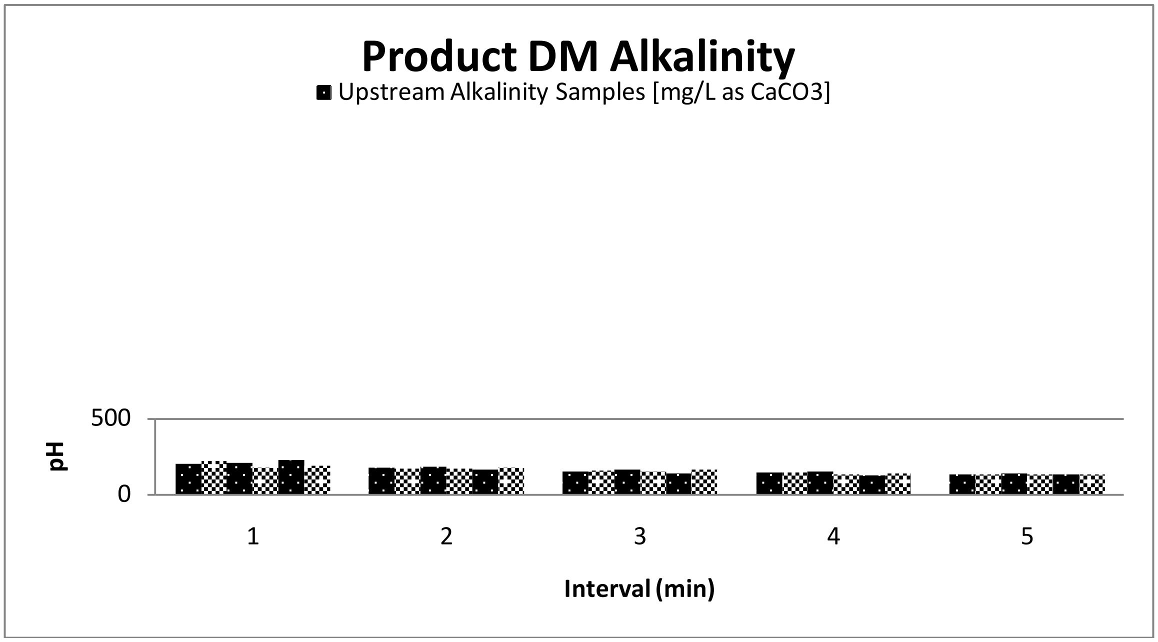

Figure 98: Sample water alkalinity for 3 rainfall events on Product DM over time

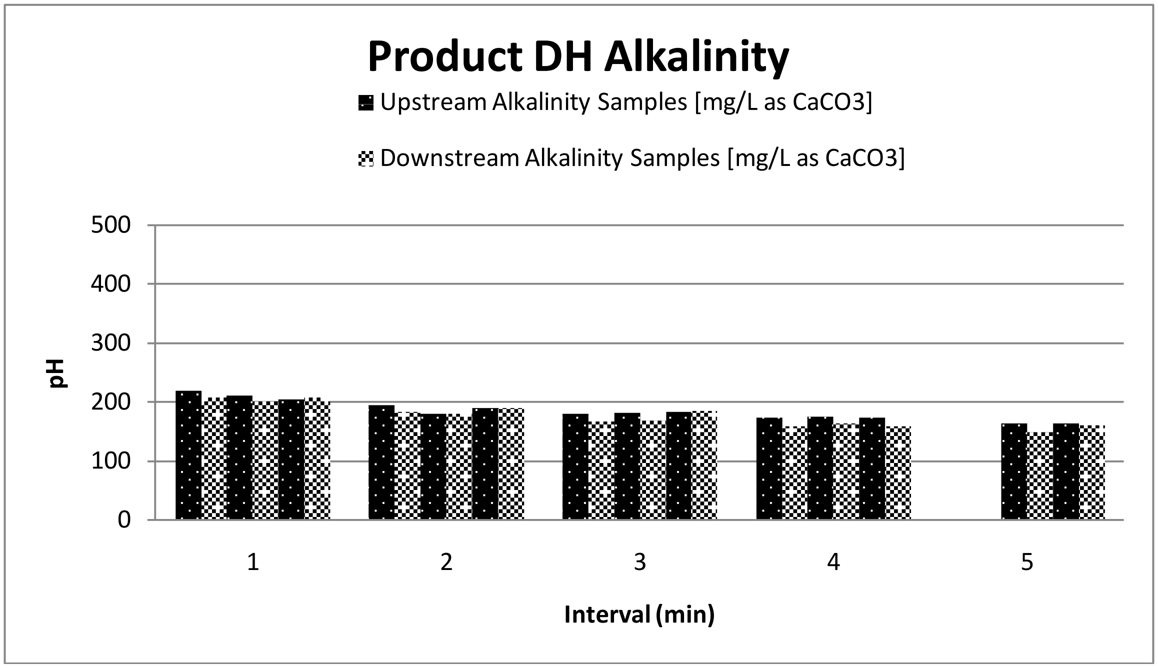

Figure 99: Sample water alkalinity for 3 rainfall events on Product DH over time

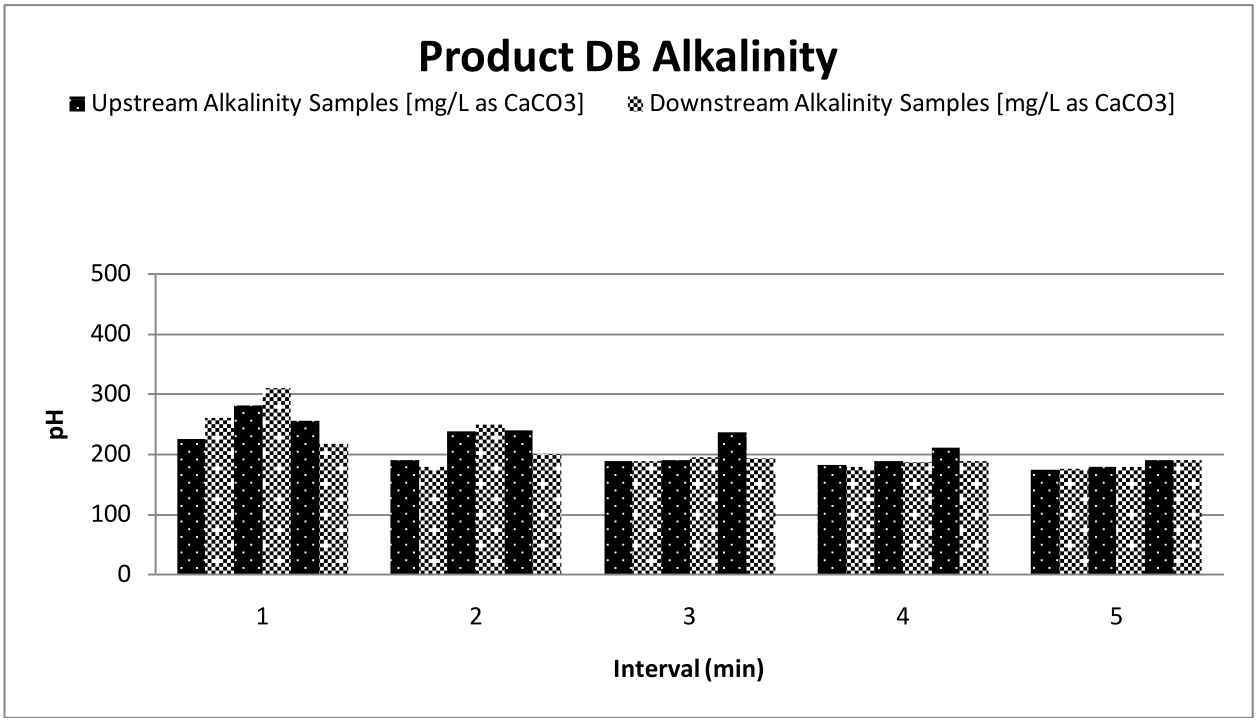

Figure 100: Sample water alkalinity for 3 rainfall events on Product DB over time

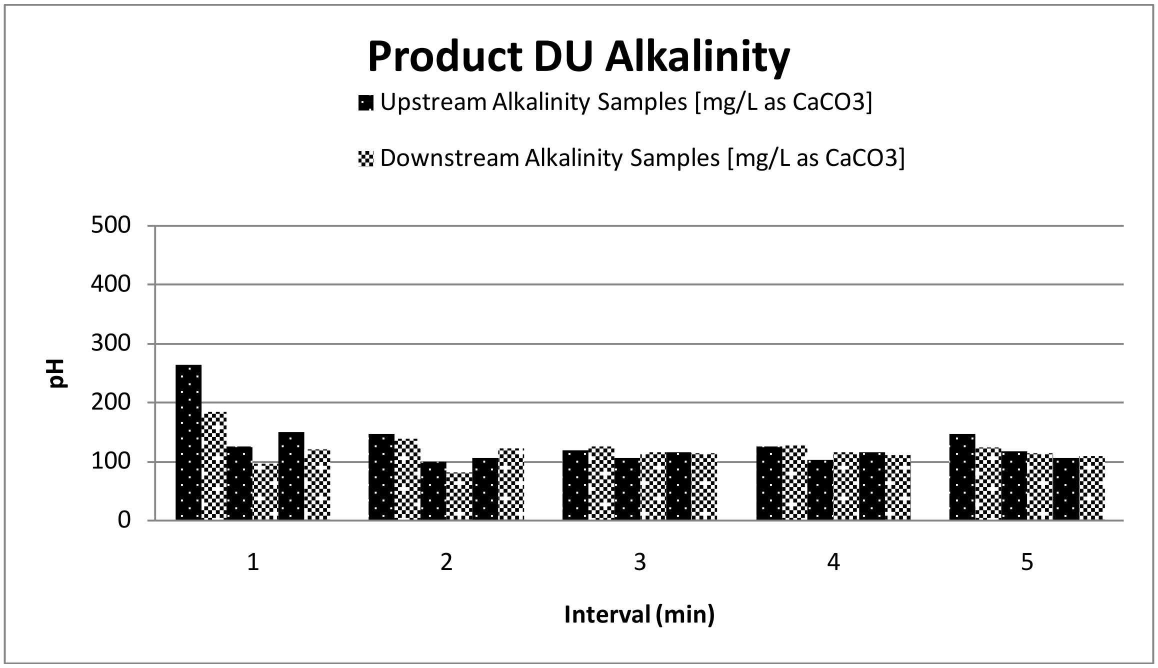

Figure 101: Sample water alkalinity for 3 rainfall events on Product DU over time

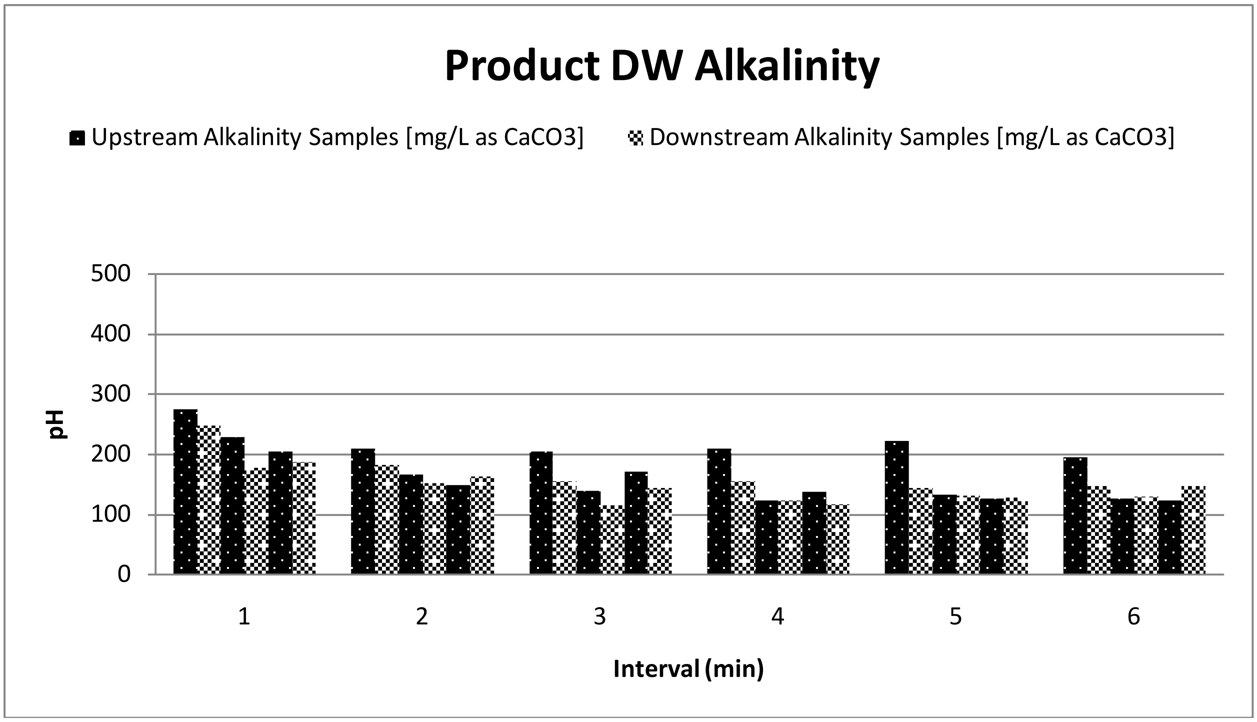

Figure 102: Sample water alkalinity for 3 rainfall events on Product DW over time

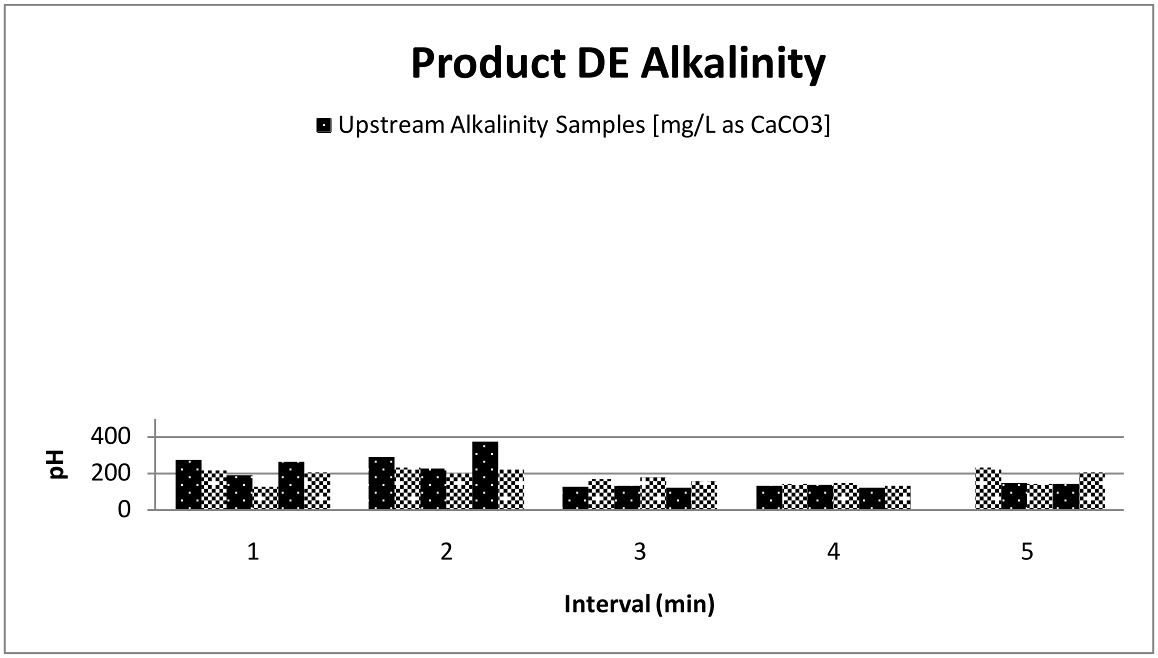

Figure 103: Sample water alkalinity for 3 rainfall events on Product DE over time

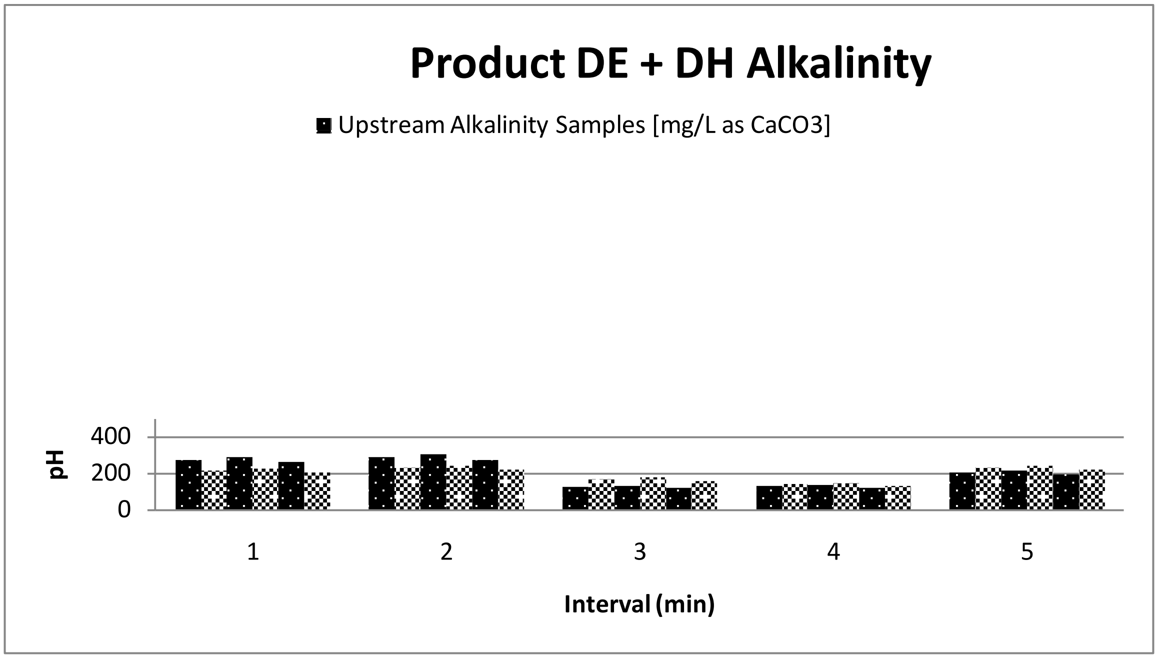

Figure 104: Sample water alkalinity for 3 rainfall events on Product DE + DH over time

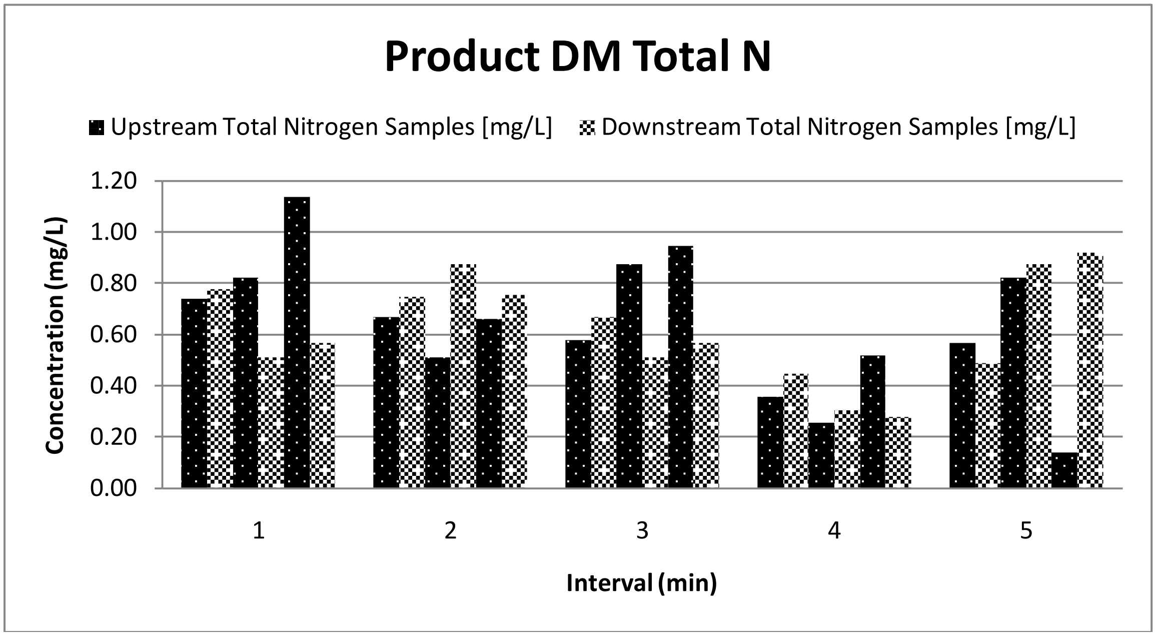

Figure 105: Sample water TN for 3 rainfall events on Product DM over time

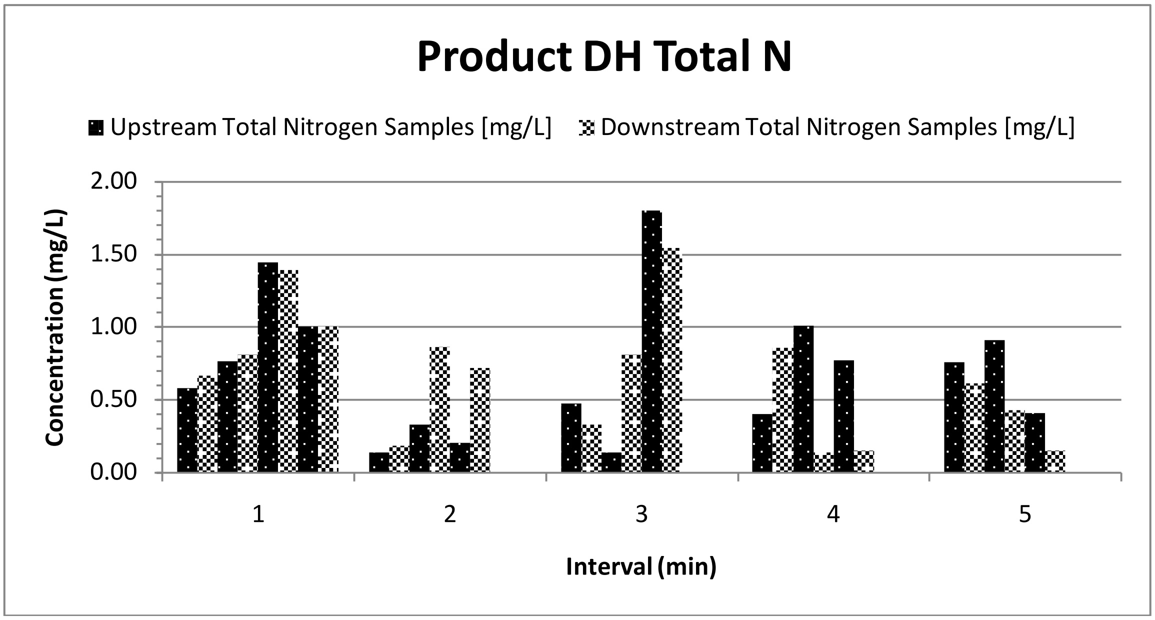

Figure 106: Sample water TN for 3 rainfall events on Product DH over time

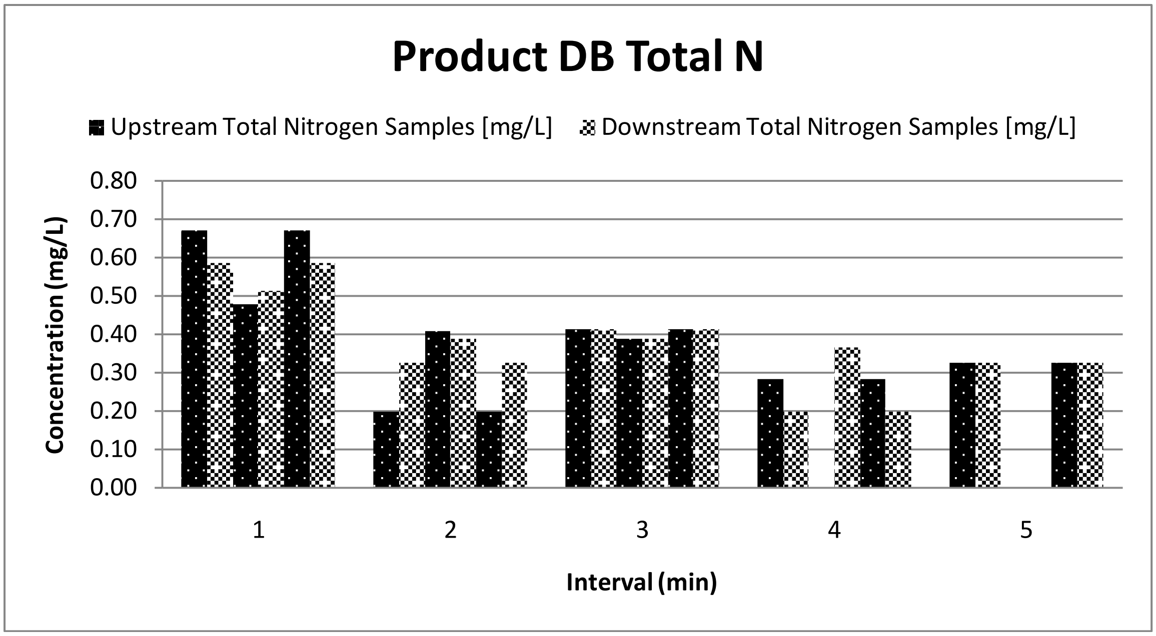

Figure 107: Sample water TN for 3 rainfall events on Product DB over Time

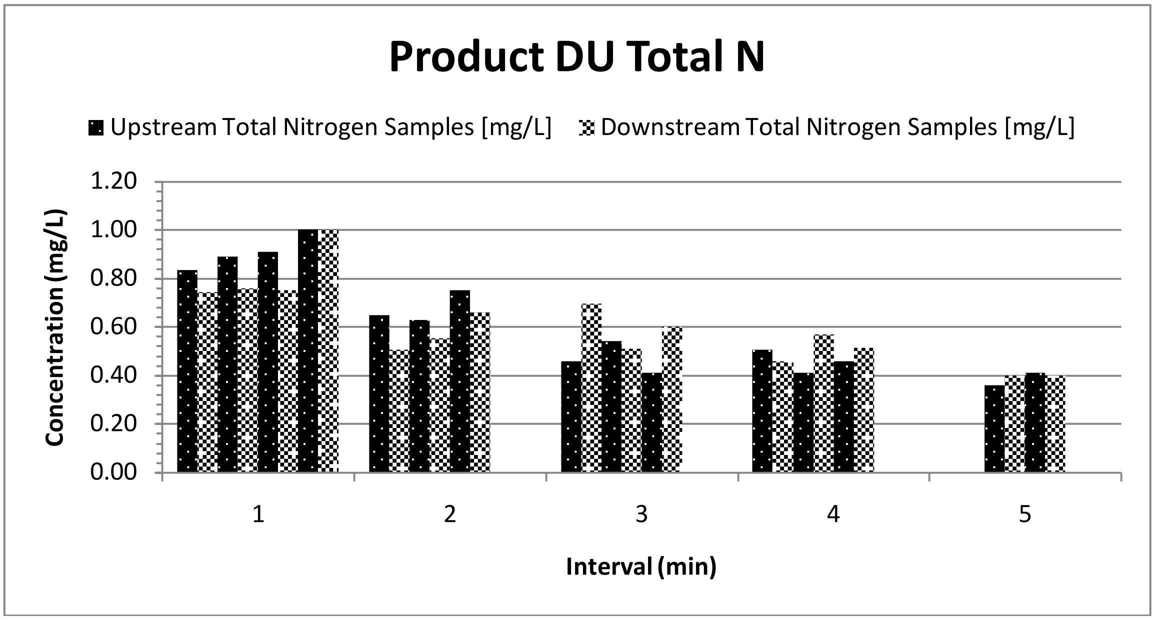

Figure 108: Sample water TN for 3 rainfall events on Product DU over time

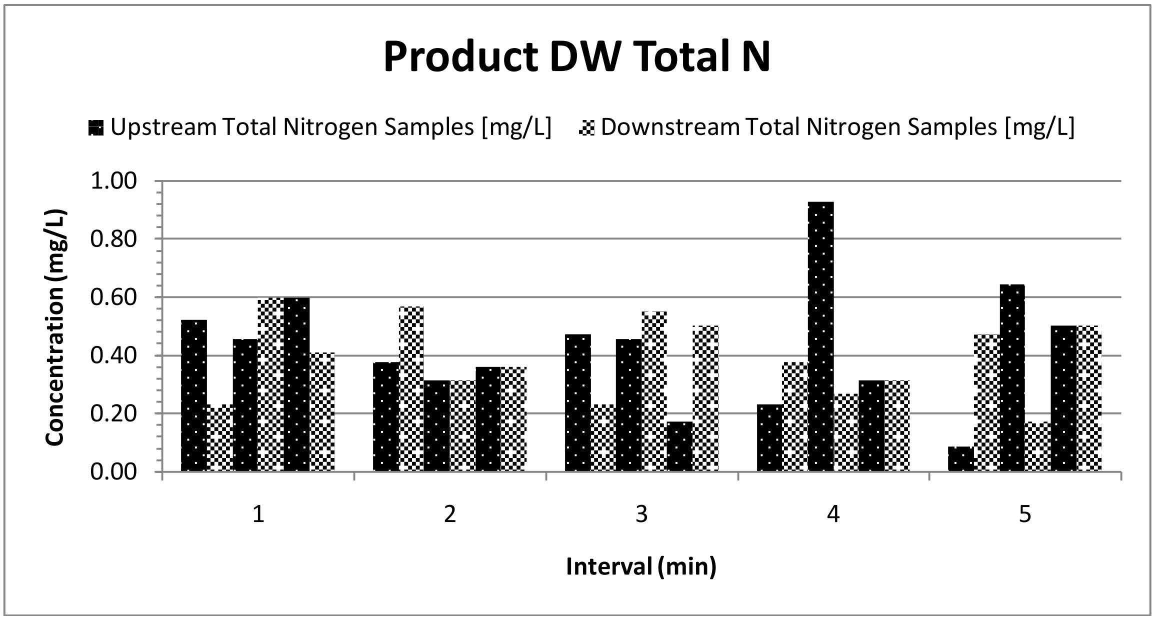

Figure 109: Sample water TN for 3 rainfall events on Product DW over time

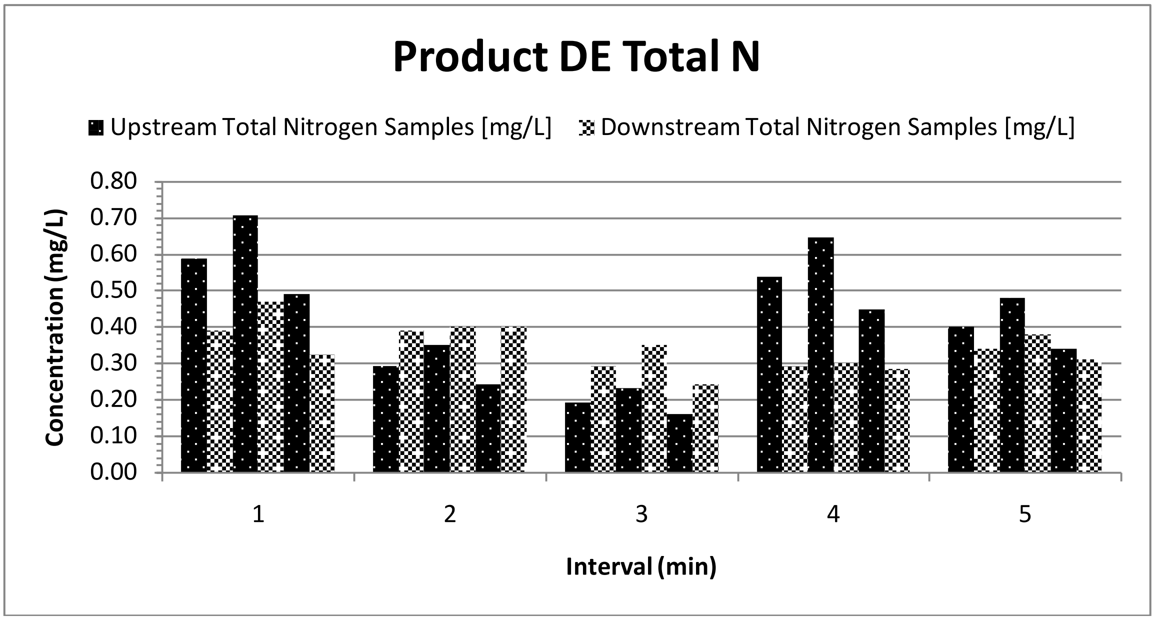

Figure 110: Sample water TN for 3 rainfall events on Product DE over time

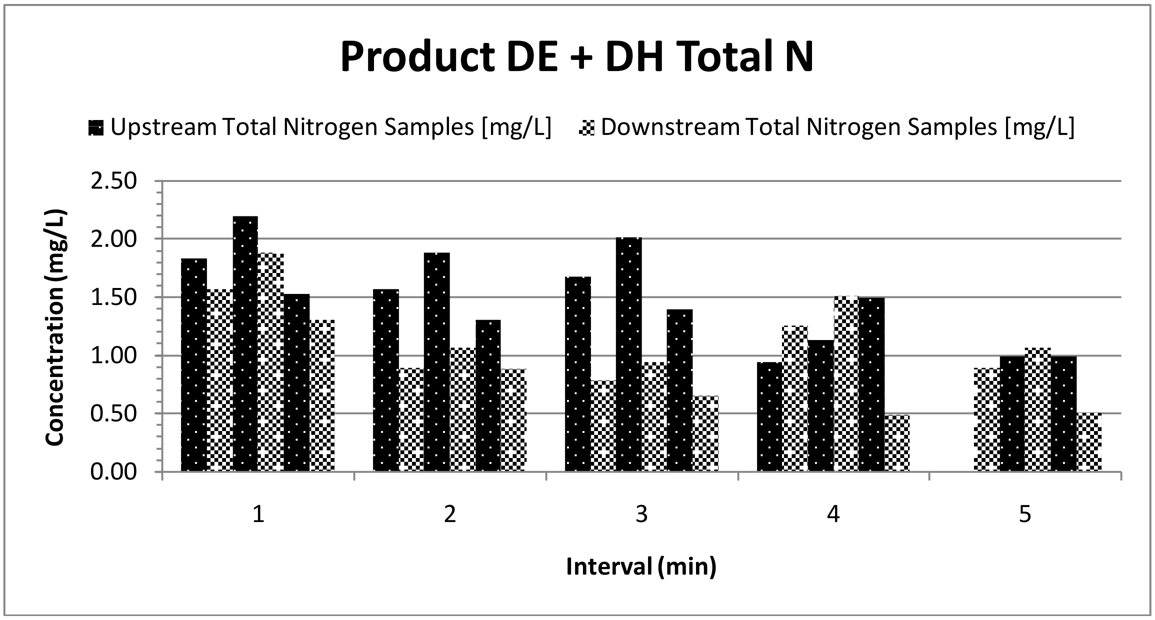

Figure 111: Sample water TN for 3 rainfall events on Product DE + DH over time

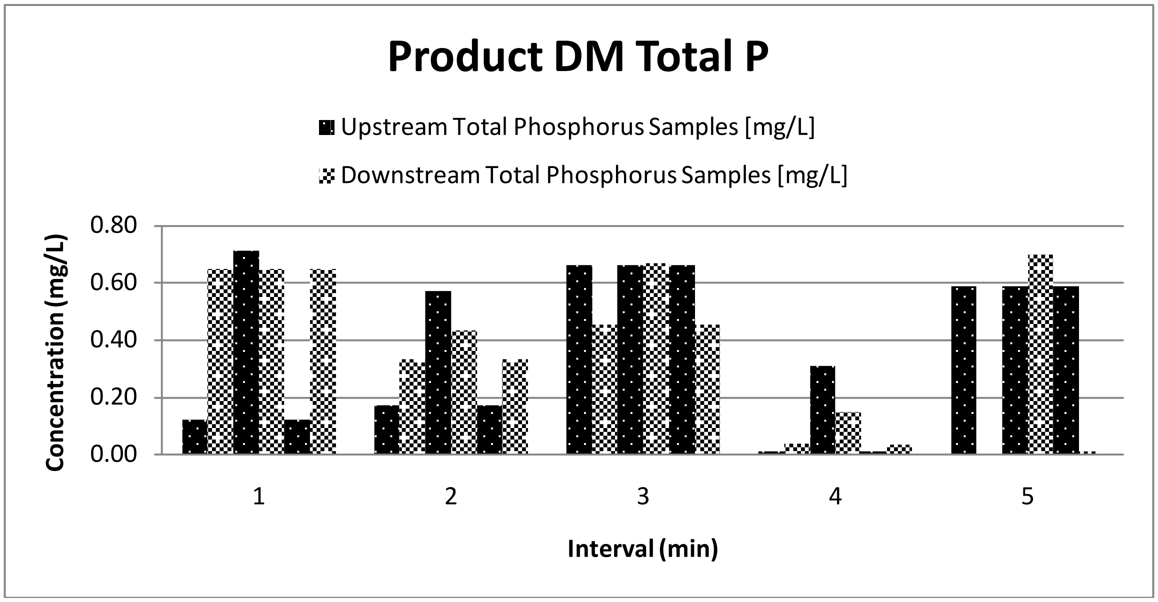

Figure 112: Sample water TP for 3 rainfall events on Product DM over time

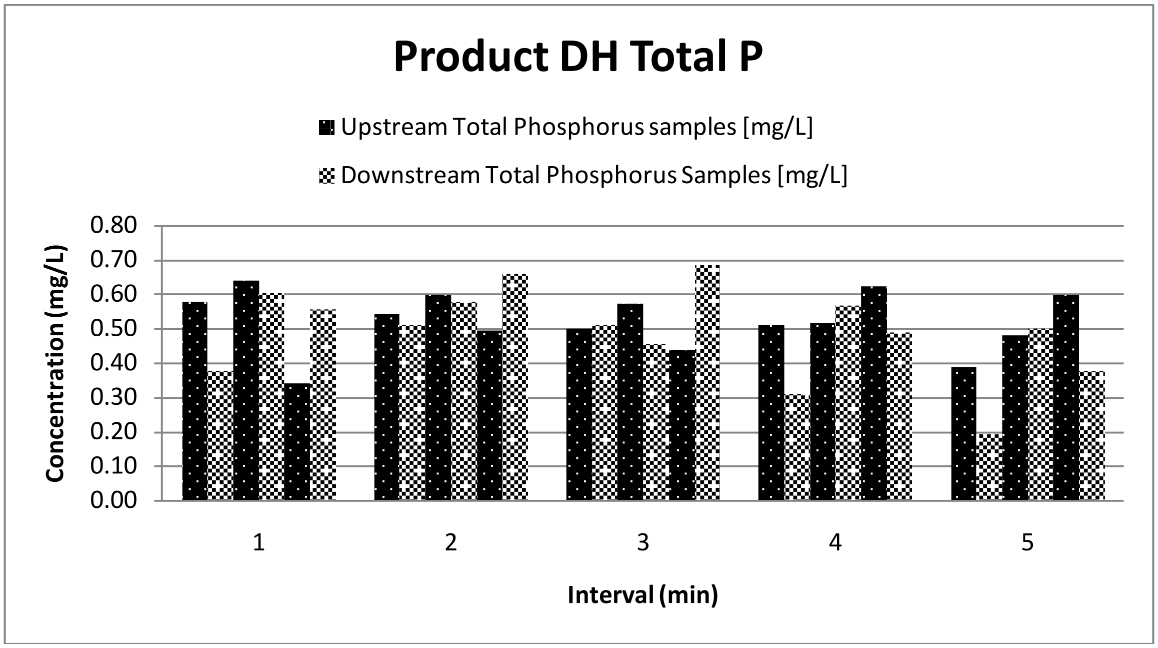

Figure 113: Sample water TP for 3 rainfall events on Product DH over time

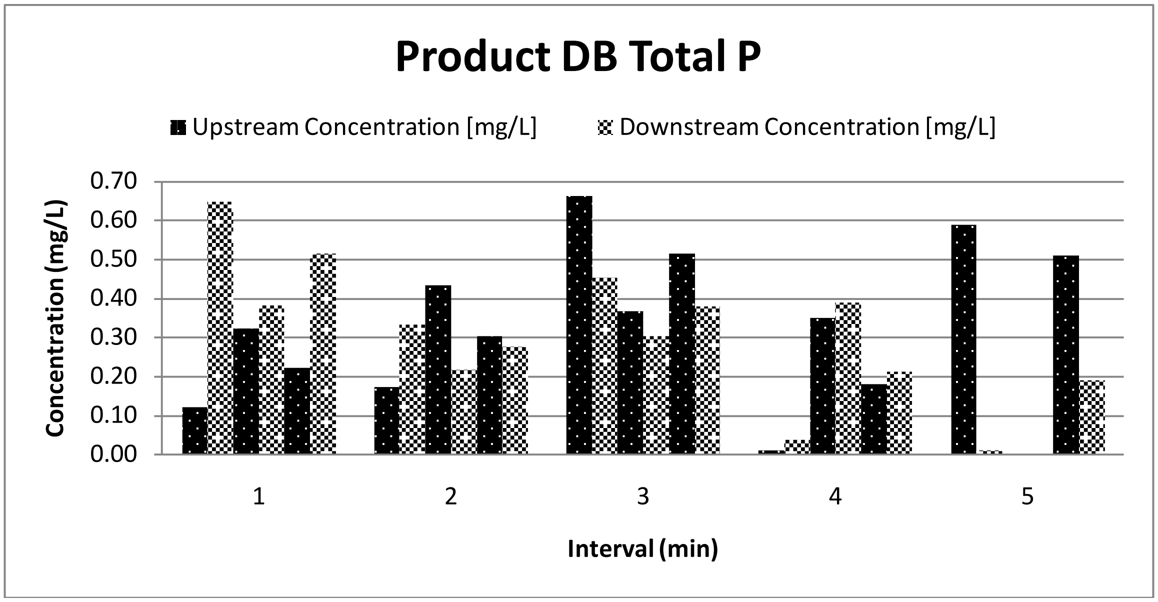

Figure 114: Sample water TP for 3 rainfall events on Product DB over time

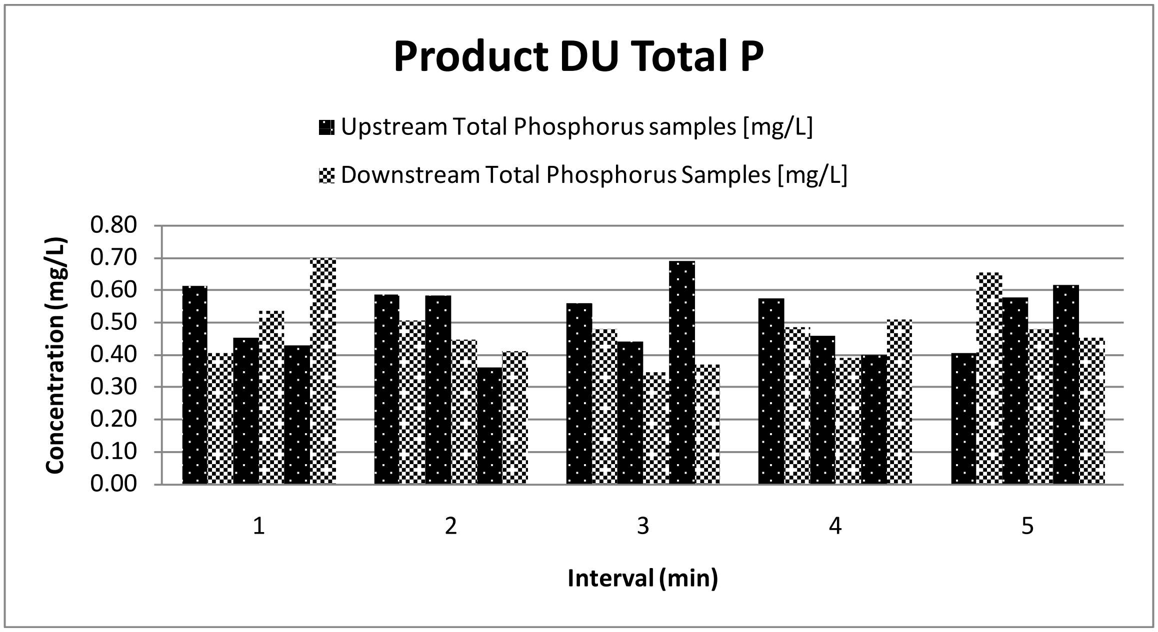

Figure 115: Sample water TP for 3 rainfall events on Product DU over time

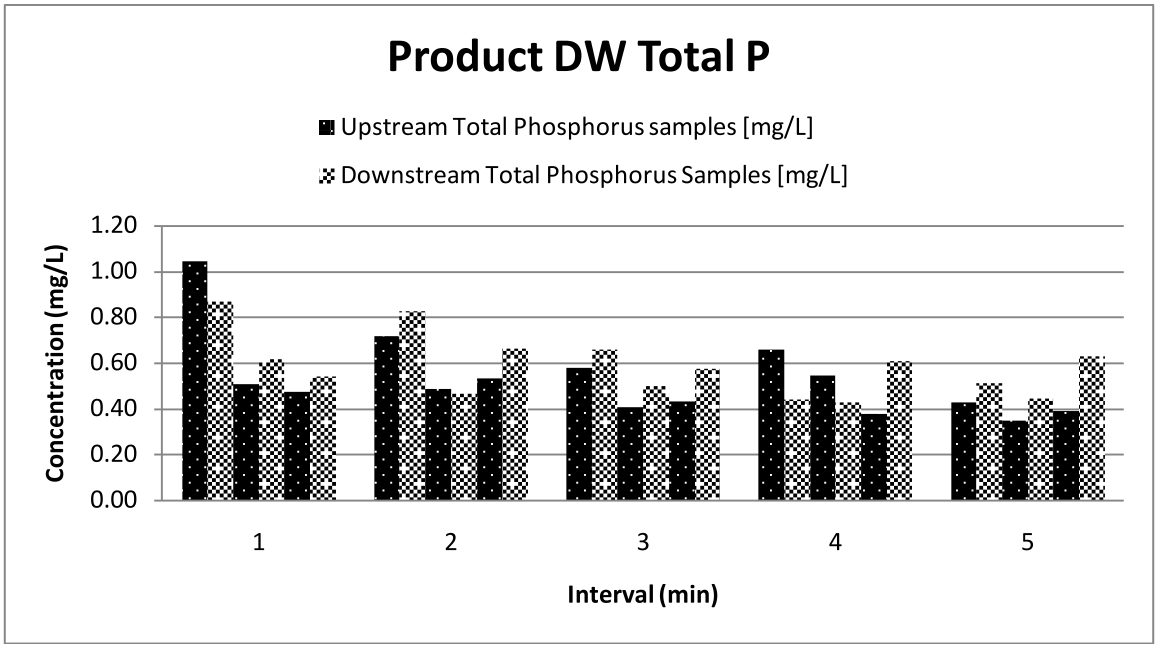

Figure 116: Sample water TP for 3 rainfall events on Product DW over time

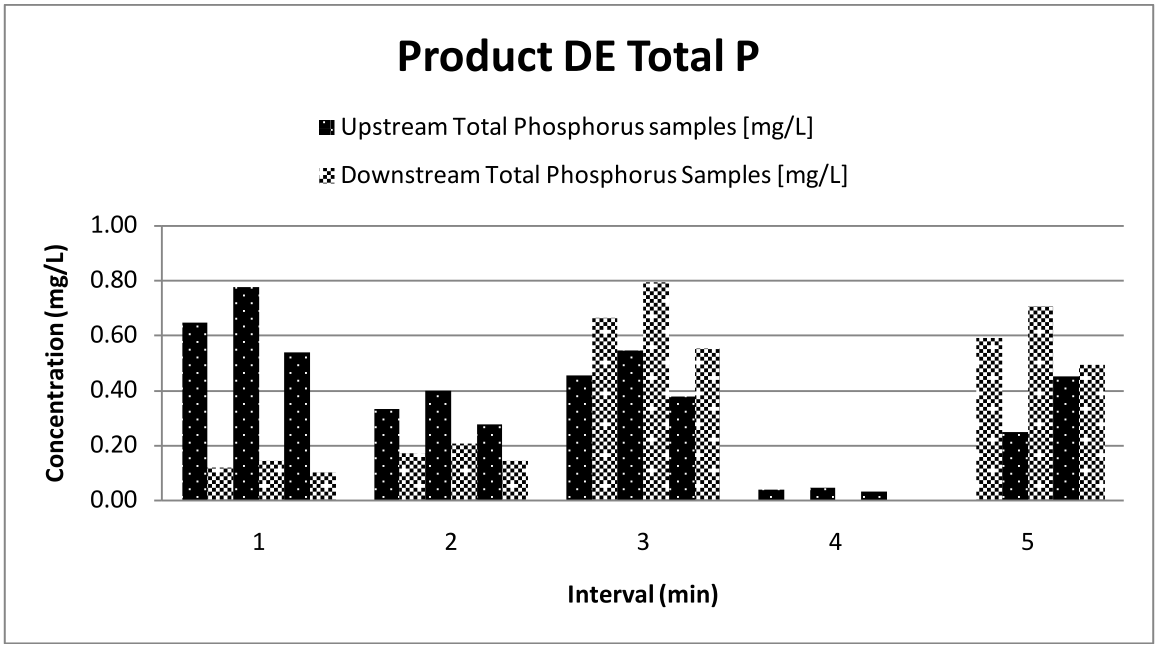

Figure 117: Sample water TP for 3 rainfall events on Product DE over time

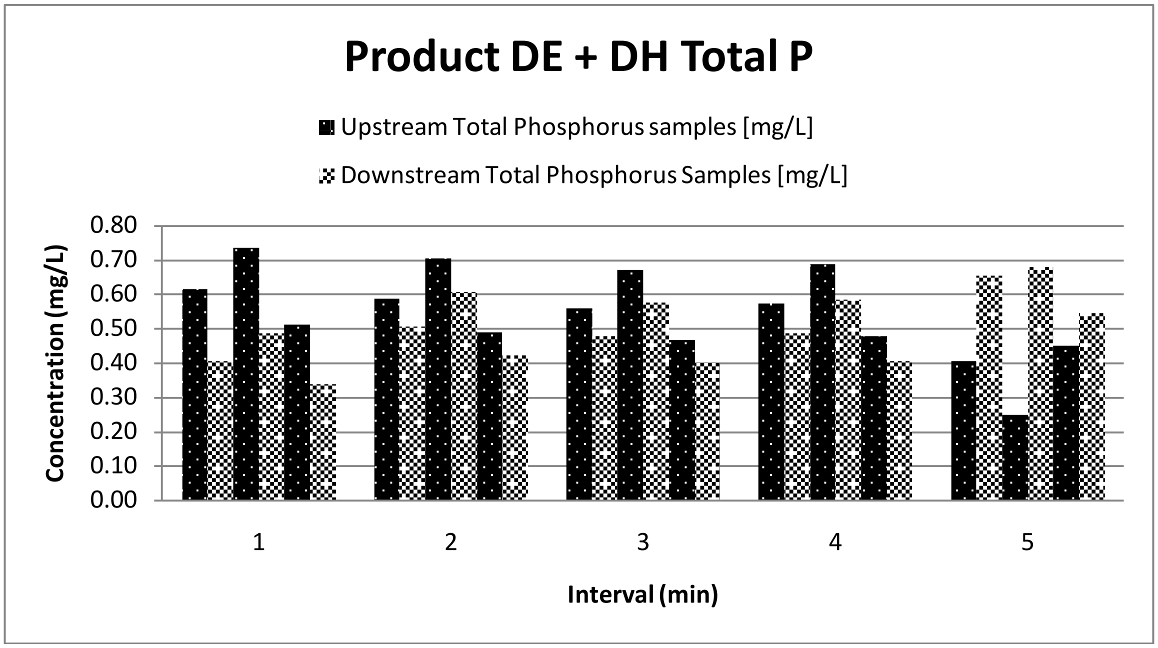

Figure 118: Sample water TP for 3 rainfall events on Product DE + DH over time

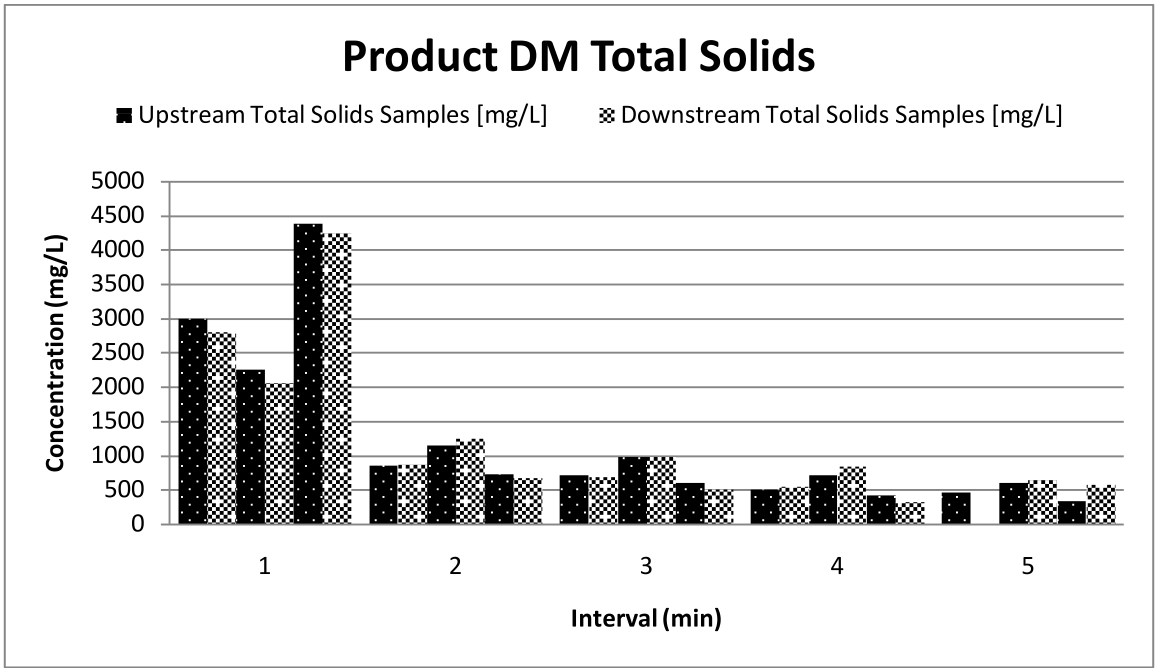

Figure 119: Sample water TS for 3 rainfall events on Product DM over time

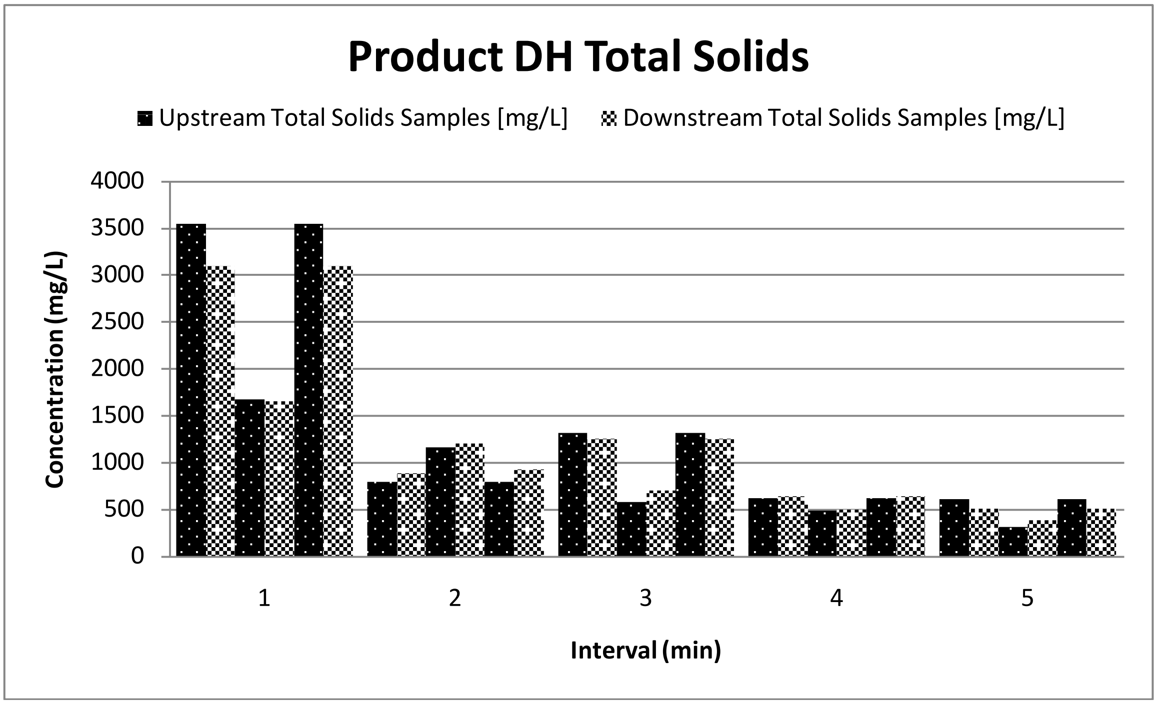

Figure 120: Sample water TS for 3 rainfall events on Product DH over time

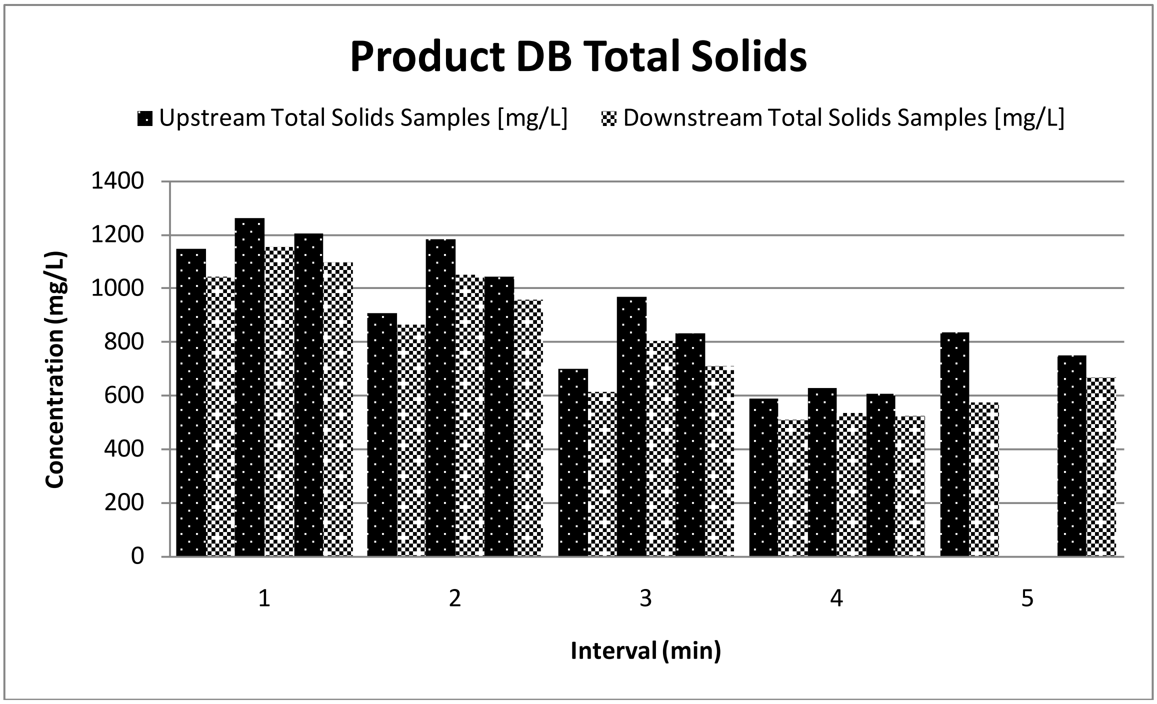

Figure 121: Sample water TS for 3 rainfall events on Product DB over time

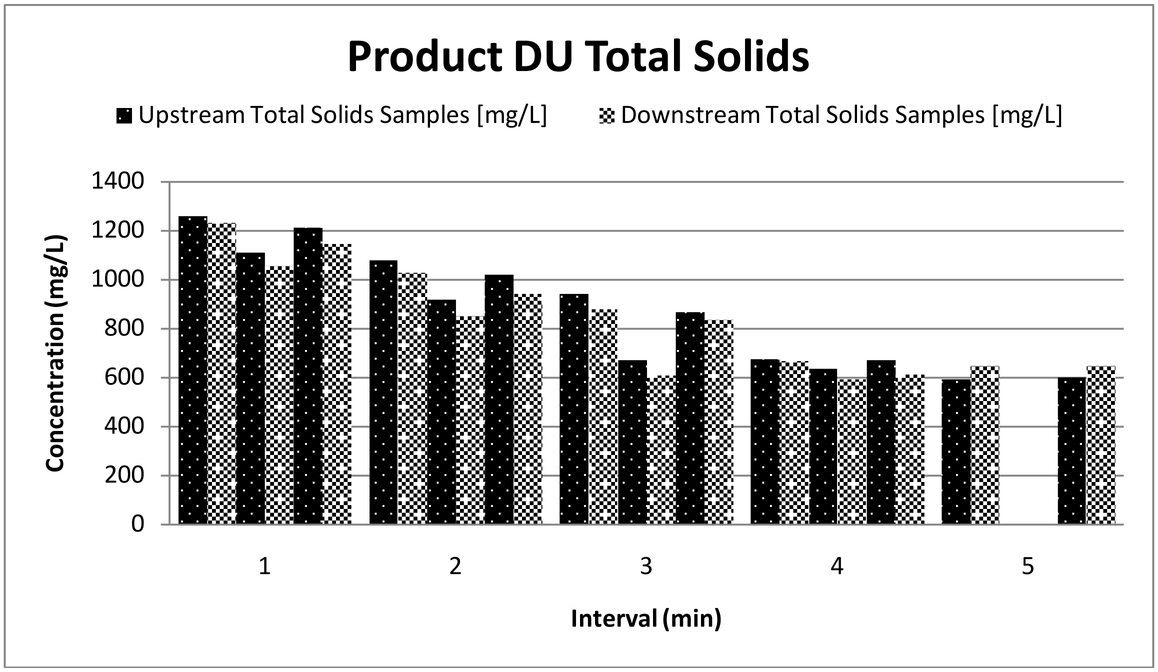

Figure 122: Sample water TS for 3 rainfall events on Product DU over time

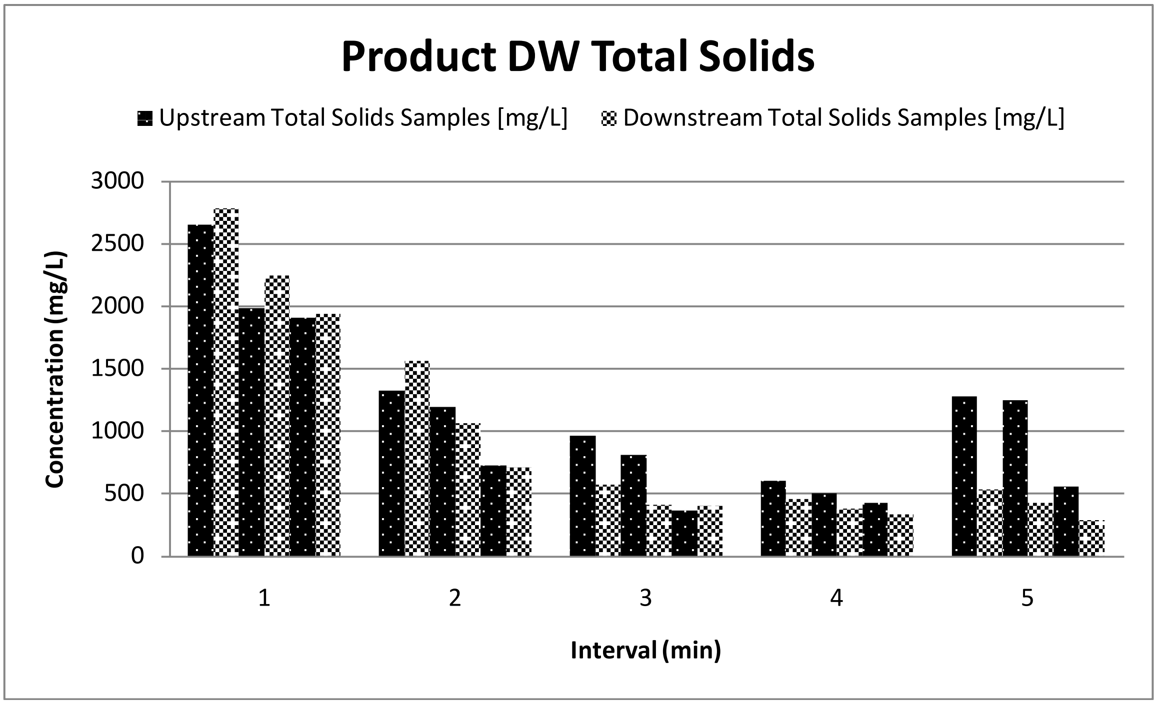

Figure 123: Sample water TS for 3 rainfall events on Product DW over time

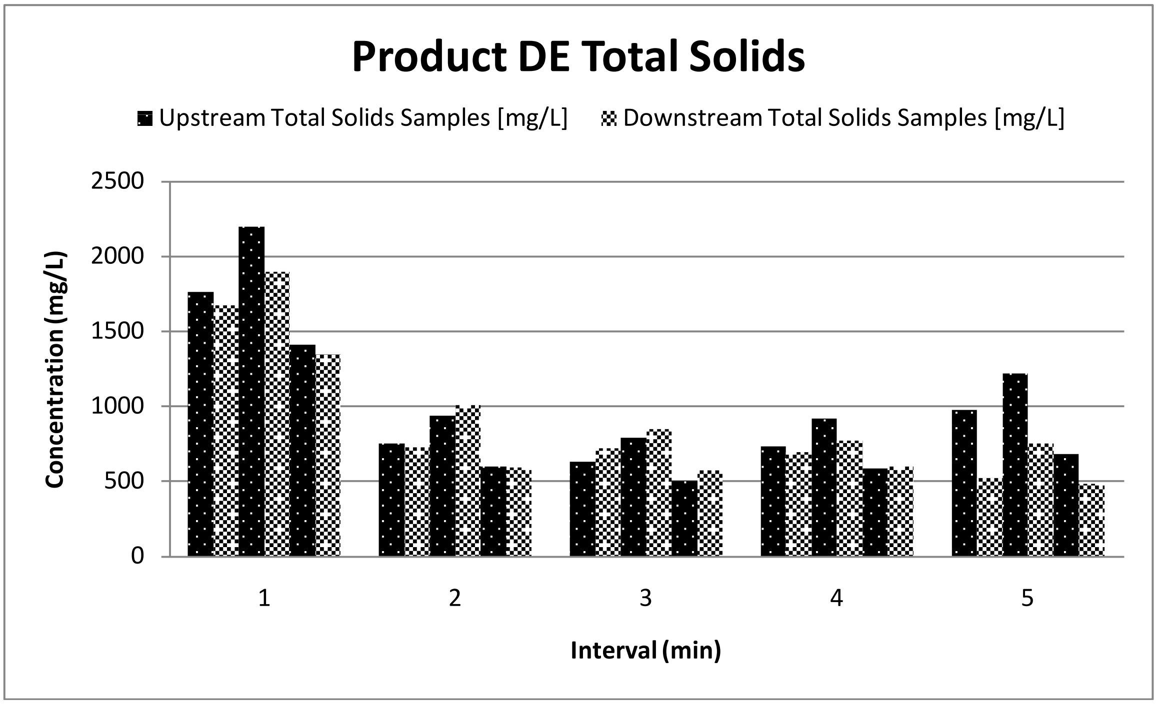

Figure 124: Sample water TS for 3 rainfall events on Product DE over time

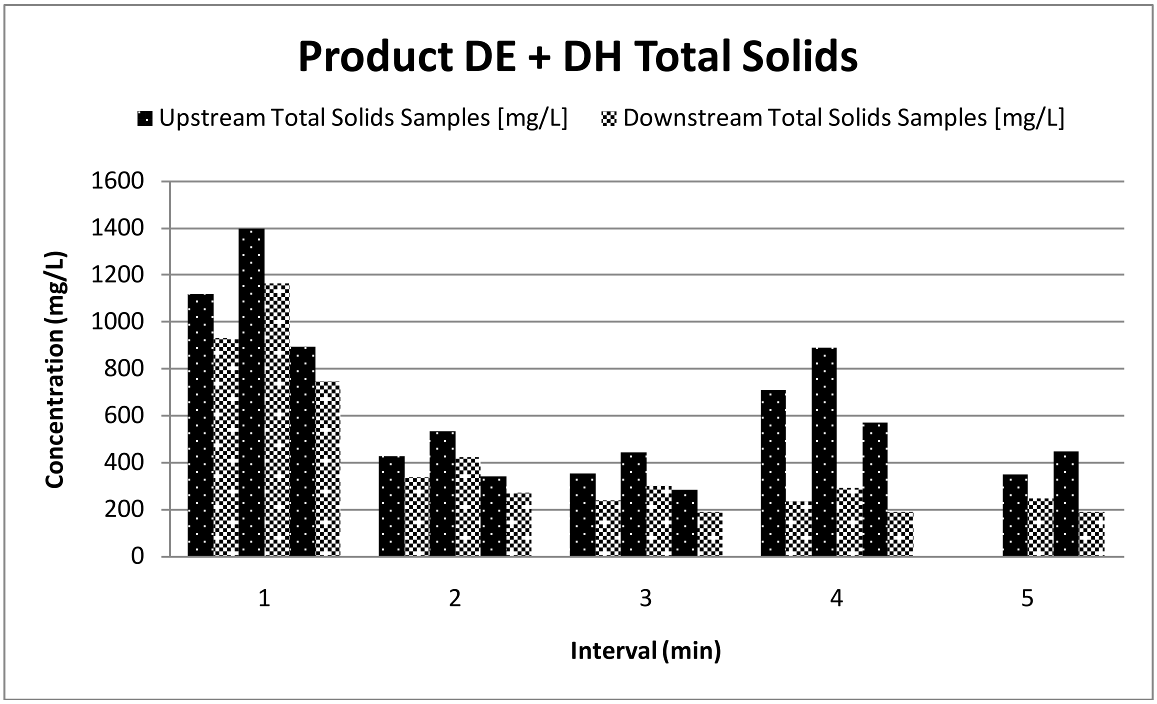

Figure 125: Sample water TS for 3 rainfall events on Product DE + DH over time

Figure 126: Curb inlet test field with sheet flow simulator

Figure 127: Cistern pump

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