IMPLEMENTING A NEIGHBOURHOOD SCALE STORMWATER RETROFIT: EFFECT OF SELF- DRAINING RAIN BARRELS ON AN URBAN STREAM

by

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Abstract

Over the past 50 years, as North America has become more urbanized, extensive research has been done to understand the impact of urbanization on the hydrological cycle. Specifically, land development is known to significantly alter the hydrological cycle and consequently the aquatic habitat by increasing the magnitude and frequency of flooding events, by increasing storm flow flashiness and by altering base flow regimes in streams. The current approach to mitigating the negative impacts of land development on receiving streams involves decentralized treatment of frequently occurring rainfall events at the source in other words on-site stormwater management. Stormwater practitioners and researchers have identified the need for pilot scale research projects to improve the current understanding of on-site stormwater management techniques. The objectives of the current study were to determine the level of effort and methods required to gain volunteer participation for on-site stormwater management retrofit projects as well as to determine if retrofitting single family lots on a neighbourhood scale can have a an effect on the hydrological response of the receiving stream. The objectives were achieved through collaborating with the City of Burnaby, to plan and implement a pilot project in two residential neighbourhoods in the Beecher Creek Watershed. It was hypothesized that with the cooperation of the municipality, sufficient landowner participation (at least 30% of the study area residents) could be gained through door-to-door meetings with residents and through offering incentives for participation in the study. It was also hypothesized that retrofitting the houses in the study area with self-draining rain barrels that detain roof runoff could have a regulating effect on the stream response. Two sub-catchments in the Beecher Creek watershed were chosen as the sites of the study and flow-monitoring stations were set up at sub-catchments' outfalls. A communication strategy was developed and executed over a seven-month period that resulted in participation of 26 (out of 77 possible) residents. Overall, 40 rain barrels were installed to capture the runoff from about 3.5% to 7% of the catchment area. Analysis of the initial collected data indicated that the rain barrels had a regulating effect on the stream response.

Preface

This dissertation is original and unpublished work of author, S. Pour. The City of Burnaby Engineering Department provided feedback for design and assisted with implementation of the communication program reported in Chapter 4. Kerr Wood Leidal Associated Ltd. (KWL) hosts the Kensington rainfall station and the Beecher flow monitoring station (described in Chapter 4) on flowwork.com. The rainfall data and Beecher flow data used in the research were downloaded from flowworks.com.

The statistical analysis presented in Section 5.4 was conducted by a group of fourth year University of British Columbia (UBC) students, Vanessa Goh, Natalie Guo, David Zhao, and Louis Zhen, as part of a fourth year UBC statistics course, STAT 450, which is taught by Dr. John Petkau. I provided the students with data and description of the analysis that I required. The students carried out the analysis and provided a report, which is included in Appendix C with the permission of the authors and the course instructor.

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List of Abbreviations

BC	British Columbia
BMP	Best Management Practices
B-IBI	Benthic Index of Biological Integrity
CBSM	Community-Based Social Marketing
DFO	Department of Fisheries and Oceans Canada
EIA	Effective Impervious Area
EPA	US Environmental Protection Agency
GIS	Geographic Information System
GVRD	Greater Vancouver Regional District
ISMP	Integrated Stormwater Management Plan
KWL	Kerr Wood Leidal Associates Ltd.
LID	Low-Impact Development
LWMP	Liquid Waste Management Plan
MAR	Mean Annual Rainfall Event
MIT	Minimum Inter-Event Time
NPDES	National Pollutant Discharge Elimination System
PSL	Puget Sound Lowlands
SSCDG	Stormwater Source Control Design Guidelines
SWMM	Stormwater Management Model
TIA	Total Impervious Area
UBC	University of British Columbia
WERF	Water Environment Research Foundation

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1 Introduction

In British Columbia (BC), the westernmost Canadian province, the impacts of urbanization on watersheds have been well documented in terms of loss of valuable tree cover, of wetlands, of streams and of biodiversity (Fisheries and Oceans Canada, 1997; Millar et al., 1997; Page et al., 1999). In addition, urbanization has resulted in erosion, flooding, and loss of stream complexity in many of the remaining BC streams (Fisheries and Oceans Canada, 1997). Surveys of the Lower Mainland region of British Columbia, conducted in the 1990s, indicate that the effective impervious area (EIA) coverage in many of the urban areas exceeded 30% (Millar et al., 1997). Significant alteration to aquatic habitat is observed once the impervious area in a watershed exceeds 10-20 % (Arnold & Gibbons, 1996; Klein, 1979; Schueler, 1994; Wang et al., 2001). Degradation of aquatic habitat in urbanizing watersheds is attributed to several factors. The change in hydrologic and disturbance regime of watersheds as the result of land development has been cited as one of the most influential factors affecting the ecological health of streams (Booth, 1991; Konrad, 2000; May, 1996). Some of the effects of urbanization on the hydrologic regime of naturally forested humid regions include: change in runoff generation mechanism of a watershed (Booth, 1991), increase infrequency and magnitude of peak flows (Hollis, 1975; Leopold, 1968), increase in stream flow flashiness(Booth et al., 2001; Henshaw & Booth, 2000; Konrad, 2000) and reduced summer base flows (Finkenbine et al., 2000).

With the advent of modern stormwater management practices (i.e. Low-Impact Development strategies), the hydrological impact of urbanization can be mitigated for new developments. However, for existing urbanized watersheds, the restoration of a viable aquatic community is at the very least challenging. Stormwater management philosophy has evolved considerably over the last 50 years from flood management to protection or even enhancement of receiving aquatic communities. The most recent iteration of stormwater management guidelines advocate for preservation and/or restoration of key hydrologic functions of watersheds by treatment of the full spectrum of rainfall events; by treatment of stormwater at the source; and by management of stormwater through decentralized simple techniques (that provide detention, retention, infiltration and evapotranspiration)(Kerr Wood Leidal, Lanarc Consultants,& Goya Ngan, 2005; King County Department of Natural Resources and Parks, 2009; Prince George’s County, 1999; Stephens, Graham, & Reid, 2002). Decentralized stormwater treatment involves treatment of stormwater on a residential scale. In the case of built environments this means redeveloping or retrofitting the existing development.

This study, a pilot project by the City of Burnaby and the University of British Columbia (UBC), was conducted to evaluatethe feasibility and effectiveness of retrofitting an urban watershed with on-site detention in order to improve the watershed’s stormwater response. The Beecher Creek watershed in the municipality of Burnaby in the Lower Mainland region of British Columbia was chosen as the site of the pilot study. A combination of factors including the hydrologic regime of the watershed, existing precipitation and flow data, previous stewardship efforts, and the willingness of the municipality to conduct a pilot study, made Beecher Creek the appropriate setting for the study. In addition, Beecher Creek is a third order stream that supports a small population of resident cutthroat trout. Third and fourth order streams provide valuable salmonid spawning and rearing habitat in the region and have been the subject of rehabilitation efforts(Millar et al., 1997). The pilot study data and findings will be reported to the City of Burnaby to inform future on-site stormwater management policies and projects.

2 Project Description

2.1 Overview

This joint project between the City of Burnaby and the University of British Columbia was a pilot project to evaluate the feasibility and the effectiveness of providing hydrological mitigation for the Beecher Creek watershed through retrofitting existing residential lots with small-scale detention basins. For the purposes of the pilot project, self-draining rain barrels were used as detention basins. Please see Section 3 for the literature review and the justification and reasoning for the design of the project.

The original pilot project scope was to retrofit single and/or two-family homes in a selected sub-catchment in the Beecher Creek watershed with up to 200 self-draining rain barrels. Due to physical site constraints, the project scope was later modified to include installation of up to 200 self-draining rain barrels in two sub-catchments. Each self-draining rain barrel would be connected to the roof and to the drain of the retrofitted property to provide detention for a portion of the roof runoff. A major component of the project was to design the self-draining rain barrel. This included determining a discharge mechanism for the rain barrel that would result in a hydrological benefit.

Another major component of the project was to retrofit as many residences as possible (within the sub-catchments) with the rain barrels and to monitor and measure the catchments' response to rainfall before and after the retrofits. The project scope included installation of flow-monitoring stations at the outfalls of the study area sub-catchments one year prior to the execution of the retrofits and also included continuously collecting data for the duration of the project. Implementing the retrofits required the permission and cooperation of private property owners in the study area. Therefore, determining how to gain landowner cooperation and subsequently gaining landowner agreement to participate in a research study was a major component of the project.

The project was carried out in two phases. Phase 1 involved installing the flow monitoring stations, designing and testing the rain barrel prototype, and gaining landowner cooperation. The focus of Phase 2 was retrofitting the properties in the study area and evaluating the impact. It is important to note that without successful completion of Phase 1, particularly gaining a minimum level of landowner participation, Phase 2 would not proceed.

The original project schedule was 30 months. The project budget for material was approximately $20,000 and it covered the following costs: flow-monitoring equipment, parts and material for retrofits, printing communication material, and mileage. Workspace was provided by UBC and the City of Burnaby. The UBC graduate student completed all the work. A detailed breakdown of costs and responsibilities is given in Section 2.5.

2.2 Objectives

The objective of the study was to answer the following questions:

1. Can capturing and detaining small frequent rainfall events have an effect on Beecher Creek hydrologic regime? Can self-draining rain barrels reduce flashiness in Beecher Creek by capturing small frequent rainfalls?

2. What does it take to get homeowners to participate in a research study? With limited resources, is it possible to get enough buy-in from homeowners in a residential neighbourhood with single-family homes to make a stormwater retrofit feasible?

3. What lessons can be learned from implementing a pilot-scale retrofit?

2.3 Hypothesis

The hypotheses of the study are informed by the literature review presented in Section 3.

Rain barrels can affect the stream response (mitigate stream flashiness) by capturing and providing detention for the small frequent rainfall events (<50% Mean Annual Runoff). If enough rain barrels are installed to capture runoff form at least 10% of the total impervious area in the sub-catchment(s), it is expected that there will be detectable change in stream response. Possible effects on stream response include:

- reduction of peak flow
- increase in lag time
- increase in the duration of response
- more gradual recession of storm flow
- increase in ex-filtration and therefore infiltration (through the storm sewer pipes by releasing water during dry periods)

Installing rain barrels on residential properties (Phase 2) is enabled if study area residents agree to participate in the study (Phase 1). Phase 2 requires at least 30% of the houses in the selected sub-catchments to agree to participate in the study. It is hypothesized that the following actions will result in adequate buy-in from the study area residents:

- *Ensuring that study area residents are aware of the project.* At the very least, achieving this requires contacting study area residents through direct mail and face-to-face meetings.

- *Ensuring that study area residents have a reason to participate in the study.* This is achieved by delivering a message (a reason to participate) that resonates with the homeowners.

- *Ensuring that it is easy for study area residents to participate in the study*. This involves reducing barriers and providing incentives for participation. The perceived barriers include: rain barrel cost, rain barrel transportation, and installation of the rain barrel. The incentives to the homeowners include: free rain barrels and extra chlorine-free water available for gardening during summer.

2.4 Previous Work Done at Beecher

Since November 2006, a precipitation station and a flow monitoring station have been in operation and continuously recording data in the Beecher Creek watershed. A watershed runoff model is in place. Multiple Benthic Index of Biological Diversity (B-IBI) studies have been carried out and an active stewardship group has facilitated creation of in-stream habitat diversity along with extensive riparian planting.

2.5 Work Plan

The proposed work plan for the project is in outlined in Table 2-1 below. The project was originally scheduled for completion in September 2011 but a nine months delay in establishing contracts between UBC and the City of Burnaby resulted in a later than anticipated project initiation date. Study area residents were first contacted in January 2011 and the rain barrel installations ended in July 2011. The one of year data collection following the installation of the rain barrels ended in August 2012. Section 5.1 gives the details of the timeline for project implementation.

Table 2-1: Beecher creek pilot project proposed work plan

Task	Schedule/ Deadline	Division of Responsibility	Material Cost
Establish a contract between UBC and the City of Burnaby	May ‘10	UBC Civil Engineering Department; City of Burnaby	
Select a project site and install flow monitoring devices (complete by July 2009)	Jul ‘09	UBC Civil Engineering Department; UBC Graduate Student; City will provide staff time for installation	$ 1500
Prepare communication material (project information package) and a communication plan	May ‘10 to Jun’10	UBC Graduate student; City of Burnaby will review and provide feedback	$ 200
Contact homeowners and consult residents through direct mail out and door step meetings	Jun ‘10 to Aug ‘10	UBC Graduate Student; City of Burnaby	
Design the rain barrel’s discharge mechanism	May ‘10 to Jul ‘10	UBC Graduate Student	$ 200
Modify and install the rain barrels and monitoring devices	Jul ‘10 to Aug ‘10	UBC Graduate Student; City will provide workspace	$15,600
Collect data	Dec ‘09 to Jul ‘11	UBC Graduate Student	
Analyze data and prepare final report	Sep ‘10 to Sep ‘11	UBC Graduate Student	

3 Literature Review

A literature review was conducted to answer the following questions.

- What are the hydrological impacts of land development and urbanization?
- Can retrofitting an urban watershed result in a meaningful change in stream hydrology?
- What type of study can determine the effect of retrofitting a developed urban watershed on a receiving stream? What are the essential components of such a study?

Section 3.1 focuses on the hydrological impacts of urbanization on streams. In North America, intensive urbanization mostly took place in the twentieth century. Although, researchers linked increase in watershed imperviousness and connectivity to decline in watershed health decades ago, time has given the scientific community deepened understanding of the mechanisms at work. As a result of advances in understanding of urban stream hydrology and geomorphology, the approaches to rainwater management have evolved over time.

Section 3.2 reviews the evolution of stormwater management strategies over the last 50 years and provides context for using retrofits as a mean of mitigating hydrological impacts of land development on aquatic habitat. The state of the art stormwater management approaches encourage implementation of decentralized technologies that treat the full spectrum of rainfall events, provide treatment at the source, reduce runoff rates and increase infiltration. These decentralized rainwater management approaches are commonly referred to as on-site stormwater management solutions as well as Low-Impact Development (LID) approaches in North America and as Source Controls in the Lower Mainland region of British Columbia. For built environments, treatment of stormwater at the source can only be achieved through retrofits or redevelopment. For both new and existing developments, there are barriers to widespread implementation of these new approaches. The barriers include: uncertainty about effectiveness of LID approaches and uncertainty about implementation methods (including financing and enforcement). As this is a relatively new field, there are several topics that would benefit from further research. A comprehensive Water Environment Federation study titled *Physical Effects of*

Wet Weather Flow on Aquatic Habitats: Present Knowledge and Research Needs (Roesner & Bledsoe, 2003) highlighted that demonstration and pilot projects that can provide guidance for municipalities on the topic are needed.

Section 3.3 reviews citywide, neighbourhood-scale and residential-scale stormwater retrofits projects to identify essential components of these projects and to identify best practices that lead to successful project implementation. Published literature on stormwater retrofits primarily focuses on social and financial aspects of project implementation and not the technical highlighting the importance of a holistic project approach and also highlighting that the published literature is lacking in technical information on retrofit projects. Section 3.3 also reviews principles of Community-Based Social Marketing (CBSM) as a tool for engagement of volunteer participants for the pilot project. One of the key principles of CBSM is reducing barriers to participation. As a technically complex, construction intensive retrofit would increase barriers to participation, the retrofit for the pilot project had to be simple and cause minimal disturbance to the homeowners' lots.

Beecher Creek, the site of the pilot scale study, has flashy flows. Although multiple LID approaches and source controls including on-site infiltration can potentially reduce flashiness in streams, study constraints limited the treatment options for the watershed to on-site detention/retention. Section 3.4 provides a summary of approaches and findings of scientific studies that have attempted to evaluate the impact of small-scale on-site detention and/or retention. Review of these studies further reinforced the need for pilot studies that demonstrate the effect of the stormwater retrofits through neighbourhood scale implementation and monitoring. Findings of Sections 3.3 and 3.4 formed the basis of the study methodology. Key findings from the literature review are:

- Land development alters the quantity and rate of water and sediment flow to streams increasing the quantity of runoff and the frequency of flooding in streams.
- The magnitude of runoff from small frequent events is proportionally more affected by land development than the magnitude of runoff from the large infrequent events.
- Small frequent events make up a significant portion of the mean annual rainfall.

- The current state of practice for rainwater management calls for decentralized low-impact development techniques that capture rainfall at the source, reduce runoff rates, and increase infiltration.
- Retrofits have many components that make them challenging including: identifying retrofit opportunities, design and application of retrofits, financing, and public education and involvement in the project.
- There is extensive literature on education and community engagement.
- Community Social Marketing is an approach that can be used for recruiting volunteer participants for a study.
- Scientific papers that have investigated the impact of on-site retrofits often rely on computer modelling. Studies that involve monitoring programs often monitor one site and extrapolate the impact on a watershed-basis using computer models.
- Paired watershed studies are often used in the field of hydrology but no paired watershed studies in urban watersheds were found.
- No studies were found where impacts of a neighbourhood scale retrofit was evaluated by monitoring stream response.

3.1 Impacts of Urbanization

3.1.1 Overview

Urbanization of watersheds in the Lower Mainland has resulted in loss of much of the viable aquatic habitat in the region and has resulted in significant alteration of the form and function of the remaining habitat (Fisheries and Oceans Canada, 1997). This can be attributed to the cumulative effects of land development, past drainage and flood management strategies, and increased human presence and activity in the region. Land development in a naturally forested environment involves removal of native vegetation, alteration of natural drainage pathways, soil compaction, and grading and paving of land (Henshaw & Booth, 2000). As a result, under post-development conditions, land base typically has lower infiltration and water storage capacity than under pre-development conditions and this can fundamentally alter the local hydrological regime. Hydrological regime changes can have profound impacts on channel morphology and in-stream habitat. Traditional engineering and flood management practices have also resulted in direct loss of physical habitat as evident by many streams that have been filled, culverted or channelized in Vancouver. Following land development, increased anthropogenic activities result in further habitat modifications. Type and extent of human activity in a watershed can affect the quantity and quality of water in urban streams as well as impacting biodiversity and population of fish and other wildlife.

Studies on consequences of urbanization and the associated imperviousness on streams date back 50 years. Over the last 50 years, several studies have generated data and evidence to support or oppose early anecdotal/empirical observations and the scientific community has had the chance to observe how urbanizing watersheds and streams change overtime. Nonetheless, the generalized understanding of the impacts of urbanization has not changed dramatically over this time. Table 3-1summarizes the contents of three publications on this topic.

Table 3-1: Summary of general impacts of urbanization (Arnold & Gibson, 1996; Klein, 1979; Clark et al., 2006)

		Authors		
		Klein (1979)	**Arnold & Gibson (1996)**	**Clark et al. (2006)**
I of Urnpactneral Impacts of Urbanization	**Flow Regime**	Increased stormwater runoff Increased frequency and severity of flooding	Increased velocity and volume of surface runoff Increased severity of flooding	Increased frequency of flooding and peak flow volumes
	Stream Morphology and Habitat Modification	Accelerated channel erosion Alteration of the streambed composition	Erosion of stream banks Wider and straighter stream channels Loss of streamside (riparian) and in-stream habitat Direct modification of physical habitat through human engineering	Widening of stream banks, downcutting of the streambeds, and increased erosion Destruction of pool and riffle sequences, removal of overhead cover and large woody debris Direct modification of physical habitat through human engineering
	Sediment Loading	Increased sediment loading during construction phase and from accelerated channel erosion	Increased erosion from construction sites, downstream areas, and stream banks	Increased sediment loading from urban runoff and from stream bank scour and erosion
	Base Flow & Groundwater	Reduced base flow	Reduced groundwater recharge	Typically decreased base flow
	Temperature	Alteration of the natural stream temperature regimen	Greater water temperature fluctuations	Increased stream temperature
	Pollution	Increased entry of toxic substances such as heavy metals, pesticides, oil, road salt, detergents, etc. Elevated nutrient inputs to the stream	Increase in the generation of pollutants. Increased runoff serves to transport these pollutants directly into waterways	Changes in pollutant concentrations in runoff

3.1.2 Hydrological Impacts of Urbanization

This section of the literature review focuses on the hydrological impacts of urbanization in a naturally forested humid region which include:

- redistribution of subsurface flows to surface flows
- higher magnitude and more frequent peak flows
- flashier flows (short duration, high peaks and rapid recession; higher ratio of storm flows to base flows)
- altered base flow
- more frequent geomorphologically significant flows

Runoff generation processes vary from region to region and depend on multiple factors including local climate, rainfall intensity and duration, vegetation cover, and soil characteristics (Booth, 1991). In a naturally forested region with low intensity rainfalls, subsurface flow regimes generally dominate (Booth & Jackson, 1997; Booth, 1991). When subsurface flow dominates, most of the precipitation is absorbed and infiltrated by soil where it lands and water moves downstream underground. Initially, only parts of the basin near the stream contribute to runoff. The portion of the watershed contributing to runoff increases over days as the water table rises in the watershed (Booth, 1991). Urbanization can change a dominantly subsurface flow regime to a dominantly surface flow regime (Booth & Jackson, 1997; Booth, 1991; Henshaw & Booth, 2000; Roesner & Bledsoe, 2003). Post-development, a larger portion of the rainfall is converted to direct surface runoff and a smaller portion is infiltrated which subsequently impacts groundwater recharge and natural base flow of the stream (Klein, 1979; Leopold, 1968; Roesner, et al., 2001). In urban areas, the runoff reaches the stream faster partially because runoff moves faster overland and partially because drainage networks increase the efficiency of runoff conveyance to streams (Leopold, 1968). Larger, shorter duration hydrograph peaks with steep recession limbs reflect these changes in the hydrological flow regime (Henshaw & Booth, 2000; Konrad, 2000; Roesner et al., 2001).

There is consensus in the literature that urbanization results in more frequent and higher magnitude peak flows (Booth and Jackson 1997; Hollis 1975; Leopold 1968). Specifically, the magnitude of peak flows of small, frequent events are increased by a greater percentage of predevelopment flows than those of large, infrequent events (Hollis, 1975; Roesner et al., 2001). Roesner et al. (2001) demonstrate this point by describing the effect of development on peak flows in Metropolitan Denver where the ratio of post-development peak flow to pre-development peak flow is 57:1 for a 2-year event and 2:1 for a 100-year event. Furthermore, following urbanization, the entire spectrum of rainfall events in a region can generate stream responses and cause rises in stream levels where, prior to development, only moderate to high rainfalls generated responses (Booth, 1991; Hollis, 1977). In fact, post-development, small frequent rainfall events can generate the majority of runoff volume in a given year.This is reflected in current stormwater management regulations on runoff volume reduction. In British Columbia, the provincial guidelines instruct that 90% of the rainfall volume in a typical year be captured at the source and be infiltrated, evaporated or reused (Stephens et al., 2002). In the Lower Mainland region of British Columbia, 90% of the rainfall volume in a typical year is generated by 6-month events and events that occur more frequently than a 6-month event (Kerr Wood Leidal, 2005). Table 3-2adopted from Roesner et al. (2001) summarizes the design storms that result in capture of 90% of annual runoff volume by detention ponds in eight cities around the world.

Table 3-2: Design storm for 90% capture of runoff (Roesner et al., 2001)

City	Overflow Frequency (times/year)	Design Storm (return interval)
Tucson, Ariz.	3	4 month
Butte, Mont.	6	2 month
San Francisco	4	3 month
Edinburgh, Scotland	4	3 month
Chattanooga, Tenn.	10	1.2 month
Detroit	12	1 month
Cincinnati	8	1.5 month
Orlando, Flo.	4	3 month

Post-development, streams experience more frequent competent flows that are capable of channel alteration and ecosystem disturbance (Booth, 1991; Hollis, 1975; MacRae, 1997; May, 1996). In the context of current stormwater management guidelines, 6-month to 2-year rainfall events are generally managed to reduce erosion and channel alteration (Prince George's County, 1999; Stephens et al., 2002). Over decades, urbanizing streams adjust to accommodate higher channel forming flows through channel enlargement (Booth, 1990; Finkenbine et al., 2000; Hammer, 1972; Henshaw & Booth, 2000) but whether these streams become ultimately stable depends on a variety of factors including level of development in the watershed and hydrologic and geomorphic characteristics of the watershed (Henshaw & Booth, 2000). For instance, a channel that experiences flashy flows might not be able to develop a stable form in response to small frequent events because the inter-storm flows are too low to re-work the sediment moved during the larger events (Booth, 1991; Henshaw & Booth, 2000). Even when streams stabilize, a re-stabilized cross section is often wider and less geo-morphologically complex which impacts habitat availability, water velocities and temperatures (Henshaw & Booth, 2000). Finkenbine et al. (2000) found that even 'mature' streams, ones that have adjusted to urbanization, can still experience slightly higher peak velocities due to higher post-development flows.

Although, there is agreement that urbanization alters base flow, the ultimate impact of urbanization on base flow is not consistent for all watersheds (Finkenbine, 1998; Hollis, 1977;

Klein, 1979; Konrad, 2000; Simmons & Reynolds, 1982). The impact of urbanization on base flow can depend on climate, time of year, surficial geology, and human activity in the area. Finkenbine (1998) found significant reduction in summer base flows in the Lower Mainland streams once impervious cover in watersheds exceed 20 to 40 percent.

Hollis (1977) describes a ‘flashy’ system as one with “frequent and rapid changes from a low flow situation to moderate or high flow and back again” (p. 62). Although streams can be naturally flashy due to physiographic conditions (Konrad, 2000), flashy flows in urban streams can be a consequence of land development (Henshaw & Booth, 2000; Konrad, 2000). An indicator of flashy flow is the percent of daily flows that exceed mean annual flow per year. Low values of the ratio indicate a watershed with flashy hydrographs (short duration and high flow peaks), and high values indicate a watershed with more gradually varying flows (Henshaw & Booth, 2000). The increase in storm flow relative to base flow and a stream becoming flashier as a result of development can have significant ecological consequences (Konrad, 2000; May, 1996). May (1996) found that once the ratio of storm flow to base flow exceeded 20, Puget Sound Lowlands(PSL) streams in western Washington suffered from major loss in habitat complexity and biological diversity. Booth et al. (2001) describe the potential consequences of flashy regimes as follows:

> lower flow depths during base flow, particularly in channels widened by increased storm flow, a shift in transport of organic material and nutrients from low flow periods to storms, and an increase in the frequency and extent of bed disturbance as storm flow is higher relative to lower flows that stabilize the stream bed. (p. 57)

Changes in hydrology of a watershed have far reaching impacts on the overall watershed health. Flood management and stormwater management strategies are therefor tied to watershed health. The next section of the literature review, examines the evolution of stormwater management strategies in North America to determine how different strategies have impacted watershed hydrology and to determine the current best practices.

3.2 Evolution of Management Strategies

This section examines the evolution of stormwater management strategies to determine what are the most recent and relevant approaches for mitigating the hydrological impacts of land development. Although stormwater management philosophy has changed significantly over the years, impervious coverage of a watershed has consistently served an important indicator of watershed health and an important tool to scientists and practitioners alike. The following sections provide an overview of the following topics: role of impervious coverage as an indicator in stormwater management, traditional and modern approaches to stormwater management, and the current legal and regulatory framework in North America, Canada, and British Columbia.

The current state of practice puts an emphasis on decentralized rainwater management at the source. There is consensus in the scientific community that treating a wide range of rainfall events, from small frequent events to larger, more infrequent events, is critical to maintaining health of watersheds. Infiltration is viewed as an essential technique for reducing volume and rate of runoff to receiving bodies. There are some guidelines and regulations in North America that support these modern ideas of stormwater management.

In addition to the current state of practise and the regulatory framework, some of the challenges of implementing modern stormwater management concepts in urban and already built environments are presented in this section.

3.2.1 Impervious Cover

Imperviousness has become the primary indicator for assessing the impacts of land development on watersheds. Various impacts of urbanization are correlated to total impervious area (TIA) and to effective impervious area (EIA) of watersheds. Effective impervious area is defined as impervious area that is hydraulically connected to the stream. Any discussion on mitigating impacts of land development is inevitably tied to a discussion on impervious cover.

After studying 27 small watersheds in the Maryland Piedmont, Klein (1979) concluded that for sensitive ecosystems, stream quality is impaired if impervious cover exceeds 10% of the watershed. He also concluded that stream quality is severely impaired once imperviousness exceeds 30% of the watershed. Booth & Jackson (1997) observed aquatic system degradation in the lowland streams of Washington once effective impervious area (EIA) exceeded 10%. After studying 47 watersheds in Wisconsin, Wang et al. (2001) concluded that 8% to 12% connected imperviousness is the threshold where small changes towards urbanizing watersheds have large consequences on stream flows. Limiting land development and/or reducing connected impervious areas in watersheds are often recommended as management strategies (Arnold & Gibbons, 1996; Booth & Jackson, 1997; Booth, 1991; Booth et al., 2004; Klein, 1979; Wang et al., 2001).

Imperviousness has also been used as a basis for developing management strategies. Schuler (1994) proposed a scheme for managing headwater urban streams based on the extent of the imperviousness in the watersheds. Schuler (1994) classifies streams into three categories: sensitive streams (0-10% impervious); impacted streams (11-25% impervious); and non-supporting streams (26-100% impervious). He goes on to define management objectives for each class of streams. For example, the resource objective for a sensitive stream should be protecting diversity and channel stability (Schuler, 1994). In contrast, the resource objective for a non-supporting stream should be minimizing downstream pollutant loads (Schueler, 1994).

Booth et al. (2004) also recommend management strategies using total impervious area in watersheds. After studying 45 sites from 16 second and third order stream in western Washington State, they use total impervious area and benthic index of biological integrity (B-IBI) as criteria for determining whether the management objective for a watershed should be protection (high B-IBI and low TIA), rehabilitation or stewardship (low B-IBI and high TIA).

3.2.2 From Flood Management to Rainwater Management

Stormwater management has evolved from flood management and nowadays involves management of water quantity, water quality, aquatic ecosystem and watershed health. Overall, the approach to runoff management has become more holistic. Stormwater management is hardly discussed outside the context of watershed management and has moved away from end of pipe solutions to decentralized source control measures. Researcher and practitioners are moving away from event-based design of stormwater control measures to designing solutions for continuous long-term rainfall records (Shaver et al., 2007). This section reviews the progression of stormwater management from a hydrology perspective.

In North America, modern drainage systems with catchments and pipes are a post-World War I era phenomenon (National Research Council, 2008; The Partnership For Water Sustainability in BC, 2011).For much of the twentieth century, drainage systems were designed and managed to quickly remove runoff from sites and discharge it to the nearest surface water body (Arnold& Gibbons, 1996; Roy et al., 2008). By the 1960s and 1970s, the local governments took note that the built drainage networks were resulting in downstream flooding and bank erosion(Murdoch, 2001; National Research Council, 2008; Stephens et al., 2002). This prompted governments to take flood control and channel stabilization measures; requiring that developers take measures to attenuate peak flows for large infrequent rainfall events that could cause harm to human life and property was one such measure (National Research Council, 2008; Roy et al., 2008). This led to popularity of end-of-pipe flood control structures such as detention basins (Booth & Jackson, 1997; Klein, 1979; Leopold, 1968; Stephens et al., 2002). The implementation of detention basins and other storm control measures that were designed to control peak flows through the 1980s to 1990s had some unintended negative consequences on downstream aquatic habitat (Murdoch, 2001). Failure of detention basins to effectively reduce erosion and flooding highlighted the need for incorporation of watershed level planning, runoff volume reduction measures and treatment of small frequent events in stormwater management planning. Consequently, reducing connected impervious surfaces and increasing infiltration became a more prominent part of stormwater management (National Research Council, 2008). Several authors in the mid to late 90s discuss the benefits of watershed based planning and managing imperviousness to mitigate consequences of land development (Arnold & Gibbons, 1996; Page et al., 1999; Schueler, 1994). In 1999, Prince George’s County published a document titled *Low-Impact Development Design Strategies: An Integrated Design Approach* that essentially describes the current approach to stormwater management. Some of the key concepts that define low-impact development include (Prince George’s County, 1999):

- preserving the key hydrological functions of a watershed
- managing small frequent events on small lots

- controlling stormwater at the source
- using simplistic, non-structural methods (more natural material and more distributed micro-control systems) versus the large end-of-pipe systems (large on-site detention)
- using multifunctional landscapes that incorporate detention, retention, infiltration and runoff use

While modern stormwater planning guidelines (King County Department of Natural Resources and Parks, 2009; Prince George's County, 1999; Stephens et al., 2002) provide direction for new developments, achieving the new stormwater objectives in existing development can be quite challenging. Although, there are challenges associated with implementation of new stormwater management guidelines in any setting (Brandes et al., 2005; Roy et al., 2008), this research focuses on the challenges associated with retrofitting existing developments.

Implementing Low-Impact Development strategies on previously developed land requires cooperation of landowners and innovative solutions that fit a built environment. The US Environmental Protection Agency recognizes these challenges and held a *National Conference on Retrofit Opportunities for Water Resource Protection in Urban Environments* in 1999. The conference held session on the following topics which is a comprehensive list of typical issues associated with retrofit projects:

> Retrofit opportunity identification, modeling and monitoring approaches for retrofit application, conservation design strategies, innovative financing approaches, evaluating results and measuring success, newly emerging technologies, urban revitalization issues, riparian reforestation, public education and involvement programs. (p. iii)

In 2003, Water Environment Research Foundation (WERF) published a study titled *Effects of Wet Weather Flow on Aquatic Habitats: Present Knowledge and Research Need* (Roesner & Bledsoe, 2003). Roesner & Bledsoes (2003) reviewed more than 400 studies and one of their key recommendations for moving the field of stormwater management forward is stated below.

> It is extremely important that further research be pragmatic and focused on developing pilot/demonstration studies that will lead to guidance that municipalities can use to design

> new systems or improve existing systems to protect not only the safety and welfare of the citizenry that it serves, but also the aquatic ecosystems in the streams that receive the wet weather discharges from these urbanized sites. (p. v.)

The goal of this study was to address the specific need highlighted by Roesner & Bledsoes (2003): a pilot study that would lead to guidance on how to improve existing systems to protect the wellbeing of people and the aquatic ecosystem for municipalities. Prior to setting up a pilot study, it was important to understand:

- the local regulatory and legal framework
- the type of pilot scale study that would be beneficial, and
- the critical components of such study.

The following sections review the regulatory context and different elements of retrofit studies.

3.2.3 Legal and Regulatory Framework

Several key regulations both in Canada and the United States have been the driving force behind the evolving stormwater management strategies. In the United States, the Clean Water Act (1972), the National Pollutant Discharge Elimination System (NPDES) Stormwater Program (1987) and the Phase II of NPDES (1999) have been critical in improving stormwater management practices (Roy et al., 2008). In Canada, the Canada Water Act (1970), the Fisheries Act, the Canadian Environmental Protection Act (1999) and Canada's Water Policy (1987) are key pieces of Federal legislation that support sustainable water resources management across the country (Brandes et al., 2005).

In the Georgia Basin, regulations are not the only drivers of action. In British Columbia, dramatic reduction in fish stocks in 1960s and 1970s motivated governments, stewardship groups and others to take action towards protecting the province's water resources (City of Burnaby Planning Department, 2003). Concern about health of the salmon population is not limited to British Columbia. In the Pacific Northwest Region of the United States, salmon are currently listed as endangered species (Booth et al., 2004).

In Canada, the Department of Fisheries and Oceans (DFO), which gets its mandate from the Federal Fisheries Act, is responsible for minimizing harmful impacts of land development on fish and fish habitat.

3.2.3.1 British Columbia Context

In addition to the Federal legislations, there are several legislations, strategies, plans and programs specific to British Columbia that pertain to sustainable water resources management and protection of aquatic habitat including the Water Act, the BC Environmental Management Act, and the BC Living Rivers Strategy (Brandes et al., 2005; Metro Vancouver, 2010).In BC, the provincial government mandates the Liquid Waste Management Plan (LWMP) under the Environmental Management Act. Metro Vancouver has a LWMP in place that has been approved by the province, signed on by all member municipalities, and is legally binding. The most recent Metro Vancouver LWMP (2010)called the *Integrated Liquid Water and Resource Management (2010): A Liquid Waste Management Plan for the Greater Vancouver Sewerage &Drainage District and Member Municipalities* has a stormwater management section. This section is designed to help member municipalities make stormwater management decisions that meet local and regional needs, priorities and objectives. The LWMP requires all of Metro Vancouver's member municipalities to have Intergraded Stormwater Management Plans (ISMPs) completed by 2014. The LWMP (2010) describes the ISMPs as follows:

> Integrated Stormwater Management Plans (ISMPs) include managing rainwater at the site level, thereby minimizing stormwater runoff. To be effective, municipalities will integrate land use into their stormwater management plans, and appropriate site-level rainwater management practices into their community development policies (p.13).

The requirement to do ISMPs for most watersheds in the Lower Mainland combined with provincial stormwater management guidelines (Stephens et al., 2002), and the Department of Fishers and Oceans (DFO) requirements to control rate, volume and quality of runoff from land development for protection of fish and fish habitat (Chilibeck & Sterling, 2001), have motivated local municipalities to consider application of on-site stormwater management solutions.

3.3 Implementation of Residential Scale Stormwater Management Retrofits

3.3.1 Introduction

This section takes a close look at programs and studies where modern stormwater management concepts have been implemented in urban and already built environments. A significant number of published studies on this topic focus on financial and social components of retrofit project indicating the importance of a well-rounded program. When it comes to stormwater retrofit projects, it is not enough to have technical solution for the problem at hand. Implementation of source controls or low-impact development techniques is not possible without landowner cooperation. Therefore, community engagement and a plan for participant recruitment is an essential part of any retrofit project. This section focuses on techniques for gaining landowner cooperation and specifically reviews the principles of community-based social marketing. The findings of this section informed the methodology of the research.

3.3.2 Review of Outreach and Communication Components of Stormwater Management Retrofits

There are a number of studies that explore beyond technical issues and investigate the financial and social issues associated with the implementation of decentralized on-site stormwater management techniques (Ando & Freitas, 2011; Belan & Nenn, 2010; Green, 2011; Hager, 2003; Hatziantoniou, 1999; Meder & Kouma, 2010; Thurston, 2006; Visitacion et al., 2009; Wright et al., 2009). Some of these cited publications discuss different market based and regulatory approaches for achieving decentralized stormwater management; however, for the purposes of the Beecher Creek pilot project, the focus of the literature review was on facilitating volunteer participation in stormwater retrofit projects. Scaling up the Beecher Creek pilot project in the future might require investigation of regulatory or market based frameworks but that is outside the scope of this study.

Five studies in which low-impact development practices were implemented on a neighbourhood or city scale were reviewed (Ando & Freitas, 2011; Belan & Nenn, 2010; Dietz et al., 2004; Meder & Kouma, 2010; Wright et al., 2009). All projects reviewed had multiple objectives including: raising awareness of some of the negative consequences of land development, raising awareness of the benefits of low-impact development techniques, assessing the effectiveness of LID practices, and simply implementing LID practices to increase their popularity. In all the reviewed studies, rain barrels, rain gardens or other green technologies were provided either at a subsidized rate or at no cost to the residents. All projects had an outreach component to recruit participants for the projects. In Milwaukee, Wisconsin, two non-profit groups trying to retrofit a mixed income ‘minority’ neighbourhood with rain barrel and rain garden, reached out to the neighbourhood association. They ran presentations for the association and the general public to raise awareness about stormwater issues and recruit volunteers to participate in the study (Belan & Nenn, 2010). In Wilmington, North Carolina, the project coordinators also reached out to a neighbourhood association, in a low-income neighbourhood, and collaborated with them to hold three educational workshops in the community. As a result, they successfully recruited participants who would allow installation of rain barrels and rain gardens on their properties (Wright et al., 2009). In the City of Lincoln, Nebraska, the City introduced their rain garden and rain barrel programs at a public meeting and collected applications for free rain barrels and rain gardens at the meeting. Having a presence and advertising at a festival was another outreach method used by project coordinators in Milwaukee (Belan & Nenn, 2010). The City of Chicago used a similar technique to promote their subsidized rain barrel program. Between 2004 and 2009, the City sold heavily subsidized rain barrels at distribution centers and special events. The City advertised their distribution efforts through newspapers and water reports that accompanied water bills (Ando & Freitas, 2011). Dietz et al. (2004) employed what they refer to as ‘intensive education efforts’, in the form of workshops and one-on-one consulting, to increase the adoption rate of Best Management Practices (BMPs) that reduce non-point source pollution in runoff. They coupled their educational efforts with implementation of structural best management practices and measured the effect on pollution levels and residents’ behaviour (Dietz et al., 2004). Although the projects had different scopes, budgets and objectives, all projects used a combination of the following outreach methods: partnering with a neighbourhood association, public meetings, presence at special events and festivals, workshops, doorstep meetings, phone calls, direct mail and general awareness campaigns (distribution of print material and newspaper, radio, and TV advertisements).

Some of the projects mentioned above evaluated their overall education and outreach efforts using surveys but the reviewed papers did not provide enough information so that the readers can evaluate the feasibility and effectiveness of each individual initiative. This paragraph summarizes the findings and recommendations of the reviewed projects as presented by the authors of the reviewed papers. Ando & Freitas (2011) reviewed the rain barrel subsidy program run by the City of Chicago to find what factors affected residents purchasing the rain barrels. They found that rain barrels were present in higher concentrations in neighbourhoods with high incomes and “green” attitudes. They also found that the sale of the rain barrels by the City had replaced the sale of private rain barrels. This could imply that some of residents who were purchasing subsidized rain barrels from the City would have purchased rain barrels with or without the City run program. Ando & Freitas (2011) also found that the rain barrel purchases were not correlated to local level of flooding, proximity to a rain barrel distribution center or proximity to a site of hydrologic information campaign. However, they did find a positive correlation between owner occupancy and adoption of a green technology. Belann & Nenn (2010) also found that home ownership is an important factor in adaption of green solutions. They also concluded that a ‘strong community social presence’ contributes to the successful implementation of neighbourhood scale LID initiatives. Wright et al. (2009) also concluded that a strong sense of community in their study area had a significant effect on the outcome of their project. Their surveys revealed that word of mouth helped promote their project and members of community in the project area had influence over other community members and neighbours. The surveys also indicated that that study participants valued beautification of their property by rain gardens (Wright et al., 2009). Meder and Kouma (2010) observed an increase in demand for rain barrels after implementation of an innovative promotional program called Artistic Rain Barrel Program. The Artistic Rain Barrel Program in the City of Lincoln invited local artists to paint rain barrels that would be displayed in public and sold at auctions. Dietz et al. (2004) found that intensive education efforts resulted in adoption of best management practices and improved water quality.

The findings presented so far are from programs that were implemented in the United States. Hatziantoniou (1999) developed a program evaluation framework and evaluated multiple aspects of the following four Canadian municipal stormwater management programs: the Downspout Disconnection Pilot Project, the Perforated Sump Pilot Project and the Rain Barrel Program in Vancouver, British Columbia, and the Downspout Disconnection Program in Toronto, Ontario. All of the programs targeted urban residential areas and participation in the programs were voluntary. One of the goals of the study by Hatziantoniou (1999) was to inform the design of future integrated stormwater management programs so that they are capable of attracting sufficient participants. Hatziantoniou(1999) made the following recommendations on increasing homeowner participation in city run stormwater management initiatives:

- provide incentives for homeowners to participate
- remove barriers to participation including: assisting the homeowners with pick up, delivery, and installation of the best management practices, and meeting the homeowners demands in terms of property aesthetics
- targeted promotion of programs in neighbourhoods and watersheds that can most benefit from it (which is a recommendation that Ando & Freitas (2011) also made for the City of Chicago)

The principles of Community-Based Social Marketing (CBSM) are one of the major tools used by Hatziantoniou (1999) to evaluate the four residential stormwater management programs. The CBSM concept is explained in the following section and is used in this research.

3.3.3 Application of Community-Based Social Marketing

Hatziantoniou (1999) used CBSM to evaluate the four residential stormwater management programs. The core of community-based social marketing, which is based on social science research, is that

"behavior change is most effectively achieved through initiatives delivered at the community level which focus on removing barriers to an activity while simultaneously enhancing the activities benefits"(Mckenzie-Mohr, 2000). CBSM is all about delivering a tailored program for a specific audience for a specific purpose instead of implementing all large-scale educational and promotional campaigns targeted at the general population. The application of principles of

CBSM are recommended for promoting environmentally friendly behaviour by the National Round Table on the Environment and the Economy (Hatziantoniou, 1999). Mckenzie-Mohr (2000) outlined the four steps of CBSM as follows:

1. Discover barriers to behaviours that are being promoted
2. Based on the information collected on barriers to behaviour change, select which behaviour to promote and design a promotional program that directly addresses the barriers identified previously.
3. Pilot the program
4. Evaluate the program (Mckenzie-Mohr, 2000)

To the extent that time and resources allowed, the principles of CBSM were applied in developing the Beecher Creek project communication strategy.As the first step of the CBSM approach is to identify barriers to behaviours that are being promoted, research was done to determine potential barriers to the volunteer participation in the Beecher Creek retrofit project. Section 4.4.1summarizes the findings of this research.

3.4 Evaluating the Impact of Source Controls/LID on Stream Hydrology

3.4.1 Introduction

The ultimate goal of the study was to determine whether or not small residential scale retrofits could have an impact on an urban streams hydrology. A literature review was conducted to determine what types of studies have been done in this field. It was found that a significant number of studies that aim to evaluate the impact of source controls exclusively rely on computer modelling. Another category of studies, combine field-testing with computer modelling. These studies generally monitor and quantify the behaviour of a source control or a combination of source controls on one site and then use modelling to determine the impact of implementing the source control on a watershed scale. Unlike other fields of hydrology,there is a lack of studies that rely on implementing pilot scale projects on a watershed scale (projects are usually implemented on a site /residential lot scale). In contrast, paired watershed studies are quite common in the field of forest hydrology where the study involves the minimum of two watersheds: one for control and one for treatment. The literature review revealed that there is a lack of studies that have directly measured the impact of implementing watershed-wide residential-scale source controls on a receiving water body. The objective of this study is to demonstrate the impact of residential scale retrofits through measuring stream response. Taking into account that the execution of such project would not be possible without cooperation of landowners, the source control had to be chosen so that the barriers to adaption of the source control would be minimal. It was hypothesised that a retrofit that requires a lot of construction would not be feasible. Self-draining rain barrels were chosen as the source control of choice for several reasons including ease of installation and the public's familiarity with the concept. Collecting rainwater in a rain barrel is an ancient concept. The next section reviews studies that evaluate the potential hydrological impact of rain barrels and other small-scale on-site retention/detention measures.

3.4.2 Rain Barrels

Rain barrels are relatively low cost and low maintenance devices for collection and storage of roof runoff on residential, commercial and industrial sites (Prince George's County, 1999). Typically, roof runoff is diverted to a barrel through gutters and downspouts until the barrel is full in which case the water bypasses the barrel through an overflow pipe (Prince George's County, 1999). The effect of rain barrels on a site's hydrologic response depends on the surface area of roof connected to the barrel, design of the barrel, and the ultimate use of the water in the barrel. Municipalities in the Lower Mainland region of British Columbia promote rain barrels as water conversation devices and encourage residents to collect rainfall and use it for irrigation and other non-potable uses. Prince George's County promotes rain barrels as water retention and detention devices that provide permanent storage for a pre-determined volume of runoff ('retention') and that provide detention through overflow pipes. In both cases (British Columbia and Prince George's County), unless residents of properties that have rain barrel on site diligently use the water stored in rain barrels, the barrels are going to provide little hydrologic benefit. Roof runoff is going to simply bypass a full rain barrel. However, self-draining rain barrels are a form of small on-site stormwater detention that can also provide runoff volume reduction given the appropriate discharge environment. There are few academic publications that discuss rain barrel design and the effect of rain barrels on runoff (Abi Aad, 2009; Brown at al., 2008; Green, 2011; Jones & Hunt, 2010; Konrad & Burges, 2001; Nehrke et al., 2001). Brief syntheses of these studies are included in this section. This literature review also draws from relevant studies on rainwater harvesting and stormwater detention.

Brown et al. (2008) evaluated rain barrels as part of an array of other Low-Impact Development techniques that can be implemented to retrofit an existing urban watershed. Their evaluation criteria included the following factors: volume reduction capability, stormwater treatment capability, ease of installation and maintenance, community acceptance, and opportunity for public participation and/or public private partnerships (Brown et al., 2008). Brown et al. (2008) state that "rain barrels […] ranked high for implementation in residential areas" (p. 336) even though in their study rain barrel had the lowest possible rankings in the volume reduction, stormwater treatment, maintenance and cost categories.

Green (2011) developed an Economic Water Model, which is a distributed deterministic model that estimates runoff generation from multiple sites using site-specific climate, soil, slope, and surface conditions data. The model does not deal with runoff conveyance. It models average annual runoff generation taking into account interception and infiltration processes. The model can be used to estimate costs and energy demands associated with different stormwater management strategies. Green (2011) found that widespread implementation of rain barrels and rain gardens in dense residential areas with small lots can have significant effects on urban runoff.

Jones & Hunt (2010) studied 208 L rain barrels amongst other rain harvesting techniques to understand the effectiveness of the barrels in reducing runoff volumes from residential sites and supplementing household irrigation needs in North Carolina. They developed a simulation tool to evaluate the performance of rainwater harvesting systems based on historical rainfall data and anticipated usage of water. Their criterion for effective reduction of runoff volume by a rain barrel was capturing more than 50% of roof runoff volume. They found that one rain barrel could effectively reduce runoff volume for a 10 m^2 roof area. They concluded that overall one rain barrel per house was not effective at reducing runoff volume from the residential site (Jones & Hunt, 2010).

Abi Aad (2009) developed modeling techniques for modeling the behaviour of a continuously draining rain barrel and an overflowing rain barrel. In addition, Abi Aad used EPA Storm Water Management Model version 5.0 (EPA SWMM-5) to develop a hydraulic model for a highly impervious residential watershed (62 % impervious) located in Hyde Park, Cincinnati and used the model to evaluate three different stormwater management techniques: rain gardens, rain barrels, and central detention. To evaluate the effect of rain barrels on roof runoff, Abi Aad developed scenarios in which every house in the watershed (310 houses in total) was retrofitted with a 284 L rain barrel. In the model, the rain barrels were connected to the roofs via downspouts and drained to a combined sewer system. The barrels were not self-draining and the following assumptions were made: the barrels were emptied between rainfall events into the combined sewer system and no water was lost to infiltration and evapotranspiration. Under those assumptions, the barrels provide temporary storage for roof runoff. Abi Aad reported the model output for three rainfall events in January of 1998 in Hamilton County in the US. The results indicate that the effectiveness of the rain barrels in attenuating peak runoff depends on rainfall intensity. Under the high intensity rainfall scenario, the volume of runoff stored in the barrels was small compared to the total runoff. Under the lower intensity rainfall scenarios, the barrels held a significant portion of the runoff volume. However, for the latter scenarios, the peaks generated by simultaneous emptying of 310 rain barrels during the dry periods were larger than the peak runoff from the rest of the watershed during the actual rain events (Abi Aad, 2009).

Konrad & Burges (2001)paper titled “Hydrologic Mitigation Using On-Site Residential Storm-Water Detention ”is a comprehensive study that investigates the role of the following factors on the effectiveness of detention systems:

- size of detention facility
- rate of discharge of detention facility
- purpose of the detention system (single-purpose versus multi-purpose)
- characteristics of the storm treated (frequency of the storm)

They used a mass balance model to simulate outflow from different types of detention basins at a residential scale and compared the output from the detention facilities to time series of measured runoff from two basins. One of the basins was a rural basin and the other was a zero ordered forested basin. They found that the detentions basins provided hydrological mitigation but for high flows (exceeded 1% of the time) and low flows (exceeded 80% of the time), the benefit was sensitive to the size of the basin and the max release rate of the basin. On the other hand, intermediate flows were mostly sensitive to release rate. They concluded that small detention basins can effectively provide hydrologic mitigation over a range of intermediate flows (exceeded 10-30% of the time) (Konrad & Burges, 2001).

Nehrke et al. (2001) do not directly discuss rain barrels but demonstrate the benefits of extended detention for small frequent events. Through continuous modeling using 50 years of hourly rainfall record, they developed flow frequency curves that take into account the effect of extended detention for small frequent storms. They did not study the impact of extended detention on flow duration curves and they warn their readers that change in flow duration curves can have significant impact on geomorphic stability of a stream (Nehrke et al., 2001).

4 Materials and Methods

The materials and methods section covers five major components of the project:

- selecting study sites
- designing a data collection program and installing data collection stations
- developing communication material and communication plan (participant engagement plan) and recruiting participants
- designing the rain barrel and the retrofits
- installing rain barrels and collecting data

Each of the listed components was unique and involved working with multiple stakeholders. Details of the different components are included in the following sections.

4.1 Study Area Background

This section provides an overview of the Beecher Creek watershed characteristics. Note that in addition to the study area figures provided in this chapter, a figure, similar to Figure 4-2 but plotted on a larger paper providing more details, is given in Appendix D.

4.1.1 Stream Location and Overall Description

Beecher Creek watershed (2.36 km^2) is in the municipality of Burnaby (Figure 4-1 and Figure 4-2) and part of the Greater Vancouver Regional District(GVRD), also known as Metro Vancouver, in southwest British Columbia. It is an urban watershed with a total impervious area (TIA) of 55% (GVRD, 2001). Beecher watershed, which contains about 3.33 km of waterways, drains to Still Creek. Still Creek subsequently drains to Brunette River through Burnaby Lake. Brunette Basin is situated in the Fraser Lowlands (Page et al., 1999) and drains to the Fraser River. While the Brunette Basin is highly urbanized, it is viewed as critical habitat for maintaining salmonid population in the Fraser. The region has put a high priority on enhancement of the Brunette Basin streams. Beecher Creek supports about 2 km of Class A Fish

Habitat. There is a small population of resident cutthroat trout in the creek that is under constant stress and attempts to re-introduce Coho have resulted in some spawner returns (City of Burnaby et al., 2001; J.Atwater, personal communication, September 2010).

Beecher Creek originates in the Capital Hill neighbourhood and drains south to Still Creek partially through underground pipes and culverts and partially through open natural or constructed channel. The main channel of the creek is an open channel. The open channel is intercepted by two major crossings. There is a road crossing at Lougheed Highway and a railroad crossing further downstream at the lower reaches. The upper reaches, which flow through parks and residential lands, have a fairly natural stream channel and riparian buffer. The lower reaches of the creek, which flow through industrial lands, have been heavily impacted by urbanization.

Beecher creek is a third order stream and one of the two major remaining tributaries to Still Creek. There is groundwater flow into the creek that allows for the maintenance of minimal flow year round. The groundwater flows over a layer of glacial till and is replenished by rainwater; there is concern that increase in impervious surfaces in the basin would further reduced summer base flows (J. Atwater, personal communication, September 2010). The stream receives drainage from several major storm sewer outfalls that drain residential areas. It also receives some industrial drainage (at the lower reaches) and drainage from a golf course (near the headwater).

The streambed is hydraulically and morphologically stable after some 40 years of response to land change (J. Atwater, personal communication, September 2010). The morphology of the creek alternates between low gradient pool/glide and artificial pool/riffle or riffle/culvert pool when culverts are present (UBC Landscape Architecture Program, 2009).Downstream of the railway crossing (lower reaches) the streambed substrate consists of sand and silts. Upstream of the railway crossing the streambed is mostly composed of cobbles and boulders (UBC Landscape Architecture Program, 2009).

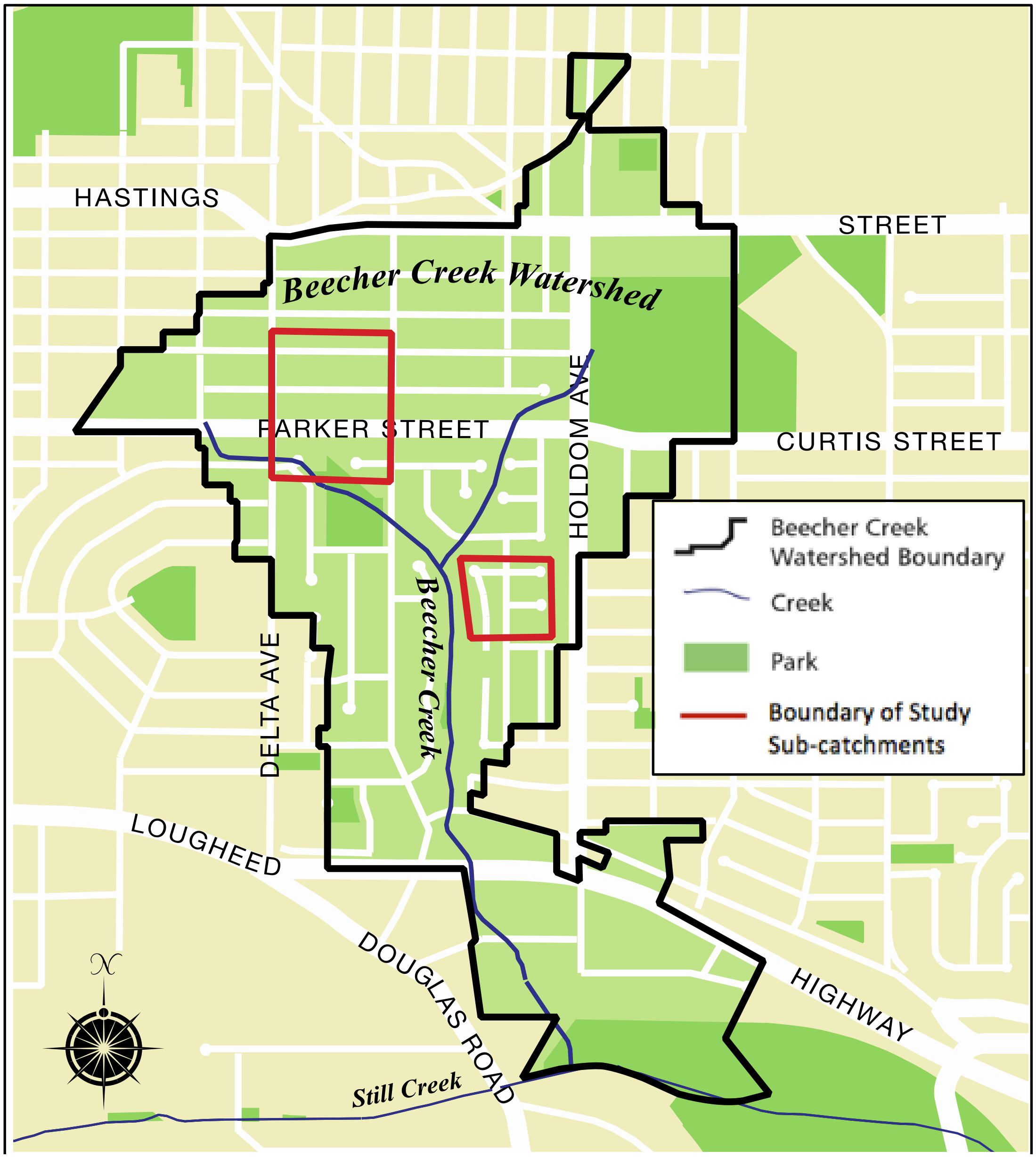

Figure 4-1: Schematic of the Beecher Creek Watershed showing the watershed boundary, the creek, and the study area sub-catchments relative to Burnaby streets (City of Burnaby Engineering Department, 2009)

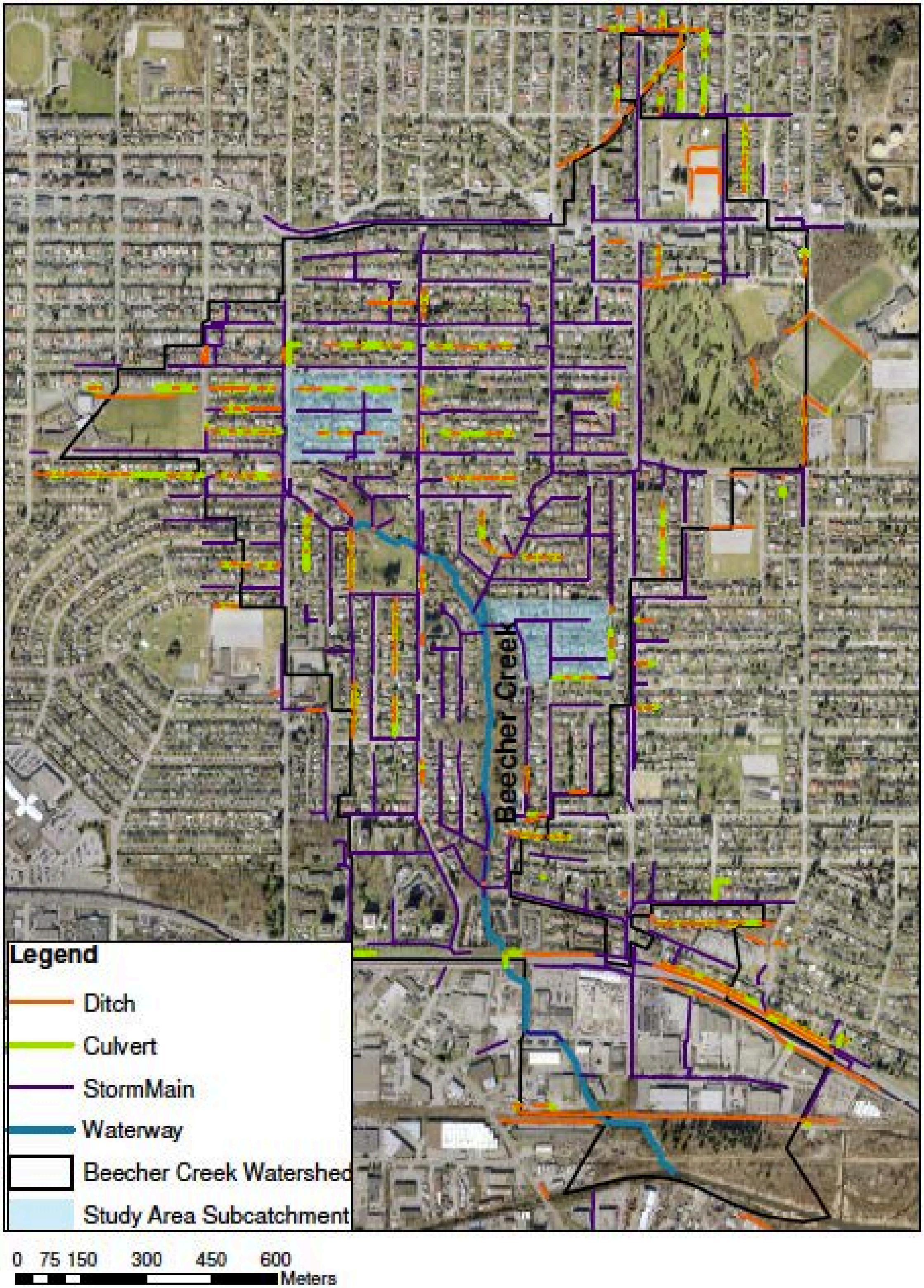

Figure 4-2: Map of Beecher Creek Watershed showing land use and the drainage network.

4.1.2 Land Use and Storm Sewer System

The 2.36 $km^2$of land use in the Beecher Creek watershed is mostly residential with some industrial uses at the lower reaches (mostly south of the Lougheed Highway). A few dispersed institutional properties, parks and a golf course make up the remainder of the catchment(City of Burnaby, DFO, & Streamkeepers of Burnaby, 2001).The Beecher Creek watershed area north of the Lougheed Highway crossing, referred to as Upper Beecher Creek watershed from this point on, is approximately 1.75 km^2. Upper Beecher Creek has a total impervious area of roughly 42%, which consists of roads and sidewalks (15% of total area), roofs (18% of total area) and driveways (8% of total area). The total pervious area of Upper Beecher Creek is approximately 58% and consists of lawns (42% of total area), parks (13% of total area) and the Beecher riparian corridor (3% of total area).

The housing in the Beecher Creek basin is dominantly single or two family home dwellings (City of Burnaby, 2006a, 2006b). The majority of the properties in the catchment are connected to the separated storm sewer. This includes the roofs, which are connected to the storm sewer via roof leaders (downspouts). There are about 8 major storm sewer outfalls that drain about 1020 lots to Beecher Creek between Parker Street and Lougheed Highway.

4.2 Study Site Selection and Description

This section describes the criteria for selection of study area sub-catchments as well as the characteristics of each of the study area sub-catchments: Beecher 1 and Beecher 3.

4.2.1 Criteria

The criteria for selection of study sub-catchment(s) were as follows:

1. the sub-catchment ideally contains about 100 single or two-family homes that are connected to the storm sewer system

2. the sub-catchment’s outfall to Beecher Creek must be conducive for setting up a flow monitoring station

3. the sub-catchment must be north of the Beecher Creek flow monitoring station at the Broadway crossing (see Figure 4-3for the location of the Beecher flow monitoring station)

There were no sub-catchments in the Upper Beecher Watershed that met all the criteria. As a result, two smaller sub-catchments were selected. There are 93 lots within the two sub-catchments' boundaries. Outfalls of the sub-catchments allowed for installation of flow monitoring stations. The study sites are called Beecher 1 and Beecher 3.Figure 4-3 shows the relative locations of the study area sub-catchments within the watershed.

Figure 4-3: Schematic showing location of Beecher 1 and Beecher 3 study areas relative to the Beecher flow monitoring station.

4.2.2 Beecher 1 Study Area

Beecher 1 study area is approximately bounded by Union St. on the north side, by Parker St. on the south side, by Delta Ave. on the west side and by an alley west of Springer Ave. on the east side (Figure 4-5).The study area (approximately 4.0 ha) is within a sub-catchment (approximately 5.0 ha) that drains south to a tributary of Beecher Creek via a stormwater outfall. The Beecher Creek tributary is a narrow open channel that passes through multiple culverts and crosses under Springer Ave. before joining the main stem of Beecher. Photos in Figure 4-4show the outfall to the tributary and the area surrounding the Beecher 1 monitoring station. On January 2010, a v-notch weir was installed upstream of the first culvert to monitor the flow out of the sub-catchment. A water level data logger (pressure transducer) was placed about 1 m upstream of the weir under the stream bank. The logger has been collecting absolute pressure and temperature readings of the stream at 5-minute intervals since it was launched.

There are 51 lots, single or two-family homes, which drain to the tributary upstream of the culvert. Some lots are directly connected to the storm sewer and some are connected via ditches and culverts that serve the alleys behind the properties. Review of the connection data (as-built drawings) from the City of Burnaby revealed that27 lots are directly connected to the storm sewer system. After site inspection, it was determined that an additional 13 lots can be classified as connected bringing the total to 40 lots that are connected to the storm sewer. Figure 4-4 shows the storm sewer network in the sub-catchment.

The area is zoned as a Residential District (R4). According to the City Bylaw, in the R4 zone:

- minimum allowed lot area for a single-family dwelling is 557.4 m^2
- minimum allowed lot area for a two-family dwelling is 758 m^2
- lot coverage should not exceed 40% for lots having garage or carport attached to the principal building
- lot coverage should not exceed 45% for lots having a garage or carport detached to the principal building

Rough estimations of average roof area and total roof area in the sub-catchment were made by using Geographic Information System (GIS) software to measure the roof areas from aerial images. Average lot size in the sub-catchment is 690 m^2. Average roof area for the main building in the sub-catchment is about 170 m^2. The total roof area covers approximately 16% of the study area.

Figure 4-4: Top Left: photo of tributary banks and channel, Top Right: photo of Beecher 1 study area outfall, Bottom: photo of the riparian area surrounding the Beecher 1 monitoring station, the v-notch weir and the culvert inlet.

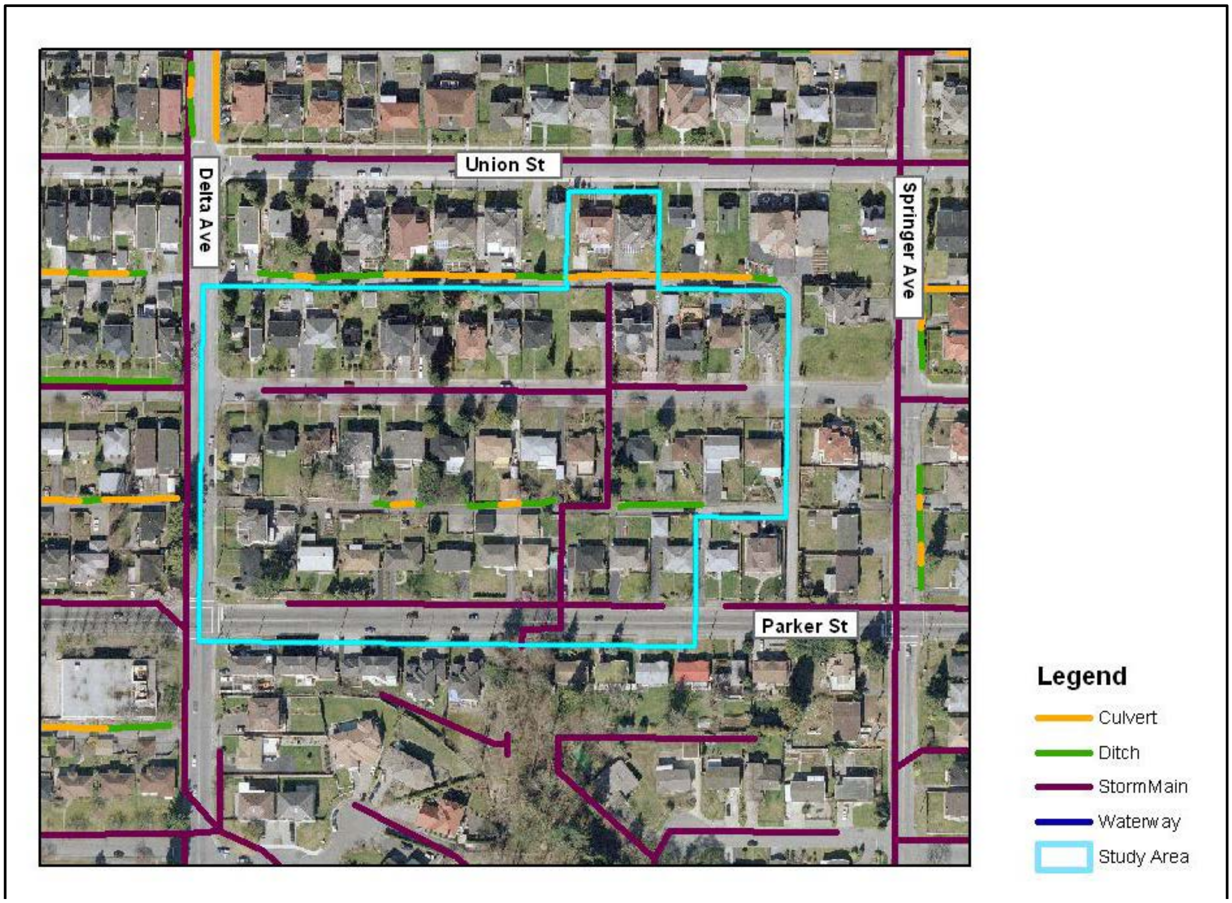

Figure 4-5: Beecher 1 study area map showing land use and connection data

4.2.3 Beecher 3 Study Area

Beecher 3 study area (approximately 4.4 ha) is bounded by the Beecher Creek riparian corridor on the west side and by Holdom Ave. on the east side. The boundary on the north side is just north of Heathdale Ct. and the boundary on the south side is just south of Tye Ct.. The sub-catchment drains west to Beecher Creek (Figure 4-6). The outfall to Beecher Creek is a300 mm pipe that drains into the creek at 2% slope. On February 2010, a square weir was installed inside the pipe to monitor the flow from the sub-catchment. A manhole about6 m upstream of the outfall allows access to the pipe. Through the manhole, a water level data logger (pressure transducer) was placed behind the weir. The logger has been collecting absolute pressure and temperature reading in the pipe at 5-minute intervals since it was launched.

There are 42 lots, single or two-family homes, which are directly connected to the storm sewer system. Figure 4-6shows the storm sewer network in the sub-catchment.

The area is zoned as a Residential District (R2). According to the City Bylaw, in the R2 zone, the minimum allowed area for a single family dwelling lot is about 669 m^2. The lot coverage by buildings and structures should not exceed 40%. On average, the lots in Beecher 3 (R2 zone) are larger than the lots in Beecher 1 (R4 zone).

Rough estimations of average roof area and total roof area in the sub-catchment were made by using GIS software to measure the roof areas from aerial photos. Average lot size in the sub-catchment is 730 m^2 Average roof area in the sub-catchment is 230 m^2. The total roof area covers about 23% of the area in the sub-catchment.

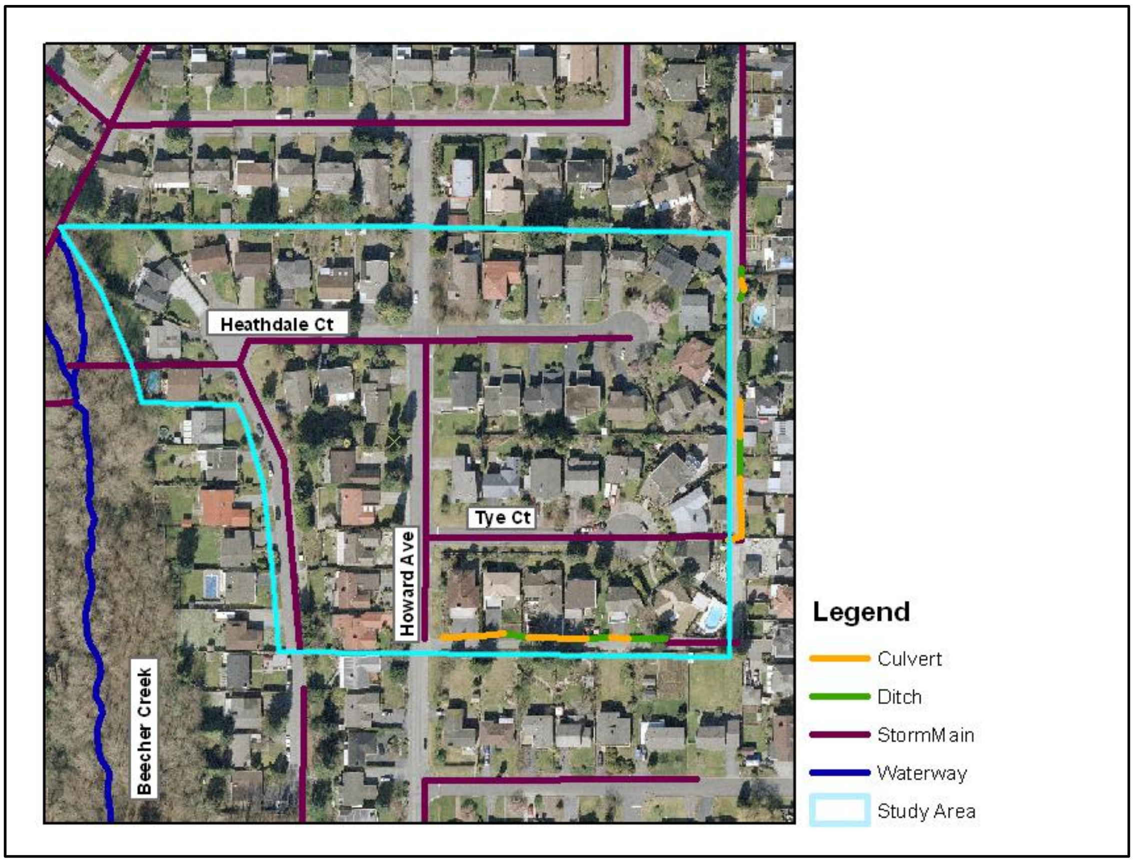

Figure 4-6: Beecher 3 study area map showing land use and connection data

4.3 Data Collection Program

This section provides an overview of the data collection program for the study including the methodology for measuring each variable and the quality control and quality assurance program.

4.3.1 Measured Variables

The following variables were continuously recorded for the duration of the study or longer: rainfall depth, Beecher flow at the Broadway culvert crossing, temperature and absolute pressure at the Beecher 1 monitoring station, temperature and absolute pressure at the Beecher 3 monitoring station, and barometric pressure at the Beecher 2 site. In addition, monthly manual flow measurements were made at the Beecher 1 weir and Beecher 3 weir.

The data collection program included using one data logger to monitor and measure water levels in two rain barrels. Each of the monitored rain barrels was part of a retrofitted site. One rain barrel was monitored during the test period. The data collected during the test period is called Beecher 4 data. Another rain barrel was monitored for the duration of the data collection program following the test period. The rain barrel data collected during this period is called Beecher 5 data.

Further details of the data collection program are described below.

Rainfall and Beecher Flow

A joint effort by the City of Burnaby, Kerr Wood Leidal Associates Ltd. (KWL), and the UBC Civil Engineering Departmental culminated in the establishment of precipitation and flow monitoring stations in the Beecher Creek Watershed. These stations, which record continuously, have been in operation since November 2006. The rainfall station is located on the roof of the Kensington Park Arena Ice Skating Rinks, at 6159 Curtis St, just outside the watershed boundaries. Beecher flow is measured at the downstream end of the culvert crossing at Broadway. The location of the Beecher flow monitoring site is shown on Figure 4-3. A broad-crested weir at the outlet of the culvert is controlling the flow. A vented tube pressure transducer, placed in a stilling well by the weir, has been recording water levels. Water level readings are converted to flow measurements using a rating curve and are available from FlowWorks (FlowWorks.com).FlowWorks is a web platform operated by KWL that hosts the Kensington Rainfall and Beecher Flow data.

Beecher 1 Sensor Depth

The Beecher Creek tributary, at Parker between Delta and Springer, receives drainage from 51 residential lots upstream of the culvert shown in Figure 4-4. This tributary is a narrow stream that flows through a ravine and Beecher Park before going underground to cross Springer and joining the main stem of Beecher. A v-notch weir was installed upstream of the culvert. An Onset HOBO U20water level data logger/pressure transducer was placed under the stream banks approximately 1 m upstream of the weir. The data logger was launched on January 2010 and has been recording continuously ever since. The logger reports absolute water pressure and water temperature every 5 minutes. Another HOBO U20 water level data logger/pressure transducer, Beecher 2, was placed in the backyard of a nearby house that is located very close to the Beecher 1 monitoring site. Beecher 2 is continuously recording barometric pressure to allow conversion of Beecher 1 absolute pressure readings to sensor depth measurements.

Manual weir readings were taken at least once a month and more frequently at the beginning of the study. Manual weir readings were used to develop a relationship between sensor depth measurements and weir flow and to check the consistency and quality of data over time. More details on quality control and quality assurance measures are provided in Section4.3.2

Beecher 3 Sensor Depth

The Beecher 3 study area outlet pipe receives drainage form 42 houses. A square weir was installed inside a 12 inch diameter pipe. A manhole, approximately6 m upstream of the pipe outlet allowed access to the pipe for dispatch of the data logger behind the square weir.

An Onset HOBO U20Water level data logger/pressure transducer was placed behind the weir. The logger reports absolute water pressure and water temperature every 5 minutes. The logger has been in operation and continuously recording data since February 2010. Readings from the

Beecher 2 data logger were used to allow conversation of the Beecher 3 absolute pressure readings to sensor depth measurements.

Manual flow measurements were taken using a bucket at least once a month. Manual flow measurements were used to develop a relationship between sensor depth measurements and pipe flow and to check the consistency and quality of data over time. More details on quality control and quality assurance measures are provided in Section 4.3.2.

Beecher 2 Barometric Pressure

An Onset HOBO U20 data logger for recording barometric pressure was placed in the backyard of a house very close to the Beecher 1 monitoring site. The location of the Beecher 2 data logger was chosen to ensure security (protection from theft and vandalism) of the logger as well as to ensure sufficient proximity to the locations and elevations of other loggers in the study area. The data logger manufacturer recommends placing the logger that is recording barometric pressure within a 10 km radius of the data loggers recording absolute pressure. All the data loggers installed for this study were within a 1 km radius of the Beecher 2 data logger.

The logger has been in operation since January 2010 and has been recording atmospheric pressure and temperature measurements every 5 minutes.

Beecher 4 and Beecher 5 - Rain Barrel Performance Monitoring

In order to monitor the performance of the rain barrels on retrofitted sites, an Onset HOBO U20 water level data logger named Beecher 4 was placed in a rain barrel from July 2011 to January 2012. The same data logger was re-launched at the end of January 2012, renamed Beecher 5, and placed in a different rain barrel for the rest of the study period.

Data Collection

Data from Beecher 1, 2, 3, 4, and 5 data loggers were downloaded on a monthly basis using a HOBO Waterproof Shuttle. The Shuttle reads out the data from the loggers in the field. It stores the data and allows data transfer to a host computer at any location. The Shuttle also resets the loggers' times to the shuttle's time and synchronizes the loggers' logging interval on re-launch.

4.3.2 Quality Control and Quality Assurance

All measured data was reviewed on a monthly basis to ensure the quality of the collected data and to take any corrective action needed to ensure the relative accuracy and consistency of data being collected. The goal of the program was to collect data that was relatively accurate and consistent and not necessary precise. For instance, the objective of the program was not to determine the true value of flow in the Beecher 3 pipe but to make sure that the relationship between the measured flow and the true value of flow is consistent over multiple years.

The following actions were taken for Beecher 1 and Beecher 3 sites:

- Ensure that the data logger is always returned to the same location after data retrieval.
- Compare time series of sensor depth before and after data is offloaded and determine if there are any sudden jumps or drops in data. If there are any sudden changes, correct the change.
- Visually inspect the data from all data loggers and ensure that the changes in sensor depth make physical sense (i.e. correlate to rainfall events, dry periods and when applicable to changes in Beecher flow).
- Take a manual weir reading (at Beecher 1) and a manual flow measurement (at Beecher 3) and compare each reading to the relevant sensor depth readings and to Beecher flow. Over time, the following relationships were defined: Beecher 1 sensor depth and v-notch weir flow; v-notch weir flow and Beecher flow; Beecher 3 sensor depth and square weir flow; square weir flow and Beecher flow. It was expected that it would be possible to detect data logger drift using the aforementioned relationships.
- Compare Beecher 2 readings to readings from nearby weather stations.

The record and results of the quality control and quality assurance activities are described in Section 5.

4.4 Communication/Engagement Material and Plan

One of the major project tasks was to install rain barrels on residential properties within the study sub-catchments. The cooperation of the study area residents and their participation in the study was crucial for successful implementation of the retrofits. This section of the study describes the methods used to determine how to consult study area residents and how to gain their cooperation. This section also describes what was implemented.

Some of the aspects of the communication/engagement plan were pre-determined by the agreement between the City of Burnaby and UBC. The following items were previously agreed upon:

1. Rain barrels will be offered to study area residents at no cost as incentive for participation.
2. The City of Burnaby will contact the study area residents via direct mail to notify them of the project.
3. The UBC graduate student will contact and recruit residents by making house visits.
4. All communication efforts will be discrete so not to attract the attention of Burnaby residents that lived outside the study area.

The foundation of the communication plan for the Beecher Creek Rain Barrel project was in place from the start of the project: direct mail and face-to-face meetings were going to be the main modes of communication. The major restriction for the communication plan was that the City did not want to attract the attention of residents that lived outside of the study area. All communication efforts had to be discrete as the City was concerned about complaints from residents that were not eligible to receive free rain barrels. This constraint prevented the use of outreach techniques that others had successfully implemented in the past such as doing presentations and recruitment at schools, public events, and public venues.

At the start of this research project, the major questions that had to be answered regarding communication were:

- What should be the content of the communication material? What type of messaging should be used to communicate with the study area residents?
- What should be the schedule and sequence of mail outs and site visits?
- What additional incentives and strategies can be incorporated in the plan to increase the probability of project success?

To answer the questions, research was done through literature review and consulting local practitioners. Two major resources were used to develop the communication material and plan: the *Landowner Contact Guide for British Columbia* (Duynstee, 1997) and to the extent that time and resources allowed, the principles of community-based social marketing (Mckenzie-Mohr, 2000). As it is outlined in Section 3.3, CBSM involves four major steps: identifying barriers and benefits to behaviour change, designing strategies, piloting the strategies, and finally evaluating the strategies (Mckenzie-Mohr, 2000). Based on the CBSM approach, the following steps were taken to develop and evaluate the communication/engagement plan for the Beecher Creek Rain Barrel Project:

1. Developed an initial promotional program and communication strategy based on preliminary research and previous experiences. The *Landowner Contact Guide* (Duynstee, 1997) was a major resource for the preliminary communication plan, which was outlined in the proposal to the City of Burnaby.
2. Conducted research to identify barriers and benefits to residents' participation in the study.
3. Based on the information collected on barriers to participation, selected which aspects of the projects to promote and developed communication material that directly addressed the barriers identified previously.
4. Evaluated the communication material using a test audience and made modifications based on the feedback.
5. Finalized the communication material and communication plan and executed the pilot.
6. Evaluated the effectiveness of the communication plan (Section 5.1).

The following sections summarize the methods and materials used for steps 2 to 5 listed above.

4.4.1 Identifying Barriers and Benefits

As per principles of CBSM, the first step taken in developing the communication material and strategy was to identify the barriers to residents participating in the Beecher Creek Rain Barrel project and the benefits to residents participating. The following steps were taken to achieve this:

- conducted a literature review of similar projects in North America (Section 3.3),
- consulted multiple project stakeholders including the City of Burnaby staff and Prof. Jim Atwater (research supervisor and Beecher Creek Streamkeeper),
- consulted Vancouver based non-governmental organizations (NGOs), which are focused on promoting sustainable behaviour around watersheds, and
- aggregated local knowledge on the issue.

The research is described below and the result is summarized in Table 4-1 and Table 4-2. A number of possible barriers were identified through the review of the five programs highlighted in Section 3.3.2. A couple of the studies found that people not owning their place of residence is a barrier to participating in retrofit programs (Ando & Freitas, 2011; Belan & Nenn, 2010). There is also some evidence that the aesthetics of the retrofit and the cost of the retrofit were barriers to participation (Hatziantoniou, 1999; Wright et al., 2009). A couple of reviewed authors indicated that a strong sense of community facilitates the execution of neighbourhood retrofits (Belan & Nenn, 2010; Wright et al., 2009). Therefore, a lack of community and social norm around can be possible barriers

In *Evaluation of Voluntary Stormwater Management Initiatives in Urban Residential Areas: Making Recommendations for Program Development in the City of Vancouver*, Hatziantoniou (1999) reviewed the following City of Vancouver programs: Rain Barrel program, Downspout Disconnection Pilot Project, and Perforated Sump Pilot Project. Hatziantoniou summarized the barriers and benefits to adoption of the technologies that the programs offered as identified by program managers and participants (Table 4-1).

In 2010, as part of their of their school curriculum, a group of UBC MBA students surveyed 100 people from the Metro Vancouver region to better understand public level of awareness of rain barrels in Vancouver and to understand barriers to purchasing of rain barrels. They found that only 50% of the survey respondents had heard of rain barrels. They also found that the most common barriers to purchasing a rain barrel were: concerns about mosquitoes, lack of knowledge about where to purchase rain barrels, and rain barrel aesthetics (Bozzer et al., 2010).

Based on the research presented in this section and conversations with the City of Burnaby staff, the barriers to participation in the Beecher Creek retrofit project and the perceived benefits to participation in the project were identified and are summarized in Table 4-2.

Table 4-1: Barriers and benefits for the City of Vancouver rain barrel program (Hatziantoniou, 1999)

Barriers to adoption as identified by program managers and study participants	• Cost to homeowner. • Poor example of others or limited exposure to appropriate role models. • Lack of motivation to participate (due to the perception that individuals cannot have an impact on the problem setting). • Lack of incentive to participate (e.g. no direct savings on water bills). • Concerns over non-feasibility of disconnection work on property. • Lack of skill or comprehension required to install SMP. • Need for contractor to conduct SMP work. • Fear of flooding/groundwater seepage resulting from SMP work. • Unsuitability of property for SMP work (due to size, slope, soil, and groundwater
Benefits of the program as identified by study participants	• Good feelings for homeowner (due to alleviation of 'environmental guilt'). • Free sump for home-builder/renovators. • Healthier garden (using rain barrel). • Flexibility in water/ability to comply with lawn sprinkling regulations (using rain barrel). • Environmental benefits. • Potential protection of property against flooding (using perforated sump). • Storage of an emergency water supply (using rain barrel).

Table 4-2: Potential barriers and benefits to participation in the Beecher Creek Rain Barrel Project

Barriers to participation	• Difficulty understanding the project's ultimate goal leading to lack of motivation to participate in the study (water quantity management is not as popular and well understood a concept as water conservation). • Concerns about construction on property. • Fear of basement flooding and flooding on property as a result of modified drainage. • Concerns about standing water and mosquitoes. • Aesthetics and size of the rain barrels • Water in the rain barrels not being available to residents for the duration of the study. • Lack of social norms around rain barrel use. Limited exposure to appropriate role models.
Benefits of participation	• Free rain barrel(s). • Free delivery and installation of the rain barrel. • Exemption of water collected by rain barrels from lawn sprinkling regulations. • Chlorine free water for gardening • Good feelings for homeowner that have a personal connection to Beecher Creek (due to doing environmental good).

Once the barriers and benefits to participation in the project were identified, the next step was to re-visit the communication/engagement plan (the components that were included in the agreement between UBC and the City) and improve it based on the research. In addition to a communication plan and schedule, communication material had to be developed and tested. The following sections describe the process for creating the communication material and plan.

4.4.2 Developing the Communication Plan

The project work plan (Table 2-1) called for contacting and engaging the study area residents through direct mail and face-to-face meetings. The communication plan incorporated these activities as well as establishing a routine for communication between UBC and the City of Burnaby. In addition, to increase the likelihood of residents participation in the study, the communication plan was developed to accommodate the implementation of some of the tools of community-based social marketing including: seeking commitment, using prompts, creating norms, communicating effectively, offering incentives and removing external barriers (Mckenzie-Mohr, 2000).The plan included communication materials that were developed and tested to communicate effectively, promote incentives, and reduce barriers. The communication plan also included a schedule that was designed so that the study area residents:

- would be prompted multiple times over the course of the project through letters from the City and door knocking;
- would have a chance to observe the early participants as rain barrel were installed in phases; and
- would be prompted by their neighbours to participate and would be motivated by a new norm in their neighbourhood.

The major components of the communication plan are summarized in Table 4-3. The research used for developing the communication material is summarized in Section 4.4.3.

Table 4-3: Beecher Creek Rain Barrel communication plan and schedule

	First Letter
Week 1	Mail out the first contact letter. This letter will give notice of the project to study area residents and ask them to contact Sara Pour for more information. Expect to get calls within 48 hours. Follow up with a second letter.
	Second Letter
Week 2	Mail out the second contact letter within a week of the first letter. This letter will give residents a second notice and will notify them of a site visit. Attach the project pamphlet to the second letter so homeowners have a chance to read it before the site visit. The four-page pamphlet provides a brief project background, project description, and an overview of the reason for the pilot project.
	First Round of Site Visits
Week 3	Start the first round of door knocking within a week of sending out the second letter. Deliver a copy of the pamphlet and introduce the residents to the project. If a resident is ready for a rain barrel, conduct a site survey of the property and schedule a date for rain barrel delivery and installation. If a resident asks for time to make a decision, schedule a follow up phone call or site visit. Prepare a brief report for the City of Burnaby that summarizes the response from the homeowners.
	Follow Up Site Visits
Week 4 - Week 8	Continue door knocking and site visits to recruit participants. Schedule as many site visits as required to have a rain barrel installed on a property. Install rain barrels for the first few residents as soon as possible so that rain barrels are on display in the neighbourhood. Schedule follow-up site visits with homeowners once the rain barrels are installed to make sure the setup is working (i.e. visit all rain barrels a month after installation). Prepare a brief report for the City of Burnaby that summarizes the response from the homeowners and the number of rain barrels delivered and installed.
	Wrap Up
End	Send the final contact letter to inform the study area residents that the study period is over, to inform them of the study results, and to let them know that they can use the rain barrels as the wish. This letter will also let the residents know that at this time, they can request that the rain barrels be removed.

4.4.3 Communication Material

Based on the requirements of the communication plan, a communication package (information package) was prepared in cooperation with the City of Burnaby. The components of the communication package are highlighted in Table 4-4 and the content is included in Appendix A. The guiding principles for developing the communication material are described in the next paragraph. The communication material was evaluated using a test audience. Feedback from the test audience and City of Burnaby staff were incorporated before finalizing the material.

Table 4-4: Communication Package

Item	Communication Package
1.	Multiple contact letters: for project initiation and wrap up (see Table 4-3 for description)
2.	Project Pamphlet: brief, simple, and graphical explanation of project background, project description, and the project goals
3.	Sample Questions and Answers: this document anticipated the questions that the study area residents might ask and provided answers to them. This was intended for City of Burnaby staff in case they received questions from the public.
4.	Site Survey: a questioner and a checklist, which had to be completed after each site visit.

To determine the content, the message and the language of the communication material, research was done through literature review and consulting local practitioners. Based on the principles of CBSM, the communication materials were developed and tested to communicate effectively, and to promote the incentives and reduce the barriers defined in Table 4-2. The following additional guidelines, which were used for developing the communication material, were compiled based on the research and discussions with the City of Burnaby.

- Use simple and direct messaging with grades 4 to grade 5 writing level (T. Stubbs, personal communication, May 25, 2010).

- The message should have the following components: who you are, why you are contacting the landowners and what you have to offer (Duynstee, 1997).
- Do not focus on how the project benefits the creek instead articulate how the project benefits the residents and their families. Benefits to the creek and the society at large should be articulated as well but are secondary (T. Stubbs, personal communication, May 25, 2010).
- Make the connection between rainfall, the properties' roofs, the flow in the creek and the impact on fish and watersheds clear (J. Atwater, J. Carne, City of Burnaby, personal communication, May 2010).
- Remove barriers (emphasize that the project requires no effort on the resident's part and address the resident's concerns) and provide extra incentives (prizes such as a credit to a local business) (T. Stubbs, personal communication, May 25, 2010).
- Provide a clear description of the changes that are going to be made to the resident's property as the result of the retrofit and provide visuals (City of Burnaby, personal communication, May 2010).
- Target a specific segment of the population. Research has shown that objectives of environmental programs are more effectively achieved if the programs target specific segments of the population versus the general public and if the communication is personal (tailored) and direct versus general messages delivered to broad segments of population through passive advertising (Ando & Freitas, 2011; Dietz et al., 2004; Duynstee, 1997; Hatziantoniou, 1999; T. Stubbs, personal communication, May 25, 2010). By their nature, pilot projects target a specific segment of the population so having a broad audience was never a concern for the Beecher Creek Rain Barrel project.

The communication package is included in Appendix A.

4.4.4 Execution of the Communication Plan

The communication collateral discussed in Section 4.4 (including Table 4-3 and Table 4-4) was used to carry out phase 1 of the project and to recruit participants for the study. The outcome of phase 1 is presented in Section 5.

4.5 Rain Barrel Design - Goals and Process

The objective of the project with regards to the rain barrels was to demonstrate that runoff storage and detention on residential sites (referred to as on-site storage) can have a regulating effect on stream flow in Beecher Creek for small frequent events. Possible indicators of rain barrels having a regulating effect are: reduction in peak flow, reduction in first peak after a storm event, increase in lag time, extended duration of storm flow, and increase in base flow. It was also hypothesized that detaining roof runoff during wet periods and releasing it during dry periods could increase exfiltration through joints in the storm sewers and consequently affect baseflow in Beecher Creek or its tributary.

The objectives of the rain barrel design were to:

- collect roof runoff from single-family residential units, provide detention, and discharge to the storm sewer in a manner that reduces flashiness in Beecher Creek
- set the discharge rate of the barrel to maximize the detention time of collected runoff while minimizing the percentage of time that rain barrels overflow during small frequent events. In other words, optimize the discharge rate so that the runoff collected in the rain barrel discharges as slowly as possible without resulting in rain barrel overflowing during consecutive rainfall events
- design a robust drainage mechanism so that rain barrels require minimal maintenance
- design a flexible retrofit so that the design can be easily implemented at different settings

Major design constraints included:

- lack of information about the physical condition at the residences that would be receiving rain barrels
- limited selection of readily available and reasonably priced small pipes, elbows and valves

The conceptual design for the rain barrel is described below.

> Each rain barrel will be modified with a siphon and a very slow releasing orifice so that the rain barrel has two different discharge mechanisms and two different release rates:

one for frequent, low intensity events and one for events with higher intensity. An orifice with a low discharge rate will continuously drain the water collected in the barrels. The orifice discharge rate will be low enough to provide some detention for the small frequent events. Every rain barrel will have a siphon with a higher discharge rate. The siphon will only get activated during higher intensity events that fill up the rain barrel. The siphon has a much higher discharge rate than the orifice and will ensure that the rain barrel has some capacity to accept runoff following a high intensity rainfall event. The advantage of the siphon over an orifice with a high discharge rate is that unlike the orifice, the siphon will not activate until the rain barrel is full allowing for some detention of the collected runoff.

Once the conceptual design for the rain barrel was in place, rain barrel proto-types were constructed and tested in the lab. The goals of the prototyping exercise were to determine a range of achievable discharge rates for the orifice and the siphon as well as to arrive at a rain barrel design that was robust and easy to construct. Once the range of achievable discharge rates was known, the overall impacts of different discharge rates and mechanisms were assessed using mass balance calculations and a continuous rainfall record (Section 4.5.3). The goal of the simple mass balance model was to determine how changing the rain barrel discharge rate and mechanism affects the volume of rainfall captured by the rain barrel. The design discharge rate for the rain barrels was finalized by taking into account the results of the prototype testing, the outcome of the mass balance modelling and the local design targets for stormwater management. The following sections provide detail descriptions of the rain barrel design process.

4.5.1 Local Design Targets for Stormwater Management

The local design targets for stormwater management (management of runoff rate and volume) are presented in this section of the report as a reference for the reader. The volume of a single rain barrel is too small to meet the requirements of any of the local targets but rain barrels can be used as part of an array of solutions to meet these targets.

The *Stormwater Source Control Design Guidelines (SSCDG) 2005* (Kerr Wood Leidal et al., 2005) presents two sets of design criteria for source control designers. One set is the requirements of the Department of Fisheries and Oceans (DFO) and the other is the province of British Columbia guidelines outlined in the *Stormwater Planning: A Guidebook for British Columbia* which was released in 2002 by the Ministry of Environment which was called the Ministry of Water, Land, and Air Protection at the time (Stephens et al., 2002). Both sets of design criteria require infiltration for the small frequent events.

The runoff volume reduction targets by DFO require retention and infiltration of the 6-month, 24-hour post-development runoff volume from impervious areas. If infiltration is not possible, the rate-of-discharge from volume reduction best management practices should be equal to the calculated release rate of an infiltration system. According to the *SSCDG 2005*, the analysis of rainfall data from a number of GVRD climate stations has shown that the 6-month, 24-hour event ranges from 67% to 76% of the 2-year, 24-hour event volume, with an average of 72%. *SSCDG 2005* also states that this result is consistent with other regional results from Washington State.

On the other hand, the provincial guidelines for runoff volume reduction require capture and subsequently infiltration, evaporation, and reuse of 0 to 50% of the Mean Annual Rainfall Event (MAR) or 90% of the rainfall volume in a typical year at the source (building lots and streets). The *Stormwater Planning Guidebook* presents the MAR 24-hour rainfall depths for different areas in the Lower Mainland based on analysis of historical rainfall record.

The storage volumes of the rain barrels were too small to capture 67% to 76% of the 2 year, 24 -hour event volumes or to capture 50% of the mean annual rainfall. The DFO volume reduction guideline states that if infiltration is not possible, the discharge rate of the volume reduction device should not exceed the release rate of infiltration system(Kerr Wood Leidal et al., 2005).

The source control design guidelines were updated in 2012 and include a maximum allowable discharge rate for flow restrictors such as orifices that are incorporated into the design of source controls (Kerr Wood Leidal, 2012). According to the *SSCDG 2012 Update*, the maximum allowable discharge rate from a flow restrictor that is considered acceptable by DFO is 0.25 L/s/ha or 0.09 mm/hr.

Beecher Creek Hydrological Design Criteria

Target Rainfall

Summer rainfall was the target rainfall to capture for the Beecher Creek Rain Barrel Project. It was assumed that the rain barrels would be overflowing for most of the winter months. Nick Page, a biologist who has extensively worked on the assessment, restoration, and management of terrestrial and aquatic ecosystem in Coastal BC and who has conducted two B-IBI studies for Beecher Creek, was consulted on the type of hydrological mitigation that would be beneficial to the benthic community in Beecher Creek. According to Page, winter flows cause the most damage to the community. Since managing high winter flows was not part of the scope of the Beecher Creek Rain Barrel Project, Page recommended regulating flows during the months of May and June since the maximum number of benthos are present during those months. He also recommended that increasing base flow during low flow periods, August, September and early October, might be beneficial (as cited in J. Atwater, personal communication, May 2010).

Discharge Rate

Based on *SSCDG 2012 Update*, maximum allowable discharge rate from the rain barrels is the equivalent of a winter base flow rate for the impervious catchment area or 0.25 L/s/ha. The winter base flow rate in the Beecher Catchment is estimate d to be 0.11 L/s/ha (20 L/s for 1.75 square kilometres). The maximum allowable discharge rate from a barrel is almost 0.04 mm/hr using the Beecher winter base flow as a criteria and it is 0.09 mm/hr using the value from the *SSCDG 2012 Update*, 0.25 L/s/ha, as a criteria.

It was assumed that each rain barrel captures runoff from a 50 m^2 roof area. It was also assumed that all rainfall is converted to runoff and none is lost to depression storage or evaporation (Konrad & Burges, 2001). Based on the presented assumptions, a 341 L rain barrel would overflow if rainfall depth exceeded approximately 7 mm. Draining at constant discharge rate equivalent to the maximum allowable rates, it would take more than 3 days for a full rain barrel to empty. In reality, it would take longer than 3 days for the barrel to empty since the discharge mechanism for the barrel is gravity driven and the outflow rate decreases with decreasing head.

These limits on discharge rates were not applied to the rain barrels, as the limited discharge rates would significantly limit the percentage of the rainfall that the rain barrels could capture.

4.5.2 Rain Barrel Descriptions

The City of Burnaby stocks two types of rain barrels. They are referred to as green rain barrels and beige rain barrels in this study.

The green rain barrel (Figure 4-7) is a product of Flexahopper Plastics Ltd. These products are half-cylinder designs that sit flush against a wall. There are two faucets on each rain barrel to accommodate hoses and watering cans. According to the manufacturer’s specifications, the barrel’s capacity is approximately 341 L (90 US Gal). The diameter at the base of the barrel is 107 cm (42 in) and the full height of the barrel is 137 cm (54 in). The barrel’s empty weight is approximately 20.5 kg (45 lb).

Figure 4-7: Green rain barrel on the left and beige rain barrel on the right are attached to downspouts via flow diverters.

The beige rain barrel (Figure 4-7) is a Systern Rain Barrel by Norseman Plastics, environmental products division of ORIBlS company. These products are full barrel designs. Each barrel can accommodate two faucets (spigots) for hose connections. According to the manufacturer's specification, the barrel's capacity is approximately 208 L (55 US Gal). The diameter of the barrel at the top of the barrel is approximately 66 cm (26 in) and the full height is approximately 86 cm (34"). The barrel's empty weight is approximately 7.3 kg (16 lb).

Both rain barrels have a mosquito mesh that covers the opening at the top of the barrel and prevents debris and bugs from getting inside. Both rain barrels can accommodate an overflow hose/pipe.

4.5.3 Rain Barrel Design and Discharge Mechanism

Once the conceptual design for the rain barrel was in place, rain barrel prototypes were constructed and tested in the lab to determine achievable discharge rates for the orifice and the siphon considering design requirements and availability of parts and material. Once the range of discharge rates for the orifice and the siphon were determined, a mass balance spreadsheet was used to estimate what portion of the total volume of runoff is captured at different discharge rates. Figure 4-8shows a typical green rain barrel after the modifications. Every rain barrel installation had four to five major parts:

1. connection to the downspout,
2. overflow pipe (often the same as the connection to the downspout),
3. siphon,
4. orifice, and
5. connection to the drain.

The processes for arriving at the final configurations for different components of the installation are described below.

Connection to the Downspout and Overflow Pipe

Two options were considered for connecting the rain barrel to the downspout. One was to simply disconnect the downspout, place the rain barrel under the downspout and install an overflow pipe on the rain barrel that connects to the drain. The second option was to use a commercially available flow diverter (top right corner of Figure 4-8), which diverts runoff from the downspout to the rain barrel and serves as an overflow pipe once the rain barrel is full.

Figure 4-8: Final green rain barrel modification

The second option was chosen for multiple reasons: simplified rain barrel design, ease of deconstruction and aesthetic qualities. All the flow out of the rain barrel including the flow from the overflow pipe, the orifice and the siphon had to be directed to the drain. Using a flow diverter simplified the design of the outflow pipe as the flow diverter eliminated the need for a separate overflow pipe. Although the diverters require more work to install than simply cutting a downspout, they simplify the disconnection of the rain barrels. With a diverter, a rain barrel can be disconnected by removing the pipe that connects the rain barrel to diverter and by placing a cap on the diverter.

Siphon

The purpose of the siphon is to empty the rain barrel during moderate to high intensity events that result in the barrel being full. The siphon only activates when the barrel is full. The siphon has a significantly higher discharge rate than the orifice. In the case of high intensity events, a rain barrel can fill up in a short period of time. Once a barrel is full, it can no longer accept significant quantities of runoff. Once a rain barrel is full, the long drain time of the slow draining orifice will likely result in the barrel not having significant capacity for accepting runoff at the time of the next rainfall event. The barrel was designed with a siphon, which drains more rapidly than the orifice, to increase the likelihood that the barrel having capacity to accept runoff from an event immediately following a moderate to high intensity event.

Figure 4-9 shows the siphon configuration without the faucet and without the connection to the drain. The faucet (which can be seen in Figure 4-8) allows for adjustment of the flow rate out of the siphon and it also facilitates the connection between the siphon and the drain. The smallest diameter rigid PVC pipe that was readily available for the project, 0.5 in schedule 40 PVC pipe, was the only pipe that was tested and used for the siphon. The main issues that the siphon design process had to address were:

- making the siphon airtight, and
- determining the head required for the siphon to activate.

To determine the minimum head required for the siphon to activate and to ensure that proper building techniques were used to make the siphon airtight, multiple rain barrel prototypes were assembled and tested. Once the siphon was designed, it was tested repeatedly to determine the behaviour of the siphon under various initial conditions. The goal was to arrive at a design that was robust and a siphon that would work every time.

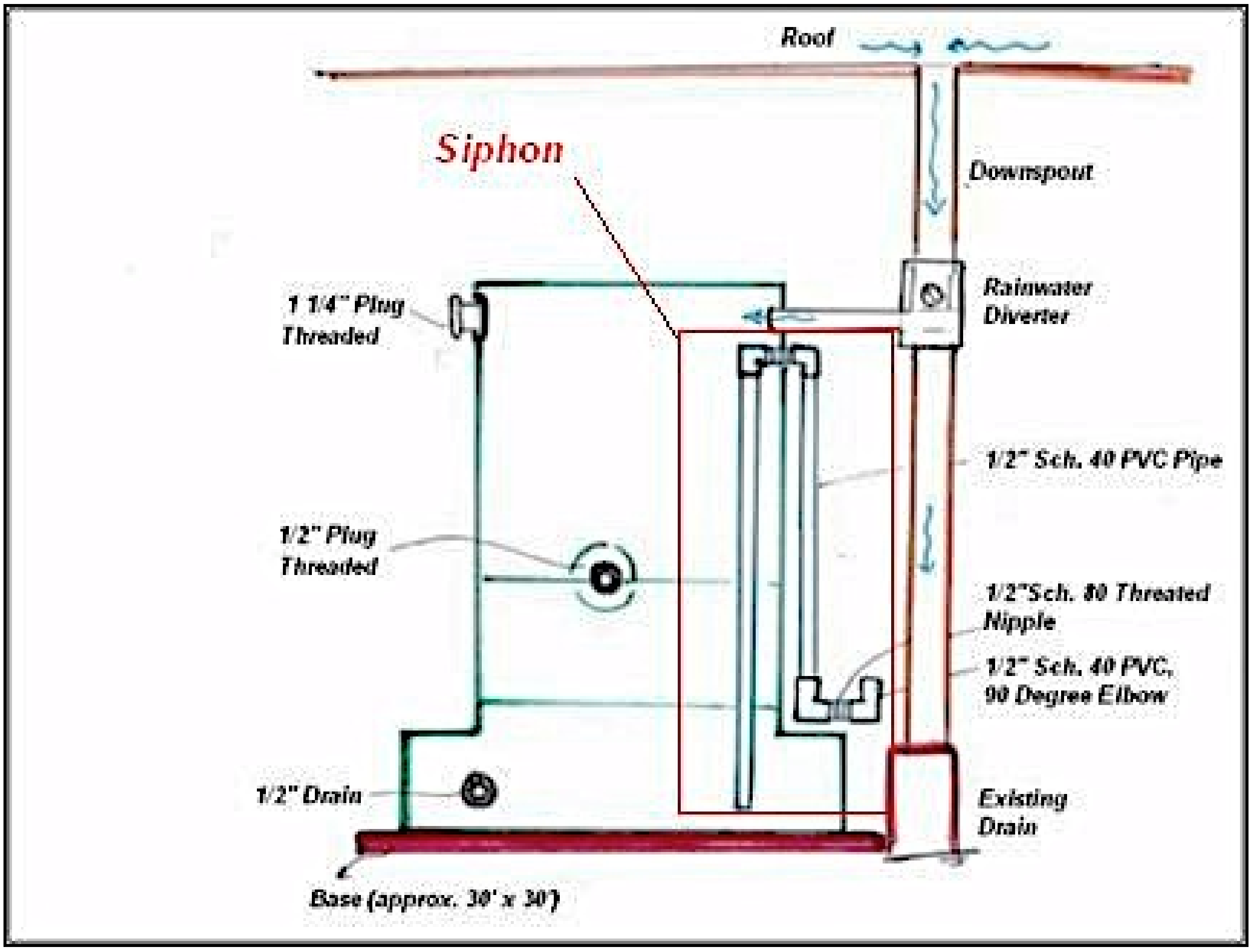

Figure 4-9: Rain barrel schematic showing parts and specifications excluding the connections to the drain.

Orifice

Both the Green and the Beige rain barrels are manufactured with 0.5 in fittings near the base of the barrel (Figure 4-9). The suppliers of both rain barrels provide faucets that can be attached to these fittings. Typically these faucets are used for hose connections. In this case, the faucets were used as orifices that controlled the flow out of the rain barrel. In Figure 4-8, the faucet with a black handle is acting as the orifice.

Connection to the Drain

To connect the rain barrel to the drain, a flexible tube Y connection was used (Figure 4-8). The Y tube fitted the fixtures that came with the rain barrel. One fixture (black faucet) was installed on the barrel to act as on orifice. The other fixture (red faucet) was attached to the end of the siphon to adjust the flow rate out of the siphon. Both faucets were connected to the Y connection, which drained the barrel. Other alternatives for the rain barrel drain connection were tested but the Y connection was selected due to ease of installation.

Summary of Prototype Testing

Two mechanisms for drainage were considered: orifice and siphon. Rain barrel prototypes were built and tested to determine how the orifice and the siphon functioned separately and together. Table 4-5 and Table 4-6 summarize the results of the test runs. General observations about the test runs are summarized in the following paragraphs.

Table 4-5: Rain barrel prototyping test results (one discharge mechanism)

Mechanism	Setting	Time to drain most of the barrel/Total Discharge Time
Orifice	Mostly Closed*	>48 hr
Orifice	Fully Open	30 min
Siphon	Partially Closed	Inconsistent, Does not work, >120 min
Siphon	Fully Open	Approximately 90 min

**refers to the lowest flow setting which allows most of the barrel to empty*

Table 4-6: Rain barrel prototyping test results (combination settings)

Mechanism	Setting	Mechanism	Setting	Time to drain most of the barrel/Total Discharge Time
Orifice	Fully Open	Siphon	Fully Open	<30 min
Orifice	Partially Closed	Siphon	Fully Open	Approximately 90 min.
Orifice	Fully Open	Siphon	Partially Closed	Approximately 30 min. Siphon’s flow is insignificant compared to the orifice.
Orifice	Partially Closed	Siphon	Partially Closed	Siphon does not perform robustly. Drain time varies depending on the setting on the orifice and can take up to 3 days.

Mass Balance Spreadsheets

Simple mass balance calculations were used to model the flow of runoff in and out of a rain barrel. The purpose of this simple modelling exercise was to determine how different discharge rates affect the total volume of water that can be captured by a rain barrel over the length of the rainfall record. The goal was to do a comparative exercise to determine what discharge rates result in maximum capture. The goal was not to determine exactly how much water a rain barrel could capture.

The spreadsheet input was rainfall events from November 2006 to June 2010. Rainfall depth data at 5-minute intervals from November 2006 to June 2010 were used to define rainfall events over the record length using a minimum inter-event time (MIT) criteria. When using MIT to define rainfall events, the rainfall record is divided up so that a fixed rainless period is reached before and after each rainfall event (Dunkerley, 2008). After reviewing a number of studies, Dunkerley (2008) found that MIT used by other researches ranges from 3 min to 24 hr. Two different MIT were used to define two sets of rainfall events for the mass balance spreadsheet and the mass balance calculations were done on both sets of data to assess the suitably of various assumptions. One set of rainfall data was defined using a MIT of 15 min and a second set of rainfall data was defined using a MIT of 2 hr. Additional assumptions for the calculation are summarized below.

- Assumed that 50 m^2 of roof runoff is contributing to the barrel.
- To model orifice flow, assumed that the barrel is continuously draining at a constant rate. The constant discharge rates used for the orifice ranged from 0.1 L/min to 2.8 L/min (0.12 mm/hr to 3.4 mm/hr for a 50 m^2 roof area).
- To model siphon flow, assumed that the siphon can only operate between rainfall events and only when the rain barrel is full following a rainfall events. The discharge rate used for the siphon was not constant and was based on the observed discharge rates in the lab. In the model, for all scenarios, the rate for the siphon was set so that the siphon emptied a full barrel (340 L) in 2 hours.

For each series of rainfall events, multiple scenarios were modelled. For one set of scenarios, the rain barrel was allowed to drain only through the orifice. For different constant discharge rates, the percentage of events that results in a rain barrel being full/overflowing was calculated. For the second set of scenarios, the rain barrel was allowed to drain both through the orifice and the siphon. The discharge time for the siphon was set to 2 hours. For different constant orifice discharge rates, the percentage of events that results in rain barrel overflowing was calculated. Table 4-7 and Table 4-8summarize some of the results from the mass balance spreadsheets. Table 4-7 shows what percentage of events that resulted in rain barrels being full and/or overflowing at different discharge rates. Table 4-8 shows the percentages of events that started when rain barrels were more than half full.

Table 4-7: Mass balance spreadsheets results - percentage of events that result in rain barrels overflowing at different discharge rates

		Percentage of Events that Result in Overflow			
		MIT 15 minutes		MIT 2 hours	
Total Discharge Time (hours)	Assumed Constant Rate (L/min)	Orifice Discharge	Orifice & Siphon	Orifice Discharge	Orifice & Siphon
2	2.83	0	0	0	0
3	1.89	1	1	1	1
4	1.42	2	1	2	2
6	0.94	4	2	5	5
8	0.71	5	3	9	9
12	0.47	10	4	14	14
24	0.24	26	6	23	23
48	0.12	44	16	36	36

Table 4-8:Mass balance spreadsheets results - percentage of events that occur when rain barrels have less than half of their full capacity available for storage

		Percentage of Events - Initial Capacity of the Barrel is Less than Half			
		MIT 15 minutes		MIT 2 hours	
Total Discharge Time (hours)	Assumed Constant Rate (L/min)	Orifice Discharge	Orifice & Siphon	Orifice Discharge	Orifice & Siphon
2	2.83	0	0	0	0
3	1.89	1	0	0	0
4	1.42	5	2	0	0
6	0.94	11	3	1	1
8	0.71	15	5	4	4
12	0.47	27	12	7	8
24	0.24	49	26	23	23
48	0.12	68	42	47	48

Based on the results from the mass balance spreadsheets, it was decided that the detention time of the rain barrel should be longer than 8 hours.

Design Setting of the Rain Barrels

Based on the information presented in this section of the report, the design setting for the rain barrels was set. During testing, the siphon only performed reliably if it was fully open. For this reason, the design setting for the siphon was fully open. The design setting for the orifice was setting the orifice at a 'mostly closed' setting. With the orifice mostly closed, the rain barrels were expected to have half of their capacity available after 24 hours and were expected to capture more than 30% of the volume of rainfall from their connected impervious area in a year.

4.6 Rain Barrel Delivery, Installation, and Monitoring

Once a homeowner agreed to participate in the study, the following procedure took place:

1. A site survey was conducted and a rain barrel delivery date was set.
2. A base/foundation for each Rain barrel was prepared.
3. Rain barrel was delivered.
4. Downspout was prepared for connection. In most cases, a flow diverter was installed.
5. Rain barrel was modified and connected to the downspout and the drain.
6. Rain barrel was tested to ensure that it is properly connected to the downspout and that the roof contributes runoff to the barrel (i.e. the rain barrel was not going to be empty for the duration of the study).
7. After the test period, the setting on the rain barrel was adjusted to the design setting.
8. After the final adjustment, the rain barrel was monitored to ensure that the barrel's drainage mechanism was working (i.e. the rain barrel was not going to be full for the duration of the study).

More details for each step are provided below.

Site Survey

The site survey had three objectives: to consult the homeowners to pick an appropriate location for each rain barrel, to create a record of the condition of the residence prior to the installation of a rain barrel, and to determine if any special parts, material or tools were required for the installation (if any modifications needed to be made to the design).

Residents were asked a set of standard questions approved by the City (Appendix A). During the site inspection, the condition of the wall, ground, and downspout were recorded. Each site survey is accompanied with photos of the site prior to installation of the rain barrel, during the installation and after the installation. All this information will be provided to the City of Burnaby after the completion of the project.

Delivery and Base Preparation

The base for the barrel received different treatments depending on the ground condition of the installation site. The base had to be level and compact prior to the installation. In some instances, the barrels were placed on concrete or other paved surfaces. In those instances, if the ground was not level, pieces of wood or rubber mats were used to level the barrel. In some instances, the barrels were placed on unpaved surfaces. In those instances, the ground was levelled by adding appropriate fill material and compacted using a large wooden rod. If needed, rubber mats and pieces of wood were also used to prepare the base.

Envirotile (cobblestone Envirotile, Terra Cotta- 18 in by 18 in – 1040 Pack), a product made from recycled rubber tires, was used as a base. Compared to other options, the product was relatively light, cheap, and easy to cut into smaller pieces. Other options considered were concrete cinder blocks and pieces of wood

Downspout Preparation

Most diverters were retrofitted with a Rain Barrel Diverter Kit from FISKARS. Due to space limitation, a few rain barrels were directly placed under downspouts. In those cases, the barrels had to be retrofitted with an overflow pipe.

Rain Barrel Modification and Connection

The rain barrels were modified on site with a siphon and then connected to the diverter and to the drain. The connection to the diverter was part of the FISKARS Rain Barrel Diverter Kits. This connection also served as the overflow pipe for the rain barrel. To connect the rain barrel to the drain, a flexible tube Y connection was used. The Y tube fitted the fixtures that came with the rain barrel. One fixture (black faucet) was installed on the barrel to act as on orifice. The other fixture (red faucet) was attached to the end of the siphon to adjust the rate of flow out of the siphon. Both faucets were connected to the Y, which drained the barrel.

Test Period and Final Setting

The initial setting on all rain barrels was a test setting: the faucet that controlled the orifice was fully closed and the faucet that controlled the siphon was fully open. After a barrel was installed, the barrel was visited occasionally and the approximate water level in the barrel was recorded. The barrels were visited under different circumstance including during a rainfall, after a rainfall, and after a long dry period. The goal of the visits was to ensure that the roof areas were contributing runoff to the barrels, the downspout diverters were installed appropriately, and that the siphon on the barrels was functioning properly.

On July 22, 2011, all the rain barrels had the same test setting.

A data logger was placed in one of the rain barrels at 5442 Tye Court. The data logger was set to record the depth in the barrel every 5 minutes.

During the test setting any necessary modifications were made to facilitate smooth operation of the rain barrels. The settings on the rain barrels were gradually changed to the design setting: a fully open siphon and a mostly closed orifice. The orifices were opened slightly to allow for continuous drainage of the rain barrels. By October 26, 2011, most rain barrels were continuously draining.

5 Results and Discussion

The result and discussion section covers three major topics:

- residents' response and rain barrel uptake
- rain barrel installations and theoretical capture, and
- rainfall and flow data analysis.

A synopsis of the results is provided here. The following sections provide detailed results and discussion. The first contact with the study area residents was made in January of 2011 and the communication and engagement efforts continued until July of 2011. During this time, 26 residences were signed up and 40 rain barrels were installed. Multiple site visits to each property were made between the first contact with a participant and the final installation. Multiple visits were made after the final installation to ensure the proper functioning of the barrels. Overall, about 6 to 8 hours of time was spent per rain barrel on signing up a participant, delivery, pick up, installation and follow up. This does not include time spent planning and reporting. The span of the fieldwork for the project was much longer than the total hour of work required. This was partially due to limited resources available and partially due to time needed to get responses from the residents.

As it was expected, each rain barrel installation was unique and some installations required modifications to the original retrofit plan. After the installations, multiple site visits were made to inspect the rain barrels and to ensure proper functioning of the barrels. It was found that 38 out of the 40 installed rain barrels were collecting significant quantities of runoff and discharging it regularly; however, the discharge pattern of the rain barrels could vary from barrel to barrel and from event to event. The water level in two of the rain barrels was monitored with data loggers and the result of the data collection is presented in Section 5.2. The scope and the budget of the project did not allow for additional instrumentation and monitoring of the barrels.

Data collected from the flow monitoring stations was analysed to determine if rain barrels had an effect on stream flow. Analysis indicated that the rain barrels did have a regulating effect.

5.1 Residents' Response and Rain Barrel Uptake

All residents were contacted via direct mail in the second week of January 2011. The mail out included a letter and the four-page communication pamphlet included in Appendix A. The purpose of the letter was to introduce residents to the project and to recruit study participants. The letter also indicated that the residents should expect a site visit. The first response to the letter was received in the third week of January. In total, 77 communication packages were sent out and in response, four study area residents volunteered to participate in the study. The first round of door-to-door visits started about two weeks after the initial letter was sent on Jan 31, 2011 and continued on Feb 1 and Feb 11, 2011. As a result, 7 additional participants were signed up, bringing the total to 11. City of Burnaby mailed out a second letter (Appendix A) to the study area residents at the end of February to update them on the status of the project and to remind them to participate. The letter prompted 2 residents to volunteer to participate in the study, one of whom was not eligible for the project as he lived outside the study area boundaries and had heard about the project from his neighbour. One of the strategies for increasing interest in the pilot was to start installing rain barrels in the neighbourhoods as soon as residents showed interest. It was hypothesized that populating the neighbourhoods with rain barrels would reduce hesitations about the process and that neighbours would inspire each other to participate. 15 rain barrels were delivered and 11 of them were installed during March and the first week of April. The second round of door knockings took place on April 7, April 11 and April 17, 2011. As a result 4 additional households signed up for the study bringing the total up to 16. Door knocking, site inspections, rain barrel delivery and installation continued until mid-July, 2011. Figure 5-1below summarizes the timeline of activities during this phase of the project. Overall 26 residents agreed to participate in the study. The effort spent to sign up the study participant is summarized in Table 5-1.

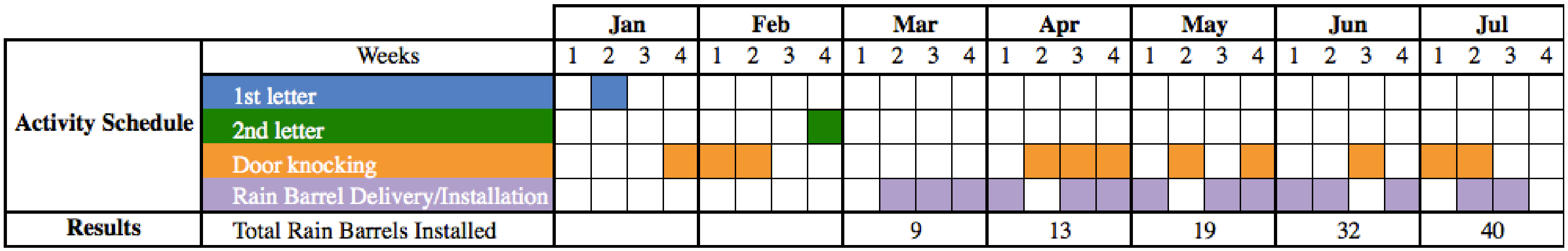

Figure 5-1: Timeline of communication activities

Table 5-1: Summary of inputs, outcomes, and results of the communication and engagement activities

Activity	**Input (hours)**	**Outcome**	**Result**
1st Mail Out		77 copies of the 1st letters & the communication pamphlet sent	4 responses and 4 signed up
1st Round of Door Knocking (Jan-Feb)	6 hours (over 3 days)		7 signed up
2nd Mail Out		77 copies of the 2nd letter	2 responses and 1 signed up
2nd Round of Door Knocking (Apr)	6 hours (over 3 days)		4 signed up
Door Knocking in May	4 hours (over 2 days)		6 signed up
Door Knocking in June	2 hours		2 signed up
Door Knocking in July	2 hours (over 2 days)		1 signed up
Total	20 hours (over 11 days and 7 months)	Received a response (yes, no, or maybe) from 66 residences	26 participants (40 rain barrels)

As is shown in Table 5-1, it took about 20 hours of door knocking over 11 days and 7 months to sign up 26 study participants who agreed to installation of 40 rain barrels. In addition to the door knocking, two letters from the City of Burnaby and the communication pamphlets were distributed to all the residences. Although, the communication material were essential for informing the study area residents about the pilot project, the study would not be possible without door knocking and face to face interactions with the study area residents. Allowing study area residents to decide whether or not they would like to participate over multiple months was required for getting the level of participation. Residents became more receptive of the idea over time. More participants could have been signed up for the study if the timeline for the project was extended. In fact, two residents volunteered to participate in the study after the deadline for participation. In the context of this pilot project, it was not feasible to extent the timeline more than it had already been extended. The next paragraph discusses the type of responses received from the residents. Although extra time would allow recruitment of additional participants, even with more time, the maximum participation in the project would not exceed 50% of the study area residents. About 40% of the residents turned down the chance to participate in the study for various reasons. The following paragraph describes and categorizes the responses from the residents.

The responses from the residents are divided into four categories: ‘Yes’, No’, ‘Maybe’ and ‘No Response’. The categories are self-explanatory. Anyone who communicated an interest in the pilot project but did not make a final decision or anyone who responded and did not explicitly state an interest in the pilot project was placed in the ‘Maybe’ category. Table 5-2 provides a summary of the number and type of responses received and compares the results to the targets set at the beginning of the study. When residents responded to the study, they usually provided a reason as to why they decided to participate or not. Their reasons were recorded and are summarized in Figure 5-2. Most study participants, about 50%, mentioned that they intend to use the water for gardening and some, about 15%, expressed a connection to Beecher Creek. Residents, who expressed a connection to Beecher, usually mentioned that they use the trail and or that their children have done some activity associated with the creek. Residents who decided not to participate in the study did not always provide a reason. About 50% of residents who refused to participate in the pilot simply stated that they were not interested. About 40% of the residents, who said ‘No’, cited reasons such as practicality, old age, lack of suitable location for the barrel, and maintenance concerns. Some of the study are residents were renting and could not make a decision without consulting the owner of the property. In those cases, the extra communication barrier generally resulted in no decision being made before the end of the study period. Some of the study area residents did not speak English. Similar to the renters, the extra communication barrier usually resulted in no decision being made before the end of study period.

Table 5-2: Break down of responses compared to the targets

Beecher 1 (Parker)					
Response	Houses		Rain Barrels		
	Num. of Houses	Percent of Total	Num. of Rain Barrels	Percent of Total	Target
Yes	11	30	16	21.6	30%
No	15	41	36	48.6	
Maybe	7	19	14		
No Response	4	11	8		
Total	37	100	74		

Beecher 3 (Howard)					
Response	Houses		Rain Barrels		
	Num. of Houses	Percent of Total	Num. of Rain Barrels	Percent of Total	Target
Yes	15	38	24	30	30%
No	16	40	38	47.5	
Maybe	8	20	16		
No Reponse	1	3	2		
Total	40	100	80		

As it can be seen from Figure 5-2, there were multiple barriers to residents participating in the study. Although some of the barriers to participation could have been overcome with more time and resources, the maximum participation in the project would likely not exceed 50%.

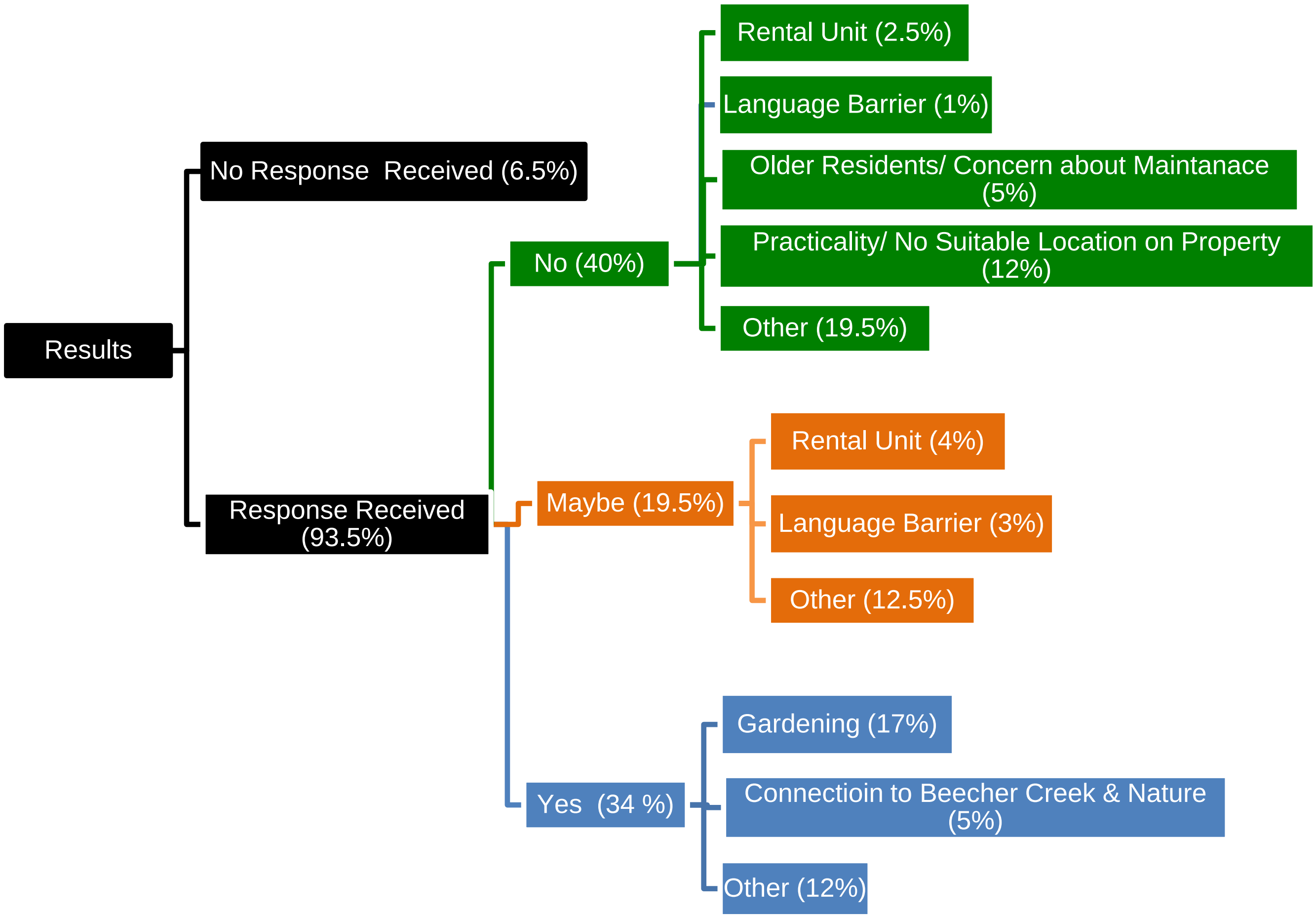

Figure 5-2: Summary of responses from study area residents

5.2 Rain Barrel Installations and Theoretical Volume Capture

As it can be seen in Figure 5-3 and Figure 5-4, 40 rain barrels were installed on 26 lots. Each rain barrel installation was unique and some installations required special materials and methods. As described in Section 4.6, after the rain barrels were installed, they were monitored to ensure that they were receiving runoff from the connected roof areas and that their discharge mechanisms were working. Follow up monitoring visits revealed that the rain barrel at 4921 Venable St and one of the rain barrels at 5020 Venable St were not receiving significant volume of runoff from the connected roof areas. Follow up monitoring also revealed that not all rain barrels were draining at the same rate. This was expected as siphons were not built exactly the same way and as the setting on the orifices was approximate.

There are 16 rain barrels in Beecher 1 study area. The type and location of the barrels in the Beecher 1 study area are summarized in Table 5-3. Out of the 16 installed rain barrels, 14 were collecting and discharging roof runoff. It is estimated that the 14 barrels capture the runoff from about 1.5% of the total study area. There are 24 rain barrels in the Beecher 3 study area. The type and location of the barrels are summarized in Table 5-4. It is estimated that barrels capture the runoff from about 3% of the study area. The estimates presented above are based on the assumption that each rain barrel is capturing runoff from 25% of the connected roof. The Upper Beecher Creek Watershed is estimated to be 42% impervious (Atwater, 2006). Assuming Beecher 1 and Beecher 3 study areas are 42% impervious as well, the rain barrels in Beecher 1 capture about 3.5% of the total impervious area and the rain barrels in Beecher 3 capture about 7% of the total impervious area. These estimates are based on simplifying assumptions. Building footprints in the Beecher 3 study area are on average about 30% larger than the building footprints in Beecher 1 and the percent impervious coverage of Beecher 3 is likely higher than that of Beecher 1. In addition, Beecher 1 is more disconnected than Beecher 3 meaning that a higher portion of the impervious area in Beecher 1 drains to ditches and sumps. This means that percent of runoff captured in rain barrels in the two study areas is likely more similar than the estimates show.

As described in Sections 5.3.5 and 5.3.6, the water level in two rain barrels was monitored using a data logger. Based on the result of the rain barrel water level monitoring, the theatrical volume of rainfall captured by one of the barrels was estimated using the mass balance spreadsheets. Based on Figure 5-18, the time for the orifice to empty a full rain barrel was estimated to be 48 hours. The time for the siphon to empty a full rain barrel was estimated to be 2 hours. Using these discharge rates and the rainfall record from 2006-2011, the mass balance spreadsheets estimated that a barrel would have been full or overflowing after a 16% to 44% of the rainfall events, with MIT of 15 minutes, depending on how well the siphon on the barrel works. The 16% of the rainfall events that resulted in a barrel being full and overflowing under all discharge scenarios made up about 61% of the total rainfall volume in the rainfall record. The numbers presented here are rough estimates.

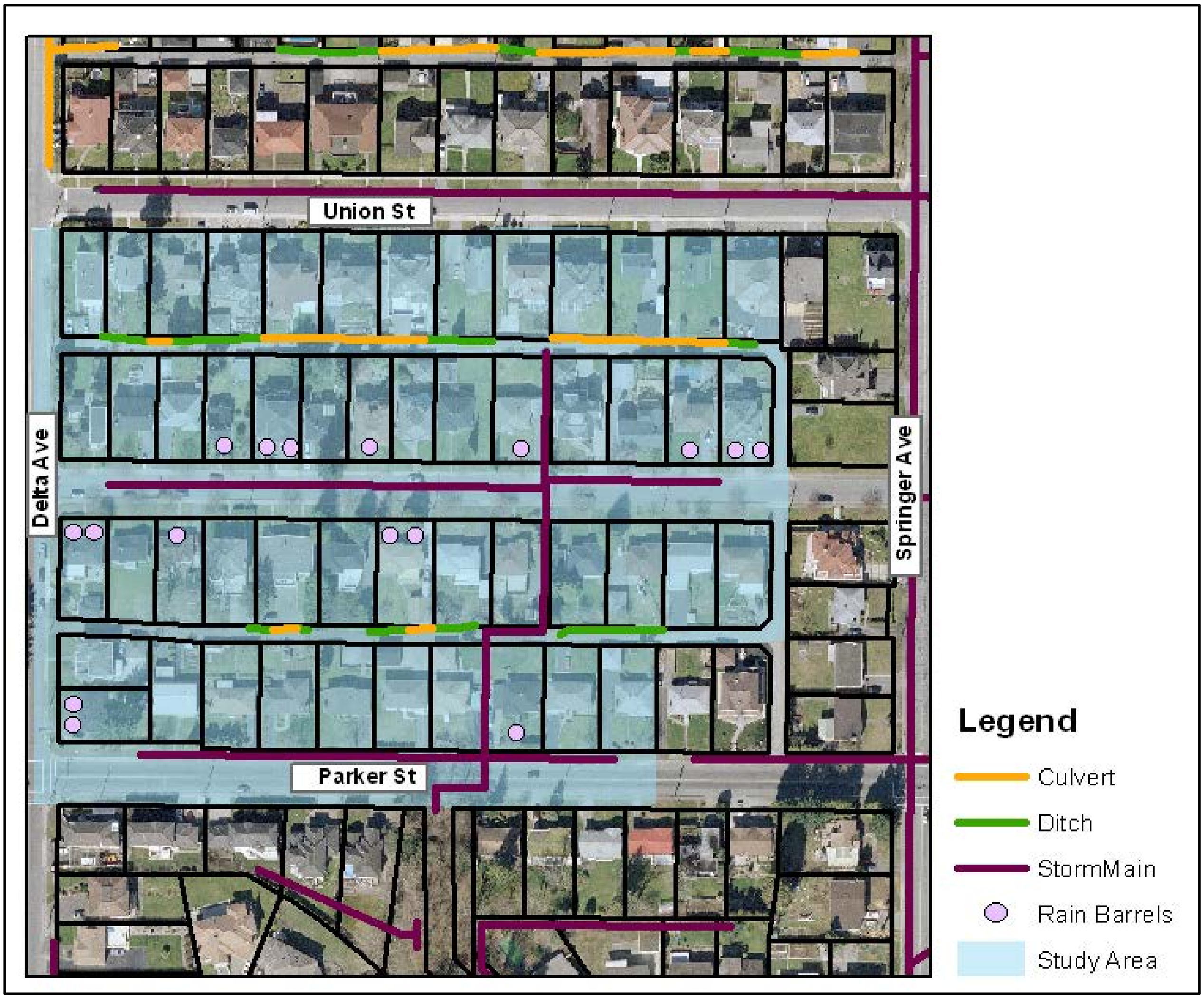

Figure 5-3: Beecher 1 rain barrel locations

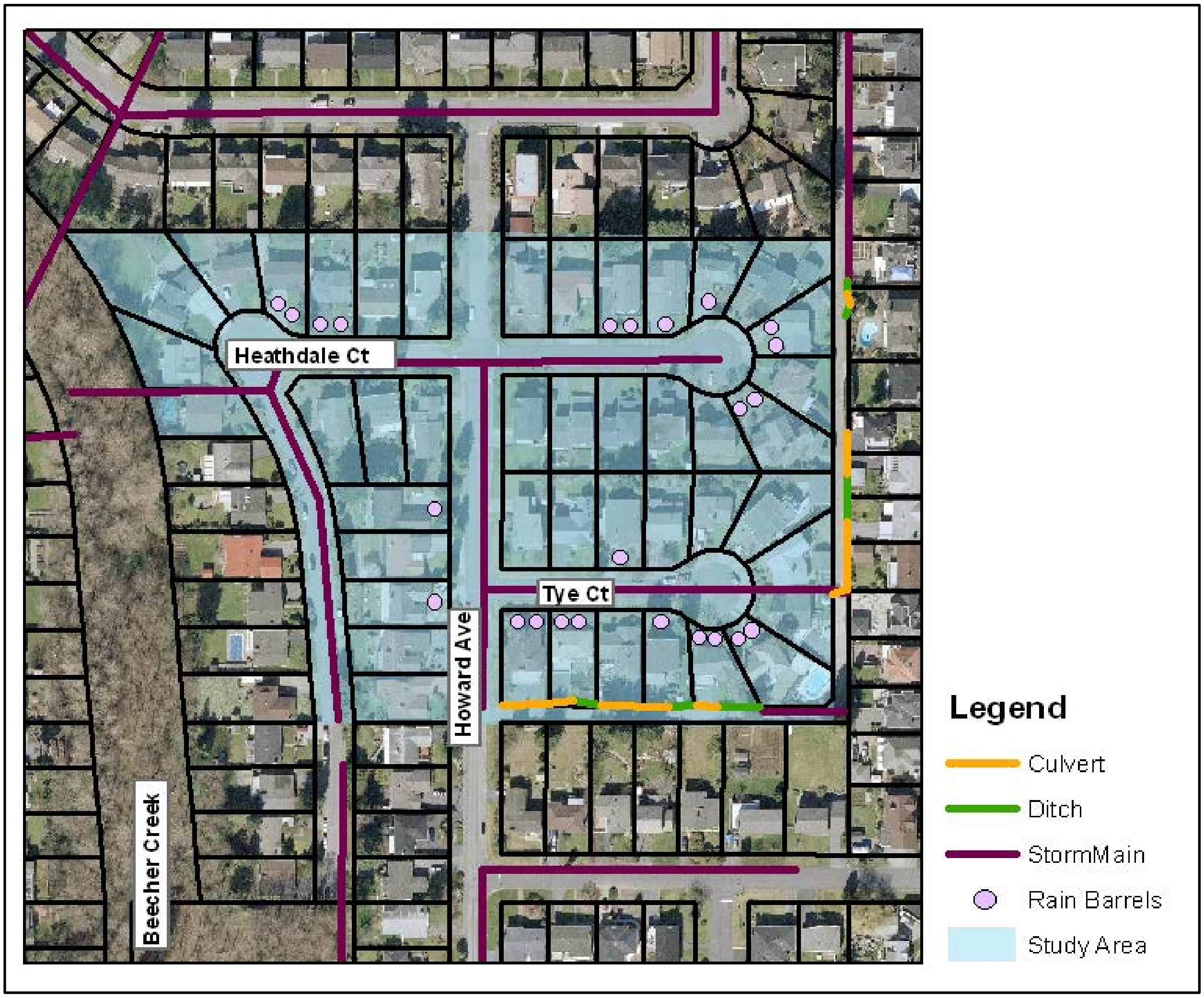

Figure 5-4: Beecher 3 rain barrel locations

Table 5-3: Addresses of Beecher 1 study area lots with rain barrels

Index	Address		Type of Rain Barrel	Number of Rain Barrels
Delta Ave				
1	950	Delta Ave	Green and Beige	2
Venables St				
2	4902	Venables St	Green	2
3	4921	Venables St	Green	1
4	4922	Venables St	Green	1
5	4927	Venables St	Green	2
6	4993	Venables St	Green	1
7	5020	Venables St	Green	2
8	5075	Venables St	Green	1
9	5111	Venables St	Green	1
10	5121	Venables St	Green and Beige	2
Parker Street				
11	5041	Parker Street	Green	1
		Total Number of Green Rain Barrels Delivered		14
		Total Number of Beige Rain Barrels Delivered		2

Table 5-4: Addresses of Beecher 3 study area lots with rain barrels

Index	Address		Type of Rain Barrel	Number of Rain Barrels
Tye Ct				
1	5441	Tye Ct	Green	1
2	5468	Tye Ct	Beige	2
3	5462	Tye Ct	Green	2
4	5456	Tye Ct	Green	1
5	5442	Tye Ct	Green	2
Howard Ave				
6	1450	Howard Ave	Grreen	2
7	1381	Howard Ave	Green	1
8	1441	Howard Ave	Green	1
Heathdale Ct				
9	5419	Heathdale Ct	Green	2
10	5425	Heathdale Ct	Green and Beige	2
11	5451	Heathdale Ct	Green	2
12	5459	Heathdale Ct	Green	1
13	5463	Heathdale Ct	Green	1
14	5464	Heathdale Ct	Green	2
15	5471	Heathdale Ct	Green	2
		Total Number of Green Rain Barrels Delivered		21
		Total Number of Beige Rain Barrels Delivered		3

5.3 Sensor Depth and Flow Measurements

Figure 5-5 shows the length of data available for different measured variables and the periods for which available data sets overlap. Note that Beecher flow data along with rainfall data (not shown in Figure 5-5) date back to November 2006. White cells in the figure indicate periods of missing data for Beecher flow and Beecher 1 Sensor Depth. Beecher 3 logger was deployed in February 2010 and therefore there is no data available for Beecher 3 Sensor Depth prior to February 2010. All the data is separated into two categories, data gathered prior to the installation of the rain barrels and data gathered after the installation of the rain barrels.

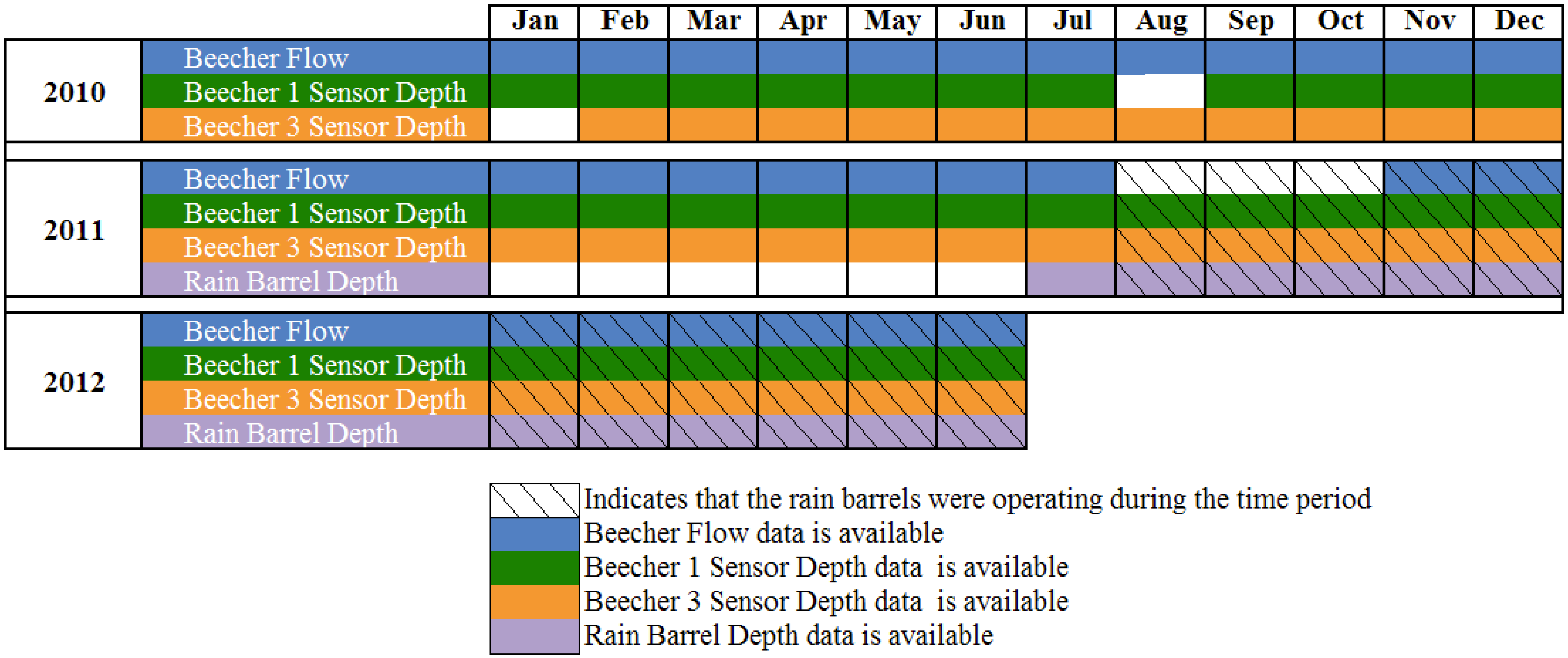

Figure 5-5: Showing data record lengths for study parameters and showing overlap of data records for Beecher flow and Beecher 1, 2, 3, 4, and 5 data loggers.

5.3.1 Quality Control and Quality Assurance

All measured data was reviewed on a monthly basis to ensure the quality of the collected data and to take any corrective action needed to ensure the relative accuracy and consistency of data being collected. The goal of the data collection program was to collect data that was relatively accurate and consistent and not necessary precise. For instance, the objective of the data collection program was not to determine the true value of Beecher flow in the Beecher 3 pipe but the goal was to make sure that the relationship between the measured flow and the true value of flow is consistent over the years.

Beecher 1 and 3 sensor depth readings were reviewed on a monthly basis according to the procedure outlined in Section 4.3.2 and minor changes were made to the data from time to time to correct small deviations.

Fluctuations in Beecher 2 readings, barometric pressure readings, caused fluctuations in water level readings from Beecher 1, 3, 4, and 5. Most of the fluctuations in barometric pressure readings are attributed to sudden changes in temperature of the Beecher 2 data logger. Spikes in the Beecher 2 temperature readings occur around 9 AM to 10 AM intermittently throughout the entire data record. Since all the sensor depth readings were adjusted with the same barometric pressure readings and since relative changes in sensor depths were used for most of the analysis, the fluctuations from the Beecher 2 readings are not perceived to be a significant source of error.

Beecher 1 sensor depth readings started to deviate from the pre-defined relationships Beecher 1 sensor depth and v-notch weir flow in January 2012. This was attributed to sediment accumulation behind the v-notch weir. Due to sediment accumulation, the effective depth between the streambed and the bottom of the v-notch had decreased to the point that the weir was probably not constricting the flow during high flow events. The accumulated sediment was cleared in July of 2012. Based on reports from monthly flow measurements, it is believed that the sediment accumulation did not start until December 2011.

5.3.2 Beecher 1 Data Logger

Beecher 1 logger has been continuously recording data since January 2010. Figure 5-3 shows the period of time when data from the Beecher 1 data logger is missing. In August of 2010, Beecher 1 data logger was displaced. It is not clear how the logger was displaced but the logger was found downstream of the monitoring station, re-launched and returned to its original location.

Figure 5-6 and Figure 5-7 are plots of the Beecher 1 sensor depth readings versus the manual v-notch weir readings over the course of the study. Figure 5-6 includes a high flow data point and Figure 5-7 shows the relationship between the two variables without the high flow data point. Similarly, Figure 5-8 and Figure 5-9 show the relationship between Beecher 1 sensor depth readings and weir flow. Figure 5-8 includes a high flow data point while Figure 5-9 defines the relationship without this point. As shown on the figures, most manual weir readings were taken during dry periods and do not reflect high flow conditions. Since only one high flow data point was gathered during the study period, key relationships are defined with and without the point. Sensor depth at Beecher 1 does get as high as 0.25 to 0.3 m during frequent rainfall events. The data points in the figures are colour coded based on calendar years to facilitate detecting unusual trends in data. In 2012, some of the weir head readings are higher than what the trendline would predict. This is attributed to sediment accumulation behind the v-notch weirs. Sediment accumulation is first mentioned in records of field visits in December 2011. The sediment behind the weir was cleared in July 2012. In July, the sediment level behind the weir was high enough to significantly impact weir readings. Two weir measurements were taken in July, one before the removal of sediments and deposits and one after. The difference in readings for a low flow condition (sensor depth was approximately 0.05 m) was about 6 to 8 mm. It is expected that the impact of the sediment deposit would be higher on higher flows.

Figure 5-10 shows the relationship between flow at Beecher 1 v-notch weir and Beecher flow at the Broadway crossing. This plot was constructed using the manual weir readings at the Beecher 1 v-notch weir. Most data points on the plot were gathered during dry periods.

Figure 5-11 shows time series of Beecher 1 sensor depth and rainfall from June 2010 to September 2010. This figure is included to show the range of flowat Beecher 1 and the type of response to rainfall during typically dry summer months. Figure 5-12shows time series of Beecher 1 sensor depth and rainfall from January 2011 to April 2011. This figure is included to show the range of flow at Beecher 1 and the type of response to rainfall during the wet winter months. Appendix B includes time series plots of Beecher 1 and rainfall from January 2010 to June 2012.

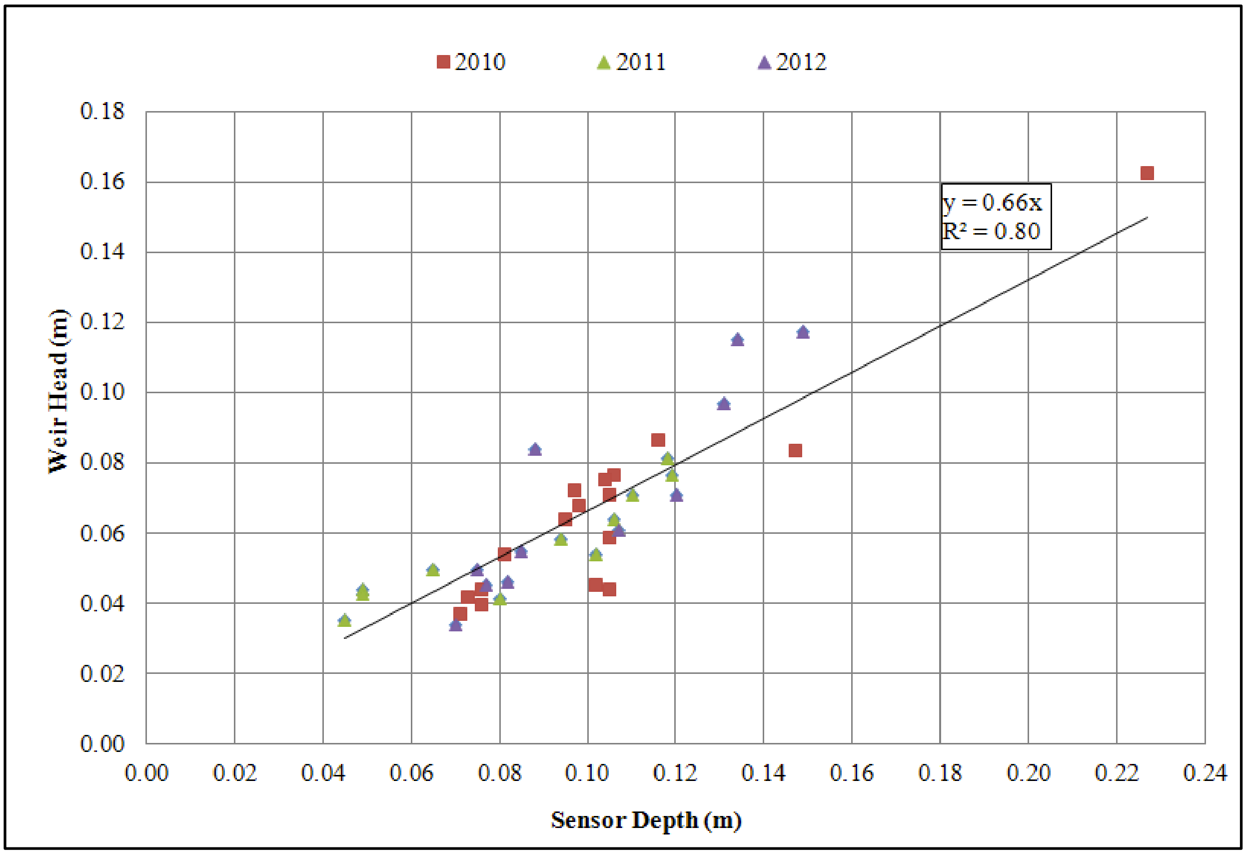

Figure 5-6: Beecher 1 sensor depth reading (m) versus the weir head measurements (m) from 2010, 2011, and 2012. The linear trendline is fitted through all the data points.

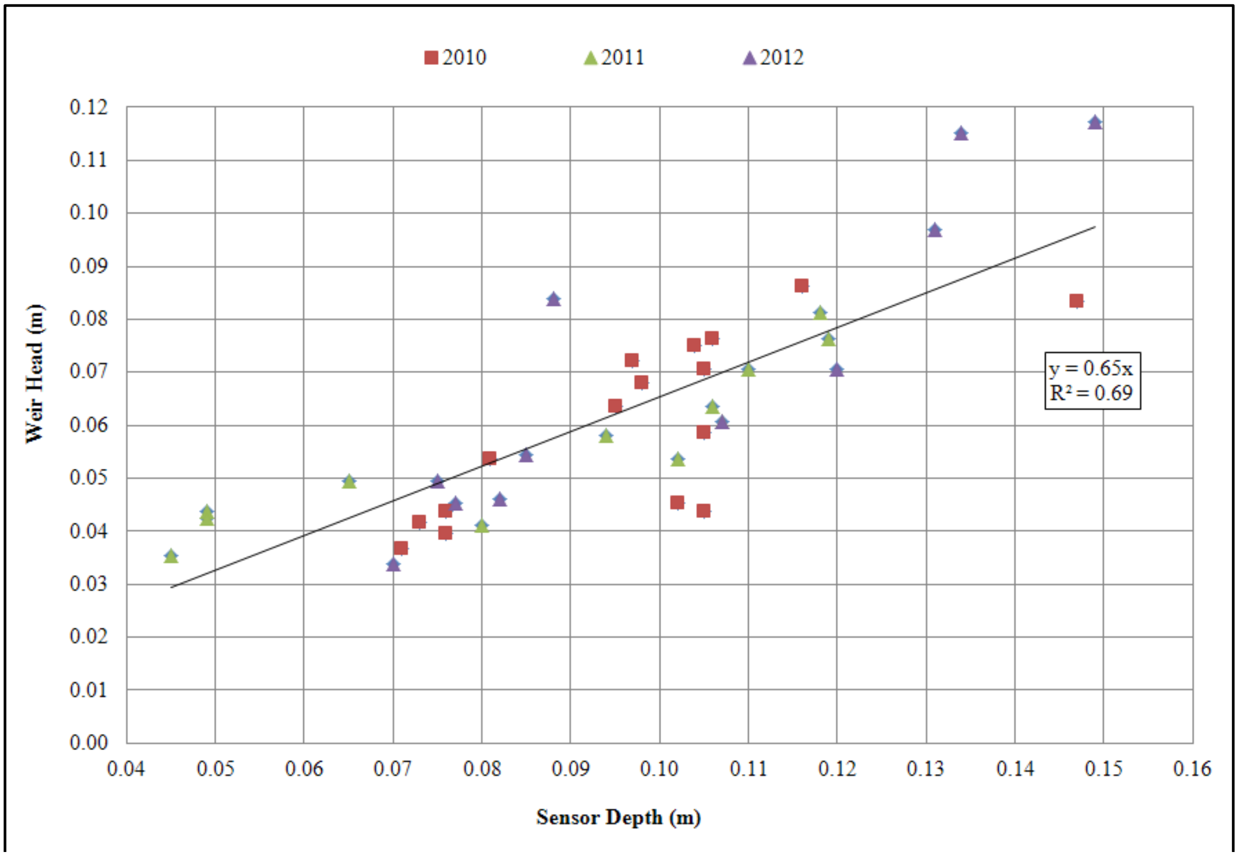

Figure 5-7: Beecher 1 sensor depth reading (m) versus the weir head measurements (m) from 2010, 2011, and 2012 without the high flow data point. The linear trendline is fitted through all the data points.

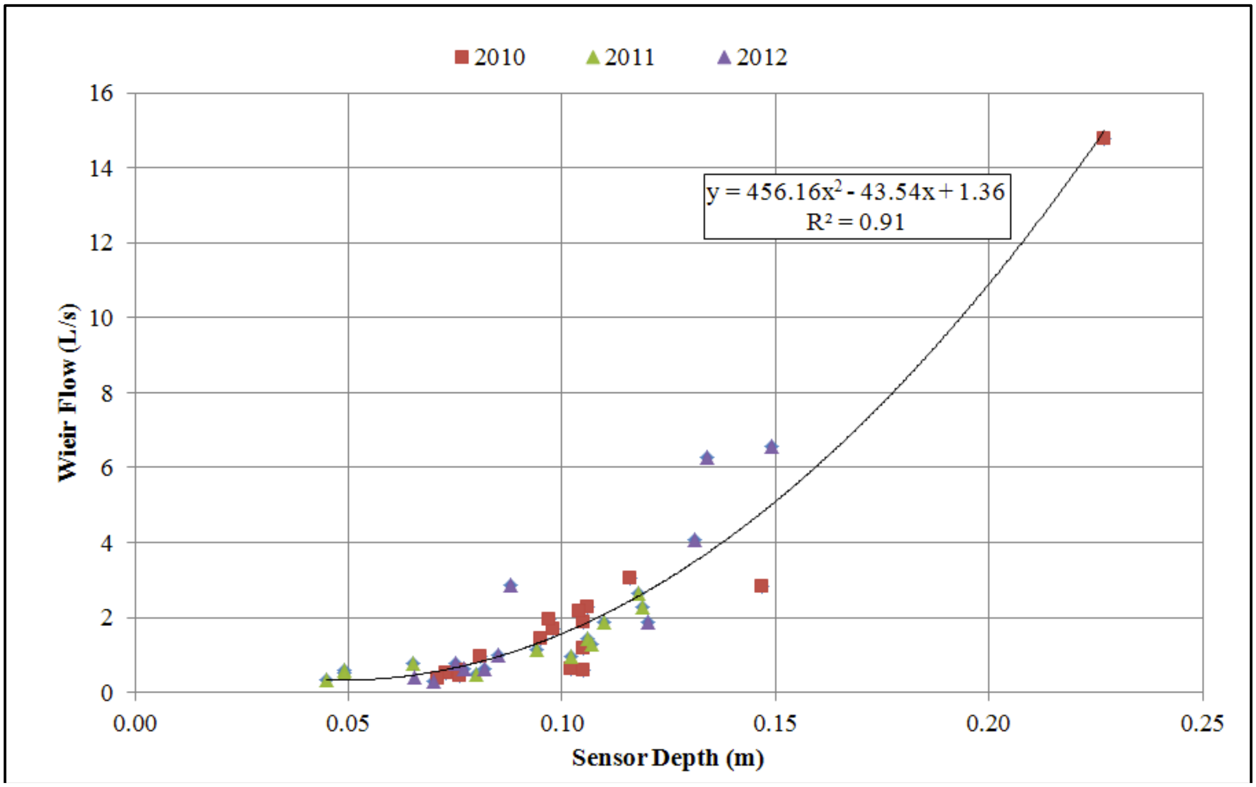

Figure 5-8: Beecher 1 sensor depth (m) and versus weir flow (L/s) from 2010, 2011 and 2012. The polynomial trend line is fitted through all the data.

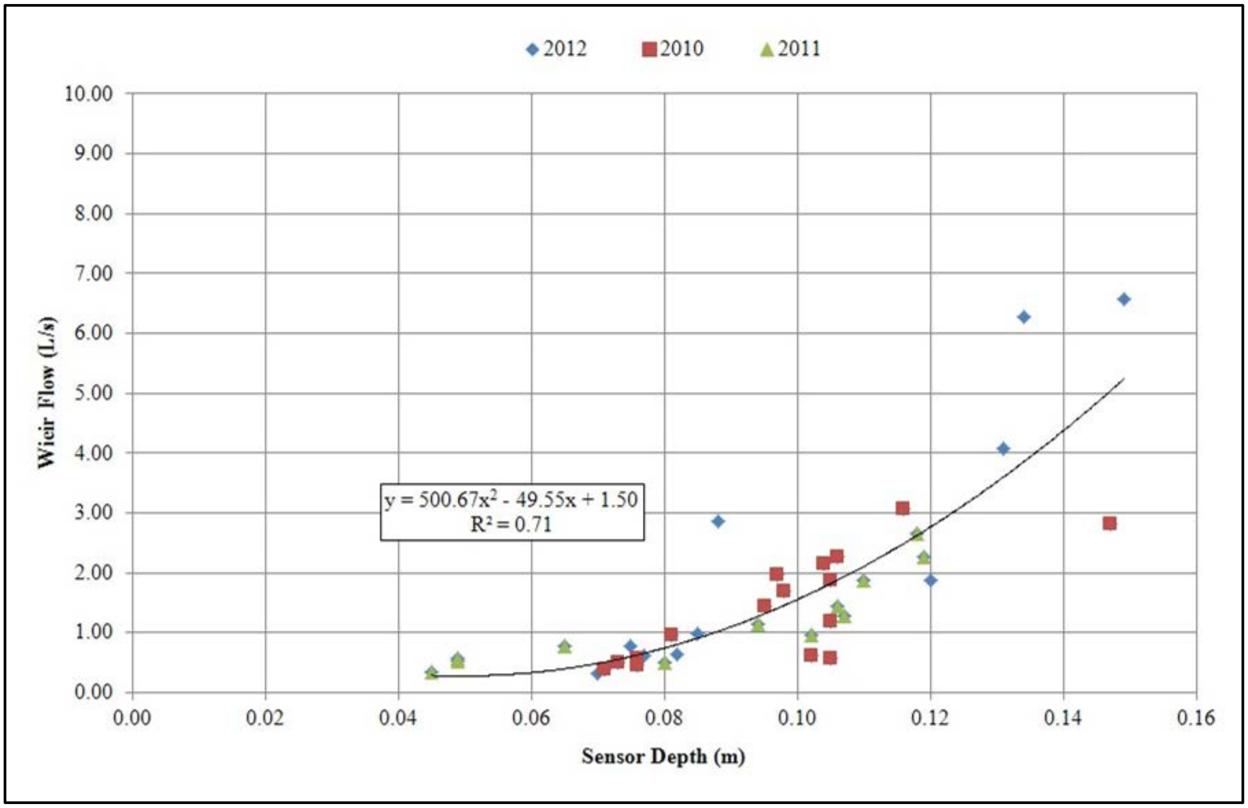

Figure 5-9: Beecher 1 sensor depth (m) and versus weir flow (L/s) from 2010, 2011 and 2012 without the high flow data line. The polynomial trend line is fitted through all the data.

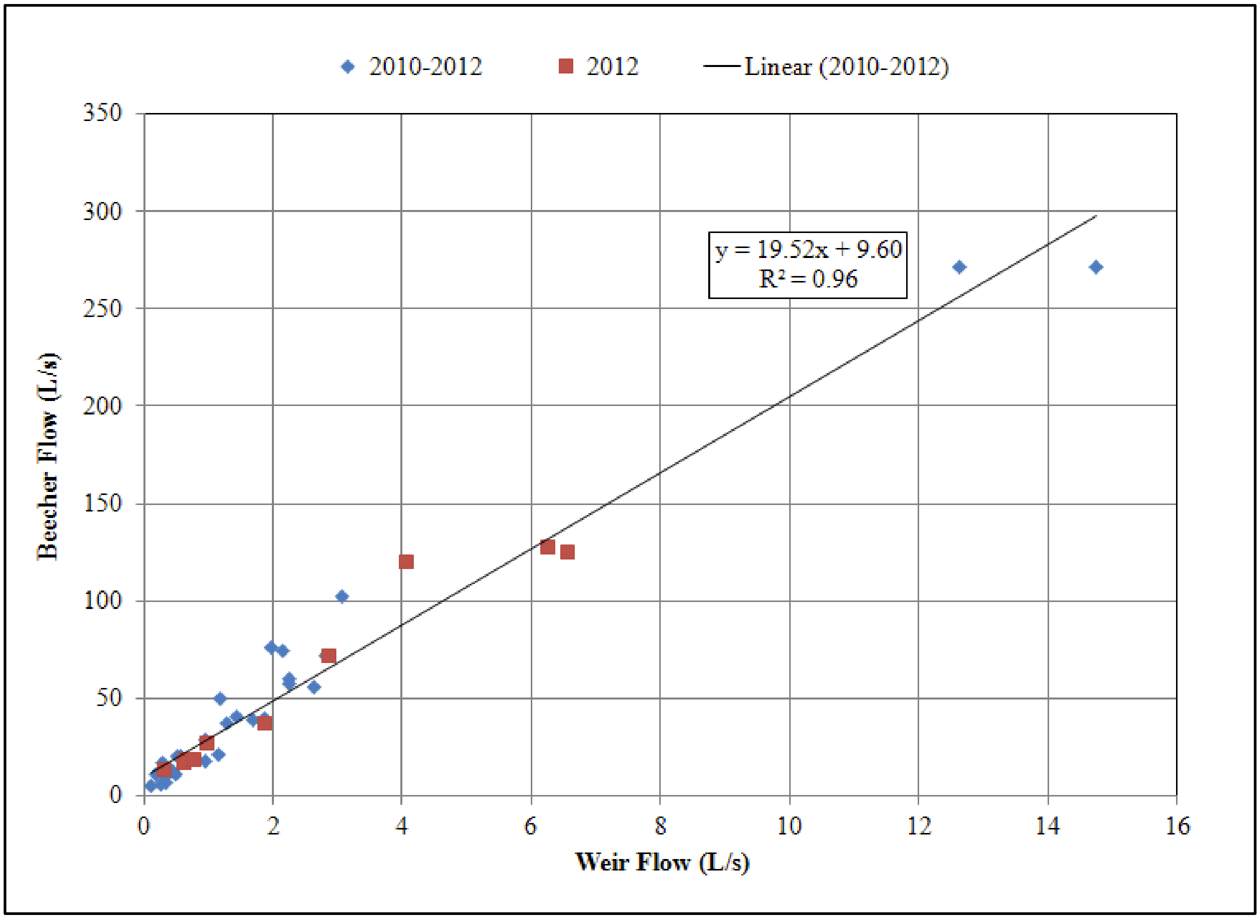

Figure 5-10: Beecher 1 weir flow (L/s) versus Beecher flow (L/s) from 2010, 2011, and 2012. The data from 2012 is shown in red and the linear trend line is fitted through all the data points.

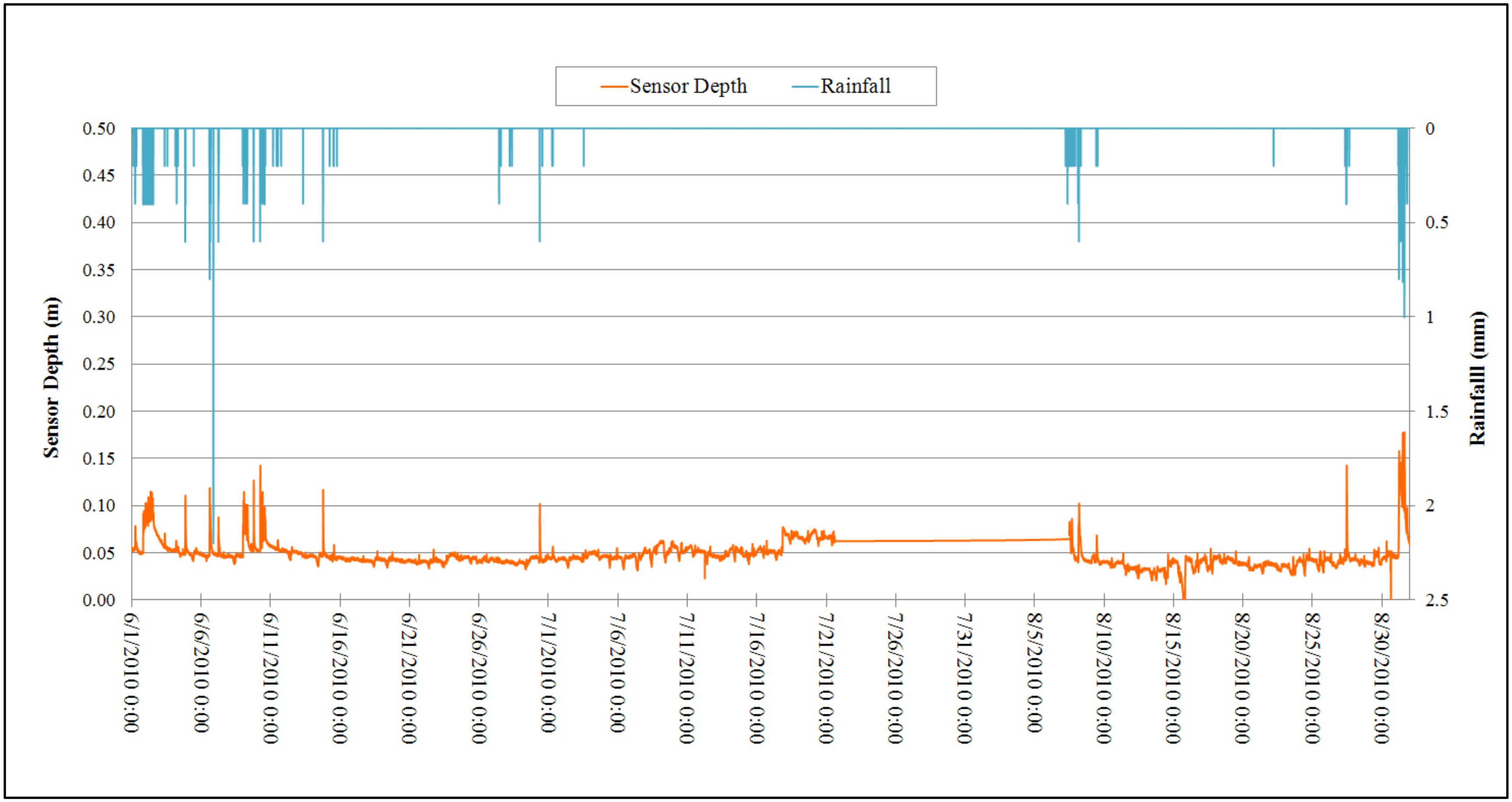

Figure 5-11: Time series of Beecher 1 sensor depth and rainfall from June 2010 to September 2010.

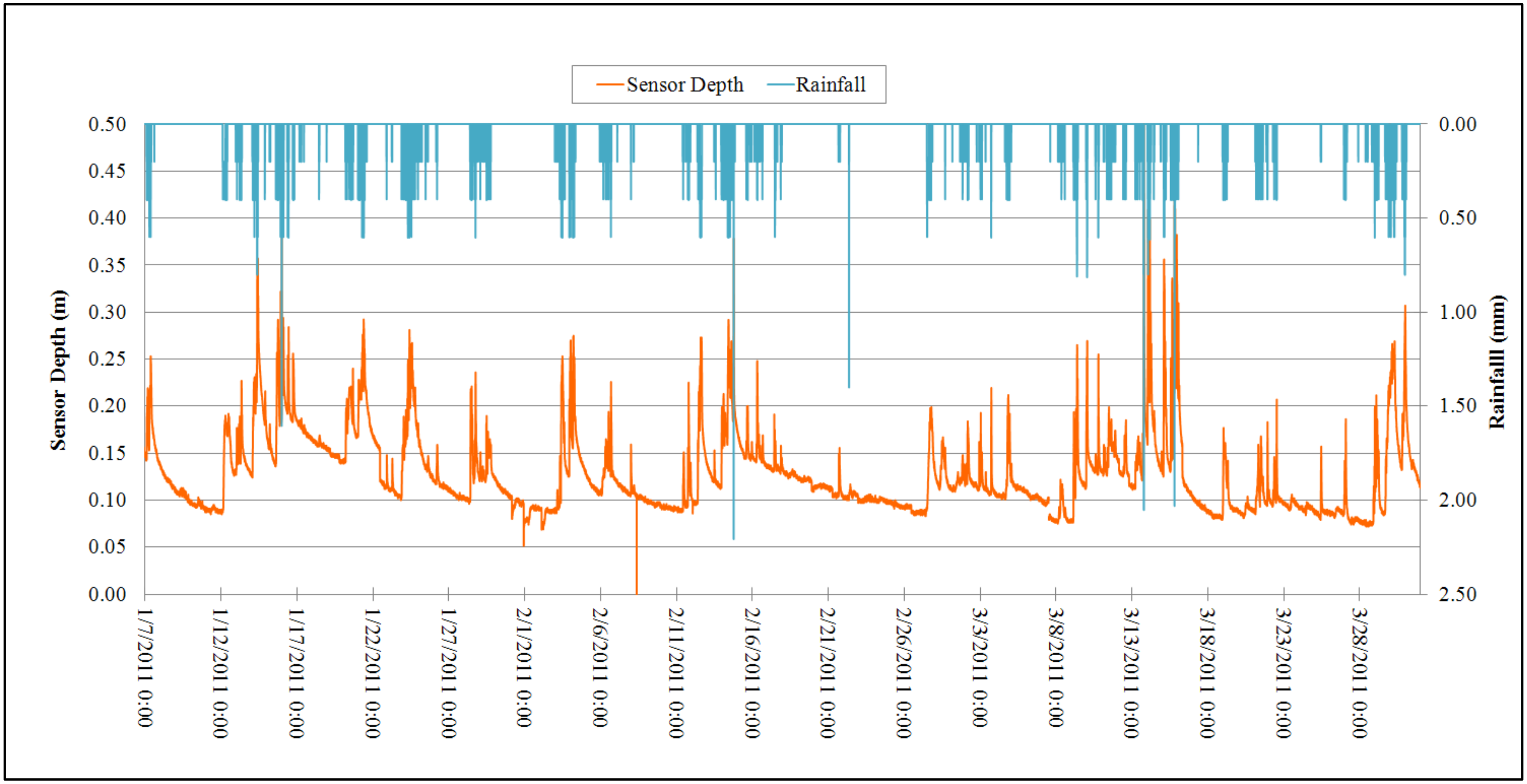

Figure 5-12: Time series of Beecher 1 sensor depth and rainfall from January 2011 to April 2011.

5.3.3 Beecher 2

Beecher 2 was recording barometric pressure. The measurements from Beecher 2 were reviewed for quality control and used to adjust the absolute pressure readings from Beecher 1, 3, 4, 5 loggers.

5.3.4 Beecher 3

Beecher 3 logger has been continuously recording data since February 2010. As it is shown in Figure 5-5, there were no interruptions in the Beecher 3 data collection program.

Figure 5-13is a plot of the Beecher 3 sensor depth readings versus the manual pipe flow measurements. Manual measurements were made for the duration of the study at least once a month. The data points in this figure and some of the following figures are colour coded based on calendar years to facilitate detecting unusual trends in data. As shown on the figures, most manual weir readings were taken during dry periods and do not reflect high flow conditions. Figure 5-14compares the square weir flow to flow in Beecher Creek. Figure 5-15shows time series of Beecher 3 sensor depth and rainfall from June 2010 to September 2010. This figure is included to show the range of flow at Beecher 3 and the type of response to rainfall during typically dry summer months. Figure 5-16 shows time series of Beecher 3 sensor depth and rainfall from January 2011 to April 2011. This figure is included to show the range of flow at Beecher 3 and the type of response to rainfall during the wet winter months. Appendix B includes time series plots of Beecher 3 and rainfall from January 2010 to June 2012.

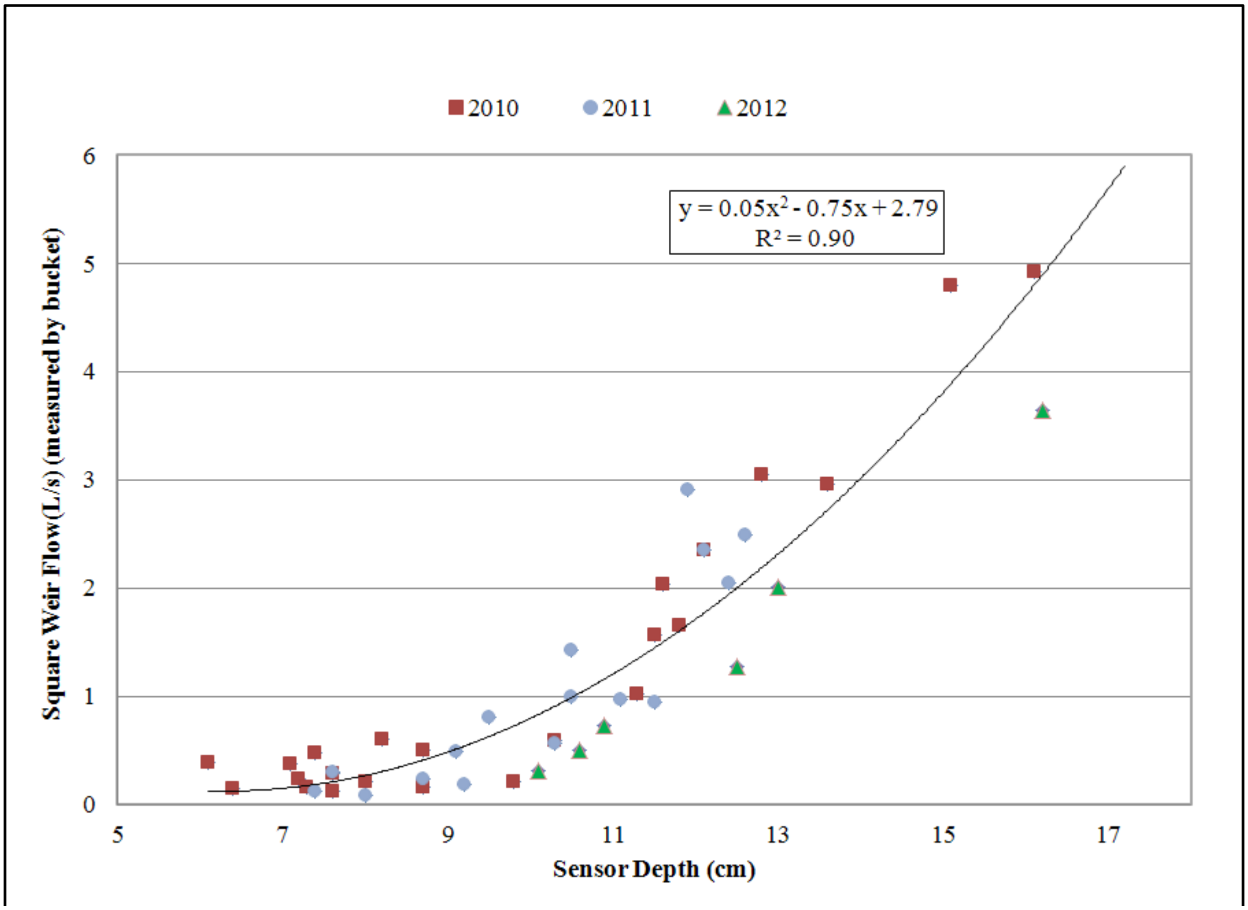

Figure 5-13: Beecher 3 sensor depth versus manual flow measurements.

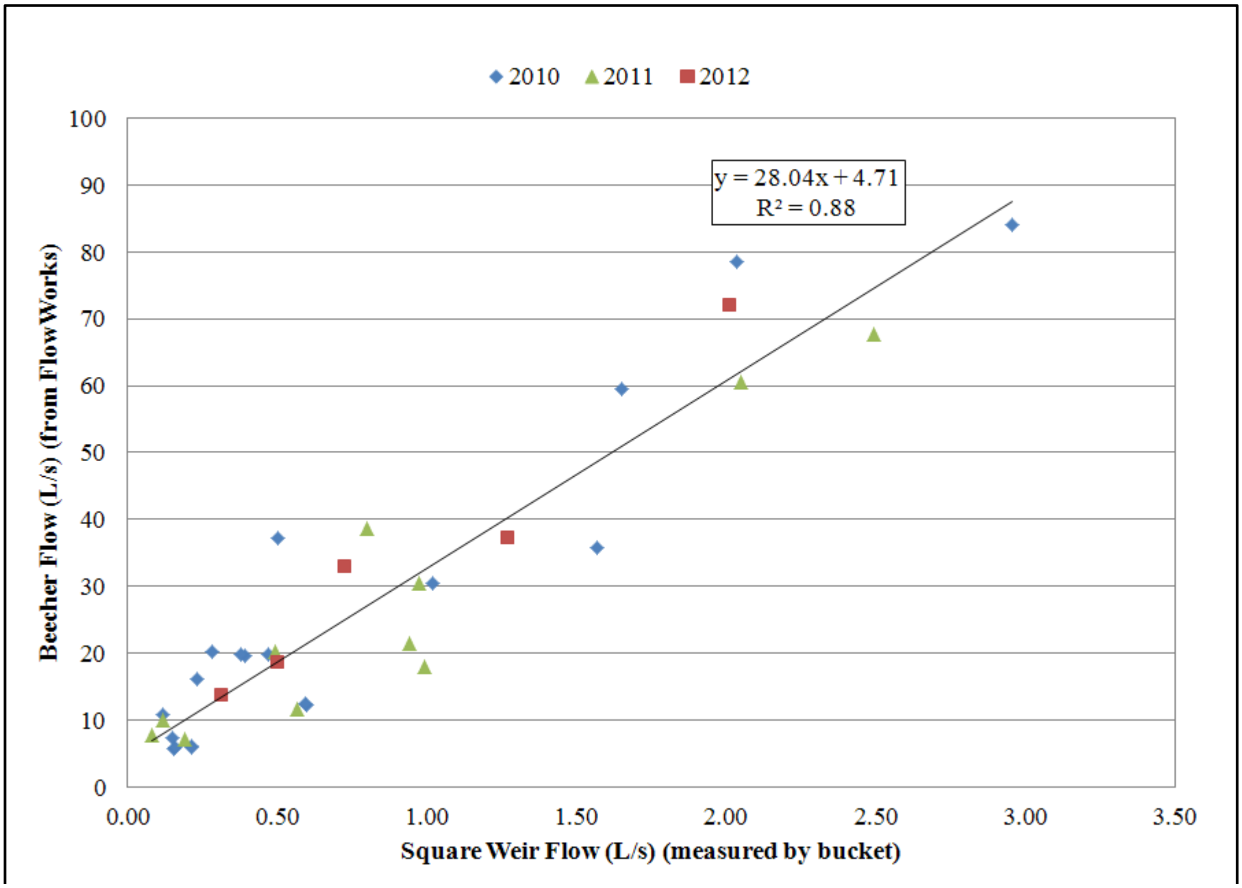

Figure 5-14: Flow at Beecher 3 monitoring station versus Beecher flow.

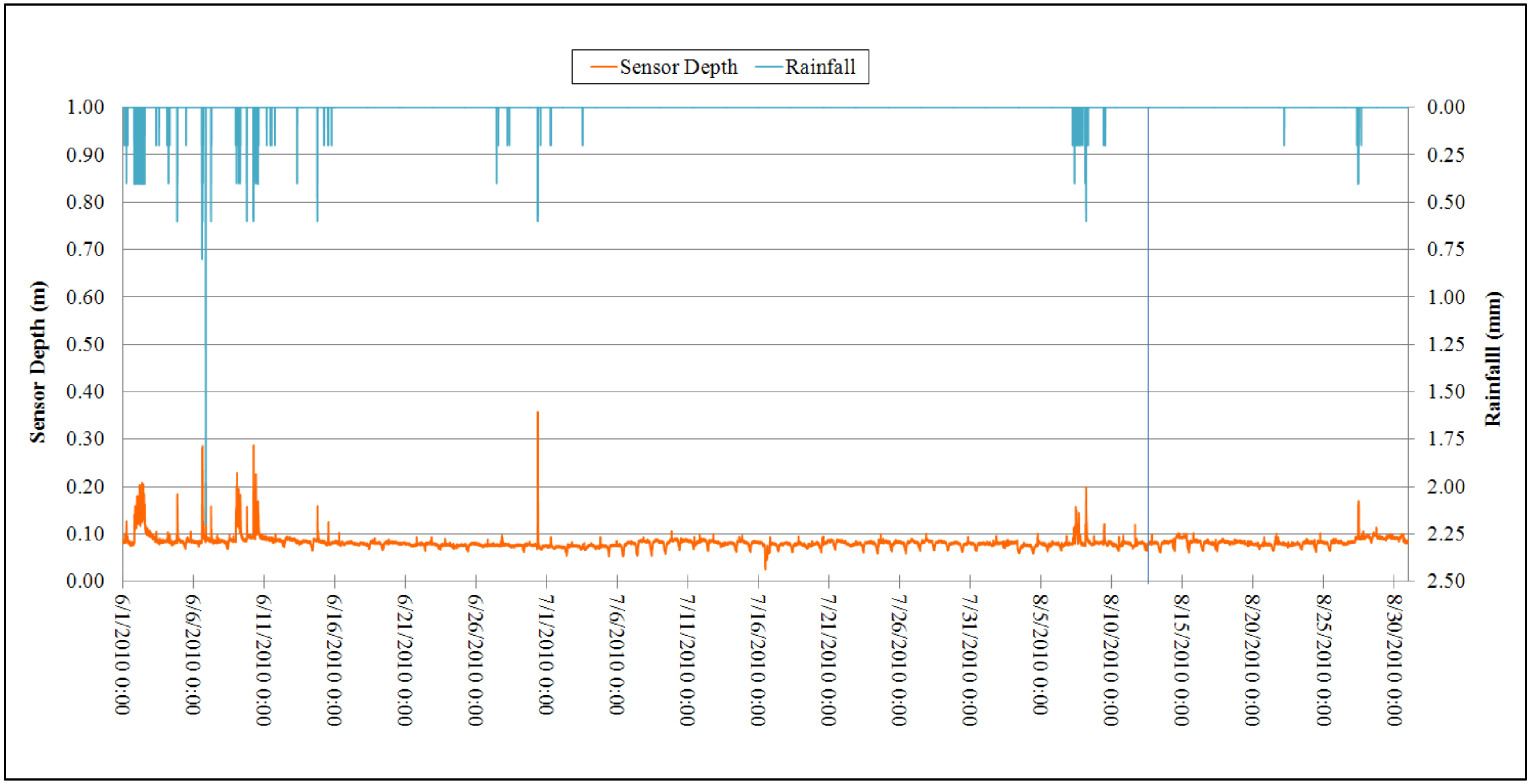

Figure 5-15: Time series of Beecher 3 sensor depth and rainfall from June 2010 to September 2010.

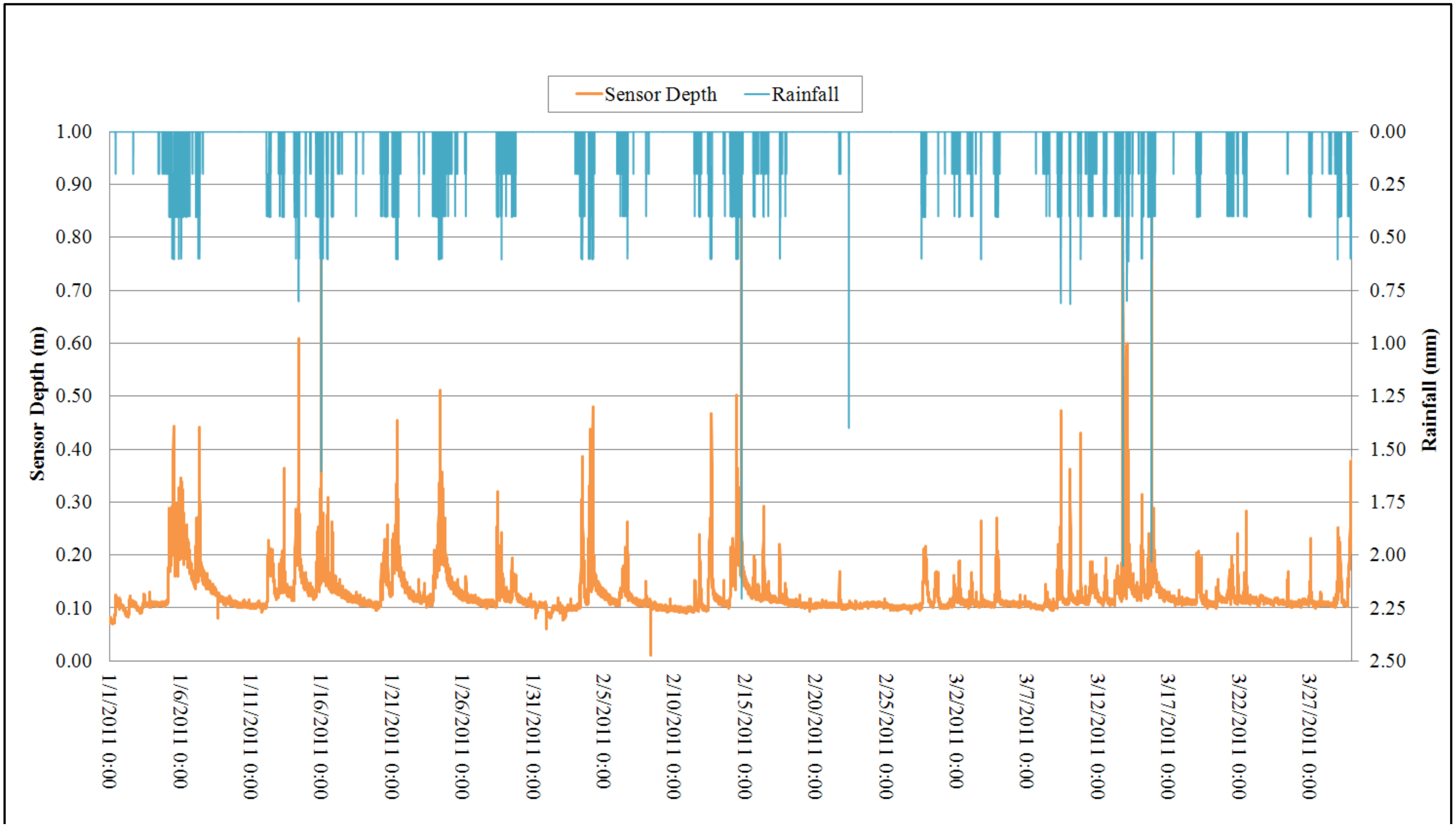

Figure 5-16: Time series of Beecher 3 sensor depth and rainfall from January 2011 to April 2011.

5.3.5 Beecher 4

The logger named Beecher 4 was recording absolute pressure in a rain barrel during the test period. The absolute pressure readings were corrected using the barometric pressure readings from Beecher 2. Beecher 4 data represents the water level readings in a rain barrel during the test period. Figure 5-17below shows the change in water level in the rain barrel during different rainfall events. The setting on the rain barrel was changed 3 times and each change is identified on the plot.

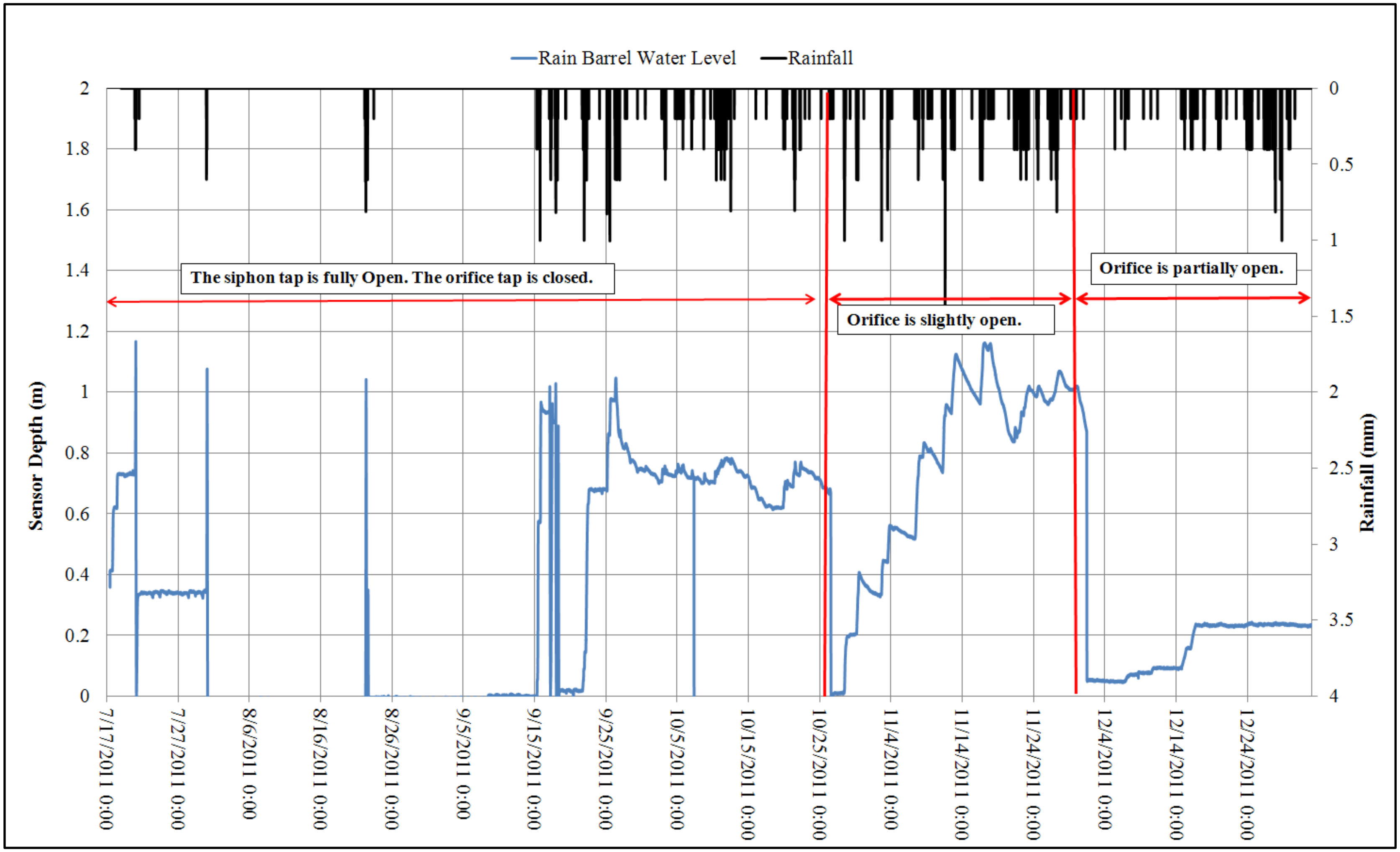

Figure 5-17: Time series of Beecher 4 data showing water level in a rain barrel during the test period.

5.3.6 Beecher 5

The logger named Beecher 5 was recording absolute pressure in a rain barrel following the test period. The absolute pressure readings were corrected using the barometric pressure readings from Beecher 2. Beecher 5 readings represent the water level in a rain barrel following the test period. The setting on the barrel was similar to the setting on most rain barrels in the study area for the duration that Beecher 5 was collecting data. Figure 5-18below shows the change in water level in the rain barrel during different rainfall events.

Figure 5-19shows the duration of rain barrel cycles to the duration of response at Beecher 1 and Beecher 3.

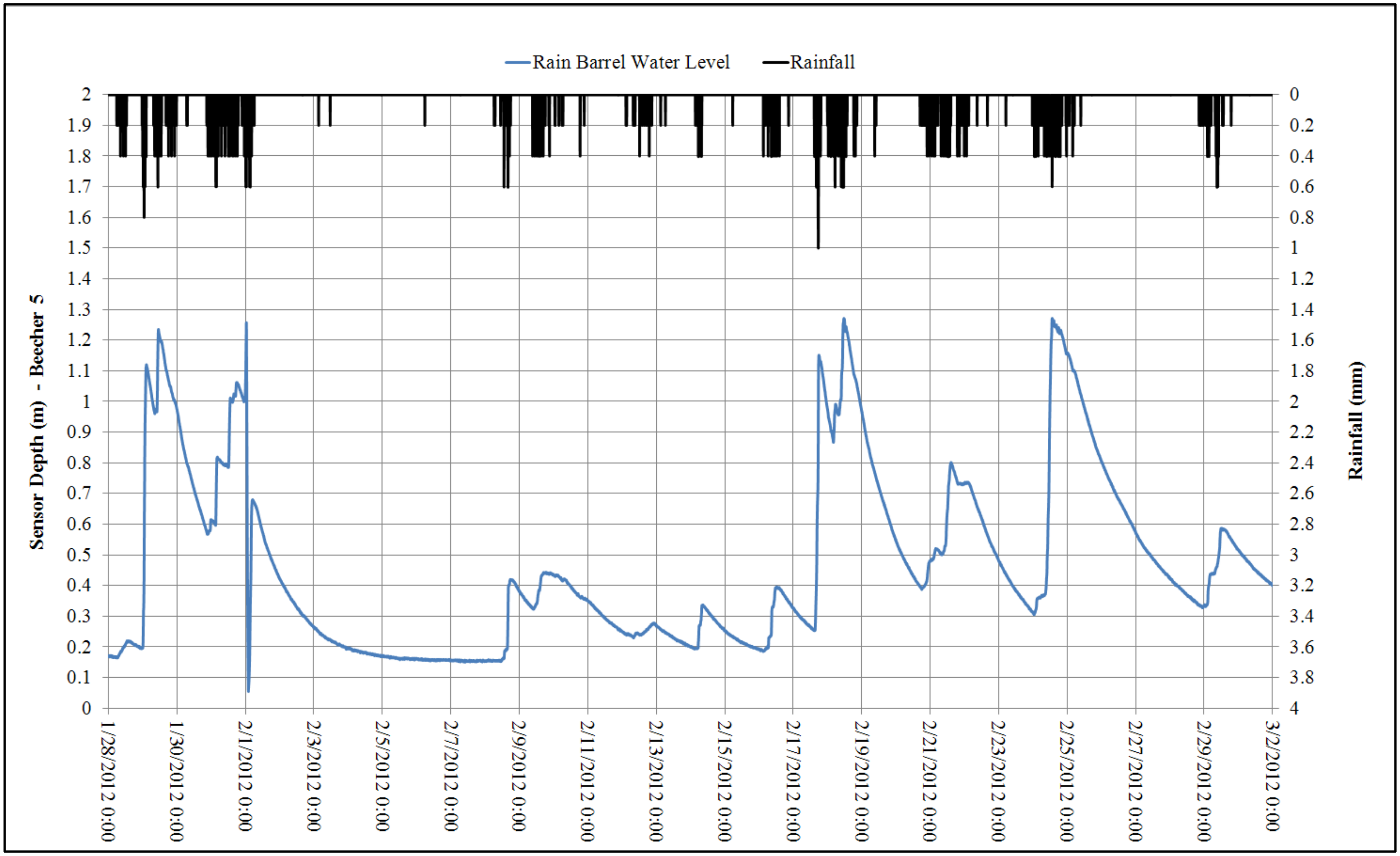

Figure 5-18: Time series of Beecher 5 data showing water level in a rain barrel with the design setting.

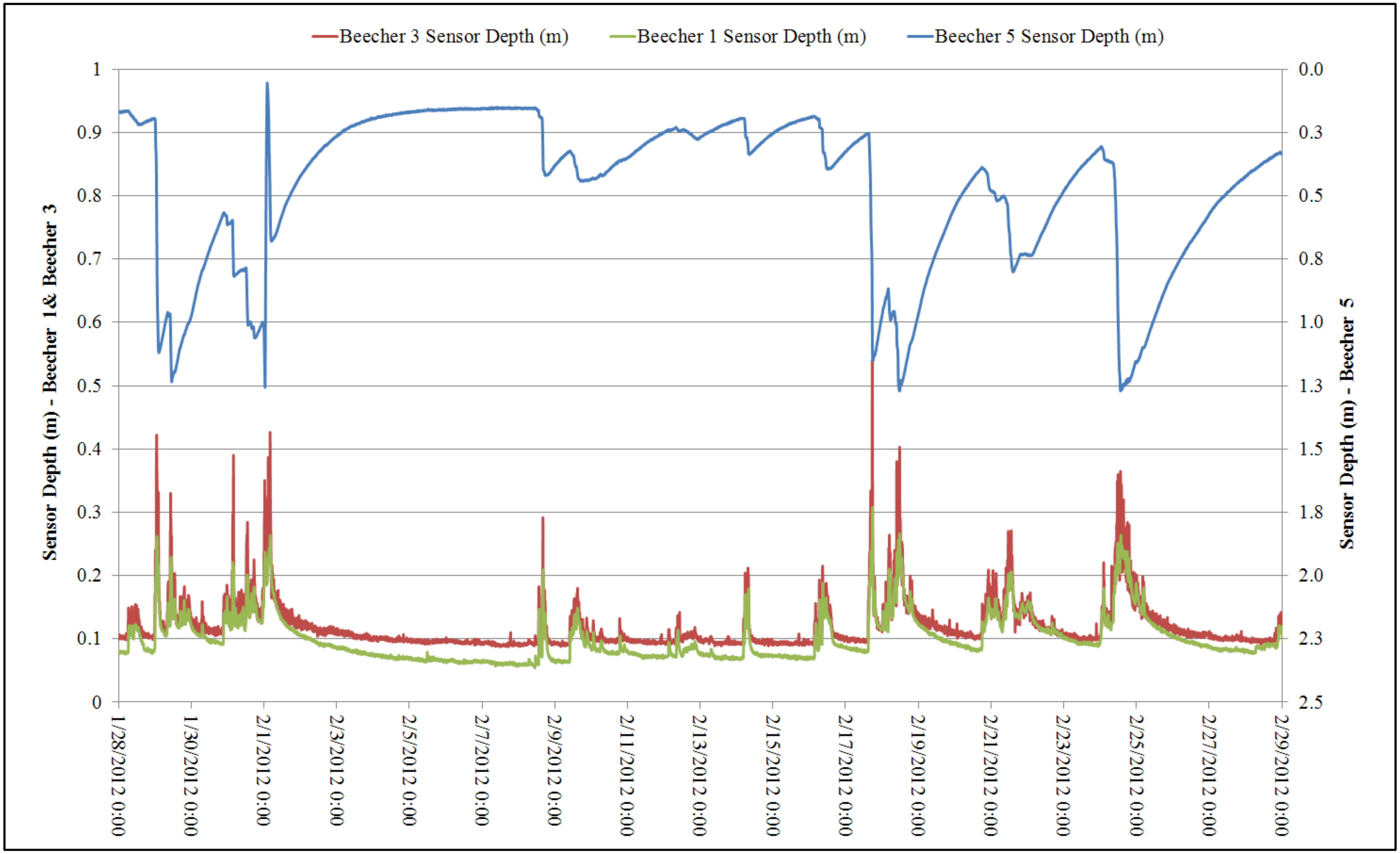

Figure 5-19: Time series comparing rain barrel detention time to duration of response at Beecher 1 and Beecher 3 monitoring stations.

5.4 Statistical Analysis

As part of a 400 level UBC Statistics Course, STAT 450, a group of fourth your students who were majoring in computer science and/or statistics carried out some statistical analysis on the data from this study and summarized their finding in a report titled "The Effect of Rainfall Events on Stream Response" (Goh, Guo, Zhao, & Zhen, 2012). The report by Goh et al. (2012) is included in Appendix C and summarized in this section.

They performed two sets of analyses. One focused on detecting change in stream response and the other focused on determining the relationship between sensor depth readings and Beecher flow. They used data from August 1, 2010 to December 31, 2010 (prior to installation of rain barrels) and data from August 11, 2011 to December 31, 2011 (following rain barrel installations). They used hourly averages of the following variables for their analysis: Beecher 1 Sensor Depth, Beecher 3 Sensor Depth, Beecher Flow, and Rainfall Depth.

Change in Stream Response

In order to determine whether steam response has significantly changed due to the installation of the barrels, they took the following steps for each set of sensor depth readings:

- Used a scatter plot to determine a suitable relationship between rainfall and sensor depth readings before the installation of rain barrels.
- Used a scatter plot to determine a suitable relationship between rainfall and sensor depth readings after the installation of rain barrels.
- Found that rainfall and sensor depth readings are linearly correlated and determined a Pearson correlation coefficient for the 2010 data and one for the 2011 data.
- Used an Autoregressive Integrated Moving Average (ARIMA) model to calculate the regression coefficient of rainfall to account for the potential lag time between rainfall and change in sensor depth.
- Compared the confidence interval for the slope of rainfall before and after the installations. If the confidence intervals did not overlap, they concluded that there has been a significant change.

They found evidence supporting a significant change in stream response after the installation of rain barrels for both data loggers (i.e. the confidence intervals for the slope of rainfall before and after did not overlap). Goh et al. (2012) stated:

> After rain barrels were installed, sensor 1 and 3 depths were less affected by rainfall with smaller slope estimates. This change is in the anticipated direction that implies rain barrels were helpful in controlling for water outflow into Beecher (p. 3).

Relationship between Sensor Depth and Beecher Flow

In order to determine a relationship for each set of sensor depth readings and Beecher Flow, Goh et al. (2012) took the following steps for each set of sensor depth readings (each data logger):

- Used a scatter plot to determine a suitable relationship between sensor depth readings and Beecher flow before the installation of rain barrels.
- Used a scatter plot to determine a suitable relationship between sensor depth readings and Beecher flow after the installation of rain barrels.
- Found that sensor depth readings and Beecher flow are not linearly correlated but assumed a linear relationship and determined a Pearson correlation coefficient for the 2010 data and one for the 2011 data.
- Used an Autoregressive Integrated Moving Average (ARIMA) model to compute the confidence interval for the slope coefficient of sensor depth for the 201 data and the 2011 data.
- Compared the confidence interval for the slope of sensor depth before and after the installations. If the confidence intervals did not overlap, they concluded that there has been a significant change.

They found that confidence intervals do not overlap for the data logger at Beecher 1 but do overlap for Beecher 3. Goh et al. (2012) concluded:

> Hence, there is evidence supporting the fact that the installation of rain barrels alters the relationship between sensor 1 depth and natural flow but not between sensor 3 depth and natural flow. (p. 5)

Discussion

The statistics team found a statically significant change in stream response to rainfall after the installation of the rain barrels. However, since this was a preliminary analysis to determine general trends in data and to determine if further analysis is warranted, the team made simplifying assumptions about the data and only considered two years of data. Further analysis should examine the simplifying assumptions such as the assumption of a linear relationship between sensor depth readings and Beecher flow despite the fact that it was found that sensor depth readings and Beecher flow are not linearly correlated. Further analysis should consider more years of data (for example 2009 data) and examine whether factors other than the rain barrels attributed to the detected changes.

5.5 Peak Discharge Analysis

One of the main objectives of the Beecher Creek Pilot project was to determine if the rain barrels could reduce flashiness in Beecher Flow. As discussed in the literature review, one of the indicators of flashy flow is the percent of daily flows that exceed mean annual flow per year. Low values of the ratio indicate a watershed with flashy hydrographs (short duration and high flow peaks), and high values indicate a watershed with more gradually varying flows (Henshaw & Booth, 2000). This indicator could not be used to assess the flashiness of Beecher since determination of mean annual flow requires a longer data record that is available for Beecher Creek. Various other indicators for assessing flashiness were considered and were eliminated based on the availability of data and the required level of effort. Ultimately, the analysis described below was carried out to examine the relationship between rainfall and the first peak in stream response as a proxy for flashiness. It was expected that the rain barrels would reduce or delay the first peak as they attenuate initial runoff. The indicator that is presented in this section is the ratio of change in sensor depth to depth of rainfall at the time of first peak. It was expected that this ratio would decrease after the installation of the rain barrels and the results (Figure 5-20 and Figure 5-21) indicate that the creek response might have changed in the expected direction.

For this analysis the rainfall record was divided into rainfall events. A minimum of 24-hour dry period before and after a wet period was required to classify it as rainfall event. For each rainfall events, for each set of sensor depth readings (Beecher 1 and Beecher 3), the following variables were recorded:

- first peak in stream response (sensor depth),
- net change in sensor depth from the beginning of the rainfall event to the time of the first peak,
- total rainfall from the beginning of the rain event until the time of the peak response,
- time between the onset of rainfall event and the first peak in sensor depth

Some rainfall events did not cause clear peaks in sensor depth. The data points from these events were omitted from this analysis. The variables listed above were plotted against each other. The data collected before the rain barrel installations (September 2010 to June 2011) were compared to the data collected after the rain barrel installations (September 2011 to June 2012). It was assumed similar rainfall events occur for any given period of the year. In other words, it was assumed that the rainfall depth and pattern observed between September 2010 and June 2011 are similar to rainfall depth and pattern observed between September 2011 and June 2012. The next section of the report (Section 5.6) attempts to evaluate this assumption. Figure 5-20 and Figure 5-21 show total rainfall versus net change in sensor depth from the onset of the rainfall to the time of the first peak. The trendlines shown in the figures are linear trendlines fitted to the data using MS EXCEL plotting tools. As it can be seen from the figures, the data from both Beecher 1 and Beecher 3 indicate that there could have been a change in stream response after the installation of the rain barrels. Given a rainfall depth, the net change in stream response at the time of the first peak appears to be lower after the installation of the rain barrels. These preliminary results indicate a positive change in stream response. The record of data after the installation of the rain barrels is much shorter than the record of data before the installation of the rain barrels. The results presented in this section should be re-evaluated once a longer data record is available.

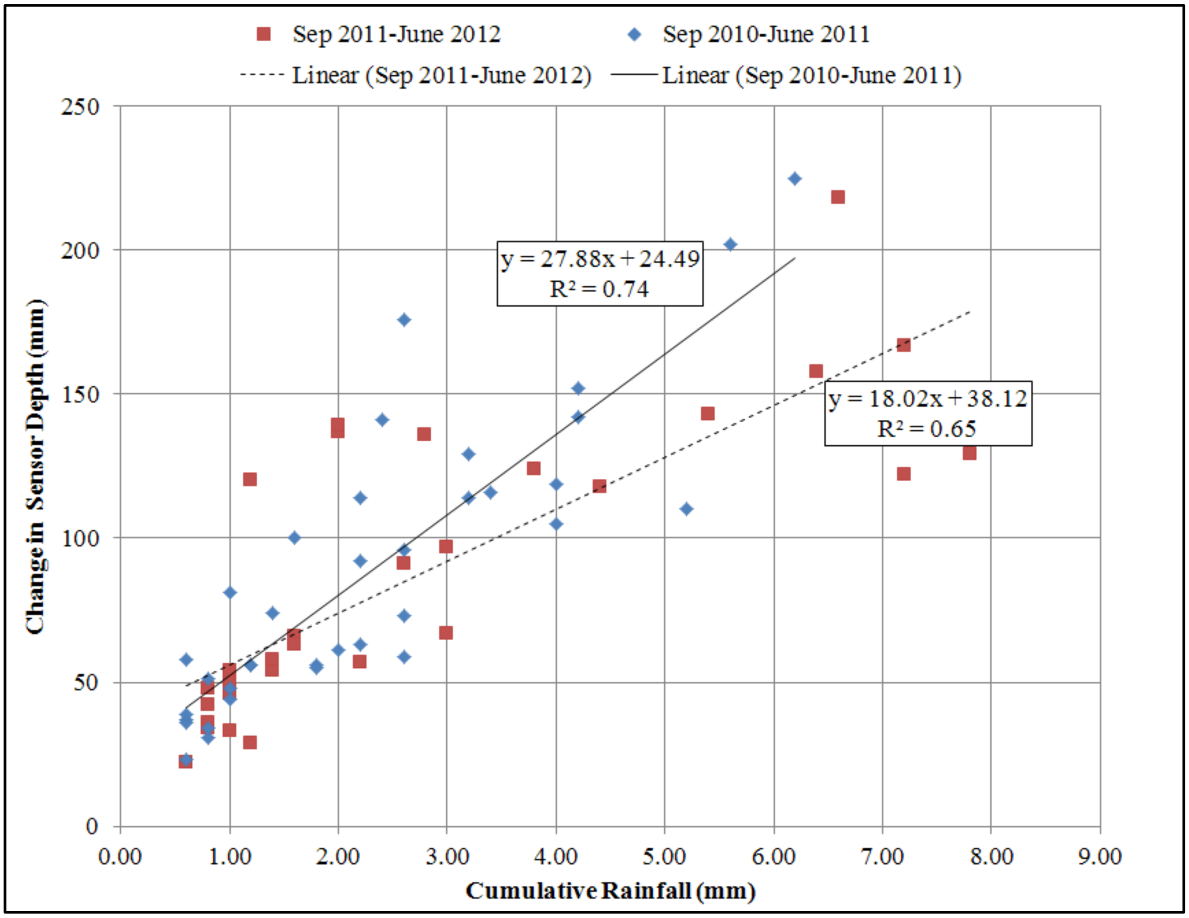

Figure 5-20: Beecher 1 peak flow analysis showing rainfall versus change in sensor depth

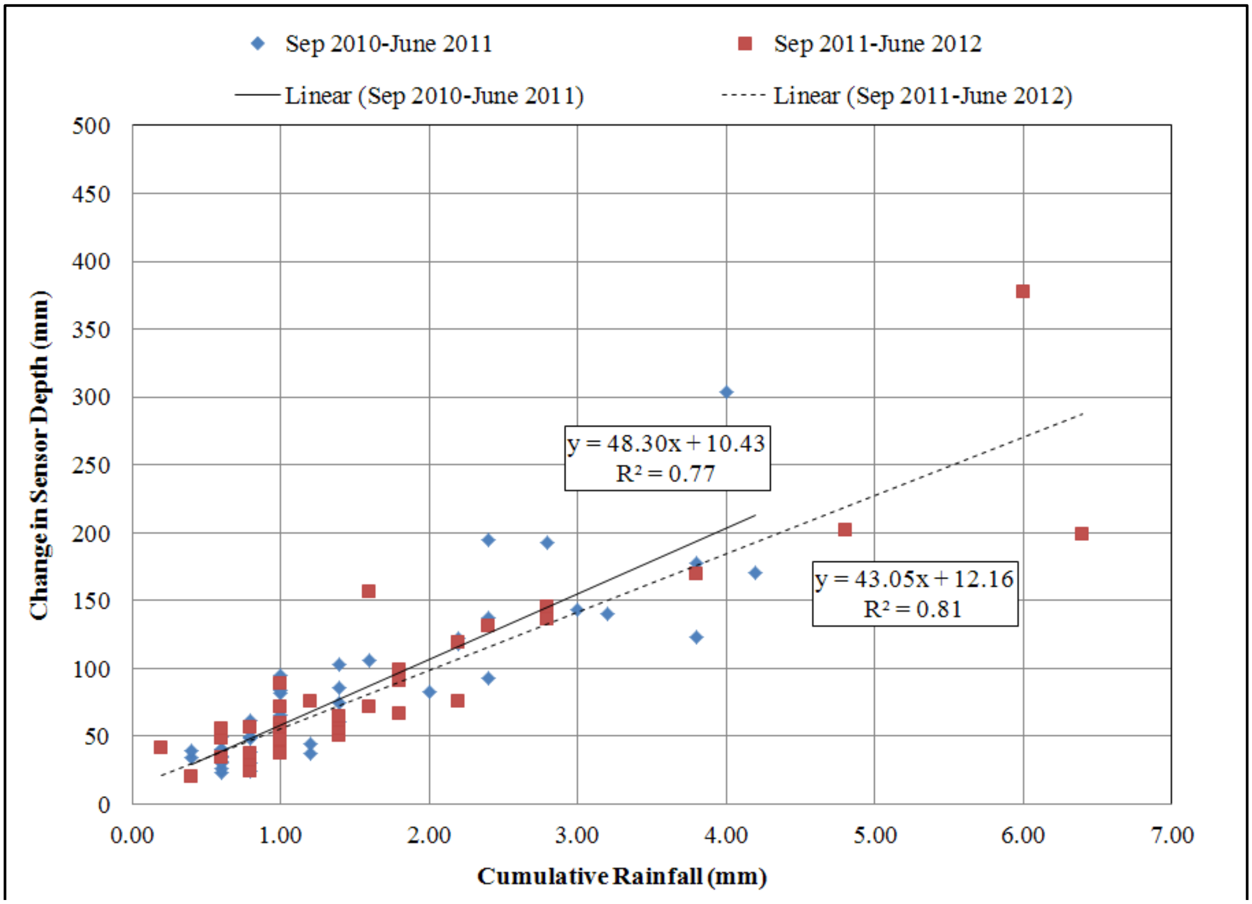

Figure 5-21: Beecher 3 peak flow analysis showing rainfall versus change in sensor depth

5.6 Flow Duration Analysis

For the analysis carried out in Section 5.5, it was assumed that rainfall depth and pattern observed between September 2010 and June 2011 are roughly similar to rainfall depth and pattern observed between September 2011 and June 2012. The assumption is evaluated in this section of the report. It is challenging to directly compare a few months of rainfall patterns. However, there are commonly used statistical methods available to evaluate flow patterns in a stream. Since the relationship between rainfall and flow patterns can be defined for a given stream over a sufficiently long data record, in this section of the report, Beecher flow pattern is used as an indicator for rainfall pattern in the watershed. It should be noted that the exercise described below was carried out to roughly compare the range of flow events in two time periods (August 2010 to June 2011 and August 2011 to June 2012) and to ensure that the range of flows that occurred in Beecher prior to the installation of the rain barrels are roughly the same as the range of flows that occurred following the installation of the rain barrels. In other words, the point of this analysis was to ensure that the rainfall and flow patterns for the duration of the study were typical of Beecher Creek and not exceptional.

To compare the Beecher flow record from the time preceding the rain barrel installations (August 2010 to June 2011) to the time following the rain barrel installations (August 2011 to June 2012), both sets of data were compared to the full length of Beecher flow record available (November 2006 to June 2012). Flow duration analysis was carried out for the full record (2006 to 2012) and different periods are highlighted in Figure 5-22 and Figure 5-23.

The following steps were taken to create the flow duration plots:

1. downloaded hourly Beecher Flow data from flowworks.com
2. calculated average daily discharge
3. eliminated the full day of data if hourly data was missing from the day
4. sorted the average daily flows from maximum to minimum
5. ranked the average daily flows from maximum to minimum
6. calculated the probability of exceedence for each day of flow using m/(n+1) where m is the rank of the data point and n is the total number of days in the record
7. plotted probability of exceedence versus average daily flow (with average daily flow on a logscale)

The plots show the flow duration curve based on the 2006 to 2012 data. In Figure 5-22, all data points between August 2010 and June 2011 are highlighted. In Figure 5-23, all the data points between August 2011 and June 2012 are highlighted. From the plots, it appears that a smaller range of flows occurred between August 2011 and June 2012 than between August 2010 and June 2011.

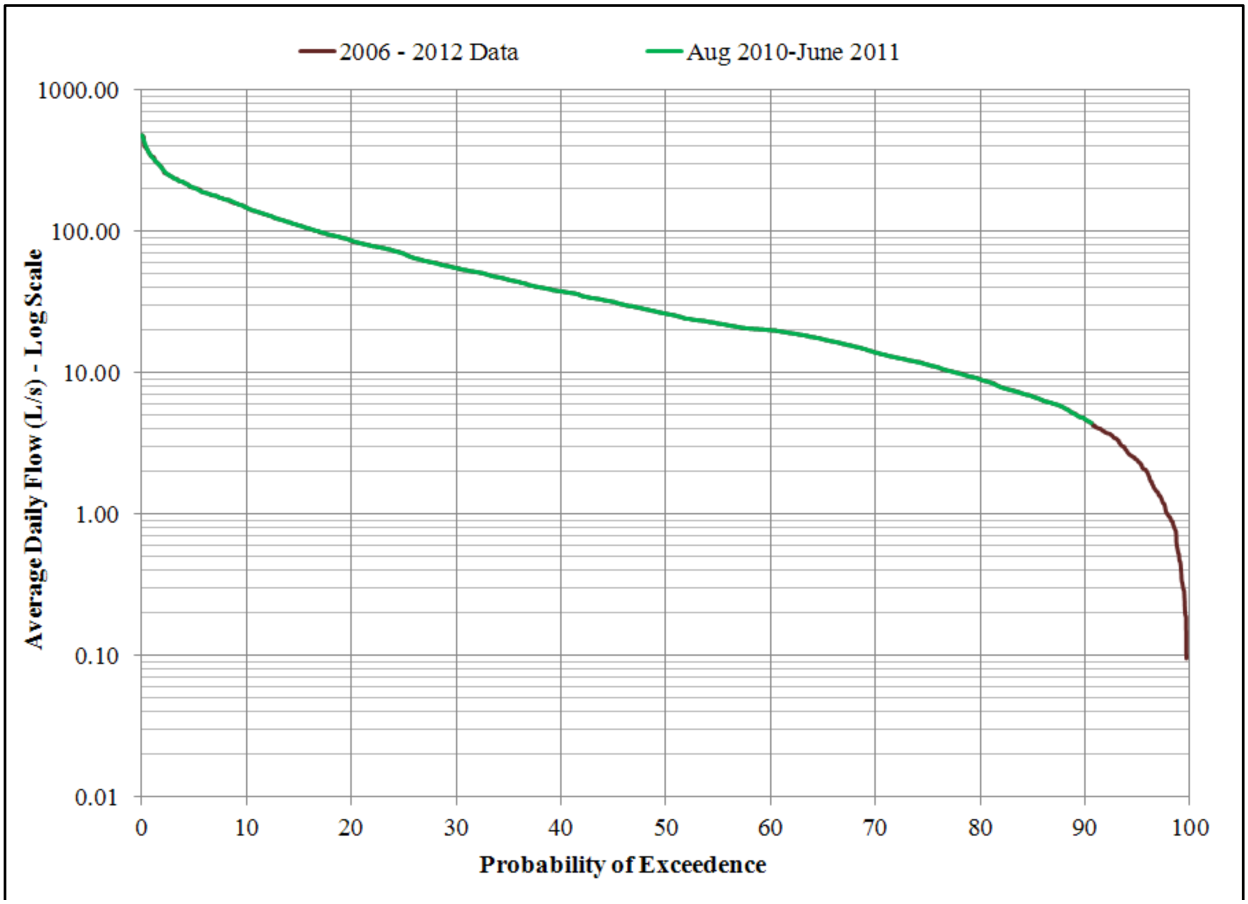

Figure 5-22: Flow duration plot comparing the Beecher flow data from Aug 2010-June 2011 to the data from Nov 2006-June 2012

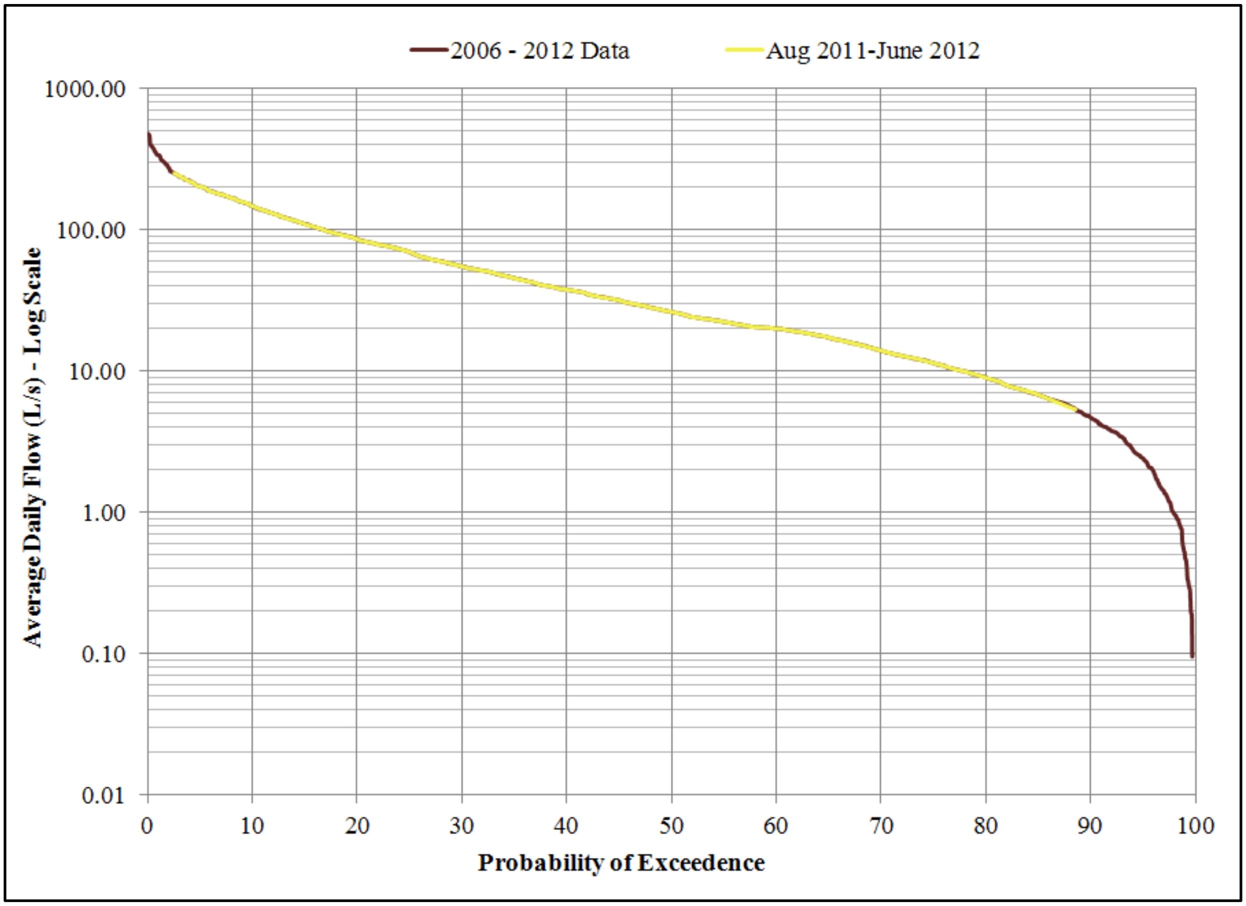

Figure 5-23: Flow duration plot comparing the Beecher flow data from Aug 2011-June 2012 to the data from Nov 2006-June 2012

6 Conclusions and Recommendations

The research attempted to answer multiple questions about the feasibility and effectiveness of stormwater retrofits in residential neighbourhoods. A pilot stormwater retrofit project was planned and executed resulting in 26 (out of 77 possible) lots being retrofitted with 40 self-draining rain barrels. The conclusions and recommendations are centred on two themes. One is volunteer landowner cooperation for retrofit projects and the other is the feasibility and effectiveness of on-site stormwater retrofits.

A major component of the research was to determine what it takes to gain volunteer landowner cooperation. A wide range of information is available on the topic of volunteer homeowner participation in environmental programs and on similar topics such as using community-based social marketing to create environmentally friendly behaviour change. Some of the findings of this research reinforced the following key themes from the existing literature:

- It is important to understand the local context of the project and to understand potential barriers to participation in a retrofit project.
- It is critical to design the retrofit project to reduce the barriers to participation and to provide incentives for participation.
- Potential participants require multiple reminders and prompts about the program.
- Local examples of successful retrofits reduce barriers to participation.

Through the execution of the project, the following additional conclusions were made:

- At this time, face to face meetings are necessary to gain volunteer precipitation. Door knocking was the most effective mean of contacting study area residents.
- Compared to the effort required to retrofit a house, the process of engaging homeowners is not effort or cost intensive but it requires time. Homeowners need time to make decisions and they also change their decisions over time. Time-bound pilot projects are not the most appropriate form for determining the potential participation in a retrofit project. An on-going pilot project with a longer time scale is better suited for tracking the rate of adoption.

- Based on the residents' response to the Beecher Creek project, overtime it is possible to gain volunteer participation from at least 50% of the study area residents. Some of the barriers to participation, such as language barriers and maintenance concerns, can be addressed overtime. Some of the other barriers such as lack of suitable space on the property for the rain barrel are unlikely to change.

Similar to other urban streams, as a result of changes to the watershed due to land development, Beecher Creek has a flashy response to rainfall. The flashy flows negatively impact the aquatic life and habitat in Beecher Creek. A major component of the project was to determine if retrofitting single family homes in a residential neighbourhood can have an effect on the receiving stream's response and can reduce flashiness. Self-draining rain barrels were used to retrofit the houses in the study area for a number of reasons including an existing rain barrel program at the City of Burnaby and the fact that installation of the rain barrels did not require significant alteration of the existing residences. To determine whether or not the rain barrels had an effect, data was collected through a continuous flow monitoring program and was analyzed. This component of the research project was unique as there is a lack of published research studies available that attempt to measure the impact of a neighbourhood scale retrofits though flow monitoring. Most studies that evaluate the impact of catchment scale retrofits are modelling studies. The following are a summary of the study findings:

- A self-draining rain barrel can capture a significant portion of the rainfall volume from the contributing impervious area depending on the maximum allowable discharge rate from the rain barrel. The current DFO guidelines limit the peak discharge rate to 0.25 L/s/ha or 0.09 mm/hr. This discharge rate is likely too low to result in significant volume capture by the self-draining barrels. For the Beecher Creek pilot project, the rain barrels were allowed to discharge at a peak discharge rate of approximately 10 L/hr (roughly double DFO guidelines). The pilot project demonstrated that the application of the self-draining rain barrels at the higher discharge rate was beneficial. If self-draining rain barrels are to be implemented at a larger scale, careful consideration of the maximum allowable peak discharge rate is recommended.
- The results indicate that the rain barrels did have a regulating effect on the stream response

despite the fact that they captured the runoff from a small percentrage of the total impervious area in the catchments. It was estimated that the rain barrels captured the runoff from about 3.5% to 7% of the total impervious area in the catchments. It was also estimated that the rain barrels probably captured less than 40% of the volume of runoff that was generated from the connected impervious areas. Despite, the small volume of total annual runoff captured, the results indicated that the rain barrels reduced flashiness at the flow monitoring stations.

The results and conclusion presented above are preliminary results and are based on limited data collected during the pilot project. The effect of the rain barrels should be evaluated using longer records of data.

Overall, the pilot project demonstrated that it is possible to gain volunteer participation for retrofit projects given the right incentives. Initial data collection and analysis results indicated that capturing and detaining even a small portion of the runoff from a small portion of the impervious area in a watershed can have a regulating effect on a stream’s response. The study offers evidence that even small and incremental stormwater retrofits can mitigate some of the negative consequences of the land development on stream response.

The literature review revealed a need for pragmatic pilot and demonstration studies that can help and support municipalities with the implementation of low impact development techniques for stormwater management. This study was a pilot study that provides insight and guidance for municipalities on how to proceed with neighbourhood scale stormwater retrofits. Municipalities can use this study to estimate the scale of time and effort that might be required for such projects. The study demonstrated through fieldwork that very small scale decentralized detention can have a regulating effect on the flows in urban streams. This is something unique; the evidence provided in support of small-scale low impact development techniques by this thesis should encourage municipalities to move forward with the implementation of such stormwater management techniques.

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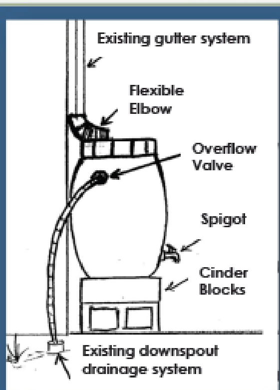
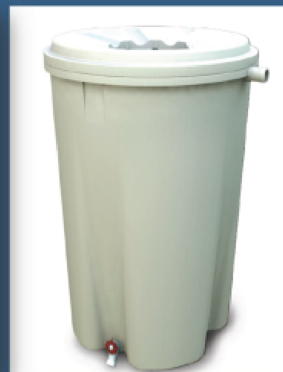
Appendix A: Supplementary Information for Materials and Methods

Beecher Creek

Choose Your Free Rainbarrel!





Installation Schematic

As a project participant, you will receive up to two FREE RAINBARRELS.

You choose the rainbarrel. The rainbarrel will be installed on your lot by the graduate student at no cost to you. The rainbarrel will be connected to your existing downspout and existing drain. The rainbarrel will be placed on a concrete pad.

363 Liters (96 Gallons)

The green rainbarrel has a half barrel design which sits flat against an exterior wall. The inlet has a micro-screen to prevent the entry of mosquitoes and to prevent debris from entering the barrel. All fixtures are included.

The rainbarrels' designs PREVENT mosquito entry.

208 Liters (55 Gallons)

The beige rainbarrel has a full barrel design with the diameter of 66 cm (26") and a height of 86 cm (34"). Like the green barrel, it also features a mosquito and debris screen. All fixtures are included.

The graduate student will provide any necessary maintenance during the project.

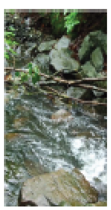
QUESTIONS/COMMENTS:

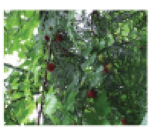
Talk To Us!

[redacted]

Sara Pour [redacted]

City of Burnaby [redacted]





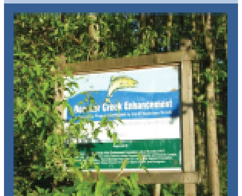
Beecher Creek

Rainbarrel Project

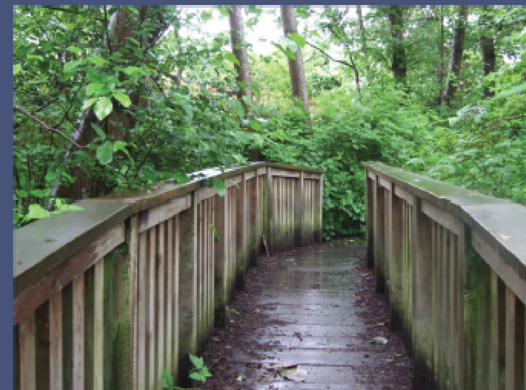
Beecher Creek: A Hidden Oasis at the Heart of North Burnaby….

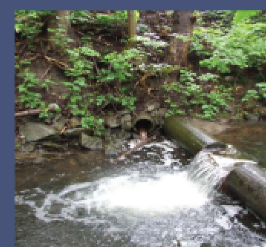
On its journey from Capitol Hill to Still Creek, Beecher Creek flows through Kensington Park and Beecher Park. It is home to salmon, trout, and other native wildlife. The creek is surrounded by green space in the midst of a busy urban area. It serves as a recreational area for the Burnaby residents.

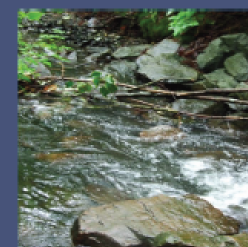
- ***Hosts Fish and Wildlife***
- ***Beautifies Your Neighborhood***
- ***Provides Green Space to Relax and Play***



Beecher Creek
Springer Ave.
Burnaby







What is the Beecher Creek Rainbarrel Project?

For the past 15 years, an active stream stewardship group, the City of Burnaby, and the University of British Columbia have been working together to protect Beecher Creek from the negative effects of land development and to keep the Beecher Creek ecosystem vibrant and healthy for the future generations.

Amongst other activities, we have been planting trees in the area and repairing damaged portions of the creek. **This information package describes the next phase of the project, the Beecher Creek Rainbarrel Project, which requires community participation to succeed.**

For more information about free rainbarrels call [redacted]

Beecher Creek

Project Area

Rainbarrel Project Description

A UBC environmental engineering graduate student, Sara Pour, is working with the City of Burnaby on the Beecher Creek Rainbarrel Project. The goal of the project is to minimize the negative effects of land development and to improve the health of Beecher Creek by using new rainwater management techniques. The project aims to install up to 200 rainbarrels in properties neighboring Beecher Creek.

We are asking the residents to participate in the project by having a rain barrel installed on their lot. The project participants will receive up to two free rainbarrels. The UBC graduate student will deliver, install and maintain the rainbarrels at no cost to the residents. The rainbarrels will be connected to the building's existing roof gutter system and to the building's existing drain. When it rains, these rainbarrels temporarily store rain before slowly releasing it back to the creek. They protect the creek by slowing the flow of water to the creek.

For more information about free rainbarrels call [redacted]

Beecher Creek

Why Rainbarrels?

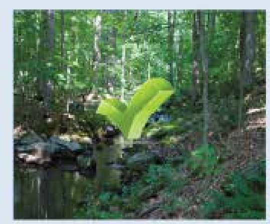
Where Does Rainwater Drain to in Your Neighborhood?

Why Rainbarrels?

Rainwater that falls on your roof ends up in Beecher Creek.

- **Rainbarrels improve how water is drained from residential lots to Beecher Creek.**
- **Reduce erosion in the creek**
- **Protect fish, trout and salmon, living in the creek**

- Rainbarrels will capture rainwater from the roof
- Rainwater is available for residents to use for landscaping and gardening after the study period of the project is complete
- Water collected in rainwater barrels is exempt from the City of Burnaby watering restrictions



Keep creek healthy and vibrant

Prevent erosion and deterioration of the creek

For more information about free rainbarrels call [redacted]

Communication with the Study Area Residents
Strategy/Timeline

1st Letter
- Send 1st letter ASAP.
- This letter will give notice of the project to study area residents and ask them to contact Sara Pour for more information.
- Expect to get calls within 48 hours.
- Follow up with a second letter.

2nd Letter
- Send the 2nd letter within a week of the 1st letter.
- This letter will give residents a second notice and will notify them of a site visit.
- Attach the communication package to the 2nd letter so homeowners have a chance to read it before the site visit.

1st Site Visit
-Visit homeowners within a week of sending out the 2nd letter
-Introduce the residents to the project.

- If a resident is ready for a rainbarrel, conduct a site survey of the property.
- If a resident asks for time to make a decision, schedule a follow up phone call or site visit.

Follow Up Site Visits
- Schedule as many site visits as required to have a rainbarrel installed on a property.
- Schedule follow up site visits with homeowners once the rainbarrels are installed to make sure the set up is working(i.e. visit all rainbarrels a month after installation)
-Schedule a visit for beginning of December to change the setting on the rainbarrels to winter setting.

Showcase Home
-Is it feasible to provide a showcase home for the study? I can use my parent's house but it is in Burnaby South.

s

- Send out the 1st letter to the residences in the study area.
- Send out the 2nd letter with the communication package attached to the residences in the study area

Note: Sara has provided Kel with addresses of the residences in the study area. Addresses are also attached.

-Is someone from Burnaby accompanying Sara on the site visits?
-Is Burnaby able to translate the communication package to any popular spoken languages in North Burnaby (i.e. Mandarin and Cantonese)?

Communication with the Study Area Residents
Sample Questions and Answers

Here are a list of anticipated questions from the residents and the answers to the question. Please let me know if you anticipate any questions that are not included here and they will be added to the list.

Why are you collecting rainwater? / Why are you installing rainbarrels?
Short Answer
-To slow down the flow of water to Beecher Creek during rainfall events.
- To mitigate some of the negative effects of land development on the creek, the fish and other organisms that live in the creek.

Long Answer
In your neighborhood, rainwater that drains from your property ends up in Beecher Creek. The rainbarrels will slow down the flow of water to Beecher Creek by temporarily storing rainwater. We are trying to protect the creek from some of the negative effects of land development like erosion and high flows. We are trying to protect the fish in the creek. We are trying to maintain the creek healthy and beautiful for you, your family and the future generations that will live in your neighborhood.

Why do you need to regulate the flow in the creek?
High flows deteriorate the stream (bed and banks). Beecher is a fish bearing stream. Irregular flows make it hard for fish and other aquatic organisms to live in the creek. For example, high flows wash away sources of food for fish.

What is going to happen to the water that is stored in the rainbarrel?
The rainbarrel will hold rainwater temporarily and will slowly return it to the storm drain which is connected to the storm sewer. The storm sewer drains water away from the property and directs it to the creek.

Can I use the water?
Yes but only after the study period. After the study period (approximately one year) is over, you can use the rainbarrel however you would like. For the duration of the study, the rainbarrels will be connected to the storm drain and will empty within an hour of a rain event. You will not be able to use the water in the rainbarrels while the study is ongoing.

How does this project help fish?
Land development changes the flow of rainwater to streams. In urban areas, most of the land is paved and rainwater cannot get into the ground. Since water can't go into the ground, in the cities, rainfall significantly increases the flow of water in a stream. When water moves at high flows, it can damage a creek through processes like erosion. It can also damage fish habitat and wash away fish food. Over time, high speed water resulting from rainfalls can turn a healthy beautiful creek into an eye sour in the neighborhood. Rainbarrels will help regulate the flow of water in the creek.

Why should I care?
- The stream corridor beautifies your neighborhood.
- It provides recreational areas for you and your family.
- Beecher is one of the last tributaries to Still Creek in Burnaby.
- Scouts, local stewardship groups and the City of Burnaby have been working together to keep the creek healthy.
- Your neighborhood can become a model for other municipalities. You can take a small action and be part of something big that has positive effects on the environment.

What are you going to do to my property?
- Cut the downspout.
- Place a rainbarrel underneath the downspout on top of a concrete pad
- Connect the rainbarrel to the drain with pipes

Your property will be restored to its original state if you decide to opt out of the study or if you decide to return the rainbarrel after the study is over.

What is happening to my street?
Rainbarrels are being installed on residential lots. The street is not going under any modifications

What is going to happen if I don't like the set up and I no longer want to participate in the study after a rainbarrel is installed?
You can contact Sara at beecher.rainbarrels@gmail.com and she will remove the rainbarrel and the concrete pad, and restore your downspout and drain to their original conditions.

Who is going to pay for it? Who is going to pay for damages to my property?
- The rainbarrels are provided for free by the City of Burnaby.
- The rainbarrels will be installed at your residence at no cost.
- Participation in the program is voluntary.

- The study should not cause any damages to the property.
- If there are no existing drainage issues on the property, the study will not create drainage problems.
- In case there is damage call Jim Atwater at or email Sara at or someone from the city?

NOTE: I can't answer this question fully until UBC and Burnaby have a contract

Are the rainbarrels going to attract mosquitoes?

No, the rainbarrels have micro-screens that prevent mosquitoes from entering the rainbarrels. Also, there won't be standing water in the rainbarrels and therefore mosquitoes should not be a problem.

How many rainbarrels are you going to install on my property? / How many rainbarrels can I have?

-Liability issues. UBC requires a contract from Burnaby before they can finalize liability issues.

-How many rainbarrels can be given to each residence?

Rainbarrel Modification/Installation Plan

There are standard modifications that will be made to all rainbarrels. A siphon will be installed on each rainbarrel. Parts required for the standard modifications will be purchased in bulk. However, there will be required modifications that cannot be anticipated prior to a site survey of a participating residence (adjustments required for connecting the rainbarrel to the drain). Parts required for site specific modifications will be purchased following the site visit. Most parts will be purchased through the UBC Civil Engineering Shop and the City of Burnaby Engineering will be billed for the parts.

Once a residence has agreed to participate in the study and has chosen a rainbarrel, a site survey will be conducted to determine specific site constraints. The site survey form is attached. At this point, any specific parts required for the rainbarrel will be purchased. Following the site survey, major modifications to the rainbarrels will be made in the Burnaby Works Yard. The modified rainbarrel will be delivered to the residence and installed on the day of the delivery (placed on a concrete pad and connected to the existing downspout and the existing drain). Minor adjustments and fine tuning of the rainbarrel will take place at the residence. The UBC Civil Engineering Department will provide a truck for transportation of the rainbarrels. The City of Burnaby Engineering will be billed for the mileage. Another UBC graduate student will assist with modification and transportation of the rainbarrels.

-The city will provide the rainbarrels
-The city will pay for parts and mileage

-What are the logistics of working in the Burnaby works yard?

Communication with the City of Burnaby Engineering

I will send monthly update reports to Burnaby. I will update Burnaby on the number of rainbarrels installed and the addresses at which the rainbarrels are installed at. I can also provide a summary of planned field activities for the following month and the required resources for the upcoming month.

-Other than the number of rainbarrels installed and the location of the installed rainbarrels, what issue does Burnaby require monthly updates on?
-If an issues requires city of Burnaby attention, who is going to be the primary contact for Sara?
-Who is going to be the primary contact for the residents of the study area? Whose phone number should be included in the communications package?
-How frequently should I submit receipts to Burnaby? What information should accompany a receipt?
-How much advance notice does Burnaby require for ordering rainbarrels?
-Is someone from Burnaby accompanying Sara on the site visits?
-Is Burnaby able to translate the communication package to any popular spoken languages in North Burnaby (i.e. Mandarin and Cantonese)?

2010 May 10 FILE: 31000-40
Rainwater Management

OWNER/OCCUPANT

47XX WATLING ST
BURNABY BC VXX-XXX

Dear Sir/Madam:

SUBJECT: BEECHER CREEK RAINBARREL PROJECT- BURNABY

In September 2009, Burnaby City Council approved a joint rainwater management project in the Beecher Creek area. The goal of the project is to improve the health of Beecher Creek, a neighbourhood ecosystem, by using new rainwater management techniques. The City of Burnaby, in cooperation with the University of British Columbia and the local Beecher Creek Streamkeepers group, will work with residents in your neighbourhood on this innovative project, the first of its kind in Canada.

In order to minimize the negative effects that land development has on the water cycle, the City will be installing rainbarrels to improve how water is diverted from residential lots to the creek. The storage of rainwater will help regulate the flow of water to the creek during periods of flooding as well as during periods of low rainfall. This will provide environmental benefits to the vibrant creek ecosystem by protecting fish and wildlife habitats, and by reducing erosion and deterioration of the creek bed.

Participating residents may receive up to two rainbarrels which will be delivered, installed, and connected to the roof gutter system at no cost to them. Each rainbarrel can store up to 360 L of rainwater which has been drained from the roof of the residence through the gutter system. This water can be used for personal landscaping and gardening purposes after the project is complete. The water collected in rainbarrels is exempt from City watering restrictions. There are 200 rainbarrels available for the project. Due to limited availability of rainbarrels, only 100 households will have the opportunity to participate.

The attached document contains information on the goals, objectives and scope of the project. A City of Burnaby staff member and a UBC environmental engineering graduate student are available in the following weeks for site visits and to answer any questions you may have. Participation in this project will be on a first-come, first-served basis. Please contact Sara Pour at (or) to sign up or to set up a personal meeting to discuss this opportunity further.

Yours truly,

L. S. Chu, P. Eng.
Director Engineering

By: Kel Coulson, M.A.Sc. (EIT)
Environmental Engineer
Phone:
Email:

Engineering Department

2011 February 24 FILE: 31000-40

Rainwater Management

Owner/Occupant

Dear Sir/Madam:

SUBJECT: RAINWATER RETROFIT PROJECT - BEECHER CREEK, BURNABY

This letter is to update you on the status of the Beecher Creek rainwater management project. A package outlining information on the goals, objective and scope of the project was delivered to your home in January of this year. The City of Burnaby, in cooperation with the University of British Columbia (UBC) and the local Beecher Creek Streamkeepers group, have been working with residents in your neighbourhood on this innovative project, the first of its kind in Canada. The project is in the process of retrofitting single family homes with rainwater barrels with the goal of improving the health of the Beecher Creek ecosystem.

To date, we’ve had a positive response from Beecher Creek residents and are on track to install 30 rainbarrels by the first week of March. If you’d like to participate, you can receive up to two rainbarrels which will be delivered, installed, and connected to the roof gutter system at no cost. This water can be used for personal landscaping and gardening purposes after the project is complete (water collected in rainbarrels is exempt from City watering restrictions during periods of dry weather). The storage of rainwater helps to reduce the peak flow of runoff and provides positive environmental benefits to the downstream creek system.

Please contact Sara Pour by March 11, 2011 at (or) to sign up or to set up a personal meeting to discuss this opportunity further.

Yours truly,

L. S. Chu, P. Eng.
Director Engineering

Kel Coulson

By: Kel Coulson, M.A.Sc.
Environmental Engineer
Phone:
Email:

KC/br

Beecher Creek
Enhancement Project

Site Visit Survey

GENRAL INFORMATION

Date ____________________
Time ____________________
Address ____
Type of Rainbarrel Requested ____________________

PRIMARY CONTACT
Name ____________________
Email ____________________
Phone ____________________
Prefer: Email / Phone

SECONDARY CONTACT
Name ____________________
Email ____________________
Phone ____________________
Prefer: Email / Phone

NEXT SITE VISIT

OPTION 1
Date ____________________
Time ____________________

OPTION 2
Date ____________________
Time ____________________

PROPERTY INSPECTION (attach photos of the property)
Do you have any existing drainage problems (i.e. water in the basement) ?

____
____
____

Comments

____
____
____

DOWNSPOUTS (attach photos of the downspout)
Number of downspouts ____
Type & Size ____

RANBARREL LOCATION (attach photos of the location)
Downspout Type & Size ____

Ground Condition ____

Wall Condition ____

Drainage Condition ____

Drain Condition ____

Other Possible Questions
Did you receive the letter and pamphlet from the City?
Do you garden?
Do you know about Beecher Creek?
How long have you lived here?

Appendix B: Additional Data

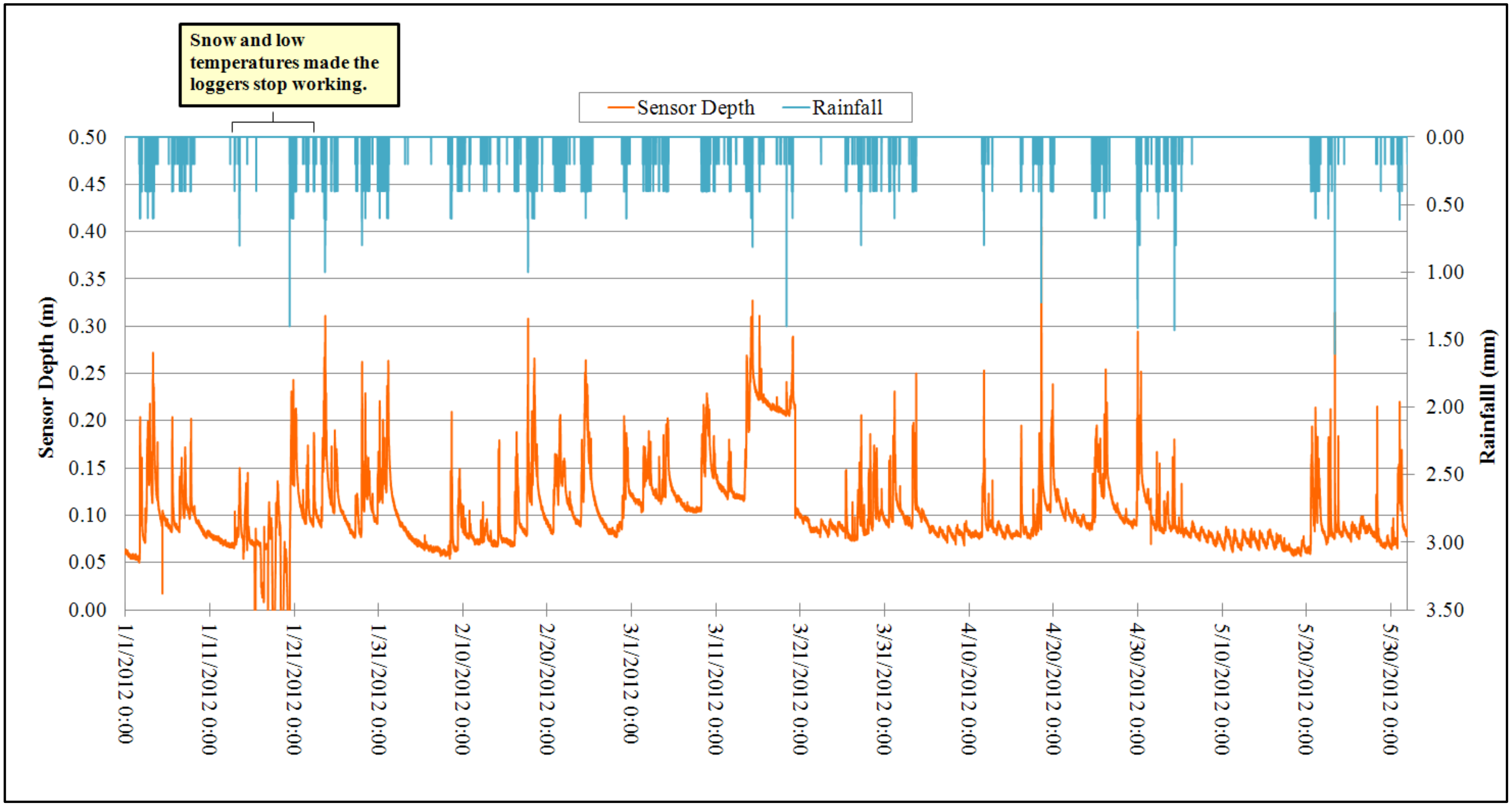


Figure B-1: Time series of Beecher 1 sensor depth readings and rainfall from January 2012 up to June 2012.

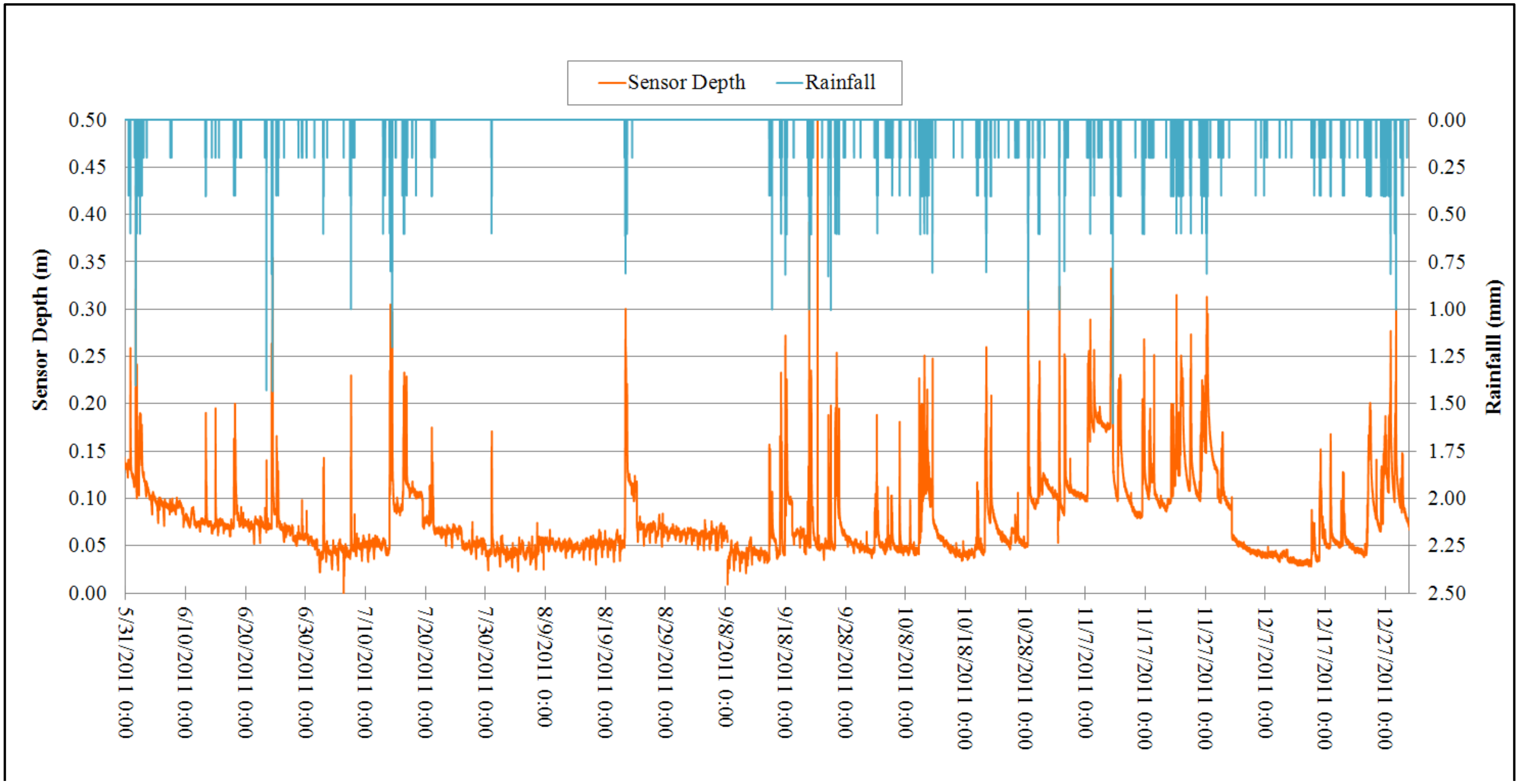


Figure B-2: Time series of Beecher 1 sensor depth readings and rainfall from June 2011 to January 2012.

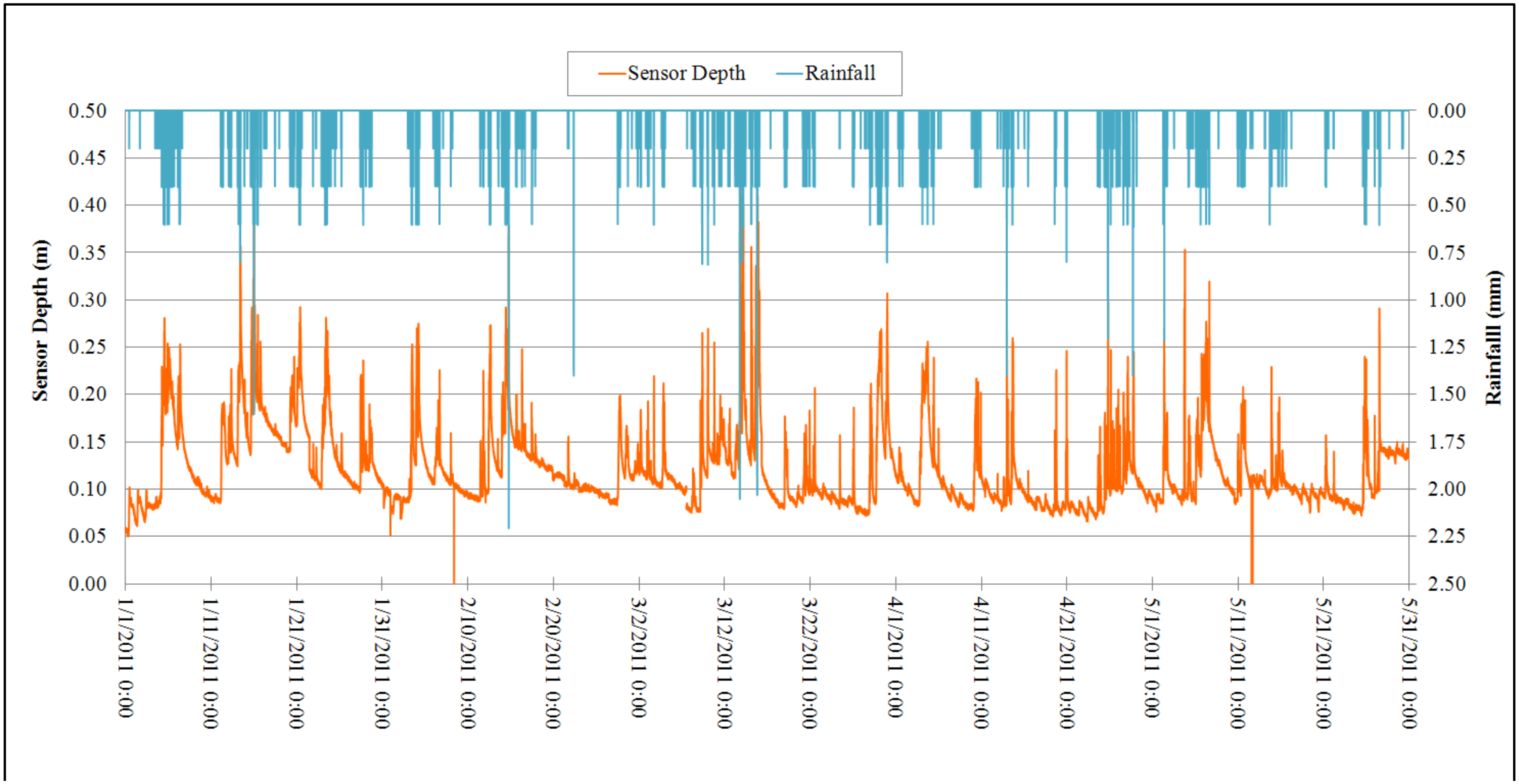


Figure B-3: Time series of Beecher 1 sensor depth readings and rainfall from January 2011 up to June 2011.

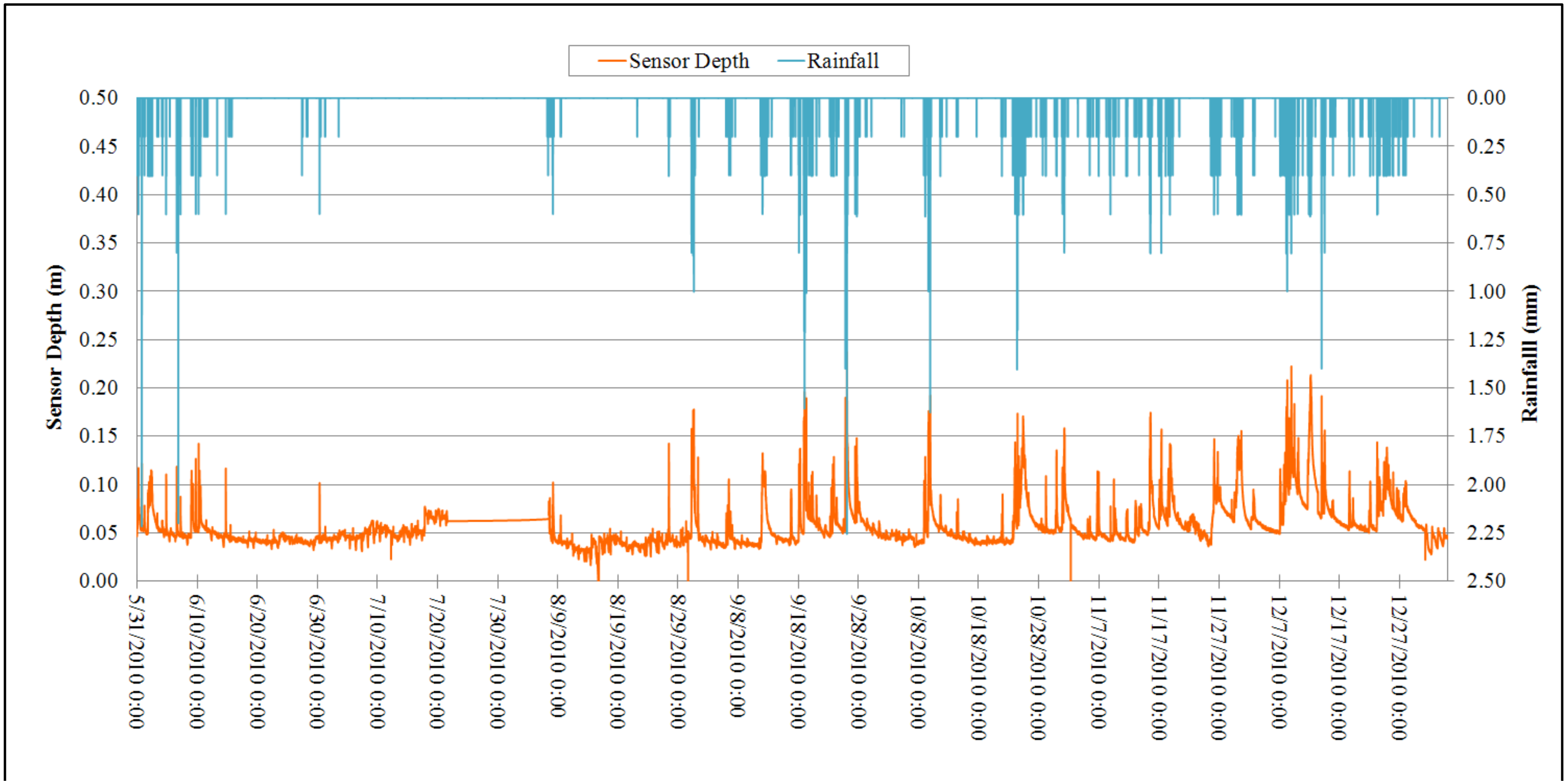


Figure B-4: Time series of Beecher 1 sensor depth readings and rainfall from June 2010 to January 2011.

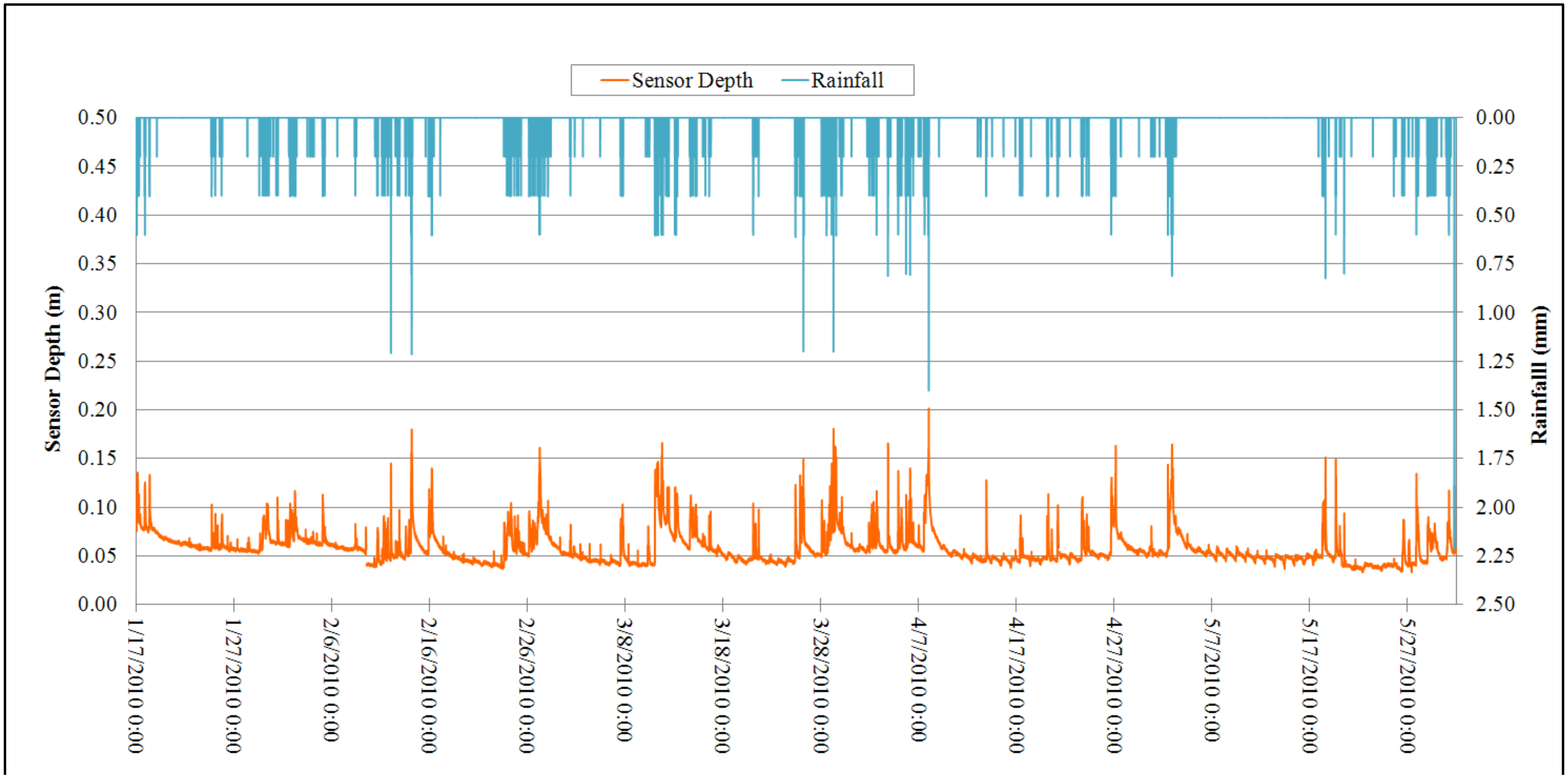


Figure B-5: Time series of Beecher 1 sensor depth readings and rainfall from January 2010 to June 2010.

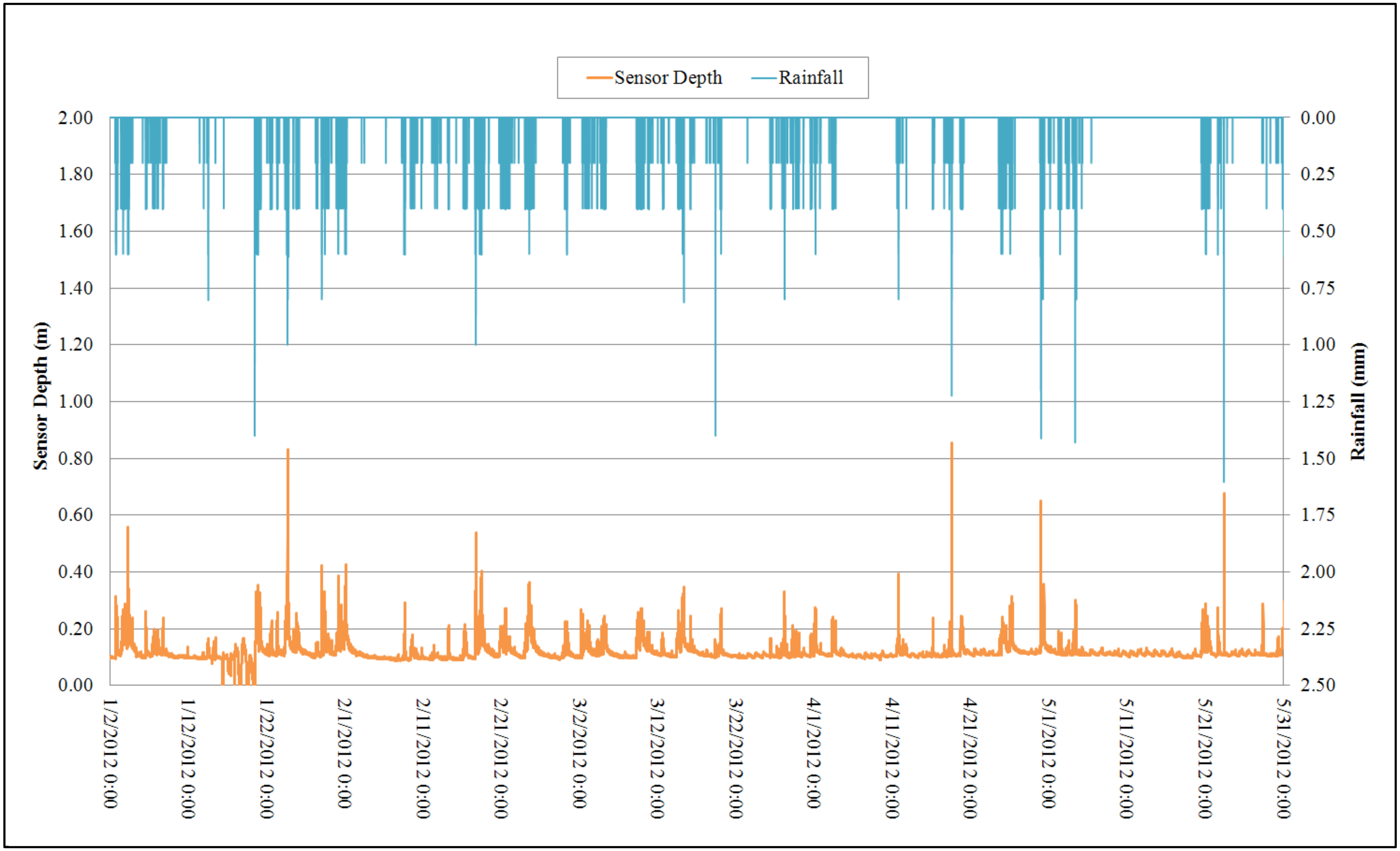


Figure B-6: Time series of Beecher 3 sensor depth and rainfall from January 2012 to June 2012.

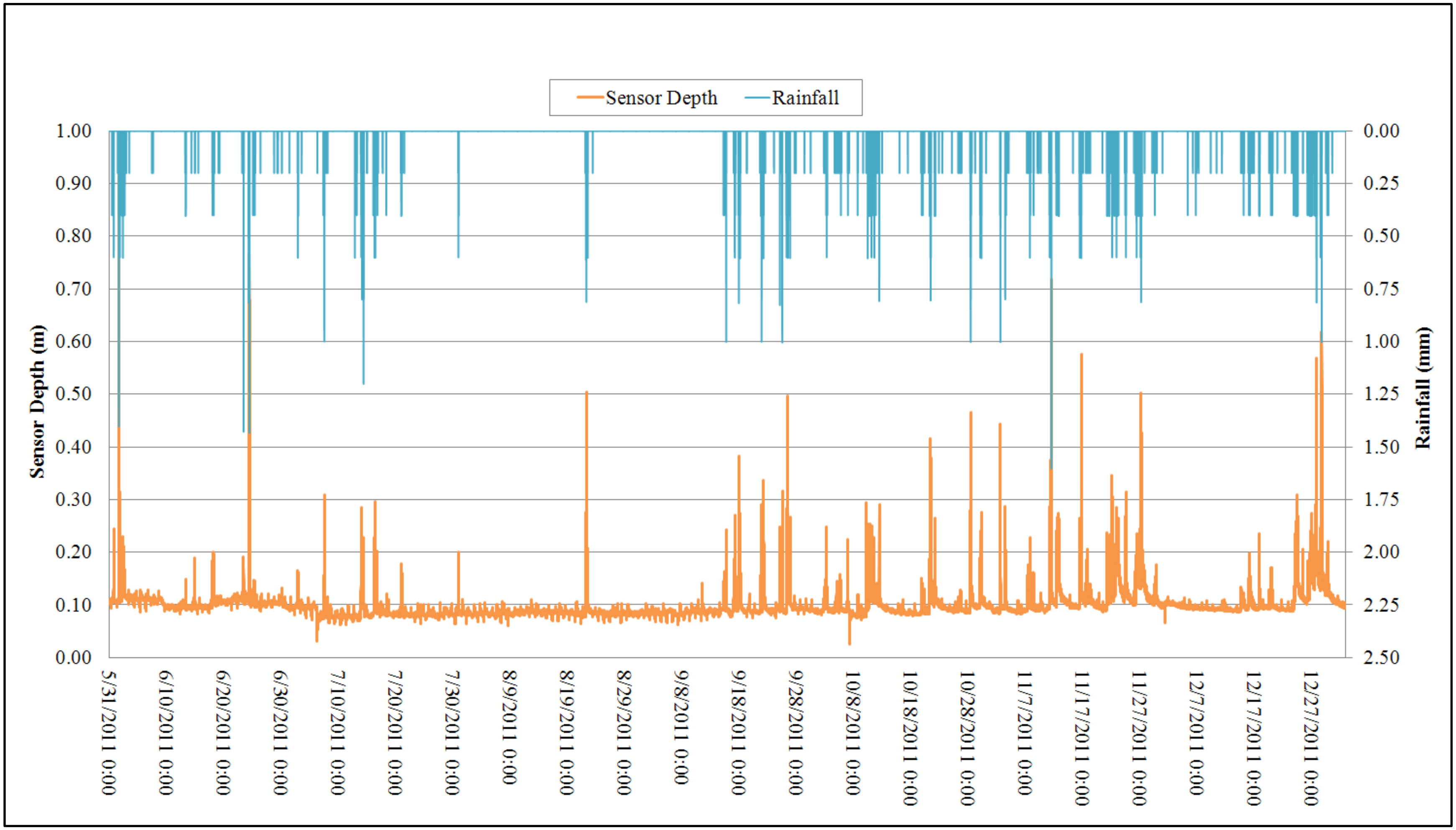


Figure B-7: Time series of Beecher 3 sensor depth and rainfall from June 2011 to January 2012.

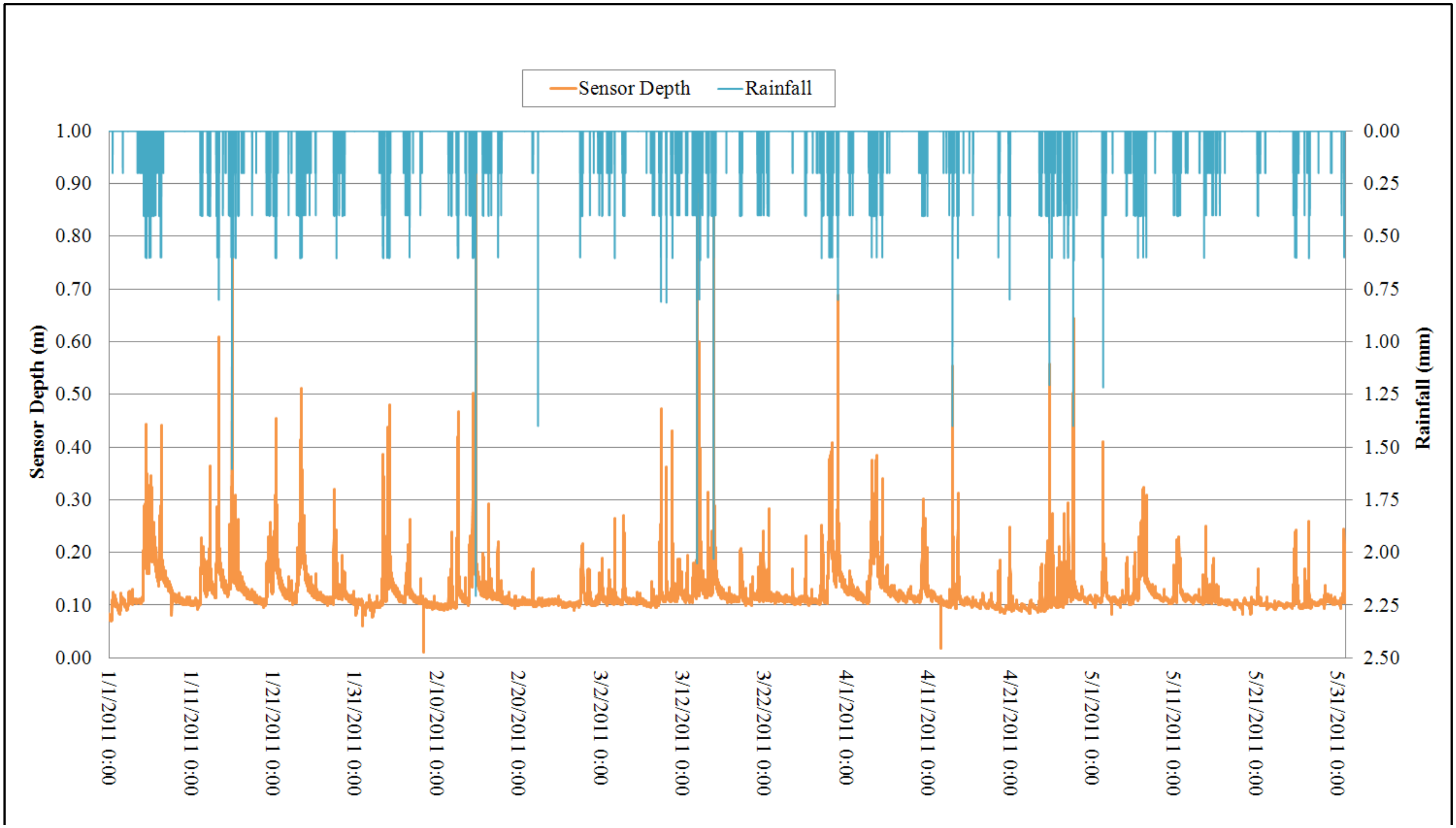


Figure B-8: Time series of Beecher 3 sensor depth and rainfall from January 2011 and June 2011.

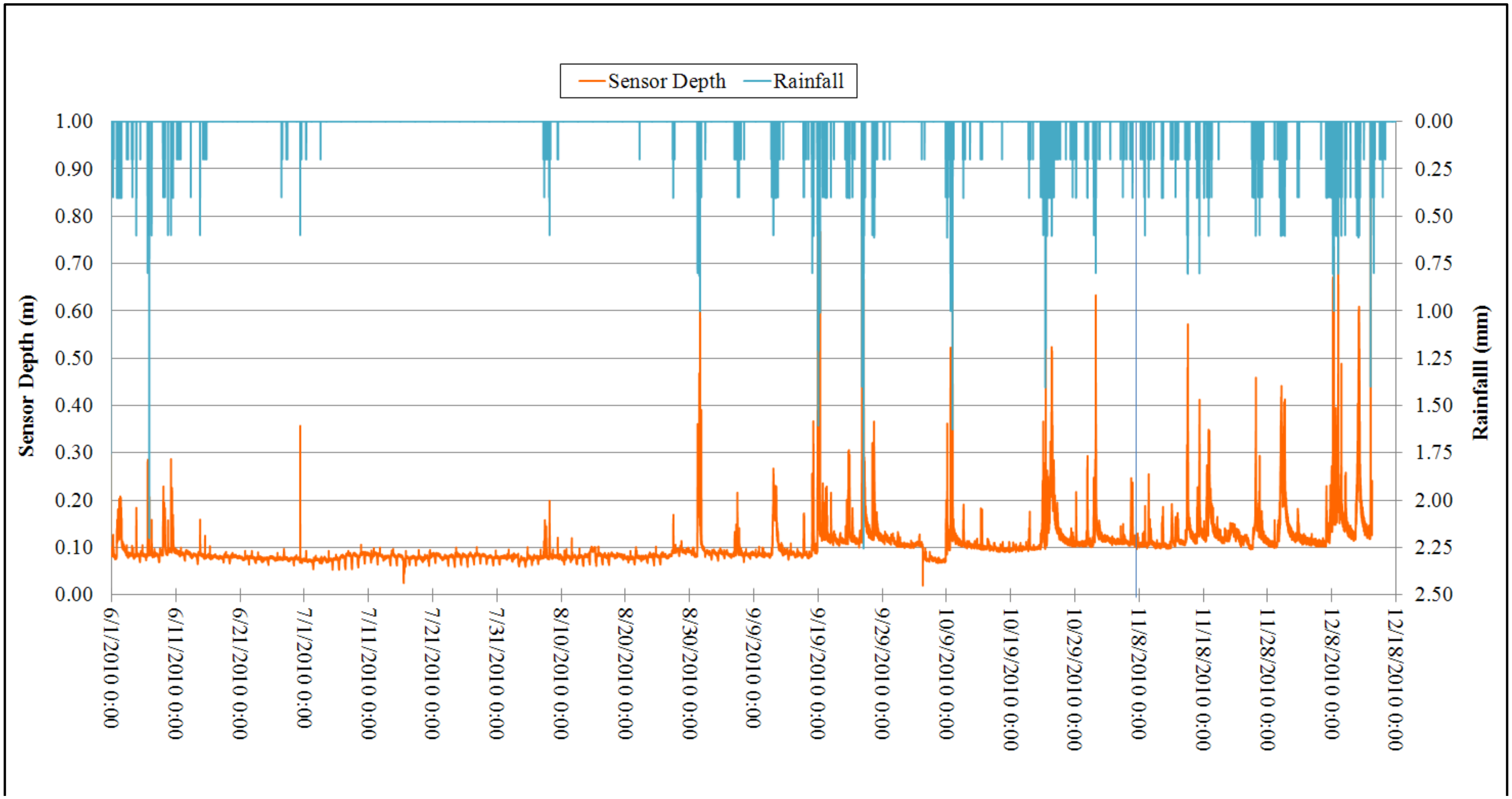


Figure B-9: Time series of Beecher 3 sensor depth and rainfall from June 2010 to January 2011.

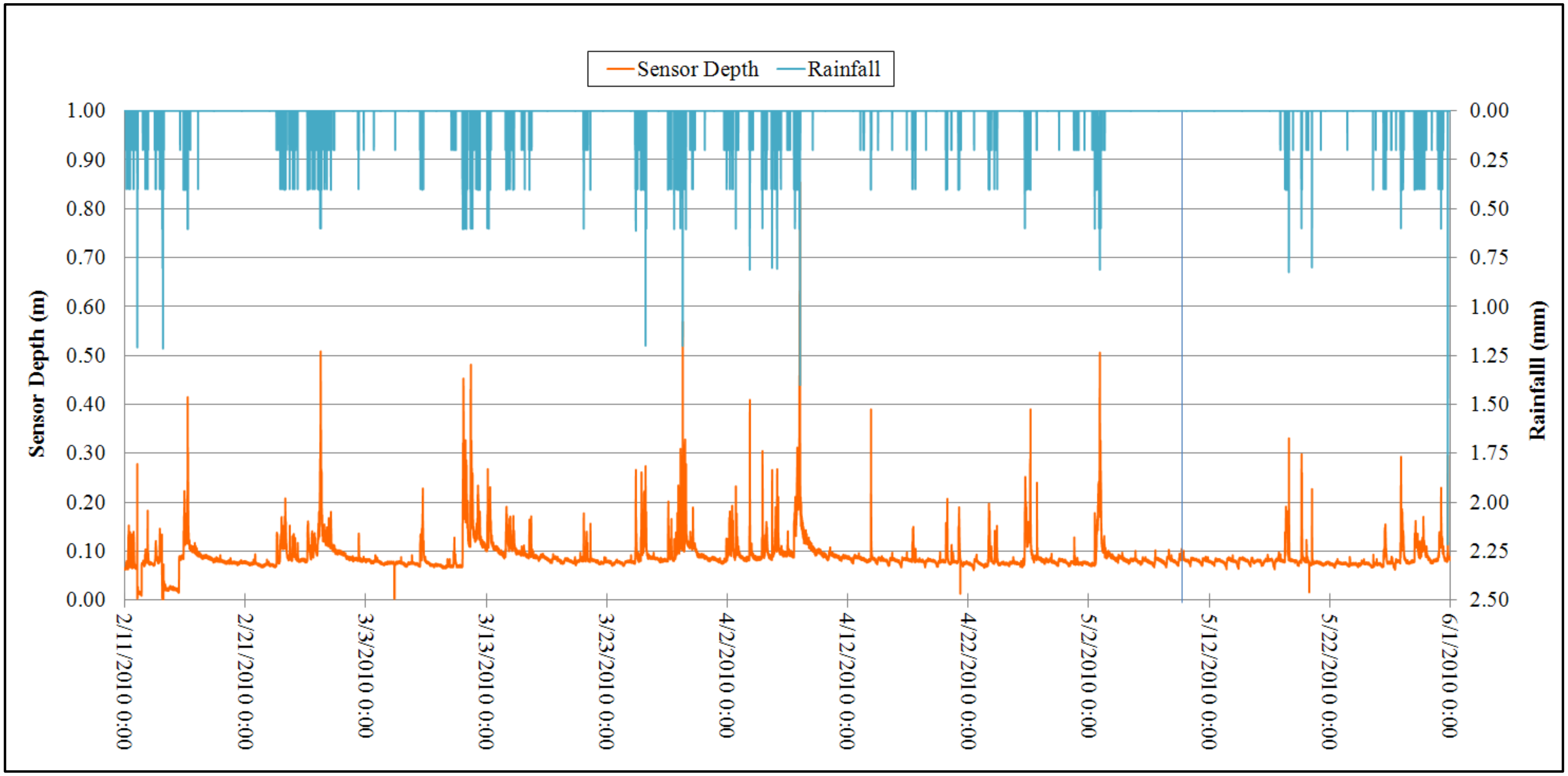


Figure B-10: Time series of Beecher 3 sensor depth and rainfall from February 2010 to June 2010.

Appendix C: STAT 450 Report

The Effect of Rainfall Events on Stream Response

Client: Sara Pour

By Vanessa Goh, Natalie Guo, David Zhao, and Louis Zhen

Introduction:

Over the years, city development has altered the way natural processes work. For example, there is less soil available today, compared to a hundred years ago, to absorb water after rainfall as concrete pavements and roads replace natural land. Negative consequences include severe water surface runoffs leading to greater erosions of streams and adverse alterations of marine life habitat. A potential method of slowing, or even stopping this harm, is the installation of rain barrels in homes located close to a creek to control the rate of surface runoff, thus slowing down the rate of erosion and alteration of the habitat of aquatic animals. The effects of rain barrels installed in homes around Beecher Creek were the main points of interest, and a study was conducted to determine if rain barrels affect the stream's response. Specifically, the primary purpose was to determine if there was any change in the response of the creek in two locations upstream and one further downstream after the installation of rain barrels.

Data Collection:

Water depths were measured at two locations upstream of Beecher Creek in Burnaby, called Beecher 1 and Beecher 3. Also, natural flow was recorded further downstream. Initially, the data was collected as per normal. Afterwards, rain barrels were installed in homes around the creek and the same measurements were again recorded.

Experimentally, it would be preferable to conduct this experiment with rain barrels installed in all the houses that drain to Beecher 1 and 3 instead of some as only then can the full effect of rain barrels be captured. Furthermore, the data would be more accurate if the sensors were ensured to remain in place at all times as some data points had readings of flow greater than 1000L/s.

Statistical Questions:

1. How can we determine if there has been a change in stream response after the installation of rain barrels?
2. How can we determine if there is a relationship between sensor depth at Beecher 1 (and 3) and the natural flow at Beecher Creek before the installation of rain barrels?
3. If there is a relationship in part 2, does the relationship still hold after the installation of rain barrels?

Statistical Methods and Results:

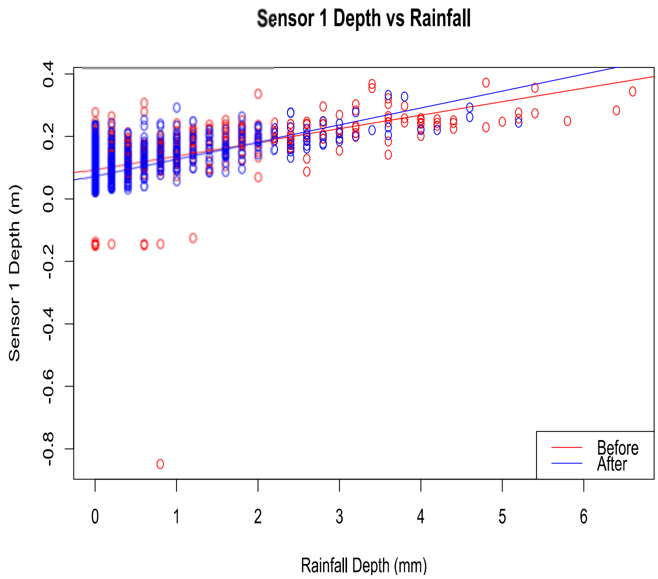
In order to condense our data set, we found the hourly averages of each variable: sensor depth 1 and 3, beecher flow and rainfall amount. We also used August 1st to December 31st, 2010 to represent the period before rain barrels were installed and the same time interval in 2011 as the period after rain barrels were installed. Furthermore, we ignored measurements corresponding to inaccurate or missing values in natural flow (i.e. data points that had flow more than 1000L/s and missing values for sensor 1 depth).

In order to clearly distinguish our groups, we classified the data for sensor 1 before and after the installation for rain barrels as $G1_{before}$ and $G1_{after}$ respectively, and similarly as $G3_{before}$ and $G3_{after}$ for sensor 3.

I. Measuring Change in Stream Response

Analysis

In order to determine if there was a significant change in the stream's response before and after rain barrels were installed, we first used a scatterplot to find a suitable relationship between rainfall and sensor depth. We show in Figure 1 that the two variables are linearly correlated with each other, with a Pearson correlation coefficient of 0.54, 0.55, 0.80, and 0.84 for $G1_{before}$, $G1_{after}$, $G3_{before}$, and $G3_{after}$.



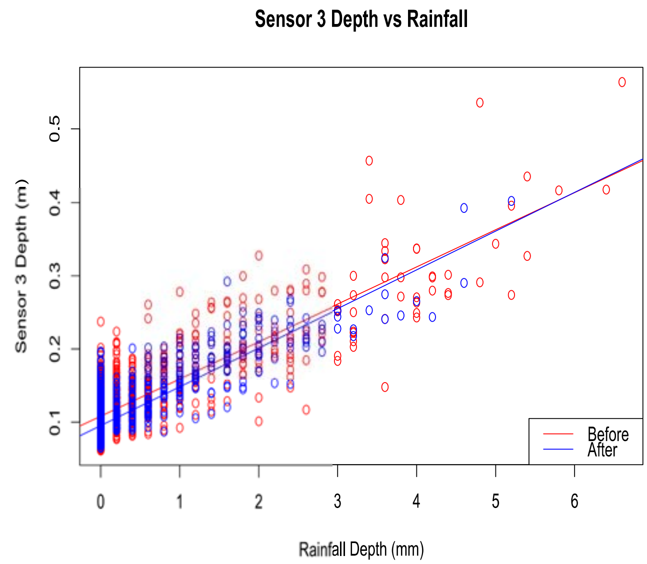


Figure 1: The plots of rainfall depth and sensor depth 1 and 3 show a linear relationship with a Pearson correlation coefficient of 0.54, 0.55, 0.80, and 0.84 for $G1_{before}$, $G1_{after}$, $G3_{before}$, and $G3_{after}$ respectively. As it can be seen from above, careful considerations need to be shown to data points with sensor 1 depth < 0.

The plots above show the existence of a linear relationship between rainfall depth and sensor depth. However, due to the nature of rainfall event, the sensor depth reading may not be an immediate response to rainfall. Hence, we decided to employ the ARIMA (Autoregressive Integrated Moving Average) model to calculate the regression coefficient of rainfall to account for the potential lagged effects. Briefly stated, we first found the appropriate order of integration for our model by observing the ACF (autocorrelation function) and PACF (partial ACF) graphs. Then, the orders of moving averages and autoregression, which are the other two parameters in our ARIMA model, were determined using the ACF and PACF graphs again respectively. An example of how this is done is displayed under Figure A1 in the Appendix.

Results

We based our analysis on the fact that if the confidence interval for the slope of rainfall before and after do not overlap, then there was a significant change in stream response after rain barrels were installed. After performing our regression analysis, this happened to be the case for both sensors; thus, we found evidence supporting a significant change in stream response after the installation of rain barrels. Refer to Table 1 for results. After rain barrels were installed, sensor 1 and 3 depths were less affected by rainfall with smaller slope estimates. This change is in the anticipated direction that implies rain barrels were helpful in controlling for water outflow into Beecher 1.

Table 1: The observed estimates for the slope coefficient from the ARIMA model. The slope coefficients for every group are significantly different from zero.

	$G1_{before}$	$G1_{after}$	$G3_{before}$	$G3_{after}$
Slope estimate for Rainfall	0.022	0.017	0.037	0.034
P-value	<0.001	<0.001	<0.001	<0.001
Confidence Interval	[0.020, 0.024]	[0.016, 0.018]	[0.036, 0.038]	[0.033, 0.035]

II. Measuring the relationship between sensor depth and natural flow (Before)

Analysis

This analysis was carried out similar by that above. We first used a scatterplot to determine a suitable relationship between sensor depth and natural flow. From Figure 2 below, we can see that they share a nonlinear relationship with a Pearson correlation coefficient of 0.78 and 0.92 for sensors 1 and 3 respectively. However, for simplicity, we decided to assume a linear model for the rest of our analysis.

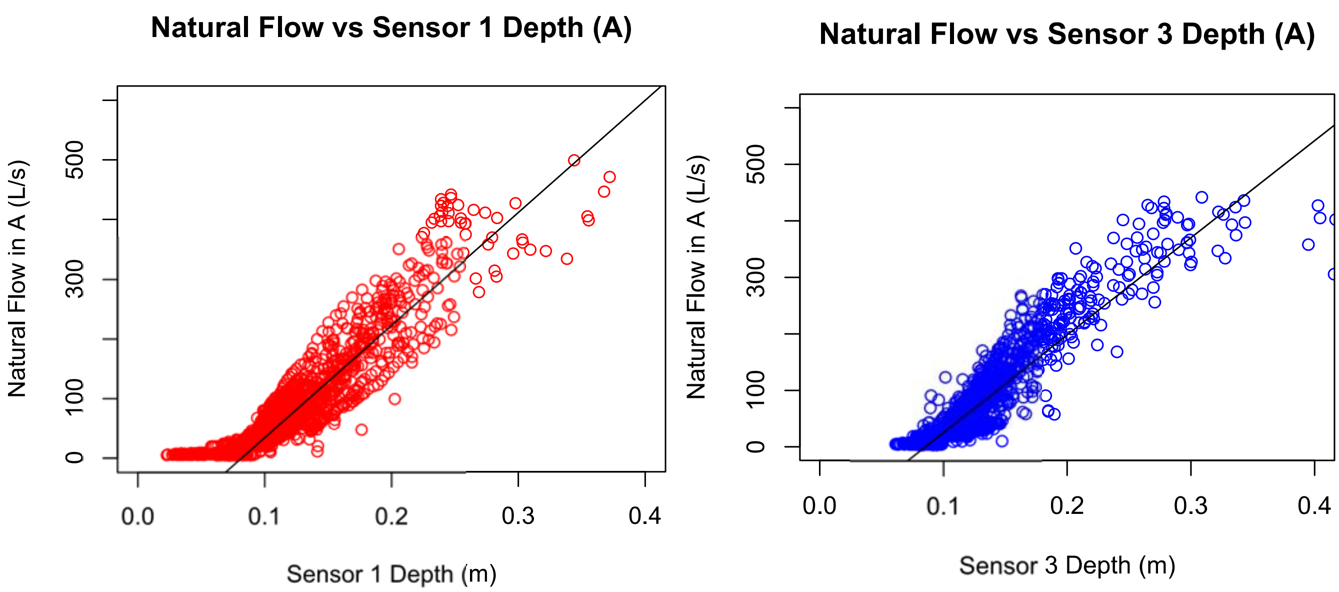


Figure 2: The plots of sensor depth and natural flow in $G1_{before}$ and $G3_{before}$ show a strong nonlinear relationship with a Pearson correlation coefficient of 0.78 and 0.92 for $G1_{before}$ and $G3_{before}$ respectively. However, for simplicity, we assume a linear model where the line of best fit is drawn in black. (A) represents the plots are for before the installation of rain barrels. Be cautious of outliers in Sensor 3 Depth,

Results

Using the linear model, we calculated the slope coefficient for the sensor depth in $G1_{before}$ and $G3_{before}$ and found them to be statistically different from zero. Hence, assuming that the true model is linear, there is evidence supporting the slope estimates to be different from zero. Results are presented in Table 2.

Table 2: Using the linear model, we found the estimates for the slope coefficients of sensor depth that are statistically different from zero. The p-values are based on the assumption that all data points are independent which is clearly not the case. They should only be used as a preliminary analysis but not relied heavily on.

	$G1_{before}$	$G3_{before}$
Slope estimate for Sensor Depth	1885.27	1718.61
P-value	<0.001	<0.001

III. Measuring the relationship between sensor depth and natural flow (After)

Analysis

From the above analysis in Part II, we see that natural flow and sensor depth share a linear relationship for both sensors 1 and 3. Now, we compare the relationship between $G1_{before}$ and $G1_{after}$, and similarly for $G3_{before}$, and $G3_{after}$. The relationship between natural flow and sensor depth for each sensor is shown graphically in Figure 3 below.

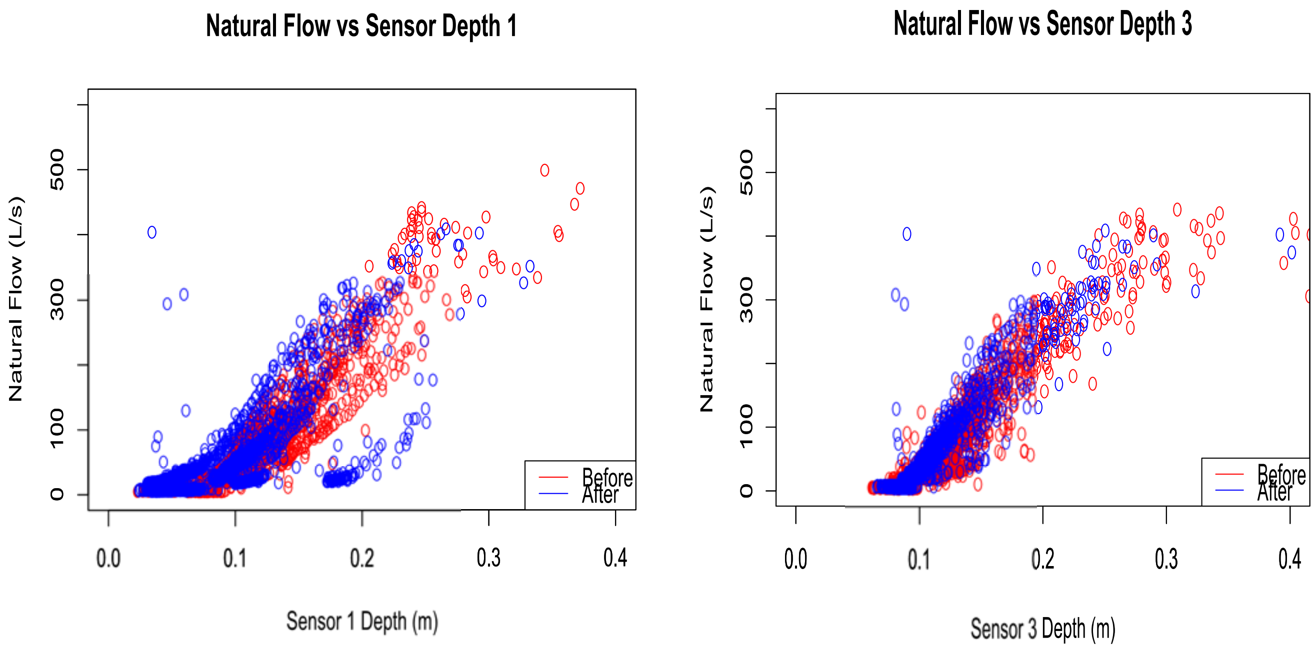


Figure 3: The plots show a strong, nonlinear relationship between natural flow and sensor depth for sensors 1 and 3 before and after rain barrels were installed, with a Pearson correlation coefficient of 0.78, 0.92, 0.73 and 0.93 for $G1_{before}$, $G3_{before}$, $G1_{after}$, and $G3_{after}$ respectively. There are outliers in both plots that may affect the analysis.

Results

In order to account for the potential lagged effects, we employed the ARIMA model again and computed the confidence interval for the slope coefficient of sensor depth. We found that the before and after confidence intervals do not intersect for sensor 1 but for sensor 3. Hence, there is evidence supporting the fact that the installation of rain barrels alters the relationship between sensor 1 depth and natural flow but not between sensor 3 depth and natural flow. Table 3 provides the results.

Table 3: The observed estimates for the slope coefficient are provided. The ARIMA model was used to calculate them.

	$G1_{before}$	$G1_{after}$	$G3_{before}$	$G3_{after}$
Slope estimate for sensor depth	2013.3	1644.6	1018.9	1112.4
Confidence Interval	[1957.6, 2068.9]	[1558.3, 1731.0]	[969.2, 1068.5]	[1004.3, 1220.6]

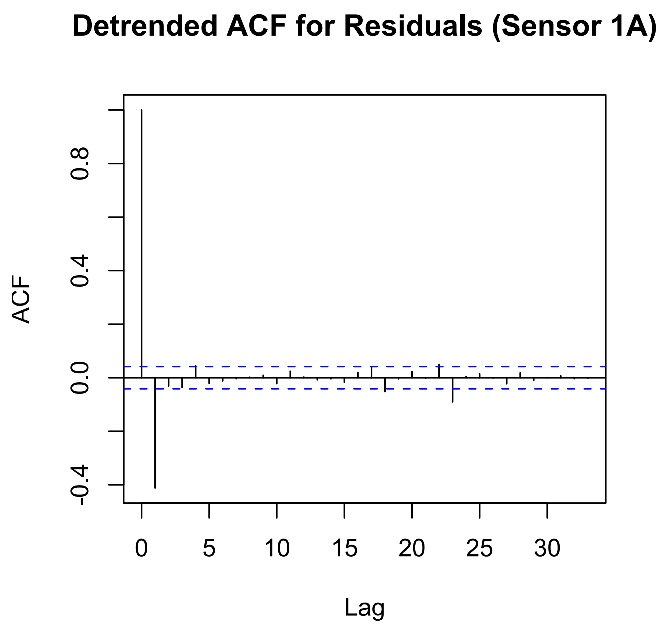
Considerations:

We decided to use the period between August and December to minimize the seasonal effect that can affect our natural flow and rainfall data. By doing so, we assumed that Vancouver rainfalls during the same season are similar. Also, finding a comparable rainfall event requires more relevant knowledge and hence we decided to monitor the overall trend instead of types specific rainfall events.

Conclusions:

We employed the ARIMA model in order to account for the potential lagged effects of rainfall. It was found that the installation of rain barrels does affect stream response in the two locations, Beecher 1 and 3. In order to determine if there was any relationship between natural flow and sensor depth before installing rain barrels, we did a scatterplot and found that a linear relationship holds. Finally, we expanded this analysis by determining if there was a difference in this relationship after rain barrels were installed. There was evidence supporting a different relationship in Beecher 1 but not in Beecher 3.

Appendix



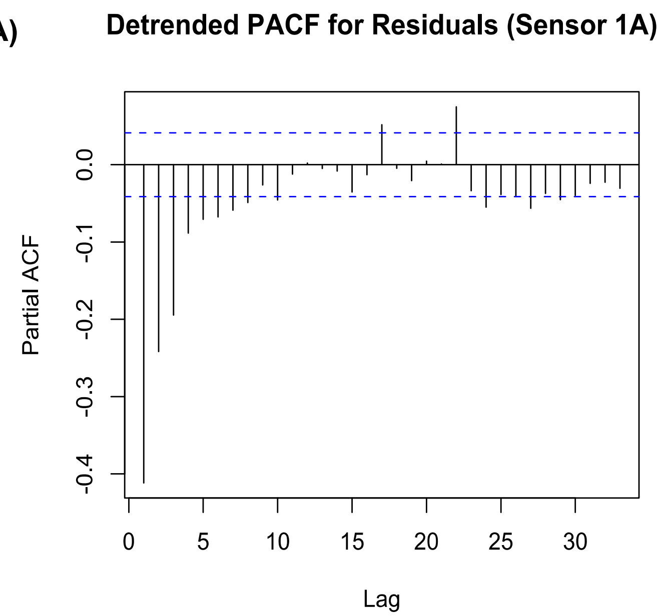


Figure A1: The graphs on the left and right show the detrended autocorrelation function (ACF) and partial ACF for the residuals in 1A respectively. The dotted blue lines represents the 95% confidence interval for the correlation values. By looking at the number of lines that exceed the confidence interval, we obtain the order of moving averages from ACF graph and the order of autoregression from PACF. (1A) stands for Sensor 1 before.

In this case, order of moving averages is 1 (ignore the first line as it will always be 1) and autoregression is 7. Using these orders as part of our ARIMA model, a linear model is then fitted to the data.

Appendix D: Study Area Figure

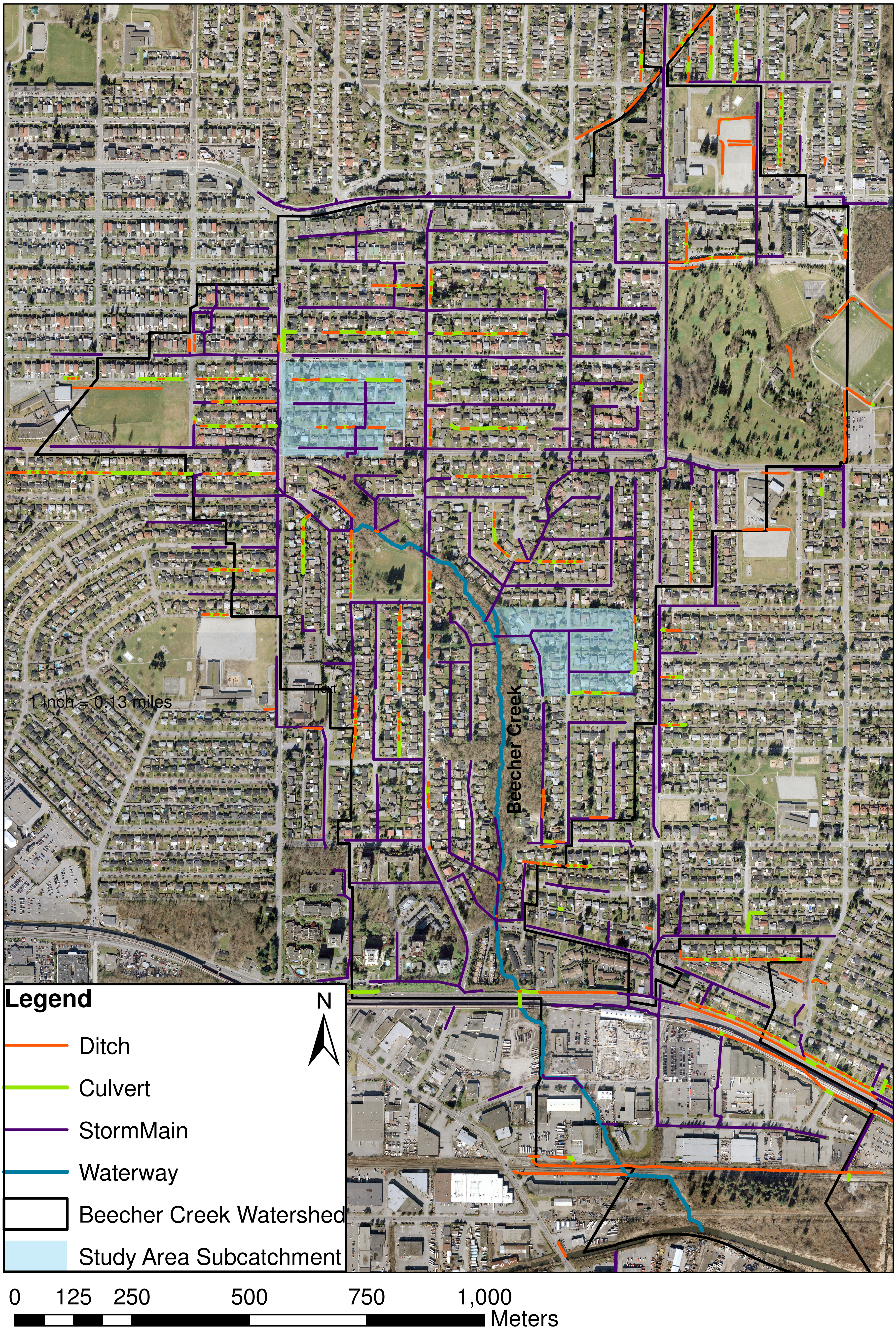


Figure D-1: Map of Beecher Creek Watershed showing land use and the drainage network.