NATURAL ORGANIC MATTER IN THE COBBLE MOUNTAIN RESERVOIR WATERSHED:

Disinfection Byproduct Precursors and Impact of Beaver Impoundments

A Master's Project

Presented by

Boning Liu

Submitted to the Department of Civil and Environmental Engineering of the University of Massachusetts in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE IN CIVIL ENGINEERING

In

Environmental Engineering

February 2007

Department of Civil and Environmental Engineering

Natural Organic Matter in the Cobble Mountain Reservoir Watershed:

Disinfection Byproduct Precursors and Impact of Beaver Impoundments

A Master's Project

Presented by

Boning Liu

Environmental Engineering Program
Department of Civil and Environmental Engineering
University of Massachusetts, Amherst

Approved as to style and content by

____
Dr. David. A. Reckhow, Chairperson

____
Dr. John E. Tobiason, Member

____
Dr. Carlton Ho
Graduate Program Director
Civil Engineering

ACKNOWLEDGEMENTS

I would like to thank Dr. David A Reckhow for his valuable time and his willingness to offer expertise, for guidance and patience throughout this study. I would also like to thank the faculty of the environmental engineering graduate program for their academic help and encouragement throughout my master's curriculum.

I would like to thank the Springfield Water and Sewer Commission as well as Massachusetts Department of Conservation and Recreation for financial support of this project. Special thanks go to SWSC personnel Ralph Tarnauskas and Dana Hachigian for helping me in my sampling campaign throughout the project.

I also want to express my gratitude to Dr. Guanghui Hua, Dr. Junsung Kim, Dr. Gladys Makdissy and so many others for their help in the lab. I'd also like to thank Alison Boutin for her help in compiling all of the land use data.

I also owe thanks to my family members and friends who have always been there to give me generous support, comfort, encouragement and love so that I can be brave and feel at ease under all circumstances.

ABSTRACT

Natural organic matter (NOM) in source water leads to disinfection by-products (DBPs) formation upon reaction with a disinfectant. Although there are means to minimize the DBP levels in finished water, watershed source control maybe is a useful approach.

The primary source water for the Springfield Water and Sewer Commission (SWSC) water supply system is from the Cobble Mountain Reservoir watershed and the Borden Brook Reservoir Sub-basin. The water is treated at the West Parish Filtration Plant, which achieves modest removal of NOM and the SWSC has been concerned about seasonal peaks in trihalomethanes and haloacetic acid levels in their distribution system for many years. For this reason, it is important to have a good knowledge of the origin and nature of NOM in their watershed. This watershed, similar to other boreal watershed in New England, has intensive beaver activities; therefore the impact of beavers in the watershed on NOM and DBP formation may be a concern.

The main objective of this research was to evaluate the sources of NOM and DBP precursors in the tributaries of Cobble Mountain Reservoir in order to understand the distribution of DBP precursors and eventually provide recommendations for watershed management in Cobble Mountain Reservoir Watershed. Samples were collected from major tributaries at different times of the year, and important water quality parameters,

such as TOC, DOC, and UV-254 were measured. Disinfection byproduct formation potential tests were conducted to quantify the DBP precursor levels for all samples. The data set was used to better understand the relationships between these water quality parameters, and correlations with other factors, such as land use, temperature and discharge. Also, water from upstream and downstream locations of several beaver impoundments was sampled and compared to investigate the impact of beavers on NOM levels and DBP formation.

Overall, DOC accounted for 96% of TOC from all tributaries and Borden Brook Reservoir samples. Ultraviolet absorbance at 254 nm correlated well with DOC, with an r^2=0.85, reflecting the consistent aromatic nature of the NOM sources. A statistically significant relationship was only found between specific THMFP levels and discharge. Data analysis also showed strong correlations between the DBP precursor levels and amount of unforested wetlands. Higher DBP precursor export was observed at tributaries with a larger portion of wetland. Lower DBP precursor levels were observed downstream of intact beaver impoundments with beaver activities; while a series of old beaver ponds seemed to export DBP precursors leading to higher concentrations downstream. Beaver dam failures were observed to contribute to the export of DBP precursor levels to downstream waters.

Table of Contents

List of Tables

List of Figures

CHAPTER 1 INTRODUCTION

1.1. Disinfection Byproduct Formation

Disinfection processes are an essential treatment step in the purification of potable water as they are needed to inactivate waterborne pathogens and protect human health. Chlorine has been extensively used as a disinfectant, with 64% of water supply systems in US using free chlorine (US EPA 2005). The availability of improved analytical methods in the early 1970s led to the discovery of a variety of disinfection byproducts (DBPs) in drinking water supplies. The DBPs produced by the reaction of chlorine with natural organic matter (NOM) in water were found to be potentially harmful to human health (Ashbolt 2004, Zavaleta *et al.* 1999). This has stimulated a long series of legislative and regulatory efforts to reduce chlorination byproduct levels in US finished water.

1.2. Natural Organic Matter

The amount of NOM in a drinking water source is usually a key parameter of concern for drinking water treatment facilities. It affects not only coagulation and filtration processes, but also the formation of DBPs depending on the type and amount of disinfectant used. Typically, an increase of NOM in the source water will translate to higher DBPs in the finished water. Therefore any treatment scheme should attempt to decrease the amount of organic matter in the water plant influent prior to disinfection. Optimizing coagulant addition in conventional treatment is one method, but does have its limitations. One possible way to reduce the organic load is to prevent it from entering the water by means of source water protection strategies in the watershed.

1.3. SWSC System

The Springfield Water and Sewer Commission (SWSC) provides treated drinking water at an annual average flow of 35 million gallons per day (MGD) to Springfield and several surrounding communities: Ludlow, Agawam, East Longmeadow and Longmeadow (Figure 1.1).

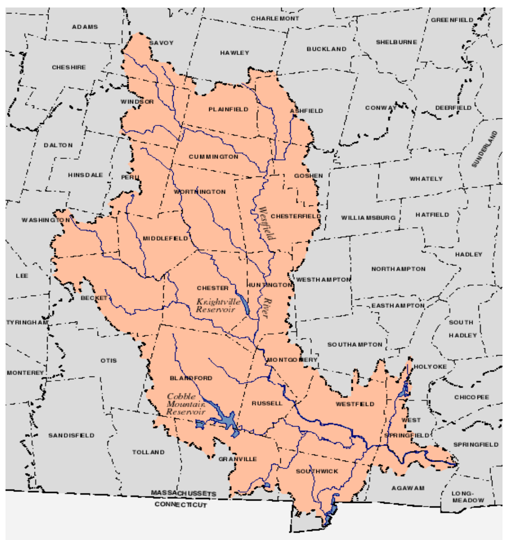


Figure 1.1 SWSC Water Supply System

This water supply system receives its raw drinking water primarily from the Cobble Mountain Reservoir, which has a capacity of 22.9 billion gallons, located primarily in the hill towns of Blandford and Granville. A secondary reservoir, Borden Brook, which has a capacity of 2.57 billion gallons, drains directly into Cobble Mountain via spillage over the Borden Brook Dam or as needed through the intake gates in the gatehouse at the dam.

The locations of Cobble Mountain Reservoir and Borden Brook Reservoir are presented in Figure 1.2.

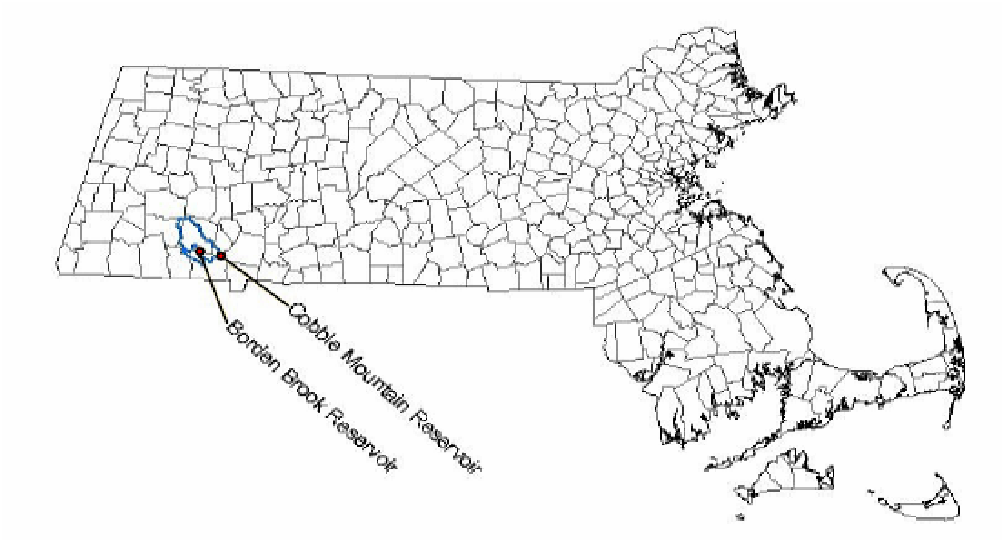


Figure 1.2 Locations of Cobble Mountain Reservoir and Borden Brook Reservoir

The Cobble Mountain Reservoir Watershed comprises 48.3 square miles of hills and valleys containing numerous streams and brooks. During normal operating conditions, water is drawn from the Cobble Mountain Reservoir through an 8000 feet long power tunnel, which was cut through a mountain and leads to a surge tank. From there the water flows to the Power Station and then to the Intake Reservoir. As shown in Figure 1.3, water from Cobble Mountain Reservoir can also bypass the power tunnel by either the division tunnel or simply over the spillway from the reservoir to the Little River. The Little River, having a small watershed, flows directly into the Intake Reservoir. All water is filtered at the West Parish Filtration Plant in Westfield, Massachusetts which is comprised of a 40 MGD slow sand filter train and a 60 MGD dual-media rapid filter train. There is no pretreatment of the influent water prior to slow sand filtration. For the dual-media direct filtration train, pretreatment includes addition of a coagulant (cationic polymer) and flocculation but no clarification. Chlorine is added to the water after the filters as it leaves the plant to provide disinfectant residual throughout the distribution system. Phosphoric acid is added to the finished water for corrosion control. The total organic carbon (TOC) concentration entering the treatment plant ranges from 2.5 to 3.5 mg/L. Since little of the NOM is removed by the filtration plant, SWSC is concerned about the trihalomethanes and haloacetic acid levels in their distribution system.

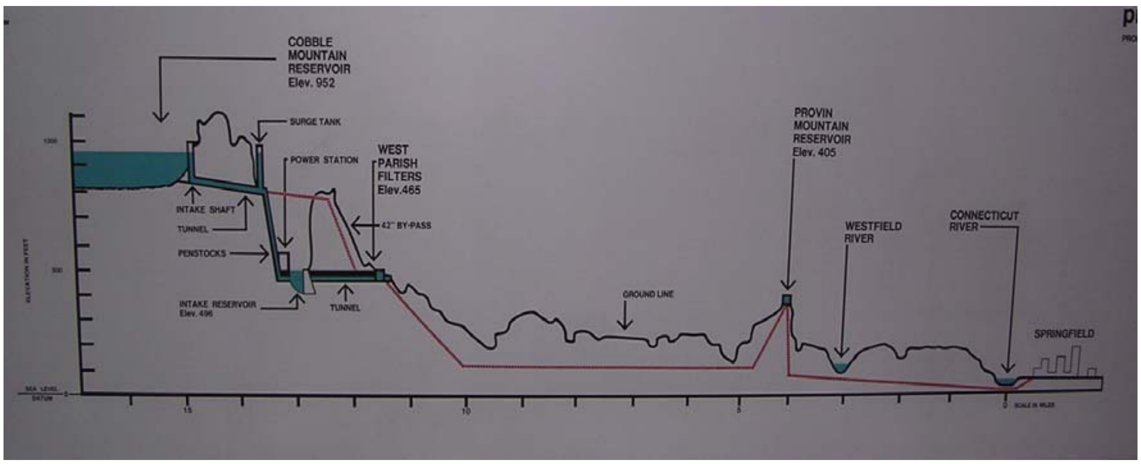


Figure 1.3 Overview of the SWSC System

Figures 1.4 and 1.5 present the total trihalomethanes and total haloacetic acids measured at the monitoring points in the SWSC distribution system from 2002 to 2004. As shown in these figures, the third quarter tends to have higher Total THM and HAA5 values, which have approached or exceeded the highest level allowed in the drinking water (Maximum Contamination Level). Compliance with MCLs was confirmed based on the Running Annual Average approach of the Stage 1 Disinfectants and Disinfection Byproducts Rule. However, the recent Stage 2 Rule and more stringent DBP rules in the future may require SWSC to consider other alternatives for decreasing DBP formation levels, including the use of alternative disinfectants, removal of disinfection byproducts after disinfection, and DBP precursor removal and source control. One way to reduce the DBP precursor load is to reduce the amount of these compounds from entering the water by means of source water protection strategies in the watershed.

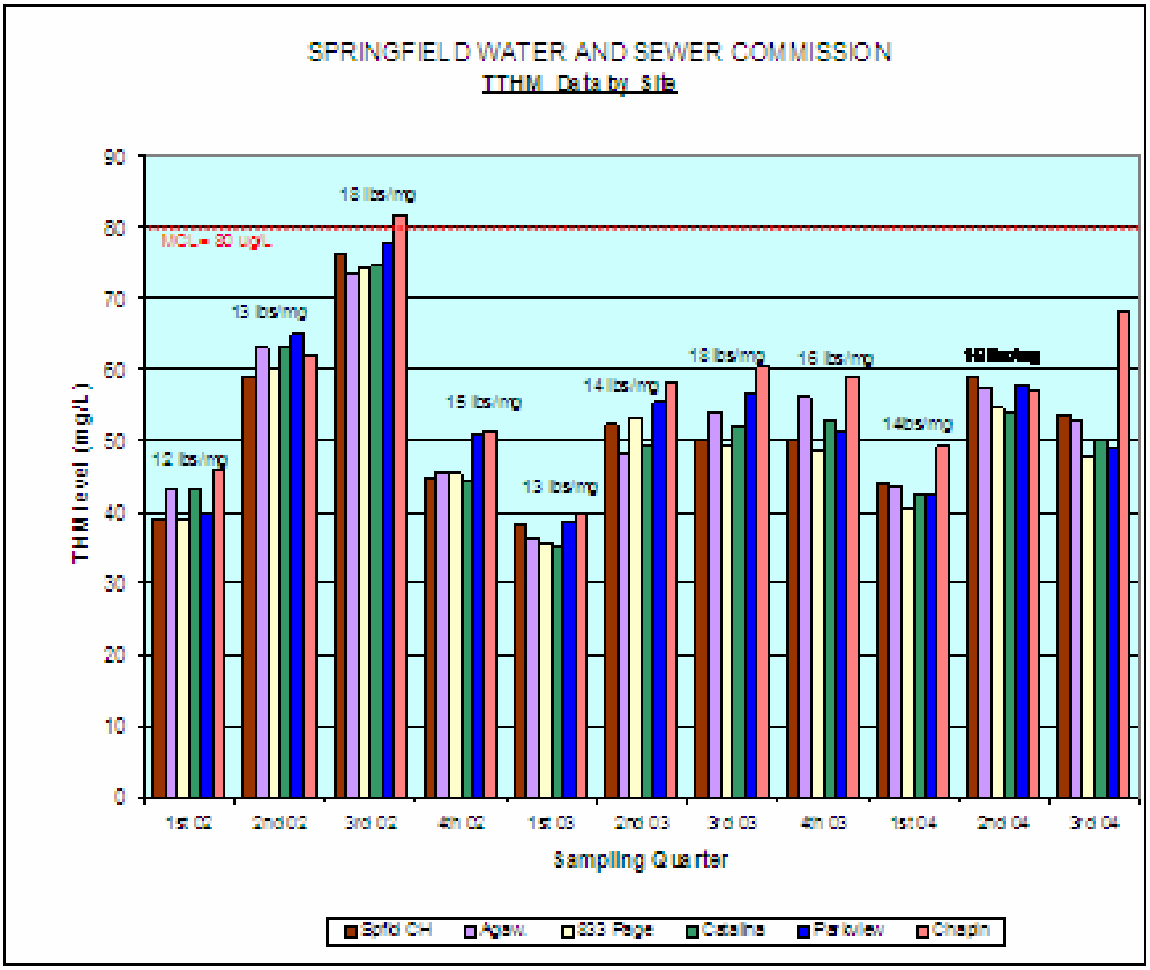


Figure 1.4 Total THM concentrations in the distribution system of SWSC (2002-2004)

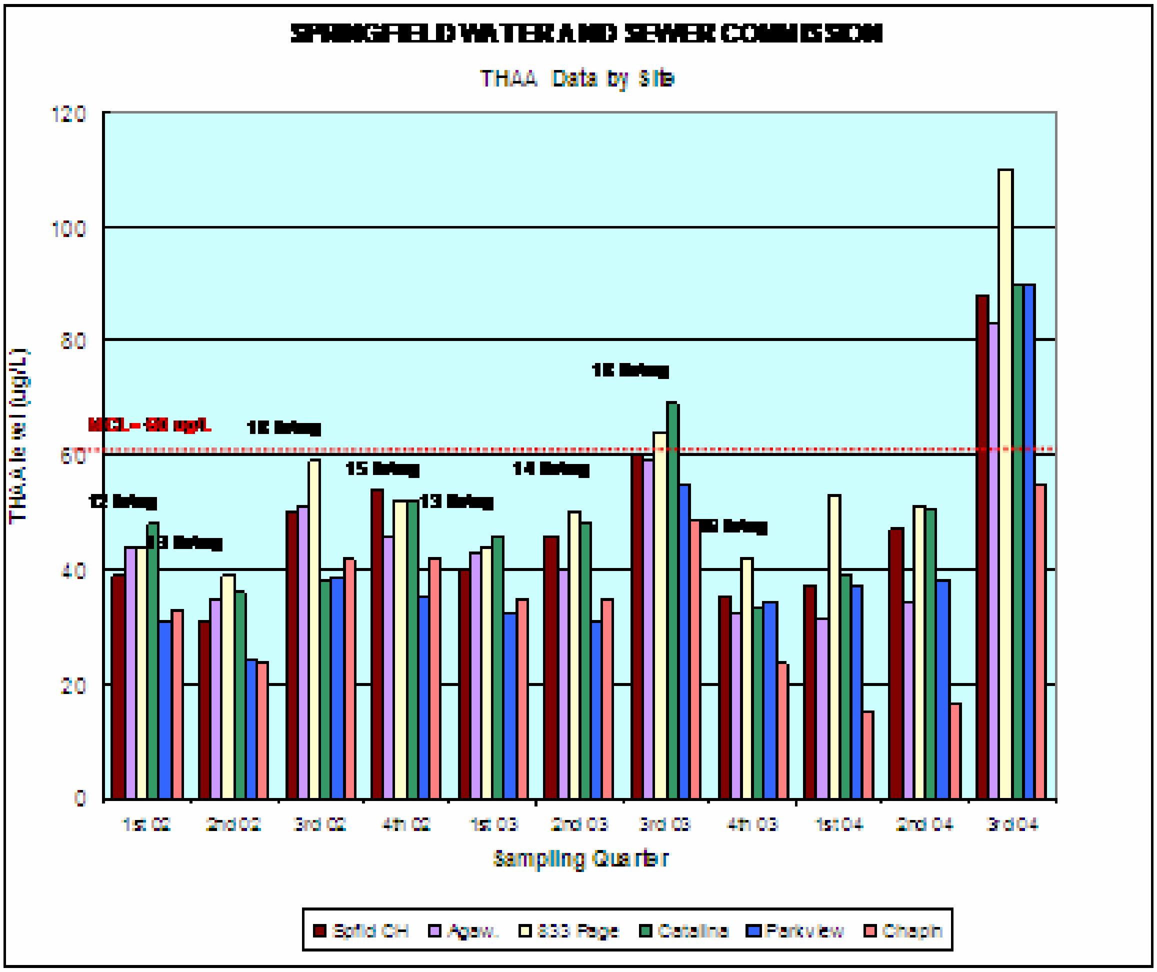


Figure 1.5 HAA5 Concentrations in the distribution system of SWSC (2002-2004)

Intensive beaver activities and beaver dams have been observed in the Cobble Mountain Reservoir watershed. There is a concern that the beaver activities and beaver dams on the tributaries may be undesirable attributes which can elevate the disinfection byproducts precursor levels.

1.4. Research Objectives

The major research objectives include:

1) Identify the major tributary sources of TOC in the Cobble Mountain watershed, and

characterize the chemical composition and DBP formation kinetics of the TOC from these sources. 2) Determine how the composition of organic material varies over seasonal time scales, and its relationship to drinking water treatment parameters such as DBP formation. 3) Identify natural biogeochemical processes occurring within the watershed and reservoir that alter the amount of TOC and DBP formation potential. 4) Identify the sources of TOC that may be most amenable to watershed mitigation efforts, and suggest potential reservoir management strategies most useful for TOC and DBP precursor mitigation.

1.5. Scope of Research

The scope of research includes:

- Monitoring the major tributaries. Sample at least 6 major tributaries and monitor the NOM parameters. These parameters include TOC/DOC, UV absorbance at 254nm, THM and HAA precursors.
- Monitoring and assessment of impacts of beaver activity and beaver ponds on NOM levels and DBP precursor levels. Samples from upstream and downstream of beaver impoundments are taken and compared for NOM levels.

CHAPTER 2 BACKGROUND

2.1. Natural Organic Matter

Natural organic matter (NOM) originates from decay of plants and animals. It is in particulate or dissolved form and can be found in every water body ocean and freshwater of all type. Most analytical methods for measuring organic matter in water actually determine the carbon content. Total organic carbon (TOC) includes suspended organic carbon (SOC) and dissolved organic carbon (DOC). In general, DOC has been found to account for 83% to 98% of TOC in surface waters (Owen *et al,* 1995).

Dissolved organic carbon in the water may be thought of as comprising two categories: autochthonous DOC and allochthonous DOC. Autochthonous DOC originates from release of photosynthetic biomolecules to the open waters by phytoplankton (Nalewajko and Marin 1969) and aquatic macrophytes in the riparian zone (Wetzel and Manny 1972, Wetzel 1990). This colorless DOC is composed primarily of carbohydrates and amino acids that are rapidly metabolized by bacteria (Wright 1970). Autochthonous DOC usually has a very short lifetime in the environment, as little as a few hours (Thurman 1985) and these compounds normally constitute one-third to one-half of the dissolved organic carbon (DOC) in natural waters (Thurman 1985). Allochthonous DOC can enter a system through precipitation, leaching, and decomposition. Highly productive wetlands can generate massive amounts of organic matter that enter lakes primarily in dissolved form (Wetzel 1992). This brown-colored DOC is usually composed of fulvic and humic acids, originating from degradation of lignin and cellulose (Engstrom 1987). The fulvic acids are mostly comprised of low molecular weight (less than 500 Da) compounds. They are usually mobile and are easily utilized by microbes. Their common structures are comprised of carboxyl, hydroxyl and carbonyl groups attached to an aromatic ring (Wetzel 2001). Overall, fulvic acids account for between 20% and 80% of DOC in aquatic systems (Steinberg and Muenster, 1985). The humic acids in the allochthonous DOC tend to have a high molecular weight (100,000-300,000 Da), and they are composed primarily of carboxyl and phenyl groups, with some methoxyl groups (Steinberg and Muenster, 1985). They usually have high aromaticity and recalcitrance to microbial degradation in the environment (Wetzel 2001), however, they account for less than 5% of DOC in aquatic systems (Steinberg and Muenster, 1995). The majority of DOC in natural freshwaters can be composed of these colored, refractory, allochthonous compounds (Hesslein *et al.* 1980, Schindler *et al.* 1992, Wetzel 1992). The lack of correlation suggested that more detailed characterization of the aromatic compounds that form THM and HAA is needed and also suggests that non-aromatic components of DOC may be significant DBP precursors in Cobble Mountain Reservoir watershed.

The prominent transport mechanisms for NOM summarized by Bryan (2004) include direct transport to streams, overland flow, flow from littoral zones, and subsurface or groundwater flow. Direct transport from leaching of leaves in streams plays a significant role during rainstorms when wind and runoff quickly deposit and leach fresh litter, which is rich in carbohydrates (Meyer 1990, Bryan 2004). The contribution of overland flow may be especially important during wet seasons, when rainfall flushes the new and old litter deposited on the forest floor to receiving water bodies (Thurman 1985, Meyer 1990;

Bryan 2004). Flushing of the freshly leached, highly concentrated pools of DOC present in riparian zone is also a very important mechanism during rain events. In addition, the subsurface groundwater input from leaching and deposition of NOM in soil upper horizons can be a significant source of DOC in streams during low flow (Wetzel 2001). The groundwater tends to contribute low DOC levels because of its forced travel through upper soil horizon (Steinberg and Muenster 1995, Meyer 1990, Bryan 2004).

Degradation process begins immediately after the NOM has reached surface waters and ultimately results in refractory organic matter with stable composition and higher aromatic carbon content (Krasner *et al.*1996, Wetzel 2001). Dissolved organic carbon in the stream can be removed by precipitation and adsorption to surfaces, resulting in the sedimentation of DOC in littoral zones and stream beds (Meyer 1990, Steinberg and Muenster, 1985, Wetzel 2001, Bryan 2004). Microbial degradation also results in a loss of biodegradable NOM and therefore, recalcitrant compounds account for a large percentage of DOC in waters (Thurman 1985). In addition, the ultraviolet degradation of NOM due to exposure to sunshine can lead to higher bioavailability of NOM to bacteria (Meyer 1990, Steinberg and Muenster, 1995, Wetzel 2001).

Isotope information for precipitation and stream flow indicates that storm flow consisted mainly of pre-event water; water that resided in the forested catchments prior to rainfall or snow-melt (Dincer *et al.* 1970, Martinec *et al.*1974). This is in contrast to the results obtained from traditional hydrograph separations by graphical methods (Hursh and Brater 1941), which indicated that storm-flow consists mainly of event water (precipitation).

The quantity of DOC export also has temporal variations. The flux of DOC in rivers is often more variable in spring than in fall (Hurley *et al.* 1995). In addition, the contribution of DOC from plant exudates and leaching from detritus is often many times higher in the summer and fall than in other seasons (Kaplan *et al.* 1980).

2.2. Disinfection Byproduct Formation

2.2.1. Introduction to Disinfection Byproduct

Disinfection byproducts are formed upon the reaction of chemical disinfectants with natural organic matter and bromide ion. The pathway of DBP formation can be presented by the following formula (Singer 1994):

$HOCl+Br^-$+Natural Organic Matter → Trihalomethanes+ Haloacetic Acids+ Other Halogenated DBPs

In chlorinated potable water supplies, trihalomethanes and haloacetic acids dominate the identifiable DBPs, and they are of regulatory interest because of their potential role in human cancer and other health effects. Trihalomethanes (THMs) are a group of compounds with three halogen atoms. The trihalomethanes are formed when individual carbon atoms are attacked by halogen-based disinfectants (mostly free chlorine). Small hydrocarbon chains are cleaved from natural organic matter molecules, and the reaction of the halogen species continues until THMs are formed. Small amounts of tetrahalomethanes (carbon tetrahalides) may also be formed in this fashion; however, THMs predominate, accounting for some 20% of the halogenated organic carbon found after disinfection (Weinberg 1999). The species of THM are listed in Table 2-1.

Table 2.1 Trihalomethanes found in potable water

Name	Formula
Trichloromethane (chloroform)	$CHCl_3$
Bromodichloromethane	$CHBrCl_2$
Dibromochloromethane	$CHBr_2Cl$
Tribromomethane (bromoform)	$CHBr_3$

Unlike the THMs, the HAAs are capable of dissociating in water. Haloacetic acids are more than 99% ionized (in the haloacetate anionic form) under drinking water conditions. However, they are regulated and usually reported in terms of the parent acids rather than the carboxylate anions. Haloacetic acids account for about 13% of the halogenated organic matter after disinfection (Weinberg 1999). The HAAs found in potable water are listed in Table 2.2.

Table 2.2 Haloacetic Acids (HAAs) found in potable water

Name	Formula
Chloroacetic	$ClCH_2CO_2H$
Dichloroacetic	Cl_2CHCO_2H
Trichloroacetic	Cl_3CCO_2H
Bromoacetic	$BrCH_2CO_2H$
Dibromoacetic	Br_2CHCO_2H
Tribromoacetic	Br_3CCO_2H
Bromochloroacetic	$BrClCHCO_2H$
Bromodichloroacetic	$BrCl_2CCO_2H$
Dibromochloroacetic	Br_2ClCCO_2H

Among these 9 HAA species, the sum of the concentrations of chloroacetic acid, dichloroacetic acid, trichloroacetic acid, bromoacetic acid, and dibromoacetic acid is commonly abbreviated HAA5 and is regulated in the USEPA Disinfectant - Disinfection Byproduct Rules.

2.2.2. Disinfection byproduct regulations

Tremendous efforts have been made by the U.S. Environmental Protection Agency (USEPA) to regulate disinfection byproducts. Most recently, in early January 2006, USEPA published its final Stage 2 Disinfectants and Disinfection By-Products Rule (DBPR) and Long-Term 2 Enhanced Surface Water Treatment Rule (LT2ESWTR). Under Stage 2 DBPR, the MCL will be calculated using locational running annual averages (LRAAs). Water supply utilities must maintain the locational running annual average (LRAA) for each compliance sampling location at or below 0.080 mg/L of total trihalomethanes (TTHM) and 0.060 mg/L of haloacetic acids (HAA5). Although the MCLs in stage 2 DBP rules for TTHM and HAA5 remain the same as in the stage 1 DBP rule, compliance based LRAA instead of RAA (running annual average) indicates that they are more stringent DBP rules.

2.2.3. Beavers and their impact on water quality

Historically, beavers (*Castor Canadensis*) inhabited most every lake, pond and stream in the Northeastern United Stated prior to the European settlement (Rudemann and Schoonmaker 1938). However, in the early 17th century, beavers were extensively hunted for the trade of their furs, and by 1900, the beavers were almost extinct in North America (Jenkins and Busher 1979, Johnson and Chance 1974). Today because of the absence of natural predators, restriction of trapping and hunting by law, the beaver population is increasing rapidly. With ever increasing beaver populations in water supply catchments in the northeastern United States, questions regarding the effects of this beaver reintroduction on downstream water quality have been raised.

Beavers are called ‘ecosystem engineers’, because these animals can cut down trees, build dams and beaver lodges, and therefore alter habitats nearby. An individual beaver cuts and bring about a metric ton of wood for food, build up and maintenance of beaver dam and beaver lodges annually (Howard 1982, Howard and Larson 1985). This results in substantial inputs of organic matter and nutrients to ponds. Fallen wood from dead trees in new beaver impoundments augment this input (Johnston and Naiman 1987).

Beavers can modify the morphology and hydrology of drainage areas in the ecosystem. By impounding streams, beavers can affect the biochemical circle by retaining the sediments and organic matter, increasing water body dimensions and decreasing water velocities, and expanding interactions between the water and sediments (Naiman *et al.*1988). Associated with reduction in stream velocity is a reduction in the sediment carrying capacity of the stream, which consequently results in an increase in deposition. Naiman *et al.* (1988) found that relatively small dams could retain as much as 2000-6500 m^3 of sediment. The movement of water within bed sediments can consequently lead to the downstream movement of dissolved and particulate substances. The source of sediment organic matter in a beaver pond is attributed to beaver inputs and the forest vegetation and soil that were initially flooded (Devito and Dillon 1993). The available pool of organic material is variable and “is a function of (1) the age of the pond and the amount of organic material accumulated (2) the beaver populations and activity and (3) the catchment configuration and dam height which would determine the amount of land and forest area flooded" (Devito and Dillon 1993).

Anoxic conditions in the sediments may slow decomposition and a considerable amount of organic matter and nutrients can remain for many years. This "reservoir" of nutrients and organic matter may be mobilized through biochemical processes, representing a low-rate, long-term source of nutrients and organic matter to the pond water and downstream (Devito and Dillon 1993). The increased water depth decreases the transmittance of solar energy to the bottom, which may contribute to the decrease in periphyton production by bottom material (Naiman *et al.*1986). A beaver dam can transform a free-running stream into a pond that floods the adjacent riparian zone. It can also lead to the draining of a pond and exposure of accumulated sediments following abandonment of a site and subsequent dam failure. Beaver ponds allow water to remain in the catchment for a relatively long time, facilitating prolonged leaching of litter and soil organic carbon. The temperature of water and sediments increases during the ice-free time of the year due to the increased surface area and slower water movement. This will accelerate organic material decomposition, and specific microbial process that are involved in aerobic and anaerobic breakdown. Increases in water temperatures in beaver ponds were recorded in Utah (Rasmussen 1941) and New Mexico (Huey and Wolfrum 1956). Crimo *et al.* (1993) found water temperature 4-5^{o}C warmer for the water entering than the water leaving the beaver impoundment. Greater water surface area reduces or eliminates shade from riparian vegetation allowing more sunlight to reach the stream water, and therefore increases temperatures. The elevated temperature and the presence of excess organic material added to ponds by the beaver encourage microbial activity.

Johnston and Naiman (1987) use the phase ‘patch body’ to describe volumetric landscape units, which were altered by beaver, and adjacent area. A beaver pond and associated riparian zone were separated into the following patch bodies: “the bedrock, the anaerobic soil, the aerobic soil, the pond, the browse zone concentric to the pond, and the overlying atmosphere” (Johnston and Naiman 1987). The transport of organic material and nutrients happens on the boundaries of these patch bodies. Transport of organic material and nutrients to beaver ponds also has a temporal character because of seasonal changes in beaver foraging and uptake of nutrients. Jenkins (1979) found beaver foraging at riparian zone is most intense during fall and early spring and more organic materials are moved to pond from riparian zone; while the transport of organic material and nutrients is from the pond to the riparian during summer, because beavers tend to defecate on land after feeding on pond vegetation at that time. In addition, beaver impoundments may reduce nutrient concentrations the most during summer (Margolis *et al.* 2001, Cirmo and Driscoll 1993, Christopher 2004). During the warmest month, high temperature and evaportranspiration can cause many headwater streams (1^{st} and 2^{nd} order (Strahler 1957)) to cease flowing and large portions of beaver impoundments to become dry.

Dissolved organic carbon is released into aquatic systems through degradation of particulate organic material. The presence of DOC in beaver ponds is associated with the organic materials in and adjacent to stream brought in by beavers through their food gathering and dam-and lodge-building activities. Naiman *et al*. (1986) found a significant difference for DOC export between in a stream altered by beavers and a different, smaller one that was not altered. However no net DOC export was observed at the beaver pond in the 2 year study, which was believed to be the result of the additional 10 beaver ponds upstream and the fact that beaver ponds were already mature. He suggested that a difference might be seen in stream water after passing through multiple impoundments.

Smith *et al.* (1991) compared the DOC of the site at the confluence of two first-order tributaries with those of two sites downstream of the beaver dam at the second-order tributary in the Adirondack Mountains. The results showed that DOC was elevated following passage of water through the beaver impoundments. Two beaver ponds in Ontario were found to retain DOC during summer months followed by significant export during a few months in winter and spring (Devito *et al.*1989) and the retention of DOC was mainly associated with low runoff and cycle of beaver dams with regard to DOC export and whether the age of the impoundment or level of upkeep is important to this issue. Moulton (2001) investigated the water quality of two branches in a stream in the Quabbin Reservoir Watershed in Central Massachusetts, U.S.A. in the summer period (June to August), one with beaver activities and one without beaver activities. Her research indicated there is a significantly higher concentration of dissolved organic carbon in the stream inhabited by beavers as compared to the one that is not. Margolis *et al.* (2001) conducted a one year study on two headwaters with beaver impacts and one tributaries without beaver impacts located on the Allegheny Plateau of the Appalachian physiographic province. They measured DOC upstream at locations of 1 m, 10 m, and 100 m downstream of beaver impoundments. The results indicated there were significant differences in DOC between upstream and downstream of beaver impoundments with active beaver colonies, but these differences generally were confined in summer. However, no significant differences in DOC were observed between the tributary with beaver impoundments and the unimpounded one, 147 m apart.

Few studies have examined the life cycle of beaver dams with regard to DOC export and whether the age of the impoundment or level of upkeep is important to this issue. Despite occasional abandonment and drainage, the area impounded is still a distinct biophysical patch, and the total area affected by an impoundment is cumulative over time (Naiman *et al.*1994). The balance between a pond acting as a net sink or source of elements to downstream communities appears to be equivocal, depending on pond age, ecological maturity, channel morphology and other factors related to the maintenance of system properties (Naiman *et al.*1994). According to Pullen (1971), there are two general types of beaver ponds: “stream channel” types, which are long, narrow and less than 0.4 ha, and “flood plain” types, which are larger impoundments and may cover several hectares of land. Stream channel ponds are typically short lived, but flood plain ponds may persist for many years. Welch (1935) listed six stages in the life of a beaver pond: young, adolescent, mature, senescent, marsh, and dry. During this progression of stages, the pond changes from oligotrophic, to eutrophic, and finally in the senescent stage it becomes dystrophic (Keiper 1966). At the young stage, usually the initial 3 years, ponds will contain living trees. For the next 4 to 10 years, there will be many standing but dead trees, and there is an abundance of emergent aquatic vegetation. Water depths are greater than 0.3m over most of the pond, and open water will cover about 40% to 50% of the pond area (adolescent to mature). Senescent ponds typically contain open water only near the dam, emergent aquatic vegetation is very extensive, and a water depth of less than 0.3 m will be characteristic of most of the area. Very few standing dead trees will be seen. Ultimately the beaver abandons the pond, and it can become a “beaver meadow”, with grasses and sedges, and finally the forest is re-established (Pullen 1971).

The excessive nutrient loading, increasing water temperatures in the beaver impoundments and beaver excrement can stimulate the growth of bacteria that are harmful to humans. The presence of beaver ponds could also cause entrapment of organisms by reducing the velocity of stream flow thereby causing bacteria to settle from stream water to bottom sediment. Beaver impoundments therefore are believed to be a source of pathogens. Foote (1937) found little effect of beaver upon the numbers of the coli-aerogens group of bacteria in water above and below beaver ponds. However, he stated that under certain circumstances beaver could excrete large numbers of these organisms. In a grazing watershed with beaver impacts, settling of Fecal Coliforms occurred was observed in the beaver impoundments, however, the authors also pointed out that beaver might be a point source of pollution by contributing bacteria to stream as a result of excretion and by stirring sediments (Skinner, 1984).

Beavers are also associated with epidemics of waterborne giardiasis, which is of high degree of public concern. Several reports have suggested beaver (Davies *et al.* 1979, Kirner *et al.* 1978, Lippy 1978, Wenigar *et al.* 1983) as potential reservoirs for Giardia sp. In three of eleven outbreaks of giardiasis, cysts were recovered from beaver and beaver feces (Cracun, 1984). Davies and Hibler (1979) found 44 of 244(18%) of beaver fecal samples collected in Colorado contained cysts of Giardia sp. Monzingo et al. (1987) determined the prevalence of *Giardia* sp. in a beaver colony in Colorado by the collection and analysis of fecal samples over a 14 month period. They concluded that the beaver served as amplification hosts for Giardia sp. and contaminated surface waters downstream from their dams in late spring and early fall.

2.2.4. Effect of land use types on water quality

The large spatial variation in the amount and properties of NOM is at least in part a reflection of the spatial variation in watershed land-use. High NOM concentrations are associated with drainage from peatland, shallow upland soils, and watersheds with a high land/water ratio, i.e. large soil pools of humus relative to mineral soil and short water retention times. Conversely, low NOM concentrations are found in watersheds with sparse vegetation poorly developed organic soils and large lakes due to the small pools of soil carbon and long water retention times (Löfgren 2003). Landscape parameters which are strongly correlated with DOC, color, and total organic carbon (TOC) in lakes and streams include the drainage ratio (Schindler 1971, Gorham *et al.* 1986, Engstrom 1987, Rasmussen *et al.* 1989, Kortelainen 1993, Houle *et al.* 1995), slope (Rochelle *et al.* 1989), water residence time (Meili 1992, Garvey 2000), and percentage of the watershed covered by wetlands (Myllymaa 1985, Eckhardt and Moore 1990, Kortelainen 1993, Watras *et al.* 1995, Garvey *et al,* 2003). Wetlands and wetland soils are often the source of much DOC input to lakes and streams (Hemond 1990, Dosskey and Bertsch 1994), even though they may occupy only a small percentage of the catchment area (Dosskey and Bertsch 1994, Hinton *et al.* 1998). Within catchments with relatively high rates of

DOC export, the presence of wetlands has been related to DOC export. Many studies have reported a relationship between the proportion of wetlands in the contributing drainage area and the average annual concentration of DOC in streams (Urban *et al*.1989, Eckhardt and Moore 1990, Hemond 1990, Garvey *et al.* 2003) and lakes (Kortelainen 1993, Gergel *et al*.1999). The presence of wetlands also has been related to DBP precursors in streams. Studies in the Sacramento–San Joaquin Delta of California (Twitchell Island), suggested that DBP precursors mainly came from the anaerobic decomposition of fresh organic matter in the wetland, and that higher levels of HAA precursors were produced than THM precursors under these wetland conditions (Fleck 2004). However, it is not fully understood how proximity and positioning of landscape units such as wetlands influence the export and resulting concentrations of watershed inputs (Allan *et al.* 1993).

CHAPTER 3 MATERIALS AND METHODS

3.1. Experimental Design

Several spatial sampling events aimed as assessing DOC loading and sampling events targeting evaluation of beaver impact were conducted over a 1-year period in order to collect information on quantity and quality of natural organic matter (NOM) in the tributaries. The sampling locations were selected based on SWSC's ultraviolet absorbance(UV) data for Cobble Mountain Reservoir (Appendix A) and on previous observations of beaver activities in the watershed. Samples were taken from all of the major tributaries of the Cobble Mountain Reservoir and Borden Brook Reservoir sub-basin. For sampling events targeting the impact of beavers, samples were taken at upstream and downstream locations near beaver impoundments or beaver ponds, which exist on Alder Brook, Middle Brook, Ripley Brook and Peebles Brook. These particular drainage systems for paired study were chosen because they were accessible and representative of beaver impacted streams. All samples were collected just below the surface of the water, after rinsing the sample bottles with stream water three times. Samples were collected in 1L amber glass bottles that had been previously acid-washed. Lab analysis includes disinfection byproduct formation potential tests and measurements of total organic carbon (TOC), dissolved organic carbon (DOC), UV absorbance at 254nm, trihalomethane (THM) precursors and haloacetic acid (HAA) precursors. The calculated specific ultraviolet absorbance (SUVA) and specific DBP formation potentials (precursors) provide information on the quality of the NOM.

3.1.1. Field Sampling

3.1.1.1. Spatial Sampling

Figure 3.1 shows a map of the watershed. Samples were collected from 8 tributaries of Cobble mountain Reservoir: Bedlam Brook, Peebles Brook, Tannery Brook, Pond Brook, Phelon Brook, Stowe Brook, Birch Meadow Brook and Middle Brook, and 2 tributaries of Borden Brook Reservoir: Alder Brook and Ripley Brook. Samples were generally taken from a downstream location near the mouth of the tributaries and at a point that is accessible by vehicle (i.e., close to a road). Samples were also collected at Borden Brook spillway to evaluate the quality of water entering Cobble Mountain Reservoir from Borden Brook Reservoir.

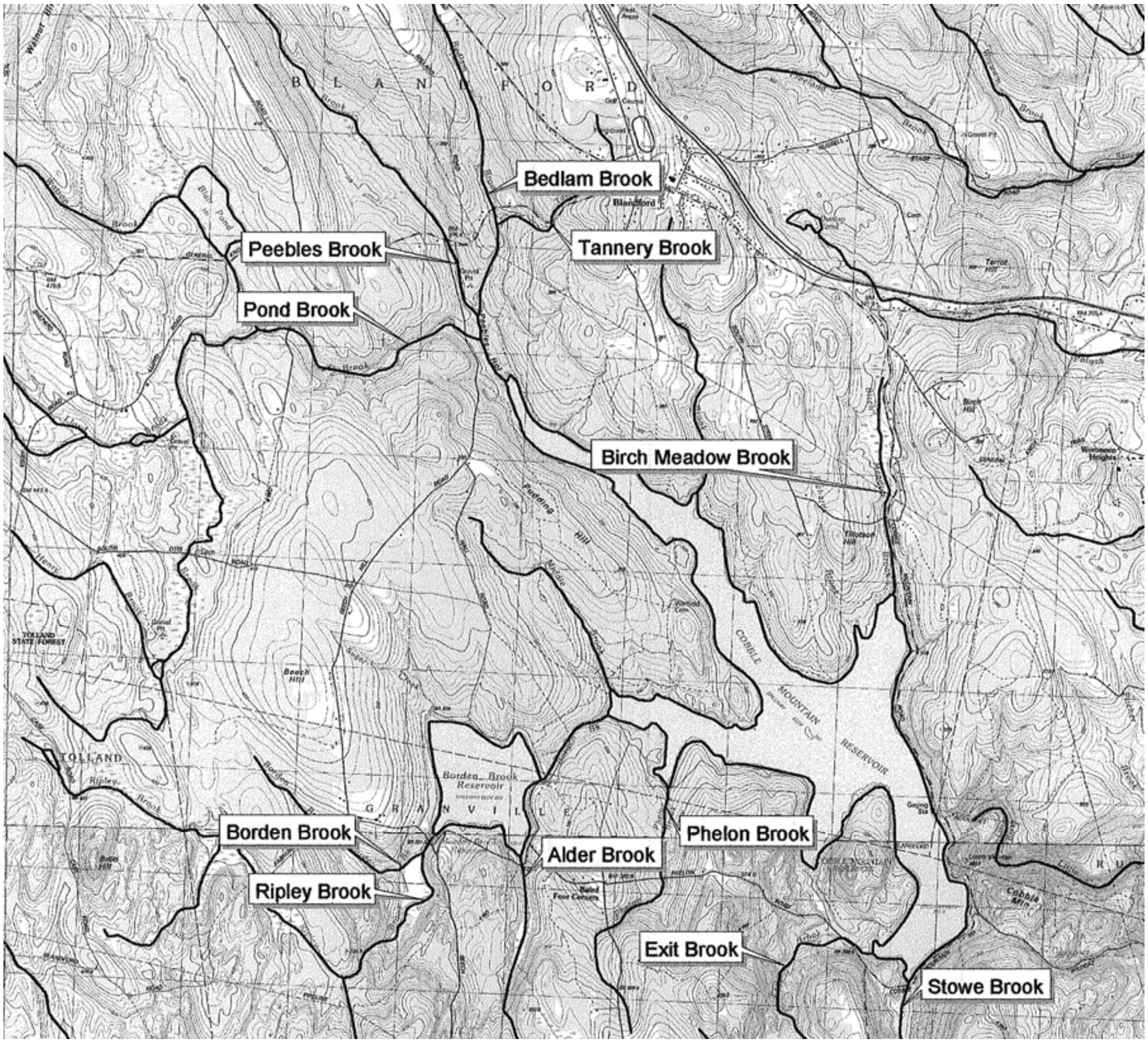


Figure 3.1 Inflows and Outflows of Cobble Mountain Reservoir Watershed and Sampling Locations

3.1.1.2. Paired Sampling at Beaver impoundments

The Cobble Mountain Reservoir watershed has intensive beaver activities and parts of some tributaries have beaver ponds and beaver meadows. Based on field observations records, there are no beaver activities at Exit Brook, Phelon Brook, Tannery Brook and Bedlam Brook. In contrast, Middle Brook and Stowe Brook had intensive beaver activities and a series of beaver impoundments. However, no beaver meadows were seen at these two tributaries. Alder Brook, Peebles Brook and Ripley Brook had both beaver meadows and beaver ponds. Samples were taken at upstream and downstream locations from single or mulitple beaver impoundments. For Peebles Brook, upstream samples were taken at the headwater. Detailed sampling locations are described in Chapter 4. No sampling events were conducted when the water table was extremely low or when there was an ice layer covering the ponds.

3.2. Analytical Methods

3.1.2. TOC and DOC

Total organic carbon and dissolved organic carbon analyises were based on Method 5310 of Standard Methods (APHA *et al.*1998). Detailed operation procedures are summarized in the UMass Standard Operation Procedure (SOP) for Analysis of Total Organic Carbon (Reckhow 2006). Measurements of TOC and DOC were made using a Shimadzu TOC-5000 Total Organic Carbon Aanlyzer with a high sensitivity catalyst (Shimadzu Corporation Kyoto, Japan). Samples for DOC analysis were filtered through pre-washed fisherbrand general filtration membrane filters with pore size of 0.45um. Potassium Hydrogen Phthalate (KHP) was used to prepare the calibration standard. All samples were acidified to a pH around 2 by adding 40 μL 6N HCl to the TOC/DOC vials prior to analysis.

3.2.2. UV absorbances

Samples were filtered through a pre-washed fisherbrand general filtration membrane filter prior to analysis of UV absorbance. Measurements were made using Hewlett Packard 8452A Diode Array Spectrophotometer at a wavelength of 254nm based on

UMass Standard Operation Procedure (SOP)(Reckhow 2006). This protocol is based on Method 5910B of Standard Methods (APHA *et al.*1998).

Specific UV absorbance (SUVA), which is defined as the UV absorbance of a water sample at a specific wavelength normalized for dissolved organic carbon (DOC) concentration, is calculated based on UV absorbance at 254nm and DOC in this study.

3.2.3. Determination of Disinfection Byproducts Formation Potential

3.2.3.1 Disinfection Byproduct Formation Potential Tests

Chlorination was used to determine the disinfection byproduct formation potential for all samples according to the UMass Standard Operating Procedures(SOP) for laboratory chlorination (Reckhow 2006). The SOP is based on widely accepted protocols: Method 2350& Method 5710 of Standard Methods (APHA 1998). UV absorbance was measured for all the samples before chlorination testing for the purpose of estimating chlolrine demands (Figure 3.2).

If the estimated chlorine demand is higher than 17 mg/L, dilution of the sample is needed. Samples were then adjusted to pH of 7 using either 1M hydrochloric acid (HCl) or 1M sodium hydroxide (NaOH). Buffer solution (1M phosphate) was added to the samples to maintain the pH. The final buffer concentration was typically 1 mM. The 300 mL chlorine-demand-free BOD bottles were first filled 60%with buffered, pH adjusted sample. Chlorine was then added to the BOD bottle using sodium hypochlorite at a dose of 20 mg/L. Then the BOD bottle was filled to the top using the remaining buffered, pH adjusted sample and stoppered. Samples were incubated headspace free in the 20°C incubator for 72 hours.

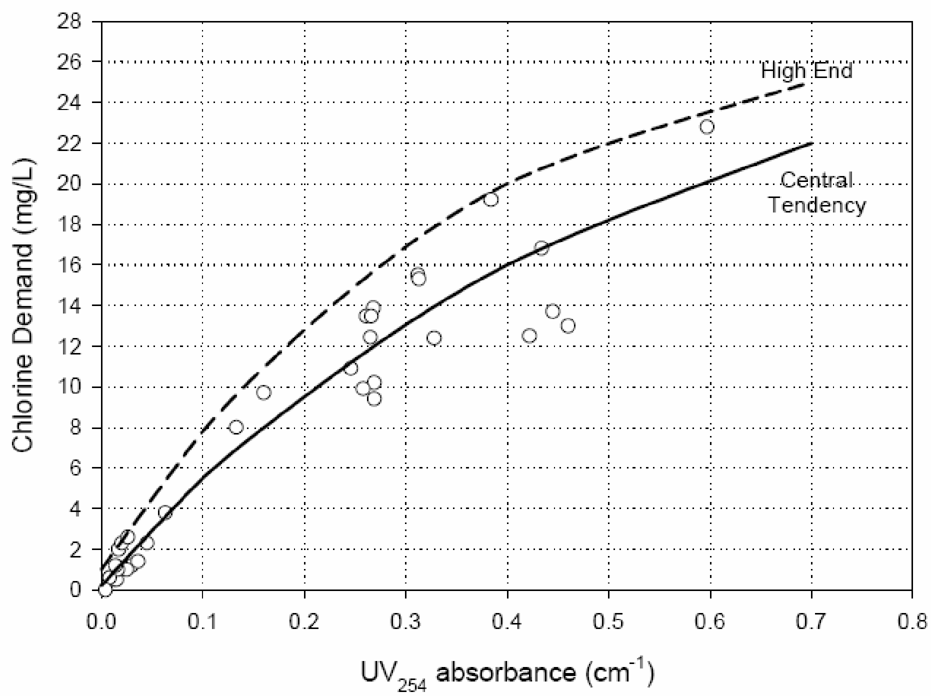


Figure 3.2 Typical 72hrs Chlorine Demand Data under UMass Formation Potential Conditions (Reckhow 2006)

Samples were removed from the incubator a few minutes before end of the 72 hour prescribed incubation time. Chlorine residual measurements were made. Two 40mL amber vials containing approximately 40mg of ammonia chloride quench and phosphate buffer were filled with incubated samples, and kept headspace free for THMFP analysis. In addition, two 40mL clear vials containing 40mg of quench were filled with at 30mL of sample for HAA analysis.

Chlorine residual measurements were made using the diethylphenylenediamine (DPD) titrimetric method (APAH *et al.* 1998) following the UMass SOP for laboratory chlorination (Reckhow 2006). Indicator solution (DPD indicator) and a buffer were added to 100mL of sample. Then the sample was titrated with ferrous ammonium sulfate (FAS) until the pink color of the solution turned to clear.

3.2.3.2 Extraction and Measurements of Trihalomethanes

The amber vials with quenched aqueous sample were stored at 4^0C for no more than 14 days before extraction. Procedures for extraction of THM were modified based on US EPA method of 551.1 and described in the UMass SOP (Reckhow 2006). Forty-mL acid-washed amber vials were filled with 20mL of samples or distilled water. A series of standards were prepared by adding an appropriate volume of pre-made Volatile Organic Mix to distilled water using EPA Method 551. The Volatile Organic Mix contains the 4 species of THM, which are listed in Table 3.1.

Table 3.1 Standard THM Analytes

Trihalomethanes	
Analyte	CAS Registry #
Chloroform($CHCl_3$)	67-66-3
Bromodichloromethane($CHCl_2Br$)	75-27-4
Chlorodibromomethane($CHClBr_2$)	124-48-1
Bromoform ($CHBr_3$)	75-25-2

The extraction procedures include the following steps:

- Add 4 mL of the pre-mixed Pentane plus internal standard (1, 2-dibromopropane), add approximately 15 g of Na_2SO_4 to each vial and then shake for 15 minutes.
- Remove water and transfer organic layer (top) to autosampler vials for GC analysis.

Samples were analyzed using Hewlett Packard (HP) 5890 series II Gas Chromatograph

(GC) with a HP 7673 autosampler. THM concentrations were calculated based on the peak area ratio of each compound to internal standard and the calibration curves. The THM formation potential is the sum of the four species of interest.

3.2.3.3 Extraction and Measurements of Haloacetic Acids.

At the end of the disinfection byproduct formation test 72 hours incubation period, the quenched samples for HAA analysis were stored at $4^{O}C$ for no more than 14 days before extraction. The UMass SOP for analysis of Haloacetic Acids (Reckhow 2006) based on US EPA method 552.2 was followed for HAA analysis in the lab. Standards were prepared by adding an appropriate aliquot of pre-made standard solution to 30 mL distilled water in the 40mL vials.

The standard solution was prepared using tribromoacetic acid (TBAA), bromodichloroacetic acid (BDCAA), chlorodibromoacetic acid (CDBAA) and an EPA 522 mix that included six of the HAA analytes: monochloroacetic acid (MCAA), monobromoacetic acid(MBAA), dichloroacetic acid(DCAA), dibromoacetic acid(DBAA), trichloroacetic acid(TCAA) and bromochloroacetic acid (BCAA). Table 3.2 shows the standard HAA analytes.

Table 3.2: Standard HAA Analytes

Analyte	CAS Registry #
Trihaloacetic Acids (THAA)	
Trichloroacetic Acid (TCAA)	76-03-9
Bromodichloroacetic Acid (BDCAA)	7113-314-7
Chlorodibromoacetic Acid (CDBAA)	5278-95-5
Tribromoacetic Acid (TBAA)	75-96-7
Dihaloacetic Acids (DHAA)	
Dichloroacetic Acid (DCAA)	79-43-6
Bromochloroacetic Acid (BCAA)	5589-96-3
Dibromoacetic Acid (DBAA)	631-64-1
Monohaloacetic Acids (MHAA)	
Monochloroacetic Acid (MCAA)	79-11-8
Monobromoacetic Acid (MBAA)	79-08-3

The extraction process includes the following steps:

- Add 1.5 mL concentrated H_2SO_4 to each vial, add 3mL of the pre-mixed MTBE plus internal standard (1, 2, 3-trichloropropane), and then add 15g of sodium sulfate, shake for 15 minutes.
- Remove 1 mL from first extract and place into prepared 20mL vials containing 2ml of acidic methanol (5% H_2SO_4) solution and incubate in the 50oC water bath for 2 hours.
- Add 5 mL saturated $NaHCO_3$ solution to each vial, add 1mL pure MTBE and shake for 2 minutes.
- Place 1 ml extract into autosampler vials, freeze, and analyze.

Samples were analyzed using a Hewlett Packard (HP) 5890 series II Gas Chromatograph (GC) with an HP 7673 autosampler. Haloacetic acid concentrations were calculated based on the peak area ratio of each compound to the internal standard and the calibration curves.

CHAPTER 4 RESULTS

Ten sampling events targeted to monitor the quantities and qualities of NOM and evaluate the impact of beavers were conducted from September, 2004 to December, 2005. The first sampling event was on September 15th, 2004 to collect general information about NOM in this watershed. After that, samplings were conducted monthly except when the watershed had ice over it, the watershed was too dry or too wet to get access to. The significant features for all the sampling events are summarized in Table 4.1.

Table 4.1 Significant features for all the sampling events

Sampling Event	Temperature Of air (^{o}F)	Discharge* (cfs)	Precipitation (in)	Purpose
09/15/2004	72	328	0	Major tributaries
12/01/2004	54	1900	0.5	Major tributaries
12/15/2004	28	1470	0.0	Impact of beavers
05/04/2005	55	1370	0	Major tributaries
06/07/2005	89	496	0	Impact of beavers,
06/28/2005	75	275	0.25	Impact of beavers
07/20/2005	87	497	0	Impact of beavers
10/14/2005	57	5090	1.6	Major tributaries
11/04/2005	69	806	0	Impact of beavers
12/08/2005	30	890	0.21	Impact of beavers

* All the discharge data are for Westfield River

4.1. First Sampling Event: September 15th, 2004

Samples for this event were taken from most of the major tributaries of Cobble Mountain Reservoir and Borden Brook Reservoir. Sampling locations are shown in Figure 4.1. Samples were generally taken from a downstream location near the mouth of the tributaries and at a point close to a road. Previous observations indicate that there are extensive beaver activities in Borden Brook Reservoir Sub-basin and there is a series of big beaver ponds in Peebles Brook, and Pond Brook, and beaver dams in Stowe Brook and Alder Brook. No beaver activities were observed in Exit Brook and Phelon Brook. Samples were not collected from Birch Meadow Brook, Tannery Brook and Bedlam Brook for this first event.

This first sampling event was at the beginning of the fall season and the weather was warm with air temperatures in the range of 70°F to 86°F. Precipitation data is collected from a rain gage near Borden Brook Reservoir and this is used as a reference for the whole watershed. There are no stream flow gauging stations in the watershed; therefore discharge data from the Westfield River (the nearest gauged river to the watershed) is used for reference. This first sampling event followed some periods of light precipitation; however the impact on discharge in the Westfield River didn't become evident until 2 days after the sampling date. Discharge values were low for the Westfield River, reflecting base flow conditions.

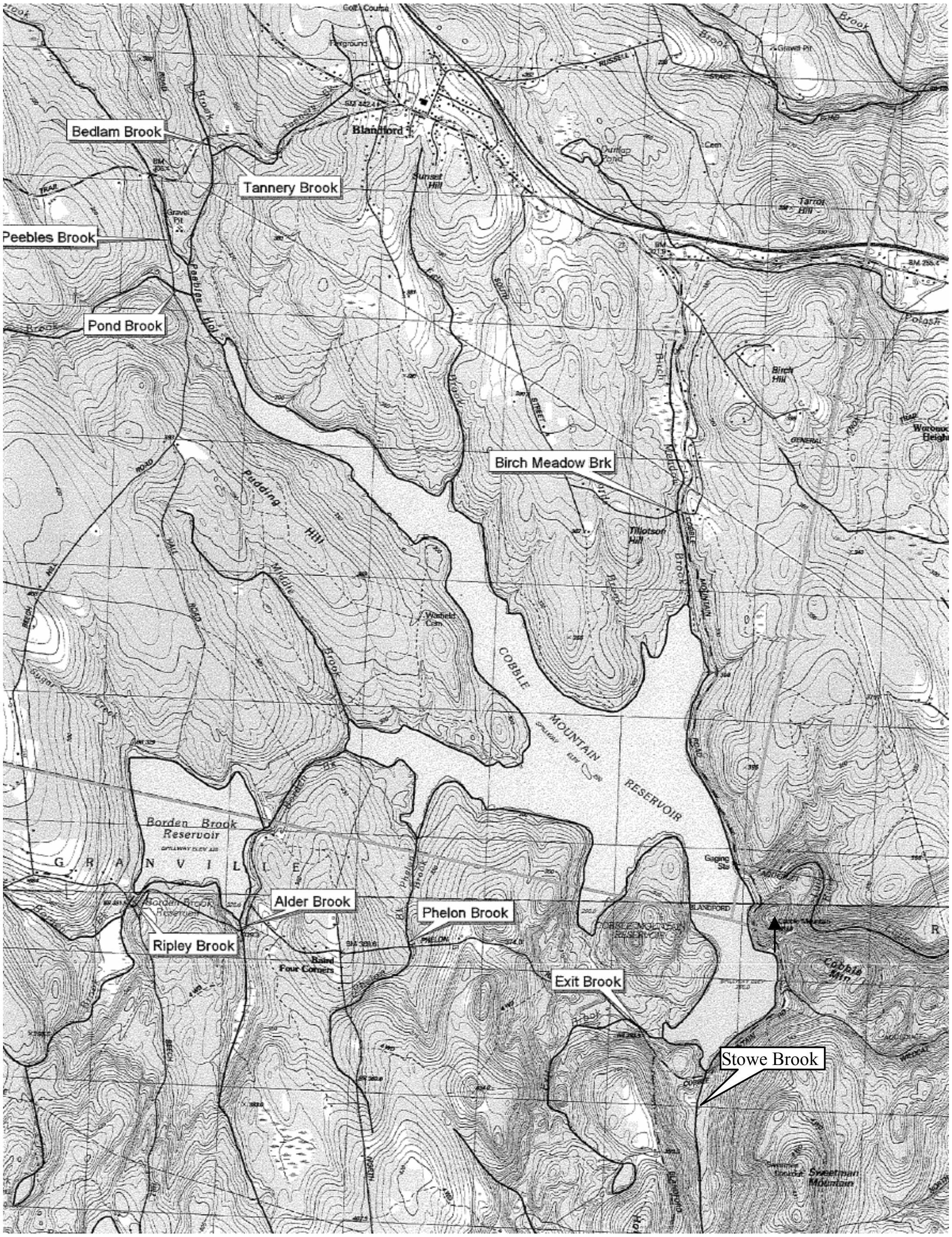


Figure 4.1 Sampling Locations for September 15th, 2004 sampling event

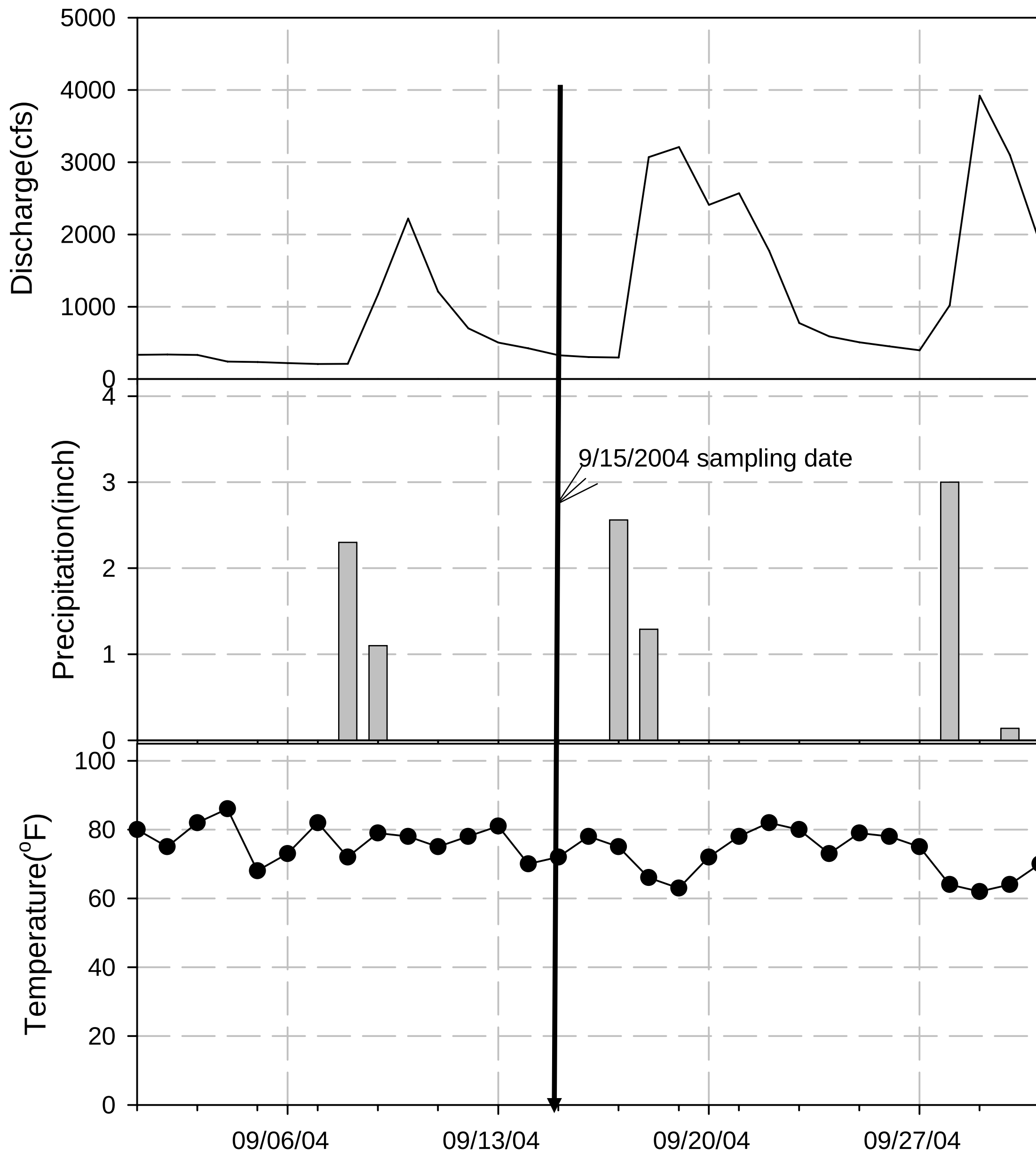


Figure 4.2 Discharge, Precipitation and Temperature data prior to and after September 15th, 2004 Event. (Precipitation: Borden Brook Reservoir; Temperature: Westfield, MA; Discharge: USGS Westfield River Station 01183500)

4.1.1. NOM Levels

Key water parameters, including UV-254, TOC, and DOC were measured for each sample. The results are summarized in Table 4.2. Total organic carbon and DOC levels were in the range of 3-7 mg/L, with the exception of samples from Ripley Brook, which had a TOC level of 13 mg/L, and Pond Brook, which had a TOC level of 10 mg/L. Dissolved organic carbon comprised about 95% of TOC in all samples. Ultraviolet absorbance values were in the range of 0.084-0.2 cm^{-1}, with the exception of samples from Ripley Brook and Pond Brook, which tended to contribute high levels of TOC. Specific UV absorbance for all of the locations ranged from 3-4 L/mg-m.

Table 4.2 TOC, DOC, UV-254 of water samples for September 15th, 2004 Event

Location	TOC	DOC	UV	SUVA
	mg/L	mg/L	cm^{-1}	L/mg-m
Exit Brook	2.6	2.6	0.084	3.2
Peebles Brook	5.7	5.1	0.181	3.5
Ripley Brook	13.1	12.5	0.509	4.1
Stowe Brook	4.6	4.1	0.172	4.2
Pond Brook	10.4	9.4	0.328	3.5
Alder Brook	7.1	7.0	0.200	2.9
Phelon Brook	4.9	3.7	0.093	2.5

Figure 4.3 shows all TOC and SUVA values for this sampling event. Of the major tributaries, Exit Brook had the lowest TOC value. Total organic carbon values within and out of the Borden Brook Reservoir sub-basin were high, indicating it is an especially rich source of organic matter in the Cobble Moutain Reservoir watershed. Samples from Ripley Brook and Stowe Brook had high SUVA values, above 4L/mg-m. Specific UV absorbance values for samples from tributaries in Cobble Moutain Reservor varied, with the lowest value of 2.5 L/mg-m for Phelon Brook and highest value of 4.2 L/mg-m for Stowe Brook.

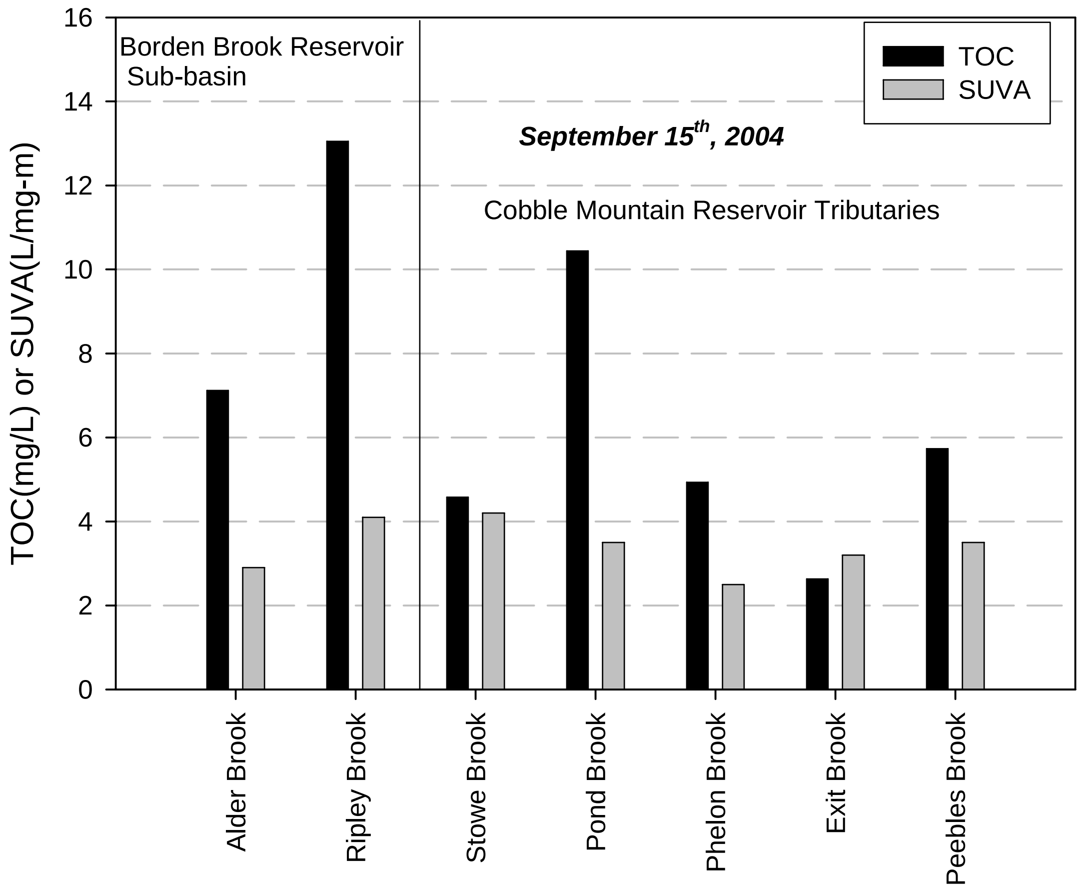


Figure 4.3 TOC and SUVA for Major tributaries and Borden Brook Reservoir Sub-basin for September 15th, 2004 Event.

4.1.2. DBP Formation Potential

Disinfection byproducts (DBP) formation potential levels for all of the sampled streams are summarized in Table 4.3 and presented in Figure 4.4. Trihalomethane formation potential (THMFP) levels ranged from 160-680 μg/L , DHAA formation potential (DHAAFP) levels ranged between 100-370 μg/L and THAA formation potential

(THAAFP) fell between 170 and 500 μg/L. Phelon Brook and Exit Brook both had formation potential levels below 250 μg/L.

Table 4.3 DBP Formation Potential Data (μg/L) for September 15th, 2004 Event

Sample Location	THMFP (μg/L)	DHAAFP (μg/L)	THAAFP (μg/L)
Alder Brook	316	234	428
Ripley Brook	587	365	822
Exit Brook	169	96	179
Peebles Brook	402	193	337
Phelon Brook	246	126	213
Pond Brook	679	357	567
Stowe Brook	397	273	492

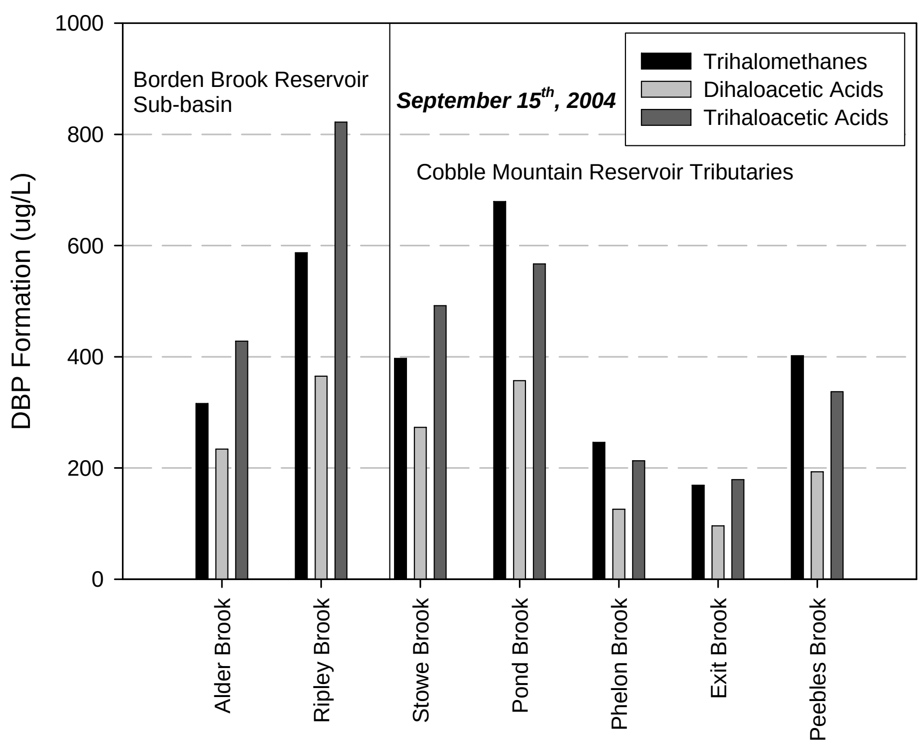


Figure 4.4 DBP Formation Potential for Major tributaries and Borden Brook Reservoir sub-basin for September 15th, 2004 Event

Figure 4.5 shows the correlation between DBP formation potential and TOC levels for each sampling location. Very good correlations exist between DBP formation potentials and TOC (r^2=0.75, 0.69, 0.80). The figure shows that the DBP formation potential increases with increasing TOC, which is entirely expected.

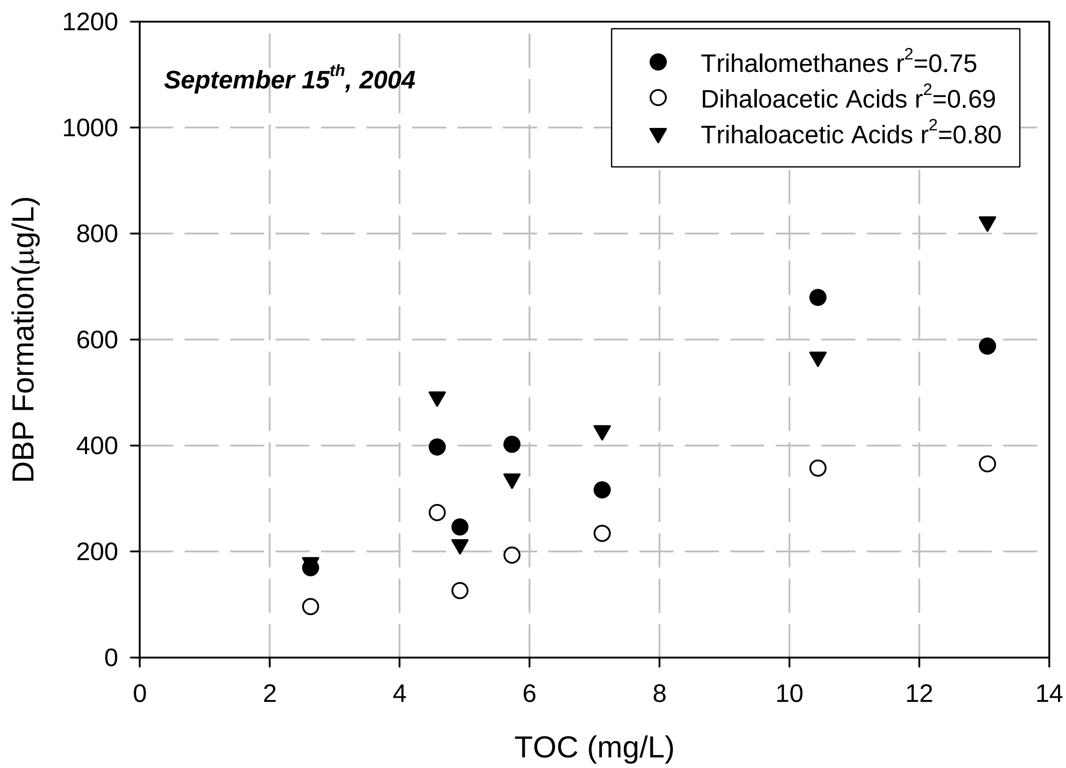


Figure 4.5 Correlation between TOC and DBP Formation Potential for September 15th, 2004 Event

4.1.3. Specific DBP Formation Potential

Specific DBP formation potential is the DBP formation potential levels normalized by the value of TOC for the water sample. Table 4.4 and Figure 4.6 summarize specific DBP formation potential levels for all of the sampling locations. Specific THMFP levels ranged between 40 and 70 µg/mg-TOC. Ripley Brook, the highest TOC source for this event, yielded the second lowest specific THMFP. Generally, Borden Brook Reservoir sub-basin had the lowest levels of THMFP. Samples from Peebles Brook and Stowe Brook had high specific THMFPs. Specifc DHAAFP levels are comparable for all the sampling locations in the range of 30-40 ug/mg TOC and specific THAAFP levels ranged from 40-70 μg/mg-TOC . Specific THAA levels are around 2 times higher than specific DHAA levels.

Table 4.4 Specific DBP Formation Potential Data (μg/mg-TOC**) for September 15th, 2004 Event**

Location	SpTHM (μg/mg-TOC)	SpDHAA (μg/mg-TOC)	SpTHAA (μg/mg-TOC)
Alder Brook	44	33	60
Ripley Brook	45	28	63
Exit Brook	64	37	68
Peebles Brook	70	34	59
Phelon Brook	50	26	43
Pond Brook	65	34	54
Stowe Brook	52	32	72

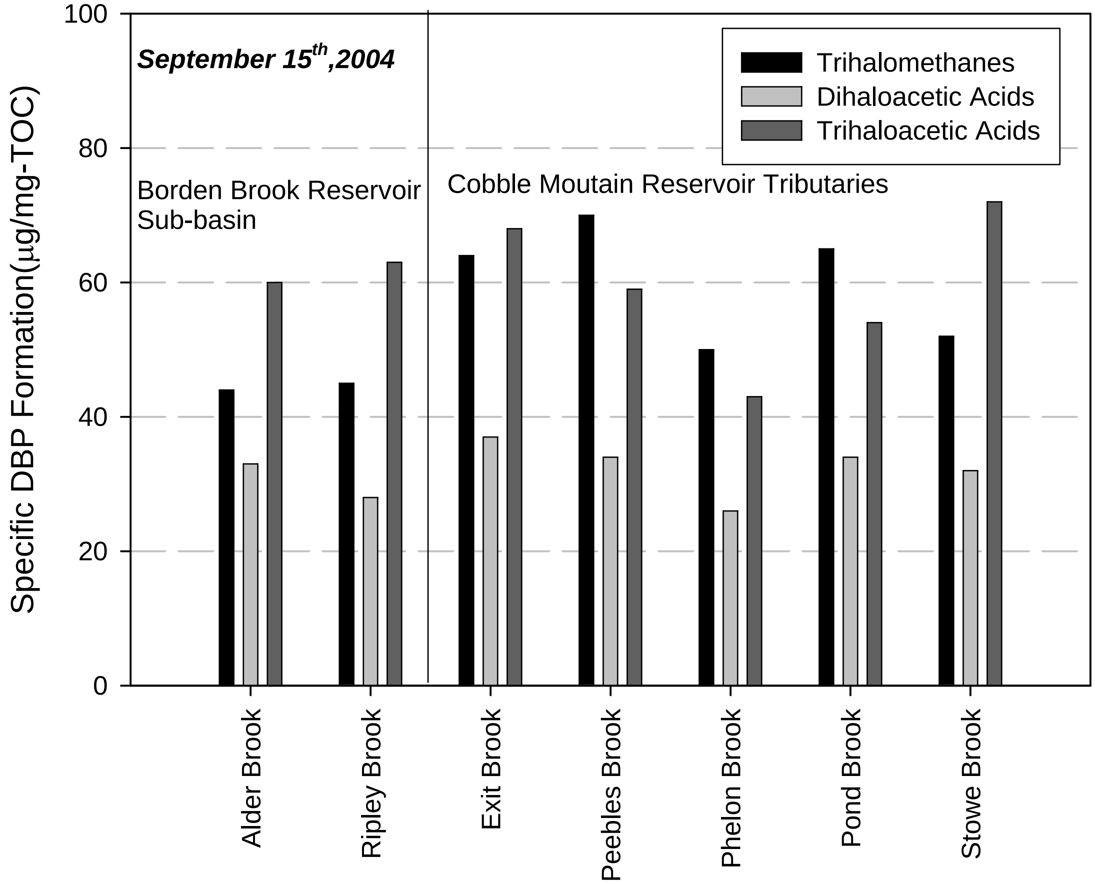


Figure 4.6 Specific DBP Formation Potential for Major Tributaries and Borden Brook Reservoir Sub-basin for September 15th, 2004 Event

Correlations between TOC and specific DBP formation potentials are presented in Figure 4.7, and there is no obvious correlation between these two parameters in this sampling event.

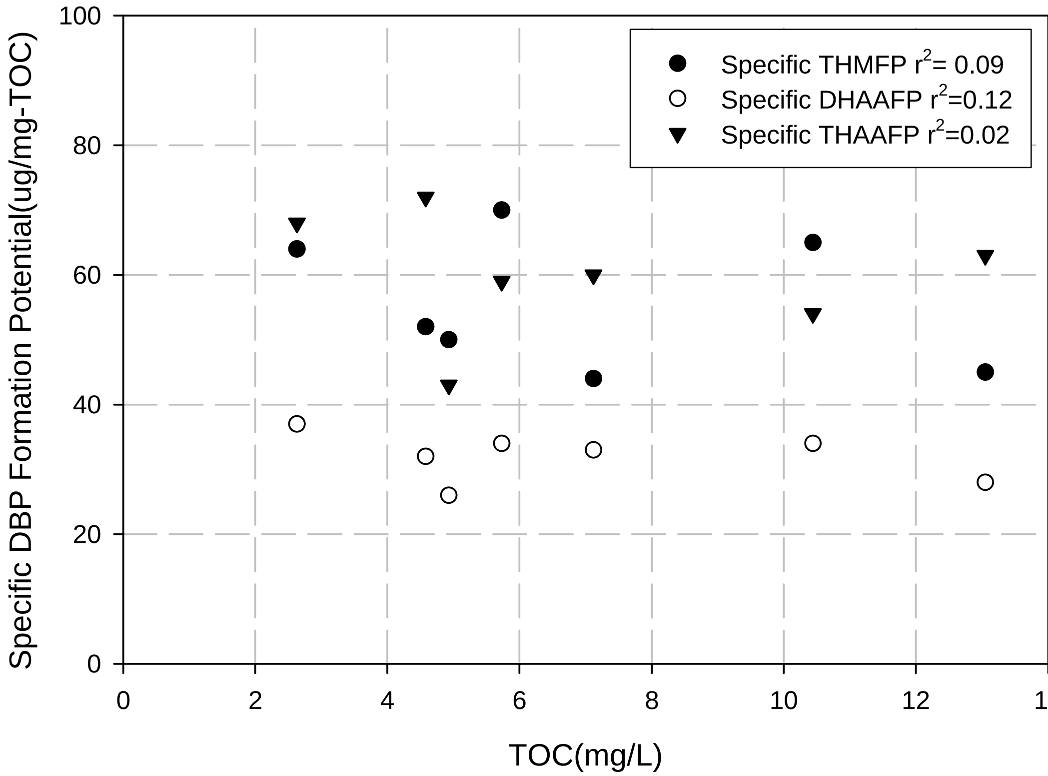


Figure 4.7 Correlation between TOC and Specific DBP Formation Potential for September 15th, 2004 Event.

4.2. Second Sampling Event: December 1st, 2004

Samples for this event were taken from most of the major tributaries of Cobble Mountain Reservoir and Borden Brook Reservoir. Samples were also taken from upstream and downstream of beaver impoundments in Alder Brook and Stowe Brook to test the effect of beaver activities on the water quality. The beaver impact sampling locations are presented in Figure 4.8, below. Bedlam Brook and Tannery Brook were sampled because Bedlam has a large portion of its land cover designated for agriculture use and Tannery Brook has a large portion of residential land-use. Birch Meadow Brook, which has a big and complex beaver-impacted system, and appears to be a major contributor of organic matter to Cobble Mountain Reservoir, was sampled at this time. Exit Brook was not sampled.

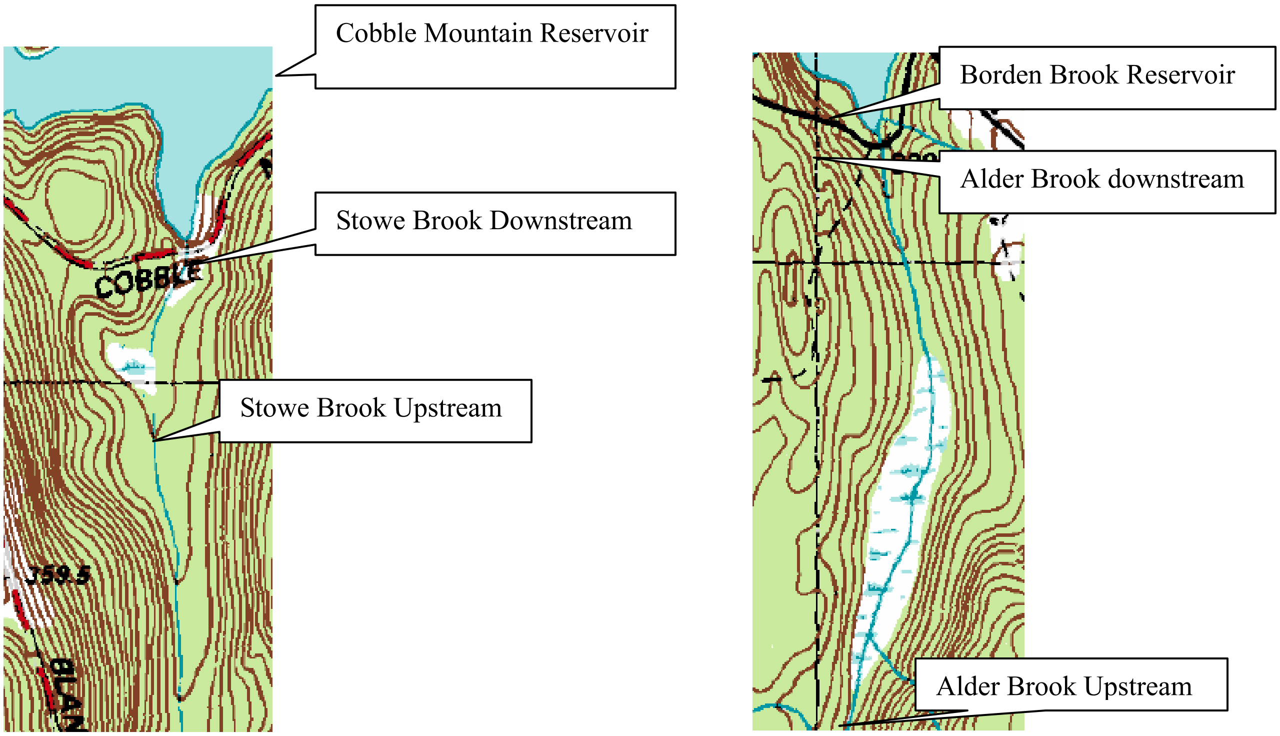


Figure 4.8 Sampling locations upstream and downstream of beaver impoundments in Stowe Brook and Alder Brook

Samples for this event were collected in the midst of a rain storm with more than a half inch of total precipitation, as shown in Figure 4.9. This wet event was at the beginning of the winter season; however, the week of the event was characterized by warm temperature. The event followed some period of precipitation at the end of November, and high discharge values were seen for the Westfield River.

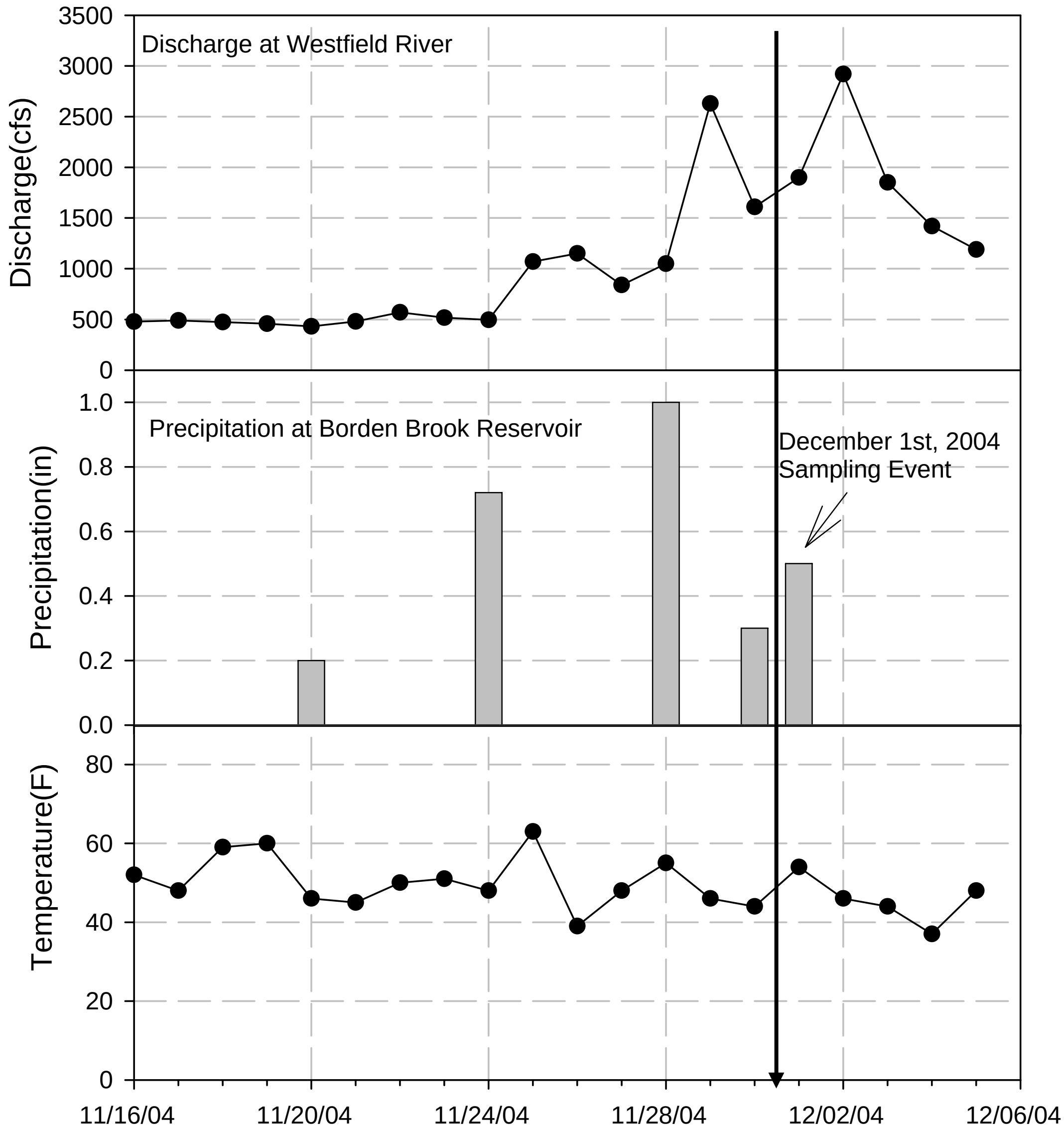


Figure 4.9 Discharge, Precipitation and Temperature data prior to and after December 1st, 2004 Event. (Precipitation: Borden Brook Reservoir; Temperature: Westfield, MA; Discharge: USGS Westfield River Station 01183500)

4.2.1. NOM levels

Important raw water parameters including UV-254, TOC, and DOC were measured for each sample, and results are summarized in Table 4.5.

Table 4.5 UV-254, TOC, DOC and SUVA of water samples for December 1st, 2004 Event

Location	TOC	DOC	UV	SUVA
	mg/L	mg/L	cm^{-1}	L/mg-m
Upstream of Stowe Brook	3.5	3.2	0.105	3.3
Downstream of Stowe Brook	3.1	2.9	0.110	3.8
Upstream of Alder Brook	7.7	7.6	0.261	3.4
Downstream of Alder Brook	6.3	5.6	0.177	3.1
Ripley Brook	8.4	8.4	0.301	3.6
Birch Meadow Brook	8.2	8.2	0.284	3.5
Phelon Brook	4.0	4.6	0.171	3.7
Peebles Brook	4.6	4.5	0.177	3.9
Tannery Brook	7.3	6.9	0.251	3.6
Pond Brook	6.2	6.2	0.275	4.4
Bedlam Brook	5.8	5.5	0.189	3.4

Total organic carbon and dissolved organic carbon levels were in the range of 3-8 mg/L. Ultraviolet absorbance values were in the range of 0.10-0.30 cm^{-1} with the exception of upstream of Alder Brook, Birch Meadow Brook, Ripley Brook and Pond Brook. Ripley Brook and Birch Meadow Brook are two tributaries with consistently high UV absorbance and TOC levels. Stowe Brook has the lowest TOC and UV-absorbance level. Specific UV absorbance values for this event range from 3-4 L/mg-m.

Figure 4.10 shows TOC and SUVA for all of the sampling locations. Borden Brook Reservoir sub-basin has high TOC and UV-absorbance levels. As mentioned previously, Stowe Brook, where beaver activities are observed, has low TOC and UV-absorbance levels. Both of the paired studies in this event (Alder Brook and Stowe Brook) show lower levels of organic matter downstream of the beaver impoundment, although these differences are rather small, which is less than 18% of TOC.

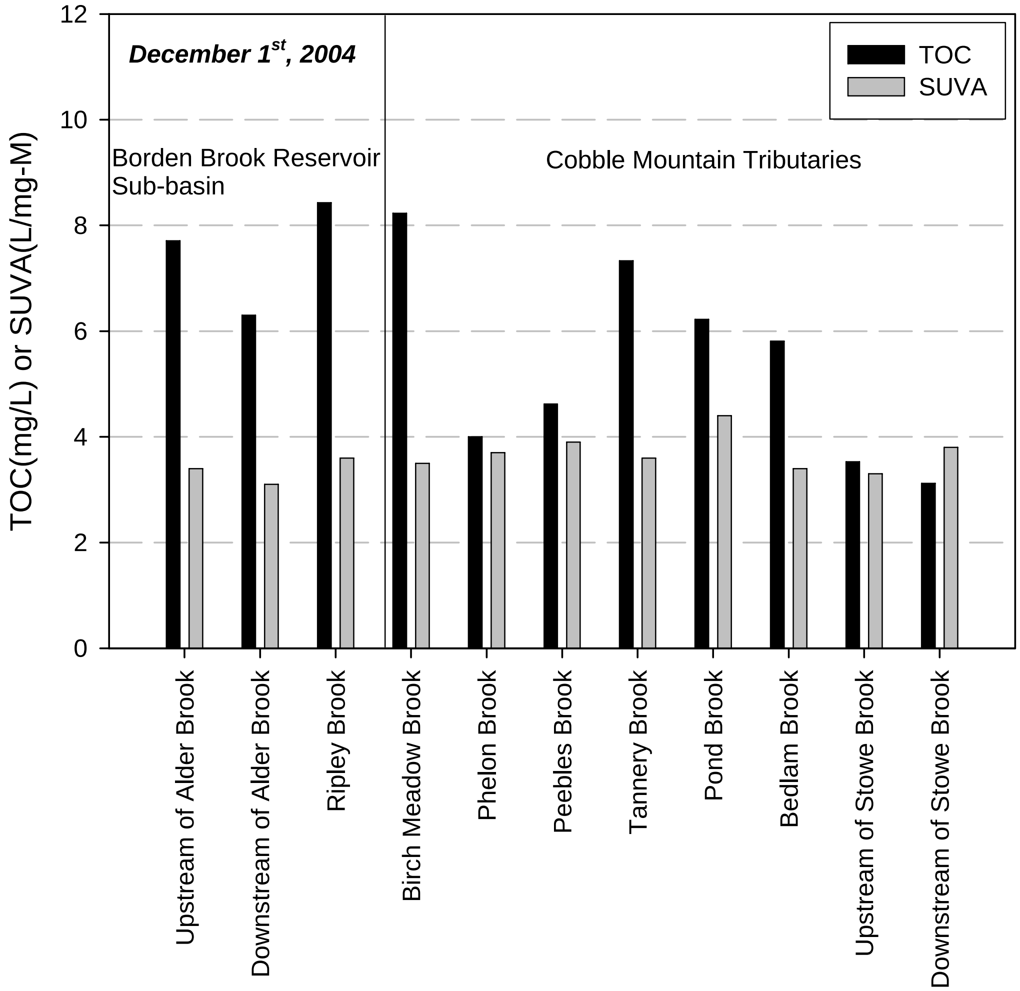


Figure 4. 10 TOC and SUVA for Major tributaries and Borden Brook Reservoir Sub-basin for December 1st, 2004 Event.

4.2.2. DBP Formation Potential

Disinfection by-product formation potential levels for this event are summarized in Table 4.6 and Figure 4.11. Trihalomethane formation potential levels were between 180 and 380 μg/L for this event, with the lowest value from downstream of the beaver impoundment in Stowe Brook and the highest at Ripley Brook and upstream of the beaver impoundment in Alder Brook. These are also the highest TOC sources for the event. Dihaloacetic acid formation potential levels ranged from 110 to 240μg/L, with Bedlam Brook and the upstream site on Stowe Brook yielding the lowest levels, and Alder Brook upstream having the highest level. Once again, THAAFP levels were much higher than DHAAFP, in the range of 170 to 500μg/L. Bedlam Brook had the lowest THAAFP readings while Pond Brook had the highest level of THAAFP. Water downstream of beaver impoundments in Alder Brook and Stowe Brook had lower DBP levels than the upstream water, with the exception of the THAA level for Stowe Brook. Overall, Borden Brook Reservoir sub-basin had high levels of DBPFP. Among tributaries of Cobble Mountain Reservoir, Pond Brook and Birch Meadow Brook had the highest levels of DBPFP. Beaver impoundments had an apparent beneficial effect of generally lowering the DBP levels.

Table 4.6 DBP Formation Potential Data (μg/L) for December 1st, 2004 Event

Location	THMFP (μg/L)	DHAAFP (μg/L)	THAAFP (μg/L)
Upstream of Alder Brook	354	241	505
Downstream of Alder Brook	280	149	275
Ripley Brook	380	219	468
Birch Meadow Brook	328	233	494
Phelon Brook	300	150	292
Peebles Brook	280	147	312
Tannery Brook	312	210	420
Pond Brook	336	184	508
Bedlam Brook	240	107	169
Upstream of Stowe Brook	257	107	214
Downstream of Stowe Brook	184	116	240

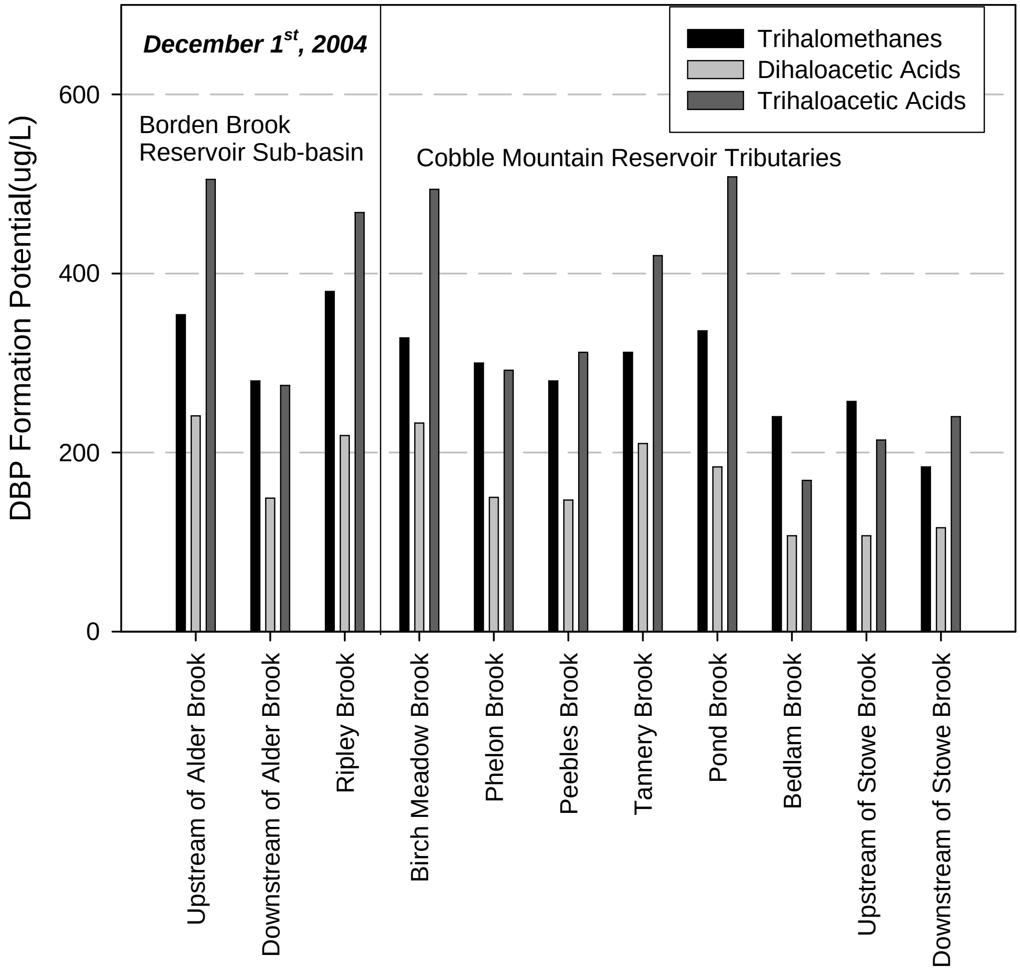


Figure 4.11 DBP Formation Potential for Major Tributaries and Borden Brook Reservoir Sub-basin for December 1st, 2004 Event

4.2.3 Specific DBP Formation Potential

Specific DBP formation values measured for each sample are presented in Table 4.7 and Figure 4.12. Specific THMFP levels lay within 40-80 μg/mg-TOC, specific DHAAFP between 20 and 40 μg/mg-TOC and specific THAAFP ranged from 30-80 μg/mg-TOC.

Stowe Brook and Phelon Brook, the two lowest TOC sources for the event, had the highest specific DBPFP levels. On the other hand, high TOC sources, Ripley Brook and Birch Meadow Brook, yielded the lowest specific THMFP levels, while the specific DHAAFP and specific THAAFP levels for these two tributaries are in the middle range. Another high TOC source, Pond Brook, had the highest level of specific THAAFP. The difference in specific THMFP between locations upstream and downstream of the beaver impoundment in Alder Brook was not significant while the downstream location had lower levels of specific DHAAFP and specific THAAFP. For another tributary under upstream and downstream paired study: Stowe Brook, the downstream had lower levels of specific THMFP, but higher levels of specific DHAAFP and THAAFP.

Table 4.7 Specific DBP Formation Potential Data (μg/mg-TOC) for December 1st, 2004 Event

Location	SpTHM (μg/mg-TOC)	SpDHAA (μg/mg-TOC)	SpTHAA (μg/mg-TOC)
Upstream of Alder Brook	46	31	66
Downstream of Alder Brook	44	24	44
Ripley Brook	45	26	56
Birch Meadow Brook	40	28	60
Phelon Brook	75	37	73
Peebles Brook	61	32	68
Tannery Brook	43	29	57
Pond Brook	54	30	82
Bedlam Brook	41	18	29
Upstream of Stowe Brook	73	30	61
Downstream of Stowe Brook	59	37	77

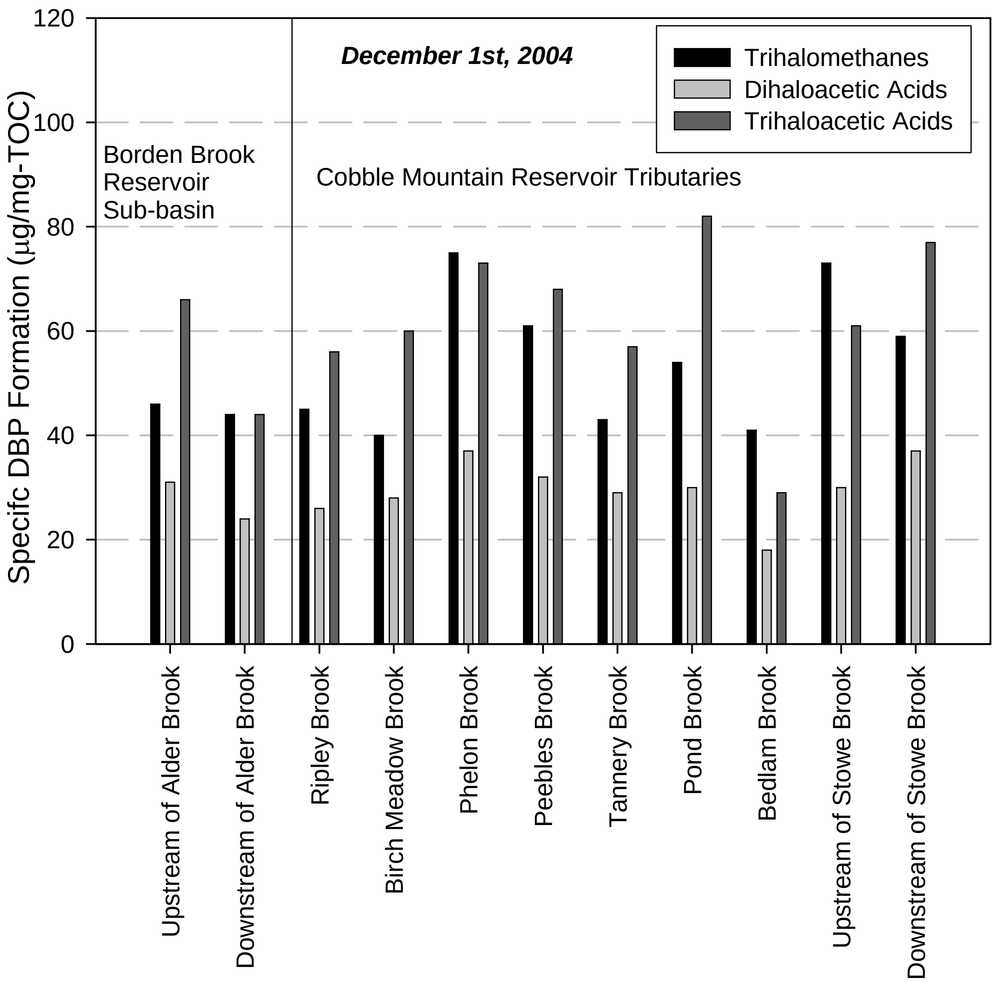


Figure 4.12 Specific DBP Formation Potential for Major Tributaries and Borden Brook Reservoir Sub-basin for December 1st, 2004 Event

Correlations between TOC and specific DBP formation potentials are presented in Figure 4.13. Figure 4.13 shows that a moderately strong negative correlation exists between specific THMFP (r^2 = 0.67) and TOC, indicating with the TOC increase, the net production of THMFP per milligram of TOC decreased. There are weak correlations between either specific DHAAFP and TOC (r^2 =0.24) or specific THAAFP and TOC (r^2 =

0.09).

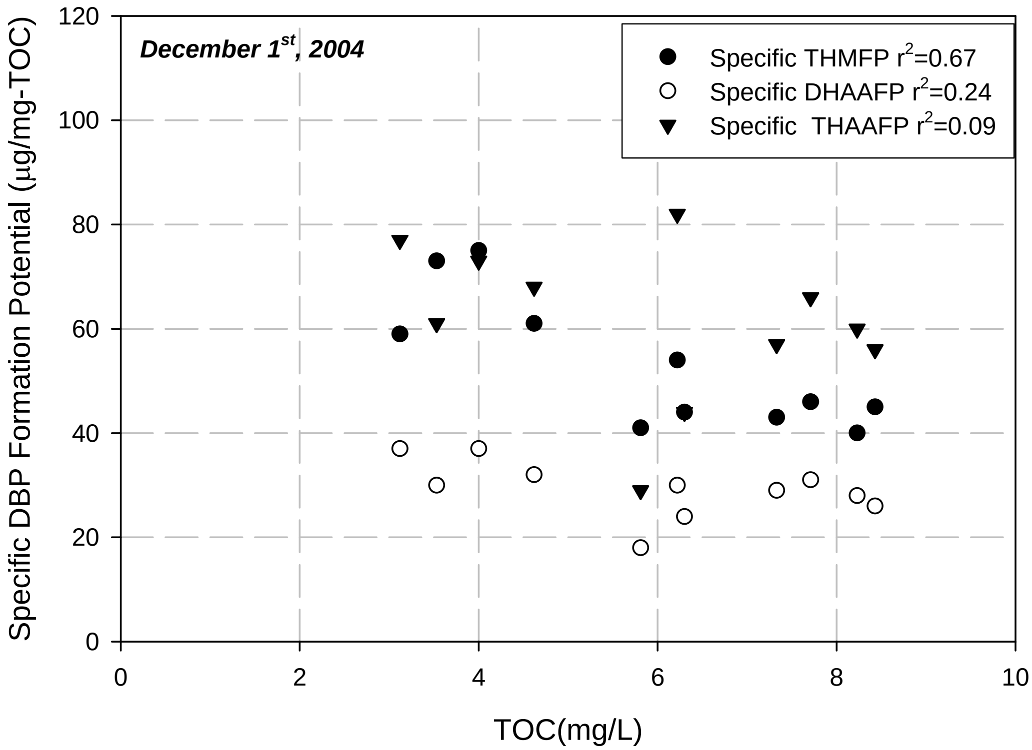


Figure 4.13 Correlation between TOC and Specific DBP Formation Potential for December 1st, 2004 Event.

4.3. December 15th, 2004

This event was conducted to study the effect of beaver impoundments on water quality. Middle Brook is another tributary of Cobble Mountain Reservoir, where beaver activities are observed. Samples were taken from upstream and downstream of beaver impoundment in Alder Brook and Middle Brook. The sampling locations are shown in Figure 4.14.

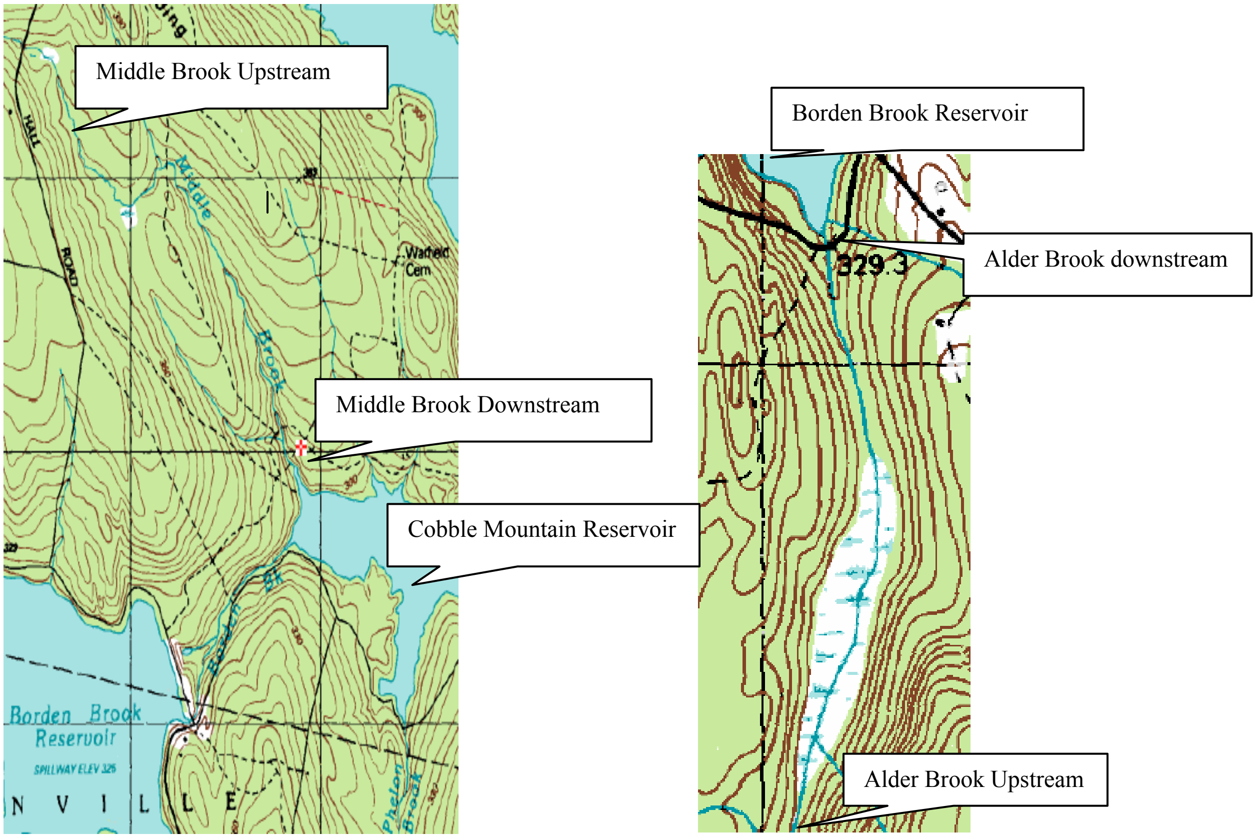


Figure 4.14 upstream and downstream of beaver impoundments in Middle Brook and Alder Brook

This sampling event was during winter season, with temperature before and after the event below 39°F, and temperature on the day of the event close to 30.2°C, as shown in Figure 4.15. There was a period of slight precipitation at the beginning of the week prior to the sampling event. The discharge on the day of sampling was around 1500 ft^3/s indicating a high flow condition for this sampling event. The precipitation and discharge data prior to and after the sampling event are presented in Figure 4.15.

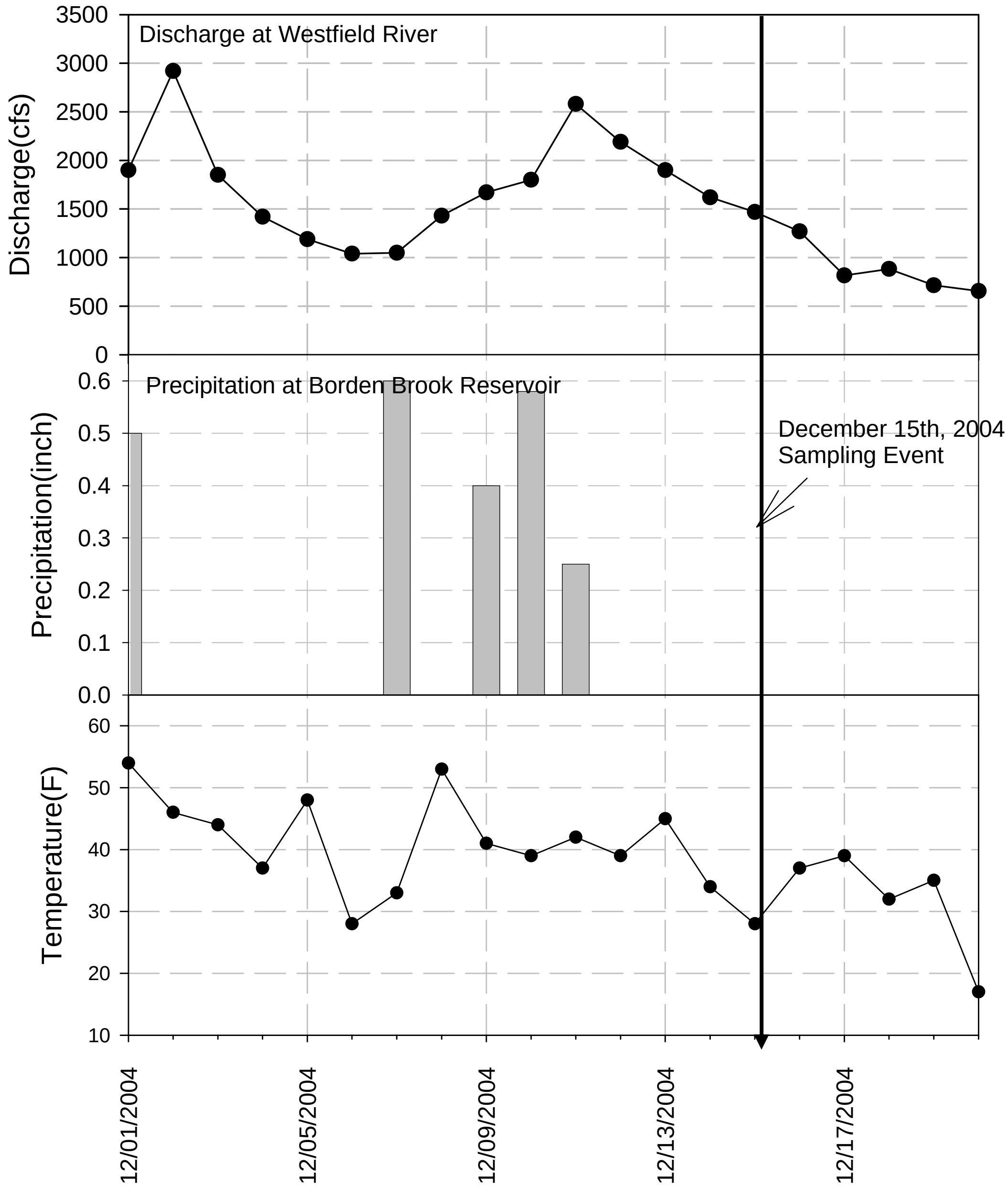


Figure 4.15 Discharge, Precipitation and Temperature data prior to and after December 15th, 2004 Event. (Precipitation: Borden Brook Reservoir; Temperature: Westfield, MA; Discharge: USGS Westfield River Station 01183500)

4.3.1. NOM Levels

Important water parameters including UV-254, TOC, and DOC were measured for each sample, and results are summarized in Table 4.8. The TOC and DOC for all the samples were in the range of 2-4 mg/L. UV 254 values ranged between 0.130 and 0.200cm^{-1}. SUVA values are in the range of 5-7L/mg-m. Figure 4.16 shows TOC and SUVA l evels for all of the sampling points and the data are characterized by low TOC values and high SUVA values. TOC were low for all the samples. Specific ultraviolet absorbance values for this event were substantially higher than the previous runs. Alder Brook downstream of the beaver impoundment has lower TOC value than upstream location. The difference in NOM levels between upstream and downstream of the beaver impoundment in Middle Brook is not significant while downstream of Middle Brook has much higher SUVA values.

Table 4.8 UV-254, TOC, DOC and SUVA of water samples for December 15th, 2004 Event

Location	TOC mg/L	DOC mg/L	UV cm-1	SUVA L/mg-m
Upstream of Alder Brook	3.8	3.6	0.197	5.5
Downstream of Alder Brook	2.9	2.7	0.159	5.9
Upstream of Middle Brook	2.5	2.3	0.141	6.1
Downstream of Middle Brook	2.3	1.9	0.131	6.9

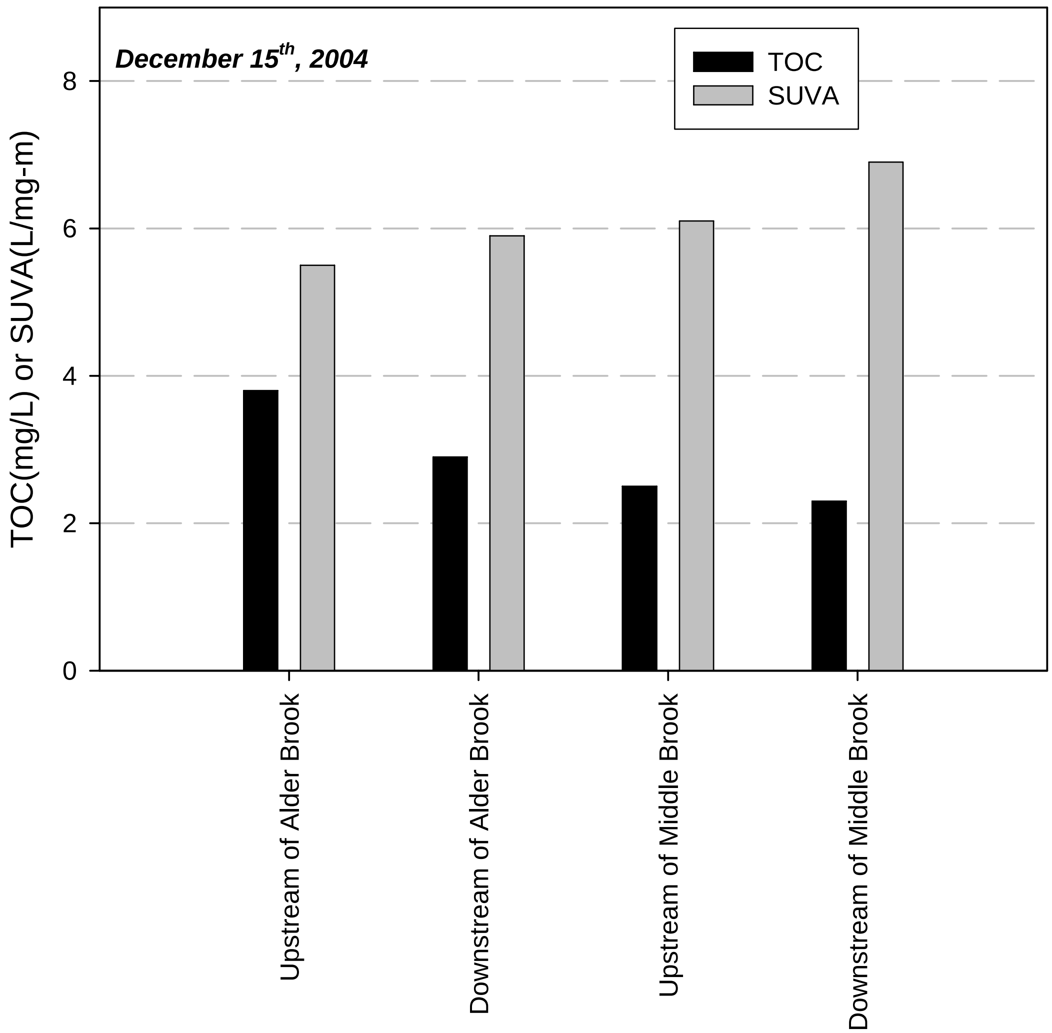


Figure 4.16 TOC and SUVA for December 15th, 2004 Event

4.3.2. DBP Formation Potential

Disinfection by-product formation potentials were measured for all of the samples collected, and the results of this analysis are summarized in Table 4.9 and Figure 4.17. THMFP levels ranged from 130 to 300 μg/L, DHAAFP levels were in the range of 90-140 μg/L and THAAFP levels extended between 160 and 290 μg/L. Overall, THAAFPs were much higher than THM and DHAA formation potentials for all of the sampling locations. Additionally, both of the downstream of beaver impoundment location in the two brooks have lower yield of DBPFP than upstream locations.

Table 4.9 DBP Formation Potential Data (μg/L) for December 15th, 2004 Event

Location	THMFP	DHAAFP	THAAFP
	μg/L	μg/L	μg/L
Upstream of Alder Brook	294	136	290
Downstream of Alder Brook	209	130	270
Upstream of Middle Brook	144	95	181
Downstream of Middle Brook	127	89	158

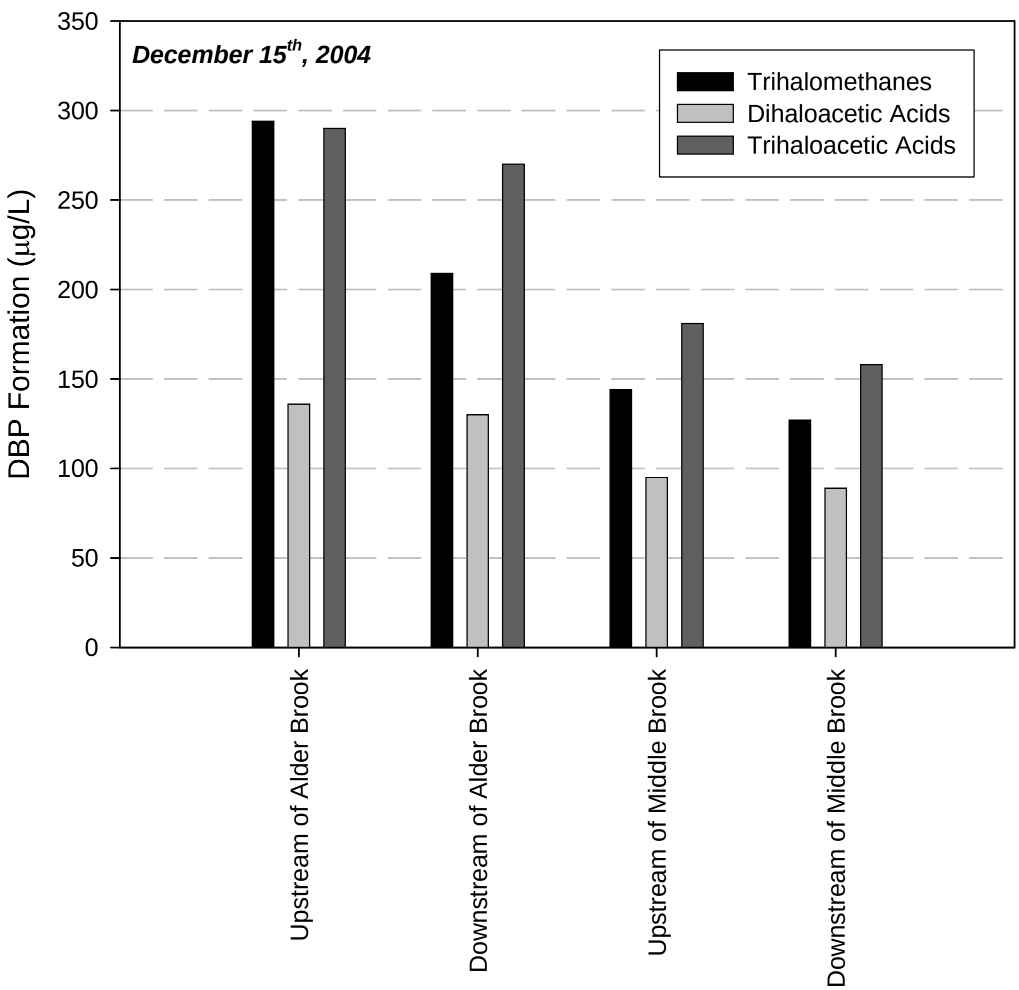


Figure 4.17 DBP Formation Potentials for December 15th, 2004 Event

4.3.3. Specific DBP Formation Potential

Specific DBPFPs were calculated for each of the locations and the results are tabulated in Table 4.10 and presented in Figure 4.18. Specific THMFP, DHAAFP and THAAFP levels ran from 60-80, 40-50, and 70-90 μg/mg-TOC respectively. Alder Brook has higher specific THMFP levels compared with Middle Brook; however, the specific DHAAFP and THAAFP levels were comparable to those for Middle Brook.

Table 4.10 Specific DBP Formation Potential Data (μg/mg-TOC**) for December 15th, 2004 Event**

Location	SpTHM	SpDHAA	SpTHAA
	μg/mg-TOC	μg/mg-TOC	μg/mg-TOC
Upstream of Alder Brook	77	36	76
Downstream of Alder Brook	72	45	93
Upstream of Middle Brook	63	41	79
Downstream of Middle Brook	55	39	69

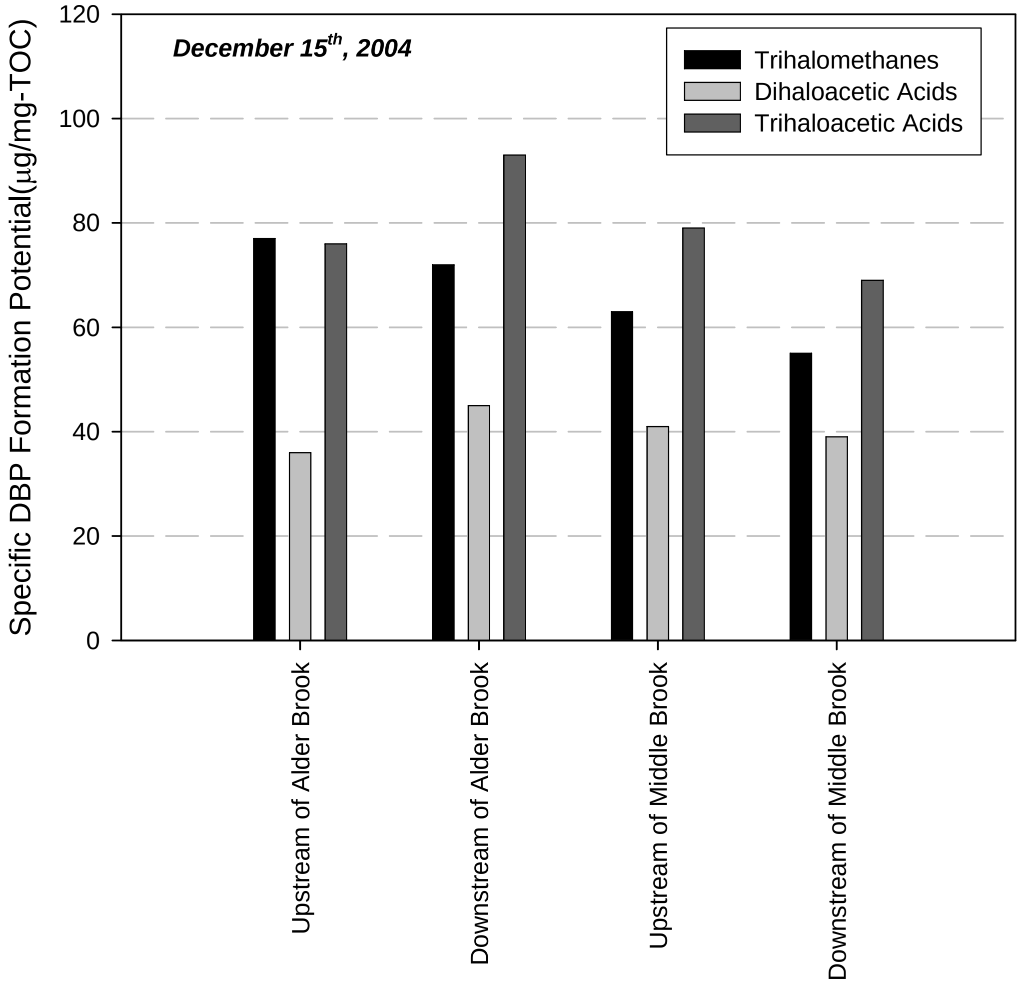


Figure 4.18 Specific DBP Formation Potentials for December 15th, 2004 Event

4.4. May 4th, 2005

During the late winter season in the watershed, ice layers formed over the tributaries, therefore, water sampling could not be conducted from January until April. After that point the snow and ice began to melt, however, samples were still difficult to collect because the watershed was too wet to let us get access to tributaries. Although we sampled Alder Brook in the previous sampling events, unfortunately, the beaver dams were breached by snow melt and the beaver impoundment became drained. This provided the opportunity to monitor a beaver impoundment in decline, which would help in assessing the effect of beaver impoundment age on water quality. The first sampling event in 2005 was conducted on May 4th. This sampling event focused on the levels of NOM in Borden Brook Reservoir. Samples were still collected from upstream and downstream of the beaver impoundment at Alder Brook. For this sampling event, samples were also taken from upstream of Borden Brook and Ripley Brook. The upstream location in Ripley Brook had another beaver impoundment at this time. The sampling locations are shown in Figure 4.19.

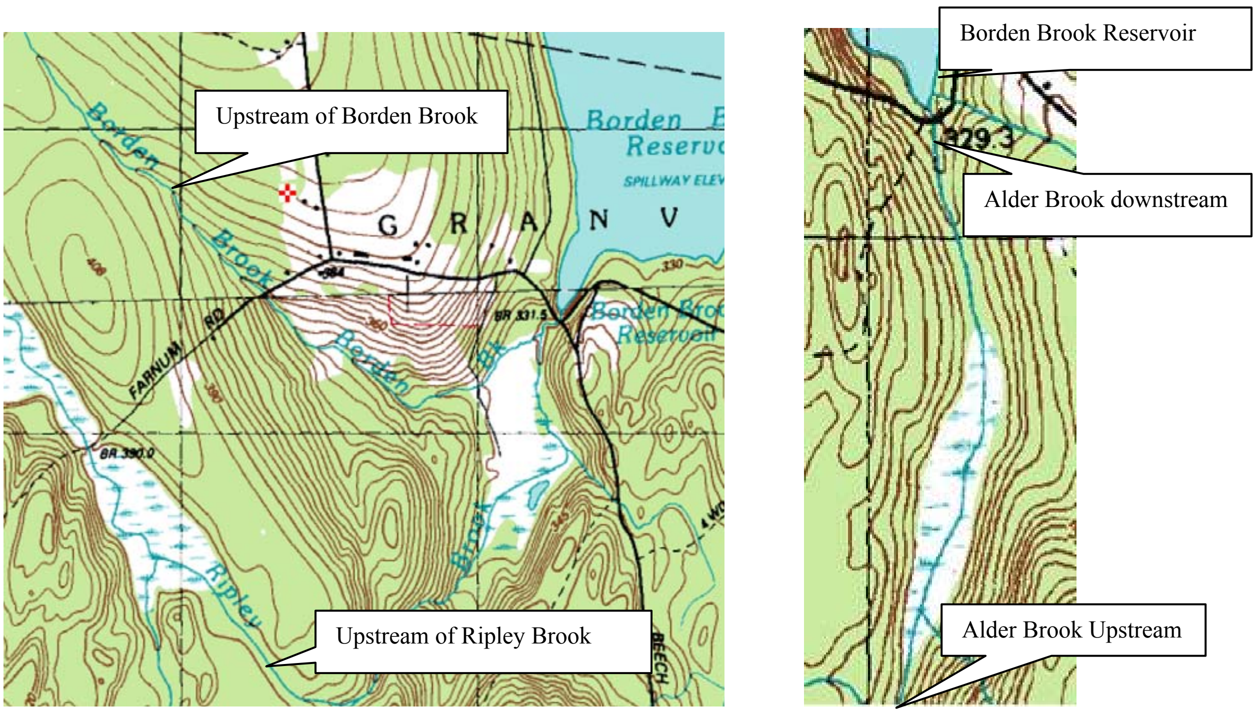


Figure 4.19 Sampling Locations for May 4th, 2005 Event

This sampling event was conducted during spring season in 2005. Discharge, precipitation and temperature data are presented in Figure 4.20. There were light periods of precipitation prior to the sampling date. The last major rain event was 11 days prior to the sampling date, where more than 2 inches of rain fell.

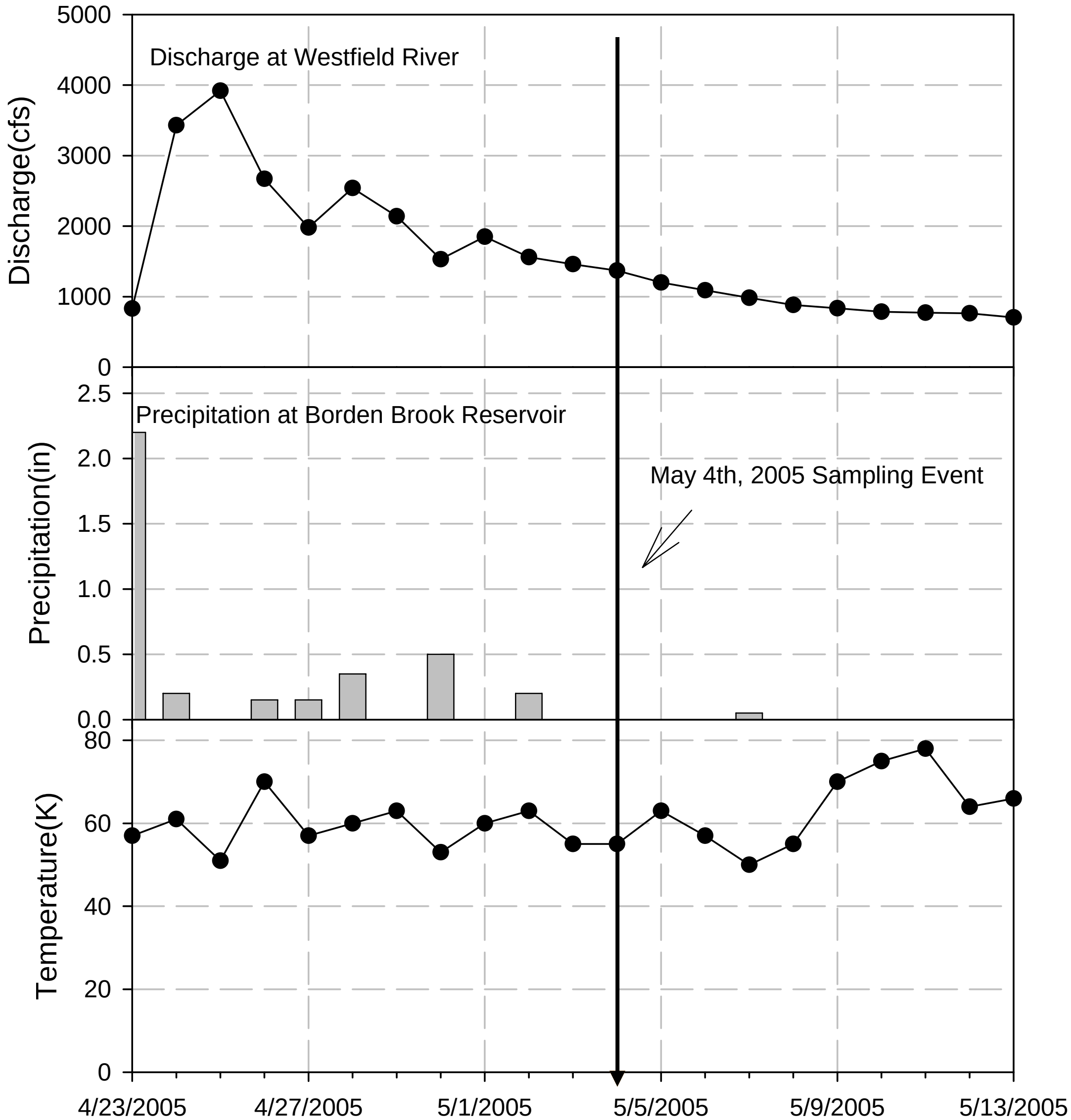


Figure 4.20 Discharge, Precipitation and Temperature data prior to and after May 4th, 2005 Event. (Precipitation: Borden Brook Reservoir; Temperature: Westfield, MA; Discharge: USGS Westfield River Station 01183500)

4.4.1. NOM Levels

Natural organic matter levels for all of the samples were measured using UV-254 and TOC analyses. In addition, SUVA was calculated for each sampling point. The results of these analyses are presented in Table 4.11.

Table 4.11 UV-254, TOC, DOC and SUVA of water samples for May 4th, 2005 Event

Location	TOC	DOC	UV	SUVA
	mg/L	mg/L	cm^{-1}	L/mg-m
Upstream of Alder Brook	2.3	2.6	0.178	7.0
Downstream of Alder Brook	3.2	3.1	0.198	6.5
Upstream of Borden Brook	1.8	1.8	0.133	7.4
Upstream of Ripley Brook	5.9	5.8	0.387	6.6

Total organic carbon levels ranged from 2 to 6 mg/L. Ultraviolet absorbance was in the range of 0.13-0.39 cm^{-1}, with a maximum of 0.387 cm^{-1} measured for Ripley Brook. SUVA for all of the samples were in the high range of 6 to 7L/mg-m.

Figure 4.21 shows TOC and SUVA for all of the sampling locations in this event. In the Borden Brook sub-basin, Ripley Brook had the highest NOM levels and Borden Brook had the lowest NOM levels in terms of TOC and UV-254. Downstream of the beaver impoundment in Alder Brook there was more TOC and higher UV-254 as compared to upstream. SUVA values are quite similar for all the samples.

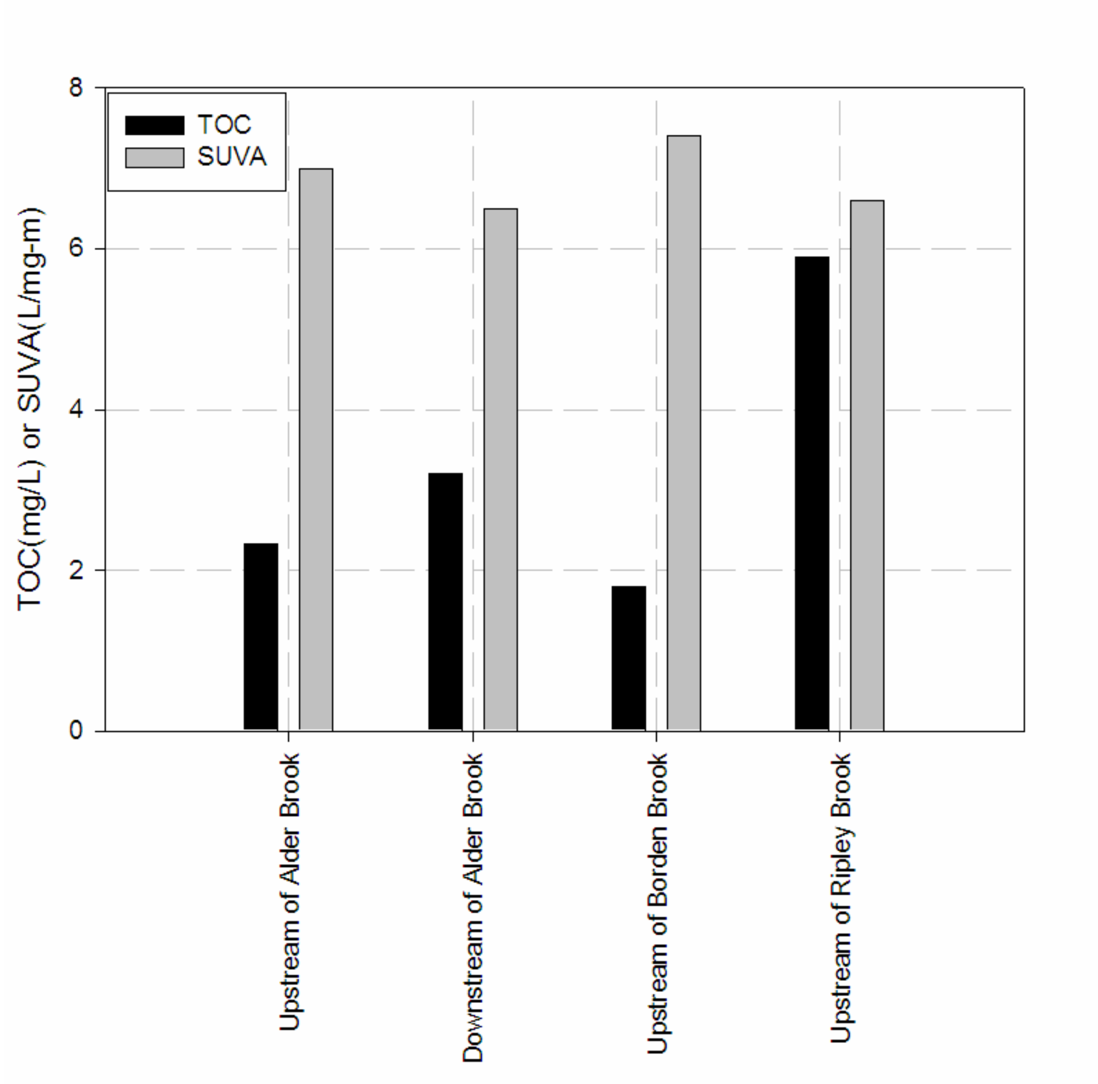


Figure 4.21 TOC and SUVA for May 4th, 2005 Sampling Event

4.4.2. DBP Formation Potential

Disinfection by-product formation potential levels for this event are summarized in Table 4.12 and Figure 4.22. THMFP levels ranged from 123 to 440 μg/L, DHAAFP levels from 50 to 192 μg/L and THAAFP levels from 103 to 515 μg/L. Overall, THMFP and THAAFP levels are much higher than DHAAFP levels for all sampling locations. As a high TOC source, Ripley Brook had high values for DBP formation potential levels. The upstream location on Borden Brook had the lowest DBP production. From the paired study of beaver impoundments, the Alder Brook location showed higher DBP formation potentials downstream than upstream.

Table 4.12 DBP Formation Potential Data (μg/L) for May 4th, 2005 Event

Location	THMFP	DHAAFP	THAAFP
	μg/L	μg/L	μg/L
Upstream of Alder Brook	196	85	170
Downstream of Alder Brook	225	98	203
Upstream of Borden Brook	123	50	103
Upstream of Ripley Brook	440	192	515

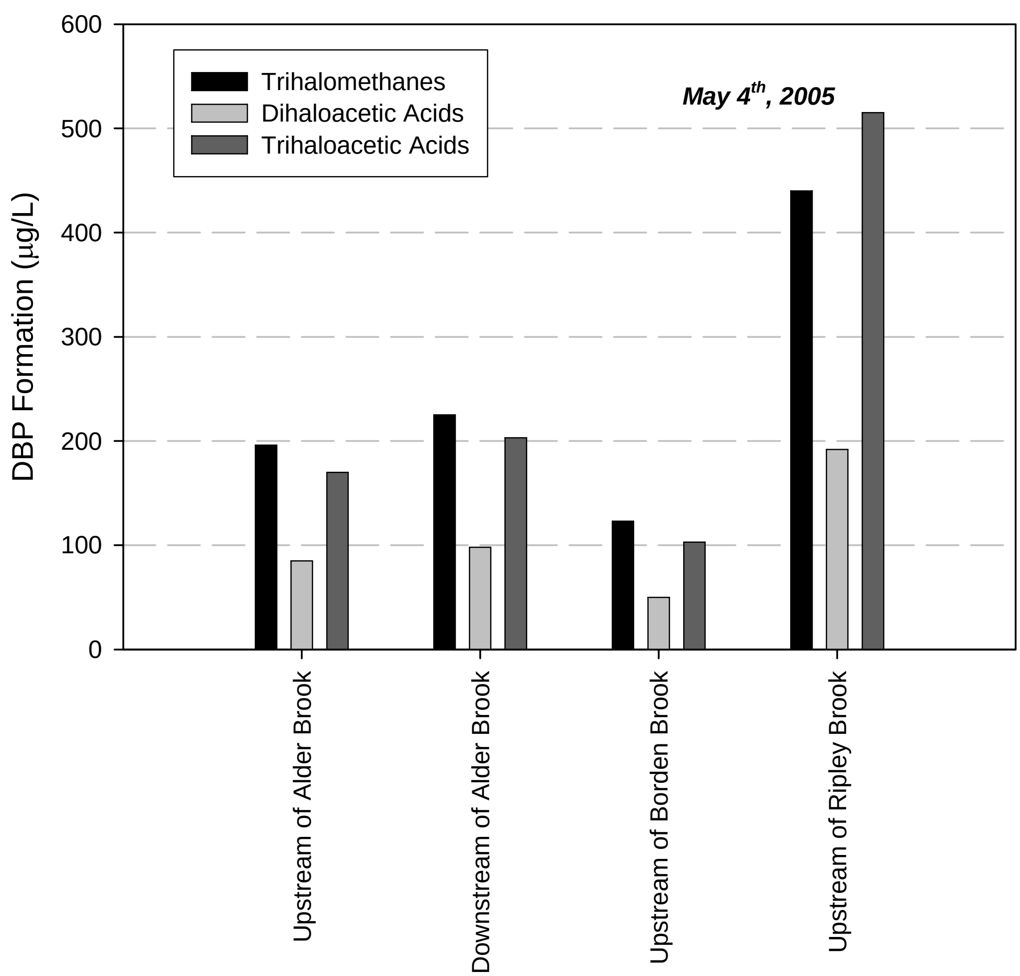


Figure 4.22 DBP Formation Potentials for May 4th, 2005 Sampling Event

4.4.3. Specific DBP Formation Potential

Specific DBP formation potential levels for this event were determined and are presented in Table 4.13 and Figure 4.23. Specific THMFP levels ranged from 65 to 84 μg/mg-TOC. Most of the levels are fairly similar, with the highest value from upstream of Alder Brook and the lowest value from upstream of Borden Brook. Specific DHAAFP values ranged from 28 to 36 μg/mg-TOC, and specific THAAFP levels fell between 63 and 87 μg/mg-TOC. Upstream of Ripley Brook, the high TOC source for this event had the highest specific THAAFP. Upstream of Borden brook, the low TOC source for this event had the lowest specific DBP Formation potential levels. Although downstream of Alder Brook had higher value of TOC, the specific DBP formation potential levels are lower than those of upstream.

Table 4.13 Specific DBP Formation Potential Data (μg/mg-TOC) for May 4th, 2005 Sampling Event

Location	SpTHM	SpDHAA	SpTHAA
	μg/mg-TOC	μg/mg-TOC	μg/mg-TOC
Upstream of Alder Brook	84	36	73
Downstream of Alder Brook	70	31	63
Upstream of Borden Brook	68	28	57
Upstream of Ripley Brook	75	33	87

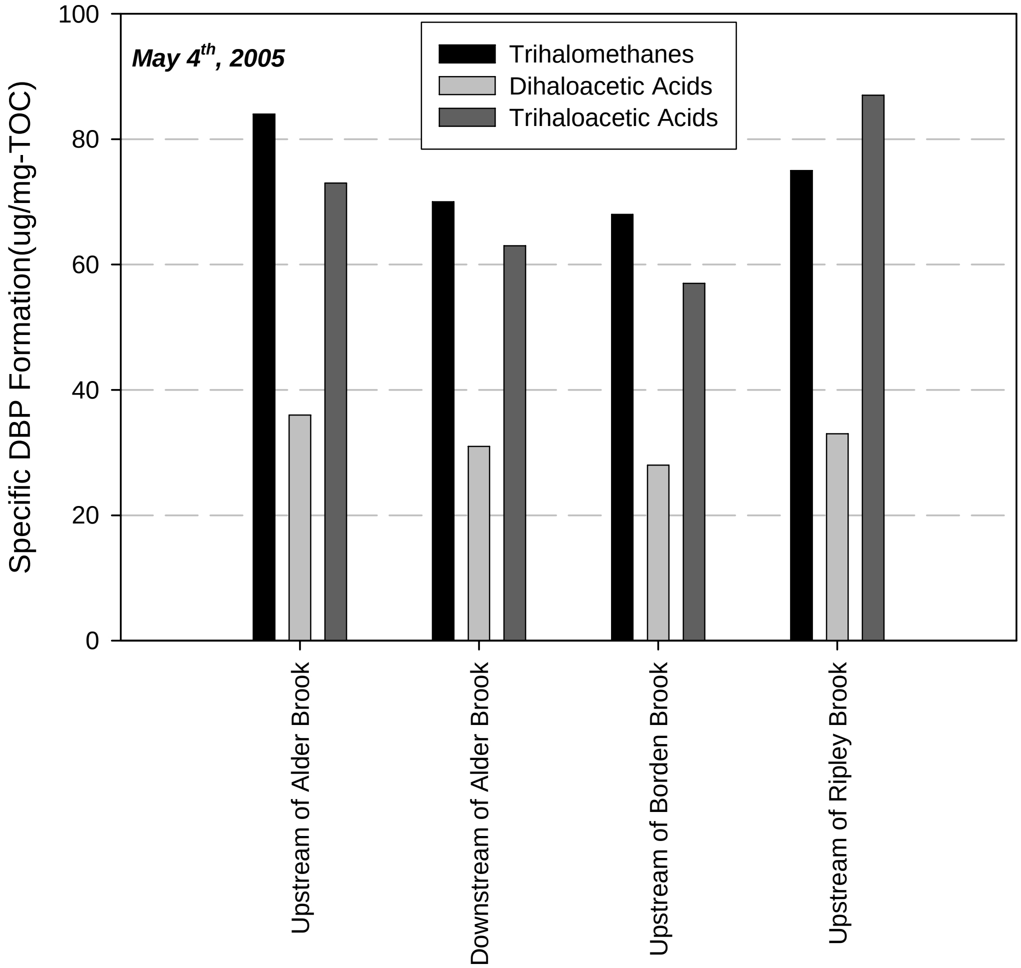


Figure 4.23 Specific DBP Formation Potentials for May 4th, 2005 Sampling Event

4.5. June 7th, 2005

This sampling event focused on Borden Brook Reservoir sub-basin. Samples were taken upstream and downstream of beaver impoundments in Ripley Brook and Alder Brook and one sample was taken at the spillway of Borden Brook Reservoir. In Ripley Brook, the lower part of the beaver impoundment has been mostly drained; however, the upper part is still intact. Sampling locations are shown in Figure 4.24.

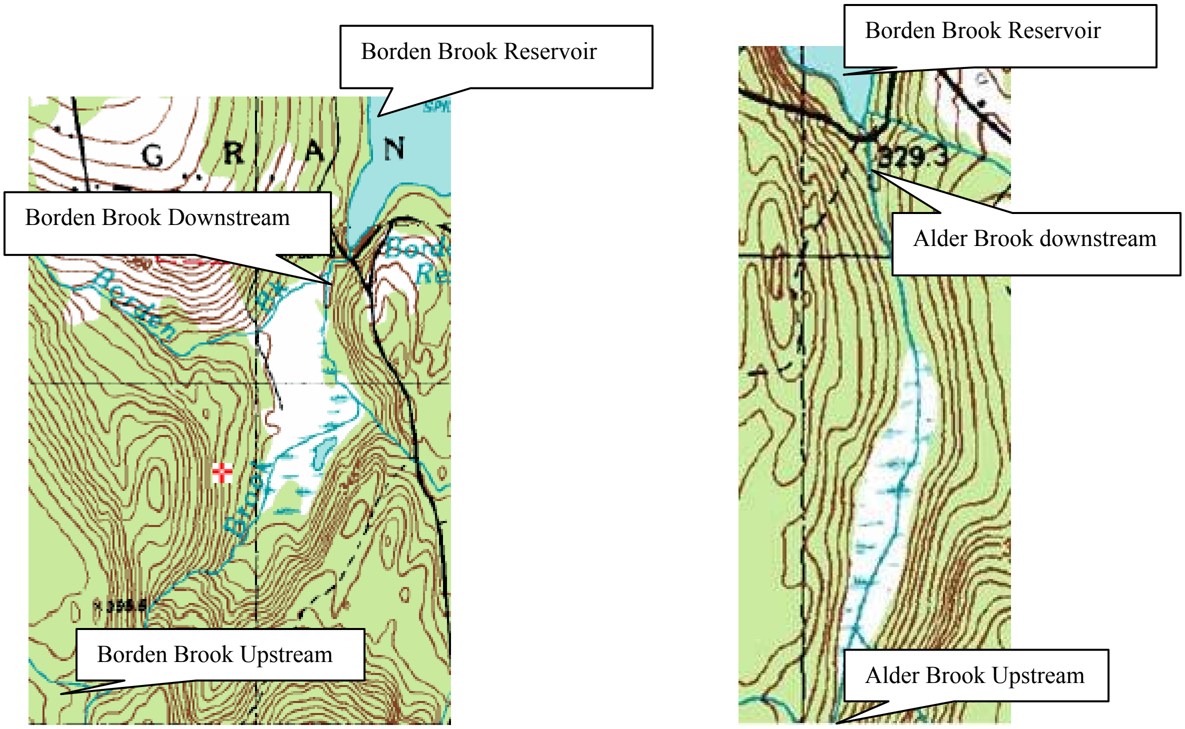


Figure 4.24 Sampling Locations for June 7th, 2005 Sampling Event.

This event was at the end of spring season, characterized by increasing temperature and periods of intense precipitation, as shown in Figure 4.25. There was a slight precipitation of 0.15 inch at the day before the sampling date. However, discharge was not increased significantly and was still in the low range.

4.5.1. NOM Levels

Several important measurements of natural organic matter levels, including UV-254, TOC and DOC were taken for each sample, and are presented in Table 4.14 along with the calculated SUVA. UV-254 values were high for Ripley Brook and low for Borden Brook at the spillway, while comparable for Alder Brook with previous runs.

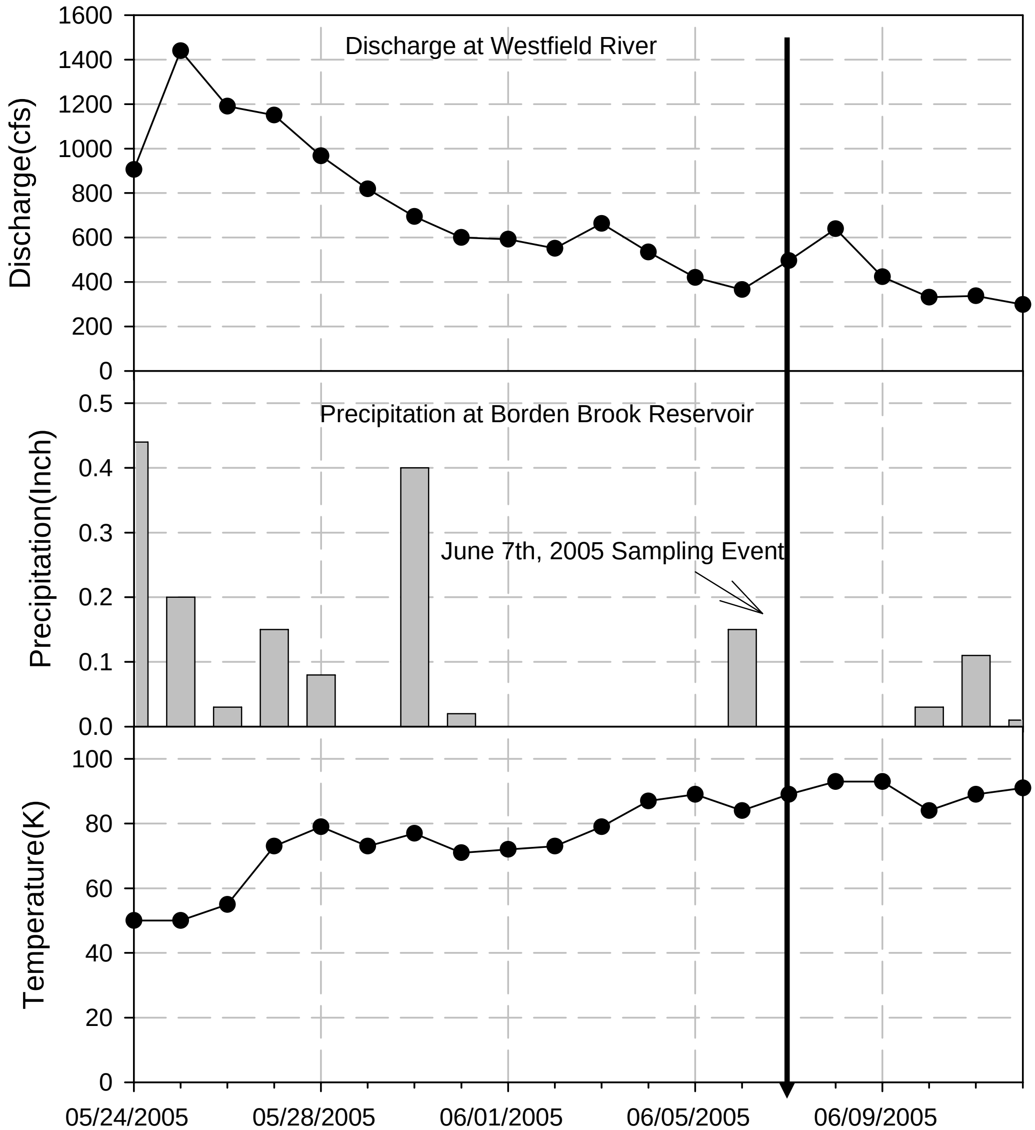


Figure 4.25 Discharge, Precipitation and Temperature data prior to and after June 7th, 2005 Event. (Precipitation: Borden Brook Reservoir; Temperature: Westfield, MA; Discharge: USGS Westfield River Station 01183500)

Table 4.14 UV-254, TOC, DOC and SUVA of water samples for June 7th, 2005 Sampling Event

Location	TOC	DOC	UV	SUVA
	mg/L	mg/L	cm^{-1}	L/mg-m
Upstream of Alder Brook	3.6	3.6	0.177	4.9
Downstream of Alder Brook	5.3	4.4	0.219	5.0
Upstream of Ripley Brook	12.3	11.1	0.623	5.6
Downstream of Ripley Brook	20.9	17.1	0.784	4.5
Borden Brook Reservoir	3.0	3.0	0.066	2.2

Figure 4.26 presents the TOC and SUVA for all of the sampling sites in this sampling event. The figure shows that TOC values are comparable for samples from Alder Brook and Borden Brook Reservoir at the spillway. However, Ripley Brook yielded a very high amount of TOC. The SUVA values were high, in the range of 4.5 to 5.6 L/mg-m with the exception of Borden Brook Reservoir at the spillway, which had a low SUVA value of 2.2 L/mg-m. Locations downstream of beaver impoundments in Alder Brook and Ripley Brook had higher NOM levels in terms of TOC, compared with upstream of beaver impoundments. It was apparent that the Borden Brook Reservoir decreased the levels of NOM based on comparing the amount of TOC entering the Borden Brook Reservoir to the amount of TOC coming out through the spillway.

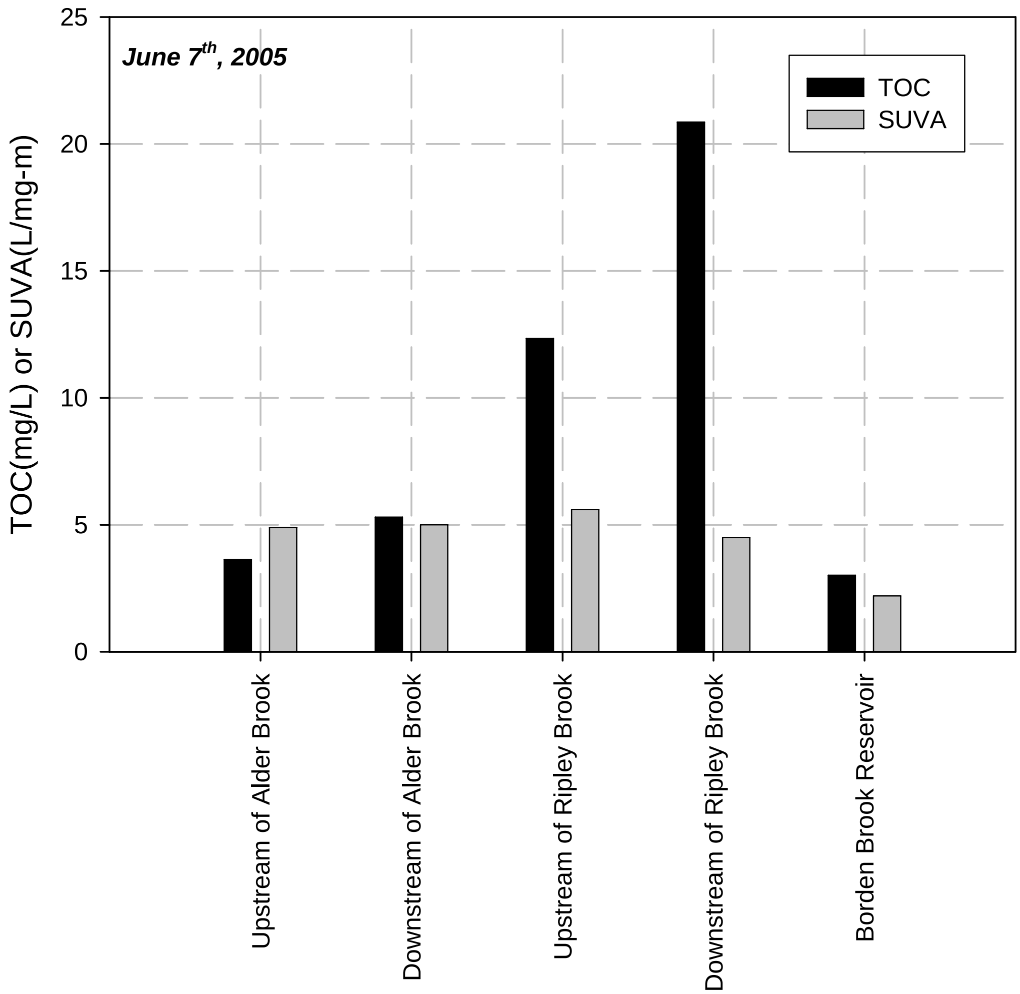


Figure 4.26 TOC and SUVA for June 7th, 2005 Sampling Event

4.5.2. DBP Formation Potential

Disinfection by-product formation potentials were measured for all of the samples collected, and the results of this analysis are summarized in Table 4.15 and presented in Figure 4.27. THMFP levels ranged from 97 and 635 μg/L, DHAAFP levels ranged between 60 and 460 μg/L and THAA levels fell between 100 and 1100 μg/L. Trihaloacetic acid levels are higher than THMFP and DHAAFP for all of the samples. Ripley Brook had the highest DBPFP levels. Borden Brook Reservoir at the spillway yielded the lowest DBPFP and had formation potential levels below 110 µg/L for all three parameters. Samples collected downstream of beaver impoundments had significantly higher DBP formation potentials than upstream.

Table 4.15 DBP Formation Potential Data (µg/L) for June 7th, 2005 Sampling Event

Location	THMFP	DHAAFP	THAAFP
	µg/L	µg/L	µg/L
Upstream of Alder Brook	215	121	249
Downstream of Alder Brook	289	150	308
Upstream of Ripley Brook	621	304	811
Downstream of Ripley Brook	635	461	1117
Borden Brook Reservoir	97	62	108

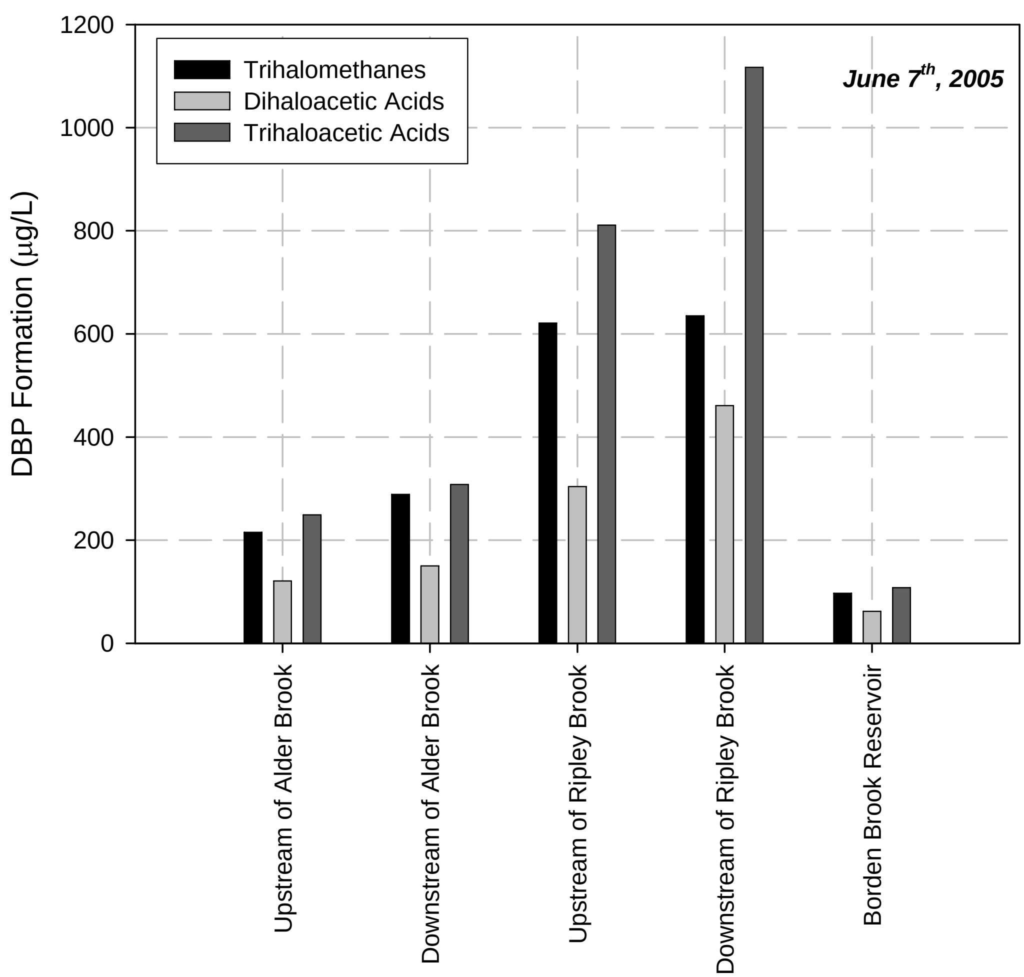


Figure 4.27 DBP Formation Potentials for Jun 7th, 2005 sampling Event

4.5.3. Specific DBP Formation Potential

Specific DBP formation potential levels for this event were determined and are presented in Table 4.16 and Figure 4.28. All of these three DBP formation potential levels are fairly uniform, with specific THMFP values ranging from 30 to 60 μg/mg-TOC; specific DHAAFP values falling between 20 and 30 μg/mg-TOC and specific THAAFP levels in the range of 36-69 μg/mg-TOC. The sample from Borden Brook Reservoir at the spillway yielded a low specific THMFP and high specific THAAFP. Downstream of the beaver ponds on Ripley Brook was water with a low value for all of these three parameters. Highest specific DBPFP values were found in the upstream location on Alder Brook.

Table 4.16 Specific DBP Formation Potential Data (μg/mg-TOC) for June 7th, 2005 Sampling Event

Location	SpTHM	SpDHAA	SpTHAA
	μg/mg-TOC	μg/mg-TOC	μg/mg-TOC
Upstream of Alder Brook	59	33	69
Downstream of Alder Brook	55	28	58
Upstream of Ripley Brook	50	22	54
Downstream of Ripley Brook	30	20	36
Borden Brook Reservoir	32	25	66

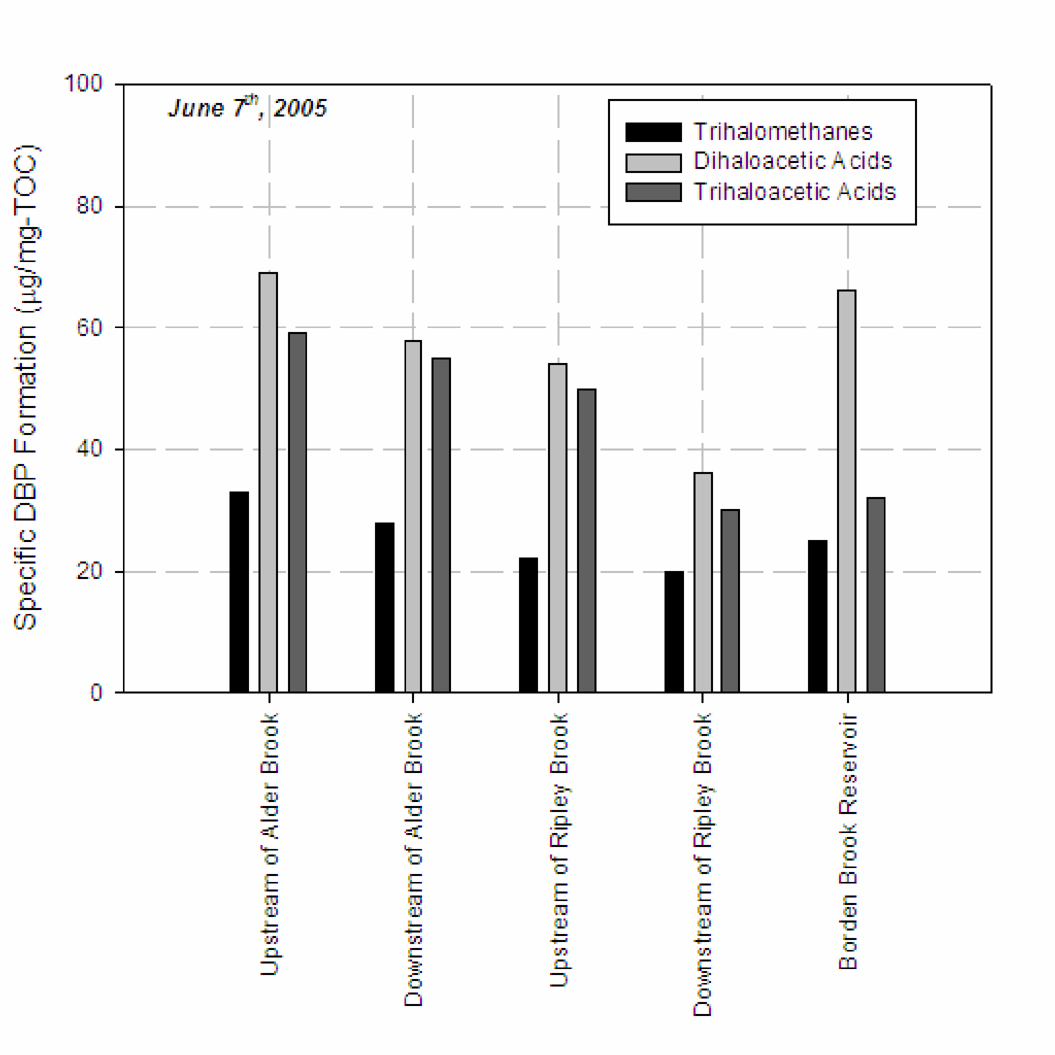


Figure 4.28 Specific DBP Formation Potentials for Jun 7th, 2005 Sampling Event

4.6. June 28th, 2005

This sampling event was conducted during a slight amount of precipitation. This sampling event focused on Borden Brook Reservoir sub-basin. Samples were taken upstream and downstream of beaver impoundments in Ripley Brook and Alder Brook and one sample was taken at the spillway of Borden Brook Reservoir. Sampling locations are the same for the June 7th, 2005 event and were presented in Figure 4.24. This sampling date preceded by five days of dry and high temperature weather, as shown in Figure 4.29. Compared with historical record for this station, discharge at the sampling date was fairly low after a period of slight precipitation a week prior to the date.

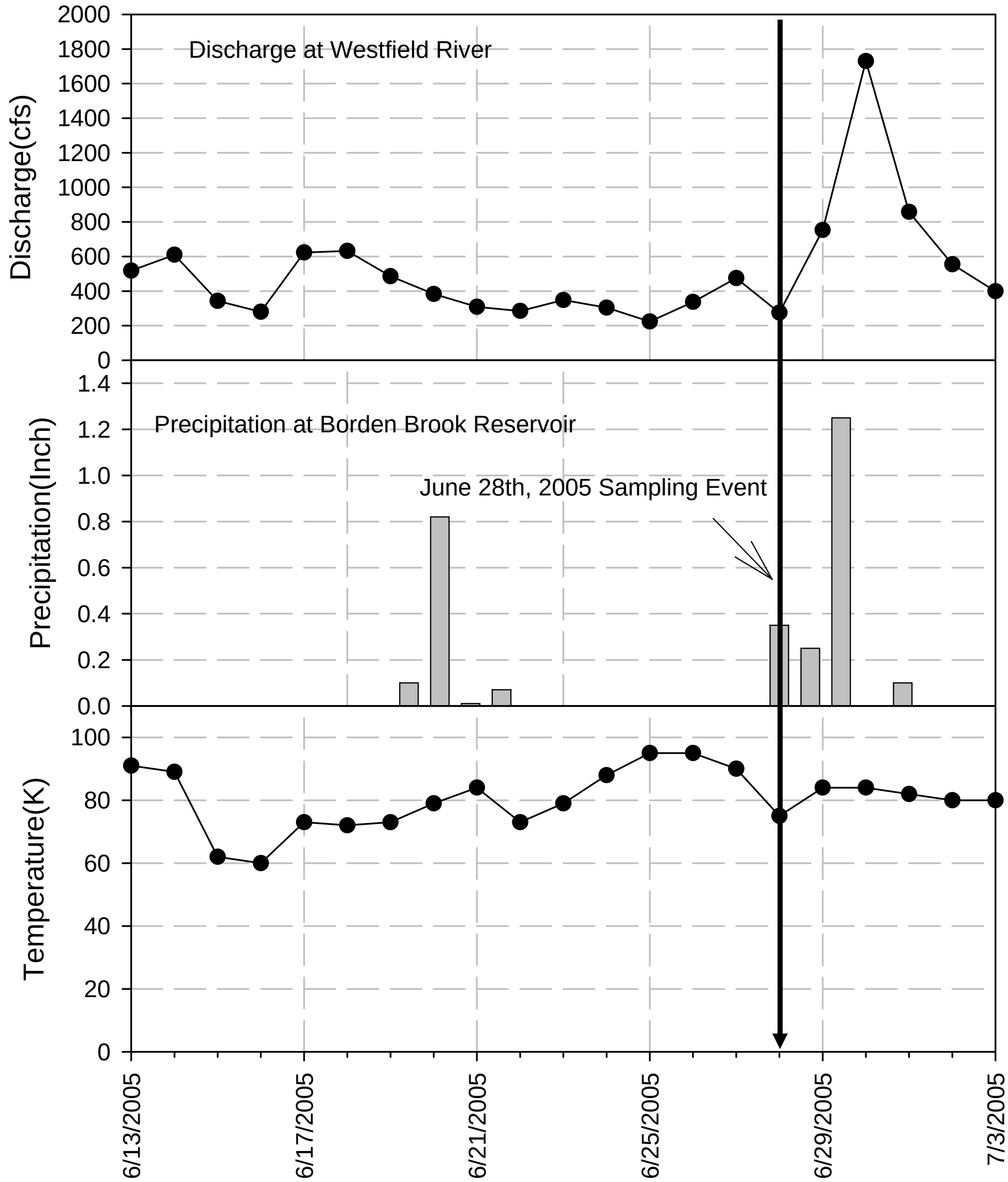


Figure 4.29 Discharge, Precipitation and Temperature data prior to and after June 28th, 2005 event. (Precipitation: Borden Brook Reservoir; Temperature: Westfield, MA; Discharge: USGS Westfield River Station 01183500)

4.6.1. NOM Levels

Several important measurements of natural organic matter levels, including UV-254, TOC and DOC were taken for each sample, and are presented in Table 4.17 along with SUVA, a calculated value. TOC values were in the range of 2.5 to 11.5 mg/L. UV-254 ranged from 0.036-0.616cm^{-1}. Specific ultraviolet absorbance values fell between 1.5-5.7 L/mg-m.

Table 4.17 UV-254, TOC, DOC and SUVA for June 28th, 2005 Sampling Event

Location	TOC	DOC	UV	SUVA
	mg/L	mg/L	cm^{-1}	L/mg-m
Upstream of Alder Brook	5.1	4.8	0.141	2.9
Downstream of Alder Brook	8.0	7.3	0.287	4.0
Upstream of Ripley Brook	10.9	10.7	0.616	5.7
Downstream of Ripley Brook	11.5	10.9	0.575	5.3
Borden Brook Reservoir	2.5	2.4	0.036	1.5

Figure 4.30 shows TOC and SUVA for all of the sampling locations. The sample from Borden Brook Reservoir at the spillway had the lowest TOC and SUVA values and Ripley Brook either upstream or downstream of the beaver impoundments had particularly high values for TOC and SUVA. The differences of water quality upstream and downstream of the beaver impoundments in Ripley Brook are not significant; however, downstream of the beaver impoundments in Alder Brook had higher natural organic matters in terms of TOC and the SUVA values were higher downstream of Alder Brook.

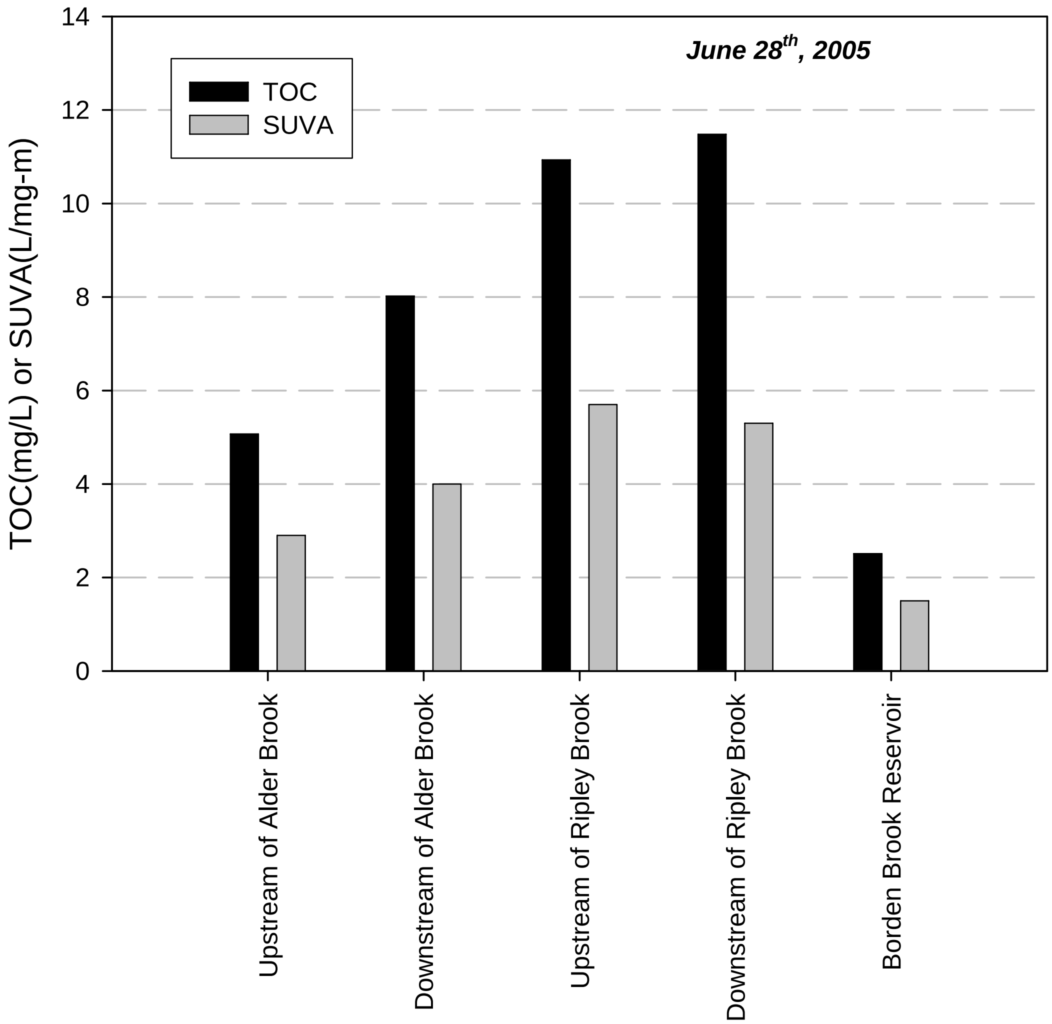


Figure 4.30 TOC and SUVA for June 28th, 2005 Sampling Event

4.6.2. DBP Formation Potential

Disinfection by-product formation potentials were measured for all of the samples collected, and the results are summarized in Table 4.18 and Figure 4.31. THMFP levels ranged from 198 to 842 μg/L, DHAAFP levels from 105 to 323 μg/L and THAAFP levels from 186 to 787 μg/L. DBP levels were extremely high for Ripley Brook regardless of sampling locations and Borden Brook Reservoir had low DBP levels. Downstream of Alder Brook and Ripley Brook apparently had higher DBP levels than upstream.

Table 4.18 DBP Formation Potential Data (μg/L) for June 28th, 2005 Sampling Event

Location	THMFP	DHAAFP	THAAFP
	μg/L	μg/L	μg/L
Upstream of Alder Brook	380	162	282
Downstream of Alder Brook	597	284	556
Upstream of Ripley Brook	750	222	658
Downstream of Ripley Brook	842	323	787
Borden Brook Reservoir	198	105	186

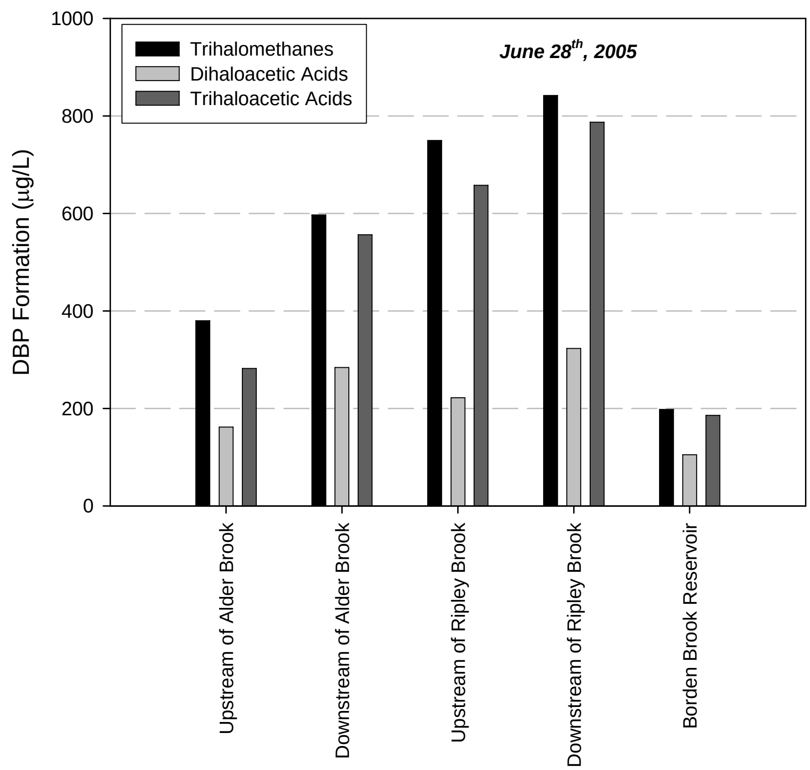


Figure 4.31 DBP Formation Potentials for Jun 28th, 2005 Sampling Event

4.6.3. Specific DBP Formation Potential

The calculated specific DBP formation potential values were listed in Table 4.19 and presented in Figure 4.32. Specific THMFP was in the range of 52-79 µg/mg-TOC. Specific DHAAFP fell between 20 and 42 µg/mg-TOC. Specific THAAFP was fairly uniform, with the values ranging from 60 to 74 µg/mg-TOC. Borden Brook Reservoir had the lowest specific DBP formation potentials. Downstream of beaver impoundments in Alder Brook had lower specific DBP formation potential than upstream in this event. However, downstream of Ripley Brook had higher specific DBP formation potential than upstream location.

Table 4.19 Specific DBP Formation Potential Data (µg/mg-TOC**) for June 28th, 2005 Sampling Event**

Location	SpTHM	SpDHAA	SpTHAA
	µg/mg-TOC	µg/mg-TOC	µg/mg-TOC
Upstream of Alder Brook	75	32	56
Downstream of Alder Brook	52	35	69
Upstream of Ripley Brook	69	20	60
Downstream of Ripley Brook	73	28	69
Borden Brook Reservoir	79	42	74

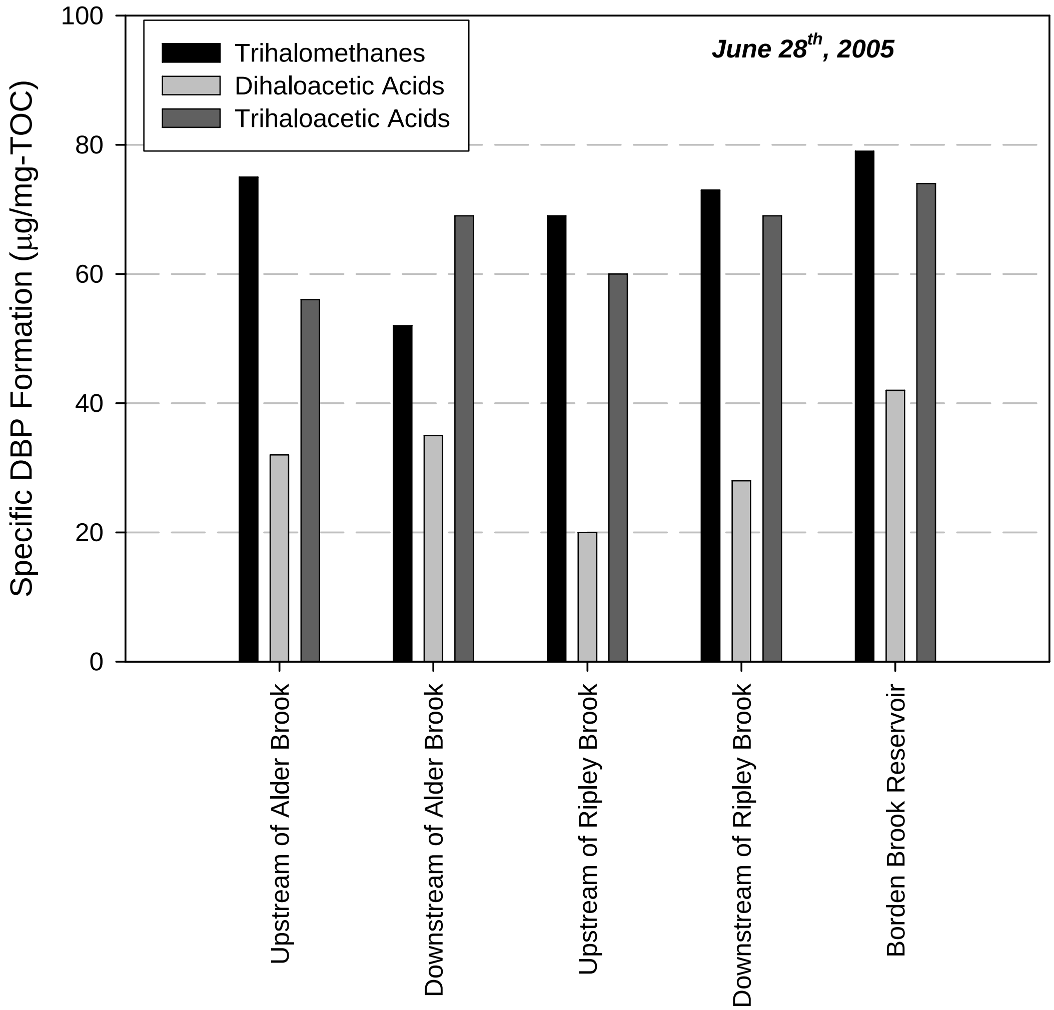


Figure 4.32 Specific DBP Formation Potentials for Jun 28th, 2005 Sampling Event

4.7. July 20th, 2005

Instead of continuing monitoring streams in the Borden Brook Reservoir sub-basin, samples were taken from the tributaries of Cobble Mountain Reservoir, where there were beaver activities and beaver ponds for this sampling event. A paired study was still adopted to monitor the effect of beavers. Peebles Brook and Middle Brook were selected.

As mentioned previously, Peebles Brook has a series of mature beaver ponds, and a pond above a mature beaver dam, which is nearly silted in and will become a meadow when the beavers leave. Based on a map of this site and onsite observations, part of this area has already been converted to beaver meadows. The upstream of Peebles Brook sample was collected at where the stream comes out from the headwater and as shown in Figure 4. 33. Sampling location for downstream of Peebles Brook was shown in Figure 4.1. Middle Brook had intensive beaver activities around the sampling date and the watershed was comprised of several shallow beaver impoundments which haven’t converted to beaver ponds and the sampling locations are shown in Figure 4.33.

This sampling date was during hot summer and there was a 0.20 inch rainfall one day before the sampling date. As shown in Figure 4.34, discharge was around 500 cfs at the sampling day, which is fairly low for the Westfield River.

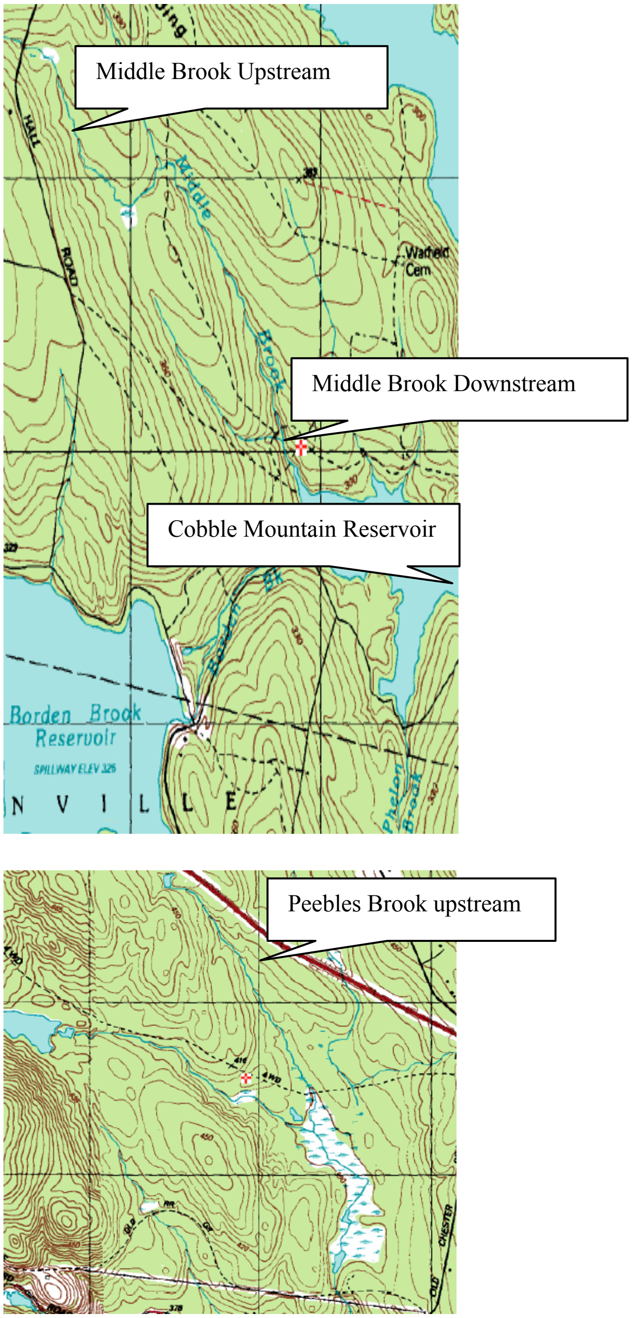


Figure 4.33 Sampling locations for July 20th, 2005 Sampling Event

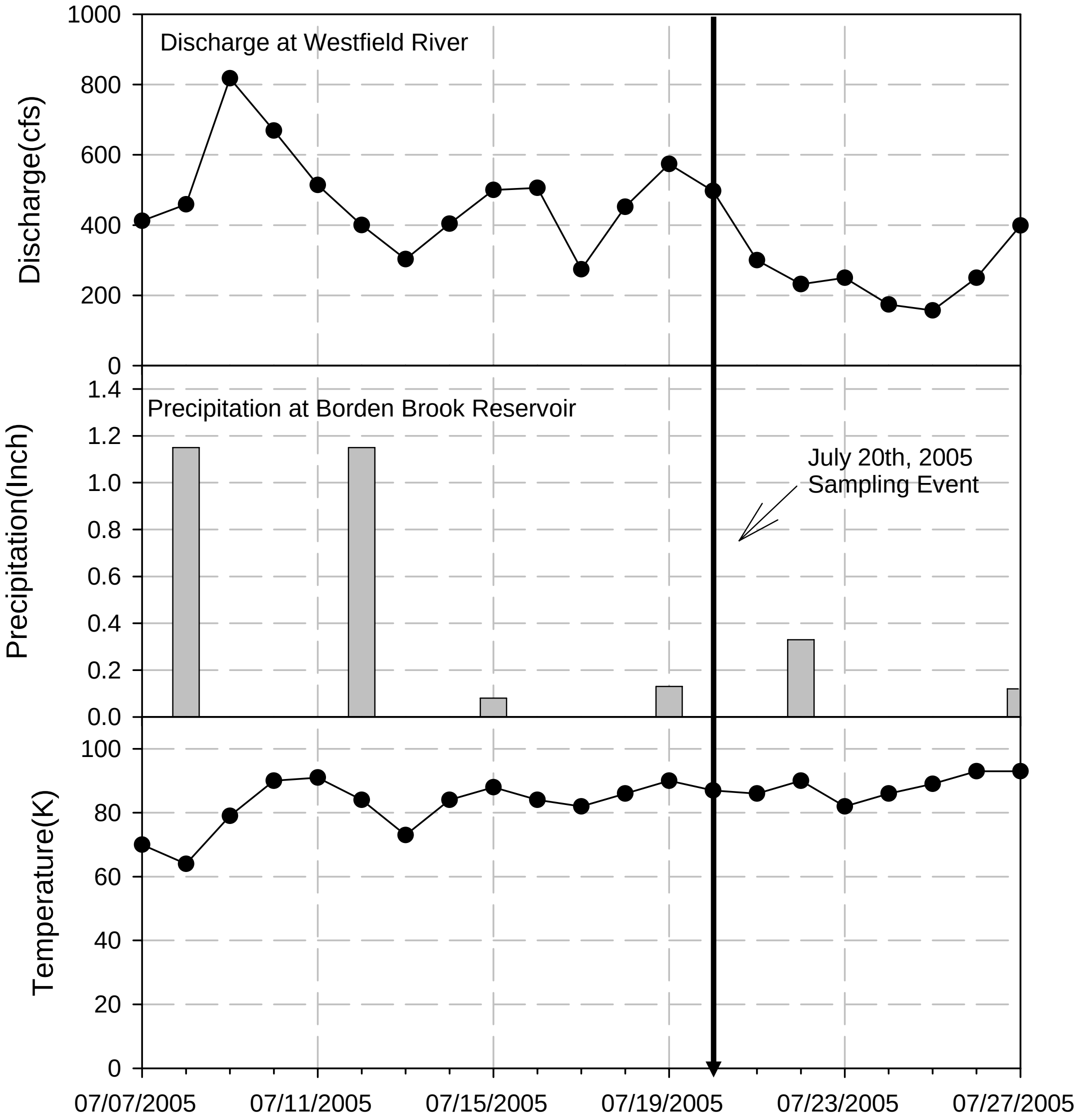


Figure 4.34 Discharge, Precipitation and Temperature data prior to and after July 20th, 2005 Event. (Precipitation: Borden Brook Reservoir; Temperature: Westfield, MA; Discharge: USGS Westfield River Station 01183500)

4.7.1. NOM Levels

Total organic carbon, DOC and UV-254 values were measured for each sample. The results along with SUVA values for each sample were listed in Table 4.20.

Table 4.20 UV-254, TOC, DOC and SUVA of water samples for July 20th, 2005 Sampling Event

Location	TOC	DOC	UV	SUVA
	mg/L	mg/L	cm^{-1}	L/mg-m
Upstream of Peebles Brook	2.2	2.2	0.070	3.2
Downstream of Peebles Brook	7.1	6.6	0.325	5.0
Upstream of Middle Brook	4.8	4.4	0.218	4.9
Downstream of Middle Brook	2.5	2.4	0.096	4.0

As shown in Table 4.20, TOC values were in the range of 2 to 7mg/L; UV-254 ranged from 0.070-0.325 L/mg-m. The calculated SUVA values fell in the range of 3-5 L/mg-m. Figure 4.35 shows TOC and SUVA for each sample in this sampling event. The sample from Peebles downstream had the highest TOC and SUVA values. Downstream of Peebles Brook had a much higher NOM level in terms of TOC than downstream of Peebles Brook and it also had higher SUVA value. For Middle Brook, the sample from downstream of beaver impoundments had a lower TOC value, which may indicate that the series of beaver impoundments in Middle Brook help improve the water quality.

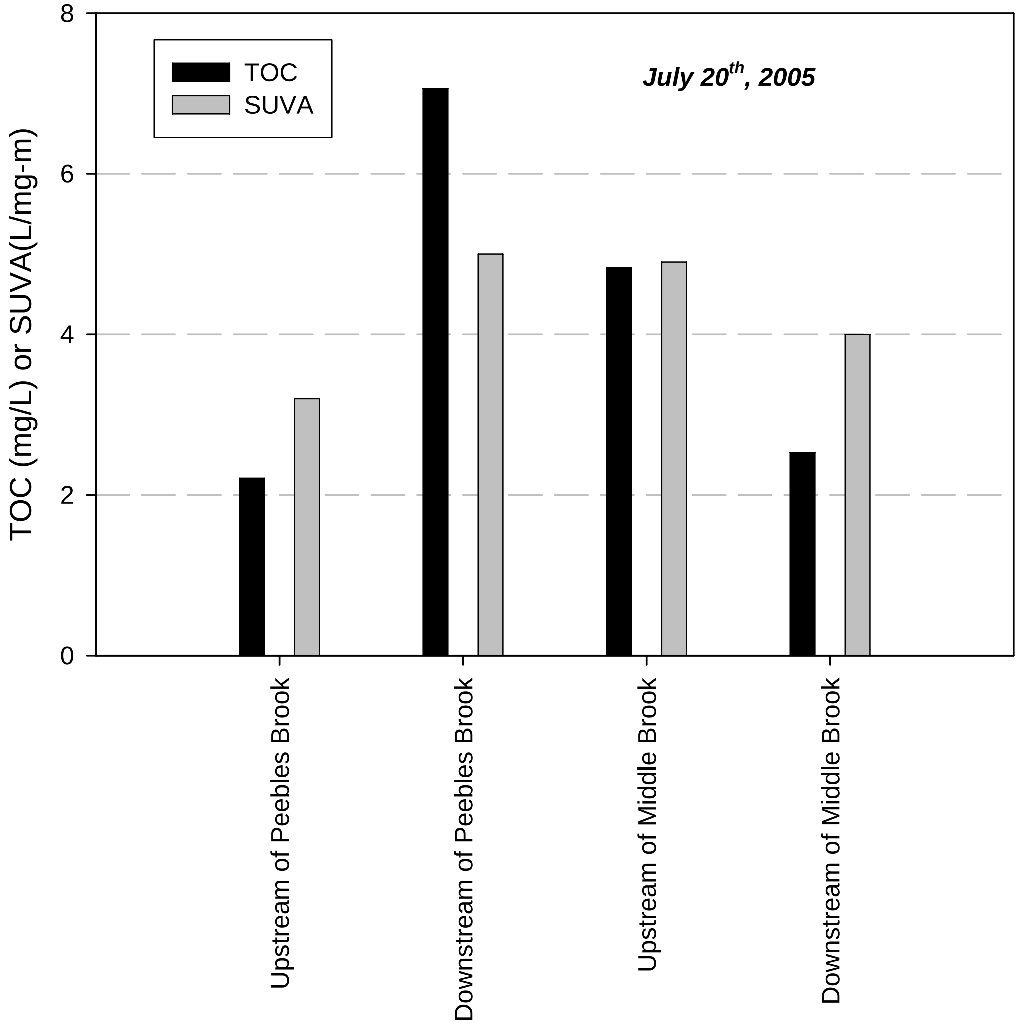


Figure 4.35 TOC and SUVA for July 20th, 2005 Sampling Event

4.7.2. DBP Formation Potential

Disinfection byproducts formation potential tests were conducted for all of the samples and the results were shown in Table 4.21 and presented in Figure 4.36.

Table 4.21 DBP Formation Potential Data (μg/L) for July 20th, 2005 Sampling Event

Location	THMFP	DHAAFP	THAAFP
	μg/L	μg/L	μg/L
Upstream of Peebles Brook	110	96	86
Downstream of Peebles Brook	444	249	517
Upstream of Middle Brook	267	164	262
Downstream of Middle Brook	129	108	109

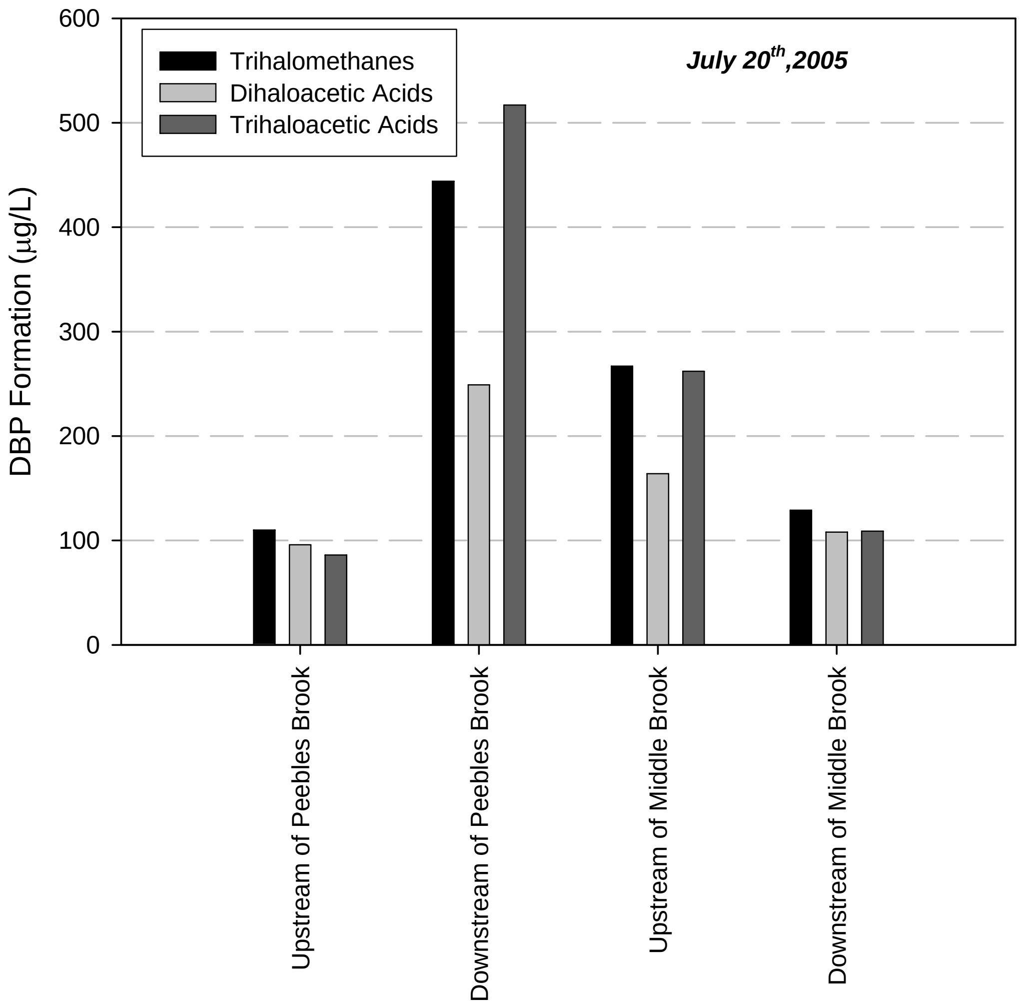


Figure 4.36 DBP Formation Potentials for July 20th, 2005 Sampling Event

Trihalomethane levels ranged from 110 to 444 μg/L, DHAAFP levels were in the range of 96-249 μg/L and THAAFP levels from 86 to 517 μg/L. Disinfection byproduct levels were particularly high for downstream of Peebles Brook and upstream of Middle Brook.

4.7.3. Specific DBP Formation Potential

Specific DBP formation potentials were calculated for each of the locations and the results are tabulated in Table 4.22 and presented in Figure 4.37. Specific THM and DHAA formation potential levels were fairly uniform, with specific THMFP values ranging from 50 to 63 μg/mg-TOC and specific DHAAFP values falling between 30 and 50 μg/mg-TOC. Variability was seen for specific THAA values, with values ranging from 40 to greater than 70 μg/ -mg TOC. Downstream of the beaver ponds at Peebles Brook had the highest specific THAA, with a value of 73 μg/mg-TOC. Overall, the difference between upstream of beaver impoundments either in Alder Brook or Peebles Brook were not significant except the higher specific THAA values were seen downstream of the beaver ponds at Peebles Brook.

Table 4.22 Specific DBP Formation Potential Data (μg/mg-TOC) for July 20th, 2005 Sampling Event

Location	SpTHM	SpDHAA	SpTHAA
	μg/mg-TOC	μg/mg-TOC	μg/mg-TOC
Upstream of Peebles Brook	50	43	39
Downstream of Peebles Brook	63	35	73
Upstream of Middle Brook	55	34	54
Downstream of Middle Brook	51	43	43

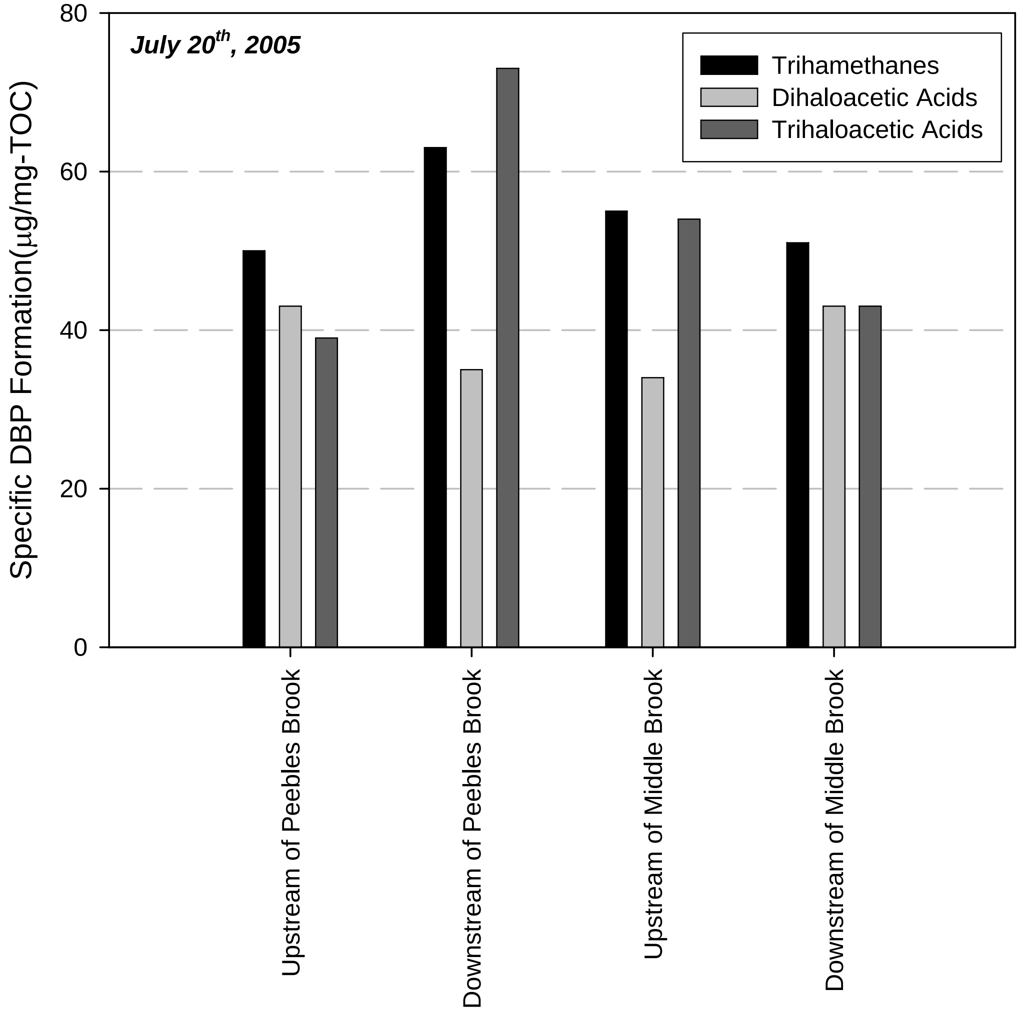


Figure 4.37 Specific DBP Formation Potentials for July 20th, 2005 Sampling Event

4.8. October 14th, 2005

Since the end of July, due to the high temperature and evaportranspiration, many of the flow of tributaries became extremely low and large portions of beaver impoundments became dry. For example, Middle Brook had no apparent flow. The volume of Cobble Mountain Reservoir was down to 58% of capacity. No sample was taken during this period. There had been almost a whole week of rainfall since October 8th, which finally provided enough flow for the streams. The Cobble Mountain Reservoir jumped to 76% of its capacity. Samples were taken upstream and downstream of beaver impoundments in Middle Brook and Alder Brook as well as downstream sampling locations of Ripley Brook, Borden Brook, Bedlam Brook and Birch Meadow Brook.

This sampling event was during the middle of the fall and the temperatures were decreasing. This sampling date was preceded by a week of precipitation and there was a heavy rainfall which was above 6 inches six days before the sampling date. Samples for this event were collected in the midst of a rain storm that was characterized by more than 1 inch of rainfall. Therefore, the discharge before and at the sampling date was extremely high, at around 5000 cfs, and it presented high flow conditions for this sampling event. Precipitation, discharge and temperature data were shown in Figure 4.38.

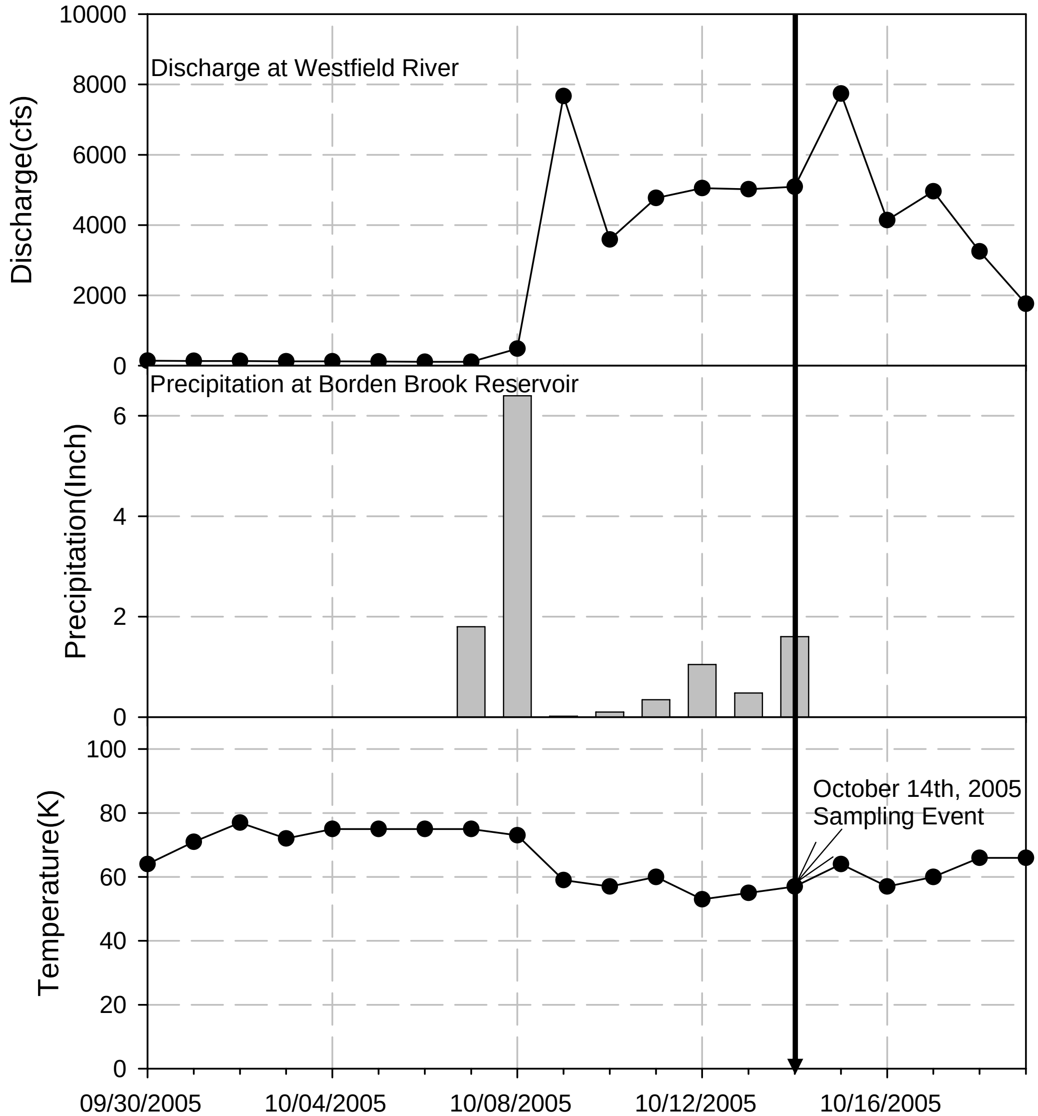


Figure 4.38 Discharge, Precipitation and Temperature data prior to and after October 14th, 2005 Event. (Precipitation: Borden Brook Reservoir; Temperature: Westfield, MA; Discharge: USGS Westfield River Station 01183500)

4.8.1. NOM Levels

Total organic carbon, DOC and UV-254 were measured for each sample collected, and the results were tabulated with SUVA values in Table 4.23.

Table 4.23 UV-254, TOC, DOC and SUVA of water samples for October 14th, 2005 Sampling Event

Location	TOC	DOC	UV	SUVA
	mg/L	mg/L	cm^{-1}	L/mg-m
Borden Brook	4.38	4.42	0.138	3.2
Ripley Brook	11.42	11.44	0.492	4.3
Upstream of Alder Brook	6.37	6.30	0.228	3.6
Downstream of Alder Brook	7.86	7.64	0.262	3.4
Birch Meadow Brook	9.13	9.04	0.379	4.3
Bedlam Brook	4.98	5.08	0.174	3.3
Upstream of Middle Brook	4.52	4.70	0.141	3.0
Downstream of Middle Brook	4.91	5.08	0.172	3.4

Total organic carbon and DOC results ranged from 4 to 11mg/L. Ultraviolet absorbance ranged from 0.140 to 0.50 cm^{-1}. Specific ultraviolet absorbances ranged from 3.0-4.0 L/mg-m. Birch Meadow and Ripley Brook had high NOM levels in terms of TOC, DOC and UV absorbance. In general, samples from Cobble Mountain Reservoir watershed had low TOC and UV-254 values with exception of Birch Meadow Brook, which had very high values for TOC and UV-254. Borden Brook Reservoir sub-basin had high content of organic carbon with exception of Borden Brook, which tended to have low values in TOC and UV-254.

Figure 4.39 shows TOC and SUVA for all of the sampling locations. As mentioned previously, Ripley Brook had a very high TOC approaching almost 12 mg/L. Alder Brook and Birch Meadow Brook all also had high TOC of almost 6 mg/L or greater. Borden Brook, Bedlam Brook and Middle Brook had low TOC levels in this event. Specific ultraviolet absorbance values were rather uniform for all of the samples. There was a very good correlation (r^2=0.82) between TOC and SUVA, as shown in Figure 4.40, which indicated that as TOC increased, SUVA increased as well.

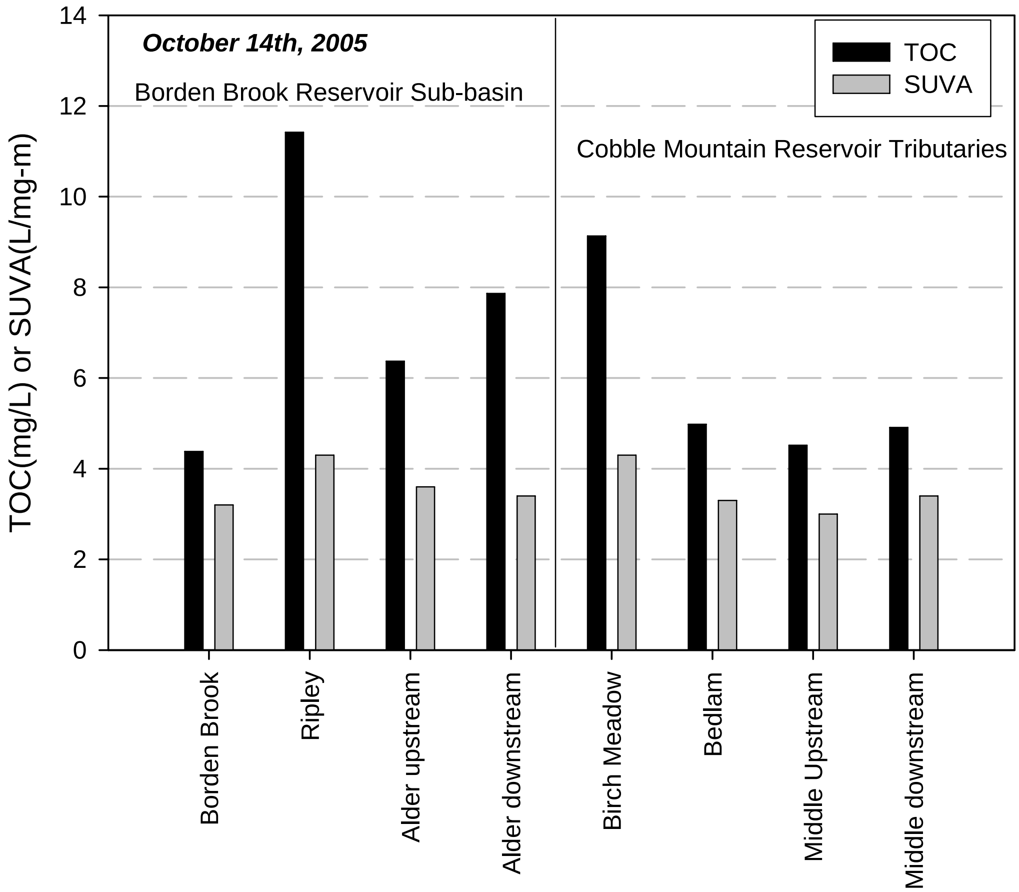


Figure 4.39 TOC and SUVA for October 14th, 2005 Sampling Event

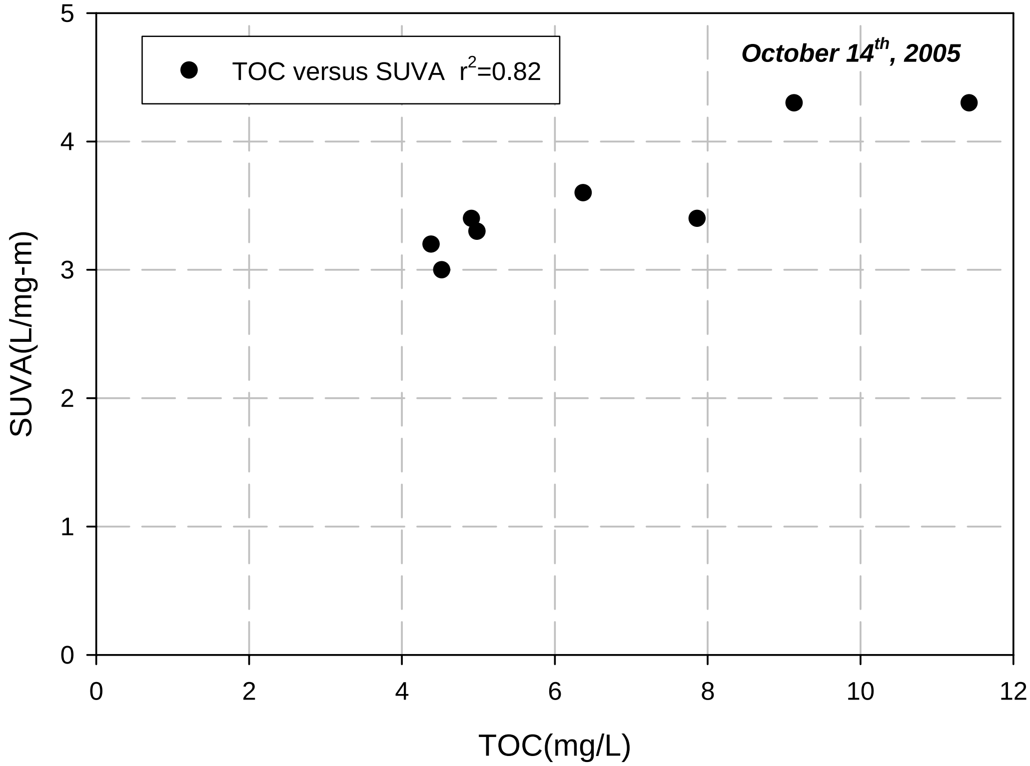


Figure 4.40 Correlation between TOC and SUVA for October 14th, 2005 Sampling Event

4.8.2. DBP Formation Potential

Disinfection byproducts formation potential analysis results for each sample are summarized in Table 4.24 and Figure 4.41. Trihalomethane formation potentials ranged from 110-620 μg/L; DHAAFP levels fell between 110-290 μg/L and THAAFP levels ranged from 200-750 μg/L. Figure 4.41 shows that of the tributaries, Middle Brook had very low THMFP levels. Birch Meadow Brook had very high THM, DHAA, and THAA formation potential levels. Of the Borden Brook Reservoir sub-basin samples, Ripley

Brook had high DBPFP levels. Alder Brook had low THMFP levels and high THAA levels while Borden Brook had very low DHAAFP level. Downstream of the breached beaver dam in Alder Brook had slightly higher DBP levels than upstream. No difference for THMFP levels upstream and downstream of beaver impoundment location for Middle Brook, however, higher DHAA and THAA formation potential levels were seen at the downstream location.

Table 4.24 DBP Formation Potential Data (μg/L) for October 14th, 2005 Sampling Event

Location	THMFP	DHAAFP	THAAFP
	μg/L	μg/L	μg/L
Borden Brook	208	115	226
Ripley Brook	619	288	746
Upstream of Alder Brook	154	167	432
Downstream of Alder Brook	186	192	486
Birch Meadow Brook	481	242	615
Bedlam Brook	284	127	259
Upstream of Middle Brook	117	124	203
Downstream of Middle Brook	119	152	259

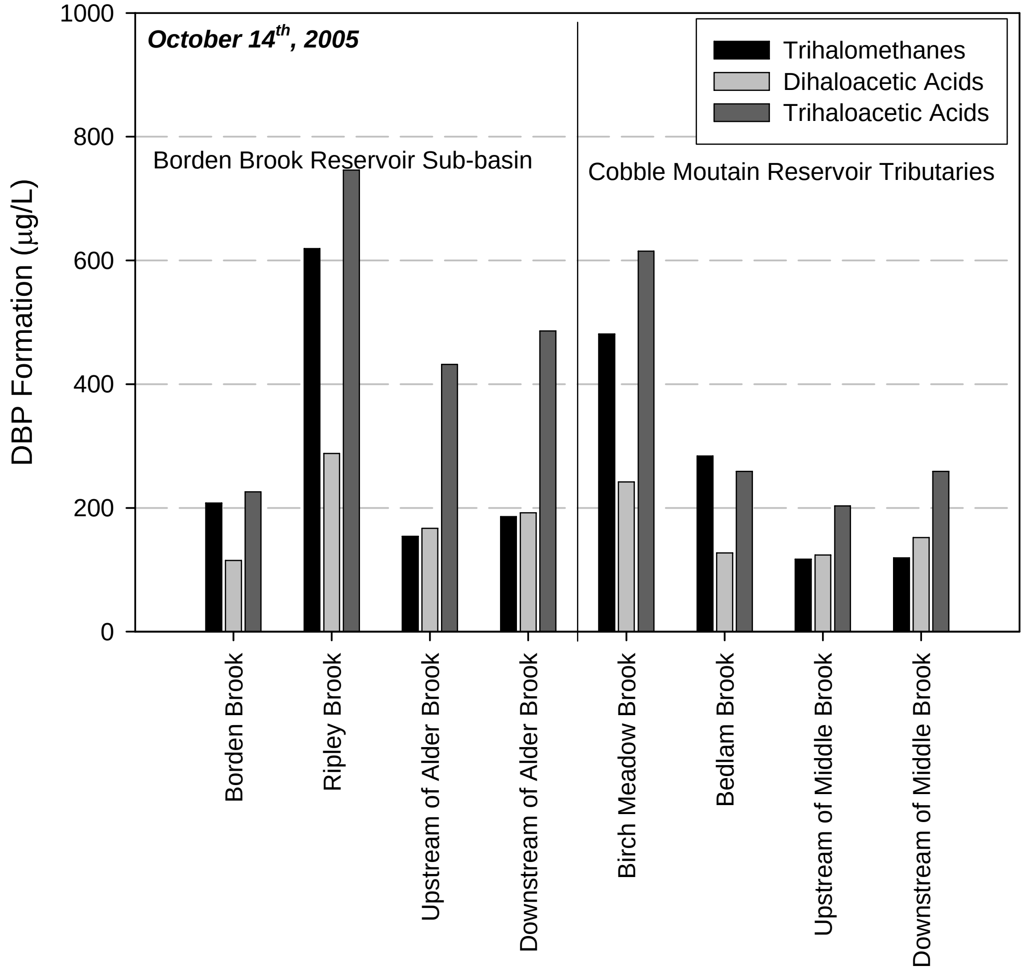


Figure 4.41 DBP Formation Potentials for October 14th, 2005 Sampling Event

4.8.3. Specific DBP Formation Potential

A summary of specific DBP formation levels for all samples is listed in Table 4.25 and graphed in Figure 4.42. Specific THMFP levels lie within 20-60ug/mg-TOC, specific DHAAFP between 20 and 30ug/mg-TOC and specific THAAFP ranged from 40-70ug/mg-TOC. Both of Alder Brook and Middle Brook had low levels of specific THMFP. On the other hand, Alder Brook had high levels of specific THAA. In general, specific THAA formation potential levels are higher than specific THMFP and DHAAFP levels. The specific DBPFP values are almost identical for locations upstream and downstream of beaver impoundments in both Alder Brook and Middle Brook.

Table 4.25 Specific DBP Formation Potential Data (μg/mg-TOC) for October 14th, 2005 Sampling Event

Location	SpTHM	SpDHAA	SpTHAA
	μg/mg-TOC	μg/mg-TOC	μg/mg-TOC
Borden Brook	48	26	52
Ripley Brook	54	25	65
Upstream of Alder Brook	24	26	68
Downstream of Alder Brook	24	30	67
Birch Meadow Brook	53	26	67
Bedlam Brook	57	26	52
Upstream of Middle Brook	26	27	45
Downstream of Middle Brook	24	31	53

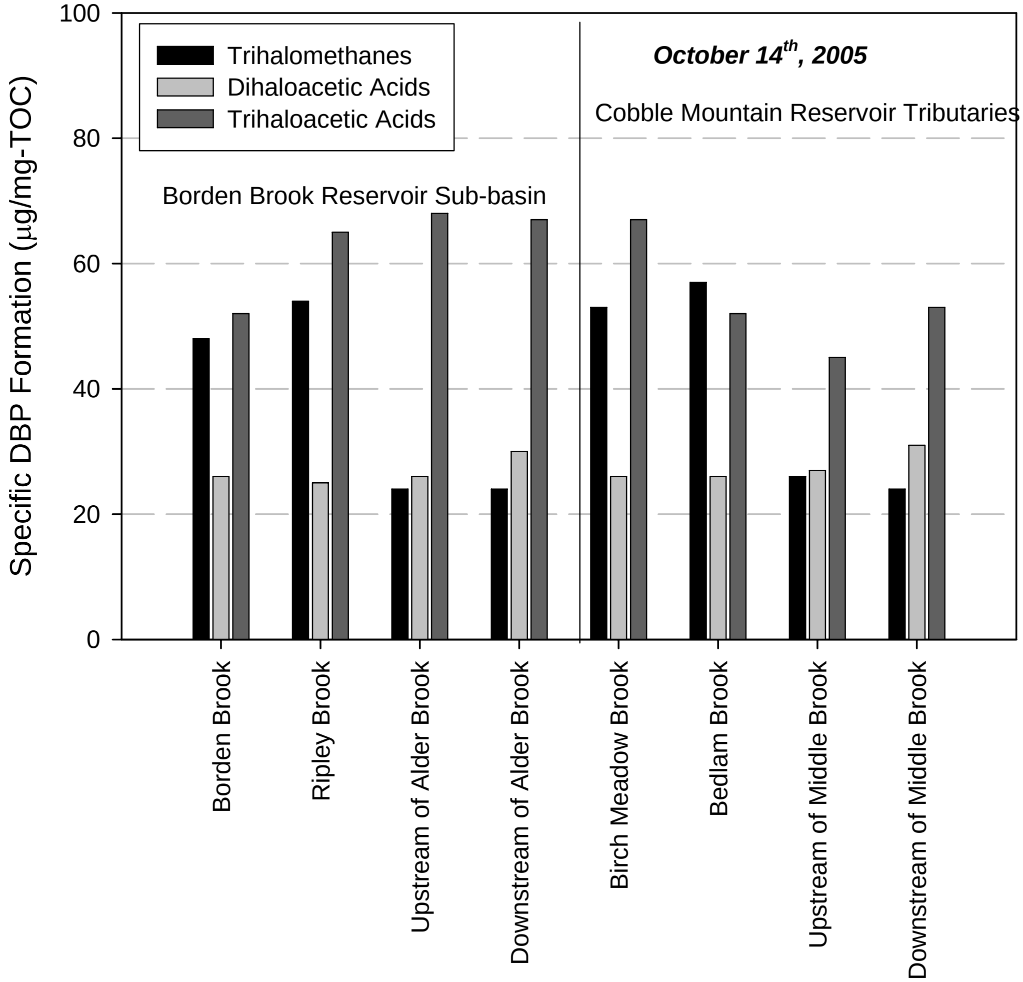


Figure 4.42 Specific DBP Formation Potentials for October 14th, 2005 Sampling Event

4.9. November 4th, 2005

Samples were taken at the upstream and downstream locations for Peebles Brook and Middle Brook. Sampling locations were shown as in Figure 4.34. This sampling event was during the middle of the fall season. There was a period of precipitation with more than 1 inch of rainfall ten days before the sampling event and also a slight precipitation one day before, and the discharge at the sampling event was almost 1000 cfs. The precipitation, discharge and temperature data prior to and after the sampling date are shown in Figure 4.43.

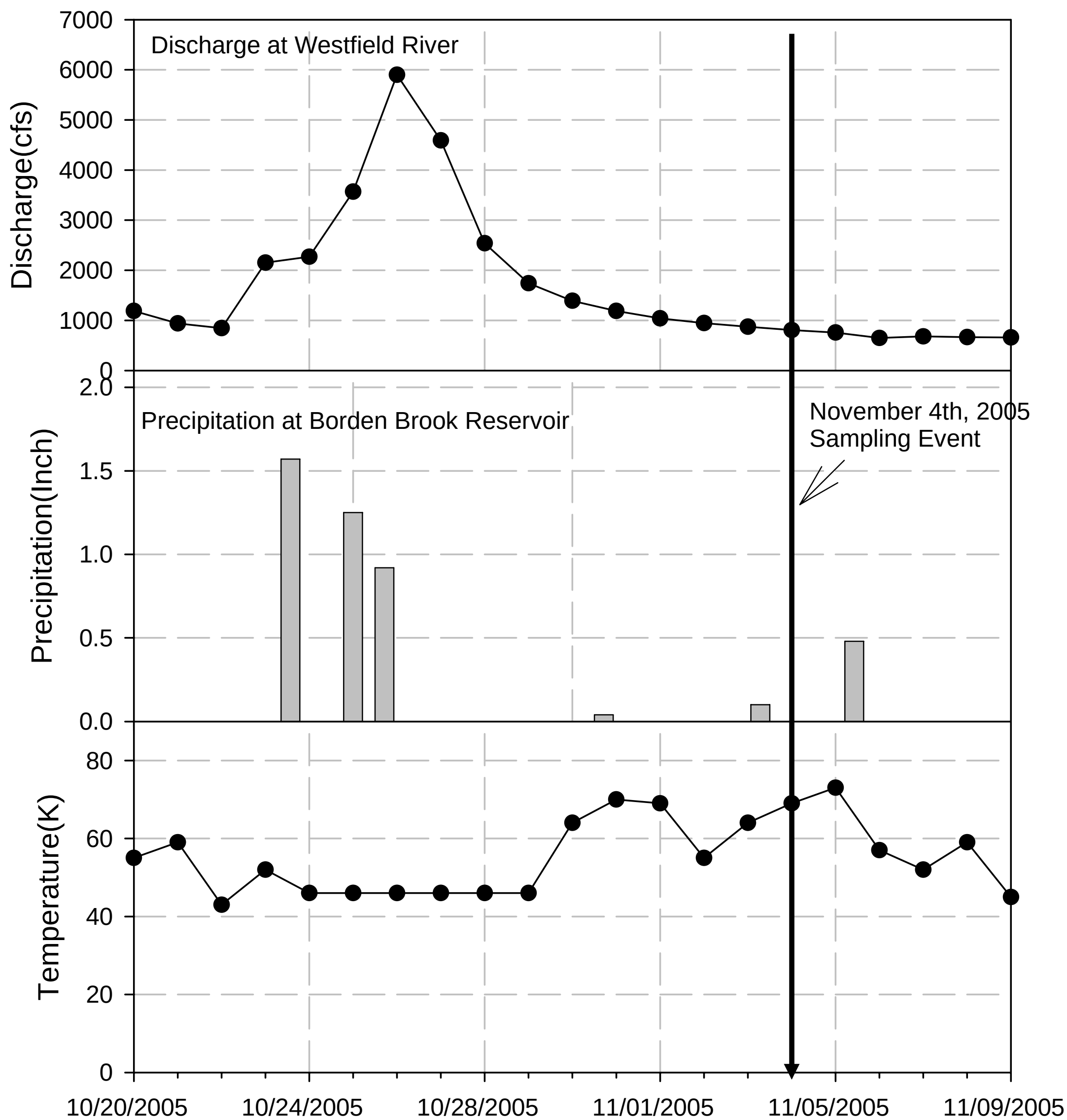


Figure 4.43 Discharge, Precipitation and Temperature data prior to and after November 4th, 2005 Event. (Precipitation: Borden Brook Reservoir; Temperature: Westfield, MA; Discharge: USGS Westfield River Station 01183500)

4.9.1. NOM Levels

Total organic carbon, DOC, UV-254 and SUVA of these samples are tabulated in Table 4.26. TOC and DOC ranged from 3 to 6mg/L. Ultraviolet absorbance values were in the range of 0.08-0.018cm^{-1} with the highest value measured in the downstream of Peebles Brook. SUVA values were similar for all of these samples, which was in the range of 2-3L/mg-m.

Table 4.26 UV-254, TOC, DOC and SUVA of water samples for November 4th, 2005 Sampling Event

Location	TOC	DOC	UV	SUVA
	mg/L	mg/L	cm^{-1}	L/mg-m
Peebles up	4.2	4.2	0.088	2.1
Peebles down	5.8	5.9	0.175	3.0
Middle Brook Up	3.7	3.5	0.094	2.7
Middle Brook down	3.3	3.4	0.079	2.3

Figure 4.45 shows TOC and SUVA values for all of the samples. Middle Brook had lower TOC values than Peebles Brook. Higher TOC level was measured and higher SUVA value was calculated for downstream of the beaver pond in Peebles Brook, suggesting that the beaver pond can export TOC downstream. Lower TOC level was measured and a smaller SUVA was calculated for downstream of the beaver impoundments in Middle Brook compared with that of upstream, indicating beaver impoundments in this tributary may improve water quality.

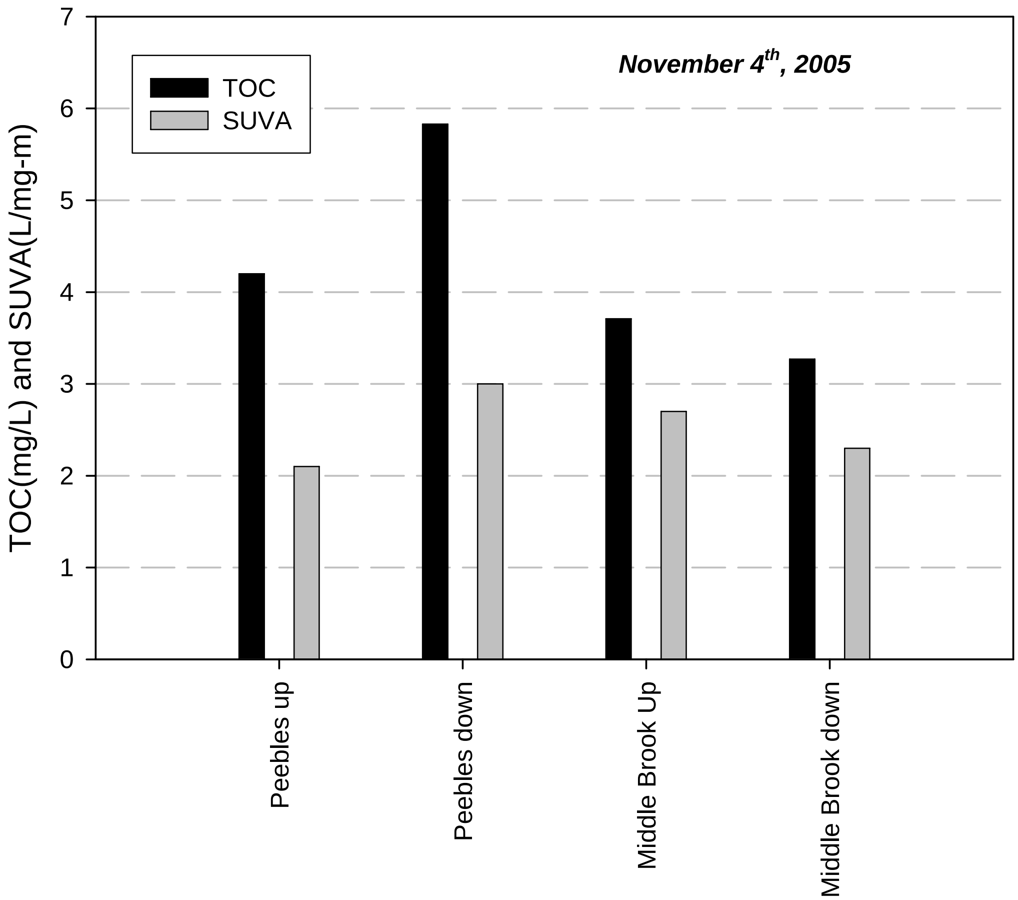


Figure 4.45 TOC and SUVA for November 4th, 2005 Sampling Event

4.9.2. DBP Formation Potential

Disinfection by-product formation potentials measured for the samples are available in Table 4.27 and Figure 4.46. Trihalomethane levels ranged from 220 to 350 μg/L for this event, with the lowest value from downstream of beaver impoundments at Middle Brook and the highest at downstream of beaver ponds Peebles Brook. Generally, Peebles Brook had higher DBP formation potential levels than Middle Brook. The downstream of beaver ponds location in Peebles Brook had obviously higher DBP formation potential levels. Once again, on the contrary, the downstream of beaver impoundments location in Middle

Brook had lower DBP formation levels.

Table 4.27 DBP Formation Potential Data (μg/L) for November 4th, 2005 Sampling Event

Location	THMFP	DHAAFP	THAAFP
	μg/L	μg/L	μg/L
Upstream of Peebles Brook	226	66	137
Downstream of Peebles Brook	347	117	268
Upstream of Middle Brook	258	95	185
Downstream of Middle Brook	214	64	132

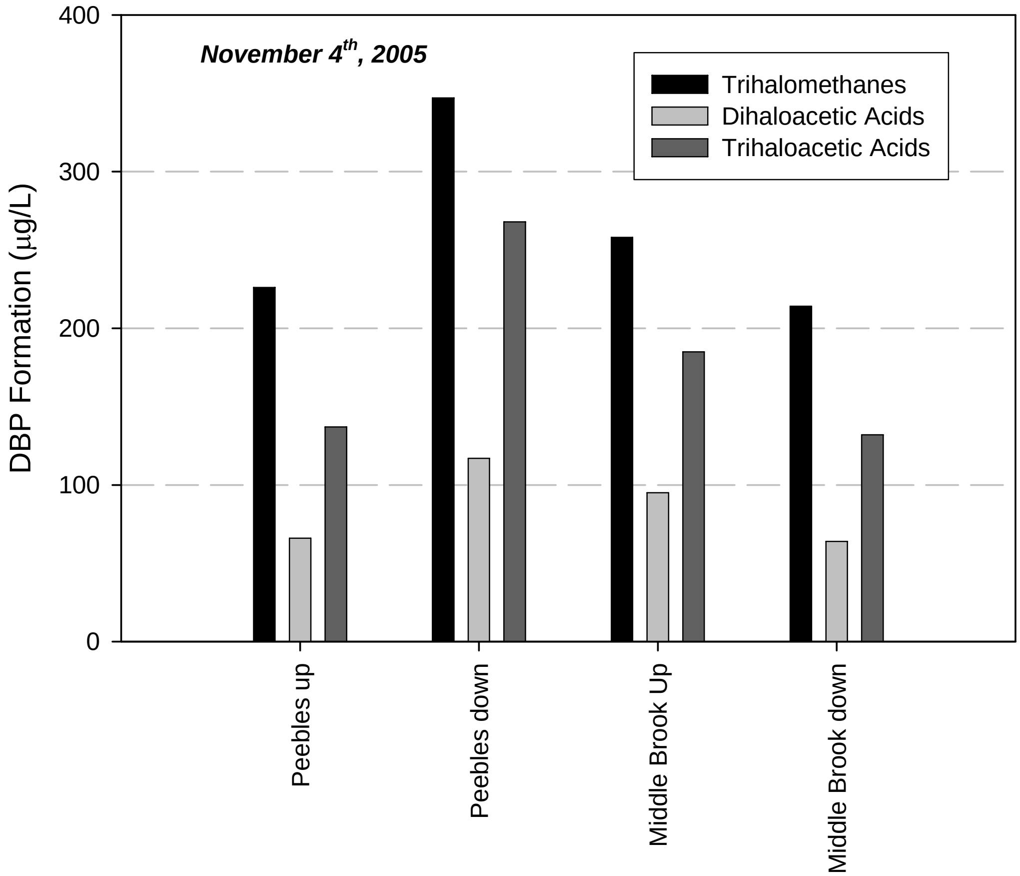


Figure 4.46 DBP Formation Potentials for November 4th, 2005 Sampling Event

4.9.3. Specific DBP Formation Potential

The calculated specific DBP formation potential values are summarized in Table 4.28 and

Figure 4.47.

Table 4.28 Specific DBP Formation Potential Data (μg/mg-TOC) for November 4th, 2005 Sampling Event

Location	SpTHM	SpDHAA	SpTHAA
	μg/mg-TOC	μg/mg-TOC	μg/mg-TOC
Upstream of Peebles Brook	54	16	33
Downstream of Peebles Brook	60	20	46
Upstream of Middle Brook	70	26	50
Downstream of Middle Brook	65	20	40

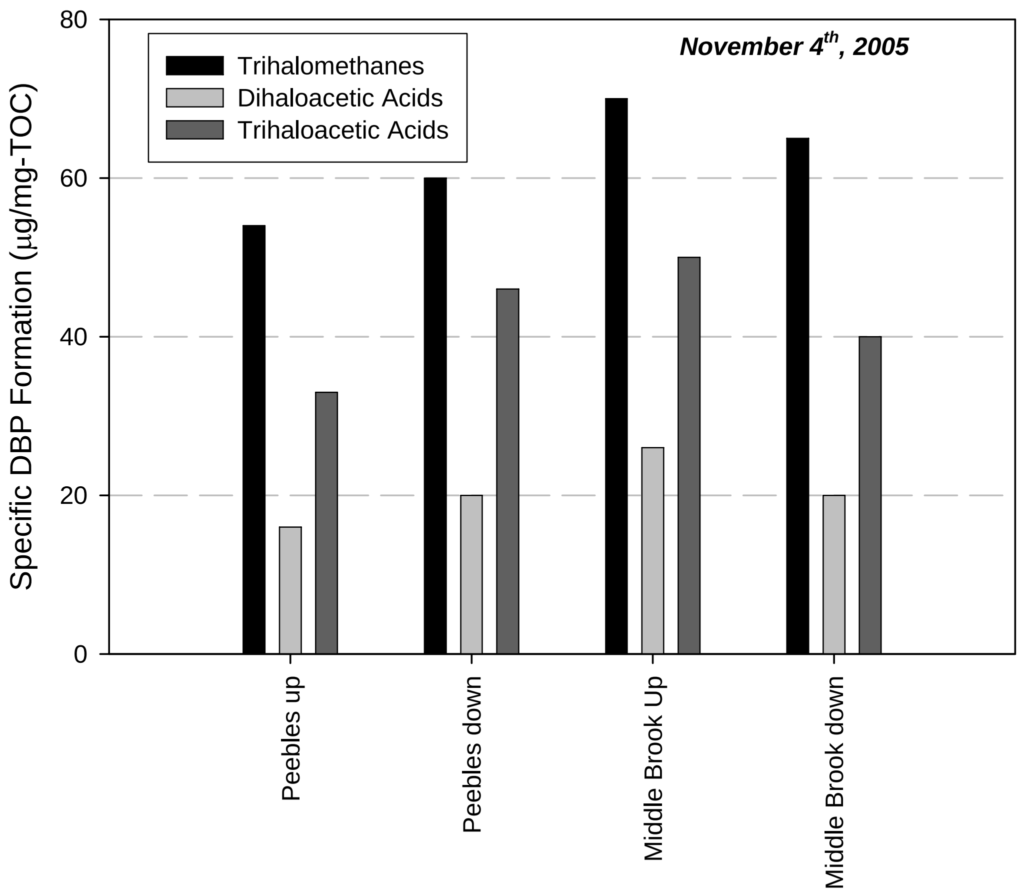


Figure 4.47 Specific DBP Formation Potentials for November 4th, 2005 Sampling Event

Specific THM, DHAA, THAA formation potentials were in the range of 50-70, 20-30 and 30-50 μg/mg-TOC respectively. For the paired study of beaver effects, downstream of beaver ponds at Peebles Brook had higher specific DBP precursors, especially THAA. Downstream of beaver impoundments at Middle Brook had slightly lower specific DBP levels.

4.10. December 8th, 2005

This sampling event was during early winter. Samples were collected at the upstream and downstream location for Alder Brook, Peebles Brook and Middle Brook to evaluate the effect of upstream beaver activities on water quality downstream. Another sample was collected at spillway of Borden Brook Reservoir to Cobble Mountain Reservoir.

The sampling date was preceded by three dry and cold days. As shown in Figure 4.48, discharge was at the peak value one week before the sampling date. The discharge value of the sampling date was at the decreasing limb, which was less than 1000 cfs. Samples for this event were collected in the morning at the sampling date, and 0.21 inch of snow happened after the sampling was done at that day.

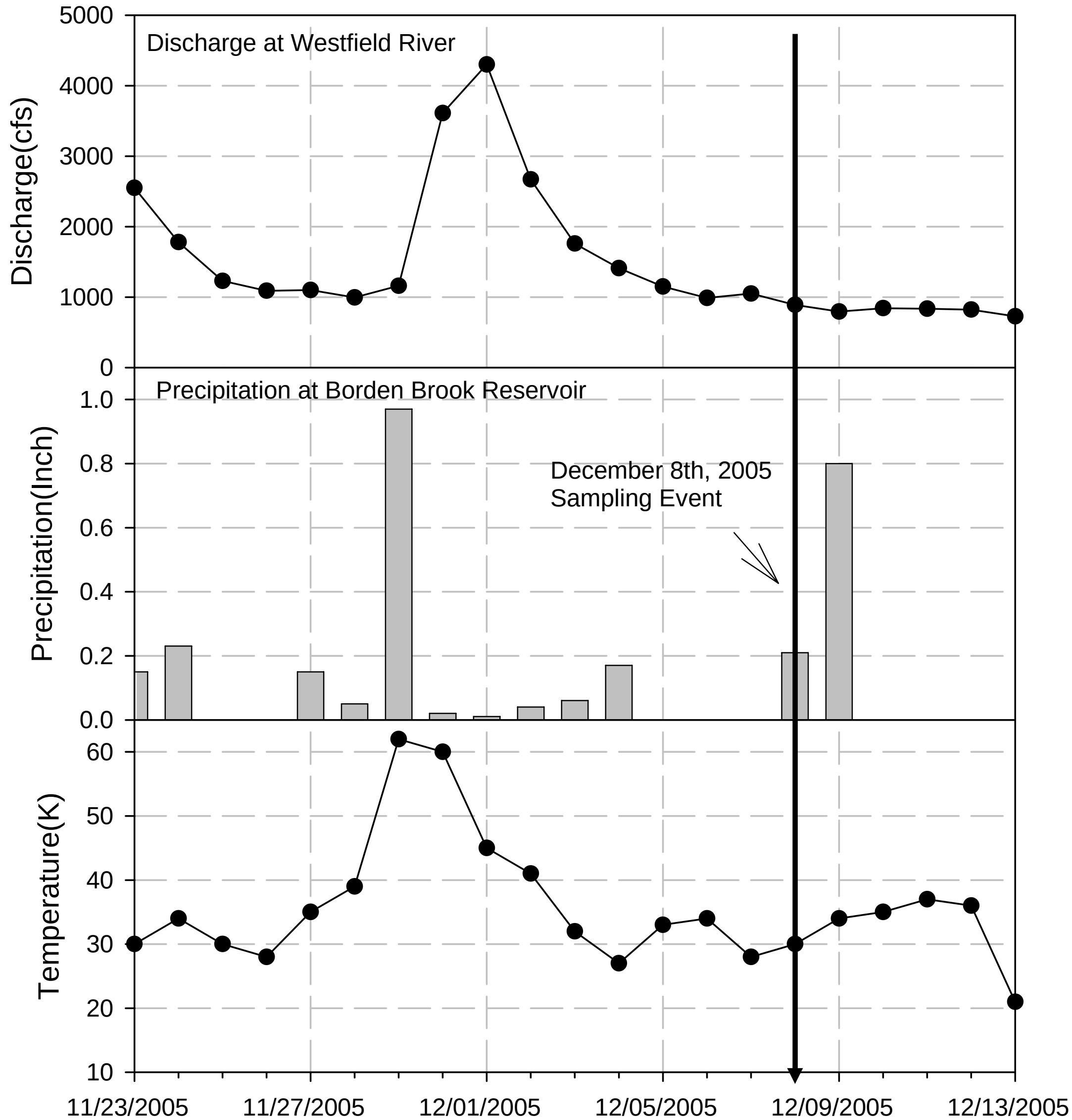


Figure 4.48 Discharge, Precipitation and Temperature data prior to and after December 8th, 2005 Event. (Precipitation: Borden Brook Reservoir; Temperature: Westfield, MA; Discharge: USGS Westfield River Station 01183500)

4.10.1. NOM Levels

Water quality for each sample was quantified by TOC, DOC and UV-254 measurements.

Specific ultraviolet absorbance values were calculated based on UV-254 and DOC values. Values of these water quality parameters for this sampling event were tabulated in Table 4.29.

Table 4.29 UV-254, TOC, DOC and SUVA of water samples for December 8th, 2005 Sampling Event

Location	TOC	DOC	UV	SUVA
	mg/L	mg/L	cm^{-1}	L/mg-m
Upstream of Alder Brook	2.6	2.5	0.094	3.8
Downstream of Alder Brook	4.1	4.0	0.147	3.7
Upstream of Middle Brook	3.7	3.6	0.080	2.2
Downstream of Middle Brook	2.8	2.7	0.060	2.2
Upstream of Peebles Brook	2.8	2.8	0.078	2.8
Downstream of Peebles Brook	4.4	4.2	0.148	3.5
Borden Brook Reservoir	5.8	4.4	0.196	4.4

Total organic carbon and DOC ranged from 2 to 6 mg/L. UV-254 values were in the range of 0.060-0.2000 cm^{-1} and SUVA fell between 2.0-4.0 L/mg-m. The sample from spillway of Borden Brook Reservoir had the highest NOM levels. Downstream of beaver impoundments in Middle Brook had lower NOM levels in terms of TOC, DOC and UV-254; however, the SUVA values were similar compared with upstream. On the other hand, higher TOC, DOC and UV-254 values were seen downstream compare to upstream of beaver impoundments and beaver ponds for Alder Brook and Peebles Brook. The TOC and SUVA values are presented in Figure 4.49.

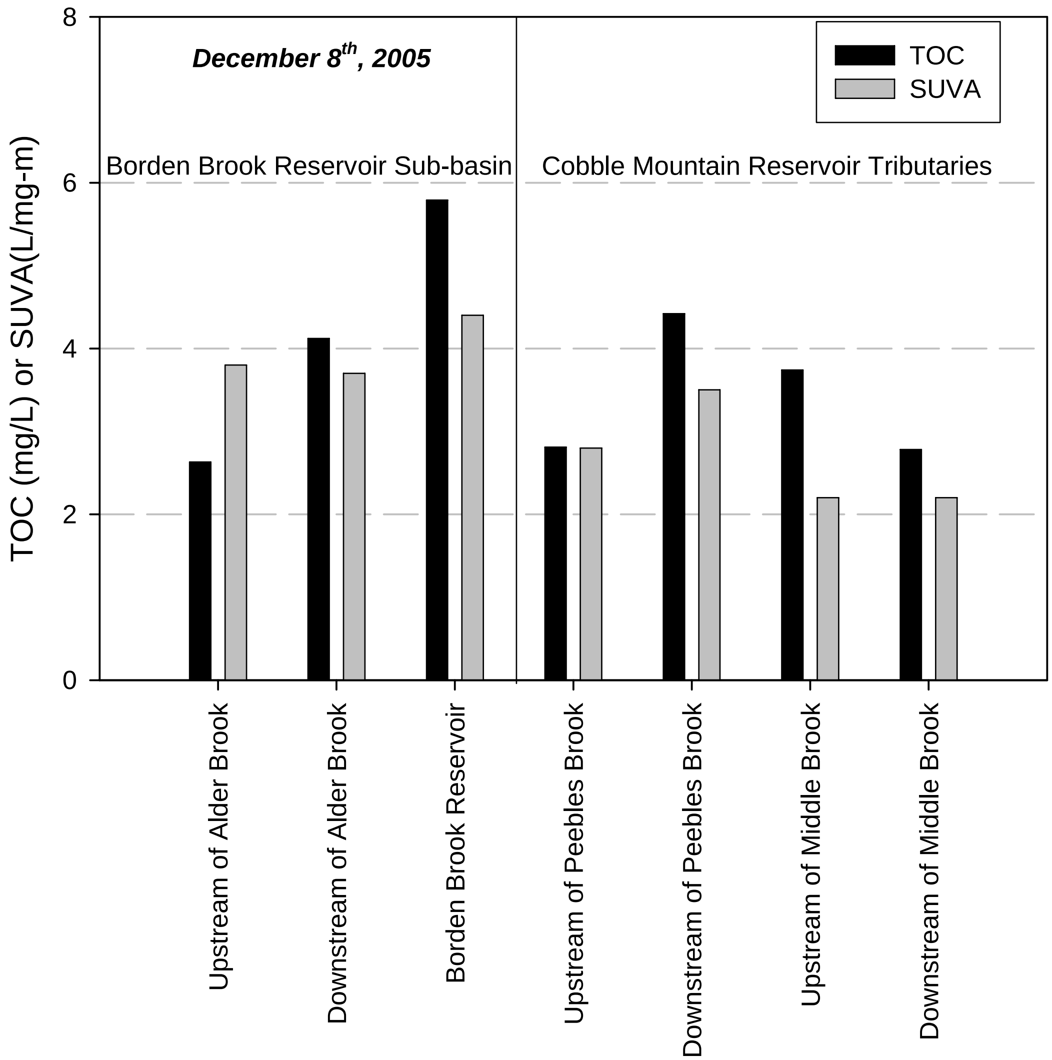


Figure 4.49 DBP Formation Potentials for December 8th, 2005 Sampling Event

4.10.2. DBP Formation Potential

Disinfection by-product formation potentials were measured for all of the samples collected, and the results of this analysis are summarized in Table 4.30 and Figure 4.50.

Table 4.30 DBP Formation Potential Data (μg/L) for December 8th, 2005 Sampling Event

Location	THMFP	DHAAFP	THAAFP
	μg/L	μg/L	μg/L
Upstream of Alder Brook	145	84	202
Downstream of Alder Brook	201	127	292
Upstream of Middle Brook	108	63	129
Downstream of Middle Brook	126	60	126
Upstream of Peebles Brook	116	118	97
Downstream of Peebles Brook	217	133	289
Borden Brook Reservoir	277	159	379

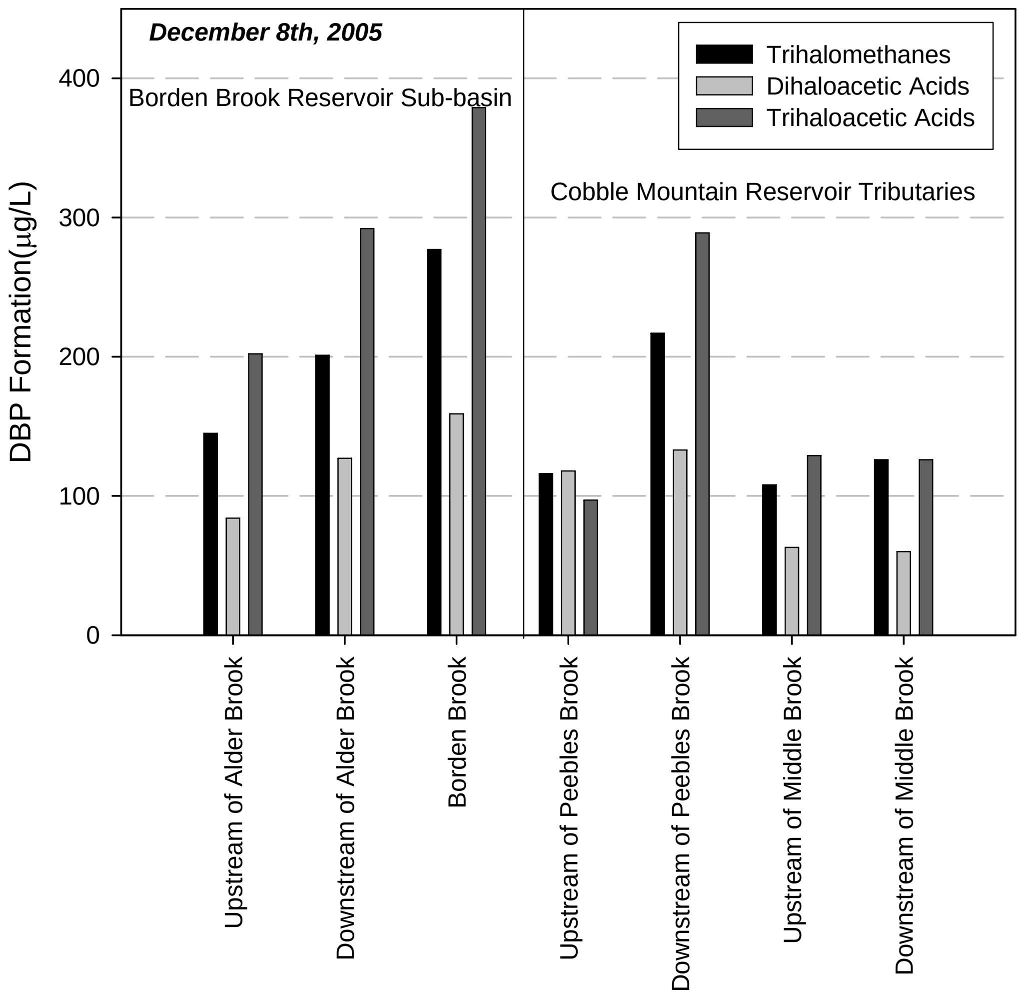


Figure 4.50 DBP Formation Potentials for December 8th, 2005 Sampling Event

THMFP levels ranged from 100 and 280 μg/L. DHAAFP levels were in the range of 60-160 μg/L and THAAFP levels fell between 90 and 380 μg/L. In general, THAAFP levels were much higher than DHAAFP and THMFP. Middle Brook and upstream of beaver ponds at Peebles Brook had low level of DBPFP. Both Alder Brook and Peebles Brook had higher DBP levels downstream location compared to upstream of beaver impoudments. There were no obvious differences between the DBP levels upstream and downstream in Middle Brook. The spillway of Borden Brook Reservoir had higher DBP levels than Alder Brook.

4.10.3. Specific DBP Formation Potential

Specific DBPFPs were calculated for each of the locations and the results are tabulated in Table 4.31 and presented in Figure 4.51. Specific THMFP levels were in the range of 30-60 μg/ mg-TOC. Specific DHAAFP and Specific THAAFP ranged from 20-40 μg/mg-TOC and 40-80 μg/mg-TOC respectively. Specific THAAFP levels were higher than specific DHAAFP and specific THAAFP, which means that the samples for this event had higher levels of THAA precursers. Borden Brook Reservoir spillway had lower DBPFP yield than Alder Brook. Downstream of beaver impoundments and beaver ponds at Middle Brook and Peebles Brook had higher levels of specific DBP precursers, although higher levels of NOM levels were seen downstream of the beaver impoudments, Middle Brook had slightly lower levels of DBP precursers in downstream of beaver impoundments.

Table 4.31 Specific DBP Formation Potential Data (μg/mg-TOC) for December 8th, 2005 Sampling Event

Location	SpTHM	SpDHAA	SpTHAA
	μg/mg-TOC	μg/mg-TOC	μg/mg-TOC
Upstream of Alder Brook	55	32	77
Downstream of Alder Brook	49	31	71
Upstream of Middle Brook	29	17	35
Downstream of Middle Brook	45	22	45
Upstream of Peebles Brook	41	42	35
Downstream of Peebles Brook	49	30	65
Borden Brook Reservoir	48	27	65

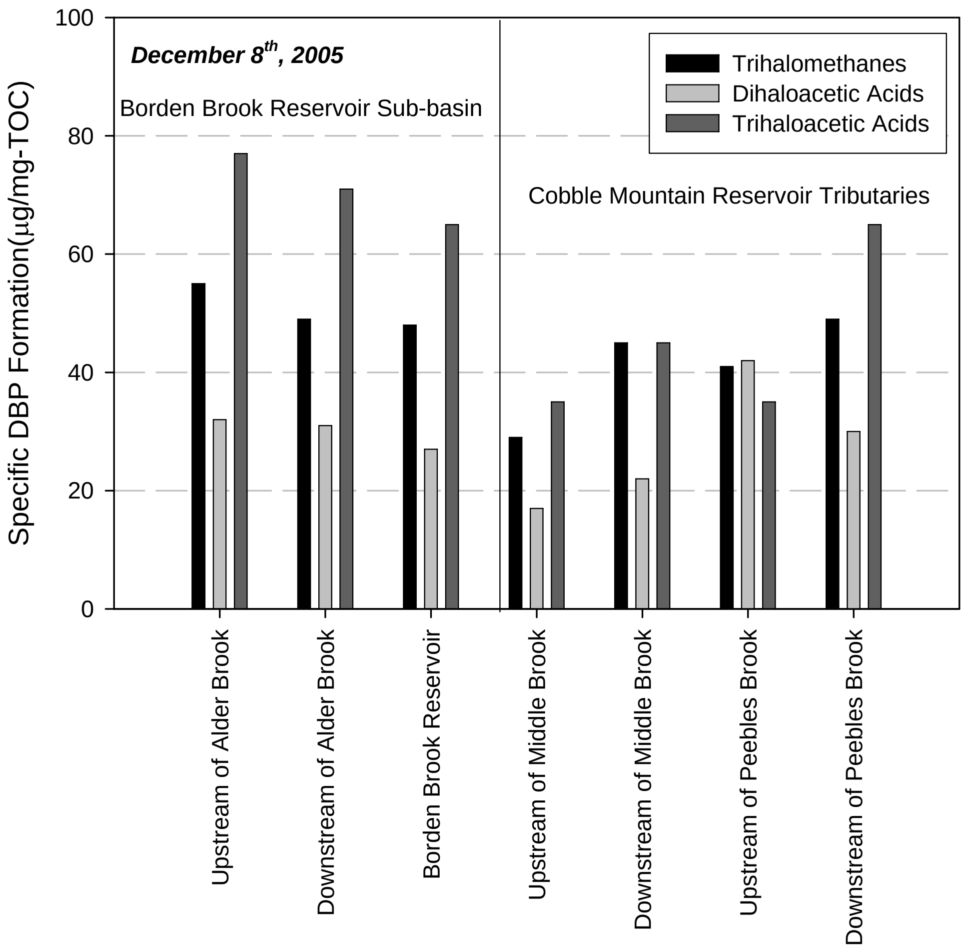


Figure 4.51 Specific DBP Formation Potentials for December 8th, 2005 Sampling Event

CHAPTER 5 DISCUSSION

5.1. Relationships Between Water Quality Parameters

5.1.1. Organic Carbon Measurements

Total organic carbon and total dissolved organic carbon were measured for each sample. The results show that a majority of the total organic carbon was in the dissolved form, averaging 96% of TOC for all events and all locations. Similar results were found for the tributaries of Quabbin Reservoir, where DOC comprised about 95% the TOC in all of the tributaries sampled (Garvey *et al.* 2003) and in the tributaries of Wachusett Reservoir, where approximately 96% of TOC was estimated to be DOC in all the sampled tributaries (Bryan 2005). Owen *et al.* (1995) summarized 9 water souces throughout the United States and found that between 83 and 98% of TOC was in the dissolved form.

Several types of organic structures that are likely present in the DOC pool are capable of absorbing UV light, including aromatic rings and conjugated dienes and carbonyls (Rao, 1975). UV abosorbance at 254 nm is believed to be a characteristic parameter for aromatic carbon content (Traina *et al.* 1990, Chin *et al.*1994). SUVA, defined by the ratio between UV-254 (in the unit of cm^{-1}) and DOC (in the unit of mg/L) multiplied by 100, provides information about DOC aromaticity. As shown in Figure 5.1, UV absorbance at 254nm correlated well with DOC, with a coefficient of determination, r^2=0.85, indicating most of the tributaries in the watershed have similar aromaticity, regardless of residence time or locations. These correlations indicate that DOC can be approximated based on the UV254 absorbance of the water. The slope for this linear regression equation was 0.0465 L/mg-cm, or 4.65L/mg-m. Work by Westphal *et al.* (2004) on Wachusett Reservoir revealed a good correlation between UV-254 and TOC, which had a UV-254 and TOC linear regression slope of 0.493L/mg-cm. Additionally, Bryan found a much lower slope of 0.039 L/mg-cm for Wachusett Reservoir watershed (Bryan 2005). The variability of the linear regression slope may be attributed to the difference in NOM aromoticity in the water sources.

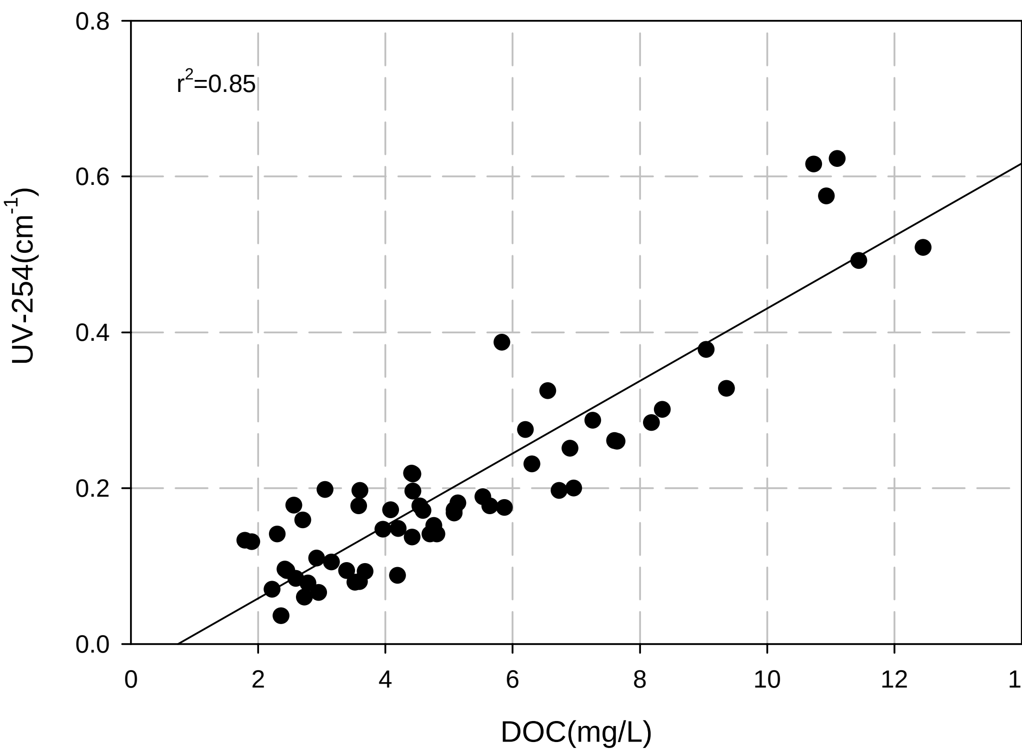


Figure 5.1 UV-Absorbance at 254nm vs. DOC for All Events (n=61)

5.1.2. DBP Formation Potential

The aromatic part of the TOC is believed to contain the major precursors of THMs (Rook 1976, Reckhow *et al.* 1990). The correlation between THMs and TOC for all events is presented in Figure 5.2. Figure 5.2 shows a reasonable linear regression between THMs and TOC, with a coefficient of determination, r^2=0.67. There was a clear trend showing that higher TOC waters have higher THM formation potential as well. However, no perfect linear correlation was found for all of the data indicating that the NOM character varied substantially from one sample to the next. Better linear correlations between TOC and THMFP were observed by other researchers based on similar standard protocols (Edzwald 1985, Randtke 1988, Garvey 2003). Chapra *et al.* (199*7)* summarized the THMFP and TOC data from a number of diverse water sources across United States and fit with a linear regression model to the log-transformed data. The positive exponential coefficient contained in this equation to TOC indicated that higher TOC corresponded to higher THM formation potential as well. Although the relationship between organic carbon sources and concentrations at individual water supply intakes is complex, the results suggest that management of organic carbon sources for drinking water quality should consider both quality and quantity, with greater emphasis on sources with the highest THMFP.

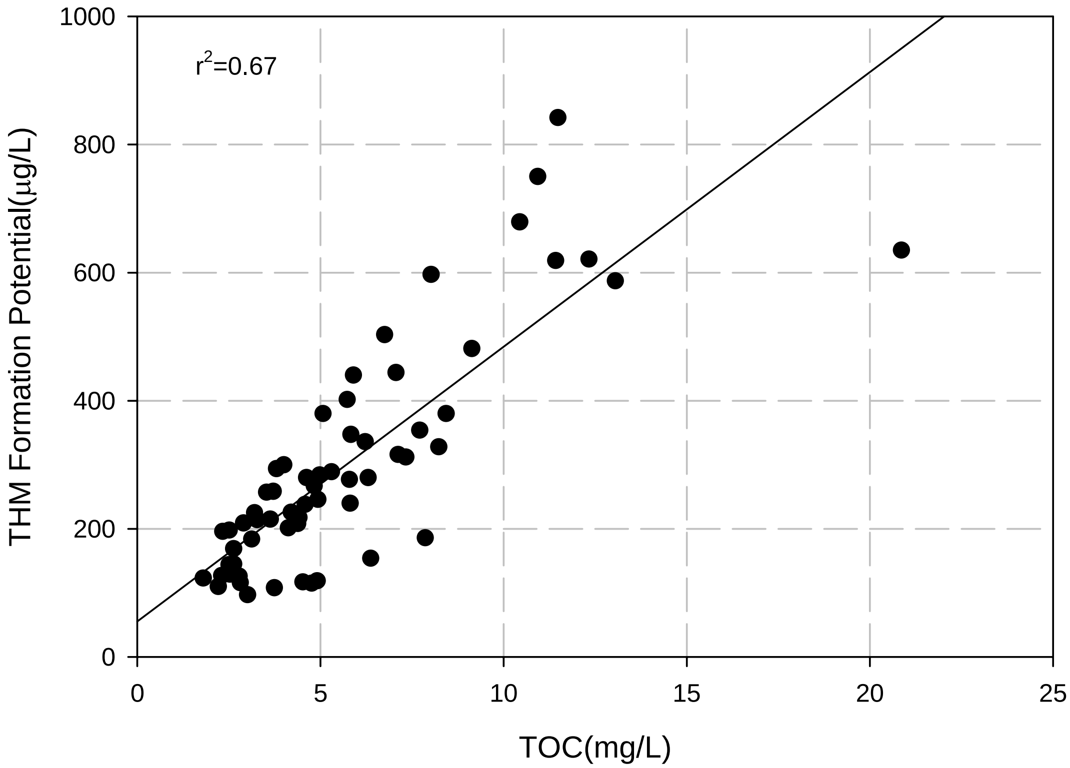


Figure 5.2 THMFP vs. TOC for All Events (n=61)

None of prior studies evaluated correlations for haloacetic acids because THMFP has been the subject of longer-term regulations in US water supply systems. The correlations between dihaloacetic acids formation potential, trihaloacetic acids formation potential and TOC for all events in this study are shown in Figure 5.3 and Figure 5.4, respectively. As shown in Figure 5.3 and Figure 5.4, DHAA and THAA correlated much better with TOC (r^2=0.86, 0.89) as compared to THMFP. In general, correlations for individual sampling events were better than the combined data from all events, especially for events in spring and summer with all of those coefficients of determinant, r^2>0.95. This is most likely the result of seasonal and hydrologic variability among events.

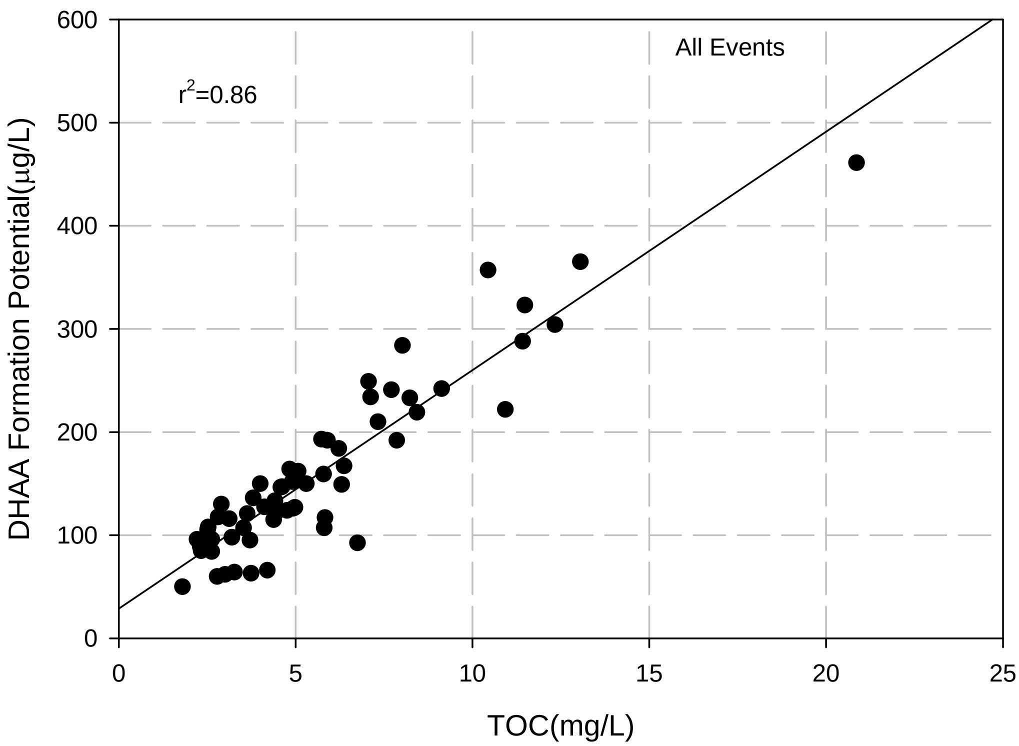


Figure 5.3 DHAAFP vs. TOC for All Events (n=61)

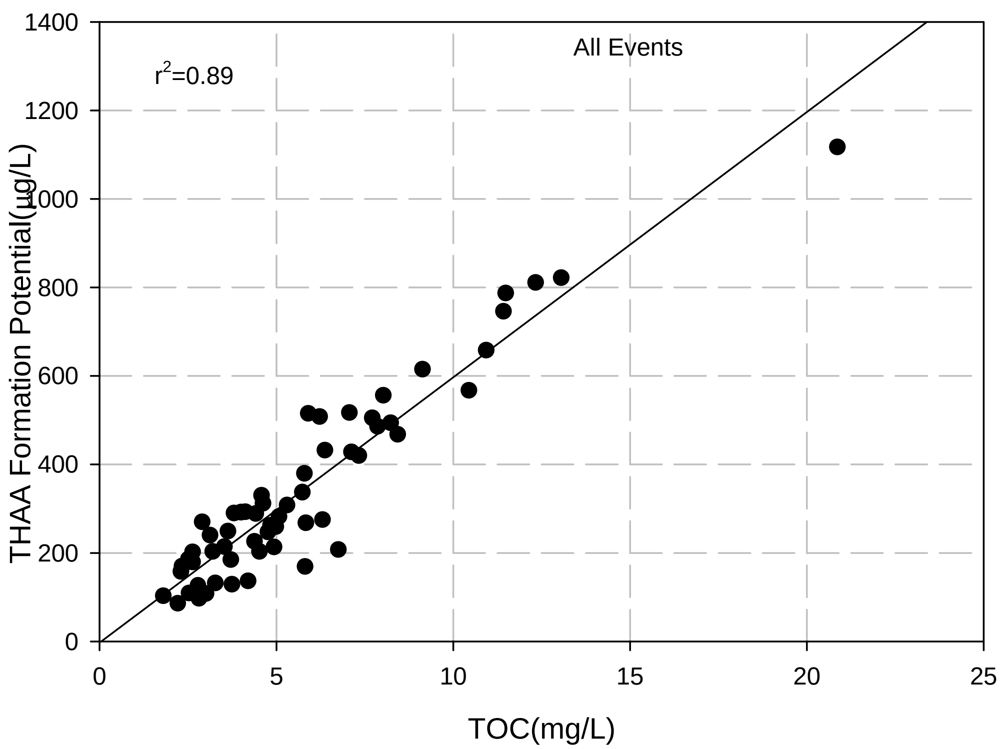


Figure 5.4 THAAFP vs. TOC for All Events (n=61)

The correlations between DBPFP and UV-254 were also studied and are presented in figures 5.5-5.7. Organic substances absorb ultraviolet radiation, and thus ultraviolet absorbance measurements at 254 nanometers (UV-254) can show a relation to concentrations of organic compounds. UV-254 measurements tend to increase as the aromaticity of DOC increases, and thus UV-254 is an indicator of the potential for NOM to form DBPs (Singer and Reckhow 1999). The correlation determinants (r^2) for THMFP, DHAAFP and THAAFP were 0.73, 0.76 and 0.90 respectively for all the data in this study. These weaker correlations for THMFP versus UV-254 and DHAAFP versus UV-254 indicate that either some of THMFP and DHAAFP precursors in the watershed didn't absorb UV light or that not all aromatic carbon reacts equally with chlorine, and the substances absorbing UV light were not THM and DHAA precursors. However, it should be noted that correlations between UV-254 and DBPs were much better for base flow conditions than higher flow conditions which is consistent with study done by Speiran (2000), because during base-flow periods, ground-water discharge and stream-bed detritus were the principal sources of DOC and DBP precursors to the streams.

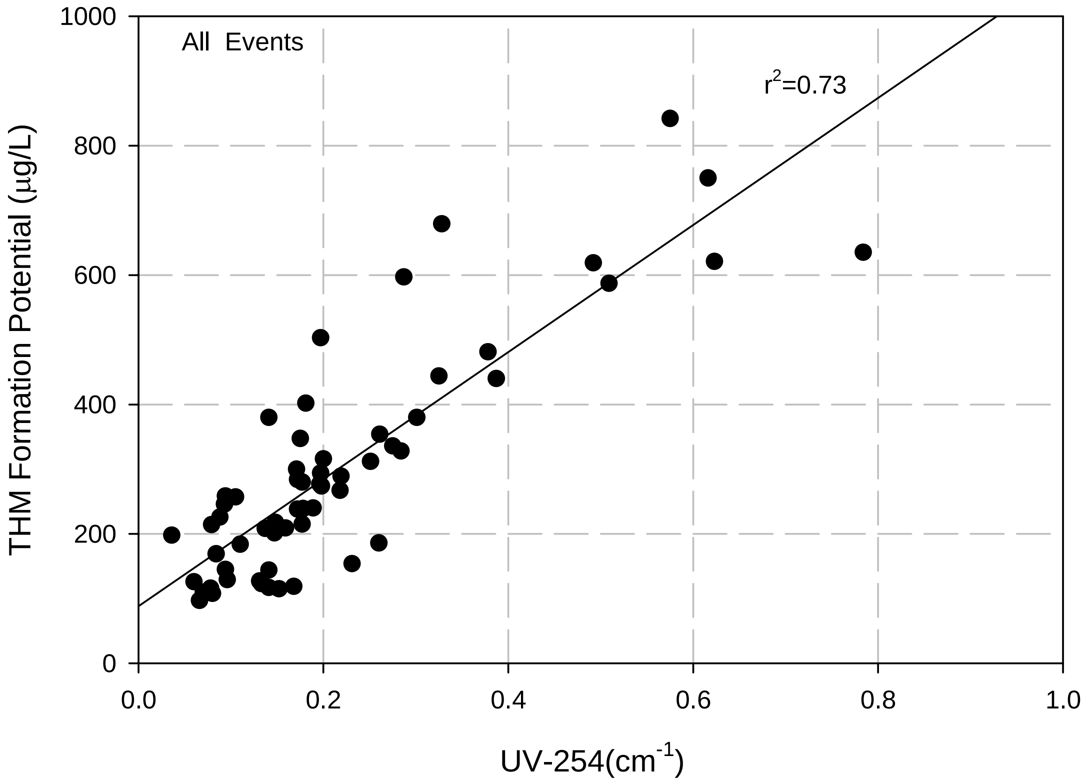


Figure 5.5 THMFP vs. UV-254 for All Events (n=61)

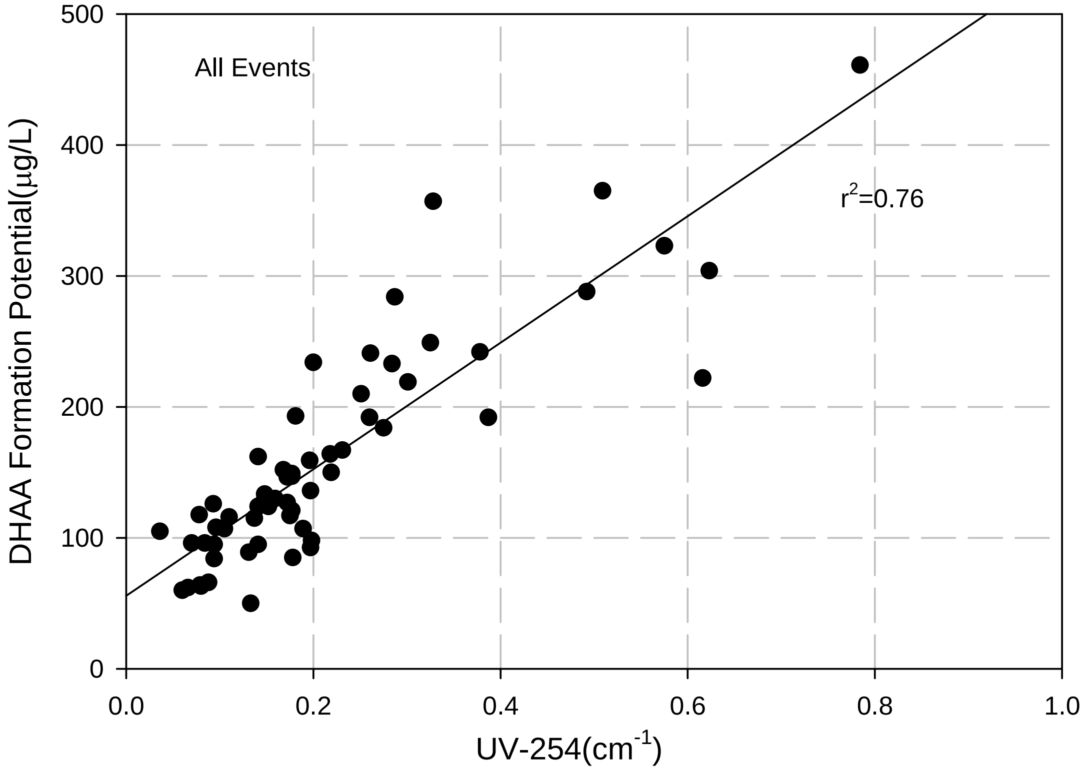


Figure 5.6 DHAAFP vs. UV-254 for All Events (n=61)

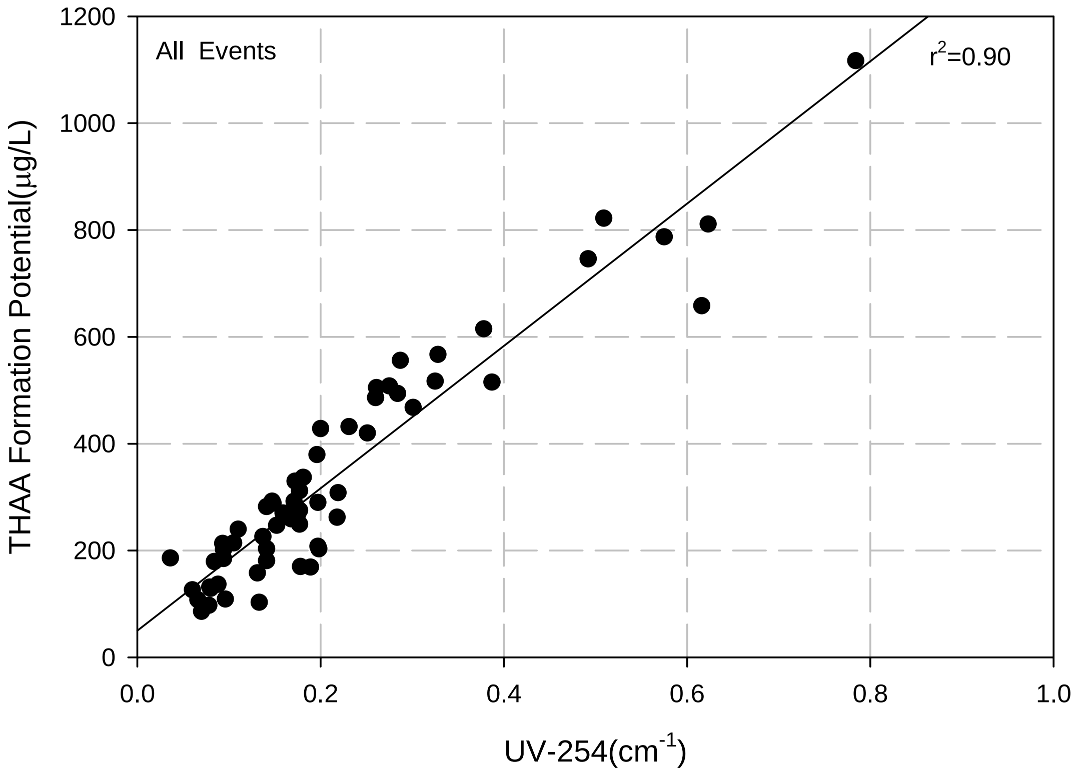


Figure 5.7 THAAFP vs. UV-254 for All Events (n=61)

5.1.3. Specific DBP Formation Potential

The correlations between specific DBPFP and TOC were evaluated and were shown in Figure 5.11-5.13. The correlations between specific DBPFP and TOC were slightly negative, indicating that as TOC level increased, the normalized DBP precursor levels decreased. Randtke (1988) and Bryan (2005) also found weak correlations between those two parameters. Stronger negative correlations existed between specific DBPFP and TOC for individual sampling events than for the whole data set.

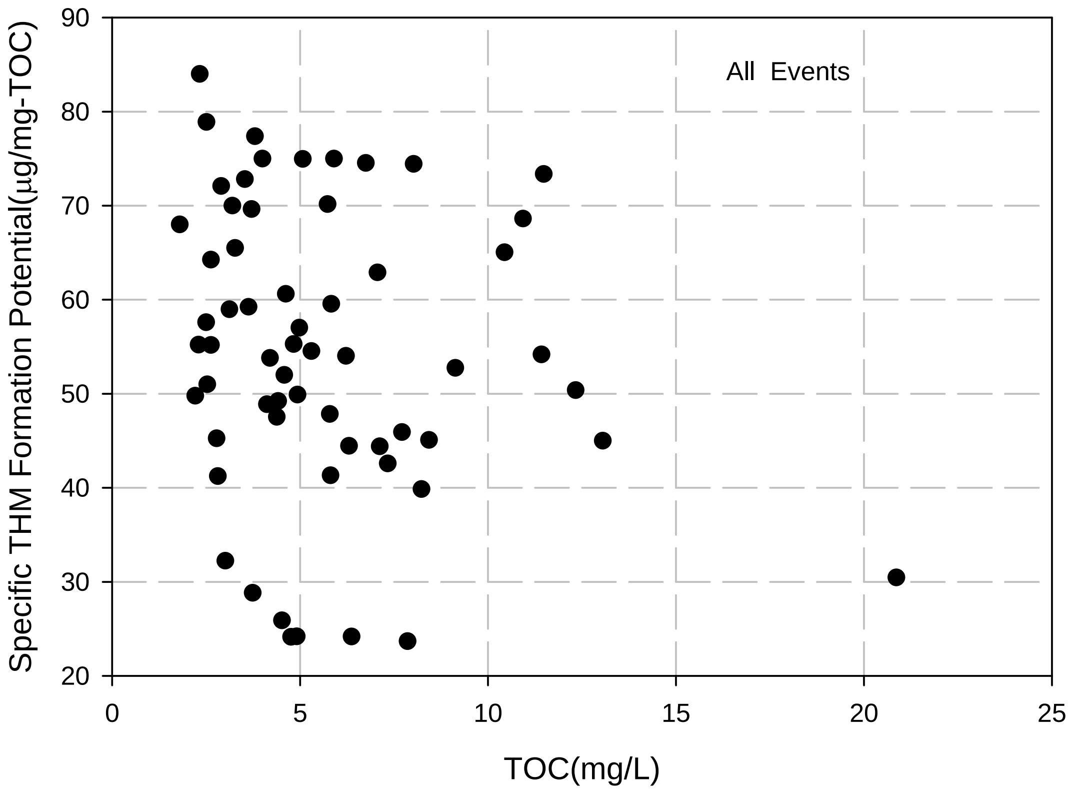


Figure 5.11 Specific THMFP vs. TOC for All Events (n=61)

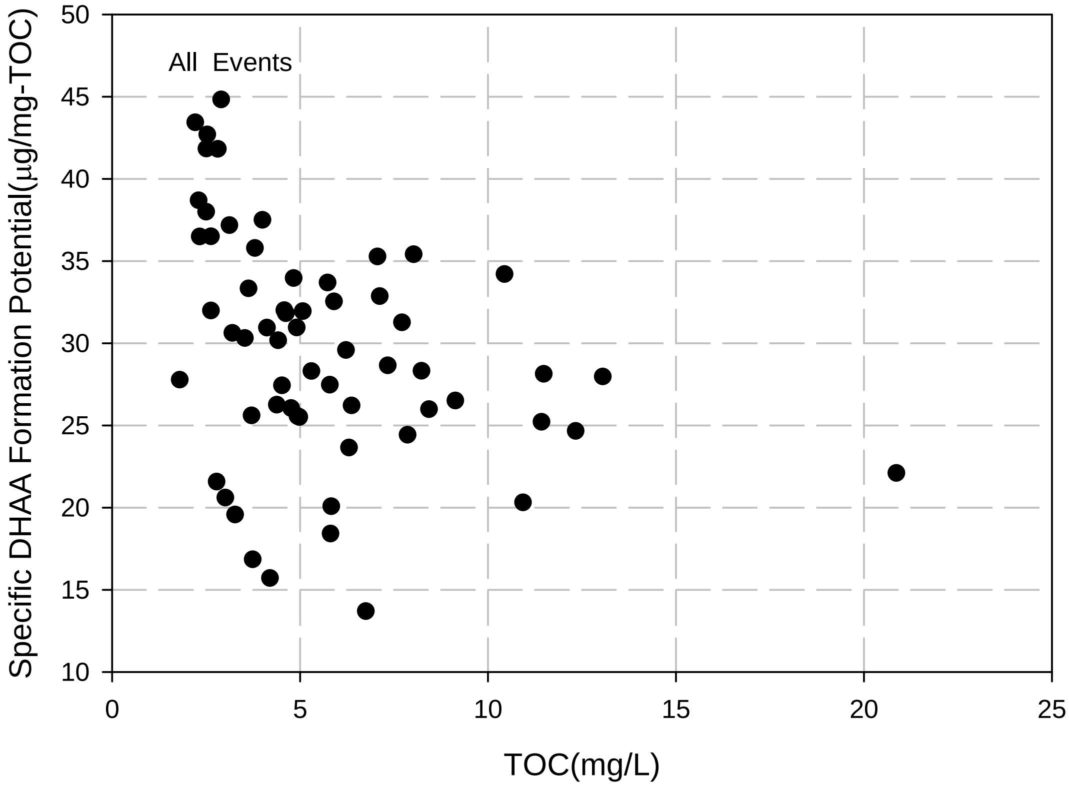


Figure 5.11 Specific DHAAFP vs. TOC for All Events (n=61)

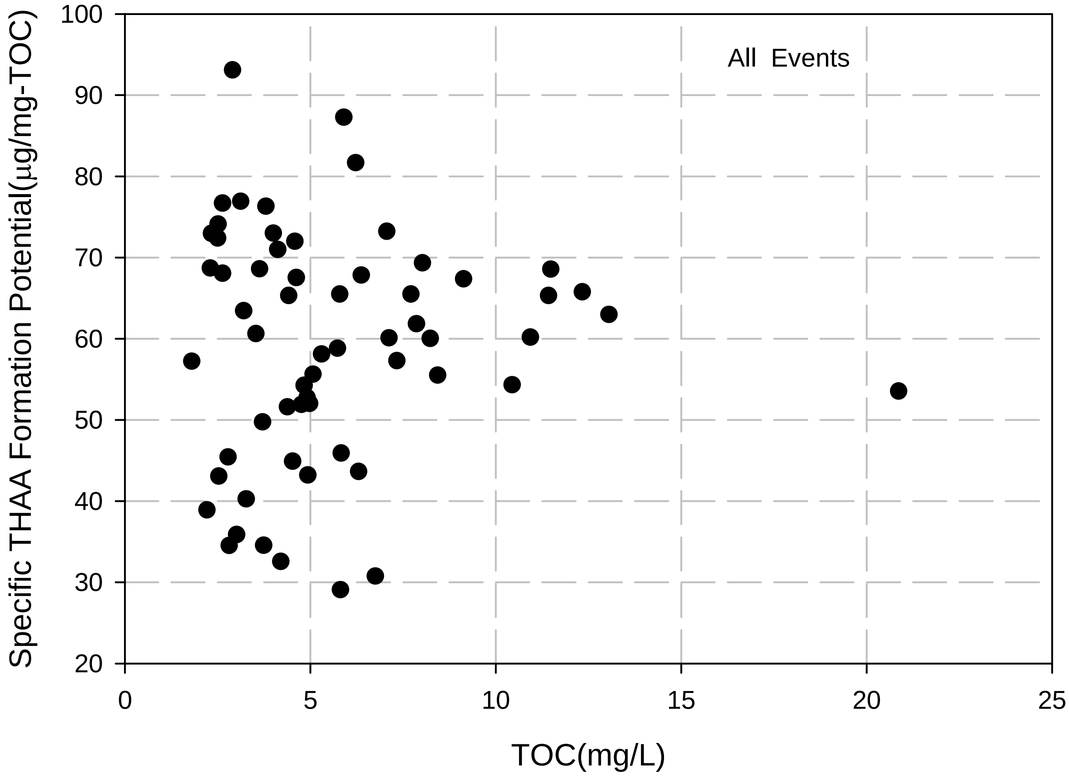


Figure 5.12 Specific THAAFP vs. TOC for All Events (n=61)

The correlations between specific THM Formation Potential and UV-254 are shown below in Figure 5.13. No apparent correlation existed in these two parameters. Simliar relationships existed in specific DHAA Formation Potential vs. UV-254 and Specific THAA Formation Potential vs. UV-254.

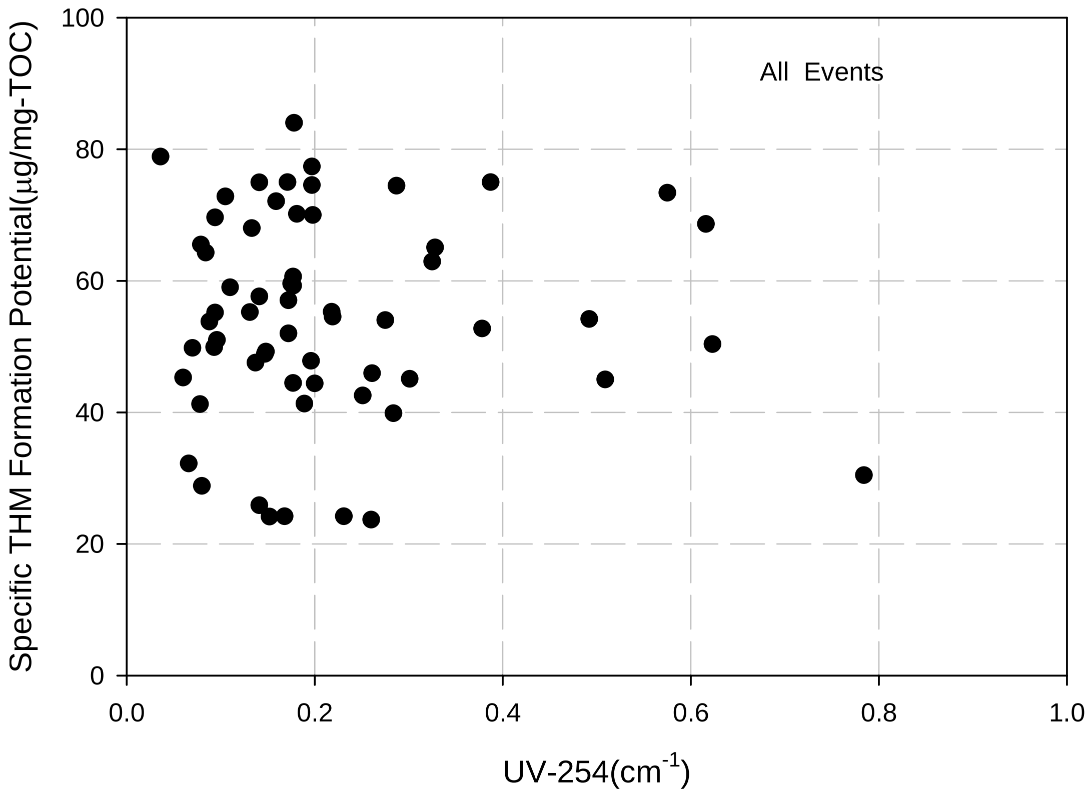


Figure 5.13 Specific THMFP vs. UV-254 for All Events (n=61)

As mentioned earlier, not all aromatic carbon is equally reactive in THM formation. Thus, SUVA is a widely used surrogate for indicating the characteristics of THM precursors in source waters (Korshin *et al.* 1997, Weishaar *et al.*2003). In order to examine the variability of DBP precursor levels indicated by SUVA, correlations between specific DBP formation potential vs. SUVA were evaluated. By plotting DBP yields (specific DBP formation potential) as a function of SUVA, it was possible to relate the reactivity to both UV absorbing and non-UV absorbing dissolved organic matter (DOM) components. As shown in Figures 5.14-5.16, weak positive correlations existed between specific DBP formation potential levels and SUVA. The best positive correlations existed between specific THAAFP and SUVA, with a linear correlation coefficient r^2=0.33. In contrast, moderate to strong linear correlations between specific DBP formation potential levels and SUVA were seen in other studies (Liang and Singer 2001, Kitis 2004). Kitis (2004) concluded that SUVA is a good predictor of the DOM reactivity with chlorine in terms of THMs and HAA9 yields and individual DBP species.

Several studies also showed a poor correlation between specific DBP formation potential levels and SUVA values (Garvey 2000, Fram *et al.* 1999). The weak correlation between specific DBP formation potential levels and SUVA in this study indicates that the variability of NOM reactivity with chlorine is not accounted for by SUVA. Several studies have suggested that the reactivity of NOM in water is subject to significant spatial and temporal variations which are not well represented by SUVA (Fram *et al.*1999, Weishaar *et al.*2003). Weishaar *et al.* (2003) concluded that since they had correlated SUVA with NMR aromaticity, and SUVA was a weak predictor of DBP precursor levels, the non-aromatic (or hydrophilic) compounds play a significant role in DBP precursor levels and SUVA values do not quantify the specific DBP formation potential of these non-aromatic compounds. The lack of correlation suggested that more detailed characterization of the aromatic compounds that form THM and HAA is needed and also suggests that non-aromatic components of DOC may be significant DBP precursors in Cobble Mountain Reservoir watershed.

It also has to be noted that SUVA has also been shown to be influenced by interferences such as pH, nitrate, and iron in water samples, although these may not be significant at the ranges of these parameters in surface waters (Weishaar *etal.*2003). The SUVA values in this study showed a noticeable variability even for the same tributary. The extremely high SUVA values are suspect to be associated with iron concentration in the stream water.

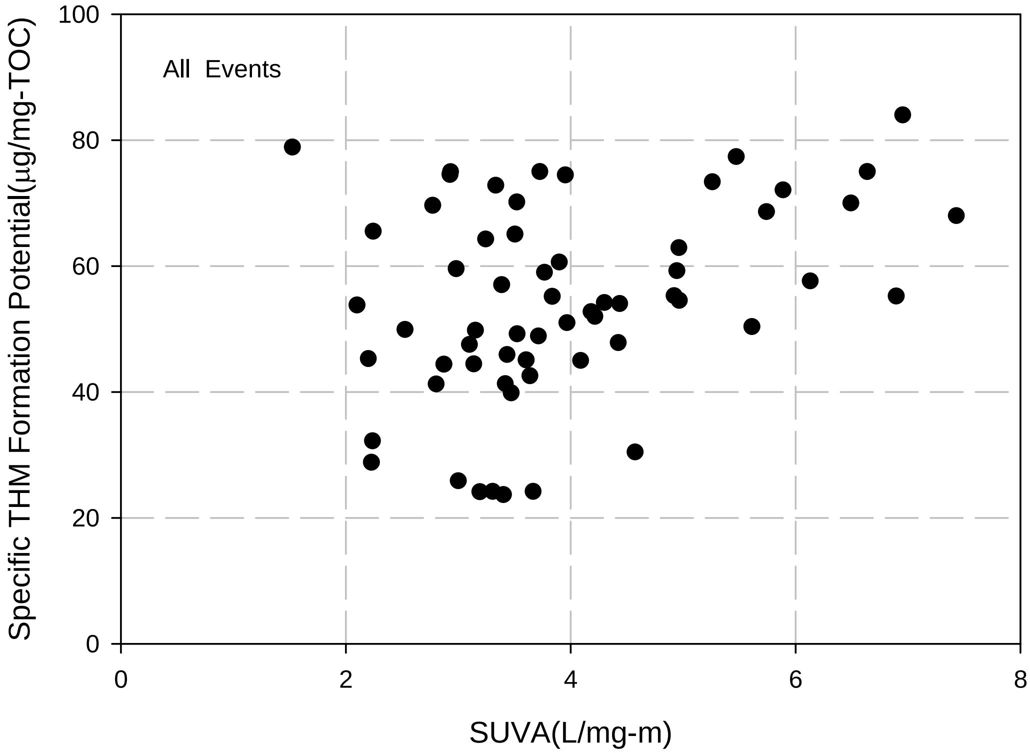


Figure 5.14 Specific THMFP vs. SUVA for All Events (n=61)

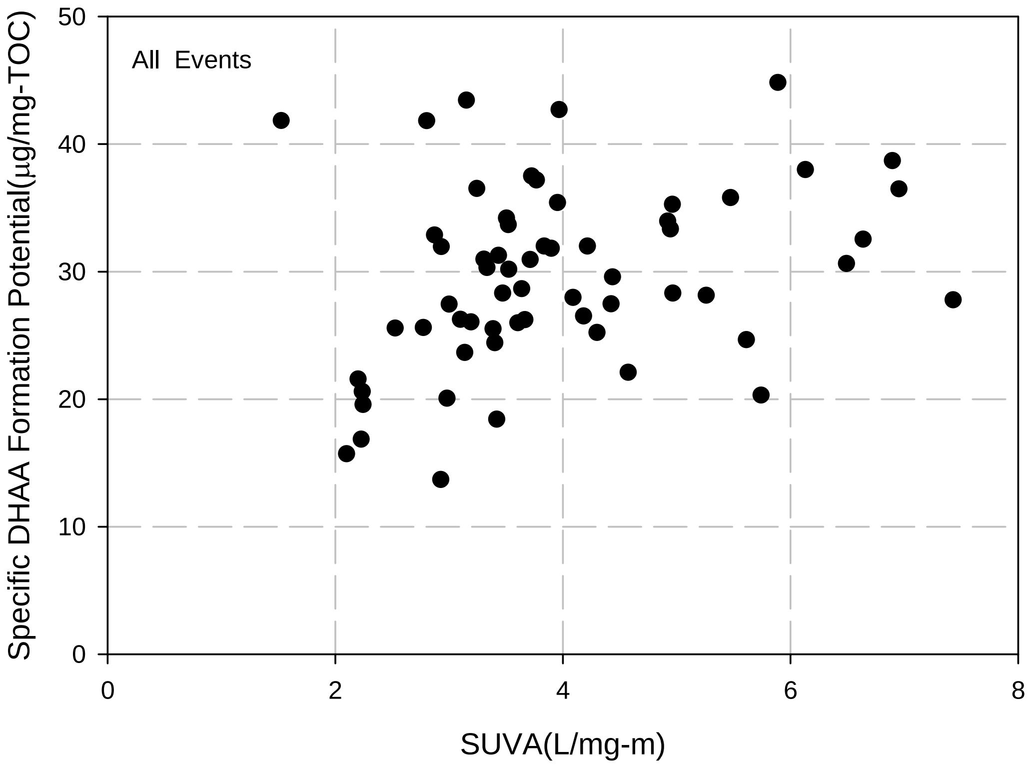


Figure 5.15 Specific DHAAFP vs. SUVA for All Events (n=61)

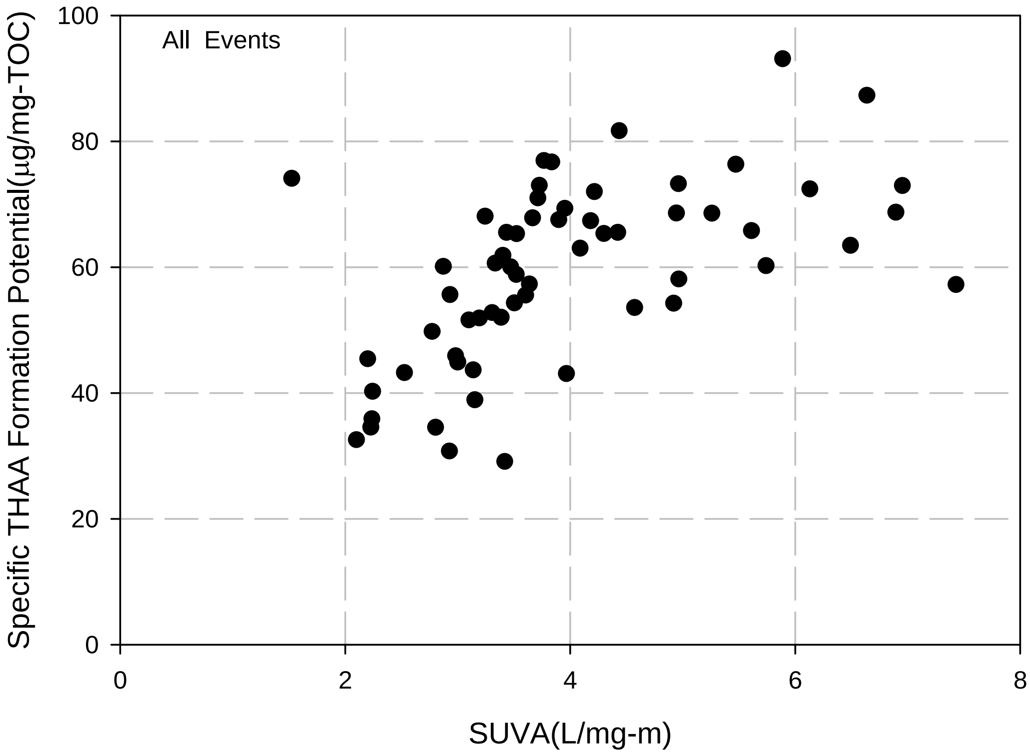


Figure 5.15 Specific THAAFP vs. SUVA for All Events (n=61)

5.2. Variation in water quality parameters

5.2.1. Variation in TOC

5.2.1.1 Temporal Variations

Alder Brook was the most frequently sampled location. All the TOC values from the watershed were normalized by dividing the values from Alder Brook on each corresponding sampling date respectively. By using the normalized data, the variations between seasons and differing hydraulic conditions between each event can be minimized and therefore those normalized data can be logically averaged. The average TOC value for Alder Brook was 5.44 mg/L, with a standard deviation of 1.88 mg/L. Figure 5.16 presents the average of normalized TOC values for downstream of each brook and the spillway of Borden Brook Reservoir.

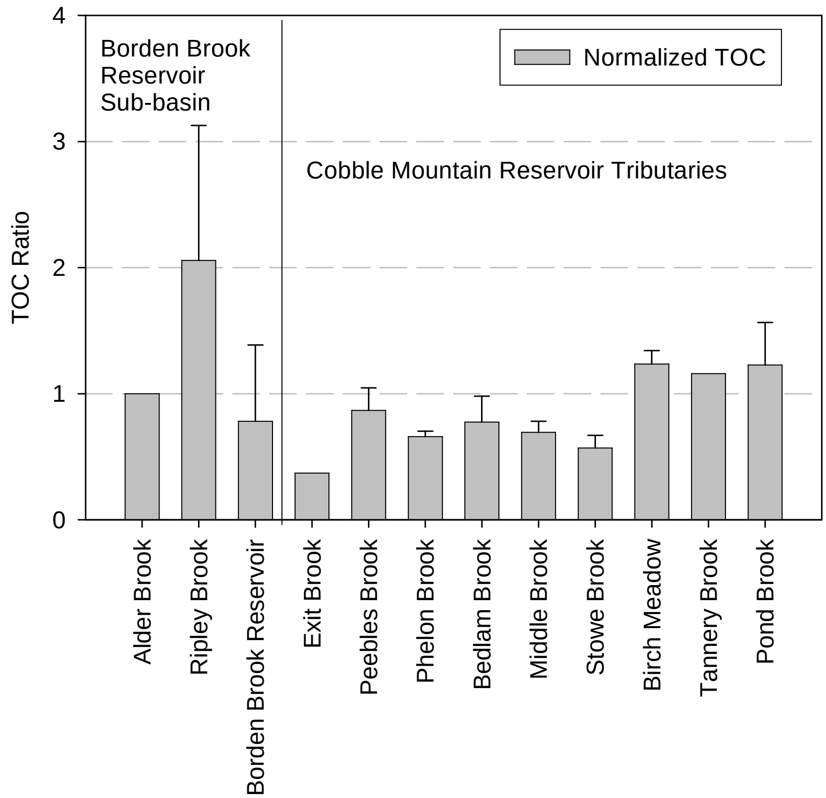


Figure 5.16 Average normalized TOC values for All Events

Ripley Brook, Pond Brook and Birch Meadow Brook are the tributaries with high TOC concentrations in the Cobble Mountain Reservoir watershed. Exit Brook had the lowest TOC levels. Ripley Brook had the highest TOC values, and the peak of around 20 mg/L was found in summer. Birch Meadow Brook and Pond Brook also had high TOC values; however seasonal variation can't be evaluated, as sampling in these two brooks was limited. Although only sampled once, Tannery showed high levels of TOC, which may be due to the large residential land use portion in the Tannery sub-basin. The large wetland area and the presence of the beaver birch meadows in the sub-basins may be responsible for the high TOC levels in Ripley Brook, Birch Meadow Brook and Pond Brook. Borden Brook Reservoir apparently had lower levels of TOC compared to its two major tributaries, Alder Brook and Ripley Brook. A substantial amount of the DOC is probably biodegraded and photolyzed in Borden Brook Reservoir because of the higher retention time, which results in lower TOC levels found in the spillway of Borden Brook Reservoir.

5.2.1.2 Variation with Temperature and Discharge

Multiple linear regressions of TOC with temperature and discharge were examined using the data set from Alder Brook. There were no discharge data available for the Cobble Mountain watershed. Instead, flow data from the nearby Westfield River was used for this analysis. No statistically significant relationship between TOC and discharge was found at a confidence level of 0.95. Typically, DOC concentrations are positively correlated with discharge, and usually show clockwise hysteresis (Steinberg 2003). Sperian (2000) found DOC concentration decreased by as much as 50% during baseflow condition in waters of the Chikahominy River basin. DOC was found to be elevated when the discharge increased in a study of Hubbard Brook Valley (McDowell, 1988). The lack of a statistically significant relationship may be due to the fact that the discharge data from Westfield River doesn't accurately reflect the discharge data for Alder Brook, Also the clockwise hysteresis may also result in the lack of correlation when sampling is not consistently done at the same point in each storm hydrograph.

The lowest TOC values were also found cold temperatures. The concentration of TOC seemed to increase as temperature increased. Peaks of TOC were found in summer, which may be due to algae growth. No statistically significant correlation was found between TOC and temperature, however.

5.2.2.1 Seasonal Variation

Seasonal variations are the results of the combining effects of temperature, precipitation and discharge. Seasonal differences were further evaluated by separating the sampling events into four seasons. TOC values for Middle Brook, Peebles Brook, Alder Brook, and Ripley Brook were used for this analysis. Seasons defined for sampling events are listed in Table 5.1. Figure 5.17 shows the seasonal variations for these four Brooks.

Table 5.1 Seasonal Sampling Events Summary

Sampling Event	Season
September 15th, 2004 October 14th, 2005 November 4th, 2005	Fall
December 1st, 2004 December 15th, 2004 December 8th, 2005	Winter
May 4th, 2005	Spring
June 7th, 2005 June 28th, 2005 July 20th, 2005	Summer

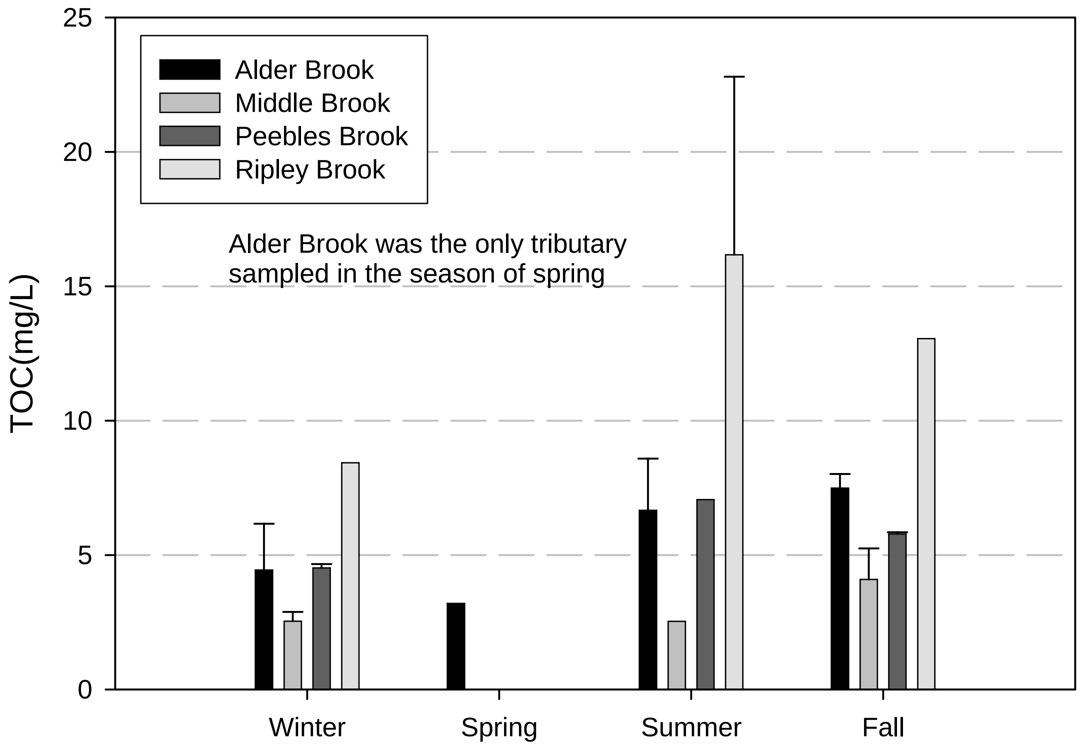


Figure 5.17 Average Seasonal TOC for Middle Brook, Alder Brook, Peebles Brook and Ripley Brook

As shown in Figure 5.17, TOC was highest in summer for all of the tributaries except Middle Brook. This is most likely due to the increase of biological production in summer. The low levels of TOC in summer for Middle Brook may be related to the low discharge and high levels of biodegradation in Middle Brook in summer time. Although several studies have shown TOC or DOC were highest during spring because of the flushing of organics stored in soil during fall and winter (Denning *et al.* 1991 and Veronica 1998), TOC values for Alder Brook during spring were the lowest compared with other seasons. This is probably because the spring sampling event was not captured immediately after an event which could flush NOM from the watershed.

The variations of DBPFP are consistent with the TOC seasonal variations. That means, higher DBPFP levels were observed during summer due to the elevated TOC values. Based on Figure 1.4 and Figure 1.5, THM and HAA5 levels were highest in SWSC distribution system during summer. This is mainly due to the fact that the rate of THM and HAA formation increases with increasing temperature and it is not necessarily the result of seasonal variations of TOC.

5.2.2. Variation in SUVA

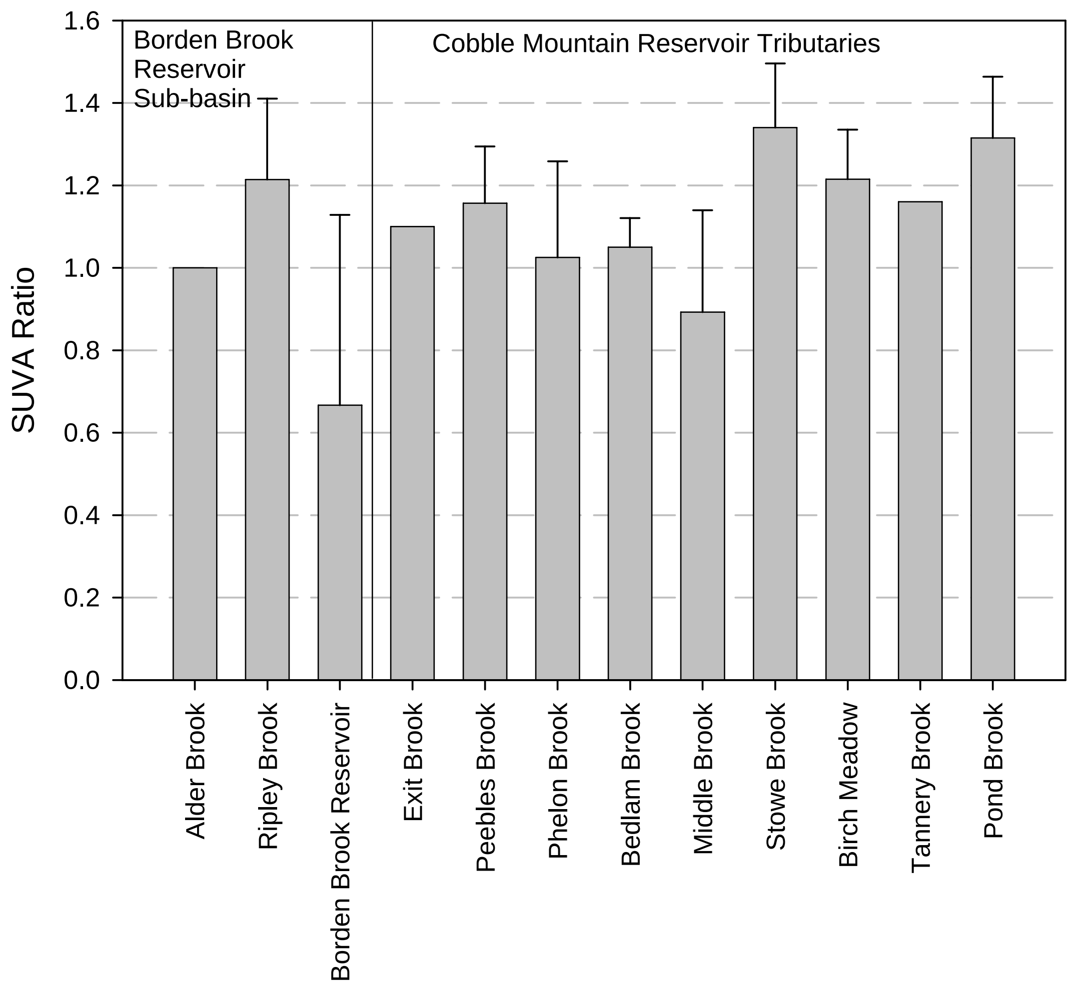


Figure 5.18 Average normalized SUVA values for All Events

5.2.2.1 Temporal Variations

Specific ultraviolet absorbance reflects the aromaticity of NOM in the water. Generally, NOM originating from woody tissues and plants tends to show higher SUVA values than NOM from algal sources. In older water, such as a reservoir, most of NOM was found to be microbially-derived and had lower SUVA, indicative of biodegradation and microbial processing, while in tributaries containing new runoff water revealed higher SUVA due to the presence of more terrestrially-derived fulvic acids (Garvey *et al.* 2003).

Specific ultraviolet absorbance values for all the major tributaries and Borden Brook Reservoir were normalized to Alder Brook. The averaged SUVA for each tributary and Borden Brook Reservoir are presented in Figure 5.18. The average SUVA value for Alder Brook is 4.4 L/mg-m, with a standard deviation of 1.3L/mg-m. This high SUVA value indicates the high aromatic content in the NOM of Alder Brook. As shown in Figure 5.18, all of the tributaries, had normalized SUVA values higher than 1, in other words, had higher SUVA values than Alder Brook, indicating NOM from all of these tributaries may originate from more woody tissue and plants than the NOM from Alder Brook. As expected, Borden Brook Reservoir had the lowest normalized SUVA, possible reflecting microbial origins and photochemical bleaching. A large standard deviation exists for this average value, which is due to the high SUVA value during a wet event during winter.

5.2.2.2 Variation with Temperature and Discharge

Statistical analysis of SUVA with either temperature data or discharge data at confidence level of 95% shows no statistically significant relationships between SUVA and these two parameters. In general, lowest SUVA values were at cold temperature and low discharge.

5.2.2.3 Seasonal Variation

Averaged seasonal values for Alder Brook, Middle Brook, Peebles Brook and Ripley Brook are presented in Figure 5.19. In general, SUVA values were higher in the spring and summer seasons. The high SUVA values during late spring season may be the result of dominant levels of plant derived NOM in the tributaries. UV-254 peaks during summer may explain the elevated SUVA.

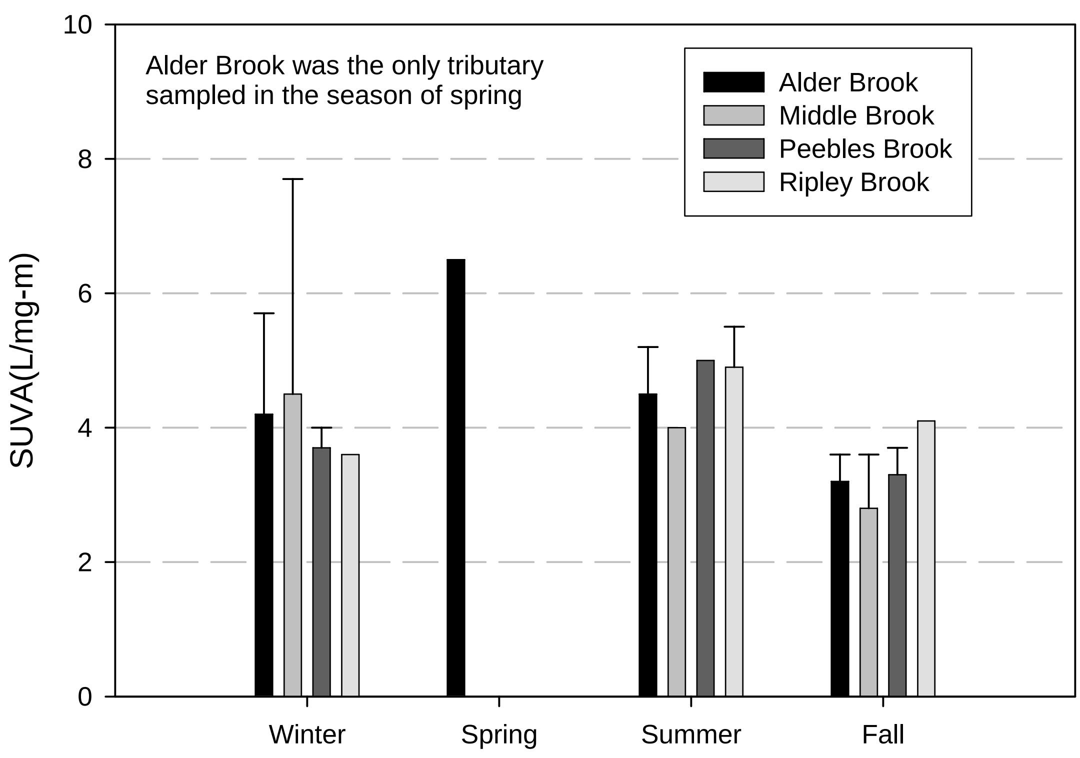


Figure 5.19 Average Seasonal SUVA for Middle Brook, Alder Brook, Peebles Brook and Ripley Brook

5.2.3. Variation in Specific THMFP

5.2.3.1 Temporal Variations

The "Alder Brook normalized" specific THMFP for all of the tributaries and Borden Brook Reservoir are presented in Figure 5.20. The average specific THMFP for Alder Brook was 54 μg/mg-TOC, with a standard deviation of 17 μg/mg-TOC. Borden Brook Reservoir had the lowest average normalized specific THMFP compared with tributaries. The specific THMFP were comparable among Cobble Mountain Reservoir Tributaries with the exception of Middle Brook and Tannery Brook. High specific THMFP levels were seen in Bedlam Brook, where THM precursors may originate from its intensive agriculture land use. In fact, Amy (2000) found that agricultural drainage water is the major source of THM precursor in the San Joaquin River delta, California.

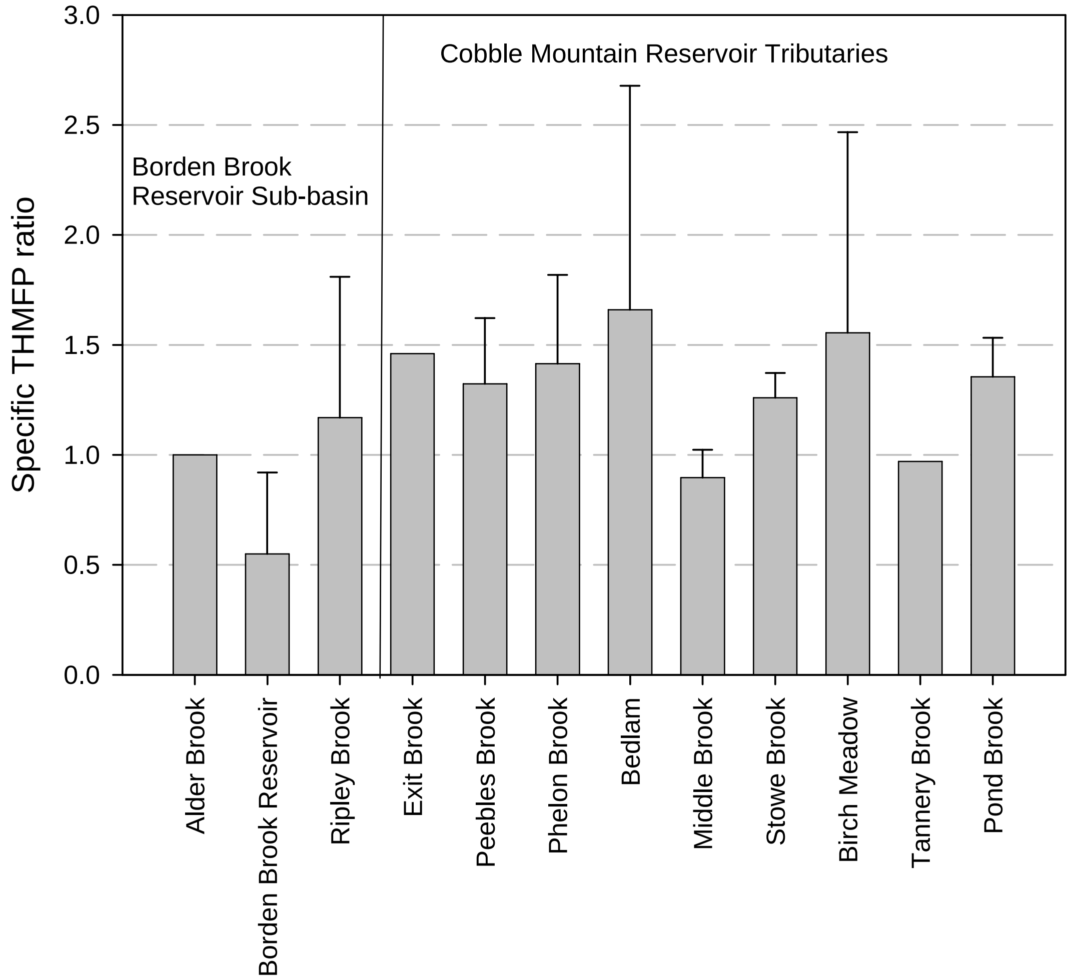


Figure 5.20 Average normalized specific THMFP for All Events

5.2.3.2 Variation with Temperature and Discharge

Multiple linear regression with temperature and discharge were analyzed. A statistically significant relationship was found for specific THMFP and discharge with a weak negative coefficient (Figure C.1 at Appendix C), suggesting that as a stream approaches baseflow conditions, the fraction of non-precursor material decreases. The extreme was seen in the October 14th, 2005 sampling event, when the discharge was about 10 times the baseflow and the specific THMFP levels were at their lowest. Specific THMFP was not found to be statistically significant (α=0.05) with temperature. However, when the effects of discharge and temperature were combined, it became evident that low specific THMFPs were observed during warm baseflow conditions. In addition, high specific THMFP levels were found during cold high flow conditions. These results suggest the importance of biodegradation of THM precursors during warm weather.

5.2.3.3 Seasonal Variation

Seasonal variation for THM precursor levels was evaluated (Figure 5.21). Middle Brook had comparable specific THMFP levels for all the seasons. The lowest THM precursor levels in winter at Peebles Brook and Ripley Brook were most likely a result of flushing of NOM dominated by neutral carbohydrates and amino sugars (Kaiser 2001), which are less ractive with chlorine. The highest THM precursor levels were observed in fall and summer at Peebles Brook and Ripley Brook. These high levels may be due to the production of aromatic NOM from decomposition process (Kaiser 2001). The peaks for specific THMFP in Alder Brook was found in spring, although NOM in spring are also believed to be controlled by leaching of fresh disrupted biomass debris with a large contribution of bacterial and fungal-derived carbonhydrates and amino sugars(Kaiser, 2001). The high specific THMFP found at the downstream site on Alder Brook may be related to the beaver dam breach in spring, which exported more THM precusors downstream. The impact of beavers and beaver impoundments on DBP precursor are elaborated in a later section.

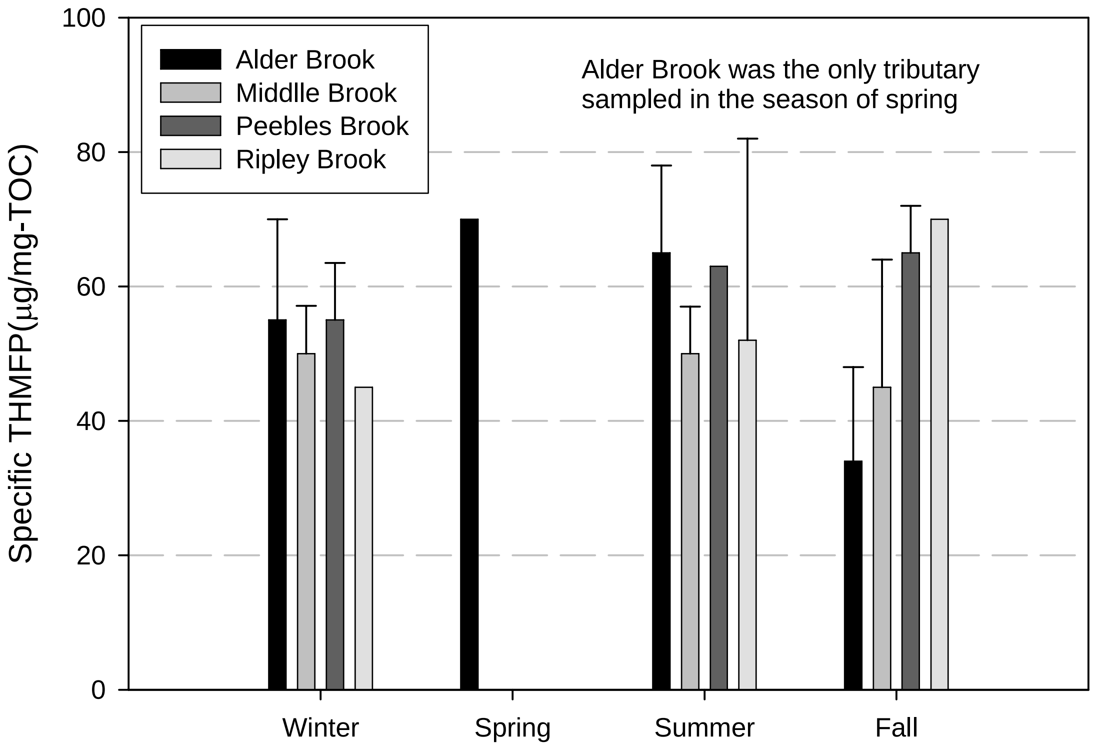


Figure 5.21 Average Seasonal Specific THMFP for Middle Brook, Alder Brook, Peebles Brook and Ripley Brook

5.2.4. Variation in Specific DHAAFP

Overall, specific DHAAFP levels are lower compared to specific THMFP levels and THAAFP levels. This is typical of most surface waters. DHAA precursors are believed to be mostly hydrophilic acids, which are less reactive with chlorine (Goslan *et al.* 2001).

5.2.4.1 Temporal Variation

The normalized specific DHAAFP levels for all of the tributaries and Borden Brook Reservoir are graphed in Figure 5.22. The average specific DHAAFP levels for Alder Brook is 32 µg/mg-TOC, with a standard deviation of 6 µg/ mg-TOC. Bedlam Brook and

Middle Brook had the lowest normalized specific DHAAFP among Cobble Mountain Reservoir tributaries, while the rest are quite comparable. In general, the Borden Brook Rerservoir sub-basin had lower specific DHAAFP levels than Cobble Mountain Reservoir tributaries.

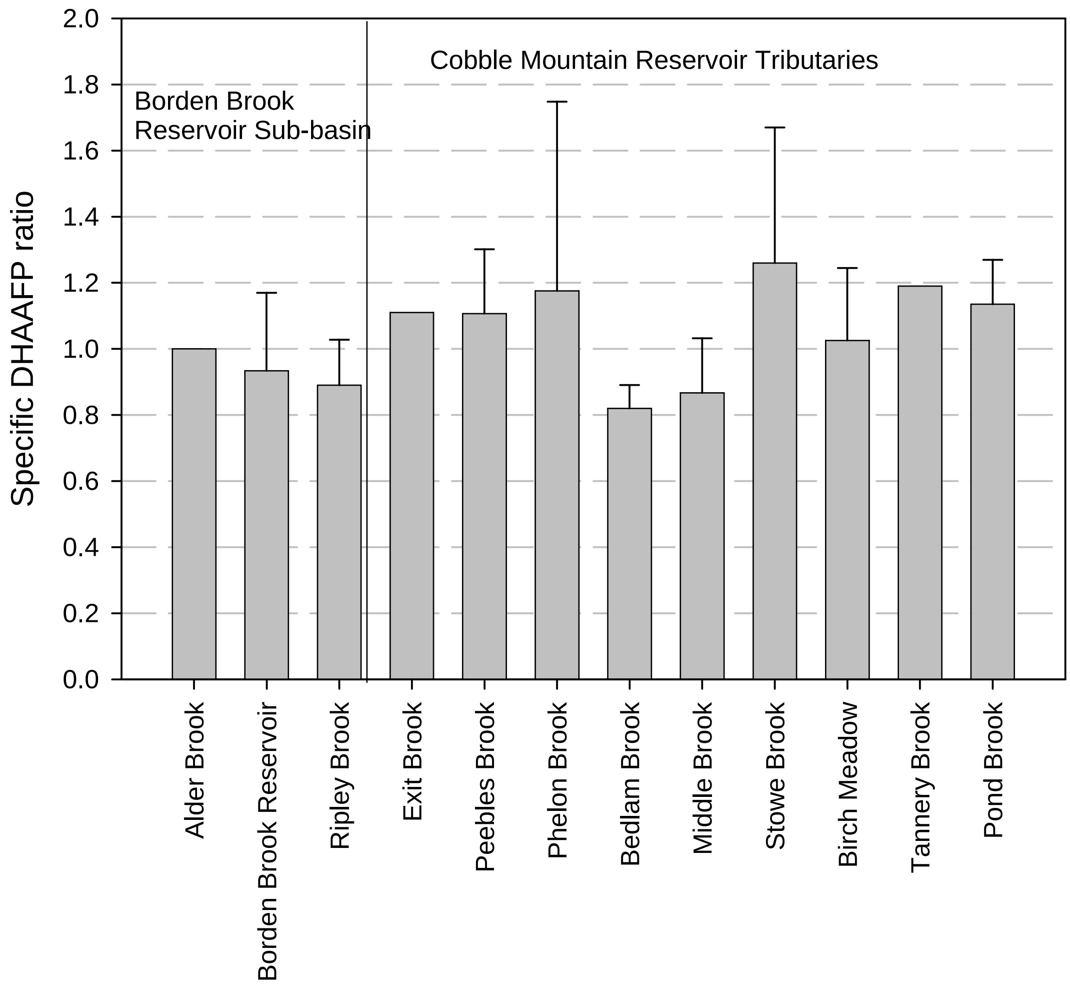


Figure 5.22 Average normalized specific DHAAFP for All Events

5.2.4.2 Variation with Temperature and Discharge

There is no statistically significant (α=0.05) relationship between either specific DHAA levels and discharge or specific DHAAFP levels and temperature. Hydrophobic acids can be selectively removed by soil profile and liable organic matter is consumed by biodegradation (Cronan and Aliken, 1985, Aikenhead-Peterson 2000), therefore, their levels are susceptible to hydraulic condition and temperature changes. However, specific DHAA precursors origniate from hydrophilic precursors and may be less susceptible to hydraulic condition and temperature changes. This may be why no correlations were found.

5.2.4.3 Seasonal Variation

The specific DHAAFP levels are seperated seasonally and shown in Figure 5.23. There is no consistent variation for all the brooks. The pattern of seasonal variations among brooks is related to the different NOM sources in these brooks. Small variations were observed for Alder Brook. Contrary to specific THMFP, specific DHAAFP in Middle Brook had a peak in summer, when it was under warm baseflow conditions.

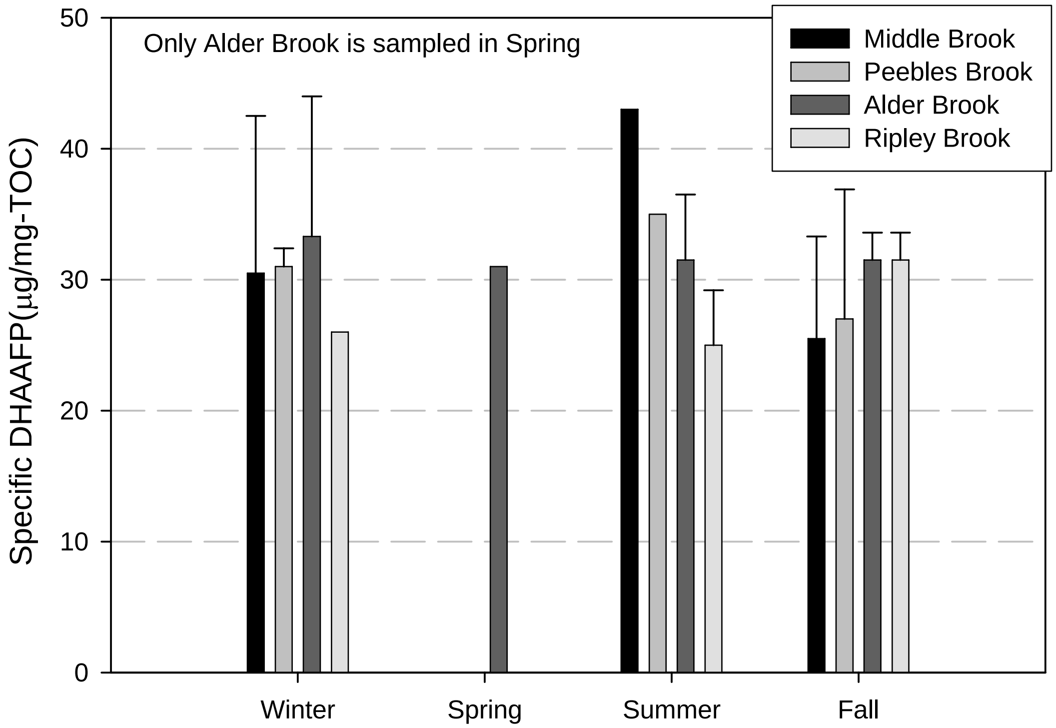


Figure 5.23 Average Seasonal Specific DHAAFP for Middle Brook, Alder Brook, Peebles Brook and Ripley Brook

5.2.5. Variation in Specific THAAFP

5.2.5.1 Temporal Variation

The specific THAAFP levels for all watershed samples are shown in Figure 5.24. The average specific THAAFP level for Alder Brook is 66 µg/mg-TOC with a standard deviation of 14 µg/mg-TOC. Higher specific THAAFP levels were seen in Cobble Mountain Reservoir tributaries than Borden Brook sub-basin except Bedlam Brook and Middle Brook, which had lowest levels of THAAFP. Stowe Brook had the highest specific THAAFP levels.

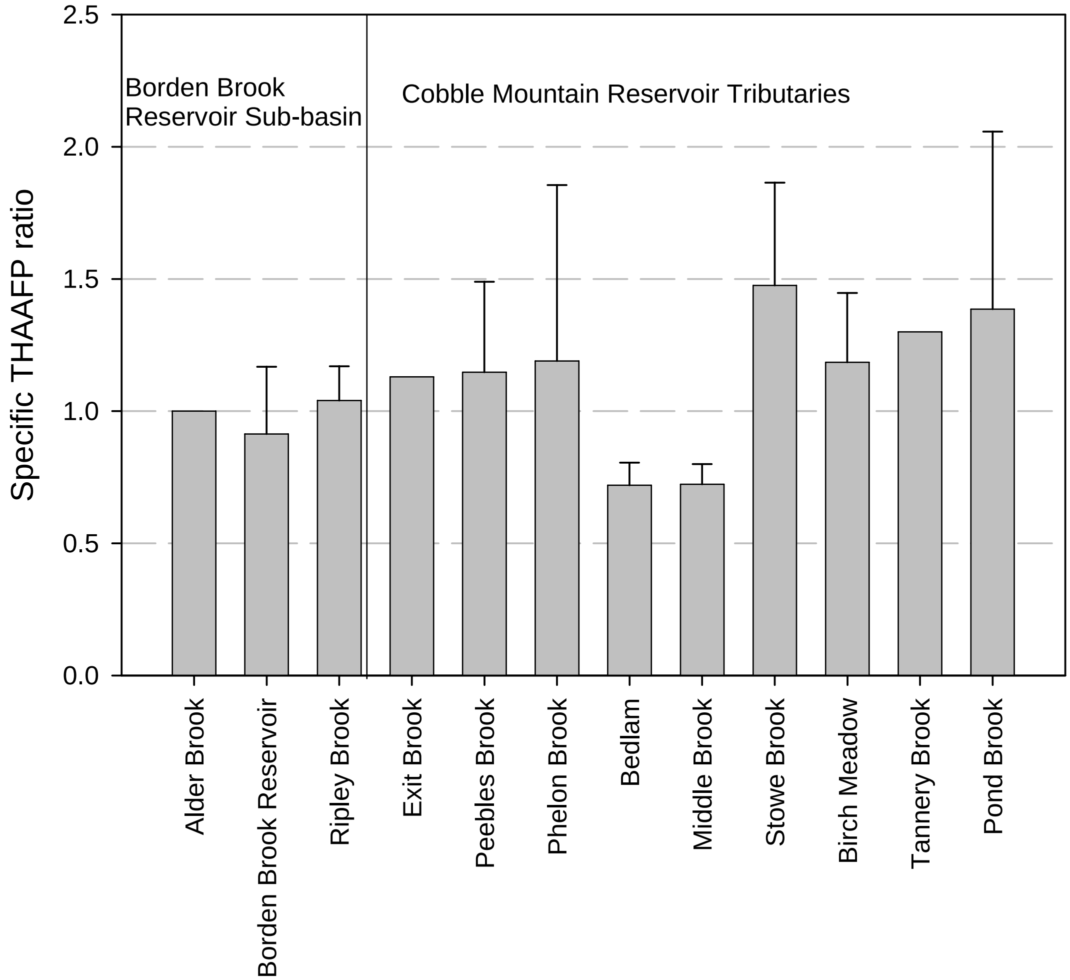


Figure 5.24 Average normalized specific THAAFP for All Events

5.2.5.2 Variation with Temperature and Discharge

Statistical anaylsis shows that there is no significant relationship between either THAA precursor levels and temperature or THAA precursor levels and discharge. However, the highest specific THAAFP levels were observed amid cold high flow weather and lowest specific THAAFP levels were seen under warm baseflow conditions. These results may indicate that THAA precursors were susceptible to biodegradation under warm and long residence time conditons, which is consistent with the findings by Speriran (2000).

5.2.5.3 Seasonal Variation

Seasonal THAA precursor levels for Alder Brook, Middle Brook, Peebles Brook and Ripley Brook are presented in Figure 5.25. As shown in Figure 5.25, Alder Brook and Ripley had comparable specific THAAFP levels over the four seasons; big standard deviation in winter may be the result of captured rain event, which caused the flushing of THAA precursors. Peebles Brook had highest THAA precursor levels in summer while Middle Brook had lowest THAA precursor levels in summer. These seasonal variations among tributaries may be the result of different THAA precursor origins.

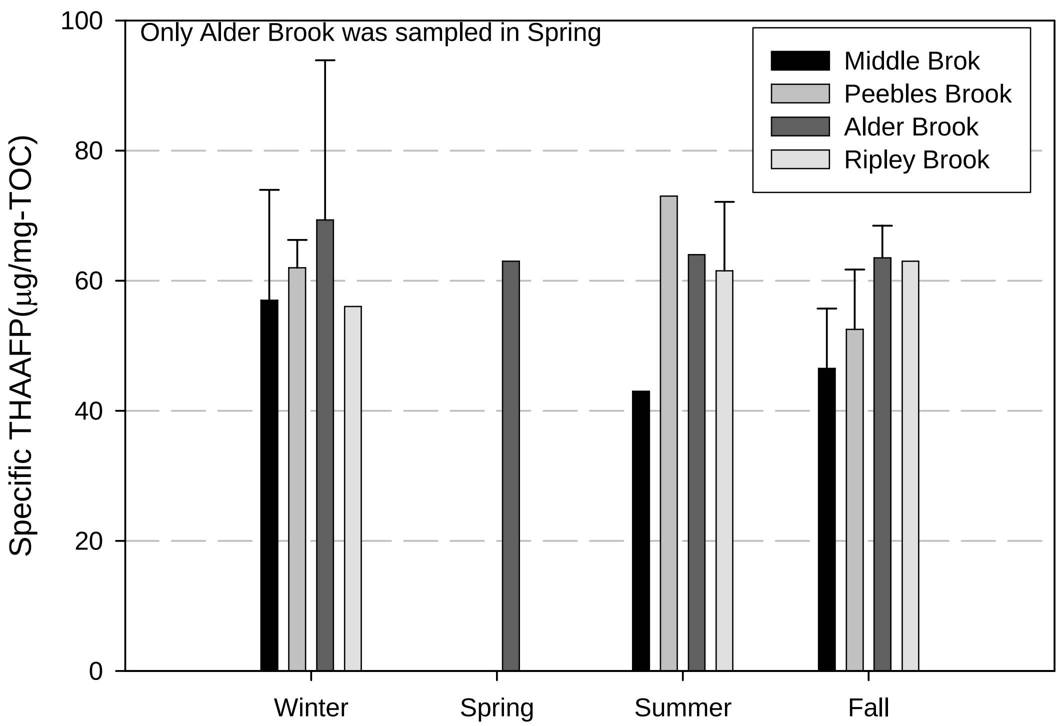


Figure 5.25 Average Seasonal Specific THAAFP for Middle Brook, Alder Brook, Peebles Brook and Ripley Brook

5.3. Effects of landuse on NOM levels

Land-use, among other factors, changes the oxidative and hydrological regimes of soils and therefore it is an important factor in NOM export levels. Amy (1990) found that agriculture runoff is the major source of THM precursor in San Joaquin River delta, California. Randtke *et al*. (1988) also mentioned the significance of agriculture runoff as a source of precursor materials. Wetlands and wetland soils are often the source of much DOC input to lakes and streams (Hemond 1990, Dosskey and Bertsch 1994), even though they may occupy only a small percentage of the catchment area (Dosskey and Bertsch 1994, Hinton *et al.* 1998). For this reason, correlations between land use and TOC, SUVA and specific DBPFP were evaluated using both the "Alder Brook" normalized data and the data from December 15^{th}, 2004 sampling event. This sampling event was characterized by high discharge and flushing of organic matter from the entire watershed. The land use information compiled for this watershed is listed in Appendix B.

5.3.1. Catchment size

Correlations between tributary catchment size and TOC, SUVA and specific DBPFP were investigated. No statistically significant correlation exists between catchment size and these water quality parameters. This may be due to the biogeochemical difference among catchments. However, Inamdar (2006) found as catchment size increases, the export of DOC concentration increases. Bryan (2005) in her master thesis found that there was a possible decrease in DOC as watershed size increased.

5.3.2. Type of land use

5.3.2.1 Wetland

Major land use types include forest, wetland, agricultural, residential and urban. Multiple linear regressions between land use area percentage and TOC, SUVA and specific DBPFP were analyzed statistically. The analysis shows that there is a statistically significant correlation between TOC and percentage of wetland in the watershed (Figure C.2 at Appendix C). The correlation coefficient is positive, indicating as wetland percentage increases, the TOC export increases as well. In fact, wetland environments and the water that discharges from wetlands contain abundant amounts of DOC (Thurman 1985). Positive correlations between DBPFP and wetland percentage also exist (Figure C.3-Figure C.4 at Appendix C). A specific link between wetlands and DBP precursors in source water is demonstrated by results of a study of DOC and DBP precursors in surface water used for a public supply in Virginia (Speiran 2000). These results showed that DOC and DBP precursors were leached from organic-rich litter in a wetland floodplain during storm events and that the subsequent discharge to streams likely accounted for large concentrations of both DOC and DBP precursors in streams. DOC derived from less decomposed anaerobic wetland soils probably would have high precursor content. There are no apparent correlations between either SUVA or specific DBPFP and wetland percentage. Research found that wetland-dominated watersheds had high SUVA and specific DBPFP (Fleck *et al.*2004).

5.3.2.2 Forest

Forest percentage was found to be correlated with THMFP with a positive coefficient, which is smaller than the correlation coefficient for wetlands. Although the possible increase of THMFP with increasing forest percentage, it should be noted, forest type is not considered in this analysis.

5.3.2.3 Agriculture

As mentioned earlier, agriculture runoff can be a major source of precursors. Multiple linear correlations showed that there is a statistically significant correlation between THMFP and percentage of agriculture area in each sub-basin with a positive coefficient.

5.3.2.4 Urban

There are no statistically significant correlations between water quality parameters with percentage of urban land.

5.3.2.5 Residential

Positive correlation between percentage of residential land use and THMFP levels are statistically significant.

5.3.2.5 Summary

Overall, land use is responsible for NOM export in the watershed. Multiple linear regressions showed that wetland percentage can be an important indicator of precursor export level. Forest, agriculture and residential percentages also exhibited possible positive correlations with NOM levels. However, the type of forest and the mean slope of each tributary also may contribute to the differences of NOM export across tributaries and needs to be considered in further evaluations of land use.

5.4. Impact of Beavers

Although there have been few studies focused on this issue, research did show DOC levels to be elevated in beaver ponds and in the wetlands beavers construct (Lovley and Philips 1986). The impact of beavers can be an important factor on water quality in watersheds. As with other northeastern watersheds, tributaries in the Cobble Mountain Reservoir watershed are intensively affected by beavers. Among the tributaries sampled, Middle Brook, Stowe Brook, Ripley Brook, Alder Brook, Birch Meadow Brook, Pond Brook and Peebles Brook have either beaver activities or beaver birch meadows. Based on section 5.2, those tributaries tend to have higher TOC and DBPFP levels than other tributaries, except Middle Brook, although it has a series of beaver impoundments. In order to further understand the impact of beavers on NOM quantity and quality, samples were taken from upstream and downstream of the beaver impoundments or beaver ponds, which exist on Alder Brook, Middle Brook, Stowe Brook, Ripley Brook and Peebles Brook. The detailed sampling locations have been provided in Chapter 4.

5.4.1. Impact on TOC

The first sets of upstream and downstream samples were taken at Stowe Brook and Alder Brook on December, 1st, 2005. Although, this was a high flow wet event; water collected downstream of beaver impoundments tended to have lower TOC levels than water upstream. Beaver impoundments seemed to act as a sink of TOC and therefore they had a positive impact on lowering the TOC levels apparently.

Alder Brook was then sampled and monitored at upstream and downstream locations from December 2004 to December 2005. The TOC levels from upstream and downstream location on Alder brook are shown in Figure 5.26.

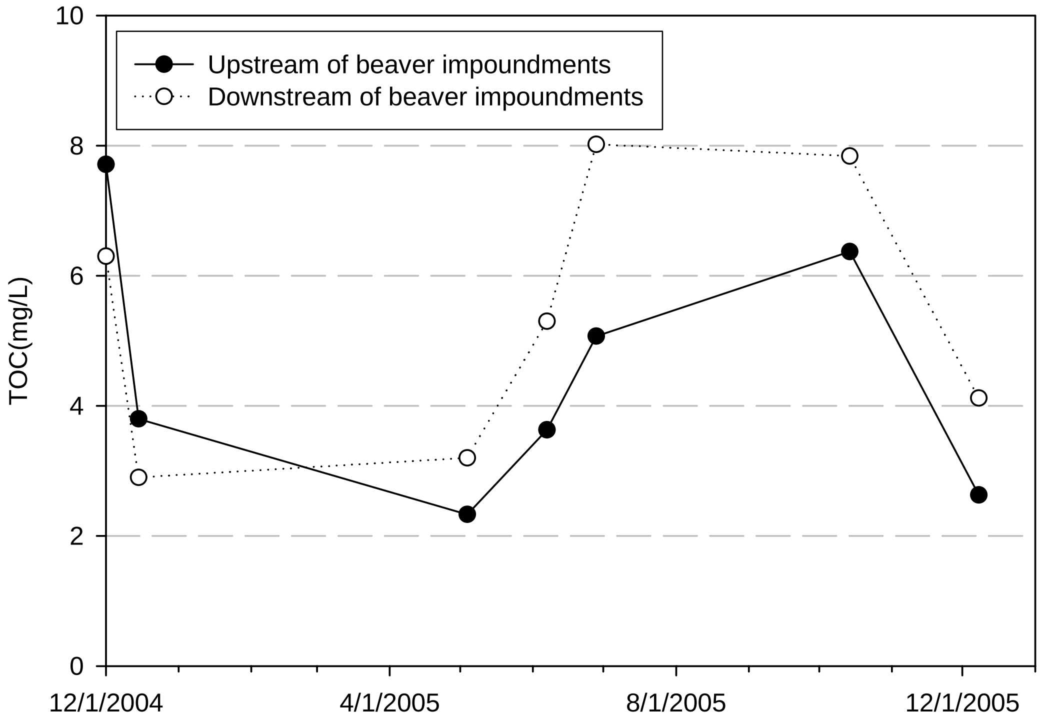


Figure 5.26 TOC levels at locations upstream and downstream of beaver impoundments at Alder Brook

As shown in Figure 5.26, downstream water had lower TOC levels than upstream water in the two events during winter 2004, which were both under high flow conditions, indicating beaver impoundments in Alder Brook mainly act as a sink of TOC. The decrease in downstream TOC may have been the result of either dilution or the retention and uptake of DOC by biotic and abiotic factors. The snowmelt and high flows in early spring of 2005 led to a breach of the beaver dams in Alder Brook. Consequently, the trend presented above reversed by the May 4th, 2005 sampling and higher TOC levels were observed downstream. Figure 5.27 shows the breached beaver dam in Alder Brook. The breaching of beaver dams may have produced large volumes of water moving at greater than normal velocities and released considerable amounts of trapped DOC. Although beavers are quick to repair the damaged beaver dam, no repair was seen at Alder Brook, As a result, the beaver impoundments become drained, and likely the beaver impoundments seem to have been abandoned by beavers. Elevated TOC values were seen after the breaching of beaver dam, and this lasted through 2005. The drained beaver impoundment may have resulted in exposure of accumulated sediments following abandonment of the site, which may be responsible for the long term elevated TOC downstream.

Figure 5.27 Breached dam in Alder Brook (June, 2005)

Samples were also taken upstream and downstream of a beaver pond at Ripley Brook, and higher TOC levels were measured at the downstream location. It should be noted, these sampling events were conducted only after the beaver dam was breached, and the upper part of the beaver dam was still intact. Therefore, dam failure may be a reason for the heavy TOC export at Ripley Brook, but this cannot necessarily be concluded as there were no paired samplings before the dam failure .The dam failure will create a domino effects when the water released destroys other dams downstream and thereby leading to the release of DOC stored behind the first beaver dam and behind those dams that were subsequently ruptured by the flood wave (Hillman 2004). Studies by Hillman *et al.* (2004) showed catastrophic beaver dam failure on Rocky Creek, Alberta, Canada may have caused the transportation of large amounts of DOC downstream. The breaching of beaver dams converted the beaver impoundments at Alder Brook and Ripley Brook to partially drained ponds and they probably represent beaver impoundments in their declining stage.

Peebles Brook is characterized by a series of big beaver ponds and beaver birch meadows. No recent beaver activities were seen in this tributary over the sampling period, and it can be viewed as having mature beaver ponds, which are beginning to drain. Higher TOC levels were always observed at the downstream locations on each of the three sampling events: July 20th, 2005; November 4th, 2005; December 8th, 2005 (all were low discharge events). The average level of TOC level was 3.51mg/L in the upstream locations, while TOC averaged 5.12 mg/L in the downstream location.

Middle Brook is a small stream having a series of beaver impoundments and intensive beaver activities. TOC levels in upstream and downstream sites on Middle Brook are presented below. Beaver impoundments seemed to act as a sink of NOM and helped decrease the TOC levels downstream of the impoundment. The extreme was seen during July 20th, 2005, which was under base flow condition. The longer retention time under these conditions and accompanying greater levels of biodegradation and photolysis may explain the larger difference. Downstream of the impoundment on Middle Brook the water had lower TOC levels than upstream except October 14th, 2005 sampling event, which was an extremely high flow conditions.

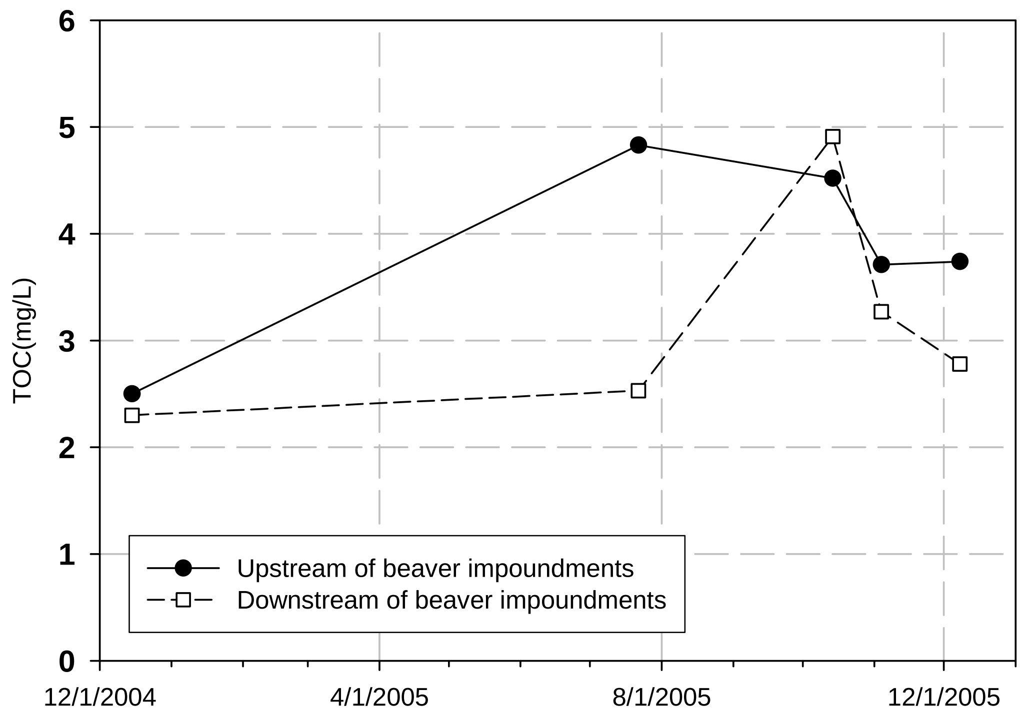


Figure 5.28 TOC levels at locations upstream and downstream of beaver impoundments at Middle Brook

5.4.2. Impact on DBPFP

The impact of beavers and beaver impoundments on DBPFP were investigated. Since DBPFP correlated positively with TOC, the trend for DBPFP is expected to be similar to that of TOC. The THMFP levels for upstream and downstream locations on Alder Brook are shown in Figure 5.29. The beaver impoundments seemed to have lowered the THMFP in the downstream waters of Alder Brook until May 4th, 2005 sampling event, which was after the time the beaver dams had been breached and at this point the trend had reversed. It is quite likely that the snowmelt brought out considerable THM precursor-rich organic matter stored in the beaver impoundments.

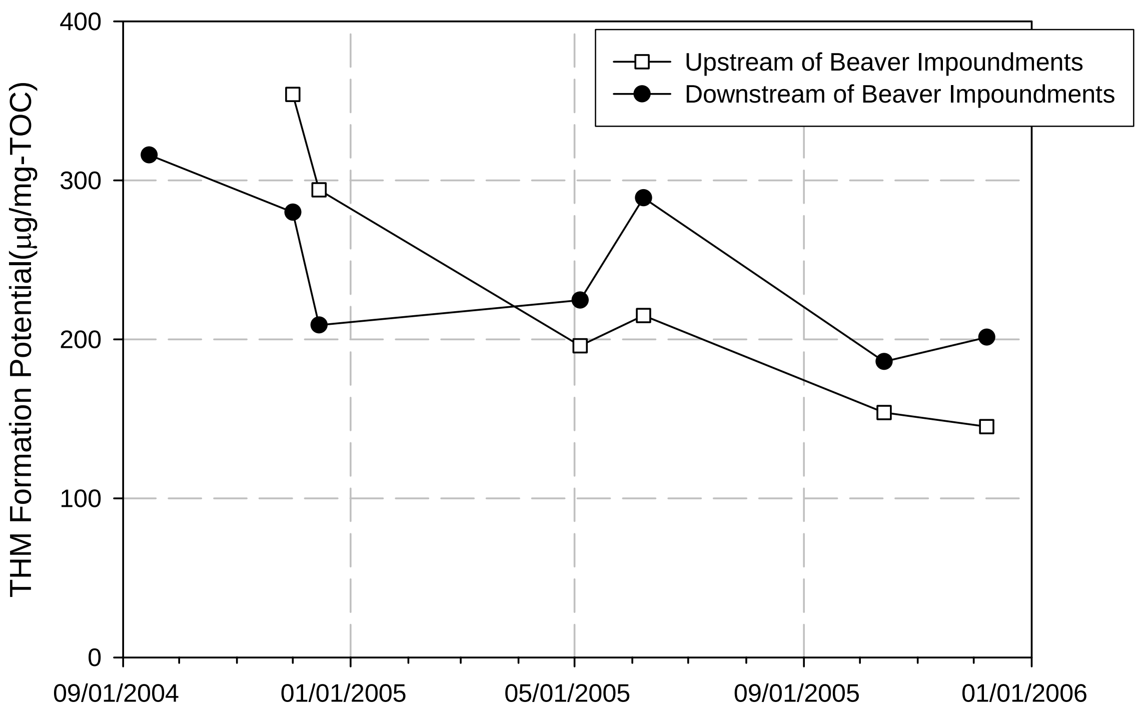


Figure 5.29 THMFP levels at locations upstream and downstream of beaver impoundments at Alder Brook

Dihaloacetic acid formation potential and trihaloacetic acid formation potential levels are presented in Figure 5.24 and Figure 5.25 respectively. As shown in Figure 5.30 and Figure 5.31, DHAAFP and THAAFP levels are lower or almost equal to downstream of beaver impoundments at Alder Brook as compared to upstream. As with the THMFP, the breaching of the beaver dams at Alder Brook reversed the trend; however, the elevated DHAAFP and THAAFP are not as obvious as THMFP. This may indicate the breaching of beaver dams at Alder Brook brought out more THMFP precursors than either

DHAAFP precursors or THAAFP precursors at that point. Downstream samples from Alder Brook did show more apparently elevated DHAAFP and THAAFP levels afterwards.

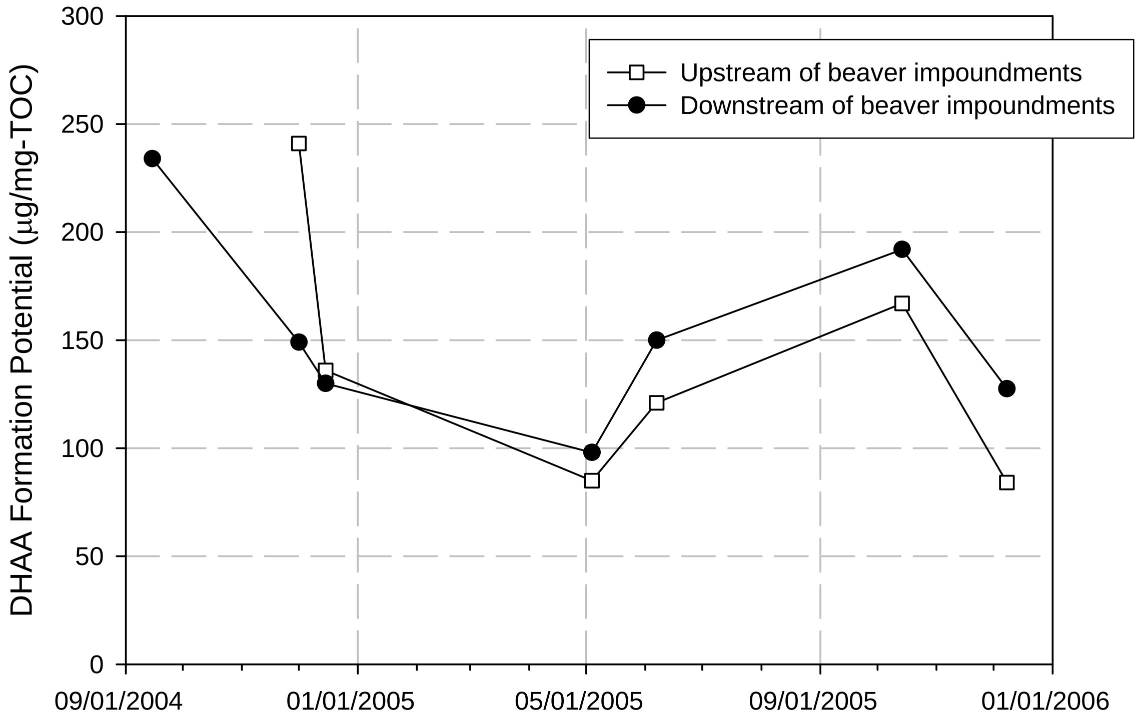


Figure 5.30 DHAAFP levels at locations upstream and downstream of beaver impoundments at Alder Brook

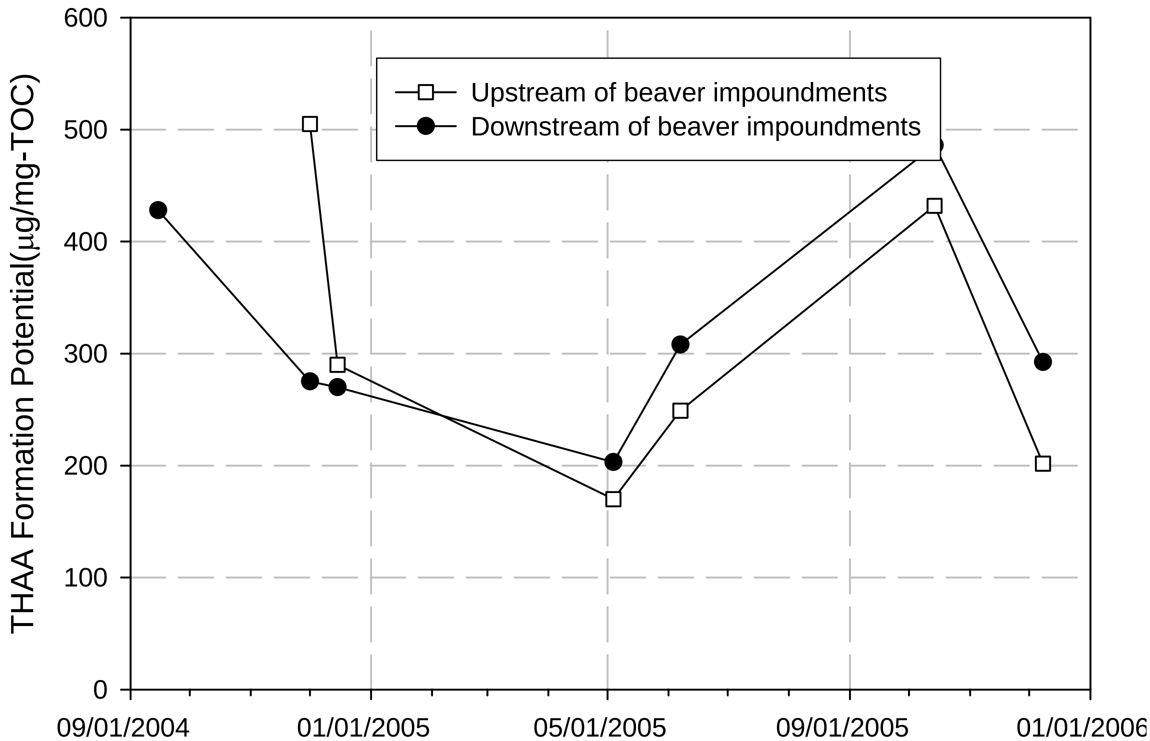


Figure 5.31 THAAFP levels at locations upstream and downstream of beaver impoundments at Alder Brook

Both Peebles Brook and Ripley Brook always had higher DBPFP levels in the downstream sample. The DBPFP levels for upstream and downstream of the beaver impoundment at Peebles Brook and Ripley Brook are shown in Table 5.2 and Table 5.3 respectively.

Table 5.2 DBPFP levels at locations upstream and downstream of beaver ponds at Peebles Brook

	Peebles Brook			
	Upstream	**S.D.**	**Downstream**	**S.D**
THMFP(μg/L)	171	78	282	92
DHAAFP(μg/L)	92	36	125	12
THAAFP(μg/L)	117	28	278	15

Table 5.3 DBPFP levels at locations upstream and downstream of beaver ponds at Ripley Brook

	Ripley Brook			
	Upstream	**S.D.**	**Downstream**	**S.D**
THMFP(μg/L)	686	91	739	146
DHAAFP(μg/L)	263	58	392	98
THAAFP(μg/L)	474	299	952	233

The THMFP levels for Middle Brook are shown in Figure 5.32. In general, downstream of Middle Brook beaver pond the water had lower DBPFP, except for the high flow events in October 14^{th}, 2005 and December 8^{th}, 2005. The THMFP levels in downstream samples are slightly higher or almost equal to the levels measured for upstream samples. Highest THMFP reduction was seen in summer, which may be attributed to the longer retention time and higher biodegradation rate in the beaver impoundments during summer.

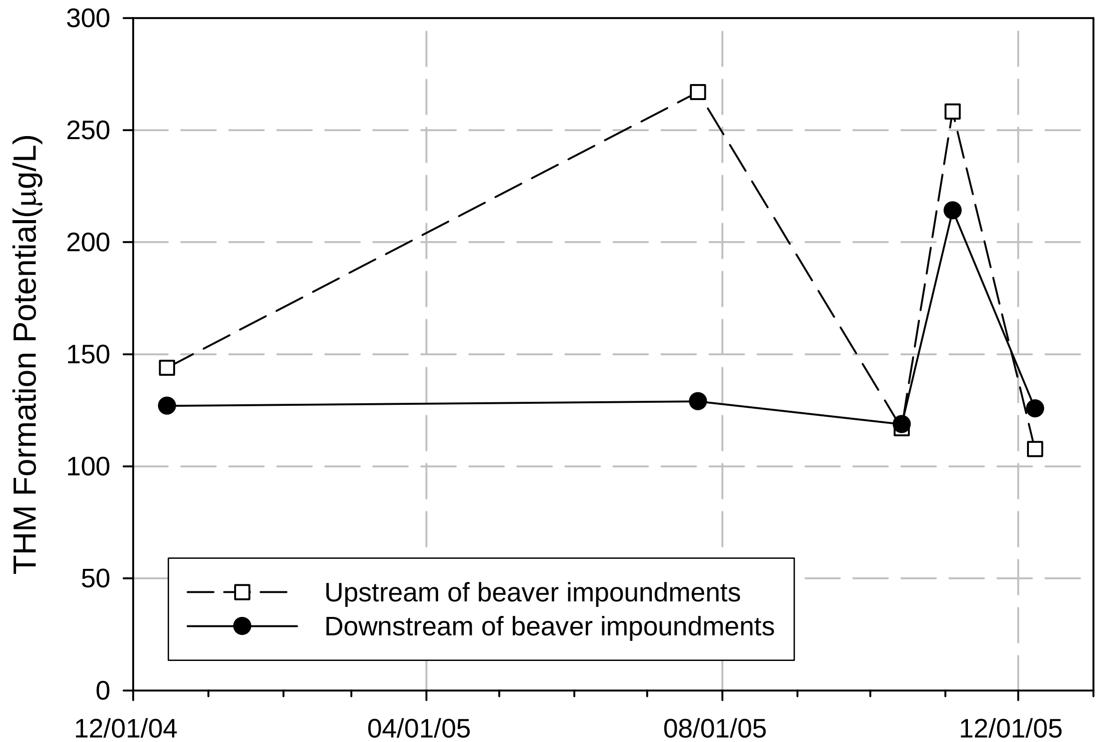


Figure 5.32 THMFP levels at locations upstream and downstream of beaver impoundments at Middle Brook

Dihaloacetic acid formation potential and trihaloacetic acid formation potential levels are presented in Figure 5.33 and Figure 5.34 respectively. Dihaloacetic acid formation potential and trihaloacetic acid formation potential showed lower concentrations in downstream samples, except for October 14th, 2005, an extremely high flow sampling event. Apparently much higher DHAAFP and THAAFP levels are seen downstream of the beaver impoundments. It should be noted, there were no big differences between THMFP levels at upstream and downstream locations on Alder Brook at that sampling event. This indicates the high flow brought out more NOM from beaver impoundments dominated by DHAA and THAA precursors.

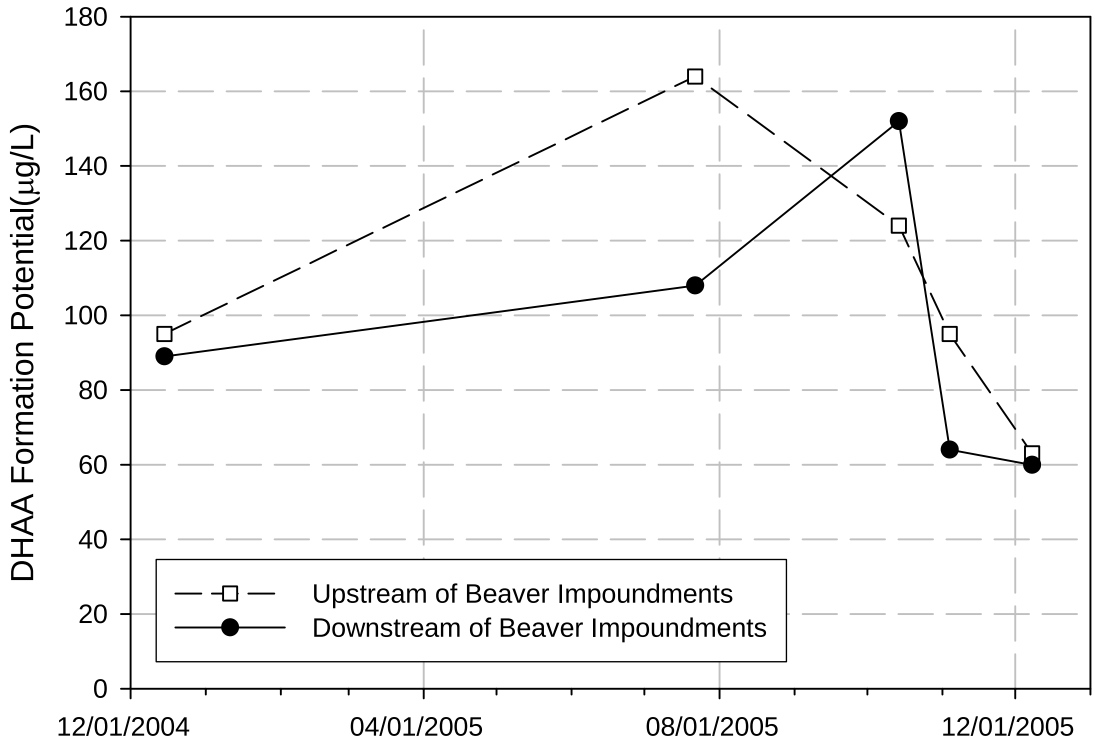


Figure 5.33 DHAAFP levels at locations upstream and downstream of beaver impoundments at Middle Brook

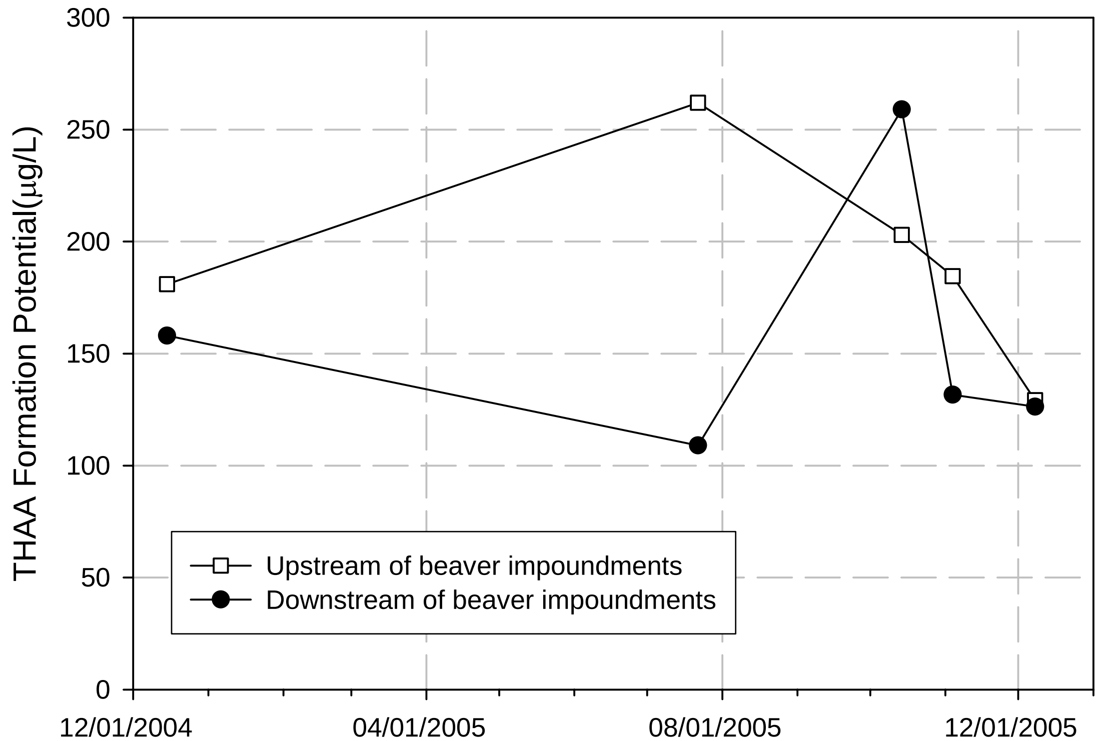


Figure 5.34 THAAFP levels at locations upstream and downstream of beaver impoundments at Middle Brook

5.4.3. Impact on Specific DBPFP

The specific THMFP levels are shown in Figure 5.35. The specific THMFP levels are comparable between upstream and downstream locations on Alder Brook. Nevertheless, there is a trend toward lower specific THMFP in the downstream location after the beaver dams were breached, which may result from the flushing of old NOM in the beaver impoundments.

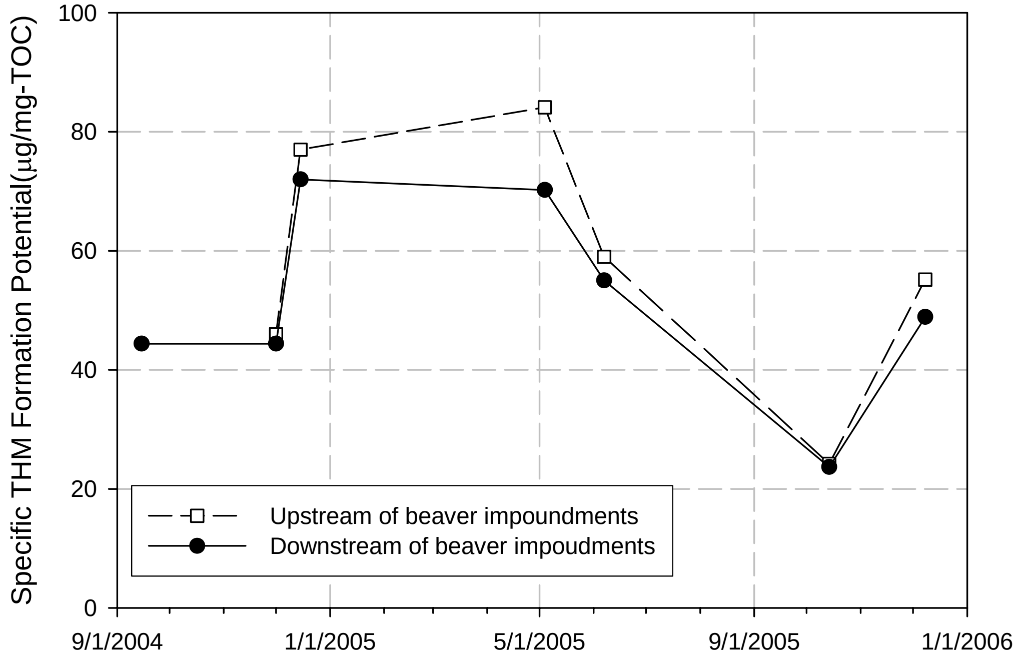


Figure 5.35 Specific THMFP levels at locations upstream and downstream of beaver impoundments at Alder Brook

The specific DHAAFP and specific THAAFP levels for Alder Brook are shown in Figure 5.36 and Figure 5.37 respectively. Downstream of beaver impoundments at Alder Brook tended to have water with lower specific DHAAFP and THAAFP than upstream except for the May 4th, 2005 sampling event and the October 14th, 2005 sampling event. Breaching of the beaver dams by snowmelt may bring some fresh NOM behind the beaver dam and cause a short-term elevated specific DHAAFP and THAAFP level in the downstream location. The beaver impoundments began to drain after the beaver dam failure and water flow may have brought out a considerable amount of older NOM, which had been leached and biodegraded for quite a while in the beaver impoundment, thus causing DHAA and THAA yield to decrease. However, the reverse trend was seen for

DHAA at October 14th, 2005 sampling event. The extreme high flow may bring out fresher NOM from the banks and elevated the specific DHAAFP.

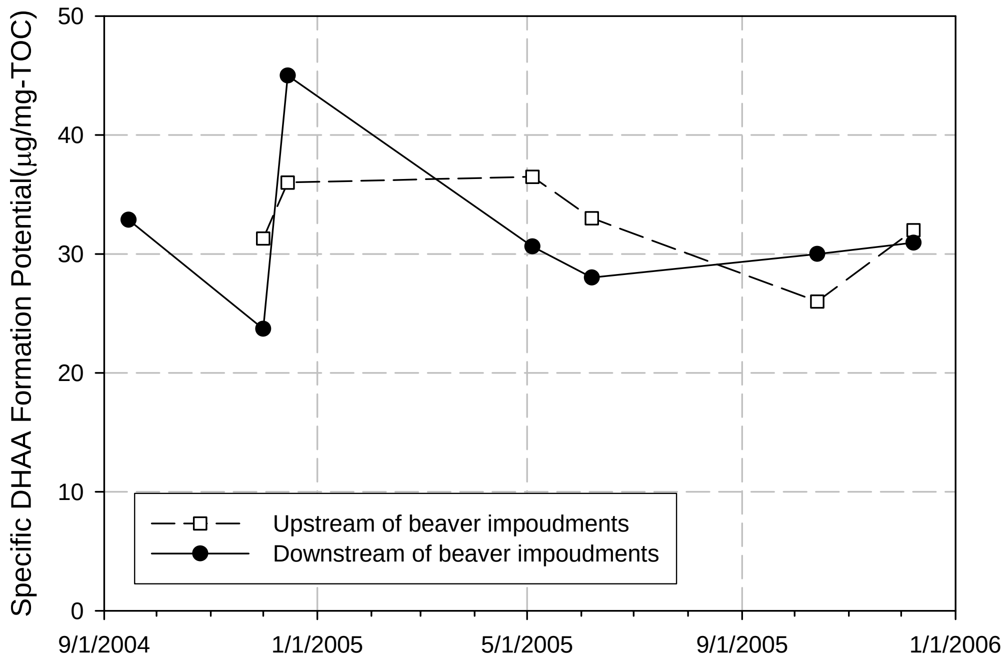


Figure 5.36 Specific DHAAFP levels at locations upstream and downstream of beaver impoundments at Alder Brook

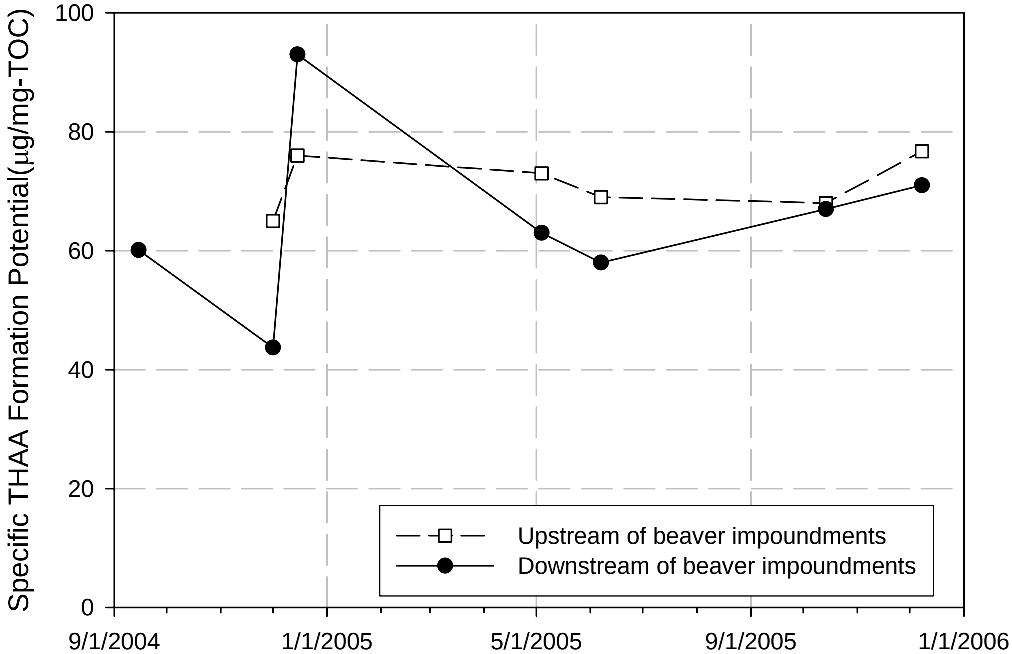


Figure 5.37 Specific THAAFP levels at locations upstream and downstream of beaver impoundments at Alder Brook

Specific DBP formation potential levels for Peebles Brook are listed in Table 5.4. The specific DBPFP levels are comparable for upstream and downstream sampling locations. Apparently higher specific trihalomethanes and specific trihaloacetic acids were measured for downstream of beaver ponds at Peebles Brook. However, downstream of beaver ponds at Peebles Brook tended to have lower specific dihaloacetic acids than upstream.

Table 5.4 Specific DBPFP levels for locations upstream and downstream of beaver ponds at Peebles Brook

	Peebles Brook			
	Upstream	**S.D.**	**Downstream**	**S.D**
SpTHMFP(µg/mg-TOC)	48	7	57	7
SpDHAAFP(µg/mg-TOC)	34	15	28	8
SpTHAAFP(µg/mg-TOC)	34	1	61	14

Specific DBP formation potential levels for Ripley Brook are listed in Table 5.5. Higher specific THMFP and THAAFP were always observed for downstream of beaver ponds at Ripley Brook. Lower specific DHAAFP levels were seen in downstream of Ripley Brook.

Table 5.5 Specific DBPFP levels for locations upstream and downstream of beaver ponds at Ripley Brook

	Ripley Brook			
	Upstream	**S.D.**	**Downstream**	**S.D**
SpTHMFP(μg/mg-TOC)	48	9	54	7
SpDHAAFP(μg/mg-TOC)	29	18	25	7
SpTHAAFP(μg/mg-TOC)	34	1.4	59	14

The specific DBPFP levels in Middle Brook were evaluated. Specific THMFP levels are presented in Figure 5.38. Lower levels of specific THMFP were seen at Middle Brook downstream for all sampling events, except for October 14^{th}, 2005. As mentioned previously, the high flow in this event caused the flushing of fresh NOM downstream, which tended to have higher chlorine reactivity than the older NOM, therefore, it introduced higher specific THMFP precursors, which minimized the difference between upstream and downstream water quality.

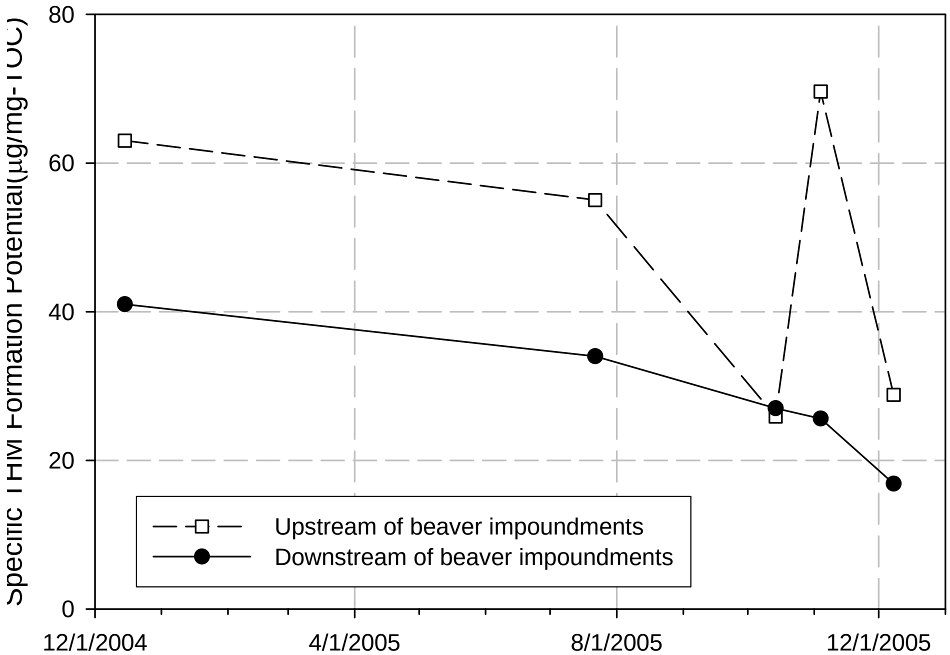


Figure 5.38 Specific THMFP levels at locations upstream and downstream location of beaver impoundments at Middle Brook

Specific DHAA formation potential levels for Middle Brook are presented in Figure 5.39. The relationships between upstream and downstream specific DHAA formation potential values fluctuated. Higher specific DHAAFP levels at downstream Middle Brook tended to respond to high flow conditions. The higher specific DHAAFP at downstream Middle Brook during summer may result from the leaching of fresh NOM brought by beavers to the beaver impoundments. The fresh NOM may be highly enriched in DHAAFP precursors.

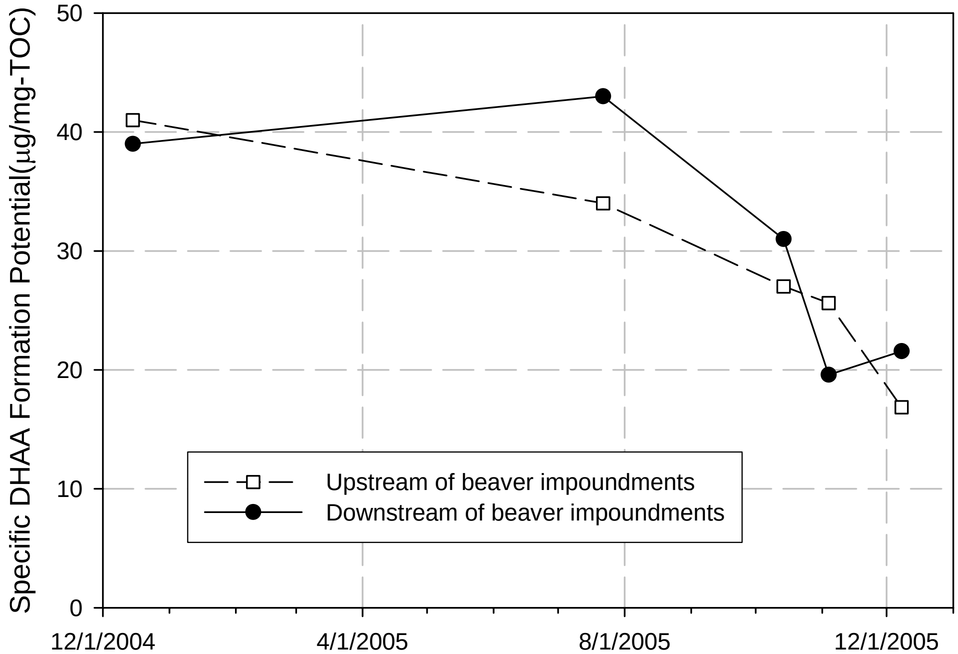


Figure 5.39 Specific DHAAFP levels at locations upstream and downstream of beaver impoundments at Middle Brook

The specific THAAFP levels are presented in Figure 5.40. Downstream location of the Middle Brook beaver dams tended to have water with lower specific THAAFP levels as compared to upstream of the beaver dam. The trend reversed at two high -flow sampling events.

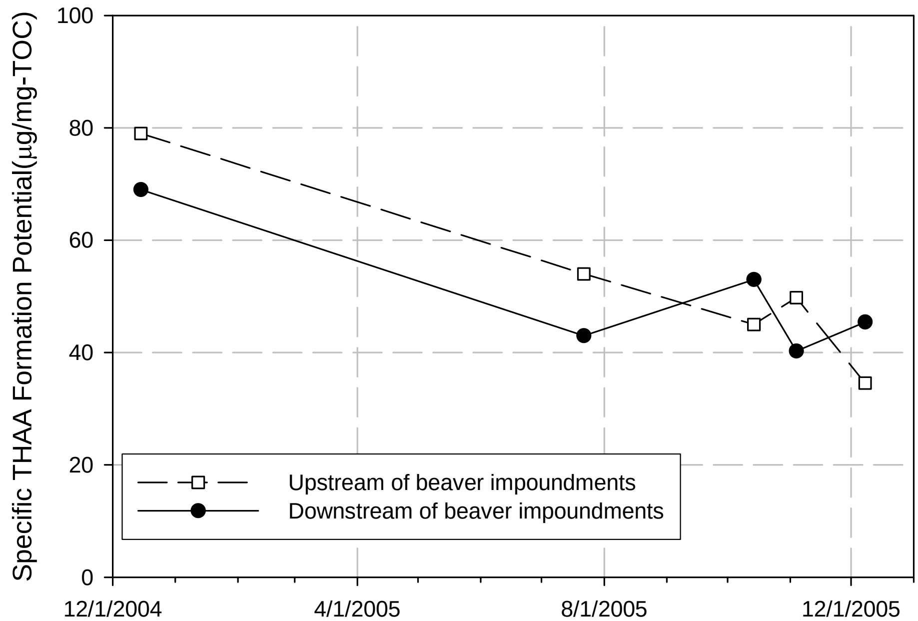


Figure 5.40 Specific DHAAFP levels at locations upstream and downstream of beaver impoundments at Middle Brook

5.4.4. Summary

Beavers and beaver impoundments probably have profound impacts on water quality in the Cobble Mountain Reservoir watershed. "The balance between a pond acting as a net sink or source of nutrients to downstream communities appear to be equivocal, depending on pond age, ecological maturity, channel morphology and other factors related to the maintenance of system properties" (Naiman et al, 1994). Lower TOC values were observed downstream of intact beaver impoundments with active beaver populations, which may result from the longer retention time, leading to greater microbial-uptake of NOM in the impoundments themselves. Under these conditions, beaver impoundments appear to be an ecologically desirable attribute for improvement in water quality. However, beaver impoundments tended to export NOM to downstream waters after the dam was breached and began to drain. The flushing of the organic debris stored behind the dam and more exposure to sediments can explain the elevated NOM levels found in downstream locations of beaver impoundments. These breached sites had been already been converted or were in the process of being converted to beaver birch meadows, which tend to export NOM to downstream waters (possibly due to high levels of macrophytes and other forms of primary productivity). The high flow can bring the organic debris of beaver dams and the debris torn out of the banks to the downstream waters, and elevate the TOC levels. The DBPFP showed a similar trend as for TOC. However, after the breaching of the beaver dam, more DHAAFP and THAAFP precursors than THMFP precursors were brought to the downstream locations. The precursors downstream tend to be dominated by very old NOM from the beaver impoundments, which had lower chlorine reactivity. The results also showed that the quality of DBPFP precursors also depend on flow conditions. Higher levels of specific DBPFP were seen under high flow conditions.

5.5. Conceptual Model

In light of the variation of DBP precursor levels for tributaries impacted by beavers, a conceptual model was formulated to help focus our current understanding of the impact of beaver on water quality during the beaver pond natural life cycle.

In the early stages of a beaver pond, beaver dams are constructed on tributaries and a large volume of stream water becomes impounded. The beaver dams are made of branches and leaves, and are rich in organic matter. The leaching of organic debris behind the dam can be an important source of DOC. For this reason, NOM levels are expected to be higher downstream of fresh beaver impoundments.

When the build up work is finally finished, the beaver ponds can be said to be mature. The beaver ponds increase the water surface area and lower the flow velocity. The mature beaver impoundments are characterized by a longer retention time. Particulate NOM forms and settles, becoming trapped in the sediments. Photodegradation and biodegradation of NOM takes place in the beaver impoundments to a greater extent than in the flowing stream. Therefore, lower levels of NOM are expected in the downstream water.

This desirable attribute lasts for a while until all the available food and materials used to build a dam are consumed. The beavers then leave their present locations and the beaver dam will no longer be repaired. Nevertheless, abandoned beaver ponds continue to accumulate sediment from upstream waters, resulting in thicker deposits of particular organic matter, and leading to short hydraulic retention time and greater exposure of water to the sediments. The un-maintained beaver dams are also likely to be breached by high flow, especially by snowmelt in early spring. The breaching of beaver dams leads to a rapid decrease in the water level in the pond, and more exposure of the water to the sediments, which are rich in NOM. The flushing of debris though the breached dam and increasing contact with sediments lead to elevated TOC levels in the downstream water.

Finally, when the water level becomes low enough, macrophytes will grow on the rich sediments and convert the original beaver impoundments to highly productive birch meadows thereby continuing the pond-wetland-meadow succession.

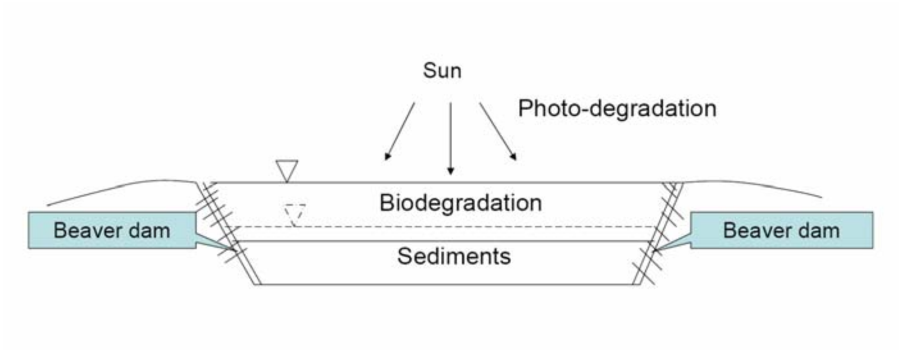


Figure 5.41 beaver pond natural life cycle.

CHAPTER 6 CONCLUSIONS AND RECOMMENDATIONS

6.1. Conclusions

6.1.1. Relationships between water quality parameters and NOM Variations in the watershed.

From the results, several conclusions can be drawn:

- Overall, DOC accounted for 96% of TOC from all tributaries and Borden Brook Reservoir samples. UV absorbance at 254nm correlated well with DOC, with an r^2=0.85. The slope for this linear correlation is 4.65L/mg-m. The NOM for most of the tributaries in the watershed have similar aromaticity, regardless of residence time or locations.
- Moderate positive correlations existed between DBPFP and TOC for all the combined data. As TOC increased, the DBPFP increased. The best correlation was seen between THAAFP and TOC, with an r^2=0.89.
- UV absorbance at 254 nm correlated better with DBPFP than TOC. The best correlation existed between THAAFP and UV-254, with an r^2=0.90. This indicates UV-254 to be a viable surrogate for DBPFP.
- Weak negative correlations between Specific DBPFP and TOC existed, with the specific DBPFP levels decreasing as TOC increased.
- No correlations were seen between DBPFP and SUVA, the highest DBPFP levels were observed at the median SUVA of 4.5.
- Moderate positive correlations were observed between specific DBPFP and SUVA.

The specific DBPFP increased as the SUVA increased.

- Ripley Brook, Pond Brook and Birch Meadow Brook had the highest TOC levels in the Cobble Mountain Reservoir watershed, while Phelon Brook and Exit Brook had the lowest TOC levels. Borden Brook Reservoir had lower TOC levels than tributaries in the sub-basin.
- Borden Brook Reservoir had the lowest SUVA values compared to the SUVA values for tributaries.
- Middle Brook, Tannery Brook and Borden Brook Reservoir had the lowest specific THMFP levels and Bedlam Brook had the highest specific THMFP levels. Bedlam Brook and Middle Brook had the lowest specific DHAAFP and specific THAAFP levels, while Stowe Brook had the highest specific DHAAFP and THAAFP levels.

6.1.2. Variations of water quality with discharge, temperature and seasonal variations

- The highest TOC values were observed for tributaries in the summer except for Middle Brook. Alder Brook had the lowest TOC values in the spring. Highest SUVA values were observed for tributaries in spring and summer. Lowest THMFP precursor levels were found in the winter for all tributaries, while the highest THMFP precursor levels were found during fall and summer. No consistent seasonal variations of specific DHAAFP and THAAFP existed for all tributaries. This indicated that different sources of DBP precursors have different seasonal variations.
- A statistically significant relationship was found between specific THMFP levels and discharge, with a negative coefficient, indicating that lower specific THMFP levels are expected for higher discharge.

6.1.3. Effects of land use on water quality

Overall, land use is a significant factor that affects NOM export in the watershed

- No statistically significant correlation existed between catchment size and water quality.
- Wetland percentage can be an important indicator of precursor export level. Higher TOC export was observed for tributaries with a larger portion of wetland.
- Forest, agriculture and residential land use portions also exhibited possible positive correlations with THMFP levels.

6.1.4. Impact of beavers

The following observations were made between changes in water quality and beaver activities.

- Beaver and beaver impoundments have profound impacts on water quality in the Cobble Mountain Reservoir watershed.
- Lower TOC values were observed for locations downstream of intact beaver impoundments with beaver activities. However, beaver impoundments tended to export NOM after the dam was breached and began to drain. In addition, birch meadows converted from beaver impoundments can be a significant source of NOM. The higher flows elevated TOC levels at locations downstream of beaver impoundments.
- More DHAAFP and THAAFP precursors than THMFP precursors were brought to the downstream after the beaver dam failure.
- Overall, specific DBPFPs were lower at the downstream of beaver impoundments.

Higher levels of specific DBPFPs were seen under high flow conditions.

6.2. Recommendations for utilities

More monitoring data are needed to finalize the best management practice for precusor control in Cobble Mountain Reservoir. Although active beaver impoundments act as an organic carbon sink, they will eventually become filled with sediments and abandoned by the beavers. The abandoned site usually converts to highly productive wetlands (e.g., high density of macrophytes), which can be a major source of natural organic matter in the watershed. Recommendations based on this study are listed below.

- Consider removing old, inactive beaver dams, before the impoundments can become birch meadows and highly productive wetlands. Care must be taken to avoid mobilizing the organic sediments.
- Consider removing active beaver dams. While, active beaver impoundments might help to improve the water quality, as beaver impoundments age, they become a source of organic matter to downstream water.
- Prevent the build up of new beaver dams. Water systems can either discourage beavers from colonizing (i.e. eliminating the preferred food of beavers (poplar, alder, willow, etc.), undermining the beaver dams (fencing out culvert beaver dams or using commercial division devices, i.e. beaver deceiver)) or trap the beavers.
- Preserve existing large reservoirs (Borden Brook Reservoir& Cobble Mountain Reservoir), which are net sinks for DBP precursors.
- Consider implementing storm water control for tributaries with drained beaver impoundments. The water system could contain a stormwater detention reservoir and

an outflow conduit from stormwater detention reservoir for conveying water from stormwater detention reservoir to a runoff channel.

- Periodic monitoring of beaver impoundments should be continued so that these recommendations and the associated conceptual model can be refined.

6.3. Recommendations for future work

- Installation of flow measuremnt devices at tributaries for acurate discharge data.
- More intensive sampling is needed to evaluate the seasonal variations of NOM in the watershed
- Capture at least one early stage beaver dam and monitor its impact on water quality. Parameters such as water levels, wetland percentage in the sub-basin of the tributary need to be recorded.
- Selection of a control tributary for the purpose of comparing the water quality changes for a tributary with beaver activity to a tributary without beavers. The control tributary should have similar length, slope, catchment size and land use as the tributary that has beaver impacts.

References

Allan, C. J., N. T. Roulet, and A. R. Hill. (1993). The Biogeochemistry of Pristine, Headwater Precambrian Shield Watersheds: An Analysis of Material Transport within a Heterogeneous Landscape. *Biogeochemistry* **22**:37–79.

Aikenhead-Peterson, Jacqueline A. (2000) "Source, Production and Export of Dissolved Organic Carbon and Nitrogen" A Doctor of Philosphy Dissertation, University of New Hampshire

Amy, G.L., J.M. Thompson, L. Tan, M.K. Davis, and S.W. Krasner. (1990) "Evaluation of THM Precursor Contributions from Agricultural Drains". *J. Am. Water Works Assoc.* **82**:57–64.

Ashbolt, Nicholas J. (2004) "Risk Analysis of Drinking Water Microbial Contamination Versus Disinfection By-Products (DBPs)". *Toxicology* **198**(1-3):255-262.

APHA; AWWA; and WPCF(1998) Standard Methods for the Examination of Water and Wastewater, 20th Edition, Washington, D.C.

Bason Christopher (2004) "Effects of Beaver Impoundments on Stream Water Quality in the Coastal Plain". M.S. Thesis, Department of Biology, East Carolina University.

Bryan (2005) "Investigation of Disinfection Byproduct Precursors in The Wachusett Reservoir Watershed" M.S. Environmental Engineering Project Report, University of Massachusetts, Amherst Department of Civil and Environmental Engineering.

Chapra, S.C., Canale, R.P., Amy, G. L. (1997) "Empirical Models for Disinfection By-Products in Lakes and Reservoir" *Journal of Environmental Engineering* **123(7)**:714-715.

Chin Y-P, Aiken, G., and O' Loughlin, E. (1994). "Molecular weight, Polydispersity, and Spectroscopic Properties of Aquatic Humic Substances". *Environmental Science and Technology* **28**:1853-1858.

Cirmo C.P., Driscoll C.T. (1993) "Beaver Pond Biogeochemistry: Acid Neutralizing Capacity Generation in a Headwater Wetland". *Wetlands* **13**:277-292.

Craun, G. F. (1984). Waterborne Outbreaks of Giardiasis, Current Status. *In Giardia* and Giardiasis, S. L. Erlandsen and E. A. Meyer (eds.). Plenum Press, New York, New York, pp. 243-261.

Cronan, C.S., Aiken, G.R. (1985) "Chemistry and Transport of Soluble Humic Substances in Forested Watersheds of the Adirondack Park, New Park", *Geochimica et Cosmochimica Acta* **49**: 1697-1705.

Denning AS, Baron J, Mast MA, Arthur M. (1991) "Hydrologic Pathways and Chemical Composition of Runoff during Snowmelt in Loch Vale Watershed, Rocky Mountain National Park, Colorado, USA". *Water, Air, and Soil Pollution* **59**: 107–123.

Davies, R. B., and C. P. Hibler. (1979). Animal Reservoirs and Cross-species Transmission of Giardia, p. 104-126. In W.Jakubowski and J. C. Hoff (ed.), Waterborne transmission of giardiasis. U.S. Environmental Protection Agency, Cincinnati, Ohio.

Devito KJ, Dillon P.J, Lazerte BD. (1989) "Phosphorus and Nitrogen Retention in Five Precambrian Shield Wetlands". *Biogeochemistry* **8**:185–204.

Devito K.J., Dillon P.J. (1993) "Importance of Runoff and Winter Anoxia to the P and N Dynamics of a Beaver Pond". Can. *J. Fish. Aquat. Sci.* **50**: 2222-2234.

Dincer T, Payne BR, Florkowski T, Martinec J, Tongiorgi E. (1970)"Snowmelt Runoff from Measurements of Tritium and Oxygen-18". *Water Resources Research* **6**: 110–124.

Don Lee Monzingo, Jr. and Charles P. Hibler (1987) "Prevalence of Giardia sp. in a Beaver Colony and the Resulting Environmental Contamination" *Journal of Widelife Disease* **23**(4): 576-585

Dosskey, M.G., and P.M. Bertsch. (1994) "Forest Sources and pathways of organic matter transport to a blackwater stream: a hydrologic approach. *Biogeochemistry*. **24**: 1-19.

Edzwald J.K., Becker, W.C., Wattier, K, L (1985) "Surrogate Parameters for Motoring Organic Matter and THM Precursors" *Journal AWWA* **77**(4):122-131.

Engstrom, D. R. (1987) "Influence of vegetation and hydrology on the humus budgets of Labrador lakes". *Canadian Journal of Fisheries and Aquatic Sciences* **44**:1306–1314.

Eckhardt, B. W., and T. R. Moore.(1990) "Controls on Dissolved Organic Carbon Concentrations in Streams, Southern Quebec". *Canadian Journal of Fisheries and Aquatic Sciences* **47**: 1537–1544.

Fram, M.S., Fujii, R., Weishaar, J.L, Bergamaschi, B.A., Aiken, G.R. (1999) "How DOC Composition May Explain The Poor Correlation Between Specific Trihalomethane Formation Potential and Specific UV Absorbance" Water Resources Investigation Report 99-4018B Charleston, SC: 423-430.

Foote, H.B (1937**)**. The Possible Effects of Wild Animals on Bacterial Pollution of Water. *Journal of Water Pollutant Control*. Fed. **29**:72-74.

Garvey, Elisa A. (2000) “Natural Organic Matter Fate and Transport in Quabbin Reservoir” A Doctoral Dissertation, University of Massachusetts, Amherst, Department of Civil and Environmental Engineering.

Garvey, Elisa A., Tobiason, John E. (2003) “Relationship Betweens Measures of NOM in Quabbin Watershed” *Journal AWWA* **95***(*11*)*: 73-84.

Gergel, S. E., M. G. Turner and T. K. Kratz. (1999) “Dissolved Organic Carbon as An Indicator of the Scale of Watershed Influence on Lakes and Rivers” *Ecological Applications* **9**:1377-1390.

Gorham, E., J. K. Underwood, F. B. Martin, and J. Gordon Ogden III. (1986) “Natural and Anthropogenic Causes of Lake Acidification in Nova Scotia”. *Nature* **324**:451-453.

Hemond, H. F. (1990) “Wetlands as the Source of Dissolved Organic Carbon to Surface Waters”. Pages 301–313 In E. M. Perdue *et al.*(ed.) Organic Acids in Aquatic Ecosystems. John Wiley & Sons, New York, New York, USA.

Hesslein, R. H., W. S. Broeker, P. D. Quay, and D. W. Schindler. (1980). “Whole-lake Radiocarbon Experiment in an Oligotrophic Lake at the Experimental Lakes Area, Northwestern Ontario”. *Canadian Journal of Fisheries and Aquatic Sciences* **37**:454–463.

Hinton, M. J., S. L. Schiff, and M. C. English. (1998) “Sources and Flowpaths of Dissolved Organic Carbon during Storms in Two Forested Watersheds of the Precambrian Shield”. *Biogeochemistry* **41**: 174–197.

Houle, D., R. Carignan, and M. Lachance. (1995) “Dissolved Organic Carbon and Sulfur in Southwestern Quebec Lakes: Relationships with Catchment and Lake Properties”. *Limnology and Oceanography* **40**: (4)710–717.

Howard, R.J. (1982) “Beaver Habitat Classification in Massachusetts” A M.S. Environmental Engineering Project Report, University of Massachusetts, Amherst Department of Civil and Environmental Engineering.

Howard, RJ; Larson, JS (1985) “A Stream Habitat Classification System for Beaver”. *Journal of Wildlife Management* **49**(1): 19-25.

Hurley, J. P., J. M. Benoit, C. L. Babiarz, M. M. Shafer, A. W. Andre, J. R. Sullivan, R. Hammond, and D. A. Webb. (1995) “Influence of Watershed Characteristics on Mercury Levels in Wisconsin Rivers”. *Environmental Science and Technology* **29**(77): 1867-1875.

Hursh, C.R. and Brater, E.P. (1941) “Separating Stream Hydrographs from Small Drainage Areas into Surface and Subsurface Flow”. *Trans. Am. Geophys.* 22: 863-871.

J. A. Fleck, D. A. Bossio and R. Fujii (2004) "Dissolved Organic Carbon and Disinfection By-Product Precursor Release from Managed Peat Soils". *J. Environ. Qual.* **33**:465-475

Jenkins, S.H., and P.E. Busher. 1979. "Castor Canadensis". *Mammalian Species*: **120**:1-8.

Johnson and Chance (1974) "Presettlement Overharvest of Upper Columbia River Beaver Populations". *Canadian Journal of Zoology* **52**(12): 1519-1521.

Johnston, C.A., and R.J. Naiman.(1987) "Boundary Dynamics at the Aquatic-Terrestrial Interface: The Influence of Beaver and Geomorphology". *Landscape Ecology* **1**:47-57.

Kaiser, K., Guggenberger, G., Haumaier, L. and Zech, W. (2001) "Seasonal Variations in the Chemical Composition of Dissolved Organic Matter in Organic Forest Floor Layer Leachates of Old-Growth Scots Pine (*Pinus Sylvestris* L.) And European Beech (*Fagus Sylvatica* L.) Stands in Northeastern Bavaria, Germany". *Biogeochemistry*, **55**(2), 103–143.

Kaplan, L. A., R. A. Larson, and T. L. Bott (1980). "Patterns of Dissolved Organic Carbon in Transport". *Limnology and Oceanography* **25**(66): 1034-1043.

Keiper, R.R. (1966) "The Distribution and Faunal Succession of the Macroscopic Bottom Fauna in Three Different Aged Beaver Ponds. A M.S. Environmental Engineering Project Report, University of Massachusetts, Amherst Department of Civil and Environmental Engineering.

Kirner, J. C., J. D. Littler, and L. A. Angelo. (1978). A Waterborne Outbreak of Giardiasis in Camas, Wash. J. Am. Waterworks Assoc**.** **70**:35-40.

Kitis, Mehmet, Karanfil, T., Kilduff, James E. (2004) "The Reactivity of Dissolved Organic Matter for Disinfection By-Product Formation" *Turkish Journal of Engineering Environmental Science* **28**: 167-179.

Korshin G. V., Li C. W. and Benjamin M. M. (1997) "Monitoring the properties of natural organic matter through UV spectroscopy: a consistent theory". *Water Res*. 31, 1787–1795.

Kortelainen P. (1993): Contribution of Organic Acids to the Acidity of Finnish Lakes. A Doctoral Dissertation at University of Helsinki. Publ. Wat. Envir. Res. Inst. **13**, 1-48

Krasner, Stuart W. (1999) "Chemistry of Disinfection By-Product Formation" In Philip C.Singer Formation and Control of Disinfection By-products in Drinking Water. *AWWA*, 27-52

Moulton, Laurel A. (2001) "Downstream Influences of Beaver Impoundments on the

Biogeochemical Characteristics of a New England Stream". A M.Sc.Thesis at Holyoke College.

Liang, Lin and Singer, Philip C. (2001)" Factors Influencing the Formation and Relative Distribution of Haloacetic Acids and Trihalomethanes Under Controlled Chlorination Conditions" *AWWA 2001* Water Quality Technology Conference Proceedings, American Water Works Association, Denver CO.

Lippy, E. C. (1978). Tracing a Giardiasis Outbreak at Berlin, New Hampshire. J. Am. Waterworks Assoc. **70**:512-520.

Lovley, Derek R.; Phillips, Elizabeth J P. (1986) "Organic Matter Mineralization with Reduction of Ferric Iron in Anaerobic Sediments". *Appl Environ Microbiol*. **51**(4):683–689

Löfgren, S. (2003) "Climate and Other Factors Important for the Humus Dynamics in Lakes and Streams". Documentation to the Workshop on Changes in Quality and Quantity of Dissolved NOM; Causes and Consequences, Sørnesset, Atnasjøen, Norway, May 21-23, 5 pp

Margolis, B.E.; Raesly, R.L.; Shumway, D.L (2001). The Effects of Beaver-Created Wetlands on the Benthic Macroinvertebrate Assemblages of two Appalachian Streams. *Wetlands* **21**:554–563.

Martinec, J., Siegenthaler, U., Oeschger, H., Tongiorgi, E. (1974) "Event Insights into the Run-off Mechanism by Environmental Isotopes". In Isotope Techniques in Groundwater Hydrology. International Atomic Energy Agency, Vienna, Austria, 129-143

McDowell, W. H. and G. E. Likens (1988). "Origin, Composition, and Flux of Dissolved Organic Carbon in the Hubbard Brook Valley". *Ecol. Monogr. 58:177-195.*

Meili, M. (1992) "Sources, Concentrations and Characteristics of Organic Matter in Softwater Lakes and Streams of the Swedish Forest Region". *Hydrobiologia* **229**: 23–41

Meyer, J.L. (1990) "Production and Utilization of Dissolved Organic Carbon in Riverine Ecosystems", *Organic Acids in Aquatic Ecosystems*, 281-299.

Myllymaa, U. (1985) "Influence of Drainage Area Factors on the Water Quality of Small Lakes in the Koutajoki River Basin with Special Reference to Metals". Publication 62 of the Water Research Institute, National Board of Waters, Finland

Naiman, Robert J., Jerry M.Melillo, and John E.Hobbie. (1986). "Ecosystem Alternation of Boreal Forest Streams by Beaver (*Castor Canadensis*)" *Ecology*.**67**:5:1254-1269.

Naiman, R.J., C.A. Johnston, and J.C. Kelley (1988). "Alteration of North American Streams by Beaver". *BioScience* 38:753-762.

Naiman, R.J., G. Pinay, C.A. Johnson, and J. Pastor. (1994) "Beaver-Induced Influences on the Long-term Biogeochemical Characteristics of Boreal Forest Drainage Networks". *Ecology* 75:905-921.

Nalewajko, C., and L. Marin. (1969) "Extra-Cellular Production in Relation to Growth of Four Planktonic Algae and of Phytoplankton Populations from Lake Ontario". *Canadian Journal of Botany* **47**:405–413.

Owen, D.M, Amy, G.L., Chowdhury, Z.K., Paode, R., McCoy, G., Viscosil, K. (1995) "NOM Characterization and Treatability" *Journal AWWA* **87**(1): 46-63.

Pullen, T, M. (1971) "Some Effects of Beaver (*Castor Canadensis*) and Beaver Pond Management on the Ecology and Utilization of Fish Populations along Warm-Water Streams in Georgia and South Carolina" A Doctoral Dissertation, University of Georgia, 81.

Randtke, S. J. (1988). "Organic Contaminant Removal by Coagulation and Related Process Combinations.'' *Journal AWWA*, **80**(5), 40–56.

Rasmussen, D. I. (1941). "Biotic Communities of the Kaibab Plateau". *Ecological Monographs* **3**:229-275.

Rasmussen, J.B., L.Godbout, and M.Schallenberg. (1989) "The Humic Content of Lake Water and Its Relationship to Watershed and Lake Morphometry. Limnol.Oceanogr. **34**: 1336-l 343.

Rao C.N.R., (1975) "Ultra-violet and Visible Spectroscopy". *Chemical Applications*. London - Butterworts, 242 pp

Reckhow, D.A, (2006) "Standard Operating Procedures for Laboratory Chlorination" Umass Envioronmental Engineering Program, Version 1, Unpublished.

Reckhow, D.A, (2006) "Standard Operating Procedures for Analysis of Total Carbon" Umass Envioronmental Engineering Program, Version 1, Unpublished.

Reckhow, D.A, (2006) "Standard Operating Procedures for Analysis of Trihalomethanes" Umass Envioronmental Engineering Program, Version 1, Unpublished.

Reckhow, D.A, (2006) "Standard Operating Procedures for Analysis of Haloacetic Acids" Umass Envioronmental Engineering Program, Version 1, Unpublished.

Reckhow, D.A., Single, P.C., and Malcolm, R.L. (1990) "Chlorination of Humic Materials: Byproduct Formation and Chemical Interpretations: *Environmental Science* *and Technology*. **24**: 1655-1664.

Rochelle, B. P., C. I. Liff, W. G. Campbell, D. L. Cassell, M. R. Church, and R. A. Nusz. (1989). “Regional Relationships Between Geomorphic/Hydrologic Parameters and Surface Water Chemistry Relative to Acidic Deposition”. *Journal of Hydrology* **122**: 103–120.

Rock, J.J., (1976) Haloforms in Drinking Water: *Journal AWWA*, **68**, 168.

Rudemann, R., and W. J. Schoonmaker. (1938). “Beaver Dams as Geological Agents”. *Science* **88**:523–524.

Schindler, D. W., S. E. Bayley, P. J. Curtis, B. R. Parker, M. P. Stainton, and C. C. Kelly. (1992). “Natural and Man-made Factors Affecting the Abundance and Cycling of Dissolved Organic Substances in Precambrian Shield Lakes”. *Hydrobiologia* **229**:1–21.

Singer, P.C. (1994) “Control of Disinfection By-Products in Drinking Water”, *Journal of Environmental Engineering* **120**(4): 727-744

Schindler, D. W. (1971). A Hypothesis to Explain Differences and Similarities among Lakes in the Experimental Lakes Area, Northwestern Ontario. *Journal of the Fisheries Research Board of Canada* **28**:295-301.

Shreeram P. Inamdar, 2006 Hydrologic and Topographic Controls on Storm-Event Exports of Dissolved Organic Carbon (DOC) and Nitrate across Catchment Scales *Water Resources Research*, **42**.

Singer, P.C. and D.A. Reckhow (1999) “Chemical Oxidation”. In Water Quality and Treatment. 5th edition. Letterman R.D. technical editor, AWWA, McGraw-Hill, New York, NY

Q.D. Skinner, J.E. Speck, Jr., M. Smith and J.C. Adams (1984) “Stream Water Quality as Influenced by Beaver within Gazing Systems in WYOMING”. *Journal of Range Management*, **37**(2) D. 142-146.

Smith, M.E., Driscoll, C.T., Wyskowski, B.J., Brooks, C.M. & Cosentini, C.C. (1991): “Modification of Stream Structure and Function by Beaver (Castor Canadensis) in the Adirondack Mountains”, New York. *Can. J. Zool*. **69**: 55-60.

Speiran, G.K., (2000) “Dissolved Organic Carbon and Disinfection By-Product Precursors in Waters of the Chickahominy River Basin, Virginia, and Implications for Public Supply”: U.S. Geological Survey Water-Resources Investigations Report 00-4175, 60 p.

Steinberg, Christian and Muenster, Uwe. (1985) “Geochemistry and Ecological Role of Humic Substances in Lakewater” in G.R. Aiken *et al.* (ed.) Humic Substances in Soil, Sediment and Water: Geochemistry, Isolation and Characterization. John Wiley and Sons, New York NY, 105-145

Stephen H. Jenkins (1979) "Seasonal and Year-to-Year Differences in Food Selection by Beavers" *Oecologia*, **44** (1):112-116.

Strahler, A. N. (1957). "Quantitative Analysis of Watershed Geomorphology". *Transactions of the American Geophysical* Union **38**:913-920.

Thurman, E.M. (1985) Organic Geochemistry of Natural Waters. Martinus Nijhoff/Dr W.Junk Publishers, Boston.

Traina, S.J., Novak, J., and Smeck, N.E. (1990) "An Ultraviolet Absorbance Method of Estimating the Present Aromatic Carbon Content of Humic Acids": *Journal of Environmental Quality*, **19**:151-153

Urban, N. R., E. Gorham, J. K. Underwood, F. B. Martin, and J. G. Underwood III. (1990) "Geochemical Processes Controlling Concentrations of Al, Fe, and Mn in Nova Scotia Lakes" *Limnology and Oceanography* **35**: 1516–1534.

USEPA (2005) www.epa.gov

USGS (2005) www.usgs.gov

Veronica A. Toth (1998) "Spatial and Temporal Variations in the Dissolved Organic Carbon Concentrations in the Vadose Karst Waters of Marengo Cave, Indiana". *Journal of Cave and Karst Studies* **60**(3): 167-171.

Watras, C. J., K. A. Morrison, and J. S. Host. (1995) "Concentration of Mercury Species in Relationship to Other Site-Specific Factors in the Surface Waters of Northern Wisconsin lakes. *Limnology and Oceanography* **40**: (3)556–565.

Weinberg H S (1999) "Disinfection Byproducts in Drinking Water: the Analytical Challenge". *Analytical Chemistry* 71 801-808

Weishaar,J.L, Aiken,G.R., Bergamaschi, B.A., Fran, M.S.,Fujii,R., Mapper, K.(2003) "Evaluation of Specific Ultraviolet Absorbance as an indicator of The Chemical Composition and Reactivity of Dissolved Organic Carbon" *Environmental Science and Technology* **37**(20): 4702-4708.

Welch, P.S. (1935) Limnology. McGraw-Hill Book Co. Inc., New York, 471 pp.

Wenigar, B. G., M. J. Blaser, J. Gedrose, E. C. Lippy, and D. D. Juranek. 1983. An Outbreak of Waterborne Giardiasis Associated with Heavy Water Runoff due to Warm Weather and Volcanic ashfall. Am. J. Public Health 73:868-872.

Westphal, K.S., S.C. Chapra, and W. Sung. (2004). "Modeling TOC and UV-254

Absorbance for Reservoir Planning and Operation". *Journal of the American Water Resources Association*. **40** (3).

Wetzel, R. G., and B. A. Manny (1972) "Secretion of Dissolved Organic Carbon and Nitrogen by Aquatic Macrophytes". *International Association of Theoretical and Applied Limnology* **18**:162–170.

Wetzel, Robert G. (1992) "Gradient-Dominated Ecosystems: Sources and Regulatory Functions of Dissolved Organic Matter in Freshwater Ecosystems". *Hydrobiologia* **229**: 181-198

Wetzel, Robert G. (2001) "Detritus: Organic Carbon Cycling and Ecosystem Metabolism" In Limnology: Lake and River Ecosystems, 3rd Edition, Academic Press, p 731-783.

Wright, R. T. (1970). "Glycolic Acid uptake by Planktonic Bacteria" In D. W. Hood (ed.) Symposium on Organic Matter in Natural Waters. Institute of Marine Science (Alaska) Occasional Publication **I**. 521-536

Zavaleta, Jennifer O., Hauchman, Fred S., Cox, Michael W. (1999) "Epidemiology and Toxicology of Disinfection By-Products" In Philip C.Singer (ed.) Formation and Control of Disinfection By-products in Drinking Water. *AWWA*. 95-118.

.

Appendix

Appendix A:

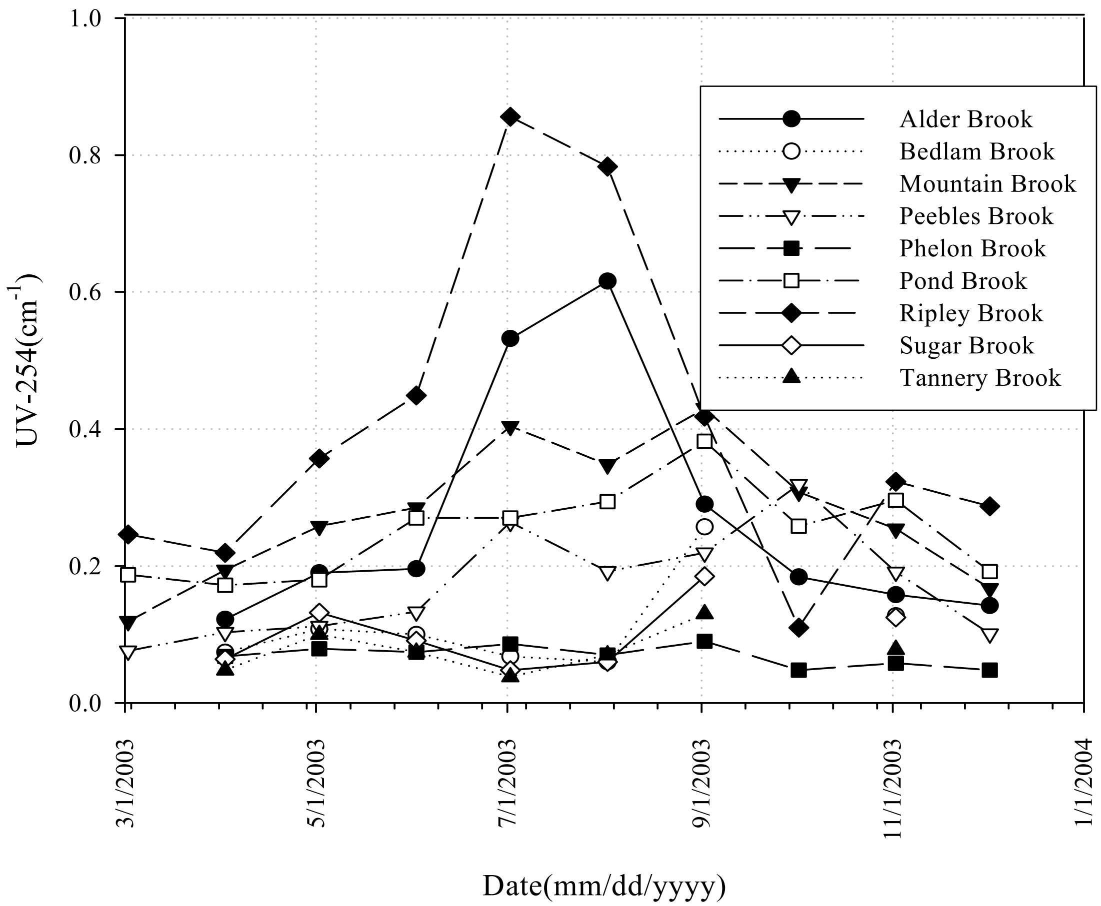


Figure A.1 UV Absorbance for Tributaries (2003-2004)(Provided by SWSC)

Appendix B:

Land Use layers were downloaded from MassGIS. All polygons and data tables were "merged" together using ArcView 3.2. (Byran 2005). The land use polygons represent MassGIS defined land use codes and boundaries that is explained in detail at: http://www.mass.gov/mgis/lus.htm. Areas for each land use polygon and the percentage of each land use type were calculated. The delineation of Cobble Mountain Reservoir watershed and land use were presented in Figure A.1

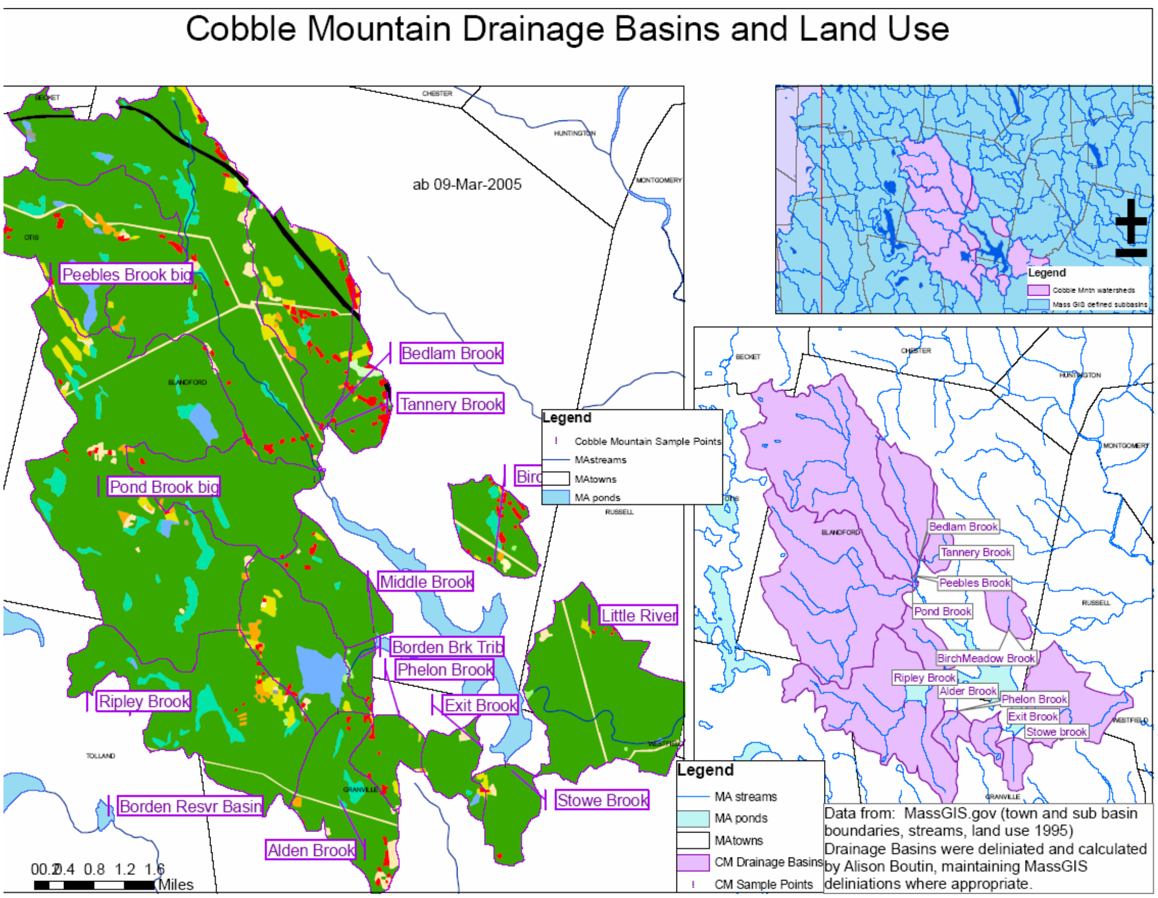


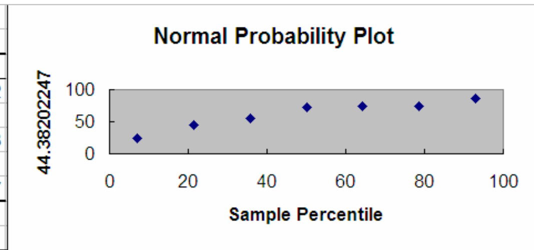
Figure B.1 Watershed Delineations for Cobble Mountain Reservoir Watershed

Table B.1 Summary of Land use Statistics for Major Tributaries of the Cobble Mountain Reservoir Watershed

			Alder Brook		Bedlam Brook		Mountain Brook	
Lu27_CODE	Category	Definition	Area(km2)	% of Land	Area(km2)	% of Land	Area(km2)	% of Land
1	Cropland	Intensive agriculture	0.01	0.22	0.45	6.83	0.02	0.90
2	Pasture	Extensive agriculture	0.04	0.76	0.10	1.48	0.02	0.78
3	Forest	Forest	4.32	87.32	5.18	78.16	2.23	81.52
4	Wetland	Nonforested Freshwater wetland	0.20	4.09	0.10	1.56	0.16	5.93
5	Mining	Sand, Gravel, Rocks	0.00	0.00	0.00	0.00	0.00	0.00
6	Open Land	Abandoned agriculture;Power lines;	0.25	5.09	0.19	2.91	0.10	3.57
7	Paticipation Recreation	Golf;tennis;Playgrounds;sking	0.00	0.05	0.00	0.00	0.00	0.00
8	Spector Recreation	Stadiums; racetracks; Fairgrounds; drive-	0.00	0.00	0.00	0.00	0.00	0.00
13	Residential	Larger than 1/2 acre lots	0.12	2.47	0.29	4.40	0.17	6.18
15	Commercial	General Urban; Shopping Center	0.00	0.00	0.00	0.00	0.00	0.00
17	Urban Open	Parks,cemeteries	0.00	0.00	0.00	0.03	0.01	0.27
18	Transportation	Airports;docks;divided highway;freight;	0.00	0.00	0.31	4.61	0.00	0.00
19	Waste disposal	Landfills;sewage lagoons	0.00	0.00	0.00	0.00	0.00	0.00
20	Water	Fresh water;Coastal embayment	0.00	0.00	0.00	0.00	0.00	0.00
21	Woody Perennial	Orchard;nursery;cranberry bog	0.00	0.00	0.00	0.00	0.02	0.85
Total			4.95	100	6.62	100.00	2.74	100.00
			Phelon		Pond		Ripley	
Lu27_CODE	Category	Definition	Area(km2)	% of Land	Area(km2)	% of Land	Area(km2)	% of Land
1	Cropland	Intensive agriculture	0.05	2.87	0.52	1.86	0.25	2.40
2	Pasture	Extensive agriculture	0.01	0.33	0.17	0.59	0.13	1.21
3	Forest	Forest	1.66	93.00	25.13	90.22	9.29	89.14
4	Wetland	Nonforested Freshwater wetland	0.00	0.00	1.26	4.54	0.59	5.64
5	Mining	Sand, Gravel, Rocks	0.00	0.00	0.01	0.03	0.00	0.00
6	Open Land	Abandoned agriculture;Power lines; areas of no vegetation	0.01	0.82	0.32	1.16	0.07	0.72
7	Paticipation Recreation	Golf;tennis;Playgrounds;sking	0.00	0.00	0.00	0.00	0.00	0.00
8	Spector Recreation	Stadiums; racetracks; Fairgrounds; drive-	0.00	0.00	0.00	0.00	0.00	0.00
13	Residential	Larger than 1/2 acre lots	0.06	3.18	0.11	0.38	0.04	0.39
15	Commercial	General Urban; Shopping Center	0.00	0.00	0.00	0.00	0.00	0.00
17	Urban Open	Parks,cemeteries	0.00	0.00	0.00	0.00	0.01	0.12
18	Transportation	Airports;docks;divided highway;freight;Storage;railroads	0.00	0.00	0.00	0.00	0.00	0.00
19	Waste disposal	Landfills;sewage lagoons	0.00	0.00	0.00	0.00	0.01	0.07
20	Water	Fresh water;Coastal embayment	0.00	0.00	0.34	1.21	0.04	0.35
21	Woody Perennial	Orchard;nursery;cranberry bog	0.00	0.00	0.00	0.01	0.00	0.00
Total			1.79	100.00	27.85	100.00	10.42	100.00
			Exit Brook		Stowe Brook		Peebles Brook	
Lu27_CODE	Category	Definition	Area(km2)	% of Land	Area(km2)	% of Land	Area(km2)	% of Land
1	Cropland	Intensive agriculture	0.02	1.40	0.07	3.39	0.45	1.62
2	Pasture	Extensive agriculture	0.01	0.34	0.00	0.00	0.20	0.72
3	Forest	Forest	1.64	93.02	1.91	94.68	24.23	87.38
4	Wetland	Nonforested Freshwater wetland	0.01	0.56	0.00	0.00	0.83	3.00
5	Mining	Sand, Gravel, Rocks	0.00	0.00	0.00	0.00	0.00	0.00
6	Open Land	Abandoned agriculture;Power lines; areas of no vegetation	0.05	2.62	0.02	1.15	0.69	2.47
7	Paticipation Recreation	Golf;tennis;Playgrounds;sking	0.00	0.00	0.00	0.00	0.00	0.00
8	Spector Recreation	Stadiums; racetracks; Fairgrounds; drive-	0.00	0.00	0.00	0.00	0.00	0.00
13	Residential	Larger than 1/2 acre lots	0.01	0.49	0.00	0.00	0.42	1.51
15	Commercial	General Urban; Shopping Center	0.00	0.00	0.01	0.69	0.00	0.00
17	Urban Open	Parks,cemeteries	0.00	0.00	0.00	0.00	0.05	0.17
18	Transportation	Airports;docks;divided highway;freight;Storage;railroads	0.00	0.00	0.00	0.00	0.38	1.36
19	Waste disposal	Landfills;sewage lagoons	0.00	0.00	0.00	0.00	0.03	0.12
20	Water	Fresh water;Coastal embayment	0.03	1.58	0.00	0.00	0.45	1.61
21	Woody Perennial	Orchard;nursery;cranberry bog	0.00	0.00	0.00	0.00	0.01	0.03
Total			1.76	100.00	2.02	100.00	27.73	100.00
			Tannery		Borden Brook		Middle Brook	
Lu27_CODE	Category	Definition	Area(km2)	% of Land	Area(km2)	% of Land	Area(km2)	% of Land
1	Cropland	Intensive agriculture	0.13	5.63	0.00	0.15	0.02	0.72
2	Pasture	Extensive agriculture	0.00	0.00	0.00	0.00	0.00	0.00
3	Forest	Forest	1.59	70.54	0.60	92.31	3.08	96.65
4	Wetland	Nonforested Freshwater wetland	0.00	0.00	0.00	0.00	0.03	0.88
5	Mining	Sand, Gravel, Rocks	0.00	0.00	0.00	0.00	0.00	0.00
6	Open Land	Abandoned agriculture;Power lines; areas of no vegetation	0.01	0.34	0.00	0.00	0.01	0.16
7	Paticipation Recreation	Golf;tennis;Playgrounds;sking	0.12	5.19	0.00	0.00	0.00	0.00
8	Spector Recreation	Stadiums; racetracks; Fairgrounds; drive-	0.04	1.77	0.00	0.00	0.00	0.00
13	Residential	Larger than 1/2 acre lots	0.33	14.49	0.02	2.62	0.05	1.51
15	Commercial	General Urban; Shopping Center	0.01	0.30	0.03	4.62	0.00	0.00
17	Urban Open	Parks,cemeteries	0.02	0.75	0.00	0.00	0.00	0.00
18	Transportation	Airports;docks;divided highway;freight;Storage;railroads	0.03	1.23	0.00	0.00	0.00	0.00
19	Waste disposal	Landfills;sewage lagoons	0.00	0.00	0.00	0.00	0.00	0.00
20	Water	Fresh water;Coastal embayment	0.00	0.00	0.00	0.00	0.00	0.08
21	Woody Perennial	Orchard;nursery;cranberry bog	0.00	0.00	0.00	0.00	0.00	0.00
Total			2.27	100.00	0.65	99.69	3.19	100.00

Appendix C:

SUMMARY OUTPUT	
Regression Statistics	
Multiple R	0.765612572
R Square	0.586162611
Adjusted R Square	0.503395133
Standard Error	15.00377401
Observations	7



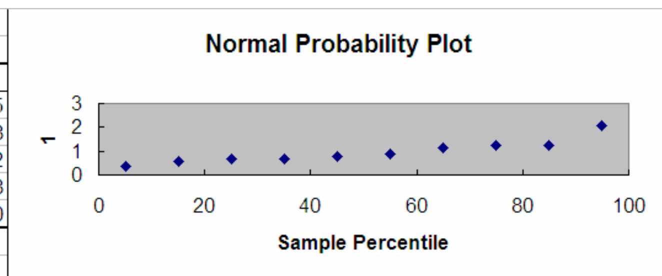
ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	1594.260992	1594.260992	7.08204	0.044818736
Residual	5	1125.566173	225.1132346		
Total	6	2719.827165			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	78.09556099	8.398668808	9.298564185	0.000242	56.50609551	99.685026	56.5060955	99.68502646
328	-0.010043012	0.003773851	-2.661210301	**0.044819**	-0.01974401	-0.000342	-0.01974401	-0.00034202

Figure C.1 Discharge with Specific THM for Alder Brook Data

SUMMARY OUTPUT	
Regression Statistics	
Multiple R	0.9431345
R Square	0.8895028
Adjusted R Square	0.7513812
Standard Error	0.2405578
Observations	10



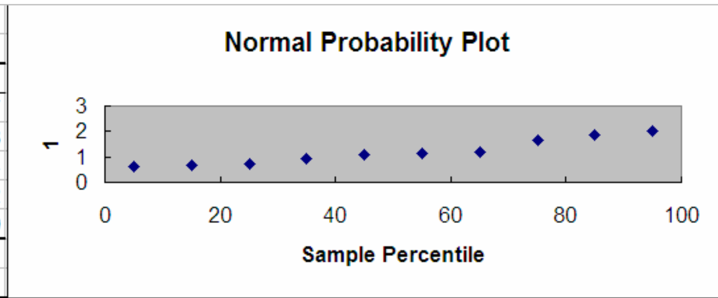
ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	5	1.863351214	0.37267	6.439999	0.047638888
Residual	4	0.231472229	0.057868		
Total	9	2.094823443			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
	-6.7586182	3.804446072	-1.77651	0.150295	-17.32145392	3.8042174	-17.321454	3.804217433
Forest	0.070117	0.037595712	1.865026	0.135609	-0.034265457	0.1744994	-0.0342655	0.174499405
Agriculture	0.2024741	0.098806436	2.049199	0.10979	-0.071856573	0.4768047	-0.0718566	0.476804721
Wetland	0.2535179	0.056441676	4.491678	**0.010892**	0.096810641	0.4102251	0.09681064	0.410225073
Urban	0.2636951	0.339888413	0.775828	0.481166	-0.679986423	1.2073766	-0.6799864	1.207376618
Residential	0.1002128	0.058829948	1.703432	0.163695	-0.063125324	0.2635509	-0.0631253	0.263550919

Figure C.2 Mulitple linear regressions on normalized TOC with land cover percentage

SUMMARY OUTPUT	
Regression Statistics	
Multiple R	0.992567
R Square	0.985188
Adjusted R Square	0.966674
Standard Error	0.092552
Observations	10



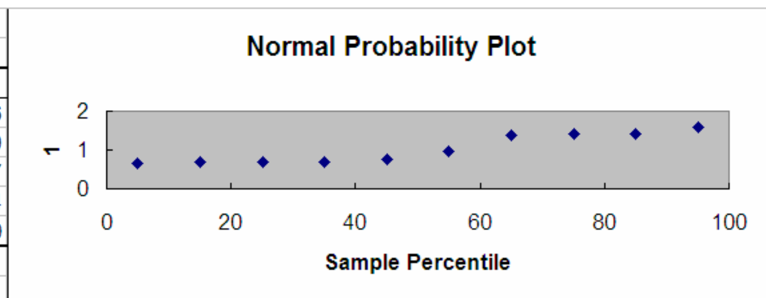
ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	5	2.278994	0.455799	53.21156	0.000945632
Residual	4	0.034263	0.008566		
Total	9	2.313257			

	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
	-4.10324	1.463712	-2.80331	0.048647	-8.16715076	-0.0393203	-8.16715076	-0.03932032
Forest	0.045187	0.014464	3.123993	0.03539	0.005027091	0.0853467	0.00502709	0.08534669
Agriculture	0.167738	0.038015	4.412464	0.011578	0.062192448	0.2732828	0.06219245	0.27328283
Wetland	0.265965	0.021715	12.24786	**0.000255**	0.205673794	0.326256	0.20567379	0.32625597
Urban	-0.10171	0.130768	-0.77778	0.480134	-0.46477847	0.2613602	-0.46477847	0.2613602
Residential	0.08091	0.022634	3.574682	0.023278	0.01806735	0.1437518	0.01806735	0.14375183

Figure C.3 Mulitple linear regressions on normalized THM with land cover percentage

SUMMARY OUTPUT	
Regression Statistics	
Multiple R	0.95706316
R Square	0.9159699
Adjusted R	0.81093227
Standard E	0.16509994
Observation	10



ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	5	1.188502533	0.237701	8.720398	0.028337631
Residual	4	0.109031956	0.027258		
Total	9	1.297534489			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
	-2.7700386	2.611072239	-1.06088	0.348552	-10.0195373	4.47946	-10.0195373	4.47946018
Forest	0.03281926	0.025802737	1.271929	0.272316	-0.03882063	0.104459	-0.03882063	0.10445914
Agriculture	0.0834169	0.067812958	1.230103	0.286057	-0.10486205	0.271696	-0.10486205	0.27169586
Wetland	0.17036599	0.038737123	4.398003	**0.011709**	0.062814494	0.277917	0.06281449	0.27791748
Urban	0.18613839	0.233272645	0.797943	0.469592	-0.46153031	0.833807	-0.46153031	0.83380708
Residential	0.07725788	0.040376244	1.913449	0.128235	-0.03484454	0.18936	-0.03484454	0.18936031

Figure C.4 Mulitple linear regressions on normalized DHAA with land cover percentage