Technical Memorandum

Stream Flow and Water Quality Monitoring in Bread and Cheese Brook (2012 - 2014)

To: Timothy King, Town Administrator, Town of Westport
Jack Reynolds, President, Westport Fishermen's Association

From: Dr. Brian Howes, SMAST, UMass – Dartmouth
Dr. Roland Samimy, SMAST, UMass – Dartmouth
Mr. Michael Bartlett, SMAST, Umass - Dartmouth

Re: Summary of Stream Flow and Water Quality Monitoring Activities in Bread and Cheese Brook (MEP watershed #3) as undertaken by the Coastal Systems Program, School for Marine Science & Technology at the University of Massachusetts – Dartmouth and the Westport River Watershed Alliance. Period of Performance: October 2012 - October 2014.

Date: October 31, 2014 (Draft)
December 3, 2014 (Revised)

cc: Betsy White, Advocacy Director, WRWA
Roberta Carvalho, Science and Director, WRWA

Overview:

In January 2012, with financial support from the Town of Westport Community Preservation Committee (CPC), the Town of Westport received the results of the Massachusetts Estuaries Project (MEP) nutrient threshold analysis for the Westport River Estuary. With the MEP results in hand and with the MEP modeling tool at its disposal, the Town was in a position to immediately begin assessing a variety of nutrient load reducing actions that could be taken in the Westport River watershed to improve nutrient related water quality in the estuarine receiving waters of the East Branch of the overall system. Based on the MEP results, sub-watershed (#3) to Bread and Cheese Brook / Upper Westport River was identified as an area that generates significant nutrient load to the head of the East Branch of the Westport River. As such, taking a more detailed look at the nitrogen loads discharging from sub-watershed #3 was considered by the Town of Westport to be a reasonable next step towards managing nitrogen loads to the East Branch of the Westport River.

As such, detailed stream gauging and water quality sampling was undertaken. From this it was envisioned that a clearer understanding of the distribution of nitrogen loads in the Bread and Cheese Brook sub-watershed would be gained and targeted design approaches for reducing loads from the sub-watershed to the East Branch of the Westport River could be developed. These load reducing strategies, in turn, could be evaluated using the MEP tool as a mechanism for evaluating the efficacy of each strategy. These additional model runs can be undertaken by the MEP Technical Team as requested by the Town. The future MEP related scenario testing would be aimed at determining the degree to which different nitrogen management alternatives for sub-watershed 3 improve water quality in the East Branch of the Westport River.

By undertaking additional study of the Bread and Cheese Brook / Upper Westport River system and by using the MEP modeling tool, the Town of Westport will be able to determine the effectiveness of restoring the Bread and Cheese Brook and associated pond resources in that specific sub-watershed to the Westport River Estuary. These nitrogen load reduction actions will be necessary in order for the Town of Westport to meet the Westport River specific nutrient restoration targets established by the MEP.

This Technical Memorandum summarizing the work completed on the Bread and Cheese Brook is organized as follows:

1. Overview
2. Introduction (Summary of Sampling Approach in Bread and Cheese Brook)
3. Results (Stream Gauging and Water Quality Monitoring)
4. Conclusions / Recommendations

***Introduction**:*

Managing watershed derived nitrogen loads and predicting changes in coastal embayment nitrogen related water quality is based, in part, on determination of the inputs of nitrogen from the surrounding contributing land relative to the tidal flushing and nitrogen cycling within the embayment basins. This watershed nitrogen input parameter is the primary term used to relate present and future loads (build-out, wastewater analysis, enhanced flushing, pond/wetland restoration for natural attenuation, etc.) to changes in water quality and habitat health in the Westport River Estuary. Therefore, nitrogen loading is one of the main threshold parameters for protection and restoration of estuarine systems. Under the initial MEP analysis of the overall Westport River Estuary, rates of nitrogen loading to the sub-watersheds of the Westport River System (for example Bread and Cheese Brook) were based upon the delineated watersheds and the existing land-use distributions, all of which are presented in the MEP Nutrient Threshold Report. Based on the MEP analysis of overall nitrogen loads to the Westport River Estuary, the watershed to Bread and Cheese Brook (#3) was found to generate a substantial percentage of the total watershed nutrient load to the East Branch of the Westport River. Intensive stream gauging of Bread and Cheese Brook with concurrent water sampling was undertaken to reveal where within Watershed #3 the major nitrogen sources are located (Figure 1).

The stream gauging and water quality monitoring of Bread and Cheese Brook was undertaken as a collaborative effort between scientists from the Coastal Systems Program (CSP) within the University of Massachusetts-Dartmouth, School for Marine Science and Technology (UMD-

SMAST) and technical staff from the Westport River Watershed Alliance (WRWA). The overall project was designed to be completed over two years in order to more accurately quantify stream flows (a critical component for calculating nitrogen loads) and capture potential seasonal changes in flows and nitrogen concentrations in Bread and Cheese Brook. The overall project was funded in two parts (year 1 and year 2) with initial funding obtained through the Community Preservation Committee (CPC) and funding in year 2 coming from both CPC and the Westport River Fisherman's Association. While the project was originally structured to capture two summers of flow and water quality data (summer 2012 and 2013), due to contracting challenges

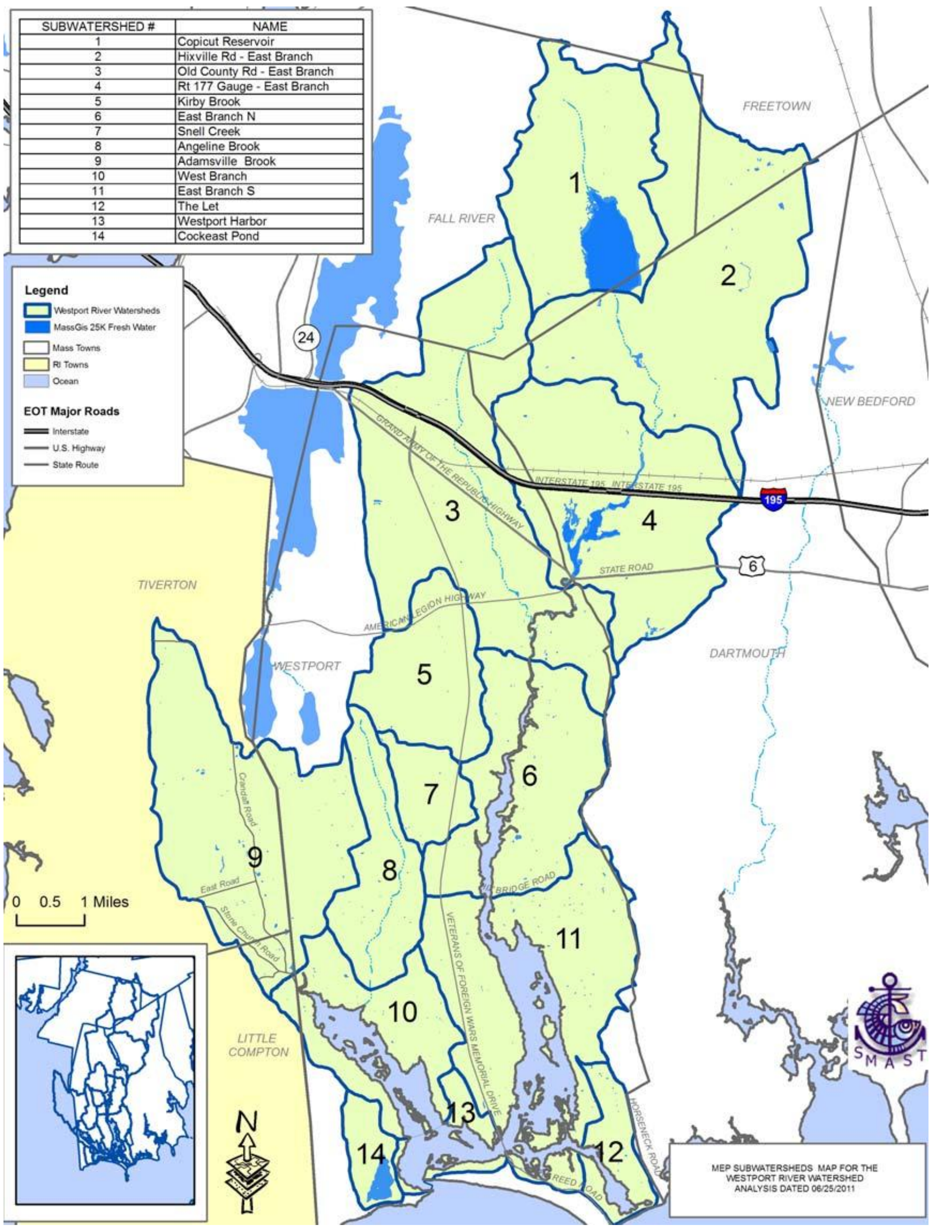

Figure 1 – Sub-watershed delineations for the Westport River Estuary as developed by the Massachusetts Estuaries Project. Bread and Cheese Brook is located within sub-watershed #3.

the project started in the fall of 2013. As such, it was decided that the overall project schedule would be extended to still capture two summer seasons (2013 and 2014) as well as meet the required minimum 20 months of stream gauging.

The scope of this two year monitoring project focused on the continuation and expansion of previous water quality monitoring in Bread and Cheese Brook and the Westport River down gradient of Route 6 and undertaken in 2008 by the University of Massachusetts (UMD), School for Marine Science and Technology (SMAST) Coastal Systems Program. Previous data collected was utilized by the Massachusetts Estuaries Project (MEP) in the development of the MEP Nutrient Threshold Report for the Westport River Estuary. Continued sampling was undertaken to further evaluate the water quality of specific areas of the Bread and Cheese Brook and the Upper Westport River in order to identify the locations of high nutrient loading. In addition, the study aimed to better determine the potential for enhancing natural attenuation of nitrogen during transport within defined segments of both tributaries. If nitrogen attenuation is significant in one portion of a watershed and insignificant in another the result is that nitrogen management would likely be more effective in achieving water quality improvements if focused on the watershed region having unattenuated nitrogen transport (other factors being equal and assuming natural surface water features exist which could be restored to enhance nitrogen attenuation through increased biological activity). Natural attenuation during stream transport and passage through ponds and wetlands can play a significant role in nitrogen management.

The work undertaken for this project included reassessing previously established sampling sites and establishing new ones in the Bread and Cheese Brook and the Upper Westport River as a mechanism for generating additional flow and water quality data to enhance the MEP analysis of sub-watershed #3 discharge to the Westport River estuary system. To achieve a more refined loading analysis of this region, stream flow and water sampling sites were established as follows:

- Bread and Cheese Brook
  Four in-stream sites
- Upper Westport River
  Three in-stream sites

All sampling sites are depicted in Figure 2 with samples being collected by trained WRWA staff as well as scientific staff from the Coastal Systems Program. Water quality samples generated under this effort were collected and analyzed in accordance to QA/QC criteria established under the MEP in its June 2003 Quality Assurance Project Plan (QAPP). As a result, water quality data generated through this effort are directly comparable to previous water quality data obtained from historical MEP related sampling efforts undertaken in the Westport River Estuary as well as all other estuaries located in the MEP study region.

The objectives of the monitoring program (flow and water quality) were two-fold: 1) quantify stream flow at critical junctures in the surface water system using standard hydrologic techniques (stream gauging, flow measurement and rating curve development) and 2) water sampling. The field effort included a range of tasks that included the collection of water samples, deployment of a network of stream gauges, conducting flow measurements, regular downloading of stream gauges, developing rating curves that relate stream stage to stream flow and synthesizing field and laboratory data. The overall field effort provided the necessary data to yield a detailed picture of nutrient load pick-up and related water quality conditions within each stream segment and the potential for N-load reduction to the East Branch of the Westport River Estuarine System as evaluated by the Massachusetts Estuaries Project.

Stream Flow Measurement and Transport of Watershed Nutrients

As indicated above, attenuation of watershed nitrogen during surface water transport can significantly reduce the amount of watershed nitrogen entering an estuary. CSP-SMAST scientists directly measured stream water levels and flows and concurrently collected water samples from strategic locations along the Bread and Cheese Brook before it discharges to the Westport River Estuary. Stream gauges were deployed and monitored at sites in both tributaries (Bread and Cheese Brook and the Westport River down-gradient of Route 6. The direct measurements of watershed freshwater and nutrient inputs were quantified as a means to: a) identify the degree of freshwater pick-up by each stream segment, b) the degree of nutrient pick-up by stream segments and associated land use and c) assess the potential for enhancing nutrient attenuation within the Bread and Cheese Brook sub-watershed. Measurement of the flow and nutrient load associated with the freshwater streams provides a direct integrated measure of all of the processes presently attenuating nitrogen in the contributing area up-gradient from the various sampling and gauging sites.

Surface water inflow volume and mass transport of nitrogen were determined using site-specific flow discharge relationships and continuous records of water levels obtained from deployed stream gauges (WL-16 water level loggers). A total of four (4) stream gauges were deployed at critical junctures in the system for the duration of the sampling period (~20 months). These stream gauges were downloaded and field calibrated at approximately monthly intervals (Figure 2). Flow measurements were made at monthly to bi-monthly intervals in order to develop a stage-discharge relationship at each gauging location. Stage measurements made at 10-minute intervals were used along with the stage-discharge relation in order to calculate daily flows at each stream gauge. Daily flows were merged with weekly measured stream nutrient concentrations obtained from the water sampling program to calculate N-load at each stream gauge location. Water samples were primarily collected and analyzed by the Coastal Systems Laboratory to determine the concentration of inorganic and organic nitrogen as well as total phosphorous and ortho-phosphate. Total nitrogen (not just inorganic forms) is required to accurately determine the attenuated nutrient input to the head of the East Branch of the Westport River via the Bread and Cheese Brook. The MEP Technical Team identified 7 critical locations were stream flow measurements and water sampling were completed (Figure 2). Four of the seven locations had a dedicated stream gauge whereas the other three locations had periodic stream flow measurements rather than continuous measures of stage using a water level logger. The stream gauges were deployed for long term measurement of stream stage and rating curve development and were the locations of intensive water sampling for nutrient load determination. Results of the stream gauging effort of Bread and Cheese Brook is the focus of this Technical Memorandum.

Stream Water Quality Monitoring

In order to quantify the nutrient characteristics of the stream system and elucidate the potential for enhancing natural attenuation of nutrients prior to discharge to the down gradient East Branch of the Westport River Estuary, water sampling was undertaken over the course of 20 months (2012-2013). Sampling during a complete hydrologic cycle sheds light on how nutrient concentrations and flows vary seasonally, critical to understanding the overall potential for improving natural attenuation through restoration of degraded ponds as well as potential for reducing load from land uses associated with specific stream segments. Generally, sampling was undertaken bi-weekly for the duration of the sampling program. Through an understanding of the flows and nutrient concentrations at critical locations in the Bread and Cheese Brook / Upper Westport River system, it was possible to isolate portions of the system that may be more/less suitable for ecological restoration.

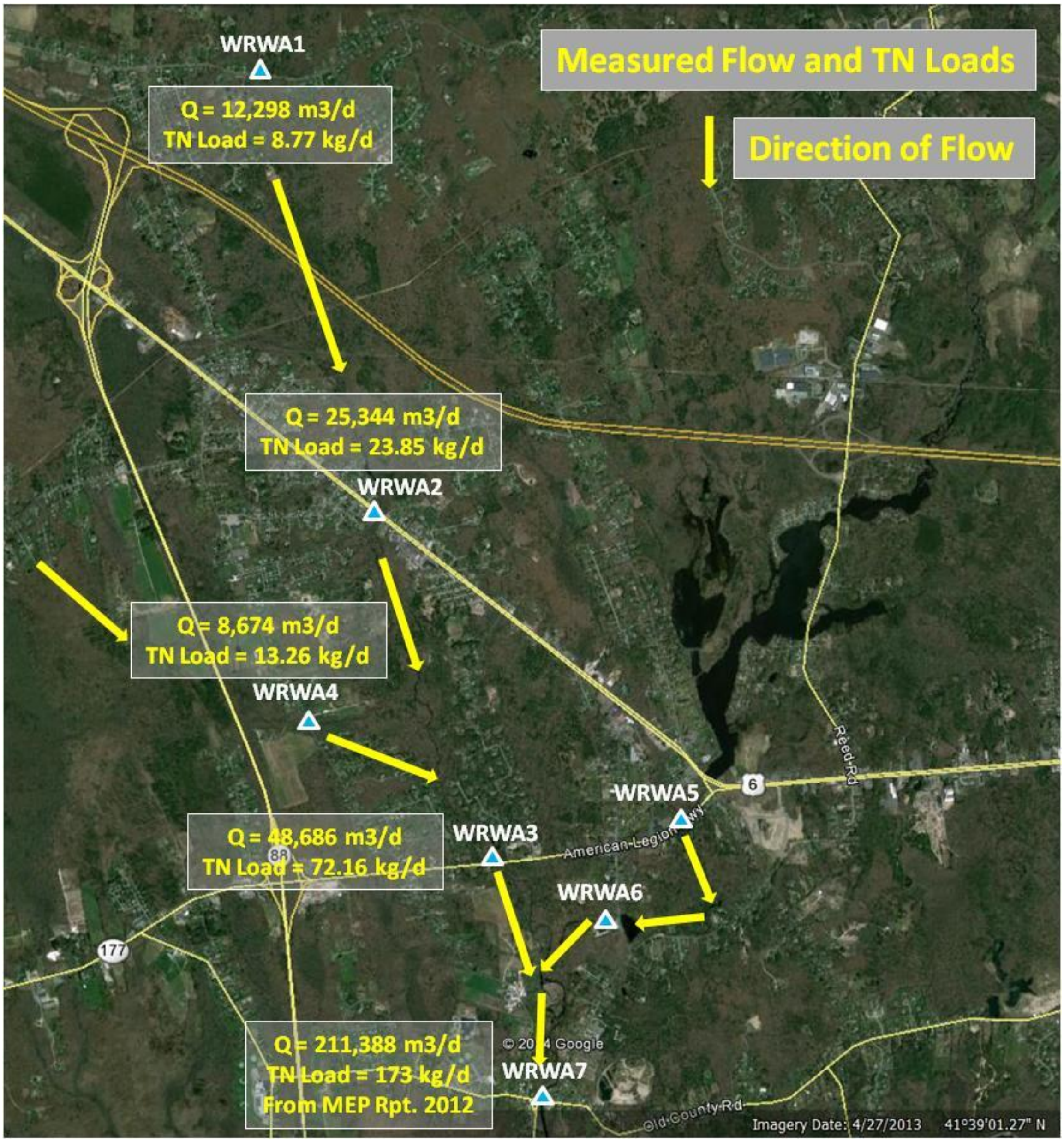

Figure 2 – Stream water quality sampling and flow measurement locations (blue triangles) within the Bread and Cheese Brook sub-watershed (3). Stream gauges were only deployed at locations along Bread and Cheese Brook (WRWA1,2,3,4) to calculate nitrogen loading from various segments of the Bread and Cheese Brook system. Periodic flow measurements were also made at the three stations along the Westport River (WRWA-5,6,7) each time water samples were collected. Two of the three Westport sampling locations (WRWA-5 and 7) were also gauged during the MEP field data collection effort.

Over the course of this project, CSP-SMAST scientists collected and assembled field data in a manner consistent with the Massachusetts Estuaries Project field protocols for laboratory filtration and processing of water samples for nutrient analyses (NH4, NO3+NO2, TDN, PO4, POC, PON). Data was retrieved by SMAST staff in accordance with accepted quality control and quality assurance procedures and is presented as tables in both hard copy (herein) and digital format. Samples were collected monthly over the project period, averaging 8 samples (7 stream locations + 1 QA sample) per event for a total of 40 sampling rounds conducted over the project period (Table 1).

All analytical methodologies have been previously approved for use by the EPA, Mass. CZM, NOAA, and NSF. Data was be compiled and reviewed by the laboratory for accuracy and evaluated to discern any possible artifacts caused by improper sampling technique. CSP senior scientists have synthesized the water quality data and is presented in the water quality results discussion section below followed by conclusions and recommendations as to possible next steps.

All sampling locations are located in sub-watershed 3 (as delineated by the MEP) were as follows:

- Bread and Cheese Brook, sampling at 4 locations (Figure 2) which were in-stream sites
    - Old Bedford Road
    - Route 6
    - Gifford Road (Hemlock Gutter)
    - Route 177

- Westport River, sampling at 3 locations
    - Forge Road south of outflow of Forge Pond (1 outflow from Pond)
    - Route 177 south of outflow from Lake Noquochoke
    - Old County Road (Head of Westport)

Single samples were taken from all the in-stream sites for each sampling event. Quality Assurance check (QA) duplicate samples were collected at a level of ~ 14% of total samples.

FD = Field Duplicate Sample taken for Quality Assurance (QA)

BREAD AND CHEESE BROOK SAMPLING LOCATIONS								WESTPORT RIVER SAMPLING LOCATIONS					
WRWA-1		WRWA-2		WRWA-4		WRWA-3		WRWA-5		WRWA-6		WRWA-7	
Date	QC	Date	QC	Date	QC	Date	QC	Date	QC	Date	QC	Date	QC
11/20/2012		11/20/2012		11/20/2012		11/20/2012		11/20/2012		11/20/2012		11/20/2012	
12/7/2012		12/7/2012		12/7/2012		12/7/2012		12/7/2012		12/7/2012	SAMPLE	12/7/2012	
1/17/2013	SAMPLE	1/17/2013		1/17/2013		1/17/2013		1/17/2013		12/7/2012	FD	1/17/2013	
1/17/2013	FD	2/5/2013		2/5/2013	SAMPLE	2/5/2013		2/5/2013		1/17/2013		2/5/2013	
2/5/2013		2/20/2013		2/5/2013	FD	2/20/2013		2/20/2013		2/5/2013		2/20/2013	
2/20/2013		3/6/2013		2/20/2013		3/6/2013		3/6/2013		2/20/2013	SAMPLE	3/6/2013	
3/6/2013	SAMPLE	3/22/2013		3/6/2013		3/22/2013		3/22/2013		2/20/2013	FD	3/22/2013	
3/6/2013	FD	4/4/2013		3/22/2013	SAMPLE	4/4/2013		4/4/2013		3/6/2013		4/4/2013	SAMPLE
3/22/2013		4/22/2013		3/22/2013	FD	4/22/2013	SAMPLE	4/22/2013		3/22/2013		4/4/2013	FD
4/4/2013		5/6/2013		4/4/2013		4/22/2013	FD	5/6/2013		4/4/2013		4/22/2013	
4/22/2013		5/20/2013		4/22/2013		5/6/2013	SAMPLE	5/20/2013		4/22/2013		5/6/2013	
5/6/2013		6/4/2013		5/6/2013		5/6/2013	FD	6/4/2013		5/6/2013		5/20/2013	
5/20/2013		6/26/2013		5/20/2013	SAMPLE	5/20/2013		6/26/2013		5/20/2013		6/4/2013	
6/4/2013	SAMPLE	7/12/2013		5/20/2013	FD	6/4/2013		7/12/2013		6/4/2013		6/26/2013	
6/4/2013	FD	7/29/2013	SAMPLE	6/4/2013		6/26/2013		7/29/2013		6/26/2013		7/12/2013	
6/26/2013	SAMPLE	7/29/2013	FD	6/26/2013		7/12/2013		8/16/2013		7/12/2013		7/29/2013	
6/26/2013	FD	8/16/2013		7/12/2013		7/29/2013		8/30/2013		7/29/2013		8/16/2013	
7/12/2013	SAMPLE	8/30/2013	SAMPLE	7/29/2013		8/16/2013	SAMPLE	9/11/2013		8/16/2013		8/30/2013	
7/12/2013	FD	8/30/2013	FD	8/16/2013		8/16/2013	FD	9/27/2013		8/30/2013		9/11/2013	
7/29/2013		9/11/2013		8/30/2013		8/30/2013		10/15/2013		9/11/2013		9/27/2013	
8/16/2013		9/27/2013		9/11/2013		9/11/2013	SAMPLE	10/30/2013		9/27/2013		10/15/2013	
8/30/2013		10/15/2013		9/27/2013		9/11/2013	FD	11/15/2013		10/15/2013		10/30/2013	
9/11/2013		10/30/2013		10/15/2013		9/27/2013		11/26/2013		10/30/2013		11/15/2013	
9/27/2013		11/15/2013		10/30/2013	SAMPLE	10/15/2013	SAMPLE	12/13/2013		11/15/2013		11/26/2013	SAMPLE
10/15/2013		11/26/2013		10/30/2013	FD	10/15/2013	FD	12/31/2013		11/26/2013		11/26/2013	FD
10/30/2013		12/13/2013		11/15/2013	SAMPLE	10/30/2013		1/13/2014		12/13/2013		12/13/2013	
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11/26/2013		12/31/2013	FD	11/26/2013		11/26/2013		2/7/2014		1/13/2014		1/13/2014	
12/13/2013		1/13/2014		12/13/2013	SAMPLE	12/13/2013		2/25/2014		1/27/2014		1/27/2014	
12/31/2013		1/27/2014	SAMPLE	12/13/2013	FD	12/31/2013		3/11/2014		2/7/2014		2/7/2014	
1/13/2014		1/27/2014	FD	12/31/2013		1/13/2014	SAMPLE	3/25/2014		2/25/2014		2/25/2014	SAMPLE
1/27/2014		2/7/2014		1/13/2014		1/13/2014	FD	4/22/2014		3/11/2014		2/25/2014	FD
2/7/2014	SAMPLE	2/25/2014		1/27/2014		1/27/2014		5/12/2014		3/25/2014		3/11/2014	
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3/11/2014		4/22/2014	SAMPLE	3/11/2014	SAMPLE	3/11/2014		6/27/2014		5/30/2014		5/12/2014	
3/25/2014		4/22/2014	FD	3/11/2014	FD	3/25/2014		7/11/2014		6/20/2014		5/30/2014	
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6/20/2014		7/11/2014		5/30/2014		6/20/2014	SAMPLE			8/11/2014	SAMPLE	7/22/2014	FD
6/27/2014	SAMPLE	7/22/2014		6/20/2014		6/20/2014	FD			8/11/2014	FD	8/5/2014	
6/27/2014	FD	8/5/2014	SAMPLE	6/27/2014		6/27/2014						8/11/2014	
7/11/2014		8/5/2014	FD	7/11/2014		7/11/2014	SAMPLE						
7/22/2014		8/11/2014		7/22/2014		7/11/2014	FD						
8/5/2014				8/5/2014		7/22/2014							
8/11/2014				8/11/2014		8/5/2014							
						8/11/2014							
Total = 48 samples		Total = 46 samples		Total = 48 samples		Total = 49 samples		Total = 40 samples		Total = 43 samples		Total = 44 samples	
QA = 8 samples		QA = 6 samples		QA = 8 samples		QA = 9 samples		QA = 0 samples		QA = 3 samples		QA =4 samples	

Table 1 - Summary of water quality samples collected at WRWA-1 through 7 sites.

Results:

In general, stream gauging and water sampling was successfully completed over a period of 21 months from November 2012 to August 2014. Four water level loggers (stream gauges) were deployed at strategic locations on the Bread and Cheese Brook and stream stage measured at 10 min intervals. The stream gauges were downloaded on approximately a monthly basis and flow measurements and water samples were collected on a bi-monthly basis. Flow measurements were utilized to develop a rating curve for each stream gauging location and the stage data was subsequently used as input to the stage-discharge equation in order to calculate daily flows at each site. Daily flow was combined with stream nutrient concentrations in order to calculate nutrient load at each stream gauging location as well as "pick-up" (increase between stations) as water flows towards the Westport River.

Stream Gauging (Stage and Flow Measurements)

Velocity and stage (water level) were measured at the stream gauges in the Bread and Cheese Brook system for a total of 21 months of record thereby enabling the development of rating curves and the calculation of flow over the entire deployment period for each stream gauging location. During the study period, velocity profiles were completed at each gauging location approximately monthly. The summation of the products of stream subsection areas of the stream cross-section and the respective measured velocities represent the computation of instantaneous stream flow (Q).

Determination of stream flow at each gauge was calculated and based on the measured values obtained for stream cross sectional area and velocity. Stream discharge was represented by the summation of individual discharge calculations for each stream subsection for which cross sectional area and velocity measurements were obtained. Velocity measurements across the entire stream cross section were not averaged and then applied to the total stream cross sectional area.

The formula that was used for calculation of stream flow (discharge) is as follows:

$$Q = \Sigma(A * V)$$

where by:

Q = Stream discharge (m3/s)
A = Stream subsection cross sectional area (m2)
V = Stream subsection velocity (m/s)

Thus, each stream subsection has a calculated stream discharge value and the summation of all the sub-sectional stream discharge values is the total calculated discharge for the stream.

Periodic measurement of velocity and calculation of flows over the entire stream gauge deployment period allowed for the development of a stage-discharge relationship (rating curve) that was used to obtain flow volumes from the detailed record of stage measured by the continuously recording stream gauges. Water level data obtained every 10-minutes was averaged to obtain hourly stages for each stream gauge location. These hourly stage values where then entered into the stage-discharge relation to compute hourly flow. Hourly flows were summed over a period of 24 hours to obtain daily flow and further, daily flows summed to obtain annual flow. A complete annual record of stream flow (365 days) was generated at the critical gauged locations along the Bread and Cheese Brook system from which freshwater pick up could be determined as Bread and Cheese Brook flows towards and into the Westport River. When combined with the water quality data, it was possible to also calculate nutrient load pick up across the Bread and Cheese Brook watershed (#3).

Bread and Cheese Brook Stream Flow at WRWA-1 Gauging Location (Old Bedford Road): The WRWA-1 stream gauging location is the uppermost flow measurement point in the Bread and Cheese Brook system (MEP subwatershed #3). The freshwater flow carried by Bread and Cheese Brook flowing towards the Westport River was determined using standard hydrologic techniques described above in concert with a continuously recording vented calibrated water level gauge (high frequency {10 min} measurements of stream stage). Calibration of the gauge was checked periodically over the gauge deployment period to confirm that the water level logger was operating accurately. The gauge was installed on November 21, 2012 and collected stage level until August 10, 2014 for a total record of 21 months inclusive of the low flow and nutrient conditions during the summer 2013. As depicted in Figure 3, the comparison of the stream stage measured by the gauge (blue line) and the field calibration points (red triangles, where stage is measured with a wading rod to determine the water level) indicates only a 2% difference over the deployment.

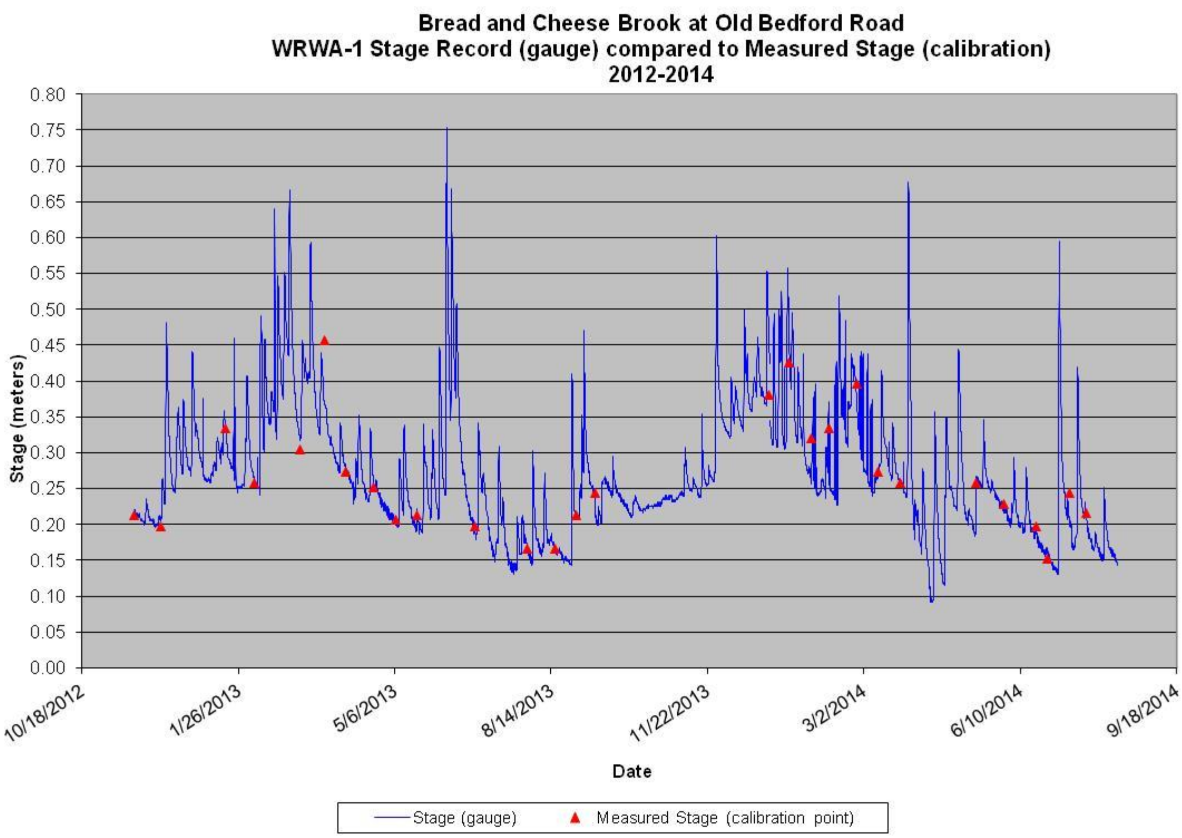

Figure 3 - WRWA-1 Measured stream stage using the WL-15 water level logger (gauge) compared to the field calibration points obtained using a wading rod and manual measurement of water level at the gauge location. The 2 methods differed by <2% over the 21 month installation.

Flow in the stream channel (volumetric discharge) was measured every 2 to 6 weeks using a Marsh-McBirney electromagnetic flow meter. A stage-discharge relation (rating curve) was developed for the gauge site based upon these flow measurements and the measured water levels at the gauge site (Figure 4). A strong relationship was determined between water levels at the gauge and flow (R^2 = 0.87) suggesting that daily flow can be accurately predicted from measured water levels. The rating curve was then used to convert the continuously measured stage data to daily freshwater flow volume (Figure 5). Inputting the stage record into the stage-discharge equation yields a "predicted" daily flow at the gauging location which when compared to measured flows shows good agreement. Based on the rating curve and the detailed stage record, flow at WRWA-1 was determined to be 4,488,794 m^3/yr for the hydrologic period November 2012 to November 2013. Dividing by 365 days yields an average daily flow of 12,298 m^3/d. The flow determined at the WRWA-1 stream gauging location represents 25% of the flow determined at the down gradient stream gauging location on the main stem of Bread and Cheese Brook at Route 177 (Table 1).

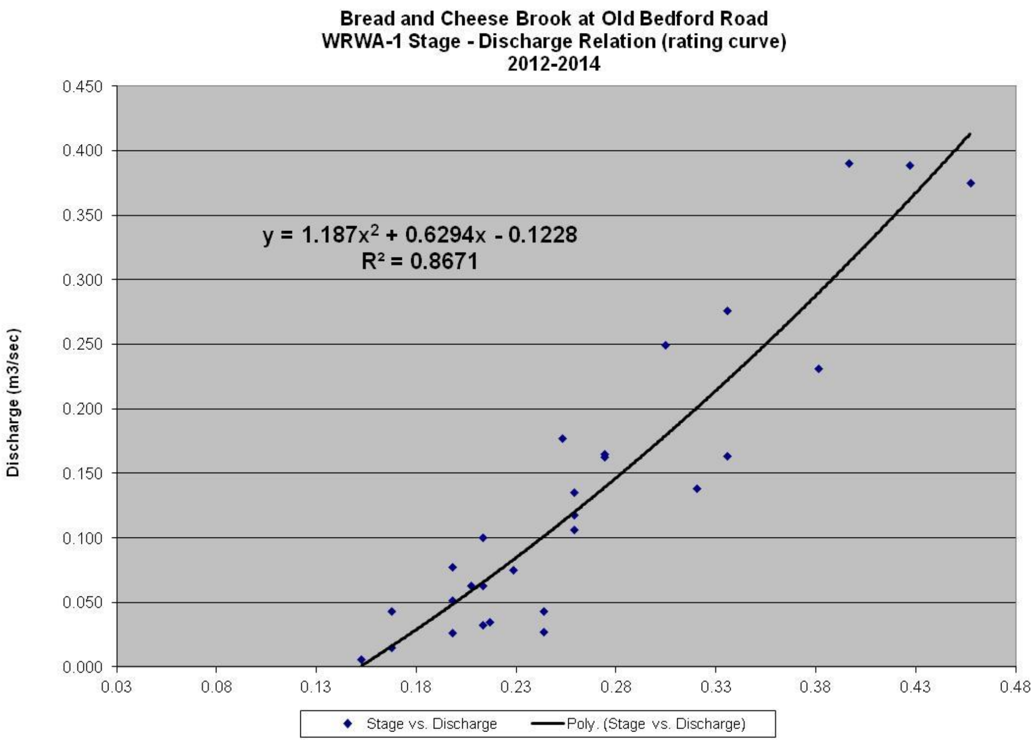

Figure 4 - WRWA-1 Stage-Discharge relation used to convert stream stage into flow.

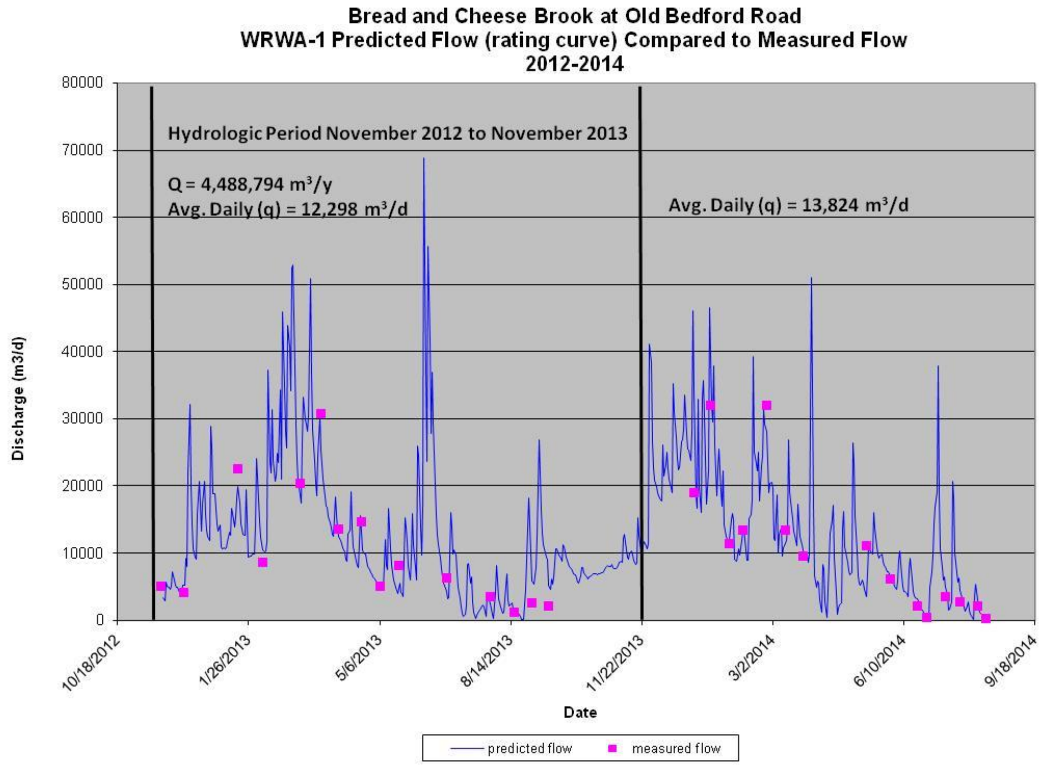

Figure 5 - WRWA-1 Predicted flows compared to measured flows for 1 year hydro period.

Bread and Cheese Brook Stream Flow at WRWA-2 Gauging Location (Route 6):
The WRWA-2 stream gauging location at Route 6 was established at an intermediate point approximately mid way between the uppermost gauging location (WRWA-1) and the lowermost gauging location (WRWA-3, Rt. 177). The freshwater flow passing through the WRWA-2 location was determined using the same standard hydrologic techniques to determine flow at WRWA-1 such that flows at all stream gauging locations could be confidently cross compared. As with all stream gauges deployed for this study, calibration of the gauge was checked periodically over the gauge deployment period to confirm that the water level logger was operating accurately. The gauge was installed on November 21, 2012 and collected water level data continuously until August 10, 2014 for a total deployment of 21 months including capturing the low flow and nutrient conditions during the summer 2013. As depicted in Figure 6, the comparison of the stream stage measured by the gauge (blue line) and the field calibration points (red triangles, where water level [stage] is measured with a wading rod) indicates that the gauge was accurate. On average there was only a 2% difference between the measured stage values obtained using the gauge and the stage calibration measurement obtained in the field using a wading rod.

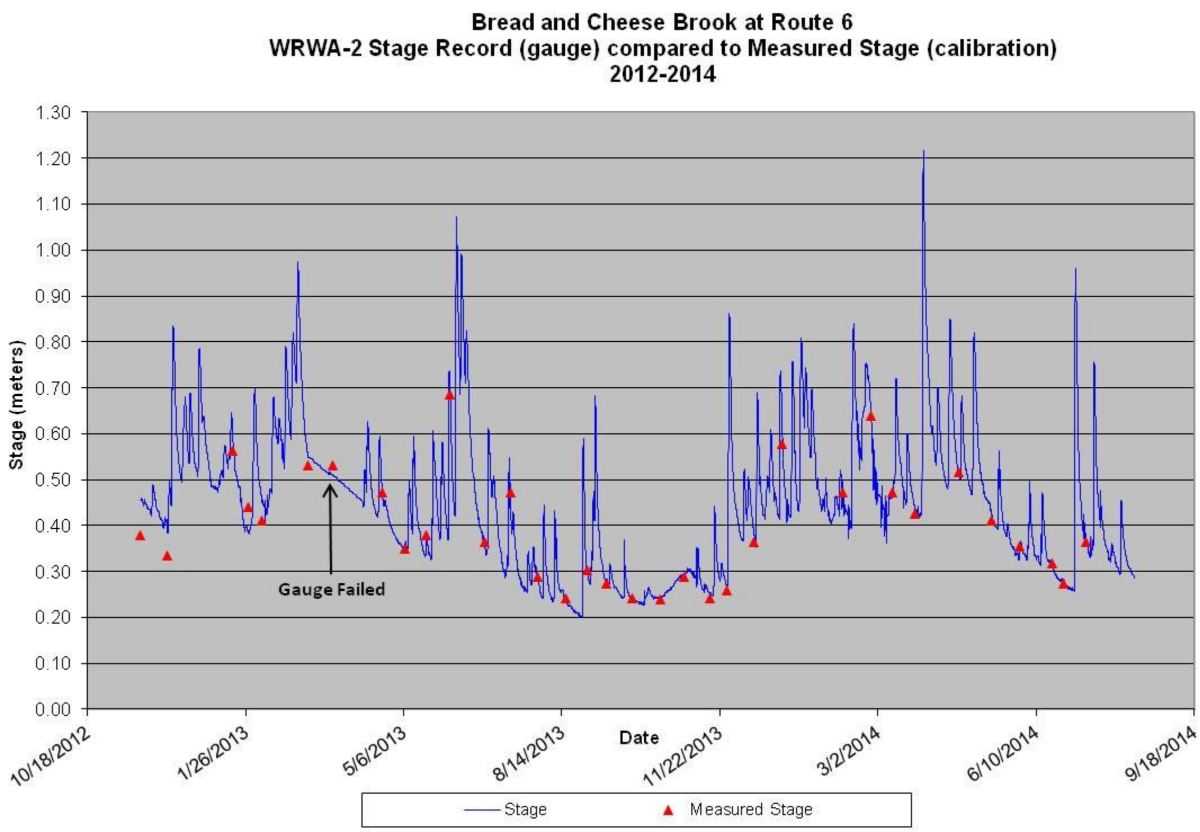

Figure 6 - WRWA-2 Measured stream stage using the WL-15 water level logger (gauge) compared to the field calibration points obtained using a wading rod and manual measurement of water level at the gauge location. There was <2% difference between the 2 level methods.

Flow in the brook (volumetric discharge) was measured every 2 to 6 weeks using a Marsh-McBirney electromagnetic flow meter. A stage-discharge relation (rating curve) was developed for the gauge site based upon these flow measurements and the measured water levels at the gauge site (Figure 7). A strong relationship was determined between water levels at the gauge and flow (R^2 = 0.978) suggesting that daily flow can be accurately predicted from measured water levels. The rating curve was then used to convert the continuously measured stage data to daily freshwater flow volume (Figure 8). Inputting the stage record into the stage-discharge equation yields a "predicted" daily flow at the gauging location which when compared to measured flows shows good agreement. Based on the rating curve and the detailed stage record, flow at WRWA-1 was determined to be 9,250,522 m^3/yr for the hydrologic period November 2012 to November 2013. Dividing by 365 days yields an average daily flow of 25,344 m^3/d. The flow determined at the WRWA-1 stream gauging location represents 52% of the flow determined at the down gradient stream gauging location on the main stem of Bread and Cheese Brook at Route 177 (Table 1). The watershed area between WRWA-1 and WRWA-2 contributes approximately 10,046 m^3/d of additional flow to the Bread and Cheese Brook system (e.g. stream pick-up).

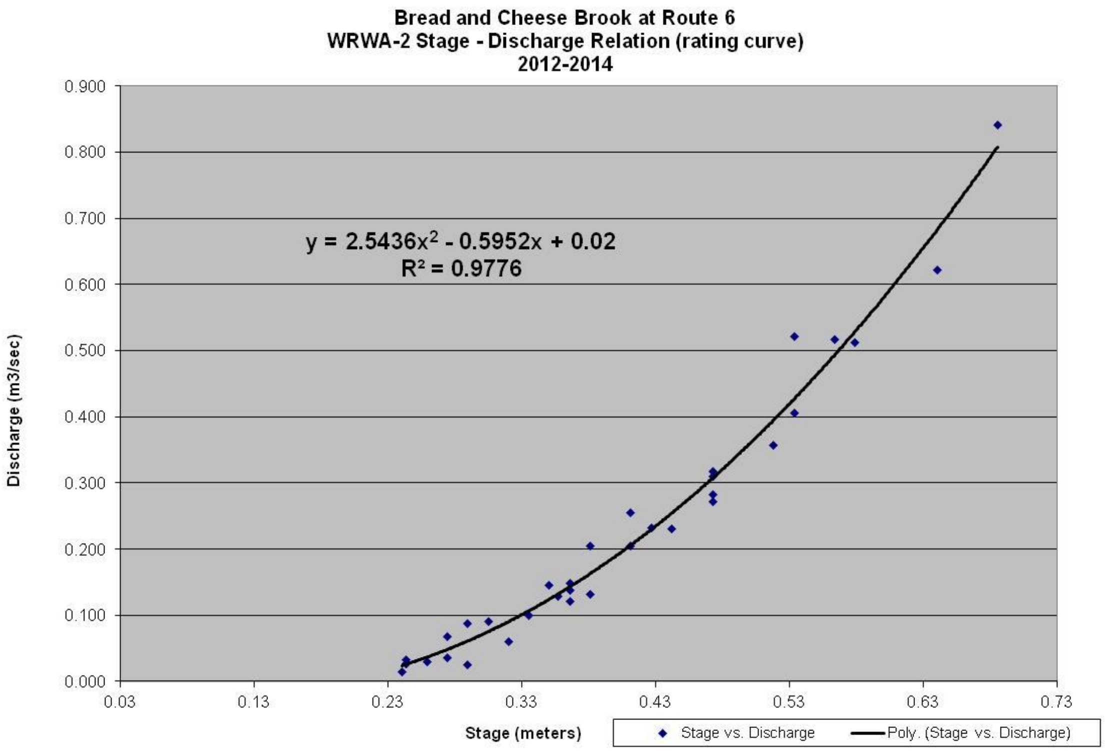

Figure 7 - WRWA-2 Stage-Discharge relation used to convert stream stage into flow.

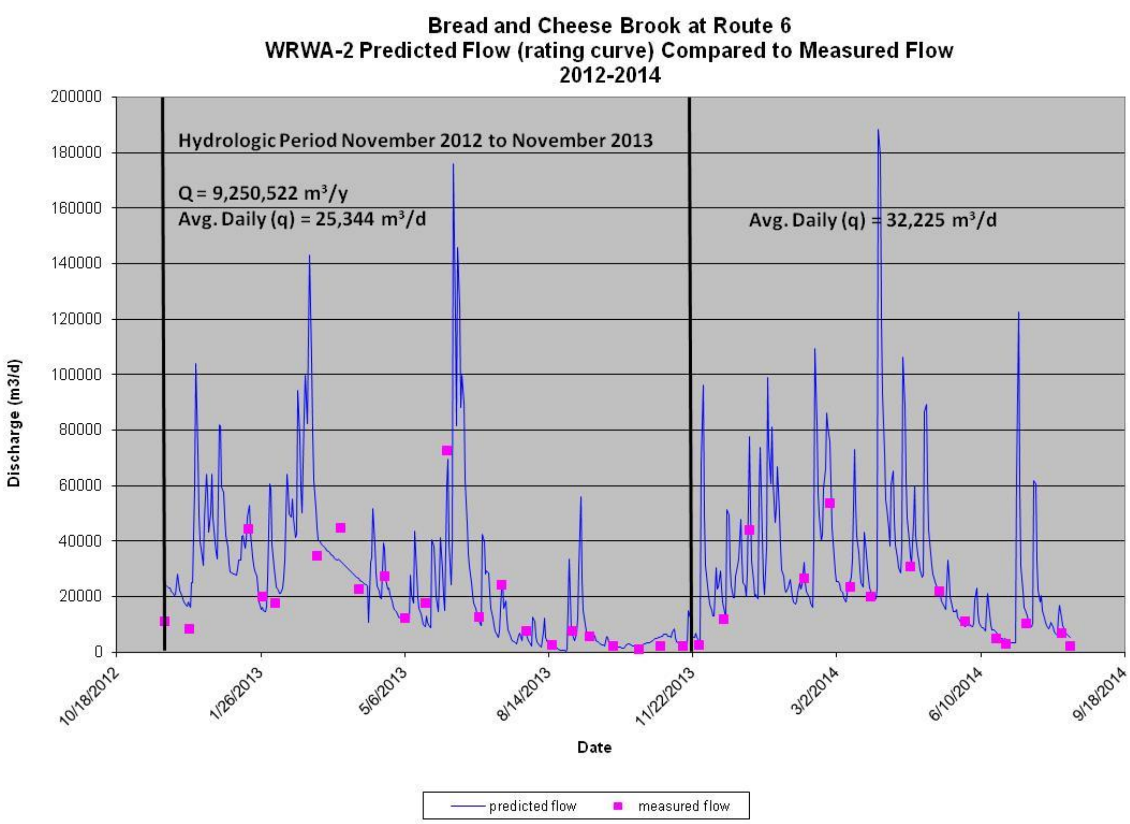

Figure 8 - WRWA-2 Predicted flows compared to measured flows for 1 year hydro period.

Hemlock Gutter to Bread and Cheese Brook Stream Flow at WRWA-4 Gauging Location (Gifford Road):

The WRWA-4 stream gauging location was established at an intermediate point slightly up-gradient of the confluence of Hemlock Gutter and the main stem of Bread and Cheese Brook. Hemlock Gutter discharges into the Bread and Cheese Brook down gradient of WRWA-2 but up-gradient of the lowermost gauging location (WRWA-3, Rt. 177). Flow measurements and stream gauging was completed at the Gifford Road crossing. The freshwater flow passing through the WRWA-4 location was determined using the same standard hydrologic techniques to determine flow at WRWA-1 and WRWA-2 such that flows at all stream gauging locations could be confidently cross compared. As with all stream gauges deployed for this study, calibration of the gauge was checked periodically over the gauge deployment period to confirm that the water level logger was operating accurately. The gauge was installed on November 21, 2012 and collected water level measurements until August 10, 2014 for a total of 21 months capturing the low flow and nutrient conditions during the summer 2013. As depicted in Figure 9, the comparison of the stream stage measured by the gauge (blue line) and the field calibration points (red triangles, where stage is measured with a wading rod to determine the water level) indicates that the gauge was measuring stage correctly. On average there was only a 0.31% difference between the measured stage values obtained using the gauge and the stage calibration measurement obtained in the field using a wading rod.

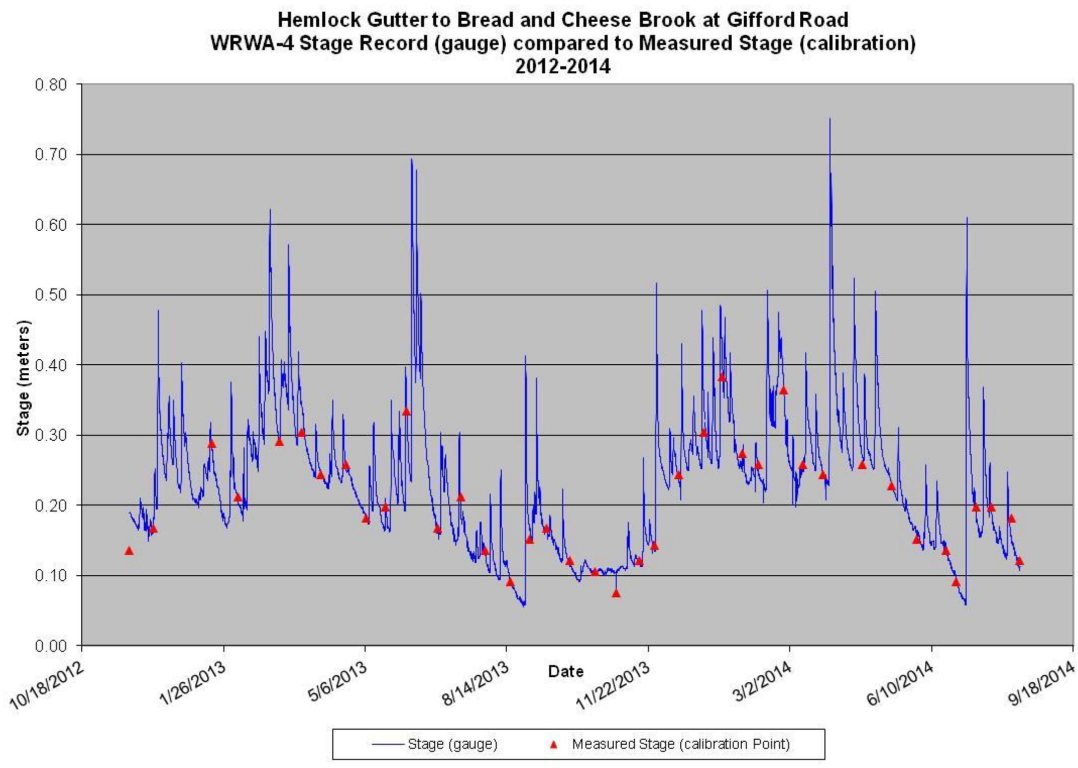

Figure 9 - WRWA-4 Measured stream stage (Hemlock Gutter tributary to Bread and Cheese Brook) using the WL-15 water level logger (gauge) compared to the field calibration points obtained using a wading rod and manual measurement of water level at the gauge location.

Flow (volumetric discharge) in the Hemlock Gutter tributary to Bread and Cheese Brook was measured every 2 to 6 weeks using a Marsh-McBirney electromagnetic flow meter. As with previous sites, a stage-discharge relation (rating curve) was developed for the gauge site based upon these flow measurements and the measured water levels at the gauge site (Figure 10). A strong relationship was determined between water levels at the gauge and flow (R^2 = 0.914) suggesting that daily flow can be accurately predicted from measured water levels. The rating curve was then used to convert the continuously measured stage data to daily freshwater flow volume (Figure 11). Inputting the stage record into the stage-discharge equation yields a "predicted" daily flow at the gauging location which when compared to measured flows shows good agreement. Based on the rating curve and the detailed stage record, flow at WRWA-4 was determined to be 3,166,011 m^3/yr for the hydrologic period November 2012 to November 2013. Dividing by 365 days yields an average daily flow of 8,674 m^3/d. The flow determined at the WRWA-4 stream gauging location represents 18% of the flow determined at the down gradient stream gauging location (WRWA-3) on the main stem of Bread and Cheese Brook at Route 177 (Table 1). The watershed area up-gradient of Gifford Road contributes approximately 8,674 m^3/d of additional flow to the Bread and Cheese Brook system.

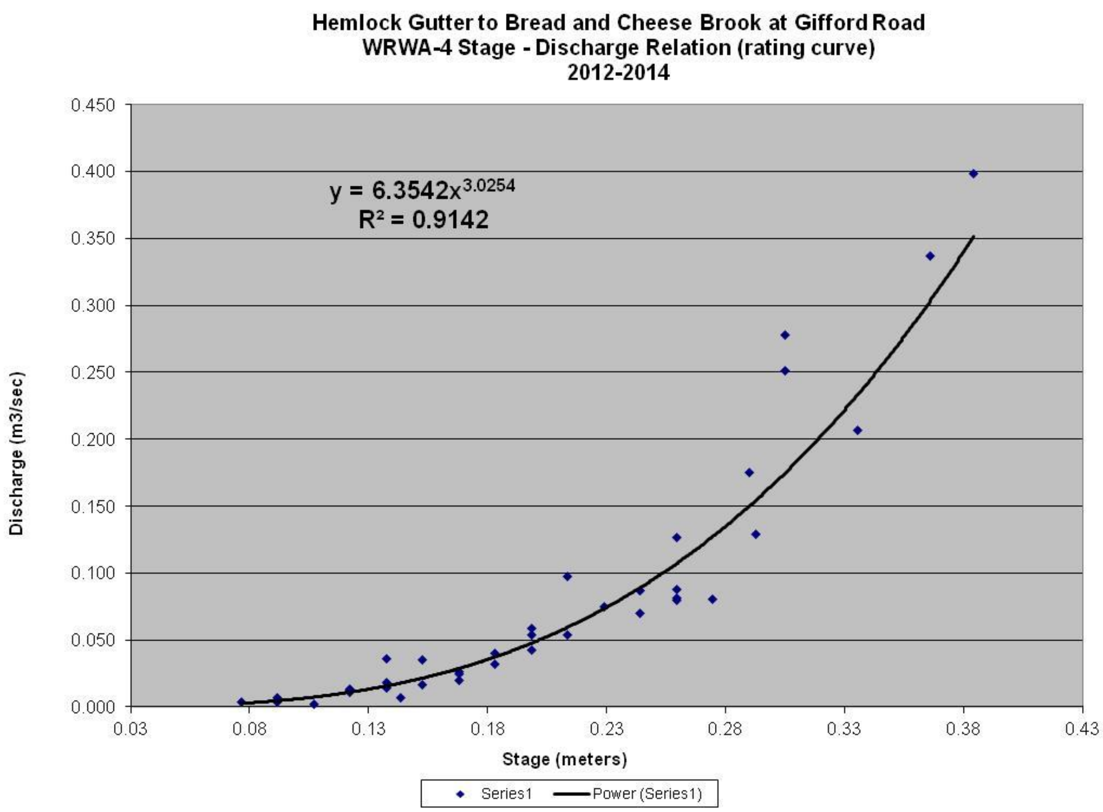

Figure 10 - WRWA-4 Stage-Discharge relation used to convert stream stage into flow.

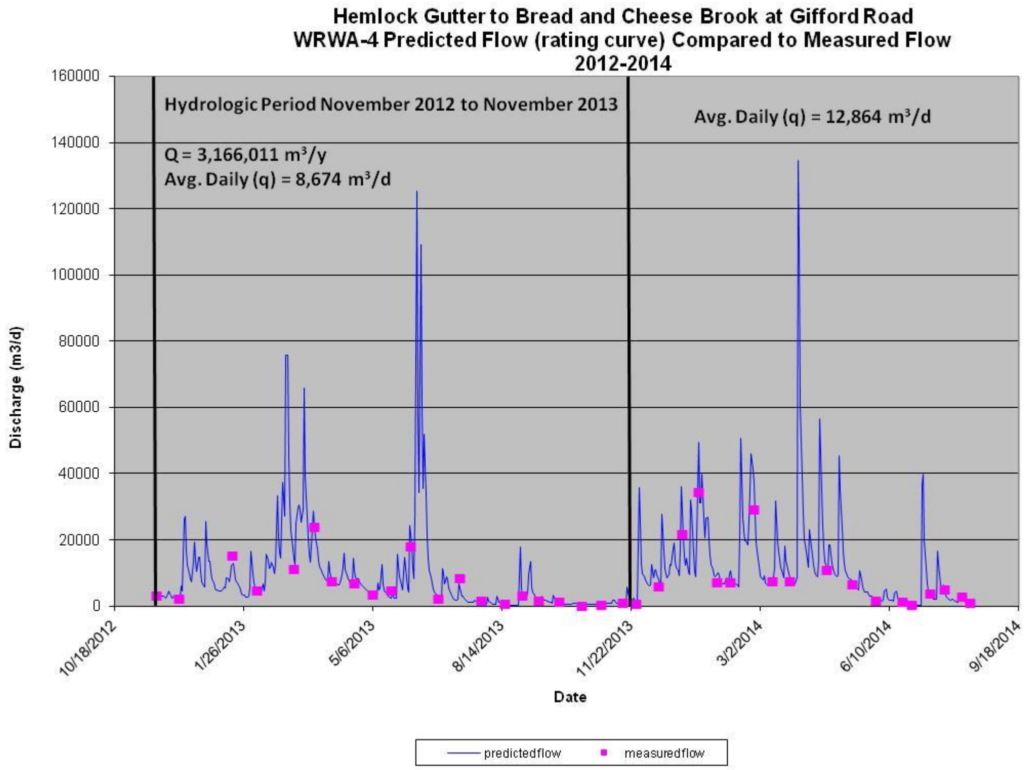

Figure 11 - WRWA-4 Predicted flows compared to measured flows for 1 year hydro period.

Bread and Cheese Brook Stream Flow at WRWA-3 Gauging Location (Route 177):

For the purpose of this flow and water quality study, the WRWA-3 stream gauging location was established as the lowermost stream gauging location on the main stem of Bread and Cheese Brook. The WRWA-3 stream gauging location was established approximately 650 meters up-gradient of the confluence with the Westport River. Both Bread and Cheese Brook and the Westport River join at the head of Head Dam Pond. Flow measurements and stream gauging was completed at the Route 177 bridge crossing. The freshwater flow passing through the WRWA-3 location was determined using the same standard hydrologic techniques to determine flow at WRWA-1, WRWA-2 and WRWA-4 such that flows at all stream gauging locations could be confidently cross compared. As with all stream gauges deployed for this study, calibration of the gauge was checked periodically over the gauge deployment period to confirm that the water level logger was operating accurately. Like all the other gauges discussed thus far, the WRWA-3 gauge was installed on November 21, 2012 and collected water level data until August 10, 2014 for a total deployment of 21 months capturing the low flow and nutrient conditions during the summer 2013. As depicted in Figure 12, the comparison of the stream stage measured by the gauge (blue line) and the field calibration points (red triangles, measured with a wading rod to determine the water level) indicates that the gauge was measuring stage correctly. On average there was only a 1% difference between the measured stage values obtained using the gauge and the stage calibration measurement obtained in the field using a wading rod. Overall, the

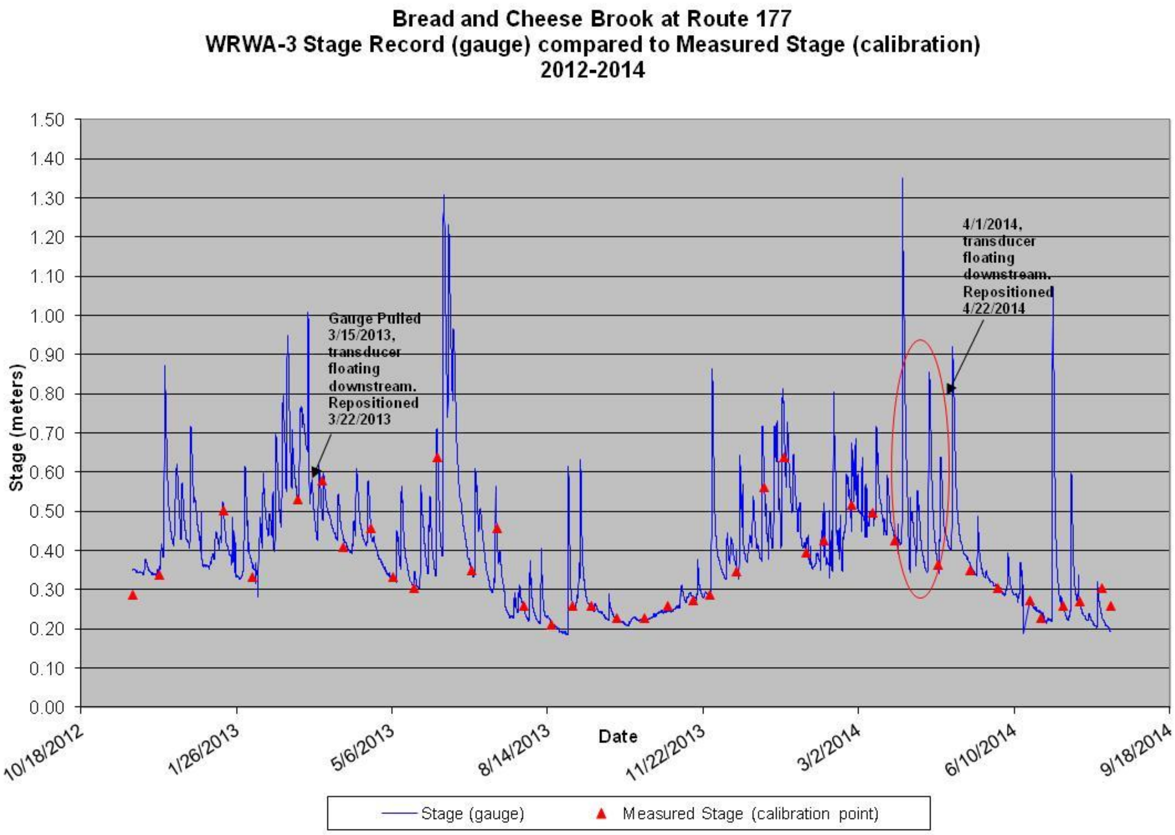

Figure 12 - WRWA-3 measured stream stage in Bread and Cheese Brook (Rt. 177) using the WL-15 water level logger (gauge) compared to the field calibration points obtained using a wading rod and manual measurement of water level at the gauge location.

stream gauge deployment was successful producing an accurate record of stream water levels, however, in two instances (3/15/13 - 3/22/13 and 4/1/14 - 4/22/14) the gauge was found to have been pulled from its anchor in the stream bed thus creating a discontinuity in the water level record. Stream water levels were measured manually at the displaced gauge as well as the original position and an offset was determined in order to adjust the stage record to the original position of the gauge.

Flow (volumetric discharge) in the Bread and Cheese Brook was measured every 2 to 6 weeks using a Marsh-McBirney electromagnetic flow meter. As for all sites, a stage-discharge relation (rating curve) was developed for the WRWA-3 gauge site based upon these flow measurements and the measured water levels (Figure 13). A strong relationship was determined between water levels at the gauge and flow (R^2 = 0.922) suggesting that daily flow can be accurately predicted from measured water levels. The rating curve was then used to convert the continuously measured stage data to daily freshwater flow volume (Figure 14). Inputting the stage record into the stage-discharge equation yields a "predicted" daily flow at the gauging location which when compared to measured flows shows good agreement. Based on the rating curve and the detailed stage record, flow at WRWA-3 was determined to be 17,770,489 m^3/yr for the hydrologic period November 2012 to November 2013. Dividing by 365 days yields an average daily flow of 48,686 m^3/d. It should be noted that watershed area down gradient of both the WRWA-4 and the WRWA-2 gauge locations adds approximately 17,668 m^3/d of flow to Bread and Cheese Brook.

The flow at the WRWA-3 gauging location was cross checked against an estimated long term average flow based upon the U.S. Geological Survey/Buzzards Bay Project/MEP (Massachusetts Estuaries Project) defined watershed delineations and average annual recharge. The measured freshwater discharge from Bread and Cheese Brook at the WRWA-3 gauge location was 6% below the long-term average modeled flow. The average daily flow based on the WRWA-3 rating curve was 48,686 m^3/day compared to the long term average flows determined by the watershed modeling effort (51,585 m^3/day)[1]. The negligible difference between the long-term average flow based on recharge rates over the watershed area and the average daily flows from the rating curve indicates that the creek is capturing the up-gradient recharge (and loads) accurately and is a strong cross check that the flow measurements and rating curves developed for the Bread and Cheese Brook are valid.

All the flows determined for the four stream gauging locations (WRWA-1,2,3,4) are summarized in Table 2 below. The values in the Table 2 clearly demonstrate how flows steadily increase as the confluence to the Westport River is approached and more land area in the watershed is included in the measured flows. Additionally, predicted flows determined at each gauge location were compared to long term average discharge based on the USGS accepted recharge rate for the region of 30.456 in./yr (Table 3). The comparison serves as a cross check on the accuracy of the rating curve, with the understanding that predicted discharge may be higher or lower than the long term average discharge depending on whether annual precipitation during the study period is above or below the long term average.

Predicted discharge across the Bread and Cheese Brook watershed generally agreed well with the long term average discharge with the exception of flow at WRWA-4. At that gauging location, the predicted flow was significantly lower than that which was calculated based on recharge across the watershed area up-gradient of the WRWA-4 gauge location. Since good agreement was observed at the three other gauging locations, the difference in flows at the WRWA-4 location could be attributable to: 1) how the watershed was delineated for the area up-gradient of the gauge (the delineated area being larger than the area that actually contributes to the gauge) or 2) enhanced evoapotranspiration compared to the factor used to estimate flow from the watershed area. The delineation could be confounded by the complexity of the small hydraulic interconnections that may exist throughout the wetland area that constitutes large areas up-gradient of the WRWA-4 gauging location. These small interconnections could increase the potential error in a watershed delineation that is more based on the topographic information presented on the USGS topo map for that area. While it is not possible to determine which is the driving factor for the difference without more detail study of the particular subwatershed up-gradient of WRWA-4, one thing is certain, the WRWA-4 subwatershed contains much more wetland area than the areas above WRWA-1, 2 and 3. Approximately 60-70% of the land area above WRWA-4 is comprised of wetland whereas wetland constitutes ~20% of the land area above WRWA-1, 10% for the area between WRWA-1 and 2 and 0% for the land area between WRWA-2, 3 and 4.

[1] Area above WRWA-3 gauge on Bread and Cheese at Route 177 is 6,013 acres. Using the 30.456 in/yr recharge the MEP used for Westport yields a resulting flow 18,828,387 m3/yr (51,585 m^3/day) or ~76% of the flow we had attributed to shed #3.

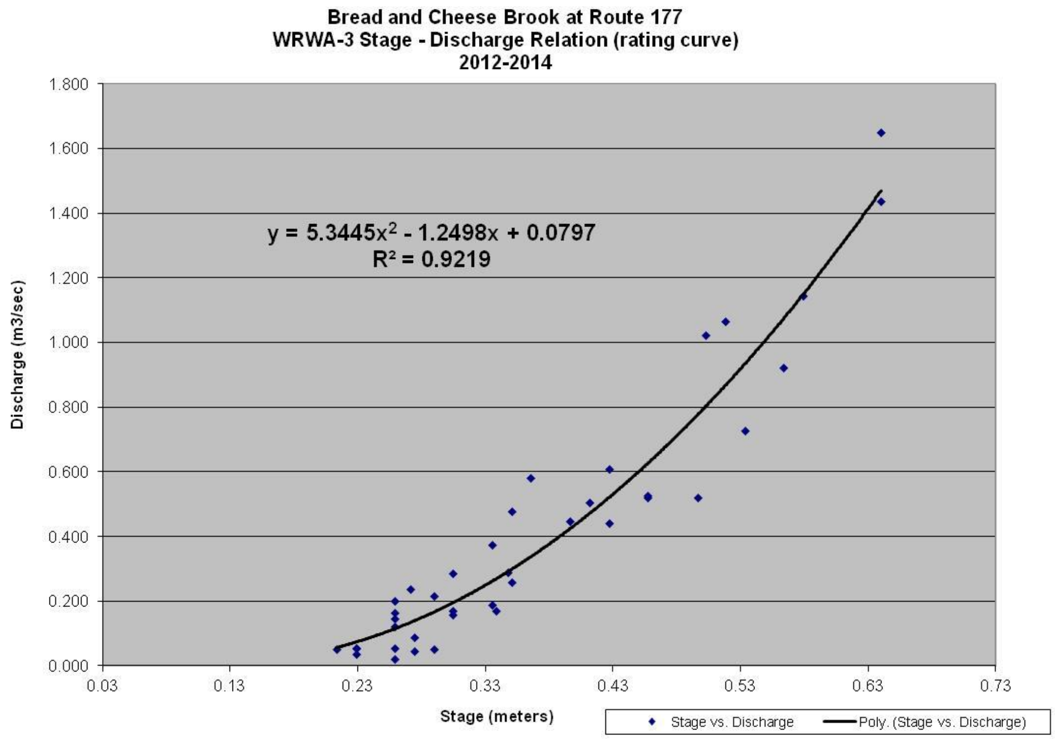

Figure 13 - WRWA-3 Stage-Discharge relation used to convert stream stage into flow.

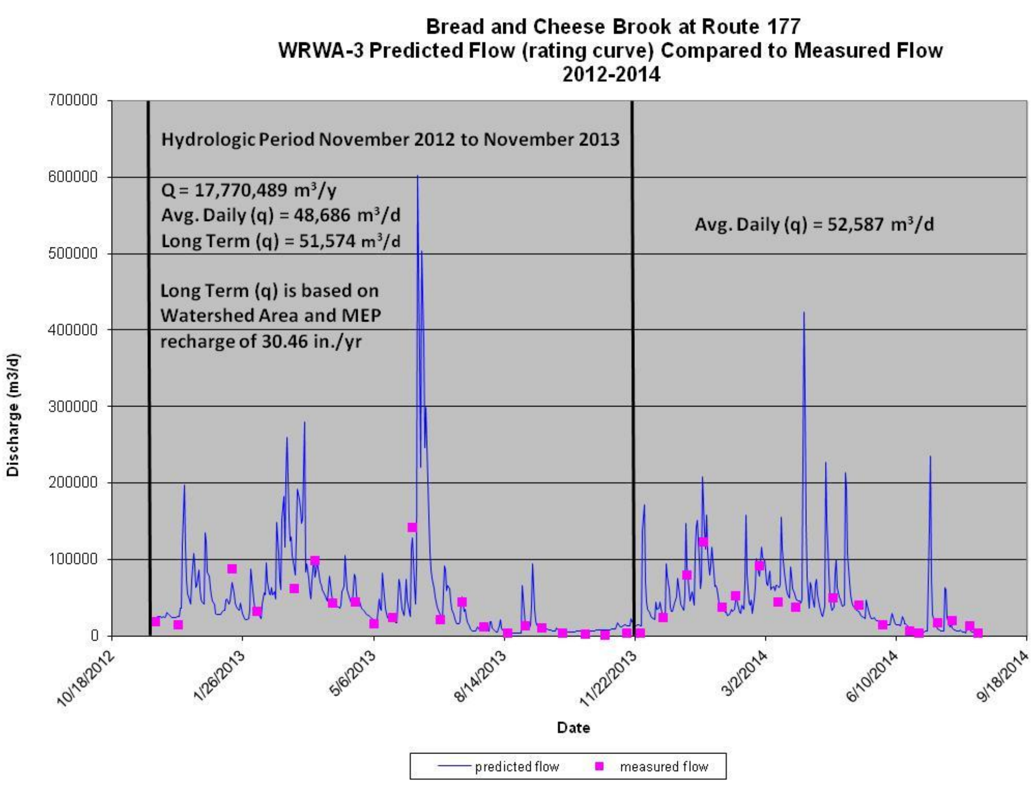

Figure 14 - WRWA-3 Predicted flows compared to measured flows for 1 year hydro period.

Table 2 - Summary of flows determined at the four stream gauging locations established in the Bread and Cheese Brook sub-watershed (#3).

Bread and Cheese Brook Flow and Water Quality Study				
UMD-SMAST Coastal Systems Program for WRWA / Town of Westport				
Performance Period: November 2012 to October 2014				
2-Oct-14				
Stream Gauging Location	**Hydrologic Period**	**Discharge (m3/yr)**	**Discharge (m3/d)**	**% of Flow Relative to WRWA-3**
WRWA-1 at Old Bedford Road	Nov. 21, 2012 to Nov. 20, 2013	4,488,794	12,298	25%
WRWA-2 at Route 6	Nov. 21, 2012 to Nov. 20, 2013	9,250,522	25,344	52%
WRWA-4 at Gifford Road	Nov. 21, 2012 to Nov. 20, 2013	3,166,011	8,674	18%
WRWA-3 at Route 177	Nov. 21, 2012 to Nov. 20, 2013	17,770,489	48,686	100%
NOTE: WRWA-1,2,3 are located on Bread and Cheese Brook				
WRWA-4 is located on Hemlock Gutter (tributary to Bread and Cheese Brook)				

Table 3 - Comparison of predicted discharge based on rating curves developed for each stream gauge location and long term average discharge based on annual recharge across each watershed area.

Stream Gauging Location	**Hydrologic Period**	**Discharge (m3/yr)**	**Discharge (m3/d)**	**Long Term Avg Discharge (m3/d)**
WRWA-1 at Old Bedford Road	Nov. 21, 2012 to Nov. 20, 2013	4,488,794	12,298	16,022
WRWA-2 at Route 6	Nov. 21, 2012 to Nov. 20, 2013	9,250,522	25,344	25,303
WRWA-4 at Gifford Road	Nov. 21, 2012 to Nov. 20, 2013	3,166,011	8,674	**21,496**
WRWA-3 at Route 177	Nov. 21, 2012 to Nov. 20, 2013	17,770,489	48,686	51,574
NOTE: WRWA-1,2,3 are located on Bread and Cheese Brook				
WRWA-4 is located on Hemlock Gutter (tributary to Bread and Cheese Brook)				
Long Term Average based on watershed area and avg annual precip. = 30.456 in./yr				

Ultimately, integrating the flow and nitrogen concentration from water samples collected at the gauges allowed for the determination of nitrogen mass discharge at each gauge location. It is important to note that the calculated nitrogen load is reflective of the biological processes occurring in the channel bed and any associated ponds, wetlands or wooded areas contributing to natural nitrogen attenuation.

Stream Water Quality Monitoring

The annual record of flow at each stream gauge was merged with the nutrient data sets (nutrient concentrations) generated through the bi-weekly water quality sampling performed at the gauge locations to determine nitrogen loading rates from critical junctures in the Bread and Cheese Brook system discharging to the Westport River system. Nitrogen load from the various stream segments was calculated using the paired daily discharge and daily (interpolated from the bi-weekly sampling) nitrogen concentration data to determine the mass flux of nitrogen through a specific gauging site. In order to pair daily flows with daily nutrient concentrations, interpolation between bi-weekly nutrient data points was necessary. These data are expressed as nitrogen mass per unit time (kg/d) and can be summed in order to obtain weekly, monthly, or annual nutrient load carried by the Bread and Cheese Brook to the Westport River and the embayment system overall (head of the East Branch of the Westport River embayment).

Bread and Cheese Brook Stream Nutrient Concentrations and Load at WRWA-1, Gauge at Old Bedford Road:

Water quality was monitored at the WRWA-1 stream gauging location over the entire gauge deployment period. A total of 40 sampling events were completed whereby concentrations were determined for all the nitrogen species (NH_4, NO_X, DIN, DON, PON, TN) as well as for total phosphorous (TP), orthophosphate (PO_4) and particulate organic carbon (POC). The constituents were coupled with previously discussed flow data in order to determine the nutrient load transported by the Bread and Cheese Brook as well as which portions of watershed #3 are generating the most significant nutrient load.

Over the entire sampling period, average TN concentration was 0.774 mg/L (s. d. 0.130) with a minimum and maximum concentration of 0.515 and 1.000 mg/L respectively (Figure 15). The average Nitrate+Nitrite (NOx) concentration at WRWA-1 was 0.159 mg/L, comprising 21% of the total nitrogen. The relatively low concentration of NOx (bioavailable form of nitrogen) likely stems from uptake and transformation by natural processes during transport through the watershed and stream systems up-gradient of the WRWA-1 gauge. The low Nitrate+Nitrite (NOx) is consistent with the fact that the majority of the land use up-gradient of the gauge at Old Bedford Road is undeveloped or public service land (Figure 19) with few nitrogen sources. "Public Service" properties in the MassDOR coding system which was used in the MEP land use analysis for the Westport River watershed are tax-exempt properties, including lands owned by government (e.g., wellfields, schools, open space, roads) and private non-profit groups like churches and colleges. The majority (69%) of the total nitrogen concentration measured in the stream flow at WRWA-1 was comprised of Dissolved Organic Nitrogen (DON), which is also consistent with the low level of available dissolved inorganic nitrogen (DIN, 24% of TN). Average concentrations for all the nitrogen species as well as TP and PO_4 are provided below in Table 4a for Bread and Cheese Brook sites WRWA-1,2,3,4 and Table 4b for the Westport River sites WRWA-5,6,7.

Average daily flow at WRWA-1 was combined with measured concentrations (interpolated daily from bi-weekly sampling) in order to calculate nitrogen loads at this uppermost monitoring location in the Bread and Cheese Brook system. Total nitrogen load at WRWA-1 was equal to 3,199 kg/yr (8.77 kg/d). The TN load from the portion of watershed #3 up-gradient of the WRWA-1 gauge represents 12% of the TN load measured at the lower most gauge in the brook just prior to discharge to the River (WRWA-3). As anticipated, DON represented 67% of the TN load and DIN only 27% of the TN load at WRWA-1. Nitrogen constituent loads are summarized in Table 5. The stream pick-up of flow and nitrogen load can be corrected to unit area of watershed to allow comparisons to measurements from different sized contributing areas. Using area specific results (kilogram per acre per year basis (kg/ac/yr)), the contributing area within subwatershed #3 to WRWA-1 generates ~1.73 kg/ac/yr (Table 6). This is the lowest TN load per unit area of all the subwatersheds to the gauges deployed in this study. Based on the above mentioned concentrations and loads, it does not appear to be cost effective to try and manage bioavailable nitrogen in this uppermost area of subwatershed #3.

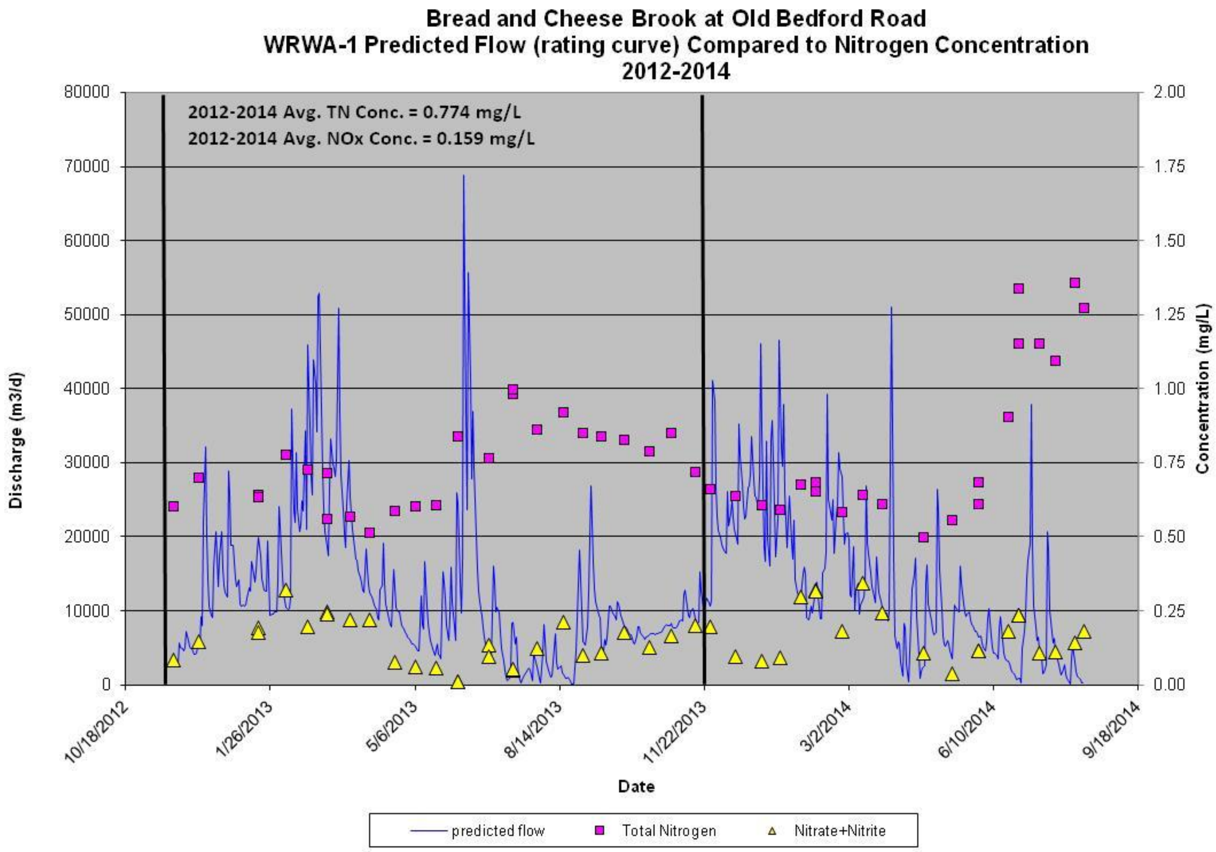

Figure 15 - Total Nitrogen and NOx (nitrate+nitrite) concentrations relative to flow determined at WRWA-1 stream gauge location. The predominance of organic forms of nitrogen is clear.

Bread and Cheese Brook Stream Nutrient Concentrations and Load at WRWA-2, Route 6: Water quality was monitored at the WRWA-2 stream gauging location over the entire gauge deployment period consistent with that for WRWA-1 to allow direct comparison to the other sites. A total of 40 sampling events were completed to assay concentrations of each nitrogen form (NH_4, NO_X, DIN, DON, PON, TN) as well as total phosphorous (TP), orthophosphate (PO_4) and particulate organic carbon (POC). The constituent concentrations were utilized in conjunction with previously discussed flow data in order to calculate nutrient load transported by the Bread and Cheese Brook as well as which portions of watershed #3 appeared to generate the largest nutrient load.

Over the entire sampling period, average TN concentration was about 1/3 higher than at WRWA-1, 1.055 mg/L versus 0.774 mg/L, respectively, with a minimum and maximum concentration of 0.724 and 1.383 mg/L and s.d. of 0.189 (Figure 16). The average Nitrate+Nitrite (NOx) concentration at WRWA-2 was 0.443 mg/L, comprising 40% of the total nitrogen concentration at this gauging location (Rt. 6). Since almost all of the nitrogen enters the water column in inorganic forms, the moderate contribution of organic forms to the total nitrogen pool suggests a modest conversion during transport by natural biological processes in the watershed and stream up gradient of the WRWA-2 gauge. However, the concentration of NO_X at WRWA-2 was significantly higher than up-gradient with the observed NOx concentration at WRWA-2 being 3 times that at WRWA-1, and represents almost half of the measured TN. This is consistent with the higher residential development in the WRWA-2 contributing area and limited potential for natural attenuation of NO_X to occur in lakes, ponds or wetlands. Nearly half (51%) of the total nitrogen concentration measured in the stream flow at WRWA-2 was comprised of Dissolved Organic Nitrogen (DON) which is consistent with the increased level of available dissolved inorganic nitrogen (DIN, 43% of TN). Interestingly, DON concentrations at both WRWA-1 and WRWA-2 were nearly the same (0.537 and 0.541 respectively). Average concentrations for all the nitrogen species as well as TP and PO_4 are provided below in Table 4a for Bread and Cheese Brook sites WRWA-1,2,3,4 and Table 4b for the Westport River sites WRWA-5,6,7.

Average daily flow at WRWA-2 coupled with concentration (interpolated daily from bi-weekly sampling) allowed calculation of nitrogen constituent loads at this intermediate monitoring location in the Bread and Cheese Brook system. Total nitrogen load at WRWA-2 was equal to 8,705 kg/yr (23.85 kg/d). It should be noted that TN load transported by Bread and Cheese Brook to WRWA-2 increased by 5,506 kg/yr due to pick-up between WRWA-1 and WRWA-2 or a 72 percent increase in total nitrogen load entering from the contributing area to this stream segment between Old Bedford Road and Route 6. The TN load entering from the portion of watershed #3 up-gradient of the WRWA-2 gauge represents 33% of the TN load measured down-gradient at WRWA-3 (the lowermost stream gauging location on the Bread and Cheese Brook just prior to discharge to the Westport River). As expected, DON represented half (52%) of the TN load at WRWA-2 whereas DIN represented 43% of the TN load at the gauge (remainder was PON). Nitrogen constituent loads are summarized in Table 5 below. On an areal basis the contributing area to WRWA-2 but below WRWA-1 generates ~5.09 kg/ac/yr (Table 6 and Figure 19). This is significantly greater than the per acre loading to the WRWA-1 gauge and most likely results from the higher level of development in this area of watershed #3. Based on the above mentioned concentrations and nitrogen load results, it appears that if suitable sites can be found that nitrogen removal may yield useful results in this contributing area.

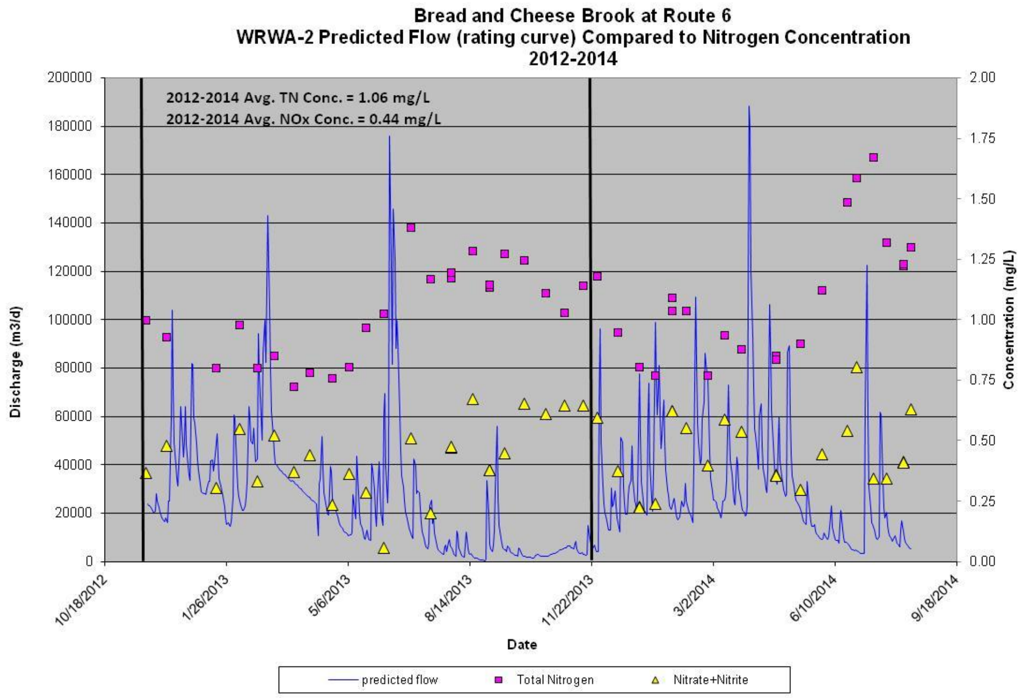

Figure 16 - Total Nitrogen and NOx (nitrate+nitrite) concentrations relative to flow determined at WRWA-2 stream gauge location.

Hemlock Gutter to Bread and Cheese Brook Stream Nutrient Concentrations and Load, WRWA-4, Gifford Road:

Water quality was monitored at the WRWA-4 stream gauging location (Hemlock Gutter tributary to the Bread and Cheese Brook) over the entire gauge deployment period consistent with the other sites to allow direct comparison to the other sites. A total of 40 sampling events were completed to assay concentrations of each nitrogen form (NH_4, NO_X, DIN, DON, PON, TN) as well as total phosphorous (TP), orthophosphate (PO_4) and particulate organic carbon (POC). The constituent concentrations were coupled with previously discussed flow data in order to calculate nutrient load transported by the Hemlock Gutter tributary as well as which portions of watershed #3 appeared to generate the largest nutrient load.

Over the entire sampling period, the average TN concentration was 2.431 mg/L (s.d. 2.030 mg/L) with a minimum and maximum concentration of 0.981 and 8.001 mg/L respectively (Figure 17). The average Nitrate+Nitrite (NOx) concentration at WRWA-4 was 1.593 mg/L, accounting for 66% of the total nitrogen concentration at the Gifford Road gauging location. The concentration of NO_X at WRWA-4 is 3.6 times the observed concentration at WRWA-2 and represents more than half of the measured TN at this location. While there is still undeveloped land up gradient of the gauge at Gifford Road, there is also an increase in residential land use in this region of subwatershed #3. Slightly less than a third (31%) of the total nitrogen concentration measured in the stream flow at WRWA-4 was comprised of Dissolved Organic Nitrogen (DON) which is consistent with the increased level of available dissolved inorganic nitrogen (DIN, 67% of TN). DON concentration at WRWA-4 was 0.743 mg/L whereas both WRWA-1 and WRWA-2 DON concentrations were nearly the same (0.537 and 0.541 respectively). Average concentrations for all the nitrogen species as well as TP and PO_4 are provided below in Table 4a for Bread and Cheese Brook sites WRWA-1,2,3,4 and Table 4b for the Westport River sites WRWA-5,6,7.

Average daily flow at WRWA-4 was coupled with measured concentrations (interpolated daily from bi-weekly sampling) in order to calculate nitrogen constituent loads at this monitoring location tributary to the Bread and Cheese Brook system. Total nitrogen load at WRWA-4 was equal to 4,842 kg/yr (13.26 kg/d). It should be noted that the TN load transported by the Hemlock Gutter tributary to Bread and Cheese Brook is 51% greater than the TN load measured at WRWA-1. The TN load from the portion of watershed #3 up-gradient of the WRWA-4 gauge represents 18% of the TN load measured at WRWA-3 (the lowermost stream gauging location collecting the combined flow from Bread and Cheese Brook). As would be expected, DON represented less than half (42%) of the TN load at the gauge whereas DIN represented 54%. Nitrogen constituent loads are summarized in Table 5 below. On an areal basis (kg/ac/yr), the subwatershed above WRWA-4 generates ~1.93 kg/ac/yr from a watershed area of 2,506 acres (Table 6). If the watershed area is re-estimated (1,133 acres) to match the predicted flow, the TN load per unit area of subwatershed increases to 4.27 kg/yr/ac. This is a lower per unit TN load than the area between WRWA-1 and WRWA-2, however, an indication that it may be worthwhile looking at the type of development that does exist in this subwatershed above WRWA-4 and the associated loads that development generates.

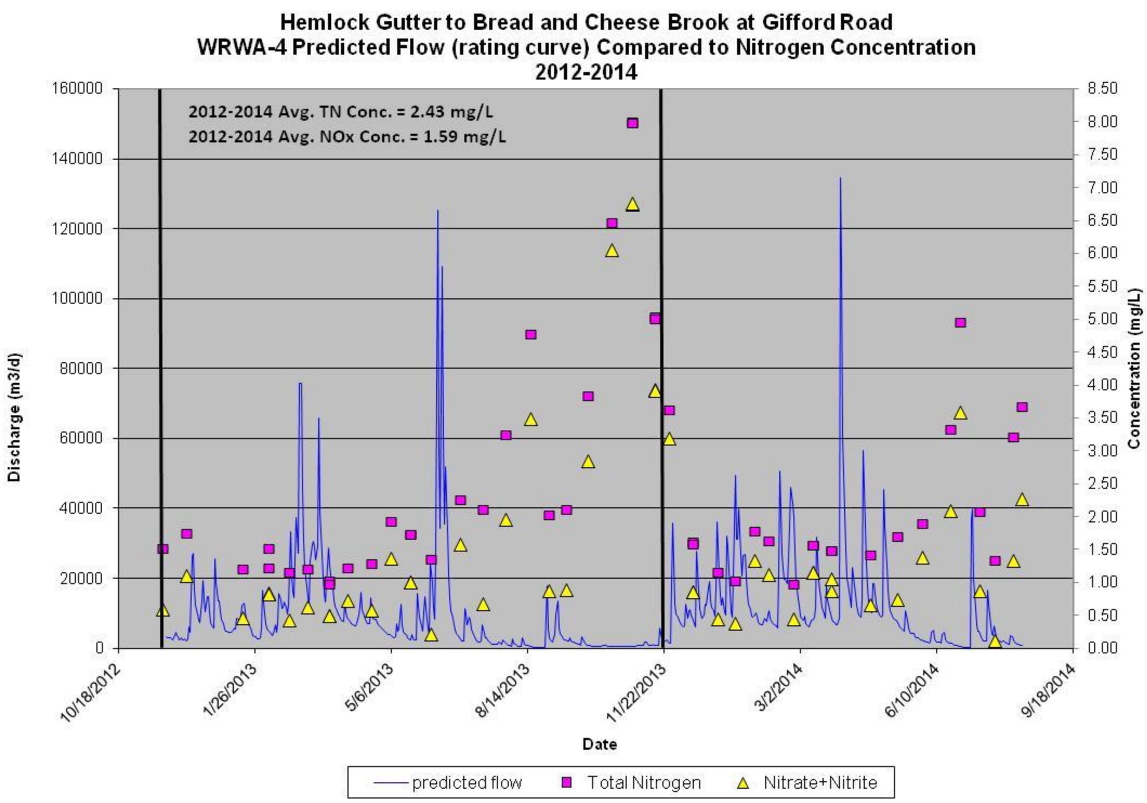

Figure 17 - Total Nitrogen and NOx concentrations relative to flow determined at WRWA-4 stream gauge location. Note the very high NOx levels during the low flow in summer.

Bread and Cheese Brook Stream Nutrient Concentrations and Load at WRWA-3 Gauging Location (Route 177):

Water quality was monitored at the WRWA-3 stream gauging location (Bread and Cheese Brook at Rt. 177) over the entire gauge deployment period consistent with the other sites to allow direct comparison to the other sites. A total of 40 sampling events were completed to assay concentrations of each nitrogen form (NH_4, NO_X, DIN, DON, PON, TN) as well as total phosphorous (TP), orthophosphate (PO_4) and particulate organic carbon (POC). WRWA-3 is the lowermost sampling point prior to discharge to the Westport River. A total of 40 sampling events were completed whereby concentrations were determined for all the nitrogen species (NH_4, NO_X, DIN, DON, PON, TN) as well as for total phosphorous (TP), orthophosphate (PO_4) and particulate organic carbon (POC). The measured concentrations were coupled with previously discussed flow data in order to calculate nutrient load transported by the Bread and Cheese Brook as well as which portions of watershed #3 are generating the largest nitrogen load.

Over the entire sampling period, the average TN concentration was 1.353 mg/L (s.d. 0.764) with a minimum and maximum concentration of 0.800 and 5.192 mg/L respectively (Figure 18). The average Nitrate+Nitrite (NOx) concentration at WRWA-3 was 0.670 mg/L and represented 50% of the total nitrogen concentration at this gauging location (Route 177). While nearly half of the bioavailable nitrogen appears to have been transformed to organic forms up gradient of the WRWA-3 gauge, the concentration of NO_X at WRWA-3 is significantly greater than the observed NOx concentration at the upper (WRWA-1) and mid gauge (WRWA-2) sites. This is consistent with the fact that there is a relatively high level of development up gradient of the gauge at Route 177 and little opportunity for natural attenuation of NO_X to occur such as in lakes, ponds or wetlands. Inorganic (51%) and organic nitrogen (49%) each represented about half of the total nitrogen pool. DON concentration at WRWA-3 was 0.626 mg/L whereas both WRWA-1 and WRWA-2 DON concentrations were slightly lower (0.527 and 0.525 respectively). Interestingly, DIN concentration at WRWA-3 and WRWA-4 were both appreciably higher than the DIN concentrations measured at WRWA-1 and WRWA-2 with the highest concentration being at the mouth of the tributary to the Brook, WRWA-4. Average concentrations for all the nitrogen species as well as TP and PO_4 are provided below in Table 4a for Bread and Cheese Brook sites WRWA-1,2,3,4 and Table 4b for the Westport River sites WRWA-5,6,7.

Average daily flow at WRWA-3 was coupled with measured concentrations (interpolated daily from bi-weekly sampling) in order to calculate nitrogen constituent loads from the entire Bread and Cheese Brook system above Rt. 177. Total nitrogen load at WRWA-3 was equal to 26,338 kg/yr (72.16 kg/d). It should be noted that the TN load transported to WRWA-3 is ~ 3 times greater than the TN load measured at the mid stream gauging location, WRWA-2. The watershed area down gradient of WRWA-2 and WRWA-4 contributed an additional 12,791 kg/yr of TN load. DON comprised more than half of the TN load, 59%, and DIN about 37%. Nitrogen constituent loads are summarized in Table 5 below. On an area specific basis (kg/ac/yr), the contributing area to the stream reach between WRWA-2/WRWA-4 and WRWA-3 generates ~22.96 kg/ac/yr given a watershed area of 557 acres (Table 6 and Figure 19). This is the highest per unit TN load of all the areas upgradient of measured stream reaches in the Bread and Cheese Brook system and is consistent with the significant development (Figure 20) that exists in this portion of the overall watershed. Based on the above mentioned concentrations and loads, it would be advisable to try and advance management of nitrogen in the watershed contributing to the stream reach between WRWA-3 and WRWA-2/WRWA-4.

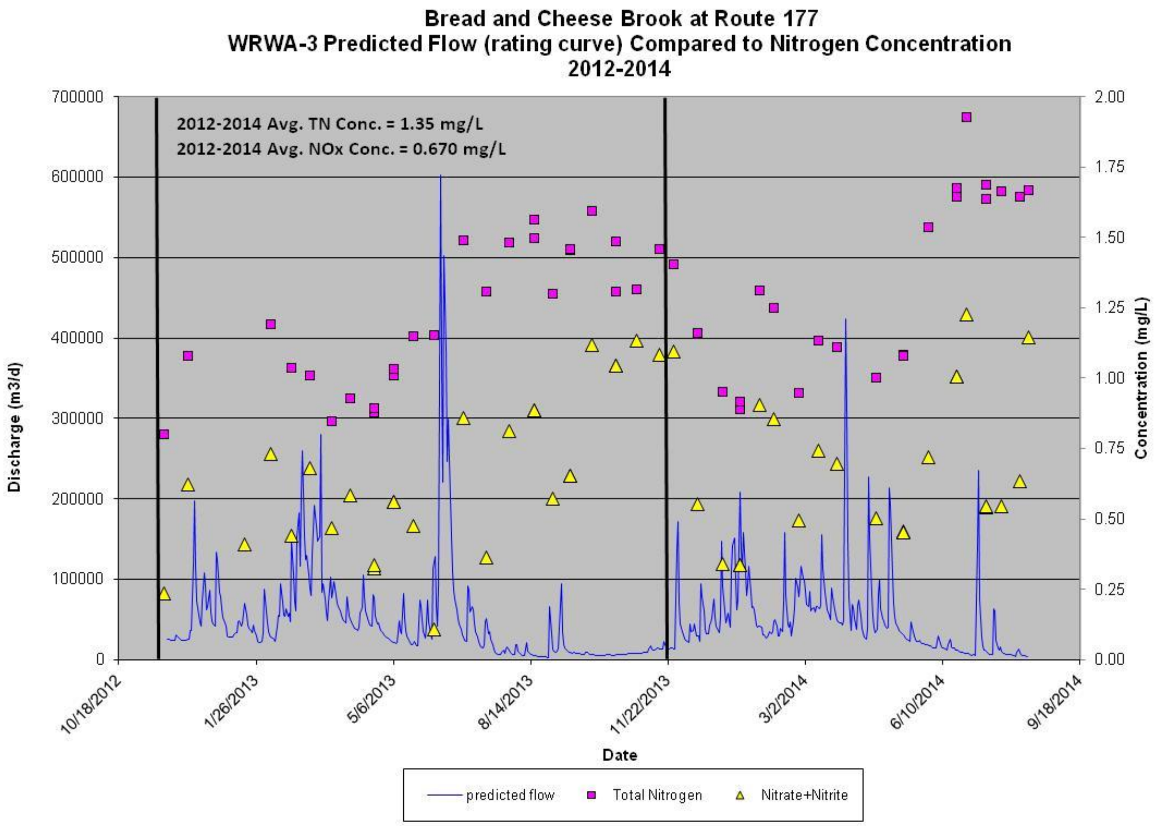

Figure 18 - Total Nitrogen and NOx concentrations relative to flow determined at WRWA-3 stream gauge location capturing the whole of Bread and Cheese Brook watershed discharge.

	Average Concentration over Sampling Period									
Stream Station Nov 12 - Aug 14	PO4 (mg/l)	TP (mg/l)	NH4 (mg/l)	NOX (mg/l)	DIN (mg/l)	DON (mg/l)	TDN (mg/l)	TN (mg/l)	POC (mg/l)	PON (mg/l)
WRWA-1	0.012	0.025	0.026	0.159	0.185	0.537	0.722	0.774	0.677	0.052
WRWA-2	0.017	0.031	0.029	0.443	0.473	0.541	1.014	1.055	0.537	0.042
WRWA-4	0.022	0.044	0.043	1.593	1.636	0.743	2.379	2.431	0.581	0.052
WRWA-3	0.016	0.030	0.019	0.670	0.689	0.626	1.315	1.353	0.476	0.038

Table 4a - Summary of average constituent nitrogen and phosphorous concentrations at each stream gauging location in the Bread and Cheese Brook System.

	Average Concentration over Sampling Period									
Stream Station Nov 12 - Aug 14	PO4 (mg/l)	TP (mg/l)	NH4 (mg/l)	NOX (mg/l)	DIN (mg/l)	DON (mg/l)	TDN (mg/l)	TN (mg/l)	POC (mg/l)	PON (mg/l)
WRWA-5	0.007	0.028	0.032	0.148	0.181	0.467	0.648	0.724	0.824	0.076
WRWA-6	0.008	0.029	0.030	0.197	0.227	0.457	0.683	0.739	0.609	0.056
WRWA-7	0.011	0.028	0.034	0.378	0.412	0.480	0.892	0.962	0.825	0.070

Table 4b - Summary of average constituent nitrogen and phosphorous concentrations at each stream gauging location in the Westport River System downgradient of Lake Noquochoke.

Comparing nitrogen concentrations from WRWA-1,2,3,4 in the Bread and Cheese Brook system to nitrogen concentration data from WRWA-5,6,7 on the Westport River below Lake Noquochoke, it is apparent the concentration of bioavailable nitrogen (DIN) is substantially higher in the Bread and Cheese Brook system. The relatively high concentrations, when combined with flow, translate to appreciable nitrogen loads being contributed from the Bread and Cheese Brook watershed (#3). By example, 26,338 kg/yr of total nitrogen was measured at WRWA-3 (12,791 kg/yr being picked up in the area bounded by WRWA-2, WRWA-4 and WRWA-3. The annual TN load measured at WRWA-3 in the period November 2012 to November 2013 represents 42% of the annual TN load measured by the MEP at WRWA-7 on the Westport River.

Stream Station Nov 2012 - Nov 2013	PO4 (load)	TP (load)	NH4 (load)	NOx (load)	DIN (load)	DON (load)	TDN (load)	TN (load)	POC (load)	PON (load)
WRWA-1 Bread and Cheese Brook at Old Bedford Road										
Annual Load (kg/y)	35	95	113	744	856	2150	3006	3199	2567	193
Avg. Daily Load (kg/d)	0.10	0.26	0.31	2.04	2.35	5.89	8.24	8.77	7.03	0.53
N as % of TN				**23%**	**27%**	**67%**	**94%**			**6%**
WRWA-2 Bread and Cheese Brook at Route 6										
Annual Load (kg/y)	109	249	291	3466	3757	4552	8309	8705	5122	397
Avg. Daily Load (kg/d)	0.30	0.68	0.80	9.50	10.29	12.47	22.76	23.85	14.03	1.09
N as % of TN				**40%**	**43%**	**52%**	**95%**			**5%**
WRWA-4 Hemlock Gutter at Gifford Road										
Annual Load (kg/y)	78	161	163	2471	2635	2046	4680	4842	1777	162
Avg. Daily Load (kg/d)	0.21	0.44	0.45	6.77	7.22	5.60	12.82	13.26	4.87	0.44
N as % of TN				**51%**	**54%**	**42%**	**97%**			**3%**
WRWA-3 Bread and Cheese Brook at Route 177										
Annual Load (kg/y)	262	638	398	9280	9678	15641	25319	26338	13490	1019
Avg. Daily Load (kg/d)	0.72	1.75	1.09	25.42	26.51	42.85	69.37	72.16	36.96	2.79
N as % of TN				**35%**	**37%**	**59%**	**96%**			**4%**

Table 5 - November 2012 to November 2013 Summary of constituent nitrogen loads at each stream gauging location.

Stream Gauge Location *** Values in Red represent PICK-UP**	**Flow (m^3/yr)**	**Watershed Area (acres)**	**Annual Unit Flow (m^3/ac/yr)**	**Annual Unit Load NOx (kg/ac/yr)**	**Annual Unit Load TN (kg/ac/yr)**
Bread and Cheese Brook (based on November 2012 to November 2013 hydrologic year)					
WRWA-1	**4,488,794**	1868	2403	0.398	1.713
WRWA-2 (incl. area above WRWA-1)	**9,250,522**	2950	3136	1.175	2.951
WRWA-2 (just area b/w WRWA-2 and WRWA-1) *	**4,761,728**	1082	4401	2.516	5.089
WRWA-4 Hemlock Gutter	**3,166,011**	2506	1263	0.986	1.932
WRWA-3 (incl. all area above WRWA-3)	**17,770,489**	6013	2955	1.543	4.380
WRWA-3 (just area b/w WRWA-2, WRWA-4 and WRWA-3) *	**5,353,956**	557	9612	6.002	22.964

Table 6 - Summary of TN and NOx loads on a kilogram per acre per year basis for the watershed areas upgradient of each stream gauge location as well as for "pick-up" (values in red). Loads are for the hydrologic year November 2012 to November 2013.

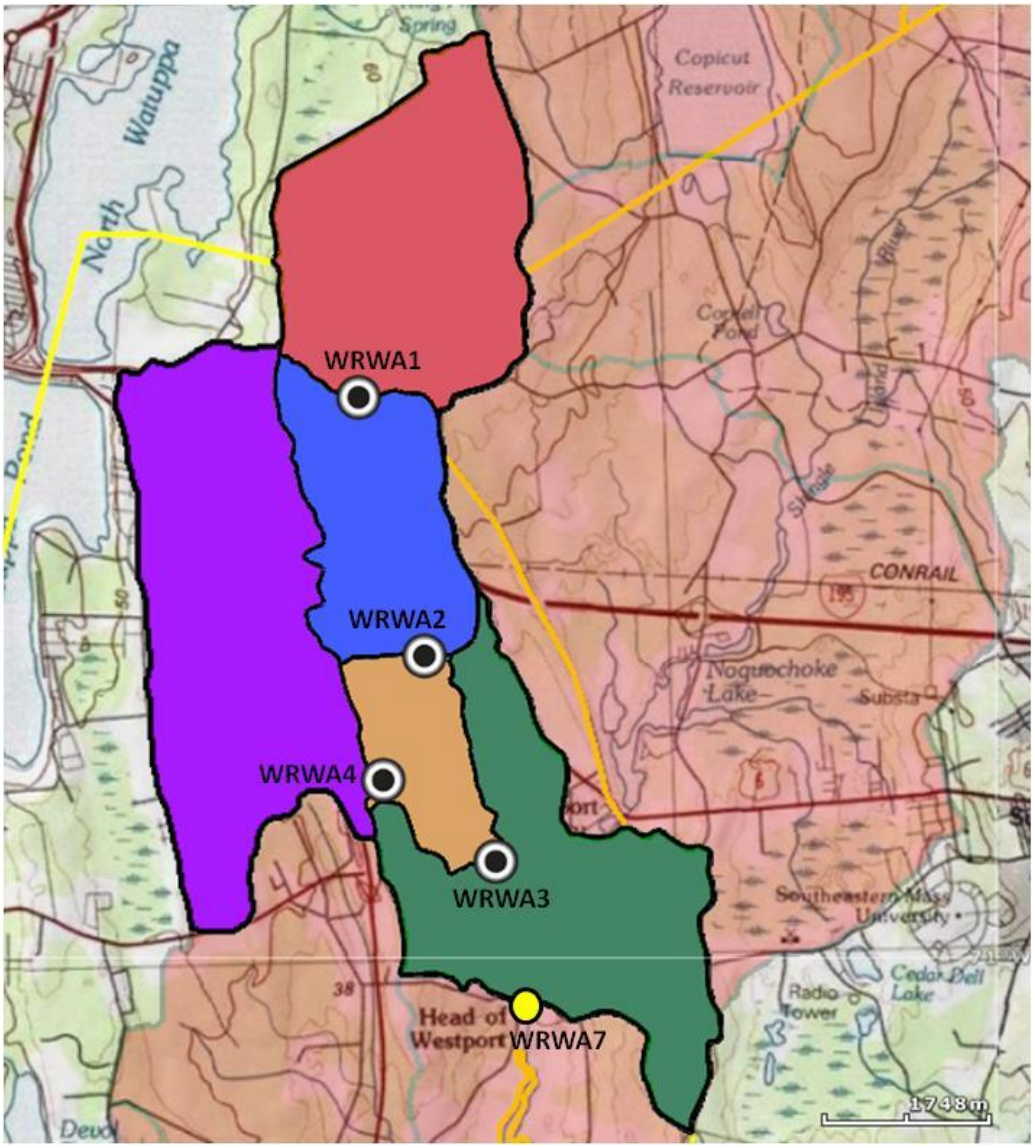

Figure 19 - Land area represented above and between each gauge to determine pick-up of flow and nitrogen load per acre of subwatershed.

In addition to the above discussion on comparative loads across the Bread and Cheese Brook watershed which were based on the hydrologic period November 21, 2012 to November 20, 2013, loads were also calculated for the remainder of the deployment period December 2013 to July 2014 (8 months). These loads were compared to the loads from the previous year over the same 8 month interval (December 2012 to July 2013) in order to make a direct comparison of loads over similar 8 month intervals in two consecutive years. Table 7a summarizes nitrogen loads for the period December 2012 to July 2013 whereas Table 7b summarizes loads for the period December 2013 to July 2014. Generally, with the exception of WRWA-1 which has a relatively less developed upgradient watershed, the nitrogen load was split approximately evenly between DIN and DON which together represented ~95% of total nitrogen for the 8 month period December 2012 to July 2013 and between 92% and 98% for December 2013 to July 2014. As DIN represents the bioavailable fraction of TN, managing inorganic nitrogen in the area between WRWA-1 and 2 as well as the area between WRWA-2, 3 and 4 would be the more effective starting point as these areas are the most developed of the Bread and Cheese Brook Watershed (#3).

Stream Station Dec 2012 - July 2013	PO4 (load)	TP (load)	NH4 (load)	NOx (load)	DIN (load)	DON (load)	TDN (load)	TN (load)	POC (load)	PON (load)
WRWA-1 Bread and Cheese Brook at Old Bedford Road										
Annual Load (kg/y)	25	70	95	609	705	1636	2341	2470	1674	130
Avg. Daily Load (kg/d)	0.10	0.29	0.39	2.51	2.90	6.73	9.63	10.17	6.89	0.53
N as % of TN				**25%**	**29%**	**66%**	**95%**			**5%**
WRWA-2 Bread and Cheese Brook at Route 6										
Annual Load (kg/y)	96	222	268	3044	3311	4075	7386	7753	4753	367
Avg. Daily Load (kg/d)	0.39	0.91	1.10	12.53	13.63	16.77	30.39	31.91	19.56	1.51
N as % of TN				**39%**	**43%**	**53%**	**95%**			**5%**
WRWA-4 Hemlock Gutter at Gifford Road										
Annual Load (kg/y)	71	149	155	2020	2175	1842	4017	4169	1668	152
Avg. Daily Load (kg/d)	0.29	0.61	0.64	8.31	8.95	7.58	16.53	17.15	6.86	0.62
N as % of TN				**48%**	**52%**	**44%**	**96%**			**4%**
WRWA-3 Bread and Cheese Brook at Route 177										
Annual Load (kg/y)	240	590	375	8144	8519	14906	23425	24413	13098	988
Avg. Daily Load (kg/d)	0.99	2.43	1.54	33.52	35.06	61.34	96.40	100.47	53.90	4.07
N as % of TN				**33%**	**35%**	**61%**	**96%**			**4%**

Table 7a - Eight month (December 2012 to July 2013) summary of constituent nitrogen loads at each stream gauging location.

Stream Station Dec 2013 - July 2014	PO4 (load)	TP (load)	NH4 (load)	NOx (load)	DIN (load)	DON (load)	TDN (load)	TN (load)	POC (load)	PON (load)
WRWA-1 Bread and Cheese Brook at Old Bedford Road										
Annual Load (kg/y)	29	45	55	521	601	1506	2097	2240	1515	146
Avg. Daily Load (kg/d)	0.12	0.19	0.23	2.15	2.47	6.20	8.63	9.22	6.24	0.60
N as % of TN				**23%**	**27%**	**67%**	**94%**			**7%**
WRWA-2 Bread and Cheese Brook at Route 6										
Annual Load (kg/y)	147	179	171	2956	3443	3903	6913	7516	3808	467
Avg. Daily Load (kg/d)	0.60	0.74	0.70	12.17	14.17	16.06	28.45	30.93	15.67	1.92
N as % of TN				**39%**	**46%**	**52%**	**92%**			**6%**
WRWA-4 Hemlock Gutter at Gifford Road										
Annual Load (kg/y)	50	99	72	2583	2655	1954	4609	4725	1353	116
Avg. Daily Load (kg/d)	0.20	0.41	0.30	10.63	10.93	8.04	18.97	19.44	5.57	0.48
N as % of TN				**55%**	**56%**	**41%**	**98%**			**2%**
WRWA-3 Bread and Cheese Brook at Route 177										
Annual Load (kg/y)	128	259	183	7630	7813	6270	14083	14531	5390	447
Avg. Daily Load (kg/d)	0.53	1.07	0.75	31.40	32.15	25.80	57.96	59.80	22.18	1.84
N as % of TN				**53%**	**54%**	**43%**	**97%**			**3%**

Table 7b - Eight month (December 2013 to July 2014) summary of constituent nitrogen loads at each stream gauging location.

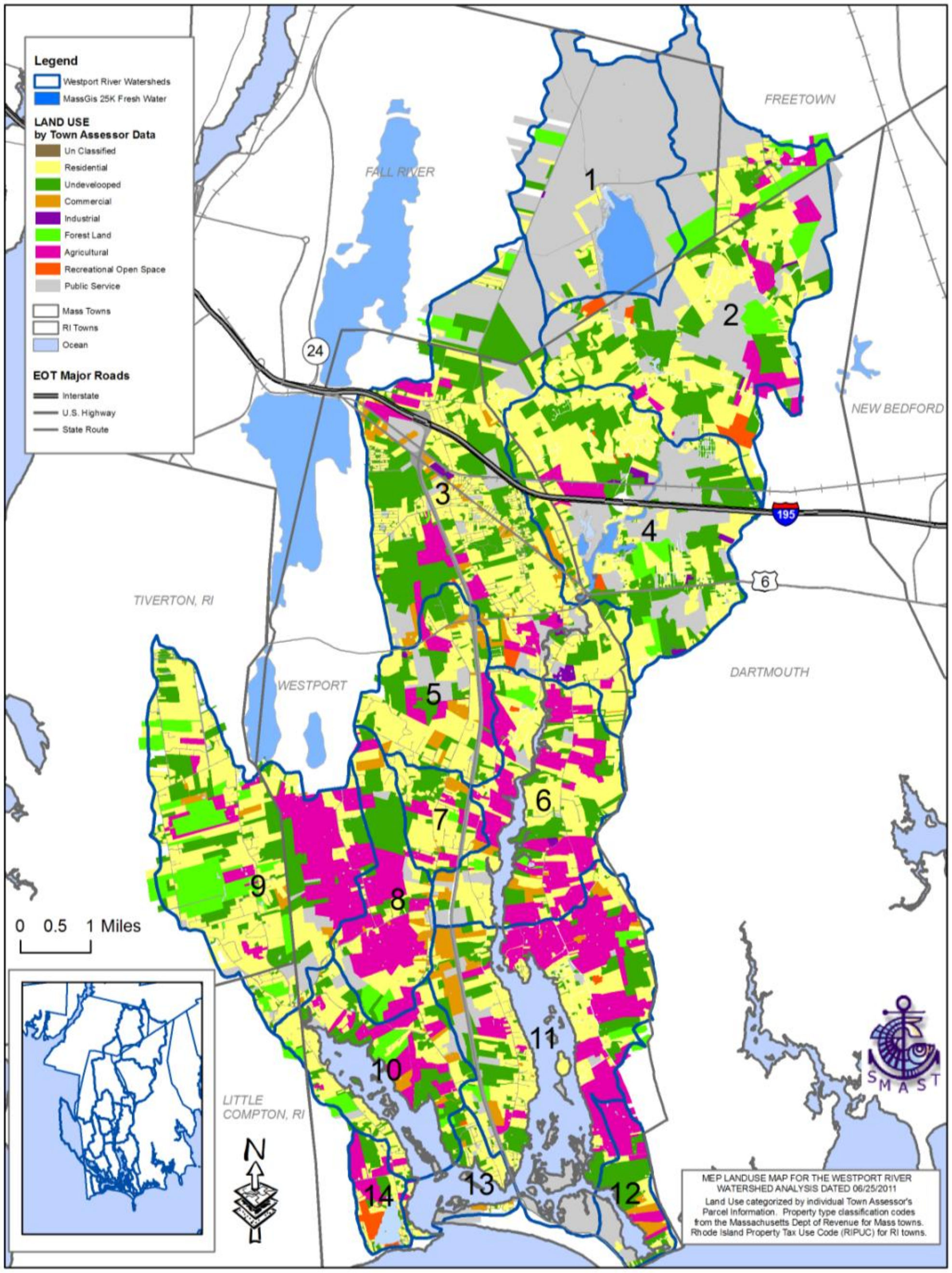

Figure 20 - Land use distribution across the watershed to the Westport River estuary as completed by the Massachusetts Estuaries Project (MEP, 2012).

Summary of "Pick-up" Along Bread and Cheese Brook:

As previously mentioned, at a macro-scale the Bread and Cheese Brook watershed (subwatershed #3 to the East Branch of the Westport River Estuary, MEP 2012) generates an appreciable total nitrogen load the Westport River at Old County Road (~42% based on data for the November 2012 to November 2013 hydrologic year). Through this study the breakdown of the loading to the Westport River from Bread and Cheese Brook has been further refined by breaking the loading down by segment of river reach, also referred to as stream pick-up. Pick-up of flow and load in the Bread and Cheese Brook can be summarized as follows:

1. Watershed area up-gradient of WRWA-1 generates flow equal to 12,298 m^3/d and a total nitrogen load of 8.77 kg/d (0.005 kg/ac/d)

2. Watershed area between WRWA-2 and WRWA-1 generates an additional 13,046 m^3/d of flow and an additional 15.08 kg/d of total nitrogen load (0.014 kg/ac/d)

3. Watershed area upgradient of WRWA-4 (Hemlock Gutter) generates flow equal to 8,674 m^3/d and a total nitrogen load of 13.26 kg/d (0.005 kg/ac/d)

4. Watershed area between WRWA-3, WRWA-2 and WRWA-4 generates an additional 14,668 m3/d of flow and an additional 35.05 kg/d of total nitrogen load (0.063 kg/ac/d)

On a per acre basis two main areas of subwatershed #3 show the most pick of total nitrogen and these areas are also presently the most developed. The first is the area between WRWA-2 on Rt. 6 and WRWA-1 on Old Bedford Road. The second is the area between WRWA-3 at Rt. 177 and WRWA-2 at Rt. 6 and WRWA-4 at Gifford Road. The Town of Westport should initially focus on these areas to reduce total nitrogen load to the head of the East Branch of the Westport River estuary as these areas are likely to be a most cost effective starting point relative to TN load removed per dollar expended.

Conclusions / Recommendations:

Managing watershed derived nitrogen loads and predicting changes in coastal embayment nitrogen related water quality requires determining the inputs of nitrogen from the surrounding contributing land relative to the tidal flushing and nitrogen cycling within a receiving water, in this case the estuarine reach of the East Branch of the Westport River. Based on the MEP Nitrogen Threshold Analysis of the Westport River Estuary, subwatershed 3 was identified as contributing significant nitrogen load (43,805 kg/yr) to the Westport River based on the MEP land use nitrogen loading analysis. The total nitrogen load generated by subwatershed #3 generally represented 58% of the nitrogen load being transported by the Westport River at the Old County Road crossing as determined by the MEP.

Based on flow measurements and sampling undertaken through the detailed monitoring of Bread and Cheese Brook, the nitrogen load measured at critical points throughout the Bread and Cheese Brook surfacewater system has enabled the CSP science team to determine the degree to which total nitrogen increases as water flows down gradient towards the Westport River. Additionally, the detailed analysis of the water samples clarified the characteristics of the load (e.g. the preponderance of various species of nitrogen) being generated in the Bread and Cheese Brook portion of subwatershed 3. The speciation of nitrogen at the various stream gauging locations shed light on which areas of the Bread and Cheese Brook subwatershed could most effectively be targeted for nitrogen management.

As would be expected, the greatest TN load was measured at WRWA-3 (25,177 kg/y) which was the most down gradient stream gauging location in the Bread and Cheese Brook system. That TN load represents 60 percent of the load generated by the MEP developed subwatershed 3 (which also includes land area that is not associated with Bread and Cheese Brook, east bank of the Westport River between Lake Noquochoke and Old County Road). Additionally, DIN represents 37 percent of the total nitrogen load (DIN stream concentration moderate to high at 0.689 mg/L) indicating that it may be worth trying to enhance the uptake of this bioavailable nitrogen by restoring natural processes in upgradient wetlands or ponds that have become impaired over time or removing DIN through targeted septic system removal or upgrade. It is important to recognize that Bread and Cheese Brook picks up ~12,791 kg/yr of TN between WRWA-3 and the upgradient WRWA-4 and WRWA-2 gauge locations. As discussed earlier that translates to 22.96 kg/ac/yr of land area, which is the highest of all the subwatershed areas considered in this study. As such, the Town of Westport should consider this portion of the Bread and Cheese Brook watershed as a priority area for targeted nutrient management.

The next largest amount of TN load generated in the Bread and Cheese Brook watershed when compared to TN load determined relative to WRWA-3 was for the area between WRWA-2 and WRWA-1. This portion of the Bread and Cheese Brook watershed generated approximately 5,506 kg/yr which is consistent with the increased level of development in this area compared to above WRWA-1 gauge location. The area of the watershed above WRWA-2 and below WRWA-1 does support moderate to dense levels of development and generates 5.09 kg/ac/yr of TN load (based on a land area of 1,082 acres). It would be advisable for the Town to consider targeted nutrient management in this portion of the Bread and Cheese Brook watershed as a second tier priority area.

Stream gauging and water quality sampling of Hemlock Gutter (WRWA-4) indicated that this tributary feeding into Bread and Cheese Brook generates ~20 percent of the measured total nitrogen load at WRWA-3. Additionally, the speciation of the nitrogen revealed that stream samples showed high concentrations of DIN (1.636 mg/L) of which NOx represented 97% of the DIN concentration. Total nitrogen concentration in Hemlock Gutter was also high (2.431 mg/L) indicating there may be a manageable source of nitrogen in this portion of the subwatershed to Bread and Cheese Brook and a more detailed look at sources of nitrogen in the land area feeding Hemlock Gutter would be worthwhile. It should be noted, however, that a large portion of the watershed above WRWA-4 is classified as wetland and as such, nutrient management in this area may be limited. Similarly, the watershed area upgradient of the WRWA-1 gauging location is largely undeveloped land that does not generate significant TN load on a per unit area basis (1.73 kg/ac/yr). As such, the Town of Westport may not benefit greatly from nutrient management in this upper most area of subwatershed #3.

ACKNOWLEDGMENTS

The Coastal Systems Program Technical Team would like to take the opportunity to thank the Westport River Watershed Alliance for its commitment to advancing environmental stewardship in southeastern Massachusetts and its proactive attitude in seeking analyses on aquatic systems in need of protection or restoration. The marriage of advocacy with science helps to ultimately advance the greater good and WRWA is a true champion in that regard.   In particular, the assistance of Roberta Carvalho and Betsy White is much appreciated. We would also like to acknowledge the support of the Town of Westport Community Preservation Committee as well as the Fisherman's Association, both of whom were supportive of this targeted monitoring project as a means for examining the variety of nitrogen management alternatives (including using restoration of freshwater habitats) that may be worth pursuing in subwatershed 3 for the overall restoration of the Westport River Estuary.