Assessing the Wood-Pawcatuck Watershed Association's Water Quality Monitoring Program

Elise Torello, WPWA Project Specialist, with Project Committee Members Denise Poyer (WPWA Project Director), Walt Galloway (WPWA Trustee), Brenda Rashleigh Ph. D. (US Environmental Protection Agency), and Tom Boving Ph. D. (University of RI)
November, 2015

1. Background

The Wood-Pawcatuck Watershed Association (WPWA) was incorporated in 1983 to "Preserve and protect the lands and waters of the Wood-Pawcatuck Watershed for natural and human communities." In 1988, WPWA monitored nine lakes and ponds in the watershed for the first time and was instrumental in establishing the University of Rhode Island Cooperative Extension's Watershed Watch program (URI WW). Since then, WPWA's monitoring program has grown extensively. Over the past 26 years WPWA has performed water quality sampling at 165 sites in the watershed, accumulating over 70,000 data points. In 2014, 14 ponds and 33 rivers and streams in the Wood-Pawcatuck Watershed were monitored for water quality; of these, WPWA financially sponsored all 14 ponds and 18 rivers and streams. Throughout the duration of WPWA's water quality monitoring program, URI WW's Linda Green and Elizabeth Herron, under the leadership of Professor Art Gold, Ph. D., has recruited and trained WPWA's volunteer monitors, assembled and provided sampling equipment, analyzed collected water samples, and entered and quality assured the analytical and field data. They meet strict quality assurance and quality control guidelines and are a state-certified water testing laboratory.

The overall goals of WPWA's water quality sampling program are to keep track of the status of water bodies in the watershed, to monitor trends in water quality (stable, improving, or declining), and to identify water quality problems which need further investigation. In the past, we have selected sampling locations based on opportunity (volunteer monitors willing to monitor a site close to them) or specific project goals. Until this project we had never done a strategic examination of the whole watershed to look at long term data trends and determine if our monitoring program meets our needs or is in need of restructuring. In particular, we wanted to ensure that we are adequately assessing stormwater impacts to waterways.

For this grant from the Bays, Rivers, and Watersheds Coordination Team, WPWA performed a comprehensive assessment of our water quality monitoring program. The assessment team consisted of Elise Torello and Denise Poyer (WPWA staff), Walter Galloway and Tom Boving, Ph.D. (WPWA trustee and former trustee, respectively), and Brenda Rashleigh, Ph.D. (US Environmental Protection Agency). The result of this assessment determined which sites WPWA will continue to monitor, which sites we would like to add to our monitoring program, and which sites we could drop or monitor on a semi-annual (or even less frequent) basis. We also decided whether additional monitoring parameters are necessary to meet the goals of our sampling program.

2. Volunteer Monitors: The Backbone of WPWA's Monitoring Program

Volunteer water quality monitors, also known as citizen scientists, are the backbone of WPWA's water quality monitoring program. Dozens of volunteers dedicate their time and efforts every year to their monitoring site or sites.

Most volunteers return to their site(s) year after year, and are well into their third decade of monitoring! We cannot possibly thank them enough for all of their efforts and dedication—they are truly amazing and inspiring.

3. Methodology

3.1 Geographic Information Systems Data Gathering and Assessment

The first step in this project was to gather relevant data with which to perform a spatial and temporal analysis of WPWA's current sampling program.

The most complete and up-to-date WPWA sampling site locations were downloaded from Google Maps as a .KMZ file which was then imported into ArcMap. To determine the sampling history of each of these sites, a crosstab query was developed from WPWA's in-house Microsoft Access water quality monitoring database showing every sampling site down the left side and every sampling year across the top. The query results were exported to Microsoft Excel and two summary fields were tallied for each site: the total number of years sampled and the number of years sampled within the latest five years in the database, 2009-2013 (Figure 1).

Next, this spreadsheet was updated to include sites monitored in 2014 but for which we have not received final data. The spreadsheet was pared to just the summary numbers and columns were added to display the sub-basin in which each site is located and the latest year it was sampled. The table was then sorted, descending, from the most recent years sampled to least, and color-coded (Figure 2). From this table it is easy to determine which current sites have a long monitoring history, which sites are fairly recent additions, which former sites were monitored for many years and then dropped for some reason, and which sites were only monitored once or twice many years ago.

The next step was to add the two columns with sampling year totals to the GIS shapefile containing WPWA's sampling sites. This allowed the concurrent display of spatial and temporal coverage of WPWA's monitoring sites

SitesAndYears.xlsx

SiteNum	Sampling Site Name	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	Total	Last 5
1010	Hundred Acre Pond	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1		25	4
1011	Hundred Acre Pond DEEP						1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1		20	4
1030	Chipuxet R @ Yawgoo Valley Rd.				1																							1	0
1040	Chipuxet R @ Wolf Rocks Rd.				1																							1	0
1050	Chipuxet R @ Rte 138 (Taylor's																1	1	1	1	1	1	1	1	1	1	1	11	5
1060	Worden Pond	1	1	1	1	1	1	1	1		1	1	1	1	1		1	1	1	1	1	1	1	1	1	1	1	24	5
1070	Tucker Pond				1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	23	5
1071	Tucker Pond DEEP									1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	18	5
1080	Larkin Pond					1	1	1					1	1							1							6	0
1081	Larkin Pond DEEP						1	1					1	1							1							5	0
1090	White Horn Bk @ Ministerial Rd																				1	1	1	1	1	1	1	7	5
1100	White Horn Brook @ Bike Trail																				1	1	1	1	1	1	1	7	5
1120	The Reservoir (Camp Canonicus)				1																							1	0
2010	Yawgoo Pond	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	26	5
2011	Yawgoo Pond DEEP						1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	21	5
2020	Chickasheen Bk @ Rte 2			1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	24	5
2030	Chicka Bk @ Col. Potter Road (Skagg's				1		1											1	1									4	0
2050	Chickasheen Bk @ Miskiania Trail			1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	24	5
2060	Mud Brook @ Rte 2			1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	24	5
2070	Barber Pond	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	26	5
2071	Barber Pond DEEP						1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	21	5
2080	Chickasheen Bk @ Barber Pond Outlet						1	1	1	1	1		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	20	5
2090	Chickasheen Bk @ Rt. 138								1		1	1	1	1	1	1	1	1		1	1	1	1	1	1	1	1	17	5
2100	Chickasheen Bk @ Liberty Ln																1	1							1	1	1	5	3
2120	Chicka @ Waites Corner Rd.								1		1	1																3	0
3010	Queen R @ Eppley (Dugway Rd)			1	1	1	1	1	1	1	1					1												9	0
3020	Fisherville Bk @ Williams Reynolds Rd			1	1	1	1	1	1	1	1		1	1			1	1	1									13	0

Qry_WQAssessment_SiteYr2 | Just Sites | Sheet2 | Sheet1

Figure 1. Partial view of crosstab query results showing every site along with the years the sites were sampled.

B	C	D	E	F
Sampling Site Name	**Sub-basin**	**Total**	**Last 6**	**Last Year Sampled (Blue<2004)**
Ashaway R @ Wellstown Rd	Ashaway	9	6	2014
Green Falls @ Rte 184/I 95 Exit 93	Ashaway	7	5	2014
Green Falls R #2 @ Putker Rd	Ashaway	11	4	2014
Wyassup Lake	Ashaway	23	3	2011
Green Falls R #3 @ Clark Falls Rd	Ashaway	10	3	2014
Parmenter Bk @ Clark Falls Rd.	Ashaway	5	3	2012
Ashaway R @ Rte 216	Ashaway	6	2	2010
Spalding Pond	Ashaway	21	1	2009
Pendelton Hill Bk @ Grindstone Rd.	Ashaway	2	1	2013
Green Falls R #1 @ Green Falls Rd	Ashaway	10	0	2004
Glade Bk @ Pine Wood Rd	Ashaway	1	0	2003
Green Falls Pond	Ashaway	1	0	1997
Spalding Pond Inlet @ Pendleton Rd.	Ashaway	1	0	1993
Wyassup Bk @ Clark Falls Road	Ashaway	1	0	2003
Beaver R @ Old Mountain Rd (#1)	Beaver	4	0	2001
Beaver R @ Rte 138 (#3)	Beaver	4	0	2001
Beaver R @ Shannock Hill Rd (#4B)	Beaver	4	0	2001
Beaver R @ Hillsdale Rd (#2)	Beaver	3	0	2000
Beaver R @ Lewiston Rd (#5)	Beaver	3	0	2000
Beaver R @ Schoolhouse Rd (#4A)	Beaver	1	0	1999
Worden Pond	Chipuxet-Pawcatuck	25	6	2014
Chipuxet R @ Rte 138 (Taylor's Landing)	Chipuxet-Pawcatuck	12	6	2014
White Horn Bk @ Ministerial Rd	Chipuxet-Pawcatuck	8	6	2014
White Horn Brook @ Bike Trail	Chipuxet-Pawcatuck	8	6	2014
Hundred Acre Pond	Chipuxet-Pawcatuck	26	5	2014
Tucker Pond	Chipuxet-Pawcatuck	23	5	2013
Larkin Pond	Chipuxet-Pawcatuck	6	0	2007
Chipuxet R @ Wolf Rocks Rd.	Chipuxet-Pawcatuck	1	0	1991
Chipuxet R @ Yawgoo Valley Rd.	Chipuxet-Pawcatuck	1	0	1991
The Reservoir (Camp Canonicus)	Chipuxet-Pawcatuck	1	0	1991
Pawcatuck R - At Boombridge Rd. bridge	Lower Pawcatuck	1	1	2009
Pawcatuck R - Upstr of Boombridge Rd. bridge	Lower Pawcatuck	1	1	2009

Figure 2. Sites sorted (descending) by total number of years sampled and number of years sampled in the last six years (2009-2014).

within the watershed's sub-basins using stacked, color-coded symbols. For each site that has been monitored within the last six years (2009-2014), the total number of years sampled was represented visually by one of five large dots: red = monitored 21-27 years; orange = 16-20 years; yellow = 11-15 years; green = 6-10 years; and blue = 1-5 years. Superimposed on these large dots are smaller dots representing how many years the sites were monitored within the last six years: light pink = 4-6 years; or dark pink = 1-3 years. Sites monitored not monitored at all within the last six years are represented by a green circle with a black "x" through it.

In Figure 3 (the upper portion of the Usquepaug (Queen) River sub-basin), the legend at the left of the image shows the mapping scheme for WPWA's sampling sites, plus the locations of US Geological Survey (USGS) stream gages (pink circles with crosshairs, from the USGS National Hydrography Dataset (NHD)) and dams (red triangles, data from RI Department of Environmental Management (RIDEM), the University of Rhode Island's RIGIS (RI Geographic Information Systems), and the University of Connecticut's CLEAR (Center for Land Use Education and Research)). The light pink linear features with darker pink and red clusters represent impervious surface data from the National Land Cover Database 2011 Percent Developed Imperviousness dataset (NLCD11). So, for example, the site *QR6 @ Sand Br (TNC)* has a dark pink dot over an orange circle, so it was sampled for a total of between 16 and 20 years, including between one and three years within the last six years. We have even more information at *QR5 @ Mail Rd*, which has three symbols stacked at its location: the bottom symbol is a dark pink circle with crosshairs, indicating an active USGS stream gage with continuous data; the middle symbol is an orange circle indicating that the site has been sampled for a total of 16 - 20 years; and the top symbol is a light pink dot indicating that the site has been sampled between four and six years within the last six years. Finally, *Queen's Fort Bk @ School Lands Rd* has a bright green dot with an "x", indicating that it has not been sampled at all within the last six years. Appendix A is a map of the entire Wood-Pawcatuck Watershed with all of WPWA's existing sampling sites.

Additional GIS data included in this assessment are: the NLCD11 land cover dataset, which was used to determine estimated percent forested cover (FC); NHD's HU12 sub-basins, flowlines, and water bodies; UCONN CLEAR's land cover dataset and impervious surface estimations for each of the three sub-basins with significant area in CT (Shunock, Ashaway, and Lower Pawcatuck); and RIGIS land cover/land use and impervious surfaces. All GIS datasets were clipped to only include data within the Wood-Pawcatuck Watershed.

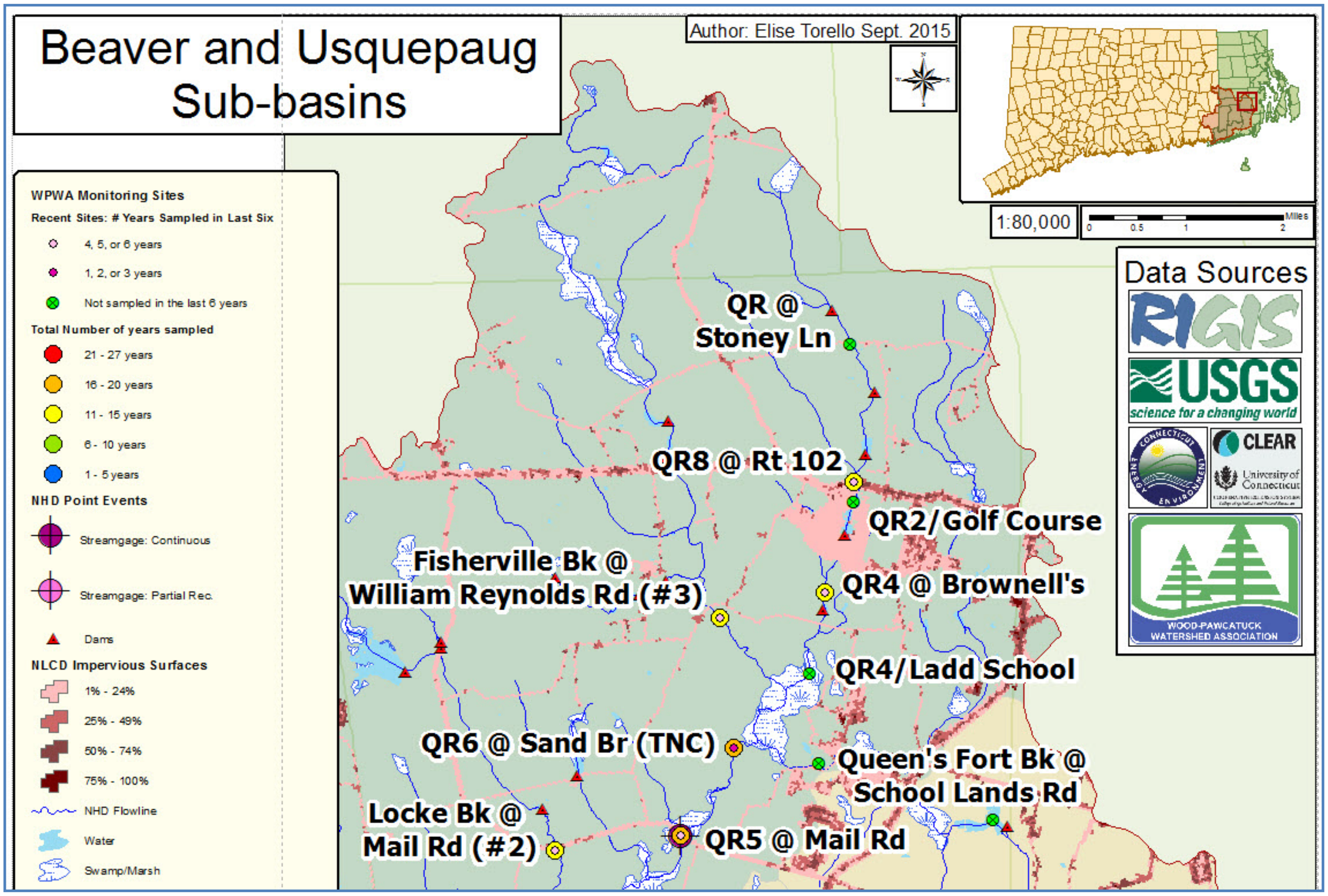


Figure 3. Map detail showing the upper portion of the Usquepaug sub-basin with WPWA monitoring station symbology.

3.2 Impervious Surfaces and Forest Cover

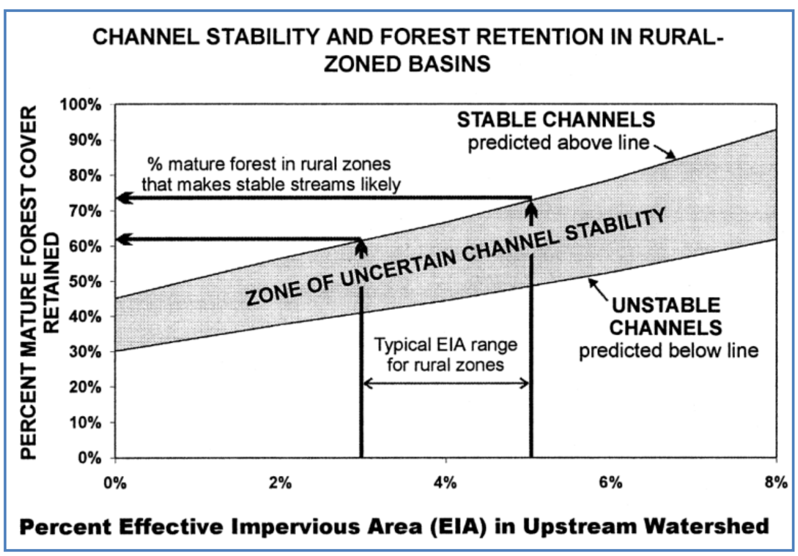
The percent of impervious surface cover in a watershed has long been known to have an impact on water quality in streams at relatively low levels, with 7% to 10% impervious cover (IC) being the most often cited as the threshold for declining stream health (Schueler, 1994; Booth et al., 2002; Brabec et al., 2002; Wang and Kanehl, 2003; Schueler et al., 2009; Clapcott et al., 2012). The percent of IC in a watershed negatively affects many aspects of stream health including: shape and instability of stream channels; habitat quality (e.g., pools and riffles, overhead cover); water quality (more pollutants including chemicals and bacteria, higher temperature, reduced dissolved oxygen concentration); fish spawning; and biodiversity of macroinvertebrates and fish (Schueler, 1994). Given the known impact of percent IC in a sub-basin on steam health, it was important to include this metric in this assessment.

3.2.1 Background

Numerous studies of IC's impact on stream health have been performed over the past few decades. In Schueler's 1994 study, "The Importance of Imperviousness," he arrives at a threshold of 10% - 15% IC for maintaining pre-development stream quality. He notes that this threshold is supported by multiple studies using widely varying methods and variables and performed in many different geographic areas. Brabec et al. (2002) cite studies that indicate impacts to fish and macroinvertebrate diversity and abundance at as low as 3.6% IC. Schueler (1994) advocates for the use of IC by watershed managers as an indicator of stream health due to the ability to measure it consistently, and that "it links activities of the individual development site with its cumulative impact at the watershed scale."

However, Brabec et al. (2002) argued that using IC alone as an indicator for degradation of stream health is a flawed approach, and that the balance between pervious and impervious surfaces within a watershed should also be assessed. In particular, the authors note that loss of forested land has a negative effect on evaporation, infiltration, and vegetative storage. They go on to assert that "Based on the importance of forest stands in the hydrologic system, it is critical to use mature forest stands as a baseline for planning watershed quality." Brabec et al. (2002) cite studies that indicate that forest stands in a watershed mitigate impacts on stream habitats from other land uses, and that catchment-wide land use and forest cover is more correlated with water quality than local riparian conditions.

Figure 2. Booth et al. (2002) model of channel stability relative to percent mature forest cover and effective impervious area (EIA). They present a range of EIA = 3% to 5% as typical for rural areas.



Booth et al. (2002) also discuss the correlation between forest cover (FC) and stream conditions, and cite 65% as a "plausible" value for a "stability criterion" for steams. They plotted percent effective impervious area (EIA-- those impervious areas that drain into a piped storm sewer and discharge into a surface-water body (Brabec et al., 2002)) with percent mature forest cover retained in rural-zoned basins to present a model for channel stability (Figure 4). Note that Brabec et al. (2002) point out that the majority of the studies they reviewed for their paper did not distinguish between EIAs and TIAs (total impervious areas); however, the water quality results for the various methods still converged “rather consistently”. In Figure 4, at the “typical” rural EIA percentages, stable stream channels are predicted at or above about 62% to 74% mature FC. The authors’ conclusion is that FC is more important than IC at rural residential densities (2% - 6% EIA), but there are no truly negligible amounts of clearing or watershed IC.

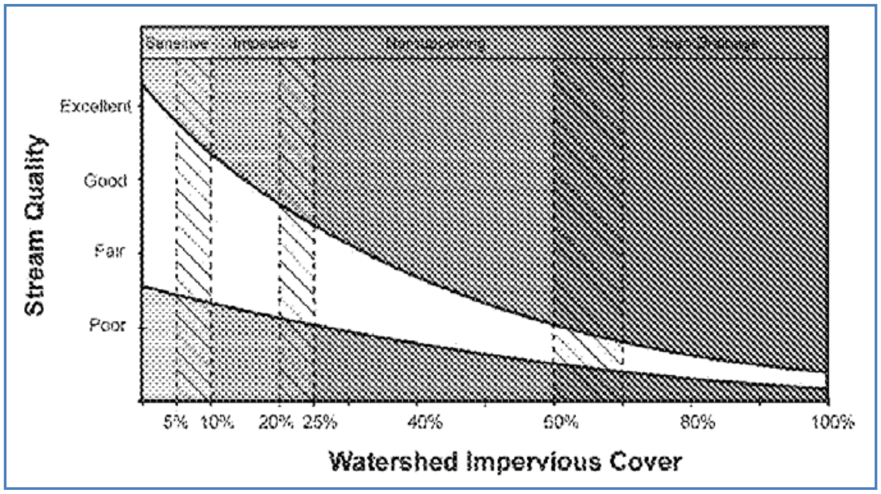


Figure 3. Schueler et al. model of stream quality related to watershed percent IC.

Schueler et al. (2009) reviewed IC studies published after 2003 and found that most (69%) confirmed or reinforced the 10% IC threshold, indicating to them that this is a robust stream quality indicator. They found this threshold to be especially robust for benthic macroinvertebrate communities. Figure 5 shows the model that they developed relating percent IC to stream quality. The model shows that the greatest variability in stream indicator scores is for sub-watersheds with less than 10% IC. The authors state that expected quality of these streams is generally influenced more by other watershed metrics such as forest cover, road density, riparian continuity, and cropping practices, and therefore IC should not be the only metric used to predict stream quality when the percent IC in the sub-watershed is very low.

2.2.2 Wood-Pawcatuck Watershed Impervious and Forested Cover

As was mentioned earlier, impervious cover GIS data for the Wood-Pawcatuck Watershed was available from several sources including RIGIS, CT/UCONN CLEAR, and the National Land Cover Percent Developed Imperviousness Dataset 2011 (NLCD11, USGS, 2011/amended 2014). The RIGIS IC raster GIS dataset has a spatial resolution of 2 feet and covers all sub-basins within RI, plus extends one half mile over the border with CT (RIGIS *Impervious11* shapefile metadata). An IC raster dataset was not available for CT; however, a GIS shapefile was available from CLEAR that had pre-calculated percent IC estimates for each sub-basin in Connecticut. CLEAR’s estimates were calculated using land cover data to run the Impervious Surface Analysis Tool (ISAT) jointly developed by CLEAR and the NOAA Coastal Services Center in 2002 (clear.uconn.edu/projects/landscapeLIS/impervious.htm). Unfortunately, neither of these datasets covered the entire watershed. Using the third IC GIS data source, NLCD11, estimated IC percentages for each sub-basin could be calculated consistently using one dataset for the entire watershed. Therefore, these are the IC percentages used in this assessment.

Figure 6 shows the location of each sub-basin in the Wood-Pawcatuck Watershed, and Table 1 lists the estimated percent impervious cover and forest cover for each sub-basin. The estimated IC percentages in the sub-basins are very low except for the Lower Pawcatuck River sub-basin, and are well within the rural residential densities discussed by Brabec et al. (2002). The percentages of FC for each sub-basin were calculated using the NLCD11 land cover dataset for consistency across the entire watershed. NLCD land cover class codes 41 (deciduous forest), 42 (evergreen forest), and 43 (mixed forest) are included in the percent forested area calculations.

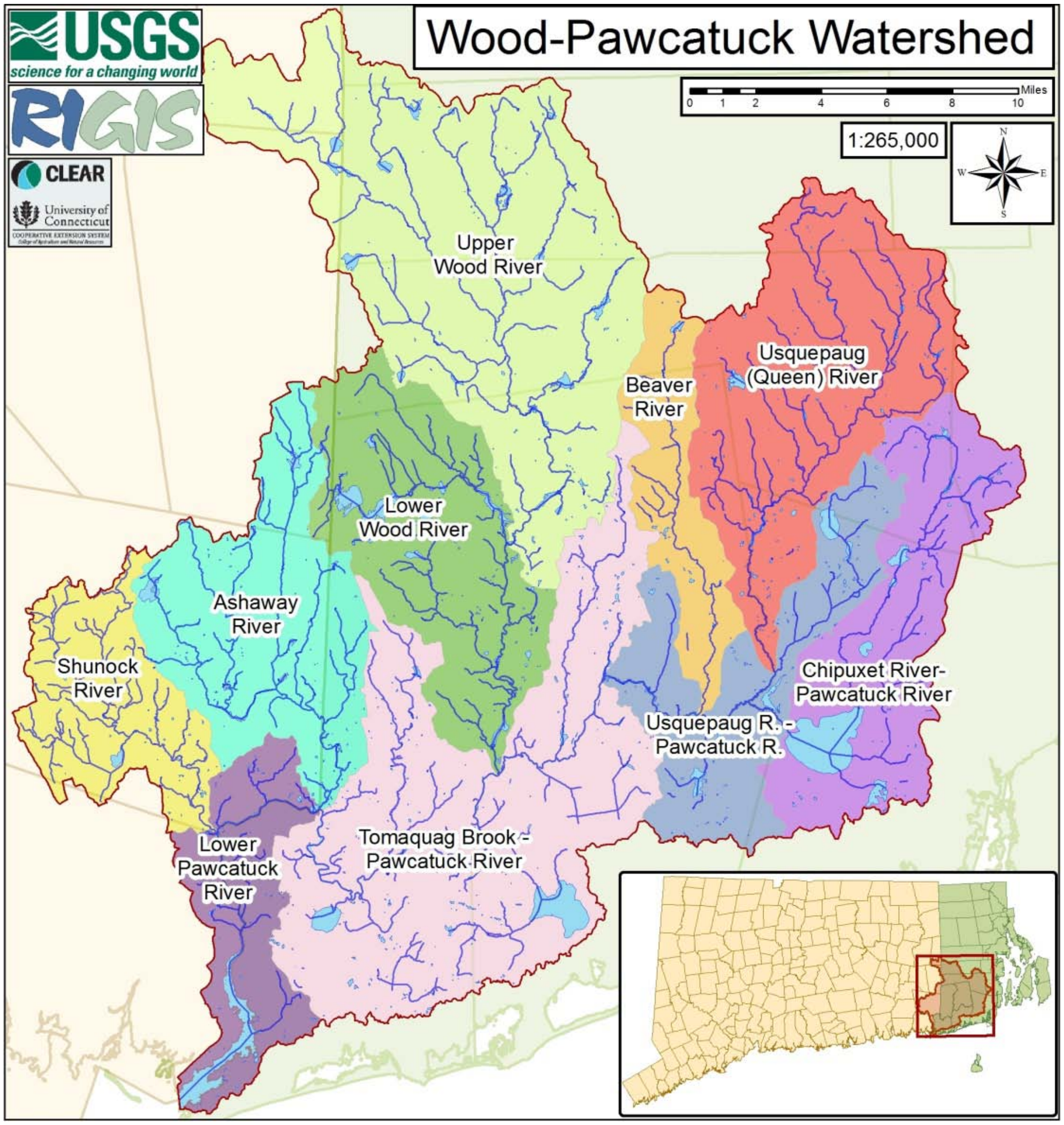


Figure 4. Sub-basins of the Wood-Pawcatuck Watershed.

Table 1. Estimated percent impervious and percent forest cover in each sub-basin of the Wood-Pawcatuck Watershed.

HUC12 Code	Sub-Basin Name	Area (Acres)	Area (Km^2)	NLCD11 % Impervious Cover	NLCD11 % Forested Cover	Predicted Stream Impact (Stable/ Uncertain/Unstable) Using Booth et al. (2002) Model
010900050302	Shunock	10591	42.9	2.5	61.4	Stable
010900050301	Ashaway	17832	72.2	1.5	67.6	Stable
010900050303	Lower Pawcatuck	10147	41.1	21.9	21.9	Unstable
010900050101	Upper Wood	39073	158.1	2.0	70.2	Stable
010900050102	Lower Wood	18309	74.1	2.2	65.5	Stable
010900050201	Chipuxet - Pawcatuck	16451	66.6	4.1	38.4	Unstable
010900050202	Usquepaug (Queen)	23333	94.4	1.6	64.0	Stable
010900050203	Beaver	7901	32.0	1.8	66.3	Stable
010900050204	Usquepaug (Queen) - Pawcatuck	13574	54.9	3.4	48.5	Uncertain
010900050205	Tomaquag - Pawcatuck	36499	147.7	4.6	47.4	Borderline Uncertain/Unstable
Percentages calculated using data for the entire watershed (not as an average of sub-basin averages):				3.7	57.1	

From the NLC11 IC data it is apparent that the Wood-Pawcatuck Watershed is largely forested (57.1%) and has very low percent IC overall (3.7%). Booth et al. (2002) and Brabec et al. (2002) agree on a plausible stream "stability criterion" of around 65% FC in rural sub-basins. Applying the model developed by Booth et al. (2002), six of the ten sub-basins in the Wood-Pawcatuck Watershed are predicted to have stable channels (Shunock, Ashaway, Upper Wood, Lower Wood, Usquepaug (Queen), and Beaver River sub-basins), two are predicted to have unstable stream channels (Lower Pawcatuck and Chipuxet-Pawcatuck River sub-basins), the Usquepaug (Queen)-Pawcatuck is of uncertain stability, and the Tomaquag Brook-Pawcatuck River sub-basin is borderline uncertain/unstable. Therefore, to assess the overall effects of stormwater on the streams in the watershed, the focus should be on sub-basins that are more vulnerable to impacts due to loss of forest and higher percentages of IC. Sampling sites should also be located in the less developed sub-basins both as reference sites and to ensure that all sub-basins are being monitored.

3.3 Current Wood-Pawcatuck Watershed Association Water Quality Monitoring Parameters

The water quality parameters currently included in WPWA's monitoring program consist of a combination of field measurements and observations along with laboratory analyses of samples collected by volunteers. All laboratory analyses are performed by University of Rhode Island Watershed Watch staff. Most parameters are collected at both lake/pond and river/stream locations, and most are collected at least monthly. Table 2 summarizes the current suite of sample analyses and observations.

Table 2. WPWA's current suite of sampling parameters.

Parameter	Lake/Pond Frequency	River/Stream Frequency	Units	Analytical Method
Temperature	Weekly	>=Every 2 wks	C	Temperature of Water by Thermometer
Dissolved Oxygen	Every 2 weeks	>=Every 2 wks	mg/L	Total Dissolved Oxygen by Titration-Azide Modification
Secchi Depth	Weekly	Not measured	M	Secchi Disk
Chlorophyll a	Every 2 weeks	Not measured	ug/L (ppb)	In-Vitro Determination of Chlorophyll, water, fluorometric method, corrected for pheophytin
Chloride	May/October	May/October	ug/L (ppb)	Chloride in Water by Colorimetry-Automated Ferricyanide Method
Nitrogen, Ammonia Dissolved as N	May/July/Oct or monthly	Monthly	ug/L (ppb)	Ammonia in Water Using Automated Phenate Method
Nitrate + Nitrite, Dissolved	May/July/Oct or monthly	Monthly	ug/L (ppb)	Nitrate in Water- Automated Cadmium Reduction
Nitrogen, Total (unfiltered)	May/July/Oct or monthly	Monthly	ug/L (ppb)	
Phosphorus, Dissolved	May/July/Oct or monthly	Monthly	ug/L (ppb)	Phosphorus in Water by Colorimetry-Automated Ascorbic Acid Method
Phosphorus, Total	May/July/Oct or monthly	Monthly	ug/L (ppb)	Phosphorus in Water by Colorimetry-Automated Ascorbic Acid Method
Enterococci	May/July/Oct or monthly	Monthly	MPN/100 mL	
pH	May/July/Oct or monthly	Monthly	S.U.	
Alkalinity	May/July/Oct	Not measured	mg/L (ppm)	Alkalinity in Water by Titration

3.4 Individual Sub-basins: A Closer Look and Assessment of Monitoring Sites

This section gives more information about each sub-basin in the watershed, along with an analysis of the water quality monitoring scheme in each sub-basin. The overall goal of this assessment is to assign WPWA's current and recent sampling locations into three tiers: tier one includes sites we definitely want to continue monitoring; tier two includes sites we would like to continue monitoring if resources allow; and tier three includes sites we will miss the least if resources do not allow us to continue monitoring them. While assessing current, recent, and older monitoring sites, the following questions were kept in mind:

- Is there at least one monitoring site in each sub-basin or larger stream/river? If there are multiple sites in a stream or river, can any site(s) be dropped?
- If there are sites that are close together in a sub-basin but not necessarily in the same stream (for example, in two adjacent tributaries), do conditions at the sites and/or existing monitoring data indicate that monitoring both (or all) is not necessary?

To help answer both of the above questions, total phosphorus data were plotted to look at whether there is an upstream-downstream gradient in water quality or whether nearby sites appear redundant. Total phosphorus is the monitoring parameter chosen for scrutiny due to its importance in determining the water quality of a stream, river, or lake even when present in very small amounts (parts per billion) (Addy and Green, 1996).

- In each sub-basin, is there a less developed (reference) site? If not, should there be?

- Are there site(s) in places near or downstream of large concentrations of impervious cover to capture the effects of stormwater runoff? Are we monitoring the right parameter(s) to assess effects of stormwater?

- Are there sites at or near all USGS stream gages, and if not, should there be?

- Is there, or should there be, a site on each larger stream/river just above the confluence with the next stream reach to catch any issues from upstream in that sub-basin? Are there sufficient sites on the Pawcatuck River below confluences with the other rivers and elsewhere?

- Should all current sites with long (e.g., greater than 10 or 15 year) sampling histories be kept for temporal continuity? Are there long-term monitoring sites that don't change much year-to-year and could be monitored every other year or even less frequently? Do we want to risk losing any dedicated monitors for some sites by cutting back sampling frequency to save money? Can lake associations pay for "their" sites?

Any proposed changes to WPWA's sampling scheme involving sites for which WPWA does not pay the laboratory fees would have to be approved by the people or groups actually supporting and sampling those sites. It may be that there are lake associations that want to continue the monitoring of a site that WPWA assigned a lower priority (tier). If these associations are willing to financially support their site, then that would be welcomed by WPWA—particularly for sites that have been monitored for a long time. If we see a location that isn't being monitored and that we would like to add, and we see a nearby and/or redundant site that could be dropped, we will ask the monitor and/or funder of that site if they would be willing to move to the un-monitored site.

2.3.1 The Shunock River Sub-basin

The Shunock River sub-basin is 10,591 acres (42.86 km^2) and is located entirely within the state of Connecticut. It is largely undeveloped, with an estimated percent IC of 2.5% and percent forested cover of 61.4%. The Booth et al. (2002) model predicts stable stream channels at these IC and FC percentages.

The four recent sampling locations are located in the southern half of the sub-basin near roads for ease of access. However, none were sampled in 2014. One site, *Shunock R @ Hewitt Rd*, was sampled for 21 years, but not since 2009. It is above the confluences with two tributaries, each of which also has a sampling site that was monitored for 17+ years but is no longer active. One of these sites (*Asseconk Swamp*) is at the impervious cover concentration at North Stonington, CT's town center and CT Rt. 2. The fourth site, last monitored in 2013, is downstream of the three other sites near the southern end of the watershed at CT Rt. 184.

To have spatial coverage of the Wood-Pawcatuck Watershed, there should be at least one monitoring site in the Shunock sub-basin. *Shunock R @ Hewitt Rd* is the farthest upstream and north of North Stonington village center, although it does have some farms and other development near it. We had considered adding this as a "reference" site but decided to use a "reference" total phosphorus (TP) concentration for the entire watershed instead of reference sites (discussed more later on). Therefore, *Shunock R @ Hewitt Rd* is assigned to tier two, as it would still be worthwhile to have more than one site in this sub-basin. The farthest downstream site is *Shunock R @ Rt 184*, which is north of I-95. Re-activating this site could pick up the effects of stormwater from CT Rt. 2, which runs roughly parallel to the Shunock River, along with the effects of CT Rt. 184. However, adding a new site on the Shunock River just south of I-95, perhaps where it passes under Rt. 49, would pick up effects of upstream stormwater just before the Shunock joins the Pawcatuck River. We consider a new site in this location to be tier one, and we assigned *Shunock R @ Rt 184* to tier two. The remaining two sites could be dropped (tier three). As all of the sampling in the Shunock sub-basin has been performed and funded by the North Stonington Citizen's Land Alliance, these monitoring site modifications would need to be acceptable to them and to their volunteer monitors.

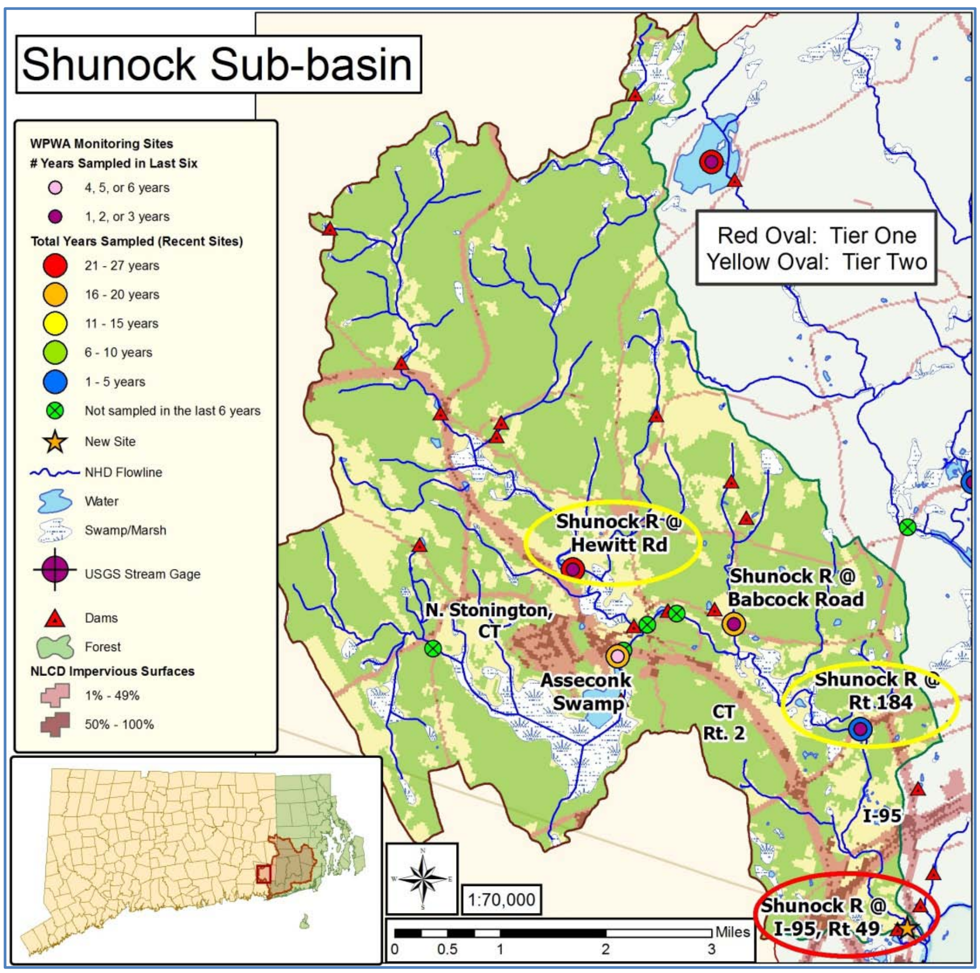


Figure 7. Shunock Sub-basin.

2.3.2 The Ashaway River Sub-basin

The Ashaway River sub-basin is 17,832 acres (72.16 km^2) and mostly in Connecticut. It is even less developed than the Shunock sub-basin, with IC=1.5% (the lowest in the watershed) and FC=67.6%. Again, the Booth et al. (2002) model predicts stable stream channels at these IC and FC percentages. There are ten active or recent sites in this sub-basin, although only five were sampled in 2014. Three of these active sites are on the Green Falls River (*#2, #3*, and *@Rt 184/I95 Exit 93*); *Green Falls R #3* is just below the confluence with Wyassup Brook, and *Green Falls @ Rt 184/I 95 Exit 93* is just below the confluence with Parmenter Brook. The latter site is subject to the effects of stormwater from several heavily used highways and some development. The fourth active site, *Ashaway R @ Wellstown Rd*, is not far downstream from *Green Falls @ Rt 184/I 95 Exit 93* and is the only site in this sub-basin that has been paid for by WPWA. The monitoring data from *Ashaway R @ Wellstown Rd* and *Green Falls @ Rt 184/I 95 Exit 93* were compared to see if they were similar enough that one of these sites could be dropped, and the data suggest that *Ashaway R @ Wellstown Rd* can be omitted. The last active site, *Pendleton Hill Bk @ Rt 49/216* was just added in 2014, so we do not yet have the analytical results.

An assessment of TP data from *Green Falls R #2 @ Putker Rd* and *Green Falls R #3 @ Clark Falls Rd* suggests that both can be omitted. Another recent site, *Pendelton Hill Bk @ Grindstone Rd.*, is located at the site of an active USGS stream gage in a relatively sparsely developed part of the basin. This site is also located downstream of the land recently conserved by Madeline Jeffery and could be a good reference site, perhaps sampled instead of *Green Falls R #2* and *#3*. Therefore, we have assigned this site to tier one. Without any monitoring data for *Pendleton Hill Bk @ Rt 49/216* it is difficult to assign it to a tier, so for now it is in tier two.

Three of the remaining recent sites include two impoundments on Wyassup Brook (Wyassup Lake and Spalding Pond) and one site on Parmenter Brook. All three sites are on less developed tributaries. Both Wyassup Lake and Spalding Pond haven't been sampled in several years (since 2011 and 2009, respectively), but TP data from both sites suggest that they are experiencing eutrophication and are unstable. Since they are not currently active sites, we will assign them to tier two for now but would like to see them monitored if possible, perhaps in alternating years. *Parmenter Bd @ Clark Falls Rd*. can be dropped (tier three). Finally, *Ashaway R @ 216* is assigned to tier one as it is at the bottom of the sub-basin above the confluence with the Pawcatuck.

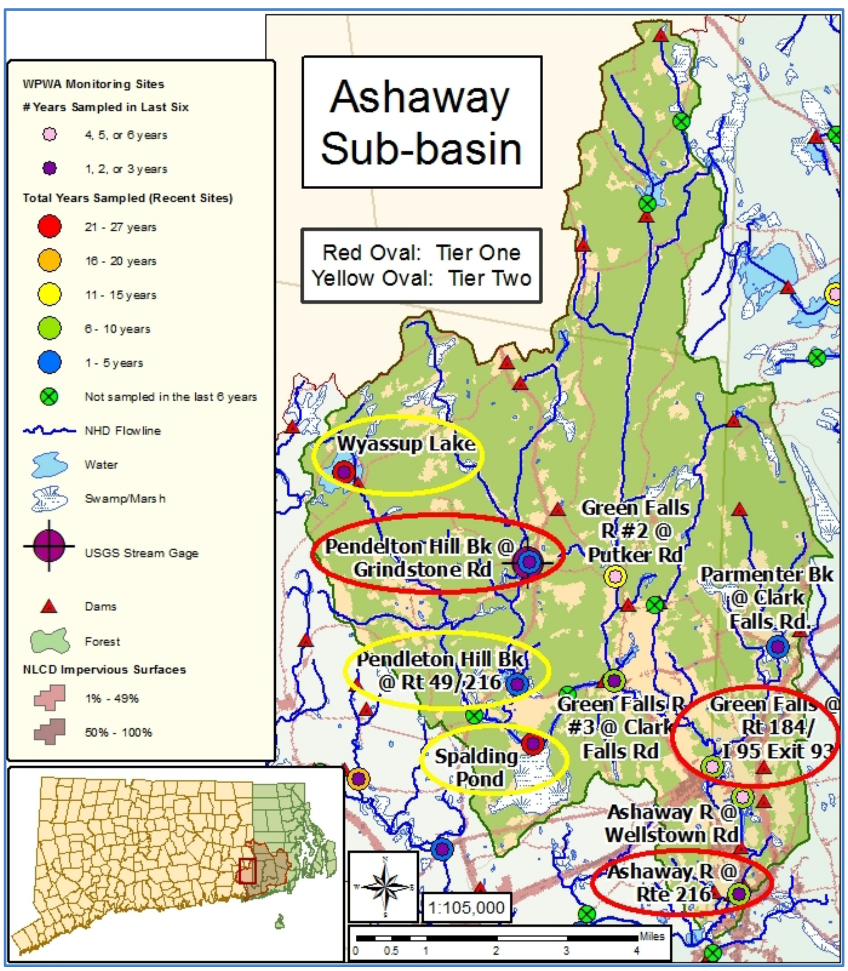


Figure 8. Ashaway Sub-basin.

2.3.3 The Upper Wood River Sub-basin

The Upper Wood River sub-basin is the largest in the watershed at 39,073 acres (158.12 km^2). It has very low impervious cover (2.0%) and has the highest percent forest cover in the watershed at 70.2%, again with the Booth et al. (2002) model predicting stable stream channels. There are six current or recent WPWA sampling sites in this basin, five of which were sampled in 2014. All six sites have been sampled for at least 15 years.

Four active sites in the Upper Wood sub-basin are on the Falls River; three of these have been sampled for 20 years including all of the last six years. The fourth of these sites, *Falls R @ Sand Banks Stairs (B)*, is just downstream of *Falls R @ Austin Farm (C)* and was not sampled in 2014. Plotting the latest six years of TP data that we currently have in our database (2008 – 2013) at *Falls R (A), (B), (C),* and *(D)* shows a surprising gradient of improving water quality moving downstream from *Falls R (D)* to *Falls R (A)* (Figure 10). Therefore, even though *Falls R (D)* would appear to be a potential reference site because it is the farthest upstream, we have placed it in tier one as it has the highest concentration of TP, not the lowest. Since 1995, *Falls R (A)* and *(B)* have had very similar TP concentrations and have been trading places over time as the site with the lowest yearly average TP; *Falls R (A)* has had the lowest average nine times, and *(B)* has had the lowest average concentration 10 times. TP concentrations at *Falls R (C)* during the 2008 – 2013 time span have been slightly higher than at *(A)* and *(B)*. We have assigned both *Falls R (B)* and *(C)* to tier three, and *Falls R (A)* to tier one. Since Trout Unlimited samples and sponsors these four sites, they would have to approve dropping two Falls River sites (or they can keep sampling them and supporting them if they so choose). One of the many inactive sites in the sub-basin is at the site of an active USGS stream gage (measures discharge data only); however, *Falls R @ Twin Bridges (A)* is only about 76 meters upstream of this gage in the adjacent stream reach of the Wood River.

The other two active sites are both impoundments, and both have been funded by WPWA. Boone Lake is an impoundment on Roaring Brook downstream of where the brook passes between I-95 and a large gravel pit. The lake is surrounded by houses and has an active lake association. Our assessment at this time is that Boone Lake should continue to be sampled (tier one), but perhaps the lake association can contribute all or part of the cost of monitoring. Roaring Brook goes on to join the Wood River at Frying Pan Pond not far up river from the WPWA campus.

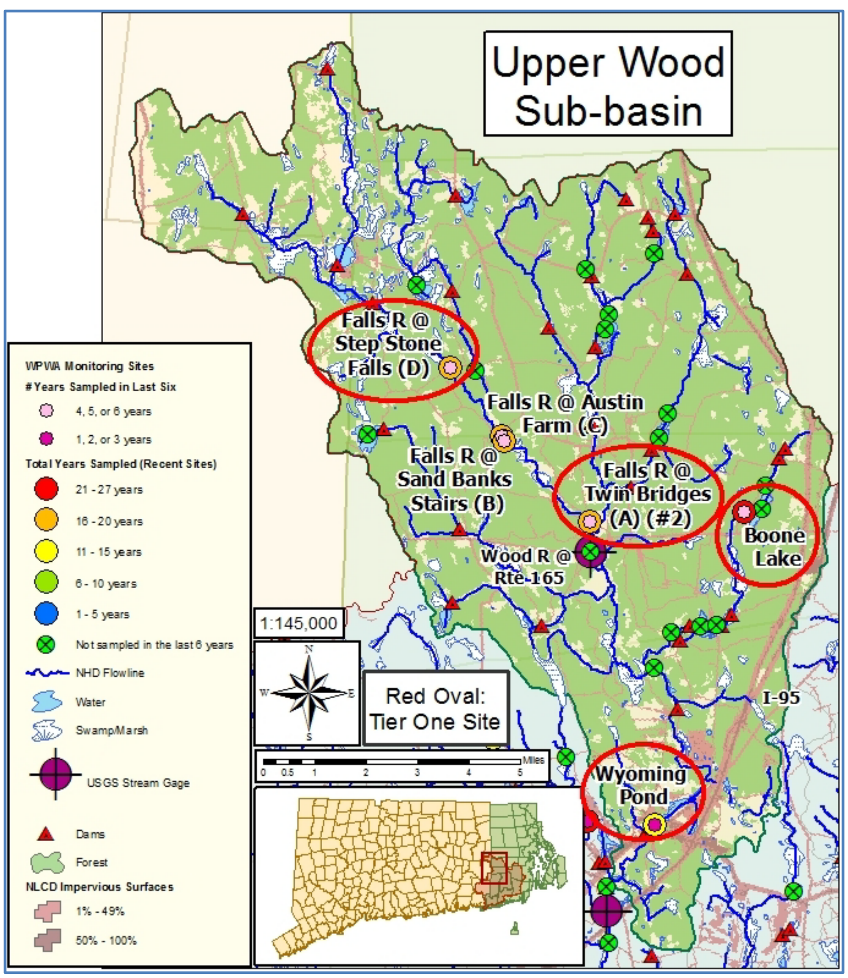
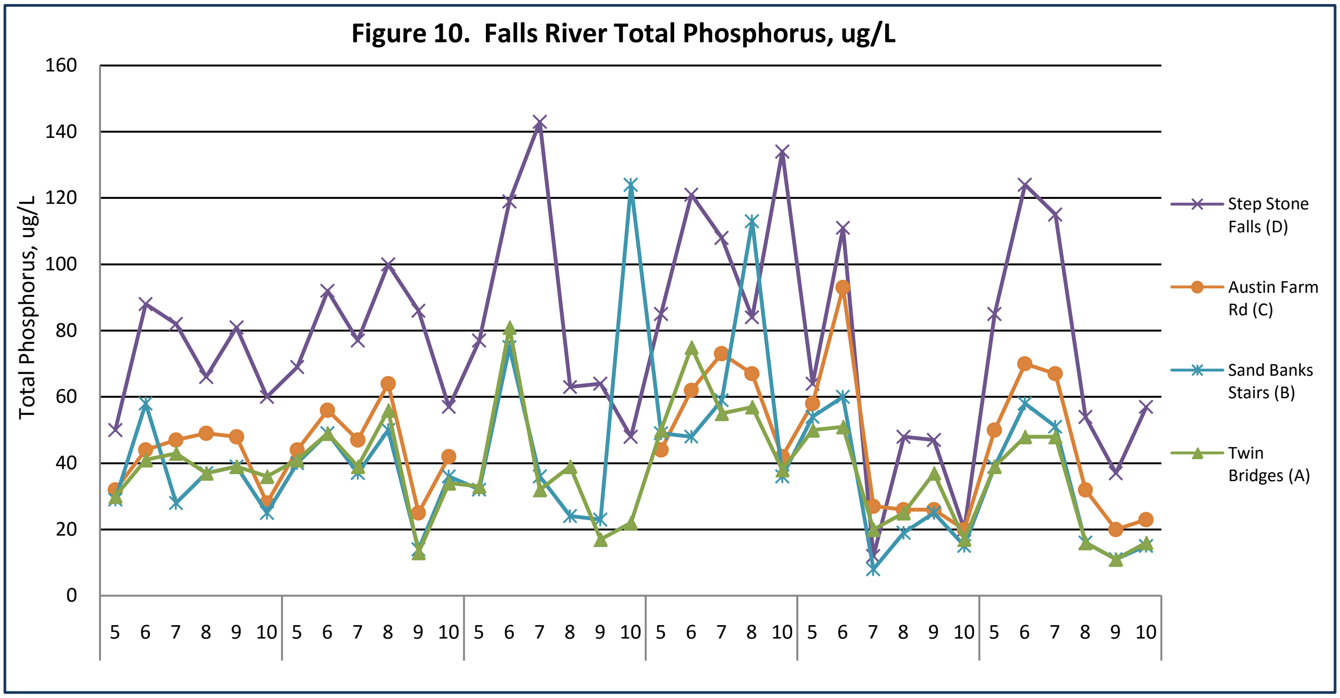


Figure 9. Upper Wood Sub-basin.

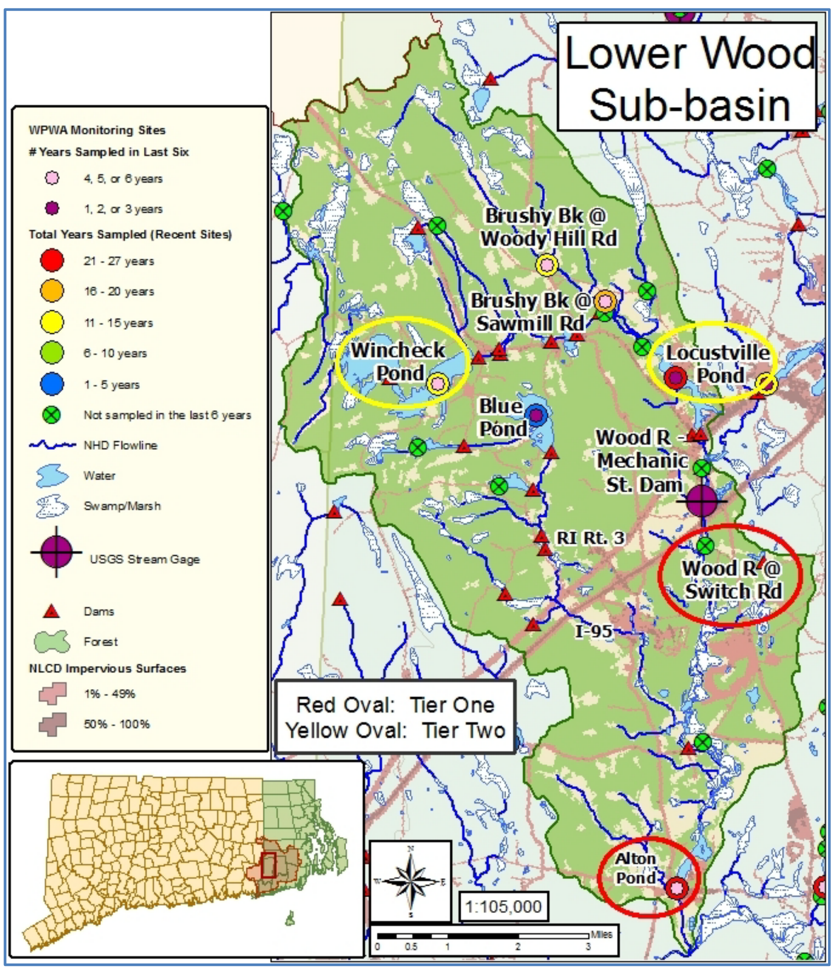
The second impoundment, this time on the Wood River, is Wyoming Pond. It is located at the southern end of the sub-basin surrounded by IC from the village of Wyoming, Rt. 138, and Rt. 3, and is not far from I-95. Wyoming Pond is impacted, with elevated TP concentrations and a significant variable milfoil invasion. Given its issues and location, we think that Wyoming Pond should continue to be monitored (tier one).



2.3.4 The Lower Wood River Sub-basin

The Lower Wood River sub-basin is 18,309 acres (74.09 km^2). Like the Upper Wood River sub-basin, it has very low percent IC (2.2%) and high percent FC (65.5%), with the Booth et al. (2002) model predicting stable stream channels. There are five current sites (all funded by WPWA) plus one recent site in this sub-basin. Three sites are on Brushy Brook (a tributary of the Wood River) including Locustville Pond, an impoundment on the brook. The other two Brushy Brook sites (*@ Woody Hill Rd* and *@ Sawmill Rd*) are not far from each other, and TP data indicate that neither site is impacted so we assigned them as third tier. Locustville Pond, which is surrounded by IC from the village of Hope Valley, has continuously low TP concentrations. It also has active volunteers and a pond association. Our assessment is that this site should be a second tier location unless the pond association wants to support it, or it could be sampled every other year.

The three remaining sites in this sub-basin are all current or former impoundments: Wincheck Pond, an impoundment of Moscow Brook; Blue Pond, a former impoundment of Canonchet Brook (not sampled since 2011, as the dam breached, draining the pond, during the floods of 2010); and Alton Pond, an impoundment of the Wood River at the southern end of the basin. Wincheck Pond has continuously low TP, plus has active volunteers and a pond association. Our assessment is that this should be a second tier site unless the pond association wants to support it, or like Locustville Pond could possibly be sampled every other year. Blue "Pond" can be dropped, as it is no longer a pond. Alton Pond has been sampled for 26 years and has IC surrounding it from the village of Wood River Junction. It is a mesotrophic pond and appears to be vulnerable to further impacts. Due to its trophic status and location at the bottom of the sub-basin, we would keep it as a first tier site.



Again, it is worth considering whether to sample Locustville and Wincheck Ponds in alternating years rather than assigning them to tier two. Both ponds have active associations, volunteers, and sampling locations.

There is a USGS stream gage on the Wood River just north of I-95 and south of RI Rt. 3, and between two inactive WPWA sampling sites: *Wood R – Mechanic St. Dam* and *Wood R @ Switch Rd.* We would like to re-activate *Wood R @ Switch Rd* as a first tier site since it is downstream of I-95, which has stormwater pipes leading directly from the highway into the river. It is also in the same NHD stream reach as the stream gage.

Figure 11. Lower Wood Sub-basin.

2.3.5 The Beaver and Usquepaug (Queen) Sub-basins

The Beaver River sub-basin is the smallest in the watershed at 7,901 acres (31.97 km^2). Its estimated percent IC is low (1.8%) and percent forested cover is high (66.3%). The adjacent Queen River sub-basin is much larger at 23,333 acres (94.43 km^2) and also has low estimated percent IC and high percent FC (1.6% and 64.0%, respectively), so the Booth et al. (2002) model predicts stable stream channels in both basins. The northern half of the Beaver River is largely undeveloped, but the southern half winds past multiple turf fields and a golf course. There are no active or recent sites in the Beaver River sub-basin. However, an inactive site—*Beaver R @ Rte 138 (#3)*—is located at a USGS stream gage and should be re-activated as a first-tier site.

There are six active sites (all funded by WPWA) and three recent sites in the Queen sub-basin. Upon examining the TP data (Figure 13), it is apparent that most of the sites have consistently low (<=25 ug/L) TP concentrations. Two sites--*QR8 @ Rt 102* and *QR4 @ Brownell's*--are just upstream and downstream of a golf course, respectively, but *QR4* was not sampled in 2014 (it was last sampled in 2013). The next site downstream, *QR6 @ Sand Br (TNC)*, was last sampled in 2011. Continuing downstream, the next site is *QR5 @ Mail Rd*, located at an active USGS stream gage. Our assessment is to keep monitoring *QR5 @ Mail Rd* as our farthest upstream site since it is at a stream gage and has very low TP concentrations, but drop (third tier) *QR8 @ Rt 102, QR4 @ Brownells,* and *QR6 @ Sand Br (TNC)* since the data are similar to *QR5 @ Mail Rd*.

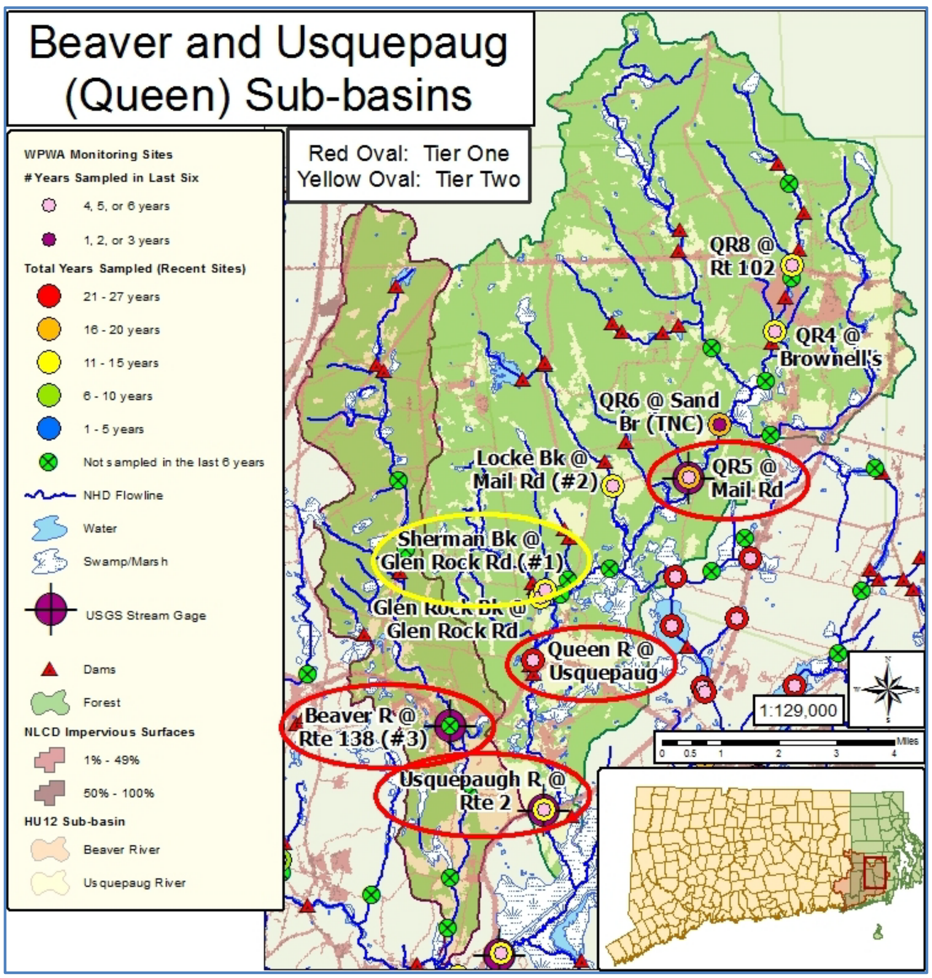


Figure 12. Beaver and Usquepaug (Queen) Sub-basins.

Continuing downstream on the Queen River main stem, the next two active sites are *Queen R @ Usquepaug* (an impoundment also known as Glen Rock Reservoir) and *Usquepaugh R @ Rte 2*; both are adjacent to turf farms. The Queen/Usquepaug River also skirts a golf course between these two sites. *Queen R @ Usquepaug* has been sampled for a long time (27 years) and appears to be trending better, although the r^2 of 0.15 for the trendline indicates a weak fit to the data (Figure 14). *Usquepaug R @ Rte 2 is* located at the southern tip of the sub-basin at the site of another active USGS stream gage. We would keep both of these sites as first tier monitoring locations.

The last two active sites are very

close to each other: one site is on Glen Rock Brook just upstream from where Sherman Brook joins it; the other site is on Sherman Brook just above the same confluence. Both brooks run through largely undeveloped land, although Sherman Brook passes to the west of a couple of turf farms at its southern end. Glen Rock Brook joins the Queen/ Usquepaug River not far after the confluence of the brooks. After comparing TP data from the two sites, our assessment is that the Sherman Brook site could be kept as an upstream, low impact site in tier two, but the Glen Rock Brook site could be dropped (third tier). Finally, a recent site on Locke Brook (*Locke Bk @ Mail Rd (QR#2)*, last sampled in 2012) passes through mostly forested land along with a few turf farms, and can be dropped (tier three).

Figure 13: Usquepaug (Queen) River Total Phosphorus, ug/L

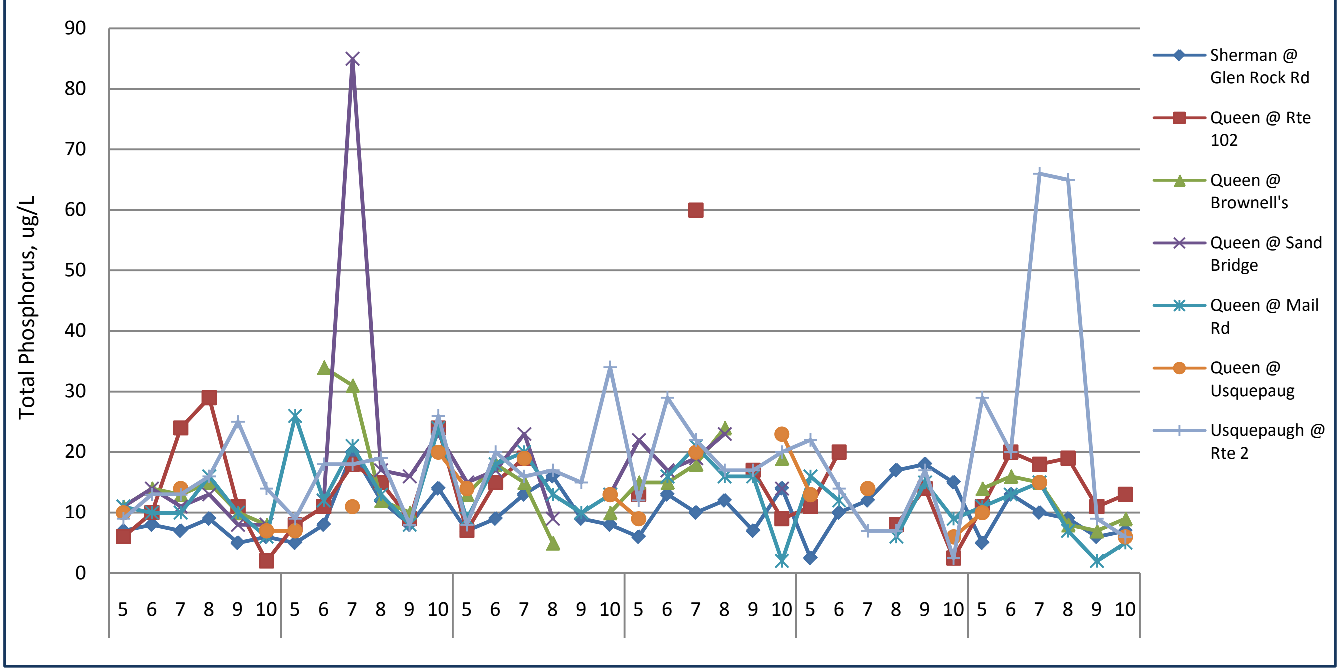
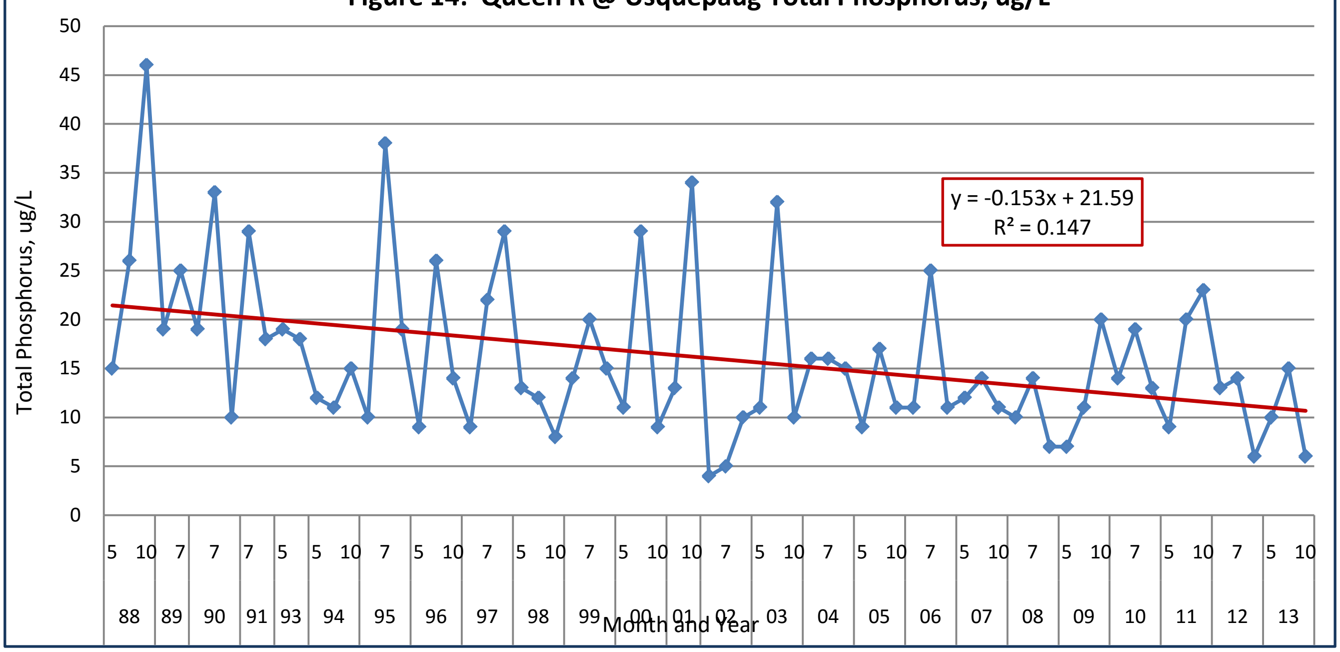


Figure 14: Queen R @ Usquepaug Total Phosphorus, ug/L



2.3.6 The Chipuxet – Pawcatuck Sub-basin

The Chipuxet-Pawcatuck sub-basin is 16,451 acres (66.57 km^2). At an estimated 4.1% IC it is still within the Booth et al. (2002) rural zone, but is only about 38.4% forested and is therefore predicted to have unstable stream channels. However, a large portion of this basin is occupied by Worden Pond, the largest natural pond in Rhode Island, and the adjacent Great Swamp to its north. The University of Rhode Island (URI) contributes the largest concentration of IC and is easy to spot in the eastern half of the basin. There are also several large turf farms occupying significant areas of this sub-basin and reducing the percentage of forest cover.

There are five active sites (all funded by WPWA) plus one recent sampling site in this sub-basin. Three sites are in ponds (Hundred Acre Pond, Worden Pond, and Tucker Pond (last sampled in 2013)). Hundred Acre Pond is actually an impoundment of the Chipuxet River; the other two ponds are natural basins. At this time, ideally we would like to keep monitoring all three ponds as they all appear to have unstable TP concentrations. If funding does not allow sampling of all three ponds every year, sampling them on a rotating basis could be an option unless private funders step forward to support the sites. If we start sampling these three ponds on a rotating schedule, dedicated samplers who want to continue monitoring the “free” parameters of temperature, dissolved oxygen, and Secchi depth could certainly do so.

Another sampling location is on the Chipuxet River north of the Great Swamp. This site is surrounded by turf farms and is not far from URI, the village of West Kingston, and the Amtrak line. It is also is located at an active USGS stream gage; therefore, we would like to keep monitoring at this site. The last two sites are located not far from each other on White Horn Brook, which passes out of URI and drains into the Great Swamp where it joins the Chipuxet River. Since these sites are close together in a relatively undeveloped area and their TP data appear similar, we would recommend keeping the *White Horn Bk @ Ministerial Rd* site but drop the *White Horn Bk @ Bike Trail* site to tier three.

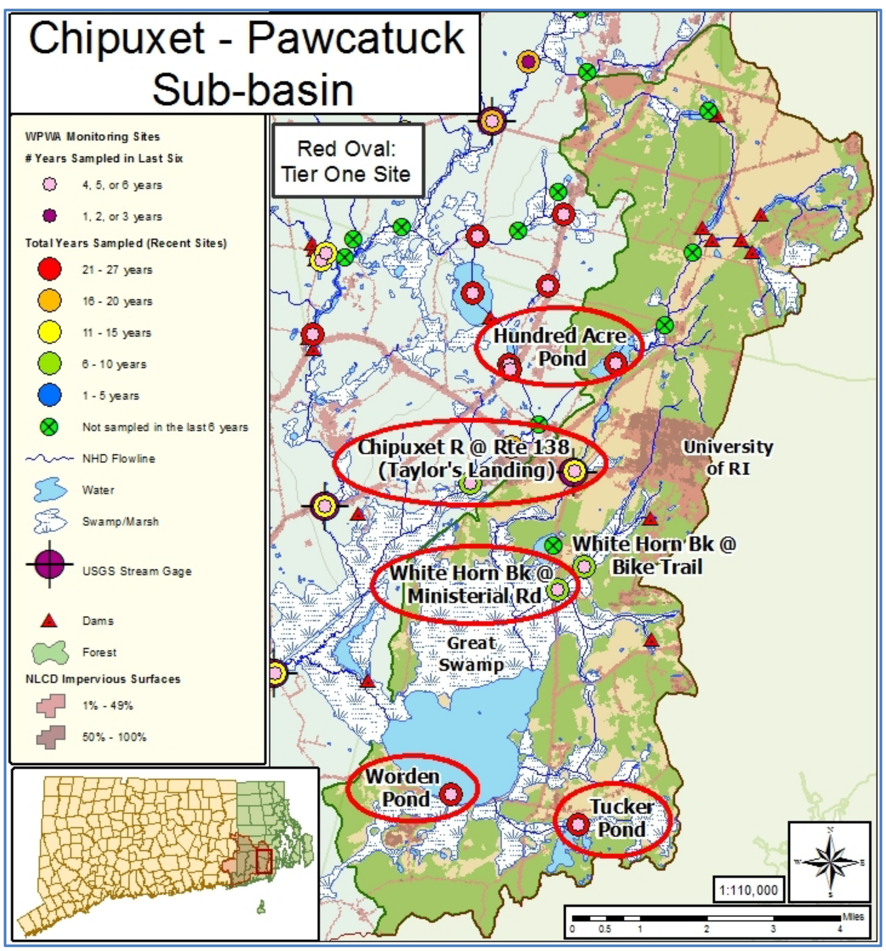


Figure 15. Chipuxet - Pawcatuck Sub-basin.

2.3.7 The Usquepaug (Queen) – Pawcatuck Sub-basin

The Usquepaug (Queen)-Pawcatuck sub-basin is where the Pawcatuck River begins as it exits Worden Pond. The basin is a 13,574 acre (54.93 km^2) lopsided V-shape, with Taney Brook entering the Pawcatuck River as it turns northwest skirting the Charlestown recessional moraine, and Chickasheen Brook (also written as Shickasheen Brook) entering from the northeast. The Usquepaug (Queen) River joins the Pawcatuck River from the north, as does the Beaver River. With 3.4% estimated percent IC and 48.5% FC, largely due to several large wetland areas and turf farms, the Booth model puts this basin in the "Uncertain" category.

There are twelve active sampling sites in this basin, mainly in its northern half, and WPWA has funded seven of these sites. Seven active sites are on Chickasheen Brook, in this order from upstream to downstream: *@ Rte 2, @ Miskiana Trail, Yawgoo Pond* (an impoundment)*, Barber Pond* (another impoundment)*, @ Barber Pond Outlet, @ Rt. 138, and @ Liberty Ln*. *Mud Brook @ Rte 2* is a sampling site on a tributary which joins Chickasheen Brook between Yawgoo Pond and Barber Pond, and was intended to serve as a reference site with which to compare the presumably more impacted Chickasheen Brook sites.

An examination of the TP data for these sites helps us to assign them into the three tiers. Barber Pond and Yawgoo Pond, both sampled for 27 years and considered separately from the brook sites, have similar TP concentrations. We assigned Barber Pond to tier one since it is downstream of Yawgoo Pond; Yawgoo Pond is in tier two. Another possibility is to sample the two ponds in alternating years. *Mud Brook @ Rte 2* turned out to be unstable and is therefore not a suitable reference site, and has been assigned to tier three. A plot of the Chickasheen Brook sites, listed from upstream to downstream, is in Figure 17. The TP data at *Chickasheen Bk @ Rte 2* fluctuate a great deal over the 25 years it has been monitored, so it is in tier one (note that three data points lie far above the plot range and were reduced for clarity; the actual data values are on the plot next to the reduced data points). *Chickasheen Bk @ Miskiana* drains from Arrow Swamp. This swamp has high phosphorus concentrations in the sediment due to past dumping by shellfish processing plants.

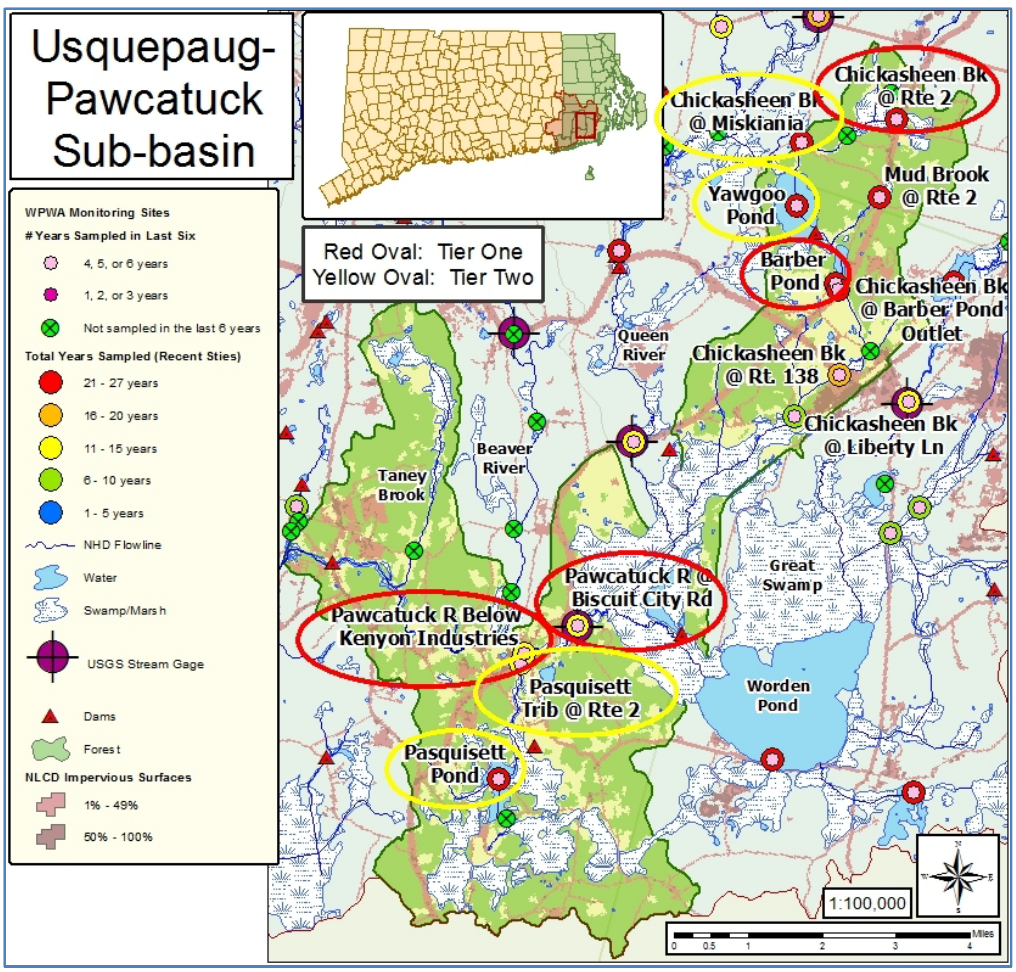
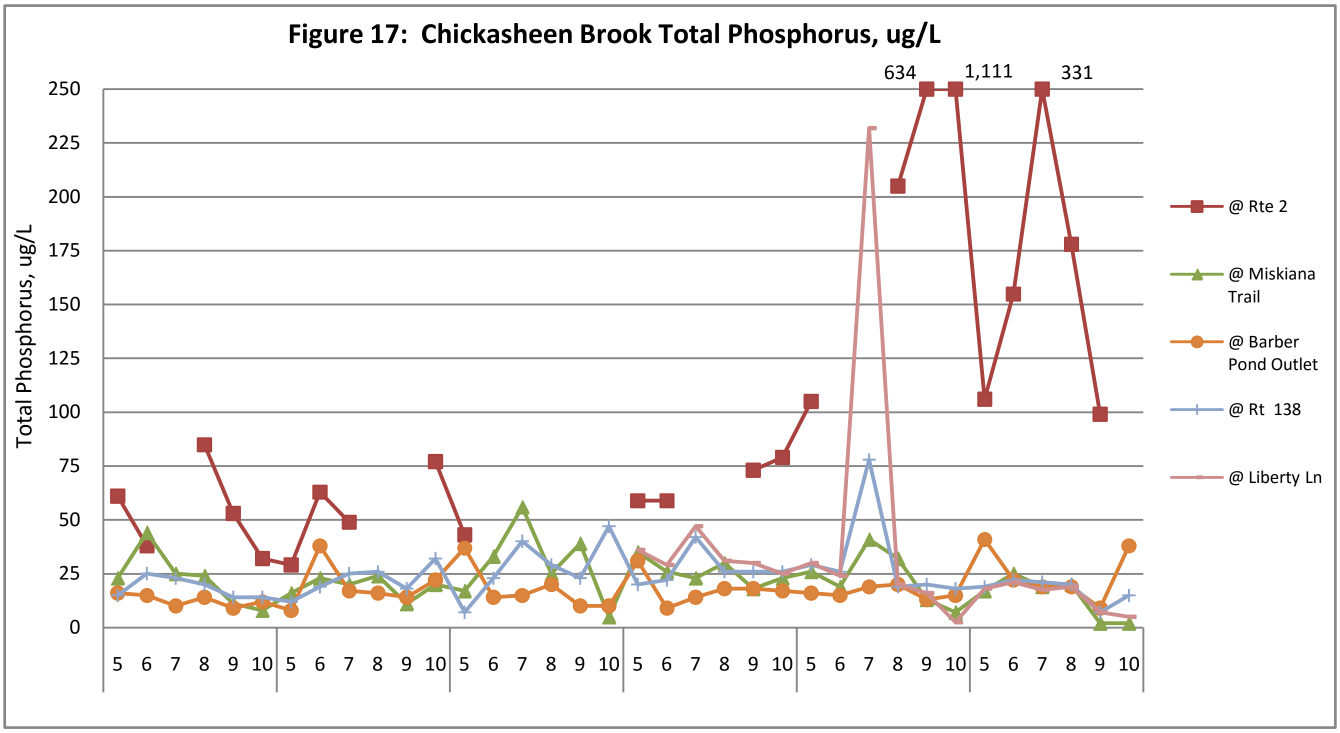


Figure 16. Usquepaug - Pawcatuck Sub-basin.



When beavers build a dam, anaerobic conditions develop in the swamp. These conditions trigger the release of phosphorus stored in the sediment back into the water column. For this reason, this site is included as tier two despite its apparent stability.

Chickasheen Bk @ Barber Pond Outlet, Chicksheen Bk @ Rt. 138, and *Chickasheen Bk @ Liberty Ln* are not far from each other and have similar, low TP concentrations; we placed all three sites in tier three. The Chickasheen discussions need to be brought to Linda Green since these sites are paid for by Watershed Watch.

There are two sites on Pasquisett Tributary: Pasquisett Pond (an impoundment) and *Pasquisett Trib @ Rte 2*, just before it joins the Pawcatuck River at Kenyon Industries. We assigned Pasquisset Pond to tier two, as the TP data at that site appear stable. We assigned the tributary to tier two as well.

The last two sites are on the Pawcatuck River. One of the Pawcatuck River sites is at the location of a USGS stream gage (*Pawcatuck R @ Biscuit City Rd*), and the other is just downstream of Kenyon Industries and has high phosphorus levels. We have assigned both sites to tier one.

2.3.8 The Tomaquag – Pawcatuck Sub-basin

The Tomaquag-Pawcatuck sub-basin is, at 36,499 acres (147.71 km^2), the second largest in the watershed and is where the Wood River joins the Pawcatuck River. In this sub-basin, the Pawcatuck is also joined by White Brook from the northeast, Tomaquag Brook from the north, and the Ashaway River from the northwest. Its estimated percent IC is 4.6% and its percent FC is 47.4%, which the Booth model predicts will result in borderline uncertain/unstable stream channels. There are several ponds and large wetlands, but also larger dense areas of IC, especially in the southwest part of the basin in the town of Westerly. Interstate 95 passes through the northwest lobe of the basin, and just to the northwest of the eastern lobe.

There are nine active sampling sites (all funded by WPWA) and one recent site (*Tomaquag Bk @ Woodville Rd*, not funded by WPWA) in this basin. *Tomaquag Bk @ Chase Hill (Rt 216)* is an active site just before Tomaquag Brook joins the Pawcatuck—this site has been assigned to tier one, and *Tomaquag Bk @ Woodville Rd* is in tier three. *White Bk @ Pine Hill Rd (Pond Inlet)* is downstream of the Carolina Trout Hatchery and has elevated TP (not surprising), so this site is in tier two.

Watchaug Pond and its tributary, Perry Healy Brook, each have active sites. Watchaug Pond has been monitored for 27 years and is slightly impacted but very stable; it is in tier two (or possibly sample every other year) and the brook site is tier three. Chapman Pond in Westerly contains a sampling site and is adjacent to a very large wetland, a quarry, and an old landfill. Monitoring in Chapman Pond started in 1988 and the TP data show possibly improving conditions; it would be informative to collect more years of data to monitor this possible trend, so it is in tier one. Meadowbrook Pond is an impoundment on Meadow Brook that has been monitored for 27 years. Its TP data indicate that it is unstable. In addition, Meadowbrook Pond is heavily fished and is often used by Chariho Middle School students; therefore, it is also in tier one. The remaining three sites are all on the Pawcatuck River, and all three sites are in tier one. *Pawcatuck R @ Rt 91* is at the location of a USGS stream gage. One inactive site (*Pawcatuck R @ Potter Hill*) is included in tier two, as we believe re-activating this site could be informative.

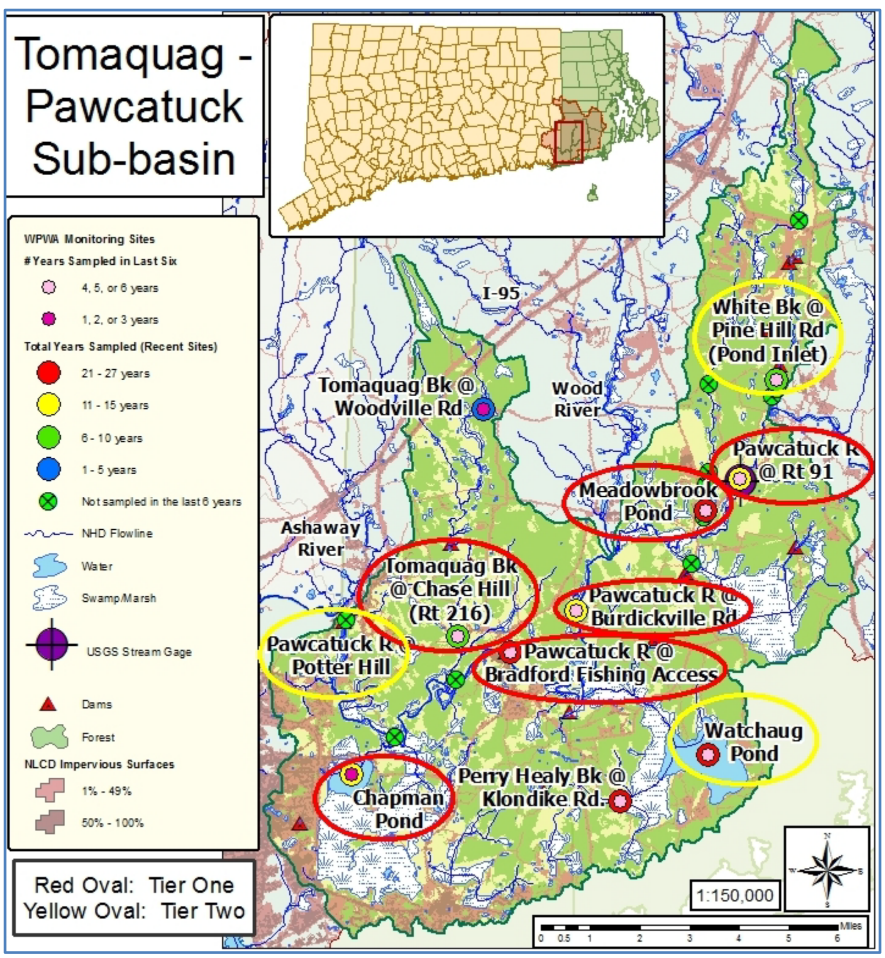


Figure 18. Tomaquag - Pawcatuck Sub-basin.

2.3.9 The Lower Pawcatuck Sub-basin

The Lower Pawcatuck sub-basin is the second smallest in the watershed at 10,147 Acres (41.06 km^2), but is the most impacted by development. It has a high estimated percent IC (21.9%) and low percent forested cover (coincidentally, also 21.9%). At these percentages, it is no surprise that the river channel is unstable and highly impacted. The river here has the town of Stonington, CT on its west side and Westerly, RI on its east side, as well as each town's wastewater treatment facility practically across the river from each other on its banks.

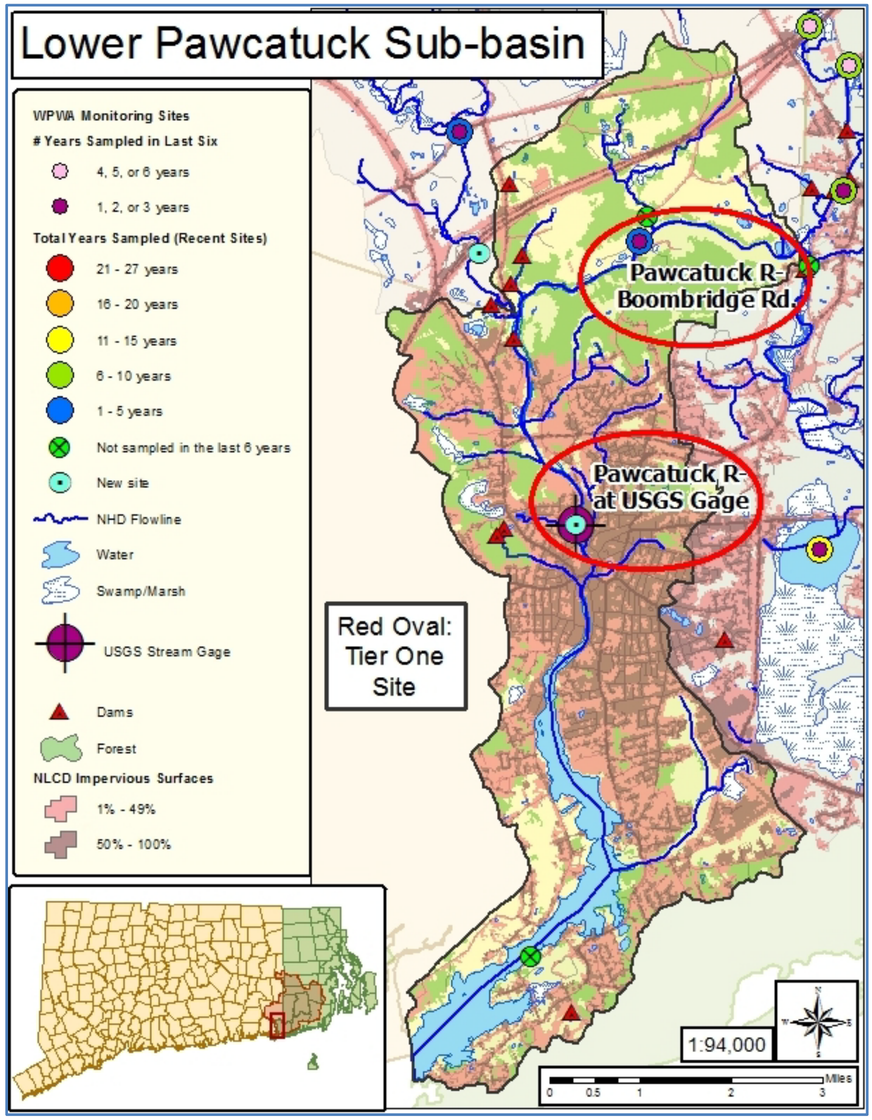


Figure 19. Lower Pawcatuck Sub-basin.

There is only one freshwater sampling location in this sub-basin, and it has only been sampled one time—in 2009 (*Pawcatuck R - Upstr of Boombridge Rd. bridge*). This site is upstream of the heavily IC-covered area of the sub-basin, and we would like to re-activate it as a tier one location. We also want to add another site to provide a more comprehensive upstream to downstream data profile, especially to capture the effects of the heavy development in the southern two thirds of the sub-basin. A good place for this site is at the USGS stream gage (number 01118500) downstream of the Stillman Avenue bridge. This USGS stream gage site has been active since 1940 and has water quality samples from the early 1950's through January 2016 (and continuing).

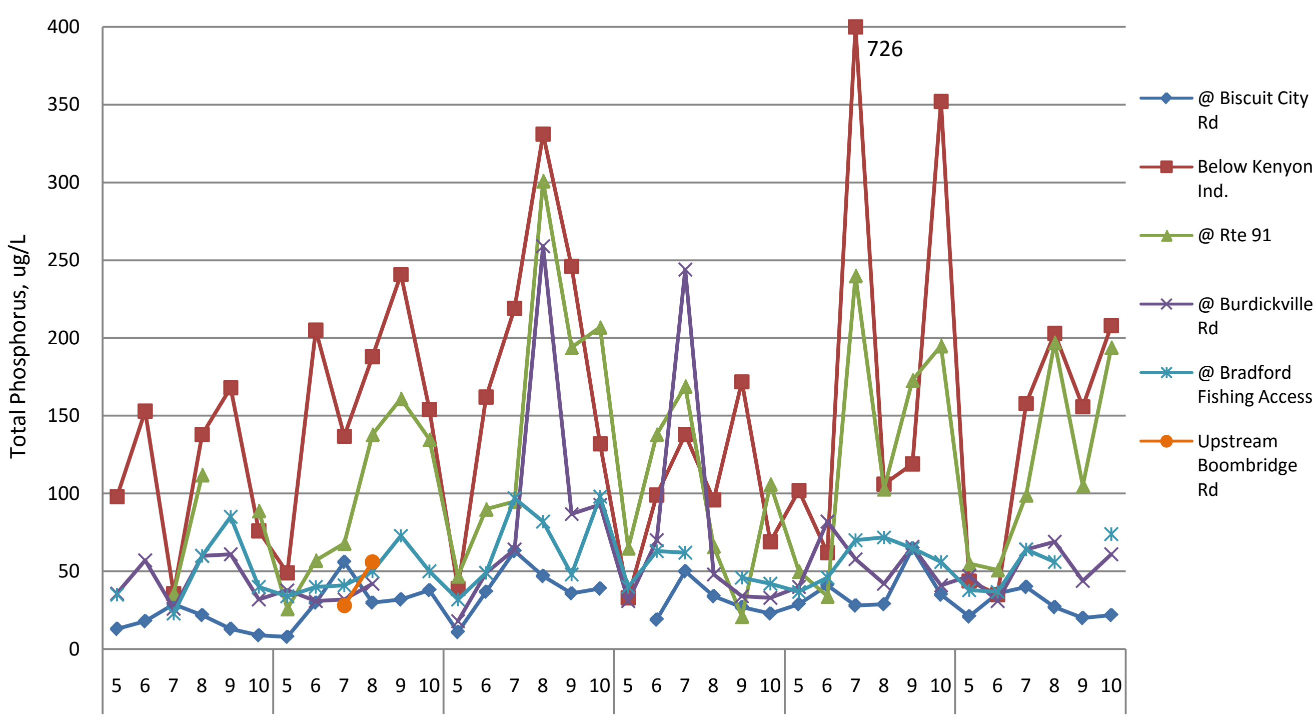
Save the Bay samples three brackish and marine sites in the river's estuary below the Route 1 (Broad St.) bridge as far south as Little Narragansett Bay in Watch Hill, RI/Stonington, CT.

4. Watershed-wide Assessment of Monitoring Site Locations and Recommendations for Keeping, Dropping, and Adding Sites

The most obvious issue revealed by our examination of the spatial coverage of our current sampling program is that two sub-basins do not have active sampling locations: the Shunock and Beaver River sub-basins. We have recommended re-activating at least one site in each sub-basin, preferably not far upstream of the confluence with the Wood or Pawcatuck Rivers. Conversely, we discovered several larger stream/river reaches that had an over-abundance of sampling locations. In these reaches, we recommended dropping some sites based on an examination of existing total phosphorus data and the location of concentrations of impervious cover. Similarly, we discovered locations in adjacent streams (Sherman Brook and Glen Rock Brook) and determined that one could be dropped. There are active sampling locations at most of the USGS stream gages in the watershed, and USGS does not perform water quality monitoring at these gages. We recommend keeping all of these sites and reactivating others in order to have monitoring sites at or near all of USGS gages.

Figure 20 includes all of the data on the Pawcatuck River in the last six years for which we have data. The most upstream location, at Biscuit City Rd., is the least impacted. The TP concentrations increase dramatically just downstream of Kenyon Industries, then decrease moving downstream toward the monitoring site at Bradford Fishing Access. Looking at the whole length of the Pawcatuck River, we determined that the lower section of the river is under-represented in our sampling program. We would like to re-activate the *Pawcatuck R - Upstr of Boombridge Rd. bridge* site. Also, we included a “new monitoring site” at the USGS stream gage below the Stillman Avenue bridge, which is surrounded by development on both sides of the river. This site is currently monitored for water quality by the USGS, so we will not be sampling it in 2016. However, if USGS should ever decide to cease their monitoring, we would want to add this site to our monitoring scheme as a tier one site.

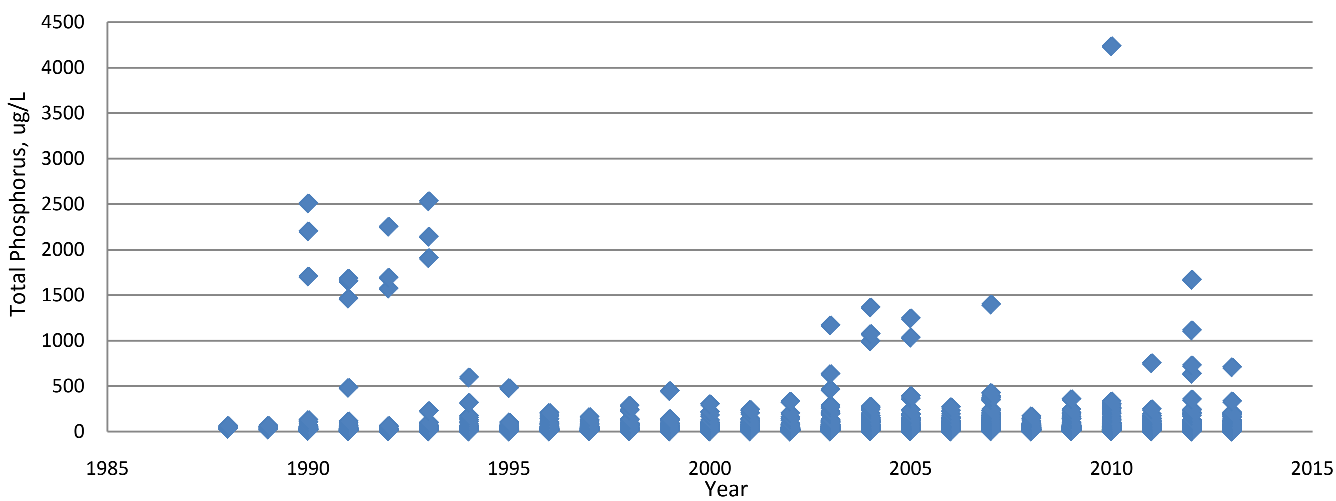
Figure 20: Pawcatuck River Total Phosphorus, ug/L



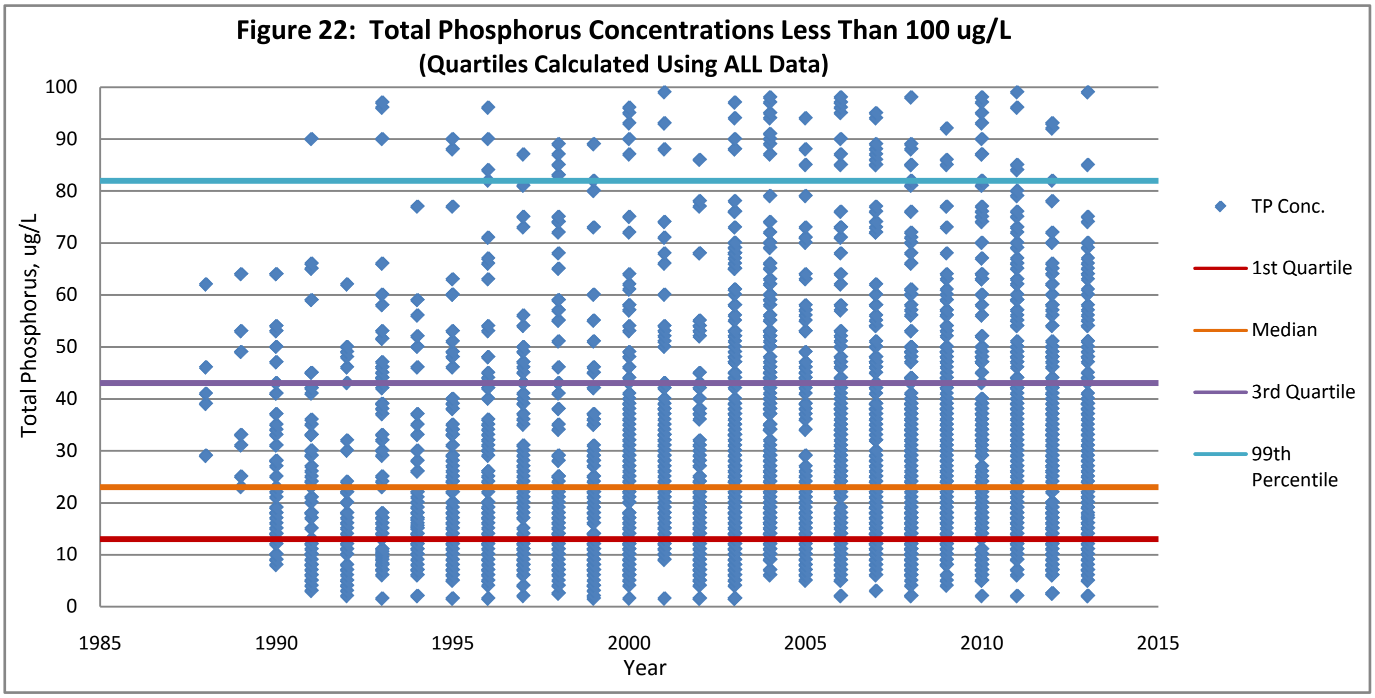
4.1 Reference Sites in All Sub-basins?

One question that we asked in this assessment is whether it is useful and/or necessary to have a reference site in each of the larger headwater sub-basins (from west to east the Shunock, Ashaway, Lower Wood, Upper Wood, Usquepaug (Queen), and Chipuxet-Pawcatuck sub-basins). Three of these sub-basins have tier one sites that could potentially serve as reference locations (Ashaway, Upper Wood, and Usquepaug), and two have recent sites identified in tier two that could possibly be considered as reference sites (Shunock and Lower Wood). If we were to have upstream reference sites we would want them to be impacted as little as possible; however, the attributes that lead to a site being truly pristine (lack of development, roads, agriculture, etc.) also make it inaccessible. In addition, we found that sites that were intended to serve as reference sites based on their location turned out to be impacted (*Mud Brook @ Rte 2, Falls River (D))*. What we decided was that in a watershed the size of the Wood-Pawcatuck, and with such a low percentage of IC and high percentage of FC, it is not necessary to have a reference site in each sub-basin. What we have done instead is look at all of the total phosphorus data that we currently have for stream and river sites in the watershed to determine a reference, or baseline, concentration against which we can compare data at our monitoring locations (Figure 21).

Figure 21: Total Phosphorus Concentration, all River and Stream Sites (ug/L)

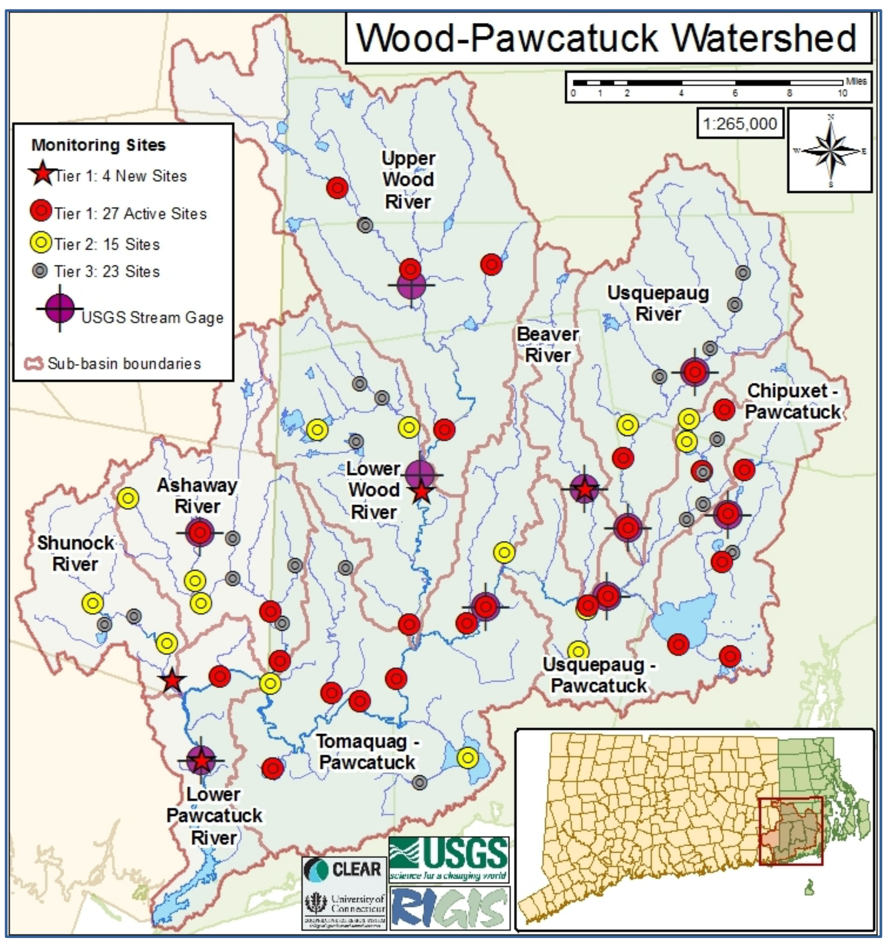


It is immediately apparent that the vast majority of data points are concentrated at the bottom of this plot thanks to the presence of a handful of high data values. Therefore, summary statistics were calculated for all of the data to produce the more readable plot in Figure 22. For the sake of clarity, this plot displays only data points less than 100 ug/L (92.5% of all TP data points), but the quartiles were calculated on all of the data: 1st quartile = 13 ug/L; 2nd quartile (median) = 23 ug/L; 3rd quartile = 43 ug/L; and the 99th percentile = 82 ug/L. The RI Department of Environmental Management's average TP criterion for lakes, ponds, kettle holes, and reservoirs in Rhode Island is 25 ug/L, and average TP in tributaries at the point where they enter such water bodies "shall not cause exceedance of this phosphorus criterion" (RI DEM, 2006). EPA guidelines suggest TP limits of 100 ug/L for streams and rivers, 50 ug/L for streams entering lakes, and 25 ug/L within lakes and reservoirs to prevent or control eutrophication (Addy and Green, 1996; Osmond et al, 1995). The Council for Environmental Quality recommends a maximum of 100 ug/L TP in-stream, and a maximum of 50 ug/L TP where a river enters a lake. Therefore, both the 1st quartile (13 ug/L) and median (23 ug/L) TP values for the entire Wood-Pawcatuck Watershed are below all of these water quality criteria. We chose the 1st quartile value of 13 ug/L as our reference (baseline) TP value for the watershed.



4.2 Final Tier One, Two, and Three Assignments

In summary, as a result of our analysis of WPWA's current sampling program, we have assigned 31 sites to tier one (including two new and two re-activated sites), 15 sites to tier two, and 23 sites to tier three. The 31 sites assigned to tier one represent a 16 site decrease from the 47 locations monitored in 2014, and a 10 site decrease from 2015. The tier assignments are mapped in Figure 23 to allow viewing of the monitoring scheme for the watershed in its entirety. Tier one sites are represented as red circles, new and reactivated tier one sites are red stars, tier two sites are yellow circles, and tier three sites are gray circles. All sites and tier assignments are listed in Appendix C.



We reluctantly decided to assign some very long term sampling sites to tier two or three. If the long term data indicate that a site is not highly impacted or is very stable, and/or another comparable

Figure 23. Final sampling site tier assignments

site is not far away, it is difficult to justify the expense and effort to continue monitoring the site. That said, if WPWA is not paying the lab fees to monitor a third-tier long-term site, the person or entity monitoring the site can certainly continue to monitor and support the site. One possibility discussed earlier in this paper was to sample some stable lakes and ponds in alternating or rotating years to save money. Upon consultation with Linda Green from URI Watershed Watch, the WPWA Water Quality Assessment Committee decided that reducing sampling at ponds from annually to bi-annually is unwise. Based on a cost/benefit discussion, it was projected that the cost to address high volunteer attrition each year would be higher than to simply continue to sample all the ponds annually. Additionally, there have been past instances where the water quality in ponds has actually fluctuated significantly year to year making annual data very valuable. Finally, issues with lakes go beyond phosphorus concentrations—they are experiencing issues with invasive species and cyanobacteria blooms. With global warming, the ecological and human health issues from cyanobacteria blooms are expected to intensify. Therefore, the recommendation is to continue to monitor ponds annually. We can still explore the possibility that active lake associations pay for the site in their lake.

4.3 Conductivity

A main focus of this assessment is to make sure that our monitoring scheme is capturing the effects of stormwater runoff in the watershed. In order to better accomplish this, the assessment committee recommended adding conductivity to our suite of monitoring parameters.

Conductivity is used to estimate the concentration of dissolved solids/ions in a waterbody as an indicator of the presence of stormwater runoff. Streams and rivers tend to have a baseline range of conductivity mostly based upon the type of geology through which they travel. Aquatic life requires a relatively constant concentration of some dissolved ions for good survival, growth, and reproduction (Lake Superior/Duluth Streams Project, date unknown). Discharges or inputs to streams such as from wastewater, a failing septic system, agricultural or lawn fertilizer runoff, road salt, or urban stormwater runoff can change conductivity significantly, making it useful as an indicator of water quality (US EPA, 2012).

We decided to monitor conductivity using continuously deployed loggers at ten locations in the watershed. Two sites are in the Wood River: just upstream of the boundary between the Upper Wood River sub-basin and the Lower Wood River sub-basin and just upstream of the

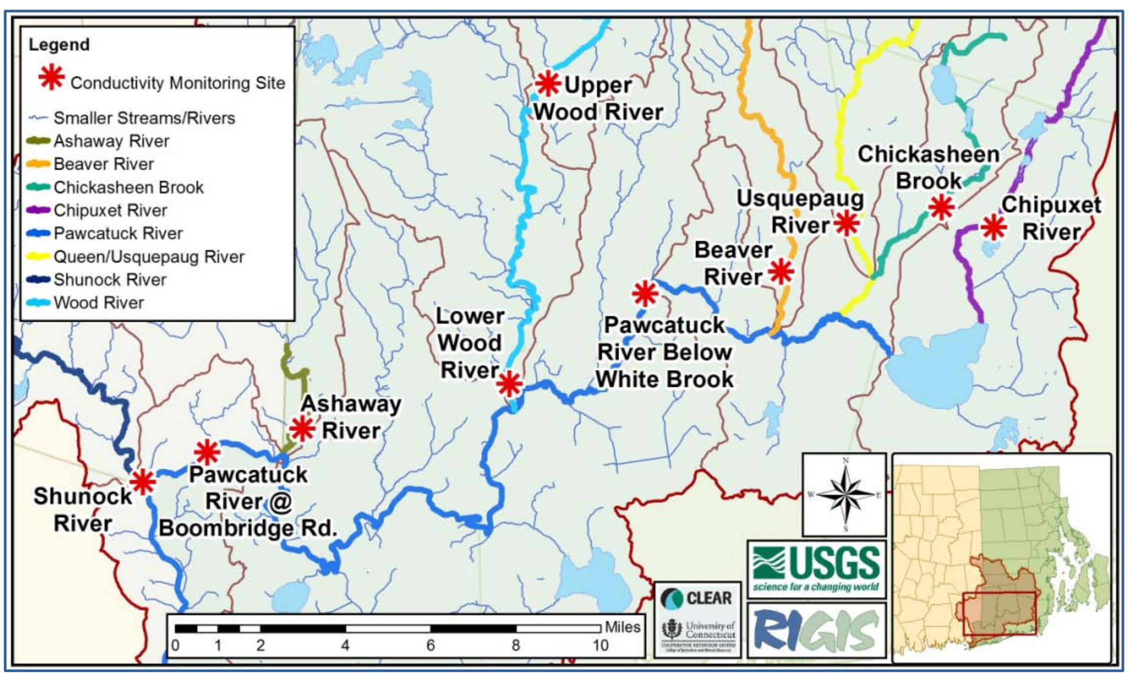


Figure 24. Conductivity Monitoring Locations

confluence with the Pawcatuck River. Six more sites are located in rivers/streams upstream of their confluences with the Pawcatuck River, but as close as possible (that is, reasonably accessible for installation and maintenance of in stream loggers) to the confluences: in the Ashaway River, Beaver River, Chickasheen Brook, Chipuxet River, Queen/Usquepaug River, and Shunock River. Finally, two sites are located in the Pawcatuck River main stem: just below where White Brook enters the River, and at Boombridge Rd. upstream of the urban centers of Westerly, RI and Pawcatuck, CT. Sites will be located upstream enough from the Pawcatuck to avoid backflow and not below bridges (B. Rashleigh, personal communication).

After investigating a range of commercially available conductivity meters which are designed to be deployed in-stream, the committee decided to purchase ten Onset Hobo Fresh Water Conductivity Meters based on their specifications (Table 3) and price. They will likely be set to record measurements every half hour, and will be calibrated before deployment and after retrieval using a handheld meter. The Hobo meters will also be retrieved and downloaded, then re-deployed, periodically (approximately every two to three months) during the monitoring season. If possible, we will have the meters deployed year round unless icing is a concern, in which case we will deploy the meters from early spring (after any ice has melted) through late fall/early winter. If elevated conductivity is found at a monitoring site, we plan to test conductivity with a handheld meter upstream from that site to look for a gradient that can help determine the source of the elevated reading.

Table 3. Specifications for the Onset Hobo Fresh Water Conductivity Meters

Memory	18,500 temperature and conductivity measurements when using one conductivity range; 14,400 sets of measurements when using both conductivity ranges (64kbytes)
Sample rate	1 second to 18 hrs, fixed or multiple-rate sampling with up to 8 user-defined sampling intervals
Battery life	3 years (@ 1 min logging)
Maximum depth	70 m (225')
Operating range	-2 to 36°C (28° to 97°F) - non freezing
Weight	193 gm (6.82 ounces), buoyancy in freshwater
Size	3.18 cm diameter x 16.5 cm, with 6.3 mm mounting hole (1.25" diameter x 6.5", ¼" hole)
Calibrated range	Conductivity
Accuracy	Conductivity
Resolution	Conductivity
Response time	1 second to 90% of changeH

4.4 Temperature Logging

WPWA and Trout Unlimited deployed electronic temperature loggers in streams during 11 summers since 2002, including 2014 and 2015 (Figure 24). Logging locations were chosen based on several factors: at sites that previously had temperature logging; at water quality monitoring sites; at sites that might have important brook trout habitat (cold water, Falls River (known brook trout population), and Flat River); into and out of impounded areas; and based on the local knowledge of members of Trout Unlimited. Unfortunately, WPWA does not currently have the data processing capacity to thoroughly analyze these data. A more in-depth assessment of the temperature logging sampling scheme will be performed when we have the ability to thoroughly analyze the data.

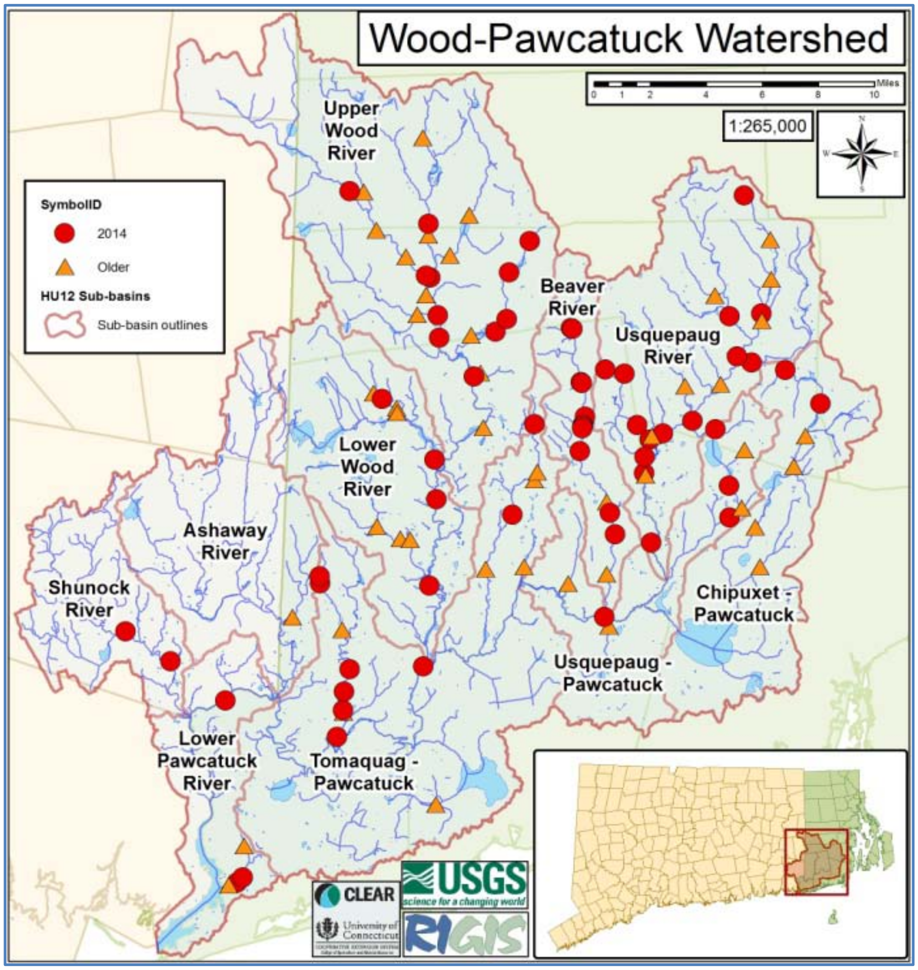


Figure 25. In-stream temperature logging sites.

5. Conclusions

This assessment of the Wood-Pawcatuck Watershed monitoring scheme has demonstrated that overall, our current sampling locations provide a good spatial coverage of the watershed. We have only identified two new sites to add and two to re-activate. Outside organizations or associations that pay for their own sampling sites can use this assessment to determine whether they want to sample all of their current tier three sites, or if they can drop or move one or more of them. Our final recommendation is that this assessment process be repeated every five years.

6. References

Addy, K. and L. Green. Phosphorus and Lake Aging. 1996. Natural Resources Facts, University of Rhode Island Department of Natural Resources Science, Fact Sheet No. 96-2, May, 1996.

Booth, D.B., D. Hartley, and R. Jackson. 2002. Forest Cover, Impervious-Surface Area, and the Mitigation of Stormwater Impacts. JAWRA Journal of the American Water Resources Association 38(3): 835–845.

Brabec, E., S. Schulte and P.L. Richards. 2002. Impervious Surfaces and Water Quality: A Review of Current Literature and Its Implications for Watershed Planning. *Journal of Planning Literature* 16: 499

Homer, C.G., Dewitz, J.A., Yang, L., Jin, S., Danielson, P., Xian, G., Coulston, J., Herold, N.D., Wickham, J.D., and Megown, K., 2015, Completion of the 2011 National Land Cover Database for the conterminous United States-Representing a decade of land cover change information. Photogrammetric Engineering and Remote Sensing, v. 81, no. 5, p. 345-354.

Lake Superior/Duluth Streams Project. http://www.lakesuperiorstreams.org/understanding/param_ec.html

Osmond, D.L., D.E. Line, J.A. Gale, R.W. Gannon, C.B. Knott, K.A. Bartenhagen, M.H. Turner, S.W. Coffey, J. Spooner, J. Wells, J.C. Walker, L.L. Hargrove, M.A. Foster, P.D. Robillard, and D.W. Lehning. 1995. WATERSHEDSS: Water, Soil and Hydro-Environmental Decision Support System, http://h2osparc.wq.ncsu.edu.

RI DEM. 2006. Water Quality Regulations. State of Rhode Island and Providence Plantations Department of Environmental Management, Office of Water Resources, July 2006, Amended December 2010.

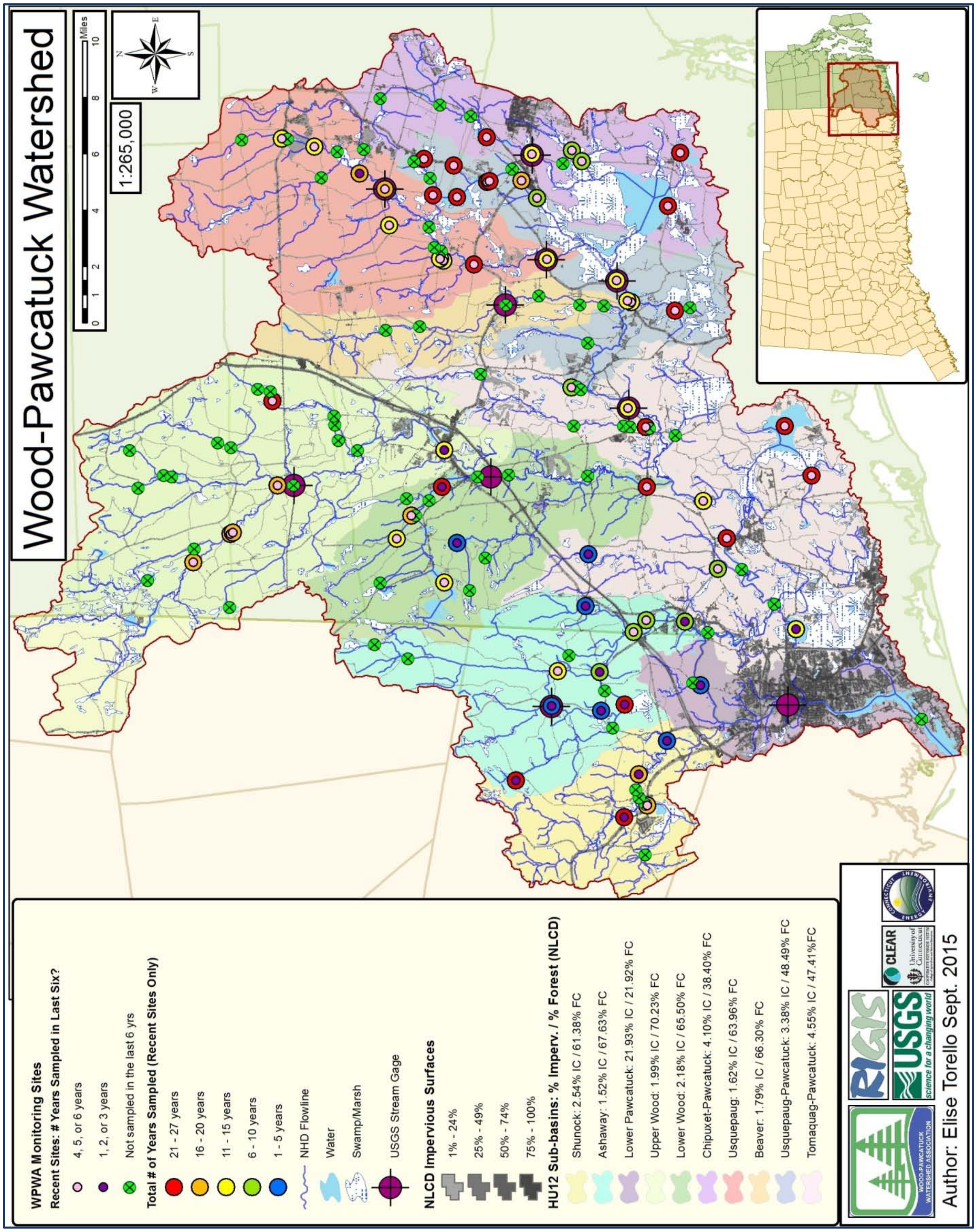
Schueler, T. R., 1994. The Importance of Imperviousness. *Watershed Protection Techniques* 1(3): 100-111.
U.S. Environmental Protection Agency. 2012. 5.9 Conductivity. http://water.epa.gov/type/rsl/monitoring/vms59.cfm, March 2012.

U.S. Geological Survey, 20141010, NLCD 2011 Percent Developed Imperviousness (2011 Ed., amended 2014) - National Geospatial Data Asset (NGDA) Land Use Land Cover: None None, U.S. Geological Survey, Sioux Falls, SD

Wang, L. and P. Kanehl. 2003. Influences of Watershed Urbanization and Instream Habitat on Macroinvertebrates in Cold Water Streams. JAWRA Journal of the American Water Resources Association
39(5): 1181–1196.

Xian, G., Homer, C., Dewitz, J., Fry, J., Hossain, N., and Wickham, J., 2011. The change of impervious surface area between 2001 and 2006 in the conterminous United States. *Photogrammetric Engineering and Remote Sensing*, Vol. 77(8): 758-762.

Appendix A. Map of the Wood-Pawcatuck Watershed showing the ten HUC12 sub-basins, WPWA sampling sites, USGS stream gages, and NLCD11 impervious cover.



Appendix B. List of WPWA monitoring locations sorted by sub-basin, number of years sampled in the last six, and total number of years sampled.

SiteNum	Sampling Site Name	Sub-basin	Total	# Yrs in Last 6	Last Year Sampled (Blue<2004)	WPWA Pays?
5380	Ashaway R @ Wellstown Rd	Ashaway	9	6	2014	WPWA
6030	Green Falls @ Rte 184/I 95 Exit 93	Ashaway	7	5	2014	
6020	Green Falls R #2 @ Putker Rd	Ashaway	11	4	2014	
6010	Wyassup Lake	Ashaway	23	3	2011	
6100	Green Falls R #3 @ Clark Falls Rd	Ashaway	10	3	2014	
6110	Parmenter Bk @ Clark Falls Rd.	Ashaway	5	3	2012	
5210	Ashaway R @ Rte 216	Ashaway	6	2	2010	
6080	Spalding Pond	Ashaway	21	1	2009	
6050	Pendelton Hill Bk @ Grindstone Rd. USGS Gage 01118300	Ashaway	2	1	2013	
6070	Green Falls R #1 @ Green Falls Rd	Ashaway	10	0	2004	
6060	Glade Bk @ Pine Wood Rd	Ashaway	1	0	2003	
6120	Green Falls Pond	Ashaway	1	0	1997	
6130	Spalding Pond Inlet @ Pendleton Rd.	Ashaway	1	0	1993	
6090	Wyassup Bk @ Clark Falls Road	Ashaway	1	0	2003	
5070	Beaver R @ Old Mountain Rd (#1)	Beaver	4	0	2001	
5100	Beaver R @ Rte 138 (#3) USGS Gage 01117468	Beaver	4	0	2001	
5130	Beaver R @ Shannock Hill Rd (#4B)	Beaver	4	0	2001	
5080	Beaver R @ Hillsdale Rd (#2)	Beaver	3	0	2000	
5460	Beaver R @ Lewiston Rd (#5)	Beaver	3	0	2000	
5450	Beaver R @ Schoolhouse Rd (#4A)	Beaver	1	0	1999	
1060	Worden Pond	Chipuxet-Pawcatuck	25	6	2014	WPWA
1050	Chipuxet R @ Rte 138 (Taylor's Landing) USGS Gage 01117350	Chipuxet-Pawcatuck	12	6	2014	WPWA
1090	White Horn Bk @ Ministerial Rd	Chipuxet-Pawcatuck	8	6	2014	
1100	White Horn Brook @ Bike Trail	Chipuxet-Pawcatuck	8	6	2014	
1010	Hundred Acre Pond	Chipuxet-Pawcatuck	26	5	2014	WPWA
1070	Tucker Pond	Chipuxet-Pawcatuck	23	5	2013	
1080	Larkin Pond	Chipuxet-Pawcatuck	6	0	2007	
1040	Chipuxet R @ Wolf Rocks Rd.	Chipuxet-Pawcatuck	1	0	1991	
1030	Chipuxet R @ Yawgoo Valley Rd.	Chipuxet-Pawcatuck	1	0	1991	

SiteNum	Sampling Site Name	Sub-basin	Total	# Yrs in Last 6	Last Year Sampled (Blue<2004)	WPWA Pays?
1120	The Reservoir (Camp Canonicus)	Chipuxet-Pawcatuck	1	0	1991	
5541	Pawcatuck R - At Boombridge Rd. bridge	Lower Pawcatuck	1	1	2009	
5540	Pawcatuck R - Upstream of Boombridge Rd. bridge	Lower Pawcatuck	1	1	2009	WPWA
5542	Pawcatuck R-Downstream of Boombridge Rd. bridge	Lower Pawcatuck	1	1	2009	
5350	Pawcatuck R @ Avondale (0.5 M)	Lower Pawcatuck	8	0	2008	
5220	Lewis Pond outlet @ Boom Bridge Rd	Lower Pawcatuck	2	0	2004	
4480	Alton Pond	Lower Wood	26	6	2014	WPWA
4040	Wincheck Pond	Lower Wood	12	6	2014	WPWA
4360	Brushy Bk @ Sawmill Rd	Lower Wood	20	5	2014	WPWA
4350	Brushy Bk @ Woody Hill Rd	Lower Wood	11	5	2014	WPWA
4110	Locustville Pond	Lower Wood	22	2	2014	WPWA
4700	Blue Pond	Lower Wood	1	1	2011	
5410	Loghouse Bk @ Sandy Pond Rd	Lower Wood	11	0	2001	
4370	Moscow Bk @ Sawmill Rd	Lower Wood	6	0	2005	
4400	Long Pond (Hopkinton)	Lower Wood	4	0	2003	
4410	Ashville Pond	Lower Wood	1	0	2003	
5480	Dawley Bk @ Dye Hill Rd	Lower Wood	1	0	2000	
4100	Locustville Pond - Inlet	Lower Wood	1	0	1991	
4600	Wood R-Mechanic St Dam USGS Gage 01118000	Lower Wood	1	0	1990	
4420	Wood R @ Switch Road between these sites	Lower Wood	1	0	2003	
4460	Wood R @ Woodville Rd (Ward's House)	Lower Wood	1	0	2000	
7090	Asseconk Swamp	Shunock	17	4	2012	
7080	Shunock R @ Hewitt Rd	Shunock	21	1	2009	
7070	Shunock R @ Babcock Rd	Shunock	20	1	2009	
7040	Shunock R @ Rt 184	Shunock	2	1	2013	
7030	Asseconk Bk @ Rte 2	Shunock	2	0	2004	
7010	Shunock R @ Main St	Shunock	2	0	2004	
7020	Asseconk Bk @ Jeremy Hill Rd	Shunock	1	0	2003	
7060	Shunock R below Parke Pond	Shunock	1	0	2004	
5190	Meadowbrook Pond	Tomaquag-Pawcatuck	27	6	2014	WPWA
5310	Watchaug Pond	Tomaquag-Pawcatuck	27	6	2014	WPWA

SiteNum	Sampling Site Name	Sub-basin	Total	# Yrs in Last 6	Last Year Sampled (Blue<2004)	WPWA Pays?
5260	Pawcatuck R @ Bradford Fishing Access	Tomaquag-Pawcatuck	26	6	2014	WPWA
5320	Perry Healy Bk @ Klondike Rd.	Tomaquag-Pawcatuck	25	6	2014	
5240	Pawcatuck R @ Burdickville Rd	Tomaquag-Pawcatuck	12	6	2014	WPWA
5160	Pawcatuck R @ Rte 91 USGS Gage 01117500	Tomaquag-Pawcatuck	12	6	2014	WPWA
5110	White Bk @ Pine Hill Rd (Pond Inlet)	Tomaquag-Pawcatuck	9	6	2014	WPWA
5250	Tomaquag Bk @ Chase Hill (Rte 216)	Tomaquag-Pawcatuck	8	5	2014	WPWA
5300	Chapman Pond	Tomaquag-Pawcatuck	11	2	2014	WPWA
5500	Tomaquag Bk @ Woodville Rd	Tomaquag-Pawcatuck	5	1	2009	
5490	Pawcatuck R @ Potter Hill	Tomaquag-Pawcatuck	12	0	1999	
5180	Meadow Brook Pond Inlet	Tomaquag-Pawcatuck	10	0	2000	
5090	Meadow Bk #1 @ Richmond School	Tomaquag-Pawcatuck	5	0	2002	
5440	White Brook Pond	Tomaquag-Pawcatuck	5	0	2008	
5120	Meadow Bk #2 @ Pine Hill Rd	Tomaquag-Pawcatuck	4	0	2002	
5150	Meadow Bk #3 @ Tuckahoe Turf Farms	Tomaquag-Pawcatuck	4	0	2002	
5370	Pawcatuck R @ Chase Hill Rd.	Tomaquag-Pawcatuck	3	0	2007	
5430	Pawcatuck R below BDA	Tomaquag-Pawcatuck	2	0	2007	
5200	Cedar Swamp Bk @ Kings Factory Rd	Tomaquag-Pawcatuck	1	0	2003	
5600	Meadowbrook Pond Outlet	Tomaquag-Pawcatuck	1	0	1993	
5530	Perry Healy outlet	Tomaquag-Pawcatuck	1	0	2003	
5520	White Brook Pond Outlet	Tomaquag-Pawcatuck	1	0	2007	
4190	Falls R @ Austin Farm Rd (C)	Upper Wood	20	6	2014	
4170	Falls R @ Step Stone Falls (D)	Upper Wood	20	6	2014	
4230	Falls R @ Twin Bridges (A) (#2) near USGS gage 01117800	Upper Wood	20	6	2014	

SiteNum	Sampling Site Name	Sub-basin	Total	# Yrs in Last 6	Last Year Sampled (Blue<2004)	WPWA Pays?
4220	Boone Lake	Upper Wood	25	5	2014	WPWA
4530	Falls R @ Sand Banks Stairs (B)	Upper Wood	19	5	2013	
4380	Wyoming Pond	Upper Wood	15	1	2014	WPWA
4200	Breakheart Pond	Upper Wood	12	0	2008	
4540	Boone Tributary #1	Upper Wood	6	0	2002	
4070	Breakheart Bk above Breakheart Pond	Upper Wood	4	0	2003	
4550	Boone Tributary #2	Upper Wood	3	0	2000	
4290	Browning Mill Pond	Upper Wood	3	0	2006	
4570	Eisenhower Lake	Upper Wood	3	0	2008	
4610	Acid Factory Bk-Eisenhower Trib @ Stubble Bk Rd.	Upper Wood	1	0	1996	
4130	Acid Factory Bk @ Plain Meeting Hse Rd	Upper Wood	1	0	2003	
4180	Kelly Bk @ Falls River Rd	Upper Wood	1	0	2003	
4280	Roaring Bk @ Arcadia Rd	Upper Wood	1	0	2003	
4310	Roaring Bk @ Summit Rd	Upper Wood	1	0	2003	
4560	Tippecansett Pond	Upper Wood	1	0	2000	
4580	Wickaboxet Pond	Upper Wood	1	0	2004	
4010	Wood R @ Frying Pan Pond	Upper Wood	1	0	1997	
4250	Wood R @ Rte 165 USGS gage 01117800	Upper Wood	1	0	2000	
3150	Queen R @ Usquepaug	Usquepaug	27	6	2014	WPWA
3060	Queen R@Mail Rd (QR#5) USGS Gage 01117370	Usquepaug	16	6	2014	WPWA
3050	Sherman Bk @ Glen Rock Rd (QR#1)	Usquepaug	14	6	2014	WPWA
3120	Glen Rock Bk @ Glen Rock Rd	Usquepaug	12	6	2014	WPWA
3080	Queen R @ Rte 102 (QR#8)	Usquepaug	12	6	2014	WPWA
3170	Usquepaugh R @ Rte 2 USGS Gage 01117420	Usquepaug	12	6	2014	WPWA
3040	Locke Bk @ Mail Rd (QR#2)	Usquepaug	11	4	2012	
3090	Queen R @ Brownell's (QR#4)	Usquepaug	11	4	2013	
3030	Queen R @ Sand Bridge (TNC) (QR#5)	Usquepaug	20	3	2011	
3020	Fisherville Bk @ Williams Reynolds Rd (QR#3)	Usquepaug	13	0	2005	
3070	Queen R @ Stoney Ln	Usquepaug	10	0	2000	
3180	Queen Riv #2/Glf Crse (0.5 mi s of Victory Hwy)	Usquepaug	10	0	2000	
3190	Queen River #4/Ladd School	Usquepaug	10	0	2000	
3010	Queen R @ Eppley (Dugway Rd) (QR#6)	Usquepaug	9	0	2002	
3140	Queen R @ Glen Rock Bridge	Usquepaug	1	0	1991	
3100	Queen's Fort Bk @ School Lands Rd	Usquepaug	1	0	2003	
3130	Rake Factory Bk @ Glen Rock Rd	Usquepaug	1	0	2003	

SiteNum	Sampling Site Name	Sub-basin	Total	# Yrs in Last 6	Last Year Sampled (Blue<2004)	WPWA Pays?
2070	Barber Pond	Usquepaug-Pawcatuck	27	6	2014	WPWA
2010	Yawgoo Pond	Usquepaug-Pawcatuck	27	6	2014	WPWA
2050	Chickasheen Bk @ Miskiania Trail	Usquepaug-Pawcatuck	25	6	2014	
2020	Chickasheen Bk @ Rte 2	Usquepaug-Pawcatuck	25	6	2014	
2060	Mud Brook @ Rte 2	Usquepaug-Pawcatuck	25	6	2014	
5010	Pasquisett Pond	Usquepaug-Pawcatuck	22	6	2014	WPWA
2080	Chickasheen Bk @ Barber Pond Outlet	Usquepaug-Pawcatuck	21	6	2014	
2090	Chickasheen Bk @ Rt. 138	Usquepaug-Pawcatuck	18	6	2014	WPWA
5170	Pasquisett Trib @ Rte 2	Usquepaug-Pawcatuck	14	6	2014	
5060	Pawcatuck R @ Biscuit City Rd USGS Gage 01117430	Usquepaug-Pawcatuck	11	6	2014	WPWA
5290	Pawcatuck River Below Kenyon Industries	Usquepaug-Pawcatuck	11	6	2014	WPWA
2100	Chickasheen Bk @ Liberty Ln	Usquepaug-Pawcatuck	6	4	2014	WPWA
2030	Chicka Bk @ Col. Potter Road (Skagg's old dam)	Usquepaug-Pawcatuck	4	0	2005	
5000	Pasquisett Trib Inlet @ SE	Usquepaug-Pawcatuck	4	0	1993	
2120	Chicka @ Waites Corner Rd. (Richmond Farm)	Usquepaug-Pawcatuck	3	0	1998	
5140	Taney Bk @ Shannock Hill Rd	Usquepaug-Pawcatuck	3	0	2005	

Appendix C. Recommended Sampling Strategy. Active and recent monitoring sites are grouped by sub-basin and separated into tiers one, two, and three. Tier one (32 sites) includes sites we definitely want to continue monitoring; tier two (15 sites) includes sites we would like to continue monitoring if resources allow; and tier three (23 sites) includes sites we will miss the least if dropped. Sites that WPWA pays for are in bold font.

<table>
<tr><th></th><th>Tier</th><th colspan="2">Active or Recent Site</th><th>Notes</th></tr>
<tr><td rowspan="5">Shunock</td><td>1</td><td colspan="2">Shunock R @ I-95 off Rt 49</td><td>New site to capture water quality status just before it joins the Pawcatuck River</td></tr>
<tr><td>2</td><td colspan="2">Shunock R @ Hewitt Rd</td><td></td></tr>
<tr><td>2</td><td colspan="2">Shunock R @ Rt 184</td><td></td></tr>
<tr><td>3</td><td colspan="2">Asseconk Swamp</td><td></td></tr>
<tr><td>3</td><td colspan="2">Shunock R @ Babcock Rd</td><td></td></tr>
<tr><td rowspan="10">Ashaway</td><td>1</td><td colspan="2">Green Falls @ Rte 184/I 95 Exit 93</td><td></td></tr>
<tr><td>1</td><td colspan="2">Pendelton Hill Bk @ Grindstone Rd.</td><td>At USGS Gage 01118300</td></tr>
<tr><td>1</td><td colspan="2">Ashaway R @ Rte 216</td><td>Above confluence with Pawcatuck River</td></tr>
<tr><td>2</td><td colspan="2">Pendleton Hill Bk @ Rt 49/16</td><td>New in 2014, so no data yet</td></tr>
<tr><td>2</td><td>Spalding Pond</td><td rowspan="2">Alternate years</td><td rowspan="2">Both are eutrophic/unstable, have not been sampled in years, we would like to re-activate them</td></tr>
<tr><td>2</td><td>Wyassup Lake</td></tr>
<tr><td>3</td><td colspan="2">Ashaway R @ Wellstown Rd</td><td>Similar and close to Green Falls @ 184/I95 Exit 93</td></tr>
<tr><td>3</td><td colspan="2">Green Falls R #2 @ Putker Rd</td><td rowspan="2">Replace with Pendelton Hill Bk @ Grindstone Rd.</td></tr>
<tr><td>3</td><td colspan="2">Green Falls R #3 @ Clark Falls Rd</td></tr>
<tr><td>3</td><td colspan="2">Parmenter Bk @ Clark Falls Rd.</td><td></td></tr>
<tr><td rowspan="6">Upper Wood</td><td>1</td><td colspan="2">Boone Lake</td><td>Surrounded by development, active lake association</td></tr>
<tr><td>1</td><td colspan="2">Falls R @ Step Stone Falls (D)</td><td>Farthest upstream, TU site</td></tr>
<tr><td>1</td><td colspan="2">Falls R @ Twin Bridges (A) (#2)</td><td>Not far upstream of USGS gage 01117800, TU site</td></tr>
<tr><td>1</td><td colspan="2">Wyoming Pond</td><td>Surrounded by IC, eutrophic, invasives, bottom of basin</td></tr>
<tr><td>3</td><td colspan="2">Falls R @ Austin Farm Rd (C)</td><td>TU site</td></tr>
<tr><td>3</td><td colspan="2">Falls R @ Sand Banks Stairs (B)</td><td>TU site</td></tr>
<tr><td rowspan="7">Lower Wood</td><td>1</td><td colspan="2">Alton Pond</td><td>Sampled 26 yrs, surrounded by development, mesotrophic, unstable, bottom of sub-basin</td></tr>
<tr><td>1</td><td colspan="2">Wood R @ Switch Road</td><td>Re-activate, in same stream reach as USGS Gage 01118000, downstream of I-95, stormwater pipe into river</td></tr>
<tr><td>2</td><td>Locustville Pond</td><td rowspan="2">Alternate years?</td><td>Surrounded by Hope Valley, low TP, active volunteers, pond association</td></tr>
<tr><td>2</td><td>Wincheck Pond</td><td>Low TP, active volunteers and pond association</td></tr>
<tr><td>3</td><td colspan="2">Blue Pond</td><td>Not a pond any more--floods of 2010 breached dam</td></tr>
<tr><td>3</td><td colspan="2">Brushy Bk @ Woody Hill Rd</td><td></td></tr>
<tr><td>3</td><td colspan="2">Brushy Bk @ Sawmill Rd</td><td>Possibly re-activate if development goes in</td></tr>
<tr><td>BR</td><td>1</td><td colspan="2">Beaver R @ Rte 138 (#3)</td><td>Re-activate, only site in sub-basin, USGS Gage 01117468</td></tr>
<tr><td rowspan="6">Usquepaug</td><td>1</td><td colspan="2">Queen R @ Usquepaug</td><td>Sampled 27 years, trending better</td></tr>
<tr><td>1</td><td colspan="2">Queen R@Mail Rd (QR#5)</td><td>At USGS Gage 01117370</td></tr>
<tr><td>1</td><td colspan="2">Usquepaugh R @ Rte 2</td><td>At USGS Gage 01117420, bottom of sub-basin</td></tr>
<tr><td>2</td><td colspan="2">Sherman Bk @ Glen Rock Rd (QR#1)</td><td>Upstream low-impact site</td></tr>
<tr><td>3</td><td colspan="2">Glen Rock Bk @ Glen Rock Rd</td><td>Similar to Sherman Brook</td></tr>
<tr><td>3</td><td colspan="2">Locke Bk @ Mail Rd (QR#2)</td><td>Passes through mostly forest, not impacted</td></tr>
</table>

	Tier	Active or Recent Site		Notes
	3	Queen R @ Brownell's (QR#4)		Data similar to QR5 @ Mail Rd
	3	Queen R @ Rte 102 (QR#8)		Data similar to QR5 @ Mail Rd
	3	Queen R @ Sand Bridge (TNC) (QR#6)		Data similar to QR5 @ Mail Rd
Chipuxet-Pawcatuck	1	Chipuxet R @ Rte 138 (Taylor's Landing)		At USGS Gage 01117350, near turf farms, URI, West Kingston, Amtrak
	1	White Horn Bk @ Ministerial Rd		Comes out of URI
	1	Hundred Acre Pond	Sample in rotating years?	Unstable TP, sample on rotating basis?
	1	Tucker Pond		Unstable TP, sample on rotating basis?
	1	Worden Pond		Unstable TP, largest natural pond in RI, rotating basis?
	3	White Horn Brook @ Bike Trail		Close to White Horn Bk @ Ministerial
Usquepaug-Pawcatuck	1	Barber Pond		Sampled 27 years. Alternate with Yawgoo Pond?
	1	Chickasheen Bk @ Rte 2		Unstable TP
	1	Pawcatuck R @ Biscuit City Rd		At USGS Gage 01117430
	1	Pawcatuck River Below Kenyon Industries		High phosphorus
	2	Chickasheen Bk @ Miskiana Trail		Drains Arrow Swamp, indicator of anaerobic swamp conditions.
	2	Pasquisett Pond		Stable. Sample every other year?
	2	Pasquisett Trib @ Rte 2		Right before Pawcatuck River confluence
	2	Yawgoo Pond		Sampled 27 years, similar to Barber Pond. Alternate with Barber Pond?
	3	Chickasheen Bk @ Rt. 138		Near Amtrak
	3	Chickasheen Bk @ Barber Pond Outlet		Similar to Barber Pond.
	3	Chickasheen Bk @ Liberty Ln		Similar to @ 138
	3	Mud Brook @ Rte 2		Not a good reference site
Tomaquag-Pawcatuck	1	Chapman Pond		Started in 1988, possibly improving
	1	Meadowbrook Pond		
	1	Pawcatuck R @ Bradford Fishing Access		
	1	Pawcatuck R @ Burdickville Rd		
	1	Pawcatuck R @ Rte 91		USGS Gage 01117500
	1	Tomaquag Bk @ Chase Hill (Rte 216)		Just before confluence with Pawcatuck R.
	2	Pawcatuck R @ Potter Hill		Inactive site to potentially re-activate
	2	Watchaug Pond		Sampled 27 years, slightly impacted, very stable. Sample every other year?
	2	White Bk @ Pine Hill Rd (Pond Inlet)		Below trout hatchery, elevated TP
	3	Perry Healy Bk @ Klondike Rd.		
	3	Tomaquag Bk @ Woodville Rd		
L. Pawc.	1	Pawcatuck R @ USGS Stream Gage		New site to complete Pawcatuck River gradient at USGS Gage 01118500
	1	Pawcatuck R - Upstr of Boombridge Rd. bridge		

Appendix D. List of 2014 monitoring locations in the Wood-Pawcatuck Watershed with the station funders identified.

Funder	MONITORING LOCATION		Funder	MONITORING LOCATION
WPWA	Alton Pond		WPWA	Queen River @ Mail Rd
WPWA	Barber Pond		WPWA	Queen River @ Rte 102
WPWA	Boone Lake		WPWA	Sherman Bk @ Glen Rock Rd.
WPWA	Chapman Pond		WPWA	Shickasheen Brook @ Liberty Lane
WPWA	Hundred Acre Pond		WPWA	Shickasheen Brook @ Rte 138
WPWA	Locustville Pond		WPWA	Tomaquag Brook @ Chase Hill Rd
WPWA	Meadowbrook Pond		WPWA	Usquepaugh @ Rte 2
WPWA	Pasquisett Pond		WPWA	White Brook Inlet
WPWA	Queen @ Usquepaugh			
WPWA	Watchaug Pond		URI WW	Barber - Mud Brook
WPWA	Wincheck Pond		Trout Unlimited	Falls River A - Twin Bridges
WPWA	Worden Pond		Trout Unlimited	Falls River C - Austin Farm
WPWA	Wyoming Pond		Trout Unlimited	Falls River D - Step Stone
WPWA	Yawgoo Pond		North Stonington Citizens Land Alliance	GFR #3 (Clark Falls Rd./Rte 216)
WPWA	Ashaway River @ Wellstown Rd.		North Stonington Citizens Land Alliance	Green Falls - Rte 184
WPWA	Brushy Brook @ Saw Mill		North Stonington Citizens Land Alliance	Green Falls #2 (@ Putker)
WPWA	Brushy Brook @ Woody Hill		North Stonington Citizens Land Alliance	Pendleton Hill Brk @ Rte 49/216
WPWA	Chipuxet River @ Rte 138		WPWA	Pasquisett Tributary
WPWA	Glen Rock Brook @ Glen Rock Rd		URI WW	Shickasheen @ Barber Pond Outlet
WPWA	Pawcatuck R @ Biscuit City Rd		URI WW	Shickasheen @ Miskiania Road
WPWA	Pawcatuck R below Kenyon Ind.		URI WW	Shickasheen Brook @ Rte 2
WPWA	Pawcatuck River @ Burdickville Rd		WPWA	Watchaug Trib - Perry Healy
WPWA	Pawcatuck River @ Bradford		URI WW	White Horn Brook @ Bike Trail
WPWA	Pawcatuck River @ Rte 91		URI WW	White Horn Brook @ Ministerial Rd.