

Appendix 2: Modeling Methodology & Attainment Stream Details to Support TMDL Development

MapShed Nutrient Loading Model Overview

MapShed is an established midrange modeling tool first developed as the Generalized Watershed Loading Function (GWLF-E) model by Haith and Shoemaker in 1987, and Haith et al. in 1992. The model was refined regularly by Evans, Corradini, and Lehning at Penn State University into an ArcView GIS-based model called AVGWLF (Evans et al., 2002); it has recently transitioned to the open-source MapWindow GIS and now is now called MapShed (Evans & Corradini, 2012). A key feature of MapShed is the availability of a high quality data set developed under a Quality Assurance Project Plan (NEIWPC 2005), and both model and data were calibrated to the New England region (Penn State University 2008).

MapShed is an aggregate distributed/lumped parameter watershed model that generates loading estimates for the surface water pollutants of phosphorus, nitrogen, total dissolved solids, and fecal coliform bacteria. The model is distributed in that it allows multiple land use/cover scenarios. However, loads originating from the watershed are lumped by land use category, and spatial routing of nutrient and sediment loads within each watershed is not available. For example, all farmland is lumped together and defined by one set of parameter values, and all forested land is lumped together and defined by a different set of parameter values. The model does not account for active forest operations within forested areas. Other factors that affect the nutrient balance of a watershed such as livestock numbers and practices, soil and groundwater nutrient loads, point-sources, and septic systems are also lumped together, with each group treated as a unique source.

MapShed consists of three components. Note that “MapShed” refers both to the overall model (all three components), as well as the first of the three individual components. Each is a standalone executable file which can be independently run.

- **MapShed**, a MapWindow-based interface using GIS to generate model inputs, (*executable: PrjMngr.exe*);
- **Generalized Watershed Loading Model (GWLF-E)**, the hydrology and nutrient loading model, (*executable: GWLF-E.exe*); and
- **PRedICT**, software to examine various best management practice (BMP) scenarios, (*executable: PRedICT.exe*)

The first component (MapShed) generates a data file that is used as an input by the second component (GWLF-E), which in turn generates a data file used as an input by the third component (PRedICT). In practice, the first component requires much more computer run-time than the following two. MapShed takes about 15 minutes to execute, while GWLF and PRedICT are nearly instantaneous.

The overall MapShed model uses well established soil and hydrologic equations along with GIS and weather data to model surface runoff and soil erosion. The Soil Conservation Service Curve Number (SCS-CN) coupled with daily precipitation and temperature from the National Climatic Data Center (NCDC) is used to model surface runoff and streamflow. Evapotranspiration is determined using daily

weather data and a cover factor dependent on land use/cover type. The Universal Soil Loss Equation (USLE) is used to model monthly erosion and sediment loss. Nutrients (nitrogen, phosphorus, and total suspended solids) are modeled using export coefficients for both the dissolved and solid phases from each type of land use. (Evans et al. 2002, 2008, 2012). The model uses geographic data (e.g. soils, watershed boundaries, land uses), land use runoff coefficients, daily weather (temperature and rainfall), and universal soil loss equations, estimates of livestock animal units, and best management practices (current and future) to compute pollutant loads in terms of daily mass and concentration.

The model was run for each of the thirty-four impaired stream segments and ten attainment streams for a 15 year period, determined by weather data availability. Running the model over this time span covered a wide range of hydrologic conditions, accounting for variations in nutrient and sediment loading over time. To estimate the TMDL reductions needed to attain water quality standards, the GWLF model results are used to estimate the existing load in each of the impaired stream segments and in respective attainment watersheds. The difference in estimated pollutant loads between the impaired and attainment watersheds is the reduction needed to achieve water quality criteria for all nonpoint source pollutants of concern. It is assumed that the reference watersheds are in attainment by a margin greater than zero. In other words, they are not at the border between attainment and impairment. By setting the TMDL target equal to the reference watershed nutrient load, an implicit margin of safety is therefore in place.

Software

The following software is downloaded from <http://www.mapshed.psu.edu/download.htm>:

- MapWindow v4.6.602 (this specific version, do not update)
- MapShed v1.0.8 or higher
- MapShed and PRedICT user manuals, plus other supporting documentation

Model Input Data Overview

In MapShed, there are two data entry phases. The first phase, called MapShed, is when GIS layers and weather data are entered using the GIS interface. The second phase, called GWLF-E, is when additional data can be entered by typing numbers directly into a series of data entry screens. Overall, a vast amount of data are entered and processed through the model. Many of these data consist of well-established soil equations and constants which were reviewed, but not adjusted. Others, such as number of livestock, agricultural stream miles, and amount of vegetative buffer in agricultural areas, were reviewed in detail through a combination of in-office and on-site methods. Each data source is described below.

Most geographic data used in the modeling were produced for the New England Interstate Water Pollution Control Commission (NEIWIPCC), are covered by an existing Quality Assurance Project Plan, and were used in model calibration for the northeast region. These data sources were downloaded from the MapShed website at Penn State, and reprojected into the standard ME Office of GIS projection (UTM NAD83 Zone 19N) by FB Environmental using ArcMap 9. Large files (all grids, plus streams) were also trimmed using ArcMap 9 to a rectangle slightly larger than the watershed extent, which greatly reduced computer processing time. These datasets are:

- New York/New England Regional data, v1.0.0 or higher
- New York/New England Sections 8 and 9, v1.0.0 or higher

Other data sets specific to this project were provided by Maine DEP, the Natural Resource Conservation Service, and/or FB Environmental, and are described below.

Input Parameters to the GIS Portion of MapShed

There are seven required input data sources, plus up to twelve additional optional sources, which are selected during the GIS portion of MapShed. Most data sources chosen were those developed and calibrated for the northeast region for NEIWPPC. Note that the Soil Phosphorus layer uses “Total P” units (not “Test P” units).

The watershed boundaries were provided by Maine DEP. The default streams layer was initially used, however, it was discovered that the original stream data showed inconsistent resolution across the state. As seen in Figure 1, there were rectangular areas in which many ephemeral streams were included, and others where they were omitted. The border between these areas corresponds to USGS quadrangles, and is believed to be an artificial boundary inherent in older source data. Stream length is a critical model parameter affecting among other things streambank erosion, therefore an older streams shapefile was adopted which provided a much more consistent stream resolution across the state. Table 1 presents all GIS level inputs and sources. Many are further described below in the GWLF-E portion of this report.

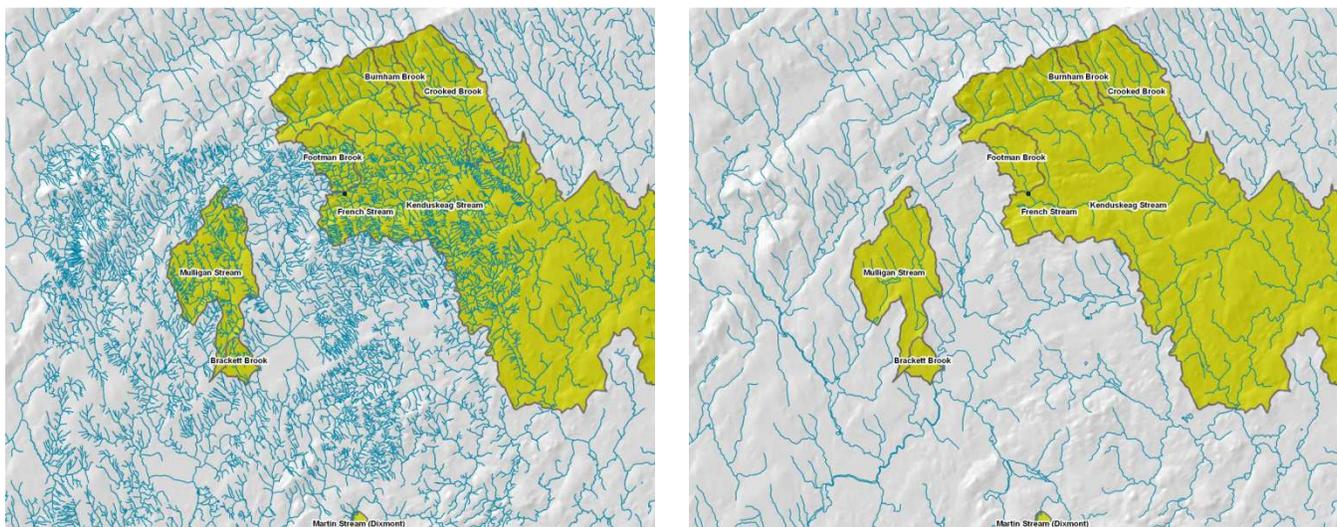


Figure 1: The image on the left shows the default streams layer provided by MapShed. The image on the right shows a shapefile (*hydrol_04202006.shp*) from Maine Office of GIS used in this modeling.

Minor changes to the weather data were also necessary. Weather data consists of a GIS shapefile (*weather_station.shp*) and an associated folder of weather data (one .csv file for each weather station). The weather data file for Madison, Maine, (*sta4927.csv*) was found to have columns out of order. This weather data was formatted of the other weather data files. Likewise, Station 860 was found to have formatting errors in the data file (*sta860.csv*) when the model attempted to use it for Moose Brook in Aroostook County. This station was labeled within the shapefile as “Brockton,” although no town or weather station of that name could be found in that vicinity. The temperatures in the file were much different than nearby Houlton, Maine, for the dates in question, therefore this station was deleted from the GIS shapefile, allowing other nearby weather stations to be used. The edited weather shapefile was renamed “*weather_station_bugfix.shp*.”

Table 1: GIS Level Input Parameters (Shaded Rows are Required by the Model)

Data Layers	Short Description	File Type	Required	File Name	Notes and Source
Weather Stations	Weather station locations	Point	Yes	Weather_station_ bugfix.shp	Source: MapShed / NEIWPCCC, edited by FBE to correct formatting issues for two stations
Weather Directory	Weather station directory	CSV-files	Yes	Individually named by weather station	Formatting corrections to Station 4927 by FBE Source: MapShed / NEIWPCCC
Point Sources	Point source discharge locations	Point	No	Newwtps.shp	No point sources identified in the project area. Possible future point sources can be entered via shapefile, or manually using GWLF-E.
Basins	Basin boundary used for modeling	Polygon	Yes	Individually named by watershed	Source: Maine DEP
Streams	Map of stream network	Line	Yes	hydrol_04202006.shp	More consistent resolution than default layer. Source: ME Office of GIS
Counties	County boundaries - for USLE data	Polygon	No	Counties.shp	Source: MapShed / NEIWPCCC
Septic Systems	Septic system numbers and types	Polygon	No	Census.shp	Source: MapShed / NEIWPCCC
Soils	Contains various soil-related data	Polygon	Yes	Soils.shp	Source: MapShed / NEIWPCCC
Physiographic Provinces	Contains hydrologic parameter data	Polygon	No	Physprov.shp	Source: MapShed / NEIWPCCC
Urban Areas	Map of urban areas boundaries	Polygon	No	UrbanAreas_ME_2010 .shp	Only used if one wants to re-distribute loads for urban watershed across MS4 boundaries. Source: US Census
Land Use/Cover	Map of land use/cover (16 classes)	Grid	Yes	Section > Landuse > sta	Source: MapShed / NEIWPCCC
DEM	Elevation grid	Grid	Yes	Section > DEM > sta	DEM with 30 meter resolution used. Some watersheds overlapped the section boundaries, so statewide DEM used in those cases. Source: MapShed / NEIWPCCC
Groundwater-N	Background estimate of N in mg/l	Grid	No	Section > GWN > sta	Source: MapShed / NEIWPCCC
Soil-P	Estimate of soil P in mg/kg of “Total P” (not “Test P”)	Grid	No	Section > SoilP > sta	Based on soil texture and land use layers. Source: MapShed / NEIWPCCC

Nutrient runoff concentrations and volumes in MapShed are based in large part on land uses, which are contained within a grid file. These land use categories are described below. FB Environmental focused field reconnaissance efforts on land uses identified as hay/pasture, cropland, and open land when estimating livestock (described in the GWLF-E section below), since this land use is subject to relatively frequent changes and may be miscategorized in the source data. While the land use grid was not edited, field observations were recorded, and observations are reflected in the livestock figures entered later in the model.

Water: *Water bodies such as lakes, ponds, large streams, etc. Grid cell value 1.*

Hay/Pasture: *Hay or pasture areas where low-lying grassy vegetation is predominant. Grid cell value 4.*

Cropland: *This category refers primarily to row crops. Cover crops may be included depending upon how closely surface erosion and nutrient runoff characteristics resemble row crops or hay/pasture. Use grid cell values of either 5 or 6 (both are treated the same in GWLF-E).*

Forest: *This category includes areas of coniferous, deciduous or mixed woodlands. Grid cell values of 7, 8 or 9 (all are treated the same in GWLF-E).*

Wetland: *This category includes both woody and emergent wetlands, and grid cell values of either 10 or 11 may be used (both are treated the same in GWLF-E).*

Disturbed: *Includes land such as coal mines, quarries, gravel pits, transitional land, etc. These types are treated as “non-vegetated, disturbed” land types in GWLF-E, and may be depicted with grid cell values 12, 13 or 15 (all of these are treated the same in GWLF-E).*126

Turf/Golf: *Any highly-managed, intensively-fertilized areas with turfgrass-type vegetation (e.g., golf courses and sod farms) may be included in this category. Grid cell value of 16 for this category.*

Open Land: *This category is intended to depict such land types similar to “open range” or “grassland”, such as found in the western part of the United States. These essentially “natural” areas are typically not cultivated or heavily pastured. Grid cell value of 21.*

Bare Rock: *Non-vegetated rocky areas such as found in mountainous areas. Grid cell value 22.*

Sandy Areas: *Use this category for land types such as beaches and deserts with little or no vegetation. Grid cell value 14.*

Low-Density Residential: *Areas with a mixture of constructed materials, with vegetation mostly in the form of lawn grasses, shrubs and/or trees. Impervious surfaces account for less than 30% of the total cover. These areas most commonly include large-lot, single-family housing units. Grid cell value 17.*

Medium-Density Residential: *Areas with a mixture of constructed materials, with vegetation mostly in the form of lawn grasses, shrubs and/or trees. Impervious surfaces account for 30-75% of the total cover. These areas commonly include low and medium density housing in suburban or smaller urban areas. Grid cell value 18.*

High-Density Residential: *Areas with a mixture of constructed materials, with vegetation mostly in the form of lawn grasses, shrubs and/or trees. Impervious surfaces account for greater than 75% of the total cover. These areas most commonly include small-lot housing or row houses. Some commercial uses,*

usually converted residences, may be present but represent less than 20% of the total area. Grid cell value 19.

Low-Density Mixed Urban: Areas with a mixture of constructed materials, with vegetation mostly in the form of lawn grasses, shrubs and/or trees. Impervious surfaces account for less than 30% of the total cover. These areas commonly include schools, hospitals, commercial areas and industrial parks with extensive, surrounding open land. Grid cell value 2.

Medium-Density Mixed Urban: Areas with a mixture of constructed materials, with vegetation mostly in the form of lawn grasses, shrubs and/or trees. Impervious surfaces account for 30-75% of the total cover. These areas are typically found in smaller cities and suburban locations. Grid cell value 20.

High-Density Mixed Urban: Areas with a mixture of constructed materials, with vegetation mostly in the form of lawn grasses, shrubs and/or trees. Impervious surfaces account for greater than 75% of the total cover. These areas are typically high-intensity commercial/industrial/institutional zones in large and small urban areas. They may include some dense residential development which should not exceed 20% of the total area. Grid cell value 3.

The GIS portion of the model was run by selecting all available weather years, selecting May through October as the growing season, and leaving the default return flow of 0.4 (fraction of irrigation water estimated to return to surface/subsurface flow). Each watershed was run individually (without sub-basins or flowlines). For each watershed, a source file was saved to facilitate re-running the model if and when necessary. Note that when running MapShed, it was found that clipping the higher resolution shapefiles and grids to the project area greatly reduced model processing time. When the GIS portion of the model was completed, a .gsm file was generated, which was used by the GWLF-E section below.

Input Parameters for the GWLF-E Portion of MapShed

The GWLF-E component of MapShed starts with the .gsm file generated above. This file consists of a large number of input parameters dealing with soil character, hydrology, weather patterns, nutrient transport, animal and human populations, and agricultural practices, which were calculated for each specific watershed based on the GIS data inputs described above. Virtually every parameter can be viewed and most can be directly overwritten through an extensive series of data entry forms. The soil, nutrient transport, and hydrology parameters are based on decades of research by Penn State, including model calibration specific to the northeast region under the NEIWPCC project. Therefore, these parameters were generally accepted. FB Environmental focused on those parameters for which accuracy could be best improved through desktop research and in-field observations. These adjusted parameters are the following.

Livestock Estimates

MapShed uses the number and type of livestock to estimate manure production within the watershed. Animals are converted to animal units with corresponding nutrient loading rates within the model. During the pollution source identification phase of this project, FB Environmental reviewed the land use shapefile as well as recent aerial photos available through Google Maps and other public sources to identify farm fields, pasture, and other open fields which could potentially be used for livestock. Given the high resolution of modern aerial photos, signs of livestock were often easy to find. In several cases, areas where livestock had direct access to streams were clearly identified.

Researchers then visited each watershed and counted livestock, or the clear evidence of livestock, to the extent possible. Many direct observations of animals at pasture were made, but in other cases, other indications were used to count livestock, such as new electric fencing, freshly trodden fields and paddocks, livestock paths, extensive hoof prints, and barns with well-tended feed and water troughs were all used to indicate the presence of livestock. Farm animal estimates were generally conservative. For example, a small paddock and barn was usually counted as one horse. Large farms were researched online after field visits for additional indication of livestock type and number. All livestock estimates are well-documented in each watershed specific appendix, as well as in the submitted source identification reports. Within MapShed, the animal units per type of livestock (correlated to much each animal weighs), as well as manure production per animal unit, were left at the default values.

MapShed uses an involved set of algorithms to simulate nutrient loading from livestock. It considers monthly time spent grazing, at pasture, direct access to stream, daily accumulation on the landscape, runoff to streams based on daily weather conditions, and certain livestock and agricultural practices such as plowing manure into the soil and manure management plans. The default values were accepted for each watershed, unless otherwise noted in the watershed appendix. There were a few watersheds in which livestock access to streams was clearly impairing water quality.

It is important to note that MapShed treats all manure produced in the watershed as remaining in the watershed in some form. The model does not directly include a mechanism for manure export out of or import into the watershed. For example, a watershed containing a large farm which produces and sells liquid manure from its livestock would probably experience lower nutrient loading in reality than what the model predicts, since much of the manure is shipped out of the drainage area. Conversely, large farms which import manure onto their fields from outside the watersheds could result in higher nutrient loading to streams than the model predicts. Whenever this import/export issue seemed likely, it was noted in the summary, although a detailed estimate of the effects on nutrient loading are probably best handled when doing individual watershed based plans.

Percent of Watershed Draining to Ponds or Wetlands

MapShed considers depositional environments such as ponds and wetland to attenuate watershed sediment loading. The degree of attenuation is entered into the model by a simple percentage of watershed draining to a pond or a wetland. Although MapShed uses GIS to calculate many variable (including slope), it is not capable of delineating flow networks. Therefore, it is necessary to enter this variable manually. FB Environmental estimated the percent of watershed draining to a pond or wetland based on visual inspection of the watershed in GIS. This estimate made a noticeable difference to the resulting sediment load estimates in many cases.

Stream Miles and Buffers Within Agricultural Land Uses

MapShed uses GIS data to calculate stream miles within agricultural land uses, and allows for manual entry of the stream miles within agricultural land uses with vegetative buffers. Vegetative buffers along streams in agricultural areas attenuate nutrient loading by about 40% for N and P, and 50% for sediment (those attenuation factors, like most, can be modified within MapShed). FB Environmental reviewed recent, detailed aerial photos from Google Maps and other publicly available sources to determine the agricultural stream miles with buffers, as well as total agricultural stream miles which were used to override the GIS calculation in the GWLF-E BMP data entry screen.

Existing Agricultural Best Management Practices

MapShed allows data on existing nutrient reduction BMPs to be entered into the model. There are twelve rural BMPs possible within MapShed, each with adjustable reduction coefficients for N, P, and Sediment. For this modeling effort, four commonly used BMPs were entered using literature values. More localized data on agricultural practices would improve this component of the model.

- *Cover Crops:* Cover crops are the use annual or perennial crops to protect soil from erosion during time periods between harvesting and planting of the primary crop. The percent of agricultural acres cover crops are used within the watersheds in this TMDL is estimated at 4%. This figure is based on information from the 2007 USDA Census stating that 4.1% of cropland acres is left idle or used for cover crops or soil improvement activity, and not pastured or grazed (USDA, 2007).
- *Conservation Tillage:* Conservation tillage is any kind of system that leaves at least 30% of the soil surface covered with crop residue after planting. This reduces soil erosion and runoff and is one of the most commonly used BMPs. This BMP was assumed to occur in 42% of agricultural land. This figure is based on a number given by the Conservation Tillage Information Center's 2008 Crop Residue Management Survey stating that 41.5% of U.S. acres are currently in conservation tillage (CTIC, 2000).
- *Strip Cropping / Contour Farming:* This BMP involves tilling, planting and harvesting perpendicular to the gradient of a hill or slope using high levels of plant residue to reduce soil erosion from runoff. This BMP was assumed to occur in 38% of agricultural lands, based on a study done at the University of Maryland (Lichtenberg, 1996).
- *Grazing Land Management:* This BMP consists of ensuring adequate vegetation cover on grazed lands to prevent soil erosion from overgrazing or other forms of over-use. This usually employs a rotational grazing system where hays or legumes are planted for feed and livestock is rotated through several fenced pastures. In this TMDL, a figure of 75% of hay and pasture land is assumed to utilize grazing land management. This figure is based on a study by Farm Environmental Management Systems of farming operations in Canada (Rothwell, 2005).

The remaining possible BMPs within MapShed include crop residue management, stream fencing, vegetated buffer strips (within farm fields, not along streams), animal waste management systems (AWMS), phytase in poultry feed, confined feeding area runoff controls, and agricultural land retirement. These BMPs were not assumed to occur within the watershed. Improved data on agricultural and livestock practices could be rapidly incorporated into the model as they become available.

Adjusting Slope Length (LS)

When reviewing the model results, an apparent error with the slope length (LS) calculation for certain watersheds was discovered. LS is calculated from elevations, watershed area, and stream length, and typically ranges from 0.1 to 1.5. Slope length is part of the Universal Soil Loss Equation. LS was zero for five watersheds (Carlton, Coloney, Mosher, Penley, and Thayer Brooks), and very close to zero for three additional watersheds (Adams, Chamberlain, and Hobbs Brooks). These zero and near-zero results were viewed as likely errors, and a second method of calculating LS was found.

An alternative digital elevation model (DEM) layer was substituted in MapShed for these watersheds. This DEM was a clip of the AVGWLF DEM30 developed for use with the NEIWPC project a few years ago. Two clips were made (northern and southern Maine watersheds) in order to reduce computer processing time and to deal with watersheds which overlapped the Section 8 and Section 9 boundary in the new MapShed dataset. It therefore matched the 30 meter pixel size and used the recommended “flow accumulation” method for that resolution. Based on visual inspection, the alternate DEM appeared to be virtually identical to the default DEM, however, the resulting LS figures were quite different and within the expected range. These LS figures were typed into the Transport Data Editor in GWLF-E, changes were saved in a new .gsm file, and GWLF-E was re-run. This revision partially resolves concerns about sediment estimates, although it remains the most variable of the three pollutants within the model. FB Environmental will communicate these findings to Penn State for model improvement.

Other Input Parameters

There is a vast number of soil, hydrological, and pollutant transport parameters which operate within the MapShed model. A brief overview of most of these is provided below. Within the “Transport Data” group, the figure for “Sediment A Adjustment,” which relates to the lateral erosion rate, was manually changed from 1.0 to 0.1 to match the New England-specific value determined when MapShed was run for NEIWPC (Penn State, 2007). All of the remaining parameters were left at the default values.

- Transport Data
 - Percentage of impervious areas are associated with each land use.
 - Curve numbers (CNI and CNP and CN) are empirically-derived values that reflect that relative amounts of surface runoff and infiltration occurring at a given location based on combination of soil and land cover and the user-defined impervious cover estimate.
 - The soil erodibility (K) factor is a measure of inherent soil erosion potential as a function of soil texture and composition and is pre-determined for every soil type.
 - Slope-length (LS) factor is a function of overland runoff and slope and uses a NRCS equation for estimating the relationship between slope length and slope gradient for a given area derived from the DEM and stream layers. The LS numbers were run a second time for certain watersheds, see section “Adjusting Slope Length” above
 - Cropping Management (C) factor represents the effect of ground cover conditions, soil conditions, and general management practices on soil erosion. Erosion Control Practice (P) factors depict the effectiveness of various structural and non-structural control practices such as terracing and crop residue management in reducing soil erosion on cultivated land. Both are derived from the *county.shp* layer based on mean values for field crops and slope characteristics. This is a representative value that may differ from actual C and P values based on local agricultural practices such as use of BMPs and crop rotations. If more accurate information on cropping practices is known during the model time period, the user can edit this information to better reflect local conditions.
 - ET Cover Coefficients are based on land use and area-weighted potential evapotranspiration (PET) values computed by the model as a function of the number of daylight hours per day, the saturated water vapor pressure, and the mean daily temperature on a given day.
 - Daylight hours are calculated using the latitude of the centroid of a given watershed and the growing season is specified directly by the user.

- Rainfall Erosivity Coefficients estimate the rainfall intensity factor and vary with season and geographic location.
- The Groundwater Seepage Coefficient (related to the fraction of infiltrated water lost to an underlying aquifer or deep saturated zone) is set to zero, because it is assumed that the water table does not fluctuate appreciably from year to year.
- Groundwater Recession Coefficient values can be estimated from historical stream flow records using standard hydrograph separation techniques. A value of 0.06 is common in the northeast (Haith *et al.*, 1992), and typically range nationwide from 0.01 to 0.2.
- Unsaturated Available Water-Holding Capacity is calculated using the soils data layer.
- Sediment Delivery Ratio is based on the premise that a certain percentage of material eroded from the land surface is deposited prior to reaching nearby waterbodies and is related to the amount that reaches the outlet of a given watershed (sediment yield).
- Lateral erosion rate (Sediment A Factor and Sed A Adjustment) estimates streambank erosion based on animal density, curve number, soil erodibility, mean watershed slope, and percent of developed land in the watershed.
- Stream and Ground Extract factors are based on the Water Extraction layer for surface and groundwater withdrawals. If no water extraction layer is provided, inputs can be entered manually if known sources of irrigation or snowmaking activities may be affecting the water budget.
- Percent of Tile Drained area is specified by the user for input to a tile drain flow equation that assumes 50% of the surface and subsurface flow each month are redistributed to tile drain flow in areas identified as being served by such systems. This volume is multiplied by the event mean concentrations provided by literature for N, P, and sediment to calculate loads for each in kg/month.
- Nutrient Data
 - Rural runoff nutrient concentrations are associated with overland runoff, point sources, and subsurface discharges to the stream. Nutrient loads from non-urban areas are transported in runoff water and eroded soil from sources areas. Default dissolved N and P concentrations are based on literature sources.
 - Urban runoff nutrient accumulation rates use the concept of nutrient build-up and wash-off to estimate nutrient loads from urban areas. It is assumed that nutrients accumulate on urban surfaces over time from various inputs (atmospheric deposition, animal litter, street refuse, etc.) and are washed off by periodic rainfall events. Default values for different urban categories are derived primarily from the literature.
 - Point Source Discharges is provided by the user or taken directly from the Point Source layer that contains information on estimated monthly N and P loads from major industrial and municipal wastewater treatment plants. It is possible for the user to specify variable effluent flows and nutrient concentrations on a monthly basis for any point source discharge using the Point Source Editor Tool.
 - N and P in groundwater are automatically calculated using a regression equation and area-weighted values of N and P concentrations in groundwater based on land use and rock type.
 - The default value of 2000 mg/kg is estimated for N in sediment. The user can specify more accurate local information. The P in sediment is estimated using a soil P grid for soil test P or total P and the area-weighted value of P concentration.

- Septic system loads are based on the number of persons served by septic systems in the watershed derived from the census tract layer. Once the nitrogen loads from septic systems for a given watershed have been determined, this total load is reduced by a factor (about 61%) to account for losses in subsurface and in-stream flow due to denitrification. Per capita values for nutrient loads in septic tank effluent and values for nutrient uptake by plants are based on suggested literature values.
- Tile drain nutrient concentrations are derived using estimated tile drain water volumes and typical in-drain concentrations drawn from the literature. These are default concentrations for N, P, and sediment.
- Animal Data
 - No confined animal feeding areas (AFO) were entered.
 - The loss rate values for manure from pasture, feedlot, and field spreading for N, P, and sediment.
 - For grazing animals, the percent of time spent grazing and percent of time spent in stream are based on literature values.
 - All values related to pathogen loadings were left unchanged.

Determining the TMDL

MapShed was run according to the detailed instruction manual provided by Penn State (Evans & Corradini 2012), using the input parameters stated above. Nutrient loading estimates in terms of mass per unit watershed area per year for total phosphorus (TP), total nitrogen (TN), and sediment were calculated for impaired streams.

The TMDL was generated by determining loading values in attainment stream watersheds. A set of attainment streams for possible use in developing the TMDL was provided to FB Environmental by Maine DEP. Both impaired and attainment watersheds had similar overall characteristics with the same range of land uses. Specifically, both groups had a meaningfully high level of agriculture, and little to no urbanized areas. From this larger list of attainment streams, a set of five representative attainment watersheds were selected from across the state based on similar watershed size and land use as the impaired streams, along with the quantity and quality of assessment data. Figure 2 indicates the locations of each attainment stream watershed used in this TMDL. A statewide TMDL was set as the average loading value of these five streams (Table 2). The difference between pollutant loading in impaired and attainment watersheds represented the percent reduction needed in each impaired watershed.

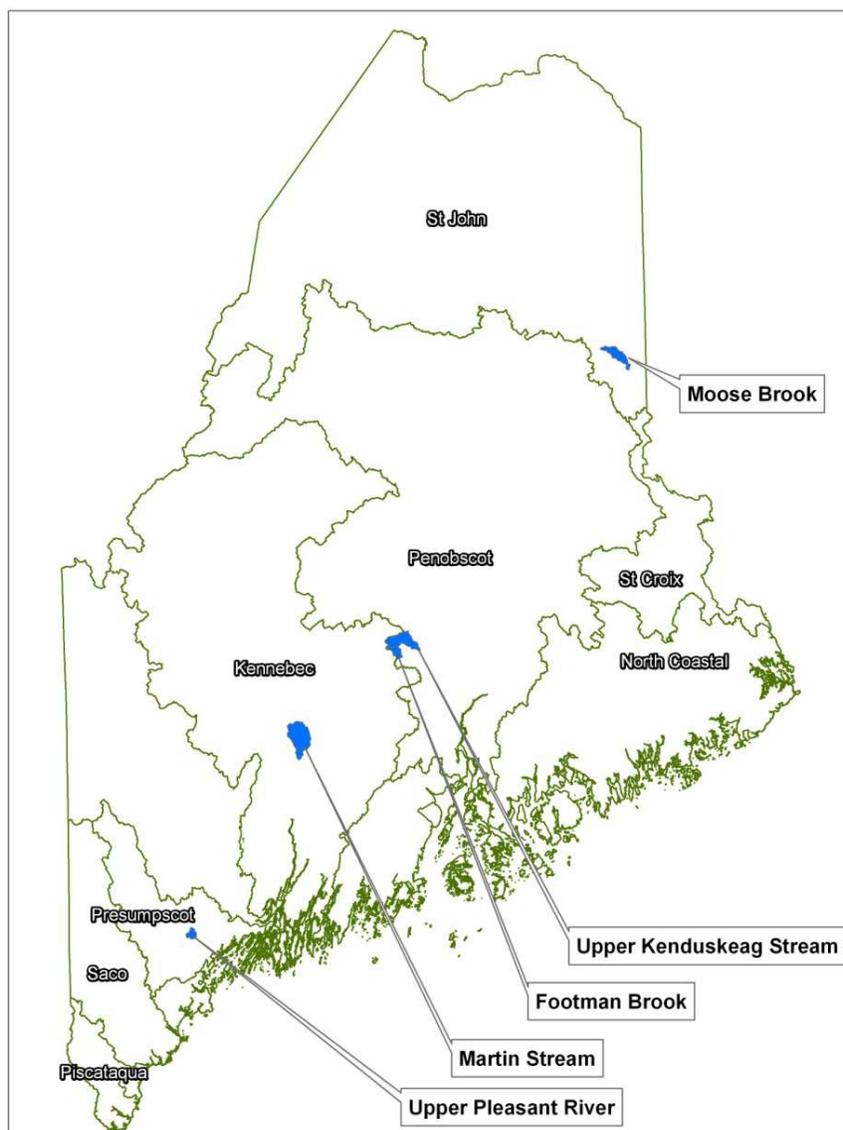


Figure 2: Attainment streams used in this TMDL.

Table 2: Attainment Streams and the TMDL Figures

Attainment Streams	Town	TP load (kg/ha/yr)	TN load (kg/ha/yr)	Sediment load (1000 kg/ha/yr)
Martin Stream	Fairfield	0.14	3.4	0.008
Footman Brook	Exeter	0.33	6.4	0.058
Upper Kenduskeag Stream	Corinth	0.29	5.6	0.047
Upper Pleasant River	Gray	0.22	4.6	0.016
Moose Brook	Houlton	0.25	5.9	0.022
Total Maximum Daily Load:		0.24	5.2	0.030

FOOTMAN BROOK DESCRIPTION

Footman Brook is located in the Penobscot Rivershed in the towns of Corinna and Exeter, Maine, with small portions of the watershed within the surrounding towns of Garland and Dexter. Covering an area of approximately 6.7 square miles, the watershed is predominantly forested (77%). Agricultural areas (15%) are located throughout the watershed and are concentrated along major roadways. The watershed is 3.6% developed, with development observed as low density rural-residential such as farm houses. Wetlands account for about 4% of the watershed and a little over 1% of the watershed consists of impervious cover.

Footman Brook is a statutory Class B stream that attained Class A numeric aquatic life criteria for benthic macroinvertebrates in 2001 at Station 309. Dissolved oxygen during the 2001 sampling event was above the Class B criterion of 7 ppm (1 data point).

Footman Brook originates in a wetland area in Corinna and flows southeast through Corinna and Exeter. Sampling was conducted at Station 309, where Footman Brook crosses Exeter Road. The immediate surrounding landscape is forested, but there are corn fields just to the north of the sampling location.

Agricultural activities in the watershed are dominated by large hayfields, some of which appeared to be unmanaged. Row crops (primarily corn) are found in the southern portion of the watershed along Cider Hill Road and Exeter Road, and in the northeast section of the watershed at the intersection of Pullen and Otis Roads. Large hay fields were noted along Atkins Road and Airport Road. The only livestock observed were a few cows and a bull located on Atkins Road. Figure 3 (below) displays land use in the Footman Brook watershed.

No portions of Footman Brook flow through or within 75 feet of agricultural areas. The entire length of Footman Brook is very well buffered, excluding the two road crossings on Cider Hill Road and Exeter Road which were also observed as well vegetated.



Footman Brook at Station 309

Photo: FB Environmental

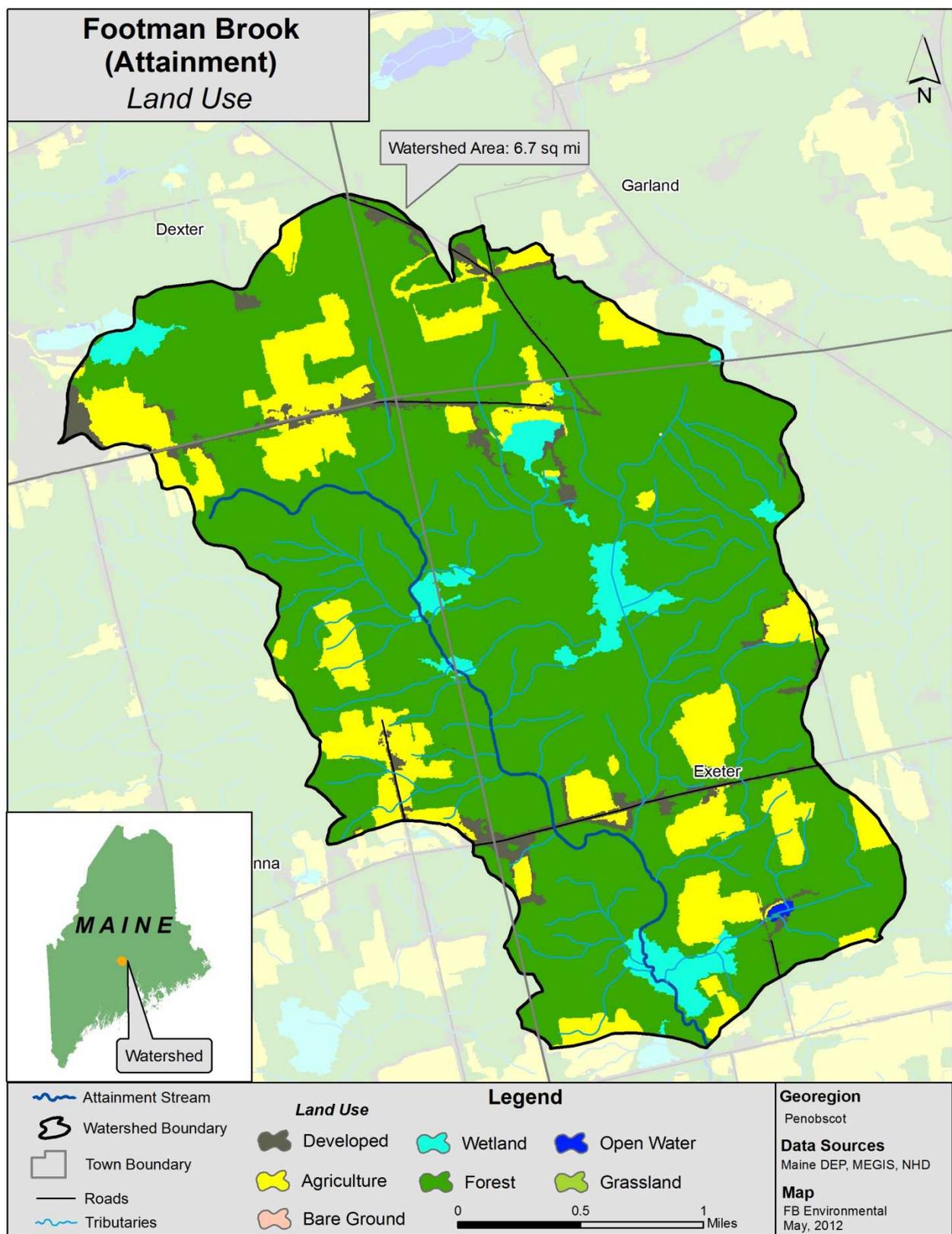


Figure 3: Land Use in the Footman Brook Watershed

MARTIN STREAM DESCRIPTION

Martin Stream is located in the Kennebec Rivershed in the towns of Fairfield, Norridgewock and Oakland. The majority of the watershed is located within the town of Fairfield but small portions of the watershed are located within the surrounding towns of Skowhegan, Norridgewock, Smithfield and Oakland. The watershed covers approximately 42 square miles and is composed primarily of forest (82%) and wetland (9%) with some areas of development (3%) and agriculture (6%).

Martin Stream is a statutory Class B stream that attained Class B numeric aquatic life criteria for benthic macroinvertebrates in 2012 at Station 609, and narrative aquatic life standards for algae in 2002 and 2012. Dissolved oxygen measured twice in 2012 at Station 609 was once slightly below the Class B criterion of 7 ppm (at 6.7 ppm) and once above the criterion. No major hotspots were found during the NPS survey.

Martin Stream begins just south of Hussey Hill Road in Oakland, ME, continues north through forested land, crosses the Oakland-Fairfield border, turns northwest to follow parallel to and cross Martin Stream Road in Fairfield, flows east at the confluence with Alder Brook, crosses Norridgewock Road (Route 139) in Fairfield, flows southeast, and ends near the sampling site (Station 609) at the Middle Road (Route 104) crossing in Fairfield. Multiple tributaries flow into Martin Stream, particularly Alder Brook and Tobey Brook in Norridgewock, and Lost Brook in Fairfield.

Low-density residential development is found along Martin Stream Road and Norridgewock Road. Some agricultural areas, mainly hayfields and some livestock, were observed on the northern end of Martin Stream Road and along Covell Road in Norridgewock and Fairfield, respectively. Figure 5 (below) displays land use in the Martin Stream watershed.

As shown in Figure 6, 1.2 miles of Martin Stream and tributaries flow through or within 75 feet of agricultural areas, and 1.1 miles, or 92%, of these areas have vegetative buffers.



*Martin Stream near Station 609
and the Middle Road (Route 104) Crossing
Photo: FB Environmental*

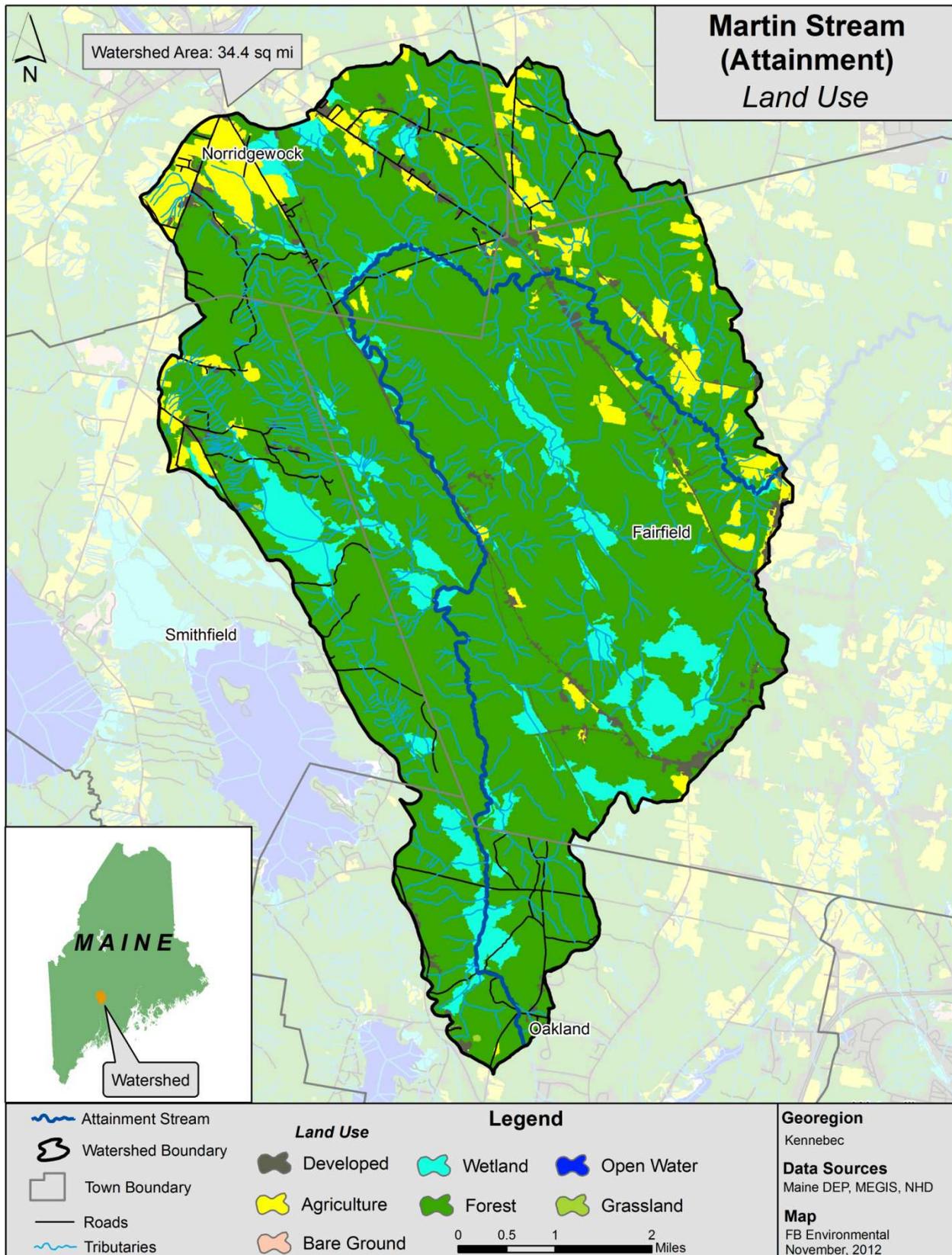


Figure 5: Land Use in the Martin Stream Watershed. Note that the watershed size is incorrectly indicated as 34.4 square miles. Martin Stream Description, above, and Figure 6, below, provide the correct size of 41.5 square miles.

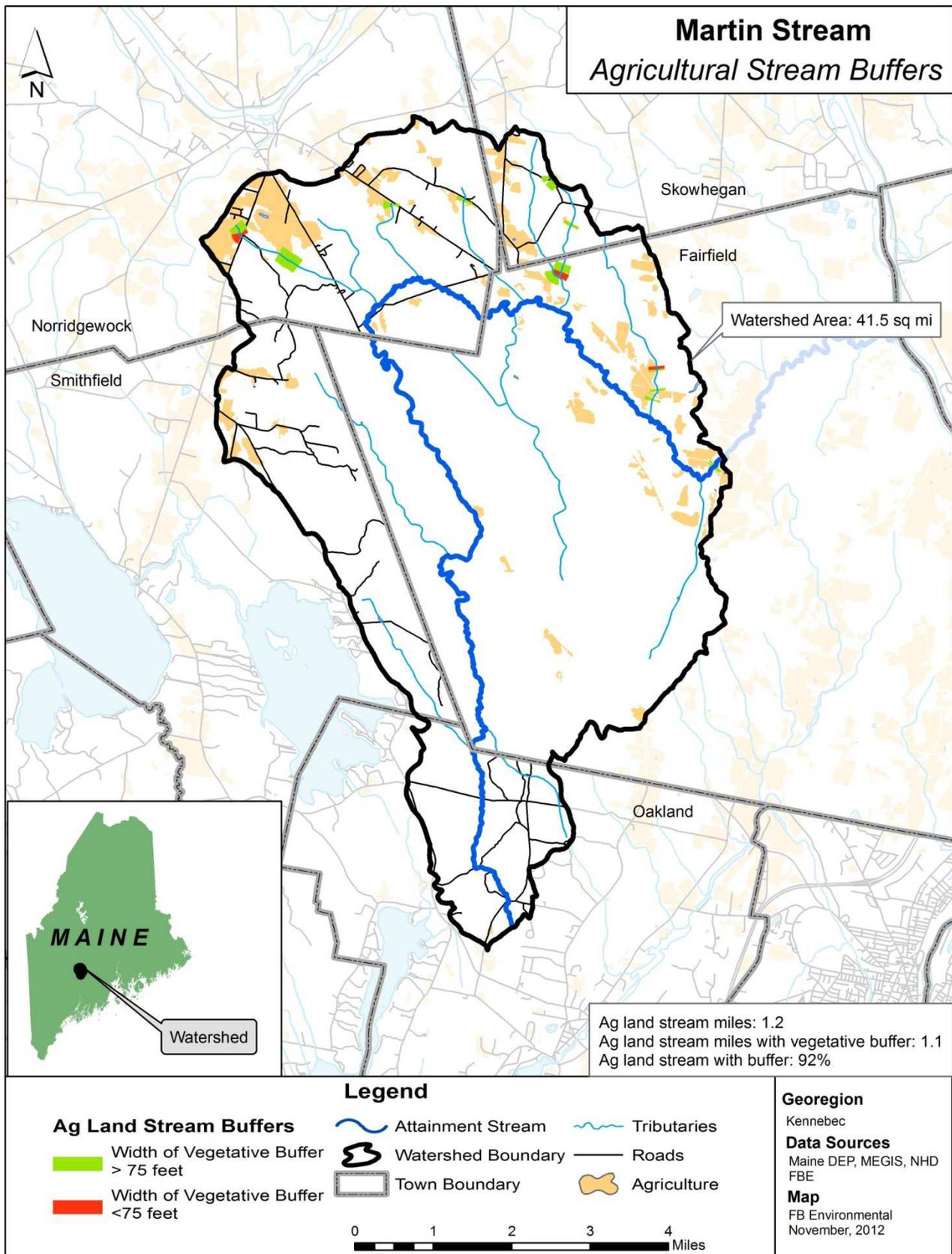


Figure 6: Agricultural Stream Buffers in the Martin Stream Watershed

MOOSE BROOK DESCRIPTION

Moose Brook located in the St. John Rivershed in the towns of Hammond, Ludlow, Houlton and New Limerick, Maine. The majority of the watershed is located within the town of Ludlow but small portions of the watershed are located within the surrounding towns of Hammond, Houlton and New Limerick. The watershed covers an area of 17.2 square miles and is mainly forested (63%) with large agricultural areas (18%) concentrated in the downstream or south-eastern portion of the watershed. The upstream forested areas and wetland complexes (16%) likely help maintain a healthy stream as it moves through more agriculturally developed areas. The stream is mostly well buffered by natural vegetation. The Moose Brook watershed has minimal development (3%).

Moose Brook is a statutory Class B stream that attained Class B numeric aquatic life criteria for benthic macroinvertebrates in 1999 and 2000 at Stations 466 and 467. It also attained narrative aquatic life standards for algae in 1999 at Stations 466 and 467, and in 2004 at Station 467. Dissolved oxygen measured on three occasions in 2004 and 2005 at Stations 466 and 467 was above the Class B criterion of 7 ppm.

Large areas of crop land in the lower watershed contain potential for erosion and runoff, but may be well buffered by the large amount of forested land within the watershed. Only 10 cows were observed in the watershed during the NPS survey. Figure 7 (below) shows land use in the Moose Brook watershed.

As shown in Figure 8, 1.2 miles of Moose Brook and tributaries flow through or within 75 feet of agricultural areas, and 0.9 miles, or 75%, of these portions have vegetative buffers.



*Moose Brook at the
Route 2 crossing.*

Photo: FB Environmental

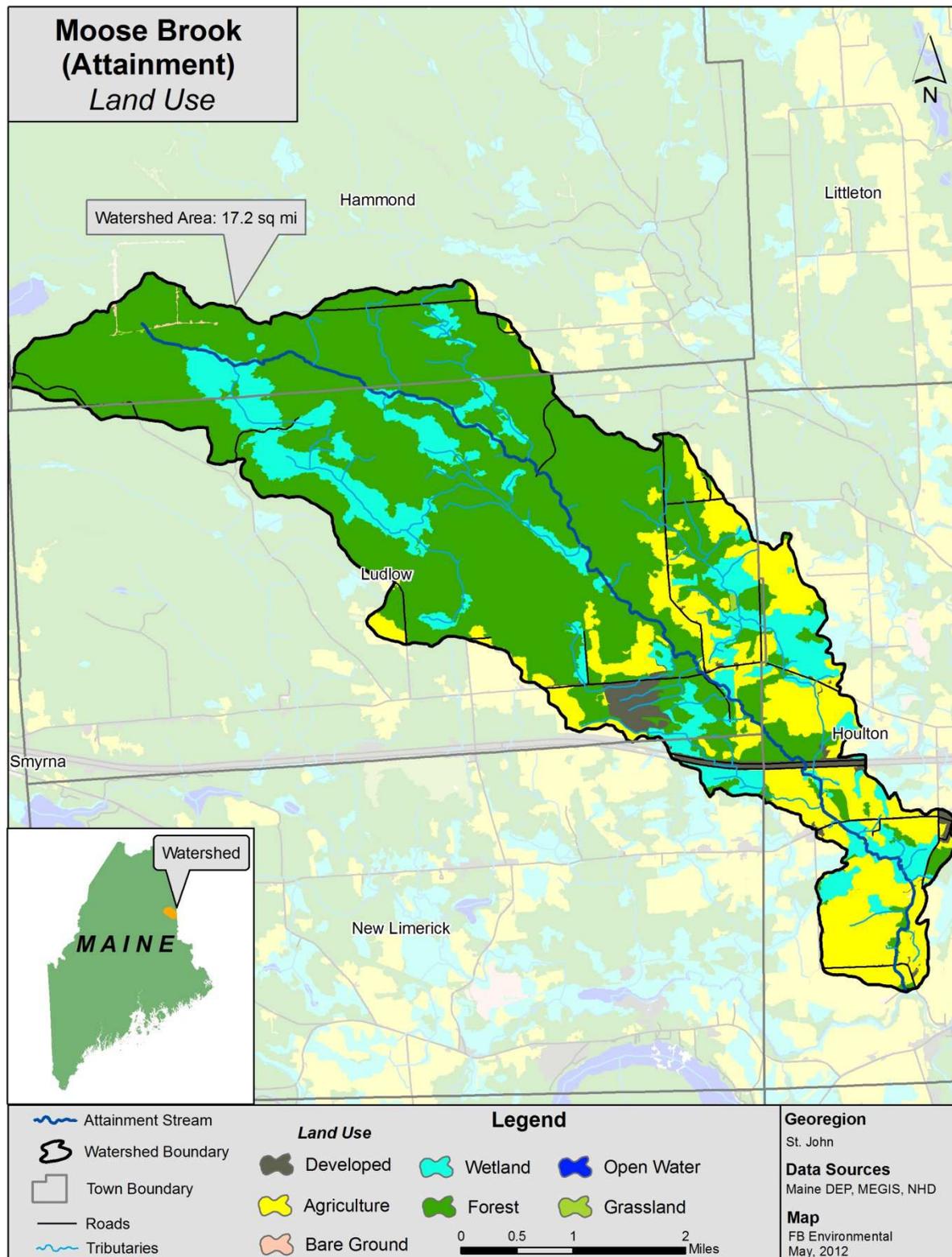


Figure 7: Land Use in the Moose Brook Watershed

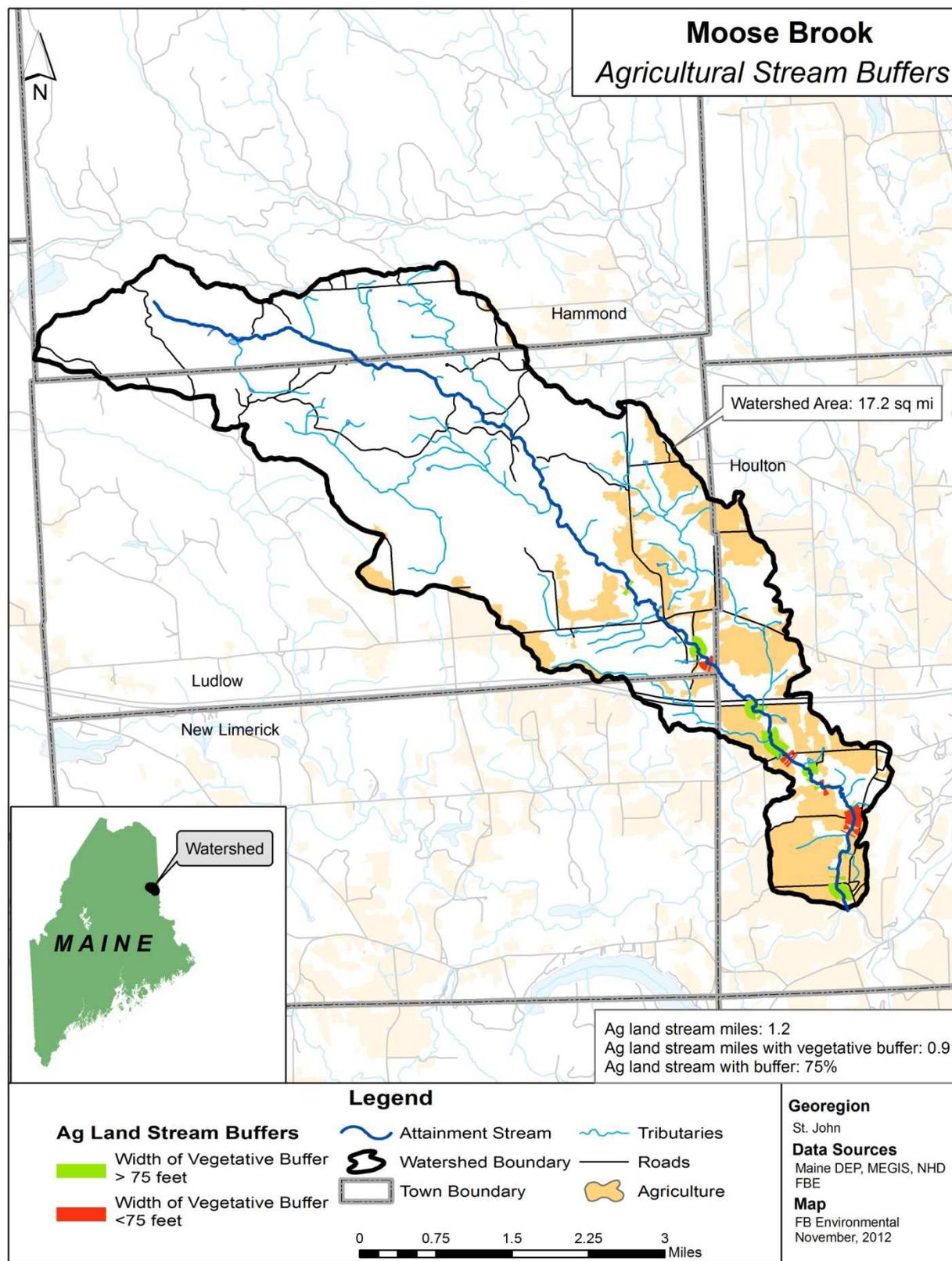


Figure 8: Agricultural Stream Buffers in the Moose Brook Watershed

UPPER KENDUSKEAG STREAM DESCRIPTION

The Upper Kenduskeag Stream is located the Penobscot Rivershed in the towns of Dexter, Garland, Exeter, and Corinth, with the majority of the watershed located within Garland; a small portion of the watershed is also located within the town of Charleston. The watershed covers approximately 26 square miles, and is predominantly forested (74%), with large agricultural fields (13%) scattered throughout and rural residential development along roadways. The Upper Kenduskeag Stream watershed is lightly developed (6%) and has some wetlands (6.5%) concentrated primarily in the downstream eastern portion of the watershed. See Figure 9 (below) for land use in the Upper Kenduskeag watershed.



Upper Kenduskeag Stream at Station 508

Photo: FB Environmental

The Upper Kenduskeag Stream originates in a wetland area in Dexter and flows east and southeast crossing multiple roads to its endpoint at the Exeter Road crossing in Corinth (DEP Station 508). A total of 60 cows, 9 horses and 4 goats were observed within the watershed.

Upper Kenduskeag Stream is a statutory Class B stream that attained Class A numeric aquatic life criteria for benthic macroinvertebrates in 2001 and in 2011 at Station 508 in Corinth. The stream did not meet narrative aquatic life standards for algae in 2001 but attained Class A standards in 2011 at Station 508. Dissolved oxygen measured on six occasions in 2001, 2005 and 2011 at Station 508 was above the Class B criterion of 7 ppm.

As shown in Figure 10, 2.3 miles of Upper Kenduskeag Stream and tributaries flow through or within 75 feet of agricultural areas, and 0.8 miles, or 35%, of these portions have vegetative buffers.

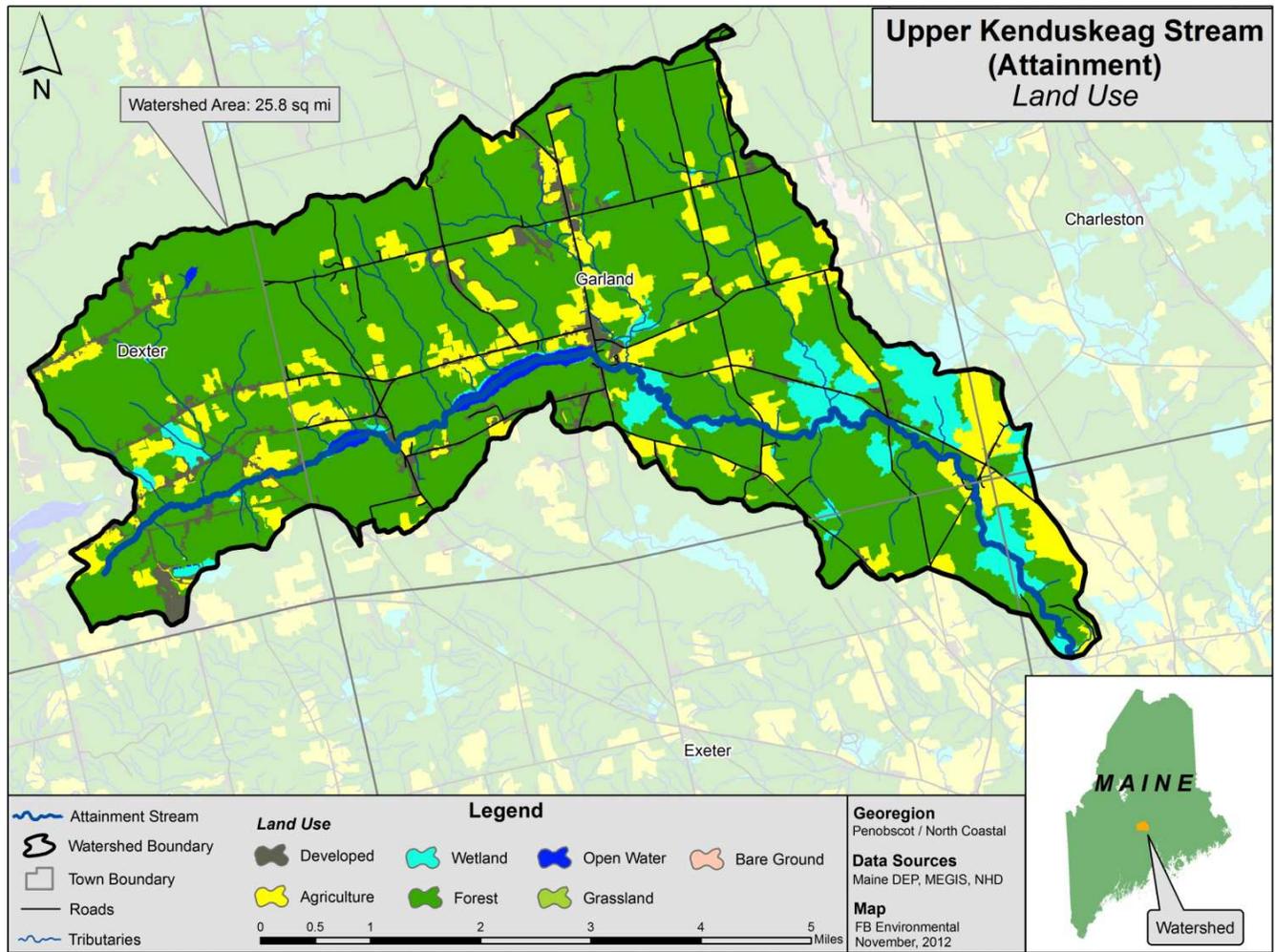


Figure 9: Land Use in the Upper Kenduskeag Stream Watershed

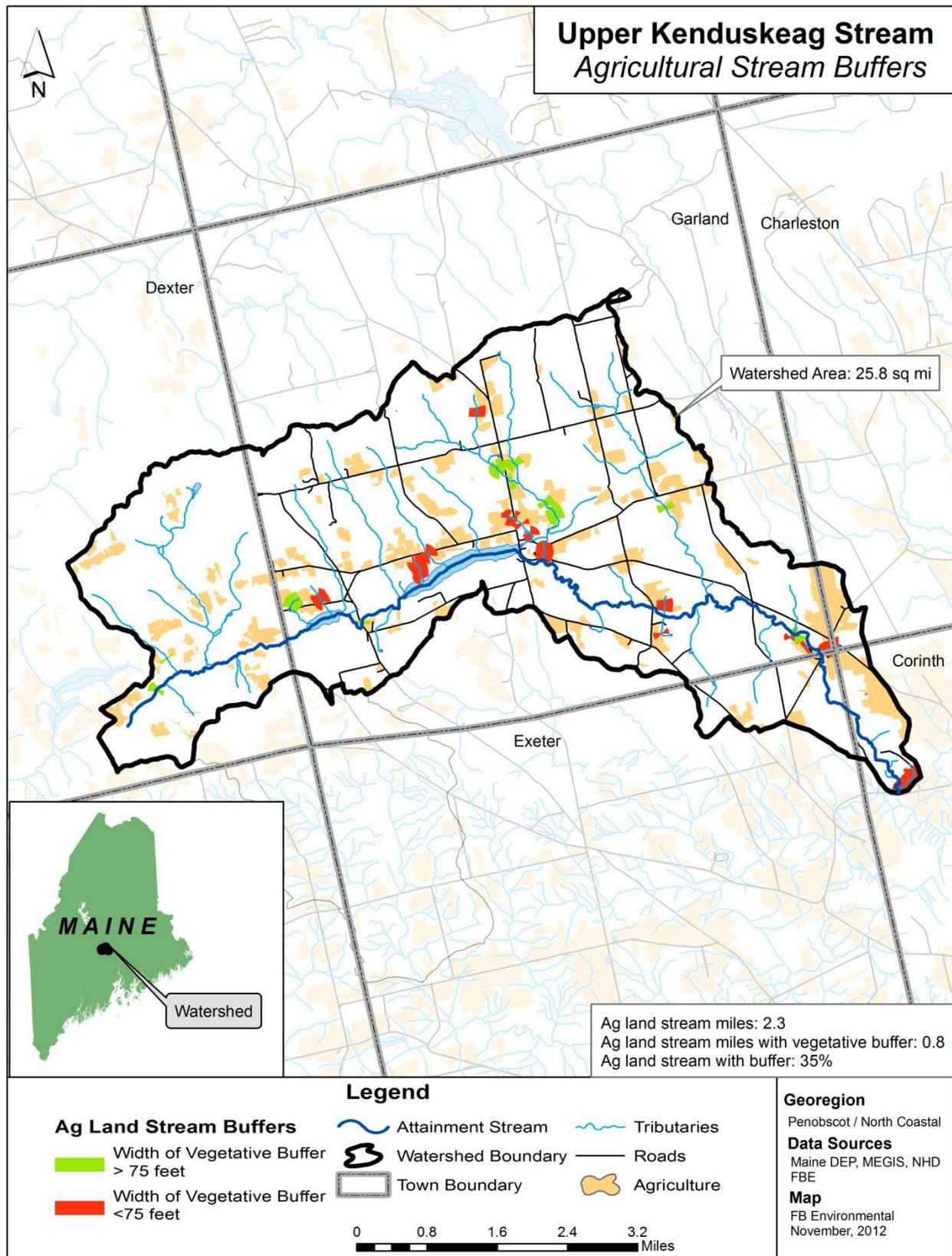


Figure 10: Agricultural Stream Buffers in the Upper Kenduskeag Stream Watershed

UPPER PLEASANT RIVER DESCRIPTION

The Upper Pleasant River is located in the south coastal region and covers 5.8 square miles in the town of Gray, Maine. The watershed is predominantly forested (71.3%), but has some agricultural areas (6.4%) and developed land (11.9%). See Figure 11 (below) for land use in the Upper Pleasant River watershed.

The river originates in a forested area in the northern portion of the watershed. It then flows southwest through a wetland and across two major roadways (Interstate 95 and Portland Road) that run north-south bisecting the watershed. The Upper Pleasant River then continues east into a low density residential area, intersects three roadways (Hunt's Hill Road, Barker Avenue, and Totten Road) before its confluence with the Pleasant River.

Upper Pleasant River is a statutory Class B stream that attained Class B numeric aquatic life criteria for benthic macroinvertebrates in 1999, 2005 and 2010 at Station 394. It also attained narrative aquatic life standards for algae at Station 394 in 1999, 2000, 2005, and 2010. Dissolved oxygen measured on seven occasions in 2005 and 2010 at Station 394 was below the Class B criterion of 7 ppm (at 6.5 ppm) on two occasions but above the criterion on five occasions. Maine DEP staff attributed the low values to the effects of the large wetland at Gray Meadows rather than nonpoint source pollution (Evers, personal communication).

As shown in Figure 12, 0.2 miles of Upper Pleasant River and tributaries flow through or within 75 feet of agricultural areas, and 0.09 miles, or 45%, of these portions have vegetative buffers.



*Upper Pleasant River at Station 394
on Totten Road in Gray.
Photo: FB Environmental*

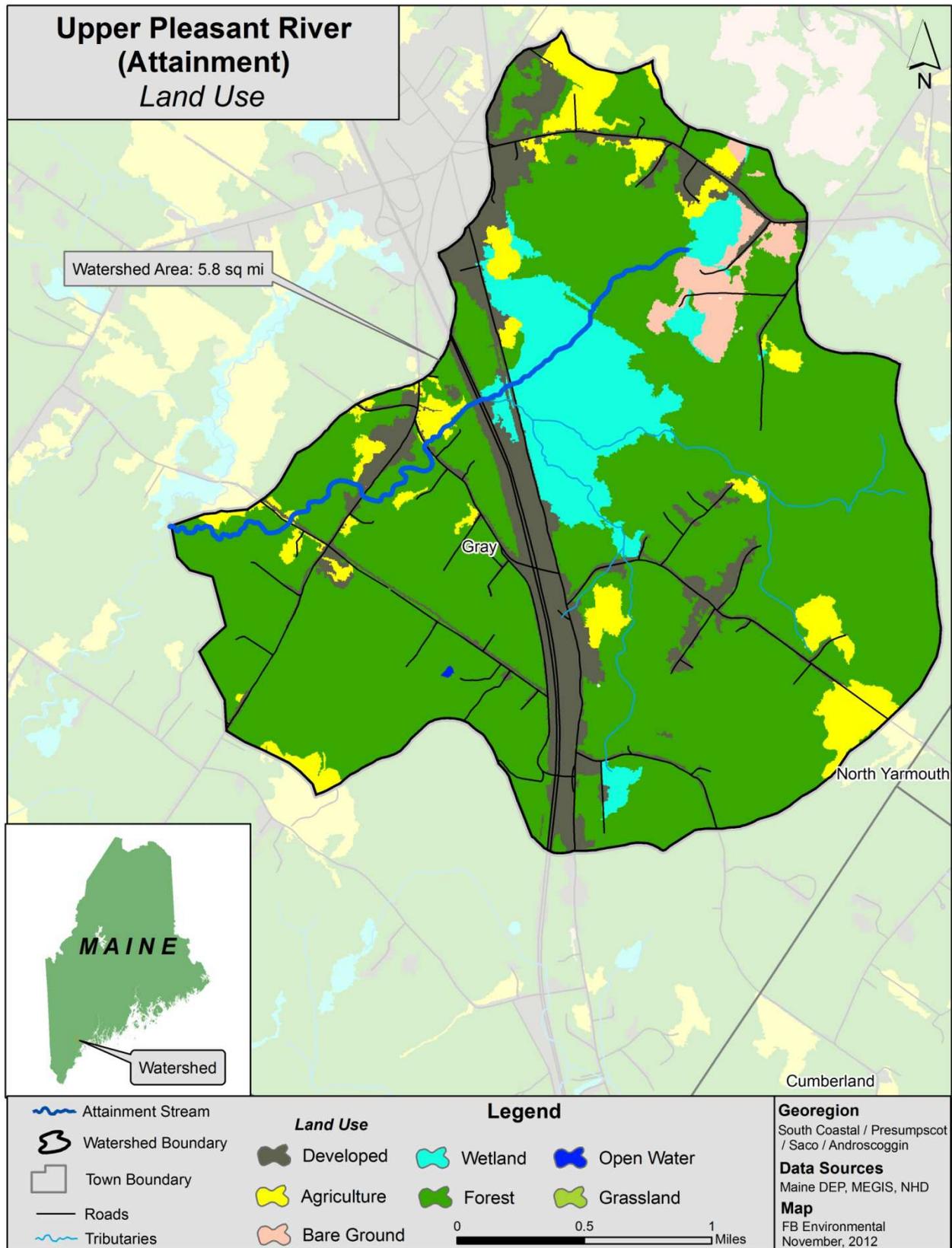


Figure 11: Land Use in the Upper Pleasant River Watershed

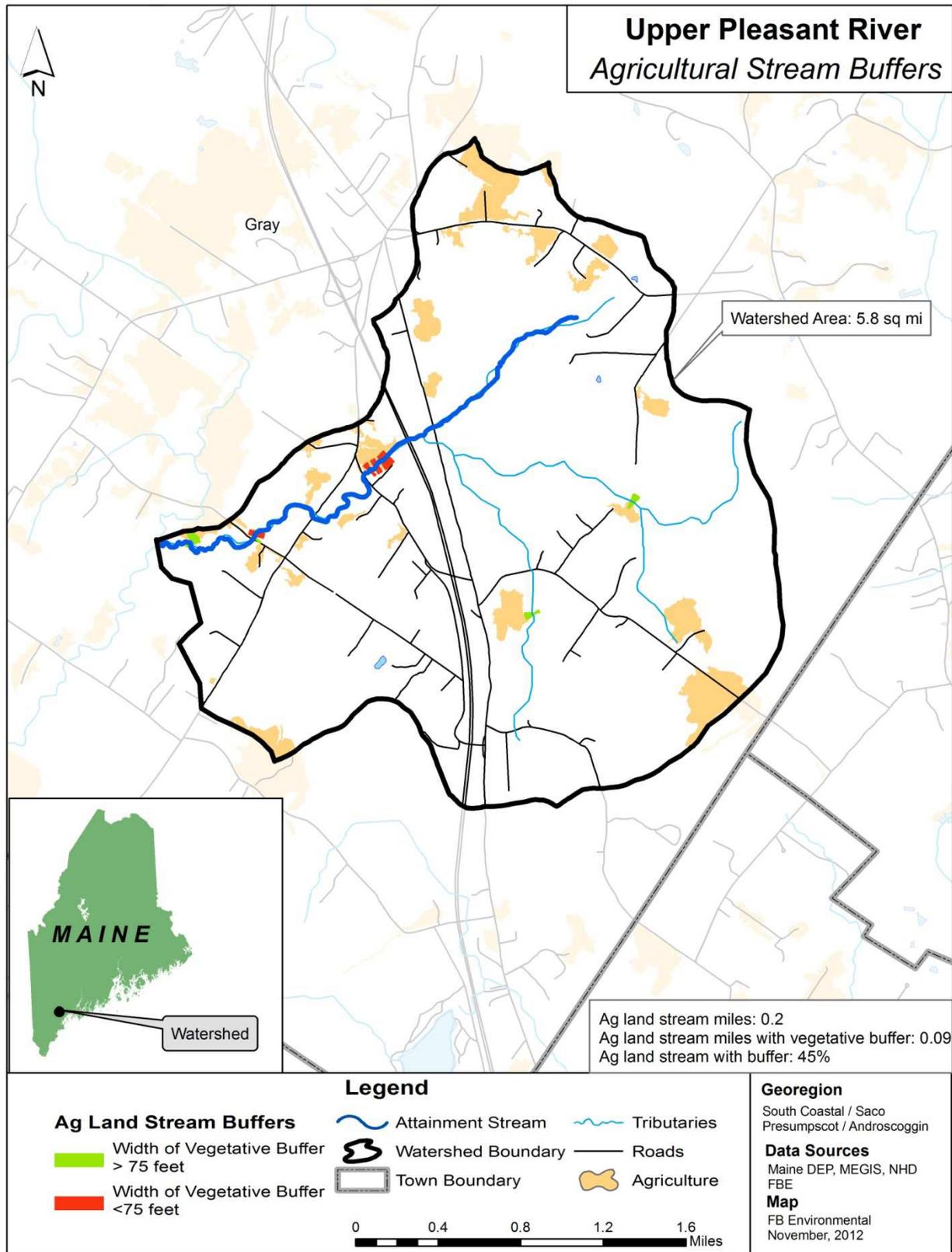


Figure 12: Agricultural Stream Buffers in the Upper Pleasant River Watershed

RAPID HABITAT ASSESSMENT

A Habitat Assessment survey was conducted on both the impaired and attainment streams. The assessment approach is based on the *Rapid Bioassessment Protocols for Use in Wadeable Streams and Rivers* (Barbour et al., 1999), which integrates various parameters relating to the structure of physical habitat. The habitat assessments include a general description of the site, physical characterization and visual assessment of in-stream and riparian habitat quality.

Based on Rapid Bioassessment protocols for low or high gradient streams, each attainment reach was given a score from 0 to 200. Higher scores indicate better quality of habitat. The range of habitat assessment scores for attainment streams was 155 to 179.

Habitat assessments were conducted on a relatively short sample reach (about 100-200 meters for a typical small stream) that was located near the most downstream Maine DEP sample station in the watershed. For both impaired and attainment streams, the assessment location was usually near a road crossing for ease of access. Further assessment of this parameter, including effects of proximity to road crossings and regional variation, is recommended. Figure 13 (right) shows habitat assessment scores for all attainment and impaired streams.

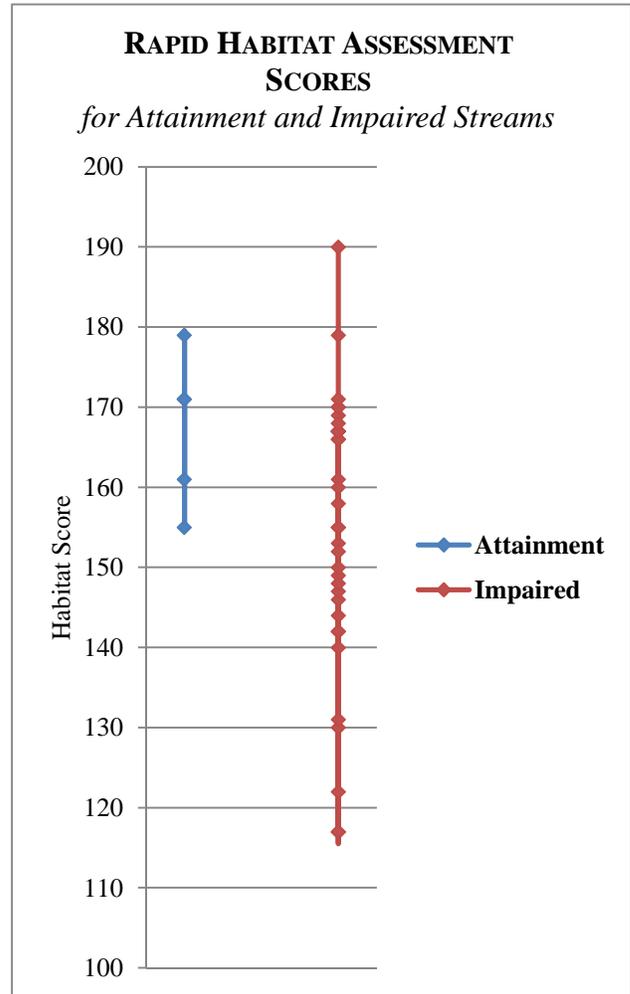


Figure 13: Habitat Assessment Scores

Livestock Estimates

MapShed automatically converts animal numbers into animal units (equal to 1000 kg of livestock), which have associated animal-specific nutrient production rates by livestock type. Manure and nutrient generation by livestock is added to nutrient runoff figures specific to each land use type. Manure is routed through three primary transport mechanisms: (1) Runoff from confined spaces, such as barnyards, (2) runoff from crop and pasture lands where animal waste has been applied, and (3) runoff from pasture from grazing animals. Pollutant loading due to livestock is provided in the MapShed results. Table 3 (below) provides estimates of livestock (numbers of animals) in the attainment stream watersheds.

The attainment streams, in general, show lower livestock numbers than in the majority of the impaired stream watersheds. Per square miles of watershed area, the figures remain very low and average just under 2 animals per square mile. In impaired watersheds, livestock numbers ranged from zero to 44 per square mile, with an average of 7.0 per square mile.

Table 3: Livestock Estimates in Attainment Stream Watersheds

Type	Footman Brook	Martin Stream	Moose Brook	Upper Kenduskeag Stream	Upper Pleasant River	Total
Dairy Cows			10	50	15	75
Beef Cows	5			10		15
Broilers						
Layers						
Hogs/Swine						
Sheep						
Horses				9		9
Turkeys						
Other				4		4
Total	5	0	10	73	15	103
Average						
Animals/sq. mi.	1	0	1	3	3	1.6

Vegetated Stream Buffer in Agricultural Areas

Vegetated stream buffers are areas of trees, shrubs, and/or grasses adjacent to streams, lakes, ponds or wetlands which provide nutrient loading attenuation (Evans & Corradini, 2012). MapShed considers natural vegetated stream buffers within agricultural areas as providing nutrient load attenuation. The width of buffer strips is not defined within the MapShed manual, and was considered to be 75 feet for this analysis. Geographic Information System (GIS) analysis of recent aerial photos along with field reconnaissance observations were used to estimate the number of agricultural stream miles with and without vegetative buffers, and these estimates were directly entered into the model.

As discussed in the attainment stream watershed descriptions above, very few portions of the attainment streams flow through or within 75 feet of agricultural lands. In cases where portions of the stream do flow near agricultural areas, the attainment streams are commonly very well buffered from agricultural runoff. Table 4 (below) displays agricultural stream miles and agricultural stream buffer miles for all attainment streams. Agricultural stream miles (as modeled) with a 75-foot vegetated buffer in the attainment stream watersheds ranged from 34% to 92% with an average of 61% buffered stream miles. By contrast, agricultural stream miles with buffers ranged from 6 to 100%, with an average of 49% in impaired watersheds.

Table 4: Vegetative Buffers to Agricultural Lands in Attainment Stream Watersheds

	Footman Brook	Martin Stream	Moose Brook	Upper Kenduskeag Stream	Upper Pleasant River	Average
Total Stream Miles* (As Modeled)	3.9	73.2	23.1	38.3	7.6	29.2
Agricultural Stream Miles	0	1.2	1.2	2.3	0.22	1.0
Percent Agricultural Stream Miles Buffered	n/a	92%	75%	35%	41%	61%

* Including tributaries.

Attenuation by Lakes, Ponds and Wetlands

MapShed considers depositional environments such as ponds and wetlands to attenuate watershed sediment loading. This information is entered into the model by a simple percentage of watershed draining to a pond or a wetland. The percent of watershed draining to a wetland in the attainment watersheds ranged from 15% to 60% with an average of 35% (Table 5, below). By comparison, the percent of watershed draining to a wetland in impaired stream watersheds ranged from 0% to 75%, with an average of 12%.

Table 5: Attenuation by Lakes, Ponds and Wetlands in the Attainment Stream Watersheds

	Footman Brook	Martin Stream	Moose Brook	Upper Kenduskeag Stream	Upper Pleasant River	Average
Watershed Area that is Wetland	4%	9%	16%	7%	9%	9%
Watershed Area Draining to Wetlands	18%	60%	20%	15%	60%	35%

NUTRIENT MODELING RESULTS

The MapShed model simulates surface runoff using daily weather inputs of rainfall and temperature. Erosion and sediment yields are estimated using monthly erosion calculations based on land use, soil composition, and slope values for each source area. A sediment delivery ratio based on the area of the watershed and a transport capacity based on average daily runoff is then applied to the calculated erosion figures. Sediment loading for each source area (i.e., land cover category) is then determined (Evans & Corradini, 2012).

Below in Tables 6, 7, and 8, loading for phosphorus, nitrogen, and sediment are presented for each of the attainment stream watersheds. There are two categories of loads: sources and pathways. The pathways represent additional loads which, according to MapShed developers, originally are derived from the same source categories, and in the same proportions, as the source loads (Evans, personal communication).

The MapShed output data selected for this TMDL is expressed as kilograms per hectare per year by source and land use category. The TMDL is the average of five attainment stream loading values for each pollutant, defining a single statewide TMDL. Daily values may be derived by dividing the annual figure by 365.

Table 6: Total Phosphorus Results and Total Maximum Daily Load Calculations for Attainment Streams

Total Phosphorus kg/yr					
Sources/Pathways	Footman Brook	Martin Stream	Moose Brook	Upper Kenduskeag Stream	Upper Pleasant River
Source Loads					
<i>Hay/Pasture</i>	57.1	93.8	36.5	204.4	47.3
<i>Crop land</i>	236.6	156.1	468.1	520.2	17.1
<i>Forest</i>	37.5	122.9	49.3	140.9	34.4
<i>Wetland</i>	3.4	28.5	27.0	20.7	6.5
<i>Disturbed Land</i>	0	0.3	3.5	0	0
<i>Sandy Areas</i>	0	0			
<i>Low Density Mixed</i>	0.3	9.1	7.8	3.9	10.7
<i>Medium Density Mixed</i>	0	0	0	0	0
<i>High Density Mixed</i>	28.0	86.7	23.1	175.2	28.0
<i>Low Density Residential</i>	0	0	0.3	0	2.7
<i>Medium Density Residential</i>	0	0	0	0	0
<i>High Density Residential</i>	0	0	0	0	0
<i>Farm Animals</i>	7.0	0.0	17.4	146.1	28.7
<i>Septic Systems</i>	0.8	19.4	0.8	3.2	4.2
Source Load Total:	370.6	516.9	633.7	1214.5	179.4
Pathway Load					
<i>Stream Banks</i>	1.0	13.2	5.7	20.1	1.7
<i>Subsurface / Groundwater</i>	197.4	953.9	496.2	718.5	142.9
Total Watershed Mass Load:	569.0	1484.1	1135.6	1953.1	323.9
Total Watershed area (ha):	1741	10,753	4564	6686	1504
Loading by Watershed	0.33	0.14	0.25	0.29	0.22
	kg/ha/yr	kg/ha/yr	kg/ha/yr	kg/ha/yr	kg/ha/yr
<u>Total Maximum Daily Load</u> <u>(average of watersheds):</u>			0.24 kg/ha/yr		

Table 7: Total Nitrogen Results and Total Maximum Daily Load Calculations for Attainment Streams

Total Nitrogen kg/yr					
Sources/Pathways	Footman Brook	Martin Stream	Moose Brook	Upper Kenduskeag Stream	Upper Pleasant River
Source Loads					
<i>Hay/Pasture</i>	140.3	277.8	94.6	541.2	157.5
<i>Crop land</i>	1820.0	1609.8	4598.7	4646.7	180.2
<i>Forest</i>	646.2	2246.5	878.9	2404.6	644.8
<i>Wetland</i>	64.5	600.8	522.1	394.1	136.4
<i>Disturbed Land</i>	0	0.8	7.9	0	0
<i>Sandy Areas</i>		0.1			
<i>Low Density Mixed</i>	2.5	90.6	71.4	35.4	105.8
<i>Medium Density Mixed</i>	0	0	0	0	0
<i>High Density Mixed</i>	275.4	927.9	227.6	1713.6	299.6
<i>Low Density Residential</i>	0	0	2.6	0	26.5
<i>Medium Density Residential</i>	0	0	0	0	0
<i>High Density Residential</i>	0	0	0	0	0
<i>Farm Animals</i>	20.4	0	93.4	753.2	153.6
<i>Septic Systems</i>	112.2	1518.0	138.4	272.2	140.4
Source Load Total:	3081.5	7272.3	6635.3	10761.1	1844.8
Pathway Load					
<i>Stream Banks</i>	2.0	46.4	15.6	55.0	7.4
<i>Subsurface / Groundwater</i>	8128.8	28926.3	20255.3	26458.9	5132.0
Total Watershed Mass Load:	11212.2	36245.0	26906.2	37274.9	6984.2
Total Watershed area (ha):	1741	10,753	4564	6686	1504
Loading by Watershed	6.44	3.37	5.90	5.58	4.64
	kg/ha/yr	kg/ha/yr	kg/ha/yr	kg/ha/yr	kg/ha/yr
<u>Total Maximum Daily Load</u> <u>(average of watersheds):</u>			5.2 kg/ha/yr		

Table 8: Total Sediment Results and Total Maximum Daily Load Calculations for Attainment Streams

Total Sediment 1000 kg/yr					
Sources/Pathways	Footman Brook	Martin Stream	Moose Brook	Upper Kenduskeag Stream	Upper Pleasant River
Source Loads					
<i>Hay/Pasture</i>	2.80	4.00	1.48	12.56	2.47
<i>Crop land</i>	82.76	21.50	59.92	149.85	4.76
<i>Forest</i>	5.51	16.92	6.06	24.72	4.87
<i>Wetland</i>	0.10	0.36	0.64	0.65	0.07
<i>Disturbed Land</i>	0	0.03	1.15	0	0
<i>Sandy Areas</i>		0.02			
<i>Low Density Mixed</i>	0.08	1.81	2.31	1.19	2.26
<i>Medium Density Mixed</i>	0	0	0	0	0
<i>High Density Mixed</i>	6.16	12.77	0.08	39.30	4.13
<i>Low Density Residential</i>	0	6.59	0	0	0.56
<i>Medium Density Residential</i>	0	0	0	0	0
<i>High Density Residential</i>	0	0	0	0	0
<i>Farm Animals</i>	0	0	0	0	0
<i>Septic Systems</i>	0	0	0	0	0
Source Load Total:	97.4	64.0	71.6	228.3	19.1
Pathway Load					
<i>Stream Banks</i>	2.89	26.78	22.75	87.74	4.43
<i>Subsurface / Groundwater</i>	0	0	0	0	0
Total Watershed Mass Load:	100.3	90.8	94.4	316.0	23.6
Total Watershed area (ha):	1741	10,753	4564	6686	1504
Loading by Watershed	0.06	0.01	0.02	0.05	0.02
	1000	1000	1000	1000	1000
	kg/ha/yr	kg/ha/yr	kg/ha/yr	kg/ha/yr	kg/ha/yr
<u>Total Maximum Daily Load</u>	0.030				
<u>(average of watersheds):</u>	1000 kg/ha/yr				

References

Barbour, M.T., J. Gerritsen, B.D. Snyder, and J.B. Stribling. 1999. Rapid Bioassessment Protocols for Use in Wadeable Streams and Rivers: Periphyton, Benthic Macroinvertebrates and Fish, Second Edition. EPA 841-B-99-002. U.S. Environmental Protection Agency; Office of Water; Washington, D.C.

Evans, B.M., D.W. Lehning, K.J. Corradini, G.W. Petersen, E. Nizeyimana, J.M. Hamlett, P.D. Robillard, & R.L. Day. 2002. A Comprehensive GIS-Based Modeling Approach for Predicting Nutrient Loads in Watersheds. *J. Spatial Hydrology*, Vol. 2, No. 2.

Evans, B.M., & K.J. Corradini. 2012. MapShed Version 1.0 Users Guide. Penn State Institute of Energy and the Environment. Retrieved from: <http://www.mapshed.psu.edu/Downloads/MapShedManual.pdf>

Evers, M., personal communication. Division of Environmental Assessment, Maine Department of Environmental Protection, Augusta, ME.

Conservation Tillage Information Center (CTIC). 2000. Crop Residue Management Survey. National Association of Conservation Districts. Retrieved from: <http://www.ctic.purdue.edu/CTIC/CTIC.html>.

Evans, B.M., D.W. Lehning, & K.J. Corradini. 2008. Users guide for the Pollution Reduction Impact Comparison Tool (PRedICT). Penn State Institutes of Energy and the Environment. Retrieved from <http://www.predict.psu.edu/Downloads/PRedICTManual.pdf>

Evans, B.M., & K.J. Corradini. 2012. MapShed version 1.0 users guide. Penn State Institutes of Energy and the Environment. Retrieved from <http://www.mapshed.psu.edu/Downloads/MapShedManual.pdf>

Haith, D.A. & L.L. Shoemaker. 1987. Generalized Watershed Loading Functions for Stream Flow Nutrients. *Water Resources Bulletin*, 23(3), pp. 471-478.

Haith, D.A., R. Mandel, & R.S. Wu. 1992. GWLF: Generalized Watershed Loading Functions Version 2.0 User's Manual. Cornell University Department of Agricultural & Biological Engineering. Retrieved from <http://www.mapshed.psu.edu/Downloads/GWLFManual.pdf>

Lichtenberg, E. 1996. Using Soil and Water Conservation Practices to Reduce Bay Nutrients: How has Agriculture Done? Economic Viewpoints. Maryland Cooperative Extension Service, University of Maryland at College Park and University of Maryland Eastern Shore, Department of Agricultural and Resource Economics, 1(2).

New England Interstate Water Pollution Control Commission (NEIWPC). 2005. Calibration and Validation of the AVGWLF Model for New England and New York State. Quality Assurance Project Plan submitted to US EPA Region 1. Retrieved from <http://www.neiwpcc.org/AVGWLF/resources.asp>

Penn State Institutes of the Environment, Penn State University (Penn State). 2007. Summary of Work Undertaken Related to Adaptation of AVGWLF for Use in New England and New York. Report submitted to New England Interstate Water Pollution Control Commission (NEIWPC), February 2007. Retrieved from <http://www.neiwpcc.org/AVGWLF/resources.asp>

Rothwell, N. 2005. Grazing Management in Canada. Farm Environmental Management in Canada. <http://publications.gc.ca/Collection/Statcan/21-021-M/21-021-MIE2005001.pdf>.

United States Department of Agriculture (USDA). 2007 Census of Agriculture: Maine. Retrieved from: http://www.agcensus.usda.gov/Publications/2007/Full_Report/Volume_1,_Chapter_1_State_Level/Maine/st23_1_008_008.pdf

Wright, T., C. Swann, K. Capiella, and T. Schueler. 2005. Unified Subwatershed and Site Reconnaissance: A User's Manual. Center for Watershed Protection. Ellicott City, MD.