# TMDL Summary    Appendix B-6

# Halfmoon Stream

## Watershed Description

This TMDL applies to an 8.5 mile section of Halfmoon Stream, encompassing the Villages of Thorndike and Knox and the watershed just upstream of the Town of Unity, Maine. Halfmoon Stream flows northeast in its headwaters, then due north, and northwest in its lower reaches, joining Sandy Stream just upstream of Berry Road. The upper portion of the stream in Monteville is predominately forested area, while the lower portion is a mixture of agricultural and forest. Major tributaries are Hall and Wing Brooks which join the mainstem downstream and upstream of Thorndike, respectively. The Halfmoon Stream watershed covers an area of 38.0 square miles.

- Halfmoon Stream is on the list of Maine's Impaired Streams as referenced in the 2016 Integrated Report (Maine DEP, 2018).
- The Halfmoon Stream watershed is predominately non-developed (81%). Wooded areas (73%) within the watershed absorb and filter pollutants helping protect both water quality in the stream and stream channel stability. The filtering ability is particularly functional in the riparian corridor, which Halfmoon Stream experiences. Wetlands also filter nutrients and are present in 5% of the watershed.
- Non-forested areas within the watershed are predominantly agricultural (14%, 12% of which is hay/pasture land).
- Developed areas (5%) contain impervious surfaces and when in close proximity to the stream may impact water quality.
- Runoff from land with applied manure originating from dairy farms is likely the largest contributor of nutrients to Halfmoon Stream. The central portion of the watershed is where managed hay fields and grazing areas exist.

### *Definitions*

- ***Total Maximum Daily Load (TMDL)*** *represents the total amount of a pollutant that a waterbody can receive and still meet water quality standards.*
- **Nonpoint Source Pollution** *refers to pollution that comes from many diffuse sources across the landscape, and are typically transported by rain or snowmelt runoff.*

### *Waterbody Facts*

**Segment ID:**
ME0103000309_326R03 (lower)
ME0103000309_326R02 (upper)

**Towns:** Unity/Thorndike/Knox, ME

**County:** Waldo

**Impaired Segment Length:** 1.6 miles (lower), 6.9 miles (upper)

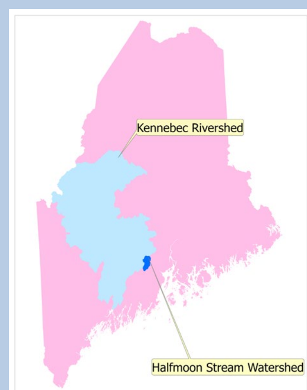
**Classification:** Class B (lower), Class A (upper)

**Direct Watershed:** 38 $mi^2$ (24,320 acres)

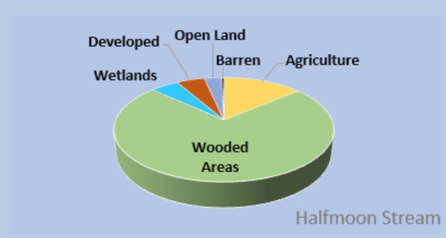
**Impairment Listing Cause:** Periphyton (both lower & upper)

**Watershed Agricultural Land Use:** 14%

**Major Drainage Basin:** Kennebec River




### Watershed Land Uses



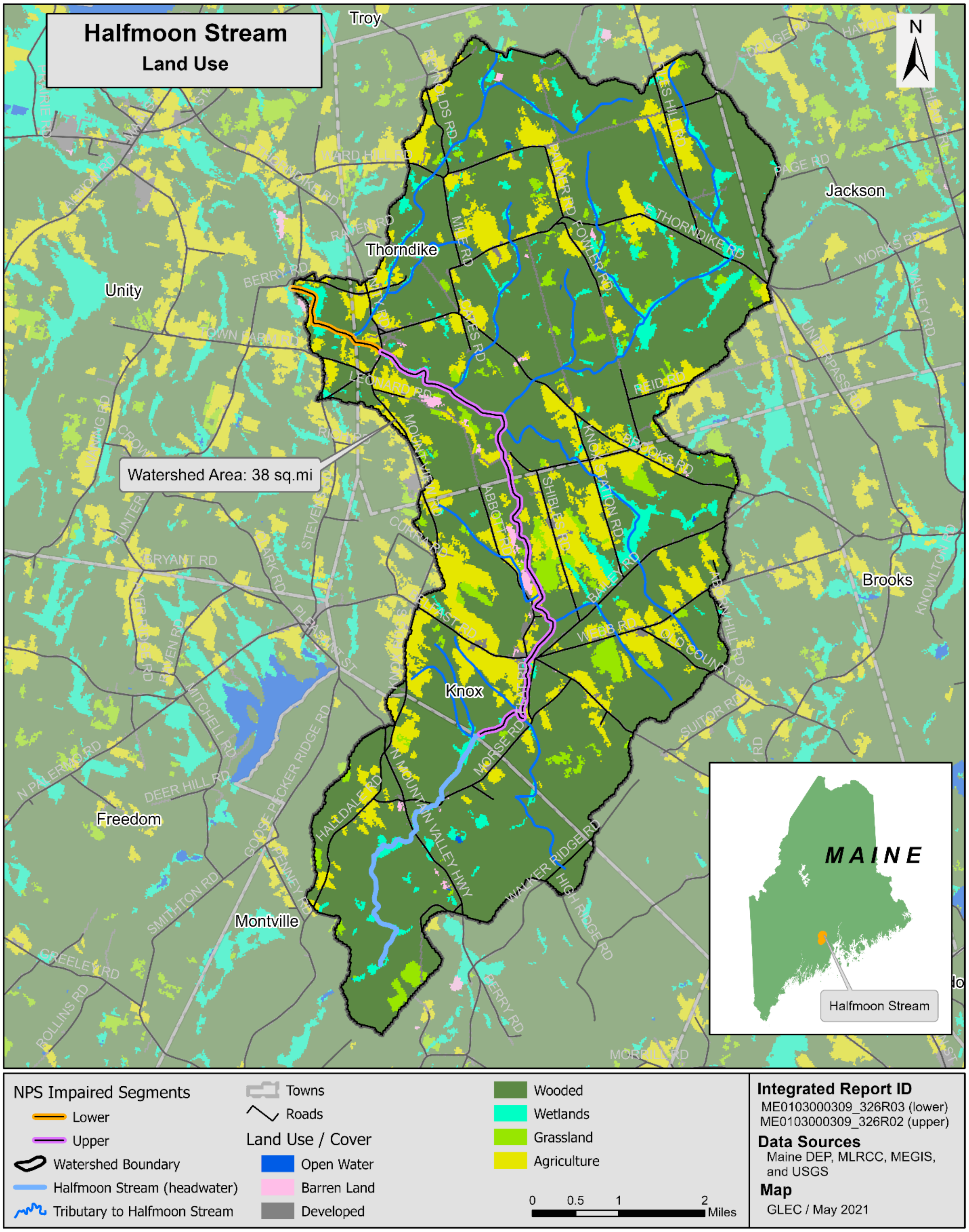



**Figure 1:** Land Use and Land Cover (from 2016) in the Halfmoon Stream Watershed

## Why Is a TMDL Assessment Needed?

Halfmoon Stream, predominantly a Class A freshwater stream (with a lower segment in Class B), has been assessed by Maine DEP as not meeting water quality standards for the designated use of aquatic life, and placed on the 303(d) list of impaired waters under the Clean Water Act. The Clean Water Act requires that all 303(d)-listed waters undergo a Total Maximum Daily Load (TMDL) assessment that describes the impairments and establishes a target to guide the measures needed to restore water quality. The goal is for all waterbodies to comply with state water quality standards.

Agriculture (hay/pasture and cropland) in the Halfmoon Stream watershed comprises 14% of the land area. This is almost three times the developed land area in the watershed. Agriculture is therefore likely to be the largest contributor of sediment and nutrient enrichment to the stream. Any close proximity of agricultural land, particularly hay crop with applied manure, to Halfmoon Stream further increases the likelihood that nutrients will reach the stream.

***Halfmoon Stream (lower impaired segment; Class B)*** *looking upstream and just upstream of the confluence with Sandy Stream and the Berry Road bridge (Unity). Photo: GLEC 2021*

***Halfmoon Stream (upper impaired segment; Class A)*** *just upstream of SR 220 (Mount View Rd, Thorndike). Photo: GLEC 2021*

## WATER QUALITY DATA ANALYSIS

Maine DEP uses a variety of data types to measure the ability of a stream to adequately support aquatic life, including; dissolved oxygen, benthic macroinvertebrates, and periphyton (algae). For benthic macroinvertebrates, DEP makes aquatic life use determinations using a statistical model that incorporates 30 variables of data collected from rivers and streams, including the richness and abundance of streambed organisms, to determine the probability of a sample meeting Class A, B, or C conditions. Biologists use the model results and supporting information to determine if samples comply with the numeric aquatic life criteria of the class assigned to the stream or river (Davies and Tsomides, 2002). Maine DEP uses an analogous model to aid in the assessment of algal communities but makes aquatic life use determinations based on narrative standards.

The aquatic life impairment in Halfmoon Stream is based on periphyton (algae) data collected from 2002 to 2017. The lower segment in the watershed has a Class B designation but the upper segment has a Class A designation. At station S-603, located on the lower segment, in 2002 periphyton did meet its designation and macroinvertebrates exceeded its designation and met Class A. At station S-697, located on the upper segment, in 2003 and 2007 macroinvertebrates met its designation of Class A while in 2007 periphyton did not meet its Class A designation (it met Class C). In 2012, 2013, 2014, and 2017 both macroinvertebrates and periphyton did not meet its Class A designation at this same station (S-697). In 2015, 2016, and 2018 periphyton was not sampled for, but macroinvertebrates did not meet Class A designation. In 2019 periphyton did not meet its Class A designation (it met Class B) while macroinvertebrates did meet.

## TMDL ASSESSMENT APPROACH: NUTRIENT AND SEDIMENT MODELING OF IMPAIRED AND ATTAINMENT STREAMS

NPS pollution is difficult to measure directly, because it comes from many diffuse sources spread across the landscape. For this reason, an online nutrient loading model, *Model My Watershed* (v. 1.32.0), was used to estimate the sources of pollution based on well-established hydrological equations (Stroud Water Research Center 2017). *Model My Watershed* makes use of the GWLF-enhanced model engine. The model incorporates detailed maps of soil, land use, and slope, daily weather and localized weather data (from the period 2009-2020), and direct observations of agriculture and other land uses within the watershed. *Model My Watershed* is derived from its parent MapShed developed by Evans and Corradini (2012). *Model My Watershed* replaced MapShed in 2017-2018.

The nutrient loading estimates for the impaired stream were compared to similar estimates for five non-impaired (attainment) streams of similar watershed land uses across the state. The TMDL for the impaired stream was set as the mean nutrient loading estimate of these attainment stream watersheds, and units of mass per unit watershed area per year (kg/ha/year) were used. The difference in loading estimates between the impaired and attainment watersheds represents the percent reduction in nutrient loading required under this TMDL. The attainment streams and their nutrient and sediment loading estimates and TMDL are presented below in Table 1.

**Table 1:** Numeric Targets for Pollutant Loading Based on Model My Watershed Outputs (2021) for Attainment Streams

| Attainment Streams | Town | Total P Load (kg/ha/yr) | Total N Load (kg/ha/yr) | Sediment Load (kg/ha/yr) |
|---|---|---|---|---|
| Footman Brook | Exeter | 0.17 | 1.73 | 35.2 |
| Martin Stream | Fairfield | 0.13 | 2.98 | 57.9 |
| Moose Brook | Houlton | 0.18 | 1.59 | 48.5 |
| Upper Kenduskeag Stream | Corinth | 0.16 | 1.72 | 100.5 |
| Upper Pleasant River | Gray | 0.16 | 4.26 | 86.5 |
| ***Total Maximum Daily Load*** | | **0.16** | **2.46** | **65.7** |

## RAPID WATERSHED ASSESSMENT

### Habitat Assessment

Habitat assessment surveys were conducted on both impaired and attainment streams (Figure 2). The assessment approach is based on the *Rapid Bioassessment Protocols for Use in Streams and Wadeable Rivers* (Barbour et al. 1999), which integrates various parameters relating to the structure of physical habitat. The habitat assessments include a 1) general description of the site and physical characterization and a 2) visual assessment of in-stream and riparian habitat quality. For both impaired and attainment streams, the assessment locations are typically near a road crossing for ease of access.

Halfmoon Stream contains two impaired, but contiguous, segments. The lower impaired segment (ME0103000309_326R03; Class B) was surveyed starting at approximately 70 m upstream from its confluence with Sandy Stream; the endpoint was 100 m upstream from this starting point. Because this segment was practically an entire run structure, a *low gradient* habitat assessment was performed on this 100 m length. A biomonitoring station exists at the upstream end of this impaired reach.

The upstream impaired segment (ME0103000309_326R02; Class A) begins near the State Route 220 bridge crossing (Mount View Rd) and continues a considerable distance (approximately 11 km) upstream. Based on the higher frequency of riffles versus runs or pools, a *high gradient* habitat assessment was performed on a 100 m length of the upper segment. The assessed segment began approximately 175 m upstream of the State Route 220 bridge to ensure clearance of any confining flow or modified habitat caused by this bridge. This beginning point was approximately 80 m upstream of the biomonitoring station (S-697).

The habitat surveys for both impaired segments were located in moderately dense vegetated riparian covers, especially for the upper segment, while the overall watershed land use is predominantly wooded yet contains a mixture of pasture, wetlands, and commercial or residential land. It is worth noting that a large quarry/aggregate operation is active in the local drainage area of the lower segment.

Figure 2 (right) shows the range of habitat assessment scores for all attainment and impaired streams, as well as for both segments of Halfmoon Stream discussed here.

Based on the *Rapid Bioassessment Protocols*, the lower (low gradient) segment earned a score of 125 while the upper (high gradient) segment earned a 175. Higher scores indicate better habitat. The range of habitat scores for attainment streams was 155 to 179.

The low score for the lower segment was attributed to lack of pool variability and channel sinuosity and poor bank stability. All habitat parameters scored high in the upper segment, but were especially optimal for channel flow status, frequency of riffles, and low channel alteration. The entire run structure of this lower segment plus unusually high bank heights (possibly incised) suggests this reach has been intentionally channelized in its past.

Habitat is clearly an issue in the impairment of the lower segment of Halfmoon Stream. But for both upper and lower segments, it is important to look for other potential sources within the watershed leading to impairment. Consideration should be given to major "hot spots" in the Halfmoon Stream watershed as potential sources of NPS pollution contributing to the water quality impairment.

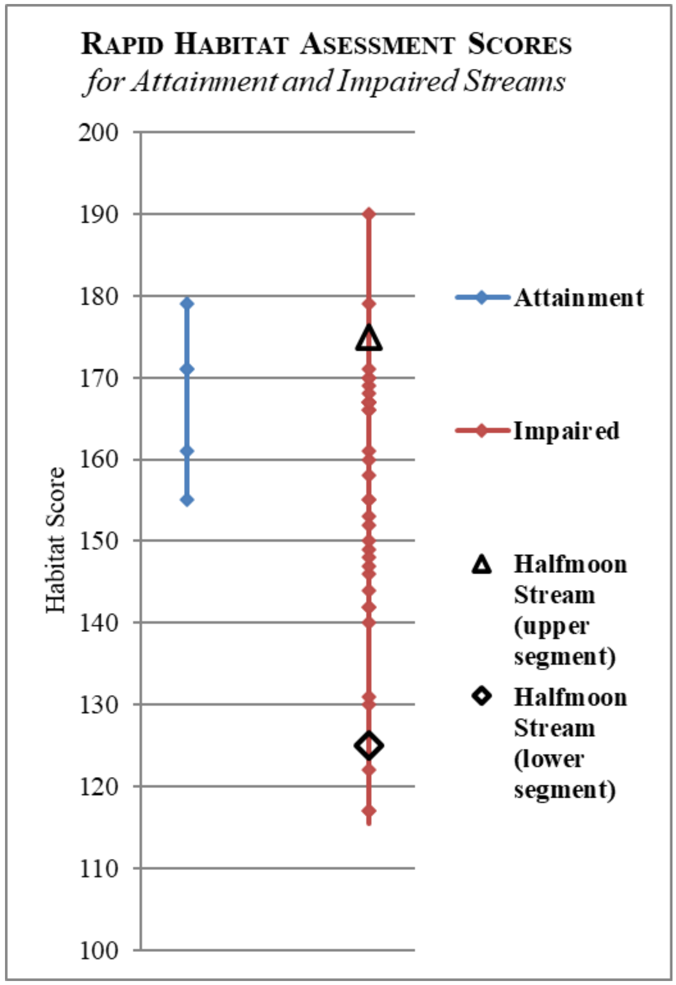



**Figure 2:** Habitat Assessment Score for Halfmoon Stream (2021) Compared to Region

**Pollution Source Identification**

Pollution source identification assessments were conducted in May 2021 for the entire Halfmoon Stream watershed. Attainment stream watersheds were assessed in 2012. The source identification work is based on an abbreviated version of the Center for Watershed Protection's Unified Subwatershed and Site Reconnaissance method (Wright et al. 2005). The abbreviated method includes both a desktop and field component. The desktop assessment consists of generating and reviewing maps of the watershed boundary, roads, land use and satellite imagery; and then identifying potential NPS pollution locations, such as road crossings, agricultural fields, and large areas of bare soil. When available, multiple sources of satellite imagery were reviewed. Occasionally, the high resolution of the imagery allowed for observations of livestock, row crops, eroding stream banks, sediment laden water, junkyards, and other potential NPS concerns that could affect stream quality. As many potential pollution sources as possible were visited, assessed, and documented in the field. Field visits were limited to NPS sites that were visible from roads or a short walk from a roadway. Neighborhoods were assessed for NPS pollution at the whole neighborhood level including streets and storm drains (where applicable). The assessment does not include a scoring component but does include a detailed summary of findings and a map indicating documented NPS sites throughout the watershed.

Based on the May 2021 field and desktop assessment, several generalizations on watershed land use for Halfmoon Stream can be made. While most of the headwater portions of the watershed are densely forested, and mainly in tributaries such as Half Brook, Wing Brook, and the upper mainstem, there is considerable intensive land operations in the central and lower segment of the mainstem that likely disturb the integrity of the stream system (Table 2, Figure 3). The village of Thorndike is situated in the lower watershed and the corresponding existence of any failing home sewage treatment systems should be explored. Knox Center village is situated in the center of the watershed, though smaller in residential use. Several junkyards occur but their contribution to nutrient enrichment or sedimentation is indirect, at most. Most attention should focus on several dairy operations throughout the central portion of the watershed. Supporting these operations are extensive hayfields throughout this portion of the watershed. The hayfields are likely nourished by land applied manure, where on occasion this was observed in the field. Winter wheat production was also observed, though not as extensive as hayfield. Also, regarding impacts to sedimentation in Halfmoon Stream, the extensive quarrying operations and any lagoon captures on the west-central flank of the mainstem should be examined.

**Table 2:** Potential Pollution Source ID Assessment (2021) for the Halfmoon Stream Watershed

| Potential Source | | | Notes |
|---|---|---|---|
| **ID#** | **Location** | **Type** | |
| **4** | Crosby Brook Rd & Berry Rd | Hotspot | Gravel piles; several large trucks; scattered debris; sediment exposed w/o containment; brush cleared |
| **5** | Crosby Brook Rd | Municipal | Fairgrounds - partly within watershed - several barns - mowed fields |
| **6** | Crosby Brook Rd | Municipal | Municipal road facility; transfer station |
| **7** | Crosby Brook Rd | Residential | House with small farm; large hayfield; chickens observed; mowed grasses |
| **8** | Berry Rd | Agriculture | Organic farm fields; plowed |
| **9** | SR 139 & SR 220 (Unity Rd & Gordon Hill Rd) | Residential / Hotspot | Thorndike – no apparent managed lawn care; older residential structures; not sewered; no new construction; 10-25% tree/shrub coverage; no curbs/gutters/drains present; Auto parts & service center (main commercial hotspot) |
| **10** | SR 220 (Unity Rd) | Agriculture | Agricultural research station - several greenhouses |
| **14** | Stevens Rd & Town Farm Rd | Agriculture | Extensive planting winter wheat; 15 barns; clearing of woodlots |
| **16** | Leonard Rd | Agriculture | Barns – alum piles – mowed hayfields |

| Potential Source | | | Notes |
|---|---|---|---|
| **ID#** | **Location** | **Type** | |
| **17** | Leonard Rd / Abbott Rd | Hotspot | Quarry - gravel pit - several large equipment pieces - extensive |
| **18** | Leonard Rd | Agriculture | Plowed - previously corn - no till - extensive odor chicken manure applied to field |
| **20** | Leonard Rd | Forestry | Managed forest – selective cutting |
| **24** | Abbott Rd & Joe Bryant Rd | Hotspot | Junked vehicles – extensively scattered |
| **25** | Abbott Rd & Clark Ln | Agriculture / Municipal | Equine riding club – horse show arena – paddock – large municipal sand pile |
| **27** | Shibles Rd | Agriculture | Dairy farm – extensive barns – manure applied to local yet extensive hayfields |
| **28** | Belfast Rd | Municipal | Salt storage – covered with tarp |
| **29** | Belfast Rd & Webb Rd | Agriculture | 12 chickens observed (free roam) – scattered junk and vehicles |
| **30** | Shibles Rd | Residential / Hotspot | Houses with several junked vehicles and trailers – extensive over several residential lots |
| **31** | Morse Rd | Agriculture | Organic vegetable farm – horses in paddock (6 observed) |
| **32** | Near Morse Rd & Flat Rd | Construction / Hotspot | Cleared vegetation and wide road foundation forming to cul-de-sac |
| **34** | E Thorndike Rd & Flies Hill Rd | Agriculture | Small sheep farm (over 10 animals observed) |
| **36** | Brooks Rd | Agriculture | Marijuana farm – fencing over hayfield present |

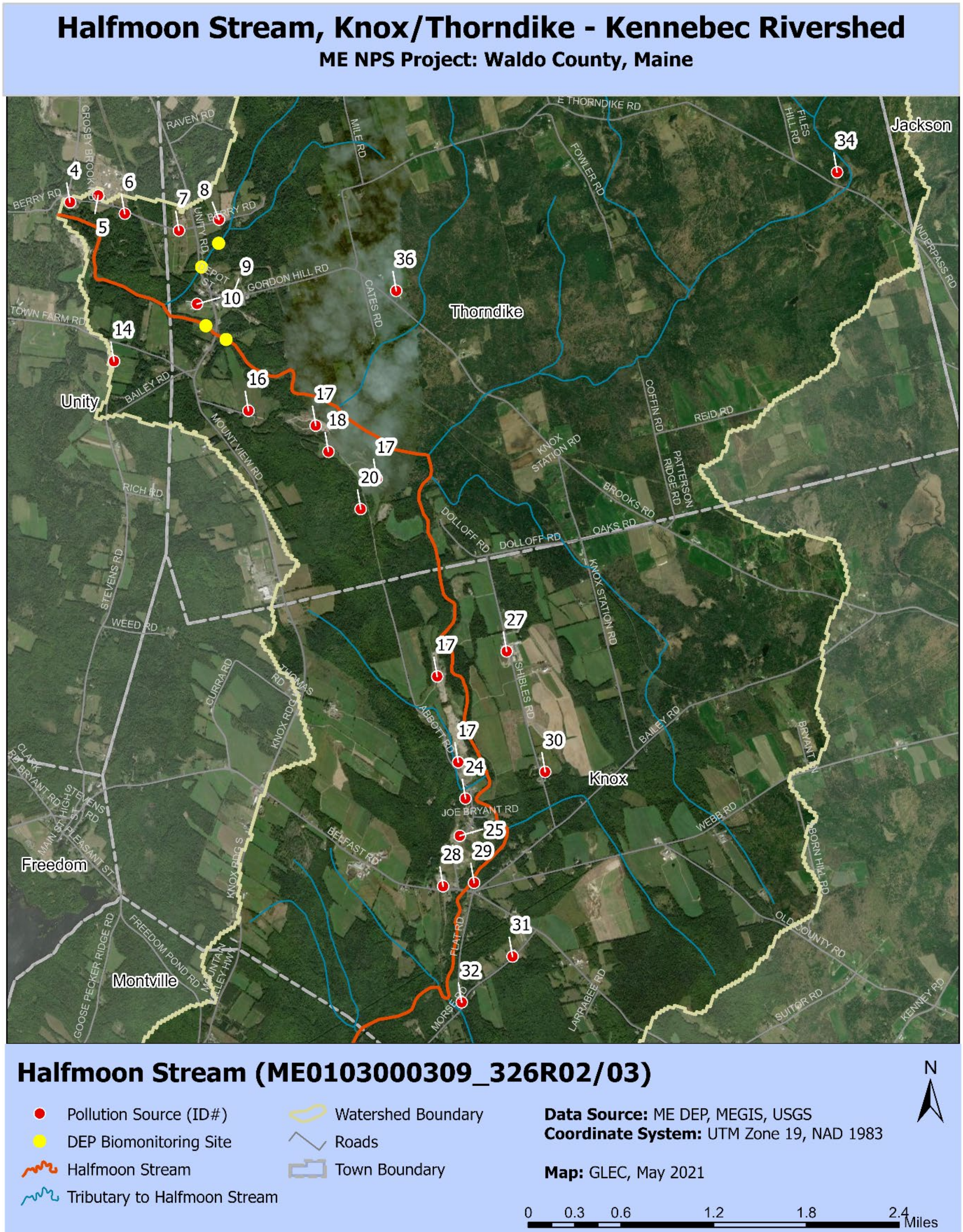



**Figure 3:** Aerial Photo of Potential Source Locations (identified in 2021) in the Halfmoon Stream Watershed

## NUTRIENT LOADING – *MODEL MY WATERSHED* ANALYSIS

The *Model My Watershed* model was used to estimate stream loading of total phosphorus, total nitrogen, and sediment in Halfmoon Stream watershed. The model estimated nutrient loads over a 12-year period (2009-2020), which was determined by local (Bangor International Airport USW00014606) weather data inserted into *Model My Watershed*. This extended period captures a recent but wide range of hydrologic conditions to account for variations in nutrient and sediment loading over time. Loads for the attainment watersheds (five total; Table 1) were computed using the same model with the same recent inputs (i.e., regional weather, 2016 land use and land cover, 2016 wetland extent, and BMPs similar to the impaired watersheds).

Many quality assured and regionally calibrated input parameters are provided with *Model My Watershed*. However, several updates to some of the default parameters were made in this TMDL effort, and namely more recent land use/cover using **MRLC-NLCD 2016** [1], more recent and local weather (precipitation and temperature) data (as described above), and more regional estimates of Best Management Practices (BMPs; see ensuing discussion). Because land use/cover is more recent, the estimated filtration fraction of wetland and open water and the amount of stream buffer in agricultural land should be more accurate. It is also worth noting that improved classification algorithms were employed by MLRC in the NCLD 2016 and these new algorithm were used in the revisions of all previous NLCD versions (including the first version in 2001).

### *Livestock Estimates*

Livestock waste contains nutrients which can cause water quality impairment. The nutrient loading model considers numbers and types of animals. Table 3 (right) provides livestock (numbers of animals) in the watershed based on the USDA National Agricultural Statistics Service (NASS) estimation for 2012. Some of these totals were modified by direct observations made in the watershed in the 2012 survey. To generate watershed-based livestock counts, NASS county-based livestock totals are converted to a per unit area (based on the total area of the county). The unit area amount is then multiplied by the total watershed area to derive a watershed total count (as seen in Table 3).

**Table 3:** Livestock Count in the Halfmoon Stream Watershed

| Type | Halfmoon Stream |
|---|---|
| Dairy Cows | 198 |
| Beef Cows | 29 |
| Broilers | 27 |
| Layers | -- |
| Hogs/Swine | 19 |
| Sheep | 62 |
| Horses | 29 |
| Turkeys | 10 |
| Other | -- |
| **Total** | **374** |

The May 2021 field survey supports the livestock totals estimated through NASS as shown in Table 3. The dairy farm on Shibles Road (Site #27 on Figure 3 and Table 2) appears to be the most extensive operation and based on the areal extent of housing barns, the dairy cow estimate in Table 3 is likely too small. Unfortunately, the drive-by survey could not reasonably estimate this larger estimate. Several small farms did show 6-10 chickens roaming in the yard, and several larger farms had horses in pasture.

[1] MRLC-NLCD 2016 : Multi-Resolution Land Characteristics – National Land Cover Dataset (version 2016) provided by the MRLC Consortium (Jin et al. 2019).

***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 and Corradini, 2012). *Model My Watershed* considers natural vegetated stream buffers within agricultural land areas as providing nutrient load attenuation. A width of approximately 98 feet (30 m) on one side of a stream is required to be considered a streamside buffer per the *Model My Watershed* technical manual (Stroud Water Research Center 2017). Analysis of recent aerial photos was used to estimate the number of agricultural land stream miles with and without vegetative buffers, and these estimates were directly entered into the model.

Halfmoon Stream is an 8.5 mile-long impaired segment. The total stream miles (including tributaries) modeled within the watershed is 46.2 miles. Of this total, 2.48 stream miles are located within agricultural areas and 1.15 miles (6,097 ft; 46.6%) of that area have a 98 foot or greater vegetated buffer (Table 4, Figure 4). From a watershed perspective, this equates to 1.33 miles or 2.9% of the total stream length running through agricultural land with less than a 98 foot buffer. By contrast, for attainment stream watersheds, the percentage of total stream miles running through agricultural land without a 75 foot vegetated buffer (calculated in 2012) ranged from 0% to 3.9% with an average of 1.3%. Differences in stream length estimates using a 98-foot or 75-foot buffer were practically insignificant.

**Table 4:** Summary of Vegetated Buffers in Agricultural Areas

| Halfmoon Stream |
| --- |
| • Agricultural Land Stream Length = 2.48 mi (13,075 ft)<br>• Agricultural Land Stream Length *with Buffer* = 1.15 mi (6,097 ft)<br>(or 46.6% of total agricultural land stream length)<br>• Percentage of total stream length flowing through non-buffered agricultural land = 2.9% |

***Home Septic System Loads***

Loads for “normally functioning” septic systems are calculated in *Model My Watershed* using an estimate of the average number of persons per acre in “Low-Density Mixed” areas. In these areas, it is assumed that the populations therein are served by septic systems rather than centralized sewage systems. All homes in such areas are assumed to be connected to “normally functioning” systems rather than those that experience “surface breakouts” (surface failures), “short-circuiting” to underlying groundwater (subsurface failures), or have direct conduits to nearby water bodies. Non-functioning systems would be modeled with a higher load contribution to the waterbody.

### *Best Management Practices (BMPs)*

Best management practices (BMPs) are typically instituted to reduce the loading of sediment and nutrients from upland (i.e., non-point) sources. Ideally, information on BMPs for a specific watershed from local and regional sources would improve this component of the water quality model. Maine DEP sought information on BMP use in early 2021 from local, regional, and state agricultural agencies for rural BMPs and from nearby municipalities for urban BMPs. Very little to no information was returned in the solicitation. Hence, estimates for typical New England watersheds were derived from information available from Vermont. An upper limit of BMP use was garnered from watersheds entering the Chesapeake Bay where BMP use is intensive.

Four agricultural BMPs were used in this modeling effort and in the following manner:

- *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 cropland area in a cover crop BMP deployed was estimated at 25% and selected as the low end of the range (25 to 30 percent) expected for cropland in New England. These same values were assigned to the five attainment watersheds.
- *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. This BMP was estimated to occur in 25% of cropland. These same values were assigned to the five attainment watersheds.
- *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. Both interview sources suggest this practice is minimal to non-existent for New England watersheds. Hence, no BMP of this type was used in this modeling effort. These same values were assigned to the five attainment watersheds.
- *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. Both interview sources were not aware of this practice being active and is likely minimal for New England watersheds. Hence, no BMP of this type was used in this modeling effort for both impaired and attaining watersheds.

Note that other agricultural and development BMPs likely exist in the watershed but their location and type were not available in a watershed-wide format that is necessary to include in the model. Agricultural BMPs recommended by Maine DEP to reduce sediment and nutrient loads include vegetated buffers, covered manure storage facilities, and stream exclusion fencing. BMPs for developed areas recommended by the Maine DEP include vegetated buffers, stormwater BMPs, and minimization of impervious cover.

### *Pollutant Load Attenuation by Lakes, Ponds and Wetlands*

Depositional environments such as lakes, ponds, and wetlands can attenuate watershed sediment and nutrient loading. This information is entered into the nutrient loading model by a simple percentage of watershed area draining to a lake, pond, or wetland. The Halfmoon Stream watershed is 5% wetland and open water (less than 1% is open water). Multiple wetlands surround tributaries throughout the watershed, but most notably in the eastern and northeastern sections. It is estimated that 10% of land area within the watershed drains to wetlands and open water. The percent of watershed draining to a wetland in the attainment watersheds, based on the 2021 analysis, ranged from 26 to 58 percent, with an average of 40%.

## NUTRIENT AND SEDIMENT MODELING RESULTS

Selected results from the watershed loading model are presented here. The TMDL itself is expressed in units of kilograms per hectare per year. The additional results shown below assist in better understanding the likely sources of pollution. The model results for Halfmoon Stream indicate significant reductions of phosphorus and sediment are needed to improve water quality. Below, loading for nitrogen, phosphorus and sediment are discussed individually.

There are two categories of loads – sources and pathways. Sources are determined by land use/cover and the overland flow they generate, livestock counts by animal type, and home sewage treatment systems in developed areas. Pathways represent additional loads derived from subsurface flow and streambank erosion. Subsurface loads are calculated using dissolved N and P coefficients for shallow groundwater and are mainly derived from atmospheric inputs. Sediment and nutrient loads produced by eroding streambanks are estimated using an approach developed by Evans et al. (2003). This pathway is comprised of loads originating from five sources, and listed in order of decreasing importance: amount of developed land area, soil erodibility (K-factor), density of livestock, runoff curve number, and topographic slope. For any given model run, the amount of developed land in the watershed is responsible for just over 72% of the total streambank load, whereas soil erodibility and animal density are responsible for 21% and 7% of the total streambank load, respectively.

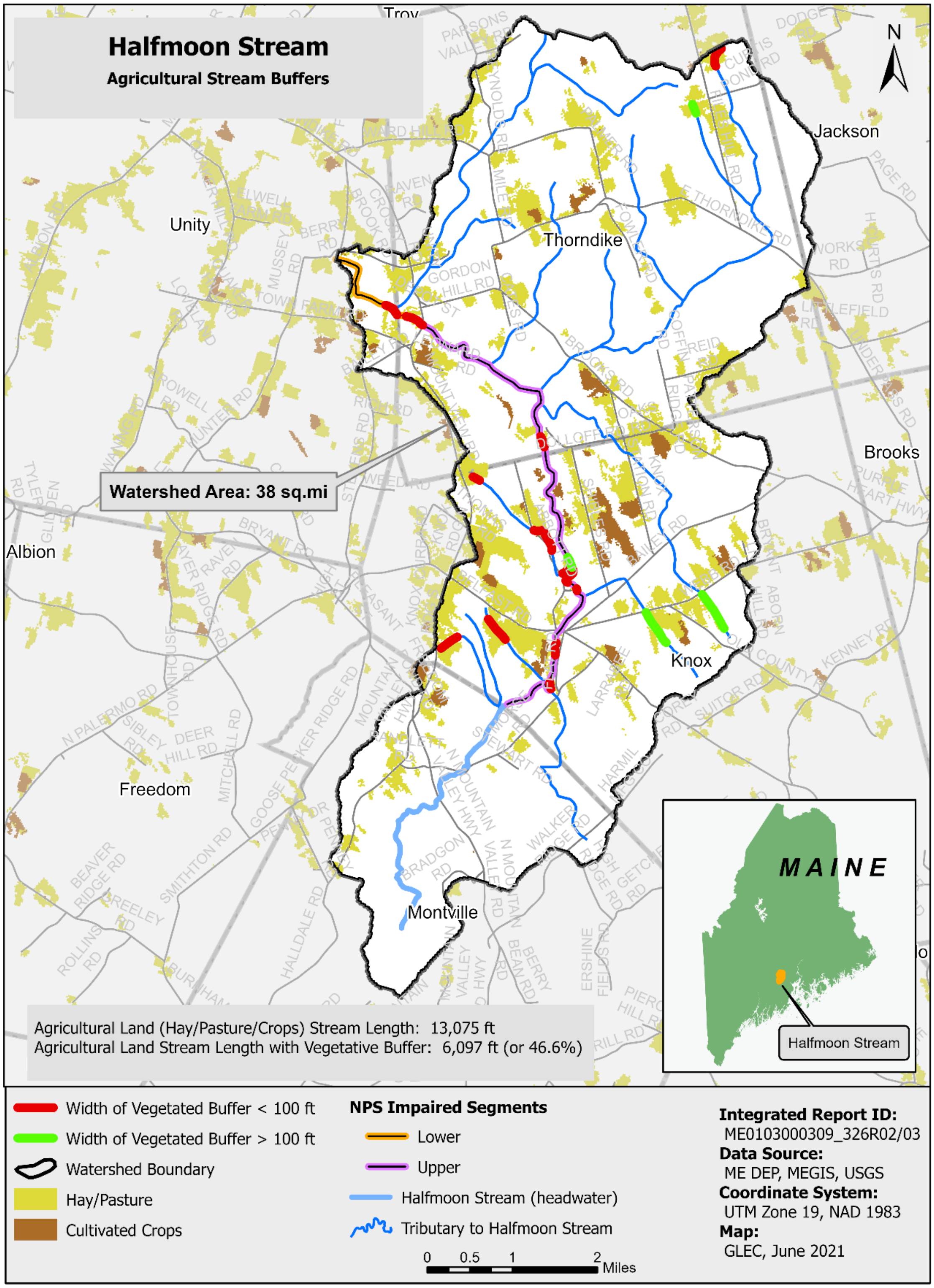



**Figure 4:** Agricultural Stream Buffers (from 2021) in the Halfmoon Stream Watershed

***Sediment***

Sediment loading in the Halfmoon Stream watershed is mainly derived from agricultural land which makes up almost 82% of the total sediment load from sources (Table 5 and Figure 5). Developed land contributes over 12% of the total source load. Of the entire watershed sediment load, stream bank erosion contributes 83.5%.

Note that total loads by mass cannot be directly compared between watershed TMDLs due to differences in watershed area. See section *TMDL: Target Nutrient Levels for Halfmoon Stream* below for loading estimates that have been normalized by watershed area.

**Table 5**: Total Sediment Load by Source

| **Halfmoon Stream** | **Sediment** (1000 kg/year) | **Sediment** (%) |
|---|---|---|
| **Source Load** | | |
| *Hay/Pasture* | 111.3 | 51.1% |
| *Cropland* | 66.9 | 30.7% |
| *Wooded Areas* | 4.1 | 1.9% |
| *Wetlands* | 0.2 | 0.1% |
| *Open Land* | 8.3 | 3.8% |
| *Barren Areas* | 0.025 | 0.011% |
| *Low-Density Mixed* | 5.7 | 2.6% |
| *Medium-Density Mixed* | 7.1 | 3.3% |
| *High-Density Mixed* | 0.9 | 0.4% |
| *Low-Density Open Space* | 13.2 | 6.1% |
| *Farm Animals* | 0 | 0 |
| *Septic Systems* | 0 | 0 |
| ***Source Load Total:*** | **217.8** | **100%** |
| | | |
| **Pathway Load** | | |
| *Stream Bank Erosion* | 1100.5 | - |
| *Subsurface Flow* | 0 | - |
| | | |
| ***Total Watershed Mass Load:*** | **1318** | |

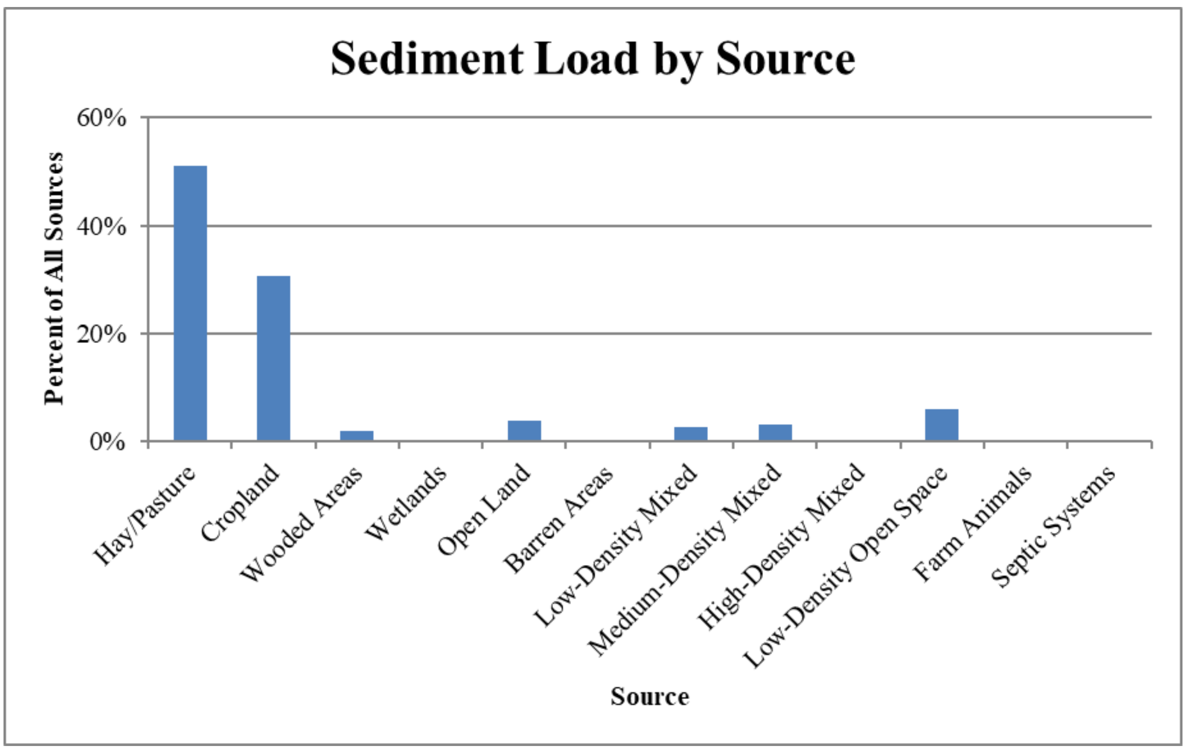



**Figure 5:** Total Sediment Load by Source in the Halfmoon Stream Watershed

***Total Nitrogen***

Nitrogen loading is attributed primarily to farm animals (22.6%) and hay/pasture land (26.7%) (Table 6 and Figure 6). Combined agricultural sources account for over 62% of the total nitrogen source load to Halfmoon Stream.

Note that total loads by mass cannot be directly compared between watershed TMDLs due to differences in watershed area. See section *TMDL: Target Nutrient Levels for Halfmoon Stream* below for loading estimates that have been normalized by watershed area.

**Table 6**: Total Nitrogen Load by Source

| Halfmoon Stream | Total N (kg/year) | Total N (%) |
|---|---|---|
| **Source Load** | | |
| *Hay/Pasture* | 2,012 | 26.7% |
| *Cropland* | 993 | 13.2% |
| *Wooded Areas* | 1,385 | 18.4% |
| *Wetlands* | 237 | 3.1% |
| *Open Land* | 431 | 5.7% |
| *Barren Areas* | 19 | 0.3% |
| *Low-Density Mixed* | 147 | 2.0% |
| *Medium-Density Mixed* | 142 | 1.9% |
| *High-Density Mixed* | 18 | 0.2% |
| *Low-Density Open Space* | 339 | 4.5% |
| *Farm Animals* | 1,701 | 22.6% |
| *Septic Systems* | 111 | 1.5% |
| ***Source Load Total:*** | **7,536** | **100%** |
| | | |
| **Pathway Load** | | |
| *Stream Bank Erosion* | 1,381 | - |
| *Subsurface Flow* | 14,501 | - |
| | | |
| ***Total Watershed Mass Load:*** | **23,417** | |

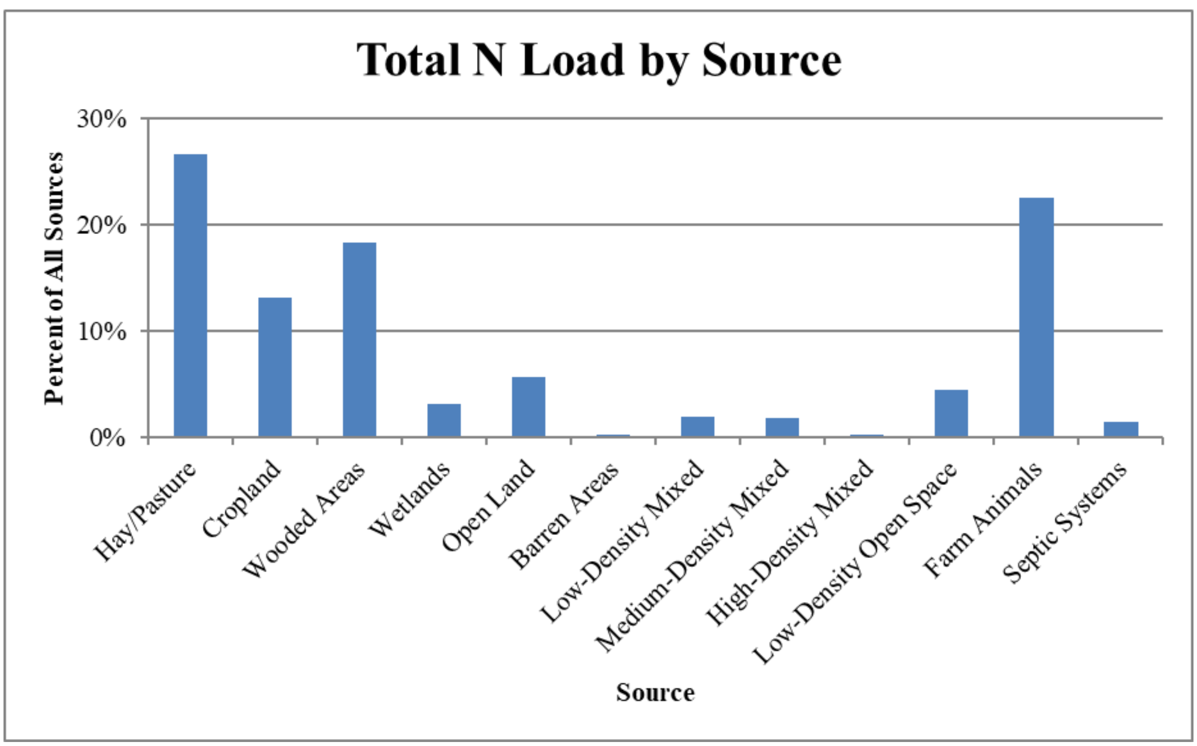



**Figure 6:** Total Nitrogen Load by Source in the Halfmoon Stream Watershed

***Total Phosphorus***

Phosphorus loading within the watershed is attributed primarily to hay/pasture land and farm animals with combined agricultural sources accounting for almost 88% of the total phosphorus load to Halfmoon Stream. Developed land only accounts for just under 5% of the source load. Phosphorus loads are presented in Table 7 and Figure 7.

Note that total loads by mass cannot be directly compared between watershed TMDLs due to differences in watershed area. See section *TMDL: Target Nutrient Levels for Halfmoon Stream* below for loading estimates that have been normalized by watershed area.

**Table 7:** Total Phosphorus Load by Source

| Halfmoon Stream | Total P (kg/year) | Total P (%) |
|---|---|---|
| **Source Load** | | |
| *Hay/Pasture* | 729.0 | 50.9% |
| *Cropland* | 190.1 | 13.3% |
| *Wooded Areas* | 76.4 | 5.3% |
| *Wetlands* | 12.5 | 0.9% |
| *Open Land* | 19.3 | 1.3% |
| *Barren Areas* | 0.7 | 0.05% |
| *Low-Density Mixed* | 15.6 | 1.1% |
| *Medium-Density Mixed* | 14.3 | 1.0% |
| *High-Density Mixed* | 1.8 | 0.1% |
| *Low-Density Open Space* | 36.1 | 2.5% |
| *Farm Animals* | 336.3 | 23.5% |
| *Septic Systems* | 0 | 0 |
| ***Source Load Total:*** | **1,432.1** | **100%** |
| | | |
| **Pathway Load** | | |
| *Stream Bank Erosion* | 385.0 | - |
| *Subsurface Flow* | 505.6 | - |
| | | |
| ***Total Watershed Mass Load:*** | **2,323** | |

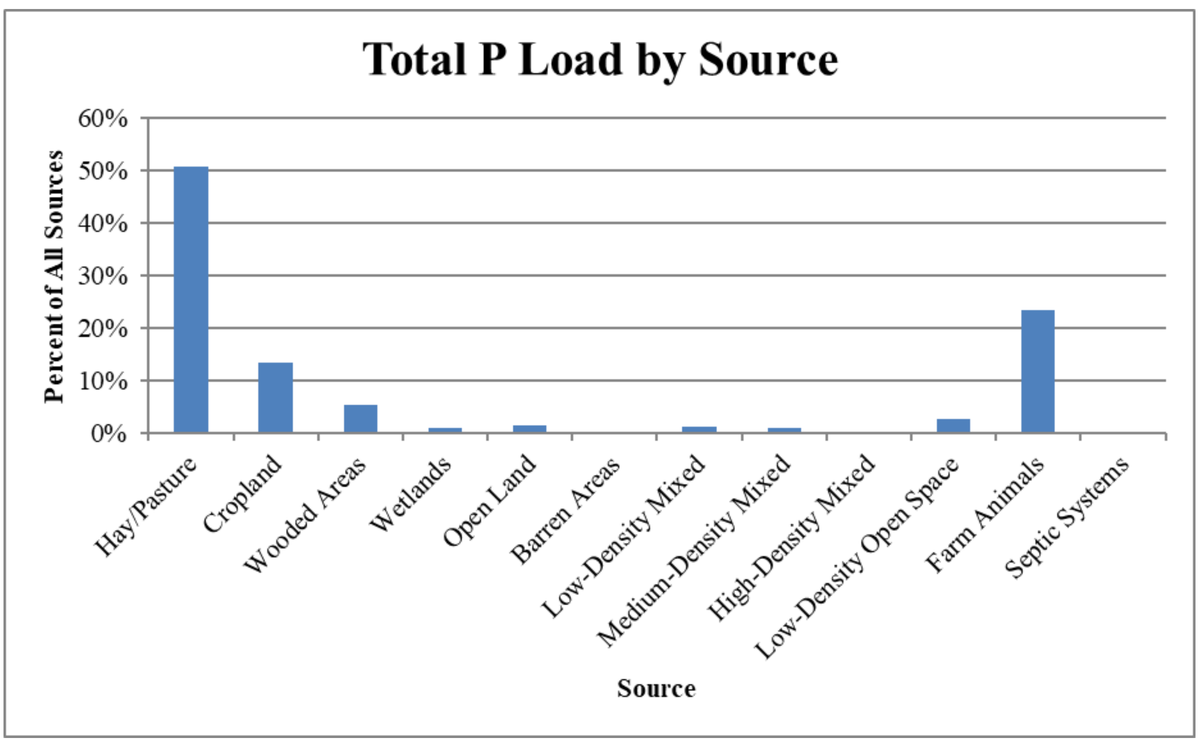



**Figure 7:** Total Phosphorus Load by Source in the Halfmoon Stream Watershed

## TMDL: TARGET NUTRIENT AND SEDIMENT LEVELS FOR HALFMOON STREAM

The existing loads for nutrients and sediments in the impaired segment of Halfmoon Stream are listed in Table 8, along with the TMDL (the allowable load) which was calculated from the average loading estimates of five attainment watersheds throughout the state. Table 8 also shows required reductions (as a percent) for each of sediment, total N, and total P pollutants. Table 9 presents a more detailed view of the modeling results and calculations used to compute the existing loads in Table 8. An annual time frame provides a mechanism to address the daily and seasonal variability associated with nonpoint source loads.

**Table 8:** Halfmoon Stream Pollutant Loading Compared to TMDL Targets

| Halfmoon Stream | | | |
|---|---|---|---|
| **Pollutant Load** | **Existing Load** | **TMDL** | **Reduction Required** |
| Total Annual Load per Unit Area | | Attainment Streams | |
| Sediment (kg/ha/yr) | 133.8 | 65.72 | 50.9% |
| Total N (kg/ha/yr) | 2.38 | 2.46 | None |
| Total P (kg/ha/yr) | 0.24 | 0.16 | 32.2% |

### Future Loading

The prescribed reduction in pollutants discussed in this TMDL reflects reduction from estimated existing conditions. Expansion of agricultural activities in the watershed have the potential to increase runoff and associated pollutant loads to Halfmoon Stream. To ensure that the TMDL targets are attained, future agricultural activities will need to meet the TMDL targets. However, between 2012 to 2017 in Waldo County, the growth in agricultural lands was decreasing, with an 18.3% decrease in the total number of farms and a 5.4% decrease in total farm area. Yet no change in the average farm size occurred in this time period. These values are extracted from the most recent (2017) Census of Agriculture (USDA 2017). Human population in Waldo County increased by 2.31% from 2000 to 2019 (US Census 2020). Future activities and BMPs that achieve TMDL reductions are addressed below.

### Next Steps

The use of agricultural and developed area Best Management Practices (BMP's) can reduce sources of polluted runoff in Halfmoon Stream. It is recommended that municipal officials in the Thorndike, Knox, and Unity villages, landowners, and conservation stakeholders work together to develop a watershed management plan to:

- Encourage greater citizen involvement through the development of a watershed coalition to ensure the long term protection of Halfmoon Stream;
- Run a "Hot-Spot Analysis" in *Model My Watershed* to determine sub-watershed locations of higher existing contributions of sediment and nutrients to the outlet of Halfmoon Stream watershed; then focus BMP mitigation in these hot-spot sub-areas of the watershed;
- Address existing nonpoint source problems in the Halfmoon Stream watershed by instituting BMPs where necessary; and

- Prevent <u>future</u> degradation of Halfmoon Stream through the development and/or strengthening of local Nutrient Management Ordinance.

**Table 9:** Annual Loads by Land Use, Other Sources, and Pathways for Halfmoon Stream Based on Modeling

| Halfmoon Stream | | | | |
|---|---|---|---|---|
| | **Area** (ha) | **Sediment** (1000 kg/yr) | **Total N** (kg/yr) | **Total P** (kg/yr) |
| **Land Uses** | | | | |
| *Hay/Pasture* | 1,175 | 111.3 | 2,012 | 729.0 |
| *Cropland* | 193 | 66.9 | 993 | 190.1 |
| *Wooded Areas* | 7,179 | 4.1 | 1,385 | 76.4 |
| *Wetlands* | 487 | 0.2 | 237 | 12.5 |
| *Open Land* | 305 | 8.3 | 431 | 19.3 |
| *Barren Areas* | 35 | 0.025 | 19 | 0.7 |
| *Low-Density Mixed* | 135 | 5.7 | 147 | 15.6 |
| *Medium-Density Mixed* | 31 | 7.1 | 142 | 14.3 |
| *High-Density Mixed* | 4 | 0.9 | 18 | 1.8 |
| *Low-Density Open Space* | 311 | 13.2 | 339 | 36.1 |
| **Total Area** | 9,855 | | | |
| **Other Sources** | | | | |
| *Farm Animals* | | 0.0 | 1,701 | 336.3 |
| *Septic Systems* | | 0.0 | 111 | 0.0 |
| | | | | |
| **Pathway Load** | | | | |
| *Stream Bank Erosion* | | 1100.5 | 1,381 | 385.0 |
| *Subsurface Flow* | | 0.0 | 14,501 | 505.6 |
| | | | | |
| **Total Annual Load** | | 1,318 | 23,417 | 2,323 |
| **Total Annual Load per Unit Area** | | 0.134 | 2.38 | 0.24 |
| | | 1000 kg/ha/yr | kg/ha/yr | kg/ha/yr |

# REFERENCES

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

Davies, S. P., and L. Tsomides (2002) Methods for Biological Sampling of Maine's Rivers and Streams. DEP LW0387-B2002, Maine Department of Environmental Protection, Augusta, ME.

Evans, B.M., S.A. Sheeder, and D.W. Lehning (2003) A spatial technique for estimating streambank erosion based on watershed characteristics. *Journal of Spatial Hydrology* 3(2).

Evans, B.M., & J.K. Corradini (2012) MapShed Version 1.5 Users Guide. Penn State Institute of Energy and the Environment. Available from : https://wikiwatershed.org/help/model-help/mapshed/

Jin, S., Homer, C.G., Yang, L., Danielson, P., Dewitz, J., Li, C., Zhu, Z., Xian, G., and Howard, D. (2019) Overall methodology design for the United States National Land Cover Database 2016 products. *Remote Sensing* 11(24).

Maine Department of Environmental Protection (Maine DEP) (2018) *2016 Integrated Water Quality Monitoring and Assessment Report*. Augusta, ME.

Stroud Water Research Center (2017) *Model My Watershed* [Software]. Available from https://wikiwatershed.org/

United States Census Bureau, Division of Population (US Census) (2020) *Annual Estimates of the Resident Population for Counties in Maine: 4/1/2010 to 7/1/2019* (CO-EST2019-ANNRES-23).

United States Department of Agriculture (USDA) (2017) Census of Agriculture: Waldo County, Maine. Table 8: Farms, Land in Farms, Value of Land and Buildings, and Land Use: 2017 and 2012 Retrieved from: https://www.nass.usda.gov/Publications/AgCensus/2017/Full_Report/Volume_1,_Chapter_2_County_Level/Maine/st23_2_0008_0008.pdf

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