Phase 1 Stream Geomorphic Assessment
New Haven River Watershed
Addison County, Vermont

October 2003
Revised June 2004

South Lincoln, Vt (Main Stem, Reach M26)

Prepared by

South Mountain Research & Consulting
2852 South 116 Road, Bristol, VT 05443
802-453-3076

Prepared under contract to

Addison County Regional
Planning Commission
79 Court Street
Middlebury, VT 05753
802-388-3141

TABLE OF CONTENTS

FIGURES

TABLES

APPENDICES

NOTES ON REVISION DATED JUNE 2004

June 2004 revisions to the October 2003 Phase 1 Stream Geomorphic Assessment of the New Haven River watershed resulted from a QA Review performed by Mike Kline of the VTDEC River Management Section on 4 November 2003. Appendix H to this revised Phase 1 report provides a detailed response to the QA review, and summarizes revisions made to the Phase 1 database, where appropriate.

In consideration of the revisions noted in Appendix H, the Total Stream and Watershed Impact Ratings (Table 8 of the Phase 1 data) were revised slightly. Total Impact Scores for eleven of the 64 reaches in the New Haven watershed were increased by 2 points; 23 reaches had Total Impact Scores increased by 1 point, and one reach's impact score was reduced by 1 point. Total Impact Scores for the remaining 29 reaches remained unchanged.

1.0 INTRODUCTION

A Phase 1 Geomorphic Assessment of the New Haven River watershed has been completed by South Mountain Research & Consulting (SMRC) of Bristol, Vermont. Work has been conducted under contract to the Addison County Regional Planning Commission, with funding provided by a Federal Emergency Management Agency Project Impact Grant.

A Phase 1 Geomorphic Assessment was conducted to delineate the New Haven River watershed and identify reaches for more detailed assessment. Phase 1 assessments are provisional, based largely on remote-sensing methods. Preliminary assessment of geomorphic condition in Phase 1 has been conducted to assist watershed stakeholders in prioritizing select reaches for further more detailed assessment and surveying in subsequent Phase 2 and 3 Geomorphic Assessments.

2.0 BACKGROUND

The New Haven River watershed is a 116-square-mile basin located primarily in Addison County, Vermont (see Appendix A). It is one of several smaller watersheds which together comprise the larger Otter Creek Basin which drains northward to Lake Champlain (Figure 1). The New Haven River watershed drains portions of eleven towns in Addison, Chittenden and Washington Counties (see Figure A.2 in Appendix A). However, the majority of the watershed is contained in Lincoln, Bristol, Middlebury, and New Haven townships (35%, 25%, 14%, and 10%, respectively).

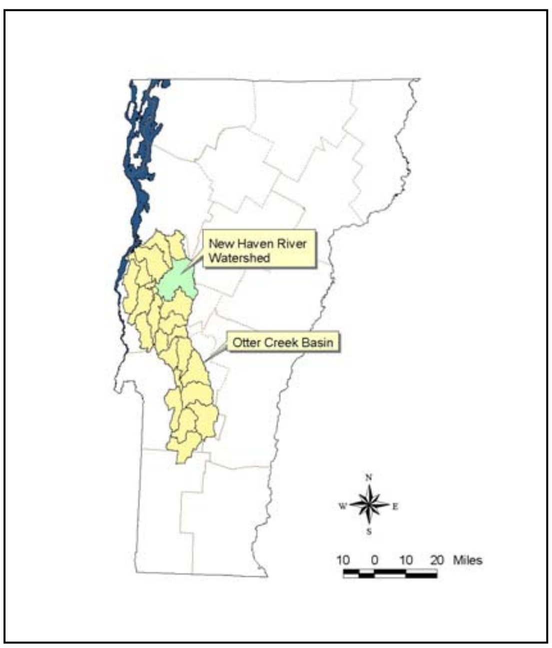


Figure 1.
Location Map
New Haven River Watershed
Addison County, VT

2.1 Regional Geologic Setting

The New Haven River watershed spans two major geologic provinces. Headwaters, including the upper 13.2 miles of the main stem, are located on the till-blanketed bedrock slopes of the Green Mountains in Lincoln, Starksboro, and Ripton. The remainder of the watershed, from below Bristol village to the confluence with Otter Creek, is located on the broad Champlain Valley. In recent geologic time (from 20,000 to 13,200 years before present) this landscape was occupied by advancing and retreating glaciers, with ice up to a mile or more in thickness above the present land surface in the Champlain Valley. As the global climate warmed and the glaciers receded, a large fresh-water lake inundated the Champlain Valley. At its highest stage, Lake Vermont's shoreline was located at the foot of the Green Mountains. A large delta deposit was built out into Lake Vermont by a younger New Haven River. Today Bristol village is established on this former delta.

Lake Vermont waters receded in stages as natural dams in southern Vermont and New York gave way. From approximately 12,800 to 10,200 years before present, marine waters inundated the valley from the St. Lawrence Seaway as the rate of rise in ocean water levels far exceeded the rate of rise, or isostatic rebound, of the land surface now relieved of its glacial burden. The maximum elevation of these brackish waters is not believed to have extended into the present-day New Haven watershed (Connally, 1970). Champlain Sea waters had receded from the greater Champlain Valley by approximately 10,000 years before present, as the rate of land rise began to outpace the rate of sea-level rise. River systems, including the New Haven River, then went to work moving sediments left in the wake of the glaciers, and further eroding the Green Mountains. Our surrounding landscape continues in this erosion phase today (Stewart and MacClintock, 1969; Cronin, 1977; Wagner, 1972; Connally and Calkin, 1972). In the last 10,000 years or so, the New Haven River has eroded more than 150 feet down through Bristol's delta deposits.

2.2 Hydrology

The New Haven River watershed is approximately 116.4 square miles in size. The basin is unregulated. A United States Geological Survey (USGS) station (# 04282525) is located near the confluence with Otter Creek at Brooksville, VT, at the Dog Team Road crossing. This location is at the downstream reach break for reach, M02 (see reach orthophotos in Appendix E). Station # 04282525 measured flow from an approximate drainage area of 115 square miles (or 99% of the watershed) and operated from 1990 to 2002. The maximum daily flow recorded during this 12 year time span was 6,880 cubic feet per second on 27 June 1998.

2.3 Flooding History

A 1986 *Flood Insurance Study* for the Town of New Haven (Anderson-Nichols, 1986) indicates that:

> "The New Haven River is subject to flash floods that are due to its steep slopes. Repeated damage to structures in the flood plains of Otter Creek and the New Haven River has occurred in 1913, 1927, 1936, 1958, 1960, and 1973, with the 1927 flood being the largest of record."

More recently, the New Haven River watershed has been impacted by the floods of late June / early July of 1998 and July of 2000.

3.0 METHODS

The Phase 1 Geomorphic Assessment of the New Haven River watershed has been conducted in accordance with the April 2003 *Vermont Stream Geomorphic Assessment, Phase 1 Handbook* published by the Vermont Agency of Natural Resources (VTANR). Reference is hereby made to this protocol for the specific scope of work. The majority of Steps 2 through 4 has been completed with use of Version 2 of the ArcView™ extension: *Stream Geomorphic Assessment Tools* (SGAT) (VTANR, April 2003).

In Phase 1, reaches are defined based on variation in valley confinement, slope, and sinuosity. The Phase 1 process results in a standardized method for identification of reaches and location of land features relative to the river system. In addition, Phase 1 provides a frame of reference for future restoration and conservation work and additional watershed-based studies (e.g., habitat and natural communities mapping, surficial geologic mapping, and water quality assessments).

As per guidance contained in the Phase 1 protocol (p.12), tributaries contributing 10% or more of the upstream watershed area at their confluence with the main stem are considered principal tributaries and are recommended for reach delineation like the main stem. Following this convention, drainage areas of the larger tributaries in the New Haven River watershed were delineated (Figure 2) and four were found to contribute more than 10% of the upstream watershed area at their point of confluence. These were assigned tributary identifications, T1 through T4, as follows:

Table 1. Identification of Principal Tributaries in the New Haven River Watershed.

Tributary Identification	Name	Drainage Area (sq mi)	Drainage Area Upstream and Including Principal Tributary (sq mi)	% of Watershed Area Upstream of Confluence	Total New Haven Watershed Drainage Area (sq mi)	% of Total New Haven Watershed Area
T1	Muddy Brook	17.0	113.8	14.9%	116.4	14.6%
T2	Little Notch	10.8	85.6	12.6%	116.4	9.3%
T3	Baldwin Creek	17.9	67.6	26.5%	116.4	15.4%
T4	Beaver Meadow	10.6	40.8	26.0%	116.4	9.1%

While substantial development has occurred within the Muddy Brook, Baldwin Creek and Beaver Meadow tributaries, in many cases leading to apparent impacts to the river network, the Little Notch tributary watershed is largely forested and undeveloped at present. Therefore, this Phase 1 assessment did not include reach delineation for the Little Notch tributary (T3). A Phase 1 addendum can be conducted, if such delineation and reach assessment becomes warranted in the future.

Appendix B provides a key to the orthophotograph and topographic resources utilized in remote sensing. Other references included the Addison County Soil Survey, surficial and bedrock geology maps, and land cover/ land use GIS coverage from the Vermont Center for Geographic Information.

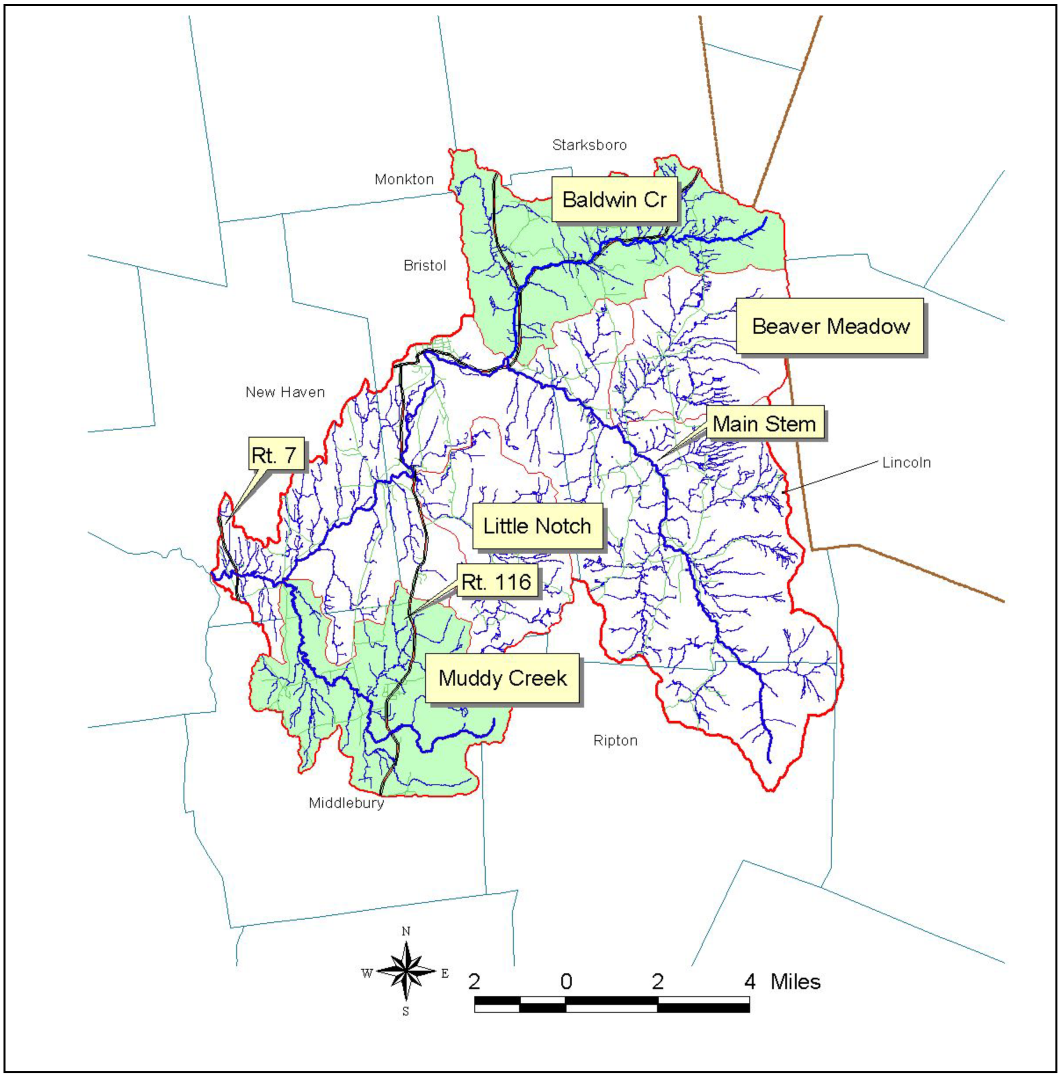


Figure 2. Location of Principal Tributaries in New Haven River Watershed, Addison County, VT

4.0 RESULTS

The Phase 1 process has delineated a total of 64 reaches for assessment in the New Haven River watershed (see Table 2). Reaches range in length from 1,885 ft to 8,681 ft, with an average length of 4,200 feet.

Table 2. Reach Delineation in the New Haven River Watershed.

Tributary Identification	Name	Drainage Area (sq mi)	Channel Length (mi)	Number Reaches
M	Main Stem	116.4	25.7	31
T1	Muddy Brook	17.0	11.0	15
T3	Baldwin Creek	17.9	8.8	11
T4	Beaver Meadow	10.6	5.5	7
			Total:	64

Reach-based sub-watersheds are depicted on Figure 3. Reach descriptions and locations are provided in Table 1 of Appendix C. Orthophotographs (dated 1995) of each reach are included in Appendix E. Topographic maps of each reach are included in Appendix F.

4.1 Preliminary Stream Typing

Table 2 of Appendix C contains the channel dimensions (length, width, sinuosity, valley confinement) for each reach, as well as the total drainage area above each reach. From these data, a preliminary stream type was assigned to each reach. Stream reaches are provisional and are not field-truthed. These assigned stream types should not be used to support channel management decisions or restoration designs.

4.2 Preliminary Assessment of Reach Impacts

Based on the proximity of roads and residential or commercial development, and the occurrence of land uses and past channel management actions within the corridor and watershed surrounding each reach, a preliminary assessment of reach impacts was compiled (see Table 8 of Appendix C). Reach impacts were defined by remote-sensing methods, with limited field-truthing of vehicle-accessible portions of select reaches. Impact scores should be considered provisional.

4.3 Preliminary Reach Condition, Adjustment Process and Sensitivity

For those reaches which could be accessed in part by vehicle, reach geomorphic condition, dominant adjustment processes and reach sensitivity were assigned preliminarily (Table 9 of Appendix C). These determinations are provisional and are not substantiated by field measurements.

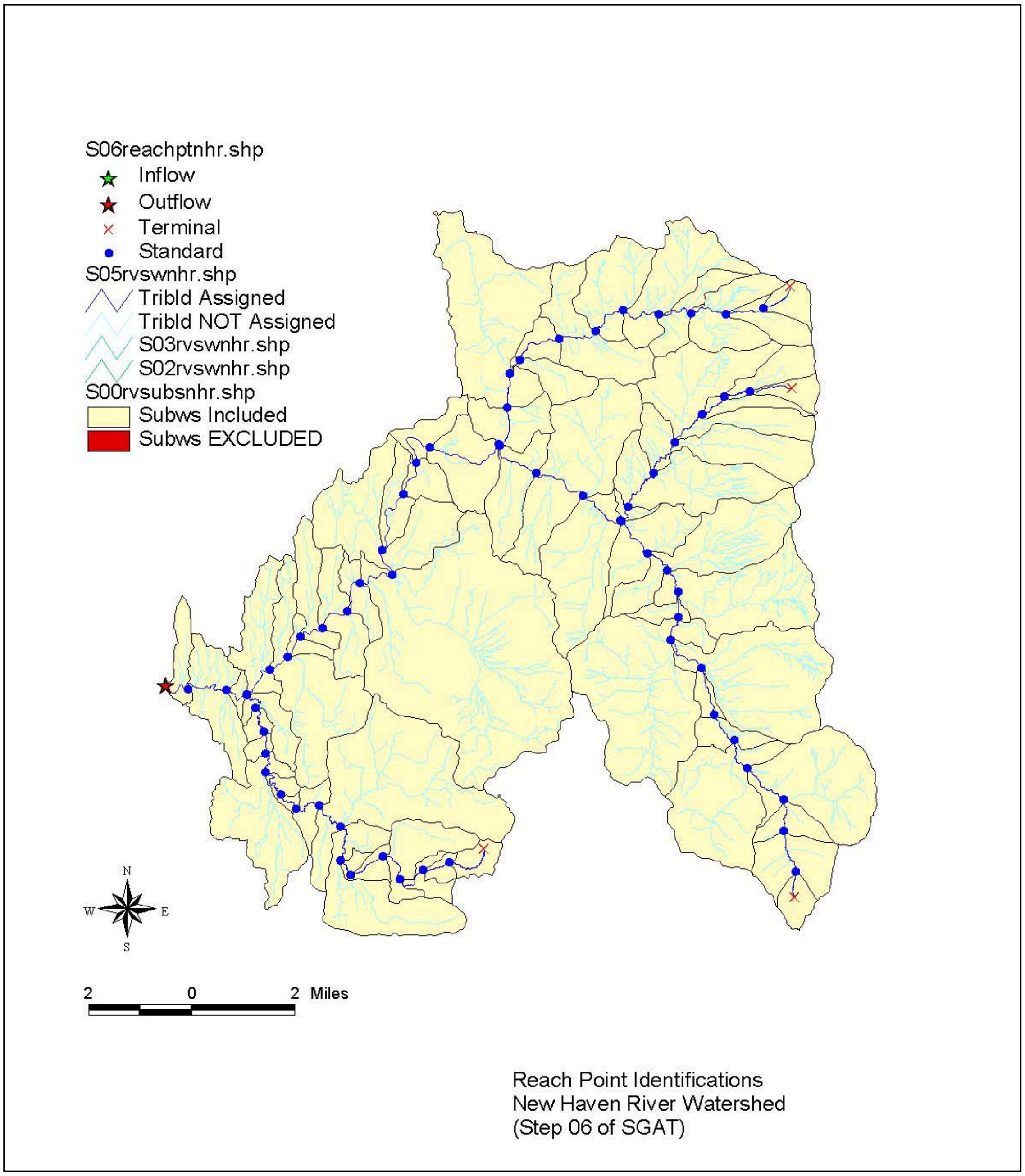


Figure 3. Reach and Reach-based Subwatershed Delineations
New Haven River Watershed, Addison County, VT

5.0 RECOMMENDATIONS

It is recommended that Phase 2 assessments (and Phase 3 assessments, where warranted) be completed on those reaches which, at present, are in conflict with human investments, including bridges, roads, culverts, residential and commercial development, and agricultural use. In general, these reaches tend to be the ones with the highest identified provisional impact scores. They are located through and south of Bristol village, through West Lincoln and Lincoln villages, through Downingsville (T4) and Jerusalem (T3). Specific reaches recommended for Phase 2 assessment are listed below:

Main Stem:
Reaches M03 through M15; M17 through M22

Baldwin Creek (T3):
Reaches T3.06 through T3.08

Beaver Meadow (T4):
Reaches T4.02 through T4.04

During Phase 2 assessments, it would also be prudent to conduct additional historical research to more thoroughly identify and characterize:

- past flood events impacting the watershed, locations and causal factors for damages;
- past channel management activities including armoring, dredging and berming, gravel extraction, floodplain encroachments, etc; and
- trends in land use and land cover over recorded time, which have an impact on channel equilibrium by altering water and/or sediment loads.

Historical research will improve assessments for both the above-recommended Phase 2 reaches and the remaining reaches assessed only through Phase 1. The Phase 1 and 2 database is intended to be a working database, able to be updated with the recognition of new information.

6.0 REFERENCES

Addison County River Watch Collaborative, 2001, Citizen Water Quality Monitoring Program.

Addison Independent, July 20, 2000, "Flood rips Lincoln, Ripton."

Addison Independent, July 18, 2002, "Future Crossing", page 3A.

Anderson-Nichols & Co., Inc., September 4, 1986. *Flood Insurance Study, Town of New Haven, VT, Addison County*, FEMA Comm. No. 500009, prepared for the Federal Insurance Administration under Contract No. H-3862. (Field work completed in June 1976).

C. L. Davis Consulting Associates, Ltd., March 2003, *Stream Geomorphic Assessment Tools: An ArcView Extension*. V.2.

Connally, G. Gordon, 1970. *Surficial Geology of the Brandon-Ticonderoga 15-Minute Quadrangles, Vermont*. Vermont Geological Survey: Studies in Vermont Geology No. 2.

Connally, G. Gordon and Parker E. Calkin, 1972, *Woodfordian Glacial History of the Champlain Lowland, Burlington to Brandon, Vermont*. New England Intercollegiate Geological Conference, 64th Annual Meeting Guidebook for Field Trips in Vermont, pp. 389-397.

Cronin, C. M., 1977, Late-Wisconsin Marine Environments of the Champlain Valley (New York, Quebec). *Quaternary Research* 7: 238-253.

Dunne, T. and Leopold, L., 1978, Water in Environmental Planning, W. H. Freeman and Co.

Montgomery, D. R. and J. M. Buffington, 1997, Channel-reach morphology in mountain drainage basins. *Geological Society of America Bulletin*, v.109, no. 5, p. 596-611.

Rosgen, D., 1996, Applied Fluvial Morphology. Wildland Hydrology Books, Pagosa Springs, Co.

Schumm, S., 1984. The Fluvial System. John Wiley and Sons, New York, NY.

Stewart, David P., 1973. Geology for Environmental Planning in the Burlington-Middlebury Region, Vermont. Vermont Geological Survey, Environmental Geology No. 3

Stewart, David P. and Paul MacClintock, 1969, The Surficial Geology and Pleistocene History of Vermont. Vermont Geological Survey Bulletin No. 31.

USGS, 2003, on-line surface water data, http://waterdata.usgs.gov/vt/nwis.

VT Agency of Natural Resources, April 2003a, Stream Geomorphic Assessment: Phase 1 Handbook.

VT Agency of Natural Resources, April 2003b, Stream Geomorphic Assessment Handbook: Rapid Stream Assessment, Phase 2 Field Protocols.

VTDEC Water Quality Division, 2001, Vermont Regional Hydraulic Geometry Curves: 2001 Provisional.

Wagner, W. Philip, 1972, Ice Margins and Water Levels in Northwestern Vermont. *New England Intercollegiate Geological Conference, 64th Annual Meeting Guidebook for Field Trips in Vermont*, pp. 319-342.

Williams, G.P., 1986. River Meanders and Channel Size. *Journal of Hydrology*, v. 88, pp. 147-164.

APPENDIX A

New Haven River Watershed Municipal Boundaries

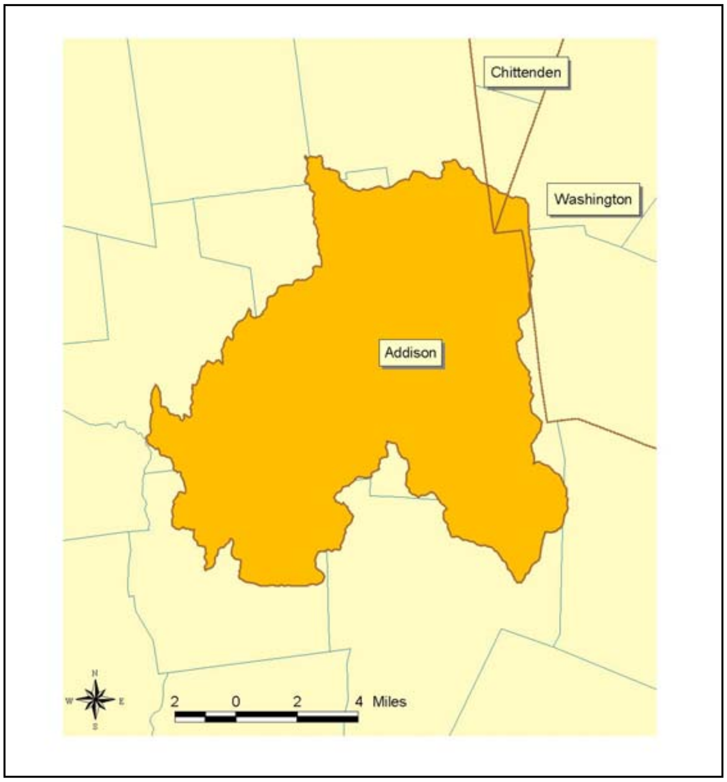


Figure A.1 County Proportions
New Haven River Watershed

County	Area (sq. mi.)	Area (%)
Addison	114.6	98.5
Chittenden	0.5	0.4
Washington	1.3	1.1
Total	**116.4**	**100.0**

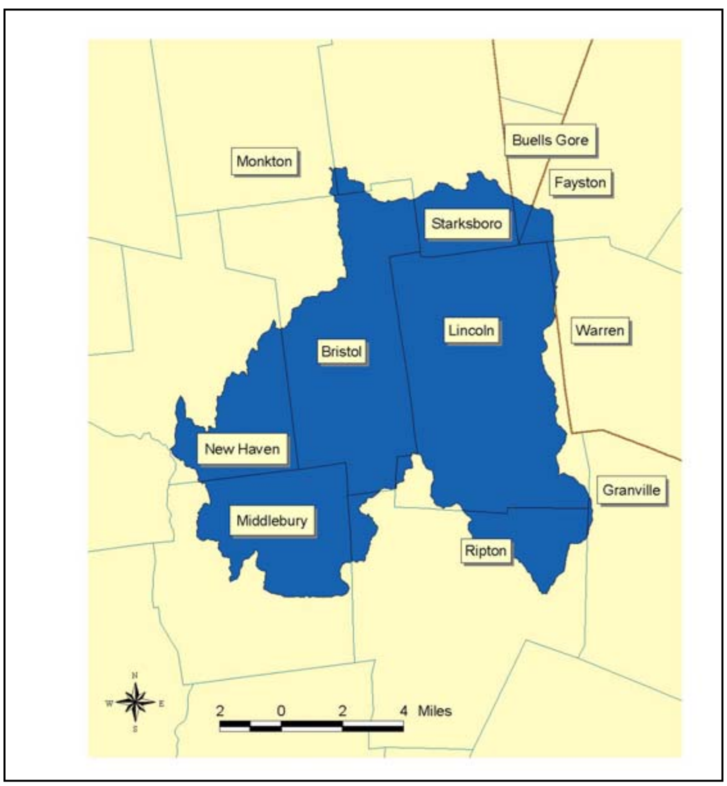


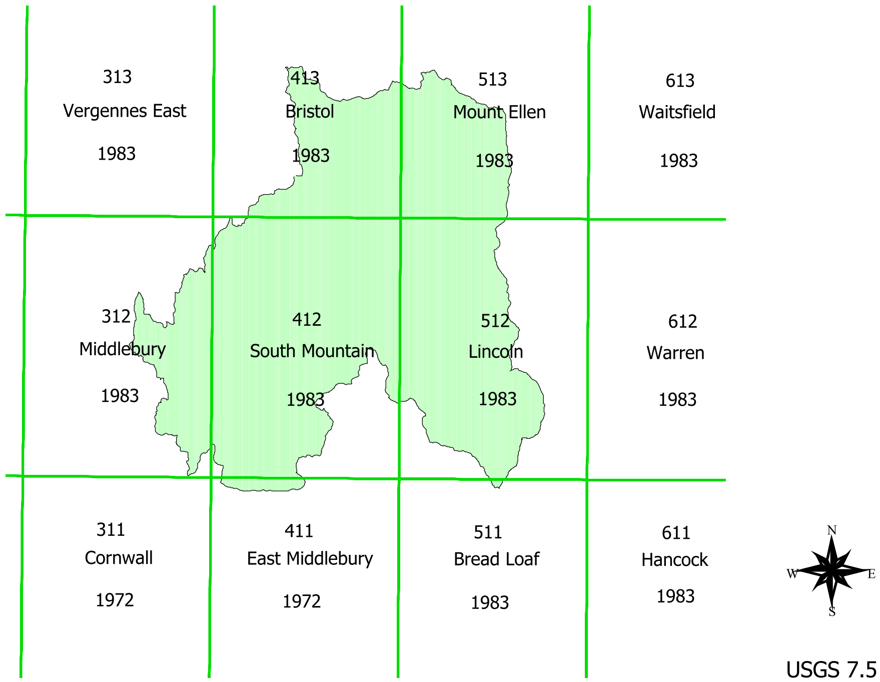
Figure A.2 Town Proportions
New Haven River Watershed

Town	Area (sq. mi.)	Area (%)
Bristol	29.4	25.2
Buells Gore	0.5	0.4
Fayston	1.0	0.8
Granville	0.1	0.1
Lincoln	41.1	35.3
Middlebury	16.6	14.3
Monkton	0.1	0.1
New Haven	11.8	10.2
Ripton	7.9	6.8
Starksboro	7.5	6.4
Warren	0.3	0.3
Total	**116.4**	**100.0**

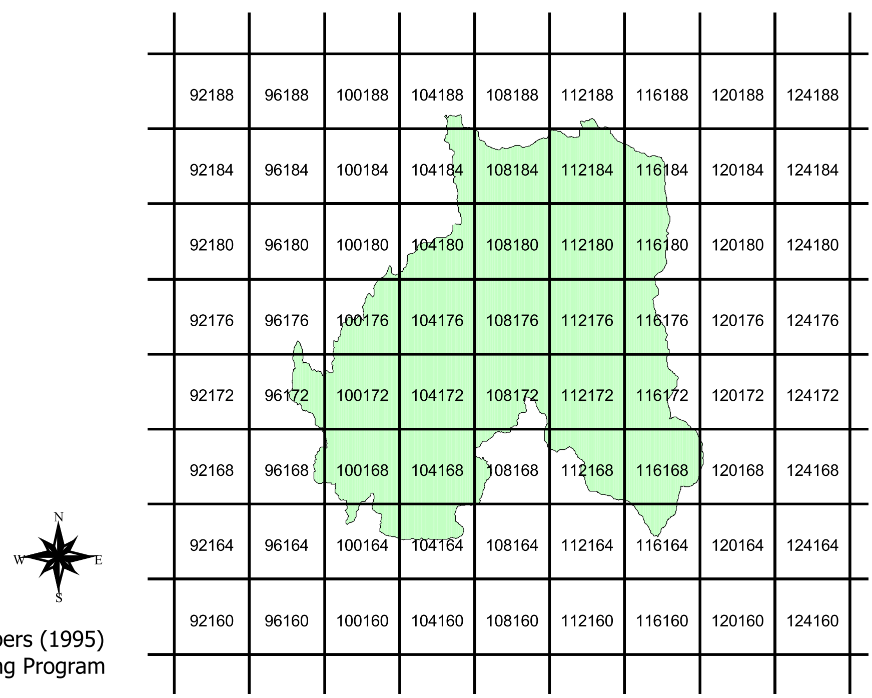
APPENDIX B

Remote Sensing Resources

Appendix B.
Remote Sensing Resources
New Haven River Watershed
Addison County, Vermont



USGS 7.5 min Topographic Map Index



Orthophotograph Grid Numbers (1995)
Vermont Mapping Program

APPENDIX C

Phase 1 Database Tables

Materials are found on Data Management System at:
https://anrnode.anr.state.vt.us/ssl/sga/security/frmlogin.cfm

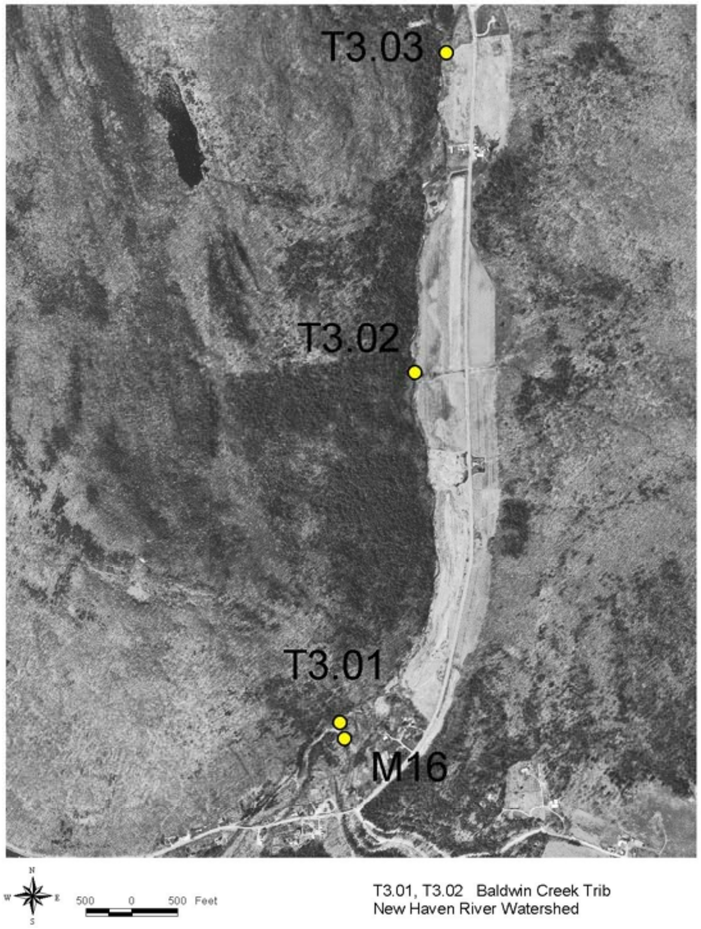
APPENDIX D

Quality Assurance / Quality Control Form

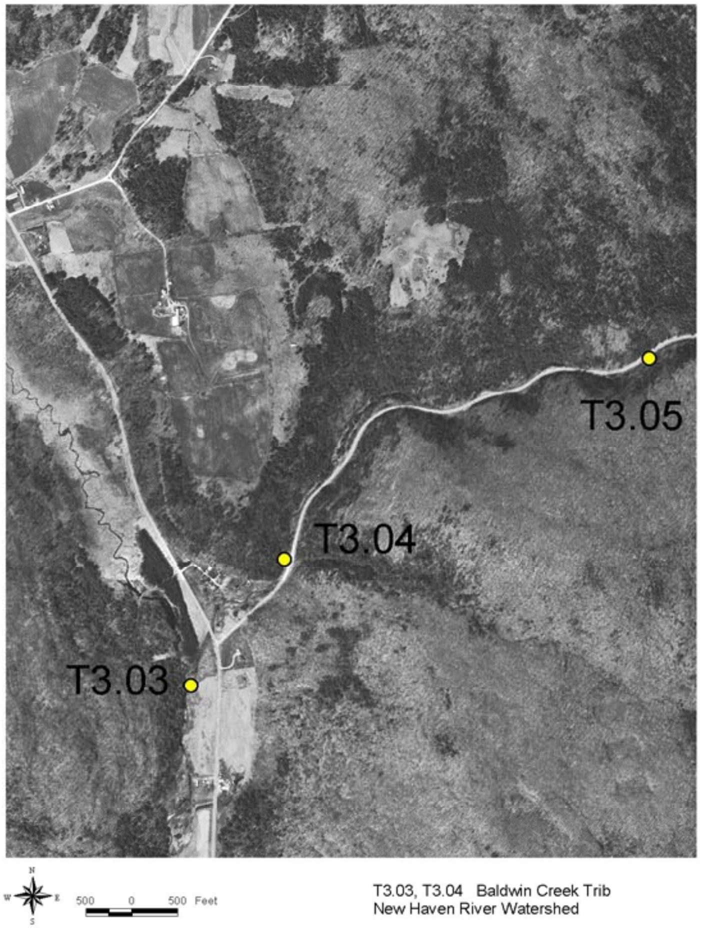
Materials are found on Data Management System at:
https://anrnode.anr.state.vt.us/ssl/sga/security/frmlogin.cfm

APPENDIX E

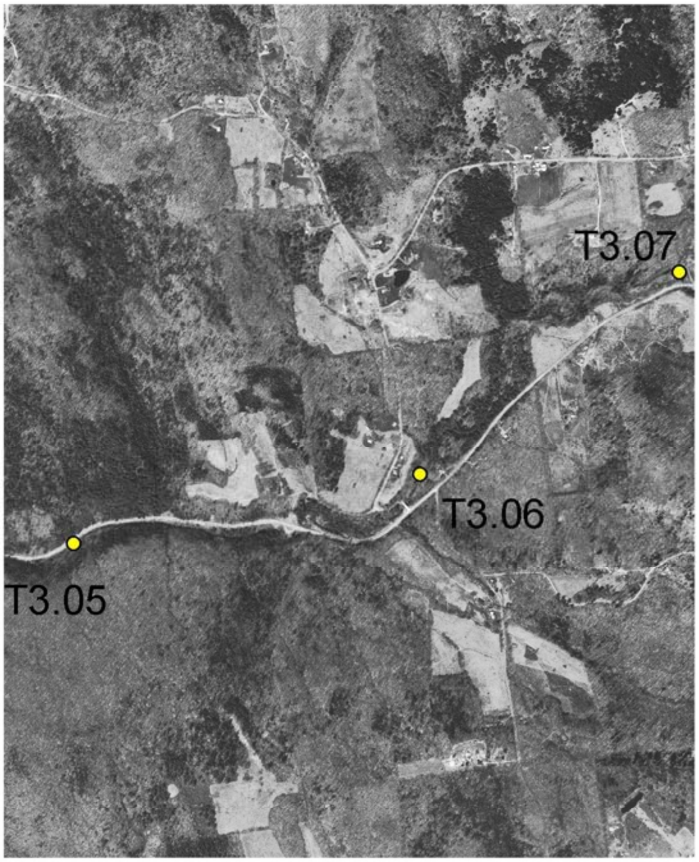
Reach-based Orthophotos



T3.01, T3.02 Baldwin Creek Trib
New Haven River Watershed

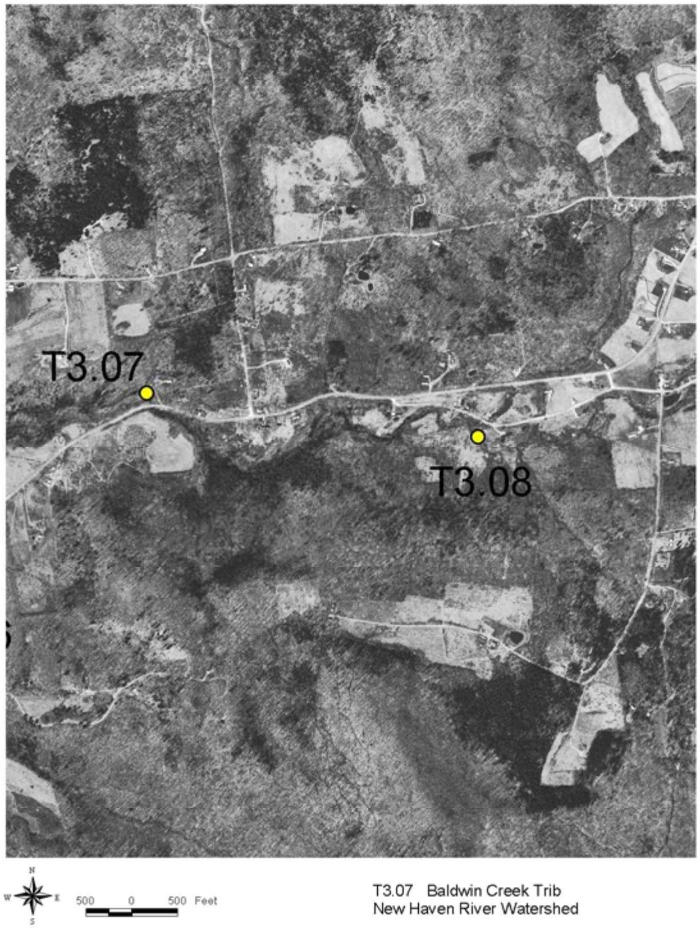


T3.03, T3.04 Baldwin Creek Trib
New Haven River Watershed

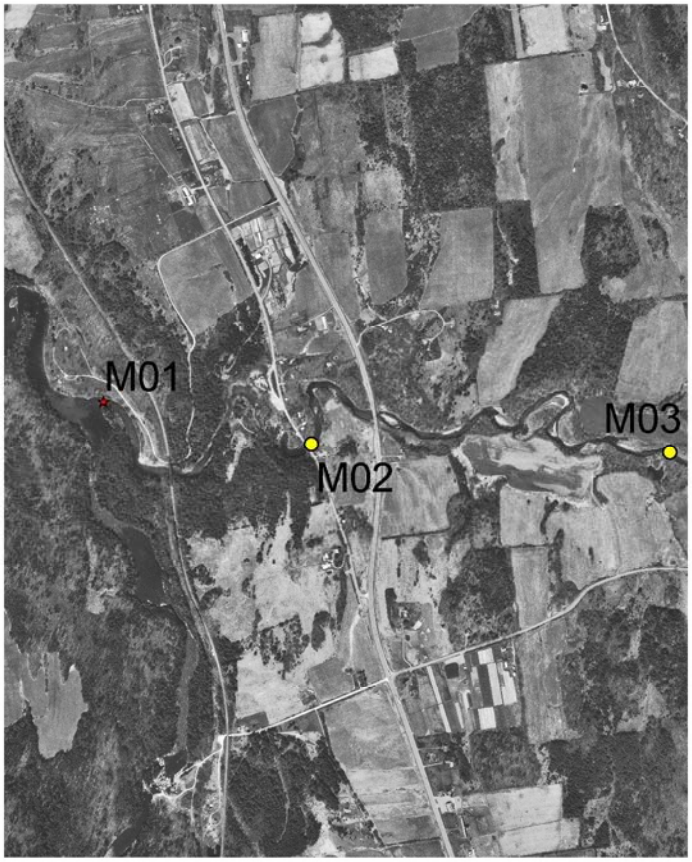


N
W E
S
500 0 500 Feet

T3.05, T3.06 Baldwin Creek Trib
New Haven River Watershed

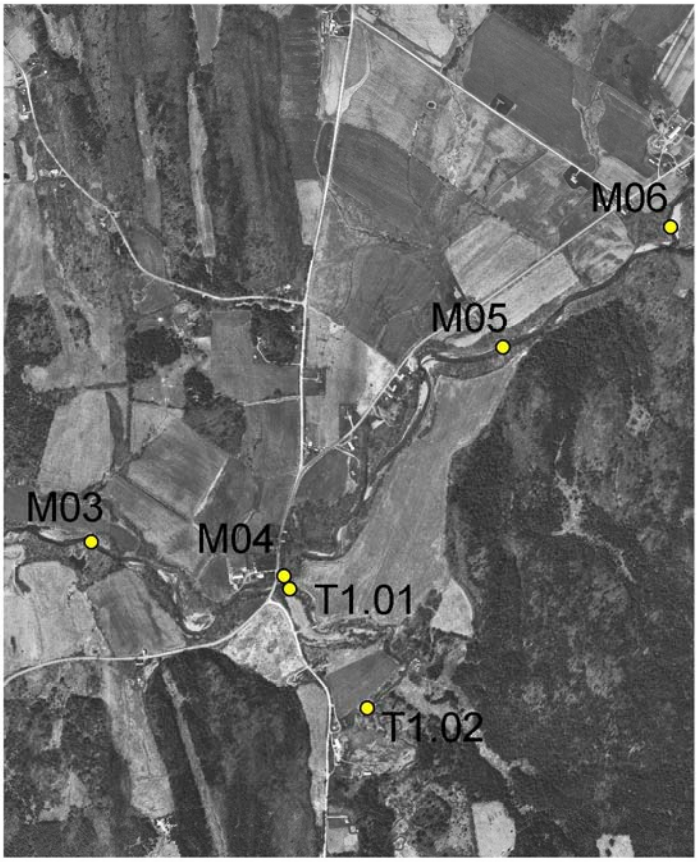


T3.07 Baldwin Creek Trib
New Haven River Watershed



N W E S 500 0 500 Feet

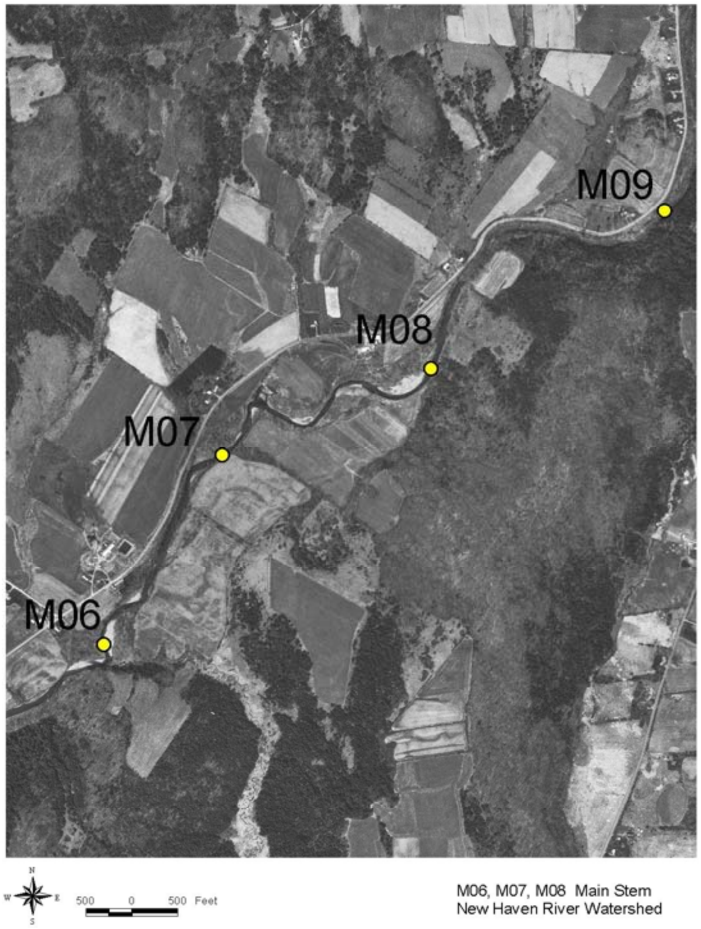
M01, M02 Main Stem
New Haven River Watershed



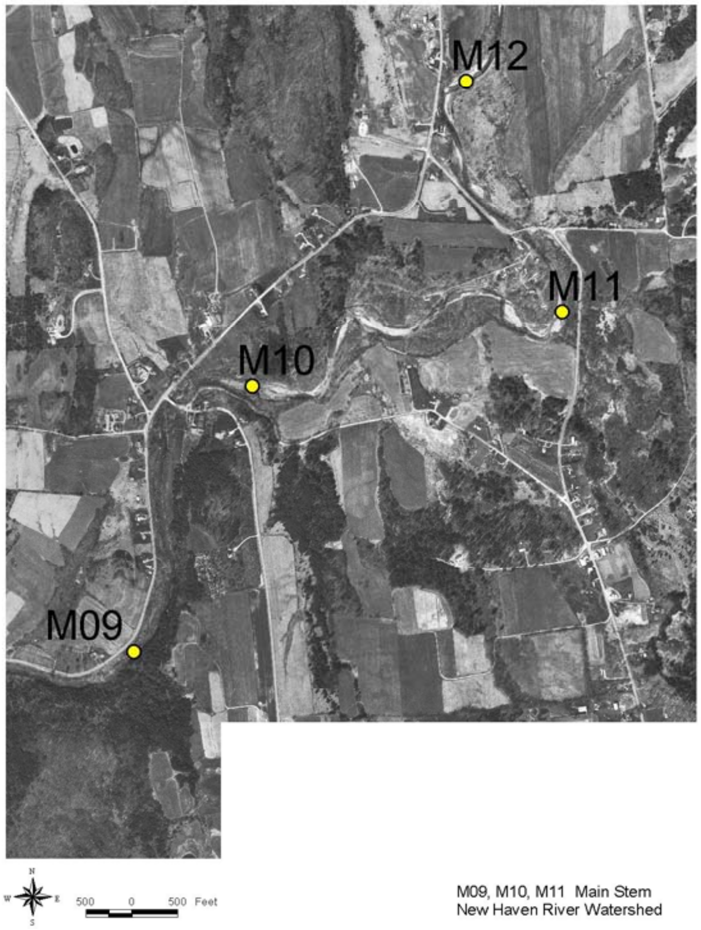
N W E S

500 0 500 Feet

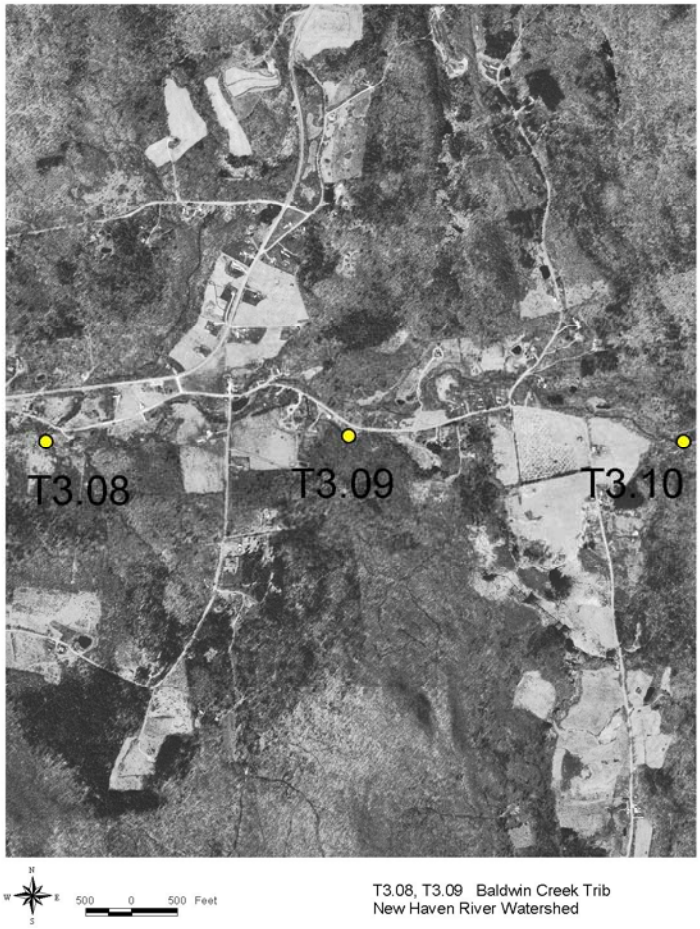
M03, M04, M05 Main Stem
New Haven River Watershed



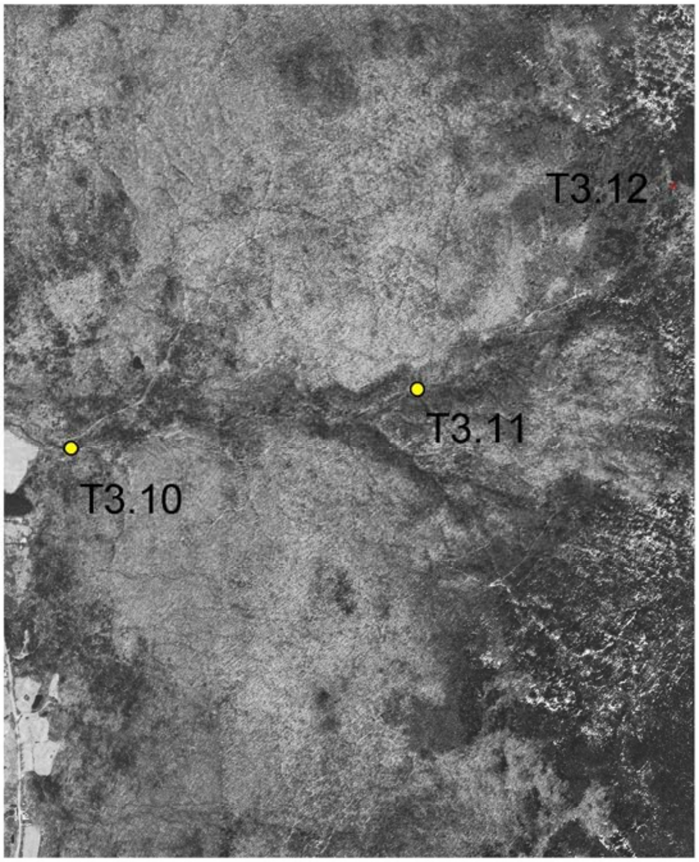
M06, M07, M08 Main Stem
New Haven River Watershed



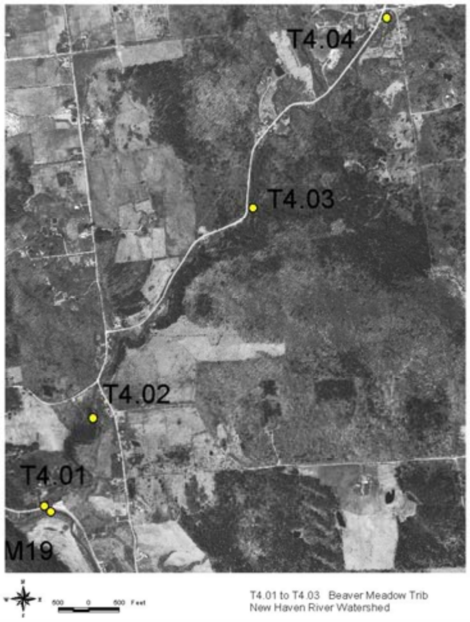
M09, M10, M11 Main Stem
New Haven River Watershed



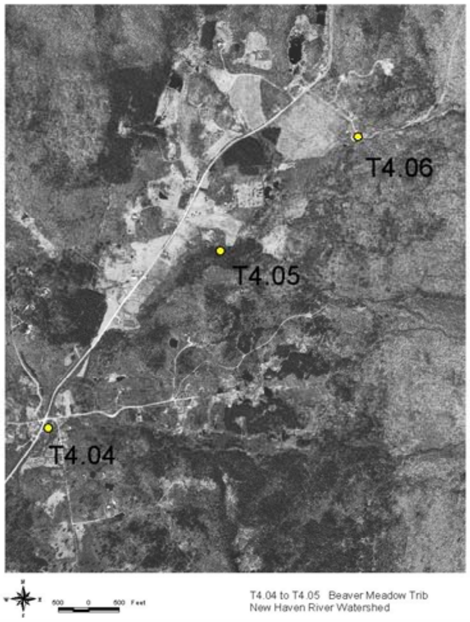
T3.08, T3.09 Baldwin Creek Trib
New Haven River Watershed



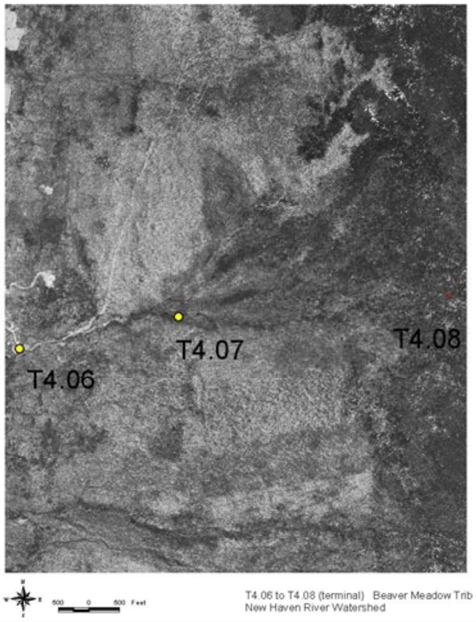
T3.10, T3.11 Baldwin Creek Trib
New Haven River Watershed



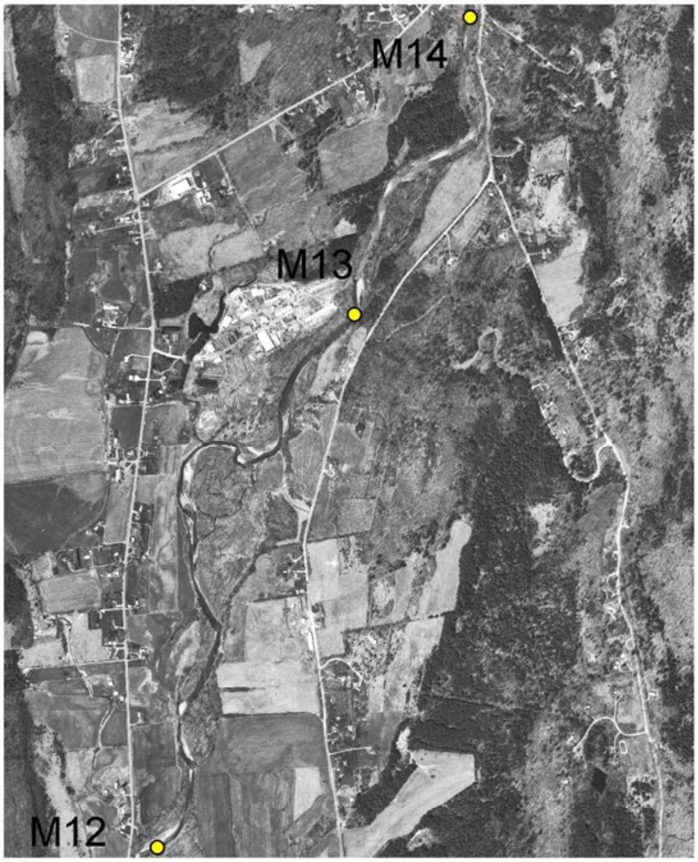
T4.01 to T4.03   Beaver Meadow Trib
New Haven River Watershed



T4.04 to T4.05 Beaver Meadow Trib
New Haven River Watershed



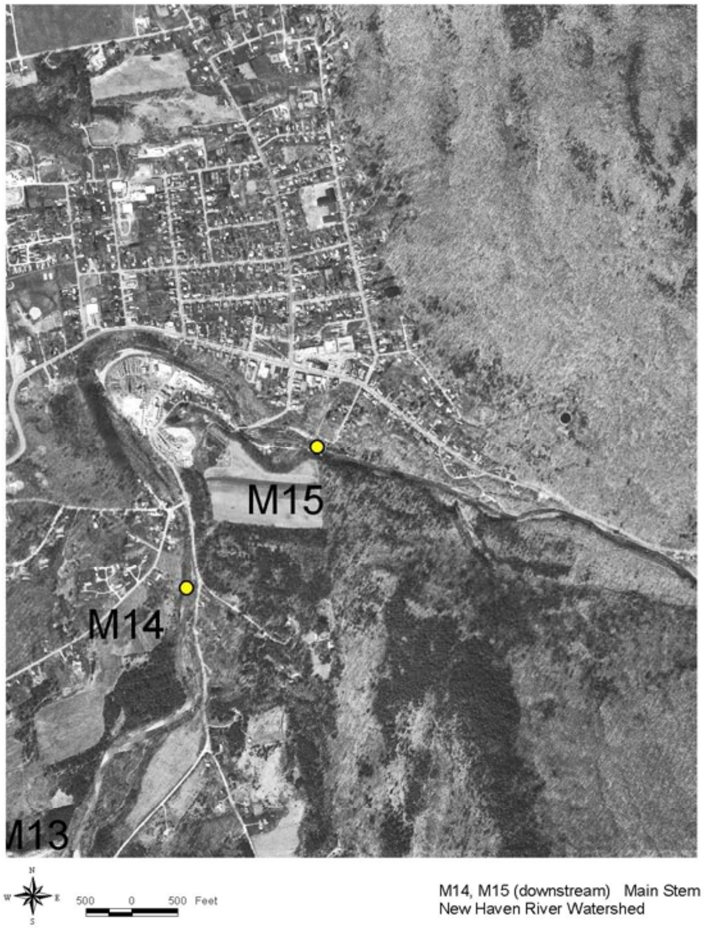
T4.06 to T4.08 (terminal)   Beaver Meadow Trib
New Haven River Watershed



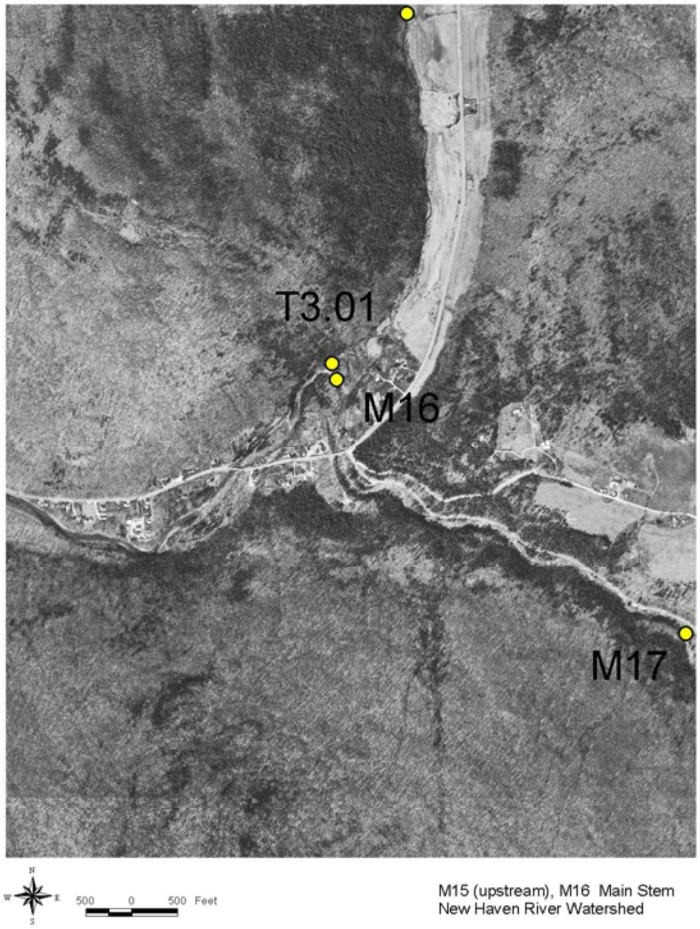
N
W E
S

500 0 500 Feet

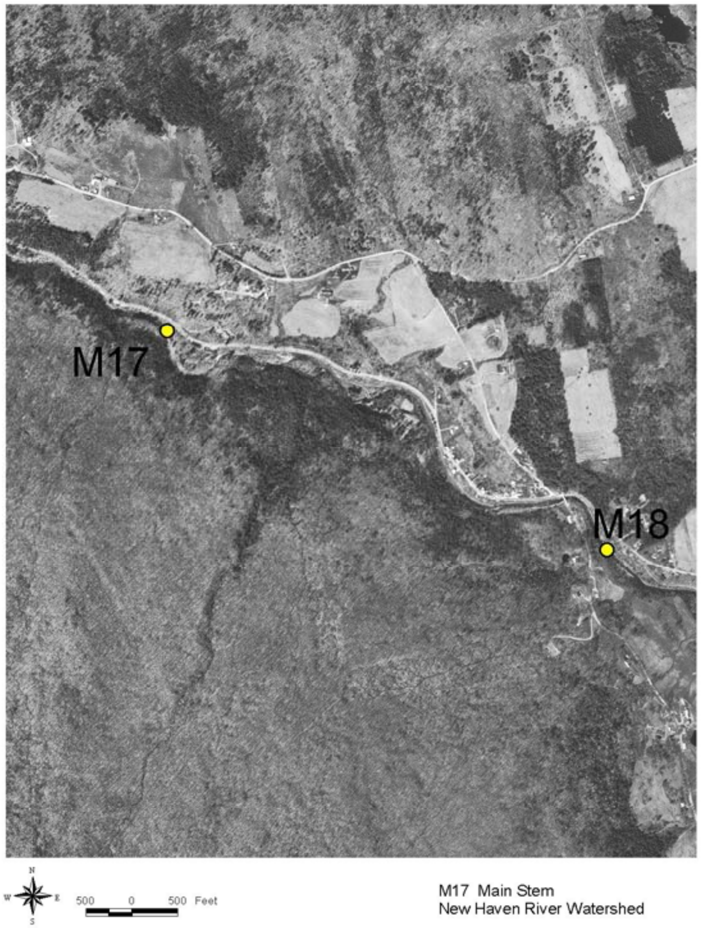
M12, M13 Main Stem
New Haven River Watershed



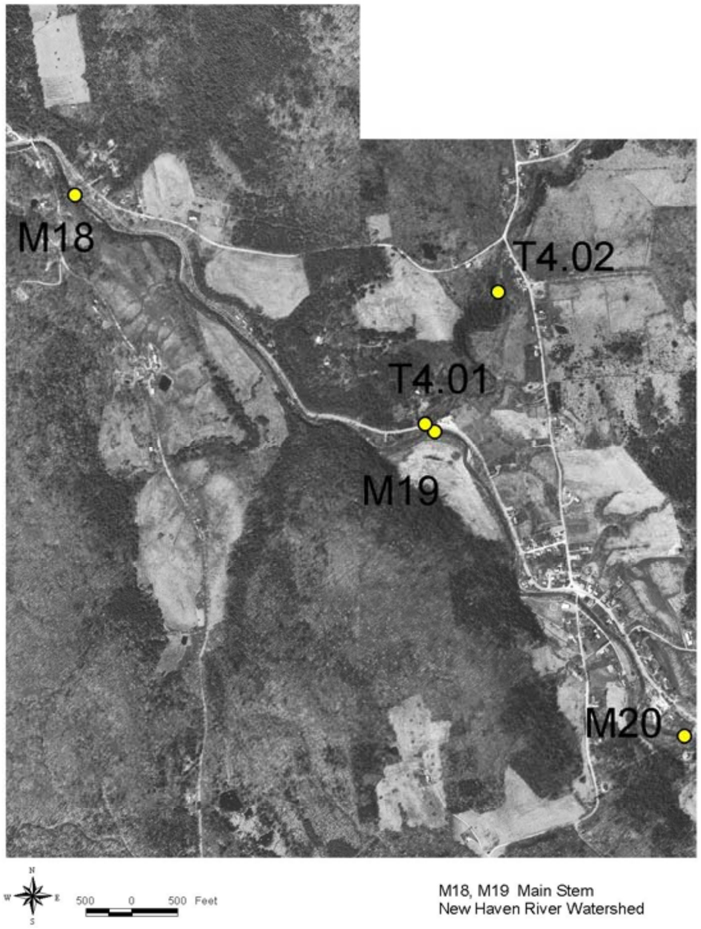
M14, M15 (downstream) Main Stem
New Haven River Watershed



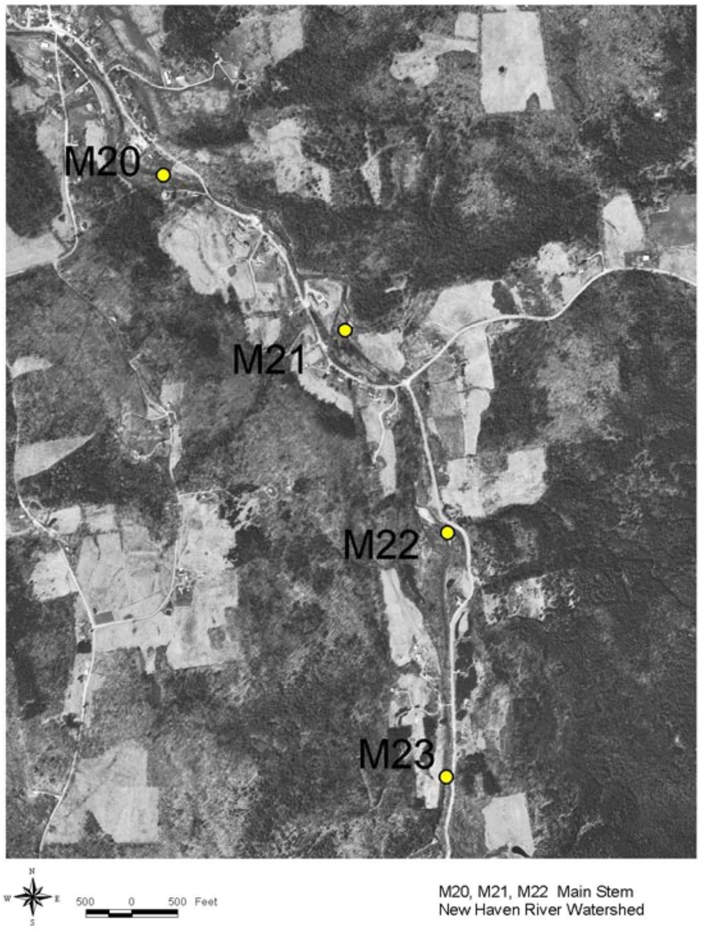
M15 (upstream), M16 Main Stem
New Haven River Watershed



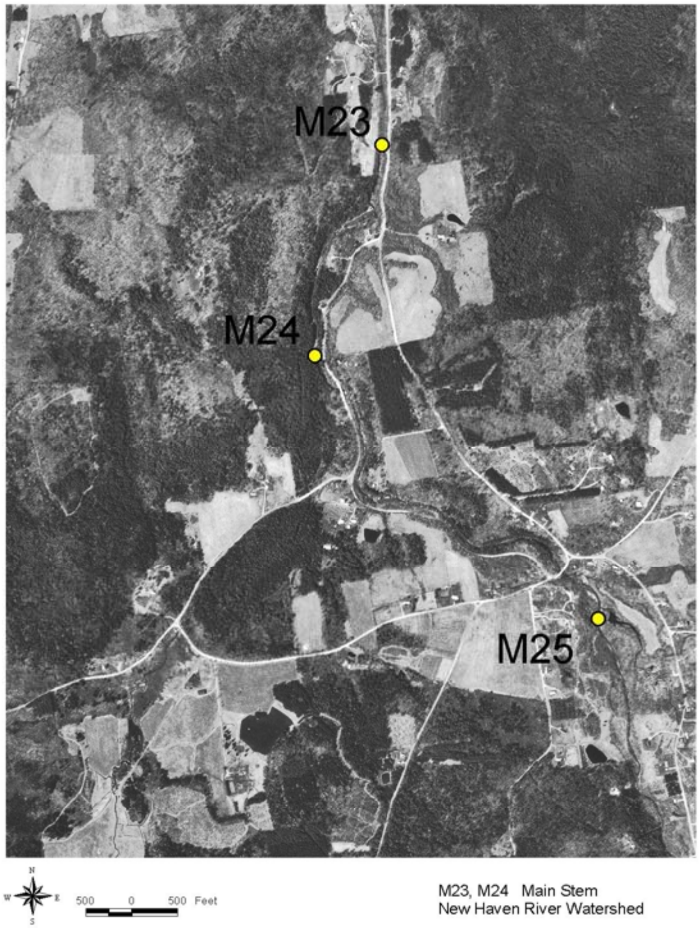
M17 Main Stem
New Haven River Watershed



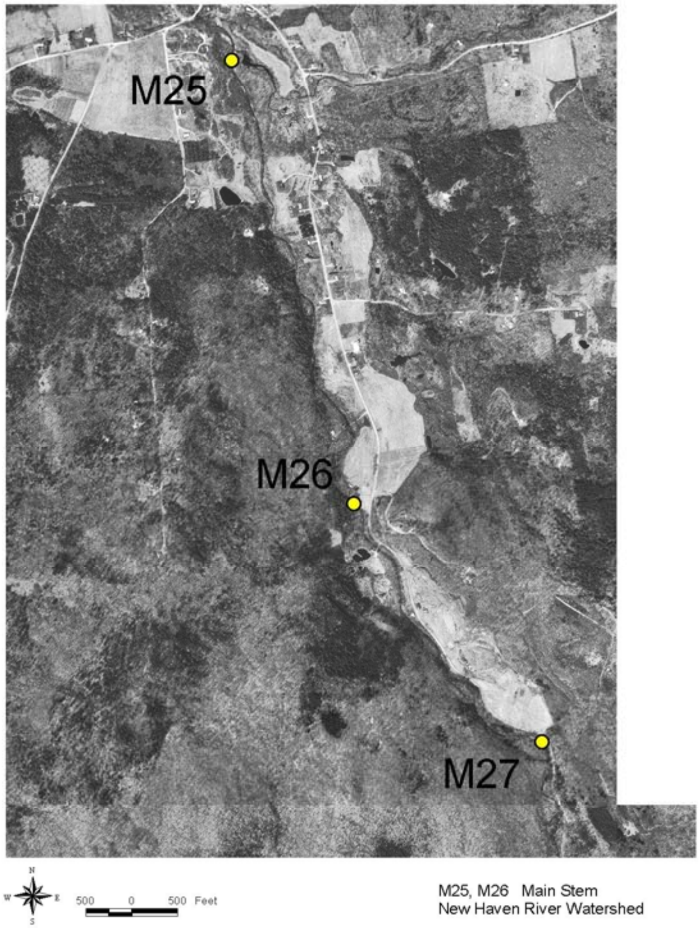
M18, M19 Main Stem
New Haven River Watershed



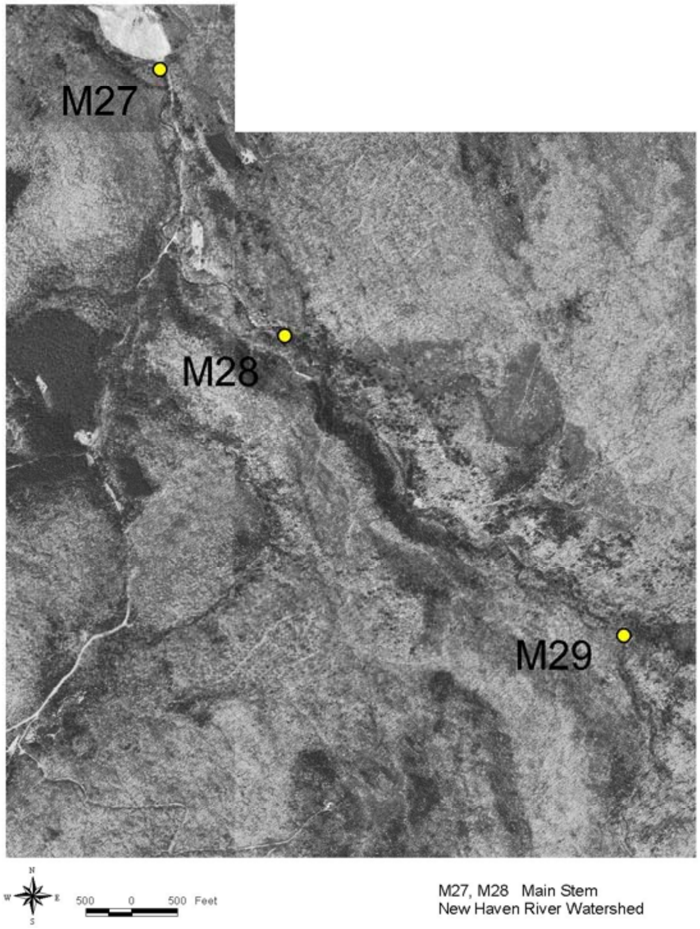
M20, M21, M22 Main Stem
New Haven River Watershed



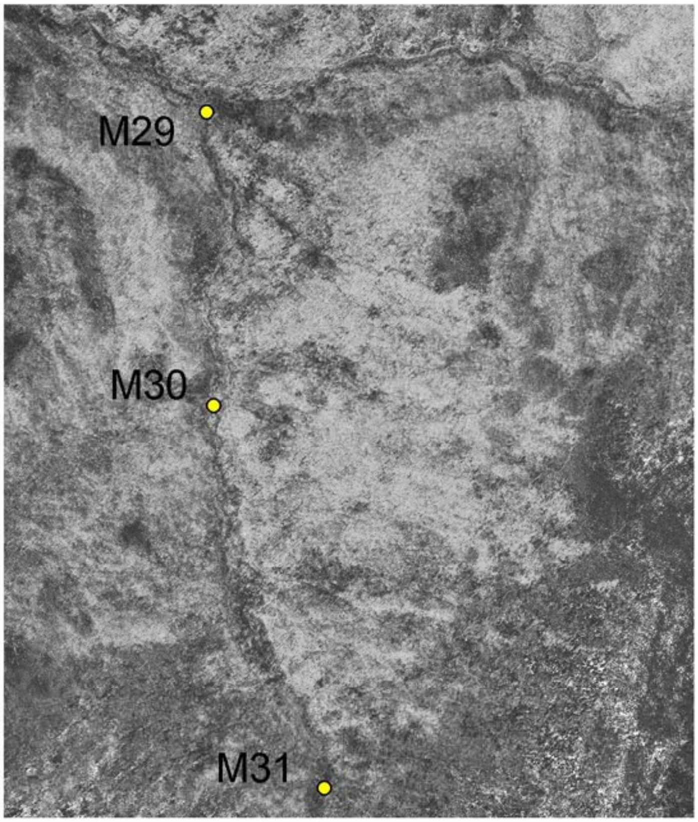
M23, M24 Main Stem
New Haven River Watershed



M25, M26 Main Stem
New Haven River Watershed

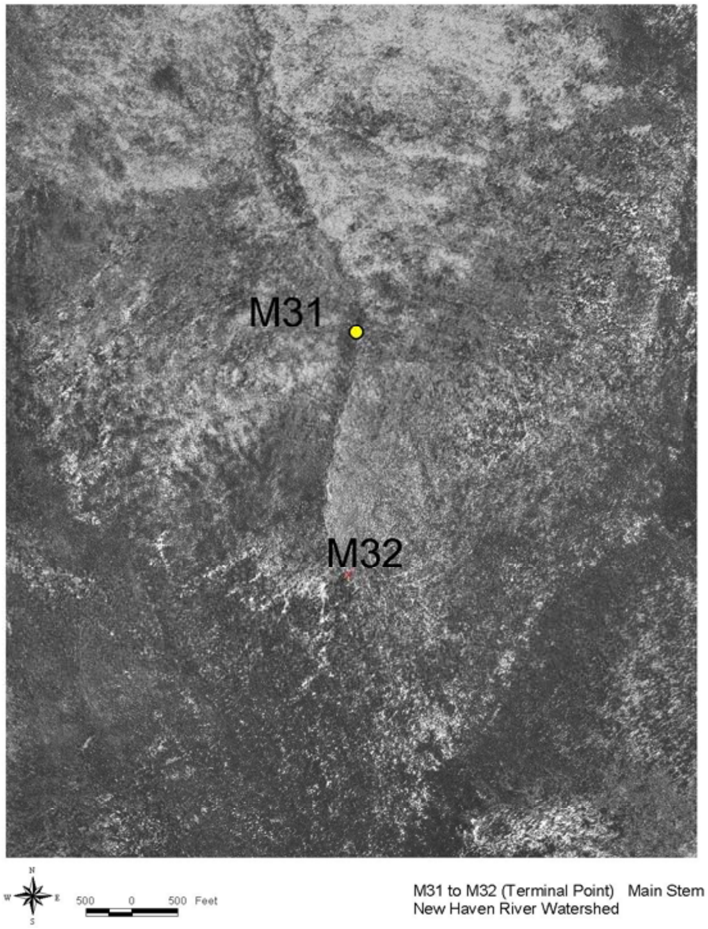


M27, M28 Main Stem
New Haven River Watershed

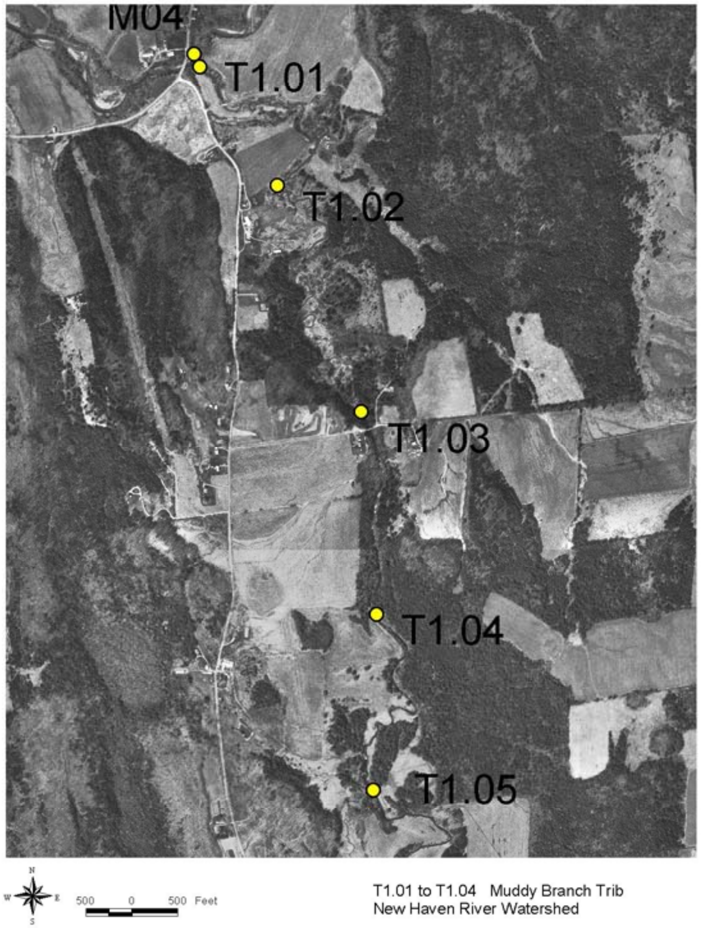


N
W E
S
500 0 500 Feet

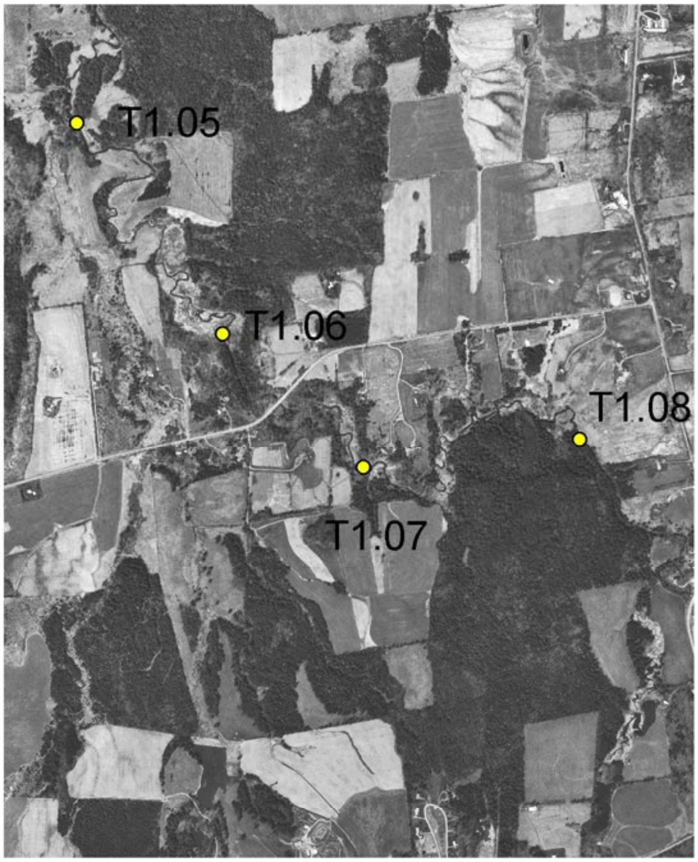
M29, M30 Main Stem
New Haven River Watershed



M31 to M32 (Terminal Point) Main Stem
New Haven River Watershed

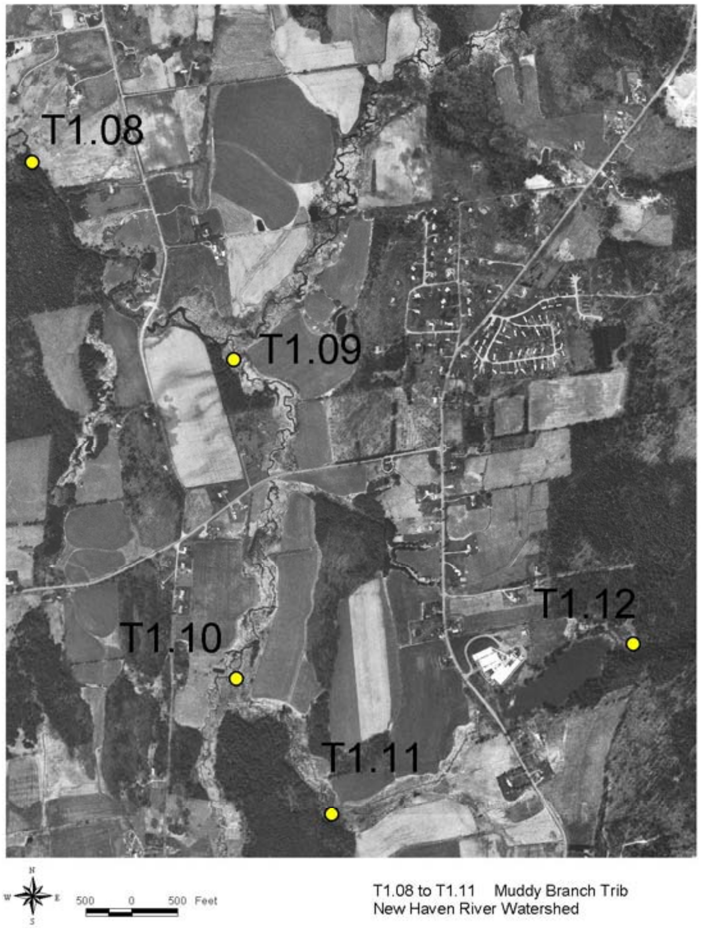


T1.01 to T1.04 Muddy Branch Trib
New Haven River Watershed

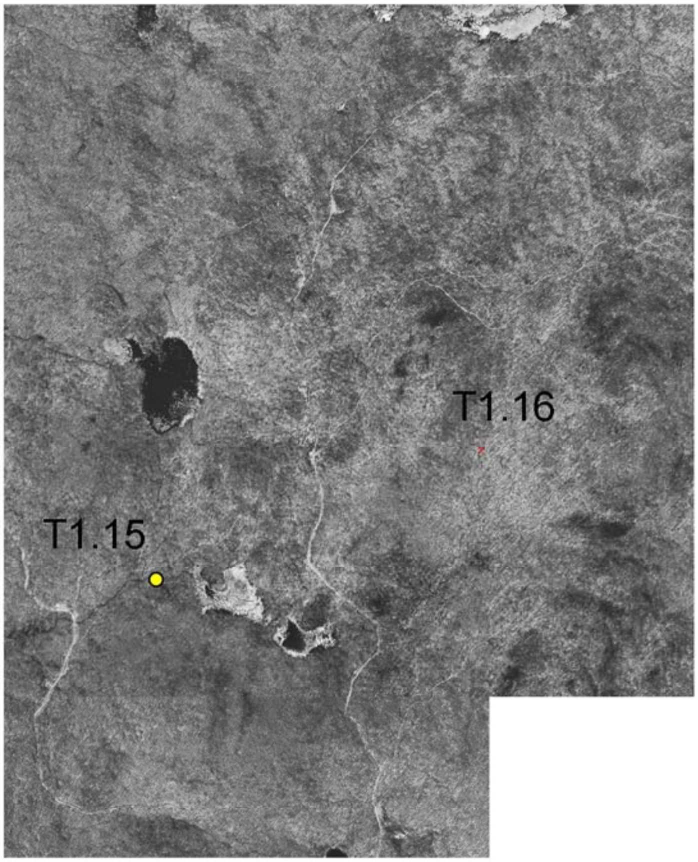


N
W E
S
500 0 500 Feet

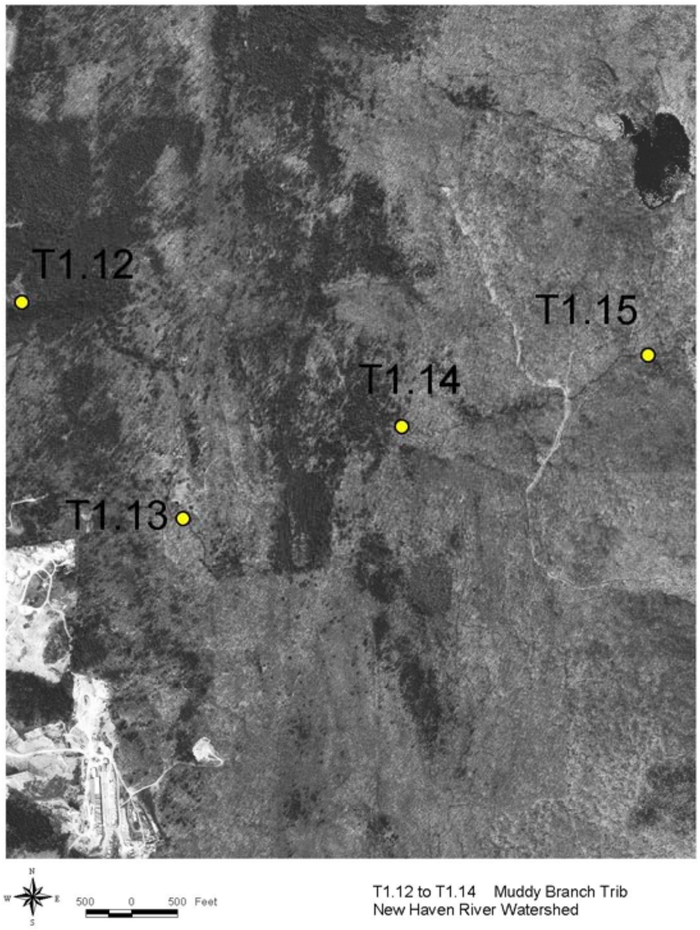
T1.05 to T1.07 Muddy Branch Trib
New Haven River Watershed



T1.08 to T1.11 Muddy Branch Trib
New Haven River Watershed

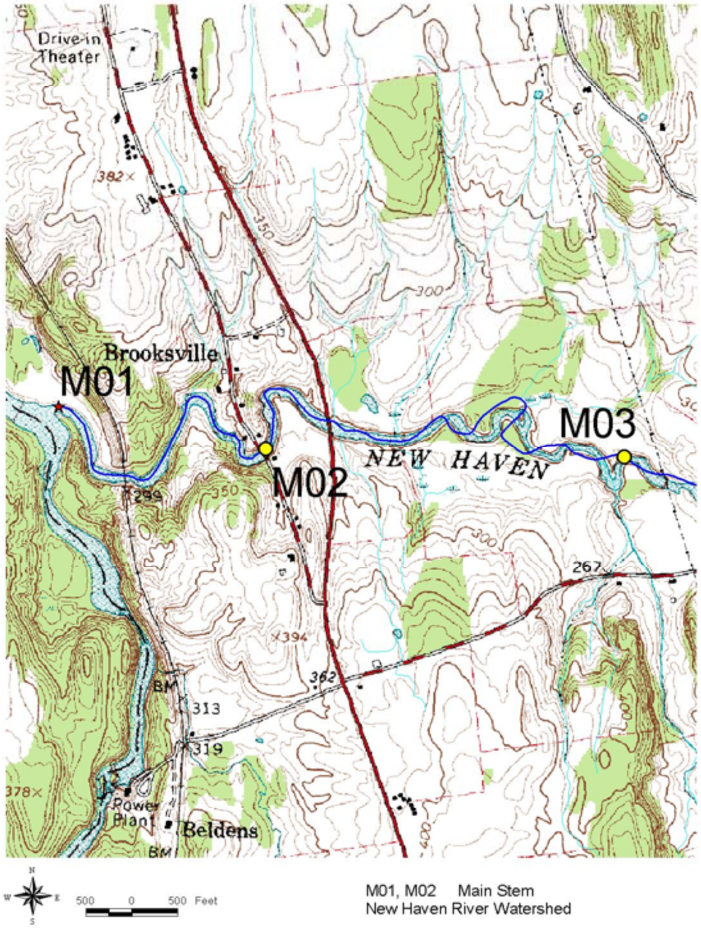


T1.15 to T1.16 (terminal) Muddy Branch Trib
New Haven River Watershed

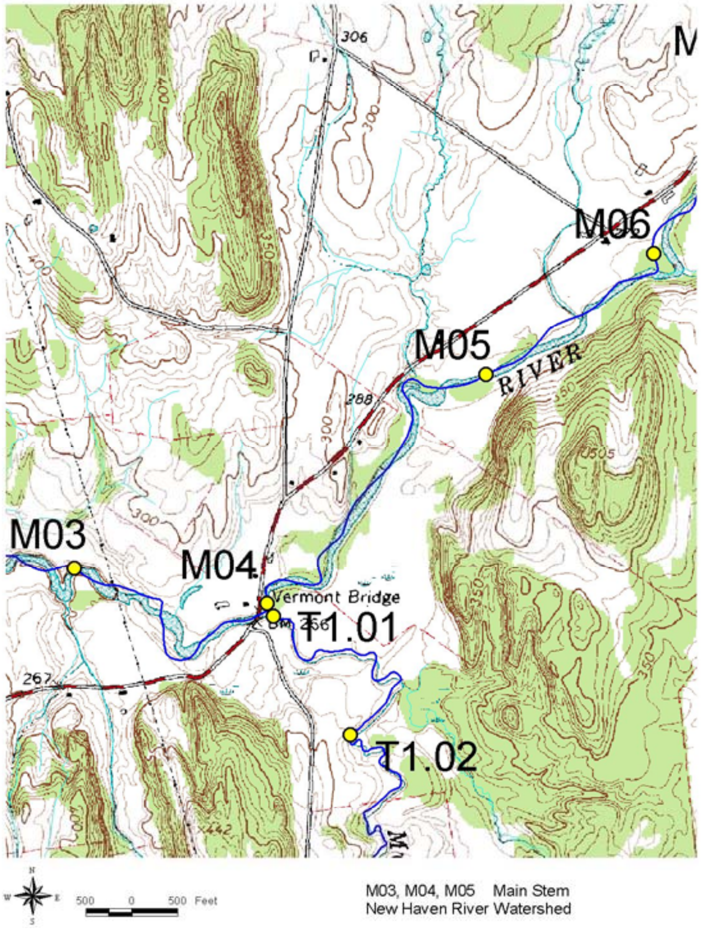

T1.12
T1.15
T1.14
T1.13
N
W
E
S
500
0
500 Feet
T1.12 to T1.14 Muddy Branch Trib
New Haven River Watershed

APPENDIX F

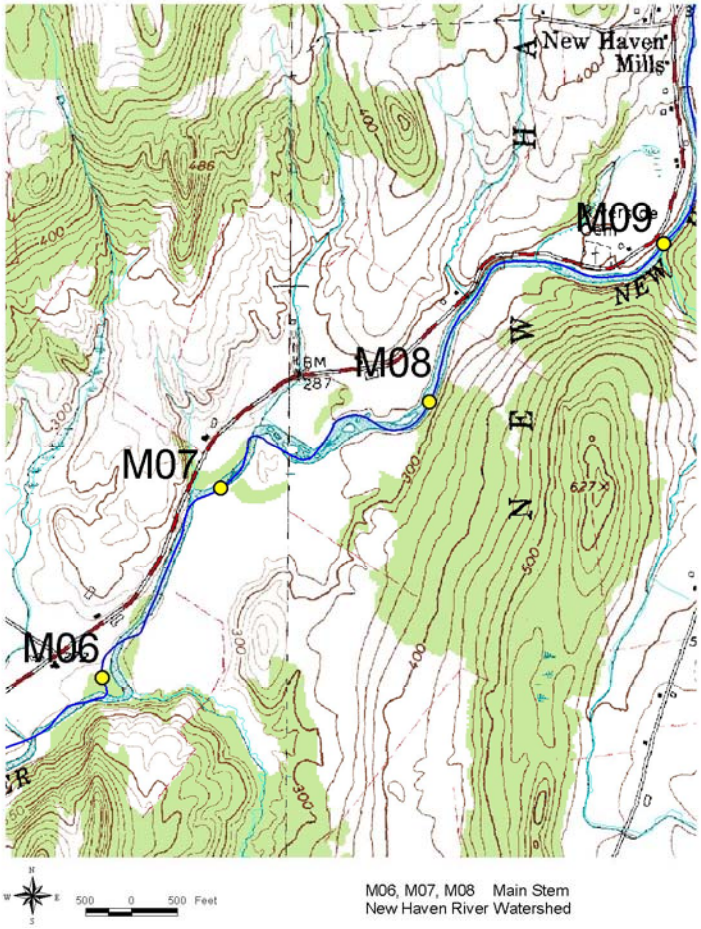
Reach-based Topographic Maps



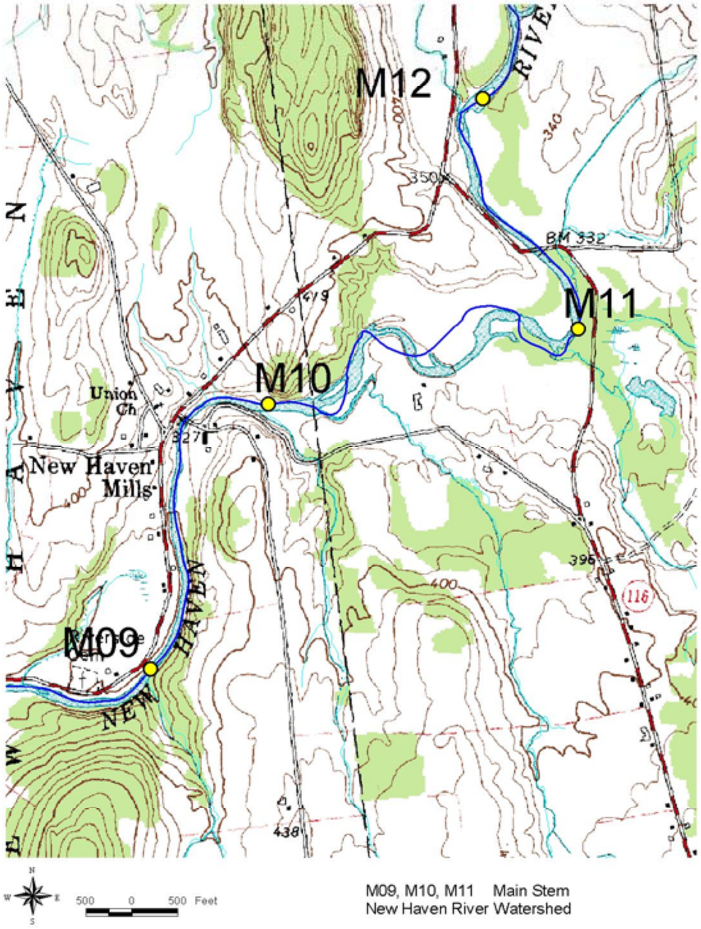
M01, M02 Main Stem
New Haven River Watershed



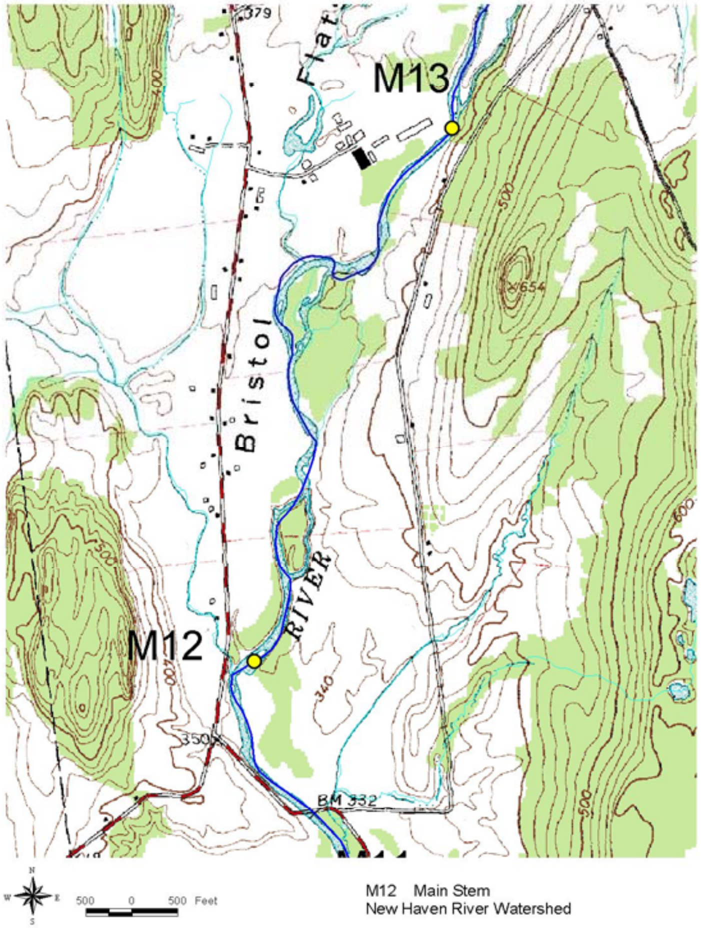
M03, M04, M05 Main Stem
New Haven River Watershed



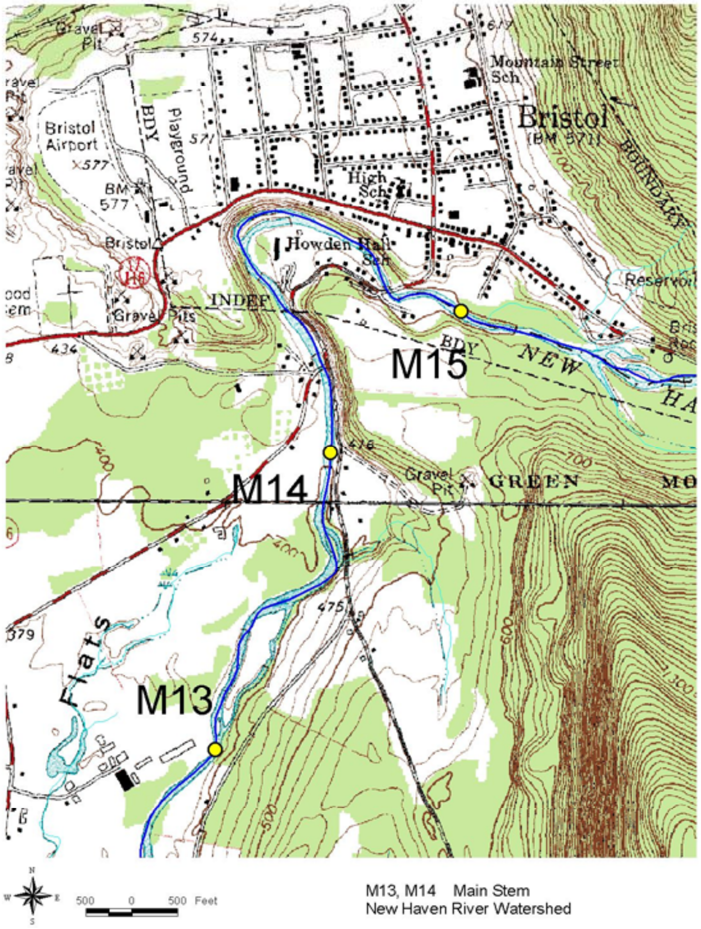
M06, M07, M08 Main Stem
New Haven River Watershed



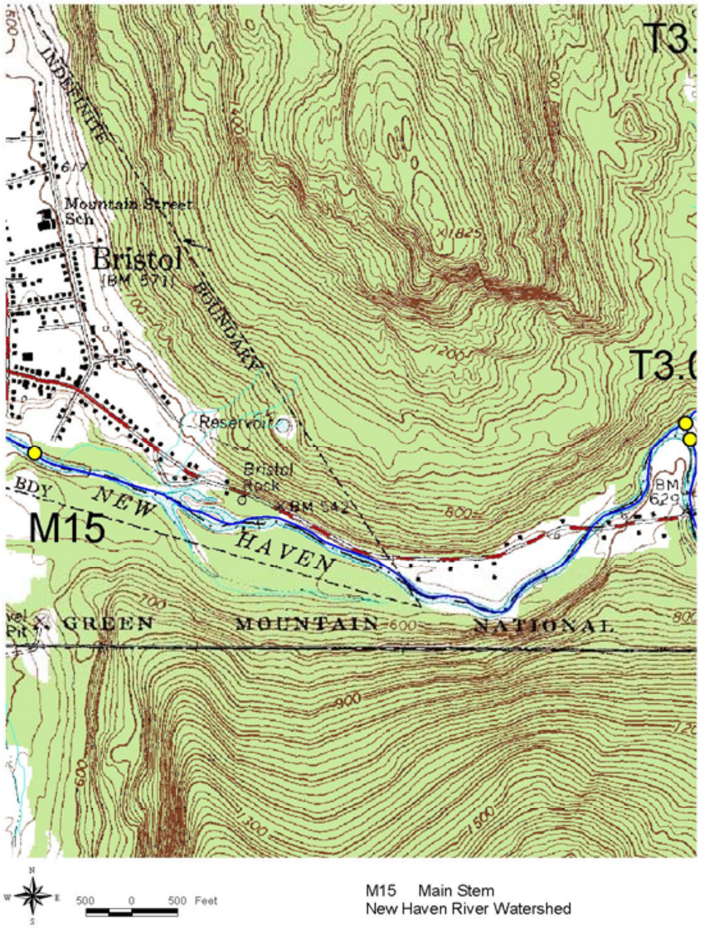
M09, M10, M11 Main Stem
New Haven River Watershed



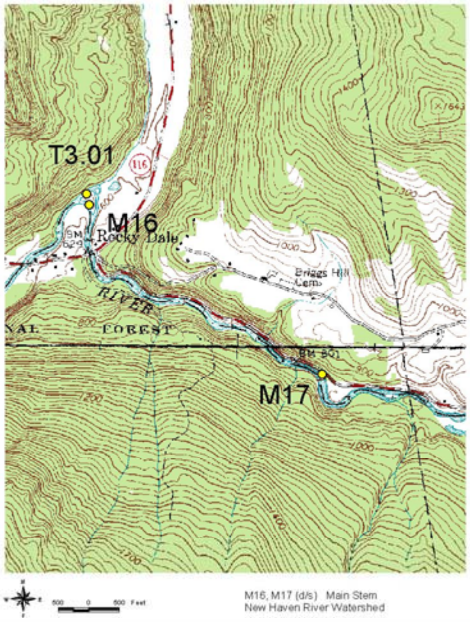
M12 Main Stem
New Haven River Watershed



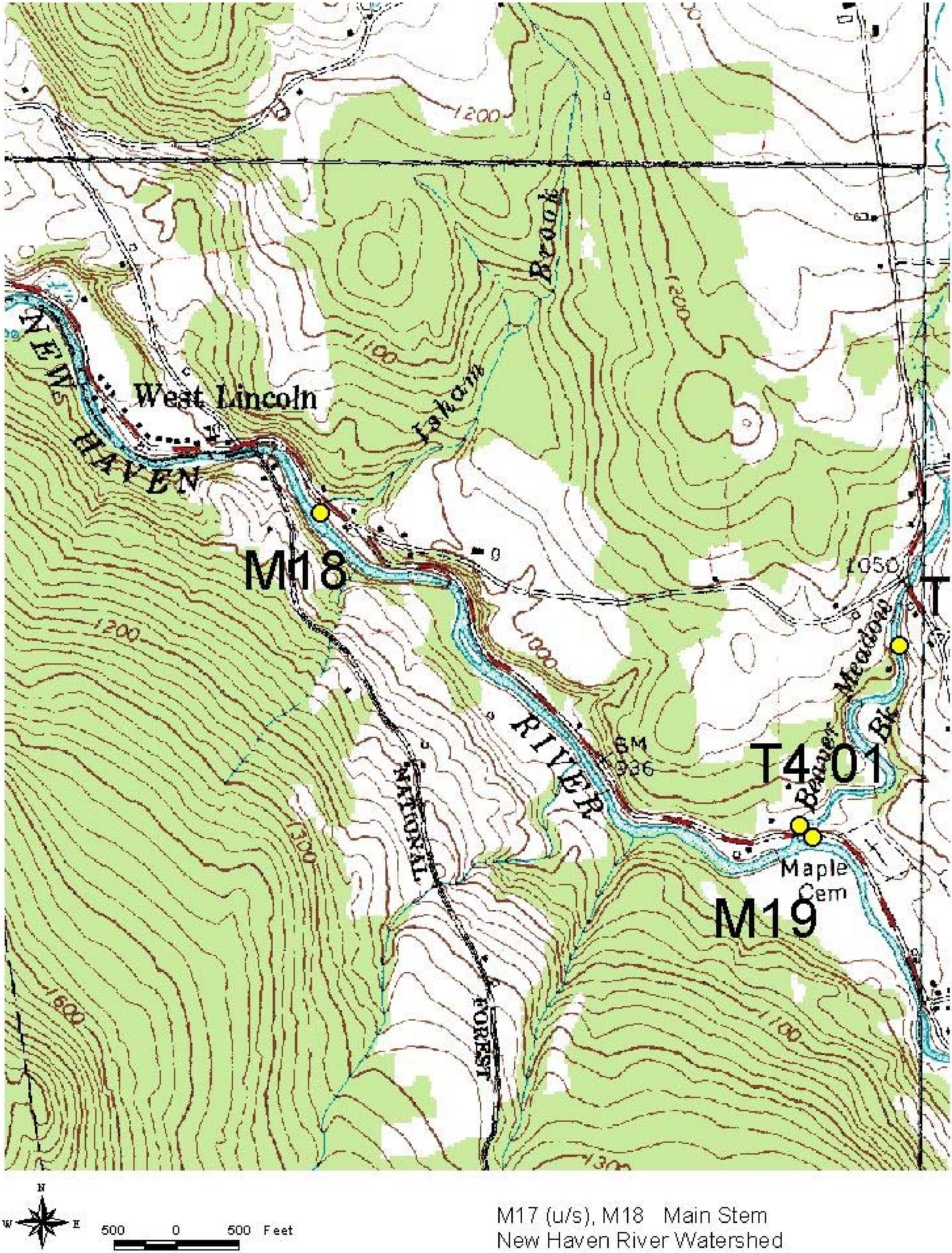
M13, M14 Main Stem
New Haven River Watershed



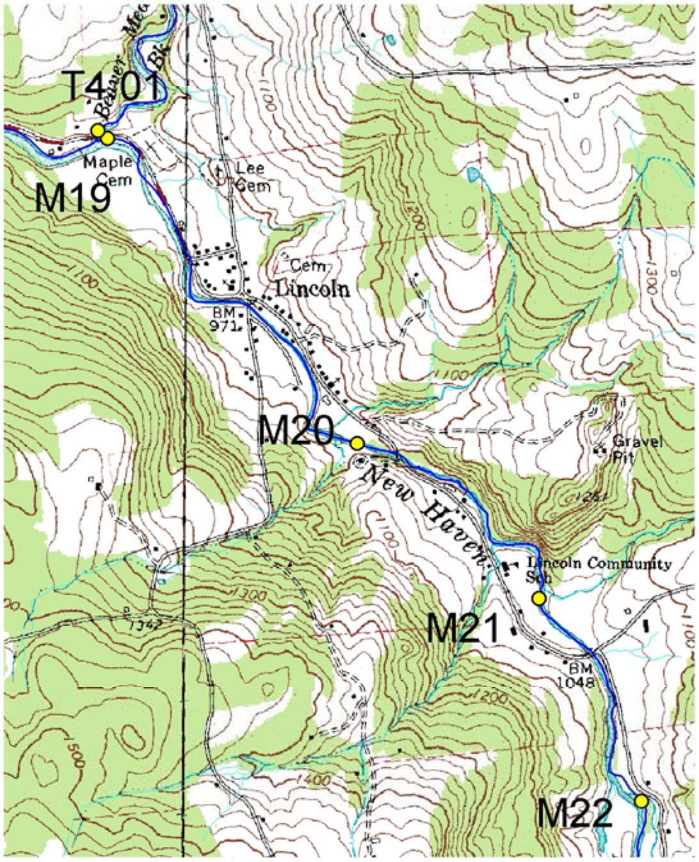
M15 Main Stem
New Haven River Watershed



M16, M17 (d/s) Main Stem
New Haven River Watershed

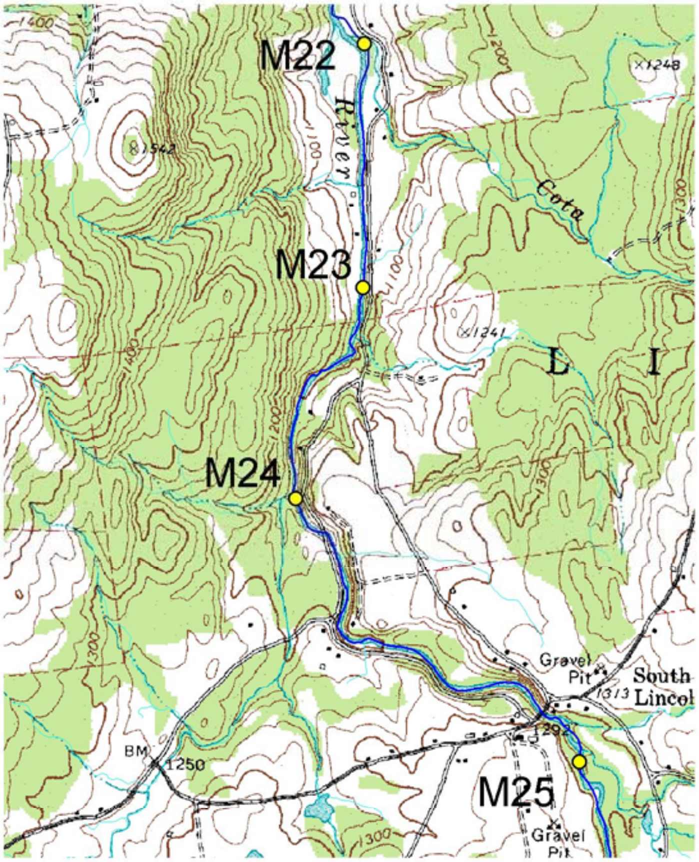


M17 (u/s), M18 Main Stem
New Haven River Watershed



500 0 500 Feet

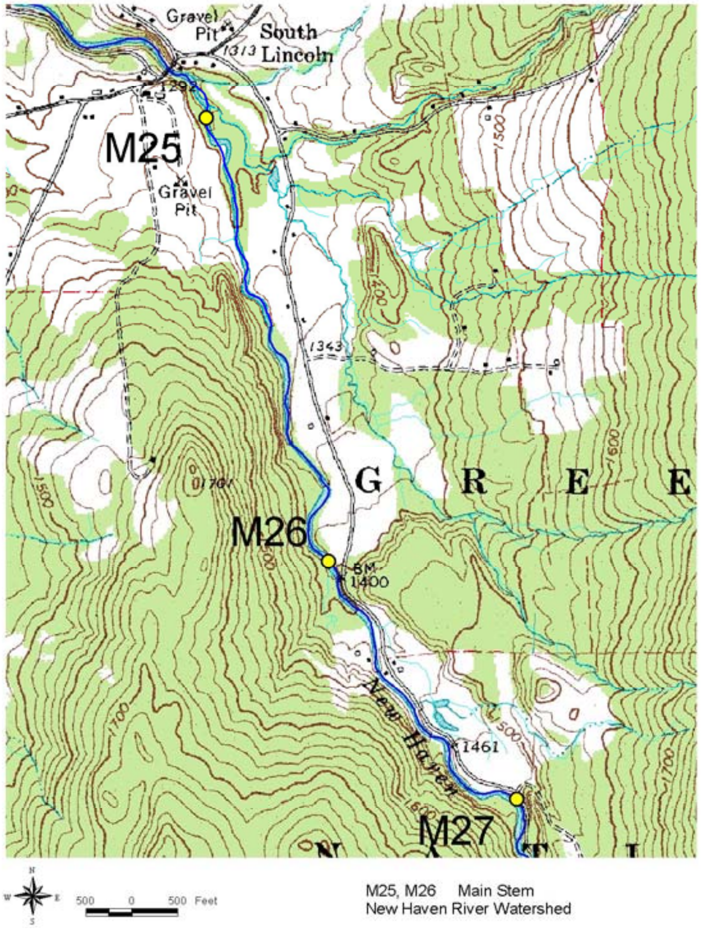
M19, M20, M21 Main Stem
New Haven River Watershed



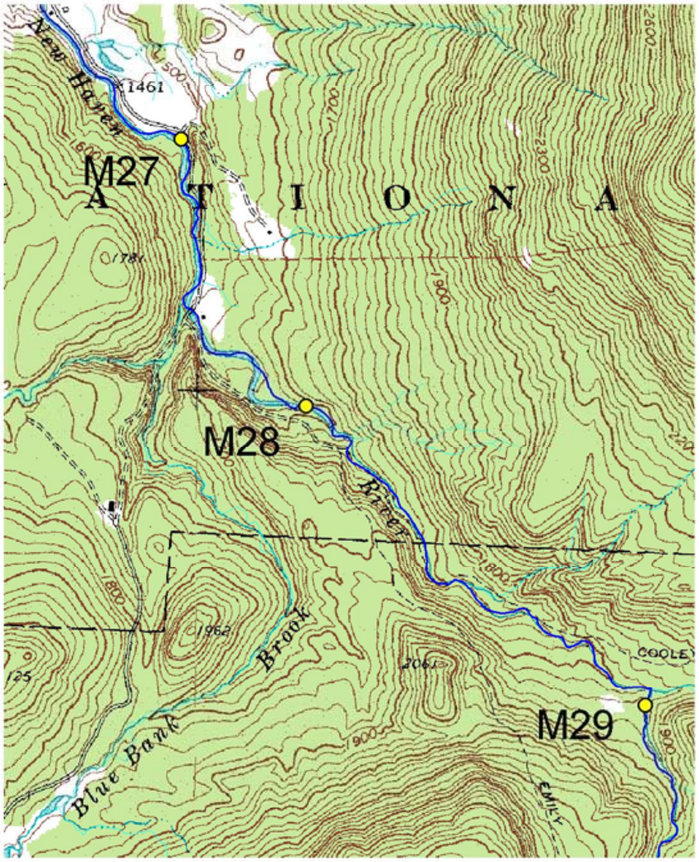
N
W
E
S

500 0 500 Feet

M22, M23, M24 Main Stem
New Haven River Watershed

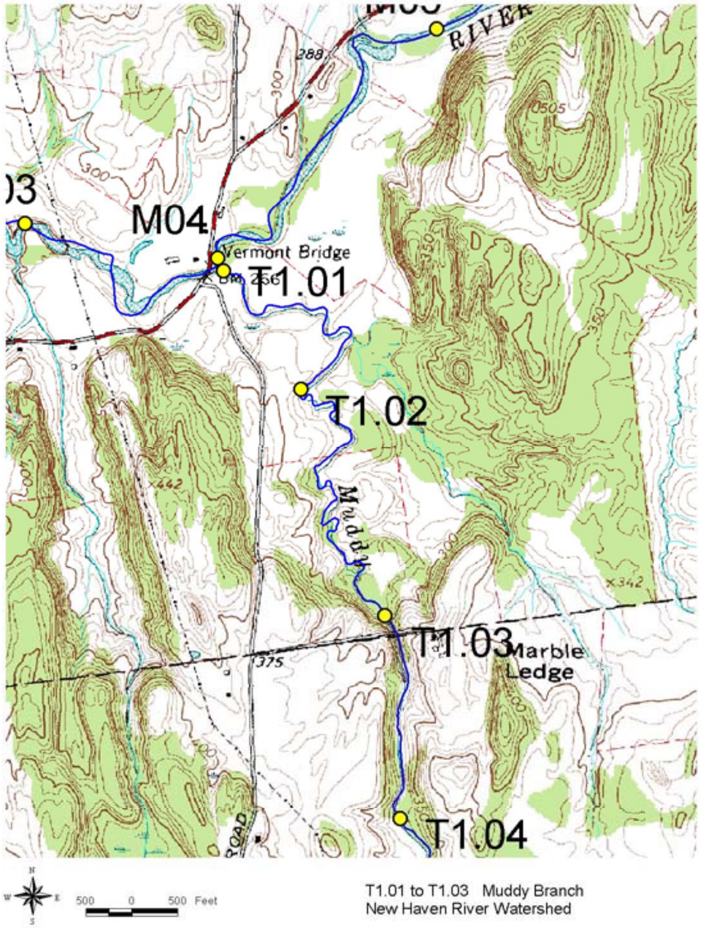


M25, M26 Main Stem
New Haven River Watershed

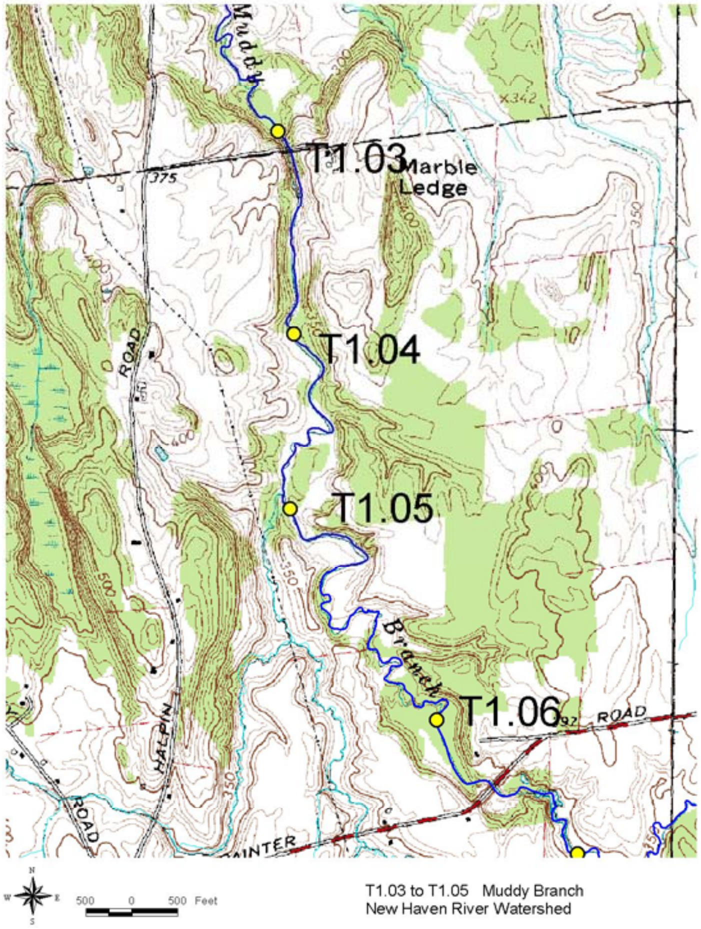


500 0 500 Feet

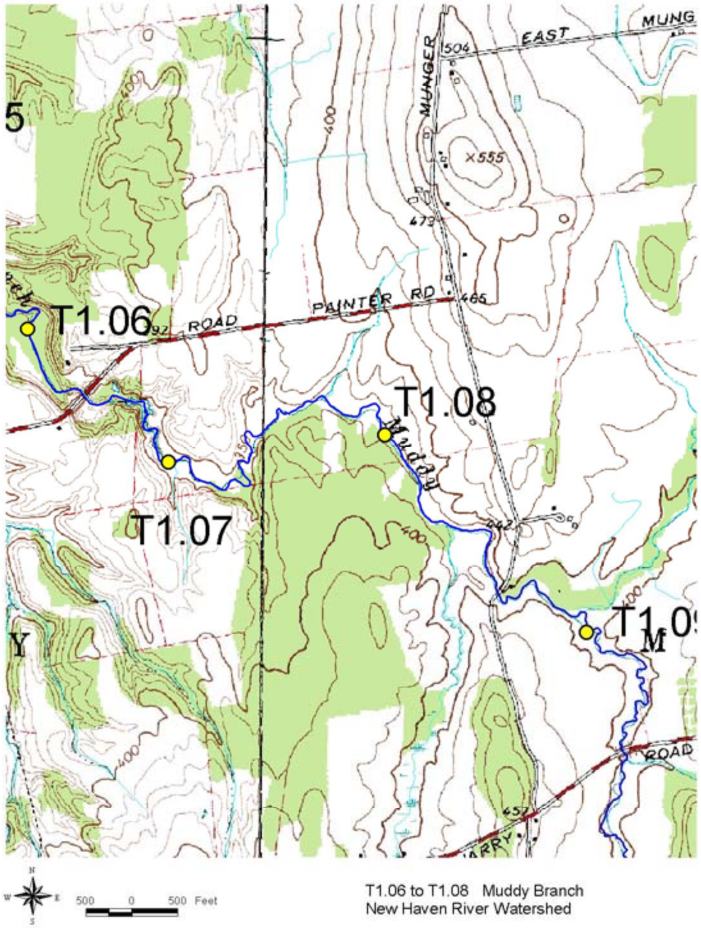
M27, M28 Main Stem
New Haven River Watershed



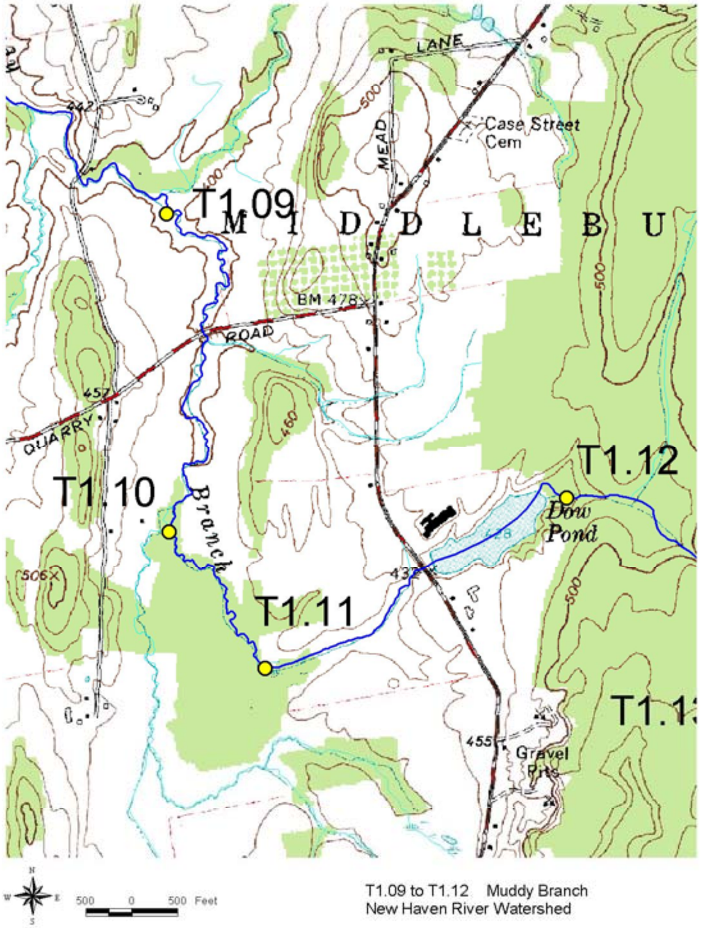
T1.01 to T1.03 Muddy Branch
New Haven River Watershed



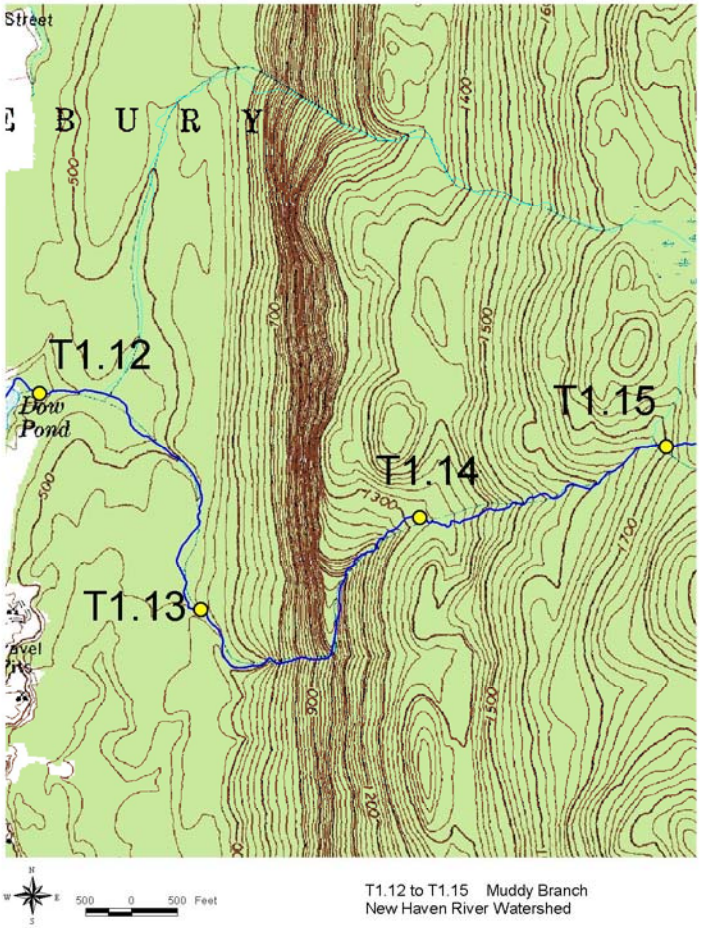
T1.03 to T1.05 Muddy Branch
New Haven River Watershed



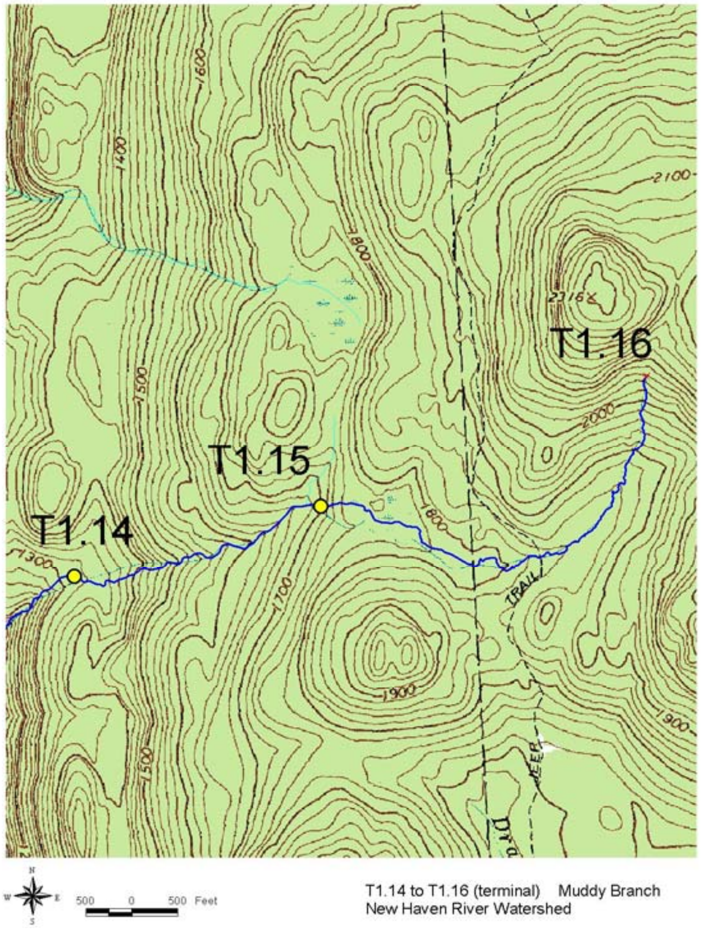
T1.06 to T1.08 Muddy Branch
New Haven River Watershed



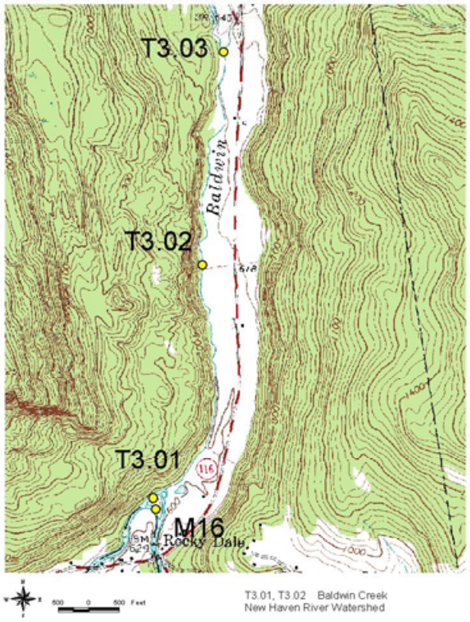
T1.09 to T1.12 Muddy Branch
New Haven River Watershed



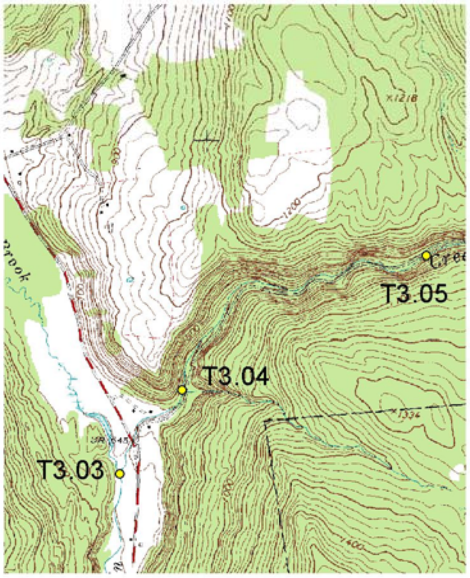
T1.12 to T1.15 Muddy Branch
New Haven River Watershed



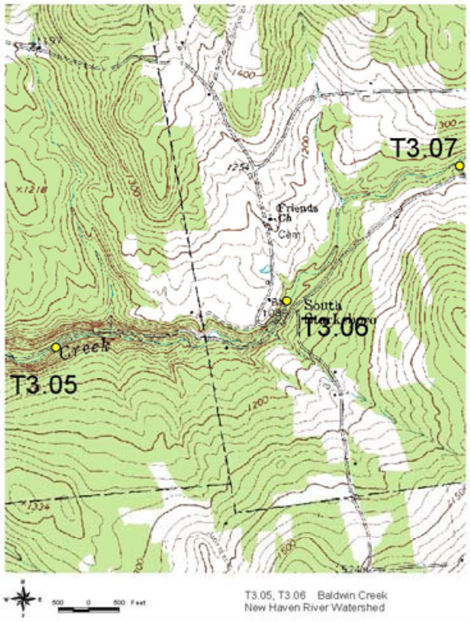
T1.14 to T1.16 (terminal) Muddy Branch
New Haven River Watershed



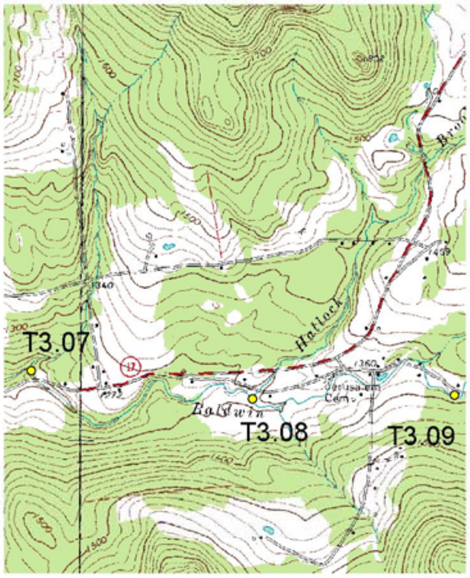
T3.01, T3.02 Baldwin Creek
New Haven River Watershed



T3.03, T3.04 Baldwin Creek
New Haven River Watershed

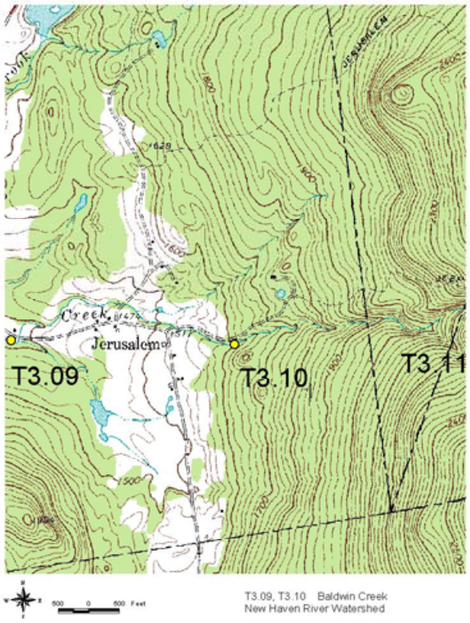


T3.05, T3.06 Baldwin Creek
New Haven River Watershed

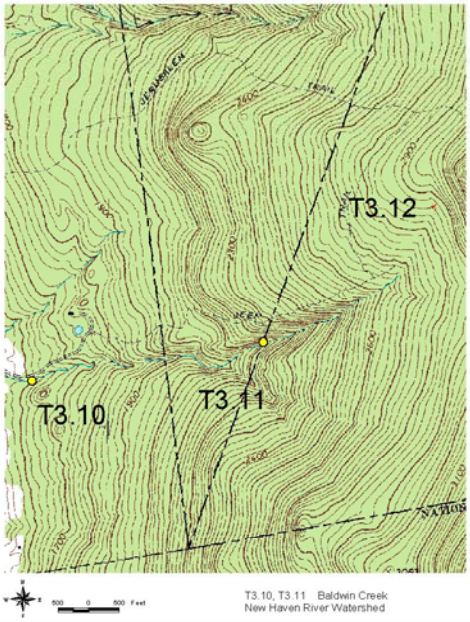


500 0 500 Feet

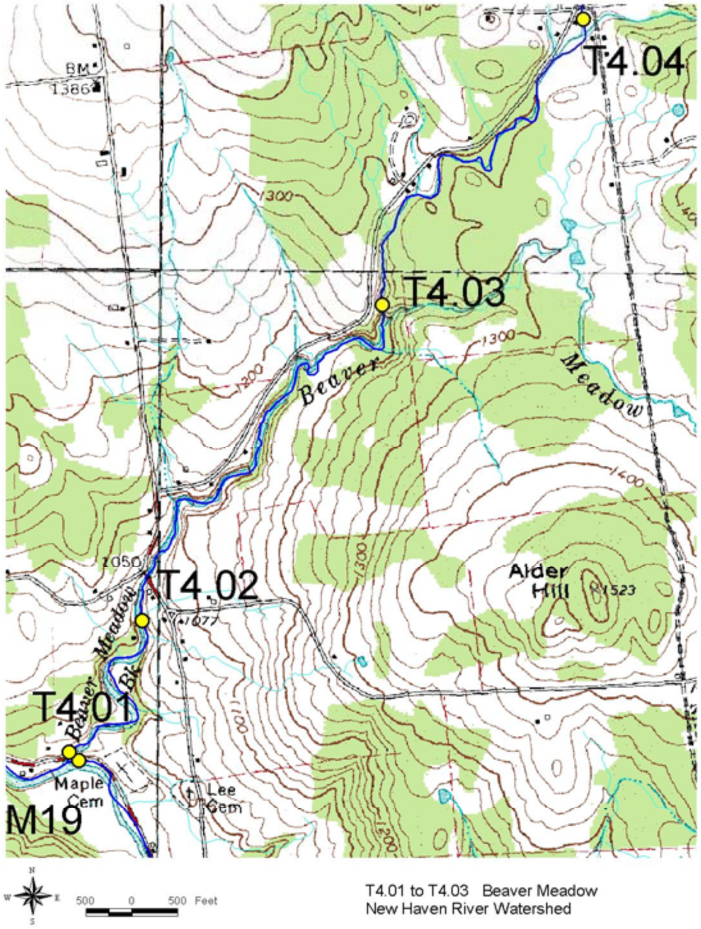
T3.07, T3.08 Baldwin Creek
New Haven River Watershed



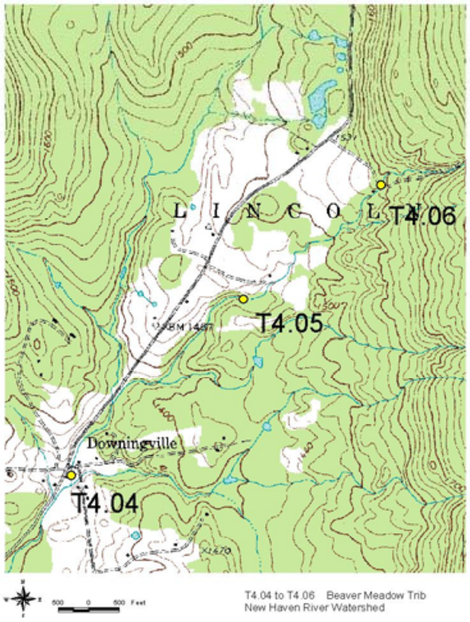
T3.09, T3.10 Baldwin Creek
New Haven River Watershed



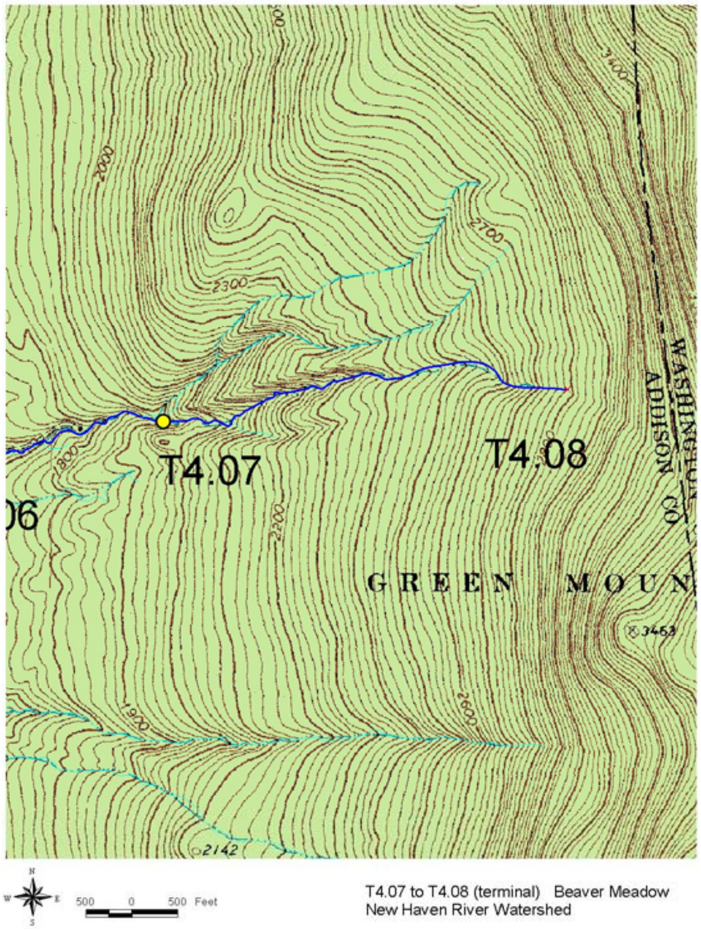
T3.10, T3.11 Baldwin Creek
New Haven River Watershed



T4.01 to T4.03 Beaver Meadow
New Haven River Watershed



T4.04 to T4.06   Beaver Meadow Trib
New Haven River Watershed



T4.07 to T4.08 (terminal) Beaver Meadow
New Haven River Watershed

APPENDIX G

Data CD

APPENDIX H

Response to QA Review

On 4 November 2003, Mike Kline of the VTDEC River Management Section conducted a Quality Assurance (QA) Review of the October 2003 report, *Phase 1 Stream Geomorphic Assessment, New Haven River Watershed, Addison County, VT* prepared by South Mountain Research & Consulting Services (SMRC) of Bristol, VT. The following comments are provided by SMRC in response to this QA review. Where appropriate, and where specifically noted below, corrections to the Phase 1 geomorphic database were made and a June 2004 revision of the Phase 1 Stream Geomorphic Assessment report has been produced, incorporating these comments as Appendix H. Funding for this effort was provided by a FEMA Project Impact grant under contract to the Addison County Regional Planning Commission, Middlebury, VT.

Reference the 4 November 2003 QA Review provided as an attachment.

Step 2 – Stream Typing / Step 7
The reviewer appropriately noted that inherent limitations in remote sensing methods of Phase 1 may have resulted in "a few reaches labeled Bs [that] might be Cs despite the confinement ratio, and a couple Cs [that] may be Bs due to the slope and despite the broad valley." The review noted a possible typographical error for confinement type on reach M29.

Stream types in Step 2.11 of Phase 1 may be revised based on closer inspection during Phase 2 assessments. Actual field work will be performed on approximately 26 of the 64 watershed reaches in the Summer of 2004, and the geomorphic database will be updated based on these findings under separate contract. For those reaches not actually evaluated in Phase 2, more frequent traveling throughout the basin during the Summer of 2004 may reveal (through additional windshield surveys) data useful for the updating of stream types in Step 2.11 of Phase 1 (where available and appropriate, these latter updates would be accomplished under the Phase 2 contract).

Valley confinement (Step 2.10) for reach M29 was originally identified as Narrow (valley width equal to 4 to 6 times the channel width). Upon review of this reach's topographic setting, SMRC acknowledges that a typographical error was made – this reach should have been characterized as Narrowly Confined (valley width 1 to 2 times the channel width). A correction was made to Step 2.10 in the database. Step 2.11 - Stream type (A2-Step Pool) was accurate for the corrected valley setting; no change was made to the stream type.

Step 3 – Erodibility (Step 3.5)
Reviewer was "curious about the high to extreme erodibility of the till and ice contact material" and expected "reaches above Bristol and through the gorge [to] have been characterized as having lower erodibility."

Phase 1 results for Step 3 were re-checked. Most of the data for Steps 3.3 to 3.5 were populated automatically by SGAT. The NRCS Table 20 soils coverage is clipped by the Appendix E corridor and cross-tabulation functions operating within SGAT summarize the parameter data by category for Step 3.3 (Geologic Material) and Step 3.5 (Soil Characteristics, including Erodibility). SMRC used version 3 of SGAT to complete the Phase 1 in September / October 2003; Phase 1 Step 3 is not fully automated in Version 3 of SGAT. The user (in this case, SMRC) manually reviews the SGAT-exported summary tables for soils to identify the Dominant and Subdominant Geologic Material (and populate Step 3.3 in the database).

The Appendix E corridor in this part of the watershed ranged from approximately 220 ft (M26) to 650 feet (M19). Corridor soils in reaches M16 through M26 (from Bristol twin bridges upstream through West Lincoln, Lincoln and to South Lincoln villages) were characterized as dominated by

Ice Contact - Outwash soils except for reach M19 (located through the Lincoln village) which was dominated by Alluvium. Select reaches (M16, M18, M23, M24) showed a subdominant geologic material, meaning that a second geologic material constituted 25 % or more of the reach corridor. In each case, this subdominant geologic material was Till and Dense Till, which was present near the outer edges of the Appendix E corridor, often farthest from the stream channel. The center of the stream valley is dominantly Ice Contact or Alluvium soils.

Review of the NRCS soil survey coverage for the corridor confirms that soil types in this valley are dominated by the gravelly sandy loams and fine sandy loams of the Adams, Colton, Duane and Stetson series – water-deposited sands and gravels derived from quartzite or schist (Griggs, et al, USDA, 1971). These findings are consistent with surficial geologic mapping (Calkin & MacClintock, 1965) which indicates predominantly kame terrace deposits along the New Haven main stem valley in this part of the watershed, with some isolated deposits of kame moraine and alluvium. Kame terrace deposits are comprised of gravels, cobbles and sands deposited by meltwaters of receding glaciers in temporary high-level lakes formed at the margin between stagnating ice blocks and the adjacent slopes of the Green Mountains. These gravel, sand and cobble deposits are typically non-cohesive and have moderate to high erodibilities when exposed in stream banks and beds.

Six of the 11 reaches considered here were characterized by Phase 1 protocols (Step 3.5) as having Severe erodibility (i.e., between 51 and 75 % of the corridor soils were designated by NRCS in Table 20 as Highly Erodible and/or Potentially Highly Erodible). One was Moderate (26 % to 50 % of the corridor soils designated as HE and/or PHE). The remaining reaches were Slight (0 % to 25% HE and/or PHE). Reaches dominated by Ice Contact – Outwash soils (Step 3.3) had erodibilities ranging from Slight to Severe, nearly the full spectrum of erodibility. Interestingly, those four Ice Contact reaches with a significant subdominance of Till and Dense Till were each ranked as Severe for erodibility.

It is important to note that soil erodibility defined by NRCS ("HELCLASS" in Table 20) has to do with the susceptibility of soils to erosion in the presence of surface runoff. NRCS erodibility, therefore, is more directly correlated with topographic slopes of the soil deposits, than it is with the nature (cohesiveness) of the parent material from which the soils were derived (e.g., till versus glacial outwash).

Upon quick review of valley dimension data for M16 to M26, those reaches designated with Severe erodibility in Step 3.5 appear to be those narrowly-confined to semi-confined reaches of steeper gradients (1.0 to 3.8 %) – that is, their soil coverage would be of steeper slope categories in NRCS Table 20 and they would therefore be classified by NRCS as Highly Erodible and Potentially Highly Erodible, and classified under Step 3.5 of the Phase 1 protocols as Severe for erodibility. The reaches classified in Step 3.5 as Moderate to Slight for erodibility were in broader valley settings (narrow, broad or very broad) and had lesser gradients (0.8 to 2.6 %) - reaches like M17 through West Lincoln, M19 through Lincoln Village, and M25 and M26 in South Lincoln.

Since the Phase 1 protocols were adhered to in this case, no changes were made to the database. However, the discussion above serves to qualify the accuracy (and uncertainty) of Step 3.5 results for this watershed.

Step 4 – Land Cover and Reach Hydrology

Step 4.1 Watershed Land Cover / Land Use
Watershed land use should represent coverages for the entire watershed upstream of the reach break, not the coverages for only the reach-based subwatershed.

Step 4.1 was corrected by exporting the "Watershed LcLU" table from the "NHR_2003_Phase1_2_LuLc_Soils" Access™ database into an Excel spreadsheet and summing areas of each Land Cover/ Land Use code for the total upstream watershed area above each reach. Dominant and Subdominant LcLu percentages were identified and Impacts were assigned based on the percentage of Crop and/or Urban lands, following Step 4.1 of the Phase 1 protocols. This revision in Impact scores in Step 4.1 resulted in a revision to the Total Impact scores for each reach in Step 8. This revision resulted in 30 out of 64 reaches (47 %) being upgraded in their impact rating. The remaining reaches were already at a HIGH or LOW impact ranking. Nineteen reaches were upgraded from a LOW to a HIGH impact rating; five reaches were upgraded from Not Significant to HIGH; and six went from Not Significant to LOW.

Step 4.2 Corridor Land Cover / Land Use
Corridor land use percentages (based on VCGI LcLu coverage) were "swamped" by "Water" (Wetland) category. A visual review of corridor land cover/ land use using orthophotographs was suggested.

Corridor land cover / land use was reviewed using the 1995 orthophotographs available for the watershed. Where appropriate, Dominant and/or Subdominant LcLu percentages were revised. Typically, where water/wetlands had been identified as the Dominant LcLu, the subdominant LcLu calculated in SGAT was shifted to the Dominant position, and the next most prevalent LcLu was shifted to the Subdominant position. No changes were made to Crop or Urban percentages; thus, Impacts assigned for this Step 4.2 (and in Step 8) remained unchanged.

Step 4.3 Riparian Buffer Width
The % woody buffers (Step 4.3) are being characterized in large degree as ">100 ft" throughout the watershed. Seems to contradict the high impact scores assigned to river corridor encroachment by Roads/Railroads/Berms, etc. (6.1) and development (6.2).

While a dominance of >100ft buffer condition might at first glance seem contradictory to a high impact for Roads/Railroads/Berms (6.1) and/or Development (6.2), these conditions can coexist (and often do in the New Haven watershed) based on the methods by which the impacts are assigned (following protocol) for Step 4.3 and Steps 6.1 & 6.2, and given the different "corridors" within which these impacts are assessed.

As an example, consider a hypothetical reach with the following composition of buffer conditions:

	Left Bank		Right Bank	
Buffers:				
	30 %	0 – 25ft	0 %	0 – 25ft
	10%	26–50 ft	0%	26–50 ft
	5 %	51-100 ft	5 %	51-100 ft
	55%	> 100 ft	95%	> 100 ft
Development:				
	40 % at 150 to 200 ft		10% at 150 to 200 ft	
Roads/ Railroads/ Berms:				
	50 % at 170 to 190 ft		15% at 170 to 190 ft	

The Left Bank of this reach would have a Dominant Buffer Width of >100 ft, and would score "Low" for Buffer Width Impact, since between 25 and 75 % of the reach length on one or more banks is in the 0–25 ft buffer category. The Right Bank would also have a Dominant Buffer Width of >100ft, but would have a "NS" score for Buffer Width Impact, since 0 % of the reach is in the 0-25 ft buffer category.

Effectively, buffers are evaluated up to 100 ft from the river bank on either side. Development (Step 6.2) and Roads/Railroads/Berms (Step 6.1) are evaluated up to the width of the Appendix E corridor on each side of the stream center line, which will be the larger value of either 100 ft or approximately 4 times the channel width (which in the New Haven ranges up to approximately 440 ft at M01). So the "corridor" area alongside the channel within with Steps 6.1 and 6.2 are evaluated is significantly larger than the 100ft to either side of the channel within which Buffers (Step 4.3) are evaluated. In the example above, the Left Bank is ranked as having a HIGH impact for both Development and Roads/RRs/Berms, since the percentage of each of these feature categories is greater than 20 %. The Right Bank ranks as a LOW impact for both categories, since the percentage of each is greater than 5% but less than 20 %.

This hypothetical example of reach conditions is illustrative of many of the actual reach conditions along the New Haven which ranked as Dominated by >100 ft buffers (and LOW or NS for Buffer Width Impact) while at the same time having Impacts (either HIGH or LOW) for Development or Roads/Railroads/Berms. In the New Haven River, these findings appear to suggest two generalizations: (1) that development and roads/RRs/berms are relatively limited longitudinally along the river channel, interspersed with substantially long stretches of woody riparian buffers greater than 100 feet in width; and (2) that development and roads/RRs/berms, where they do exist along the river channel, are positioned a substantial distance laterally away from the channel, often outside 25 ft from the channel.

To check for possible typographical and other errors in data development for Step 4.3 Buffer Width, a QC review of woody buffer determinations for the New Haven watershed was performed utilizing the "Riparian Condition Summary" report available as a standard database report template. For the assignment of the Dominant Buffer Width condition and the assignment of Buffer Width Impact rating (dependent on the % of reach in the 0-25 ft buffer category), a 100% data entry check (all 64 reaches, both banks) was performed. A 15 % check of buffer category determinations was performed (on 7 reaches out of 64) by reviewing the orthophotos in GIS and re-estimating the percentage of the Left Bank and Right Bank buffer length in each of the four buffer quartiles: 0-25 ft, 26-50 ft, 51-100 ft, and > 100ft. The buffer width QA check records are included as an attachment to this document.

Updated estimates for these seven reaches were entered into the database replacing the original estimates. In general, original results were repeatable. One typographical error reversing entry of the Left Bank and Right Bank dominant buffer conditions was noted. Two typographical errors improperly assigning a "Low" impact rather than "NS" impact were noted. These typographical errors impacted two of the 64 reaches (3%). For the seven reaches (14 reach-banks) where buffer widths were remeasured on the orthophotographs, on three occasions the estimated percentages differed enough from the original estimates to result in a change in the assigned dominant buffer width. On two occasions the revised percentages caused the Buffer Width Impact score to change: one from NS to Low, the other from Low to NS. These measurement variations affected four of the 7 reaches evaluated. The affected reaches were ones which either had measurable percentages of all four buffer width quartiles represented fairly equally, or which had a subdominant buffer width close in percentage points to the dominant buffer width. In these cases the resolution of the orthophotographs (i.e., distinguishing between one quartile and the next) and operator variability have a much greater influence on the accuracy of estimating percentages. There can be considerable variability between observers, resulting in a difference in the determination of dominant buffer width and/or the assigned rating for Buffer Width Impact if the 0-25 ft category is affected. Comparing SMRC's original estimates (October 2003) and these repeat estimates conducted 9 months later, is in some ways analogous to comparing estimates made by two different observers. The degree of variability determined from this comparison may indicate the degree of variability (and thus estimation uncertainty) that may be expected by practitioners in general. It should be noted that SMRC has recently completed (June 2004) Phase 2 assessments on two of the seven reaches chosen for repeat measurements. Field knowledge of riparian conditions may have also influenced the repeat estimates for these two reaches.

Step 5 – Instream Channel Modifications
Reviewer identified the "need to interview Stream Alt Engineers to get more detail on dredging history".

An interview with VTDEC River Management Program Stream Alteration Engineer, Barry Cahoon was conducted on 1 April 2004 to more comprehensively characterize channel management histories on the New Haven River and tributaries. Appropriate revisions were made under Step 5.5 to reflect new information obtained from Mr. Cahoon. These revisions resulted in changes to four reaches which previously had been identified as "No Info". Limited gravel mining with an impact rating of Low was identified for reaches M04, M21 and M22. Historic commercial gravel mining, with a High impact by protocol, was identified for reach M11. Accordingly, total impact ratings (Step 8) for these four reaches were increased as a result of these revisions.

Stream Alteration Engineer, Fred Nicholson, was contacted during the week of 13 June 2004, for additional channel management histories. As of this reporting, a response had not been received from Mr. Nicholson. Channel management histories will continue to be pursued during Phase 2 assessment work in July, and any necessary updates to the database will be made prior to the August / September 2004 reporting of Phase 2 efforts.

Step 6 – Floodplain Modifications and Plan Form Adjustments
Meander Width (Step 6.5) and Wavelength Ratio (Step 6.6)

Calculations of meander geometries and their associated impact ratings were revisited for two reasons (see 6.a and 6.b below):

6.a. QA review pointed out that meander geometries in the New Haven River did not often match expected patterns based on Williams, etc.

Researchers (Leopold, 1994; Williams, 1986) have suggested empirical relationships between channel width and meander wavelength as well as meander belt width. Regime equations developed for gravel-bed, low gradient (< 2%), alluvial channels flowing through narrow to broad valleys underlain by reasonably homogeneous surficial deposits, indicate that meander wavelength can be expected to approximate 10 to 14 channel widths (Leopold, 1994). Meander wave lengths in these stream types that are significantly more or less than 10 to 14 channel widths, and meander belt widths greater or lesser than 5 to 8 channel widths, are therefore highlighted in the Phase 1 protocols as an indication that a channel reach is out of equilibrium or otherwise disturbed or manipulated, presumably from human-induced channel or watershed stressors. Also the reviewer pointed out, if a given reach's belt width is lower than the expected range, then typically its wavelength is higher than the expected range, and visa-versa. With respect to this point, the reviewer noted that the meander belt width and wavelength ratios reported for the New Haven reaches in Phase 1 appeared inconsistent with each other. The reviewer also noted that impacts for belt width and wavelength ratios appeared inconsistent with impacts identified under Step 5.4 Channel Modification (specifically, straightening). This latter point is addressed in Section 6.b below.

A more comprehensive evaluation of meander geometries in the watershed was undertaken. The role of underlying geology in the region was explored as a contributing factor to the data outliers under Steps 6.5 and 6.6, as well as the limitations inherent in the regional relationships expressed by Williams and others. The New Haven River watershed provides a clear demonstration that meander geometry data outliers (i.e., low sinuosity, lower-than-predicted MBW, higher-than-predicted MWL) are not exclusively an indication of channel straightening, dredging or other channel management activities.

By VTANR protocol, calculations of meander belt width (MBW) and meander wavelength (MWL) and their respective ratios to channel width (Steps 6.5 and 6.6) are completed only for "C or E riffle-pool or ripple-dune reference stream types in narrow (NW) and unconfined (BD and VB) valleys in Step 2.10" (Phase 1 protocols [2003], p. 55). Accordingly, Table H.1 summarizes the meander geometries measured for the 32 reaches provisionally typed as C type streams in NW, BD, or VB valley settings; there were no E streams typed in the watershed in Phase 1. Phase 1 stream typing is preliminary, and as discussed in Section 2, stream types may be refined during Phase 2 assessments in the watershed. Many of the C stream types in Table H.1 are NW channels with slopes close to or exceeding 2.0 %. It is likely that some of these stream types may be revised to B type, and the MBW and MWL measurements made for those reaches would therefore become inappropriate, by protocol.

MBW and MWL were measured in October 2003 following protocols (VTANR, 2003) under Steps 6.5 and 6.6. These measured values are recorded in Table H.1 (gray-shaded columns). By protocol, these represent the average of measurements from at least three sets of meanders per reach. However, it was not always possible to locate three sets of standard meanders per reach (due to the low overall sinuosity and/or bedrock control and/or history of channel straightening).

In Table H.1, Williams Equations 32 and 30 are utilized to calculate an expected MBW and MWL, respectively, for each reach based on the Phase 1 channel width. The channel width is that value predicted for the upstream drainage area of each reach based on the Vermont Regional Hydraulic Geometry Curves (VTDEC, 2002). Williams' equations are derived from a best-fit line through data with considerable scatter about this line. Standard deviation values are published in Williams (1986) to express this variability. These standard deviation values were used to calculate an acceptable range about the predicted value for MBW and MWL for each reach (values in italics in Table H.1).

The protocol limitation to measuring meander geometries for only C and E type streams in broader valley settings is designed to focus this parameter estimation on alluvial, mobile-bed stream channels, since these were the stream types measured to develop the meander geometry relationships published by Williams (1986). Put another way, the Williams' equations relating MBW and MWL to channel width that are the basis for the Impact ratings in Steps 6.5 and 6.6 are applicable only to alluvial stream channels, and should not be used to evaluate meander geometries in stream channels controlled laterally and/or vertically by bedrock.

The New Haven River is predominantly a mountainous, bedrock-controlled watershed. Approximately 63 % of the New Haven River watershed occupies the Northern Green Mountain province (Capen, 1998), where channel gradients and valley confinement are largely controlled by underlying bedrock topography and structure (joints, faults, strike and dip of bedding planes and schistosity) (Canavan, 1989; DelloRusso & Stanley, 1986; Tauvers, 1982). Reaches M15 through M31 along the main stem, upstream reaches T1.13 through T1.15 of the Muddy Branch, all eleven reaches of Baldwin Creek (T3), and all seven reaches of Beaver Meadow (T4) are located in the Northern Green Mountain province. There are several lower-gradient, narrow valley, C-type reaches or segments of channel within the Upper Watershed coincident with the village settlements of West Lincoln, Lincoln, and South Lincoln (see Table H.1 for listing). However, these are closely bounded on upstream and downstream ends by steeper-gradient, bedrock controlled B and A type channels. These short reaches of alluvial channel may be insufficient in length to develop regime-based channel meander geometries. Human-induced changes to channel geometry cannot be discounted in these Upper Watershed C-type reaches, since they tend also to be common settings for residential and commercial development.

The remaining 37 % of the watershed is positioned in the Champlain Valley province (reaches M01 through M14 along the main stem and reaches T1.01 through T1.12 of the Muddy Branch). Valley sediments are comprised of boulder clays and silts from former Lake Vermont and local alluvium, punctuated in many locations by outcropping or shallowly buried limestone and dolostone bedrock (Stewart & MacClintock, 1969; Calkin & MacClintock, 1965). Bedrock outcroppings in the Valley have influenced channel planform in reaches M09, M08, M06 and M05.

Williams' equations are also limited for application to streams with channel widths ranging from 4.9 to 13,000 feet (all selected New Haven reaches are in this range) and channel sinuosity values greater than or equal to 1.2. Several of the selected C type streams in the New Haven watershed have sinuosities less than 1.2 (highlighted in Table H.1). Often these are reaches in bedrock controlled locations of the watershed (e.g., M05, M06, M08, M09, M17, M19-M22, M25, M26). Heterogeneity of streambank sediments has been identified as a causal factor in reduction of channel sinuosity (Friedkin, 1945 as cited in Leopold et al, 1964); this may account for some of the low sinuosities in the Lower Watershed reaches (e.g., M07, or M05, M06). And floodplain development and channel encroachment by roads and infrastructure cannot be ignored as a contributing factor to meander geometry data outliers. More details will be available for several of these reaches following completion of Phase 2 assessments in the Summer of 2004.

So, to appropriately compare measured MBW and MWL values in the New Haven watershed with predicted values based on Williams (1986), the following reaches in Table H.1 should be removed from consideration:

- bedrock-controlled reaches (shaded purple)
- reaches of sinuosities less than 1.2 (shaded tan) –
  M05-M09, M11, M13, M15, M17, M19-M22, M25, M26, T1.11, T1.12, T3.01, T3.02, T3.06
- reaches of channel gradient greater than 2 % (shaded tan) –
  M26, T1.12, T3.08
- reaches estimated to be straightened along 50% or more of their length (shaded tan) –
  M04, M05, M06, M13, T1.11

This leaves 10 reaches: M03, M10, M12, T1.01, T1.02, T1.04, T1.07, T1.08, T1.09, and T1.10.

For nine out of these 10 reaches, the estimated values of MBW and MWL are within the range of values predicted by William's equations. One of the nine reaches (T1.08) has a measured average MBW of 116 ft which is at the low end of the range predicted by the Williams Equation 32 (119 to 356 ft). The tenth reach, T1.04, has a MBW and a MWL significantly lower than either range of values predicted by Equations 32 and 30, respectively. Review of NRCS soils mapping for the Muddy Branch (T1) indicates that unlike neighboring reaches which flow through silty and sandy loams, a large length of T1.04 flows through Vergennes clay soils. It is possible that these more cohesive, erosion-resistent soils developed on glacio-lacustrine deposits have influenced the meander geometry and caused it to be inconsistent with geometries predicted for alluvial channels.

Finally, the inherent subjectivity in these methods of graphically analyzing river planform patterns should be recognized as a source of data outliers in Steps 6.5 and 6.6. Williams (1986), himself, acknowledged a 15 % variability between two observers measuring wavelength, bend lengths and belt width on the same set of meanders ("well-defined…with no intervening straight reaches").
.
Since, measurements in Steps 6.5 and 6.6 were conducted following protocol, no changes or revisions to these values were made (except for the changes noted under Section 6.b, below). Since no changes were made to the values for Steps 6.5 and 6.6, the Impact ratings in each Step remain unchanged. The above discussion serves to qualify the limitations of the estimates and characterize the uncertainty associated with measurements of these parameters, and the assignment of corresponding impacts. Given the above discussion, the impact ratings assigned to bedrock-controlled reaches for which evidence of significant channelization / straightening is absent (e.g., M08, M09) are perhaps overstated.

6.b. Step 6.5 and 6.6 – Meander Belt Width Ratio (MBWR) and Meander Wavelength Ratio (MWLR) – The QA review and subsequent discussions with Mike Kline clarified a new requirement in the 2003 protocols that if a reach was more than 50% straightened (as evaluated in Step 5.4, resulting in a "HIGH" impact), then for Step 6.5, the channel width should be entered rather than the meander width, which forces the MBWR (meander belt width / channel width) to a value of "1", resulting in a "HIGH" impact rating for MBWR. Similarly, for Step 6.6, the channel width should be entered rather than the meander wavelength, forcing the MWLR to 1, with a corresponding impact rating of HIGH.

The October 2003 Phase 1 data were reviewed to confirm adherence to the above protocol. Six reaches were characterized as having been straightened for 50% or more of the reach: M04, M05, M06, M13, T1.11, and T3.03. Original data entries for Step 6.5 did not conform to the above requirement. One of the six reaches, T3.03 (located along the Appalachian Gap Road) was preliminarily typed as a Semi-Confined B3 Step Pool stream, for which meander geometries are not estimated, according to protocol. For the remaining 5 reaches, Steps 6.5 and 6.6 were revised to indicate the curve-based channel width as the Meander Belt Width and Meander Wavelength, forcing the MBWR and MWLR each to "1". As it happens these revisions did not change the MBWR Impact ratings for these five reaches. Four of the five were already at "HIGH", based on MWR values ranging from 1 to 2 estimated in the traditional way as Meander Belt Width / Channel Width. The fifth (T1.11) had inadvertently had a "0" value for Meander Belt Width, which also forced the MWR to 0, and resulted in a "HIGH" impact rating. The MWLR Impact ratings for four of the five reaches were increased from either Low or Not Significant.

It is important to note that several other C-type reaches in the watershed were determined to be straightened, but at percentages less than 50 %. The estimate of percentage straightened is a subjective one, and different practitioners may have estimated higher or lower values for percent straightened. SMRC was perhaps conservative (estimating on the low side) knowing the influence of the underlying bedrock structure and isolated clay deposits and heterogeneous surficial deposits in the watershed (see Section 6.a)

SUMMARY

In consideration of the above revisions, the Total Stream and Watershed Impact Ratings (Table 8 of the Phase 1 data) were revised, as follows:

Change to Total Impact Score	Number of Reaches	Percent of Reaches
+ 2	11	17 %
+ 1	23	36 %
- 1	1	2 %
0	29	45 %

REFERENCES

Calkin, Parker E. and MacClintock, 1965. *Surficial Geology of the Lincoln Mountain Quadrangle, Vermont*. Report to the State Geologist, Open-File Report, no. x-2.

Canavan, William A., 1989, *The Fluvial Geomorphology of a Northern Appalachian Bedrock Stream, New Haven River, Central Vermont*. Masters Thesis, Southern Illinois University at Carbondale.

Capen, David E., 1998, Biophysical regions of Vermont from the VT Biodiversity Project (GeologicOther_BIOPHYSRG), downloaded from Vermont Center for Geographic Information <http://www.vcgi.org/>.

DelloRusso, V. and Rolfe S. Stanley, 1986, *Bedrock Geology of the Northern Part of the Lincoln Massif, Central Vermont*. Vermont Geological Survey Special Bulletin No. 8.

Leopold, Luna B., 1994, *A View of the River*. Cambridge, MA: Harvard University Press.

Leopold, Luna B., M. Gordon Wolman, and John P. Miller, 1964. *Fluvial Processes in Geomorphology*. New York, NY: Dover Publications, Inc.

Stewart, David P. and Paul MacClintock, 1969, *The Surficial Geology and Pleistocene History of Vermont*. Vermont Geological Survey Bulletin No. 31.

Tauvers, Peter R., 1982, *Bedrock Geology of the Lincoln Area, Vermont*. Vermont Geological Survey, Special Bulletin No. 2.

VT Agency of Natural Resources, April 2003a, Stream Geomorphic Assessment: Phase 1 Handbook.

VT Agency of Natural Resources, April 2003b, Stream Geomorphic Assessment Handbook: Rapid Stream Assessment, Phase 2 Field Protocols.

Williams, G.P., 1986. River Meanders and Channel Size. *Journal of Hydrology*, v. 88, pp. 147-164.