Bear Creek Environmental

Phase 1 and Phase 2 Stream Geomorphic Assessments
Moon Brook Watershed
Rutland City, Rutland Town, and Mendon, Vermont

Final Report
January 25, 2006

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ACKNOWLEDGEMENTS

Bear Creek Environmental (BCE) would like to thank several individuals for assisting with the Phase 1 and 2 Geomorphic Assessments of the Moon Brook Watershed. We express gratitude to Alan Shelvey, Engineer for Rutland City, for providing information relating to the development and flooding history of the Moon Brook watershed and for assisting with the mailings and fieldwork. BCE would like to acknowledge Shannon Hill, Ethan Swift, and Jennifer Callahan of the Vermont Agency of Natural Resources for assisting with field data collection and Shannon Hill and Steve Schild (Rutland Regional Planning Commission) for providing technical expertise specific to this project. We express our appreciation to Nancy McGuire of the Rutland Natural Resource Conservation District for organizing the public meetings. We would like to thank Shannon Hill, Jennifer Callahan, and Jim Pease for providing review comments on the draft report. The BCE project team is also grateful to the riparian landowners within the Moon Brook watershed for granting us access to our study reaches.

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EXECUTIVE SUMMARY

Phase I and Phase 2 Stream Geomorphic Assessments within the Moon Brook watershed were completed by Bear Creek Environmental (BCE) during summer 2005. These stream geomorphic assessments provide information about the physical condition of streams within the Moon Brook watershed and the factors that influence the stability of these systems. The project was funded through the Vermont Clean and Clear Program. The Stormwater Section of the Vermont Department of Environmental Conservation (DEC) sponsored the project, and the VDEC River Management Program provided technical expertise and shared quality control/quality assurance responsibilities with Bear Creek Environmental. The study included the main stem of Moon Brook and two major tributaries: Mussey Brook and an unnamed tributary that flows in the vicinity of the Rutland Regional Medical Center (herein referred to as Hospital Brook).

The study followed the Phase 1and 2 assessment protocol developed by the DEC River Management Program. Information from the study came from the DEC, the Vermont Mapping Program, the Vermont Center for Geographic Information, the City of Rutland, and field data collected by Bear Creek Environmental. The Phase 1 study used a combination of remote sensing (i.e. mapping) and windshield surveys to understand the stream's response to natural and human disturbances that have influenced the Moon Brook watershed. As part of the Phase 1 study, Moon Brook's watershed was divided into 20 reaches based on confinement, slope, soils, and tributary influence (see Figure 1). Three reaches and one segment were excluded from the Moon Brook watershed assessment due to impoundments. The Phase 2 Rapid Stream Assessment included field observations and measurements that are used to verify the Phase 1 stream geomorphic data and provide field evidence of channel adjustment processes and habitat quality of the study reaches. The project also involved BCE's participation in two public meetings, one training workshop, and several site visits with landowners to provide education and outreach to the Moon Brook watershed community.

The focus of the Phase 1 study is to evaluate parameters that may cause channel adjustment such as floodplain modifications, channel modifications, and land use. Of the four impact categories measured during the Phase 1 Assessment, floodplain modification and land use were identified as having the greatest potential for causing channel adjustment in the Moon Brook

watershed. The floodplain modification parameters: berms and roads, river corridor development, and meander belt width all received high impact scores. Eighty two percent of the reaches resulted in a watershed/land use and a river corridor land cover/land use impact rating of high. Approximately half of the reaches received a high impact rating for riparian buffer, due to over 75 percent of the reach having little or no vegetation on one or more banks. In stream channel modification was also significant within the Moon Brook watershed with high impact ratings for flow regulation and channel straightening. Ice debris jam potential, also resulted in a high impact score.

Based on the review of current and historical aerial photographs, channel migration was evident on the main stems of Moon Brook and Mussey Brook. Migration, or movement of the channel by eroding its outer bank on meander bends, appeared to be the primary mechanism for lateral migration of the channel. Meander width ratios measured on Moon Brook indicate the river has become straighter and steeper (likely through channelization and straightening), resulting in degradation and loss of access to its floodplain in some locations.

Six of the seventeen reaches resulted in a Phase 1 reach condition of poor. Reaches in poor condition were isolated to the mid to lower portions of Mussey Brook and the mid portion of Moon Brook (from Combination Pond to Hospital Brook). Approximately half of the unconfined reaches were in the poor category and half were in the fair category. One of the 17 reaches (the lower reach on a tributary to Mussey Brook) was placed in the good category. Streams in reference condition were found in the headwaters and were all high gradient systems with narrow valleys.

A strong positive correlation was found between the percentage of urban land use within the Moon Brook corridor and the Phase 1 impact rating. This is not surprising given floodplain encroachment (e.g. berms, roads, railroads, improved paths, and development), channel modification activities (e.g. channel straightening), and buffer disturbance are typically related to the density of development within the corridor.

The Phase 2 data assessment focused on data collection relating to the stream channel, the riparian corridor, and aquatic habitat. This information can be used in watershed planning, for the establishment of erosion hazard zones, and for the identification of watershed improvement projects. The Phase 2 assessment consists of field notes that are collected through a reach and the completion of a Rapid Geomorphic Assessment (RGA) and Rapid Habitat Assessment (RHA).

The Phase 2 RGA is important for understanding the geomorphic stability of a reach. The RGA includes an evaluation of reach condition (departure from reference condition), channel adjustment process, and the reach sensitivity. The reach condition describes the degree of departure of the channel from its reference stream type. The channel adjustment process is a change in the form of the channel due to natural causes or human impacts. Reach sensitivity describes how sensitive a stream reach is to changes within the watershed, and is dependent upon the existing stream type and the condition of the reach.

Of the 23 segments where Phase 2 Stream Geomorphic Assessments were undertaken, eleven segments rated in the good category, as well as eleven rating in the fair category. One each rated in reference and poor geomorphic condition. The segment rating in the poor condition is on Moon Brook within the Route 7 corridor. A very short segment, located in a wetland, downstream of what was formerly know as Eddy Pond, was found to be in reference condition.

The reach condition rating of Moon and Mussey brooks indicate that many of the reaches are actively in a process of minor or major physical adjustments. Adjustment processes in river systems include four major categories: degradation, aggradation, widening, and planform. Degradation is the term used to describe the process whereby the stream bed lowers in elevation through scour of bed materials. Aggradation is a term used to describe the raising of the bed elevation through an accumulation of sediment. Channel widening occurs when streamflows are contained in a channel as a result of degradation or floodplain encroachment, or when sediments overwhelm the stream channel and the energy is concentrated into both banks. The planform is the channel shape as seen from the air. Planform change can be the result of a straightened course imposed on the river through different channel management activities, or a channel response to other adjustment processes such as aggradation and widening.

Major to extreme aggradation was noted on the lower Moon Brook in the segment downstream of Route 7, as well as the reach on Moon Brook directly upstream of Combination Pond. This aggradation is likely due to a combination of sediment from stormwater runoff and bank erosion. Two of the ten Moon Brook segments showed signs of extreme vertical adjustment. These areas include the reach that runs through downtown Rutland (below Route 7), where historic incision has occurred in response to floodplain encroachment, and a segment located above a private on-stream pond in the upper part of Moon Brook. This upper segment is actively incising through several large head cuts. This active incision will be followed by channel widening and planform adjustment.

Five of the fourteen Mussey Brook segments are going through major to extreme channel adjustment due to aggradation, degradation, widening and/or planform adjustment. Significant adjustment processes were most prevalent in the more heavily urbanized areas at the lower end of Mussey Brook.

The Rapid Habitat Assessment (RHA) is used to evaluate the physical components of a stream (the channel bed, banks, and riparian vegetation) and how the physical condition of the stream affects aquatic life. The results can be used to compare physical habitat condition between sites, streams, or watersheds, and also serve as a management tool in watershed planning or similar land-use planning.

Overall, the RHA score was similar to the RGA score, implying that the ecological health of the Moon Brook is intricately tied to the geomorphic condition of the stream. For fifteen of the twenty-four assessed segments, the RHA resulted in a fair rating. Three segments shared an RHA and RGA rating of good. Only one segment, M22-S1.01-S1.01-B, located on Mussey Brook through the fairgrounds placed poorly in habitat condition. In general, the study reaches lacked strong bedform features, lacked adequate riparian buffers, were impaired with sediment, and had significant intrusion into their river corridor.

A high percentage of the streams assessed in the Moon and Mussey Brooks are characterized by narrow deep channels, with high sinuosity. These types of streams are very susceptible to shifts in both lateral and vertical stability caused by direct channel disturbance (riprap), straightening, riparian buffer removal and changes in the flow and sediment regimes of the contributing watershed. Rates of lateral adjustment are influenced by the presence and condition of riparian vegetation. For this reason, the acquisition of easements, streamside plantings, and buffer protection should be a high priority for restoration planning and design work within the Moon Brook Watershed.

In summary, the Phase 1 and 2 stream geomorphic assessments identified several important stressors to the geomorphic condition of the Moon Brook watershed. Land use, lack of riparian buffers, floodplain encroachment, and channel straightening were identified as primary factors influencing the geomorphic condition of Moon and Mussey Brooks. In addition, stormwater runoff and the influence of Piedmont and Combination Ponds have both altered the hydrology and sediment regime of the watershed. Recommendations for improvements within the Moon Brook watershed are provided at the end of the report.

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SECTION 1: PROJECT OVERVIEW AND BACKGROUND

1.1 PROJECT OVERVIEW

Bear Creek Environmental was retained by the Vermont Department of Environmental Conservation (VTDEC) to conduct Phase 1and Phase 2 Stream Geomorphic Assessments of Moon Brook and its Major Tributaries[1]. Moon Brook flows into Otter Creek in the central part of the Otter Creek watershed (Figure 1). As shown in Figure 2, the Phase 1 assessment was conducted on the main stem of Moon Brook, Mussey Brook, and one other major tributary (Figure 2). The Phase 2 assessment was conducted on the entire mainstem of Moon Brook and Mussey Brook. Three reaches were excluded from both assessments due to impoundments.

The primary goal of this study was to assess the geomorphic condition of Moon Brook and its major tributaries in order to address the impaired segments. Moon Brook from the mouth to river mile 2.3 is listed on the 2004 State of Vermont 303(d) list of impaired waters due to stormwater runoff and erosion (Figure 3). The main objectives of the study were to provide an overview of the general physical characteristics of the watershed, assess the impact of parameters such as land use, channel modification, floodplain modification, erosion and

[1] Per the ANR protocols major tributaries constitute ten percent or more of the watershed area at the confluence with the main stem.

debris/ice-jam potential on each reach, and determine which reaches may be in channel adjustment. The primary objective of the Phase 2 Assessment was to provide the VTDEC with information that can be used for watershed planning and restoration activities.

Data and information for the Moon Brook watershed was obtained from the Vermont Department of Environmental Conservation (VDEC) and the Vermont Center for Geographic Information (VCGI). A windshield survey of the watershed was conducted in June 2005 by Michael Blazewicz and Alyssa Borowske of Bear Creek Environmental.

1.2 BACKGROUND INFORMATION

1.2.1 Description of Study Area

The Moon Brook Watershed has a watershed size of 8.74 square miles just above the confluence of the Otter Creek in Rutland (Figure 1). The Moon Brook watershed is located within the City of Rutland and the Towns of Rutland and Mendon (Figure 2). As shown in Figure 2, the Phase 1 assessment was conducted on Moon Brook, Mussey Brook, and one other major tributary (herein referred to as Hospital Brook). The Phase 2 Assessment included only the main stems of Moon Brook and Mussey Brook.

The Moon Brook watershed is located within a fairly flat area in the lower reaches. In the upper reaches of Moon Brook, the gradients become much steeper (15-60%). Mussey Brook and Hospital Brook are characterized by flat slopes in the lower reaches and moderate slopes in the upper reaches (about 5%).

The Moon Brook watershed is located in the physiographic region of the Vermont Valley in between the Green Mountains and Taconic Mountains. This valley contains broad marble bands on the valley floor that are easily eroded and a band of quartzite east, west, and north of the City of Rutland (Van Diver, 1987). The Mendon moraine, a glacial deposit containing glacial till and sand and gravel, extends to the north and east of Rutland. The surficial geology of the Moon Brook watershed is dominated by alluvium, glacial till, glacial lake, and ice-contact deposits.

Moon Brook is located within a highly urbanized area in Rutland, Vermont. The upper portions of the watershed are predominantly forested, but urban land use dominates throughout most of the mainstem reaches and lower reaches of the tributaries.

Historically much of the lower watershed was used for agriculture. A map of Rutland County, dated 1854, provides documentation that Mussey Brook originally flowed directly into the Otter Creek south of Park Street (Scott 1854). It is thought to have been redirected to dry up lands for agricultural purposes (Shelvey 2006). Today, Mussey Brook is a tributary to Moon Brook whose watershed is slightly less urbanized than Moon Brook's watershed. Reviews of orthophotos from the 1970s have shown that the Moon Brook watershed was dominated by urban, agricultural fields, forest, and shrub land.

Rutland city was founded in the late 1700s. There was a growth spurt in the mid 1800s from the development of the railroad through town (Shelvey, 2005). Historic maps in city records show that many of the current roads and downtown buildings were constructed by 1900. The outskirts of the city, where there is strip development, was constructed mostly sometime around the 1960s.

Because the Moon Brook watershed is so small, there were no records available regarding channel management history. However, many sections in Moon Brook show evidence of channel straightening through urbanized areas.

1.2.2 Flood History

There are no USGS stream gages within the Moon Brook watershed. In order to better understand the flood history, long term data from the U.S. Department of the Interior, U.S. Geological Survey (USGS) gage on Otter Creek in Rutland, VT (gage #04282000) was obtained. The Otter Creek gage was selected because it is located near Moon Brook. Although the drainage area at the Otter Creek gage is much larger (307 sq. miles) than the Moon Brook watershed, it does provide some useful information about when large flood events occurred. Seventy-six years of record are available for the Otter Creek gage in Rutland. The gage provides a continuous record of flow from 1929 through the present. The long term record shows peak discharges between a ten year and 25 year recurrence interval occurred during water years[2] 1947, 1949, 1973, 1976, 1977, and 1987. Floods less frequent than the 25 year discharge occurred during the water year 1938.

According to Alan Shelvey, City Engineer for the City of Rutland, Moon Brook has flooded between Strongs Ave. & South Main Street along the south side of Clover Street. The subwatershed for reach M22-S1.02 includes this area. The frequency of the flooding has been about two times in the last 30 years, approximately 1972 and 2001. This area is located within Zone A10 according to the city's flood maps, which means that it is within the 100 year floodplain. Another location in the watershed that floods about every spring is in the meadows by Forest Street (M22-S1.01). There is no development in this area that is impacted. This area is designated as Zone A8 according to the flood maps.

[2] A water year is the twelve month period from October 1 through September 30.

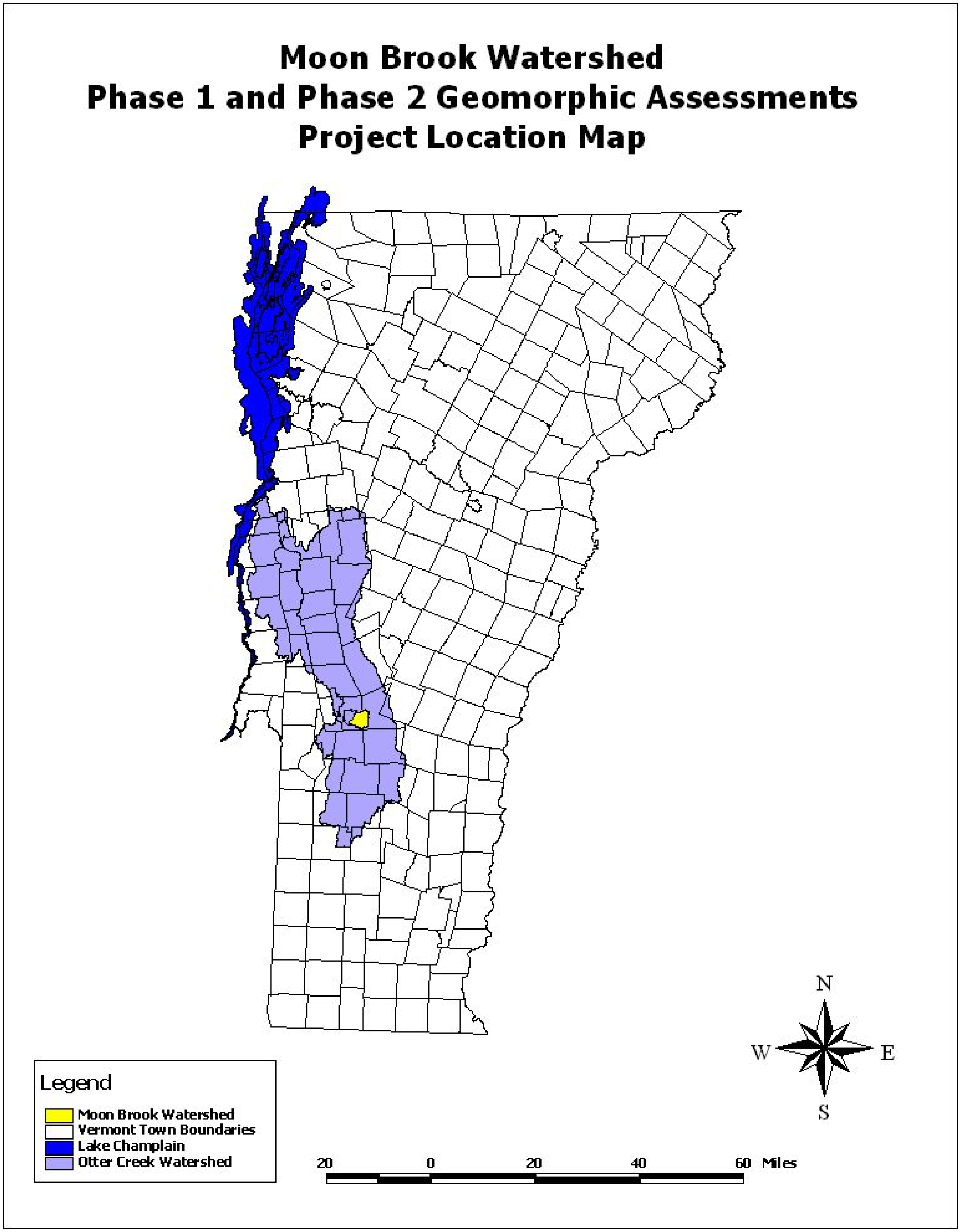

Figure 1. Project Location Map for the Phase 1 and Phase 2 Assessments

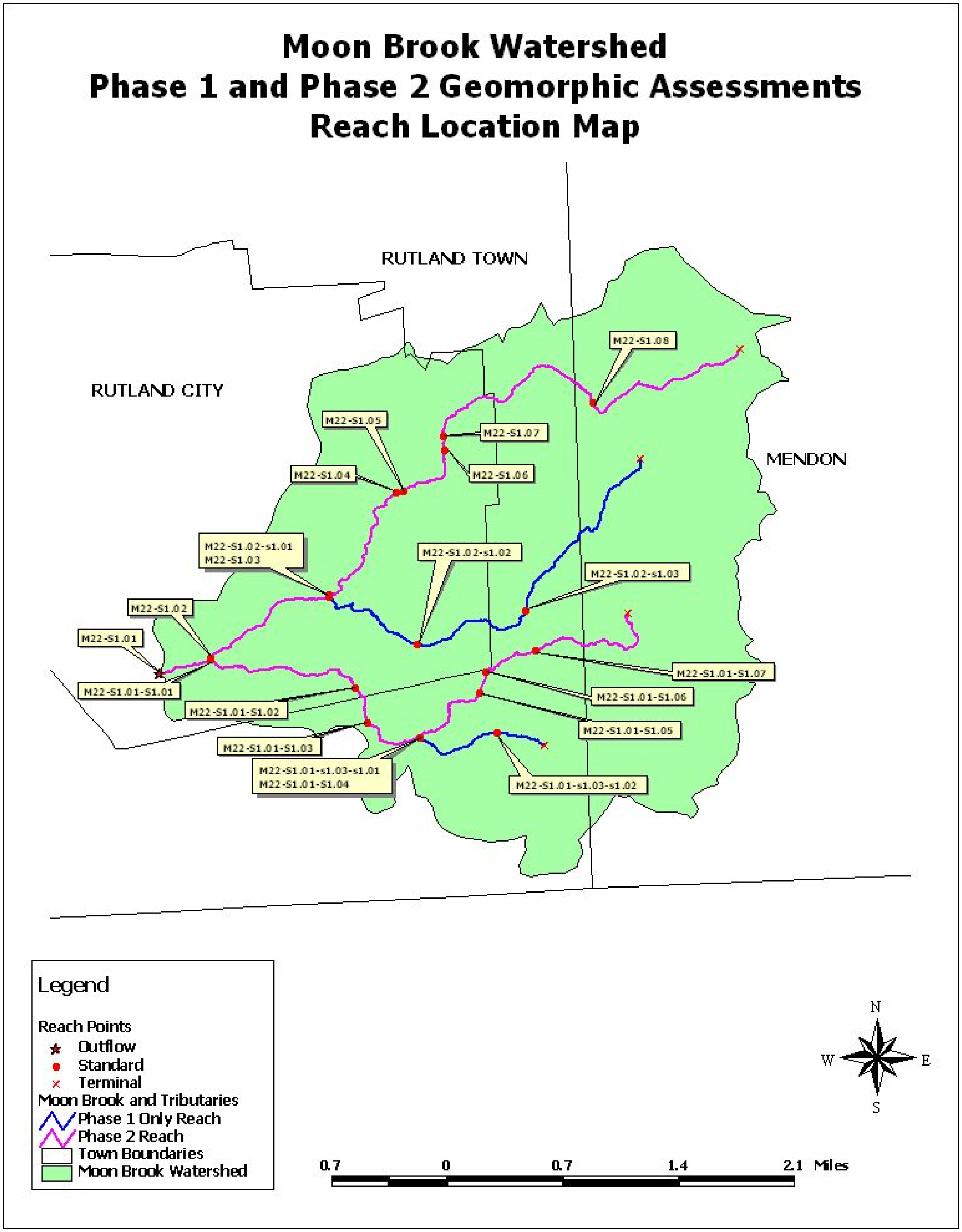

Figure 2. Reach Location Map for the Phase 1 and Phase 2 Stream Geomorphic Assessments

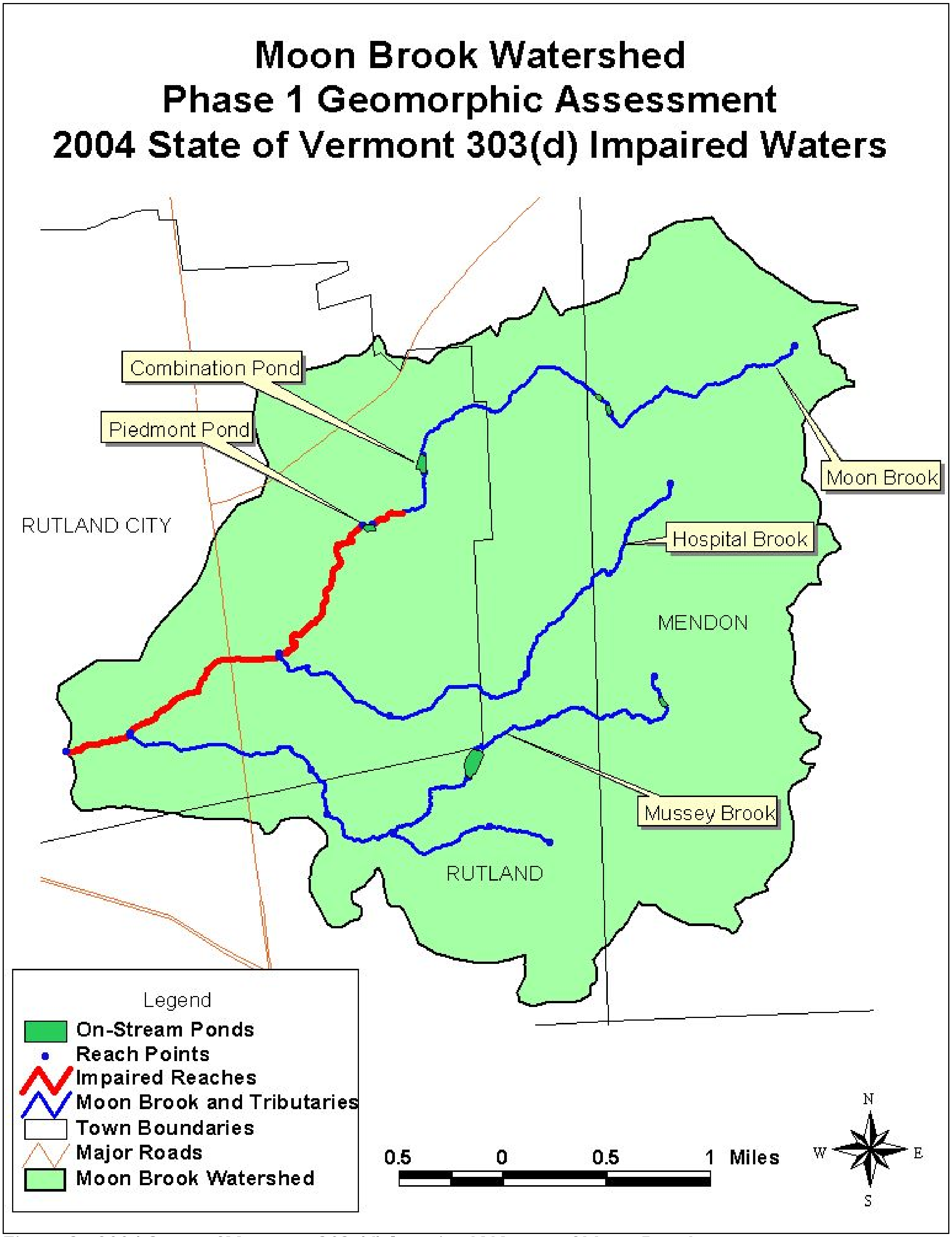

Figure 3. 2004 State of Vermont 303 (d) Impaired Waters of Moon Brook

SECTION 2: PHASE I STREAM GEOMORPHIC ASSESSMENT

2.1 PHASE I METHODOLOGY

The Phase I assessment followed procedures specified in the Vermont Stream Geomorphic Assessment Phase 1 Handbook (Vermont Agency of Natural Resources 2005), and used version 3.02 of the Stream Geomorphic Assessment Tool (SGAT) GIS extension. All assessment data were recorded on the Agency of Natural Resources (ANR) Phase I data sheets, and were entered into the ANR Data Management System (DMS).

2.1.1Parameters

During the Phase 1 Assessment, data was collected for each parameter in Table 1. The parameters were then rated according to the following menu options (NS – not significant, low impact, high impact or No info –no information). A zero was scored for options NS and No info, a one for low impact and a two for high impact.

The reach indexing tool (RIT) was used to document steps 5.3, 5.4, and 6.1. This tool is an extension of ArcView and utilizes the Vermont Hydrography Dataset (VHD) (VCGI, 2003) to automate measuring the length of stream segments. The impacts were entered into an attribute table, which was uploaded to the DMS.

Table 1. Parameters Included in Impact Scores

Step #	Parameter
4.1	Watershed Land Cover/ Land Use
4.2	Corridor Land Cover/ Land Use
4.3	Riparian Buffer Width
5.1	Flow Regulations and Water Withdrawals
5.2	Bridges and Culverts
5.3	Bank Armoring and Revetments
5.4	Channel Modifications
5.5	Dredging and Gravel Mining History
6.1	Berms and Roads

Table 1. Parameters Included in Impact Scores	
Step #	**Parameter**
6.2	River Corridor Development
6.3	Depositional Features
6.4	Meander Migration / Channel Avulsion
6.5	Meander Width Ratio
6.6	Wavelength Ratio
7.2	Bank Erosion – Relative Magnitude
7.3	Debris and Ice Jam Potential

2.1.2 Quality Control/Quality Assurance Procedures

To assure a high level of confidence in the Phase 1 and 2 SGA data, strict quality assurance/quality control (QA/QC) procedures were followed by BCE. These procedures involved a thorough in-house review of all data as well as automated and manual QC checks with the DEC River Management Program. The three base shapefiles (valley walls, meander centerlines, and subwatershed) were submitted to Shannon Hill for QA review prior to running the SGAT extension. After Step 2 of the Phase 1 Assessment was completed, Bear Creek Environmental conducted its own manual QA review of the reference stream types. Then the SGAT project and resultant shapefiles were sent to the River Management Program for another QA review, which included a manual QA review of reference stream types. In early June 2005, Phase 1 ArcView shapefiles were submitted to Shannon Hill for a QA review following the completion of Step 7 of the Phase 1 assessment.

BCE completed its own in-house QA review after all the Phase 2 data were entered into the DMS and the Phase 1 data were updated. Lengths of armoring, berms, and erosion on field forms were checked against DMS values as well as calculated lengths in GIS shapefiles. Then the Phase 2 GIS shapefiles were submitted to the ANR for a third QA review. Some minor revisions were made by Bear Creek Environmental to the

DMS following this review. These change included one stream type revision, a sub-class slope change, and filling in blank spaces in the DMS.

2.2 PHASE 1 RESULTS

2.2.1 Reach Locations

The Moon Brook watershed was divided into 20 reaches for the Phase I Assessment. Reaches M22-S1.04 (Piedmont Pond), M22-S1.06 (Combination Pond), and M22-S1.01-S1.05 did not receive a full Phase I assessment, because these reaches are not fluvial systems. Report Number 1 on page 1 of Appendix A provides the reach locations including reach description, town where the reach is located, and latitude and longitude generated from SGAT. Figure 2 shows the location of study reaches used in the Phase 1 Assessment. Each point represents the downstream end of the reach.

2.2.2 Reference Stream Types

Reference stream types are defined as stream channel forms and processes that would exist in the absence of human-related changes to the channel, floodplain, and/or watershed. Stream and valley characteristics including valley confinement, and slope determined from digital USGS topographic maps were used to determine the stream type. The reference reach characteristics were later refined during the windshield survey and Phase 2 Assessment. Reference reach typing was based on both the Rosgen (1996) and the Montgomery and Buffington (1996) classification systems.

Report 2 on page 2 of Appendix A provides a complete listing of reference stream types for each reach within the project area. The reference stream types, based on the Phase 1 Geomorphic Assessment are shown in Figure 4. The majority of the stream reaches fall within the E or C stream types (see Table 2). E stream types comprised 46 percent of the assessed reaches by length. Approximately 32 percent of the study reaches by length were C type streams. Both C and E streams are unconfined, have moderate to gentle slopes, and gravel or finer bed material except for some of the plane bed systems, which were dominated by cobbles.

Two reaches, comprising approximately 12 percent of the study area by length, fall into the A stream type. Cascade systems are narrowly confined, very steep (valley slope greater than 6.5%), with boulder or cobble dominated bed material. One of the 20 reaches (approximately 10 percent of the study area by stream length) falls within the B stream type. This reach was categorized as a step-pool system. This step-pool B stream is narrow, has a steep slope, and cobble bed material. Reach M22-S1.01-S1.03-S1.02, located in the upper part of the watershed, was not easily accessible and was not visited during the windshield survey. Best professional judgment was used to assign a bed form for this reach.

Table 2. Reference Stream Type

Stream Type	Confinement	Channel Slope	Bed Material	Percentage by channel length of Assessed Reaches
A/ Cascade	Narrowly or semi confined	Very steep	Boulder	12
B/Step-pool	Narrow	Steep	Cobble	10
C/Plane Bed	Narrow, Broad or Very Broad	Moderate to gentle	Cobble or finer	17
C/Riffle-pool	Narrow, Broad or Very Broad	Moderate to gentle	Gravel	15
E/Riffle-pool	Narrow, Broad or Very Broad	Moderate to gentle	Gravel or finer	20
E/Dune-ripple	Narrow, Broad or Very Broad	Moderate to gentle	Sand	26

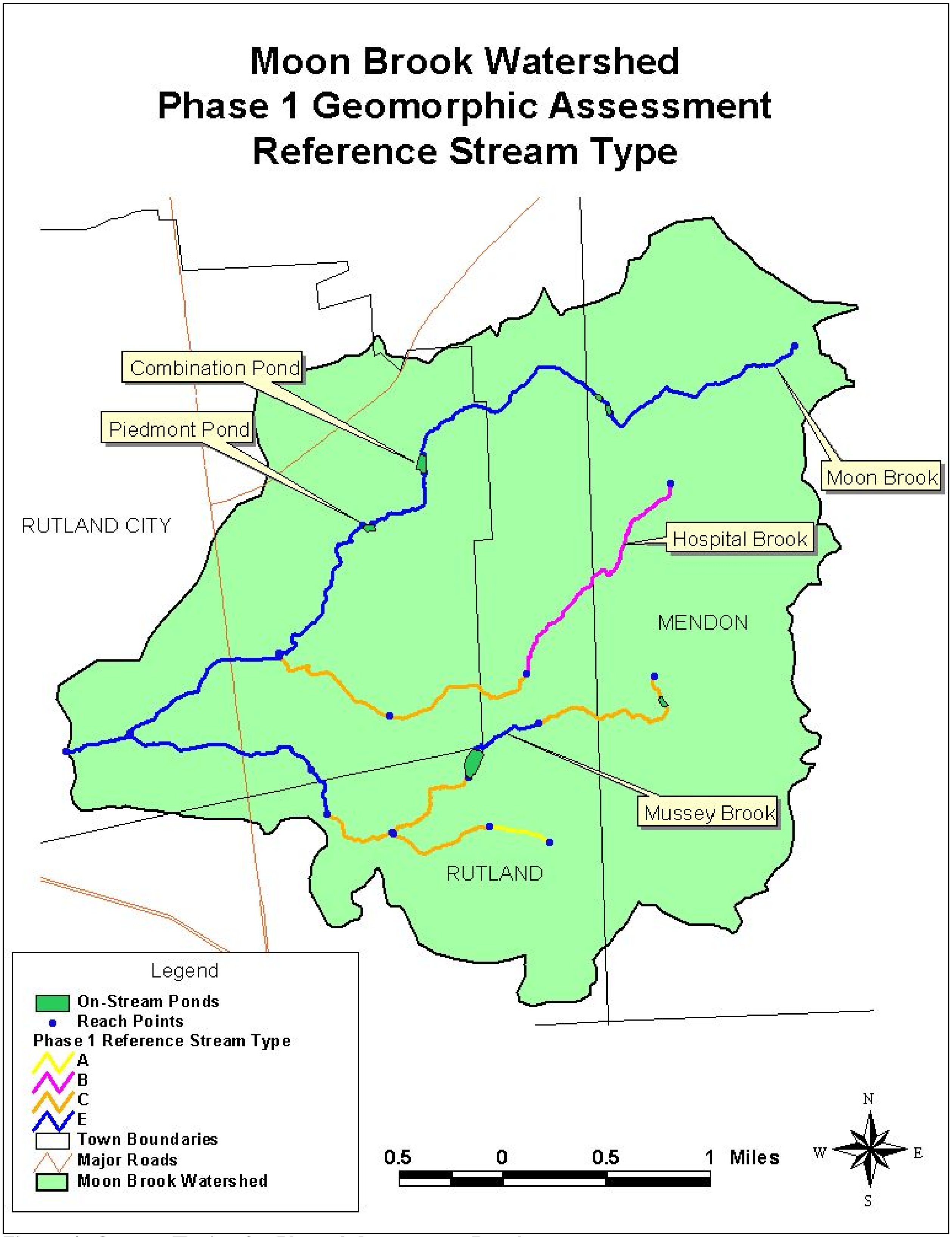

Figure 4. Stream Typing for Phase I Assessment Reaches

2.2.3 Basin Geology and Soils

The characteristics of the Moon Brook watershed were determined using a combination of soils data, review of topographic maps, and information acquired during the windshield survey. Report Number 3, located on page 3 of Appendix A, provides a summary of the basin characteristics, such as alluvial fans, grade control structures, geologic materials, valley side slopes, and soil characteristics.

One possible alluvial fan was identified in reach M22-S1.02-S1.03 due to a sharp break in valley slope that was noted on the topographic map. The soil map indicated that the parent soils in this reach are glacial outwash or till and not alluvium, and there was no evidence of an alluvial fan in the field. For this reason, the Phase 1 DMS was updated to specify no alluvial fan for reach M22-S1.02-S1.03. Grade control structures such as ledge and dams were noted during the windshield survey. Dams were found in four of the study reaches (M22-S1.01-S1.04, M22-S1.02-S1.01, M22-S1.03 and M22-S1.05). The steepness of the valley side slopes was determined using a combination of a topographic map and the soils layer. The valley side slope steepness was variable, but overall flat to hilly slopes dominated the watershed.

As shown on page 4 of Appendix A, the dominant surficial geology of the Moon Brook watershed consists of alluvium, glacial till, and ice contact deposits. The reaches characterized as C channels within the watershed have glacial till, glacial lake and ice-contact deposits as the dominant geologic materials. These soils are rarely flooded and their erodibility is moderate to very severe. The E type channels have a dominant geologic materials consisting of alluvium, ice-contact, glacial till, glacial lake and ice-contact deposits. These soils flood frequent to rarely and have a slight to very severe erodibility. For the A and B type channels, the geologic materials are dominated by till and ice contact deposits. These soils are rarely flooded and have a very severe erodibility.

2.2.4 Land Cover – Reach Hydrology

The land use within the watershed plays a role in the hydrology of the receiving waters. The percentage of urban and cropland development within the watershed are factors which change a watershed's response to precipitation. The most common effects of urban and cropland development is increasing peak discharges and runoff by reducing infiltration and travel time (United States Department of Agriculture 1986). The land use/land cover within the stream corridor itself is also an important parameter to evaluate. This land use/land cover plays an important role in the sediment deposition and erosion which occurs during annual flood events (Vermont Agency of Natural Resources 2004).

As outlined in the Phase I handbook, impact ratings were assigned for watershed land cover/land use and stream corridor land cover/land use as follow:

High – 10% or more is crop and/or urban
Low – Between 2 and 10 % is crop and/or urban
NS – Not Significant – Less than 2 % is crop and/or urban

As provided in Report Number 4 (see page 5 of Appendix A) the dominant watershed land cover/land use within the Moon Brook watershed in Rutland is urban and forest. Fourteen of the twenty reaches resulted in a watershed /land use impact rating of high. The dominant land cover/land use within the river corridor is urban land. Fourteen of the reaches also resulted in a high impact rating for corridor land cover/use, as shown on page 5 of Appendix A. Orthophotos from the 1970s were reviewed and showed that the Moon Brook watershed was dominated by urban, agricultural fields, forest, and shrub land. The data shows that some areas within the Moon Brook watershed may have been reforested. However, some other agricultural and forested areas were cleared for development.

Riparian buffers provide many benefits. Some of these benefits are protecting and enhancing water quality, providing fish and wildlife habitat, providing streamside shading, and providing root structure to prevent bank erosion. As summarized on page 6 of Appendix A, seven of the stream reaches had 75 percent or more of the reach with little or no buffer on at least one bank. These stream reaches which lack a high quality riparian buffer are at significantly higher risk of experiencing high rates of lateral erosion.

2.2.5 Historic Channel Modifications

Channel modifications may impact a stream reach by affecting the hydraulics and the sediment regime. Historic channel modifications were assessed in this Phase I study by evaluating flow regulations, impacts of bridges and culverts, bank armoring, windrowing, straightening, and dredging. The percentage by length of reach impacted by one or more of these channel modifications was estimated and is summarized in Report Number 5 (see pages 7 and 8 of Appendix A).

Flow Regulations

There were five on-stream ponds noted in the watershed (three on Moon Brook and two on Mussey Brook). Reaches downstream of these impoundments were all given an impact rating of high for flow regulation. The Moon Brook watershed is very small and therefore there are no records at the Vermont Water Quality Division and the Facilities Engineering, Dam Safety Section regarding any water withdrawals. The dams within the watershed are not be used for water withdrawal but were rated high for changing the flow regime and disrupting natural sediment transport within the watershed.

Bridges and Culverts

As part of the Phase 1 Stream Geomorphic Assessment, the number of bridges and culverts within the study reach were counted by identifying stream crossings on the topographic maps and orthophotos. These stream crossings were confirmed during the windshield survey and Phase 2 Assessment. The length of the reach impacted by stream crossing structures was estimated during the windshield survey and from orthophotos. Percentages of the reach impacted were then automatically calculated in the DMS.

Impact ratings for bridge and culverts were evaluated by determining the percentage of the reach length that is channelized, has split flow, or makes a sharp "S" bend upstream or downstream of bridges or culverts. All but two reaches (M22-S1.01-S1.02 and M22-S1.01-S1.03-S1.02) had an impact rating of low for bridges and culverts. No reaches received an impact rating of high for bridges and culverts.

Bank Armoring

The amount of bank armoring within a watershed is often indicative of the occurrence of channel processes, which result in bank erosion. Bank armoring, also called revetments, can be made of a variety of material including wooden cribs, gabions, logs, and rock riprap. The most common type of revetment in Vermont is rock riprap. The following criterion was used to provide an impact rating for human placed bank armoring.

H	High – Greater than 30% of the reach length is armored
L	Low – Between 10 and 30% of the reach length is armored
NS	Not Significant – Less than 10% of the reach length is armored
No Info	Bank armoring has not been evaluated for the entire reach and impact at the reach level is unknown

Rock riprap, rock walls and wood retaining walls were the three types of revetment noted within the study area. During the field assessments, rock riprap was noted in nine of the reaches. Hard bank revetments (rock walls) were noted in three of these reaches which also had rock rip-rap. Two reaches had wood retaining walls in place. Of the nine reaches with bank armoring, four reaches received an impact rating of low and the other five were not significant.

Channel Modifications (Windrowing and Straightening)

The reach indexing tool (RIT), an extension of ArcView, was used to document the length of reach impacted by channel modifications. Using orthophotos, the Vermont hydrography dataset (VHD), and topographic maps, lengths of stream where the channel appeared to have been straightened were measured. During the field assessments, evidence of historic channelization projects were recorded or verified. The reach lengths (in feet) directly impacted by the channel modification were noted and then updated in the RIT attribute table. Categories considered as part of the Step 5.4 (Channel Modifications) included the following menu options:

- Straightening – Manual straightening of a channel without windrowing.
- With Windrowing – pushing gravel up from the stream bed onto the top of either bank as part of the straightening of the river.
- None – No known channel straightening.
- Not evaluated – All data sources have not been evaluated.

The only channel modification noted within Moon Brook was straightening. Channel straightening was identified by reviewing orthophotos and through field confirmation during the windshield survey and Phase 2 Assessment. Portions of stream reaches that have been historically channelized or straightened are identified below in Figure 5. The majority of the channel straightening within the Moon Brook watershed was associated with roads that run parallel to the stream, farm fields, and development within the Route 7 corridor.

Dredging History

Since the Moon Brook watershed is so small (<10 square miles), there are no records at the Vermont Agency of Natural Resources regarding dredging of the channel. Therefore, no information was available for channel dredging. However, where the channel showed that it had been straightened, there was probably some dredging that may have occurred during the straightening process.

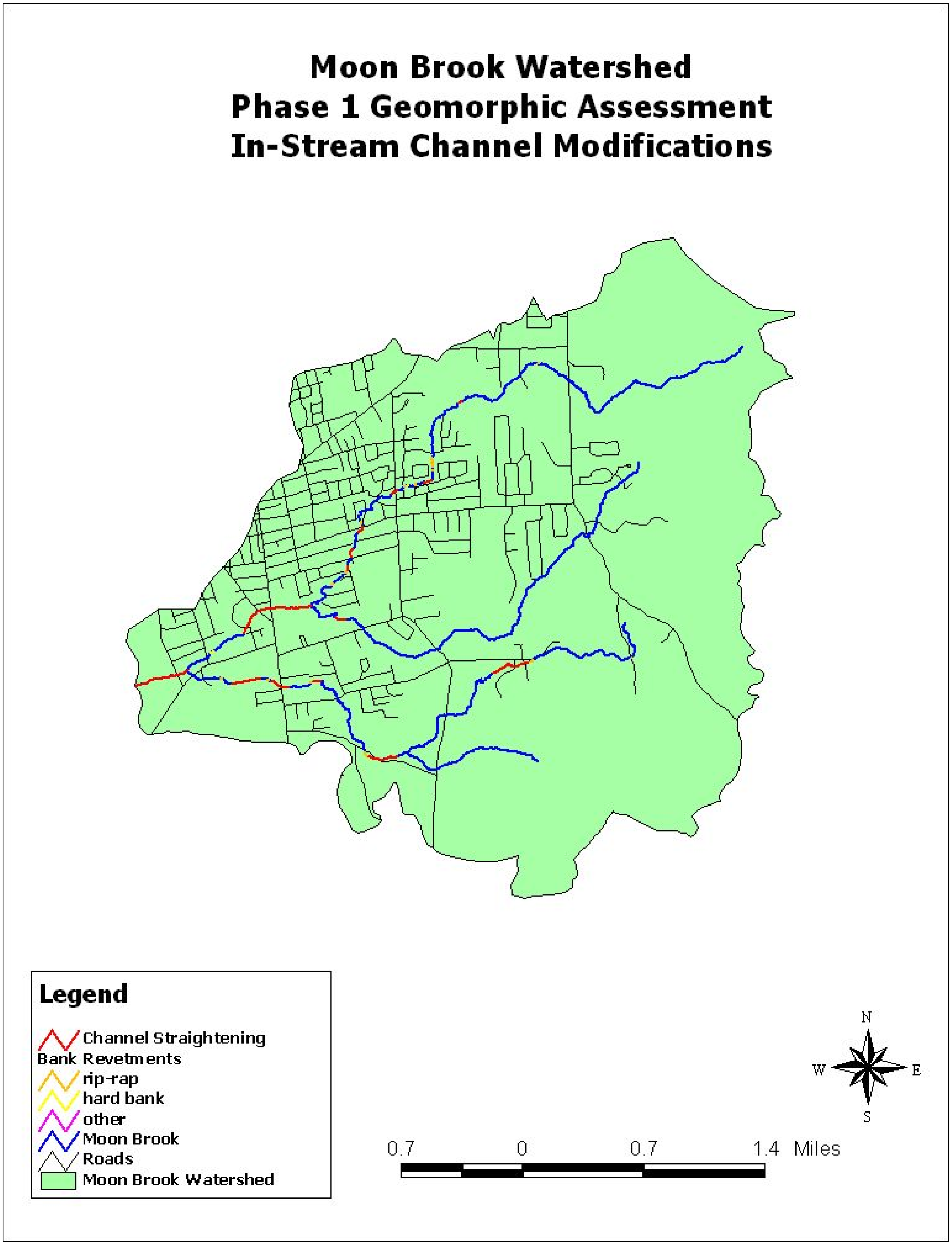

Figure 5. In stream Channel Modifications Identified for Phase I Reaches

2.2.6 Floodplain Modifications

In this step of the Phase I assessment, careful attention is paid to infrastructure and other development which restricts access to the floodplain, resulting in vertical or lateral confinement of flood flows. The parameters included in this step are: Berms and Roads, River Corridor Development, Depositional Features, Meander Migration/Channel Avulsion, Meander Width Ratio, and Wavelength Ratio. Some of the primary factors, which may influence floodplain function in Moon Brook, are discussed below: Report 6, which is included on page 9 of Appendix A, contains the Phase 1 information for floodplain and planform changes.

<u>Berms and Roads</u>

The RIT was also used to document the lengths of reach impacted by berms and roads. Using information from maps, orthophotos, and the windshield survey, the river corridor length along which berms, roads, railroad, or improved paths run parallel to the stream was measured. These measurements are summarized on page 10 of Appendix A. Reaches where berms, roads, railroads or improved paths were located along 20 percent or more of the river corridor were given impacted ratings of high. Reaches M22-S1.01-S1.03 (Mussey Brook), M22-S1.01-S1.04 (Mussey Brook), M22-S1.01-S1.06 (Mussey Brook), M22-S1.03 (Moon Brook) and M22-S1.05 (Moon Brook) received an impact rating of high for berms and roads. Cold River Road, Perkins Road, long driveways and berms are the primary impacts from berms and roads along Mussey Brook. Wesley Ave. and Ronaldo Court are the main impacts for M22-S1.03 on Moon Brook. Catherine Drive is the main impact for M22-S1.05 on Moon Brook.

<u>River Corridor Development</u>

The river corridor development parameter looks at whether developments within the river corridor are effectively decreasing the belt width. The length of one or both banks of the reach with houses, fill, parking lots or other development within the river corridor was measured using maps, orthophotos, and knowledge from the windshield survey. Seven reaches were given an impact rating of high for river corridor development. These reaches include: M22-S1.01-S1.01, M22-S1.01-S1.03, and M22-S1.01-S1.06 (Mussey Brook), M22-S1.02, M22-S1.03 and M22-S1.05 (Moon Brook), and M22-S1.02-s1.01 (Hospital Brook).

Depositional Features

The 1990s orthophotos series (1:5000) as well as results from the windshield survey were used to evaluate depositional features within the Moon Brook watershed. The presence of bars (mid channel or point bars) and deltas were noted in each of the study reaches. The ANR has included depositional features as a component of the Phase I analysis because these features are indicative of an increased sediment load and a high likelihood that the streambed is actively aggrading and/or undergoing lateral migration. An unvegetated bar indicates the bar has recently formed or is in the process of growing.

No depositional features were observed as part of the Phase 1 Assessment for Moon Brook. It was very difficult to view these features at the scale of the orthophotos and none were observed in the windshield survey either. During the Phase 2 Assessments, depositional features were discovered on nine reaches. These Phase 2 field observations were used to update the Phase I data. One reach, M22-S1.01-S1.01, was shown to have a high impact for depositional features, while the other reaches were either low or not significant.

Meander Migration

Orthophotos were used to evaluate areas where the Moon Brook and its tributaries have migrated, bifurcated, or avulsed[3]. Current orthophotos from 1994 and historic orthophotos from the 1974 were overlayed to compare the location of the river channel over time. The current and the historic orthophotos span a range of approximately 20 years. Two reaches within the Moon Brook watershed received an

[3] An avulsion is a change in planform resulting form a meander cut-off.

impact rating of high for meander migration, while six reaches received an impact rating of low. The reaches with the high impact rating were M22-S1.01-S1.03 (Mussey Brook) and M22-S1.02-S1.03 (Hospital Brook). Migration, or movement of the channel by eroding its outer bank on meander bends, appeared to be the primary mechanism for lateral migration of the channel. Reaches M22-S1.03 (Moon Brook) and M22-S1.01-S1.06 (Mussey Brook) reached an impact rating of low for channel avulsions.

Meander Width and Wavelength

The 1990 series (1:5000) orthophotos in conjunction with topographic maps and VHD data were used to determine the meander belt width and the meander wavelength for streams typed in Step 2.10 as C or E riffle-pool or ripple dune reference stream types (i.e. unconfined systems). The topographic maps were used to determine the valley direction, while the most current orthophoto series or VHD data were used to provide the accurate location of channel meanders.

The meander belt width is the horizontal distance between opposite, outside banks on fully developed meanders. The meander width ratio is calculated by dividing the average belt width for the reach by the bankfull width. The ANR Phase 1 protocol considers unconfined, gravel dominated streams with moderate to gentle gradients, which are in regime, to have belt widths in the range of 5 to 8 times the channel width.

Ninety two percent of the unconfined reaches (12 of 13) measured for meander width ratio fell outside of the range expected for channels which are in regime. Nine of the study reaches were rated as high impact for meander width ratio, three reaches received an impact rating of low, and one reach had an impact rating of not significant. All of the stream reaches which resulted in a high impact rating had meander width ratios of less than 3. These low values may indicate the stream has become straighter and steeper, possibly resulting in degradation and loss of access to its floodplain.

The meander wavelength consists of two bendways. The wavelength ratio is calculated by dividing the average wavelength by the bankfull channel width. Leopold 1994 and Williams 1985 (cited in Vermont Agency of Natural Resources, 2004a) have shown unconfined, gravel dominated streams in shallow-sloped valleys to have wavelengths in the range of 10 to 12 times the channel width.

Two of the reaches within the Moon Brook watershed resulted in a low impact rating for meander wavelength. Six of the thirteen unconfined stream reaches measured for wavelength ratio received an impact rating of high. For all of these six reaches, the wavelength ratio was less than 6, suggesting the stream is starting to aggrade and become more sinuous. This has resulted in a decrease in channel slope as the stream migrates laterally. The evidence of meander migration and bank erosion on many of the Moon Brook and Mussey Brook reaches supports the finding that Moon Brook is aggrading

2.2.7 Bed and Bank Windshield Survey

The dominant bed form, dominant bank material, bank erosion/bank height, and debris/ ice jam potential were recorded during the windshield survey, and these results are summarized in Report 7, on page 11 of the Appendix. For reaches where Phase 2 assessments were performed, this information was updated using the Phase 2 data. The dominant bed form and dominant bank material were previously discussed under Section 4.2, Stream Typing. The amount of bank erosion observed along a reach and the bank height were evaluated in conjunction with each other to provide a bank erosion impact rating. Bank erosion was rated as low or high impact for eleven of the 17 assessed reaches. As illustrated in Figure 6, high impact bank erosion is an issue on the main stem of Mussey Brook on reaches M22-S1.01-S1.01 and M22-S1.01-S1.02.

<u>Debris/Ice Jam Potential</u>

Undersized culverts or bridges with spans less than the average channel width or bridges with piers in the middle of the channel were the primary factors identified as potential for ice and debris jams. These structures, which are likely to cause constrictions during high flow events may result in lateral erosion or channel avulsions or may even endanger infrastructure. Debris/ice-jam potentials were found on 12 reaches. Five of these reaches received an impact rating of high for debris/ice-jam potential and six reaches received an impact rating of low.

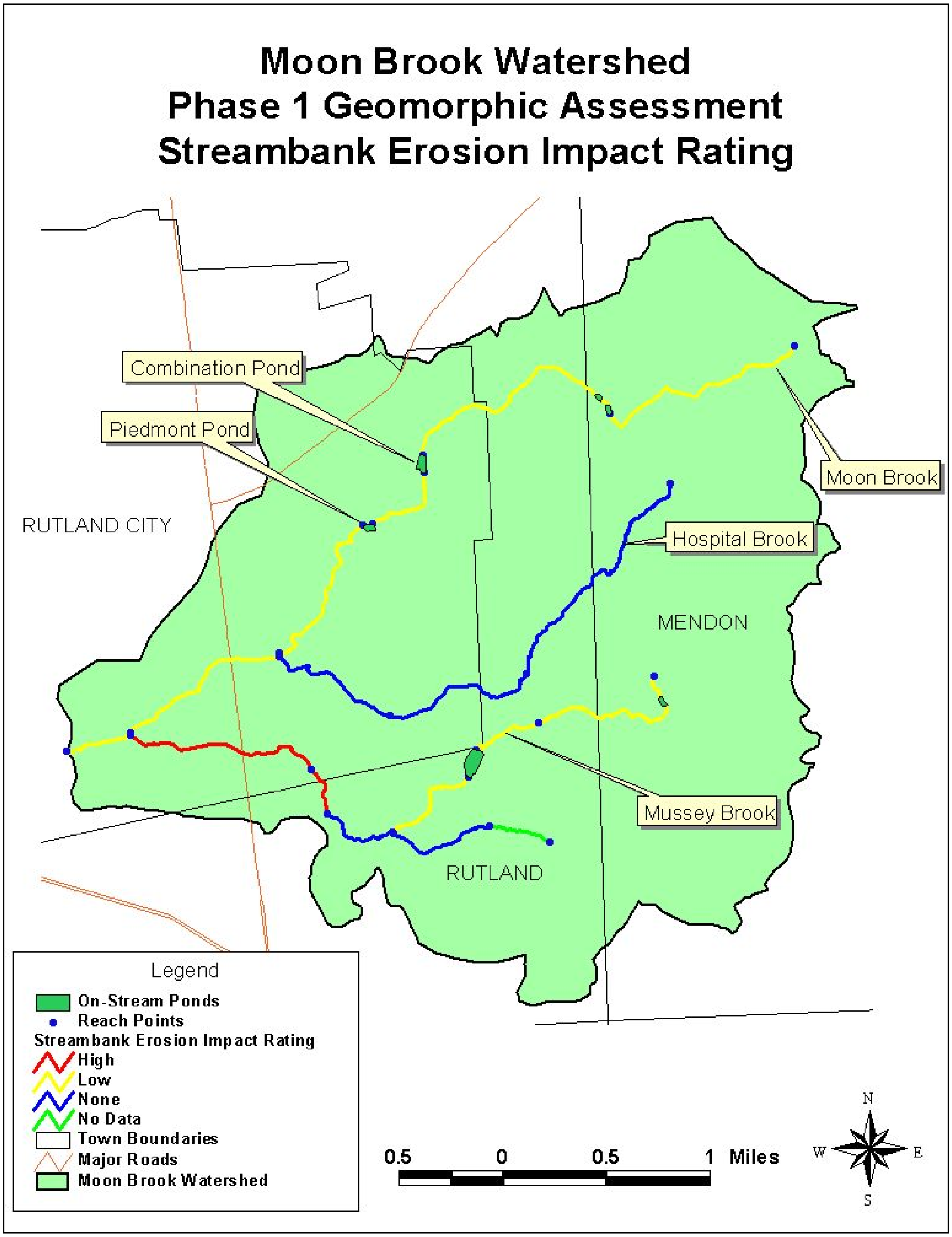

Figure 6. Streambank Erosion Impact Rating for Moon Brook Watershed

2.3 DATA ANALYSIS

2.3.1 Impact Scores

The Phase 1 evaluates parameters that may cause channel adjustment. These parameters are grouped into four major categories: land use, in stream modifications, floodplain modifications, and bed and bank windshield survey. For each parameter, the maximum impact score for the entire watershed is 34 (17 reaches times impact score of 2). As shown below in Figure 7, all three parameters in the land use category received high impact ratings for the watershed. The parameters berms and roads, river corridor development, belt width and ice debris jam potential also resulted in high scores. The total impact scores and categorical impacts for the Phase 1 assessment are provided in Report 8 on pages 12 and 13 of Appendix A.

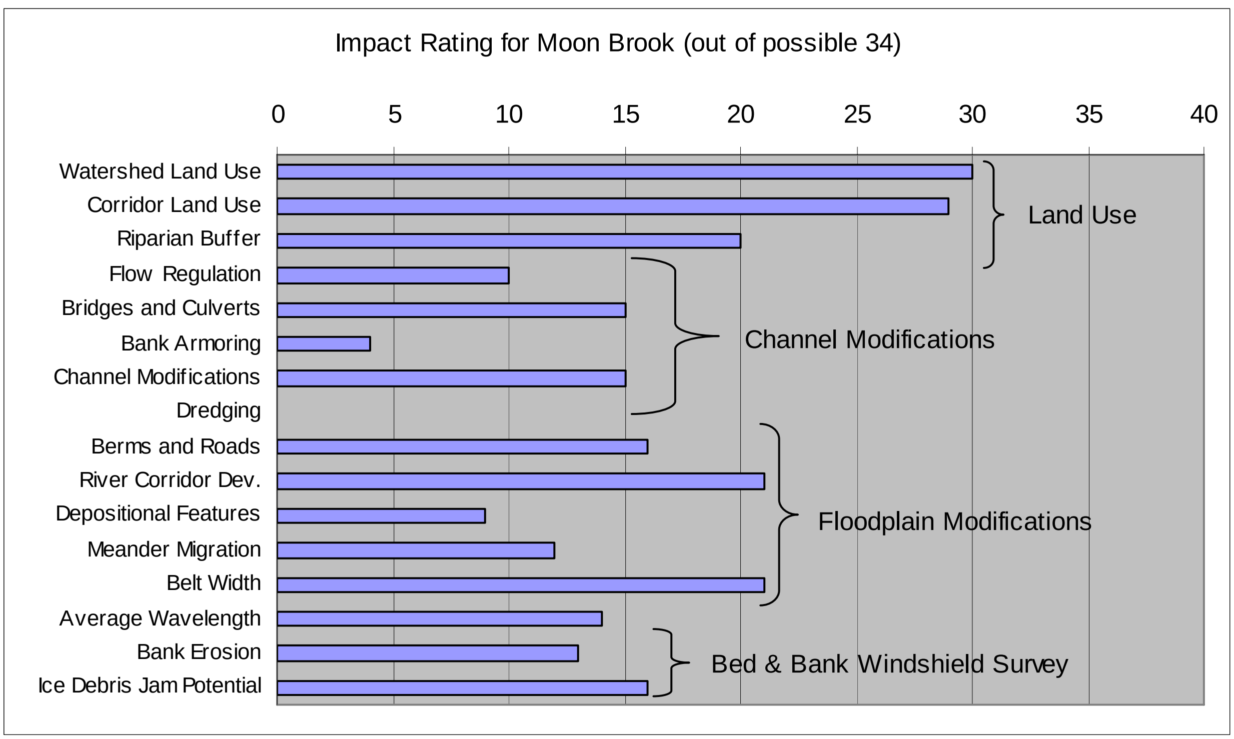

Figure 7. Impact Rating for Moon Brook Watershed by Parameter and Category

The ANR's DMS automatically generates a Phase 1 reach condition for the project using the impact scores assigned. This reach condition along with the confinement, total impact score, and watershed size is summarized below in Table 3 for the 17 reaches assessed. The reach condition for the Moon Brook watershed is mapped in Figure 8.

Table 3. Reach Assessment for Moon Brook Watershed

Reach Number	Confinement	Total Impact Score	Watershed Size (miles^2)	Reach Condition (from Phase I Database)
M22-S1.01	VB[4]	17	8.74	Fair
M22-S1.01-S1.01	VB	23	3.03	Poor
M22-S1.01-S1.02	VB	11	2.68	Fair
M22-S1.01-S1.03	VB	20	2.57	Poor
M22-S1.01-S1.03-S1.01	BD[5]	9	0.64	Good
M22-S1.01-S1.03-S1.02	NC[6]	0	0.08	Reference
M22-S1.01-S1.04	VB	18	1.62	Poor
M22-S1.01-S1.06	VB	19	1.00	Poor
M22-S1.01-S1.07	SC[7]	14	0.82	Fair
M22-S1.02	VB	20	5.43	Fair
M22-S1.02-S1.01	VB	12	1.81	Fair
M22-S1.02-S1.02	VB	8	1.65	Fair
M22-S1.02-S1.03	NW[8]	8	0.67	Fair
M22-S1.03	VB	19	3.10	Poor
M22-S1.05	VB	23	1.97	Poor
M22-S1.07	VB	17	1.64	Fair
M22-S1.08	SC	7	0.33	Reference

[4] Very Broad
[5] Broad
[6] Narrowly Confined
[7] Semi-confined
[8] Narrow

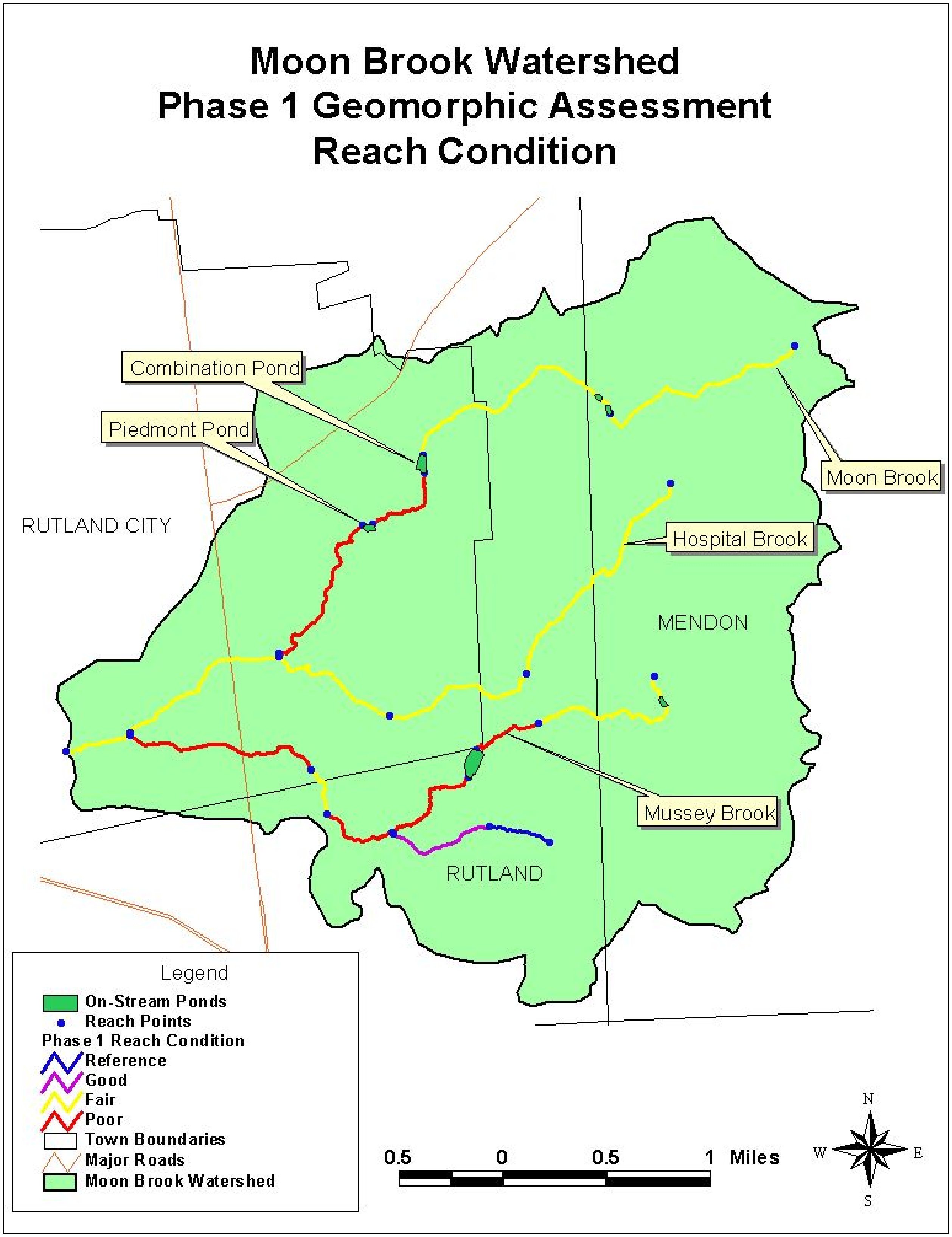

Figure 8. Reach Condition Moon Brook Watershed

Streams in fair condition are fully in adjustment and are experiencing major and rapid changes due to floodplain and channel modifications, land cover changes, and/or loss of riparian buffer. Approximately half of the unconfined stream reaches were in the poor category and the other half in the fair category. Only one confined reach (M22-S1.01-S1.07) resulted in a reach condition of fair.

One of the 17 reaches given a reach condition rating of good. The stream reach in the good condition was located on the unnamed tributary of Mussey Brook. This reach had experienced some degree of human-induced change to their watershed (land use changes and floodplain modifications) and appeared to be undergoing only minor adjustments.

A reference reach has no significant channel or floodplain modifications and has a forested buffer adjacent to the channel. In other words, these reaches are close to the natural condition. Streams in reference condition were found in the headwaters of the Moon Brook and the unnamed tributary of Mussey Brook. These reaches were both "A" type streams.

The change in impact rating between the headwaters of Moon Brook (Reach M22-S1.08) and mid to lower Moon Brook is clearly illustrated in Figure 9. This sharp increase in impact rating between Reach M22-S1.08 and M22-S1.07 may largely be due to land use. The watershed land cover drops form 88.3 percent forested in Reach M22-S1.08 to 49.4 percent in Reach M22-S1.07. A similar trend occurs with the corridor land cover/land use. The riparian corridor of M22-S1.07 consists of approximately 60 percent urban land use (i.e. moderate to high density residential, commercial, industrial, roads), while the land use with M22-S1.08 is zero percent urban.

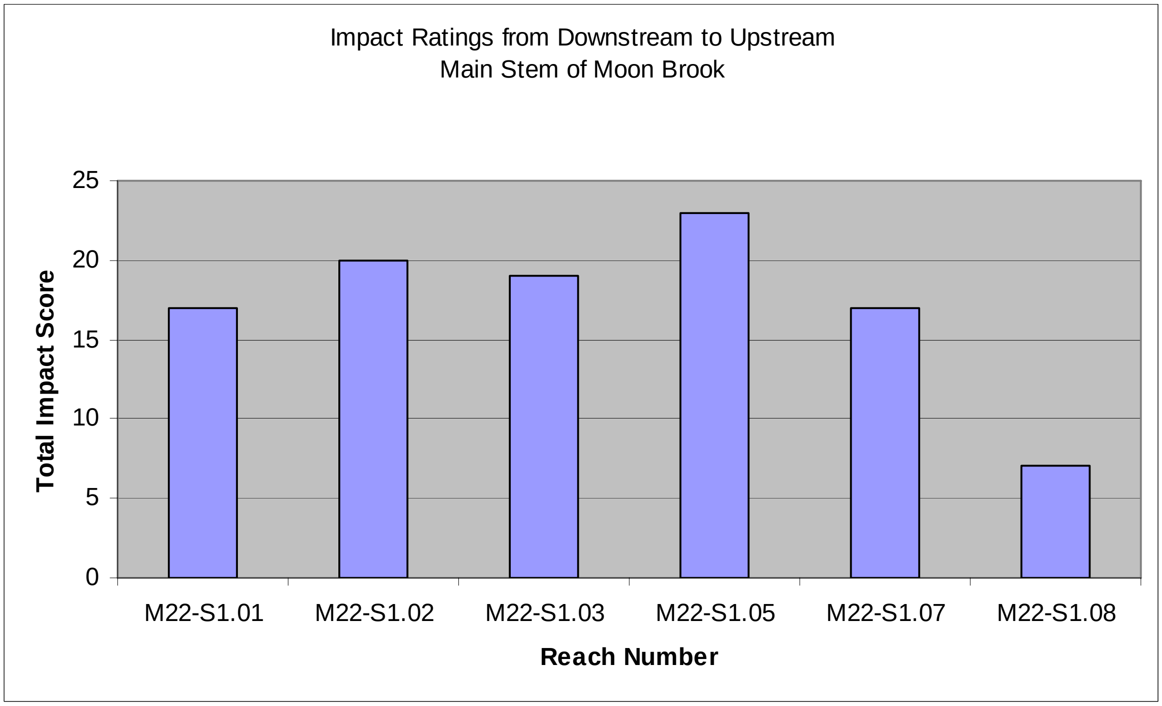

Figure 9. Impact Ratings from downstream to upstream on the main stem of Moon Brook

As shown below in Figure 10, a strong positive correlation (R=0.85) was found between the percentage of urban land use within the Moon Brook watershed (all 17 reaches) and the impact rating from the Phase 1 assessment. This means that the percentage of urban development within the corridor appears to be a good predictor of reaches that may be at risk of channel adjustment within the Moon Brook watershed.

2.3.2 Adjustment Processes

Report Number 9, on page 14 of Appendix A, provides a summary of the primary adjustment processes that were predicted based on the Phase 1 Stream Geomorphic Assessment. The Phase 1 data suggest that most of the stream reaches are experiencing more than one type of channel adjustment process. No one channel adjustment process appeared to be dominant.

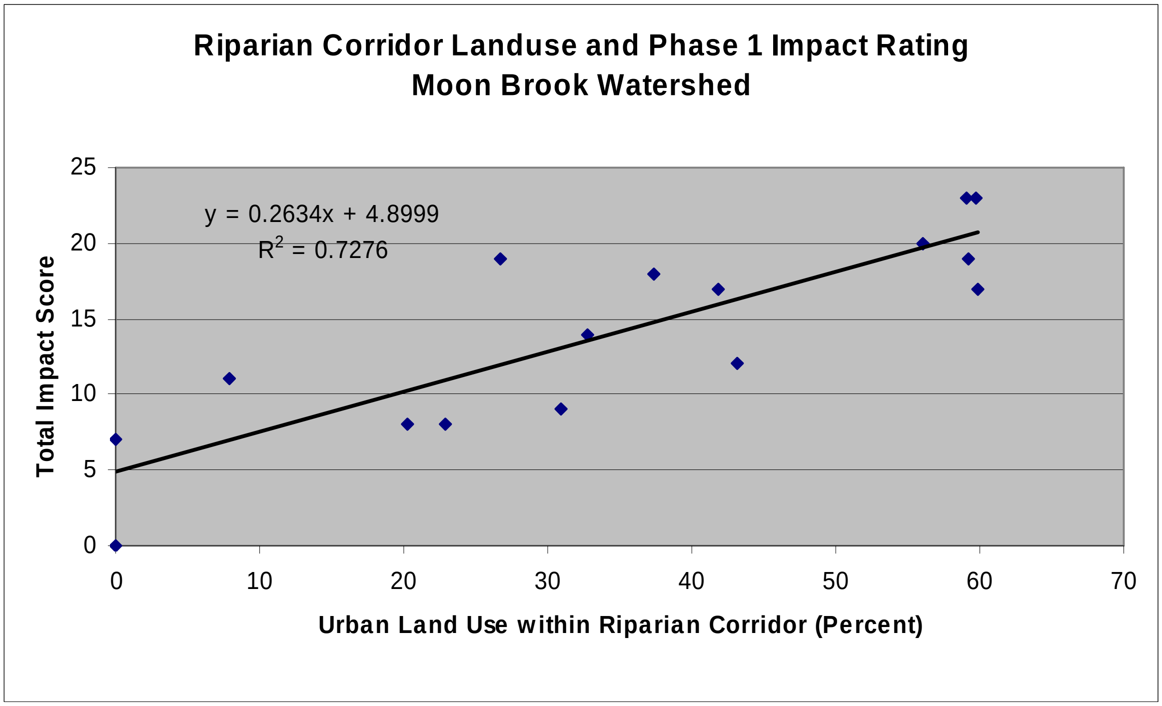

Figure 10. Relationship between urban land use within riparian corridor and Phase I impact rating.

2.3.3 Reach Sensitivity

The Phase 2 Handbook (Vermont Agency of Natural Resources, 2004b) was used to assign a stream sensitivity based on existing stream type and condition. Highly sensitive reaches are more likely to be in adjustment, and are very sensitive to land use changes within the watershed. The reach sensitivity is summarized in report 9 on page 14 of Appendix A. All except two reaches resulted in a reach sensitivity of high. These two reaches had moderate reach sensitivity. Both reaches were located on Hospital Brook. One reach is a type C stream and one is a type B stream. There will be additional discussion about stream sensitivity in the next section of the report, which discusses the Phase 2 Stream Geomorphic Assessment.

SECTION 3: PHASE 2 STREAM GEOMORPHIC ASSESSMENT

3.1 PHASE 2 METHODOLOGIES

The Phase 2 assessment of the Moon and Mussey Brook's followed procedures specified in the Vermont Stream Geomorphic Assessment Handbook Phase 2 (ANR 2005). All assessment data were recorded on the Agency of Natural Resources Phase 2 data sheets, and were entered in to the ANR Stream Geomorphic Assessment data management system (DMS). The Phase 1 database was updated using the field data from the Phase 2 assessment in October and November, 2005.

3.1.1 Phase 2 Field Protocols

The ANR's Phase 2 stream geomorphic assessment protocol includes seven categories of investigation. These categories are as follows:

1. Valley and River Corridor
2. Stream Channel
3. Riparian Banks, Buffers and Corridor
4. Flow Modifiers
5. Channel, Bed and Planform Changes
6. Rapid Habitat Assessment (RHA)
7. Rapid Geomorphic Assessment (RGA)

The parameters and protocols used for undertaking each of the above steps are outlined in the Phase 2 Handbook (Vermont Agency of Natural Resources 2005). The entire length of each Phase 2 reach was walked to determine segment breaks. Bank erosion, grade control structures, bank revetments, debris jams, depositional features, stormwater inputs, flood chutes and other important features were mapped within all segments.

3.1.2 Phase 2 QA/QC Review

The DMS and the ArcView shapefiles for the Moon Brook Phase 2 study were submitted to Shannon Hill of the ANR for a Quality Assurance review in late November 2005. The Phase 1 DMS and ArcView shapefiles were updated by Michael Blazewicz and Pamela DeAndrea based on the Phase 2 field assessment work during the Phase 2

QA/QC process in early November 2005. Mary Nealon and Michael Blazewicz provided QA/QC to critical components of the RGA data in October of 2005.

3.2 PHASE 2 RESULTS

The results of the Phase 2 study are summarized by reach number, and reports from the Phase 2 database are included on pages 1 through 50 of Appendix B.

3.2.1 Reach M22-S1.01

Reach M22-S1.01 is the most downstream reach on Moon Brook and drains a watershed area of 8.74 square miles. It begins at the confluence with the Otter Creek and continues upstream to the confluence with Mussey Brook. This reach is an "E" type channel with a ripple-dune bedform (Figure 11).

Riparian conditions on the banks of this reach have been influenced by agricultural practices which have removed much of the riparian buffer leaving only 5-25 feet on each side. Orthophotographs and a local landowner have confirmed that this reach had historically been extensively straightened. The reach, however, does not appear to have incised. This may be due to one or a combination factors including; cohesive substrates on the bed and banks, increased sedimentation from upstream that have continued to fill in the channel, and/or grade control provided by the concrete footing of the Forest Street Bridge. The reach is currently undergoing some minor planform adjustment, evident by minor bank erosion on the outside bends.

Figure 11: Typical cross section along M22-S1.01. Note opening of the riparian buffer along the right bank. Also the minor erosion on the outside bank associated with planform adjustment in response to historic straightening.

3.2.2 Reach M22-S1.02

Reach M22-S1.02 was segmented into three sub-reaches because of a change in the entrenchment ratio that occurs midway through the reach in Segment B. This change in the entrenchment ratio is due to floodplain encroachment in the vicinity of the highly developed corridor near Route 7 in downtown Rutland.

Segment M22-S1.02-A

Segment M22-S1.02-A begins just above the confluence with Mussey Brook. This segment is an "E" channel that has undergone historic degradation, perhaps as a result of a head cut that began in the straightened reach M22-S1.01 below (prior to the concrete footing grade control of the Forest Street Bridge. The reach has rebuilt a small floodplain at a lower elevation and is approaching stage V of the channel evolution model. The segment has a relatively healthy riparian buffer (51-100 feet) through which to dissipate floodwaters and build meanders (Figure 12).

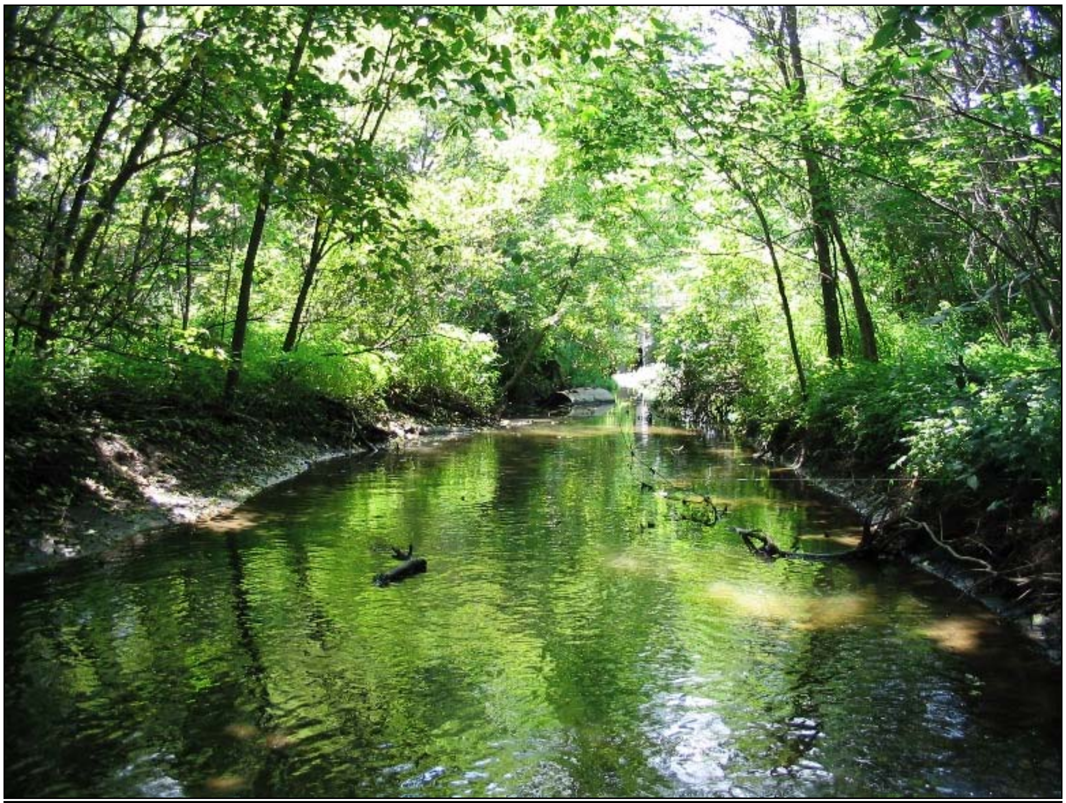

Figure 12. Reach M22.S1.02-A is an "E" channel dominated by sand substrates.

Segment M22-S1.02-B

Segment M22-S1.02-B runs through the Route 7 corridor of Rutland City. It is an "E" type channel by reference, however, due to floodplain encroachment (there is quite a bit of fill, development, and retaining walls on both sides of the streambank) and historic channelization, this segment is now an entrenched "G" type channel (Figure 13). In addition to floodplain encroachment, there are also several undersized structures that are constricting the channel and disrupting sediment transport within this reach.

Figure 13. Segment M22-S1.02-B is heavily urbanized and has become an entrenched and extremely sensitive "G" type channel which has lost access to its historic floodplain.

Segment M22-S1.02-C

Segment M22-S1.02-C is located between downtown Rutland and White's Pool. Although the stream corridor is still heavily developed, it is not incised like segment B and therefore has remained an "E" type channel with access to its floodplain (Figure 14). The reach has been impacted by riparian vegetation removal, however, overall is in good geomorphic condition.

Figure 14: Segment M22-S1.02-C is an unentrenched "E" channel with a ripple-dune bedform. Alteration of the riparian vegetation is evident by the amount of sunlight reaching the stream in this photograph.

3.2.3 Reach M22-S1.03

Reach M22-S1.03 of Moon Brook begins at the confluence of a major tributary, M22-S1.02-S1.01. Reach M22-S1.03 was divided into two segments because of a change in land use in the river corridor.

Segment M22-S1.03-A

This segment is a moderately sinuous "E" type channel with a healthy riparian buffer that has only slightly been influenced by development in the river corridor. The segment has no bank revetments and the dense vegetation, as depicted in Figure 15, has kept bank erosion to a minimal.

Figure 15: Segment M22-S1.03-A is an E5 ripple dune system with a healthy riparian buffer and moderate sinuosity.

Segment M22-S1.03-B

Segment M22-S1.03-B is a slightly widened segment of Moon Brook that is an "E" channel with a riffle-pool bedform. As depicted in Figure 16, over half of this reach has development in the river corridor. In some instances, the naturally steep banks of the "E" channel have been sloped back and the riparian vegetation has been lost. Some historic channel straightening was also noted in this segment. Additionally, a small tributary, Paint Mine Brook, enters half-way through this reach. According to field data collected by the ANR Stormwater Section, this tributary had been historically dredged during the development of the area and has become very incised (Pease 2006). Inputs of sediment from this incision may have affected Moon Brook.

M22-S1.03-B is exhibiting minor adjustment. Planform adjustment, in particular, is indicated by the moderate amounts of bank erosion and bank revetments found in this segment. Even with the influence of development, M22-S1.03-B generally has good floodplain access throughout much of this segment.

Figure 16: Segment M22-S1.03-B is an E4 riffle pool system that has been significantly altered by historic channel straightening and development in the floodplain.

3.2.4 Reach M22-S1.05

This reach starts at Piedmont Pond and continues upstream to Combination Pond, a large impoundment that is known to be affecting sediment transport and thermally impacting Moon Brook. Reach M22-S1.05 is a somewhat entrenched "E" type channel. In areas where floodplain development and/or straightening have occurred, the stream has undergone incision and widening and appears more as a "C" type channel, but rapidly becomes an "E" channel again where it has floodplain access, streamside vegetation, and sinuosity have been preserved. There are isolated areas within this reach where floodplain access is limited due to historic and recent floodplain encroachments. These areas with floodplain encroachment were noted to be more incised and were associated with higher rates of bank erosion. The riparian buffer of this reach has been largely disturbed and averages between 5 and 25 feet wide (see Figure 17). There are both moderate amounts of erosion and riprap along the reach indicating active planform adjustment and widening. Overall the reach appears to be in fair to good geomorphic condition and would benefit from improved floodplain access and the reestablishment of a healthy riparian buffer.

Figure 17: Segment M22-S1.05 is an E4 riffle-pool system that has been altered by development in the floodplain and historic channel straightening. Streamside vegetation (as along the right bank of the photograph) has been disturbed along much of the reach.

3.2.5 Reach M22-S1.07

Reach M22-S1.07 begins upstream of Combination Pond and continues until a small on-stream pond located off of Birch Road. It travels much of its length through a wetland system and a mature pine forest. It is an "E" type channel dominated by gravels with a fairly high slope of 3.2%. There is some evidence of historic incision through this reach; however, the most active adjustment processes are channel widening and aggradation of sediment in the channel (see Figure 18). Multiple mid-channel bars, islands, and channel avulsions indicate active planform adjustment as well within this reach.

Figure 18: Segment M22-S1.07 is an E4 riffle-pool system that has a healthy riparian buffer. The channel has widened and is aggrading. There are lots of fine sands and gravels in the stream bottom.

3.2.6 Reach M22-S1.08

Reach M22-S1.08 begins at an unnamed on-stream pond and ends high in the headwaters of Moon Brook. The reach was broken into two segments by BCE scientists because of a change in channel slope and stream type.

Segment M22-S1.08-A

Segment M22-S1.08-A begins upstream of a private on-stream pond and continues for approximately 3000 feet until a major change in slope occurs in the watershed. This lower segment is an "E" type channel with a healthy riparian buffer; however, some floodplain development has occurred. The stream is actively incising through several large head cuts (Figure 19) which have an unidentified origin. Continued headcutting and incision through the reach will be followed by channel widening and planform adjustments as the stream works to redevelop a floodplain at a lower elevation. Property loss may be a concern for several landowners whose land borders this reach (Note yard in Figure 19). Sediments from this active erosion will likely be retained by the pond at the end of this reach. The portions of this segment that have not degraded are in good geomorphic condition (Figure 20). These, however, may be affected in the future as the headcuts migrate upstream.

Figure 19: An active head cut is seen in this photograph of segment M22-S1.08-A. Downstream of the white survey rod the stream has incised approximately three feet exposing tree roots and the streambanks to fresh erosion.

Figure 20: Typical cross section through segment M22-S1.08-A where active headcutting has not occurred.

Segment M22-S1.08-B

Segment M22-S1.08-B begins at approximately 1100 feet in elevation and continues into the high elevation headwaters of East Mountain. As shown in Figure 21, stream segment M22-S1.08-B is a steep "A" type channel with a healthy riparian forest that appears to have good geomorphic stability.

Figure 21: Typical cross section through segment M22-S1.08-B.

3.2.7 Reach M22-S1.01-S1.01

Reach M22-S1.01-S1.01 is the lowest reach of Mussey Brook. At its confluence with Moon Brook, it drains a watershed area of 3.03 square miles. Reach M22-S1.01-S1.01 was segmented by BCE scientists into three sub-reaches based on changes in land use, river corridor vegetation, and historic channel alterations.

Segment M22-S1.01-S1.01-A

This segment begins at the confluence with Moon Brook and continues upstream to the Rutland railroad tracks. The reach is an "E" type channel with a ripple-dune bedform (Figure 22). Several bridges and culverts create channel constrictions along this reach and may be affecting sediment transport and causing localized flooding. Floodplain encroachment has been moderate through this reach.

Figure 22: Typical cross section through segment M22-S1.01-S1.01-A.

Segment M22-S1.01-S1.01-B

The reach flows through the Rutland Fairgrounds. It begins at the culvert under the Rutland railroad tracks and continues upstream to the cement culvert underneath Route 7. This segment has been greatly altered by floodplain encroachment, floodplain fill, channel straightening, and the disturbance and removal of riparian vegetation (see Figure 23). Bank erosion seems to have accelerated through the reach and the in-stream habitat was the only in the entire study area that received a rating of poor.

Figure 23: Typical cross section through segment M22-S1.01-S1.01-B. Channel straightening, floodplain encroachments, undersized structures, and no riparian vegetation typify this reach.

Segment M22-S1.01-S1.01-C

This reach begins at the upstream end of the Fairgrounds and continues upstream to a culvert (Figure 24) that lies just above a bedrock waterfall (Figure 25) below the former Eddy Pond. The reach is an "E" type channel in "fair" geomorphic condition. It has a significant amount (50% on the right bank) of development within the stream corridor. The reach is actively undergoing planform adjustment and aggrading as it works to regain sinuosity and floodplain access that has been altered by this development.

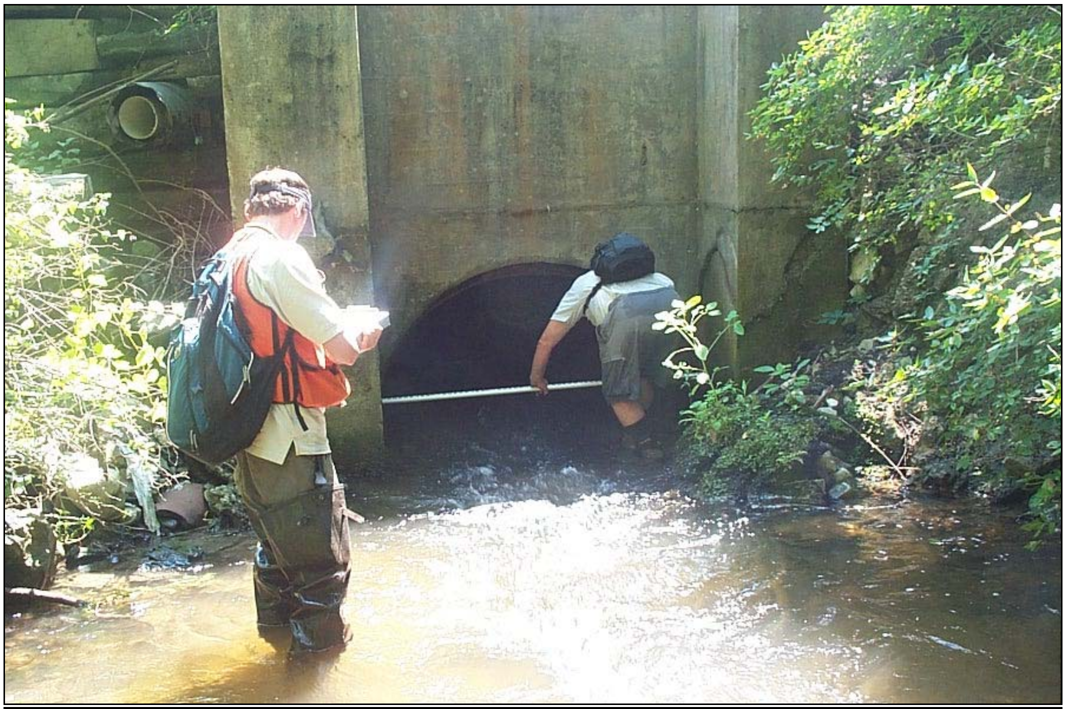

Figure 24: This undersized culvert is one of several along segment M22-S1.01-S1.01-C.

Figure 25: Bedrock ledge provides grade control at the upstream end of segment M22-S1.01-S1.01-C of Mussey Brook.

3.2.8 Reach M22-S1.01-S1.02

Reach M22-S1.01-S1.02 flows through a wetland that used to be artificially flooded as an outdoor skating rink, formally known as Eddy Pond. Reach M22-S1.01-S1.02 was broken into two segments because of a change in slope, stream type, and stage of channel evolution.

<u>Segment M22-S1.01-S1.02-A</u>

This short (500 feet) segment of Mussey Brook flows through a natural wetland that is created by the bedrock constriction at the downstream end. As shown below in Figure 26, segment M22-S1.01-S1.02-A has a very low slope, high sinuosity, and very dense riparian vegetation. It is an "E" type channel. This is the only reach in the Moon Brook watershed that received a geomorphic condition rating of "reference".

Figure 26: Dense riparian vegetation stabilizes the narrow, deep, "E" type channel of segment M22-S1.01-S1.02-A.

Segment M22-S1.01-S1.02-B

Segment B is also within the area once occupied by a human-made pond. The channel has incised and is in the process of building a new lower floodplain bench through widening and planform adjustment (Figure 27). This segment, with a high width to depth ratio is a currently a "C" type channel, a departure from its reference stream type of "E". This segment is actively storing sediment though point and side bars and will narrow itself after it has recreated a floodplain. The reach has a healthy riparian forest that will lend to long term stability in this reach.

Figure 27: Segment M22-S1.01-S1.02-B is actively rebuilding a new floodplain bench through widening and planform adjustment. The formation of bars, such as the side bar on the right, is an indicator of this process.

3.2.9 Reach M22-S1.01-S1.03

Reach M22-S1.01-S1.03 begins upstream of the former Eddy Pond and continues to the confluence with tributary M22-S1.01-S1.03.S1.01. The reach has been significantly altered by floodplain encroachment and historic channel straightening (Figure 28). It is a C-type channel by reference; however, a human caused change in valley width has created a more entrenched "B" type channel through most of this segment. This stream type departure has also occurred in the bedform of the reach, where it has lost its habitat supporting riffle-pool bedform and is instead a plane bed system. Bank erosion appeared low in this reach in part due to the large cobble materials that lined the banks, stone walls, and log revetments that were installed to prevent channel migration and erosion.

Figure 28: Segment M22-S1.01-S1.03 has been altered by floodplain encroachments and historic channel straightening. It no longer has access to a wide floodplain and has become a plane bed, "B" type stream.

3.2.10 Reach M22-S1.01-S1.04

This reach begins at the confluence of a tributary at the lower end of a hay field and continues upstream to a large dam and pond. Reach M22-S1.01-S1.04 has several drastic changes in slope where it flows through two wetlands. These changes in slope and bed materials create different streams types. For this reason, BCE scientists split

M22-S1.01-S1.04 into four segments to account for the diverse habitat and stream types contained within this reach.

Segment M22-S1.01-S1.04-A

M22-S1.01-S1.04-A begins at the confluence of a major tributary to Mussey Brook. It is in good geomorphic condition, has a healthy riparian canopy and stable stream channel (see Figure 29). The larger riparian corridor, however, is impacted by hay fields. These hayfields have limited the buffer and are only between 5 and 25 feet wide on average.

Figure 29: Dense riparian vegetation stabilizes the "E" type channel of segment M22-S1.01-S1.04-A.

Segment M22-S1.01-S1.04-B

Segment B is a "C" type channel. It has a steeper slope, and has developed a mid-channel bar, a point bar, and several side bars. It too is in good geomorphic condition and does not look to be undergoing any major adjustment process. No photograph is available for this segment.

Segment M22-S1.01-S1.04-C

In segment C, the reach returns to an "E" type channel through an area that has been historically dammed by beavers. The stream through this reach flows through a healthy riparian corridor with wetland plants along the near bank and conifer and deciduous trees outlying the wetland. This segment is in good geomorphic condition and is not undergoing any major channel adjustment process. No photograph is available for this segment.

Segment M22-S1.01-S1.04-D

Segment M22-S1.01-S1.04-D begins at a crossing with Stratton Road and continues upstream to an on-stream pond. This segment is a "C" type channel with a riffle-pool bedform (Figure 30). Sediment storage is occurring in the form of multiple mid-channel, point and side bars. There is some evidence of planform change, including an avulsion and flood chute; however, the reach is only slightly entrenched and appears to have access to its floodplain and the ability to meander as needed. Overall the segment is in good geomorphic condition and with the exception of a few areas has a healthy riparian buffer.

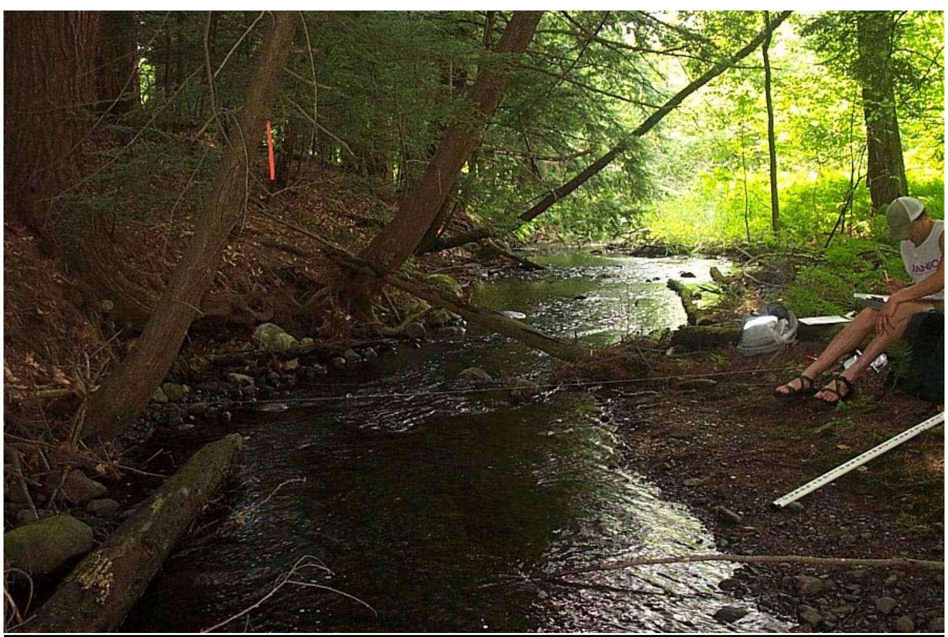

Figure 30: Segment M22-S1.01-S1.04-D is a riffle-pool "C" type channel in good geomorphic condition.

3.2.11 Reach M22-S1.01-S1.06

Mussey Brook reach M22-S1.01-S1.06 begins at the upstream end of an on-stream pond and continues just past a culvert on Dailey Road. Although much of the reach has been historically straightened, it appears to be in stable geomorphic condition and is not undergoing any major adjustments at this time (see Figure 31). Future stability might be encouraged by increasing the riparian buffer of this reach, which averages between 5 and 10 feet wide (see Figure 32), as well as by allowing it to regain access to its floodplain by removing berms that line approximately one quarter of the reach. An additional issue with this reach is the culvert at Dailey Road which has blown out in past floods. Residents have reported flooding of nearby buildings.

Figure 31: Cross section near the lower end of M22-S1.01-S1.06.

Figure 32: Historic channel alteration as well as development and livestock in the river corridor have affected reach M22-S1.01-S1.06.

3.2.12 Reach M22-S1.01-S1.07

Reach M22-S1.01-S1.07 is the uppermost reach of Mussey Brook considered in this Phase 2 geomorphic assessment. It flows through a diversity of habitats and stream types beginning just above Dailey Road and continuing up to South Mendon Road. It was segmented by BCE scientist primarily due to the change in stream type related to variations in slope, historic widening, and grade control.

Segment M22-S1.01-S1.07-A

The first segment of this reach begins just above the culvert on Dailey Road. It is a "C" channel by reference and is one of the more active reaches in the watershed in terms of adjustment. The largest factor relating to instability has been historic and active incision that has occurred within this segment. The degradation of the bed is coupled with channel widening and planform adjustment as the stream seeks to rebuild a new floodplain at a lower elevation.

As shown below in Figure 33, segment M22-S1.01-S1.07-A is currently an "F" type channel and will continue to rework its banks and planform as it evolves back into a "C" channel.

Figure 33: Segment M22-S1.01-S1.07-A has incised. It is currently attempting to rebuild a new floodplain through planform adjustment and widening.

<u>Segment M22-S1.01-S1.07-B</u>

This reach begins at a ledge approximately 2000 feet from the beginning of the reach. The entire segment is dominated by a bedrock bottom stream that is mostly a cascade and step-pool bedform. It is an "A" type channel and is relatively stable. Bedrock control did not exist on the banks, however, and there exists the potential that the stream may widen or go through planform adjustment. As seen in Figure 34, there exists a healthy riparian buffer on both sides of this stream segment that are acting to slow and stabilize geomorphic adjustment processes as well as provide healthy habitat and shade to Mussey Brook.

Figure 34: Segment M22-S1.01-S1.07-B is an "A" channel dominated by a bedrock bottom.

Segment M22-S1.01-S1.07-C

Segment M22-S1.01-S1.07-C is the highest reach surveyed by the Phase 2 team on Mussey Brook. It begins several hundred feet downstream of South Mendon Road where the bedrock control ends and continues to an on-stream pond that is upstream of South Mendon Road. This reach is a "C" type channel with a riffle-pool bedform (Figure 35). The Phase 2 assessment of this reach noted some minor signs of degradation, aggradation, widening, and planform adjustment. The reach has a healthy riparian buffer and floodplain access.

Figure 35: The riffle pool system of M22-S1.01-S1.07-C.

Segment M22-S1.01-S1.07-D

This segment begins at South Mendon Road. Due to several human made on-stream ponds, this segment was not assessed by BCE scientists.

3.3 GEOMORPHIC CONDITION EVALUATION

Understanding the response to changes in the sediment regime, hydrology, and channel of the Moon Brook is highly useful for informing restoration efforts. Natural and anthropogenic impacts alter the delicate equilibrium of sediment and discharge in natural stream systems and set in motion a series of morphological responses (e.g. incision, widening, aggradation, and/or planform change) as the channel tries to reestablish equilibrium. Small to moderate changes in slope, discharge or sediment supply can alter sediment transport capacity and channel geometry; while large changes can transform stream types of entire reaches (Ryan 2001). Human-induced practices that have contributed to stream instability within the Moon Brook watershed include:

- Channelization
- Berming

- Alteration of woody riparian vegetation
- Floodplain encroachments
- Urbanization (increase stormwater runoff)
- Poor road maintenance practice and infrastructure installation (Figure 36).

These anthropogenic practices have altered the delicate balance between water and sediment discharges. Channel morphologic responses to these practices contribute to channel bed degradation and/or aggradation that further create unstable channels. These morphologic changes tend to migrate both upstream and downstream contributing to system-wide instability. (Ryan 2001)

Figure 36. Undersized culverts, like this one on reach M22-S1.01-S1.01-B, disrupt the sediment transport capacity of the steam and often lead to both upstream and downstream destabilization.

3.3.1 Reach Condition

The reach condition is determined using the RGA protocol, and is based on the degree of departure of the channel from its reference stream type (VANR 2005b). The reference condition for each of the Phase 2 reaches was previously identified in Figure 4. Of the 10 segments where Phase 2 RGA's were conducted on Moon Brook, five segments rated in the good category and four segments rated in the fair category (see Table 4 and page 51 of Appendix B). Only one segment, on Moon Brook within the Route 7 corridor, rated in the poor condition. Center of Watershed Protection et al. (1999) used a modified RGA to evaluate channel stability of lower Moon Brook within reach M22-S1.02 and M22-S1.03. The results of the modified RGA showed Moon Brook was in adjustment, and was found to be outside of the expected range of variance for channels of similar type.

Table 4. Phase 2 Reach Condition for Moon Brook

Segment Number	Existing Stream Type	RGA Score	Reach Condition
M22-S1.01	E5	0.66	Good
M22-S1.02-A	E5	0.63	Fair
M22-S1.02-B	G5	0.29	Poor
M22-S1.02-C	E5	0.68	Good
M22-S1.03-A	E5	0.80	Good
M22-S1.03-B	E4	0.65	Good
M22-S1.05	E4	0.61	Fair
M22-S1.07	E4b	0.55	Fair
M22-S1.08-A	E4b	0.53	Fair
M22-S1.08-B	A3a+	0.79	Good

As shown in Table 5, approximately half the segments on Mussey Brook were in good condition, while the other half were in fair condition. One very short segment, located in a wetland, downstream of what was formerly know as Eddy Pond, was found to be in reference condition. Figure 37 illustrates the geomorphic condition of the streams in relation to the watershed.

Table 5. Phase 2 Reach Condition for Mussey Brook			
Segment Number	**Existing Stream Type**	**RGA Score**	**Reach Condition**
M22-S1.01-S1.01-A	E5	0.53	Fair
M22-S1.01-S1.01-B	E5	0.59	Fair
M22-S1.01-S1.01-C	E4	0.53	Fair
M22-S1.01-S1.02-A	E5	0.88	Reference
M22-S1.01-S1.02-B	C4	0.46	Fair
M22-S1.01-S1.03	B4c	0.53	Fair
M22-S1.01-S1.04-A	E5	0.65	Good
M22-S1.01-S1.04-B	C4	0.66	Good
M22-S1.01-S1.04-C	E5	0.65	Good
M22-S1.01-S1.04-D	C4	0.66	Good
M22-S1.01-S1.06	E4b	0.65	Good
M22-S1.01-S1.07-A	F4	0.49	Fair
M22-S1.01-S1.07-B	A1	0.69	Good
M22-S1.01-S1.07-C	C4	0.60	Fair

3.3.2 Channel Evolution

The reach condition ratings of Moon and Mussey brook indicate that many of the reaches are actively in a process of minor or major geomorphic adjustment. The most common adjustment processes in Moon Brook seem to be aggradation, planform change, and widening. The major adjustment processes in Mussey Brook appear to be degradation, planform change, and widening.

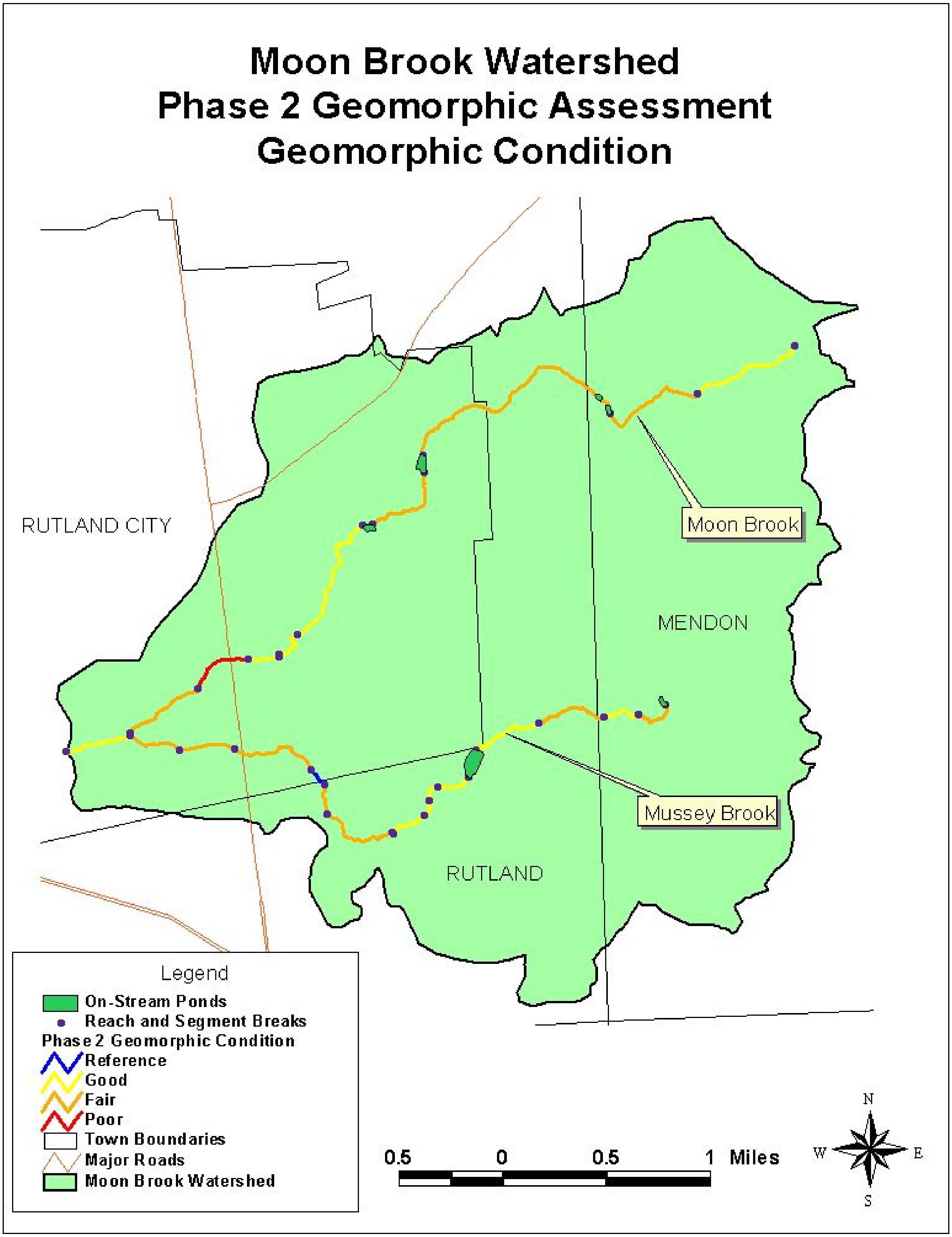

Figure 37: Phase 2 Geomorphic Condition of the Moon Brook Watershed

Degradation is the term used to describe the process whereby the stream bed lowers in elevation through erosion, or scour, of bed material. Aggradation is a term used to describe the raising of the bed elevation through an accumulation of sediment. The planform is the channel shape as seen from the air. Planform change can be the result of a straightened course imposed on the river through different channel management activities, or a channel response to other adjustment processes such as aggradation and widening. Channel widening occurs when streamflows are contained in a channel as a result of degradation or floodplain encroachment, or when sediments overwhelm the stream channel and the energy is concentrated into both banks.

The quantity of sediment and sediment size is proportional to the slope of the stream and the amount of water the stream is discharging. A change in any one of these variables will result in a corresponding change in the other variables to achieve equilibrium. A large change in one of these variables will be followed by channel evolution as the stream works to regain equilibrium through incision, aggradation, widening, and/or planform change. According the F-stage Channel Evolution Model (see Appendix C) the stages of channel evolution include:

- A pre-disturbance period
- Incision – Channel degradation and headcutting
- Aggradation and channel widening
- The gradual formation of a stable channel with access to its floodplain at a lower base of elevation.

Additionally, some streams, such as the E type channels of Moon Brook, may undergo a different channel evolution process. In unconfined, low to moderate gradient valleys where the stream is not entrenched and has access to its floodplain, and where soils and or bed material tend to be cohesive, a stream may not undergo any channel incision. As is the case in several segments of Moon Brook, these channels adhere to the D-stage channel evolution model where they may have seen historic channel straightening and are now undergoing channel widening and planform adjustment in order to regain the balance between stream power and boundary materials.

Channel evolution processes in the Moon Brook watershed are occurring in response to large scale changes in its sediment, slope, and/or discharge associated with the human influences on the watershed. In terms of the channel evolution model, reaches in the Moon Brook are either in a D-IIc channel evolution stage as described above, or fall within the F 11 through IV channel evolution stage as a result of some recent or historic incision. Aggradation in the Moon Brook is not only associated with widening as the stream has increased sediment load from eroding banks, however it appears that stormwater runoff is carrying large amounts of fine sediments into the system. As the stream widens it no longer effectively transports its bedload and begins to build large bars and undergo planform adjustment. Bank erosion becomes more prevalent, particularly on the outside meander bends as the channel moves to regain sinuosity. Unvegetated mid channel bars and side bars confirm the channel is undergoing extensive lateral migration. As sinuosity increases, the channel slope decreases and the balance between stream power and boundary material is reestablished.

Table 6 refers to the channel evolution for each Moon Brook study reach. The lower reach appeared to be undergoing major aggradation and some minor planform adjustment in response to being historically straightened. There was no evidence within reach M22-S1.01 that it had incised and was undergoing channel adjustment in response to this incision. Reach M22-S1.01 was found to be at stage 1Ic of the D-stage channel evolution model. Reach M22-S1.02 was found to be in a variety of stages of the channel evolution model. M22-S1.02-A, the lowest segment in reach 2, was found to be in stage 1V. This segment likely historically incised due to floodplain encroachments and channel modifications in the vicinity of the Route 7 corridor. Segments M22-S1.02-C through M22-S1.05 all appeared to be undergoing planform adjustment and widening in response to historic channel straightening and fell into D stage IIc. Reach M22-S1.07 and M22-S1.08-A are in active channel adjustment.

Table 6. Stream Type and Channel Evolution Stage – Moon Brook

Segment Number	Entrench -ment Ratio	W/D Ratio	Reference Stream Type	Existing Stream Type	Channel Evolution Model - Stage	Primary Adjustment Process
M22-S1.01	51.3	9.0	E	E5	D-IIc	**Aggradation** Planform
M22-S1.02-A	3.6	10.4	E	E5	F-IV	**Aggradation**
M22-S1.02-B	1.3	11.5	E	G5	F-II	**Degradation** **Aggradation** **Widening** **Planform**
M22-S1.02-C	54.5	9.7	E	E5	D-IIc	Planform Aggradation
M22-S1.03-A	16.4	7.4	E	E5	F-I	Aggradation Planform
M22-S1.03-B	12.9	22.5	E	E4	D-IIc	Aggradation Widening Planform
M22-S1.05	3.1	11.4	E	E4	D-IIc	Aggradation Widening Planform
M22-S1.07	10.0	9.3	E	E4b	F-IV	**Aggradation** Widening Planform
M22-S1.08-A	2.6	7.6	E	E4b	F-II	**Degradation** Aggradation Widening Planform
M2-S1.08-B	2.3	8.5	A	A3a+	F-I	Widening

Red bold lettering - denotes extreme adjustment process
Bold Black lettering – denotes major adjustment process
Black lettering (no bold) – denotes minor adjustment process

Mussey Brook generally appears to be between stage I and stage IV in the F channel evolution model. Much of the Mussey Brook watershed has retained its natural character, however, many segments have been impaired by floodplain encroachments, undersized structures, and changes in hydrology associated with stormwater. Historic and active degradation is more evident in the Mussey Brook than in the Moon Brook. An incised channel begins to widen and undergo planform adjustment as it works to establish a new floodplain at a lower elevation.

Table 7 refers to the major channel adjustment processes occurring in Mussey Brook. The lowest reach, M22-S1.01-S1.01, seems to be undergoing major planform adjustment and widening in response to historic channel straightening, floodplain encroachment, and degradation. Reaches M22-S1.01-S1.01-A and all of M22-S1.01-S1.04 flow through more undisturbed lands. These reaches all appear to not be undergoing any major channel adjustment processes. The upstream reaches M22-S1.01-S1.06 and M22-S1.01-S1.07A and C are all in active channel adjustment.

Table 7. Stream Type and Channel Evolution Stage – Mussey Brook

Segment Number	Entrench -ment Ratio	W/D Ratio	Reference Stream Type	Existing Stream Type	Channel Evolution Model - Stage	Primary Adjustment Process
M22-S1.01-S1.01-A	28.9	7.7	E	E5	F-III	**Aggradation** **Planform** Degradation Widening
M22-S1.01-S1.01-B	6.8	6.8	E	E5	F-III	**Planform** Widening
M22-S1.01-S1.01-C	28.9	7.7	E	E5	F-III	**Aggradation** **Planform** Degradation Widening
M22-S1.01-S1.02-A	14.2	5.4	E	E5	F-I	None
M22-S1.01-S1.02-B	9.5	13.5	E	C4	F-III	**Widening** **Planform**
M22-S1.01-S1.03	1.5	13.7	C	B4c	F-II	Planform Aggradation
M22-S1.01-S1.04-A	10.5	7.9	C	E5	F-V	None
M22-S1.01-S1.04-B	4.5	22.0	C	C4	F-V	None
M22-S1.01-S1.04-C	10.5	7.9	C	E5	F-V	None
M22-S1.01-S1.04-D	4.5	22.0	C	C4	F-V	None
M22-S1.01-S1.06	45.5	8.3	B	E4b	F-III	Aggradation Planform
M22-S1.01-S1.07-A	1.2	15.9	C	Fb	F-III	**Degradation** **Widening** Planform
M22-S1.01-S1.07-B	1.5	10.8	A	A3	F-I	None
M22-S1.01-S1.07-C	2.3	13.3	C	C4	F-I	Aggradation Widening Planform

Red bold lettering - denotes extreme adjustment process
Bold Black lettering – denotes major adjustment process
Black lettering (no bold) – denotes minor adjustment process

3.3.3 Stream Type and Sensitivity

Sensitivity refers to the likelihood that a stream will respond to a watershed or local disturbance or stressor, such as; floodplain encroachment, channel straightening or armoring, changes in sediment or flow inputs, and/or disturbance of riparian vegetation. Assigning a sensitivity rating to a stream is done with the assumption that some streams, due to their setting and location within the watershed, are more likely to be in an episodic, rapid, and/or measurable state of change or adjustment. A stream's inherent sensitivity may be heightened when human activities alter the setting characteristics that influence a stream's natural adjustment rate including: boundary conditions; sediment and flow regimes; and the degree of confinement within the valley. Streams that are currently in adjustment, especially those undergoing degradation or aggradation, may become acutely sensitive (ANR 2004).

There are many variables that are contributing to the sensitivity of the streams in the Moon Brook watershed. Cohesive bed and bank substrates in many of the "E" type channels of Moon Brook are more resistant to lateral and vertical adjustment and therefore seem to be in reality less sensitive streams. Additionally, bank vegetation and its soil holding roots, help to improve the boundary condition between water and land and have reduced the sensitivity of Moon Brook streams. Removal of this vegetation tends to make stream segments more sensitive to channel adjustment.

The location and slope of a stream also affects is morphology and sensitivity. Streams that are transporting sediment through the channel are geomorphologically less sensitive than streams that are storing and responding to sediment. Low gradient streams, like many in the Moon Brook watershed, with high sediment supplies are very sensitive and may undergo adjustment following minor changes in channel geometry or boundary conditions.

Additionally, flow regime and floodplain constrictions may be affecting the sensitivity of Moon Brook streams. Changes in land use and land cover that increase impervious cover, peak discharges, and/or the frequency of high flows will heighten a stream's sensitivity to change and adjustment. Confinement becomes a significant sensitivity concern when structures such as roads, railroads, and berms significantly change the confinement ratio, reduce or restrict a stream's access to floodplain, and result in higher stream power during flood stage. Figure 37 is a map presenting the existing stream types found in the Moon Brook watershed. The stream sensitivity of these reaches, generalized according to stream type and condition as per the ANR protocol, is depicted in Tables 8 and 9 and in Figure 38.

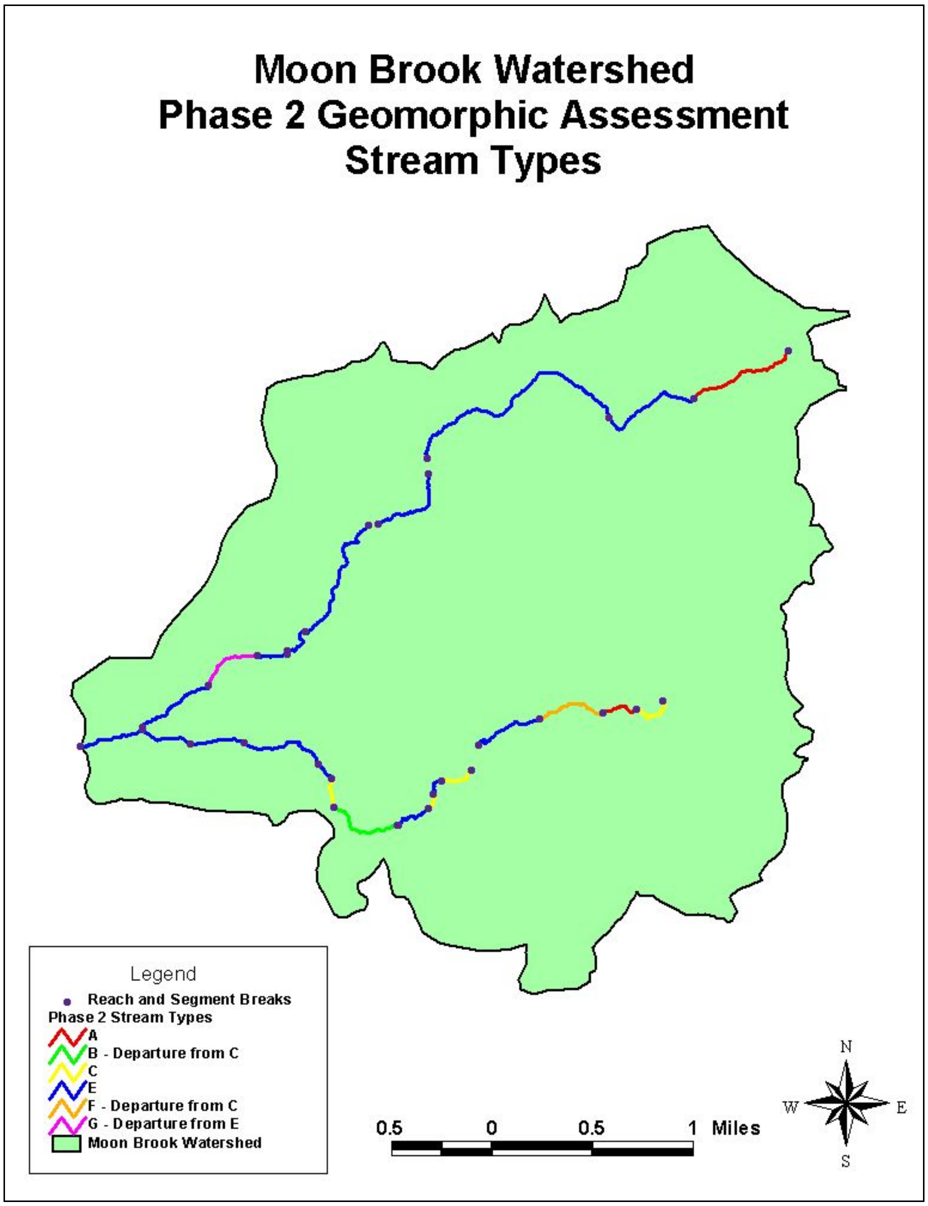

Figure 37: Phase 2 Stream Types in the Moon Brook Watershed

Table 8. Phase 2 Stream Sensitivity for Moon Brook

Segment Number	Existing Stream Type	Stream Type Departure	Condition	Sensitivity
M22-S1.01	E5	No	Good	High
M22-S1.02-A	E5	No	Fair	Very High
M22-S1.02-B	G5	Yes	Poor	Extreme
M22-S1.02-C	E5	No	Good	High
M22-S1.03-A	E5	No	Good	High
M22-S1.03-B	E4	No	Good	High
M22-S1.05	E4	No	Fair	Very High
M22-S1.07	E4b	No	Fair	Very High
M22-S1.08-A	E4b	No	Fair	Very High
M22-S1.08-B	A3a+	No	Good	High

Table 9. Phase 2 Stream Sensitivity for Mussey Brook

Segment Number	Existing Stream Type	Stream Type Departure	Condition	Sensitivity
M22-S1.01-S1.01-A	E5	No	Fair	Very High
M22-S1.01-S1.01-B	E5	No	Fair	Very High
M22-S1.01-S1.01-C	E4	No	Fair	Very High
M22-S1.01-S1.02-A	E5	No	Reference	High
M22-S1.01-S1.02-B	C4	Yes	Fair	Very High
M22-S1.01-S1.03	B4c	Yes	Fair	Very High
M22-S1.01-S1.04-A	E5	No	Good	High
M22-S1.01-S1.04-B	C4	No	Good	High
M22-S1.01-S1.04-C	E5	No	Good	High
M22-S1.01-S1.04-D	C4	No	Good	High
M22-S1.01-S1.06	E4b	No	Good	High
M22-S1.01-S1.07-A	F4	Yes	Fair	Extreme
M22-S1.01-S1.07-B	A3	No	Good	High
M22-S1.01-S1.07-C	C4	No	Fair	Very High

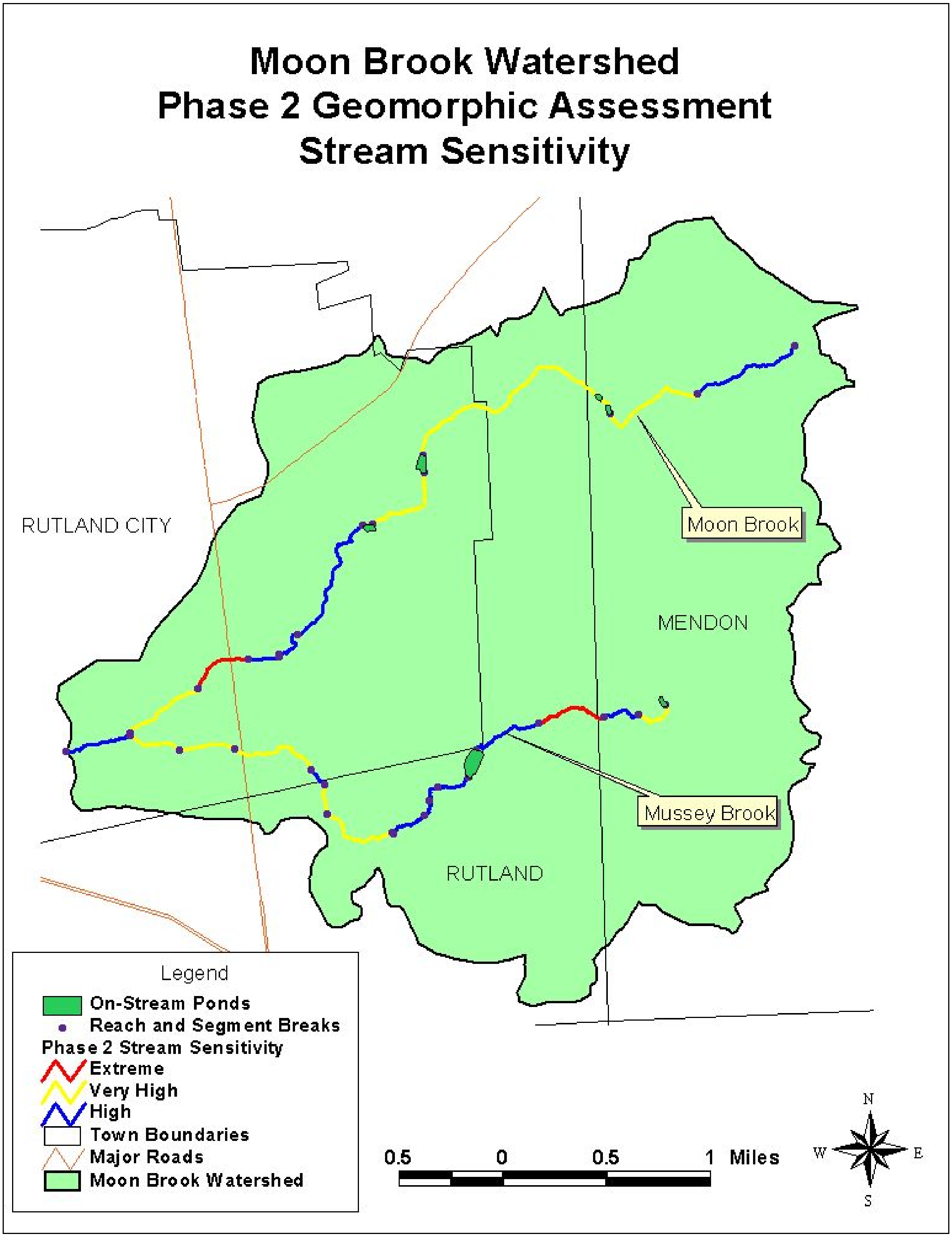

Figure 38: Phase 2 Stream Sensitivity in the Moon Brook Watershed

3.4 PHASE 2 HABITAT EVALUATION

The Rapid Habitat Assessment (RHA) is used to evaluate the physical components of a stream (the channel bed, banks, and riparian vegetation) and how the physical condition of the stream affects aquatic life. The results can be used to compare physical habitat condition between sites, streams, or watersheds, and also serve as a management tool in watershed planning or similar land-use planning.

The results of the Rapid Habitat Assessment (RHA) are provided on page 52 of Appendix B. Tables 10 and 11 below shows a comparison of the habitat condition based on the RHA and the geomorphic condition based on the RGA. For eight of the twenty-four assessed segments, both the RHA and the RGA resulted in ratings of fair. Three segments shared an RHA and RGA rating of good (Figure 39). Eight segments had good RGA results, however were only rated fair for the RHA. Only one segment, M22-S1.01-S1.01-B, located on Mussey Brook through the fairgrounds (Figure 40) placed poorly in habitat condition.

In general the study reaches lacked strong bedform features (several were plane bed) and the diversity of habitat features that this brings. Additionally, sediment contributions of sand and fine gravel from the watershed, as well as localized contributions from banks that were eroding as the river adjusts, have created an embedded river bottom along much of the study area. Many reaches had significant intrusion into their river corridor and lacked adequate riparian buffers. Overall, the RHA score was similar to the RGA score, implying that the ecological health of the Moon Brook is intricately tied to the geomorphic condition of the stream.

Table 10. Comparison of RGA and RHA for Phase 2 Reaches Moon Brook				
Segment Number	**RGA Score**	**RHA Score**	**Rating RGA**	**Rating RHA**
M22-S1.01	0.66	0.53	Good	Fair
M22-S1.02-A	0.63	0.52	Fair	Fair
M22-S1.02-B	0.29	0.39	Poor	Fair
M22-S1.02-C	0.68	0.47	Good	Fair
M22-S1.03-A	0.80	0.71	Good	Good
M22-S1.03-B	0.65	0.57	Good	Fair
M22-S1.05	0.61	0.51	Fair	Fair
M22-S1.07	0.55	0.67	Fair	Good
M22-S1.08-A	0.53	0.61	Fair	Fair
M22-S1.08-B	0.79	0.78	Good	Good

Table 11. Comparison of RGA and RHA for Phase 2 Reaches Mussey Brook				
Segment Number	**RGA Score**	**RHA Score**	**Rating RGA**	**Rating RHA**
M22-S1.01-S1.01-A	0.53	0.52	Fair	Fair
M22-S1.01-S1.01-B	0.59	0.34	Fair	Poor
M22-S1.01-S1.01-C	0.53	0.55	Fair	Fair
M22-S1.01-S1.02-A	0.88	0.72	Reference	Good
M22-S1.01-S1.02-B	0.46	0.59	Fair	Fair
M22-S1.01-S1.03	0.53	0.51	Fair	Fair
M22-S1.01-S1.04-A	0.65	0.50	Good	Fair
M22-S1.01-S1.04-B	0.66	0.60	Good	Fair
M22-S1.01-S1.04-C	0.65	0.54	Good	Fair
M22-S1.01-S1.04-D	0.66	0.60	Good	Fair
M22-S1.01-S1.06	0.65	0.44	Good	Fair

Table 11. Comparison of RGA and RHA for Phase 2 Reaches Mussey Brook

Segment Number	RGA Score	RHA Score	Rating RGA	Rating RHA
M22-S1.01-S1.07-A	0.49	0.64	Fair	Fair
M22-S1.01-S1.07-B	0.69	0.69	Good	Good
M22-S1.01-S1.07-C	0.60	0.68	Fair	Good

Figure 39. Reach M22-S1.03-A (Moon Brook) rated good for habitat. As depicted in the photograph the stream had an abundance of bank cover, riparian vegetation, and deep pools.

Figure 40. Reach M22-S1.01-S1.01-B (Mussey Brook) rated poorly for habitat. As depicted in the photograph the stream lacked instream habitat, riparian vegetation, a riffle-pool system due to historic straightening, and was heavily embedded with fine particles of sand.

SECTION 4: PUBLIC OUTREACH AND EDUCATION

Concomitantly with the Moon Brook watershed assessment, Bear Creek Environmental provided education and outreach to the Moon Brook community at two formal public meetings, one training workshop, and several private site visits with local landowners. The first public meeting was held on July 27, 2005. This initial meeting focused on introducing the Rutland community to the geomorphic assessment process and identifying where the study would be taking place. It provided an opportunity for residents to obtain information and voice concerns before the study began. A training workshop was held on September 26, 2005 at the Rutland Fairgrounds. This meeting provided basic instruction in the Phase 2 field protocol for assessing watersheds. Students from the Strafford Technical School and member of the Upper Otter Creek Watershed Council participated in the workshop. A final public meeting was held on November 30, 2005 at the Rutland High School. Bear Creek Environmental prepared a presentation and executive summary to report on the results of the Phase 1 and 2 study of the Moon Brook watershed to the Rutland community and its federal, state, and non-profit partners.

In addition to these formal meetings, BCE scientists also met with several landowners during the course of the study. Several landowners had specific concerns regarding streambank erosion on their property and BCE found time to incorporate site visits with the assessment work that was being performed. Additionally, BCE scientists were approached by numerous landowners in the field and utilized those opportunities to provide general education about the Moon Brook watershed and the Phase 2 geomorphic assessment.

SECTION 5: RECOMMENDATIONS

Based on the 2005 Phase 1 and 2 Assessment of the Moon Brook watershed, Bear Creek Environmental recommends the following:

1. Develop restoration projects to reconnect Moon Brook around Piedmont and Combination Ponds. This will restore sediment and water transport to the brook.

2. Implement stormwater control efforts whenever possible. Sedimentation, particularly in the Route 7 corridor, would be reduced through stormwater control efforts.

3. Develop an active restoration project to prevent migration of head cuts where they are present in the upper reaches of Moon Brook.

4. Conduct a bridge and culvert survey following ANR protocols to gather specific information about undersized structures in the Moon Brook watershed. Replace undersized structures when opportunities and/or funding become available.

5. Develop and implement a river corridor protection plan. The implementation of a river corridor protection plan goes a long way towards toward reducing fluvial erosion hazards and minimizing land use conflicts. As a starting point, fluvial geomorphic relationships can be used to determine the width of a river corridor which is needed to accommodate the meander geometry under equilibrium conditions. As discussed in the Defining River Corridors Fact Sheet, prepared by the Vermont DEC River Management Programs, rivers with gentle gradients and narrow to broad valleys require a meander

belt width of 6 times the channel width to accommodate the meanders. At the lowest end of the Phase 2 study area, this equates to a meander belt width of 180 feet (or approximately 90 feet on each side of the meander center line). The River Corridor Plan would also provide some structure for identifying river restoration and corridor protection project types and effective approaches.

6. The three watershed towns should consider adopting a zoning ordinance(s) to strictly limit further floodplain encroachments and to protect riparian buffer zones.

7. Floodplain access is the most effective means at controlling streambank erosion and for streams to attenuate excess sediment. Encroachment in the Moon Brook watershed has led to loss of habitat and geomorphic instability. Reconnecting floodplains and floodplain wetlands would provide critical stormwater retention, sediment reduction, and would improve the overall health of the stream system.

8. The reference stream type for much of the mainstem of the Moon Brook and Mussey Brook is "E". E type stream channels are highly dependent upon riparian vegetation for stability. For this reason, the establishment and protection of vegetated buffers should be high priority in restoration planning and design work. Riparian buffers provide many benefits. Some of these benefits are protecting and enhancing water quality, providing fish and wildlife habitat, providing streamside shading, and providing root structure to prevent bank erosion.

9. Carefully consider the stream type, evolution stage, and sensitivity before conducting any active geomorphic restoration projects in the main channel of Moon or Mussey Brook

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