Phase 2 Stream Geomorphic Assessment

Upper Winooski Watershed
Towns of Cabot, Marshfield, Plainfield, East Montpelier, Barre, and Montpelier
Washington County, Vermont

April 2007

Prepared for:

Winooski Natural Resources Conservation District

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April 4, 2007

Ms. Abbey Willard
Winooski Natural Resources Conservation District
617 Comstock Road, Suite 1
Berlin, Vermont 05602

Re: Phase 2 Stream Geomorphic Assessment
Upper Winooski Watershed
Washington County, Vermont
JCO Project No. 1-2384-3

Dear Ms. Willard:

The Johnson Company is pleased to present the following Phase 2 Stream Geomorphic Assessment report to the Winooski Natural Resources Conservation District. This report includes the results of Phase 2 Geomorphic Assessments performed in accordance with the Vermont Agency of Natural Resources (VTANR) Stream Geomorphic Assessment Protocols on 11 reaches of the upper Winooski mainstem and one on a major tributary Stevens Branch.

Should you have any questions or require additional assistance, please do not hesitate to contact The Johnson Company at (802) 229-4600. Thank you for the opportunity to be of assistance to the WNRCD on this project.

Sincerely,
THE JOHNSON COMPANY, INC.

By: ______________________
Noelia Báez Rodríguez
Staff Scientist

cc: Kari Dolan, VTANR
Ann Smith, FWR

Reviewed by: SAS

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EXECUTIVE SUMMARY

The Johnson Company was retained by Winooski Natural Resources Conservation District to perform Phase 2 Geomorphic Assessments on 11 reaches of the upper Winooski mainstem (R18, R19, R22, R25, R28 through R34) and a reach of one its major tributaries, Stevens Branch (M1.01), during the summer of 2006. In addition, Bridge and Culvert Assessments were conducted on all structures within the 12 reaches. The Phase 2 Assessments were conducted in accordance with the 2006 Vermont Agency of Natural Resources (VT ANR) Stream Geomorphic Assessment Protocols (VT ANR 2006) Steps 1-7. All of the collected data were recorded on the VT ANR Phase 2 data sheets and entered into the VT ANR Stream Geomorphic Assessment Web Based Data Management System (DMS). A thorough internal QA review was performed by The Johnson Company in November 2006. An independent QA review was performed by VT ANR in January 2007 and the Phase 1 and 2 DMS were updated in January 2007. Goals and Objectives for the project included the following:

- Determine the existing stream type for each targeted reach and field verify the previously collected Phase 1 assessments;
- Conduct geomorphic condition evaluations for each reach which detail the current condition and sensitivity to existing and future natural and anthropogenic stressors;
- Collect and interpret the Phase 2 data to assess which reaches are responding to anthropogenic and natural modifications, and help prioritize which reaches warrant further study and/or restoration activities and;
- Educate the public about the results of the study and the need for future work.

Reaches were selected for Phase 2 Analysis based on: impact scores from the Phase 1 Assessment; erosion hazards; known or likely water quality impairment (sedimentation, *E. coli*) and local priorities. Individual narratives for each assessed reach are included as Appendix A.

A river is dynamic landscape feature that will create different channel configurations within its floodplain over time. If changes in the watershed stream corridor cause a river to lose access to its floodplain, it will undergo a series of changes in order to develop a new flood plain. Stream geomorphologists describe this process in terms of five Stages of Evolution. Based on the field measurements taken during the Phase 2 Assessments, it appears most of the assessed reaches in the watershed are in evolution Stage II (degradation and loss of access to floodplain) or III (widening, aggradation, and lateral migration). None of the study reaches were found to be in equilibrium (Stage I or V). A description of the different channel evolution stages can be found in Section 5.1 of this report and the VT ANR Stream Geomorphic Assessment Protocols, which may be found online at: http://www.anr.state.vt.us/dec/waterq/rivers/htm/rv_geoassess.htm.

Stream type departures from the reference type determined in the Phase 1 Assessment were observed in ten of the twelve reaches: R18A, R19, R22, R25, R29, R30, R31, R32A, R33C and M1.01B (see Appendix A). The other two reaches have experienced some degree of historic degradation, though not enough to eliminate floodplain access totally. The dominant sediment regime for the watershed is degradation; however, a large amount of aggradation was also observed throughout as seen by enlarged point, side, mid-channel, diagonal, delta bars and islands. Aggradation as a secondary geomorphic process results from the anthropogenic modifications to the river, the surficial geology of the watershed which is made up of erodable soils, and the number of tributaries to the river that are also contributing sediment.

The results of the Phase 2 Geomorphic Assessment are summarized in the following table.

Summary of Results
Upper Winooski SGA Phase 2 2007

Reach	Stream Type	Reference Type	Stages of Evolution	Geomorphic Condition	Habitat Condition
18 A	F	C	II	Poor	Fair
18 B	B	C	III	Poor	Poor
19	F	C	III	Poor	Fair
22A	F	C	III	Poor	Poor
22B	F	C	III	Fair	Fair
25	C	E	III	Fair	Fair
28	C	C	III	Fair	Fair
29	C	B	IV	Fair	Fair
30A	C	E	III	Fair	Fair
30B	C	E	III	Fair	Fair
31A	F	E	III	Poor	Fair
31B	F	E	III	Poor	Fair
32A	B	C	II	Fair	Fair
32B	C	C	III	Fair	Fair
33A	C	C	II	Fair	Fair
33C	F	C	II	Fair	Fair
34	C	C	II	Fair	Fair
M01.01A	C	C	III	Fair	Fair
M01.01B	F	C	II	Fair	Fair

Nearly all of the reaches have a sensitivity of moderate to extreme with potential to continue widening and eroding, and many areas of both the upper Winooski and Stevens Branch have been lined with rock revetment (often called "rip-rap") in response to bank erosion. All of the study reaches had areas with inadequate buffers; and these areas are most sensitive to further widening. Some of the reaches are already showing widening as evidenced by rip-rap failures.

River corridor restoration may be accomplished through active or passive approaches. Passive approaches such as corridor protection easements were recommended in areas where the river could still utilize its own energy and watershed inputs to re-establish its meanders and floodplain and maintain equilibrium conditions. Corridor protection easements intend to limit further encroachment in the stream corridor, to allow the river to re-establish access to floodplains, and to prevent further degradation. Active approaches such as structure replacement and/or removal and planting of woody buffers were recommended in areas where river channel restoration is needed in a shorter period of time and infrastructure will remain in the corridor.

Some reaches have residential, commercial or industrial properties within the natural meander belt width of the stream (approximately six times the bankfull width). These reaches should be targeted for buffer reestablishment and/or active bank stabilization to limit potential property loss from erosion. At the same time, those reaches without significant development (R25, R28, R30, and R31) may be good candidates for corridor protection so that the river may be allowed to move naturally through the evolutionary process.

Bridges were threatened by nearby bank erosion or undermining abutments on the following reaches: R19, R28, R29, R30, R31, and R33. Several bridges are slightly undersized and act as local channel and floodplain constrictions. During future bridge replacement projects, the data should be used to ensure that the new bridges are correctly sized. Nine dams were identified in the watershed: four within the main stream provide grade control and the other five create reservoirs on the tributaries. The removal of inactive dams should be considered due to sediment discontinuities.

Based on the results of the Phase 2 Assessments and visual observations, potential restoration/corridor protection projects identified within the watershed are described below. Figures 4 through 24 depict the project locations. Photos of some of the project areas are also shown in Appendix A.

- Winooski R18 (Figures 4 & 5) –Actively eroding banks (approximately 10 feet high and 320 feet long) due to overwidening and planform adjustments exist on the Two River Center property (“Food Works Project”). The main restoration/conservation project associated with R18 is floodplain restoration and riparian buffer enhancement. The River Management Program (RMP) has been evaluating the Two River Center property as a potential site for a Phase 3 Stream Geomorphic Assessment and a restoration project that includes floodplain restoration on the land downstream of the confluence with Stevens Branch. This project would likely involve some bank stabilization opposite the confluence of the Stevens Branch and floodplain restoration. The restoration effort would also involve re-establishment of adequate woody buffers between the fields and the stream channel.

- Winooski R19 (Figure 6) - The main restoration/conservation project associated with R18 is floodplain restoration in conjunction with riparian buffer enhancement. The most likely area for this type of project is on the left bank downstream from the bridge on Route 2, which is one of the few locations along the reach that is not encroached upon by development.
- Winooski R22 (Figures 7 & 8) – The reach has lost access to the floodplain and has been armored due to development on East Montpelier. There may be some opportunities for floodplain restoration near the confluence of Mallory Brook with the upper Winooski.
- Winooski R 25 (Figures 9 & 10) – Multiple eroding banks exist on both sides (approximately 9 feet high and 250 feet long) along with mass failures with an average failure height of 40 feet affecting mainly right bank at the valley wall. Some of the factors increasing the sediment input to this reach are glacial geology, highly erodable soils, lack of riparian buffer, and the re-location of the channel to accommodate Route 2, which has moved the channel close to the valley wall. Restoration and/or conservation projects for this reach include corridor protection and/or possible floodplain restoration to allow the expected channel adjustments to occur and increase the sediment and nutrient retention potential of the area. Part of the restoration effort should also include buffer enhancement to reduce erosion hazards and improve wildlife habitat.
- Winooski R 28 (Figures 11 & 12) – The eroding banks, approximately 6 feet high and 250 feet long, extend along most of the reach, particularly near Martin's old covered bridge abutments. One mass failure, approximately 40 feet high, is located adjacent to the corn field on the lower portion of the reach. The reach represents a unique habitat for the State Threatened pearl mussel (Engstrom, 2007). This reach may represent a good opportunity to implement a floodplain restoration and corridor protection project that focuses on the preservation and enhancement of mussel habitat. These recommendations could be incorporated into Marshfield's recreational park plans. The project could be an ideal place to demonstrate how floodplain restoration and corridor protection can be used to re-establish geomorphic equilibrium and enhance the sediment and nutrient retention potential of the river while improving wildlife habitat.
- Winooski R 29 (Figures 13 & 14) – The eroding banks extend approximately 50 feet long by 6 feet high along areas where meander bends are cutting the banks adjacent to Route 2. One potential restoration/conservation project for the reach is a corridor protection plan near the confluence with Nasmith tributary to allow the inherent instability associated with the alluvial fan formed at the confluence to progress without human encroachments or conflicts. Part of the corridor plan should include buffer vegetation to improve wildlife habitat and improve bank stability. This project area is near Twinfield High School and could be used as an experiential learning process that integrates stream processes and restoration into the student curriculum. The Onion River Camp ground is also a potential site for riparian buffer enhancement.

- Winooski R 30 (Figures 15, 16, and 17) – This reach was segmented but both segments provide undeveloped areas, although the land uses are different. A corridor easement plan should be implemented with an emphasis on a wetland protection, buffers, and how to restore equilibrium conditions to reduce bank instability over time. A farm bridge is located on the lower portion of the segment. The structure is in poor condition--undersized, with failing rip-rap, and scour features upstream and downstream. Another potential restoration project for this area is to replace the bridge with a more appropriately sized structure.
- Winooski R31 (Figures 18 & 19) – In this reach, the river no longer has access to its original floodplain. The vast majority of the area has not been developed. A corridor easement plan should be implemented including floodplain restoration along with riparian buffer, sediment attenuation and wetland protection. A bridge replacement project should be considered for the bridge to the entrance of the Bean family's property due to its poor condition. Bridge replacement will be required in the near future. The current bridge is undersized and should be replaced with a wider structure. Within the Bean family property, the stream is very sinuous and the changes in planform are evident. One meandering bend is cutting one of the banks significantly threatening barn stability and creating a hazard.
- Winooski R33 (Figures 20 & 21) – This reach was segmented into three subreaches, due to the presence of a dam in mid-reach. A berm approximately 114 feet long is located on the downstream portion of the most downstream segment on the left bank representing a floodplain constriction. This is virtually the only portion of the reach not encroached upon by residential development. Thus, a berm removal project should be considered here in order to let the stream gain some floodplain access.
- Stevens Branch M1.01 (Figures 22, 23, 24) – This reach has experienced adverse impacts due to the development within the stream corridor. However, some floodplain access remains at the downstream end of the reach. A Corridor Protection plan should be implemented on the right side at the confluence with the Winooski including a floodplain restoration to attenuate sediment and nutrients. A floodplain restoration plan along with riparian buffer, and wetland protection should be implemented.

There are federal programs which could potentially provide funding in support of these projects such as the Conservation Reserve Enhancement Program (CREP) and the Environmental Quality Improvement Program (EQIP), which compensate landowners for the loss of cropland to enhance riparian buffers and river functions. Funds from the Vermont River Management Program (RMP) may also be available for projects that focus on re-establishing or maintaining the equilibrium conditions of the stream.

TABLE OF CONTENTS

LIST OF FIGURES

THE FOLLOWING FIGURES ARE IN APPENDIX A

LIST OF APPENDICES

1.0 PROJECT OVERVIEW

The Johnson Company was retained by Winooski Natural Resources Conservation District to perform Phase 2 Geomorphic Assessments on 11 reaches of the Upper Winooski mainstem (R18-19, R22, R25, R28 through R34) and one reach of Stevens Branch (M1.01), a tributary of the Winooski, during the summer of 2006 (Figure 1). Funding for the project was provided by the Vermont Agency of Natural Resources (VT ANR) Rivers Management Program. Quality Assurance responsibilities were coordinated between The Johnson Company and the Vermont Agency of Natural Resources (VT ANR). Phase 1 Geomorphic Assessments of the watershed were completed by Central Vermont Regional Planning Commission, Winooski Natural Resources Conservation District and Friends of the Winooski River in 2006.

The upper Winooski watershed encompasses approximately 396 square miles within the towns of Cabot, Marshfield, Plainfield, East Montpelier, Barre, and Montpelier. The study area included the mainstem of the upper Winooski, from the Main Street Bridge in Montpelier upstream to Molly's Falls Reservoir (R18, R19, R22, R25, R28 through R34), as well as one upstream reach of the Stevens Branch (M1.01).

Goals and Objectives for the project included the following:

- Determine the existing stream type for each targeted reach and field verify the previously conducted Phase 1 assessments;
- Evaluate the geomorphic condition for each reach by documenting the current condition and sensitivity to existing and future natural and anthropogenic stressors;
- Collect and interpret the Phase 2 data to assess which reaches are responding to anthropogenic and natural modifications, and help prioritize which reaches warrant further study and/or restoration activities;
- Educate the public about the results of the study and the need for future work.

2.0 BACKGROUND INFORMATION

2.1 GEOGRAPHIC SETTING

The Upper Winooski watershed encompasses lies within the towns of Cabot, Marshfield, Plainfield, East Montpelier, Barre, and City of Montpelier. The watershed elevation ranges from approximately 507 feet above mean sea level at downtown Montpelier to more than 859 feet at Molly's Falls Reservoir. Figures 1 through 3 show the geographic setting for the watershed.

The downstream portion of the study watershed includes portions of the cities of Barre and Montpelier. The urban development of these cities has affected areas adjacent to the river. The more upstream reaches are in a rural area which includes four villages: East Montpelier, Plainfield, Marshfield, and Cabot. This portion of the watershed historically has been dominated by agricultural crops, pasture, forestry, and rural development; and these uses continue.

The Stevens Branch watershed encompasses approximately 129 square miles within the towns of Barre and Berlin and cities of Montpelier and Barre. The studied reach is located in Montpelier and its elevation ranges from approximately 526 feet above mean sea level at the confluence with the Winooski to 528 feet at Point Ridge Road. Historically, land uses have been dominated by urban development.

2.2 GEOLOGIC SETTING

The upper Winooski watershed is located to the east of the Green Mountains. Bedrock in the study area is dominated by a combination of the Moretown and Barton River Members (Waits River Formation), Gile Mountain and Northfield Formations and Knox Mountain Granite, which are comprised of various types of quartzite, phyllite, schist, slate, limestone, greenstones and granite (Doll 1961) (Konig 1961). The surficial geology is comprised of lake bottom deposits as silt, silty clay and clay, littoral sediments as pebbly sand, and recent alluvium as fluvial sand, gravels and silt (Doll 1970) (Stewart and MacClintock 1970) (Larsen 1999). Soils in the study area are dominated by sandy loam, silt loam, fine sand, fine sandy loam, silt loam, and sand predominantly associated with the following series: Salmon very fine sandy loam, Waitsfield silt loam, Sunny silt loam, Sunday fine sand, Buxton silt loam, Rumney fine sandy loam, Dummerston fine sandy loam, Nicholville silt loam, Vershire-Dummerston Complex, Buckland silt loam, and Adams loamy fine sand (USDA SCS 1979).

2.3 GEOMORPHIC SETTING

The locations of the assessed reaches are shown on Figures 1, 2, and 3. The study area included the upper mainstem of the Winooski (R18 to R34) from the Main Street Bridge in Montpelier to Molly's Falls reservoir, with the exception of five reaches (R20, R21, R23, R24, and R27). The study area for Stevens Branch included the most downstream reach (M1.01) from its confluence with the mainstem of the upper Winooski (R18).

The channel slopes for the study area reported in the Phase 1 assessment ranged from 0.03% (R31) to 1.81% (R33) within the upper Winooski and was 0.07% in Stevens Branch (Central Vermont Regional Planning Commission, 2006). Based on the field observations and review of topographic maps, none of the reaches assessed are located in an alluvial fan. Bedrock grade controls were noted in R33 and R34. Based on the Phase 1 data, all 12 reaches within the study have C, B and E reference stream types characterized by slopes of less than 2% with substrate ranging from sand to boulder. The valley types for all assessed reaches range from broad to very broad with the exception of reach R33 which is located within a narrow valley. The calculated valley widths ranged from 587 feet in R33 to nearly 1,614 feet in R19 (Central Vermont Regional Planning Commission, 2006).

2.4 HYDROLOGY

The nearest USGS gage for the study area is on the upper Winooski at its outlet downstream from the confluence of the North Branch with the Winooski in Montpelier and downstream from the lowest study reach R18. Several flood events have occurred over the last

45 years including the years 1964, 1973, 1978, 1981, and 1992 (Montpelier Flood and Hazard Mitigation Plan, 1998). The flooding history in the area is mostly related to ice jams and the number of constrictions and impoundments. There was a relatively large flood event which occurred in the spring of 1992, during which people from Montpelier neighborhoods and businesses were evacuated. Nine dams are located in the upper Winooski and on its tributaries.

2.5 ECOLOGICAL SETTING

The study area includes a variety of aquatic and upland habitat types which include forest, agricultural crop and pasture land, riparian wetland complexes, and beaver ponds. The primary aquatic habitat consists of a riffle-pool community which has been affected by active degradation which leads to a large amount of aggradation, filling of pools, embedding of riffle substrates, and bank instability. The impoundments along the stream also have an impact on the aquatic habitat (Montpelier Flood and Hazard Mitigation Plan, 1998). The lower portion of the upper Winooski and the Stevens Branch offer poor habitat due to urban development and encroachment of development into the stream bed zone (Montpelier Flood and Hazard Mitigation Plan, 1998). The upper portion consists of agricultural pasture and cropland intermixed with hardwood and softwood forests. The Stevens Branch watershed is highly developed. The lower reach shows a narrow wooded riparian corridor and several wetlands.

3.0 METHODOLOGY

3.1 FLUVIAL GEOMORPHIC ASSESSMENT PROTOCOLS

All of the Phase 2 Assessments were conducted in accordance with the 2006 Vermont Agency of Natural Resources (VT ANR) Stream Geomorphic Assessment Protocols (VT ANR 2006) Steps 1-7:

1) Valley and River Corridor
2) Stream Channel
3) Riparian Banks, Buffers and Corridors

4) Flow and Flow
5) Channel Bed and Planform Changes
6) Rapid Habitat Assessment
7) Rapid Geomorphic Assessment

In accordance with the protocols each reach was walked in its entirety prior to collecting any measurements to allow for reach segmentation where appropriate and identification of potential bankfull identifiers and cross section locations. A detailed Site Sketch Map was created for each reach documenting the locations of cross sections, photo points, pebble counts, bank erosion and revetments, grade controls, debris jams, depositional features, channel cut-offs and avulsions, and other important features. Cross sections were measured at representative locations within each reach using a staff gage and measuring tape.

All of the collected data were recorded on the VT ANR Phase 2 data sheets and entered into the VT ANR Stream Geomorphic Assessment Web Based Data Management System (DMS). Copies of the DMS Reports are provided in Appendix B. Following a thorough quality assurance (QA) review, the previously collected Phase 1 data were updated based on the findings of the Phase 2 Assessments. Bridge and Culvert Assessments were also conducted throughout the study area and the collected data were recorded on the appropriate VT ANR Bridge and Culvert Data Sheets and later entered into the VT ANR Bridge and Culvert Database.

3.2 QUALITY ASSURANCE AND QUALITY CONTROL

A thorough internal QA review was performed by The Johnson Company in November 2006. An independent QA review was performed by VT ANR in January 2007 and the Phase 1 and 2 DMS were updated on January 31, 2007. All of the collected data are stored in the DMS and original copies of the data sheets may be found at The Johnson Company's office in Montpelier, VT.

4.0 RESULTS

The results of the Phase 2 Assessment are summarized below. Detailed reach by reach discussion is presented in Appendix A. Reach scale stressors and potential project areas are shown on orthophoto base maps in Appendix A.

4.1 WATERSHED SCALE STRESSORS

4.1.1 *<u>Hydrologic Alterations</u>*

The upper Winooski and Stevens Branch watershed is dominated by residential/ commercial/industrial development on the lower portion and agricultural and forest land on the upper portion. Most of the riparian corridor is characterized by agricultural and forest land, but urban development is evident in the city of Montpelier R18, R19 and M1.01 and in the villages of Marshfield, R33, Plainfield, R27, and East Montpelier, R22 and R23. Based on field observations and historic maps, it appears that a significant amount of wetland loss has occurred in the watershed in the recent past.

Most of the urban reaches are affected by stormwater runoff from storm sewers and road runoff. The impervious surfaces created by roads and urban development diminish infiltration capacity and cause increased peak flows during precipitation events. Loss of wetland and increase in impervious surfaces in a watershed tends to increase hydrologic input and stream power.

4.1.2 *<u>Dams</u>*

There are nine dams located on the upper Winooski and its tributaries. The dams have been used for hydropower at mill operations, and hydroelectric generation. Some are currently in use for hydropower and flood control. Four dams are located within the studied reaches: two in R18, one in Reach 27, and one in R33. These dams are no longer in use but represent grade controls. There are hydroelectric dams at the main stem of the Winooski at Molly's Falls operated by the Green Mountain Power Corporation and at the Levesque (Montpelier

Hydroelectric Dam #4). There are three dams located on tributaries: Laird Pond Dam at Nasmith Brook; the Bailey Dam at Marshfield Brook; and the North Montpelier Pond Upper Dam at the Kingsbury Branch serving as flood control. There is also a small hydroelectric generator at the dam on the Kingsbury Branch.

4.1.3 Sediment Load Indicators

Many of the agricultural lands are not buffered and extend directly up to the stream bank. As can be expected, many areas of bank erosion are located along these un-buffered fields which represent large contributors to the overall sediment regime of the study area. In the Barre-Montpelier reaches, there is a significant amount of residential, commercial, and industrial development in the river valley. Discussion of individual reaches and areas of erosion is presented in Appendix A.

Large mass failures were observed in reaches R22, R25, R28, R30, and R31. These mass failures, combined with many other extensive bank erosion sites, are the major contributing factors to the overall sediment regime of the watershed. Several of the reaches assessed within the study area contained evidence of enlarged large point bars, mid, delta, diagonal, and side bars and islands, and other signs of aggradation. Flood chutes were noted in the following reaches: R22, R25, R28, R29, R30, R31, and R33. Four large channel avulsions were noted in the following reaches: M1.01, R18, R25, and R31. The avulsions are present in reaches that are experiencing planform adjustment. A few braided channels were observed at the mouths of some tributaries: Cold Brook R30; Beaver Pond R30; and Marshfield Brook R32 mainly related to beaver activity. The mouths of the tributaries have been blocked by beaver dams which subsequently developed into wetland complexes.

4.2 REACH SCALE STRESSORS – BOUNDARY CONDITIONS

Individual narratives for each assessed reach are included as Appendix A. Below is a summary of the dominant reach scale stressors observed throughout the watershed.

4.2.1 Channel Bed Modifiers

Nearly every assessed reach within the study area was found to have some degree of historic degradation. Numerous natural and anthropogenic grade controls, holding a significant amount of sandy and silty sediment were observed. Despite the numerous grade controls observed throughout the watershed, the degradation process is widespread. The incision ratios in the study area range from 1.5- 2.3, evidencing that incision has taken place so the streams have little to no access to their floodplains during high flow events. Evidence of degradation was mostly related to the river corridor encroachment and straightening associated with development and agricultural practices. No signs of active gravel mining from within the stream bed were observed.

4.2.2 Bank and Riparian Vegetation Modifiers

Straightening and lack of buffer vegetation are the two predominant bank and riparian vegetation modifiers for the upper Winooski and the Stevens Branch. The locations of bank armoring and active erosion are shown on the reach orthophotos in Appendix A. Significant portions of the assessed reaches have been armored, with rip-rap being the most common method. While the rip-rap has helped to limit the amount of bank erosion, where it has been applied, it has also prevented the stream from adjusting its slope and depth to re-establish equilibrium conditions. The amount of rip-rap has increased the slope, velocity of the flow, and sediment transport, transferring energy downstream to erode the nearest unprotected bank. Examples can be seen in the upper Winooski at Reach 19 and in the Stevens Branch at M1.01 where long sections of both banks have been armored. The unarmored banks just downstream of the rip-rap are constantly eroding. This effect is an additional stressor contributing to the active degradation and overwidening process at the confluence of the Stevens Branch with the upper Winooski.

Lack of riparian buffer and woody vegetation is perhaps one of the largest stressors to the upper Winooski watershed, as is common in many areas historically dominated by agricultural crops and pasture. Riparian buffers serve many functions. They help to stabilize stream banks and prevent erosion, provide shade and cover for aquatic species, and serve as natural filters to help remove excess nutrients and organic matter from the system. Areas of inadequate buffer were observed along all of the study reaches. The lack of buffer on the lower reaches of the upper Winooski watershed is directly related to encroachment from urban development. In the upper reaches of the watershed lack of adequate buffer is related to the agricultural land use practices. In addition to the lack of adequate buffer, portions of a few of these reaches (R25, R30 and R31) are utilized for pasture with cows having access to segments of the stream channel. This not only contributes additional nutrients directly to the water column, but often leads to additional areas of erosion.

4.3 REACH SCALE STRESSORS – ENERGY GRADE

4.3.1 Slope Modifiers

Channelization has had a major geomorphic impact on the watershed. This was common practice to provide a flood control. Straightening increases the channel slope and power and velocity of the water within the stream. This can lead to degradation and increased stream bank erosion. Based on review of aerial photos, field observations, and the calculated meander ratios in the Phase 1 Assessment (the meander width measured from the outside of one meander bend to another divided by the bankfull channel width – in an undisturbed system this number is typically near 6) all of the study reaches appear to have segments that were straightened in the past. Most of these reaches have not begun to re-establish new meander patterns because the amount of straightening combined with the degree of degradation has caused most of the reaches to lose access to the floodplain. Some of the reaches were physically moved to the valley wall to accommodate transportation, development, and agricultural practices. There are many human land uses such as homes, businesses, and agricultural fields that have been placed in the river corridor that can be adversely affected by stream adjustment processes. A further discussion of the impacts of channelization within the watershed is presented in Section 5 below.

Channel constrictions were observed throughout the watershed. These include both natural constrictions, such as bedrock gorges, and human made ones, such as bridges and dams. Naturally occurring bedrock channel constrictions were found in reaches R33 and R34. Bridges were observed in all of the study reaches except R34. Dams occurred in R18, R20, R27, and R33. R27 was not evaluated in this study. At a small scale, the effects of these constrictions were observed on the immediate area upstream and downstream of the constriction; these effects primarily include accumulation of excess sediment above the constriction and scour creating bank instability downstream. At a larger scale, the effects of the constriction combine with the impoundment to intensify the degradation and overwidening processes, causing loss of flood plain access and enlargement of bars resulting in a “poor” river geomorphic condition Some of the reaches with this condition are R18, R19, R22 and R31.

Some geomorphologic conditions are driven by the presence of multiple dams along the upper Winooski. Three dams were located in the study reaches. A dam immediately downstream of R18 impounds water at the downstream end of R18. Releases from the hydroelectric dam at Molly’s Falls, upstream of R34, affect the flow in the downstream reaches. For example, the Molly’s Falls releases can go for periods of more than 12 hours when the reservoir is at the maximum capacity (GMP, 2006). The effects of the releases are increasing the erosion of the banks and channel flow carrying a significant amount of sediment. Inactive dams located within the study reaches R18 and R33, both at the mid-reach, were constructed in naturally occurring bedrock constrictions originally as hydropower dams. The Plainfield Dam is in R27, a reach that was not assessed in this study. These dams are grade controls that hold back sediment. The releases from the active hydropower dams at Molly’s Falls, upstream of R34, and the Levesque Station (Montpelier hydroelectric Dam number 4), in R20, have a direct impact on sediment transport and deposition, enlarging bars and degrading the bank. These results are observed in the following reaches: R18, R19, R25, R30, R31, and R32.

4.3.2 <u>Floodplain Modifiers</u>

Active head cuts were observed throughout the watershed. Nearly all of the reaches had calculated incision ratios of more than 1 and up to 2.3, indicating that degradation has occurred and is actively occurring. It is likely that this degradation is a result of a combination of historic straightening in developed areas, encroachment, channel constrictions and water releases from the dams which have lowered the streambed elevation. Nearly all of the reaches have lost access to their historic floodplain, which explains the severe erosion and other adjustments observed.

River corridor encroachments were concentrated in the villages of East Montpelier, Plainfield and Marshfield, and the City of Montpelier due to residential and commercial development. The Route 2 and 302 road corridors and the railroad transportation system were also significant river corridor encroachments in the studied reaches. Constructed berms for the transportation system and for flood protection were additional encroachments. Limited berm construction not associated with transportation infrastructure was observed in R25, R33 and M1.01.

4.4 BRIDGE AND CULVERT ASSESSMENTS

A total of 21 Bridge Assessments were completed within the study area. Summary reports from the VT ANR DMS are included in Appendix B. Ten of the assessed bridges are slightly undersized and act as local channel and floodplain constrictions. Bridges were threatened by nearby bank erosion or undermining abutments on the following reaches: R19, R28, R29, R30, R31, and R33. During future bridge replacement projects the collected data should be used to ensure that the new bridges are correctly sized.

5.0 PRELIMINARY PROJECT IDENTIFICATION

5.1 DEPARTURE ANALYSIS – CHANNEL EVOLUTION STAGE

Based on the field measurements taken during the Phase 2 Assessments, it appears most of the assessed reaches in the watershed are in evolution Stage III (widening). The basic evolution model has five stages. In Stage I the stream is in equilibrium condition. In equilibrium condition the sediment and water input from the watershed are in balance. Thus, a stream in fluvial geomorphic equilibrium experiences little erosion, stores organic material and nutrients in its floodplain, and provides aquatic and riparian habitat diversity. In Stage II, stream degradation is triggered by some stressor whereby the stream bed elevation is lowered and the stream no longer has adequate access to its floodplain. Without floodplain access, which dissipates the energy during high flow events, the stream banks erode and the channel widens (Stage III). The widened channel does not have the force to move all of the sediment through the system so sediment buildup and aggradation occur and a new floodplain begins to form at a lower elevation (Stage IV). Once the new floodplain is fully developed the stream is back in equilibrium (Stage V). Further information regarding stream evolution models can be found at http://www.anr.state.vt.us/dec/waterq/rivers/htm/rv_geoassess.htm.

Stream type departures from the reference type determined in the Phase 1 Assessment were observed in ten of the twelve reaches (See Appendix A). The other two reaches have experienced some degree of degradation, but still have some floodplain access. However, geomorphic and habitat conditions in these reaches were found to be only fair. Stream conditions are summarized in Table 5-1.

Table 5-1 Summary of Results Upper Winooski SGA Phase 2 2007					
Reach	**Stream Type**	**Reference Type**	**Stages of Evolution**	**Geomorphic Condition**	**Habitat Condition**
18 A	F	C	II	Poor	Fair
18 B	B	C	III	Poor	Poor
19	F	C	III	Poor	Fair
22A	F	C	III	Poor	Poor
22B	F	C	III	Fair	Fair
25	C	E	III	Fair	Fair
28	C	C	III	Fair	Fair
29	C	B	IV	Fair	Fair
30A	C	E	III	Fair	Fair
30B	C	E	III	Fair	Fair
31A	F	E	III	Poor	Fair
31B	F	E	III	Poor	Fair
32A	B	C	II	Fair	Fair
32B	C	C	III	Fair	Fair
33A	C	C	II	Fair	Fair
33C	F	C	II	Fair	Fair
34	C	C	II	Fair	Fair
M01.01A	C	C	III	Fair	Fair
M01.01B	F	C	II	Fair	Fair

Straightening (discussed in Sections 4.2.1 and 4.3.1) has occurred in the reaches and likely accounts for the bulk of the observed degradation. The extensive over widening is fundamentally due to anthropogenic factors. The watershed is located within a relatively wide valley with steep, primarily alluvial and glacial till valley walls which are not resistant to erosion when the stream channel "bumps" against them. In addition, a significant number of stream banks in the watershed are rip-rapped, which would impede lateral movement. Reaches R18B, R19, R22, R25, R28, R30, R31, R32B, and M1.01A were determined to be in evolution Stage III, and are developing some floodplain at a lower elevation. Reaches R18A, R32A, R33A, R33C, R34C, and M1.01B were found to be in Stage II. Only R29 was found to be in Stage IV. None of the assessed reaches were found to be in equilibrium (Stage I or V).

The dominant sediment regime for the watershed is degradation; however, a large amount of aggradation was also observed throughout as seen by enlarged point, side, mid-channel, diagonal, delta bars and islands. Aggradation as a secondary geomorphic process results from the anthropogenic modifications to the river, the surficial geology of the watershed which is made up of erodable soils, and the number of tributaries to the river that are also contributing sediment.

5.2 SENSITIVITY ANALYSIS – DOMINANT ADJUSTMENT PROCESS

The dominant adjustment process for the overall watershed is widening and degradation, with some aggradation. As stated above, most of the assessed reaches are in evolution Stage III, though those in Stage II are still actively degrading. Based on the evolution stage and stream type, nearly all of the reaches have a sensitivity of moderate to extreme with the potential for further widening and bank erosion. Many areas of both Upper Winooski and Stevens have been lined with rip-rap in an attempt to address the localized areas of bank erosion; however, in some of the reaches that are undergoing adjustment, the rip-rap is failing. Those areas with limited riparian buffer are most sensitive to further widening. Although all the reaches have development within the river corridor, those portions of the reaches with fewer properties or structures at risk may be good candidates for corridor protection so that the river may be allowed to move within its corridor, adjusting its slope and depth to move its sediment load, in order to re-establish equilibrium conditions.

5.3 POTENTIAL PROJECT AREAS

Based on the results of the Phase 2 Assessments and visual observations, potential restoration/corridor protection projects identified within the watershed are described below. Figures 4 through 24 in Appendix C depict the potential project locations.

- Winooski R18 (Figures 4 & 5) –Actively eroding banks (approximately 10 feet high and 320 feet long) due to overwidening and planform adjustments exist on the Two River Center property ("Food Works Project"). The main restoration/conservation project associated with R18 is floodplain restoration and riparian buffer enhancement. The River Management Program (RMP) has been evaluating the Two River Center property as a potential site for a Phase 3 Stream Geomorphic Assessment and a restoration project that includes floodplain restoration on the land downstream of the confluence with Stevens Branch. This project would likely involve some bank stabilization opposite the confluence of the Stevens Branch and floodplain restoration. The restoration effort would also involve re-establishment of adequate woody buffers between the fields and the stream channel.

- Winooski R19 (Figure 6) - The main restoration/conservation project associated with R18 is floodplain restoration in conjunction with riparian buffer enhancement. The most likely area for this type of project is on the left bank downstream from the bridge on Route 2, which is one of the few locations along the reach that is not encroached upon by development.

- Winooski R22 (Figures 7 & 8) – The reach has lost access to the floodplain and has been armored due to development on East Montpelier. There may be some opportunities for floodplain restoration near the confluence of Mallory Brook with the upper Winooski.

- Winooski R 25 (Figures 9 & 10) – Multiple eroding banks exist on both sides (approximately 9 feet high and 250 feet long) along with mass failures with an average failure height of 40 feet affecting mainly right bank at the valley wall. Some of the factors increasing the sediment input to this reach are glacial geology, highly erodable soils, lack of riparian buffer, and the re-location of the channel to accommodate Route 2, which has moved the channel close to the valley wall. Restoration and/or conservation projects for this reach include corridor protection and/or possible floodplain restoration to allow the expected channel adjustments to occur and increase the sediment and nutrient retention potential of the area. Part of the restoration effort should also include buffer enhancement to reduce erosion hazards and improve wildlife habitat.

- Winooski R 28 (Figures 11 & 12) – The eroding banks, approximately 6 feet high and 250 feet long, extend along most of the reach, particularly near Martin's old covered bridge abutments. One mass failure, approximately 40 feet high, is located adjacent to the corn field on the lower portion of the reach. The reach represents a unique habitat for the State Threatened pearl mussel (Engstrom, 2007). This reach may represent a good opportunity to implement a floodplain restoration and corridor protection project that focuses on the preservation and enhancement of mussel habitat. These recommendations could be incorporated into Marshfield's recreational park plans. The project could be an ideal place to demonstrate how floodplain restoration and corridor protection can be used to re-establish geomorphic equilibrium and enhance the sediment and nutrient retention potential of the river while improving wildlife habitat.

- Winooski R 29 (Figures 13 & 14) – The eroding banks extend approximately 50 feet long by 6 feet high along areas where meander bends are cutting the banks adjacent to Route 2. One potential restoration/conservation project for the reach is a corridor protection plan near the confluence with Nasmith tributary to allow the inherent instability associated with the alluvial fan formed at the confluence to progress without human encroachments or conflicts. Part of the corridor plan should include buffer vegetation to improve wildlife habitat and improve bank stability. This project area is near Twinfield High School and could be used as an experiential learning process that integrates stream processes and restoration into the student curriculum. The Onion River Camp ground is also a potential site for riparian buffer enhancement.

- Winooski R 30 (Figures 15, 16, and 17) – This reach was segmented but both segments provide undeveloped areas, although the land uses are different. A corridor easement plan should be implemented with an emphasis on a wetland protection, buffers, and how to restore equilibrium conditions to reduce bank instability over time. A farm bridge is located on the lower portion of the segment. The structure is in poor condition--undersized, with failing rip-rap, and scour features upstream and downstream. Another potential restoration project for this area is to replace the bridge with a more appropriately sized structure.

- Winooski R31 (Figures 18 & 19) – In this reach, the river no longer has access to its original floodplain. The vast majority of the area has not been developed. A corridor easement plan should be implemented including floodplain restoration along with riparian buffer, sediment attenuation and wetland protection. A bridge replacement project should be considered for the bridge to the entrance of the Bean family’s property due to its poor condition. Bridge replacement will be required in the near future. The current bridge is undersized and should be replaced with a wider structure. Within the Bean family property, the stream is very sinuous and the changes in planform are evident. One meandering bend is cutting one of the banks, significantly threatening barn stability and creating a hazard.

- Winooski R33 (Figures 20 & 21) – This reach was segmented into three subreaches, due to the presence of a dam in mid-reach. A berm approximately 114 feet long is located on the downstream portion of the most downstream segment on the left bank representing a floodplain constriction. This is virtually the only portion of the reach not encroached upon by residential development. Thus, a berm removal project should be considered here in order to let the stream gain some floodplain access.

- Stevens Branch M1.01 (Figures 22, 23, 24) – This reach has experienced adverse impacts due to the development within the stream corridor. However, some floodplain access remains at the downstream end of the reach. A Corridor Protection plan should be implemented on the right side at the confluence with the Winooski including a floodplain restoration to attenuate sediment and nutrients. A floodplain restoration plan along with riparian buffer, and wetland protection should be implemented.

There are federal programs which could potentially provide funding in support of these projects such as the Conservation Reserve Enhancement Program (CREP) and the Environmental Quality Improvement Program (EQIP), which compensate landowners for the loss of cropland to enhance riparian buffers and river functions. Funds from the Vermont River Management Program (RMP) may also be available for projects that focus on re-establishing or maintaining the equilibrium conditions of the stream.

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FIGURES

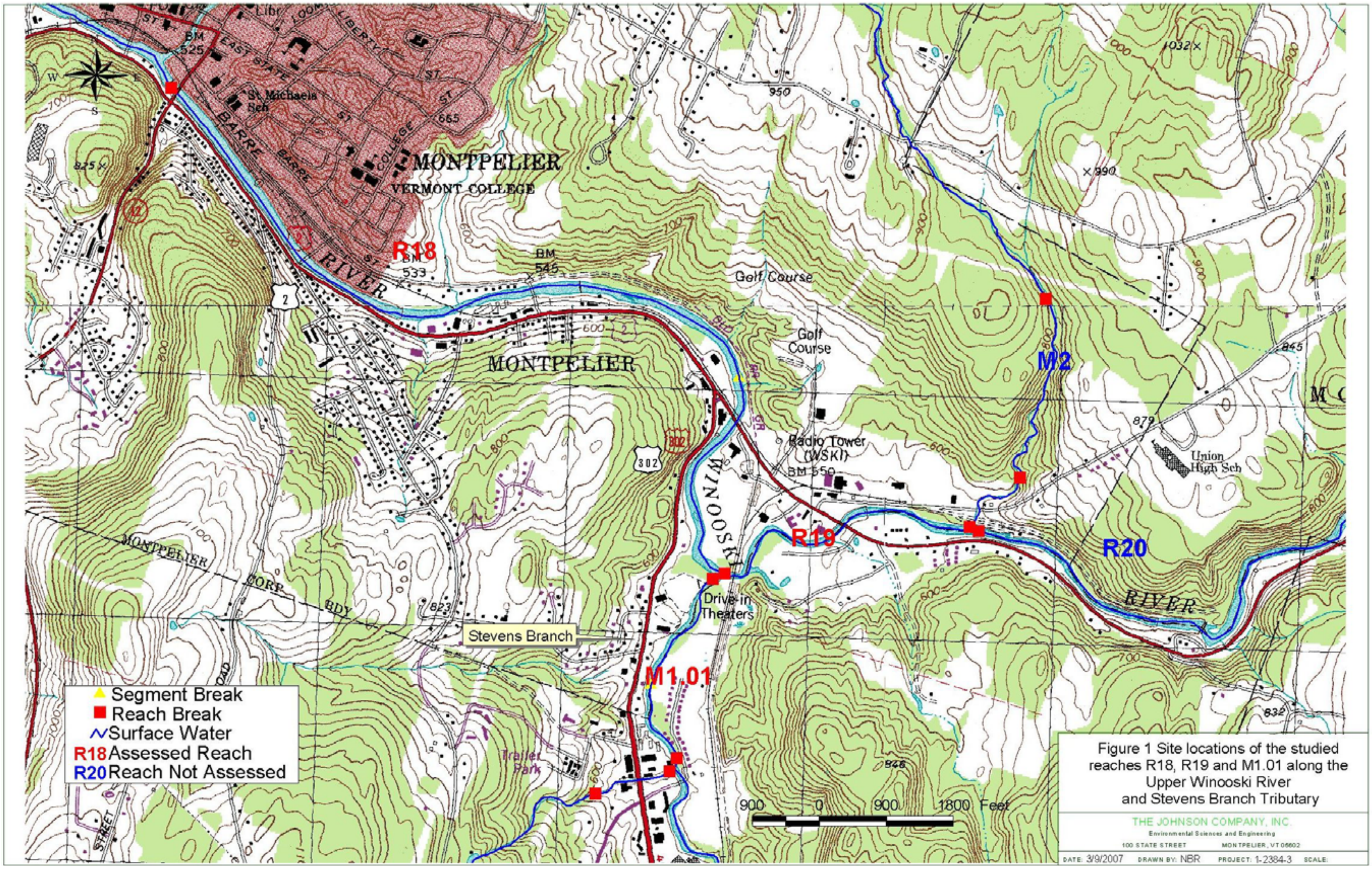

Figure 1 Site locations of the studied reaches R18, R19 and M1.01 along the Upper Winooski River and Stevens Branch Tributary

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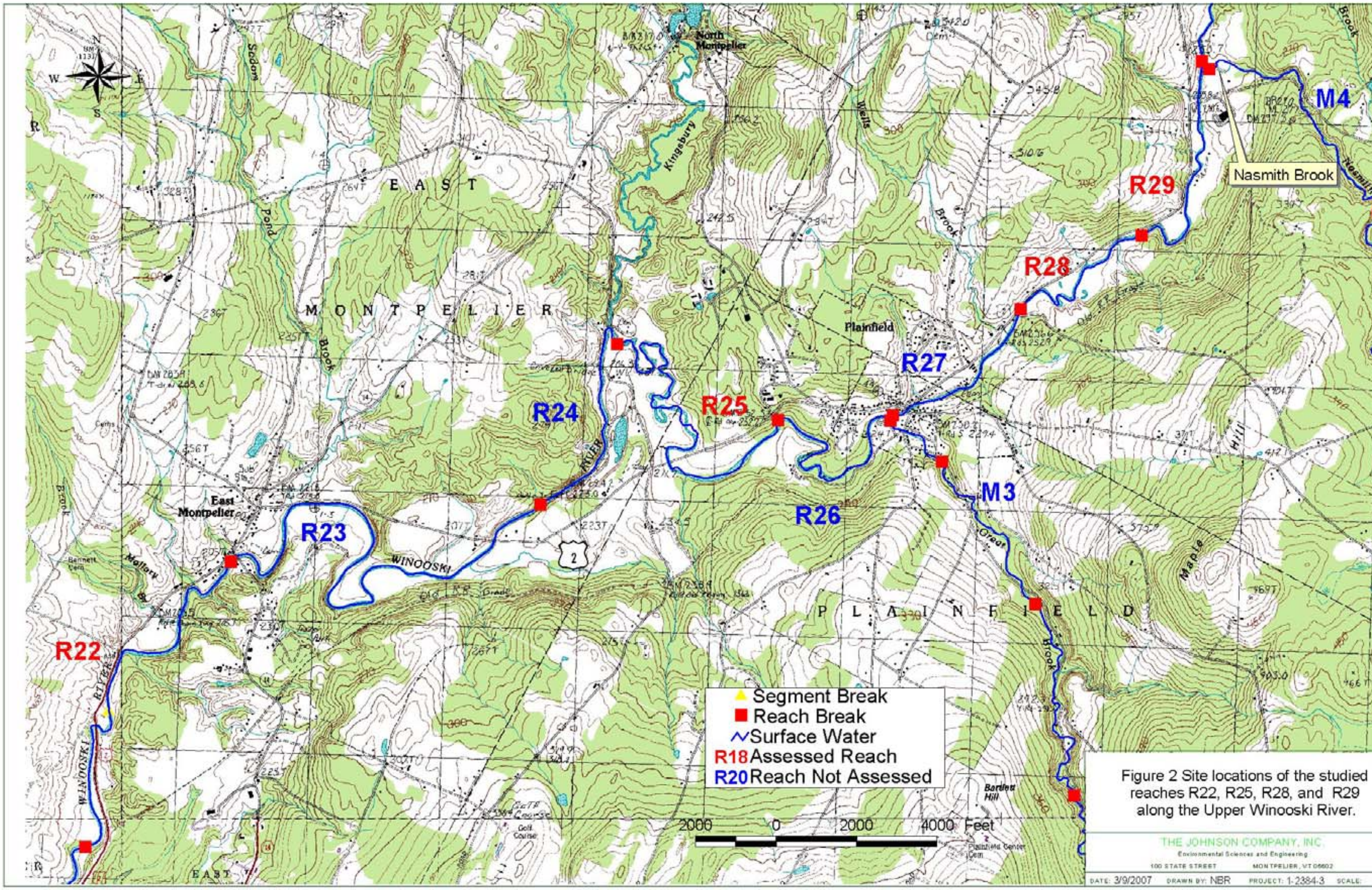

Figure 2 Site locations of the studied reaches R22, R25, R28, and R29 along the Upper Winooski River.

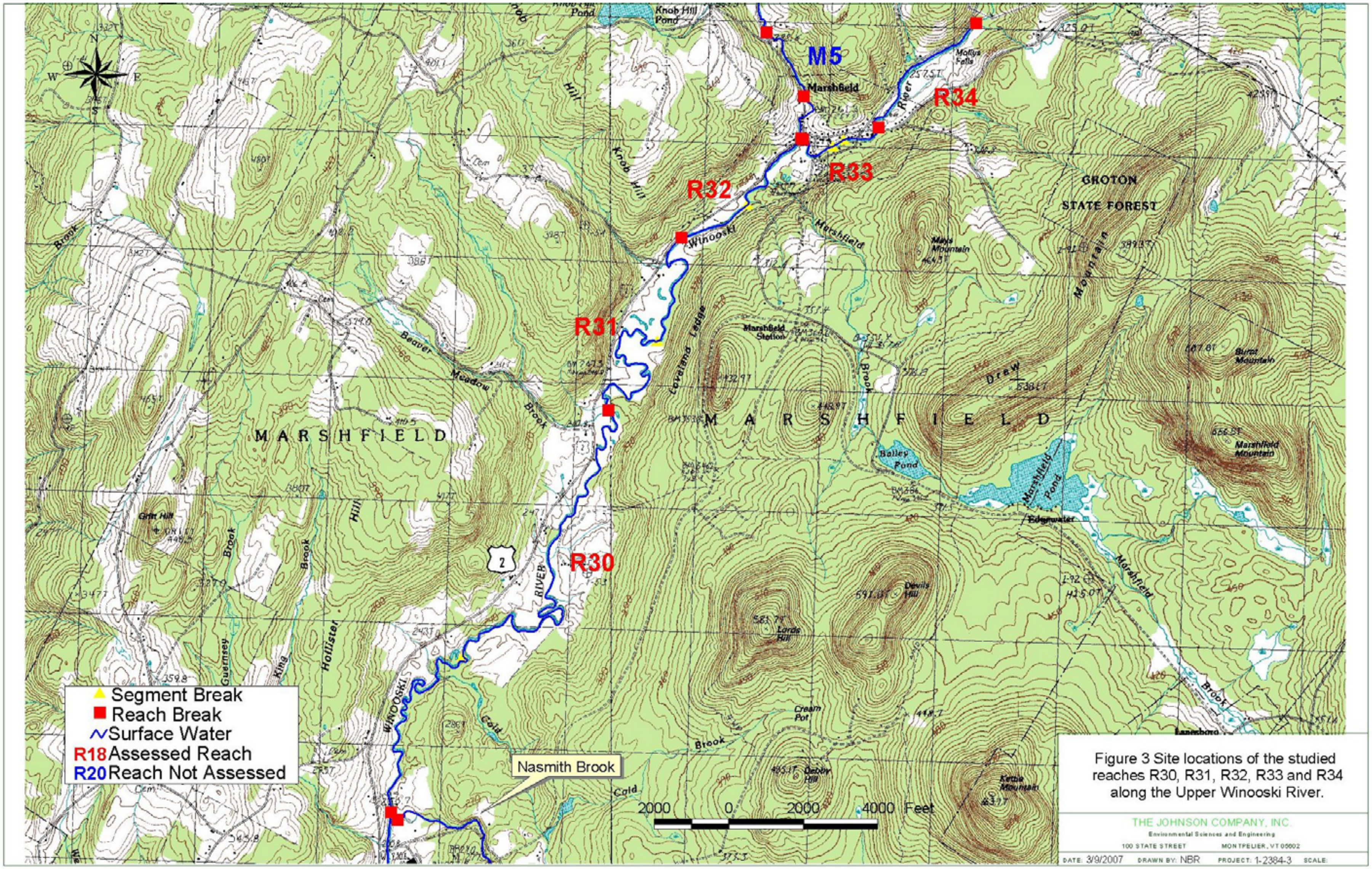

Figure 3 Site locations of the studied reaches R30, R31, R32, R33 and R34 along the Upper Winooski River.

APPENDIX A
INDIVIDUAL REACH NARRATIVES

APPENDIX B
PHASE 2 DATA MANAGEMENT SYSTEM REPORTS