Allen Brook Watershed Departure Analysis and Project Identification Summary

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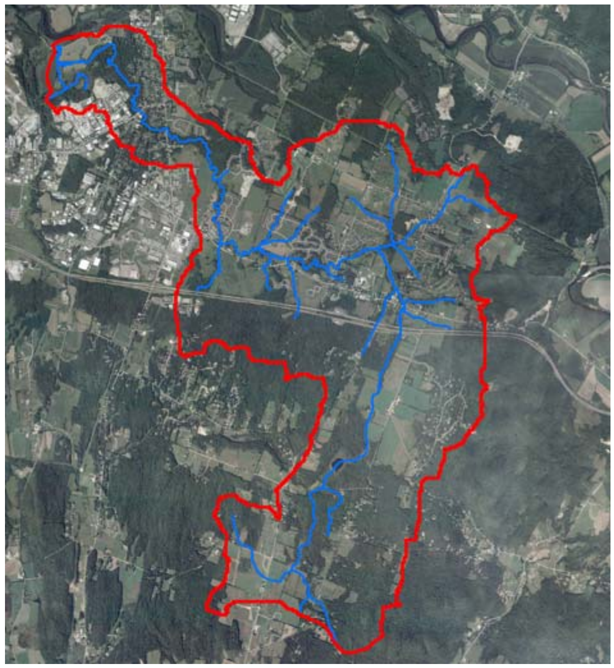

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Executive Summary

- Allen Brook is drained by a small, urbanizing watershed located in the Town of Williston. The middle reaches of the watershed have been officially designated by the Vermont Agency of Natural Resource (VTANR) as impaired by stormwater runoff from impervious surfaces.

- Allen Brook was identified for geomorphic assessment during 2005 as part of a joint UVM-VTANR research project to collect data for: 1) assessing the relative contribution of endogenous sediment loading (e.g., channel banks and bed) in the watershed, and 2) establishing baseline data for long-term monitoring purposes by VTANR. As part of this project, and additional work completed by Fitzgerald Environmental Associates, LLC (FEA) in 2007, a total of 17 stream segments have been assessed using the Phase 1 and 2 approach of the VTANR Stream Geomorphic Assessment (SGA) Protocols.

- FEA tested the RMP River Corridor Planning Guide (VTANR, 2007) methods for identifying restoration projects in the Allen Brook watershed. FEA completed an analysis of stressors to the hydrologic and sediment regimes and riparian and boundary conditions, including the mapping of channel features identified during the field surveys. The data and mapping formed the basis for developing a list of potential restoration and protection projects using a step-wise procedure developed by VTANR.

- The results of the stressor and departure analysis indicate that increases in impervious cover and man-made drainage infrastructure, and loss of wetlands have impacted the hydrologic regime in the lower and middle reaches of the watershed. Degradational and lateral channel adjustment processes dominate much of the channel network, resulting in many reaches with high sediment transport capacity and a high supply of sediment from eroding banks and mass failures. Natural grade controls (e.g., ledges) in the lower reaches limit the migration of channel incision upstream of these features.

- A total of 21 unique project opportunities were identified for the main stem reaches, including 9 corridor protection sites, 7 riparian buffer planting sites, 1 active channel restoration site, and 4 structure replacement projects. A select group of 12 projects were prioritized according to their compatibility with a corridor approach to geomorphic restoration.

- The prioritized list of projects was divided into two groups: 1) projects which *do not require* further study for VTANR to pursue implementation, and are generally "passive" by nature (i.e., conservation based); 2) projects which *will require* further study prior to implementation (e.g., berm removal). Special consideration has been given to the feasibility of active restoration projects in light of the long-term restoration approach outlined in VTANR's TMDL document for the watershed (see Section 3.2).

1.0 Background

Allen Brook is found entirely within the Town of Williston and is drained by an urbanizing watershed with an area of 11.2 square miles (Figure 1). Biotic samples collected in the middle watershed zone have shown an impaired condition due to excess urban runoff. Various studies have been conducted over the past 5 years in an attempt to identify the sources of impairment (Barg et al., 2003; Fitzgerald, 2005). The Vermont Agency of Natural Resources (VTANR) designated the watershed impaired by stormwater runoff on the 2004 303(d) list submitted to EPA. A hydrologically-based Total Maximum Daily Load (TMDL) will be developed by VTANR for the watershed in 2008. The forthcoming TMDL will assert that the mitigation of stormwater runoff will reduce the impacts of other pollutants of concern in the watershed, such as sediments, nutrients, heavy metals, and fecal bacteria.

Vertical and lateral channel adjustments caused by upslope urbanization have been shown to be a significant source of fine sediment loading in watersheds around the world (Trimble, 1997; Simon and Rinaldi, 2006). Due to ongoing channel adjustments in the Allen Brook watershed in response to watershed urbanization (Fitzgerald, 2005), VTANR asserts that endogenous sources of sediment (e.g., channel bed and banks) far outweigh the exogenous sources (e.g., colluvial and runoff-generated) in the stormwater impaired watersheds of Vermont (VTANR, 2006a). Therefore, a hydrologically-based approach to restoration that addresses the underlying watershed stressors (e.g., increased impervious cover), as prescribed in the approved TMDL, will promote long-term channel stability through the redevelopment and maintenance of dynamic equilibrium channel conditions.

Allen Brook was identified for geomorphic assessment during 2005 as part of a joint UVM-VTANR research project to collect data for: 1) assessing the relative contribution of endogenous sediment loading in the watershed, and 2) establishing baseline data for long-term monitoring purposes. As part of this project, 15 stream segments along the main stem were assessed using the Phase 2 approach of the VTANR Stream Geomorphic Assessment Protocols (SGA; VTANR, 2006b). The assessments were carried out by Evan Fitzgerald and a crew of UVM graduate and undergraduate students in August 2005. Fitzgerald Environmental Associates, LLC (FEA) was later retained by the VTANR River Management Program (RMP) in 2007 to complete Phase 2 assessments on 2 additional tributary segments, making for a total of 17 assessed segments in the watershed. As part of this project, FEA has tested the RMP River Corridor Planning Guide (VTANR, 2007) methods for identifying restoration projects in three urbanized watersheds in Chittenden County: Allen Brook, Potash Brook, and Indian Brook. What follows is a summary of the methods and results of the project identification process for 15 segments on the Allen Brook main stem. Data collected for the 2 tributary reaches were not selected for the project identification effort.

2.0 Stressor Identification and Departure Analysis

The data collected through the Phase 1 and 2 SGA studies provides the basis for assessing the impacts to the hydrologic and sediment regimes, and the channel riparian and boundary conditions. This data, when combined with other watershed-scale data developed in this study and using relationships derived from recently completed research in the study area (Fitzgerald, 2007), also allows for the assessment of physical departure from reference conditions, and serves to validate watershed-scale patterns and stream conditions observed in the field.

Table 1. Reach Summary Statistics

Reach/ Segment	Stream Type	Dominant Bed Material	Channel Bedform	RHA Score	RHA Condition	RGA Score	RGA Condition	Reach Sensitivity	CEM†	CEM† Stage
M01	C	Gravel	Riffle-Pool	0.60	Fair	0.56	Fair	Very High	F	III
M02	C	Gravel	Riffle-Pool	0.60	Fair	0.43	Fair	Very High	F	III
M03A	C	Gravel	Riffle-Pool	0.69	Good	0.51	Fair	Very High	F	III
M03B	C	Gravel	Riffle-Pool	0.60	Fair	0.59	Fair	Very High	F	II
M03C	C	Gravel	Plane Bed**	0.50	Fair	0.29	Poor	Very High	F	III
M03D	C	Cobble	Plane Bed	0.63	Fair	0.55	Fair	High	F	III
M04A	F*	Gravel	Plane Bed**	0.42	Fair	0.40	Fair	Extreme	F	II
M04B	E	Sand	Plane Bed	0.62	Fair	0.54	Fair	Very High	F	II
M05A	E	Sand	Plane Bed	0.65	Good	0.69	Good	Very High	F	IV
M05B	C	Gravel	Riffle-Pool	0.61	Fair	0.41	Fair	Very High	F	III
M06	B	Cobble	Step-Pool	0.85	Good	0.78	Good	Moderate	F	I
M07	E*	Gravel	Plane Bed**	0.43	Fair	0.56	Fair	Extreme	F	II
M08/9	E	Sand	Plane Bed	0.67	Good	0.74	Good	High	F	I
M10A	C	Cobble	Plane Bed	0.62	Fair	0.64	Fair	High	D	IIb
M11	F*	Sand	Plane Bed**	NE	NE	0.45	Fair	Extreme	F	IV
T1.01	E	Sand	Plane Bed**	0.59	Fair	0.59	Fair	Very High	F	II
T1.01-S1	E	Gravel	Riffle-Pool	0.64	Fair	0.58	Fair	Very High	F	III

* Stream type departure (Rosgen, 1996)
** Departure from reference bedform (Montgomery & Buffington, 1997)
† Channel evolution model (VTANR, 2006)
NE: Not evaluated

The stream segments studied in the Allen Brook watershed have a diversity of natural forms and sensitivities (Table 1). Three segments have undergone severe channel adjustments, resulting in a departure from reference conditions. The average score from the Rapid Geomorphic Assessment (RGA) stability assessment was 0.60, or within the range of fair conditions, indicating that the impacts of urbanization have resulted in many segments that are not in regime and have channels experiencing some degree of floodplain disconnection. Similarly, the Rapid Habitat Assessment (RHA) results indicate fair conditions overall, with degraded conditions typically reflective of increased substrate embeddedness (due to excess fine substrate), limited pool variability and depth, limited presence of coarse and large woody debris, and poor bank vegetation. Many of the study segments in the lower and middle watershed are in a state of channel incision (stage II of channel evolution; VTANR, 2006b), or channel widening (stage III) due primarily to vertical adjustments brought on by the altered hydrologic regime.

The following sections summarize the methods used to develop the stressor identification and departure maps found in Appendix A. The mapping of physical stressors and natural or human constraints allowed for 1) a process-based approach to understanding stream conditions at different scales, and 2) an evaluation of the connectivity of stressors along the channel network. The maps were referenced during the project identification process summarized in Section 3.

2.1 Hydrologic Regime Stressors

The following description of the hydrologic regime of a watershed, and the general response to watershed-scale land use changes and stressors is included from the most recent version of the VTANR River Corridor Planning Guide (VTANR, 2007).

> The hydrologic regime may be defined as the timing, volume, and duration of flow events throughout the year and over time. The hydrologic regime may be influenced by climate, soils, geology, groundwater, watershed land cover, connectivity of the stream, riparian, and floodplain network, and valley and stream morphology. The hydrologic regime, as addressed in this section, is characterized by the input and manipulation of water at the watershed scale and should not be confused with channel and floodplain "hydraulics," which describes how the energy of flowing water affects reach-scale physical forms and is affected by reach-scale physical modifications (e.g., bridges modify channel and floodplain hydraulics).
>
> When the hydrologic regime has been significantly changed, stream channels will respond by undergoing a series of channel adjustments. Where hydrologic modifications are persistent, the impacted stream will adjust morphologically (e.g., enlarging when stormwater peaks are consistently higher) and often result in significant changes in sediment loading and channel adjustments in downstream reaches.

The Allen Brook watershed contains a mixture of land cover types (Table 2), including significant amounts of agricultural land cover (mostly in the upper watershed). Large, contiguous areas of forest cover are found in the southern portions of the watershed south of Interstate 89. The watershed has a low to moderate degree of impervious cover (7.4%), below levels typically associated with degraded stream conditions at the national level (CWP, 2003), but above the 5% impact threshold noted in urbanizing watersheds in Chittenden County (Fitzgerald, 2007).

The current day stressors to the hydrologic regime have been mapped using the variables extracted from the Phase 2 field dataset, watershed-scale loss of wetlands, and the degree of impervious cover at the subwatershed scale (Figure 2).

Table 2. Allen Brook Watershed Land Cover

Land Cover Type	Percent Cover
Forested	30.3%
Agriculture	48.1%
Water & Wetland	6.9%
Residential	7.0%
Commercial/Industrial	1.8%
Transportation	5.9%

† UVM Spatial Analysis Data (SAL, 2005)

Wetland loss was mapped as the area where hydric soils (NRCS mapping) intersect with urban or agricultural land uses in the watershed, with the remaining areas assumed to be intact wetland (the majority found in forested conditions). This approach allows for the interpretation of loss of hydrologic attenuation of surface runoff at the reach and watershed scale. In addition, stormwater outfall densities mapped during the Phase 2 assessments are included to depict areas of increased stormflows. A summary of the local (reach-scale) and upslope impacts to the hydrologic regime for each main stem reach based on Figure 2 is provided in Table 5 at the end of this section.

2.2 Sediment Regime Stressors

The following description of the sediment regime of a watershed, and the general response to watershed-scale land use changes and stressors is included from the most recent version of the VTANR River Corridor Planning Guide (VTANR, 2007).

> The sediment regime may be defined as the quantity, size, transport, sorting, and distribution of sediments. The sediment regime may be influenced by the proximity of sediment sources, the hydrologic regime, and valley, floodplain and stream morphology. Understanding changes in sediment regime at the reach and watershed scales is critical to the evaluation of stream adjustments and sensitivity. The sediment erosion and deposition patterns, unique to the equilibrium conditions of a stream reach, create habitat. In all but the most dynamic areas (e.g., alluvial fans), they provide for relatively stable bed forms and bank conditions.

The current day stressors to the sediment regime have been mapped using the variables extracted from the Phase 2 field dataset, and the percent of agriculture within each subwatershed (Figure 3). Four classes of percent agriculture were mapped to depict the relative impact of sediment delivery from agricultural lands at the reach and watershed scales. In addition, depositional and migration features mapped during the Phase 2 assessments are included to depict areas of increased vertical and lateral channel adjustments due to aggradation. Mass failures and bank erosion depict where sediment delivery from the channel boundaries is occurring. A summary of the local and upslope impacts to sediment loading for each main stem reach based on Figure 3 is provided in Table 5.

2.3 Channel Slope and Depth Modifiers

Many of Vermont's rivers and streams have been historically manipulated and straightened to maintain an unnaturally steep slope in a state of sediment transport, allowing for a short term sense of security from flooding and subsequent encroachment of infrastructure in the floodplain. Over time, alluvial rivers seek to redevelop a sinuous planform through the deposition of sediments in unconfined valleys. Following flood events when alluvial rivers have become energized enough to transport large amounts of coarse sediment into depositional zones of the watershed, lateral channel migration ensues and further channel straightening is required to protect infrastructure found in the floodplain. Straightening and channelization typically ranges between 25 and 75 percent of the total river channel length in Vermont (VTANR, 2007).

In addition to historic alterations to channel slope in Vermont's alluvial rivers, the lowering of stream beds (e.g., dredging) and the raising of floodplains (e.g., berming) have resulted in an increase in channel depth (VTANR, 2007). Channel depths have typically been increased through the encroachment on the floodplain by roads and railroads and subsequent filling and armoring required to construct and maintain this infrastructure. Increases in impervious cover have also led to the deepening and eventual widening of channels throughout urbanized areas of Vermont (Fitzgerald, 2007).

Alterations to channel slope and depth in the Allen Brook watershed have been mapped using the variables extracted from the Phase 2 field dataset (Figures 4 and 5). Channel straightening mapped during the Phase 1 and 2 assessments are included to depict areas of increased channel slope. Corridor encroachment data highlights where roads and development have reduced the floodplain area, typically resulting in increased stream power and channel deepening. Areas with "high" encroachment indicate those reaches where at least 20 percent of the reach is affected by encroachment. Additional data showing the location of natural channel features (e.g., ledges) depict areas that have a resistance to vertical channel change. The presence of beaver activity in each reach indicates where temporary controls on vertical adjustments may be found. A summary of the local and upslope impacts to channel depth and slope for each reach is provided in Table 5.

2.4 Modifications to Channel Boundary and Riparian Conditions

The boundary conditions of a river encompass the bed and bank substrate, and the vegetation and root material found along the riverbank. Human alterations to the river boundary conditions are often made to increase the resistance of the banks and bed to reduce lateral and vertical adjustments. In addition, the removal of riparian vegetation can cause a decrease in boundary resistance, and lead to increased lateral migration. Other natural and human-installed features within the channel, such as bedrock ledges and dams, affect boundary resistance in an upstream and downstream direction by controlling vertical adjustment processes.

Alterations to the channel boundary conditions and riparian areas in the Allen Brook watershed have been mapped using the variables extracted from the Phase 2 field dataset (Figure 6). Relative bank armoring (e.g., rip-rap) highlights areas of increased resistance to lateral migration, whereas relative bank erosion highlights reaches where significant lateral adjustments are found. Additional data showing the location of natural channel features (e.g., ledges) and channel modifications (e.g., weirs) depict areas that have a resistance or propensity for channel change, respectively. A summary of the local impacts to channel boundary conditions, including impacts to riparian vegetation, for each main stem reach based on Figure 6 is provided in Table 5.

In the Allen Brook watershed only four natural grade controls (e.g., ledges and waterfalls) were noted during the field surveys, with three of these located in the lower watershed in the vicinity of the Route 2A crossing. These conditions limit the amount of natural armoring within the remaining reaches (where no grade controls were noted), and allow for vertical adjustments (e.g., nickpoints) to migrate up the channel network. Channel armoring was found to be significant in only two reaches where corridor encroachments (e.g., berms and roads) were located; only 2 of the 15 main stem segments had bank armoring exceeding 5 percent of the total segment length. Many reaches had significant reductions in woody riparian vegetation, leading to decreased boundary resistance.

2.5 Sediment Regime Analysis

Much research has shown that alluvial river channels in wide valleys will adjust their geometry and planform to accommodate changes in the discharge and sediment loading from the upslope watershed (Dunne and Leopold, 1978). This concept was summarized by Lane (1955) to show that stream power and sediment (size and distribution) will seek a dynamic equilibrium condition in the absence of anthropogenic disturbance or catastrophic natural storm events. Slight changes from one year to another, such as variation in rainfall amounts (and a resulting variation in discharge), may cause subtle changes in channel form. However, the shape and profile of a river is typically stable under reference watershed conditions, and predictable given knowledge about 1) the geologic conditions of the watershed and corridor, 2) the topography of the watershed, and 3) the regional climate.

Analysis of a watershed’s sediment regime is a useful approach for summarizing the reach and watershed-scale stressors affecting the equilibrium conditions of river channels. Sediment regime mapping provides a context for understanding the sediment transport and channel evolution processes (Schumm, 1977; see supporting materials in Appendix B) which govern changes in geometry and planform for river channels in a state of disequilibrium. The VTANR River Corridor Planning Guide (2007) outlines a methodology for understanding the reference and altered sediment regimes of reaches according to data collected during the Phase 2 field assessments. The sediment regime types used in this analysis are summarized below in Table 3.

Table 3. Sediment Regime Types (VTANR, 2007)

Regime	Narrative Description
Transport	Steeper bedrock and boulder/cobble cascade and step-pool stream types; typically in more confined valleys, do not supply appreciable quantities of sediments to downstream reaches on an annual basis; little or no mass wasting; storage of fine sediment is negligible due to high transport capacity derived from both the high gradient and/or natural entrenchment of the channel.
Confined Source and Transport	Cobble step pool and steep plane bed streams; confining valley walls, comprised of erodible tills, glacial lacustrine, glacial fluvial, or alluvial materials; mass wasting and landslides common and may be triggered by valley rejuvenation processes; storage of coarse or fine sediment is limited due to high transport capacity derived from both the gradient and entrenchment of the channel. Look for streams in narrow valleys where dams, culverts, encroachment (roads, houses, etc.), and subsequent channel management may trigger incision, rejuvenation, and mass wasting processes.
Unconfined Source and Transport	Sand, gravel, or cobble plane bed streams; at least one side of the channel is unconfined by valley walls; may represent a stream type departure due to entrenchment or incision and associated bed form changes; these streams are not a significant sediment supply due to boundary resistance such as bank armoring, but may begin to experience erosion and supply both coarse and fine sediment when bank failure leads to channel widening; storage of coarse or fine sediment is negligible due to high transport capacity derived from the deep incision and little or no floodplain access. Look for straightened, incised or entrenched streams in unconfined valleys, which may have been bermed and extensively armored and are in Stage II or early Stage III of channel evolution.
Fine Source and Transport & Coarse Deposition	Sand, gravel, or cobble streams with variable bed forms; at least one side of the channel is unconfined by valley walls; may represent a stream type departure due to vertical profile and associated bed form changes; these streams supply both coarse and fine sediments due to little or no boundary resistance; storage of fine sediment is lost or severely limited as a result of channel incision and little or no floodplain access; an increase in coarse sediment storage occurs due to a high coarse sediment load coupled with the lower transport capacity that results from a lower gradient and/or channel depth. Look for historically straightened, incised, or entrenched streams in unconfined valleys, having little or no boundary resistance, increased bank erosion, and large unvegetated bars. These streams are typically in late Stage III and Stage IV of channel evolution.
Coarse Equilibrium (in = out) & Fine Deposition	Sand, gravel, or cobble streams with equilibrium bed forms; at least one side of the channel is unconfined by valley walls; these streams transport and deposit coarse sediment in equilibrium (stream power—produce as a result of channel gradient and hydraulic radius—is balanced by the sediment load, sediment size, and channel boundary resistance); storage of fine sediment as a result of floodplain access for high frequency (annual) floods. Look for unconfined streams, which are not incised or entrenched, have boundary resistance (woody buffers), minimal bank erosion, and vegetated bars. These streams are Stage I, late Stage IV, and Stage V of channel evolution.

The reference and existing sediment regime types have been mapped using data from the Phase 1 and 2 assessments. Figures 7 and 8 summarize the sediment regime types for reference and existing conditions for 15 main stem segments. The analysis of sediment regime types reveals that the main stem channel of Allen Brook has experienced many areas of departures from the reference regime conditions. All of the reaches with slopes less than 2 percent are assumed to have been fine or coarse-bottomed streams in equilibrium, where there was a balance between sediment transport and supply. Only one main stem segment, M06, had a sediment transport regime under reference conditions where the channel slope is greater than 2 percent. Only 2 main stem segments assessed for Phase 2 data were determined to be in regime. All other segments were determined to have departed from their reference regime (Figure 8), resulting in areas with reduced floodplain deposition of fine sediments, and increased bank erosion.

Table 4. Allen Brook Departure Analysis Summary

River Segment	Constraints		Transport		Floodplain Sediment and Flow Attenuation (Storage)		
	Vertical	Lateral	Natural	Converted	Natural	Increased	Asset
M01	Beaver Activity (N)				X	X	X
M02	Ledge; Waterfall (N)				X	X	X
M03-A	Ledge (N)	Development; Roads (H)			X	X	X
M03-B		Development; Roads (H)			X		X
M03-C				partially	X		future
M03-D					X	X	X
M04-A		Development; Roads; Berms (H)		X	X		
M04-B	Beaver Activity (N)				X		X
M05-A	Beaver Activity (N)				X		X
M05-B		Development (H)			X	X	X
M06	Ledge (N)		X				
M07				partially	X		X
M08/9	Beaver Activity (N)				X		X
M10-A					X	X	X
M11				X	X		future

N = Natural
H = Human Constructed
“future” indicates a segment with potential for sediment attenuation if corridor is managed sustainably.
“partially” indicates a portion of the segment has been converted to a transport reach.

Table 4 summarizes both the departure of sediment regime conditions based on the transport and storage capacity, as well as the constraints to the connectivity of the adjustment processes along the channel network, and the redevelopment of equilibrium conditions in the reach. The summary of transport regimes (transport versus storage) indicates whether the regime is naturally dominated by sediment transport processes, or whether it has been converted to this state due to human constraints (with a resulting attenuation decrease). The flow and sediment attenuation summary indicates where streams have an inherent tendency to store sediment (natural), where sediment deposition is increasing, and whether the reach has potential for future sediment deposition (asset).

2.6 Stream Sensitivity Analysis

The following description of the sensitivity of various stream types to changes in sediment and flow regimes, boundary conditions and channel morphology, is included from the most recent version of the VTANR River Corridor Planning Guide (VTANR, 2007).

> Certain geomorphic stream types are inherently more sensitive than others, responding readily through lateral and/or vertical adjustments to high flow events and/or influxes of sediment. Other geomorphic stream types may undergo far less adjustment in response to the same watershed inputs. In general, streams receiving a large supply of sediment, having a limited capacity to transport that sediment, and flowing through finer-grained, non-cohesive materials are inherently more sensitive to adjustment and likely to experience channel evolution processes than streams with a lower sediment supply, higher transport capacity and flowing through cohesive or coarse-grained materials (Montgomery and Buffington, 1997). The geometry and roughness of the stream channel and floodplain (i.e., the width, depth, slope, sediment sizes, and floodplain relations) dictate the velocity of flow, how much erosive power is produced, and whether the stream has the competence to transport the sediment delivered from upstream (Leopold, 1994). If the energy produced by the depth and slope of the water is either too little or too great in relation to the sediment available for transport, the stream may be out of equilibrium and channel adjustments are likely to occur, especially during flood conditions (Lane, 1955).

The methods outlined in the Corridor Planning Guide have been used to describe the stream sensitivities of the studied segments of Allen Brook. Using the stream geometry and substrate data (Rosgen, 1994; see supporting materials in Appendix B) and overall geomorphic stability (RGA score) as determined during the Phase 2 surveys, stream sensitivity ratings have been assigned to each segment. In addition, the active adjustment processes described during the field effort have been summarized. An adjustment process was considered “active” if it received a score in the fair to poor range during the RGA scoring process. Figure 9 summarizes the current stream sensitivities and adjustment processes for the Allen Brook watershed.

Due to the inherent propensity of meandering, sand and gravel bed channels to adjust in response to watershed and reach-scale impacts, 13 out of 15 assessed segments have a stream sensitivity rating of very high or above. Many of the main stem reaches are going through the initial stages of channel evolution (stage II; incision), while others and are beginning to aggrade fine and coarse sediments (stage III). Only 2 of the study reaches show signs of floodplain redevelopment that typically follows a prolonged period of channel incision (stage IV), indicating that the hydrologic regime stressors are likely maintaining much of the channel network in a state of degradation (excess sediment transport).

Three reaches have experienced a departure of channel morphology from reference conditions (see Appendix B for further description of the Rosgen classification system), resulting in a stream sensitivity rating of extreme:

- **M04-A:** Channel has been straightened and stabilized on both banks with rip rap, more so on right bank along adjacent development. Stream type has departed from original C-type to F-type with plane bed features. Entrenchment is largely a result of long-term incision brought on by extensive bank armoring; only a small portion of lower reach is not straightened, near downstream section at Old Stage Rd. Human caused changes in valley width were noted for this segment, although these changes were not observed in upslope segment M04-B.

- **M07**: Under reference conditions this reach most likely had C-type channel geometry, but has been altered due to historic straightening and berming along the upper section of the reach. Current channel geometry is an E-type stream with lower than expected width to depth ratio (7.0), resulting from possible historic dredging and straightening. Some beaver activity along the reach is also causing natural changes in planform as the channel adjusts within the current floodplain.

- **M11:** This reach has undergone extensive historic straightening and berming throughout farm fields, especially in the lower part of the reach east of Oak Hill Rd. Although channel dimensions suggest a B or C type due to entrenchment, F-type channel dimensions dominated most of lower reach, reflecting the high degree of encroachment and berming and disconnectivity from floodplain.

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Table 5. River Stressors Identification Table summarizing watershed and reach-scale stressors impacting dynamic equilibrium conditions. Figures used to summarize regime stressors (figures include value ranges) are noted for each. For example: "Sediment (3)" – Figure 3 was referenced.

River Segment (CEM;RGA†)	**Regime Stressors** Hydrologic (2,3)	Sediment (3)	**Reach-Scale Stressors** Stream Power (4,5)	Boundary Resistance (6)
M01 (III;Fair)	*Increased Flows* • High local and upslope TIA* • Moderate stormwater inputs in reach • Moderate local wetland loss	*Increased Load* • Extreme cropland (>20%) in local drainage • Abundant depositional features • Lateral channel adjustments • High bank erosion (>20%) • One mass failure	*Increase* • Moderate stormwater inputs in reach *Decrease* • Abundant depositional features	*Increase* • Moderate bank armoring (5-20%) *Decrease* • Reduced riparian vegetation • High bank erosion (>20%)
M02 (III;Fair)	*Increased Flows* • High local and upslope TIA* • Major stormwater inputs in reach and upslope • High upslope wetland loss	*Increased Load* • Extreme cropland (>20%) in upslope drainages • Abundant depositional and migration features • Lateral channel adjustments • High bank erosion (>20%) • Multiple mass failures	*Increase* • Major stormwater inputs in reach and upslope *Decrease* • Abundant depositional and migration features	*Increase* • Multiple grade controls *Decrease* • High bank erosion (>20%)
M03-A (III;Fair)	*Increased Flows* • Moderately-high local and upslope TIA* • Major stormwater inputs in reach and upslope • High local wetland loss.	*Increased Load* • Extreme cropland (>20%) in local and upslope drainage • Abundant depositional and migration features • Lateral channel adjustments • High bank erosion (>20%) • One mass failure	*Increase* • Moderate corridor encroachment • Major stormwater inputs in reach and upslope *Decrease* • Abundant depositional and migration features	*Increase* • Single grade control *Decrease* • Reduced riparian vegetation • High bank erosion (>20%)
M03-B (II, Fair)	*Increased Flows* • Moderately-high local and upslope TIA* • Extreme stormwater inputs in reach and upslope • Very high local wetland loss	*Increased Load* • Extreme cropland (>20%) in local and upslope drainage • Migration features present • High bank erosion (>20%)	*Increase* • High corridor encroachment • Moderate channel straightening • Major stormwater inputs in reach and upslope	*Decrease* • Reduced riparian vegetation • High bank erosion (>20%)

River Segment (CEM;RGA[†])	Regime Stressors Hydrologic (2,3)	Sediment (3)	Reach-Scale Stressors Stream Power (4,5)	Boundary Resistance (6)
M03-C (III;Poor)	*Increased Flows* • Moderately-high local and upslope TIA* • Major stormwater inputs in reach and upslope • High local wetland loss	*Increased Load* • Extreme cropland (>20%) in local and upslope drainage • Abundant depositional and migration features • Lateral channel adjustments • High bank erosion (>20%)	*Increase* • Major stormwater inputs in reach and upslope • Stream type departure due to channel incision *Decrease* • Abundant depositional and migration features	*Decrease* • Reduced riparian vegetation • High bank erosion (>20%)
M03-D (III;Fair)	*Increased Flows* • Moderately-high local and upslope TIA* • Major stormwater inputs in reach • High local wetland loss	*Increased Load* • Extreme cropland (>20%) in local and upslope drainage • Abundant depositional and migration features • Lateral channel adjustments • High bank erosion (>20%) • Multiple mass failures	*Increase* • Major stormwater inputs in reach *Decrease* • Abundant depositional and migration features	*Decrease* • High Bank Erosion (>20%)
M04-A (II;Fair)	*Increased Flows* • Moderately-high local and upslope TIA* • Moderate stormwater inputs in reach • Very high local wetland loss	*Increased Load* • Extreme cropland (>20%) in local and upslope drainage • High bank erosion (>20%) • Limited sediment loading from banks due to extensive armoring • Multiple mass failures	*Increase* • Moderate stormwater inputs in reach • Stream type departure due to channel incision • High corridor encroachment • High channel straightening	*Increase* • High bank armoring (>20%) *Decrease* • Reduced riparian vegetation • High bank erosion (>20%)
M04-B (II;Fair)	*Increased Flows* • Moderately-high local and upslope TIA* • Very high local wetland loss	*Increased Load* • Extreme cropland (>20%) in local and upslope drainage • Abundant depositional features • High bank erosion (>20%)	*Decrease* • Abundant depositional features	*Decrease* • High Bank Erosion (>20%)
M05-A (IV;Good)	*Increased Flows* • Moderately-high local and upslope TIA*	*Increased Load* • Extreme cropland (>20%) in local and upslope drainage	*No significant increases or decreases*	*Decrease* • Reduced riparian vegetation • High erodibility potential of

River Segment (CEM;RGA[†])	Regime Stressors		Reach-Scale Stressors	
	Hydrologic (2,3)	Sediment (3)	Stream Power (4,5)	Boundary Resistance (6)
	• High local wetland loss	• High bank erosion (>20%)		bed/bank substrate** • High Bank Erosion (>20%)
M05-B (III;Fair)	*Increased Flows* • Moderately-high local and upslope TIA* • High local wetland loss	*Increased Load* • Extreme cropland (>20%) in local and upslope drainage • Abundant depositional and migration features • High bank erosion (>20%)	*Increase* • Moderate channel straightening *Decrease* • Abundant depositional and migration features	*Decrease* • High Bank Erosion (>20%) • Reduced riparian vegetation
M06 (I;Good)	*No Significant Stressors Causing Increased or Decreased Flows*	*Increased Load* • Extreme cropland (>20%) in local and upslope drainage • Abundant depositional and migration features • High bank erosion (>20%) • One mass failure	*Decrease* • Abundant depositional and migration features	*Increase* • Single grade control *Decrease* • Moderate bank erosion (5-20%)
M07 (II;Fair)	*No Significant Stressors Causing Increased or Decreased Flows*	*Increased Load* • Extreme cropland (>20%) in local and upslope drainage • Abundant depositional and migration features • Moderate bank erosion (5-20%)	*Increase* • High channel straightening *Decrease* • Abundant depositional and migration features	*Decrease* • Reduced riparian vegetation
M08/9 (I;Good)	*No Significant Stressors Causing Increased or Decreased Flows*	*Increased Load* • Extreme cropland (>20%) in local and upslope drainage • Depositional features present • Moderate bank erosion (5-20%)	*Decrease* • Depositional features present	*Decrease* • High erodibility potential of bed/bank substrate**
M10-A (II;Fair)	*No Significant Stressors Causing Increased or Decreased Flows*	*Increased Load* • Extreme cropland (>20%) in local and upslope drainage • Abundant depositional and migration features	*Decrease* • Abundant depositional and migration features	*Decrease* • Moderate bank erosion (5-20%)

River Segment (CEM;RGA†)	Regime Stressors Hydrologic (2,3)	Sediment (3)	Reach-Scale Stressors Stream Power (4,5)	Boundary Resistance (6)
		• Moderate bank erosion (5-20%)		
M11 (II;Fair)	*No Significant Stressors Causing Increased or Decreased Flows*	*Increased Load* • Extreme cropland (>20%) in local and upslope drainage	*Increase* • High channel straightening	*Decrease* • High erodibility potential of bed/bank substrate** • Reduced riparian vegetation

*Total Impervious Area
** Reaches with high erodibility potential having fine bed substrate and limited bank cohesiveness (e.g., sands)
Note: local scale for wetland loss and road density/TIA includes the corridor and the adjacent subwatersheds draining directly to the reach
† Channel evolution stage (F model for all reaches) and Rapid Geomorphic Assessment categorical score

3.0 Preliminary Project Identification

3.1 Step-wise Methodology

The projects outlined in Table 6 meet the criteria for geomorphically compatible projects as outlined in Step 6 of the Preliminary Project Identification methodology (VTANR, 2007). The listed projects are prioritized based on the benefit to geomorphic stability, the project's technical feasibility, and a consideration of the site size and location in the watershed. For example, undeveloped floodplain areas downstream of building and road constraints are high priority areas for corridor protection to attenuate flow and sediment transported through the channelized areas.

It is important to note that the projects opportunities listed in Table 6 were identified through an unbiased, scientifically-defensible approach (step-wise procedure; VTANR, 2007) using the best available data about the watershed and channel conditions. The projects are initially presented in this section without significant knowledge of social constraints to project implementation. A prioritized list of projects, which incorporates limited information about social constraints (e.g., review of parcel boundaries), is provided in Section 4 of this report.

3.2 Considerations for Active Channel Restoration Projects

Much research in the field of urban stream geomorphology has been carried out in the Pacific Northwest in recent years, in settings with land use pressures similar to those in Chittenden County. The clear strategy advocated as a result of these studies is the restoration of the hydrologic regime **prior** to "active" restoration of stream channel forms and habitats (Booth et al., 2002; Booth, 2005). From these studies, it is also clear that the failure to work towards restoration of the hydrologic regime will lead to watershed conditions which may preclude stream ecosystem recovery (e.g., lack of controls on increased impervious cover, failure to implement best management practices). The VTDEC strategy for restoration in the Allen Brook watershed accounts for this knowledge, as outlined in the TMDL approach for other Chittenden County watersheds (VTDEC, 2006a).

The restoration projects summarized in the following section have accounted for the stated goal of the VTANR TMDL approach to watershed-scale restoration. This approach considers the altered hydrologic regime as the primary controlling factor influencing hydraulic geometry and stream power, and thus the physical habitat that supports aquatic biota (VTDEC, 2006a). Certain active channel restoration projects, such as natural channel design, are summarized below but are generally discouraged in the short term due to the recognition that watershed-scale restoration of the hydrologic regime is likely to occur over a long-term period (greater than 5 years). However, other active restoration projects that will aid in the reestablishment of channel equilibrium conditions regardless of the timing of watershed-scale restoration, such as berm removal or culvert replacements, are summarized and prioritized accordingly.

3.3 Conserved Corridor Lands

Some areas of the Allen Brook corridor already have a high degree of protection through easements or other permanently conserved lands (e.g., school properties). Figure 10 highlights the areas of the watershed and corridor that are currently protected from future development, using data compiled by the Town of Williston (Williston, 2008). The conservation status of each segment was considered in the project identification analysis, and in the prioritized list of restoration opportunities. Some stream segments whose corridors are completely protected against future development are not included in the project summary if no other project opportunities, such as buffer plantings or culvert replacements, were identified (e.g., Segments M04-B and M05-A).

Table 6. Preliminary Project Identification Summary Table. The stepwise number in column 3 refers to the restoration project option prescribed from the VTANR River Corridor Planning Guide, pages 44-52 (VTANR, 2007).

Reach/Project, Stream Type, CEM[†], RGA/RHA[†]	**Site Description and Importance, Including Stressors and Constraints**	**Project/Strategy Description - Stepwise Number (#)**	**Priority, Technical Feasibility & Relative Costs**	**Other Social Benefits**	**Potential Partners**
M01-1, C, III, Fair/Fair	Channel was altered by historical straightening due to adjacent agricultural uses. Corridor encroachments from agricultural uses have directly affected the buffer vegetation, however the channel maintains a high degree of sinuosity with low incision, suggesting recovery from previous direct impacts	High priority stream corridor protection (3). Develop conservation easements for parcels on lower and middle reach. Ideally completed in conjunction with buffer planting project described below. Detailed site mapping is provided in Figure 11.	High priority because this is the last reach before outlet and has good floodplain connectivity and sinuosity. Feasibility depends on land ownership (one parcel associated with the farm covers the entire reach), cost of land acquisition and extent of wetlands. Some wetlands mid-reach may preclude development, making conservation more feasible.	Attenuation of fine sediment will further protect WQ in Winooski River and Lake. Protection of fish refugia for salmonids seeking cooler tributary waters during late summer months.	Town of Williston; WNRCD; VLT
M01-2, C, III, Fair/Fair	See above general reach description. The lower half of the reach lacks a woody vegetative buffer due to historic agricultural use and vigorous herbs (*Phalaris spp, Solidago, spp.*).	Plant buffer (4) with native woody vegetation in the middle and lower reach. Detailed site mapping is provided in Figure 11.	High priority because of 1) high lateral channel migration, and 2) adequate vertical stability of reach. Relatively low cost for native plant materials and labor.	Improved biotic habitat and increased shading. Reduced erosion risks, especially in lower reach around main road crossing.	Town of Williston; WNRCD; VYCC
M01-3, C, III, Fair/Fair	See above general reach description. Two channel constrictions (bridges) in reach. Constrictions are 73% (River Rd) and 71% (path) of bankfull channel width. Mid-channel deposition present in vicinity of upper crossing.	Replace bridges (26) with appropriately sized structures. Follow new RMP guidelines to accommodate 100% of equilibrium channel width.	Lower crossing at River Road is protected against adjustments with bank armoring. This replacement is lower priority, however long-term planning should consider structure replacement. Upper crossing (recreational path) may be non-essential, and is causing channel adjustments. Replacement	Improved biotic habitat and fish migration. Reduced flood/erosion risks.	Town of Williston; VTRANS

Reach/Project, Stream Type, CEM†, RGA/RHA†	Site Description and Importance, Including Stressors and Constraints	Project/Strategy Description - Stepwise Number (#)	Priority, Technical Feasibility & Relative Costs	Other Social Benefits	Potential Partners
			or removal is higher priority depending on landowner willingness and feasibility.		
M02-1, C, III, Fair/Fair	Numerous mass failures are causing aggradation, leading to debris jams and flood chutes (2 noted). High number of stormwater inputs (7 in reach) also causing oscillating areas of incision and aggradation. Two areas of reach are controlled by bedrock in the upper section of the reach, with the higher degree of adjustment occurring below these areas (below Industrial Ave.)	Lower priority stream corridor protection (3). Develop conservation easements for parcels on lower section of reach where lower sloped land adjacent stream channel could face development pressure in future.	Corridor protection for this reach is lower priority for 2 reasons: 1) adjacent residential/commercial development extends only to the corridor boundary (not within) for most of reach, due to high slope of valley side walls; 2) due to channel slope approaching 2%, this reach has some sediment transport capacity, and may not play significant role in watershed-wide sediment attenuation.	Attenuation of fine sediment will further protect WQ in Winooski River and Lake. Protection of fish refugia for salmonids seeking cooler tributary waters during late summer months (below large grade controls in upper reach).	Town of Williston; WNRCD; VLT
M03-A-1, C, III, Fair/Good	Reach undergoing adjustments dominated by incision (IR=1.4) and bank failure. Widening and active flood chutes (2) in areas where aggradation is beginning to occur. High degree of stormwater inputs and local wetland loss.	Medium priority stream corridor protection (3). Develop conservation easements for parcels on west bank parcels in middle and upper segment where adjacent land could face development pressure in future. Upper third of segment (right bank) corridor is conserved.	Corridor protection for this reach is a higher priority than the Reach M02 for 2 reasons: 1) due to lower channel slope (<1%), this reach will play a significant role in watershed-wide sediment attenuation; 2) Upstream segments are going through degradational processes that will export sediment to this segment (last significant attenuation area before Reach M01).	Attenuation of fine sediment will further protect WQ in Winooski River and Lake.	Town of Williston; WNRCD; VLT

Reach/Project, Stream Type, CEM†, RGA/RHA†	Site Description and Importance, Including Stressors and Constraints	Project/Strategy Description - Stepwise Number (#)	Priority, Technical Feasibility & Relative Costs	Other Social Benefits	Potential Partners
M03-B-1, C, II, Fair/Fair	Very high residential development in reachshed. Fringe of stream corridor developed throughout, resulting in very high concentration of stormwater inputs. Only minor aggradation observed, suggesting nascent channel evolution/incisional processes.	Plant stream buffer (4) in 2 areas of segment: 1) downstream of north Talcott Rd crossing where ~500’ of channel banks are unvegetated; 2) downstream of south Talcott Rd crossing where ~800’ of channel banks are unvegetated;	Medium priority because of beaver activity in the area. Native alder shrubs and other woody trees may be limited due to beavers and abundance of reed canary grass. Relatively low cost for native plant materials and labor.	Improved biotic habitat and increased shading. Potential for reduced erosion risks, especially around road crossings.	Town of Williston; WNRCD; VYCC
M03-B-2, C, II, Fair/Fair	See above general segment description. Two culvert crossings in reach (both Talcott Road) are undersized. North and south crossings are 40% and 53% of bankfull channel width. Scour noted below north crossing, and lateral adjustments (neck cutoff) noted below south crossing.	Replace culverts with appropriately sized structures (24). Follow new RMP guidelines to accommodate 100% of equilibrium channel width.	Medium priority due to potential continued erosion around road. Relatively high cost due to road fill, etc. Long-term planning should consider replacement of both structures in event of continued long-term moderate erosion, or catastrophic erosion.	Improved biotic habitat and fish migration. Reduced flood/erosion risks. Improvement of channel incision in downstream area.	Town of Williston; VTDEC; VTRANS
M03-C-1, C, II, Poor/Fair	Incision is leading to entrenchment and loss of floodplain access in lower section of the segment, where stream type is close to G-type geometry. C-type geometry dominates most of segment.	High priority stream corridor protection (3). Develop conservation easements for parcels on lower and middle segment, on the left bank. Ideally completed	High priority because this segment is undergoing highly active adjustment, and represents a significant sediment attenuation asset into the future. A large portion of the corridor (lower both banks; upper right	Attenuation of fine sediment will further protect WQ in Winooski River and Lake. DEC biotic sampling in lower reach may continue	Town of Williston; WNRCD; VLT

Reach/Project, Stream Type, CEM†, RGA/RHA†	Site Description and Importance, Including Stressors and Constraints	Project/Strategy Description - Stepwise Number (#)	Priority, Technical Feasibility & Relative Costs	Other Social Benefits	Potential Partners
	A second cross-section taken in the lower segment indicates higher degree of incision (IR=1.3) with a low entrenchment ratio (ER~1.3), where G-type geometry is more prevalent. Similar geometry noted below Southridge Rd crossing.	in conjunction with buffer planting project described below. Detailed site mapping is provided in Figure 12.	bank) is protected from development (Figure 10). Further protection feasibility depends on land ownership (2 parcels), cost of land acquisition and extent of wetlands. Some wetlands mid-reach may preclude development, making conservation more feasible.	to indicate impaired biota due to sediment exported downstream from this segment. Improvement of channel adjustments segment will aid habitat downstream.	
M03-C-2, C, II, Poor/Fair	See above general segment description. Significantly reduced boundary resistance due to limited woody vegetation is leading to increased lateral migration and sediment export.	Plant buffers (4) in middle-lower segment where no woody vegetation exists on either side, and in upper segment on left bank where there is limited woody vegetation. Detailed site mapping is provided in Figure 12.	Medium to high priority given lack of beaver activity and protected status of significant portions of corridor (see Figure 10). Further determination of historical beaver activity should be researched during project planning. Relatively low cost for native plant materials and labor.	Improved biotic habitat and increased shading. Potential for reduced erosion risks, especially around road crossings.	Town of Williston; WNRCD; VYCC
M03-D-1, C, II, Fair/Fair	Significant aggradation and lateral migration occurring in segment. Multiple mass failures, and channel migration features suggest stage III of channel evolution. Segment has higher slope (~2%) than downstream segments, resulting in sediment transport processes.	Protect stream corridor (3) where it is not currently protected.	Low priority corridor protection for this segment due to the following: 1) steep valley side slopes preclude development encroaching on channel, 2) lower corridor already protected on right bank (see Figure 10), 3) segment has little sediment attenuation capacity due to high slope.	Habitat that supports good biotic community would be protected from degradation.	Town of Williston; WNRCD; VLT

Reach/Project, Stream Type, CEM[†], RGA/RHA[†]	Site Description and Importance, Including Stressors and Constraints	Project/Strategy Description - Stepwise Number (#)	Priority, Technical Feasibility & Relative Costs	Other Social Benefits	Potential Partners
M04-A-1, F, II, Fair/Fair	Stream type departure noted from C to F-type geometry due to straightening, incision, and bank armoring mid-segment. Some areas of reduced bank vegetation in lower segment have reduced boundary resistance.	Plant stream buffer (4) in areas above Old Stage Rd where bank vegetation is lacking. See additional site details in Figure 13.	Medium to high priority given lack of beaver activity and noted channel incision due to reduced boundary resistance. Plantings may be at risk to ongoing channel adjustments and these should be considered for siting and tree selection. Implementation depends on landowner interest. Relatively low cost for native plant materials and labor.	Improved biotic habitat and increased shading. Potential for reduced erosion risks, especially upstream of Old Stage Rd crossing where mass failure and erosion was noted.	Town of Williston; WNRCD; VYCC
M04-A-2, F, II, Fair/Fair	See above general segment description. Old Stage Rd culvert width (12' CMP) is only 40% of equilibrium channel width, causing aggradation, erosion, and slope failure above the structure. A large plunge pool is found at the outlet.	Replace culvert with appropriately sized structure (26). Follow new RMP guidelines to accommodate 100% of equilibrium channel width. See additional site details in Figure 13.	Medium priority due to potential continued erosion upstream of crossing. Relatively high cost due to road fill, etc. Long-term planning should consider replacement of both structures in event of continued long-term moderate erosion, or catastrophic erosion.	Improved biotic habitat and fish migration. Reduced flood/erosion risks. Improvement of aggradation and bank erosion in upstream area.	Town of Williston; VTDEC; VTRANS
M04-A-3, F, II, Fair/Fair	Stream type departure C to F due to straightening, incision, and bank armoring mid-segment. Channel slope (~1.8%) is borderline for depositional/transport reach.	Restore incised reach (34) and pursue high priority stream corridor protection in downstream segments. See additional site details in Figure 13.	Investigate whether active restoration of bedforms and floodplain features in equilibrium with increased stream power is feasible mid-segment. Significant bank armoring exists on the right bank, preventing a meandering planform. Very high costs due to earthwork, property issues, etc.	Improved biotic habitat and fish migration. Reduced flood/erosion risks. Improvement of erosion downstream by Old Stage Rd crossing is sediment attenuation is	Town of Williston; VTDEC; WNRCD

Reach/Project, Stream Type, CEM†, RGA/RHA†	Site Description and Importance, Including Stressors and Constraints	Project/Strategy Description - Stepwise Number (#)	Priority, Technical Feasibility & Relative Costs	Other Social Benefits	Potential Partners
				increased upstream.	
M05-B-1, C, III, Fair/Fair	Extensive bank erosion throughout, with one avulsion and multiple flood chutes above Rt 2. This suggests planform changes are dominating where slope lessens from above reach (M06) and is constricted through I-89 culvert. See Figure 14 for detailed site mapping of this reach.	High priority stream corridor protection (3). In areas where corridor is not developed, pursue conservation easements for parcels in upper reach in between Rt. 2 and I-89.	Corridor protection for area in between Rt. 2 and I-89 northbound lane very high priority due to extensive lateral migration. Currently no development is located in corridor, however flat land appears suitable for future development. Protection feasibility depends on land ownership (3 parcels cover corridor area), cost of land acquisition and extent of wetlands.	Important sediment attenuation reach due to location above Williston village and infrastructure downstream. Improved downstream habitat and water quality would result from corridor protection.	Town of Williston; VTDEC; WNRCD; VLT
M05-B-2, C, III, Fair/Fair	See above general segment description. Some areas of segment have reduced riparian vegetation, leading to decreased boundary resistance and high bank erosion.	Plant stream buffers (4) in vicinity of Rt. 2 crossing. Stream boundaries lack native woody vegetation above and below crossing for ~300’ on both sides.	Medium to high priority given lack of beaver activity and noted bank erosion due to reduced boundary resistance. Implementation depends on landowner interest. Relatively low cost for native plant materials and labor.	Improved biotic habitat and increased shading. Potential for reduced erosion risks, especially around Rt. 2 crossing.	Town of Williston; WNRCD; VYCC
M06-1, B, I, Good/Good	High-gradient reach with high bank erosion and depositional and migration features. These features likely natural due to LWD loading and colluvial inputs. Channel well buffered by intact forest. Good channel stability and habitat noted in	Protect stream corridor (3) in areas where it is not already protected. Middle and lower reach may be protected on right corridor, but left side of corridor remains unprotected. Develop	Lower priority corridor protection area because: 1) reach is dominated by sediment transport processes, with little attenuation potential; 2) steep side slopes will likely limit development in corridor; 3) corridor is protected in upper reach, and may have further	Maintained forest corridor would provide protection to above average biotic habitat observed in reach.	Town of Williston; WNRCD; VLT

Reach/Project, Stream Type, CEM[†], RGA/RHA[†]	Site Description and Importance, Including Stressors and Constraints	Project/Strategy Description - Stepwise Number (#)	Priority, Technical Feasibility & Relative Costs	Other Social Benefits	Potential Partners
	middle and upper reach.	conservation easements for parcels along left corridor.	protection due to large conserved parcel to the east (see Figure 10).		
M06-2, B, I, Good/Good	See above general reach description. Culvert crossings beneath both I-89 lanes are undersized (50-60% of current bankfull channel width). This may be causing channel adjustments upstream (mass failure) and downstream (high degrees of planform change noted in segment M05-B.	Replace culverts with appropriately sized structures (26). Follow new RMP guidelines to accommodate 100% of equilibrium channel width.	Low priority due to very high costs associated with culvert replacement, and limited aggradation observed upstream of structures. However, long-term planning should consider replacement of both structures in event of continued long-term moderate erosion, or catastrophic erosion.	Improved biotic habitat and fish migration. Reduced flood/erosion risks.	Town of Williston; VTDEC; VTRANS
M07-1, E, II, Fair/Fair	Reference condition likely C-type channel geometry, which has been altered due to historic straightening and possible berming in upper reach. Current channel geometry is an E-type stream with lower than expected width to depth ratio (7.0). One small headcut noted mid reach. Lack of buffer impacts lower reach.	Plant stream buffer (4), and install fencing to exclude grazing animals from stream channel in lower reach. Project would encompass ~1500 linear feet of channel. See Figure 15 for detailed mapping of the site.	Note that corridor protection not suggested for reach due to current protection status (see Figure 10). Medium to high priority given protected status, and potential to further improve habitat conditions of reach. Relatively low cost for native plant materials and labor.	Improved biotic habitat and increased shading. Reduced inputs of bacteria and nutrients originating from cattle.	Town of Williston; WNRCD; VYCC
M10-A-1, C, IIb,	Plane-bed, cobble-bottomed reach (slope ~ 2.5%) exhibits aggradation and planform	Protect stream corridor (3). Develop conservation easements	Lower priority corridor protection area because: 1) reach is dominated by sediment transport	Maintained forest corridor would provide protection to	Town of Williston; WNRCD;

Reach/Project, Stream Type, CEM†, RGA/RHA†	Site Description and Importance, Including Stressors and Constraints	Project/Strategy Description - Stepwise Number (#)	Priority, Technical Feasibility & Relative Costs	Other Social Benefits	Potential Partners
Fair/Fair	changes, with a high degree of bank erosion and channel migration features noted. It is unclear what is the source of sediment, or whether legacy sediments from upslope segment (with beaver activity) influence segment.	for parcels throughout corridor.	processes, with little attenuation potential; 2) steep side slopes will likely limit development in corridor.	biotic habitat.	VLT
M11-1, F, II, Fair/Fair	Reach underwent extensive historical straightening and berming throughout farm fields, especially in the lower part of the reach east of Oak Hill Rd. F-type channel geometry found in lower reach, reflecting the high degree disconnectivity from floodplain.	Protect stream corridor (3). Develop conservation easements for parcels throughout corridor. Note that due to small channel size active channel restoration is not appropriate for site.	Low priority corridor protection area because small headwaters reach lacks stream power and sediment supply to adjust laterally over time. Most appropriate restoration approach in this setting is stream buffer plantings (see below).	Corridor protection would prevent development from encroaching on channel as to limit recovery of streamside vegetation.	Town of Williston; WNRCD; VLT
M11-1, F, II, Fair/Fair	See above general reach description. Native woody vegetation lacking in buffer for entire reach, leading to increased stream temperatures, negatively affecting biota.	Plant stream buffers (4) throughout entire reach with native woody vegetation.	Medium to high priority due to extensive area without buffer vegetation, resulting in elevated stream temperatures. Relatively low cost for native plant materials and labor.	Improved biotic habitat and increased shading. Possibly reduced inputs of bacteria and nutrients originating from cattle.	Town of Williston; WNRCD; VYCC

† Channel evolution stage, Rapid Geomorphic Assessment, and Rapid Habitat Assessment Scores.

4.0 Prioritized Projects

The following is a list of 12 restoration projects identified in Section 3.0. All of the site-specific projects are considered high or medium priority (as indicated) and are recommended to be evaluated by VTDEC for possible implementation. The site level list is divided into two groups: 1) projects which *do not require* further study for VTDEC to pursue implementation, and are generally "passive" by nature (i.e., conservation based); 2) projects which *will require* further study prior to implementation. Only limited additional study may be needed for buffer plantings (e.g., general buffer planting plans). Details for site level projects (listed below by reach and project number), and rationale for the prioritization can be referenced in Table 6.

4.1 Projects Ready to Pursue Implementation (Passive Restoration)

1. M01-1: Develop conservation easements for parcels on lower and middle reach. Ideally completed in conjunction with buffer planting project described in project M01-2. Detailed site mapping is provided in Figure 11 (high priority).

2. M02-1: Develop conservation easements for parcels on lower section of reach where lower sloped land adjacent stream channel could face development pressure in future (medium priority).

3. M03-A-1: Develop conservation easements for parcels on west bank parcels in middle and upper segment where adjacent land could face development pressure in future (medium priority).

4. M03-C-1: Develop conservation easements for parcels on lower and middle segment, on the left bank. Ideally completed in conjunction with buffer planting project described in project M03-C-2. Detailed site mapping is provided in Figure 12 (high priority).

5. M05-B-1: In areas where corridor is not developed, pursue conservation easements for parcels in upper reach in between Route 2 and I-89 (high priority).

4.2 Projects Requiring Further Study (Active Restoration)

1. M01-2: Plant buffer with native woody vegetation in the middle and lower reach. Detailed site mapping is provided in Figure 11 (high priority).

2. M01-3: Replace bridges with appropriately sized structures. Follow new RMP guidelines to accommodate 100% of equilibrium channel width. Detailed site mapping is provided in Figure 11 (medium priority).

3. M03-C-2: Plant buffers in middle-lower segment where no woody vegetation exists on either side, and in upper segment on left bank where there is limited woody vegetation. Detailed site mapping is provided in Figure 12. Note that other active restoration approaches for this segment, such as restoration of channel geometry, are discouraged in the short term due to the current state of channel adjustment (high incision; stage II CEM; medium priority).

4. M04-A-1: Plant stream buffer in areas above Old Stage Rd where bank vegetation is lacking. See additional site details in Figure 13 (medium priority).

5. M04-A-2: Investigate feasibility of active channel restoration of bedforms and floodplain features in upper segment. See Figure 13 for detailed site mapping and further explanation (medium priority).

6. M05-B-2: Plant stream buffers in vicinity of Route 2 crossing. Stream boundaries lack native woody vegetation above and below crossing for ~300' on both sides. See Figure 14 for detailed site mapping (medium priority).

7. M07-1: Plant stream buffer, and install fencing to exclude grazing animals from stream channel in lower reach. See Figure 15 for detailed site mapping (high priority).

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Williston Town, 2008, GIS layer of conserved lands in the Allen Brook watershed, provided by Carrie Deegan, Environmental Planner

APPENDIX A

WATERSHED AND SITE MAPPING

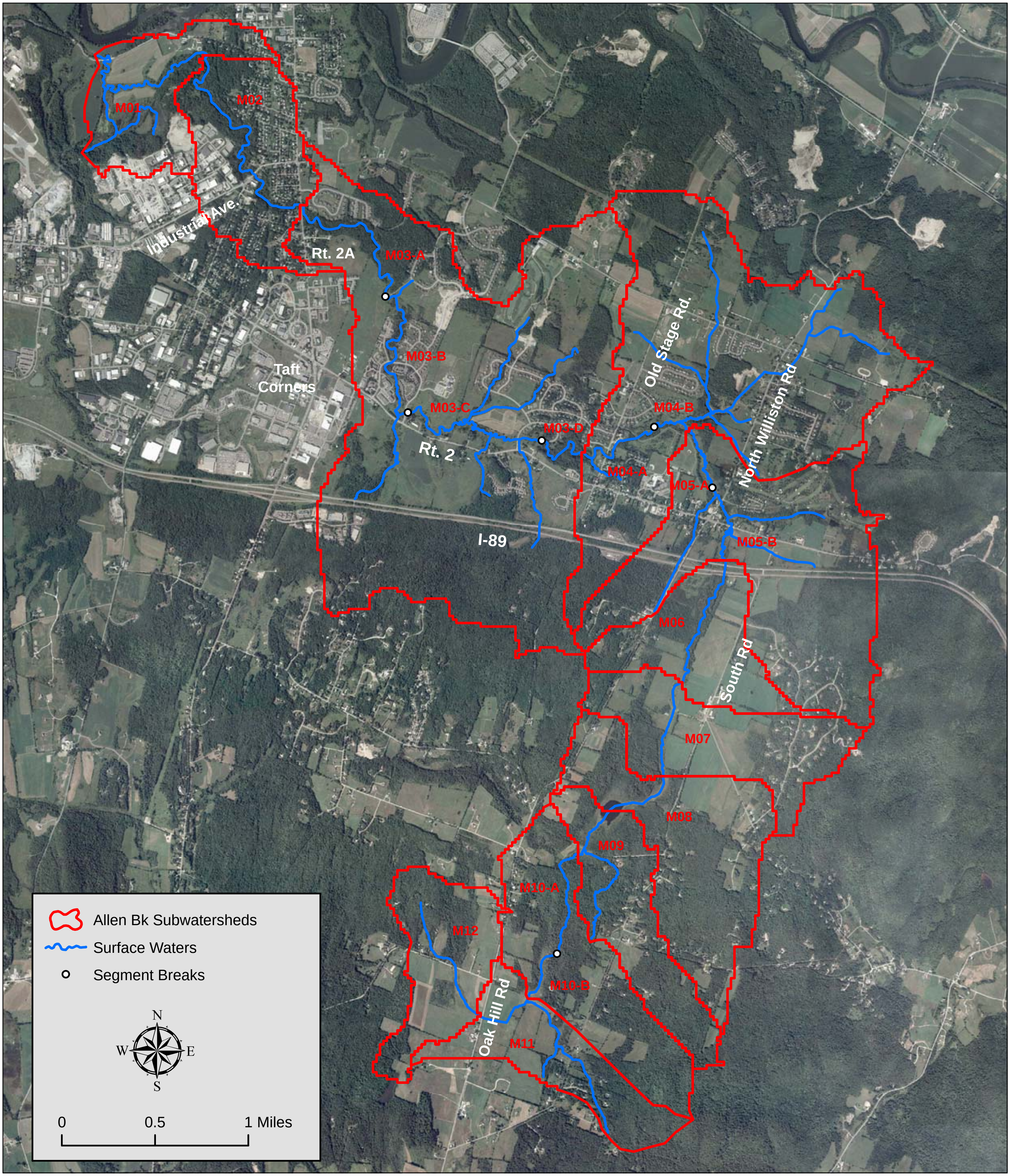

Figure 1
Allen Brook Subwatersheds and Study Reaches

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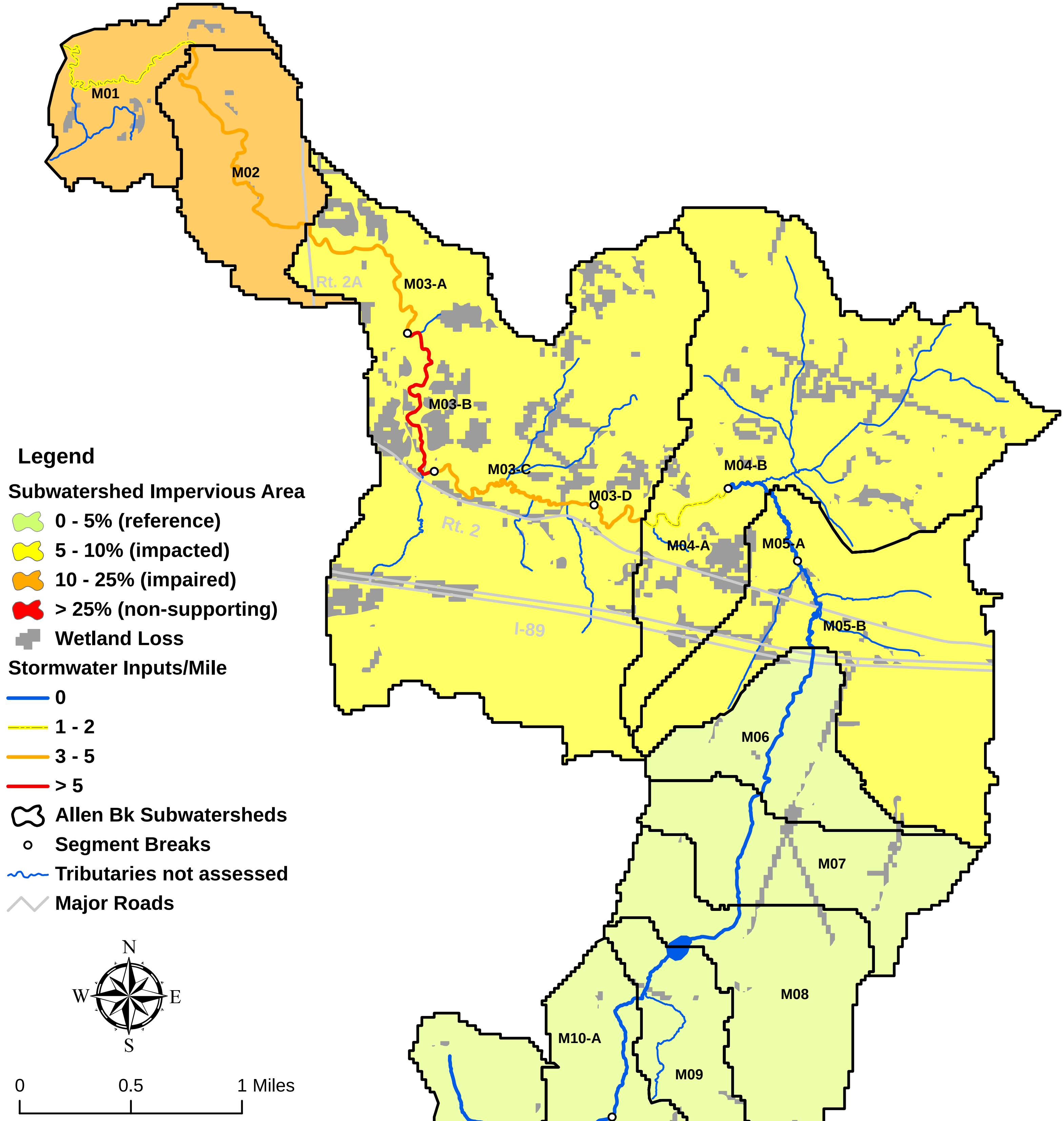

Allen Brook Watershed Hydrologic Regime Stressors

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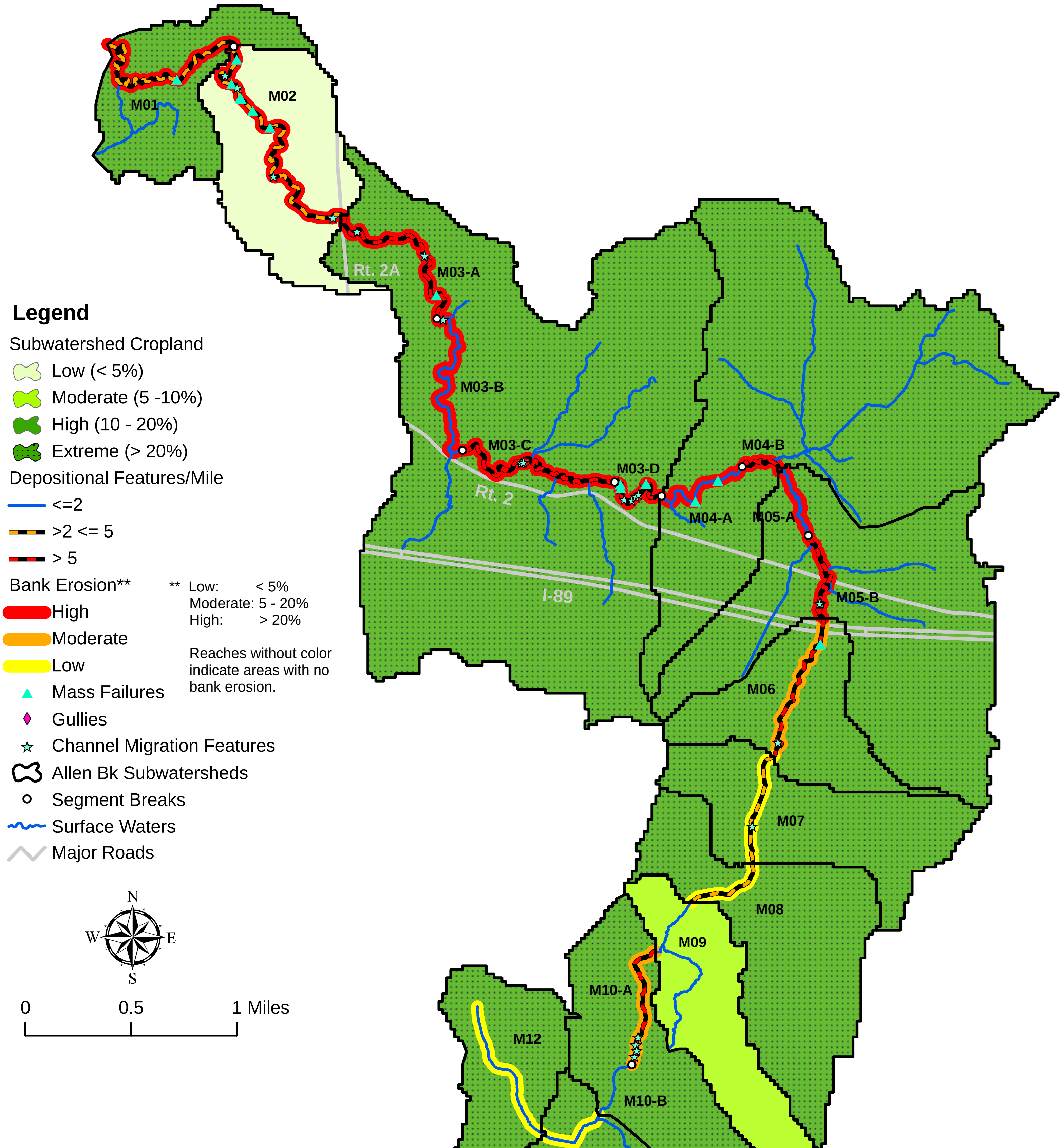
A2 - Figure 2



Allen Brook Watershed Sediment Load Indicators

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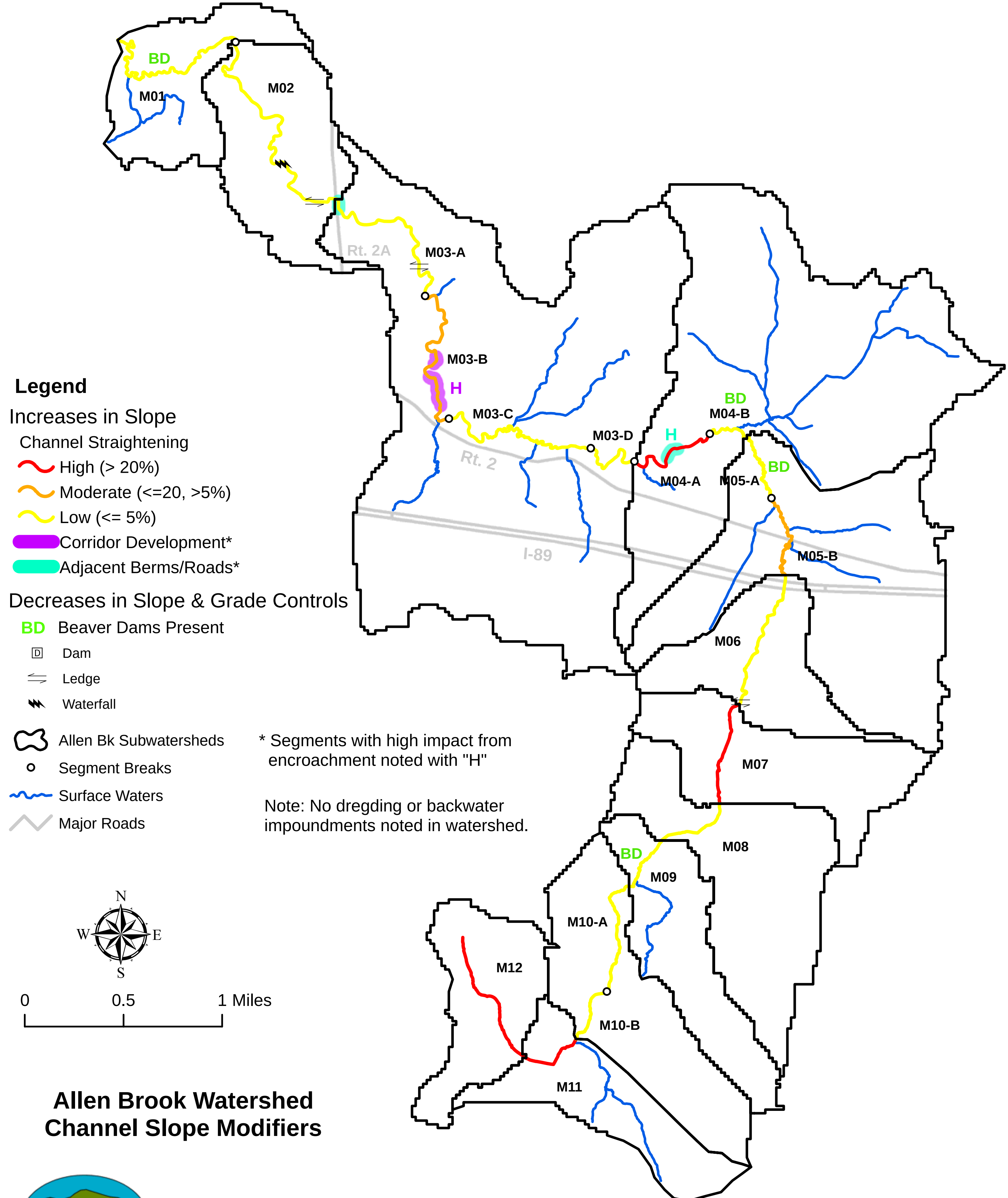
A3 - Figure 3



Allen Brook Watershed Channel Slope Modifiers

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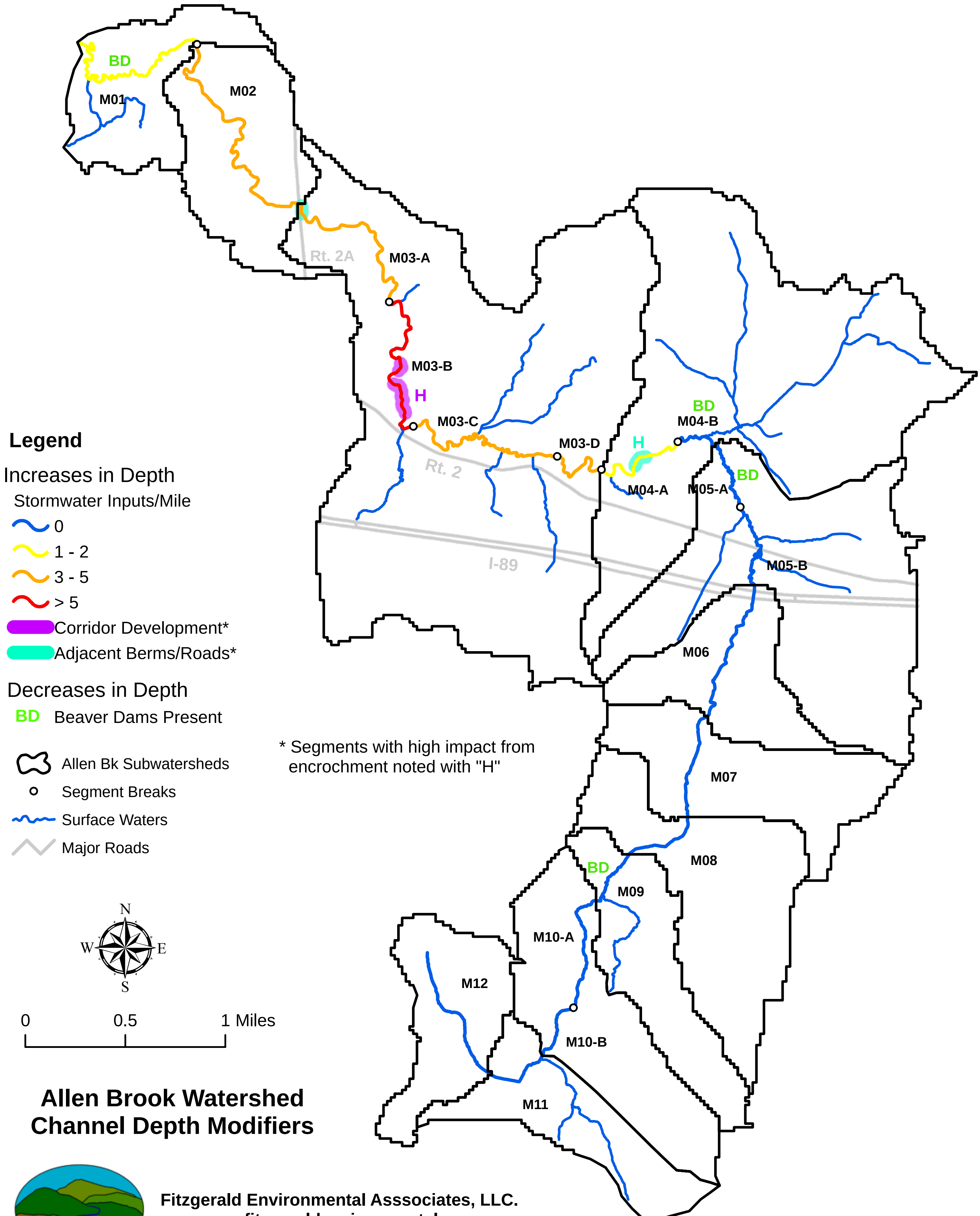
A4 - Figure 4



Allen Brook Watershed
Channel Depth Modifiers

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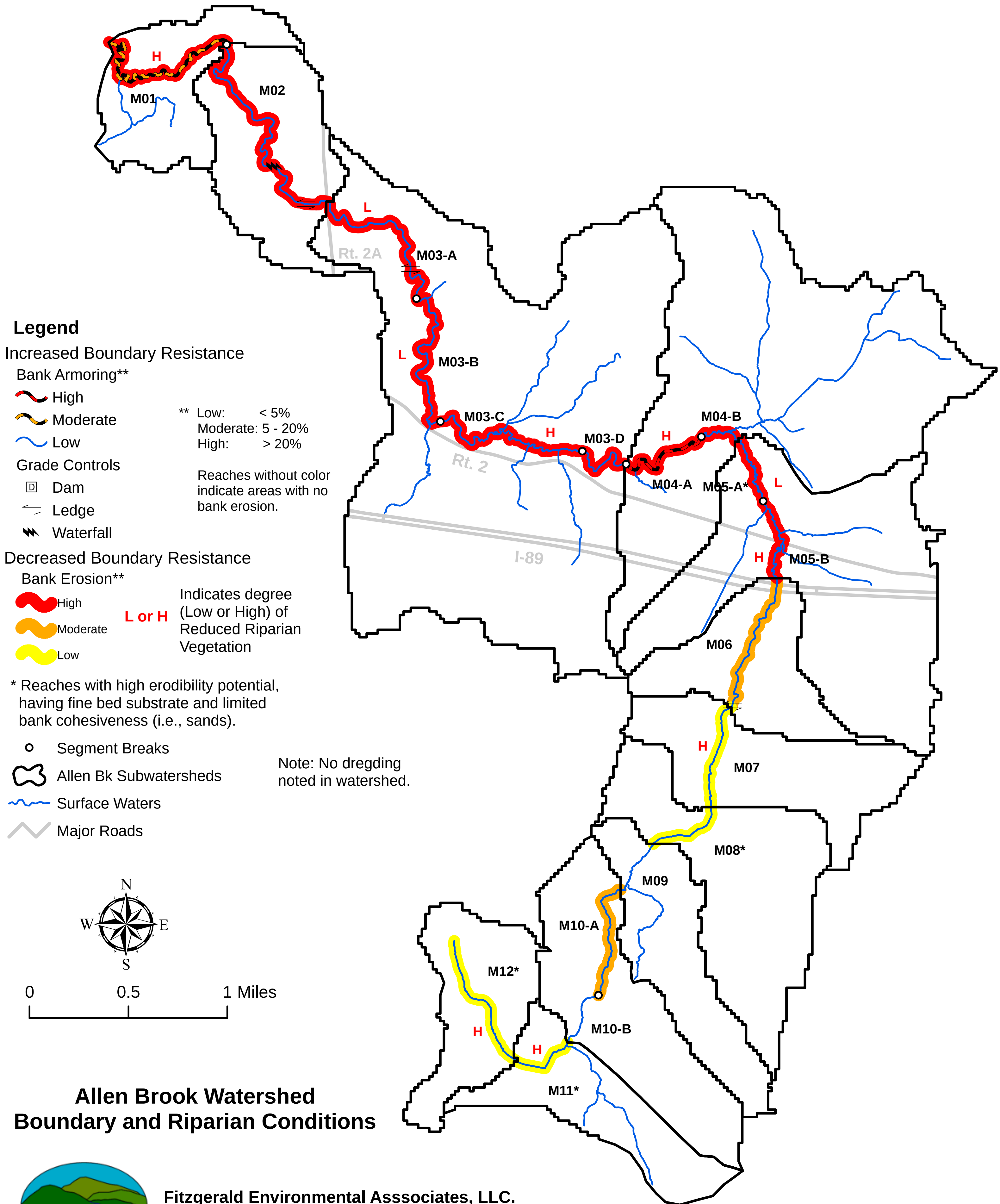
A5 - Figure 5



Allen Brook Watershed
Boundary and Riparian Conditions

Fitzgerald Environmental Asssociates, LLC.
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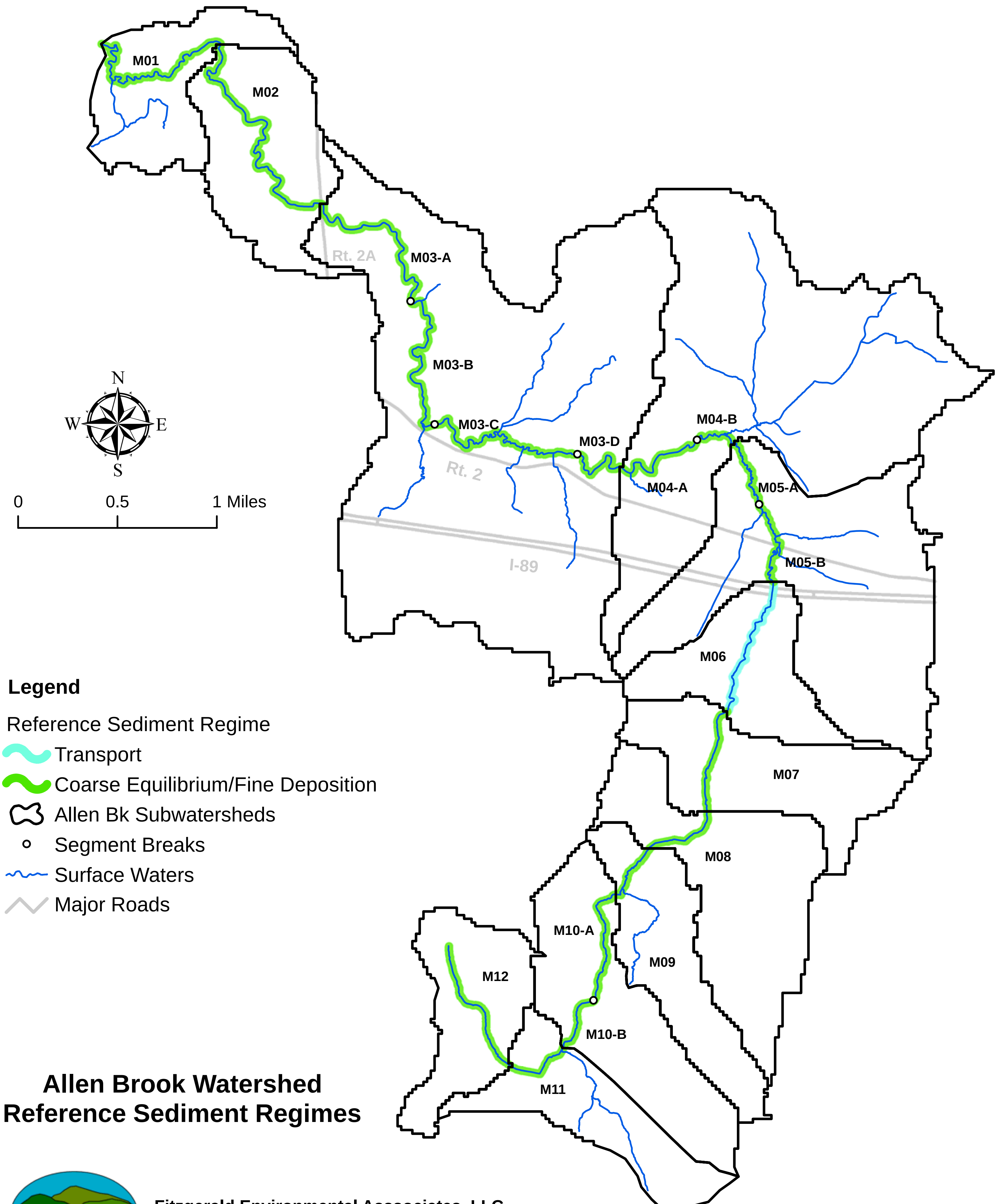
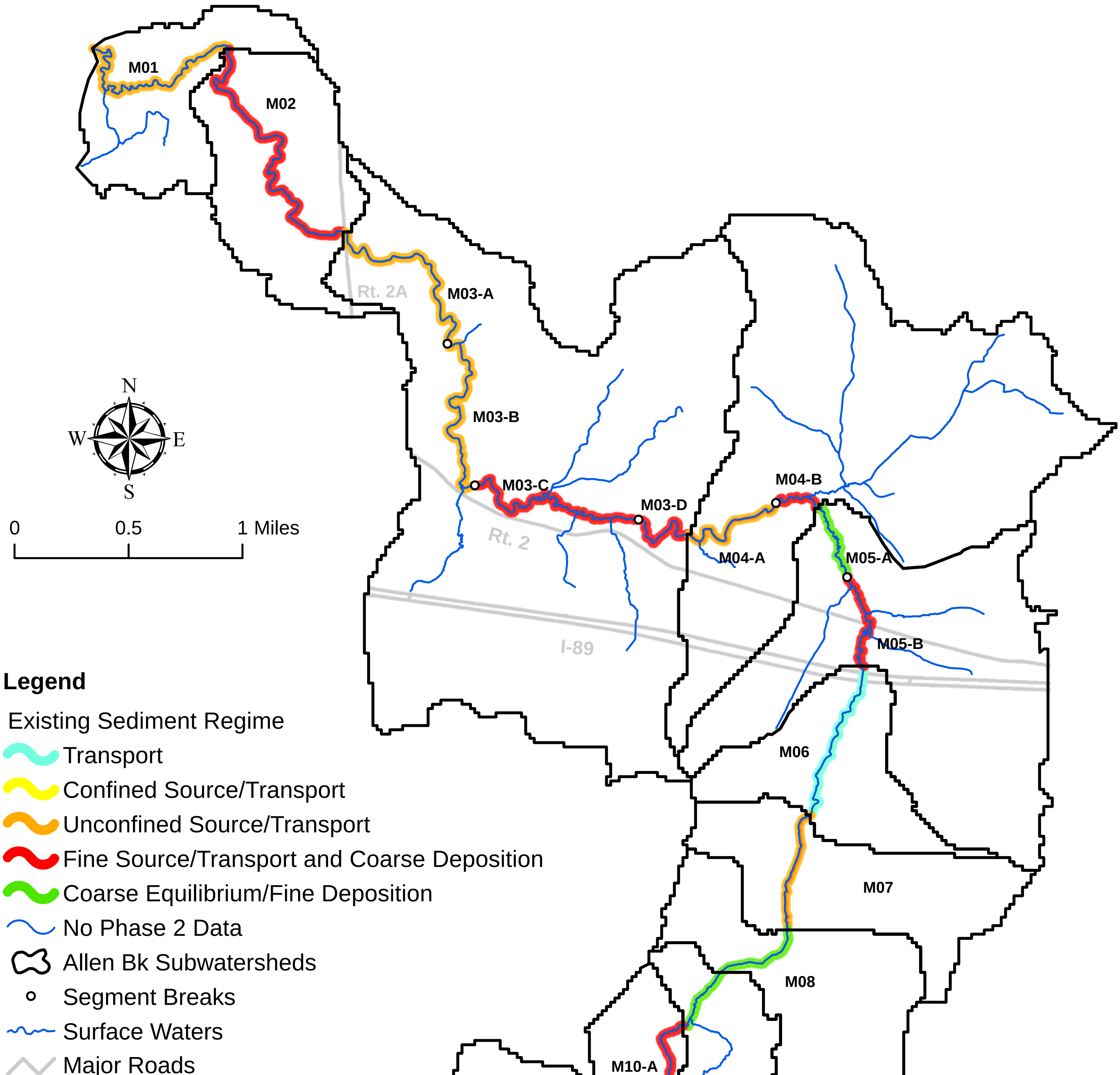


Allen Brook Watershed Reference Sediment Regimes

Fitzgerald Environmental Asssociates, LLC.
www.fitzgeraldenvironmental.com

A7 - Figure 7



Allen Brook Watershed Existing Sediment Regimes

Fitzgerald Environmental Asssociates, LLC.
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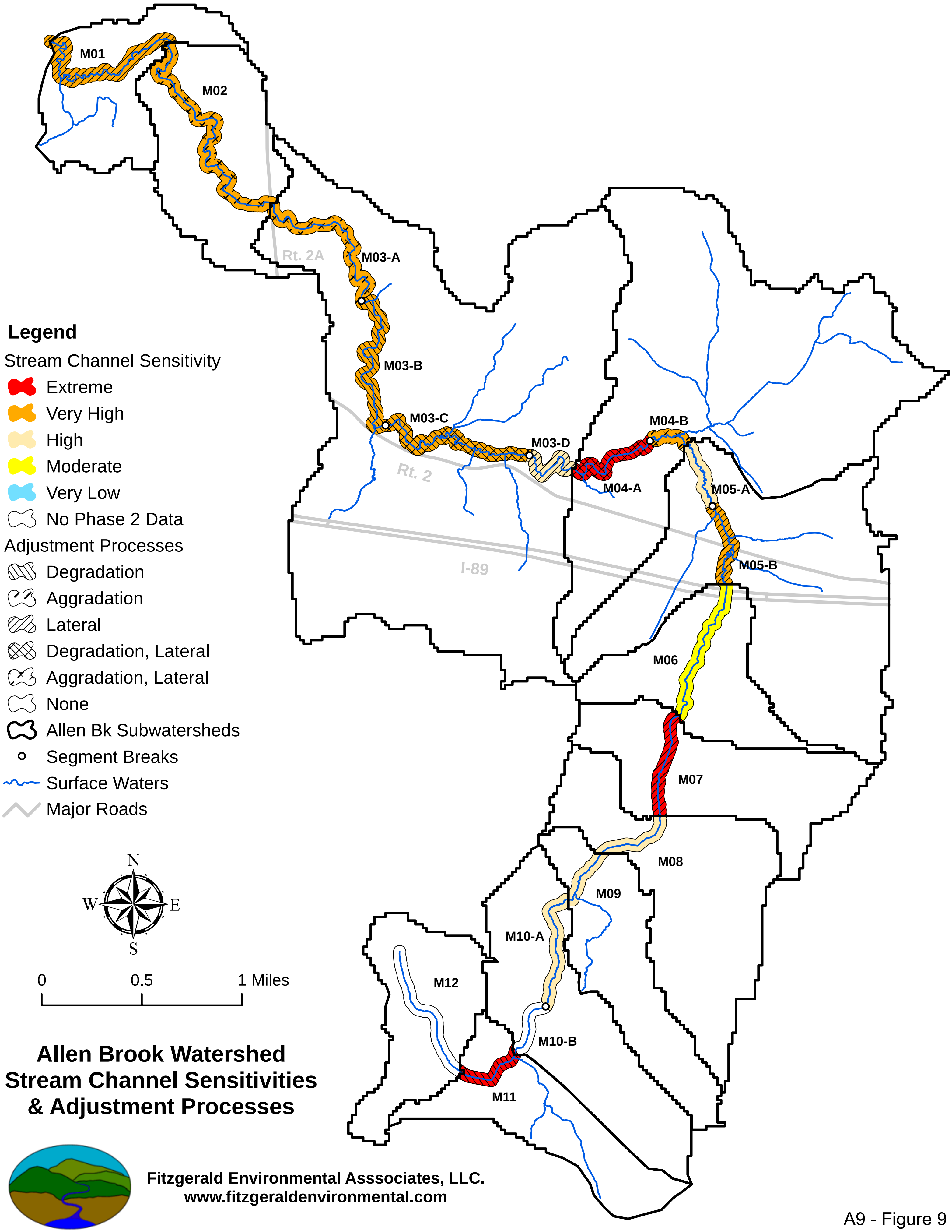

Allen Brook Watershed
Stream Channel Sensitivities
& Adjustment Processes

Fitzgerald Environmental Asssociates, LLC.
www.fitzgeraldenvironmental.com

A9 - Figure 9

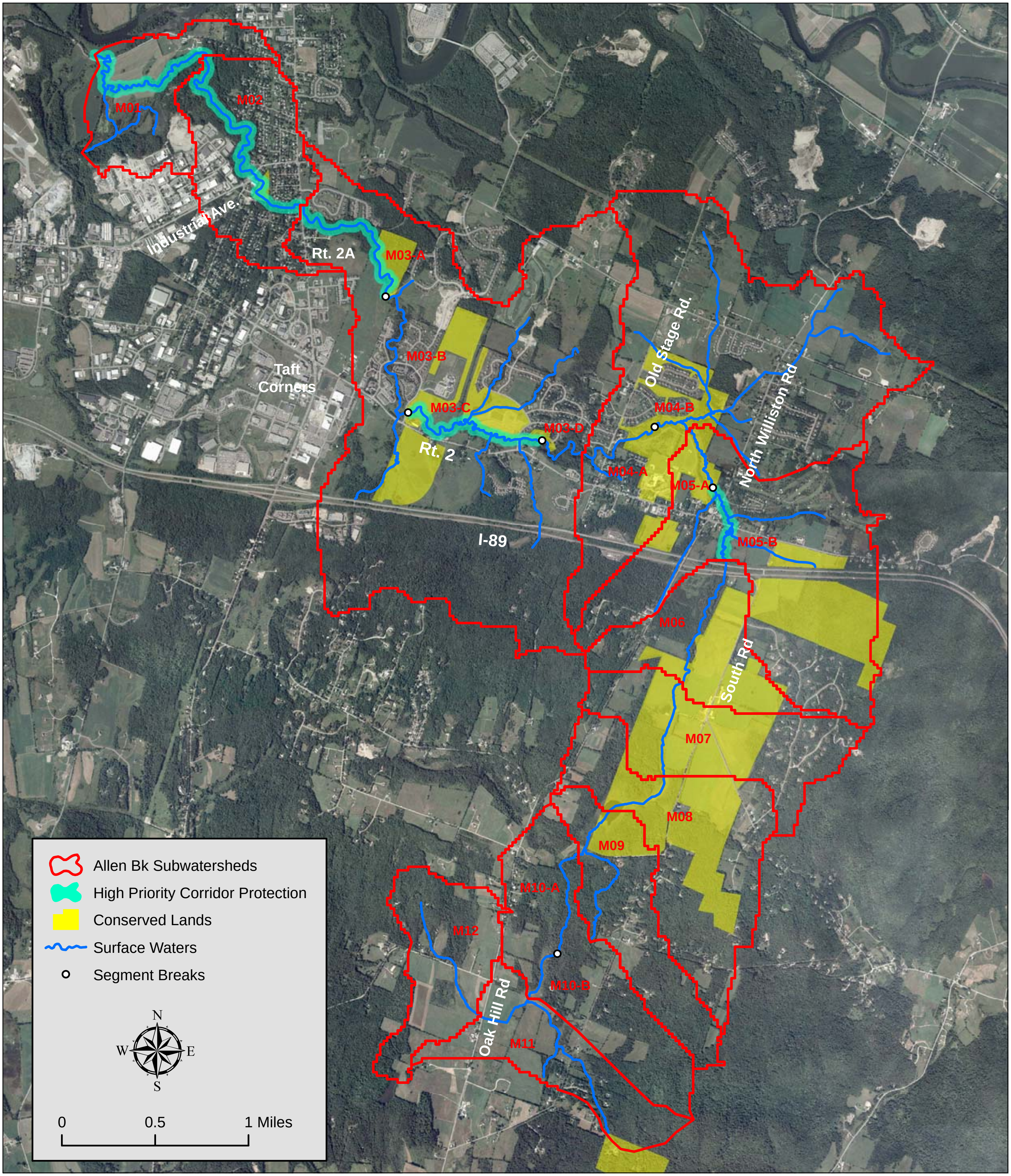

Figure 10
Allen Brook Watershed Conserved Lands and Stream Corridor Protection Sites

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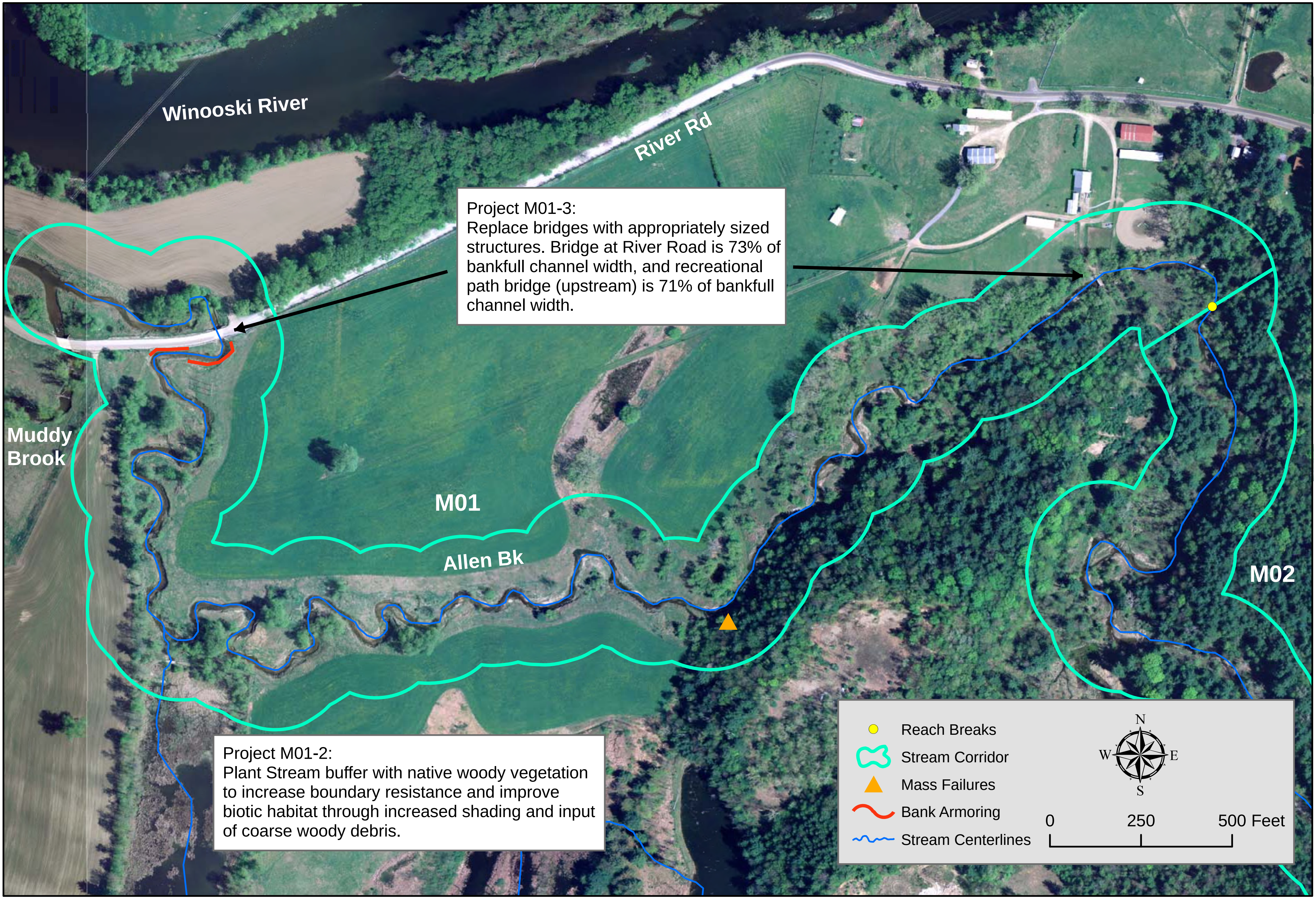

Figure 11
Reach M01 Project Locations

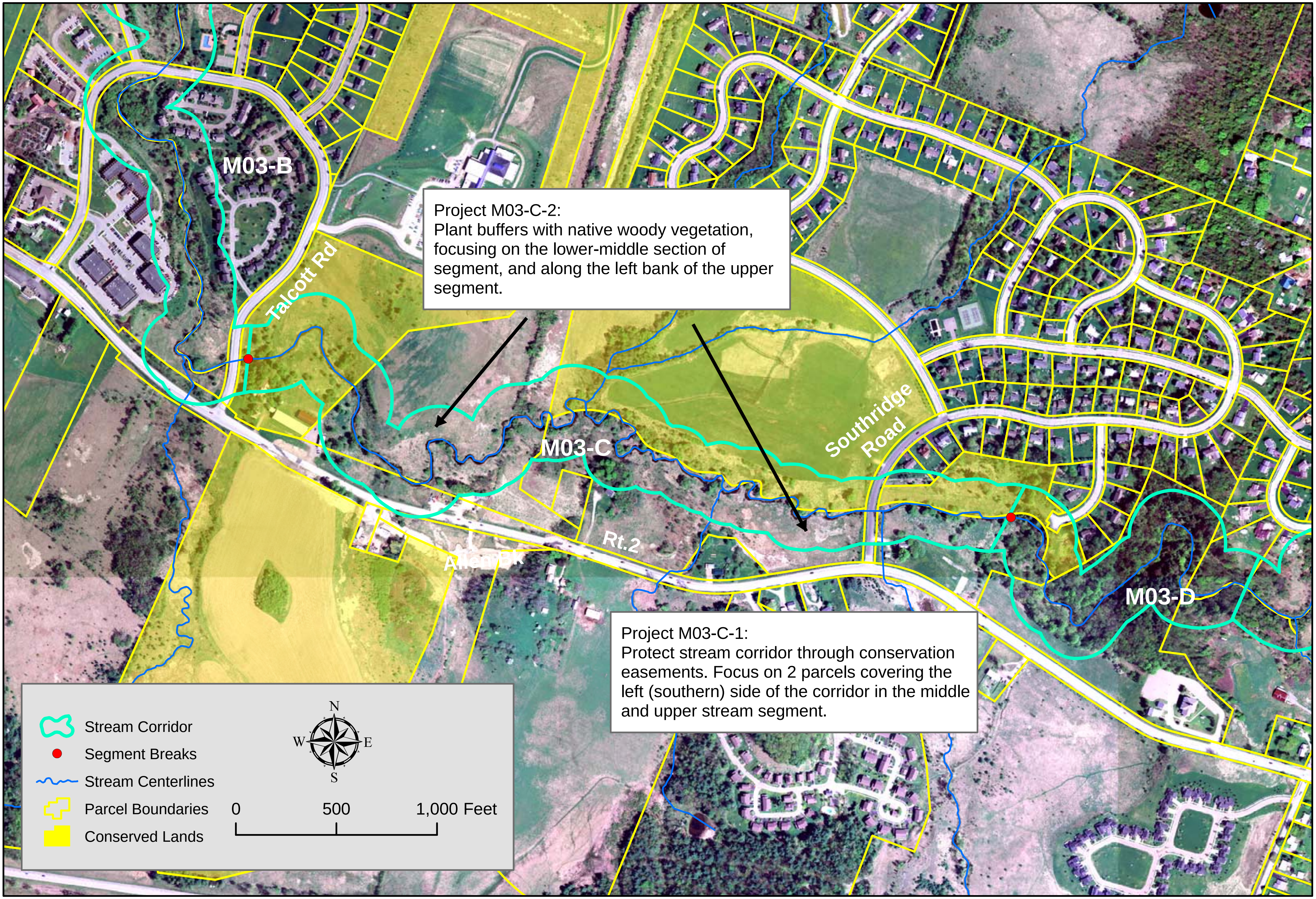

Figure 12
Segment M03-C Project Locations

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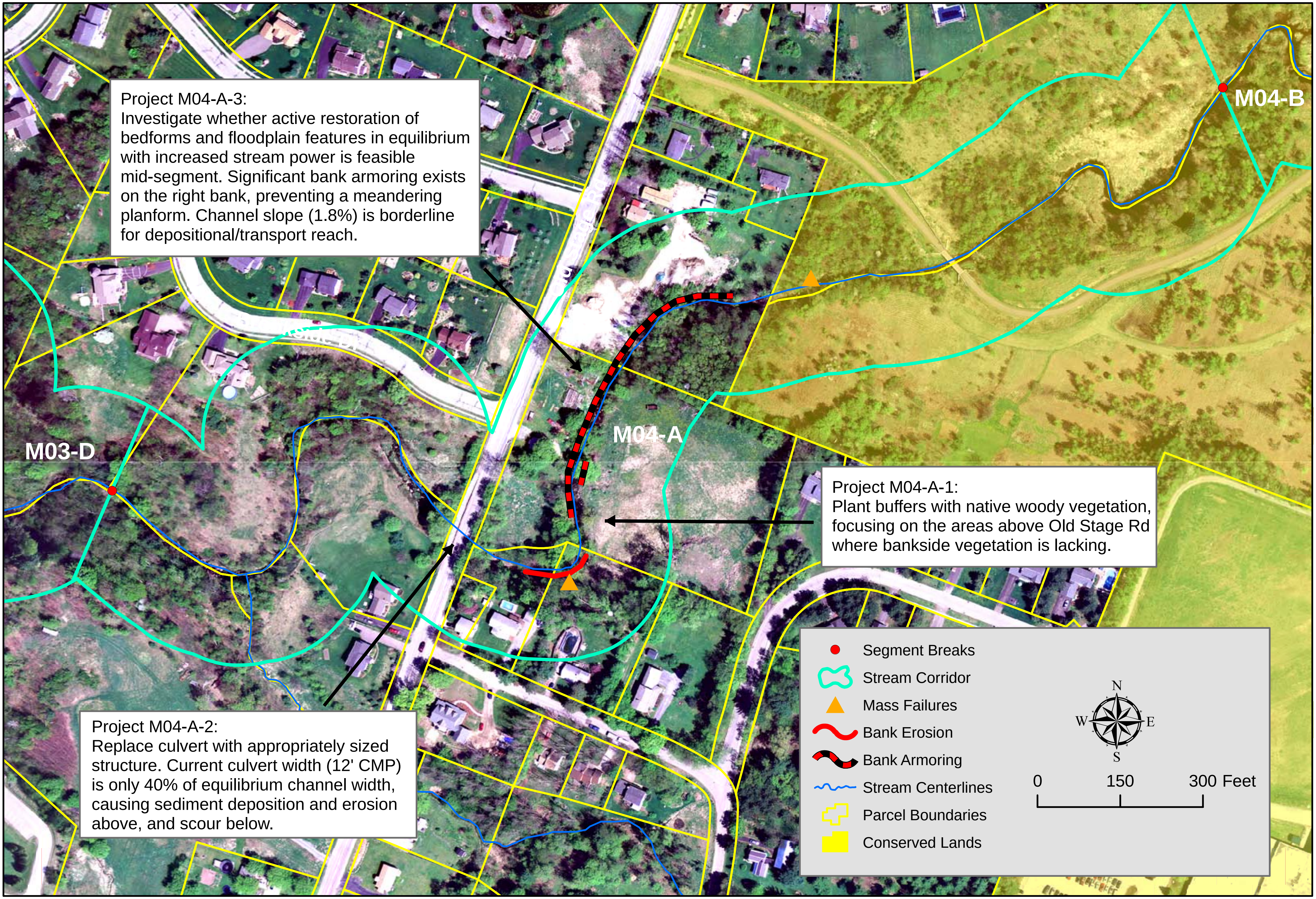

Figure 13
Segment M04-A Project Locations

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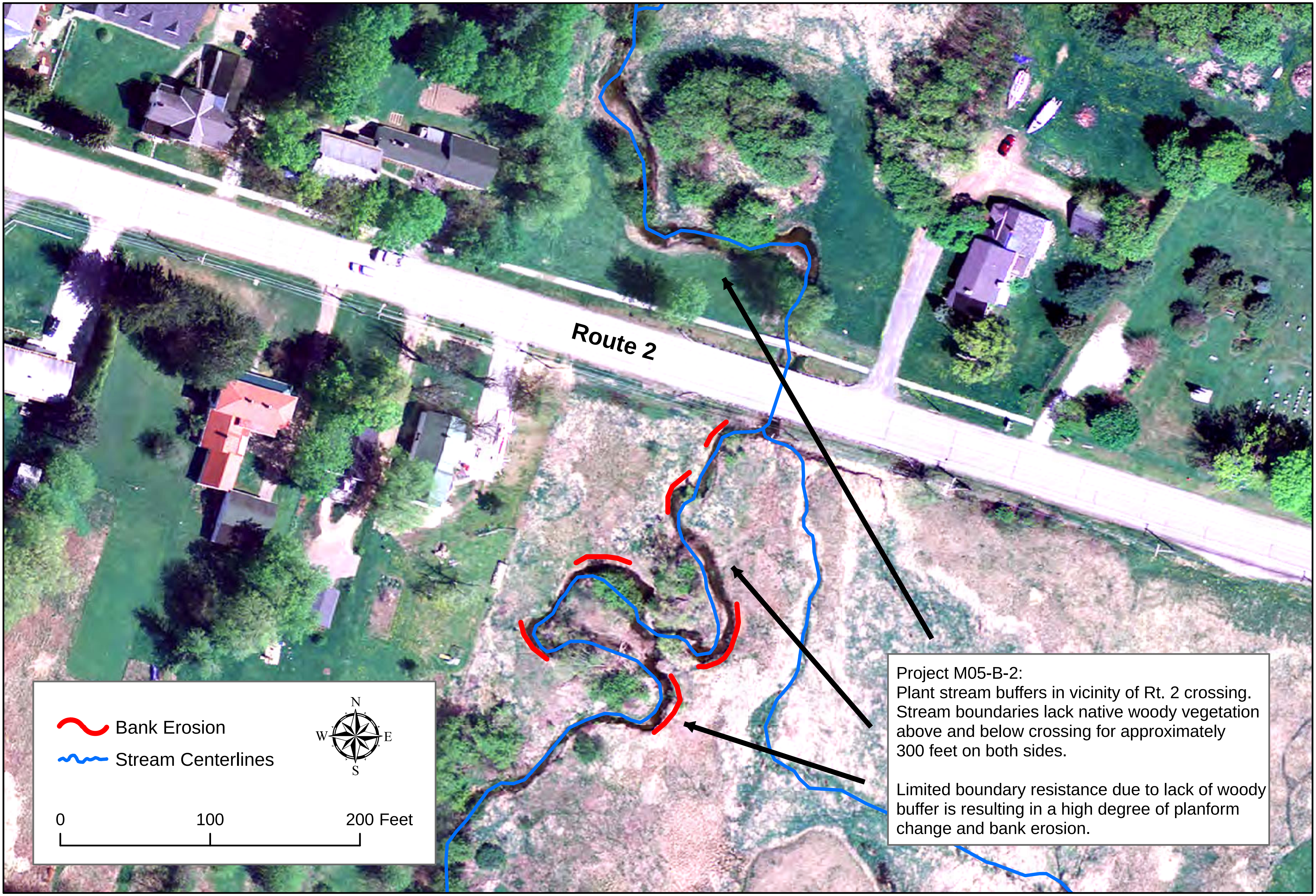

Figure 14
Project Location for Segment M05-B

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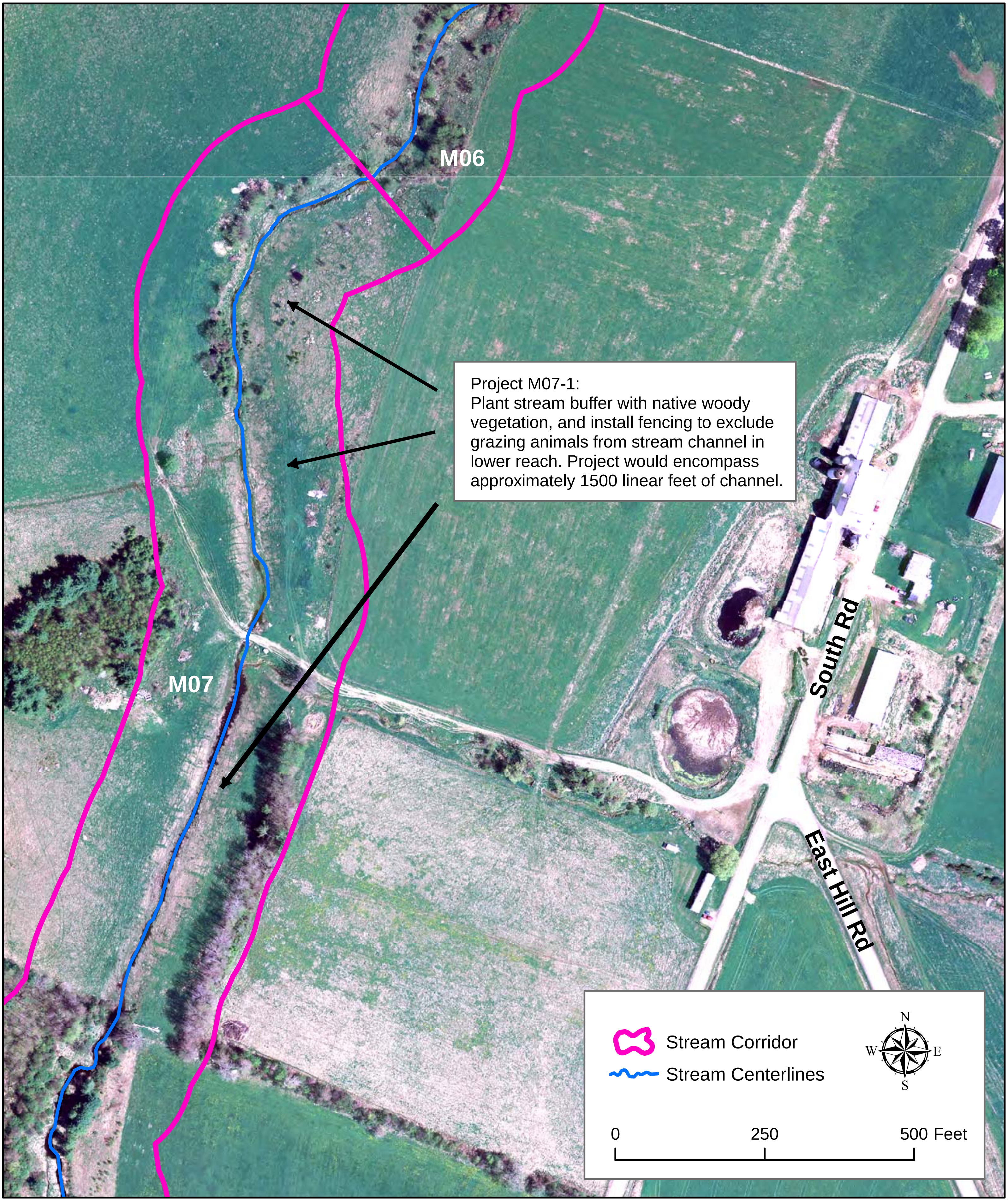

Figure 15
Project Location for Reach M07

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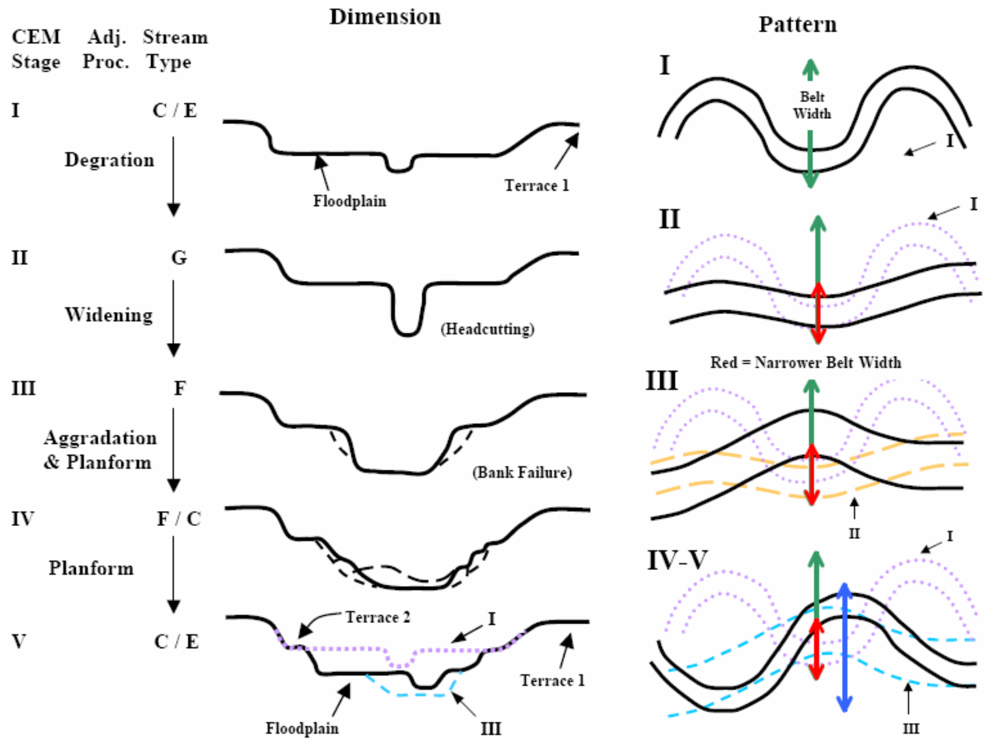
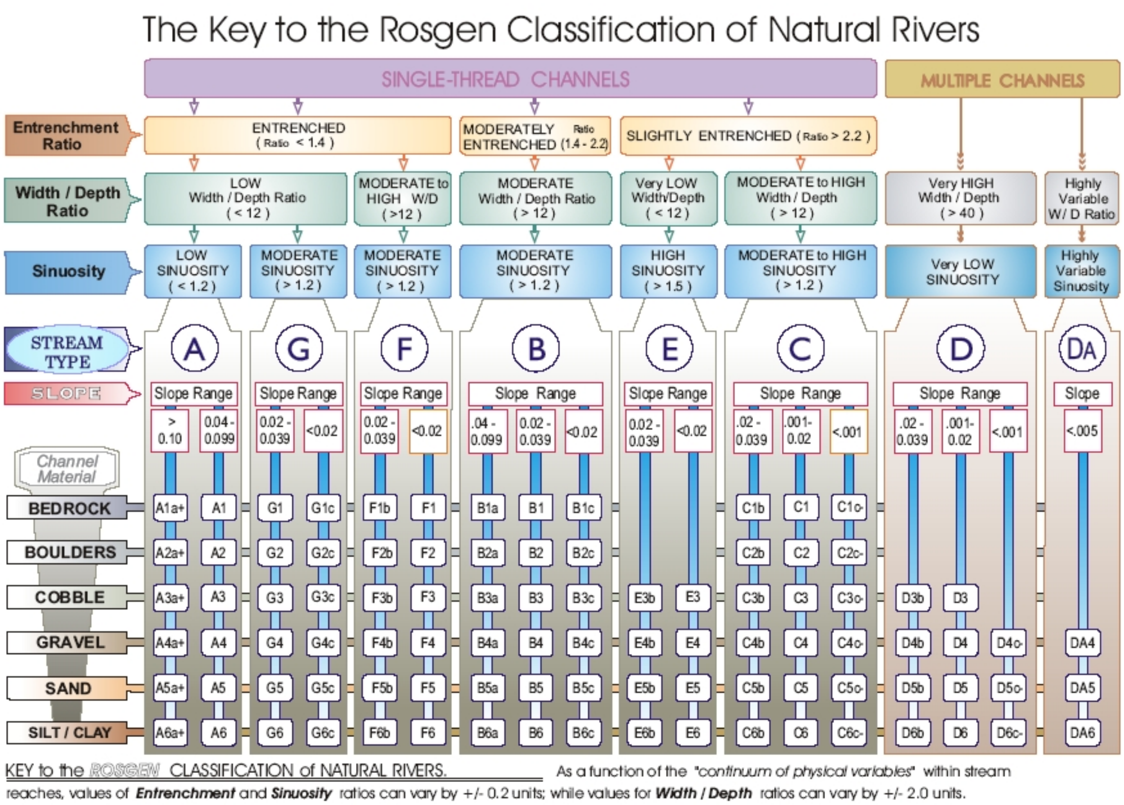
APPENDIX B

SUPPORTING BACKGROUND MATERIALS AND RESEARCH

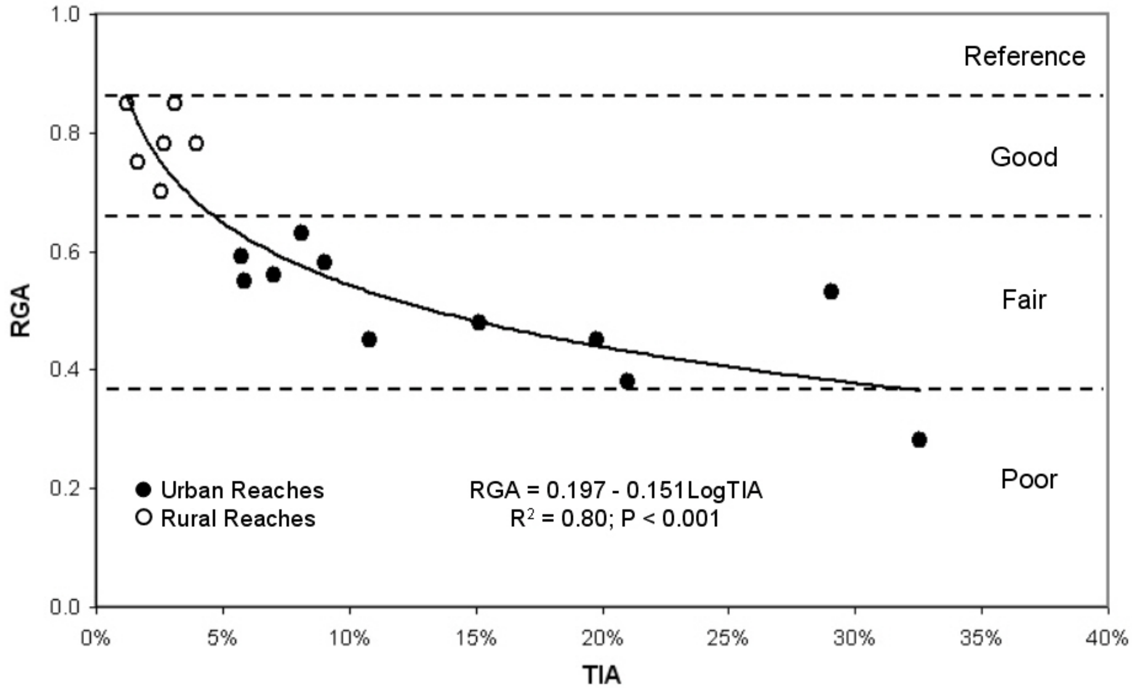


Typical channel evolution processes observed in rivers of VT (modified from Schumm, 1977)

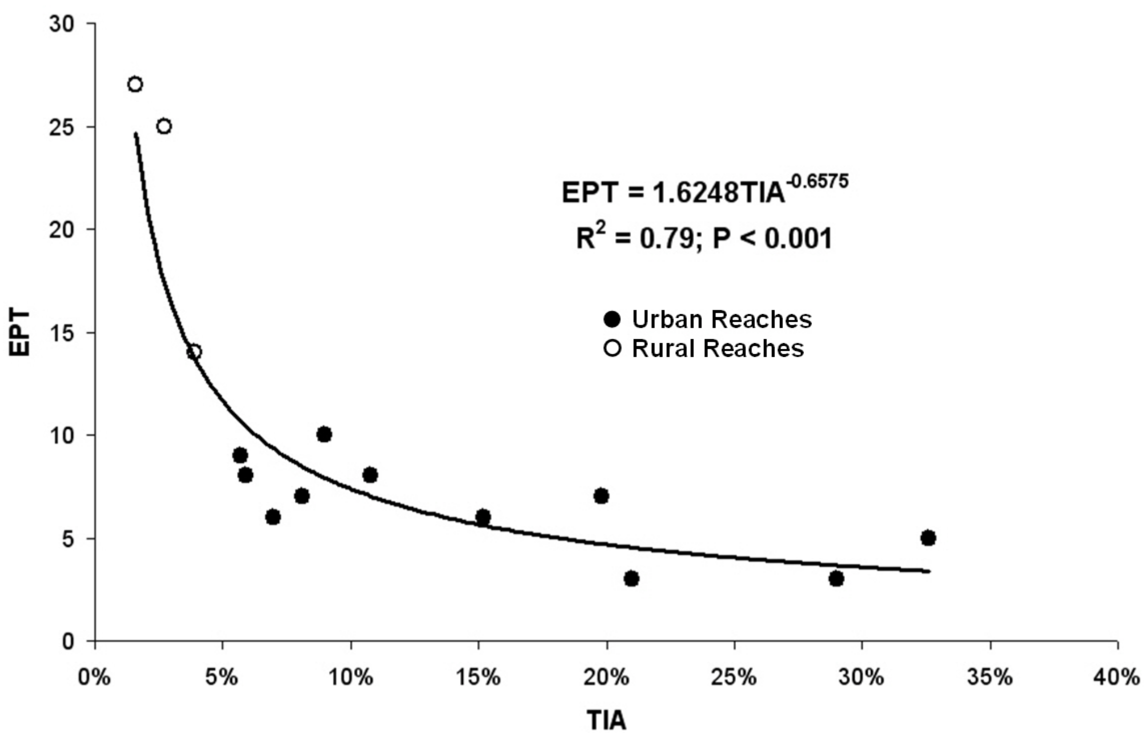


The Rosgen (1994) classification of streams based on channel morphology. Key parameters for classification include 1) the entrenchment ratio (floodprone width / bankfull channel width), 2) width to depth ratio (bankfull width / mean channel depth), and 3) channel sinuosity (channel length / straight-line valley length). Entrenched channels are typically dominated by sediment transport processes, whereas slightly entrenched channels (C and E types) have sediment transport and depositional processes.

Plot of the relationship between RGA and percent upslope Total Impervious Area (TIA) for high-gradient study reaches in Chittenden County. Categorical groupings of physical stream condition provided on right (Fitzgerald, 2007).



Plot of relationship between EPT richness and percent upslope TIA for high-gradient study reaches in Chittenden County (Fitzgerald, 2007).



SPATIAL ANALYSIS OF TOTAL IMPERVIOUS AREA (FIZGERALD, 2007)

Land use data derived from two separate sources for the study area was utilized to quantify Total Impervious Area (TIA) percentages for each drainage area. Statewide Landsat imagery collected in 2002 using a 30 m grid was processed by UVM's Spatial Analysis Laboratory (SAL), resulting in the following four spectral classes: (1) forest; (2) urban; (3) open (agricultural and open recreational uses); (4) water and other (SAL, 2005). In addition, a separate dataset of TIA derived from high-resolution Quickbird satellite scenes collected between 2003 and 2005 was utilized (Morrissey and Pelletier, 2006). The multispectral bands (2.4 m resolution) from the Quickbird scenes were analyzed by SAL using Definiens eCognition® software to classify the data into three classes: (1) impervious; (2) pervious; (3) water.

Quickbird-derived TIA data was only available for a select group of watersheds during the time of this analysis. Given this limitation, a correlation analysis was performed using the Landsat-derived urban class and the Quickbird-derived TIA class for 4 of the 16 study watersheds. The dataset used for the correlation analysis included 40 independent subwatersheds with a wide distribution of drainage areas (ranging from 0.07 km^2 to 3.8km^2) and TIA percentages (ranging from 1.2% to 40.6%). The analysis resulted in a robust linear relationship that was used to calculate TIA for all study watersheds at each spatial scale.

Plot of relationship between Urban Land Cover and TIA for 40 independent subwatershed areas from 4 of the study watersheds.