Indian Brook Watershed Departure Analysis and Project Identification Summary

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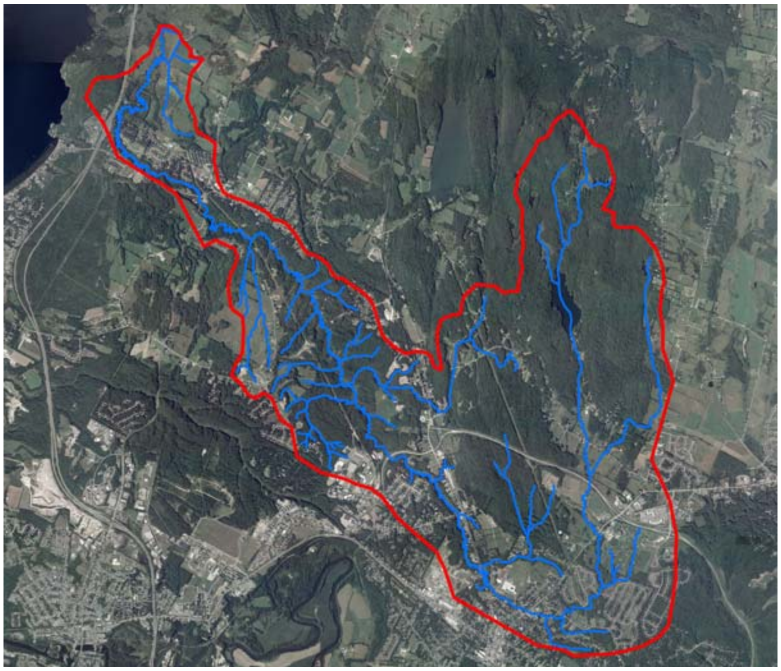

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Executive Summary

- The Indian Brook watershed is found in the towns of Colchester and Essex, Vermont. The results of recent biotic sampling in the middle reaches led to the watershed being officially designated by the Vermont Agency of Natural Resource (VTANR) as impaired by stormwater runoff from impervious surfaces.

- Indian 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, a total of 23 stream segments were 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 Indian 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 in the vicinity of the Route 15 crossings have impacted the hydrologic regime in the middle reaches of the watershed. Degradational and lateral channel adjustment are found along this section of the channel network, resulting in many reaches with high sediment transport capacity and a high supply of sediment from eroding banks and channel beds. The lack of urban land cover and stream corridor encroachment in the lower watershed allow for stable channel conditions.

- A total of 34 unique project opportunities were identified for the main stem reaches, including 20 corridor protection sites, 5 riparian buffer planting sites, 4 active channel restoration sites (including bank stabilization), and 4 structure replacements. A select group of 13 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

Indian Brook is found in the towns of Colchester and Essex, and is drained by an urbanizing watershed with an area of 12.0 square miles (Figure 1). Biotic samples collected in the middle watershed zone have shown an impaired condition due to excess urban runoff. 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 Indian 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 watershed (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.

Indian 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, 23 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 an watershed-wide analysis of stressors to geomorphic stability. 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: Indian Brook, Potash Brook, and Allen Brook. What follows is a summary of the methods and results of the project identification process for 23 reaches on the Indian Brook main stem.

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	E	Sand	Dune-Ripple	0.71	Good	0.73	Good	High	F	I
M02	E	Sand	Dune-Ripple	0.64	Fair	0.65	Good	High	F	I
M03	E	Sand	Dune-Ripple	0.74	Good	0.66	Good	High	F	I
M04	E	Sand	Dune-Ripple	0.76	Good	0.63	Fair	Very High	F	II
M05	E	Sand	Dune-Ripple	0.69	Good	0.64	Fair	Very High	F	I
M06	E	Sand	Dune-Ripple	0.72	Good	0.74	Good	High	F	I
M07	E	Sand	Dune-Ripple	NE	NE	0.69	Good	High	F	I
M08	E	Sand	Dune-Ripple	0.71	Good	0.70	Good	High	F	I
M09A	C	Gravel	Riffle-Pool	0.64	Fair	0.58	Fair	Very High	F	III
M09B	F*	Cobble	Step-Pool	0.56	Fair	0.49	Fair	Extreme	F	III
M10A	E	Sand	Dune-Ripple	0.53	Fair	0.64	Fair	Very High	F	II
M10B	E	Sand	Dune-Ripple	0.57	Fair	0.64	Fair	Very High	F	I
M11A	E	Sand	Plane Bed	0.34	Poor	0.48	Fair	Very High	F	II
M11B	C	Gravel	Plane Bed	0.36	Fair	0.39	Fair	Very High	F	IV
M11C	C	Gravel	Plane Bed	0.70	Good	0.65	Good	High	F	IV
M12	B	Cobble	Plane Bed	0.84	Good	0.70	Good	Moderate	F	I
M13A	E	Gravel	Plane Bed	0.77	Good	0.65	Good	High	F	I
M13B	B	Boulder	Plane Bed	0.87	Reference	0.73	Good	Very Low	F	I
M13D	E	Sand	Dune-Ripple	0.60	Fair	0.61	Fair	Very High	F	II
M15	E	Sand	Plane Bed	0.63	Fair	0.61	Fair	Very High	F	II
M16A	B	Gravel	Plane Bed	0.60	Fair	0.49	Fair	High	D	IIb
M16B	E	Gravel	Dune-Ripple	0.58	Fair	0.61	Fair	Very High	F	I
M18	B	Cobble	Step-Pool	0.71	Good	0.59	Fair	High	F	II

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

The stream segments studied in the Indian Brook watershed have a diversity of natural forms and sensitivities (Table 1). Only one segment has undergone severe channel adjustments, resulting in a departure from reference conditions (M09B). The average score from the Rapid Geomorphic Assessment (RGA) stability assessment was 0.62, 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 segments studied in the 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 and corridor encroachments. However, there is a recovery of channel stability and habitat conditions in the lower reaches, where increased floodplain connectivity was noted throughout (many reaches in stage I of channel evolution). The good floodplain connectivity observed in the lower reaches may be explained by: 1) the steep valley side slopes and extensive wetland conditions within the valley, which may have limited historic channel manipulation; 2) a generally lower degree of urbanization in the lower watershed; 3) limited stormwater inputs directly to the channel.

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 Indian Brook watershed contains a mixture of land cover types (Table 2), including significant amounts of agricultural land cover and forest cover. The watershed has a low degree of impervious cover (6.0%), below levels typically associated with degraded stream conditions at the national level (CWP, 2003), but slightly 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. Indian Brook Watershed Land Cover

Cover Type†	Percent Cover
Forested	37.3%
Agriculture	34.6%
Water & Wetlands	11.0%
Residential/Recreational	8.1%
Commercial/Industrial	2.0%
Transportation	7.0%

† 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 (Figures 3 and 4). 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, gullies 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 Indian Brook watershed have been mapped using the variables extracted from the Phase 2 field dataset (Figures 5, 6 and 7). 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 Indian Brook watershed have been mapped using the variables extracted from the Phase 2 field dataset (Figure 8). 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) depict areas that have a resistance to channel change. A summary of the local impacts to channel boundary conditions, including impacts to riparian vegetation, for each main stem reach based on Figure 8 is provided in Table 5.

In the Indian Brook watershed, many reaches along the main stem have a combination of fine bed substrate and limited bank cohesiveness. In the lower and middle watershed zones (where the greatest urbanization is found), only two natural grade controls (waterfalls) were noted during the field surveys. 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 only in one area where corridor encroachments (e.g., berms and roads) are common around the Route 15 crossing. 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 9 and 10 summarize the sediment regime types for reference and existing conditions for 23 main stem and 3 tributary segments. 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 5 of 23 main stem segments had sediment transport regimes under reference conditions where channel slopes were greater than 2 percent. The analysis of sediment regime types reveals that the main stem channel of Indian Brook has experienced many areas of departure from the reference regime conditions, especially in the middle watershed zone. Many of the reaches in the lower watersheds were determined to be in regime, protected from encroachment by steep valley side slopes and wide alluvial valleys with abundant wetlands. Five segments located in the middle watershed zone 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 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).

Table 4. Indian 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
M02	Beaver Activity (N)				X		X
M03	Beaver Activity (N)				X	X	X
M04	Beaver Activity (N); Waterfall (N)	Development; Roads (H)		X	X		X
M05	Beaver Activity (N); Dam (H)				X		X
M06	Beaver Activity (N)				X		X
M07	Beaver Activity (N)				X		X
M08	Beaver Activity (N)				X	X	X
M09-A	Beaver Activity (N)			partially	X	X	X
M09-B	Waterfall (N)	Development; Roads (H)	X			X	
M10-A		Development; Roads (H)			X		X
M10-B		Development; Roads (H)			X		X
M11-A		Development; Roads (H)		X	X		future
M11-B		Development; Roads (H)		X		X	

River Segment	Constraints		Transport		Floodplain Sediment and Flow Attenuation (Storage)		
	Vertical	Lateral	Natural	Converted	Natural	Increased	Asset
M11-C					X		
M12	Waterfalls (N)	Development; Roads (H)	X			X	
M13-A					X	X	X
M13-B						X	
M13-D	Beaver Activity (N)				X		X
M15	Beaver Activity (N)				X		X
M16-A			X			X	
M16-B	Beaver Activity (N); Ledges (N)	Development (H)			X	X	X
M18	Ledges (N)		X			X	

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.

Reach M04 has been converted to a sediment transport reach in some areas due to channel incision and subsequent bank and slope failure. Segment M09-B is experiencing severe aggradation of coarse substrate being transported from upslope reaches. M09B has been partially converted to a transport reach due to aggradation and bank failure, but maintains some floodplain connectivity. Segments M11-A and M11-B have been historically straightened and bermed, leading to a sediment transport regime in a valley setting that would have included depositional reaches under reference conditions.

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 Indian 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 11 summarizes the current stream sensitivities and adjustment processes for the Indian 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 23 segments have a stream sensitivity rating of very high or above. Many of the main stem reaches with higher sensitivities are going through the initial stages of channel evolution (stage II; incision), while some and are beginning to aggrade fine and coarse sediments (stage III). Only two 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).

One reach has 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:

- **M09-B:** This segment is a high gradient segment found in the vicinity of the Susie Wilson Road Bypass. Under reference conditions we would expect B-type stream geometry, however significant corridor encroachment and channel incision have resulted in F-type geometry with lower than expected entrenchment (ER = 1.2). As a result of the stream type departure, the segment has an extreme sensitivity to further stressors. Areas of extreme aggradation are occurring in the segment directly downstream of M09-B, where gradient changes from steep to moderate.

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: "Hydrologic (2,3)" – Figures 2 and 3 were referenced.

River Segment (CEM;RGA[†])	**Regime Stressors**		**Reach-Scale Stressors**	
	Hydrologic (2,3)	**Sediment (3,4)**	**Stream Power (5-7)**	**Boundary Resistance (8)**
M01 (I;Good)	*Increased Flows* • Moderate stormwater inputs in upstream reaches	*Increased Load* • Moderate bank erosion (5-20%) • High cropland (10-20%) in local drainage	*Increase* • Moderate stormwater inputs in upstream reaches	*Decrease* • Moderate Bank Erosion (5-20%) • High erodibility potential of bed/bank substrate** • Reduced riparian vegetation
M02 (I;Good)	*Increased Flows* • Moderate stormwater inputs • Moderate to high local and upslope TIA* • Some local wetland loss	*Increased Load* • High bank erosion (>20%) • Moderate cropland (5-10%) in local drainage • Multiple mass failures	*Increase* • Moderate stormwater inputs	*Decrease* • High bank erosion (>20%) • High erodibility potential of bed/bank substrate** • Reduced riparian vegetation
M03 (I;Good)	*Increased Flows* • High local TIA* • Moderate stormwater inputs	*Increased Load* • Abundant depositional and migration features • Multiple mass failures	*Increase* • Moderate stormwater inputs *Decrease* • Abundant depositional and migration features	*Increase* • Waterfall (grade control) upstream *Decrease* • High erodibility potential of bed/bank substrate** • Reduced riparian vegetation
M04 (II;Fair)	*Increased Flows* • Moderate local TIA* • Moderate stormwater inputs *Decreased Flows* • Upslope dam/reservoir	*Increased Load* • High bank erosion (>20%) • Extreme cropland (>20%) in local drainage • Multiple mass failures and one gully • Abundant depositional and migration features	*Increase* • Minor corridor encroachment • Moderate stormwater inputs *Decrease* • Abundant depositional and migration features • Upslope dam/reservoir	*Increase* • Waterfall (grade control) • Dam (grade control) upslope *Decrease* • High bank erosion (>20%) • High erodibility potential of bed/bank substrate** • Reduced riparian vegetation
M05 (I;Fair)	*Increased Flows* • Moderate local TIA* • Major stormwater inputs	*Increased Load* • Moderate bank erosion (5-20%)	*Increase* • Major stormwater inputs *Decrease*	*Increase* • Dam (grade control) in reach *Decrease*

River Segment (CEM;RGA†)	Regime Stressors: Hydrologic (2,3)	Regime Stressors: Sediment (3,4)	Reach-Scale Stressors: Stream Power (5-7)	Reach-Scale Stressors: Boundary Resistance (8)
	Decreased Flows • Dam/reservoir in reach	• Moderate depositional features	• Moderate depositional features • Dam/reservoir in reach	• Moderate Bank Erosion (5-20%) • High erodibility potential of bed/bank substrate** • Reduced riparian vegetation
M06 (I;Good)	*Increased Flows* • Moderate stormwater inputs in reach	*Increased Load* • High cropland (10-20%) in local drainage	*Increase* • Moderate stormwater inputs	*Decrease* • High erodibility potential of bed/bank substrate** • Reduced riparian vegetation
M07 (II;Fair)	*Increased Flows* • Moderate upslope TIA*	*Increased Load* • High cropland (10-20%) in local drainage • Moderate bank erosion (5-20%)	*No significant increases or decreases*	*Decrease* • High erodibility potential of bed/bank substrate** • Moderate Bank Erosion (5-20%) • Reduced riparian vegetation
M08 (I;Good)	*Increased Flows* • Moderate upslope & local TIA*	*Increased Load* • High cropland (10-20%) in local drainage • Abundant depositional features • Channel migration features present • Moderate bank erosion (5-20%)	*Decrease* • Abundant depositional features	*Decrease* • High erodibility potential of bed/bank substrate** • Moderate Bank Erosion (5-20%) • Reduced riparian vegetation
M09-A (III;Fair)	*Increased Flows* • Very high upslope & local TIA* • Major stormwater inputs	*Increased Load* • Lateral and aggradational channel adjustments • Abundant depositional and migration features	*Increase* • Major stormwater increases • Moderate channel straightening *Decrease* • Abundant depositional and migration features	*Decrease* • Reduced riparian vegetation
M09-B (III;Fair)	*Increased Flows* • Very high upslope & local	*Increased Load* • Lateral and aggradational	*Increase* • High channel straightening	*Increase* • Bank armoring present

River Segment (CEM;RGA†)	Regime Stressors: Hydrologic (2,3)	Regime Stressors: Sediment (3,4)	Reach-Scale Stressors: Stream Power (5-7)	Reach-Scale Stressors: Boundary Resistance (8)
	TIA* • Major stormwater inputs	channel adjustments • Abundant depositional features • Moderate bank erosion (5-20%)	• Major stormwater increases • High corridor encroachment *Decrease* • Abundant depositional features	• Multiple grade controls in reach *Decrease* • Moderate Bank Erosion (5-20%)
M10-A (II;Fair)	*Increased Flows* • Very high upslope & local TIA* • Major stormwater inputs	*Increased Load* • High bank erosion (>20%) • Channel migration features present	*Increase* • Moderate corridor encroachment • Major stormwater inputs *Decrease* • Abundant depositional features	*Decrease* • High bank erosion (>20%) • High erodibility potential of bed/bank substrate** • Reduced riparian vegetation
M10-B (I;Fair)	*Increased Flows* • Very high upslope & local TIA* • Extreme stormwater inputs	*Increased Load* • High bank erosion (>20%) • Channel migration features present	*Increase* • Extreme stormwater inputs	*Decrease* • High bank erosion (>20%) • High erodibility potential of bed/bank substrate** • Reduced riparian vegetation
M11-A (II;Fair)	*Increased Flows* • Very high local and upslope TIA* • Extreme stormwater inputs • Very high local wetland loss	*Increased Load* • High bank erosion (>20%) • Abundant depositional features	*Increase* • Extreme stormwater increases • Very high channel straightening • Major corridor encroachment *Decrease* • Abundant depositional features	*Increase* • Bank armoring present *Decrease* • High bank erosion (>20%) • High erodibility potential of bed/bank substrate** • Reduced riparian vegetation
M11-B (IV;Fair)	*Increased Flows* • Very high local and upslope TIA* • Extreme stormwater inputs • Very high local wetland loss	*Increased Load* • High bank erosion (>20%) • Lateral and aggradational channel adjustments • Abundant depositional features	*Increase* • Extreme stormwater increases • Very high channel straightening • Major corridor encroachment *Decrease* • Abundant depositional features	*Increase* • Moderate Bank Armoring (5-20%) *Decrease* • High bank erosion (>20%) • High erodibility potential of bed/bank substrate** • Reduced riparian vegetation

River Segment (CEM;RGA†)	Regime Stressors		Reach-Scale Stressors	
	Hydrologic (2,3)	Sediment (3,4)	Stream Power (5-7)	Boundary Resistance (8)
M11-C (II;Fair)	*Increased Flows* • Very high local and upslope TIA* • Extreme stormwater inputs • Very high local wetland loss	*Increased Load* • High bank erosion (>20%) • Abundant depositional features	*Increase* • Extreme stormwater increases • Very high channel straightening *Decrease* • Abundant depositional features	*Increase* • Bank armoring present *Decrease* • High bank erosion (>20%) • Reduced riparian vegetation
M12 (I;Good)	*Increased Flows* • Very high local and upslope TIA* • Major stormwater inputs • Very high local wetland loss	*Increased Load* • Extreme cropland (>20%) in local and upslope drainage • Moderate bank erosion (5-20%) • Abundant depositional and migration features	*Increase* • Major stormwater increases • Very high channel straightening • Major corridor encroachment *Decrease* • Abundant depositional features	*Increase* • Bank armoring present • Multiple grade controls *Decrease* • Moderate Bank Erosion (5-20%)
M13-A (I;Good)	*Increased Flows* • Very high local and upslope TIA* • Very high local wetland loss	*Increased Load* • Extreme cropland (>20%) in local and upslope drainage • Abundant depositional features	*Decrease* • Abundant depositional features	*Decrease* • Reduced riparian vegetation
M13-B (I;Good)	*Increased Flows* • Very high local and upslope TIA* • Very high local wetland loss	*Increased Load* • Extreme cropland (>20%) in local and upslope drainage • Abundant depositional and migration features	*Increase* • Abundant depositional and migration features	*No significant increases or decreases*
M13-D (II;Fair)	*Increased Flows* • Very high local and upslope TIA* • Moderate stormwater inputs • Very high local wetland loss	*Increased Load* • Extreme cropland (>20%) in local and upslope drainage • Moderate bank erosion (5-20%) • One mass failure	*Increase* • Moderate stormwater increases • Very high channel straightening	*Decrease* • Moderate Bank Erosion (5-20%) • High erodibility potential of bed/bank substrate** • Reduced riparian vegetation
M15	*Increased Flows*	*Increased Load*	*Increase*	*Decrease*

River Segment (CEM;RGA[†])	Regime Stressors: Hydrologic (2,3)	Regime Stressors: Sediment (3,4)	Reach-Scale Stressors: Stream Power (5-7)	Reach-Scale Stressors: Boundary Resistance (8)
(II;Fair)	• Moderate stormwater inputs • Moderate local wetland loss	• High cropland (10-20%) in local drainage • Channel migration features present	• Moderate stormwater increases • Moderate channel straightening	• High erodibility potential of bed/bank substrate** • Reduced riparian vegetation
M16-A (IIb;Fair)	*Increased Flows* • Moderate local wetland loss *Decreased Flows* • Upslope dam/reservoir	*Increased Load* • High bank erosion (>20%) • Lateral and aggradational channel adjustments • Abundant depositional features • Channel migration features present	*Decrease* • Abundant depositional and migration features • Upslope dam/reservoir	*Decrease* • High bank erosion (>20%) • Reduced riparian vegetation
M16-B (I;Fair)	*Increased Flows* • Moderate local wetland loss *Decreased Flows* • Upslope dam/reservoir	*Increased Load* • Moderate bank erosion (5-20%) • Abundant depositional features • Channel migration features present	*Increase* • Moderate corridor encroachment *Decrease* • Abundant depositional and migration features • Upslope dam/reservoir	*Increase* • Multiple grade controls (ledges) • Dam (grade control) upslope *Decrease* • Moderate Bank Erosion (5-20%) • Reduced riparian vegetation
M18 (II;Fair)	*No Significant Increase or Decrease in flows*	*Increased Load* • Moderate cropland (5-10%) in local drainage • Abundant depositional features	*No significant increases or decreases*	*Increase* • Multiple grade controls (ledges)

*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 Indian Brook watershed accounts for this knowledge, as outlined in the TMDL approach for similar 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.

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 Indicated (#)**	**Priority, Technical Feasibility & Relative Costs**	**Other Social Benefits**	**Potential Partners**
M01-1, E, I, Good/Good	Some historic straightening near a farm bridge crossing mid-reach. Overall, stable channel despite little woody vegetation on near bank. Multiple small beaver dams throughout lower section of reach only affect ~500 feet of channel. Moderate bank erosion w/o significant incision.	High priority stream corridor protection (3). Develop conservation easements for parcel occupying entire reach and corridor. Ideally completed in conjunction with buffer planting project described below.	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 in lower and mid-reach may preclude development, making conservation more feasible.	Attenuation of fine sediment will further protect WQ in Lake Champlain. Surrounding wetland complex is an important wildlife zone close to Lake.	Town of Colchester; CLT; VLT
M01-2, E, I, Good/Good	See general reach description above. Near bank and corridor vegetation dominated by Vigorous reed canary grass (*Phalaris spp.)*. Corridor was likely hay in past, but natural vegetation type would be silver/red maple (*Acer spp.)* and alder (*Alnus rugosa)*.	Plant buffer (6) with native woody vegetation in the middle and upper reach. See Figure 14 for site details. **Assess risk of loss of planted stock to beavers prior to planting**	High priority because of 1) adequate vertical stability of reach, and 1) importance of refugia for fish from nearby Malletts Creek and Bay. Relatively low cost for native plant materials and labor.	Improved biotic habitat and increased shading. Enhancement of wetland complex.	Town of Colchester; VTDEC; VYCC
M02-1, E, I, Good/Fair	Very sinuous channel with one area that will likely have a neck cutoff in future. Beaver dams affected high % of reach, with signs of beaver	Medium to high priority stream corridor protection (3). Develop conservation easements for parcel occupying	Medium to high priority because this is the second to last reach before outlet and has good floodplain connectivity and sinuosity. Feasibility depends on	Attenuation of fine sediment will further protect WQ in Lake Champlain.	Town of Colchester; CLT; VLT

Reach/Project, Stream Type, CEM†, RGA/RHA†	Site Description and Importance, Including Stressors and Constraints	Project/Strategy Description - Stepwise Number Indicated (#)	Priority, Technical Feasibility & Relative Costs	Other Social Benefits	Potential Partners
	activity throughout. No evidence of significant incision. Bank erosion high (>20%), but natural and expected in this channel type and valley bottom soils.	entire reach and corridor (same parcel as M01). No planting plan noted for reach due to good woody vegetation observed throughout.	land ownership (one parcel associated with the farm covers the entire reach), cost of land acquisition and extent of wetlands. Some wetlands along reach may preclude development, making conservation more feasible.	Surrounding wetland complex is an important wildlife zone close to Lake.	
M02-2, E, I, Good/Fair	See general reach description above. The bridge at Creek Farm Rd has a 13' span, representing 52% of bankfull channel width. No significant erosion or deposition around structure.	Replace the structure (26) with appropriately sized structures. Follow new RMP guidelines to accommodate 100% of equilibrium channel width.	Low priority replacement because structure is not causing significant adjustments. However, long-term planning should consider the widening of the span to accommodate the equilibrium width.	Reduced risk of erosion hazard at upstream and downstream properties.	Town of Colchester; VTRANS; VTDEC
M03-1, E, I, Good/Good	No apparent channel historical straightening. Channel very sinuous and located down in a steep-side sloped valley. Reach has numerous depositional and migrational features typical of setting with high beaver activity. Bank erosion high (>20%), but natural and expected in this channel type and valley bottom soils.	Medium priority stream corridor protection (3). Develop conservation easements for parcels occupying corridor in lower reach (~5 parcels). No planting plan noted for reach due to good woody vegetation observed throughout.	Medium priority because reach is located in lower watershed downstream of urbanized areas and has good floodplain connectivity and sinuosity. Feasibility depends on land ownership, cost of land acquisition and extent of wetlands. Extensive wetlands along reach would likely preclude development, making conservation more feasible.	Attenuation of fine sediment will further protect WQ in Lake Champlain. Protection of good wildlife habitat corridor from Lake up through suburban area to upper reaches.	Town of Colchester; CLT; VLT
M04-1, E, II,	Channel has high sinuosity, leading to many mass failures on both valley walls. Changes	Medium priority stream corridor protection (3). Develop conservation	Medium priority because reach is located in lower watershed downstream of urbanized areas	Attenuation of fine sediment will further protect WQ in Lake	Town of Colchester; CLT;

Reach/Project, Stream Type, CEM[†], RGA/RHA[†]	Site Description and Importance, Including Stressors and Constraints	Project/Strategy Description - Stepwise Number Indicated (#)	Priority, Technical Feasibility & Relative Costs	Other Social Benefits	Potential Partners
Fair/Good	in planform and high bank erosion appear to be natural part of the system b/c of highly erodible substrate, high LWD loading, and high beaver activity. Some channel incision at lower cross section (IR=1.4), with no incision in upper reach (IR=1.0).	easements for parcels occupying corridor in reach (3 parcels). No planting plan noted for reach due to good woody vegetation observed throughout.	and has good floodplain connectivity and sinuosity. Feasibility depends on land ownership, cost of land acquisition and extent of wetlands. Extensive wetlands along reach would likely preclude development, making conservation more feasible.	Champlain. Protection of good wildlife habitat corridor from Lake up to upper reaches..	VLT
M04-2, E, II, Fair/Good	See general reach description above. The box culvert at the Route 7 crossing has an 18' span, representing 72% of bankfull channel width. Moderate deposition noted upstream.	Replace the structure (26) with appropriately sized structures. Follow new RMP guidelines to accommodate 100% of equilibrium channel width.	Low priority replacement because structure is not causing significant adjustments. However, long-term planning should consider the widening of the span to accommodate the equilibrium width.	Reduced risk of erosion hazard at upstream and downstream properties.	Town of Colchester; VTRANS; VTDEC
M05-1, E, I, Fair/Good	Much of reach affected by the dam at Mill Pond Rd, causing ponding far upstream. Two stormwater inputs from channels coming down the right valley wall, with only minor impacts. Some channel incision noted (IR=1.2), likely resulting from channel cutting through aggraded sediments behind dam.	Medium priority stream corridor protection (3). Develop conservation easements for parcels occupying corridor in reach (3 parcels). No planting plan noted for reach due to high beaver activity in the area.	Lower priority because reach corridor is not likely to be developed due to the wetlands around the old mill pond. If the dam removal were pursued (see below), corridor protection would be high priority. Feasibility depends on land ownership, cost of land acquisition and extent of wetlands.	Attenuation of fine sediment will further protect WQ in Lake Champlain. Protection of good wildlife habitat corridor from Lake up to upper reaches.	Town of Colchester; CLT; VLT
M05-2, E,	See general reach description above. A derelict dam is	Remove the dam (27) to allow channel upstream	Need to further investigate the elevation of the ledge beneath the	Improved biotic habitat and fish	VTDEC; VTFW

Reach/Project, Stream Type, CEM†, RGA/RHA†	Site Description and Importance, Including Stressors and Constraints	Project/Strategy Description - Stepwise Number Indicated (#)	Priority, Technical Feasibility & Relative Costs	Other Social Benefits	Potential Partners
I, Fair/Good	located just upstream of Mill Pond Rd. The floodplain behind the dam is sedimented with fine sands/silts. Channel is incised above the dam.	to redevelop equilibrium profile. Headcut protection may not be necessary due to natural grade control (ledge) at reach break.	dam. High costs associated with dam removal and possible reshaping of the channel upstream of site to avoid severe incision and sediment export.	migration. Reduced flood/erosion risks.	
M06-1, E, I, Good/Good	Long stretch of channel unaffected by local land use. High beaver activity throughout reach. Channel mostly stable without incision. Planform changes related to past/present beaver dams and sediment deposition.	Low priority stream corridor protection (3). Develop conservation easements for parcels occupying corridor in reach (6 parcels). No planting plan noted for reach due to high beaver activity in the area, and native woody vegetation.	Lower priority because reach corridor is not likely to be developed due to the wetlands and steep valley side slopes. Feasibility depends on land ownership, cost of land acquisition and extent of wetlands.	Attenuation of fine sediment will further protect WQ in Lake Champlain. Protection of good wildlife habitat corridor from Lake up to upper reaches.	Town of Colchester; CLT; VLT
M07-1, E, I, Good/Good	Short reach with no development pressure in corridor. Ponding behind a large beaver dam affected reach during 2005 survey. Stable channel without significant human-caused erosion or incision.	Low priority stream corridor protection (3). Develop conservation easements for parcel occupying entire reach corridor (1 parcel). No planting plan noted for reach due to high beaver activity in the area, and native woody vegetation.	Lower priority because reach corridor is not likely to be developed due to the wetlands and steep valley side slopes. Feasibility depends on land ownership, cost of land acquisition and extent of wetlands.	Attenuation of fine sediment will further protect WQ in Lake Champlain. Protection of good wildlife habitat corridor from Lake up to upper reaches.	Town of Colchester; CLT; VLT
M08-1,	Another short reach without	Low priority stream	Lower priority because reach	Attenuation of fine	Town of

Reach/Project, Stream Type, CEM†, RGA/RHA†	Site Description and Importance, Including Stressors and Constraints	Project/Strategy Description - Stepwise Number Indicated (#)	Priority, Technical Feasibility & Relative Costs	Other Social Benefits	Potential Partners
E, I, Good/Good	development pressure in corridor. No large beaver dams in reach at time of survey (2005). Stable channel without significant human-caused erosion or incision.	corridor protection (3). Develop conservation easements for parcel s occupying reach corridor (~3 parcels). No planting plan noted for reach due to high beaver activity in the area, and native woody vegetation.	corridor is not likely to be developed due to the wetlands and steep valley side slopes. Feasibility depends on land ownership, cost of land acquisition and extent of wetlands.	sediment will further protect WQ in Lake Champlain. Protection of good wildlife habitat corridor from Lake up through suburban area to upper reaches.	Colchester; CLT; VLT
M09-A-1, C, III, Fair/Fair	Segment experiencing major aggradation with resulting bars and flood chutes present. High potential for further changes in planform. Beaver activity noted in lower reach, and dam was constructed between 2005 and 2008 field visits. Minor incision (IR=1.2) with high upslope urbanization and stormwater inputs.	High priority stream corridor protection (3). Develop conservation easements for parcels occupying entire segment corridor.	High priority because this segment is downstream of a transport segment in an urbanized area. Feasibility depends on land ownership (three parcels cover segment), cost of land acquisition and extent of wetlands. Some wetlands throughout segment may preclude development, making conservation more feasible.	Attenuation of fine sediment will further protect WQ in Lake Champlain. Protection of good wildlife habitat corridor from Lake up through suburban area to upper reaches.	Town of Essex; VLT
M09-B-1, C, III, Fair/Fair	Channel geometry data indicate a departure from a B channel to F due to historic and current incision, especially the segment area above Susie Wilson Rd. Areas of extreme aggradation	The culvert at the Susie Wilson Rd crossing has a 10’ span, representing 30% of bankfull channel width. Replace the structure (26) with appropriately sized	Not likely feasible because road was constructed within the last 20 years and culvert is found beneath 20-30 feet of fill. However, long-term planning should consider the replacement of	Reduced risk of erosion hazard at upstream and downstream properties. Improved biotic habitat and fish migration.	Town of Essex; VTRANS; VTDEC

Reach/Project, Stream Type, CEM†, RGA/RHA†	Site Description and Importance, Including Stressors and Constraints	Project/Strategy Description - Stepwise Number Indicated (#)	Priority, Technical Feasibility & Relative Costs	Other Social Benefits	Potential Partners
	are occurring in the reach directly downstream of M09-B, where gradient changes from steep to moderate.	structures. Follow new RMP guidelines to accommodate 100% of equilibrium channel width.	the culvert to accommodate the equilibrium width.		
M10-A-1, E, II, Fair/Fair	Appears to be some historic straightening in old fields through the segment. Above and below derelict stream crossings (old abutments, etc) there are some alignment problems that have led to changes in planform.	Medium priority stream corridor protection (3). Develop conservation easements for parcels occupying segment corridor (~7 parcels). No planting plan noted for reach due to high beaver activity in the area.	Medium priority because this segment is downstream of an urbanized area, and upslope segment has many stormwater inputs. Feasibility depends on land ownership (multiple parcels), cost of land acquisition and extent of wetlands. Some wetlands in lower and mid-reach may preclude development, making conservation more feasible.	Attenuation of fine sediment will further protect WQ in Lake Champlain. Protection of good wildlife habitat corridor from Lake up through suburban area to upper reaches.	Town of Essex; VLT
M10-A-2, E, II, Fair/Fair	See above for general segment description. One derelict crossing constricts the channel causing deposition upstream and changes in planform. See Figure 12 for a site map of project area.	Remove derelict structure (27) associated with old crossing. Abutments create a constriction of ~8’, or 66% of bankfull channel width.	High priority because structure no longer functions as a stream crossing. Feasibility depends on parcel ownership (2 parcels) and cost of roadbed fill removal (likely high costs).	Reduced risk of erosion hazard in vicinity of structure. Increased continuity in the sediment regime, allowing for long-term equilibrium conditions.	Town of Essex; VTRANS; VTDEC
M10-B-1, E, I, Fair/Fair	Significant beaver activity throughout the reach causing changes in planform and decreased geomorphic	High priority stream corridor protection (3). Develop conservation easements for parcels	High priority because this segment is downstream of a highly channelized area of sediment transport in an urbanized area.	Attenuation of fine sediment will further protect WQ in Lake Champlain.	Town of Essex; VLT

Reach/Project, Stream Type, CEM†, RGA/RHA†	Site Description and Importance, Including Stressors and Constraints	Project/Strategy Description - Stepwise Number Indicated (#)	Priority, Technical Feasibility & Relative Costs	Other Social Benefits	Potential Partners
	stability. Changes in planform and bank erosion appear to be natural part of the system b/c of highly erodible substrate, high LWD loading, and beaver activity.	occupying entire segment corridor (~7 parcels).	Feasibility depends on land ownership, cost of land acquisition and extent of wetlands. High degree of wetlands throughout segment may preclude development, making conservation more feasible.	Protection of good wildlife habitat corridor from Lake up through suburban area to upper reaches.	
M11-A-1, E, II, Fair/Poor	Severe straightening and hydrologic alterations (urban) have caused a departure in bedform (dune-ripple to plane bed). Active incision (IR=1.3) due to greater stream power could lead to loss of floodplain and G type channel geometry in near future.	Plant stream buffer (4) along right bank south of the intersection with Grove St. and Educational Dr. Currently lawn is maintained up to bank. See Figure 13 for site details.	Although reach is incising, banks are relatively stable around Grove St crossing, making this a higher priority planting. Relatively low costs. Potential for involving Essex High School students in planting and monitoring of the area.	Improved biotic habitat and increased shading. Reduced mowing area for adjacent high school.	Town of Essex; EWA; VYCC
M11-A-2, E, II, Fair/Poor	See above segment description. Greater than 75% of reach length has been historically straightened, leading to an incised channel with limited floodplain access. See Figure 13 for site and project details. Historical channel (1930's) was highly sinuous, and likely a sand-bottomed, E-type channel with wide floodplain and good floodplain access.	Restore incised reach (32) to reestablish meanders and create equilibrium profile and geometry along section adjacent to school. 700 linear feet of straightened stream channel south of Essex High School parking lots could be restored using natural channel design techniques to encourage	Segment is located downstream of transport segments (M11-B, M11-C, M12), making it a high priority floodplain restoration location. Feasibility depends on: 1) Town/School willingness to cooperate, and 2) compatibility with DEC approach to the mitigation of the overall hydrologic regime (i.e., TMDL permitting). Active restoration costs typically very high. Risk of short-term failure of restored reach	Attenuation of fine sediment will further protect WQ in Lake Champlain. Improved biotic habitat. Potential for educational program for post-restoration monitoring.	Town of Essex; VTDEC

Reach/Project, Stream Type, CEM†, RGA/RHA†	Site Description and Importance, Including Stressors and Constraints	Project/Strategy Description - Stepwise Number Indicated (#)	Priority, Technical Feasibility & Relative Costs	Other Social Benefits	Potential Partners
		deposition of fine sediment.	needs assessment, as well as timing and scope of TMDL.		
M11-B-1, C, IV, Fair/Fair	Residential encroachment upon the channel throughout segment. Severe straightening in lower reach since 1930's (see Figure 13). Channel incised in many locations but redeveloping a small floodplain at lower elevation. Approx. 20 stormwater inputs within segment, leading to increased stream power.	Plant stream buffer (4) along right bank east of the Route 15 crossing. Currently lawn is maintained up to bank.	Although reach is incised in some locations, banks are relatively stable upstream of Route 15 crossing, making this a higher priority planting. Relatively low costs for labor and planting materials.	Improved biotic habitat and increased shading. Reduced mowing area for adjacent property.	Town of Essex; EWA; VYCC
M11-B-2, C, IV, Fair/Fair	See above segment description. Stream banks are unstable due to lack of woody vegetation for ~150' upstream of Route 15 crossing. Roadway and paved parking lot are within 50' of eroding banks.	Stabilize right stream bank (10) in conjunction with stream buffer planting (described above) to protect adjacent roadway and parking lot. See Figure 13 for site details.	This area of reach is less incised than lower section (stage IV CEM), and has encroachment along both banks. High priority project to protect narrow strip of adjacent land that could be established as a buffer in the future.	Protection of Route 15 roadway and parking lot from ongoing bank erosion.	Town of Essex; VTDEC
M11-C-1, C, IV, Good/Good	Segment less affected by historical straightening than downstream segments. Channel is readjusting to equilibrium profile (no incision), with plane bed features and good floodplain connectivity. Small section of	High priority stream corridor protection (3). Only small area of segment corridor is developed, with potential to protect entire corridor in upper segment	Due to high degree of urbanization in the area, with limited opportunities for corridor protection (and high development pressure), this segment has a high priority for corridor protection. 3 parcels occupy corridor, with 2 parcels appearing to have common	Attenuation of fine sediment will further protect WQ in Lake Champlain. Recreational opportunities for surrounding	Town of Essex; VLT; Adjacent Home-owners Assoc.

Reach/Project, Stream Type, CEM[†], RGA/RHA[†]	Site Description and Importance, Including Stressors and Constraints	Project/Strategy Description - Stepwise Number Indicated (#)	Priority, Technical Feasibility & Relative Costs	Other Social Benefits	Potential Partners
	corridor encroachment mid-segment (residential).		land associated with adjacent homeowners associations.	residents.	
M11-C-2, C, IV, Good/Good	See above segment description. Stream banks are unstable within 30 feet of Brickyard Condos at sharp bend immediately upstream of Brickyard Rd. Stormwater outfall is contributing to unstable banks.	Stabilize right stream bank (10) to protect adjacent residential buildings. See Figure 15 for site details.	Very high priority given proximity of buildings to channel and unstable banks. Feasibility depends on willingness of adjacent property owners. Relatively high costs.	Reduced risk of future property damage due to continued erosion.	Town of Essex; VTDEC; Adjacent Home-owners Assoc.
M12-1, B, I, Good/Good	Reach is relatively stable and was not historically impacted as severely as M11. Step-pool channel with 2 grade controls. Natural channel armoring protects against changes in hydrology due to urbanization in vicinity. Minor encroachment on corridor mid-segment, with only limited impacts on floodplain.	High priority stream corridor protection (3). Only small area of segment corridor has encroachment. Potential to protect nearly entire corridor.	Due to high degree of urbanization downstream, with limited opportunities for corridor protection (and high development pressure), this reach has a high priority for corridor protection. 1 parcel occupies large section of corridor, and is likely common land associated with adjacent homeowners association.	Attenuation of fine sediment will further protect WQ in Lake Champlain. Recreational opportunities for surrounding residents.	Town of Essex; VLT; Adjacent Home-owners Assoc.
M13-A-1, E, I, Good/Good	Low-gradient segment with recent beaver activity. Good channel stability, with limited impacts (armoring) around Hubbells Falls Rd. Steep valley side slopes prevent development from encroaching on corridor.	Protect stream corridor (3). One parcel occupies large percentage of corridor on west side.	Low to medium priority corridor protection. Lower priority because reach corridor is not likely to be developed due to the wetlands and steep valley side slopes. Feasibility depends on land ownership, cost of land acquisition and extent of wetlands.	Attenuation of fine sediment will further protect WQ in Lake Champlain. Protection of good wildlife habitat corridor for middle reaches of watershed.	Town of Essex; VLT; Adjacent Home-owners Assoc.

Reach/Project, Stream Type, CEM†, RGA/RHA†	Site Description and Importance, Including Stressors and Constraints	Project/Strategy Description - Stepwise Number Indicated (#)	Priority, Technical Feasibility & Relative Costs	Other Social Benefits	Potential Partners
M13-B-1, B, I, Good/Reference	Small segment through wooded, non-farmed section of stream. Large beaver dam upstream causing ponding and perhaps reduces sediment supply to this segment. Steep valley side slopes prevent development from encroaching on corridor.	Protect stream corridor (3). One parcel occupies large percentage of corridor on east side.	Low to medium priority corridor protection. Lower priority because reach corridor is not likely to be developed due to adjacent steep valley side slopes. Feasibility depends on land ownership, cost of land acquisition and extent of wetlands in corridor.	Attenuation of fine sediment will further protect WQ in Lake Champlain. Protection of good wildlife habitat corridor for middle reaches of watershed.	Town of Essex; VLT; Lang Farm Golf Course
M13-D-1, E, II, Fair/Fair	Historical straightening mid-segment along agricultural field. Bank vegetation limited mid-segment, which may limit redevelopment of sinuosity due to low LWD loading. Some areas of segment have regained sinuosity. Some incision noted in lower segment. Corridor undeveloped.	Protect stream corridor (3). Four parcels occupy entire corridor.	Medium to high priority corridor protection due to the apparent development pressure in surrounding land. Upper and lower segment have regained sinuosity, and mid segment will likely redevelop meanders, making corridor protection important.	Attenuation of fine sediment will further protect WQ in Lake Champlain.	Town of Essex; VLT
M13-D-2, E, II, Fair/Fair	See general segment description above. No woody bank vegetation in lower and upper segment. One mass failure and bank failure in lower segment may be caused by lack of woody vegetation.	Plant stream buffer (4) in lower and upper segment with woody, native vegetation.	Medium to high priority when carried out in conjunction with corridor protection (see above). Relatively low cost for materials and labor.	Improved biotic habitat and increased shading. Reduced mowing area for adjacent property.	Town of Essex; VYCC
M15-1, E,	Beaver activity throughout reach. Some channel incision,	Protect stream corridor (3). Approximately five	Low priority corridor protection. High degree of wetlands and	Attenuation of fine sediment will further	Town of Essex;

Reach/Project, Stream Type, CEM[†], RGA/RHA[†]	Site Description and Importance, Including Stressors and Constraints	Project/Strategy Description - Stepwise Number Indicated (#)	Priority, Technical Feasibility & Relative Costs	Other Social Benefits	Potential Partners
II, Fair/Fair	perhaps resulting from channel downcutting through aggraded beaver sediments. Changes in planform and bank erosion appear to be natural part of the system b/c of highly erodible substrate, high LWD loading, and beaver activity.	parcels occupy entire corridor.	beaver activity likely preclude development. Parcels within corridor are associated with established homes with low likelihood of further subdivision and development.	protect WQ in Lake Champlain. Protection of good wildlife habitat corridor and beaver habitat for upper reaches of watershed.	VLT
M15-2, E, II, Fair/Fair	See reach description above. No woody vegetation along banks in vicinity of Lost Nation Road crossing.	Plant stream buffers (4) along banks. 3 properties border stream and would need to be involved in planting.	Medium to high priority. Approximately 600 linear feet of channel to be planted. Relatively low cost for materials and labor. Feasibility depends on landowner willingness.	Improved biotic habitat and increased shading. Reduced mowing area for adjacent property.	Town of Essex; VYCC
M16-A-1, B, IIb, Fair/Fair	Significant sediment deposition from gravel road wash-off along segment. Reference D50 determined to be cobble, but is now a gravel-dominated bed. Channel incision noted where aggraded gravel is found.	Protect stream corridor (3). Two parcels occupy entire corridor.	Low priority corridor protection. High degree of wetlands and beaver activity upstream and downstream likely preclude development. Parcels within corridor are associated with established homes with low likelihood of further subdivision and development.	Attenuation of fine sediment will further protect WQ in Lake Champlain. Protection of good wildlife habitat corridor and beaver habitat for upper reaches of watershed.	Town of Essex; VLT
M16-A-2, B, IIb, Fair/Fair	See reach description above. Significant amounts of sand and fine gravel are being delivered to the channel in M16-A and M16-B, appears	Work with Town of Essex to improve road and ditch maintenance on Indian Brook Rd.	Medium to high priority due to impacts on entire reach. Relatively high costs over time to maintain and improve road and ditch conditions.	Improved biotic habitat and increased shading. Attenuation of fine sediment will further protect WQ in	Town of Essex; Better Backroads Program

Reach/Project, Stream Type, CEM†, RGA/RHA†	Site Description and Importance, Including Stressors and Constraints	Project/Strategy Description - Stepwise Number Indicated (#)	Priority, Technical Feasibility & Relative Costs	Other Social Benefits	Potential Partners
	to be due to lack of proper maintenance of Indian Brook Rd.			Lake Champlain.	
M16-B-1, E, I, Fair/Fair	Segment is also experiencing aggradation of gravel from nearby road. Reference D50 would likely be sand for dune-ripple segment, but is now gravel due to the road runoff.	Protect stream corridor (3). Five parcels occupy entire corridor.	Low priority corridor protection. High degree of wetlands and beaver activity upstream and downstream likely preclude development. Low likelihood of further subdivision and development.	Attenuation of fine sediment will further protect WQ in Lake Champlain. Protection of beaver habitat for upper reaches of watershed.	Town of Essex; VLT
M18-1, B, II, Fair/Good	Much of reach has been historically straightened and is still lined by old stone walls. Forests have grown up around old fields and stone walls. Channel still shows signs of historic disturbance, as vertical adjustments continue.	Protect stream corridor (3). Four parcels occupy entire corridor.	Low priority corridor protection. High degree of wetlands and ownership of lower reach area by Essex Town (Indian Brook Reservoir). Low likelihood of further subdivision and development.	Protection of beaver habitat for upper reaches of watershed.	Town of Essex; VLT

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

4.0 Prioritized Projects

The following is a list of 13 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 and in the noted figures. An overall watershed map depicting high priority corridor protection sites is provided in Figure 16.

4.1 Projects Ready to Pursue Implementation (Passive Restoration)

1. M01-1: Develop conservation easements for parcel occupying entire reach and corridor. Ideally completed in conjunction with buffer planting project described in project M01-2 (high priority).

2. M02-1: Develop conservation easements for parcel occupying entire reach and corridor, including the same parcel described in reach M01 (high priority).

3. M09-A-1: Develop conservation easements for parcels occupying entire segment corridor (high priority).

4. M10-B-1: Develop conservation easements for parcels occupying entire segment corridor including approximately 7 parcels (high priority).

5. M11-C-1: Develop conservation easements for parcels occupying entire segment corridor. Only small area of segment corridor is developed, with potential to protect entire corridor in upper segment (high priority).

4.2 Projects Requiring Further Study (Active Restoration)

1. M01-2: Plant buffer with native woody vegetation in the middle and upper reach. Assess the risk of loss of planted stock to beavers prior to developing planting plan. See Figure 14 for a site map of the project area (high priority).

2. M10-A-2: Remove derelict structure associated with old crossing. See Figure 12 for a site map of the project area (high priority).

3. M11-A-1: Plant stream buffer along right bank south of the intersection with Grove St. and Educational Drive. See Figure 13 for a site map of the project area (high priority).

4. M11-A-2: Restore incised reach to reestablish meanders and create equilibrium profile and geometry along section adjacent to school. See Figure 13 for a site map of the project area (requires further study to assess priority).

5. M11-B-1: Plant stream buffer along right bank east of the Route 15 crossing. See Figure 13 for a site map of the project area (high priority).

6. M11-B-2: Stabilize right stream bank in conjunction with stream buffer planting (project M11-B-1, see below) to protect adjacent roadway and parking lot. See Figure 13 for a site map of the project area (high priority).

7. M11-C-2: Stabilize right stream bank to protect adjacent residential buildings. See Figure 15 for a site map of the project area (high priority).

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APPENDIX A

WATERSHED AND SITE MAPPING

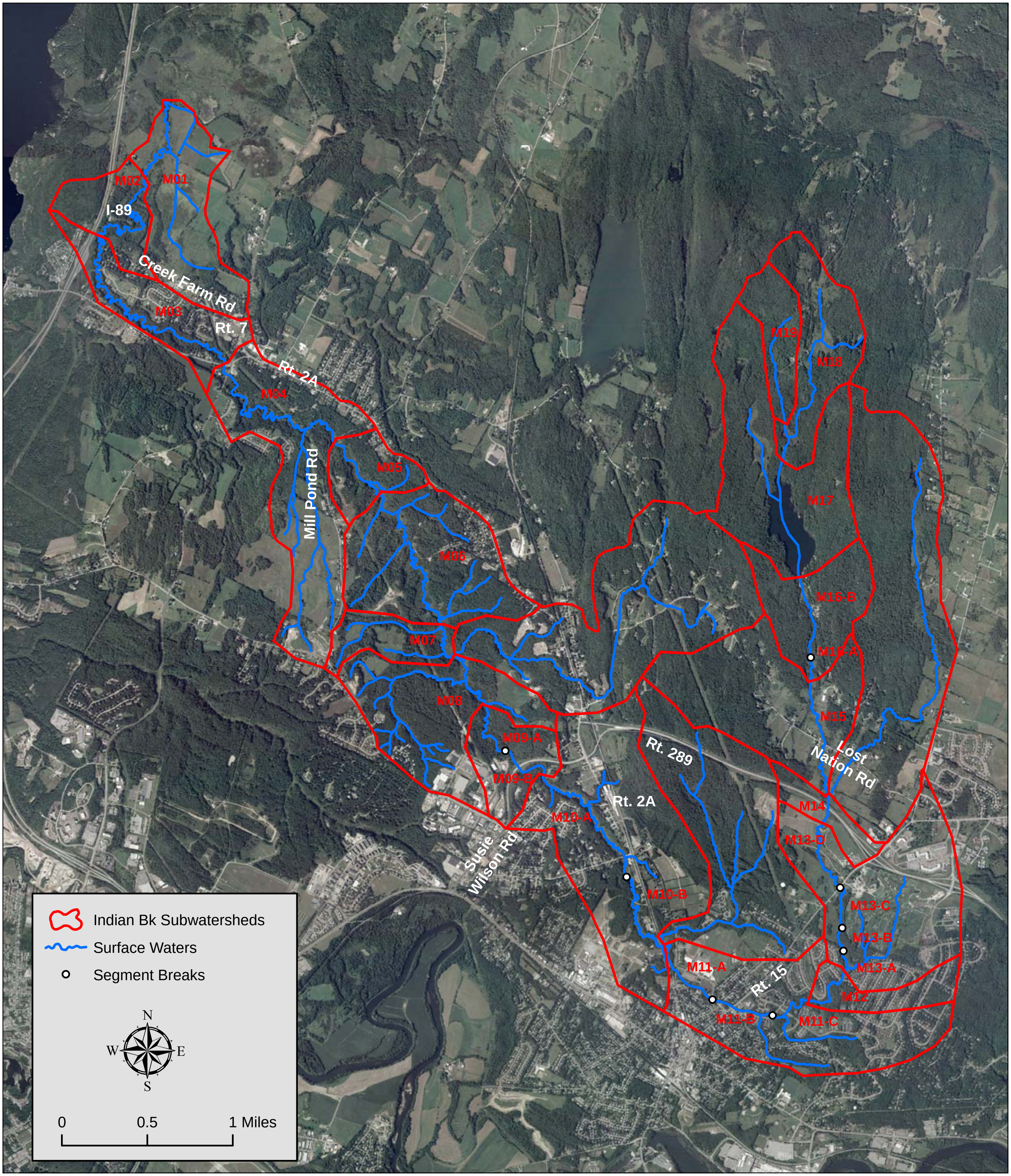

Figure 1
Indian Brook Subwatersheds and Study Reaches

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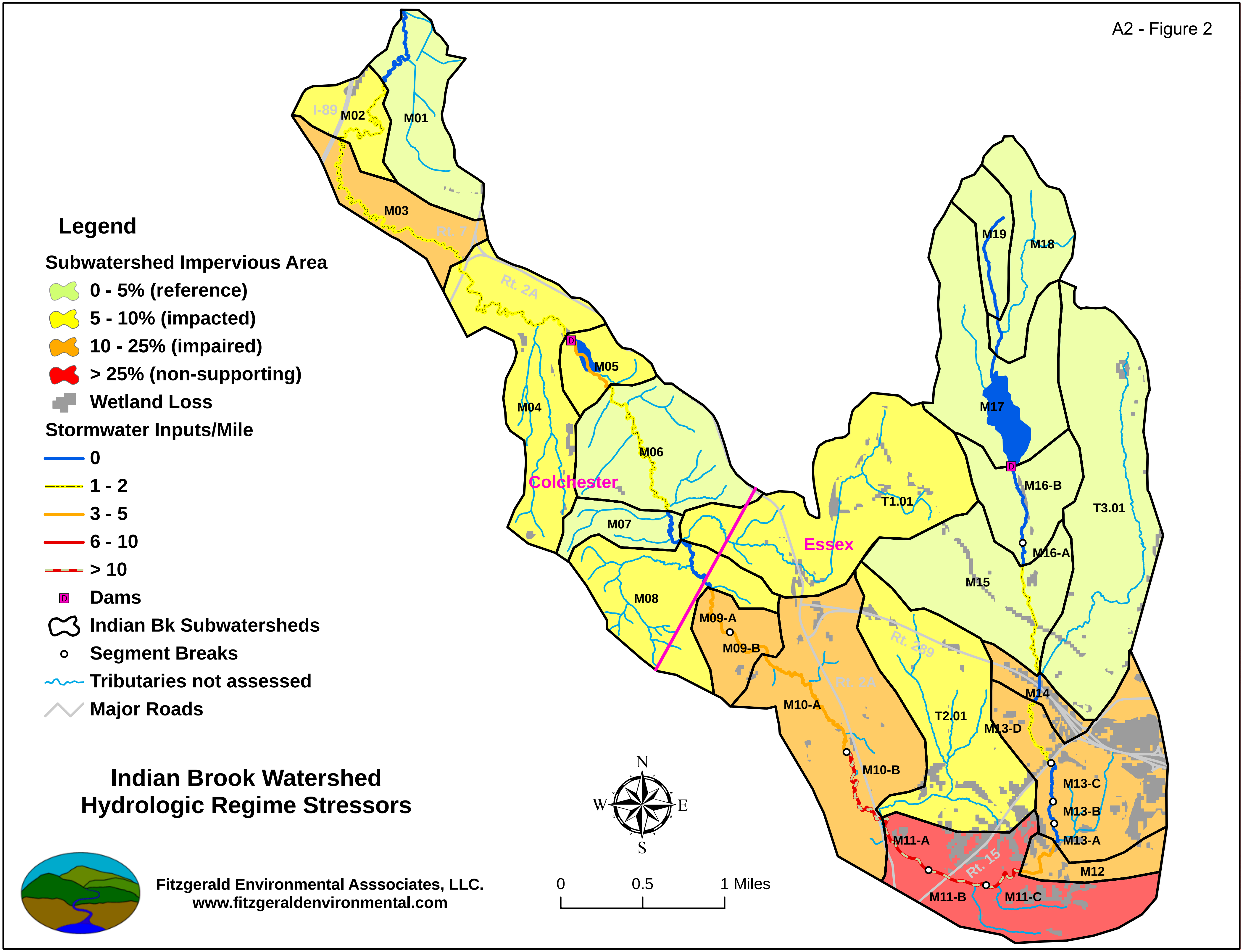
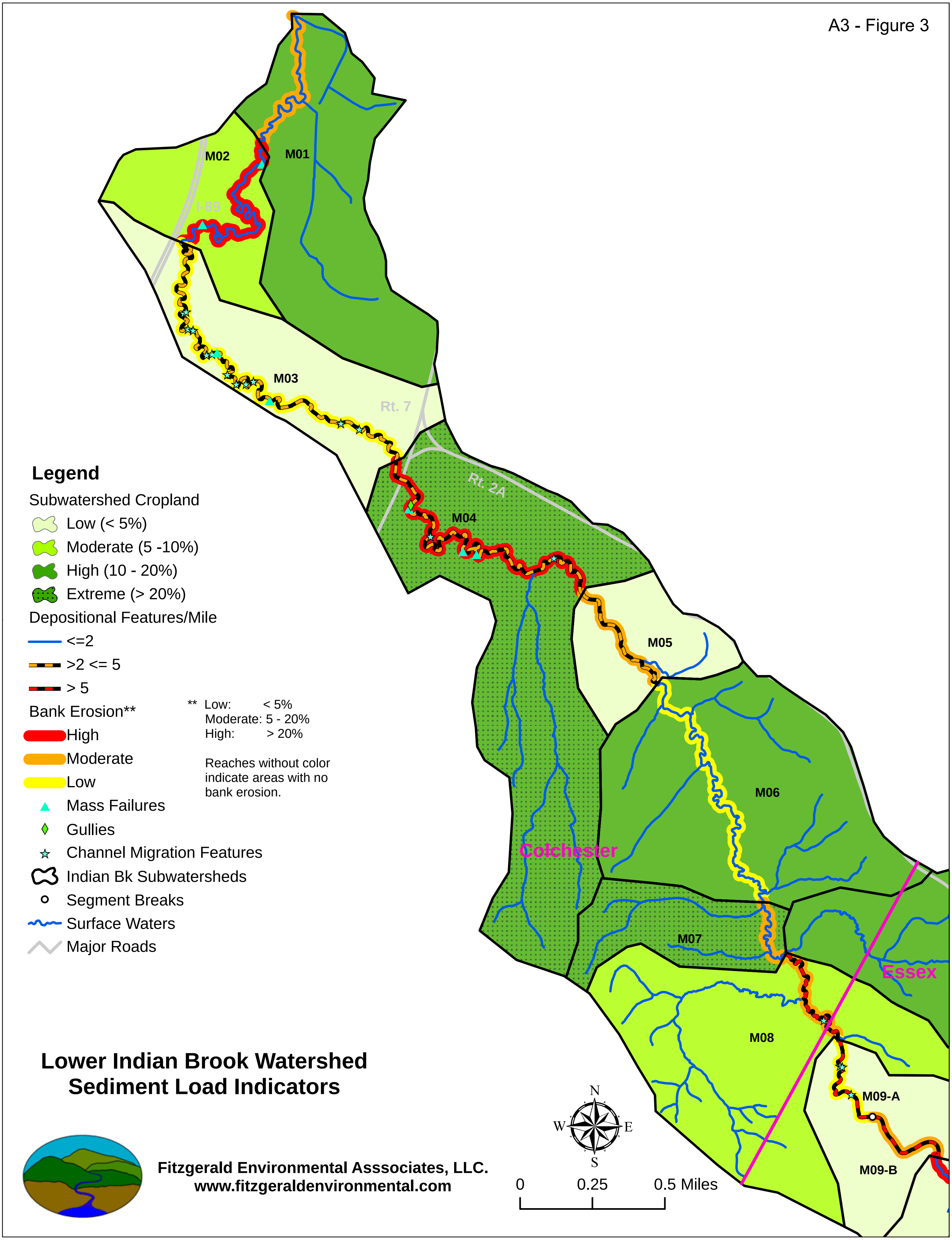

A2 - Figure 2
Legend
Subwatershed Impervious Area
0 - 5% (reference)
5 - 10% (impacted)
10 - 25% (impaired)
> 25% (non-supporting)
Wetland Loss
Stormwater Inputs/Mile
0
1 - 2
3 - 5
6 - 10
> 10
Dams
Indian Bk Subwatersheds
Segment Breaks
Tributaries not assessed
Major Roads
Indian Brook Watershed
Hydrologic Regime Stressors
Fitzgerald Environmental Asssociates, LLC.
www.fitzgeraldenvironmental.com
0
0.5
1 Miles
N
S
W
E
Colchester
Essex
I-89
Rt. 7
Rt. 2A
Rt. 289
Rt. 15
M01
M02
M03
M04
M05
M06
M07
M08
M09-A
M09-B
M10-A
M10-B
M11-A
M11-B
M11-C
M12
M13-A
M13-B
M13-C
M13-D
M14
M15
M16-A
M16-B
M17
M18
M19
T1.01
T2.01
T3.01



Lower Indian Brook Watershed Sediment Load Indicators

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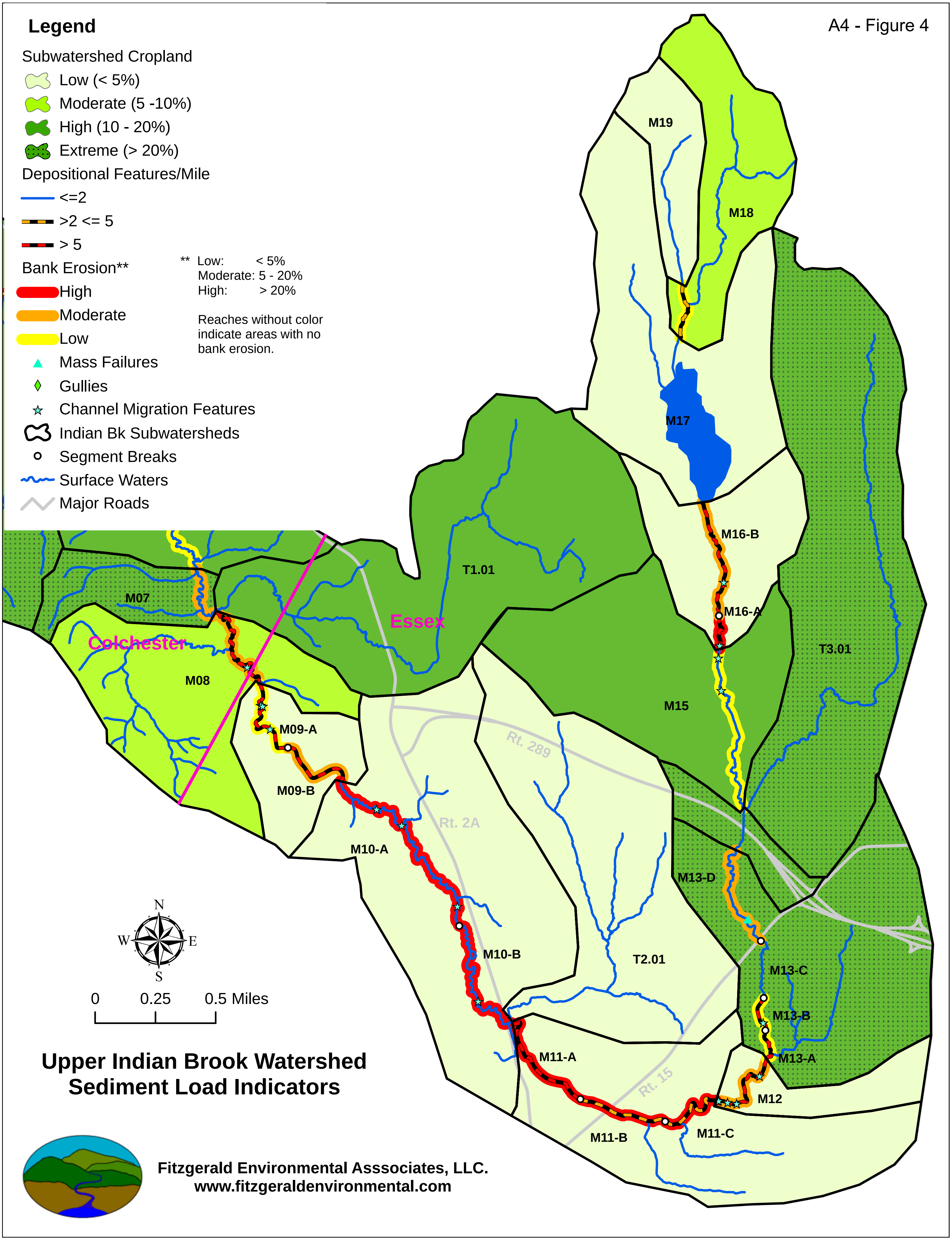
A4 - Figure 4
Legend
Subwatershed Cropland
Low (< 5%)
Moderate (5 -10%)
High (10 - 20%)
Extreme (> 20%)
Depositional Features/Mile
<=2
>2 <= 5
> 5
Bank Erosion**
High
Moderate
Low
Mass Failures
Gullies
Channel Migration Features
Indian Bk Subwatersheds
Segment Breaks
Surface Waters
Major Roads
** Low: < 5%
Moderate: 5 - 20%
High: > 20%
Reaches without color indicate areas with no bank erosion.
M19
M18
M17
M16-B
M16-A
T3.01
T1.01
M15
Essex
Colchester
M07
M08
M09-A
M09-B
M10-A
M10-B
Rt. 289
Rt. 2A
M13-D
M13-C
M13-B
M13-A
M12
T2.01
M11-A
M11-B
M11-C
Rt. 15
N
W
E
S
0
0.25
0.5 Miles
Upper Indian Brook Watershed
Sediment Load Indicators
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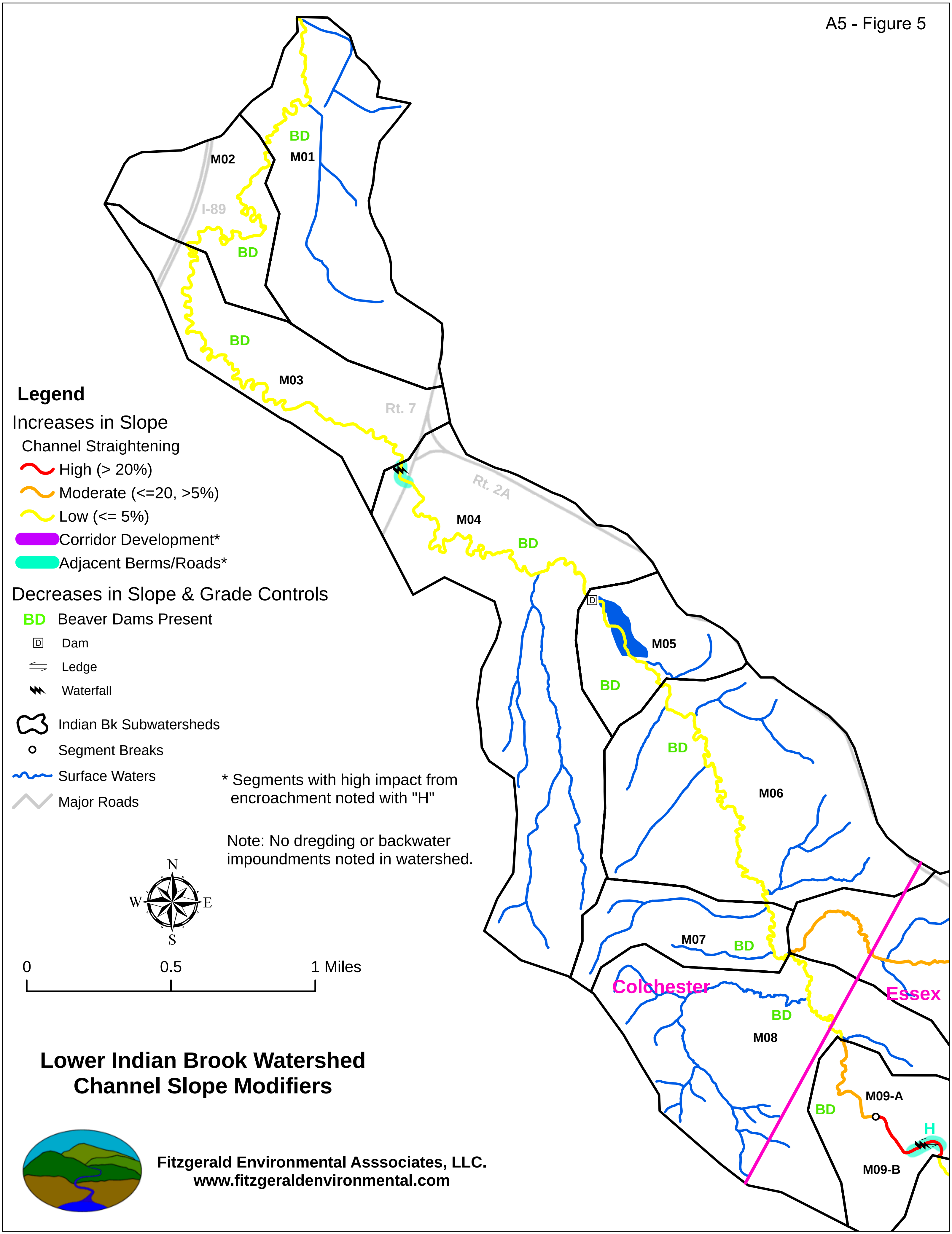
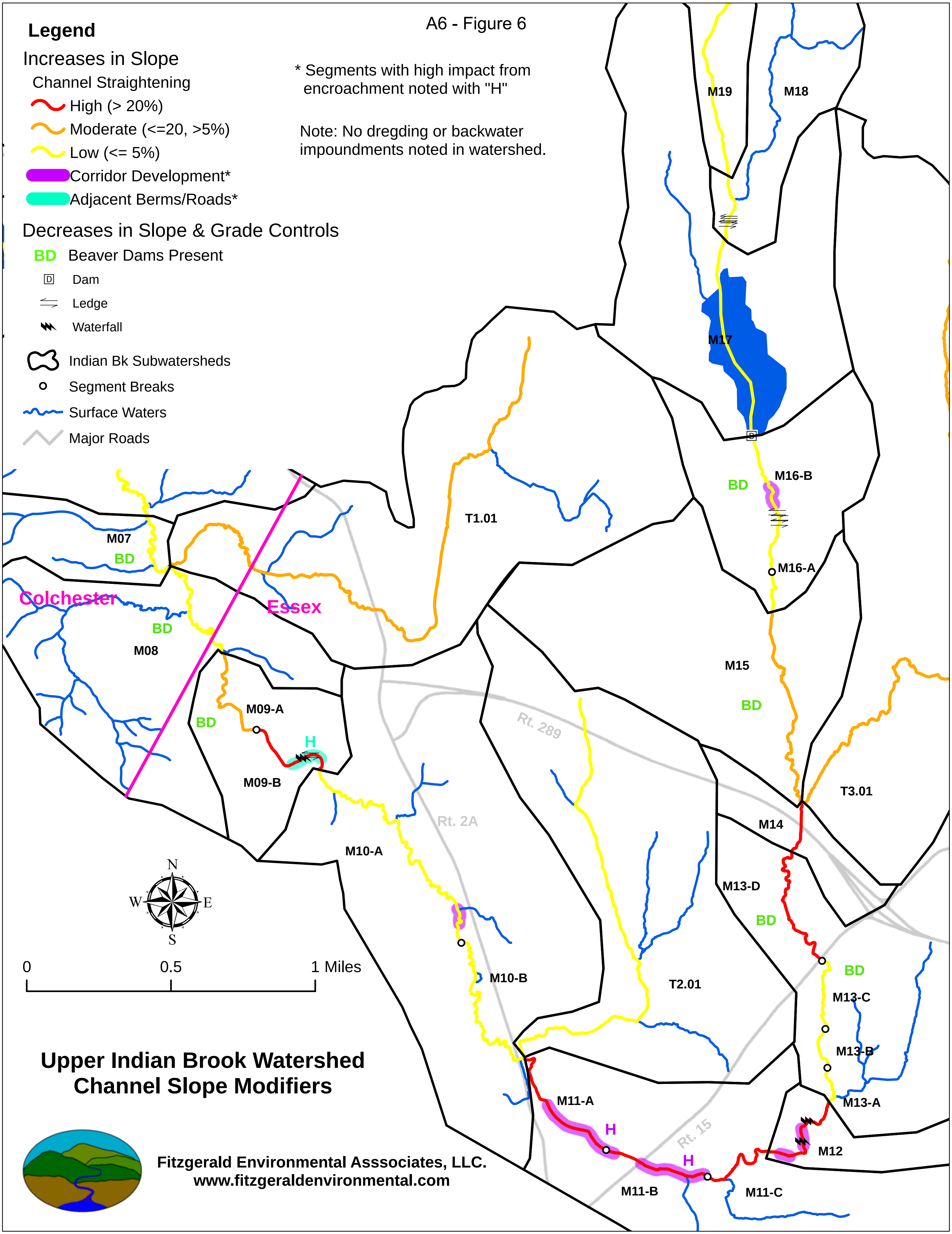
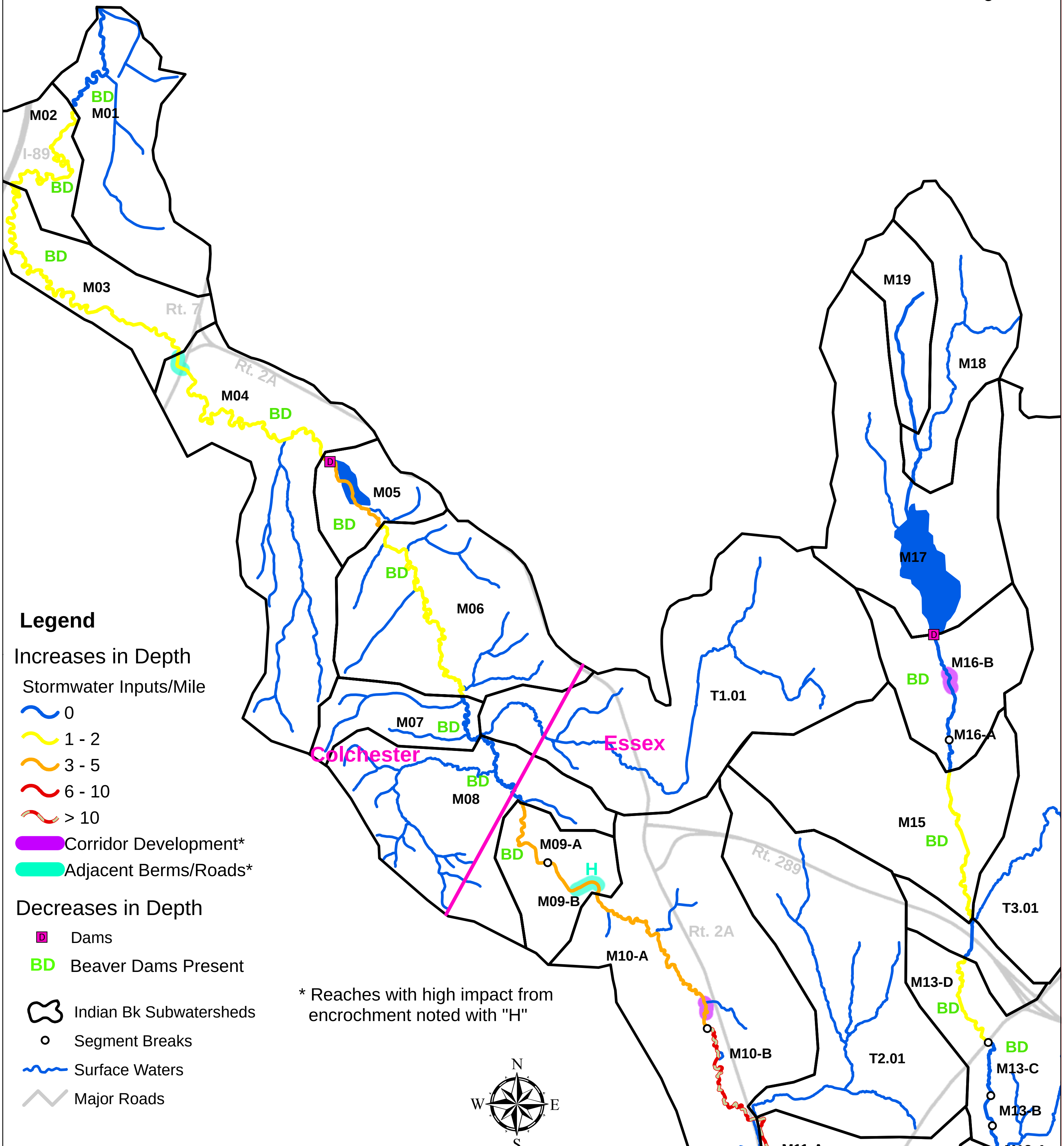

A5 - Figure 5
M01
M02
M03
M04
M05
M06
M07
M08
M09-A
M09-B
BD
I-89
Rt. 7
Rt. 2A
D
H
Colchester
Essex
Legend
Increases in Slope
Channel Straightening
High (> 20%)
Moderate (<=20, >5%)
Low (<= 5%)
Corridor Development*
Adjacent Berms/Roads*
Decreases in Slope & Grade Controls
BD Beaver Dams Present
Dam
Ledge
Waterfall
Indian Bk Subwatersheds
Segment Breaks
Surface Waters
Major Roads
* Segments with high impact from encroachment noted with "H"
Note: No dredging or backwater impoundments noted in watershed.
N
W
E
S
0
0.5
1 Miles
Lower Indian Brook Watershed
Channel Slope Modifiers
Fitzgerald Environmental Asssociates, LLC.
www.fitzgeraldenvironmental.com



A6 - Figure 6

Upper Indian Brook Watershed Channel Slope Modifiers

A7 - Figure 7



Indian Brook Watershed Channel Depth Modifiers

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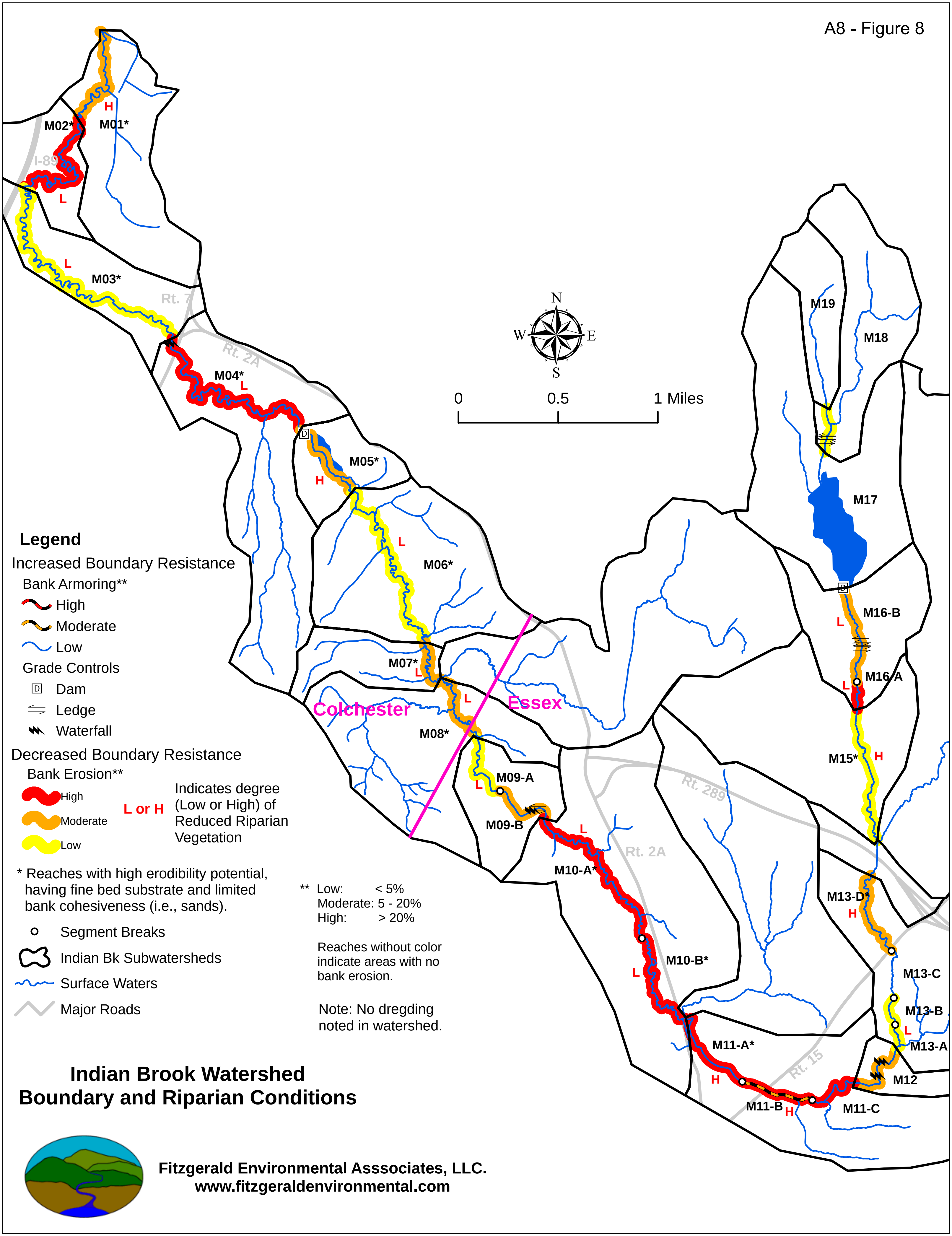
A8 - Figure 8
M01*
M02*
M03*
M04*
M05*
M06*
M07*
M08*
M09-A
M09-B
M10-A*
M10-B*
M11-A*
M11-B
M11-C
M12
M13-A
M13-B
M13-C
M13-D*
M15*
M16-A
M16-B
M17
M18
M19
I-89
Rt. 7
Rt. 2A
Rt. 289
Rt. 15
Colchester
Essex
N
S
E
W
0
0.5
1 Miles
Legend
Increased Boundary Resistance
Bank Armoring**
High
Moderate
Low
Grade Controls
Dam
Ledge
Waterfall
Decreased Boundary Resistance
Bank Erosion**
High
Moderate
Low
L or H
Indicates degree (Low or High) of Reduced Riparian Vegetation
* Reaches with high erodibility potential, having fine bed substrate and limited bank cohesiveness (i.e., sands).
Segment Breaks
Indian Bk Subwatersheds
Surface Waters
Major Roads
** Low: < 5%
Moderate: 5 - 20%
High: > 20%
Reaches without color indicate areas with no bank erosion.
Note: No dregding noted in watershed.
Indian Brook Watershed
Boundary and Riparian Conditions
Fitzgerald Environmental Asssociates, LLC.
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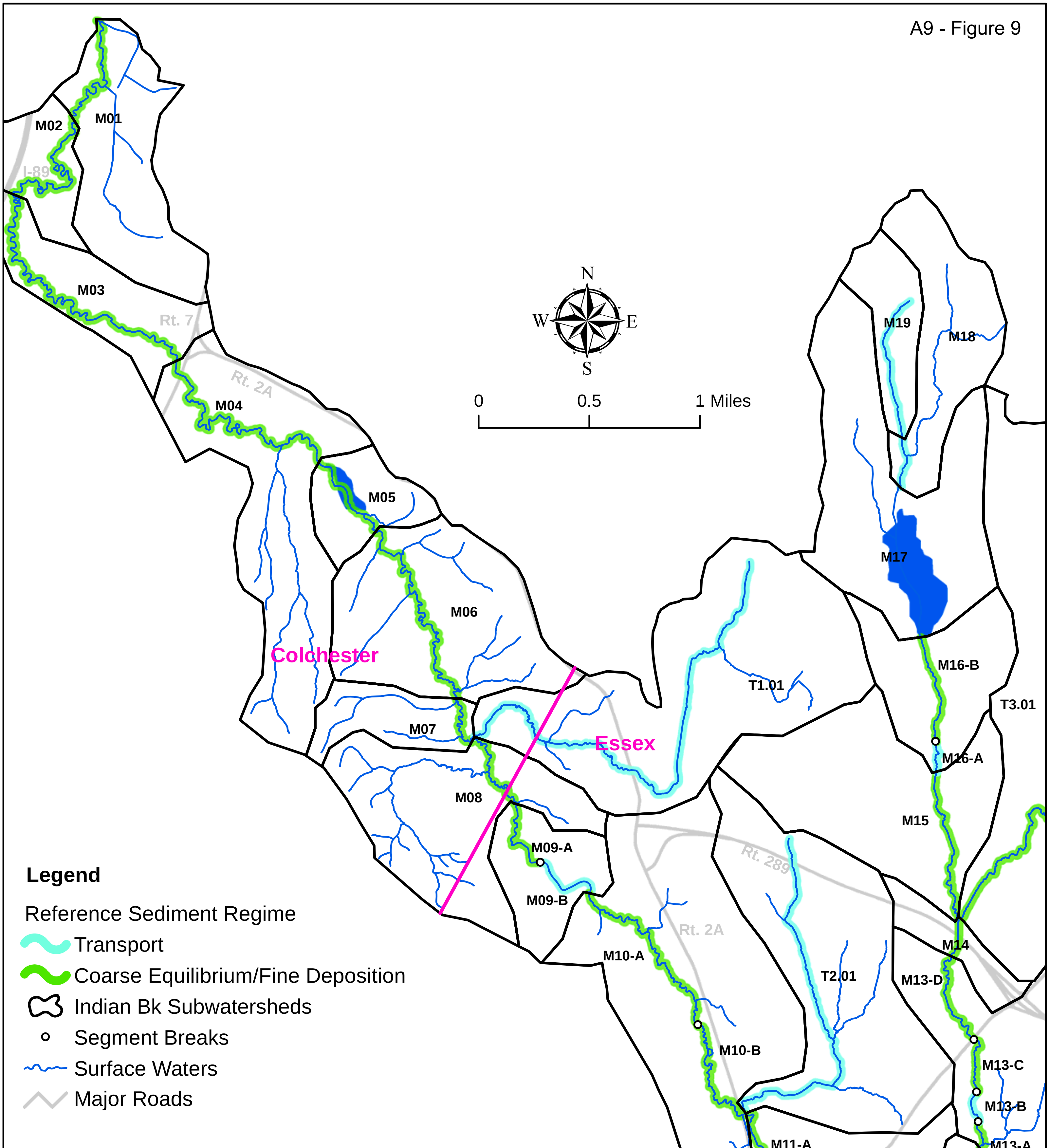

Indian Brook Watershed Reference Sediment Regimes

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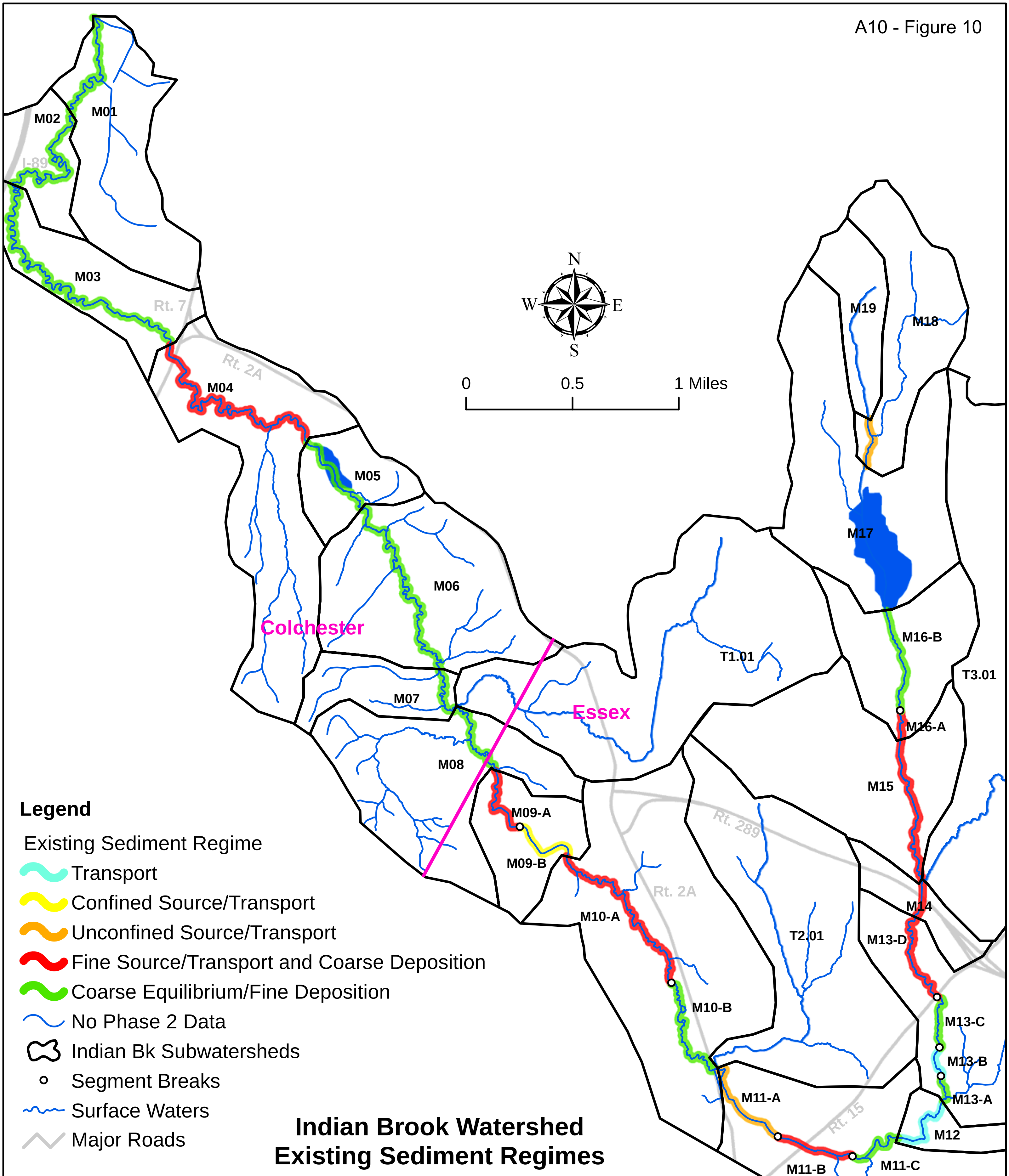

Indian Brook Watershed
Existing Sediment Regimes

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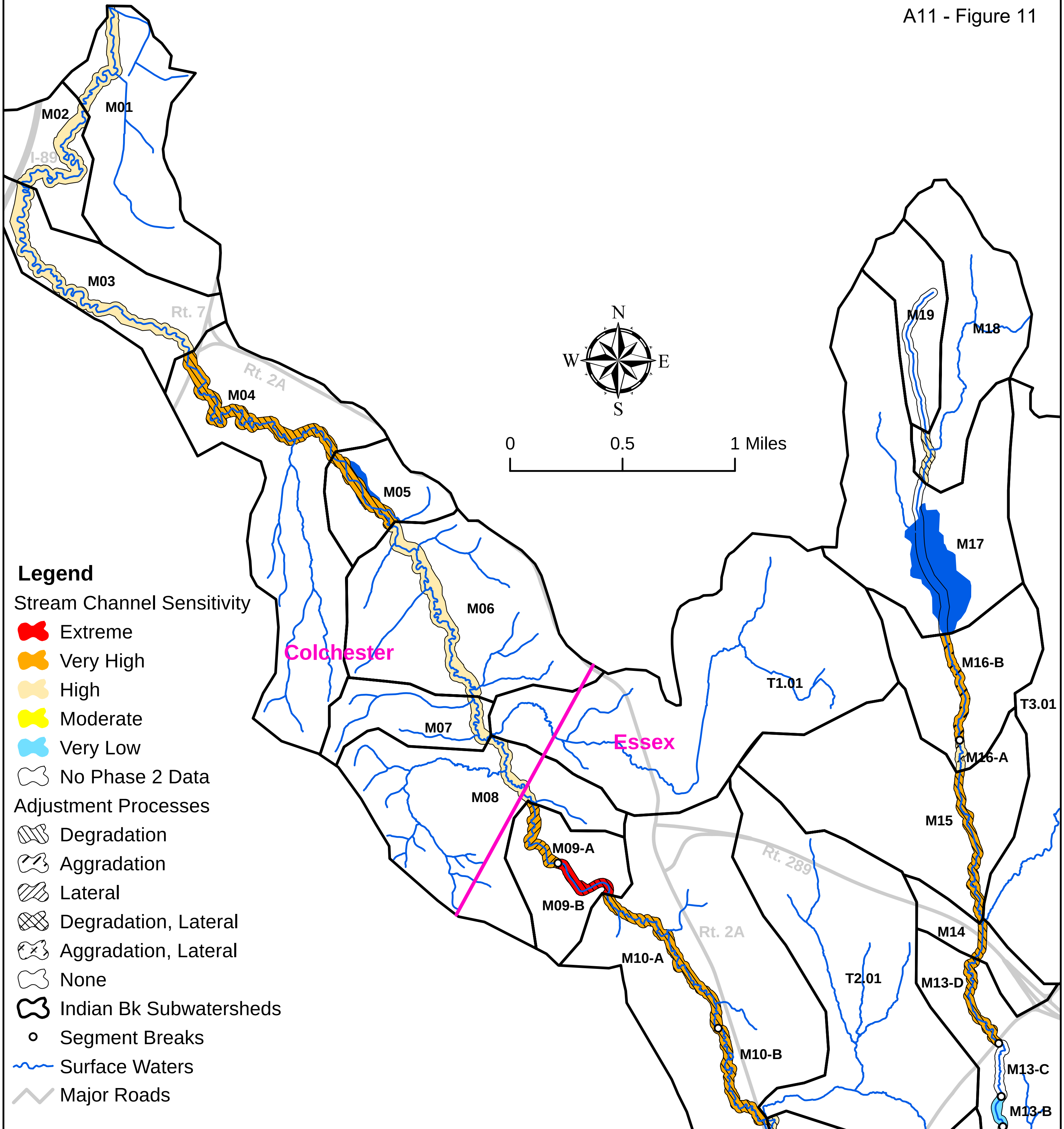

Indian Brook Watershed
Stream Channel Sensitivities
& Adjustment Processes

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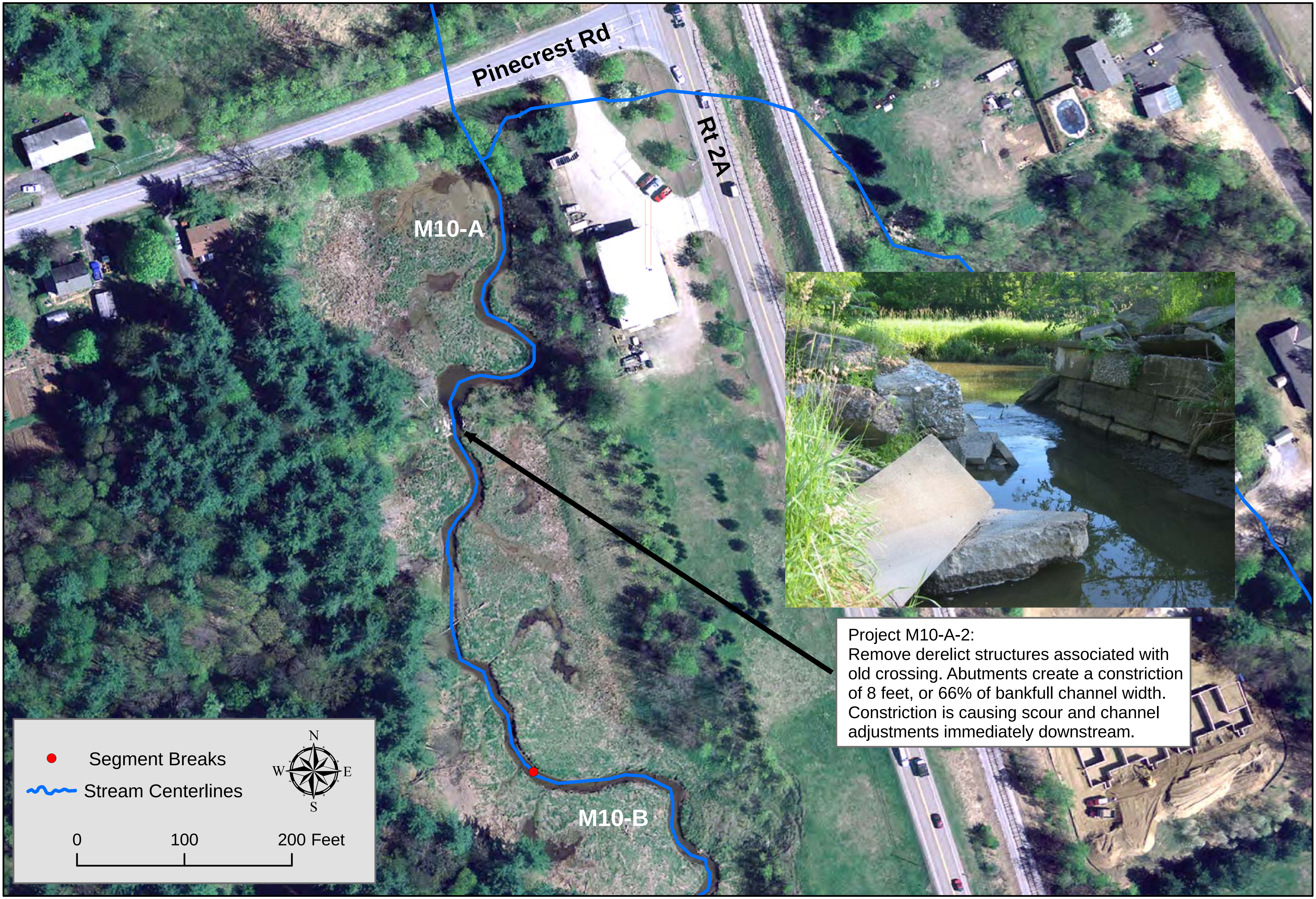

Figure 12
Segment M10-A Project Location

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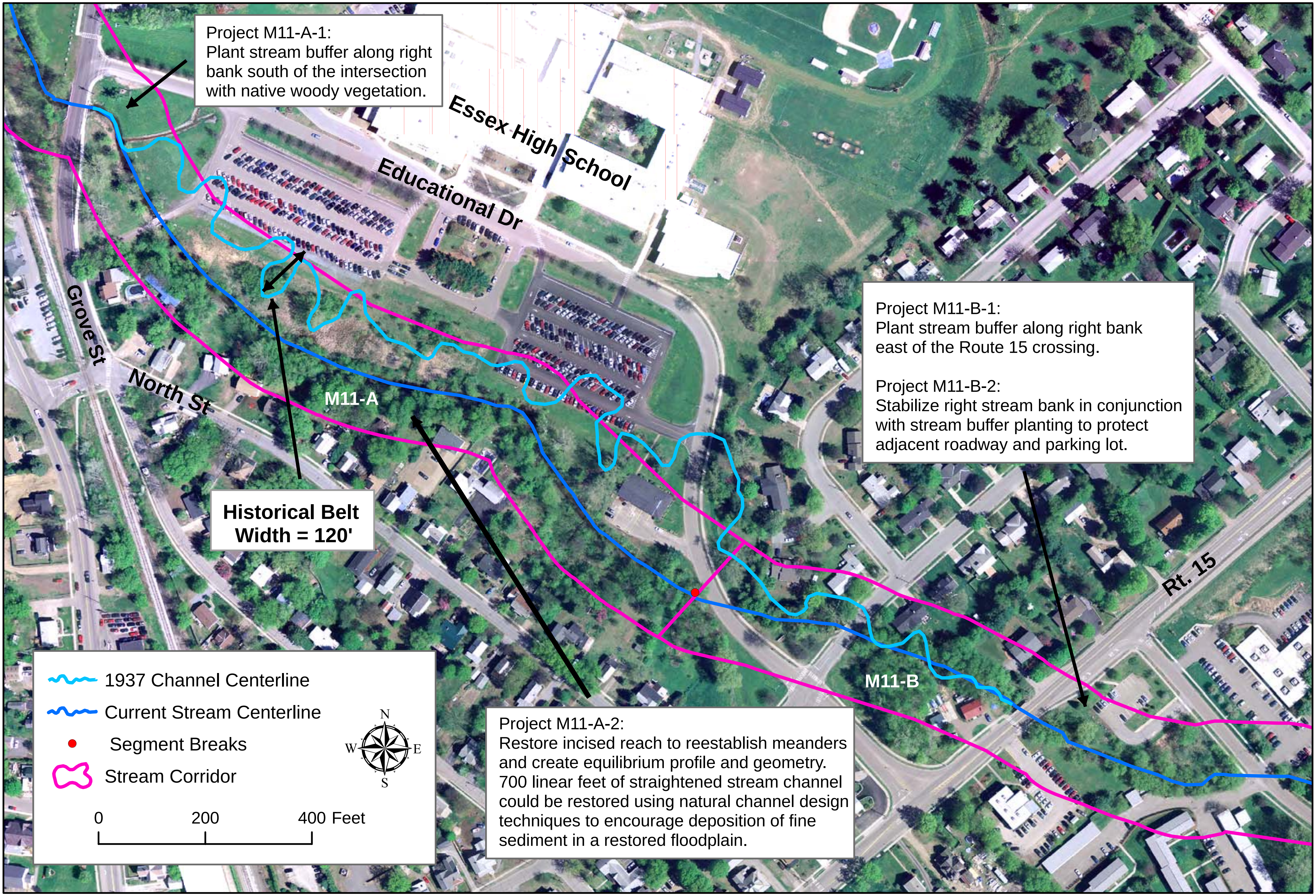

Figure 13
Project Locations for Segments M11-A & M11-B

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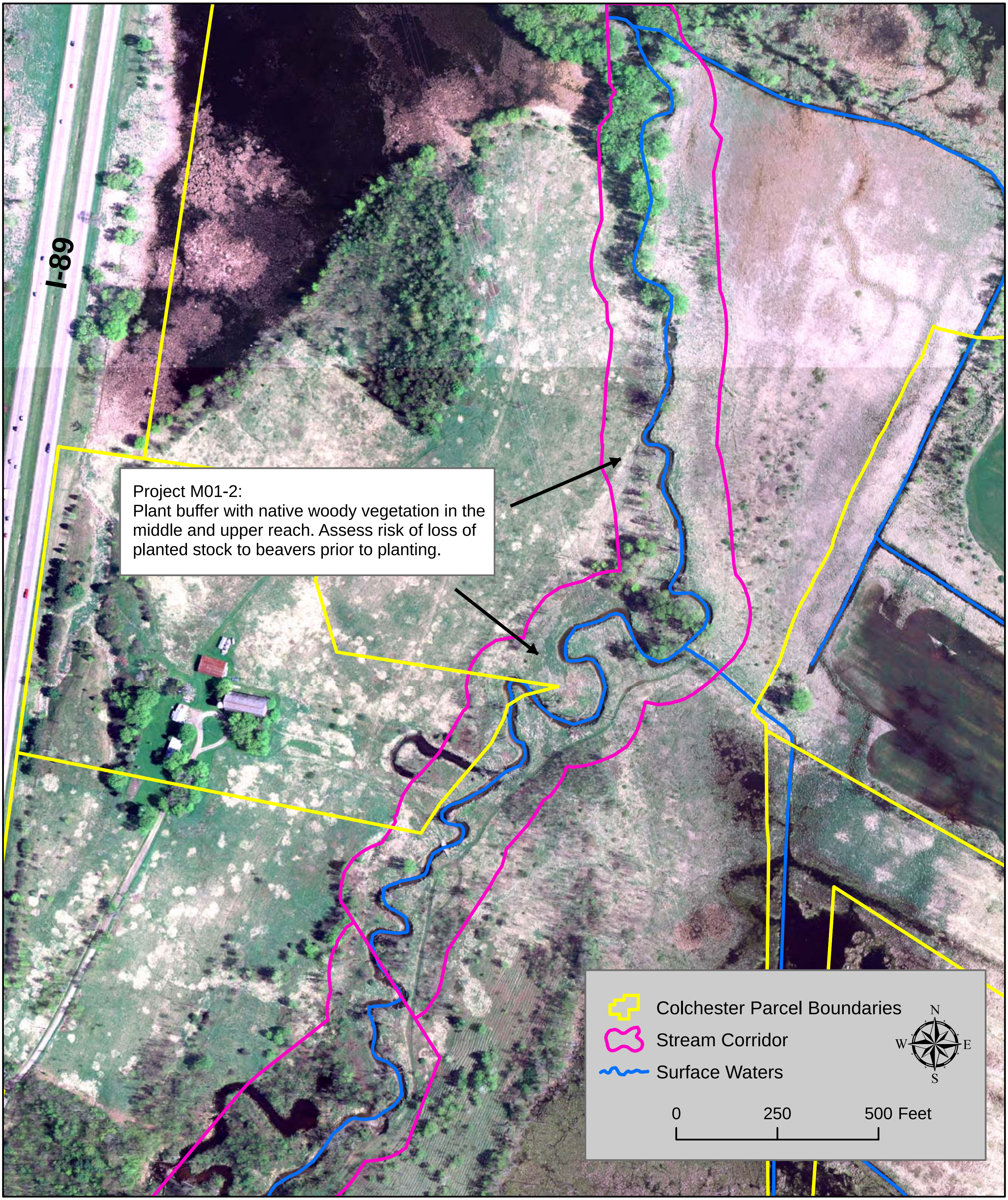

Figure 14
Reach M01 Project Location

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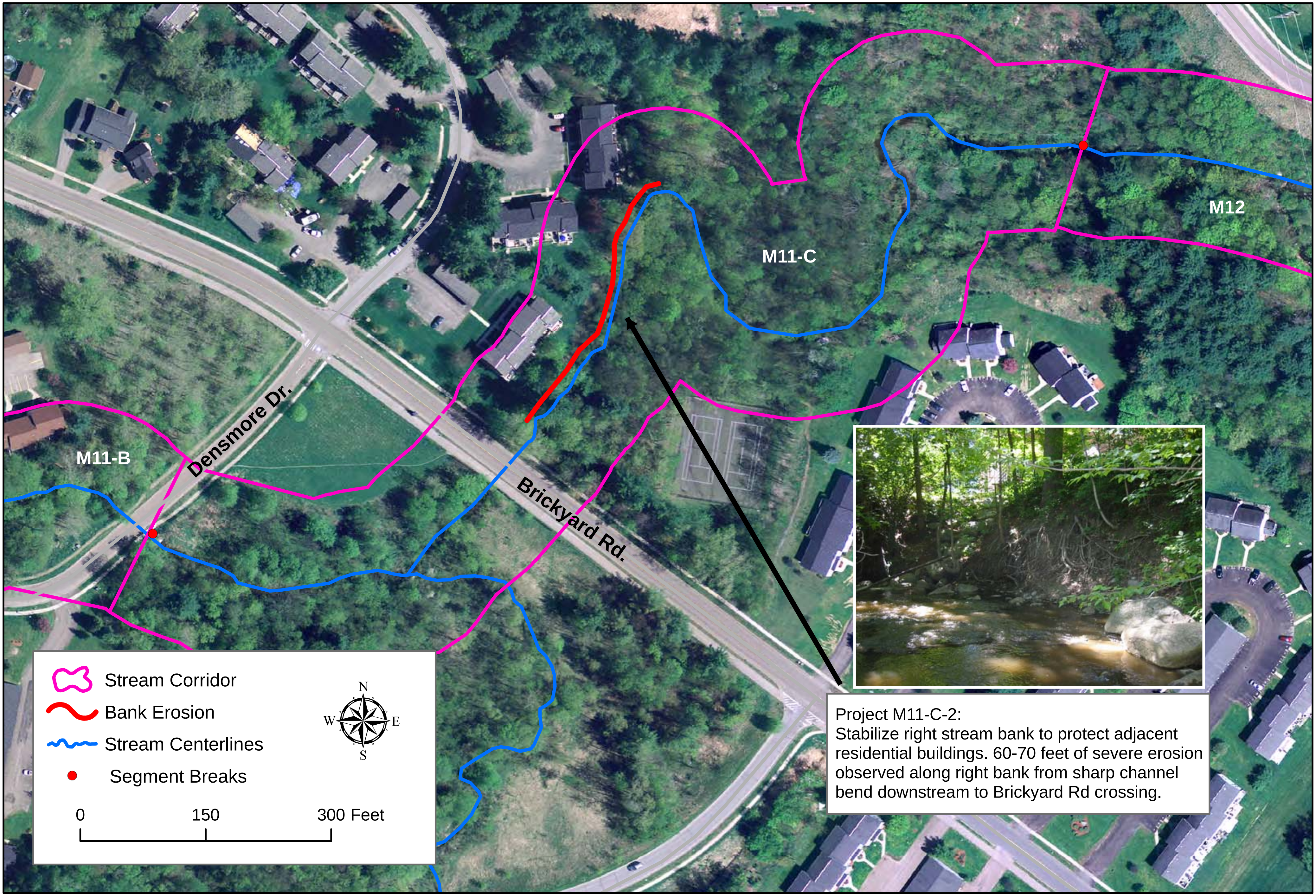

Figure 15
Project Location for Segment M11-C

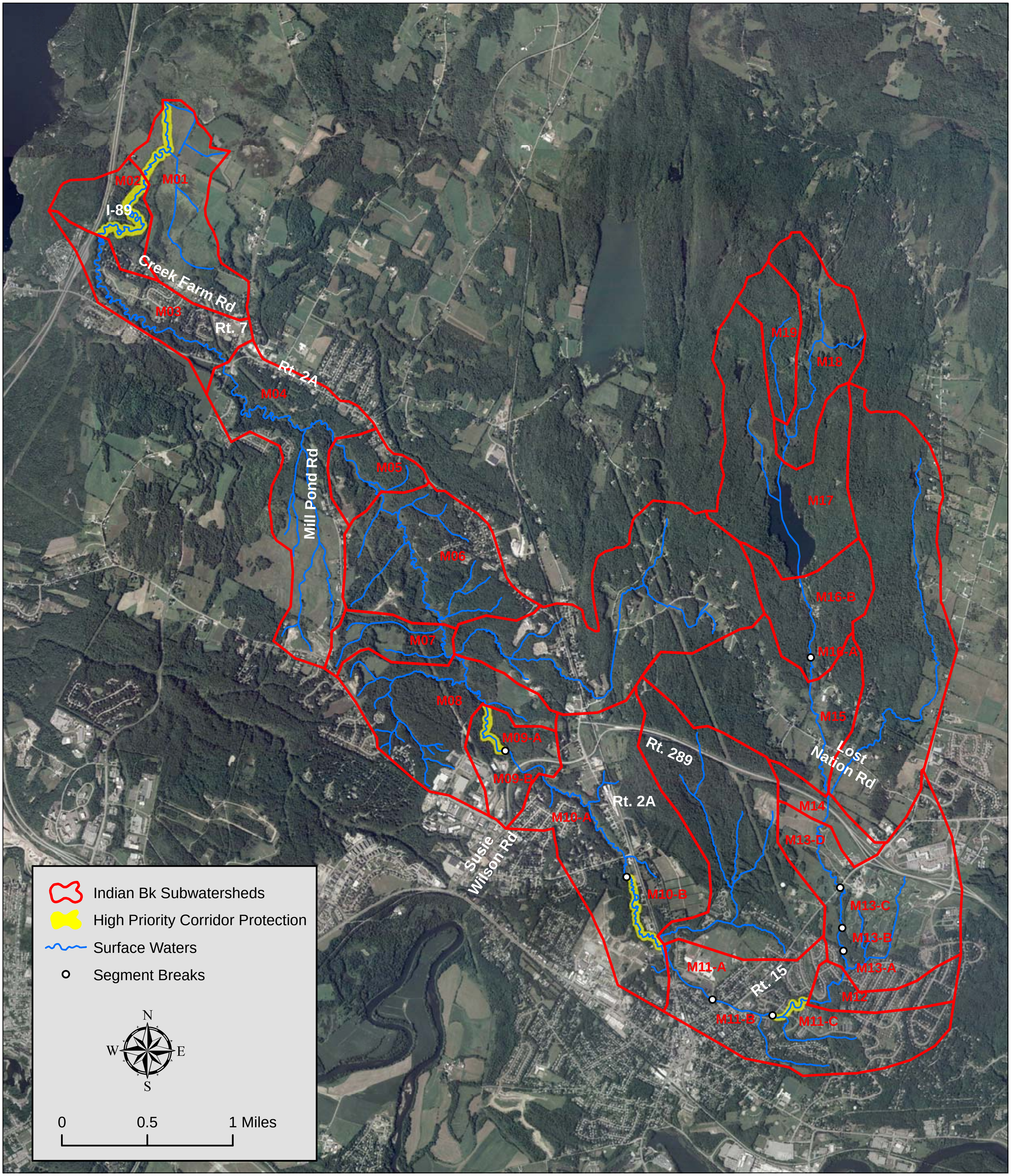

Figure 16
Indian Brook High Priority
Stream Corridor Protection Sites

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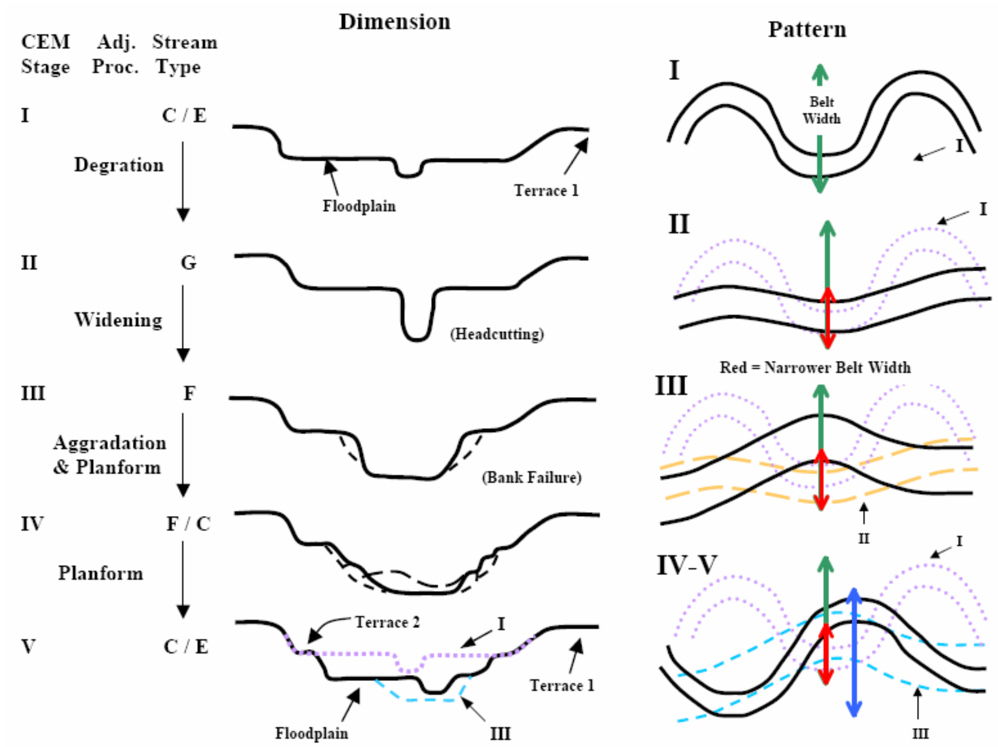
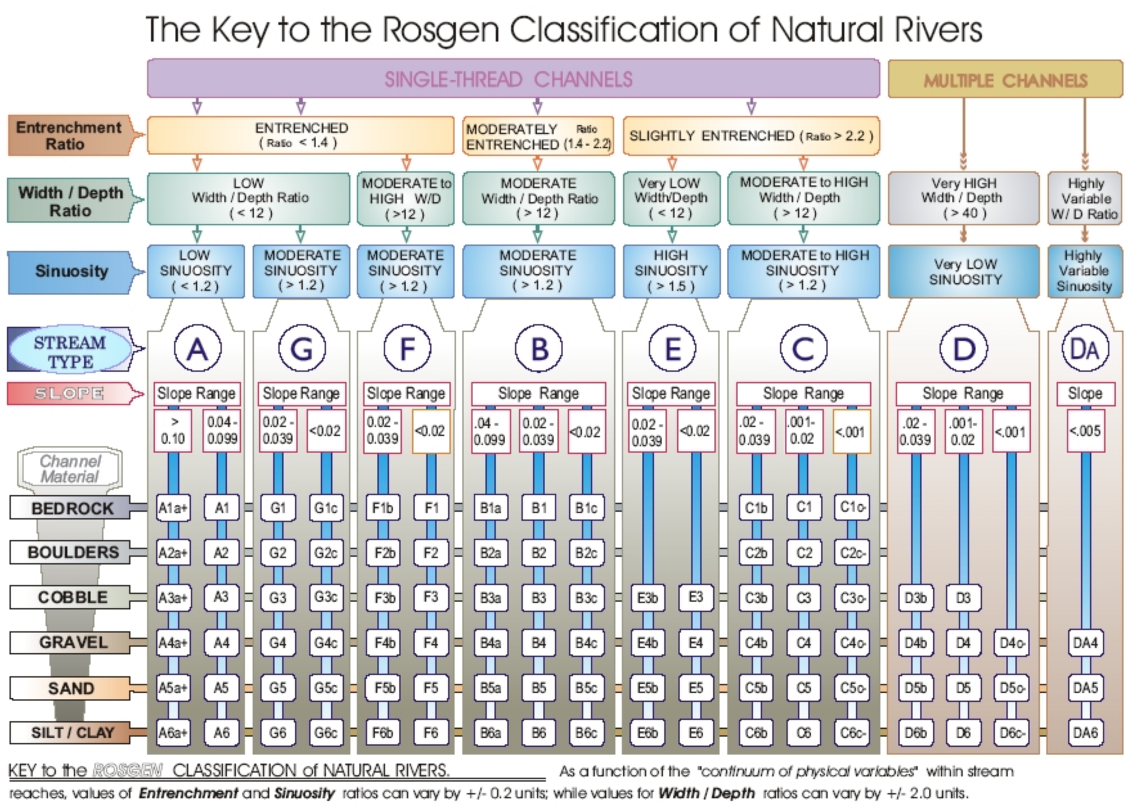
APPENDIX B

SUPPORTING BACKGROUND MATERIALS AND RESEARCH

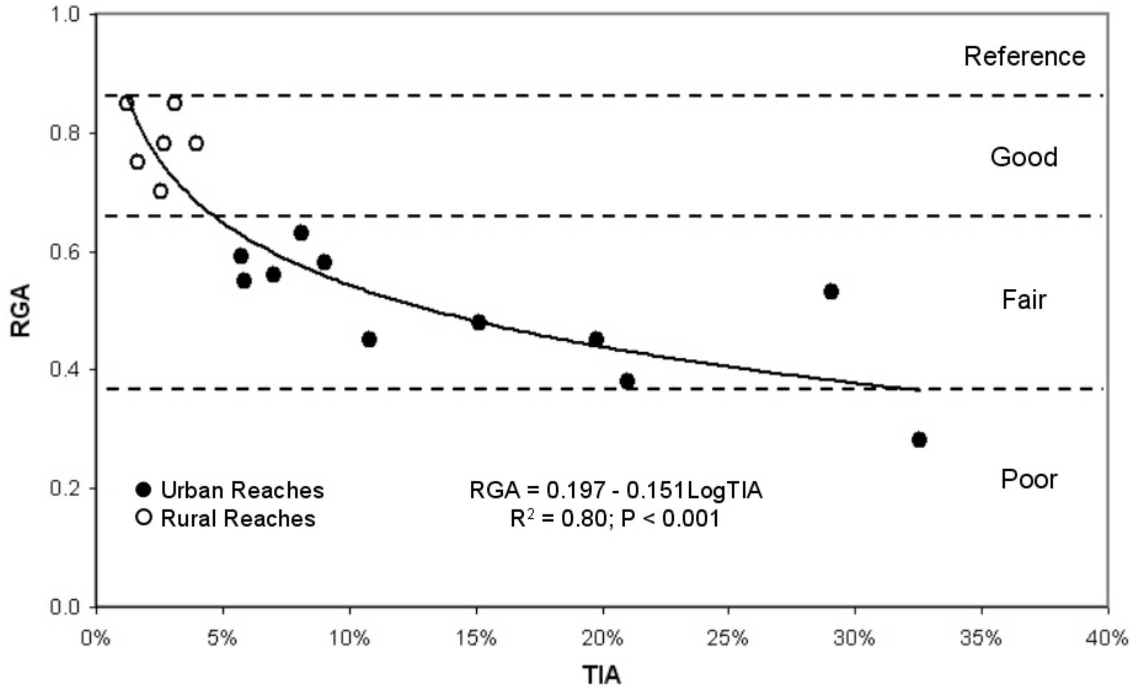


Typical channel evolution processes observed in rivers of VT (modified from Schumm, 1977)

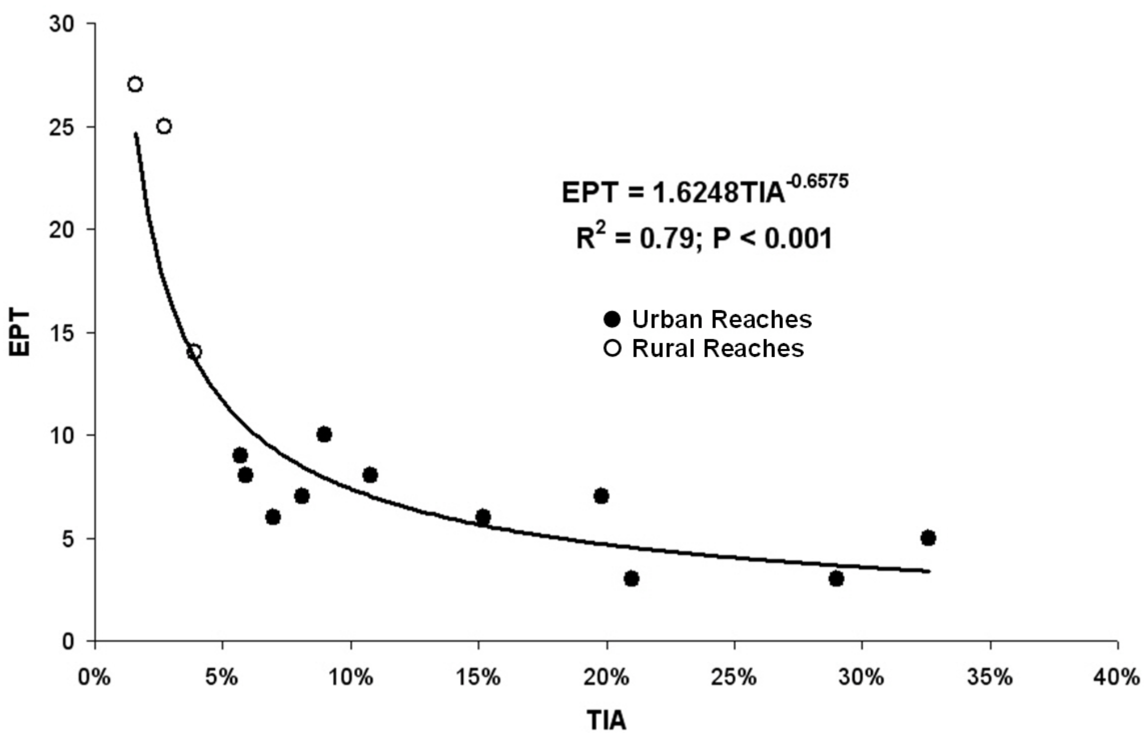


The Rosgen (1994) classification of streams based on channel morphology. Key parameters for classification include 1) the entrenchment ratio (floodprone width / bankfull channel width), 2) width to depth ratio (bankfull width / mean channel depth), and 3) channel sinuosity (channel length / straight-line 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.