Conservation Assessment and Prioritization System (CAPS) South Coast Rail Analysis

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Introduction

CAPS (the Conservation Assessment and Prioritization System) was used to assess several alternative routes of the proposed South Coast Rail system in southeastern Massachusetts. A CAPS analysis was conducted for each of the proposed routes (Attleboro, Stoughton, and Stoughton-Whittenton) and compared to a base scenario representing current conditions. Versions of the Stoughton and Stoughton-Whittenton route were analyzed with and without a trestle through Hockomock Swamp. The CAPS landcover grid was modified to include proposed rail lines, and CAPS was run to estimate the Index of Ecological Integrity (IEI) for each route scenario. The difference between the IEI for each route scenario and the base IEI values provided an estimate of the loss in ecological integrity for that route. These differences are expressed graphically and in terms of IEI units. A sensitivity analysis was run to assess the effect of uncertainty in parameters.

Overview of CAPS

The Conservation Assessment and Prioritization System (CAPS) is an ecosystem-based (coarse-filter) approach for assessing the ecological integrity of lands and waters. We define *ecological integrity* as the ability of an area to support biodiversity and the ecosystem processes necessary to sustain biodiversity, over the long term. CAPS is a computer software program and an approach to prioritizing land for conservation based on the assessment of various ecological communities (e.g. forest, shrub swamp, headwater stream) within an area. This approach combines principles of landscape ecology and conservation biology with the capacity of modern computers to compile spatial data and characterize landscape patterns.

The CAPS approach begins with the characterization of both the developed and undeveloped elements of the landscape (Appendix A). With a computer base map depicting various classes of developed and undeveloped land, we then evaluate a variety of landscape-based variables ("metrics"; Appendix C). A metric may, for example, take into account how well a point in the landscape is connected to similar points, the intensity traffic on nearby roads, or the expected vulnerability to invasions by exotic plants. The results of each metric are rescaled by percentiles for each community so that, for instance, the best 10% of marshes have values ≥ 0.90, and the best 25% have values ≥ 0.75. This is done to adjust for differences in units of measurement among metrics and to account for differences in the range of metric values for each community. The rescaling by community is done to facilitate identifying the "best" of each community, as opposed to the best overall – which is strongly biased towards the dominant, matrix-forming communities.

Various metrics are applied to the landscape and then integrated in weighted linear combinations as models for predicting ecological integrity. The rescaled values are weighted using weights determined by expert teams, to reflect the relative importance of each metric for each community (Appendix D), and then added together to compute an overall IEI. Thus, the final index of ecological integrity for each cell is a weighted combination of the metric outputs for that cell, based on the community the cell falls in. This process results in a final Index of Ecological Integrity (IEI) for each point in the landscape based on models constructed separately for each ecological community.

Because CAPS provides a quantitative assessment of ecological integrity it can be used for comparing various scenarios. In essence, scenario analysis involves running CAPS separately for each scenario, and comparing results to determine the loss (or gain) in IEI units. This scenario testing capability can be used to evaluate and compare the impacts of development projects on habitat conditions as well as the potential benefits of habitat management or environmental restoration. CAPS is an objective and flexible approach for assessing ecological integrity and supporting decision-making for land protection, habitat management, ecological restoration, project review and permitting to protect habitat and biodiversity.

Methods

This analysis was based on the most recent CAPS statewide run (CAPSma 2009; Conservation Assessment and Prioritization System (CAPS) Preliminary Statewide Massachusetts Assessment, June 2, 2009), with modifications as necessary to more fully represent the effects of railroads.

Study area – The study area consisted of the entire Taunton watershed, plus a 5 km buffer around the Northeast Main Line, the New Bedford Corridor, and all rail lines included in various scenarios (Fig. 1). This buffer allows CAPS to capture all changes in

IEI among scenarios. Using the entire Taunton watershed gives CAPS a large enough context to reasonably scale IEI.

Scenarios – Six scenarios were represented in the analysis (scenario abbreviations, used in grid names, are supplied in brackets):

1. [X] Current (base) scenario
2. [A] Attleboro
3. [S] Stoughton at grade
4. [ST] Stoughton with trestle
5. [W] Stoughton-Whittenton at grade
6. [WT] Stoughton-Whittenton with trestle

The base scenario represents the current conditions. It was determined that the Rapid Bus alternative would essentially be the same as the base scenario because this alternative would at most differ in CAPS only in a very slight increase in traffic rate (on the order of 0.01%). In fact one could argue that the bus scenario would actually result in a decrease in traffic.

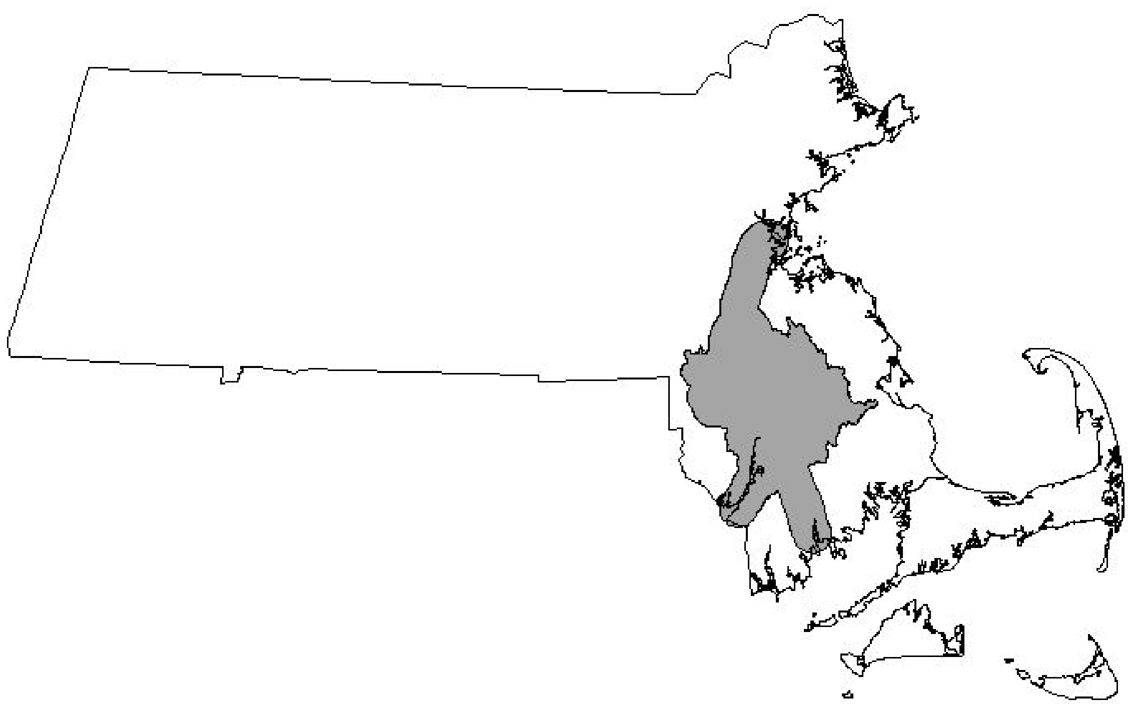

Fig. 1. Study area for South Coast Rail analysis.

Representing rail lines – We added several new cover types to CAPS to adequately represent rail lines. We split the abandoned rail class into “abandoned rail with tracks” and “abandoned rail without tracks.” New classes were added for freight, passenger, and commuter rail lines, as well as “commuter rail line with a trestle” and “commuter rail line with a retaining wall." Abandoned rail lines represented in CAPS (from MassGIS trains layer) were considered to have no tracks. Existing abandoned rails were replaced where they were more accurately represented in SCR data. The classes of trains (freight, passenger, commuter, and combinations of these) were derived from MassGIS data and SCR data. The number of tracks on each line were estimated based on supplied track numbers in MassGIS data. In general, lines from SCR scenarios were represented as having two sets of tracks, with the exception of the Northeast Corridor from Readville to the Attleboro bypass, which has three sets.

The frequency of trains was estimated as 2 trains/day for freight, as 33 trains/day for commuter (based on a survey of MBTA schedules), and passenger lines were assigned a number of trains/day by line from Amtrack schedules, varying from 2 to 20 trains/day. The number of cars per train were estimated at 25 for freight, 8 for passenger, and 6 for commuter rail.

Abandoned rail beds without tracks were assumed to have lost their ballast due to erosion over time; abandoned rails with tracks were assumed to have retained ballast. All rails were assumed to be unfenced; although commuter rails are generally fenced in populated areas, these areas generally have little value in CAPS anyway.

Parameters for rail lines – New cover types were parameterized by an expert team consisting of Mark Anderson, Andy Finton, and Jessica Dyson, from The Nature Conservancy, James deNormandie from MassAudubon and MassWildlife, and Brad Compton and Scott Jackson from UMass Amherst. The group met on July 16 and came up with a scheme for parameterizing a new variable, terrestrial barriers (Table 1; including barriers on highways and other anthropogenic barriers to movement). This expert team also decided to represent traffic rates for rails based on a multiple of the estimated number of train cars per day. We discounted the traffic rate for trains running over a trestle because collision mortality would be essentially eliminated, although avoidance because of noise would remain essentially unchanged. Parameters used for trains are shown in Table 2. Rail stations were given the same values as the commercial and industrial land cover class.

Analysis – CAPS was run for each scenario. Watershed metrics, which are essentially unaffected by the various scenarios, were used directly from the 2009 statewide run. Direct loss (where rail lines or stations fell on undeveloped land) was calculated by the complete loss of IEI for affected cells. Indirect loss was calculated for each metric, and the integrity model was used to create an overall indirect loss grid for each scenario. Finally, direct and indirect losses were combined to give a delta grid for each scenario. A sensitivity analysis was conducted by varying the relative traffic rate for trains from 1 train car = 5 automobiles to 1 train car = 100 automobiles. The sensitivity analysis was run for the three metrics that are affected by traffic rate: connectedness, similarity, and traffic intensity. The sensitivity analysis gives a range of percent loss for each scenario, to help bracket our uncertainty.

Appendices – Land cover classes and codes are given in Appendix A. Input data sources are described in Appendix B. Appendix C describes the CAPS metrics, and

Appendix D gives the weights used for each metric and community or group of communities. Appendix E lists the GIS grids and coverages supplied with the results. Finally, Appendix F includes detailed images of the IEI change grids.

Table 1. Scheme for assigning values for terrestrial barriers. A feature with multiple values (e.g., double rail with ballast) is assigned the sum of the maximum value and one half of other values.

Value	Terrestrial Barriers
1	No barrier Abandoned rail without tracks Trestle (≥ 3 m high)
2	Single set of rails Ballast Trestle (<3 m high)
3	Standard fence* Double set of rails Abandoned rail with tracks Single rail + ballast
4	Double rail + ballast [Triple rail + ballast =4.5]
5	
6	
7	Jersey barrier
8	Enhanced fence†
9	
10	Noise barrier wall Retaining wall

* Standard fence = 4’ chain link, poorly maintained
† Enhanced fence = 10’ chain link, barbed ware on top, well-maintained

Table 2. Assignment of scores for terrestrial barriers and traffic rate for rail lines.

Rail type	Ballast?	Number of tracks	Fence?	Terrestrial barrier score	Trains/ day	Cars/train	Traffic rate
Rail trail	No	0	No	1	0	0	cars/day × 20*
Abandoned railbed no tracks	No	0	No	1	0	0	
Abandoned rail with tracks	Yes	1-3	No	single track: 3 double track: 4 triple track: 4.5	0	0	
Train (freight)	Yes	1-3	No		2	25	
Train (passenger)	Yes	1-3	No		*ntrains*	8	
Train (commuter)	Yes	1-3	No		33	6	
Train (freight + passenger)	Yes	1-3	No		Combined	Combined	
Train (freight + commuter)	Yes	1-3	No				
Train (passenger + commuter)	Yes	1-3	No				
Train (freight + passenger + commuter)	Yes	1-3	No				
Train (retaining wall)	No	1-3	Retaining wall: 10	10	33	6	
Train (trestle)†	No	0	No	2	33	6	As above / 3

* Varied for sensitivity analysis, range from 5-100.
† Assumed to be commuter rail.

Results

The results of the CAPS scenario analysis are shown graphically in Fig. 2, Appendix F, and summarized in Table 3. Overall the two routes through Hockomock Swamp showed the greatest estimated loss in ecological integrity, followed by the Attleboro route with considerably less influence (77-80% of the loss for the various Stoughton and Stoughton-Whittenton alternatives). The trestle alternatives through Hockomock Swamp reduced the modeled loss of ecological integrity somewhat, although many of the benefits of a trestle are likely to occur at a local scale below that of the CAPS analysis.

Differences among the various scenarios are obscured to some degree by large sections of the routes common to all the alternatives. To better highlight the differences among the scenarios we computed IEI loss for each scenario only for those sections that were not shared among all alternatives (Fig. 3, Table 3). Focusing only on those sections of the routes that differ among the alternatives serves to further differentiate the Attleboro route as the alternative with the least impact on IEI values.

Table 3. Assessment of South Coast Rail scenarios in terms of IEI units.

Scenario	Loss of IEI Units Full Extent	Loss of IEI Units Excluding Common Route Sections
Base	0.0	0.0
Attleboro	379.3	206.8
Stoughton with trestle	474.5	302.0
Stoughton-Whittenton with trestle	481.8	309.3
Stoughton at grade	484.6	312.1
Stoughton-Whittenton at grade	492.0	319.5

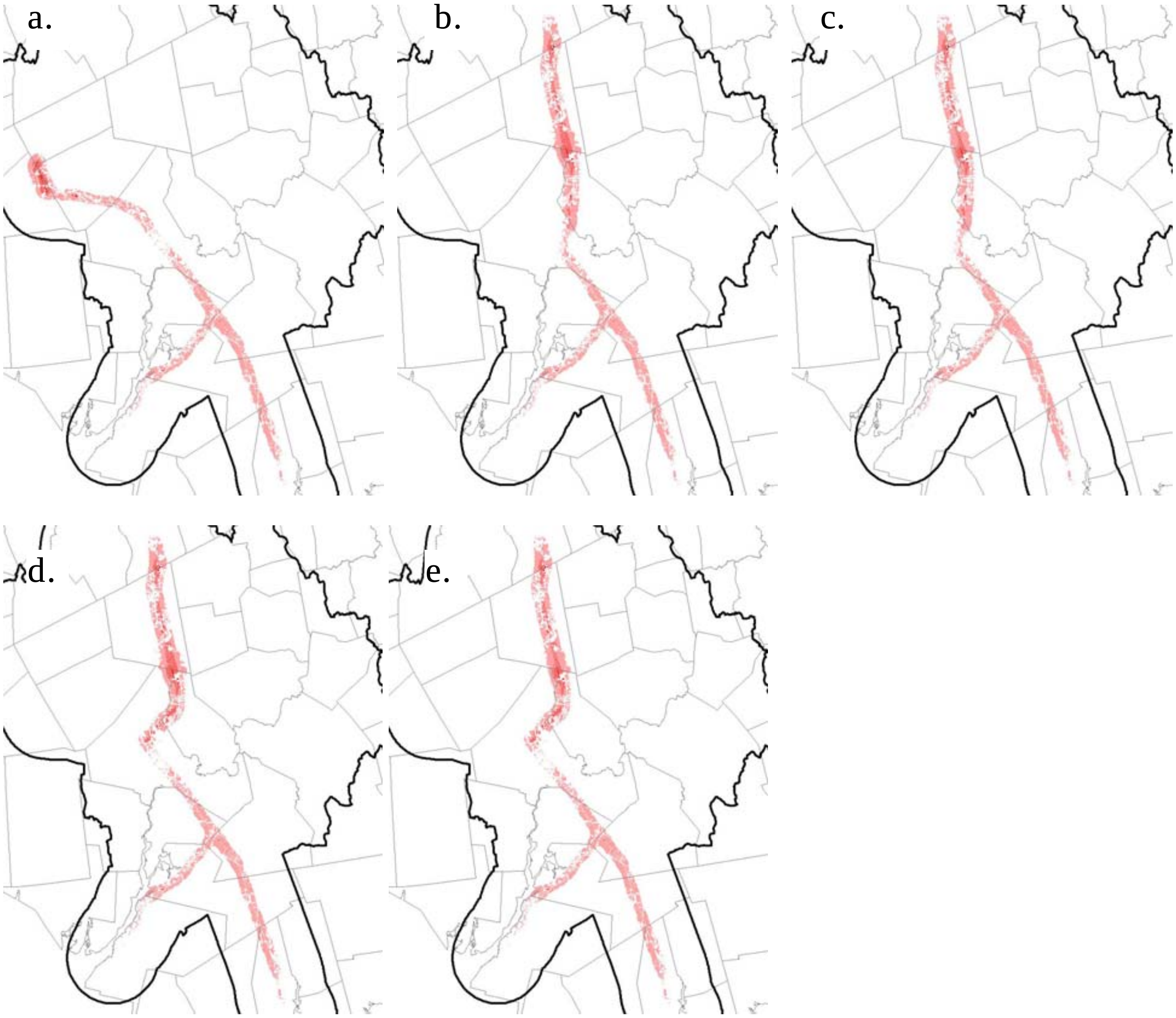

Fig. 2. Modeled loss in ecological integrity for (a) the Attleboro route, (b) the Stoughton route at grade, (c) the Stoughton route with the proposed trestle, (d) Stoughton-Whittenton route at grade, and (e) the Stoughton-Whittenton route with the proposed trestle. Darker areas represent greater loss. See Appendix F for more detailed versions of these images.

Table 4 shows loss split into direct loss (within the footprint of new development) and indirect loss. Not surprisingly, direct loss is a small proportion of the total IEI loss, mostly attributable to stations, because most of the rails would run on land already mapped as developed (such as abandoned rail beds).

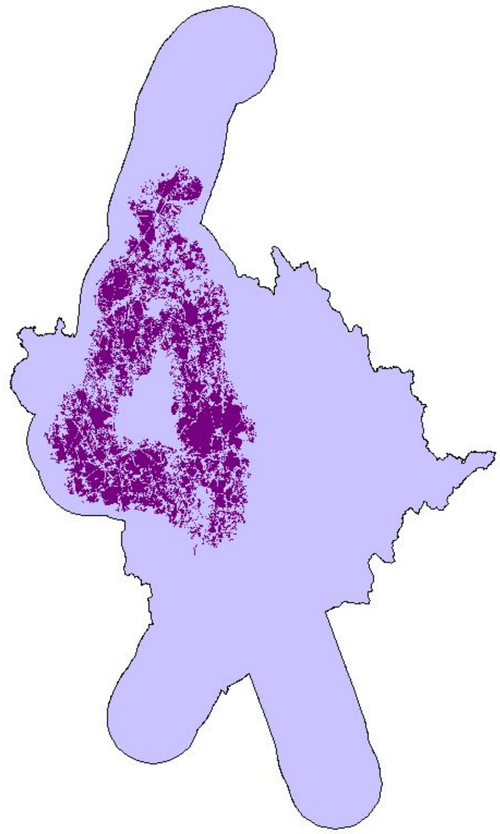

Fig. 3. Areas (denoted in purple) in which the IEI of two or more scenarios differ from each other. Areas that are not highlighted are either unaffected by any of the scenarios, or affected identically by all scenarios.

Table 4. Loss of IEI Units (from Table 3) split into direct and indirect loss.

Scenario	Direct loss (IEI units)	Indirect loss (IEI units)
Base	0.0	0.0
Attleboro	54.6	324.8
Stoughton with trestle	17.6	456.9
Stoughton-Whittenton with trestle	17.7	464.1
Stoughton at grade	17.6	467.1
Stoughton-Whittenton at grade	17.7	474.3

Results of the sensitivity analysis for three metrics, showing the range of expected results given the uncertainty in the effects of train traffic, are given in Table 5. Note that the ranking of the scenarios does not change under either the high or low traffic parameterization, and only the Attleboro route shows more than a very slight change in percent as compared to the worst-case scenario. The sensitivity analysis suggests that our uncertainty in parameterizing traffic effects of railroads has only a minor effect on the results. (Note that these losses are not directly comparable with those in Table 3, because the sensitivity analysis only takes three metrics into account.)

Table 5. Results of sensitivity analysis for three metrics (connectedness, similarity, and traffic intensity), showing range of loss in acres and loss in terms of percent of worst-case scenario for each scenario, given uncertainty in equivalent traffic rates of trains.

	Loss in IEI units		Range in percent	
Scenario	**Minimum**	**Maximum**	**Minimum**	**Maximum**
Base	0.0	0.0	0.0	0.0
Attleboro	325.5	367.9	82.5	71.2
Stoughton with trestle	379.6	500.5	96.2	96.9
Stoughton-Whittenton with trestle	384.6	506.8	97.5	98.1
Stoughton at grade	390.0	510.4	98.8	98.8
Stoughton-Whittenton at grade	394.6	516.7	100.0	100.0

The bulk of the effect of these scenarios is reflected in three metrics: connectedness, similarity, and traffic intensity. Connectedness, with its broader scale and integration of landscape resistance, is the most relevant single metric. Images of connectedness deltas are shown for four focal areas: Assonet Swamp (Fig. 4), Hockomock Swamp (Fig. 5), Pine Swamp (Fig. 6), and the Attleboro Bypass area (Fig 7). Note that the color gradient used in these four figures are the same, thus they are visually comparable.

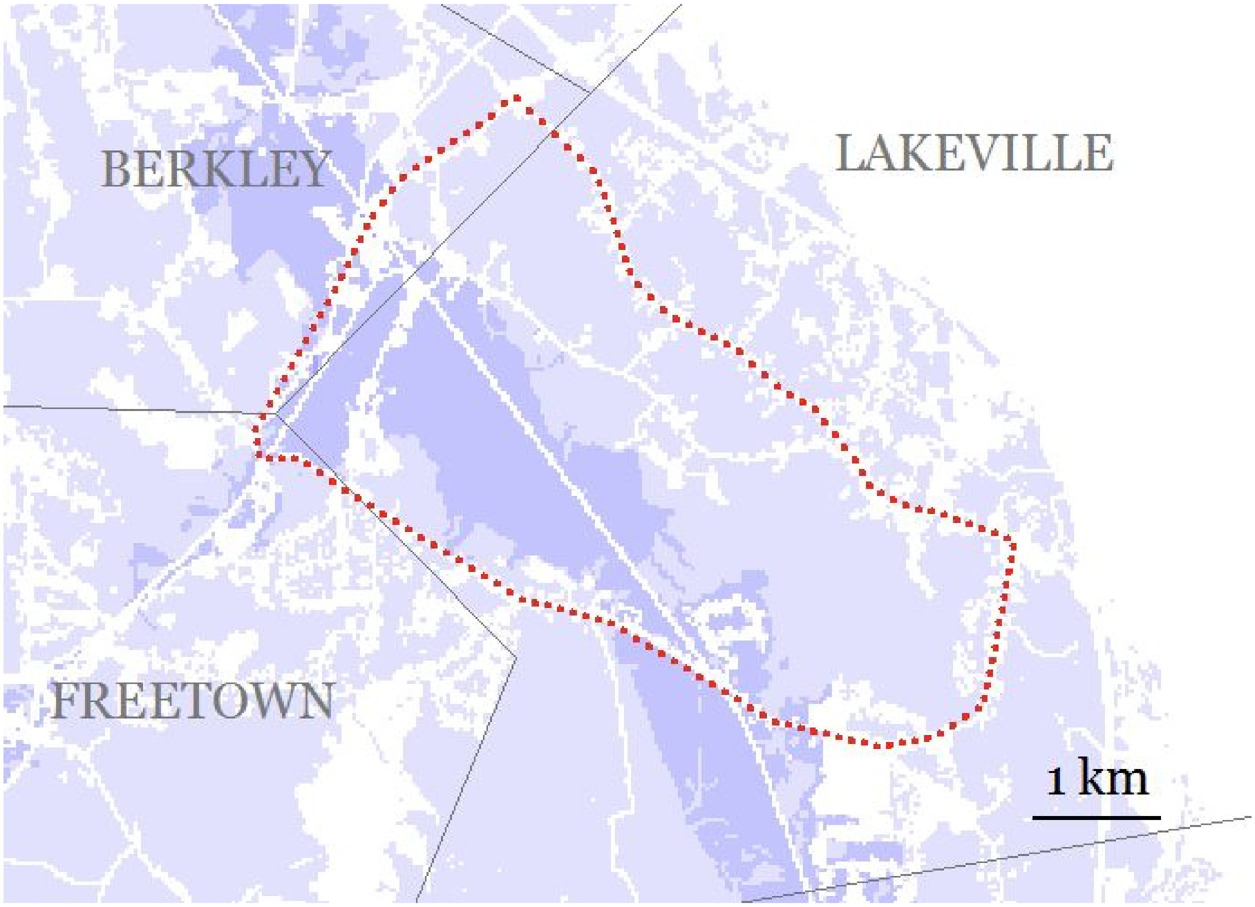

Fig. 4. Connectedness delta (darker areas = higher loss) for Assonet Swamp focal area for all scenarios. Note that color gradient is scaled the same for Figs. 4-7.

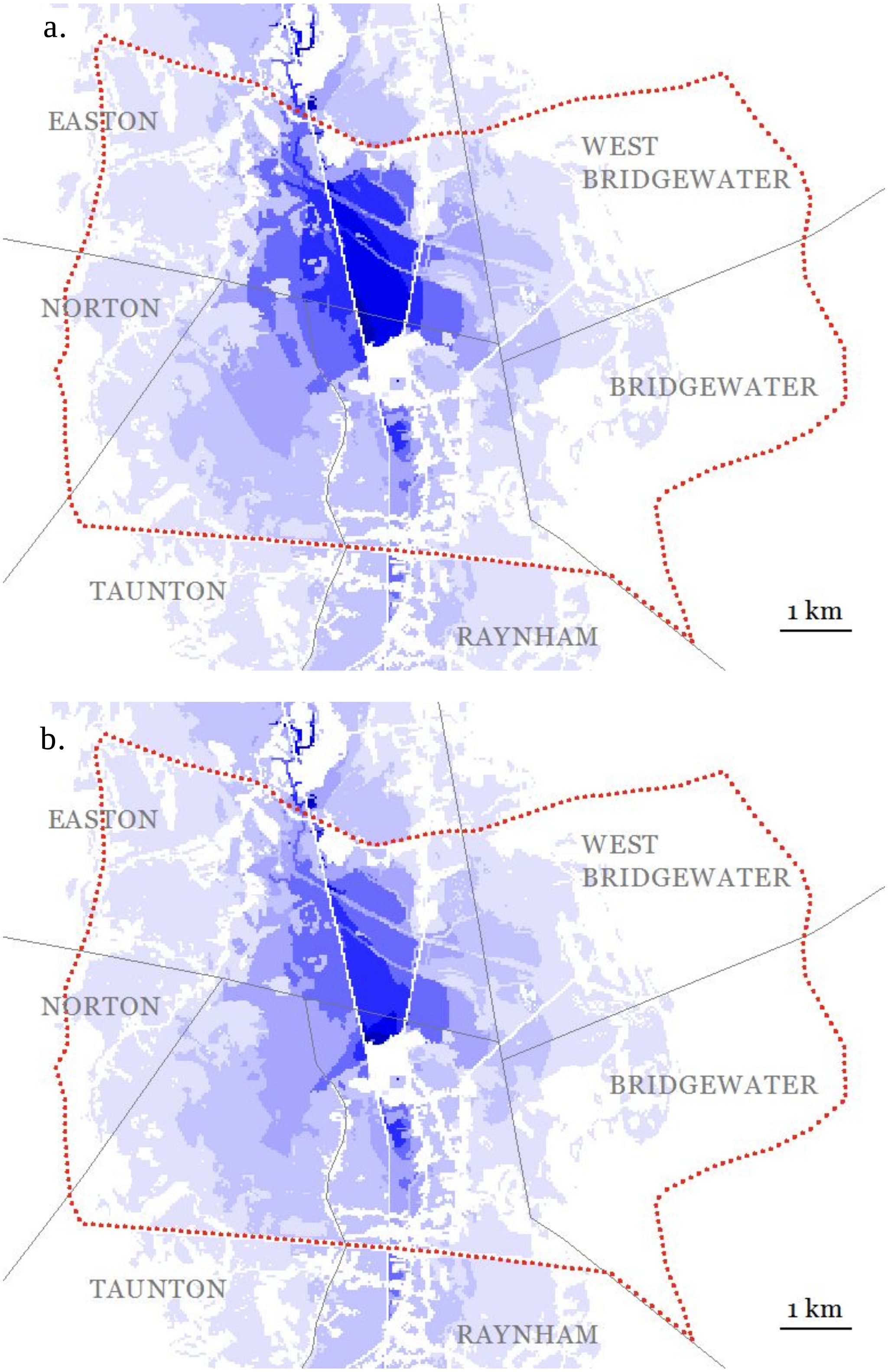

Fig. 5. Connectedness delta (darker areas = higher loss) for Hockomock Swamp focal area for (a) Stoughton at grade, and (b) Stoughton with trestle. The Stoughton and Stoughton-Whittenton scenarios are the same within Hockomock Swamp.

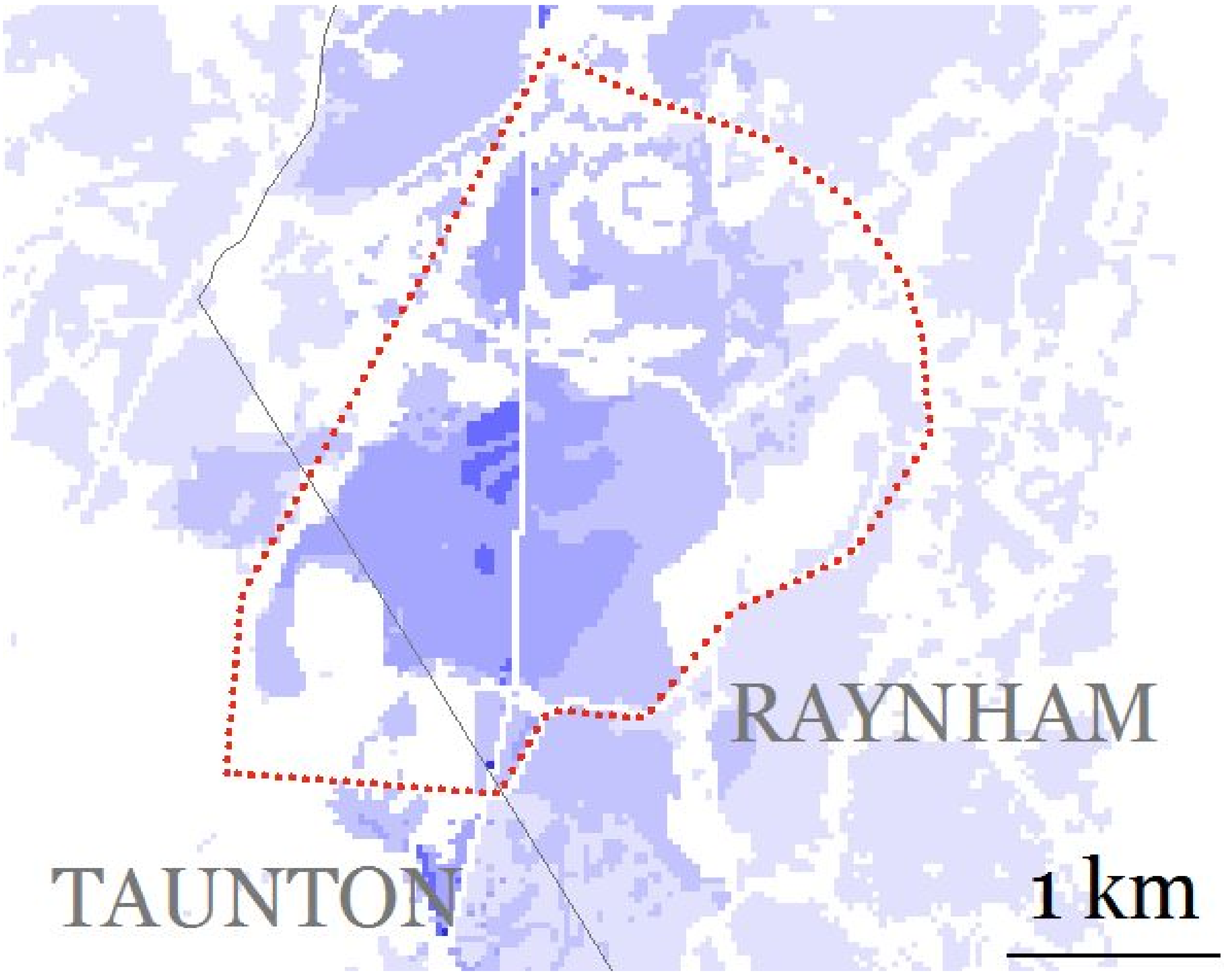

Fig. 6. Connectedness delta (darker areas = higher loss) for Pine Swamp focal area for Stoughton scenarios.

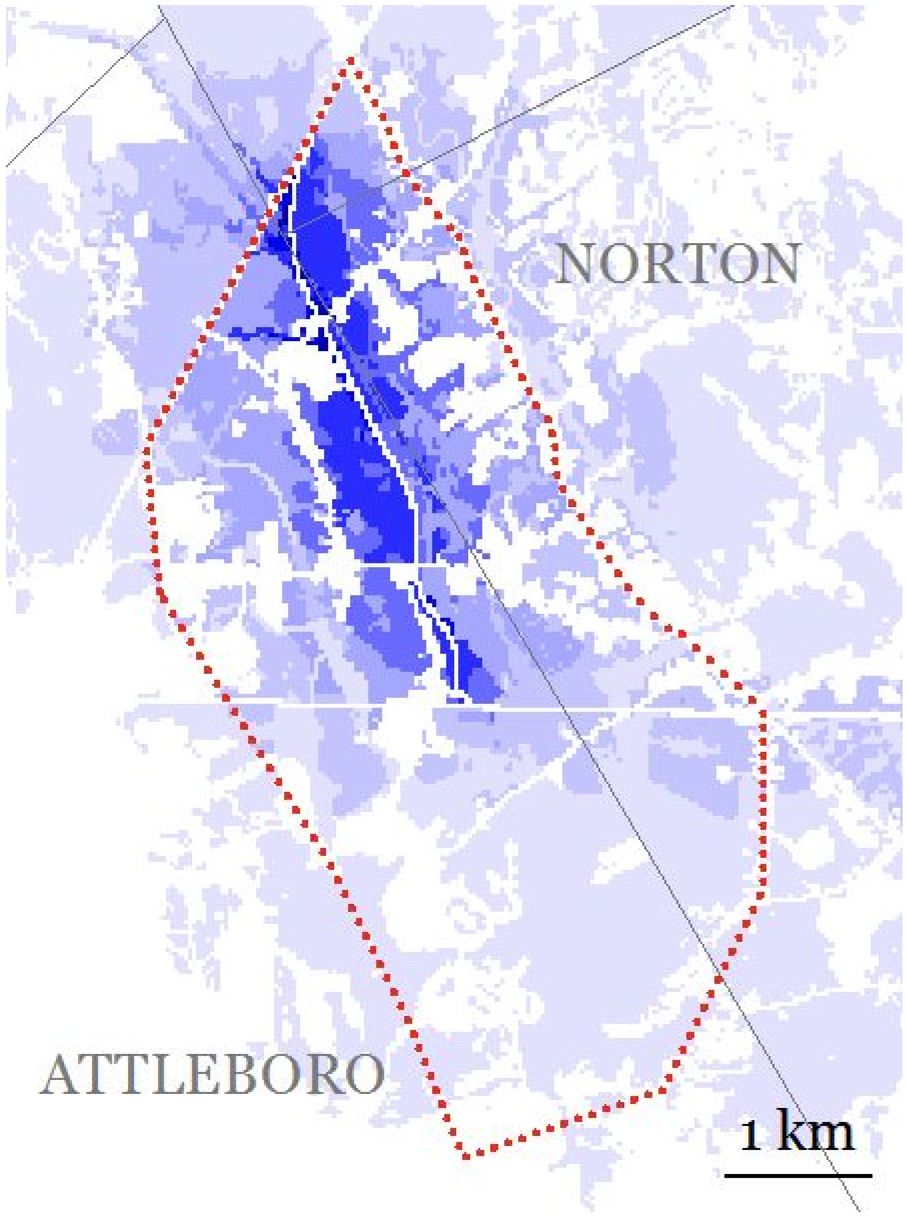

Fig. 7. Connectedness delta (darker areas = higher loss) for Attleboro bypass focal area for the Attleboro scenario.

Appendix A: Land cover classes

Land cover classes are listed below, with numeric codes for each class. New classes added for the South Coast Rail project are italicized.

Developed

1 Cropland
5 Mining
7 Participatory recreation
8 Spectator recreation
9 Water based recreation
10 Multi-family residential
11 High-density residential
12 Medium-density residential
13 Low-density residential
15 Commercial
16 Industrial
17 Urban open
18 Transportation
19 Waste disposal
26 Golf
29 Marina
31 Urban public
34 Cemetery
35 Orchard
36 Nursery
39 Junkyard
41 Train station
61 Large dam
62 Medium dam
63 Small dam
64 Tiny dam
71 Expressway
72 Primary highway
73 Secondary highway
74 Light duty road
75 Unpaved road
77 Rail trail
78 Abandoned railbed no tracks
79 Abandoned rail with tracks
81 Train (freight)
82 Train (passenger)
83 Train (commuter)
84 Train (freight + passenger)
85 Train (freight + commuter)
86 Train (passenger + commuter)
87 Train (freight + passenger + commuter)
88 Train (trestle)
89 Train (retaining wall)
91 Bridge
92 Culvert

Terrestrial

102 Pasture
103 Forest
106 Open land
124 Powerlines
151 Sea cliff
152 Barrier beach system
156 Coastal dune
167 Barrier beach coastal beach
169 Barrier beach coastal dune
191 Deciduous forested wetland
192 Mixed forested wetland
193 Coniferous forested wetland

Palustrine

331 Pond
354 Bog
355 Cranberry bog
357 Deep marsh
358 Shallow marsh
362 Shrub swamp
396 Vernal pool

Riverine

411 First order flatwater
412 First order pool-riffle
413 First order plane-bed
414 First order step-pool
415 First order cascade
421 Second order flatwater
422 Second order pool-riffle

423 Second order plane-bed
424 Second order step-pool
425 Second order cascade
431 Third order flatwater
432 Third order pool-riffle
433 Third order plane-bed
434 Third order step-pool
435 Third order cascade
441 Fourth order flatwater
442 Fourth order pool-riffle
443 Fourth order plane-bed
444 Fourth order step-pool
445 Fourth order cascade
451 Fifth order flatwater
452 Fifth order pool-riffle
453 Fifth order plane-bed
454 Fifth order step-pool
455 Fifth order cascade
461 Sixth order flatwater
462 Sixth order pool-riffle
463 Sixth order plane-bed
464 Sixth order step-pool
465 Sixth order cascade

Lacustrine
532 Lake
581 Reservoir

Estuarine
621 Salt pond
622 Bay
652 Barrier beach pond
661 Salt marsh
668 Barrier beach bog
670 Barrier beach deep marsh
671 Barrier beach marsh
673 Barrier beach shrub swamp
674 Barrier beach deciduous forested wetland
675 Barrier beach coniferous forested wetland
676 Barrier beach mixed forested wetland
677 Barrier beach salt marsh
681 First order estuary
682 Second order estuary
683 Third order estuary
684 Fourth order estuary
685 Fifth order estuary
686 Sixth order estuary

Marine
753 Coastal beach
760 Rocky intertidal
763 Tidal flat
790 Ocean

Appendix B: Input Data Layers

Note: changes from the 2009 preliminary Massachusetts run are denoted with change bars.

Nonforested Uplands – Three of these communities came from the MassGIS 2005 Land Use: pasture, powerlines, and open land (formerly called old fields in CAPS).

Wetlands – We used Massachusetts DEP Wetlands. DEP wetlands were photo-interpreted, and are generally of high quality, although beaver pond disturbance/succession has introduced many “errors,” most commonly current shrub swamps mapped as forested wetland. Note that many new coastal wetlands have been added for this run.

Vernal Pools – We used Potential Vernal Pools from MassWildlife’s Natural Heritage and Endangered Species Program. Potential vernal pools that fell within a terrestrial type were treated as a single pixel pool (30 m × 30 m). When a potential vernal pool fell within a wetland mapped by DEP, we retained DEP’s classification. We added a number of vernal pools and dropped one spurious PVP in the vicinity of proposed rail lines based on surveys by NHESP.

Streams and Rivers – Streams and rivers are based on our work for Natural Heritage and Endangered Species Program’s Living Waters project. MassGIS 1:25k stream centerlines were used to define streams. Streams are classified by order and gradient. Order is calculated from the stream centerline data; and gradient is based on the digital elevation model. We identified rivers that flow into the state to correct the order of these stream networks. For rivers wider than 30 m, the open water class from Land Use was used to represent the entire river basin, and the class based on order and gradient was applied to the entire width.

Developed Land – Developed land comes directly from the MassGIS 2005 Land Use. Proposed rail stations were added from SCR data.

Dams – Dams (in four size classes) were developed in collaboration with DEP and Mass Riverways as part of Natural Heritage’s Living Waters project. Dams were derived from a MassDEP point shapefile and digitized as lines over stream centerlines overlaid on the MassGIS 1 meter, 1:5000 black and white orthophotos. Dams are treated as a developed type.

Roads and Railroads – Roads are railroads are from MassGIS’s 1:25k EOT roads and trains layers. Roads were reclassified into five types based on original road classes as well as surface type (for unpaved roads). We also used interpolated traffic rates from the EOT roads layer. Railroads from MassGIS were mapped in several classes: abandoned railbed without tracks, rail trail, and combinations of freight, passenger, and commuter rail. Additional rail types were mapped for various scenarios from SCR data, including abandoned railbed with tracks, proposed commuter rails, commuter rail on trestle, and commuter rail with retaining walls. Rail traffic rates were based on an estimated number of trains per day and cars per train.

Elevation – A digital elevation model (DEM) was created by David Goodwin of the UMass Resource Mapping Unit from MassGIS digital terrain model (DTM) elevation contours, elevation points, and topographic breaklines as part of the Living Waters project.

Flow – A flow grid (giving the direction of expected water flow for each cell) based on a digital elevation model was created for all of mainland Massachusetts by our lab as part of the Living Waters project. This flow grid conforms to MassGIS centerline data. We used this flow grid directly.

Aquatic Resistance – We modified the approach of Randhir et al. 2001 (Forest Ecology and Management 143:47-56) to build a time-of-travel grid for each cell in the project area, based on land cover, slope, flow, and stream gradient. This grid was used to define the influence area within the watershed of each point for our watershed metrics.

Point-source Pollution – Point-source pollution was defined by Massachusetts Natural Heritage and Endangered Species Program as part of their Living Waters project. These data are based on an assessment of pollution risk compiled from six DEP and EPA data layers: TRI (Toxic Release Inventory), RCRIS (Resource Conservation and Recovery Information), PCS (Permit Compliance System), MINES (Mineral Industry Locations), IFD (Industrial Facility Discharge Sites), and CERCLIS (Superfund National Priority List Sites) from the EPA Basins 3.0 website (http://www.epa.gov/waterscience/basins/metadata.htm). UST (Underground Storage Tank Locations), GRWTR (Ground Water Discharge Permits), and DEP Solid Waste Facilities point sources are available from MassGIS. See Heritage's Living Waters Technical Report for details.

Imperviousness – Impervious surfaces are from MassGIS. This layer is at 1 m resolution, based on the 2005 orthophotos. Imperviousness is summarized as percent impervious in 30 m cells.

Appendix C: CAPS integrity metrics

These ecological integrity metrics are included in the Conservation Assessment and Prioritization System (CAPS). Integrity metrics include both anthropogenic *stressor* metrics that measure the level of anthropogenic activities exclusively and *resiliency* metrics that measure the combined effect of anthropogenic stressor and landscape context.

Stressor Metrics	
Development & roads	
Habitat loss	Measures the intensity of habitat loss caused by all forms of development in the neighborhood surrounding the focal cell, based on a logistic function of Euclidean distance.
Wetland buffer insults	Measures the adverse effect of impervious surfaces within the 100-foot regulatory buffer around a wetland.
Traffic	Measures the intensity of road and rail traffic (based on measured road traffic rates) in the neighborhood surrounding the focal cell, based on a logistic function of distance.
Microclimate alterations	Measures the adverse effects of induced (human-created) edges on the microclimate of patch interiors, such as moisture, temperature, and wind. The edge effects metric is based on the “worst” edge effect among all adverse edges in the neighborhood surrounding the focal cell, where each adverse edge is evaluated using a “depth-of-edge” function in which the “effect” is scaled using a logistic function of distance.
Pollution	
Road salt	Measures the intensity of road salt application in the watershed above an aquatic focal cell weighted by road class and the modeled “influence value” for each cell, which is the aquatic distance from the focal cell based on a time-of-flow model. This metric is a surrogate for road salt application rates.

Sedimentation	Measures the intensity of road sediment production in the watershed above an aquatic focal cell weighted by road class (i.e., size, substrate, gradient) and the modeled "influence value" for each cell, which is the aquatic distance from the focal cell based on a time-of-flow model. This metric is a surrogate for road sediment production rates.
Nutrient loading	Measures the intensity of fertilizer application in the neighborhood surrounding the focal cell, based on the aquatic distance from the focal cell based on a time-of-flow model to development classes (primarily agriculture and residential land uses). This metric is a surrogate for fertilizer application rate.
Toxic pollution	Measures the intensity of actual or potential point-sources of pollution (such as permitted discharges into streams, municipal and industrial sewage plants, and underground storage tanks) in the watershed above an aquatic focal cell, weighted by type and size of point source and by the modeled "influence value" for each cell, which is the aquatic distance from the focal cell based on a time-of-flow model.
Biotic alterations	
Domestic predators	Measures the intensity of development associated with sources of domestic predators (e.g., cats) in the neighborhood surrounding the focal cell, based on a logistic function of distance to development classes. This metric is a surrogate for domestic predator abundance measured directly in the field.
Edge predators	Measures the intensity of development associated with sources of human commensal mesopredators (e.g., raccoons and skunks) and nest parasites (cowbirds) in the neighborhood surrounding the focal cell, based on a logistic function of distance to development classes. This metric is a surrogate for mesopredator/nest parasite abundance measured directly in the field.
Non-native invasive plants	Measures the intensity of development associated with sources of non-native invasive plants in the neighborhood surrounding the focal cell, based on a logistic function of distance to development classes. This metric is a surrogate for non-native invasive plant abundance measured directly in the field.

Non-native invasive earthworms	Measures the intensity of development associated with sources of non-native invasive earthworms in the neighborhood surrounding the focal cell, based on a logistic function of distance to development classes. This metric is a surrogate for non-native invasive earthworm abundance measured directly in the field.
Hydrological alterations	
Imperviousness	Measures the intensity of impervious surface in the watershed above the focal cell, based on imperviousness and the modeled "influence value" for each cell, which is the aquatic distance from the focal cell based on a time-of-flow model.
Percent impounded	Measures the proportion of the watershed above an aquatic focal cell that is impounded by dams, weighted by the modeled "influence value" for each cell, which is the aquatic distance from the focal cell based on a time-of-flow model.
Upstream road crossings	Measures the number of upstream road crossings per kilometer of stream above an aquatic focal cell weighted by the modeled "influence value" for each cell, which is the aquatic distance from the focal cell based on a time-of-flow model.
Dam intensity	Measures the number of dams in the watershed above an aquatic focal cell weighted by dam size and the modeled "influence value" for each cell, which is the aquatic distance from the focal cell based on a time-of-flow model.

Resiliency Metrics	
Connectedness	Measures the disruption of habitat connectivity caused by all forms of development between each focal cell and surrounding cells as well as the "resistance" of the surrounding undeveloped landscape. A hypothetical organism in a highly connected cell can reach a large area with minimal crossing of "hostile" cells. This metric uses a least-cost path algorithm to determine the area that can be reached from each focal cell. The focal cell gets a "bank account," which represents the distance a hypothetical organism could move through the undeveloped landscape. Each cell is assigned a travel cost, based on a resistance matrix, as a function of its ecological similarity to the focal cell. The algorithm then creates a least-cost hull around the focal cell, representing the maximum distance that can be moved from the cell until the "bank account" is depleted.
Similarity	Measures the amount of similarity between the ecological setting at the focal cell and those of neighboring cells, weighted by a logistic function of distance. Similarity is based on the ecological distance between the focal cell and each neighboring cell, where ecological distance is a multivariate distance across all ecological setting variables.

Appendix D: Metric Parameterizations

This table gives relative weights for each metric by community.

	Development & roads	Habitat loss	Watershed habitat loss	Wetland buffer insults	Road traffic	Microclimate alterations	Pollution	Road salt	Sedimentation	Nutrient loading	Toxic pollution	Biotic alterations	Domestic predators	Edge predators	Non-native invasive plants	Non-native invasive earthworms	Hydrological alterations	Imperviousness	Percent impounded	Upstream road crossings	Dam intensity	Resiliency metrics	Connectedness	Similarity
Terrestrial																								
Forest		2			2	1							1	2	2	2							5	3
Deciduous forested wetland		2		1	2	1		1	1	1	1			1	2	1							4	2
Mixed forested wetland		2		1	2	1		1	1	1	1			1	2	1							4	2
Coniferous forested wetland		2		1	2	1		1	1	1	1			1	2	1							4	2
Powerlines		4			2								1	2	2	1							5	3
Open land		4			2								1	2	2	1							5	3
Pasture		4			2								1	2	2								5	4
Sea cliff		4												1	1								2	1
Barrier beach system		4			2									2	1								2	1
Coastal dune		4			2									3	1								2	1
Barrier beach coastal beach		4			2									3	1								2	1
Barrier beach coastal dune		4			2									3	1								2	1
Palustrine																								

	Development & roads	Habitat loss	Watershed habitat loss	Wetland buffer insults	Road traffic	Microclimate alterations	Pollution	Road salt	Sedimentation	Nutrient loading	Toxic pollution	Biotic alterations	Domestic predators	Edge predators	Non-native invasive plants	Non-native invasive earthworms	Hydrological alterations	Imperviousness	Percent impounded	Upstream road crossings	Dam intensity	Resiliency metrics	Connectedness	Similarity
Bog		2		2	1			2	1	2	1			1	1			1					4	2
Deep marsh		2		2	2			1	1	1	1			1	2			1					4	2
Shallow marsh		2		2	2			1	1	1	1			1	2			1					4	2
Shrub swamp		2		2	2			1	1	1	1			1	2			1					4	2
Pond		2		2	2			1	1	2	1			1	1			1					4	2
Vernal pool		2			2			2	1	1	1			1	1			1					4	2
Cranberry bog		2		2	2			2	1	2	1			1	2			1					4	2
Lacustrine																								
Lake		2		2	1			1	1	2	2			1	1			1					4	2
Reservoir		2		2	1			1	1	2	2			1	1			1					4	2
Riverine																								
First order streams					1	1			1	1	1			1	1			2	1	1	1		6	
Second order streams					1	1			1	1	1			1	1			2	1	1	1		6	
Third order streams					1	1			1	1	1			1	1			2	1	1	1		6	
Fourth order streams					1				1	1	1			1	1			2	1	1	2		6	
Fifth order streams					1				1	1	1			1	1			2	1	1	2		6	
Sixth order streams					1				1	1	1			1	1			2	1	1	2		6	
Estuarine																								

	Development & roads	Habitat loss	Watershed habitat loss	Wetland buffer insults	Road traffic	Microclimate alterations	Pollution	Road salt	Sedimentation	Nutrient loading	Toxic pollution	Biotic alterations	Domestic predators	Edge predators	Non-native invasive plants	Non-native invasive earthworms	Hydrological alterations	Imperviousness	Percent impounded	Upstream road crossings	Dam intensity	Resiliency metrics	Connectedness	Similarity
First order estuary					1				1	1	1			1	1			1	1	1	1		6	
Second order estuary					1				1	1	1			1	1			1	1	1	1		6	
Third order estuary					1				1	1	1			1	1			1	1	1	1		6	
Fourth order estuary					1				1	1	1			1	1			1	1	1	2		6	
Fifth order estuary					1				1	1	1			1	1			1	1	1	2		6	
Sixth order estuary					1				1	1	1			1	1			1	1	1	2		6	
Salt pond		2		2	2				1	2	1			1				1					4	2
Bay					1				1	1	3												6	
Barrier beach pond		2		2	2				1	2	1			1	1			1					4	2
Salt marsh		2	2	2	1				1		2			1				1					3	3
Barrier beach bog		2		2	1				1	2	1			1	1			1					4	2
Barrier beach deep marsh		2		2	2				1	1	1			1	2			1					4	2
Barrier beach marsh		2		2	2				1	1	1			1	2			1					4	2
Barrier beach shrub swamp		2		2	2				1	1	1			1	2			1					4	2
Barrier beach deciduous forested wetland		1		1	2	1			1	1	1			1	2								4	2
Barrier beach mixed forested wetland		2		1	2	1			1	1	1			1	2								4	2
Barrier beach coniferous forested wetland		2		1	2	1			1	1	1			1	2								4	2
Barrier beach salt marsh		2	2	2	1				1		2			1				1					3	3

	Development & roads	Habitat loss	Watershed habitat loss	Wetland buffer insults	Road traffic	Microclimate alterations	Pollution	Road salt	Sedimentation	Nutrient loading	Toxic pollution	Biotic alterations	Domestic predators	Edge predators	Non-native invasive plants	Non-native invasive earthworms	Hydrological alterations	Imperviousness	Percent impounded	Upstream road crossings	Dam intensity	Resiliency metrics	Connectedness	Similarity
Marine																								
Coastal beach		4			2									3	1								2	1
Rocky intertidal		2							1		1												2	1
Tidal flat		2							1	1	3												1	2

Appendix E: GIS Data Directory

This appendix lists all GIS data provided on our FTP site. Each directory is supplied as a .zip file. All data are Arc/Info grids unless otherwise noted.

Grids listed with a trailing dash are provided for each scenario; for instance, iei- refers to grids named ieiX (base scenario), ieiA (Attleboro alternative), etc. Grids for sensitivity analyses are not provided.

Landcover grids (landcover.zip)

landcover\flc-	Landcover map, including roads and streams

Final results (final.zip)

final\iei-	Index of Ecological Integrity
final\delta-	Difference grids from base for each scenario

Scaled landscape metric* results (scaled.zip)

scaled\...	Rescaled landscape metric results

Raw landscape metric* results (raw.zip)

raw\...	Raw (unscaled) landscape metric results

Indirect loss for each landscape metric* (deltas.zip)

deltas\...	Raw (unscaled) landscape metric results

* For a list of landscape metrics and their corresponding grid names, see *CAPS Landscape Metrics*, below.

CAPS Landscape Metrics

The following grids are supplied in the \results folder, both in raw and scaled forms. Raw metrics are the original, unscaled results. Scaled metrics are rescaled by percentiles within each community, thus values of "connect" ≥ 0.90 represent the 10% best locations for connectedness for each community. These scaled metrics were combined using the weights listed in Appendix C to create the final Indices of Ecological Integrity. Note that watershed-based metrics were the same across all scenarios.

Grid name	Landscape metric
Development & roads	
habloss-	Habitat loss
whabloss	Watershed habitat loss
insults	Wetland buffer insults
traffic-	Road traffic
edges-	Microclimate alterations
Pollution	
salt	Road salt
sediment	Sedimentation
fertilize	Nutrient loading
pointsource	Toxic pollution
Biotic alterations	
cats-	Domestic predators
edgepred-	Edge predators
badplants-	Non-native invasive plants
worms-	Non-native invasive earthworms
Hydrological alterations	
imperv	Imperviousness
impound	Percent impounded
roadx	Upstream road crossings
damint	Dam intensity
Resiliency metrics	
connect-	Connectedness
sim-	Similarity

Appendix F: Difference Images

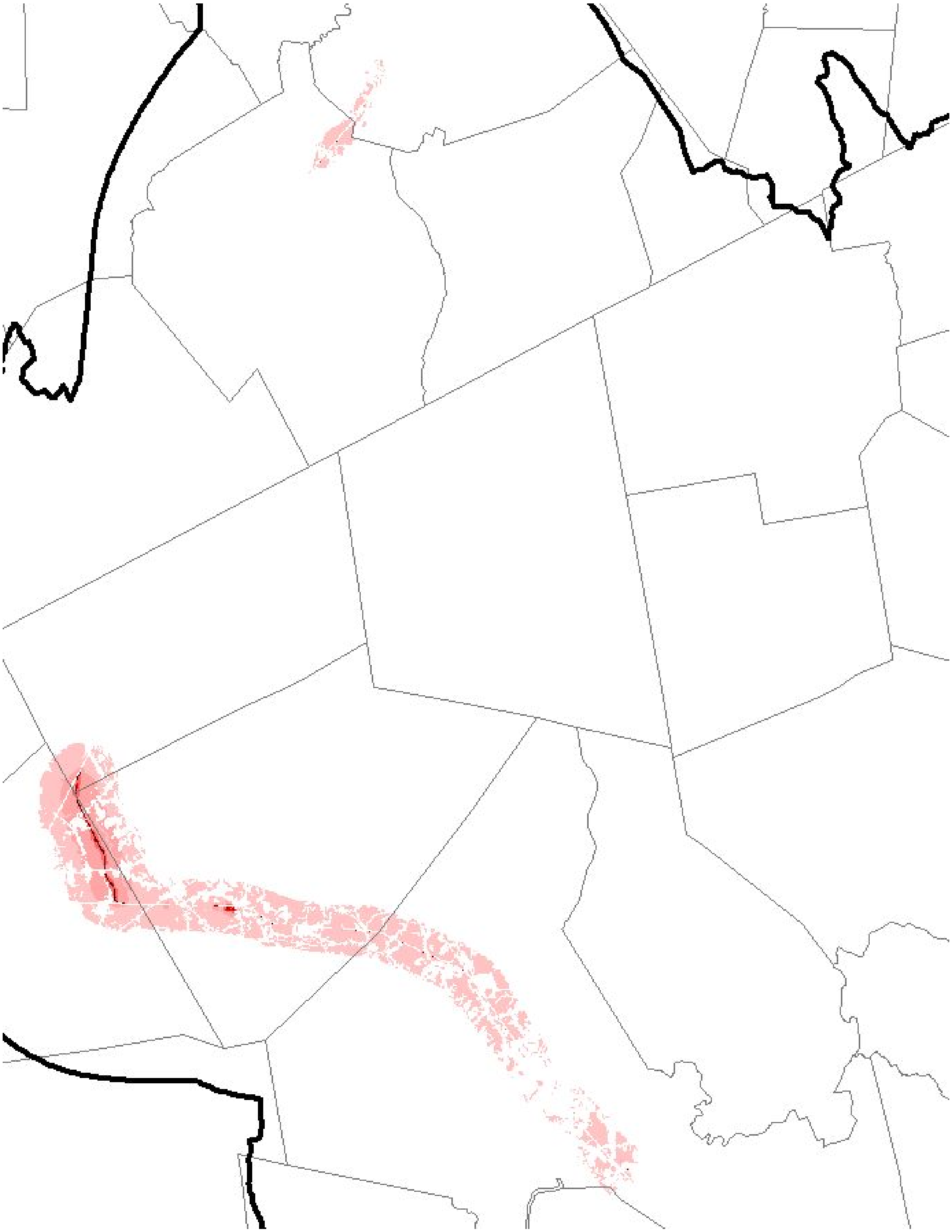

Fig. F-1. Difference image for Attleboro scenario.

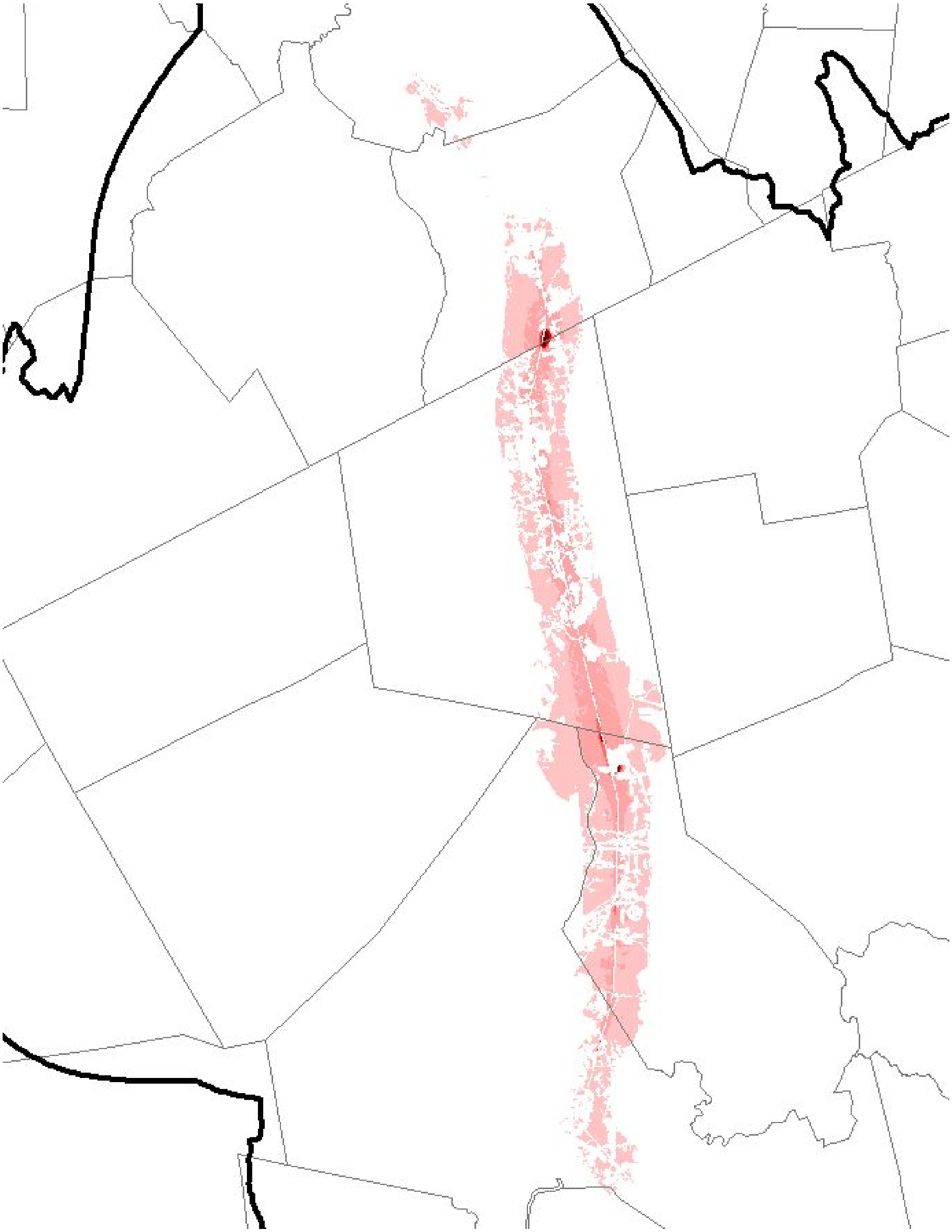

Fig. F-2. Difference image for Stoughton at-grade scenario.

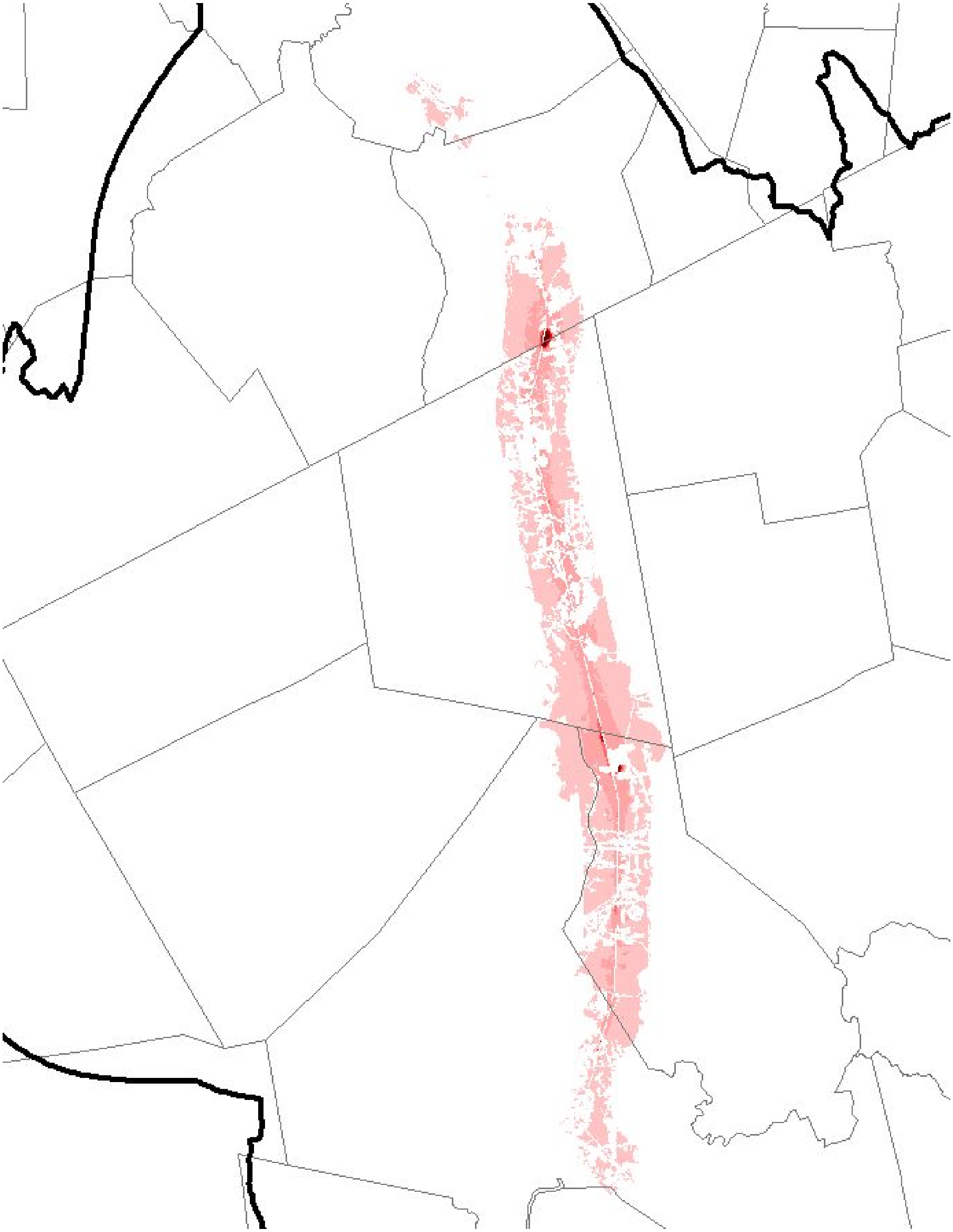

Fig. F-3. Difference image for Stoughton with trestle scenario.

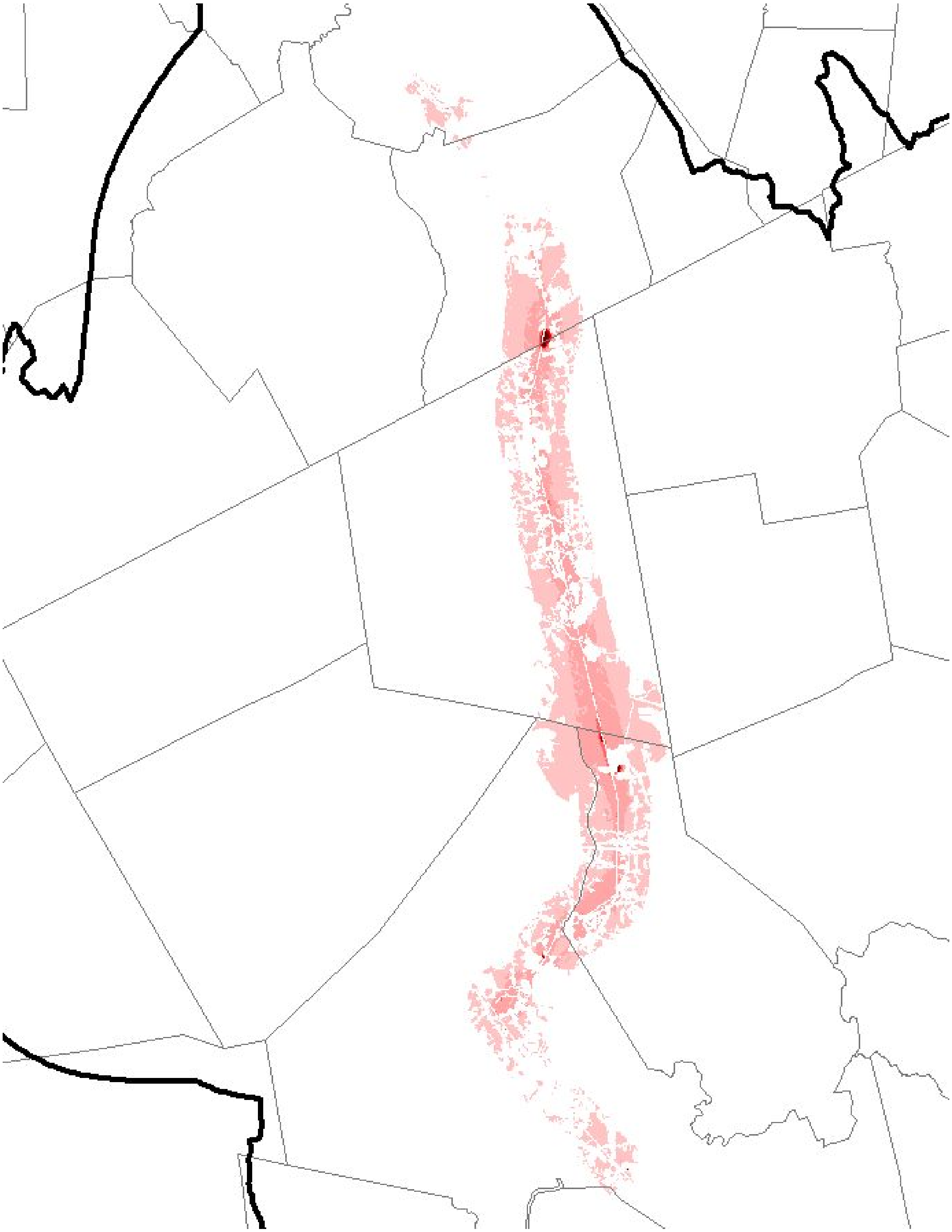

Fig. F-4. Difference image for Stoughton-Whittenton at-grade scenario.

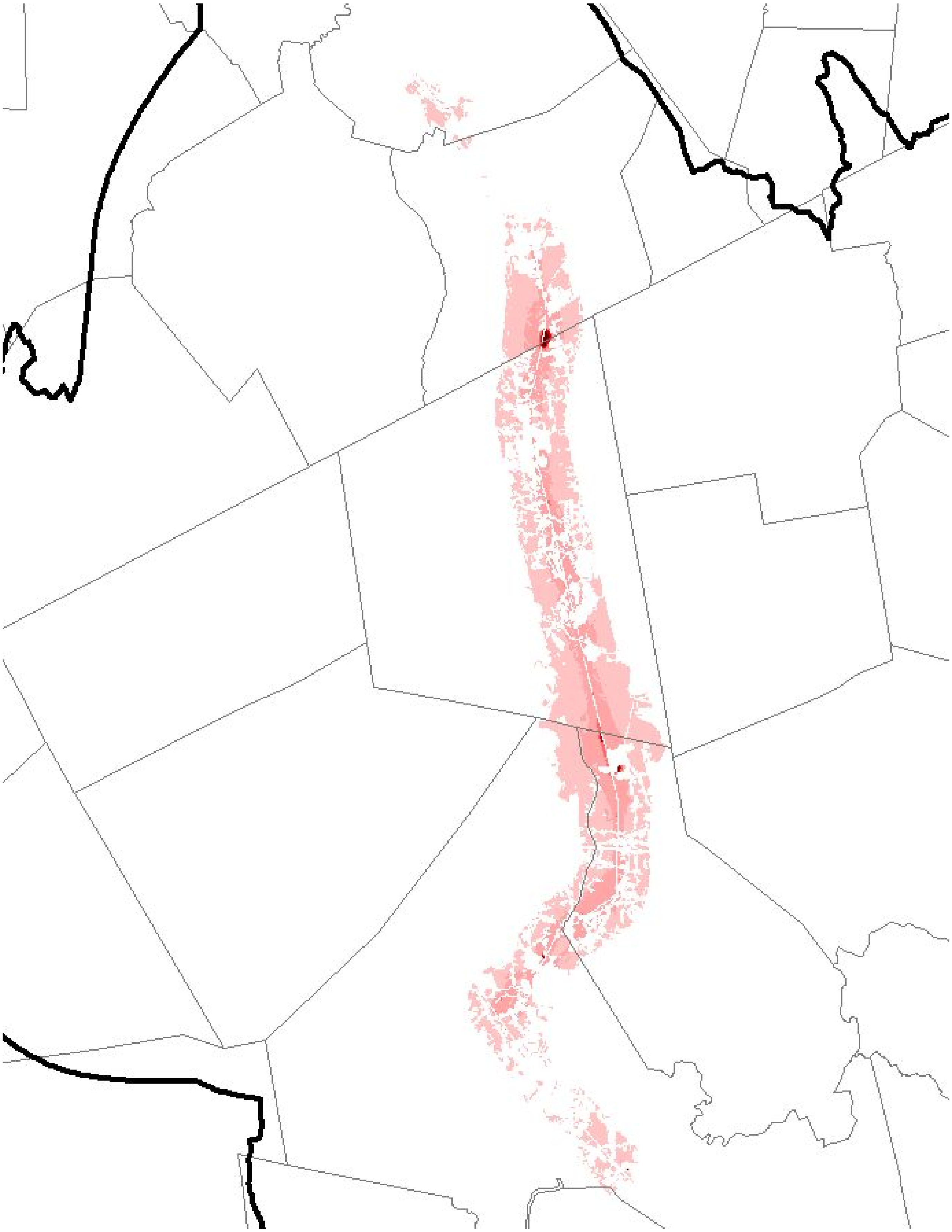

Fig. F-5. Difference image for Stoughton-Whittenton with trestle scenario.