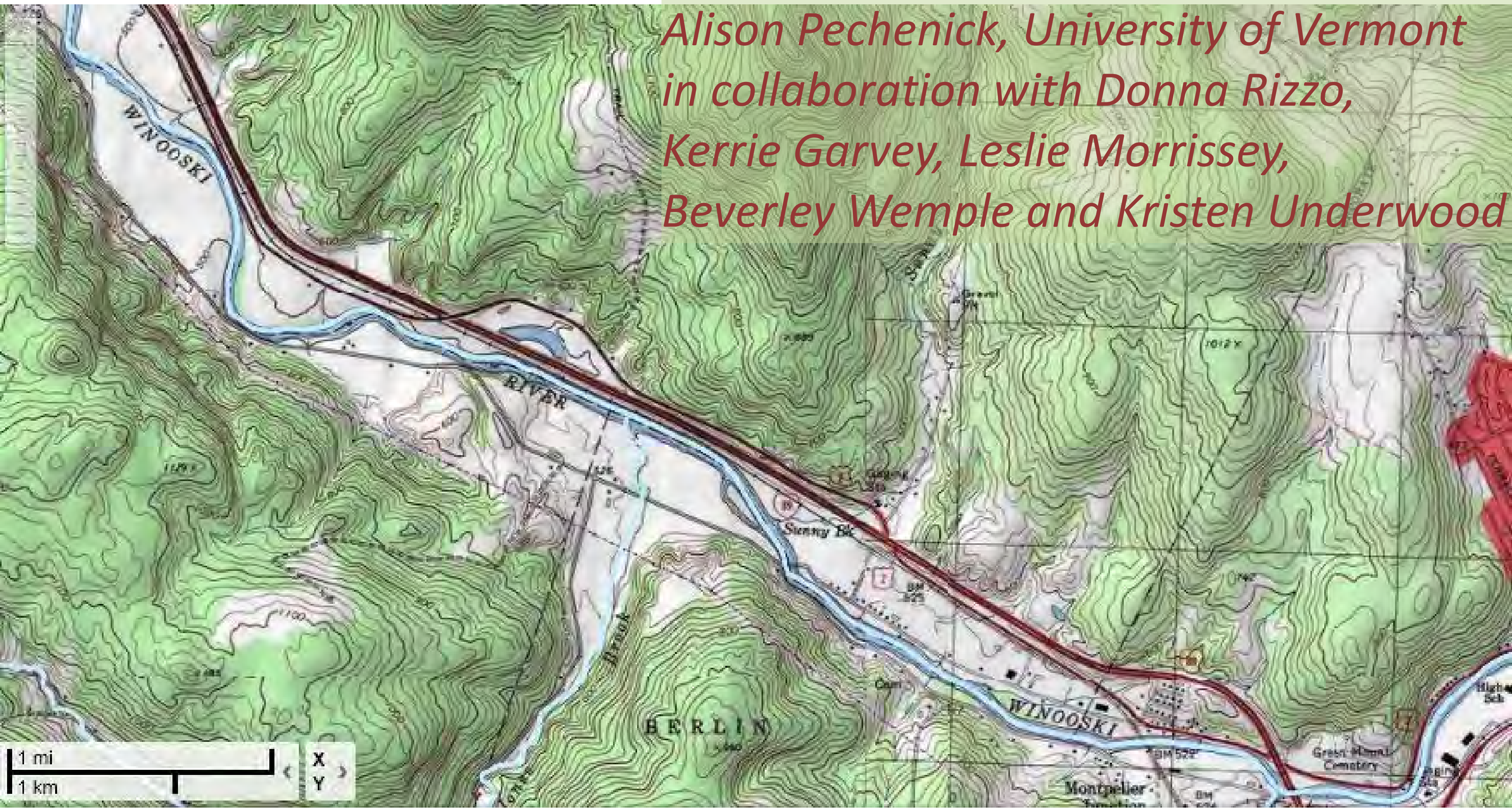
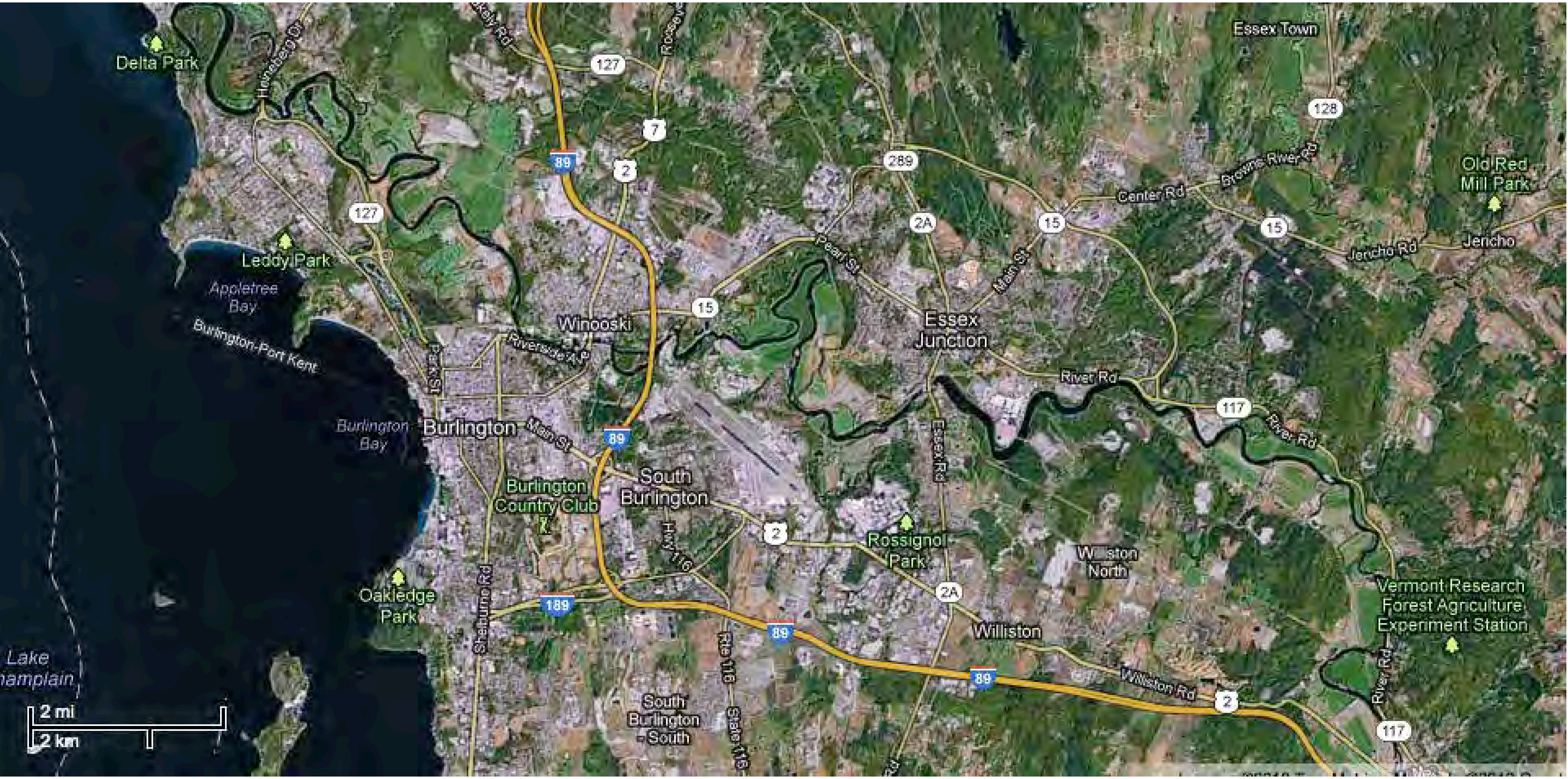
A MULTI-SCALE APPROACH TO ASSESS THE HYDROLOGICAL CONNECTIVITY OF ROAD AND STREAM NETWORKS

Do Road Orientation and Proximity Matter?

Alison Pechenick, University of Vermont in collaboration with Donna Rizzo, Kerrie Garvey, Leslie Morrissey, Beverley Wemple and Kristen Underwood



Winooski River Valley:
A river seeks “dynamic equilibrium”



Energy dissipates in a slow and predictable manner…
unless otherwise constrained

~~~ Motivation ~~~

Roads stress watersheds by...

- *dramatically impacting the movement of water and sediment across the landscape*
- *altering drainage paths*
- *concentrating overland flow in roadside ditches.*

Roads threaten...

- *watershed health*
- *water quality and quantity*
- *riparian and aquatic habitats*
- *flood management*
- *stream geomorphic stability*

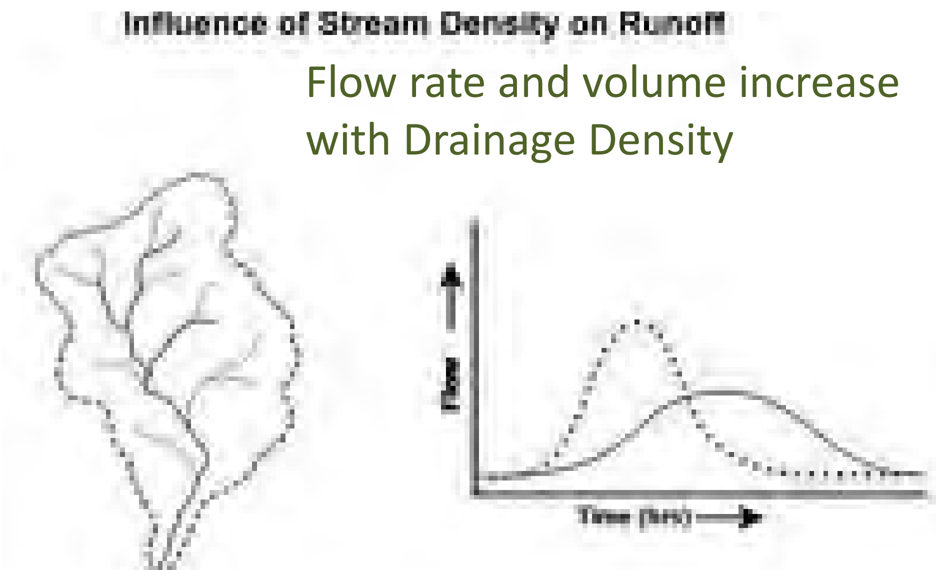
Road proximity has a negative impact on stream geomorphic health. This is especially true with respect to roads located within the riparian corridor.

Road orientation plays a role in determining stream geomorphic health. Parallel and perpendicular roads present multiple opportunities for redirecting runoff into streams.

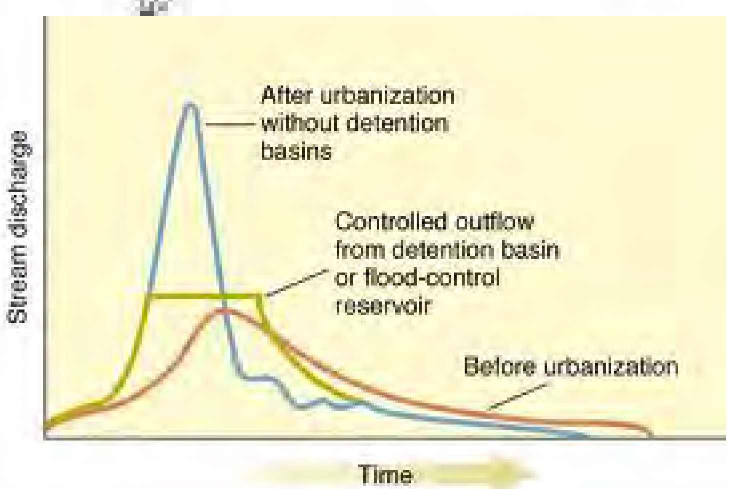
~~~ Hypotheses ~~~

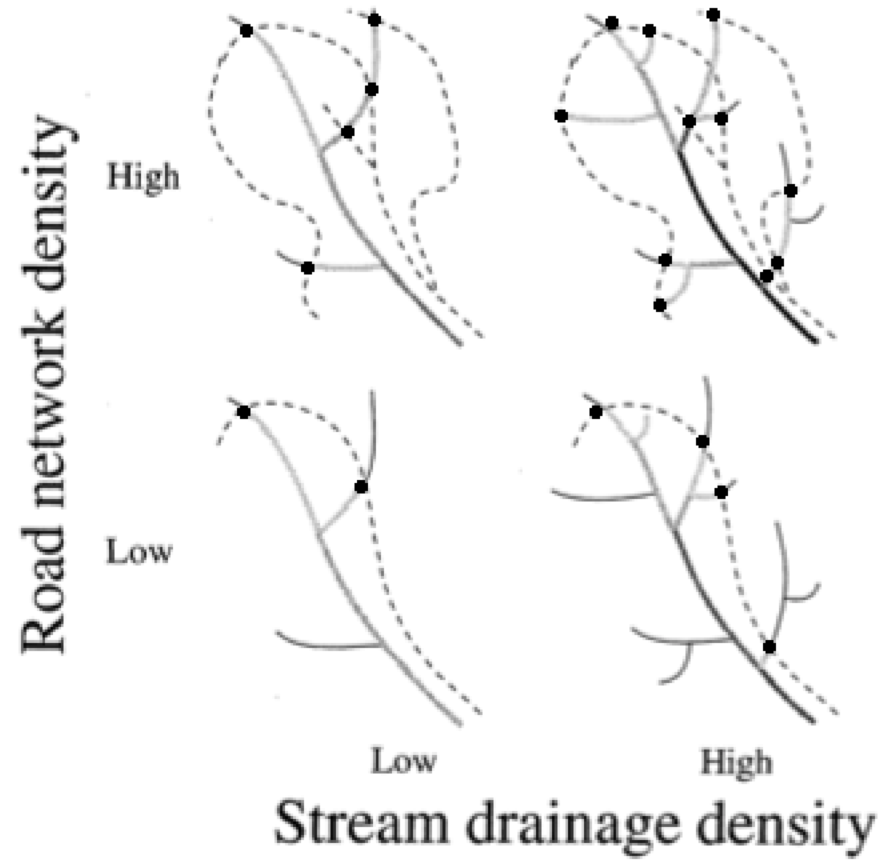
Drainage Density Increases with Hydrologically-Connected Roads

Roads (including compacted, unpaved) and other impervious surfaces act like streams.



Flow rate and volume increase with Drainage Density

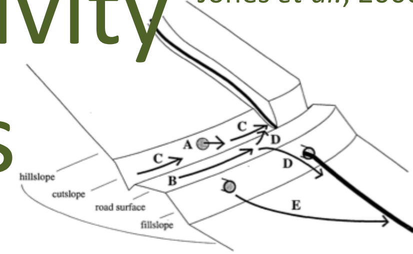




Jones JA, Swanson FJ, Wemple BC, Snyder KU. 2000. Effects of roads on hydrology, geomorphology, and disturbance patches in stream networks. *Conservation Biology* 14:76-85

Hydrologic Connectivity on the Hillslopes

Jones *et al.*, 2000



- Road prism intercepts overland and sub-surface flows (gw flow rates << overland flow rates)

By S. Yasir Usman

- Roads channel overland flow and sediment to streams

Hydrologic Connectivity via Ditches & Culverts

Vermont Agency of Natural Resources
River Management Program

Channel and watershed management

Restore dynamic equilibrium

Predict channel instability

Statewide data collection

- Phase 1 data

  Combine local knowledge with remotely-sensed and other map information to characterize watershed and channel corridor features (*land use, soils, channel slope, sinuosity, etc.*)

- Phase 2 data

  Expert field evaluation using blend of well-established protocols to characterize stream geomorphic condition according to a variety of assessment parameters (e.g., incision and entrenchment ratios, access to flood plain, grain size distribution, etc.)

Vermont Watersheds

Vermont Agency of Natural Resources

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  (land use, soils, channel slope, sinuosity, etc.)

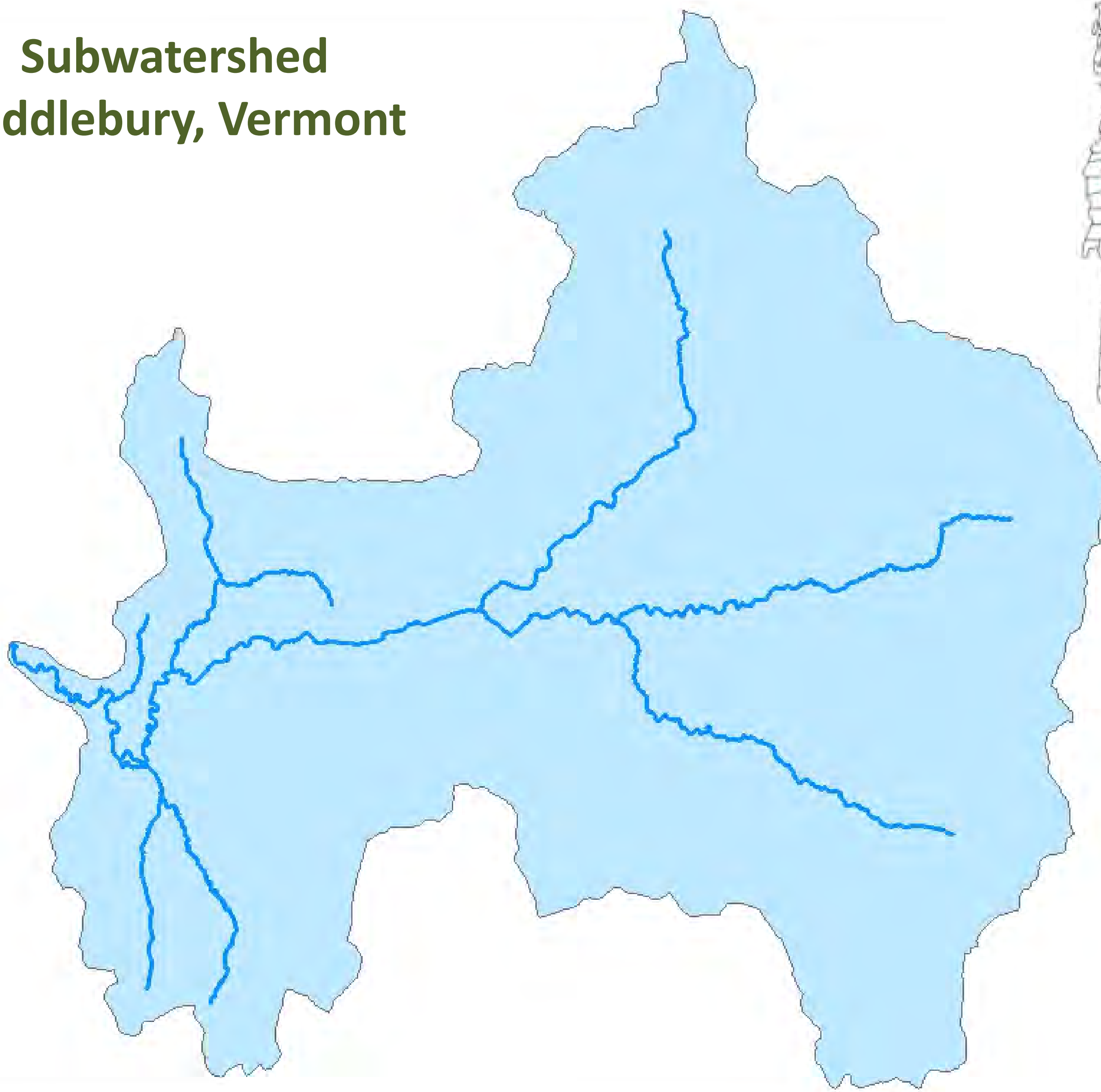
https://anrnode.anr.state.vt.us/SGA/default.aspx

- Phase 2 data

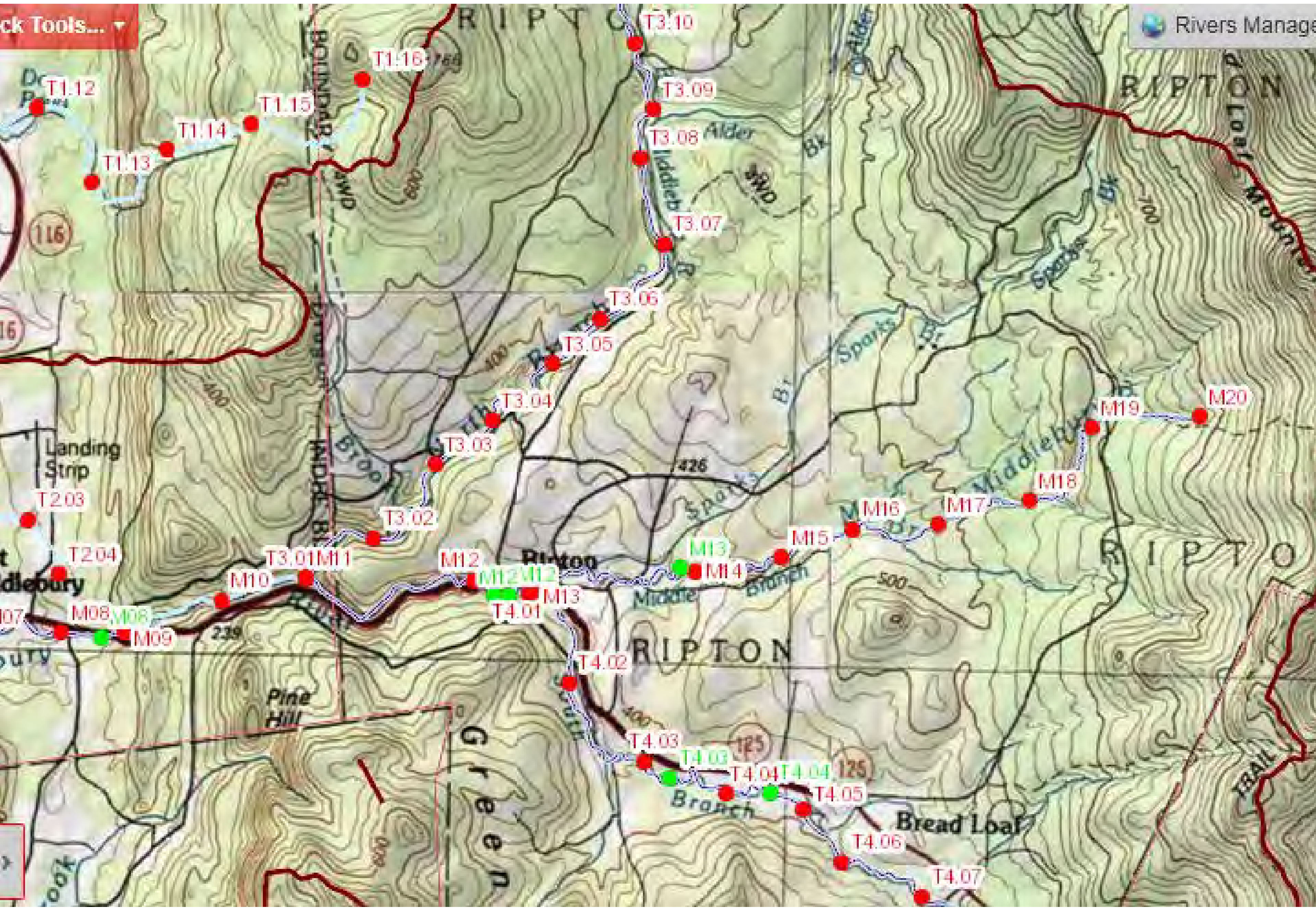
  Expert field evaluation using blend of well-established protocols to characterize stream geomorphic condition according to a variety of assessment parameters (e.g., incision and entrenchment ratios, access to flood plain, grain size distribution, etc.)

Vermont Watersheds

Subwatershed Middlebury, Vermont



Wikipedia Commons



http://anrmaps.vermont.gov/websites/anra/

Channel & watershed management

Restore

dynamic equilibrium

Predict

channel instability

VT ANR River Management Program
Rapid Geomorphic Assessment

Adjustment Process	Condition Category		
	Reference	Good	
7.1 Channel Degradation (Incision)	☐ Little evidence of localized slope increase or nickpoints.	☐ Minor localized slope increase or nickpoints.	☐ Sharp ch cuts present, rejuvenating.
• Exposed till or fresh substrate in the stream bed and exposed infrastructure(bridge footings)	☐ Incision Ratio ≥ 1.0 < 1.2 and Entrenchment ratio > 2.0	☐ Incision Ratio ≥ 1.2 < 1.4 and Entrenchment ratio > 2.0	☐ Incision I a Entrench
• New terraces or recently abandoned floodplains. • Headcuts, or nickpoints that are 2-3 times steeper than typical riffle.	☐ Riffle heads complete and comprised of courser sediments (≥D80). Full complement of expected bed features.	☐ Riffle heads mostly complete. Riffle lengths may appear shorter. Full complement of expected bed features.	☐ Riffles o incomplete; t nated by runs
• Freshly eroded, vertical banks. • Alluvial (river) sediments that are imbricated (stacked like dominoes) high in bank.	☐ No significant human-caused change in channel confinement or valley type.	☐ Only minor human-caused change in channel confinement but no change in valley type.	☐ Significa change in ch enough to ch but still unco
• Tributary rejuvenation, observed through the presence of nickpoints at or upstream of the mouth of a tributary. • Bars with steep faces, usually occurring on the downstream end of a bar.	☐ No evidence of historic / present channel straightening, gravel mining, dredging and/or channel avulsions.	☐ Evidence of minor bar scalping on a point bar and/or channel avulsion; but no historic channel straightening, gravel mining, or dredging.	☐ Evidence historic chan dredging, gra channel avul
Stream Type Departure ☐ Type of STD:______	☐ No known flow alterations (i.e., increases in flow or decreases in sediment supply).	☐ Minor flow alterations, some flow increase and/or reduction of sediment load.	☐ Major his tions, greater duction of se

RGA score

7.6 Stream Condition

0.85 – 1.0	Reference Condition
0.65 – 0.84	Good Condition
0.35 – 0.64	Fair Condition
0.00 – 0.34	Poor Condition

Adjustment Process	Condition Category																			
	Reference					Good					Fair					Poor				
	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1

7.5 Channel Adjustment Scores – Stream Condition – Channel Evolution Stage

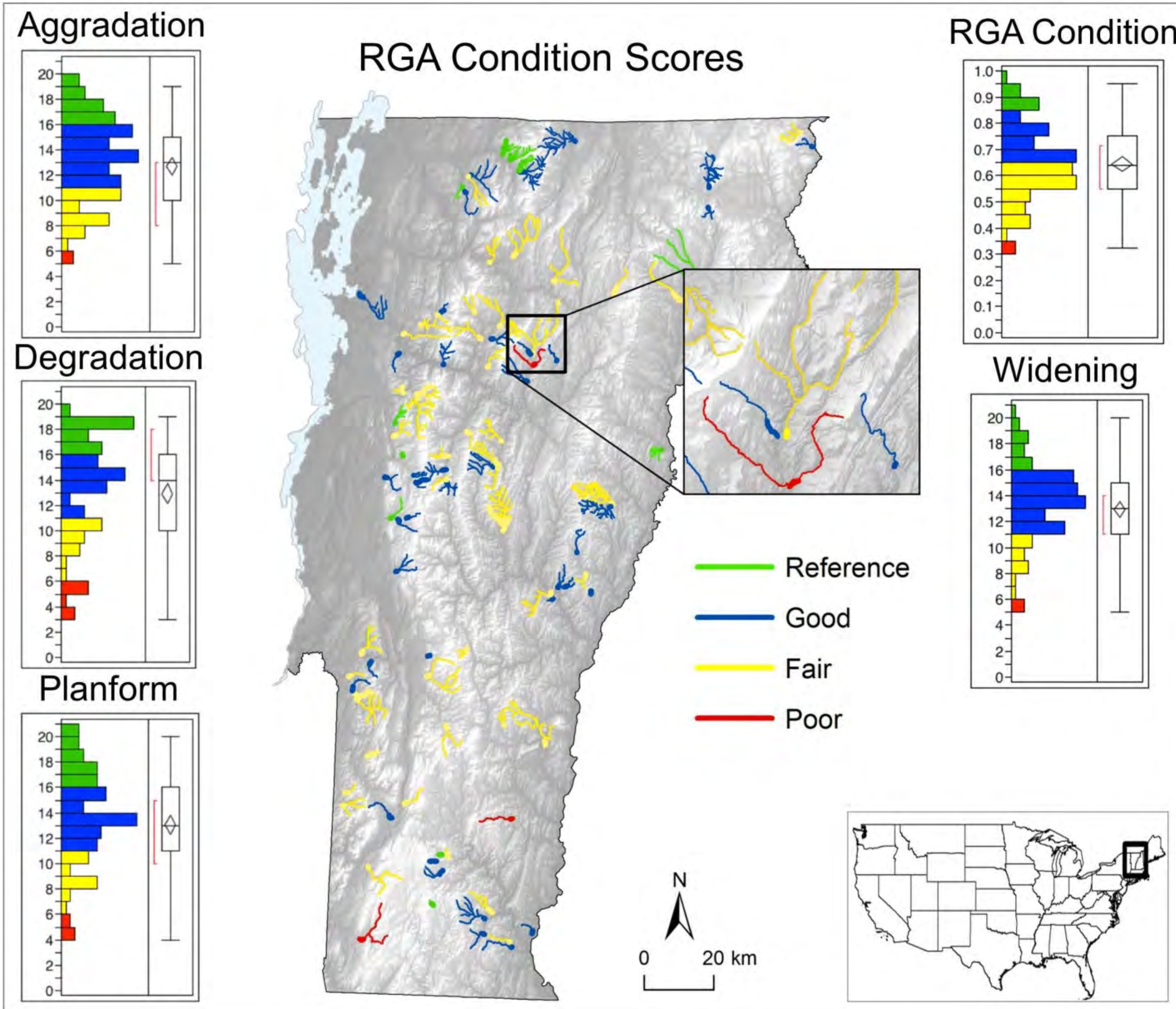
Condition Departure	Reference N/S	Good Minor	Fair Major	Poor Extreme	STD*	Historic	Condition Rating: (Total Score / 80)
Degradation							
Aggradation							
Widening							7.6 Stream Condition:
Planform							
Sub-totals:					Total Score:		

Mining the Phase 2 Stream Reach Data: Sole anthropogenic influence = *Road Development*

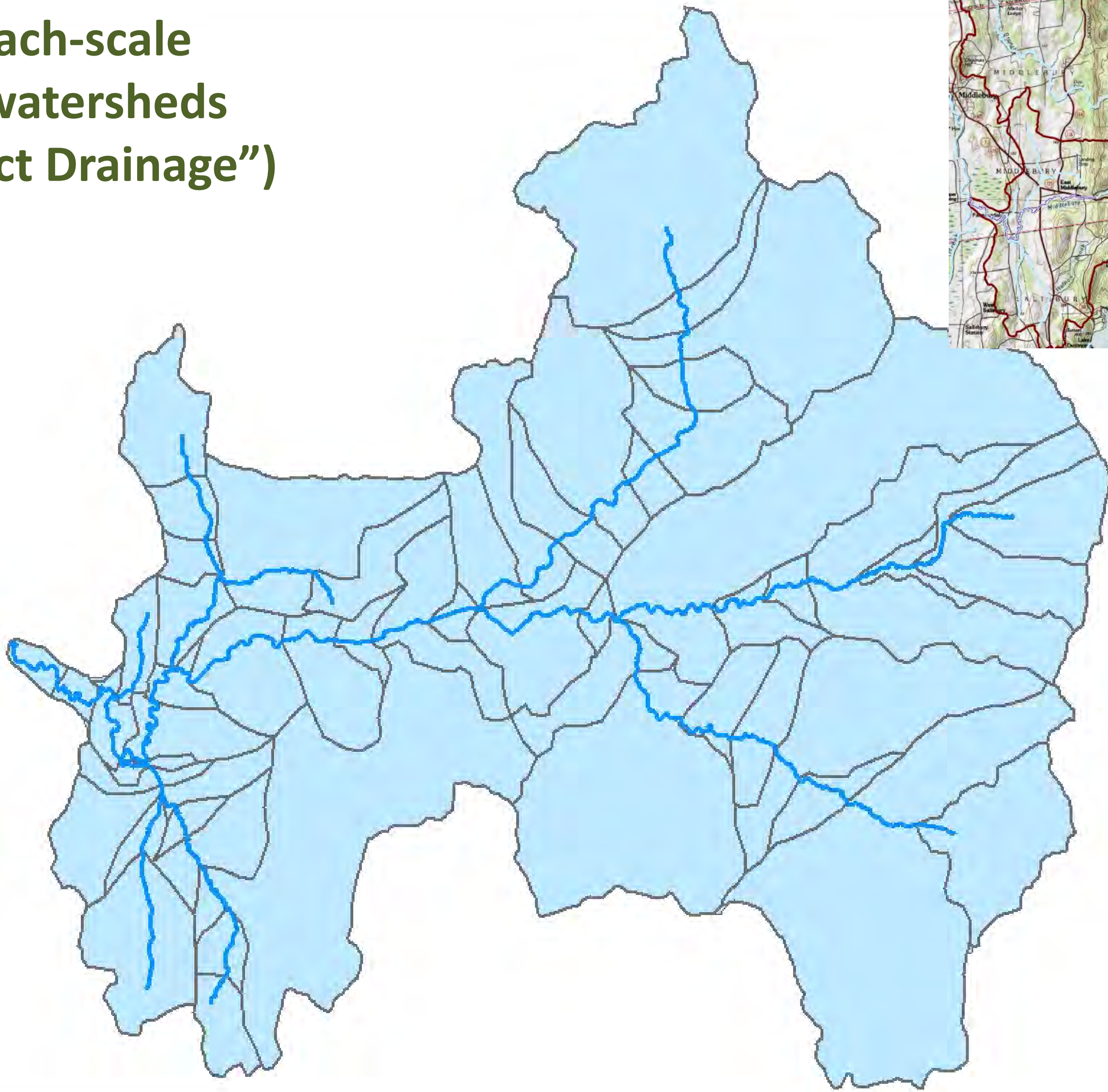
- ~2300 assessed reaches, 112 different VTANR RMP projects
- Selection criteria:
  - drainage area < 50 mi^2
  - forest cover ≥ 75%
  - remove of reaches with development > 10%, railroad lines, impoundments (e.g., dams), straightening not due to roads
- If multiple reaches in same river network, select reach furthest downstream

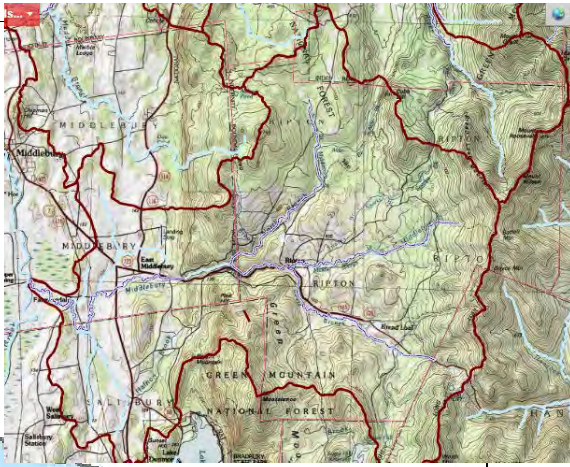
Result: N=102 statistically independent reaches believed to be free of anthropogenic influences with the exception of roads.

Distribution of 102 study reaches

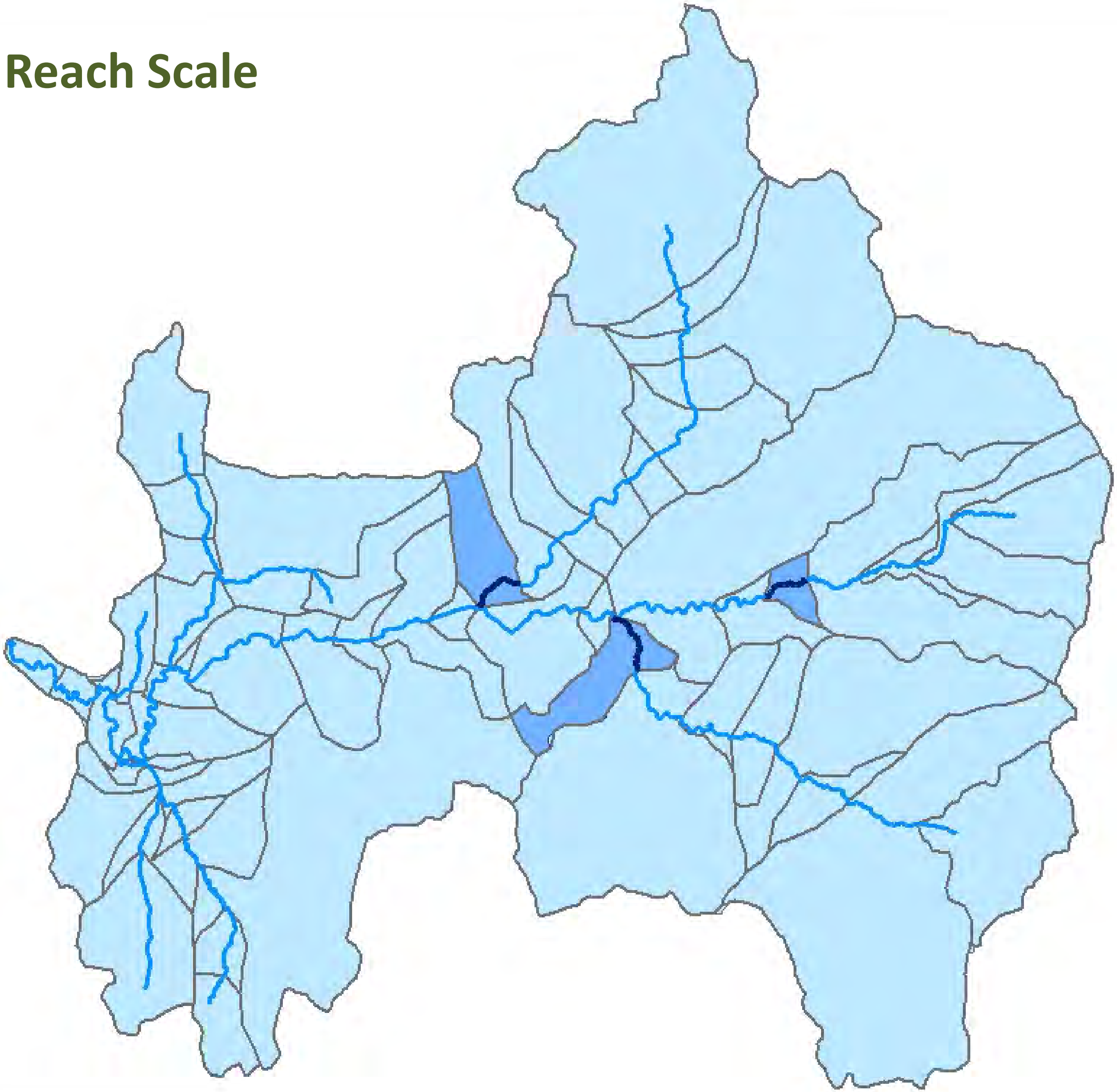


Reach-scale subwatersheds (“Direct Drainage”)

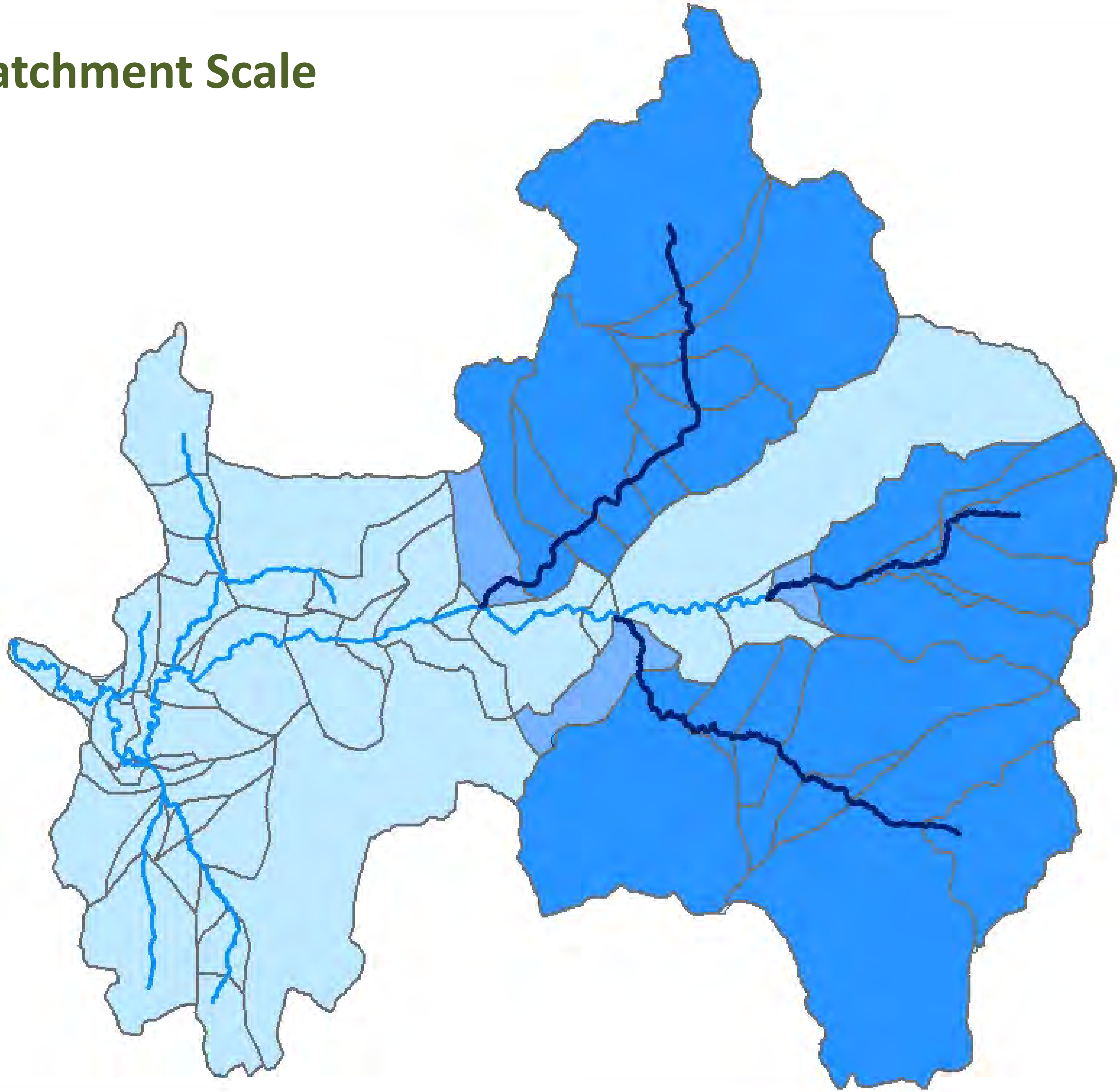




Reach Scale

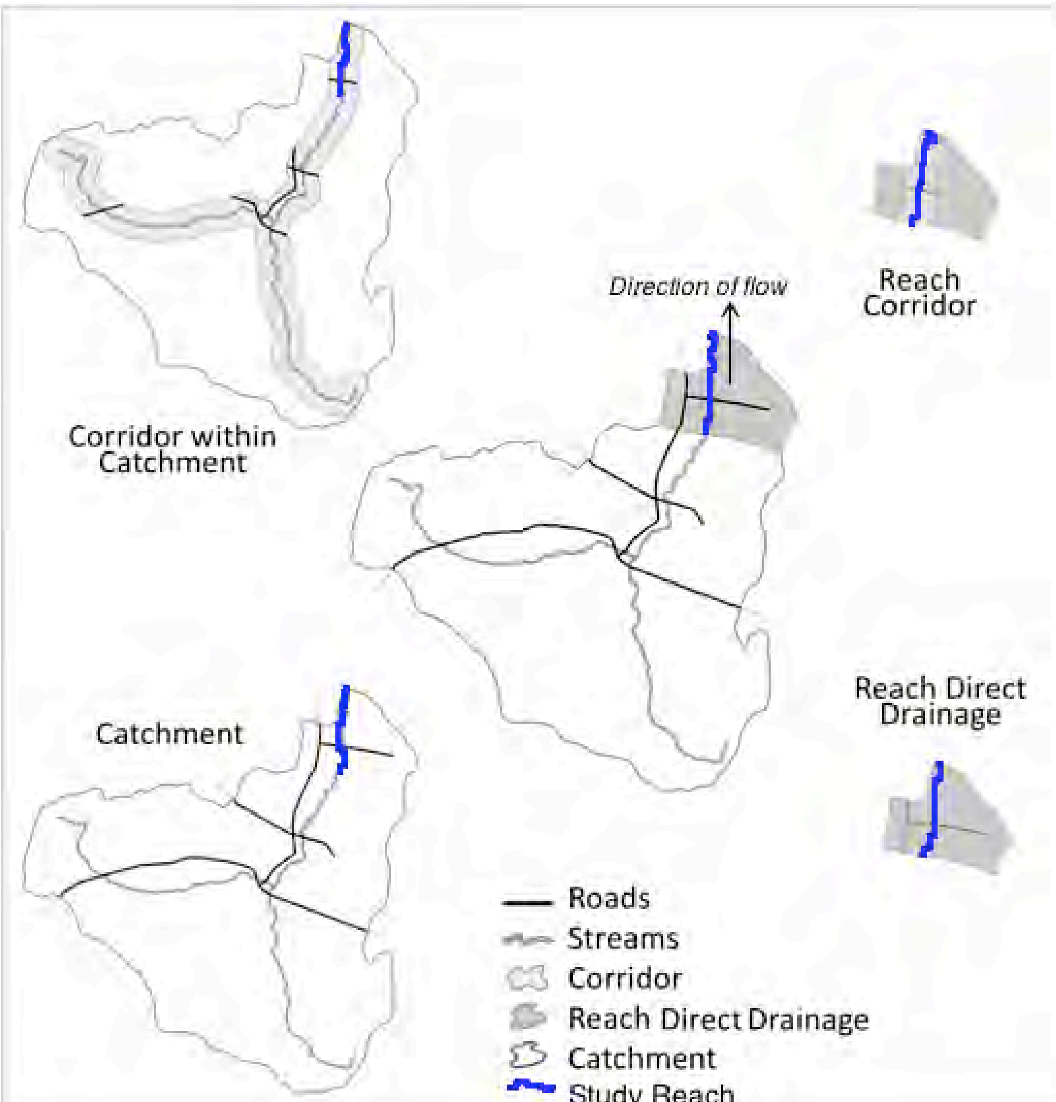


Catchment Scale

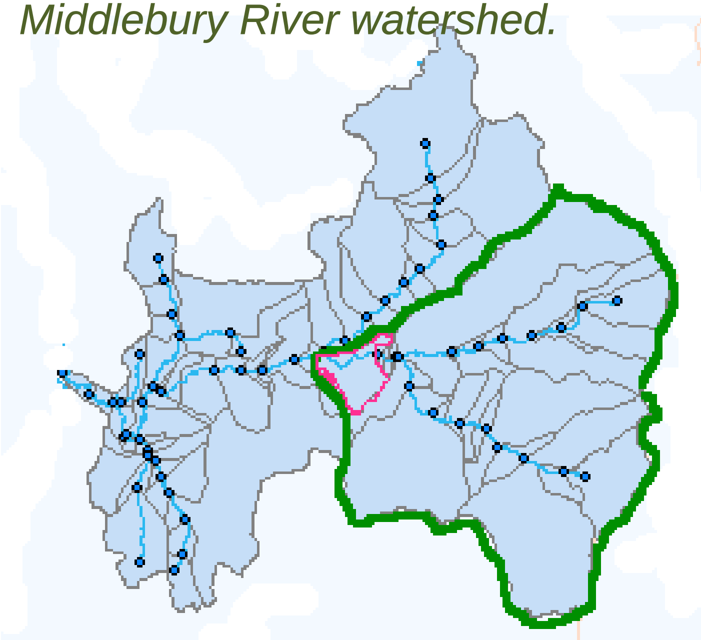


Road metrics were evaluated over four geographic regions, characterized by channel proximity and drainage scope.

RGA scores are always the reach score assigned in the field.



Streams (blue segments), reach breaks (circles), and subwatersheds (polygons) for the VTANR-RMP assessment of the Middlebury River watershed.



Reach Direct Drainage = Local

Catchment = Total Upstream Network

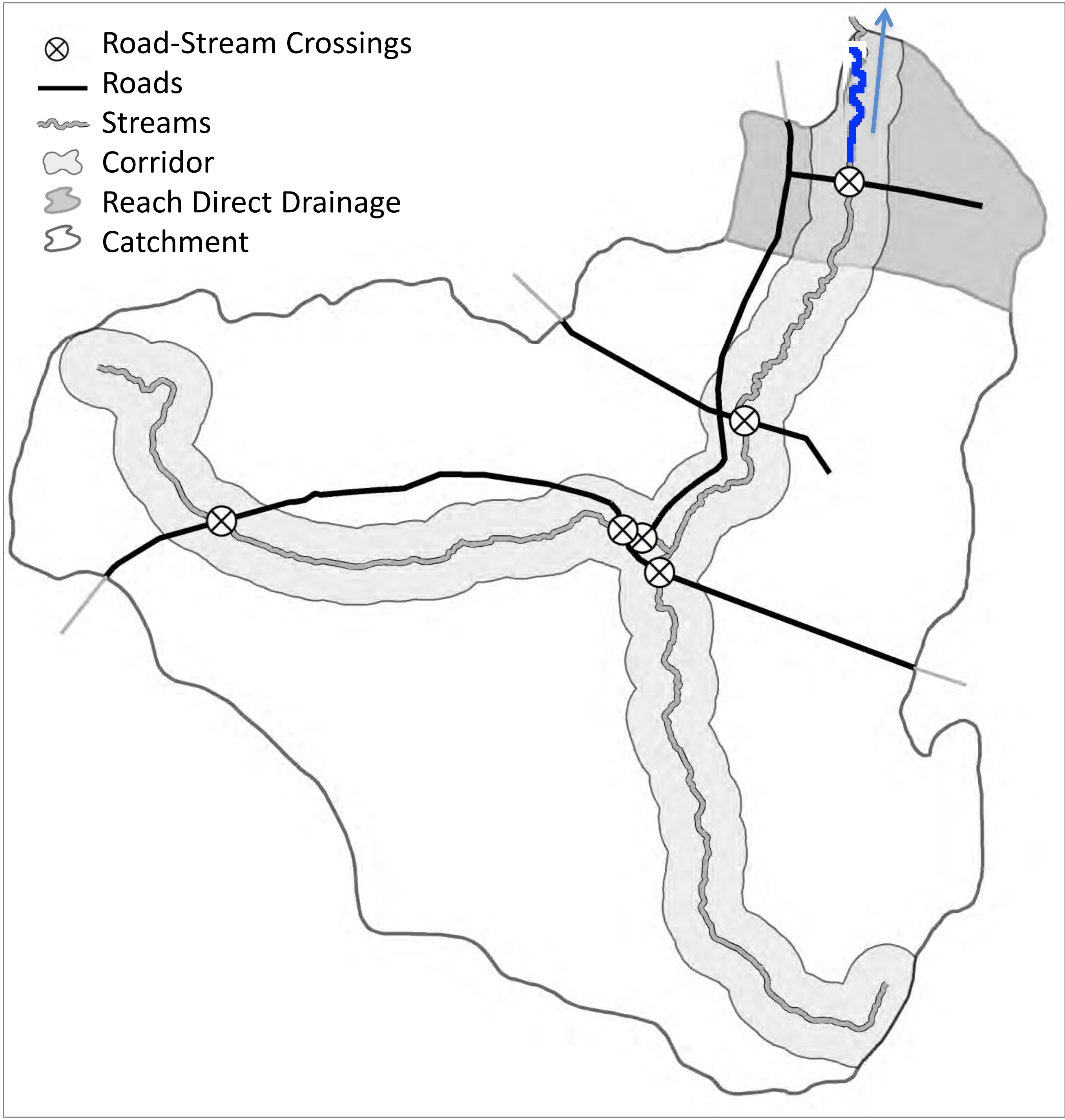
Road Metric #1: Road-Stream Crossings

Raw Count (old)

Number per Unit Area (old)

Number per Unit Length of Stream *(new, also now in USGS pub rel 2013)*

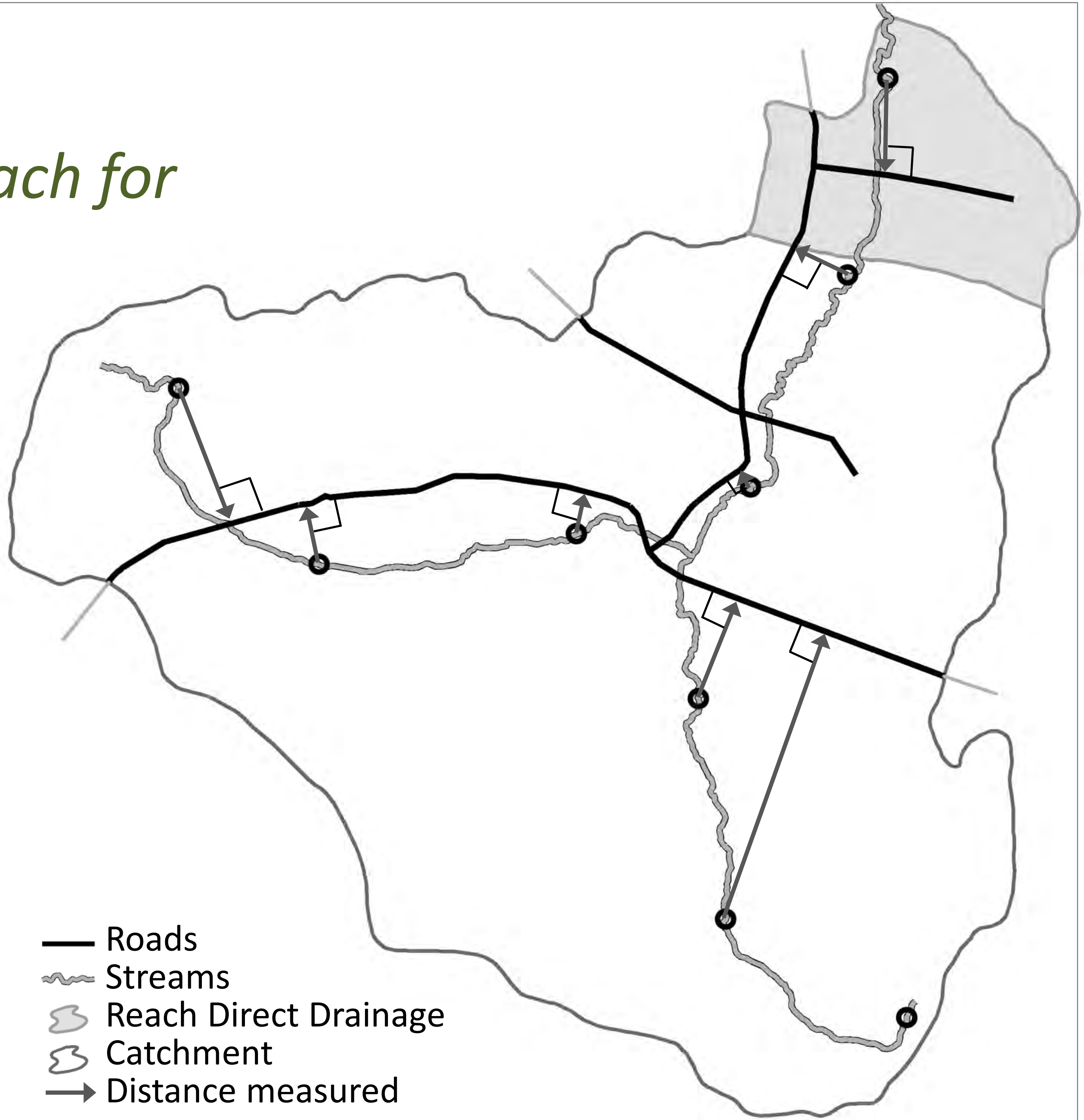
→Recognition of Direct and Dramatic Impacts of Crossings on Stream Condition



Road Metric #2
Our new approach for characterizing PROXIMITY

Sum of distances, stream to nearest roads

(m/m)



**similar to a USGS metric found in 2013 publication.*

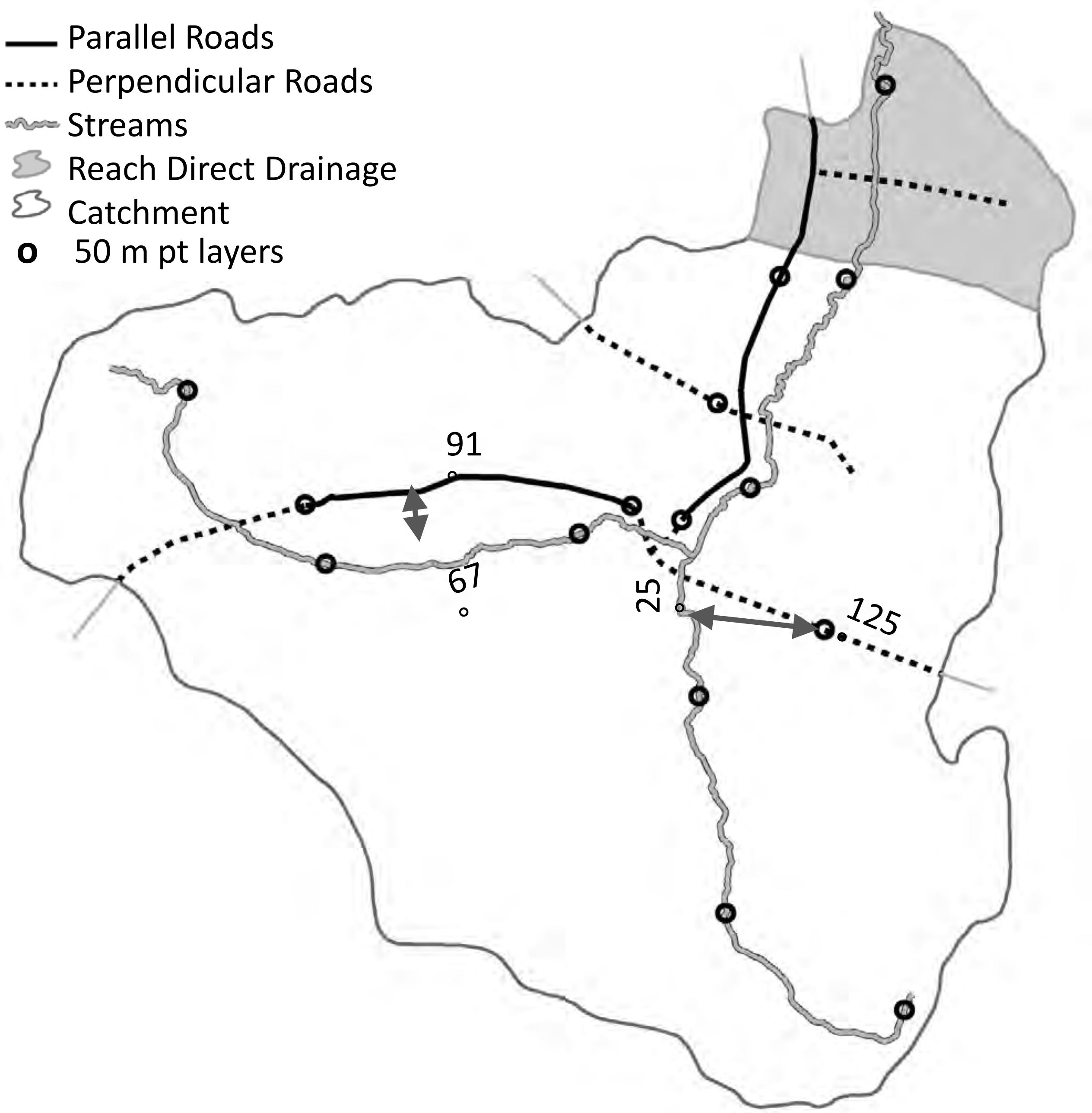
Road Metrics #3, *Our new approach for characterizing ORIENTATION*

For Each of Parallel and Perpendicular:

Sum of distances, roads to nearest streams *(m/m)*

***Mean** of distances, roads to nearest streams (m)*

***Percent** of roads in orientation category*



ArcGIS Tools

Graphics and Shapes > Calculate Geometry (for azimuth calculations - extension downloaded from ArcScripts website)

Near (distance between roads and streams - proximity metric)

Construct Points (create points at 50m intervals)

Split (split lines at 50m intervals)

Spatial Join (used like the "Near" function but for the orientation metric as it also joins the fields from the two joined features - i.e. a road and stream segment with azimuth calculated will result in the stream segment with both azimuths listed in the attribute table)

Calculations for the proximity results of parallel and perpendicular done in *attribute table* - use the two azimuths after performing spatial join (*if statement* assigns "parallel" and "perpendicular").

New road metrics sensitive at multiple scales

Table entries are p-values from inspecting individual metrics using Logistic Regression Analysis p=0.05 considered significant

	Riparian Corridor		Catchment Area	
Region	*ReachCorr*	*CatchCorr*	*ReachDD*	*Catch*
Traditional Density Metrics				
Roads Present (*yes*, *no*)	**.05** D .02			
Road Density, km/km^2	D .01	D .02	**.002** A .004	
Road X Stream by drainage area, #/km^2	**.005** A .0003 D .002	**.02**	**.0003** A .0007 D .0006	
Proximity Metrics				
Road X Stream*, #/m	**.02** A .006 D .03	**.006**	**.02** A .006 D .03	**.006**
Sum of distances, stream to nearest roads*, m/m	**.002** A .02 D <.0001	A .02 D .02	**.01** A .01 D .0003	A .03
Orientation Metrics				
PARALLEL ROADS TO NEAREST STREAM				
Sum of distances*, m/m	D .02	**.03** D .03	A .002	**.02** A .02 D .0005
Mean of distances, m	**.02**			D .007
Roads, % Parallel		**.0004** D .002		
PERPENDICULAR ROADS TO NEAREST STREAM				
Sum of distances *	D .04			A .03 D .0002
Mean of distances		D .02		D .04
Roads, % Perpendicular	A .0007		**.03** A .04 D .05	

- *normalized by stream length*

USGS GIS guidelines released 2013

Region	Riparian Corridor: ReachCorr	Riparian Corridor: CatchCorr	Catchment Area: ReachDD	Catchment Area: Catch
Traditional Density Metrics				
Roads Present (yes, no)	**.05** D .02			
Road Density, km/km^2	D .01	D .02	**.002** A .004	
Road X Stream by drainage area, $\#/km^2$	**.005** A .0003 D .002	**.02**	**.0003** A .0007 D .0006	
Proximity Metrics				
Road X Stream*, #/m	**.02** A .006 D .03	**.006**	**.02** A .006 D .03	**.006**
Sum of distances, stream to nearest roads*, m/m	**.002** A .02 D <.0001	A .02 D .02	**.01** A .01 D .0003	A .03
Orientation Metrics				
PARALLEL ROADS TO NEAREST STR				
Sum of distances*, m/m	D .02			
Mean of distances, m	**.02**			
Roads, % Parallel				
PERPENDICULAR ROADS TO NEARE				
Sum of distances *	D .04			
Mean of distances				
Roads, % Perpendicular	A .0007			

Mean of the distances @ 30m

•*normalized by stream length*

“Anthropogenic Factors”

National Water-Quality Assessment Program: *Methods to Characterize Environmental Settings of Stream and Groundwater Sampling Sites for National Water-Quality Assessment*

USGS, 2012. Released 2013.

Discriminant Analysis

Classification tool using continuous predictor variables to categorize a dependent variable into pre-defined classes (e.g., Fair, Good, ...)

	N = 99	Predictions			
		Poor	Fair	Good	Reference
Actual	*Poor*	**3**	1	*0*	*0*
	Fair	10	**24**	7	*5*
	Good	*6*	11	**18**	3
	Reference	*0*	*1*	1	**9**

DA contingency table showing counts for *RGA* classification using combined *Inherent* and *Proximity* metrics as inputs at the *Reach Direct Drainage* scale: Predictions 55% exact, 88% within one class.

Discriminant Analysis on individual metric categories...

Metric Set	Inherent	Density	Proximity	Orientation
Geographic Region				
REACH CORR				
% Correctly classified	44.1	36.7	29.3	33.3
% Correct, +/- 1 class	77.5	73.5	77.3	72.5
-2 Log Likelihood	244.7	255.2	194.3	127.6
N	102	98	75	51
REACH DD				
% Correctly classified	44.1	24.5	29.3	43.3
% Correct, +/- 1 class	77.5	72.5	75.8	82.2
-2 Log Likelihood	244.7	272.6	262.2	216.0
N	102	102	99	90
CATCH CORR				
% Correctly classified	*NA**	16.2	40.0	37.0
% Correct, +/- 1 class		66.7	88.4	76.1
-2 Log Likelihood		267.4	244.8	239.7
N		99	95	92
CATCH				
% Correctly classified	*NA**	18.6	32.0	33.0
% Correct, +/- 1 class		63.7	73.0	79.0
-2 Log Likelihood		276.7	269.6	257.5
N		102	100	100

** Metrics not available*

Inherent metrics dominate at 2 Reach scales;

Orientation metrics comparable for Reach DD;

Proximity metrics strong for Catchment Corridor

Inherent Metrics:

Bedform, Bed material, Confinement, Slope

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N		102	100	100

** Metrics not available*

Inherent metrics dominate at 2 Reach scales; Orientation comparable for Reach DD

Proximity metrics strong for Catchment Corridor

Proximity and Orientation valuable for Catchment; improvement over traditional road density

Inherent Metrics:

Bedform, Bed material, Confinement, Slope

"NA": Can we characterize inherent metrics at the catchment (channel network) scale?

Discriminant Analysis on combinations of two metric categories...

Metric Sets	Inherent Density	Inherent Proximity	Inherent Orientation	Density Proximity	Density Orientation	Proximity Orientation
Geographic Region						
REACHCORR						
% Correctly classified	49.0	56.0	58.8	5.3	7.8	49.0
% Correct, +/- 1 class	85.7	86.7	94.1	53.3	56.9	80.4
-2 Log Likelihood	217.2	139.5	94.14	.	.	113.7
N	98	75	51	75	51	51
REACHDD						
% Correctly classified	50.0	54.5	58.9	34.3	45.6	48.9
% Correct, +/- 1 class	81.4	87.9	87.8	78.8	83.3	81.1
-2 Log Likelihood	234.4	219.2	173.4	257.1	210.1	208.6
N	102	99	90	99	90	90
CATCHCORR						
% Correctly classified	26.3	43.2	38.0	43.2	30.4	41.3
% Correct, +/- 1 class	66.7	86.3	76.1	80.0	72.8	85.9
-2 Log Likelihood	265.8	242.8	238.6	236.9	234.4	217
N	99	95	92	95	92	92
CATCH						
% Correctly classified	30.4	37.0	29.0	39.0	36.0	37.0
% Correct, +/- 1 class	66.7	81.0	78.0	85.0	77.0	79.0
-2 Log Likelihood	272.5	267.9	257.3	243.5	244.2	246.9
N	102	100	100	100	100	100

Reach Scales:

Proximity and Orientation best predictors of stream condition, both enhanced by Inherents

At catchment scales, "Inherent" is slope (%) of main channel for the total upstream river network

Discriminant Analysis on combinations of two metric categories...

Metric Sets	Inherent Density	Inherent Proximity	Inherent Orientation	Density Proximity	Density Orientation	Proximity Orientation
Geographic Region						
REACHCORR						
% Correctly classified	49.0	56.0	58.8	5.3	7.8	49.0
% Correct, +/- 1 class	85.7	86.7	94.1	53.3	56.9	80.4
-2 Log Likelihood	217.2	139.5	94.14	.	.	113.7
N	98	75	51	75	51	51
REACHDD						
% Correctly classified	50.0	54.5	58.9	34.3	45.6	48.9
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% Correctly classified	26.3	43.2	38.0	43.2	30.4	41.3
% Correct, +/- 1 class	66.7	86.3	76.1	80.0	72.8	85.9
-2 Log Likelihood	265.8	242.8	238.6	236.9	234.4	217
N	99	95	92	95	92	92
CATCH						
% Correctly classified	30.4	37.0	29.0	39.0	36.0	37.0
% Correct, +/- 1 class	66.7	81.0	78.0	85.0	77.0	79.0
-2 Log Likelihood	272.5	267.9	257.3	243.5	244.2	246.9
N	102	100	100	100	100	100

Field *and* GIS GIS only

Reach Scales:

Proximity and Orientation best predictors of stream condition, both enhanced by Inherents

Corridor Scales:

*Proximity best predictor, enhanced both by Density and Inherent **

** At catchment scales, "Inherent" is slope (%) of main channel for the total upstream river network*

Discriminant Analysis on combinations of three metric categories...

Metric sets	Inherent Density Proximity	Inherent Density Orientation	Inherent Proximity Orientation	Density Proximity Orientation
Geographic Region				
REACH CORR				
% Correctly classified	5.3	7.8	66.7	7.8
% Correct, +/- 1 class	53.3	56.9	90.2	56.9
-2 Log Likelihood	.	.	75.0	.
N	75	51	51	51
REACH DD				
% Correctly classified	54.6	57.8	58.9	47.8
% Correct, +/- 1 class	83.8	86.7	88.9	82.2
-2 Log Likelihood	216.2	170.8	166.1	206.1
N	99	90	90	90
CATCH CORR				
% Correctly classified	45.3	35.9	42.4	48.9
% Correct, +/- 1 class	82.1	75.0	87.0	92.4
-2 Log Likelihood	235.2	233.0	215.6	203.2
N	95	92	92	92
CATCH				
% Correctly classified	43.0	35.0	36.0	43.0
% Correct, +/- 1 class	85.0	77.0	78.0	83.0
-2 Log Likelihood	241.8	243.9	246.7	216.1
N	100	100	100.0	100

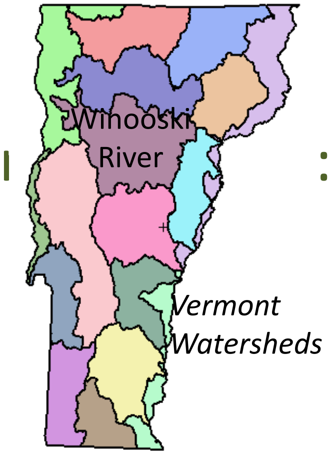
Strongest reach-scale predictions involve Proximity, Orientation, and Inherent metrics

Strongest catchment-scale predictions always include the Proximity metrics

At catchment scales, "Inherent" is slope (%) of main channel for the total upstream river network

In conclusion…

First study to examine relationships between road network geometry and river channel :



- **Extensive** dataset of stream reaches (VTANR RMP data unique)
- Nearly **exclusive** of other **anthropogenic** influences
- Field-based, stream geomorphic **assessment protocols**
- Road metrics included traditional (density) and **newly-derived** (orientation, proximity)

After accounting for inherent channel characteristics*, measures of road network geometry provided important explanatory power:
Discriminate channel condition*, especially at the* ***largest (catchment) scale****.*

Metrics were derived by geospatial analyses of **remotely-sensed data**:
Identify other reaches at risk without requiring intensive "Phase 2" field assessments.

**bedform, slope, confinement, dominant bed material*