WIN-System: A Decision Tool for Cumulative Watershed Effects Assessment in Alberta

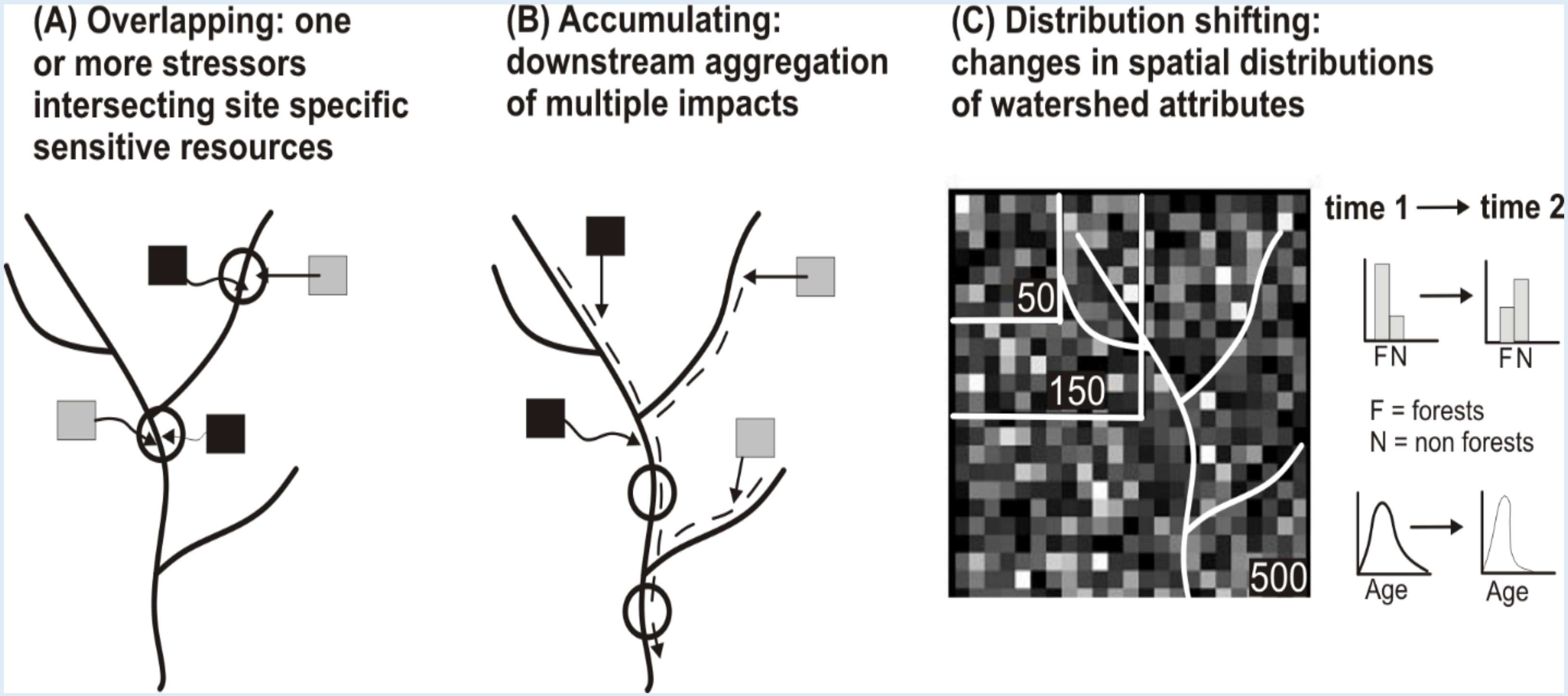
Forest Program Management Section/Forest Management Branch of Alberta Government

TerrainWorks Mt. Shasta, CA/Seattle, WA

April 18, 2016

Table of Contents

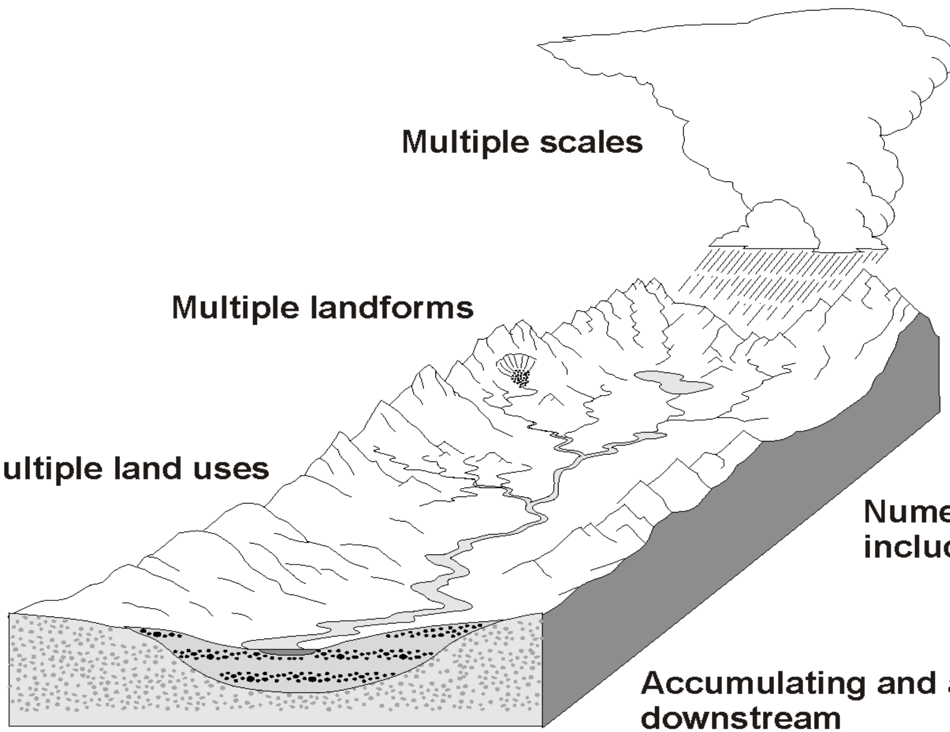
Conceptual Framework



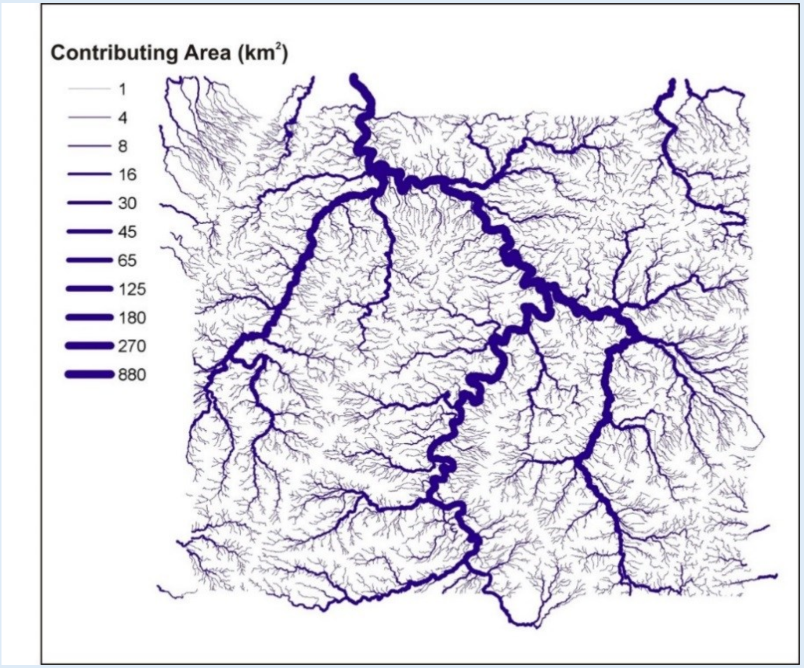
Apply an approach that is less about studying cause and effect and more about applying first principles already well established between land use stressors and potential habitat impacts. Use existing tools (NetMap and others) to identify existing and potential future areas of impacts, and design management prescriptions to eliminate or avoid them.

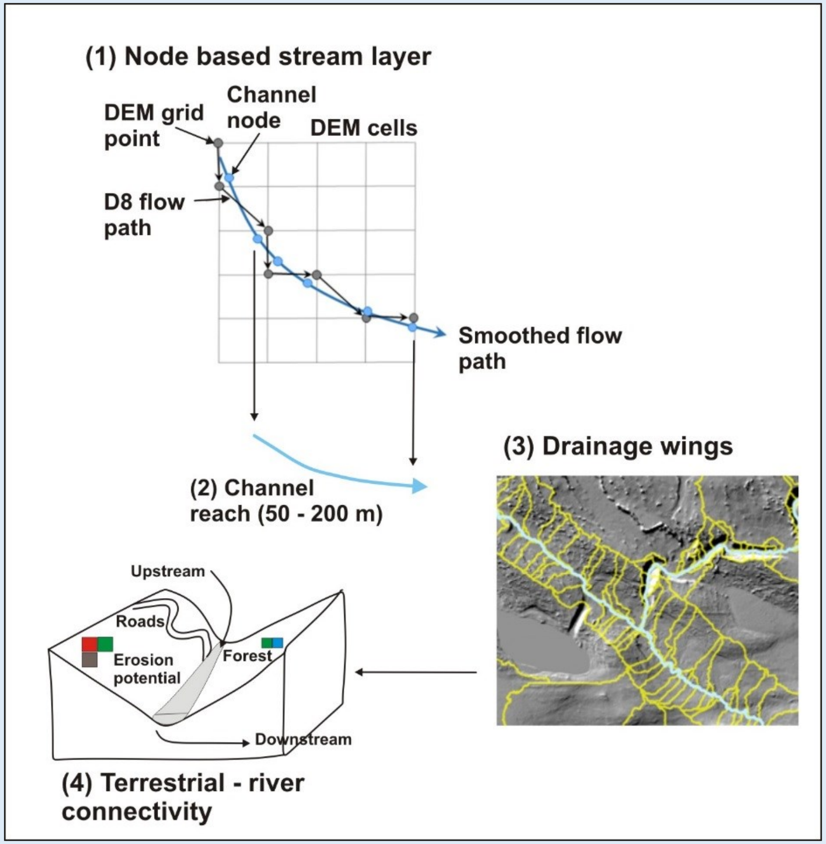
Land Use Category	Habitat-Related Issues	Water Quality Issues
Forestry	Channel modification Pool quantity and quality Large wood abundance Shade and canopy Substrate quality Flow alteration Passage barriers	Temperature Turbidity Fine sediments Pesticides and herbicides
Crop-land grazing	Channel modification Pool quantity and quality Large wood abundance Shade and canopy Substrate quality Flow alteration	Temperature Dissolved oxygen Turbidity Fine sediments Suspended sediments Nutrients, bacteria Pesticides and herbicides
Feedlots and dairies	Channel modification	Suspended Sediments Nutrients Bacteria
Urban areas	Flow alteration Channel modification Pool quantity and quality Large wood abundance Shade and canopy Substrate quality Passage barriers	Temperature Dissolved oxygen Turbidity Suspended sediments Fine sediments Nutrients Organic and inorganic toxics
Mining	Channel modification Pool quantity and quality Substrate quality	Turbidity Suspended sediments Fine sediments Heavy metals
Dams and irrigation works	Flow alteration Channel modification Pool quantity and quality Substrate quality Passage barriers	Temperature Dissolved oxygen Fine sediments
Road networks	Flow alteration Channel modification Pool quantity and quality Substrate quality Passage barriers	Turbidity Suspended sediments Fine sediments

Key Elements of Cumulative Watershed Effects Analysis and Resource Use Decision Support

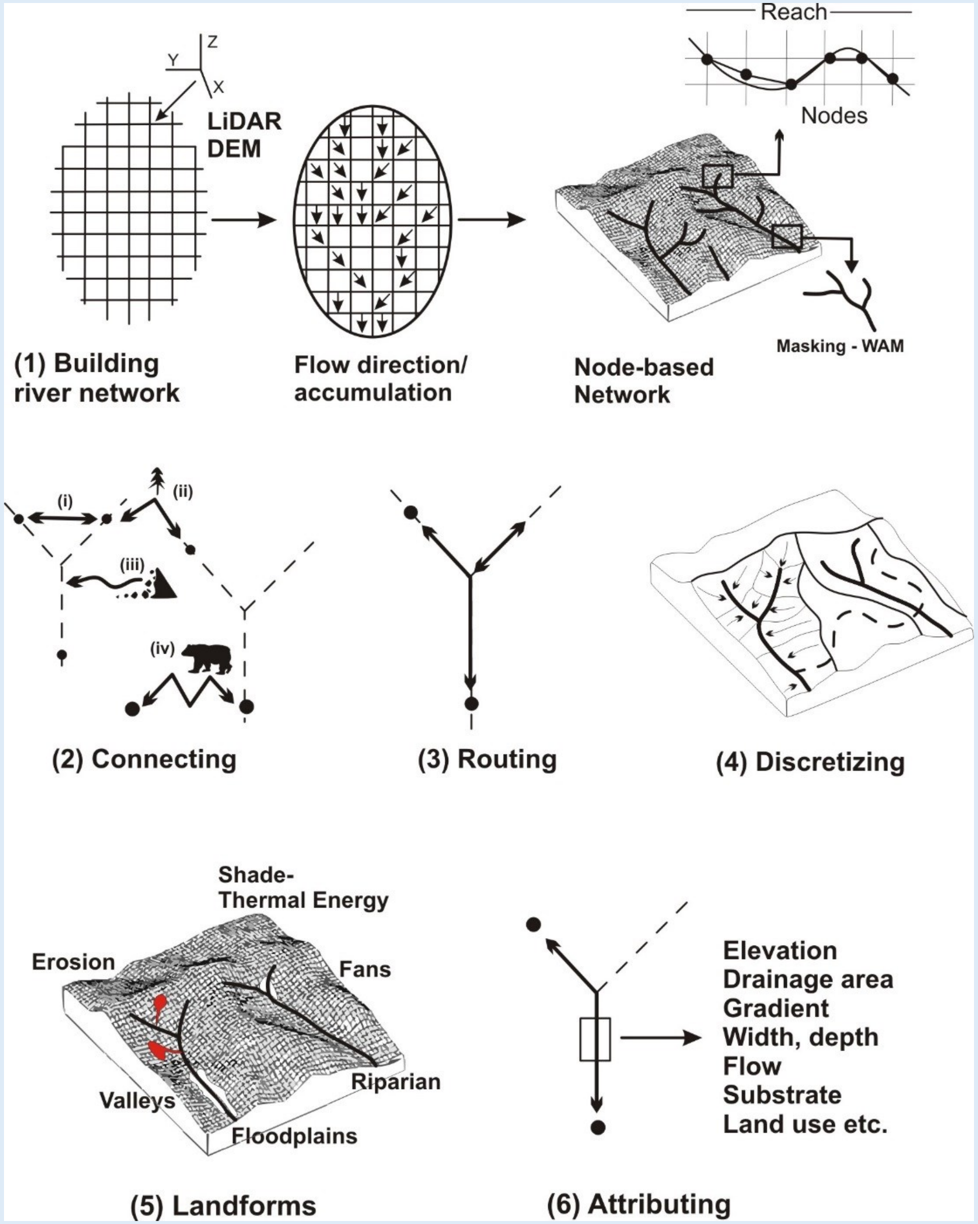


River network mirrored on the WAM flow lines, but utilizing NetMap's node based data structure

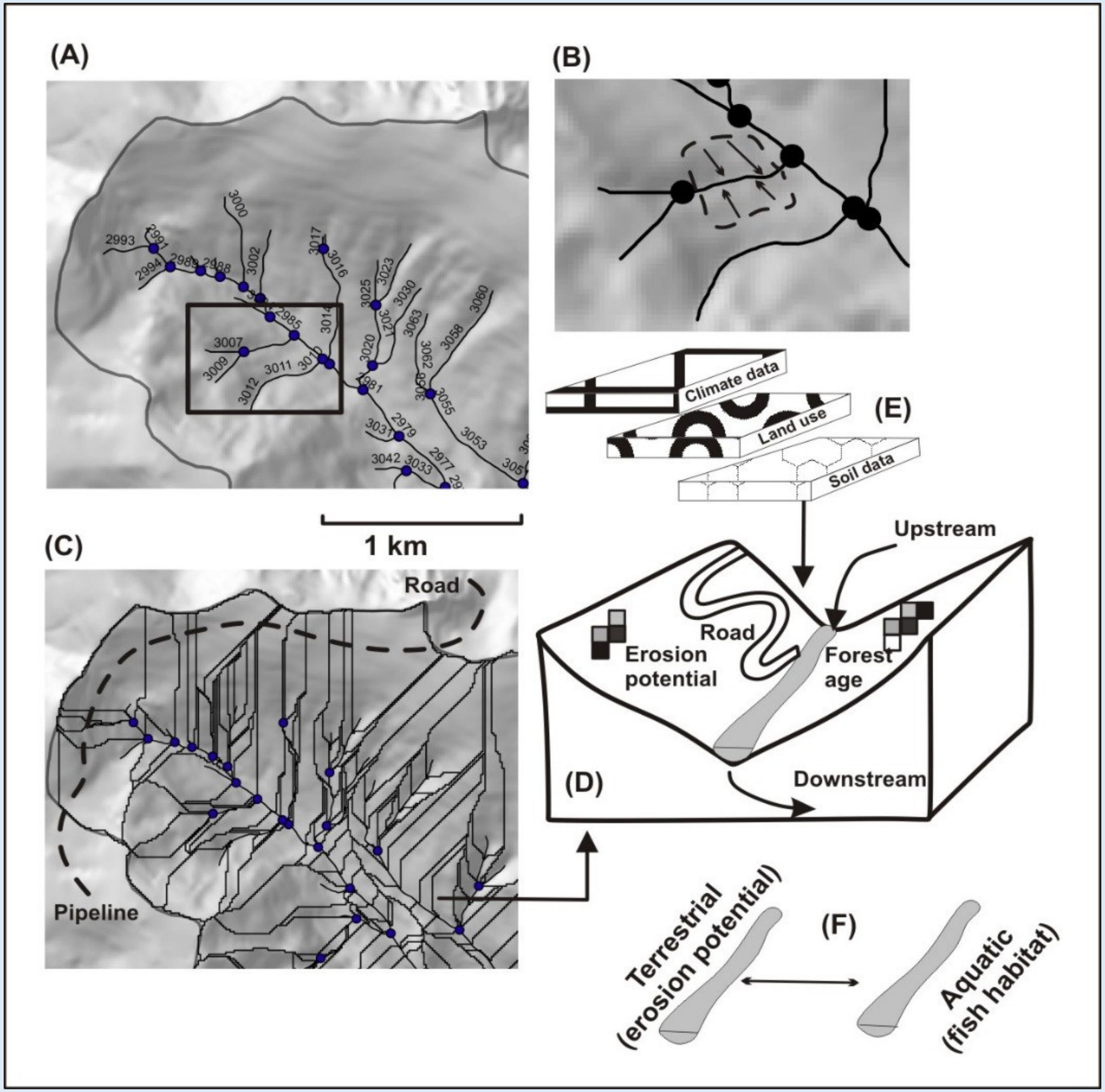




Key functional elements of the coupled stream terrestrial system (virtual watershed)



Key functional elements of the coupled stream terrestrial system (virtual watershed)



Channel Attributes	Landform and Process Characterization
Gradient	Floodplains
Elevation	Terraces
Distance to outlet	Alluvial fans
Drainage area	Hillslope-gradient and convergence (mass wasting)
Mean annual flow	Tributary confluences
Stream order	Erosion potential
Channel width and depth	Hillslope–slope profile
Bed substrate	(surface erosion)
Channel sinuosity	Valley width and transitions
Channel classification	Debris flows
Fish habitats	Earthflows
Radiation loading	Floodplains
Mean annual precipitation	Terraces
Gradient	Alluvial fans

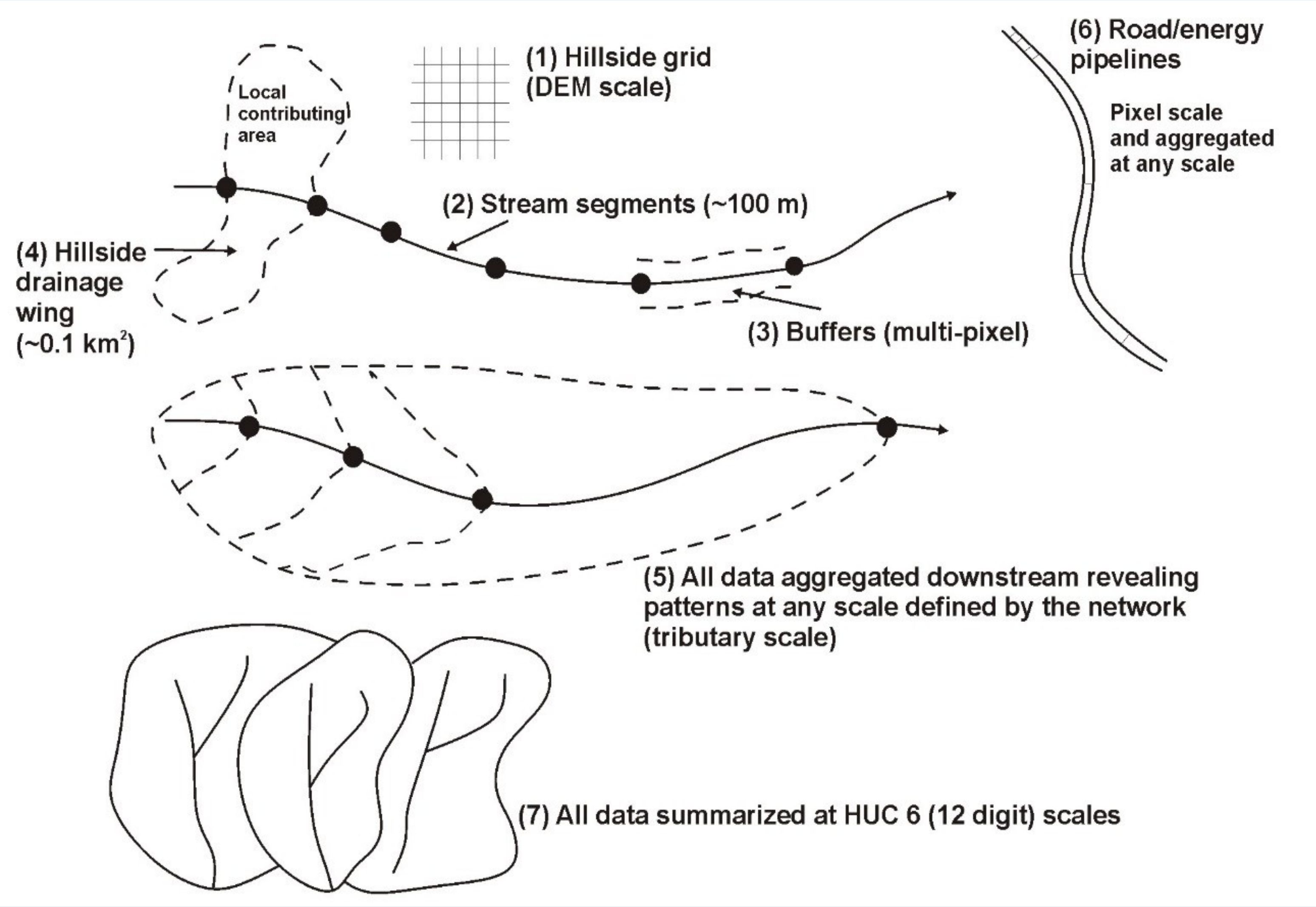
Table 4. A listing of analysis tools available in the *WIN-System*. New tools can be built and incorporated in the future.

***WIN-System* Analysis Tools**	37) Westslope cutthroat habitat
Module: Analysis Tools	38) Coastal cutthroat habitat
1) Define fish distribution	39) Habitat diversity
2) Calculate channel gradients (multiple length scales)	40) Cumulative habitat length and quality
3) Query watershed databases (n=5)	41) Beaver habitat
4) Profile graphing (longitudinal and x-sectional)	42) Channel disturbance index
5) Attribute aggregation, downstream – upstream, routing of buffer and hillslope attributes	43) Piscidide tool
6) Google Earth zoom and map data transfer	
7) Data management (n = 5)	**Module: Riparian**
8) Risk analysis (n = 2)	44) Delineate variable width riparian zones
9) Sub-basin classification (n=2)	45) In-stream wood recruitment, project scale
10) Watershed delineation	46) In-stream wood recruitment, watershed scale
11) Construct drainage wings	47) Upslope wood recruitment
	48) Thermal energy sensitivity
Module: Fluvial Processes	49) Shade-thermal energy
12) Flow calculation	50) Thermal refugia (4 types)
13) Mean annual flow	
14) Stream power	**Module: Erosion**
15) Bankfull flow	51) Hillslope gradient
16) Channel width	52) Shallow landsliding
17) Channel depth	53) Debris flows
18) Flow velocity	54) Flash floods
19) Bed shear stress/D50	55) Gully erosion
20) Channel sinuosity	56) Earthflow/deep seated
21) Reach gradient adjustment	57) Convert to sediment yields
22) Maximum downstream gradient	58) Sediment delivery adjustment
23) Drainage area	59) Hillslope gradient
24) Stream order	
25) Stream power	**Module: Roads**
26) Tributary confluence effects	60) Import road layer
27) Valley width	61) Road density – basin scale
28) Azimuth	62) Road density – channel segment scale

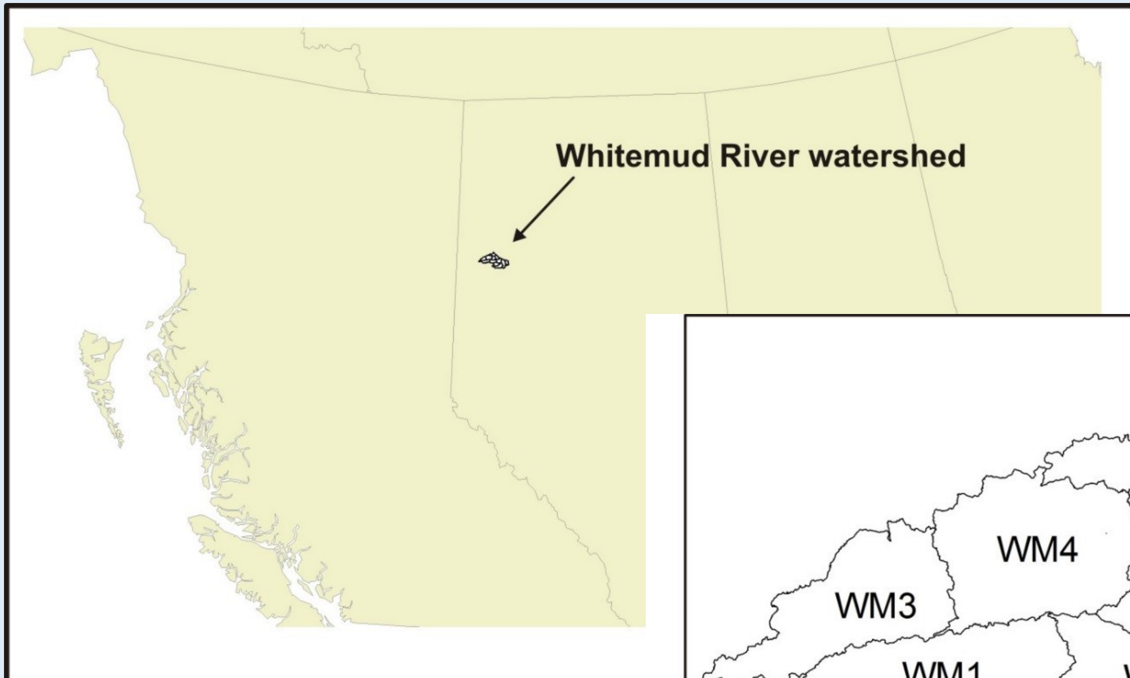
Table 4, continued.

29) Channel classification (4 types)	63) Road hydrologic connectivity
30) Drainage and tributary junction density	64) Road erosion and sediment delivery (n = 3)
31) Valley floor elevation mapping	65) Optimized drain locations
32) Floodplain mapping	66) Optimized road surface erosion remediation
33) Landslide – channel interactions	67) Road stability
34) In-stream wood accumulation types	68) Roads in floodplains
	69) Habitat upstream of crossings
Module: Aquatic Habitats	
35) Create aquatic habitats (HIP model builder)	**Module: Wildfire/Climate change**
36) Bull Trout habitat	70) Wildfire Cascade
	71) Climate change vulnerability

Multiple scales of analysis



Demonstration Analysis: Whitemud River watershed, Alberta (1,230 km^2)



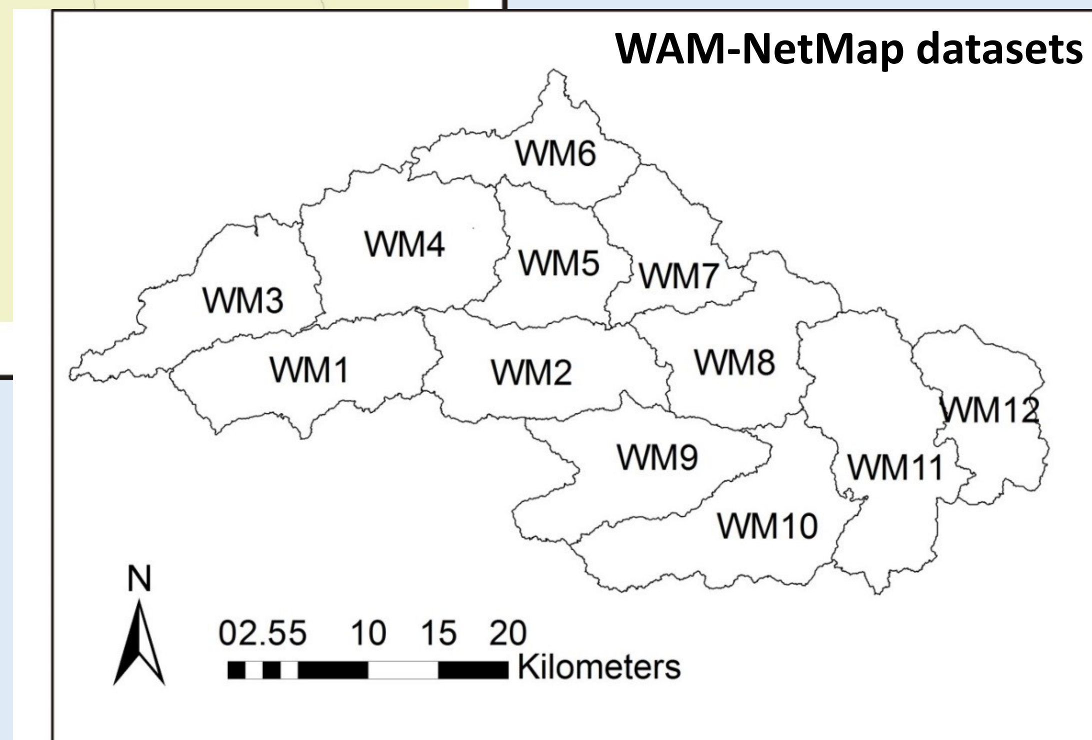


Table 5. The *WIN-System* CWE analysis that is demonstrated within the Whitemud River watershed addressed land uses associated with: 1) forest/energy sector road construction, use and maintenance, 2) forestry - timber harvest, 3) energy development (road infrastructure), 4) post-fire salvage logging, 5) pre-fire fuels reduction, and 6) beetle kill salvage logging.

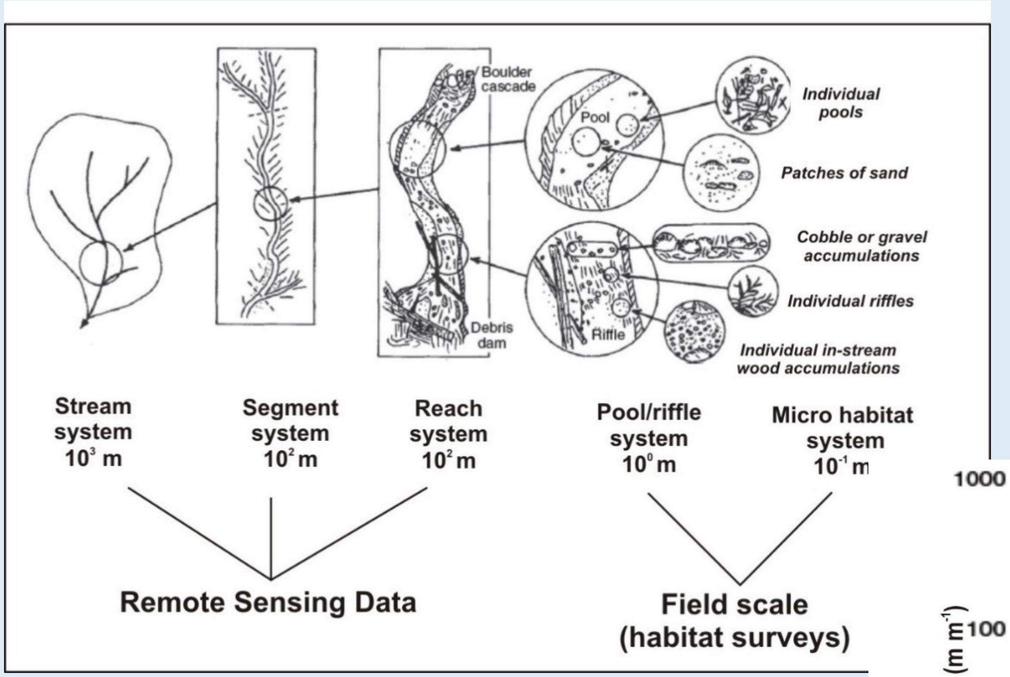
Components of Cumulative Watershed Effects Analysis	Remediation/ Restoration Opportunities	Future Avoidance Opportunities	Importance in CWE Analysis
(1) Location (distribution) of fish habitats	Unknown[1]	Yes	Moderate – habitat sensitives unknown
(2) Channel sensitivity to disturbances	Unknown[1]	Yes	Most larger channels are sensitive
(3) Location of floodplains/flood zones	Unknown[1]	Yes	High
(4) Location of wet areas (WAM)	Unknown[1]	Yes	High
(5) Location of variable width, high value riparian zones	Unknown[1]	Yes	High
(6) Unpaved forest road sediment production and delivery to streams	Yes	Yes	High
(7) Forest road drainage optimization	Yes	Yes	High
(8) Forest road surface improvement optimization	Yes	Yes	Moderate
(9) Ground disturbance – surface erosion and sediment delivery potential	Unknown[1]	Yes	High to low, emphasis on steep areas adjacent to streams
(10) Ground disturbance – gully potential	Possible, but very local	Minor	Mostly low, locally moderate
(11) Ground disturbance – shallow landslide potential	Possible, but very local	None to minor	None to low
(12) Timber harvest cut blocks erosion potential	Possible	Yes	High to low, emphasis on steep areas adjacent to streams
(13) Beetle kill trees – shade/thermal energy impacts	Yes	na	Low to moderate
(14) Wildfire – erosion potential impacts	Yes	In a pre-fire context	Low to moderate

[1] Requires site specific field observations/measurements, information not available during this study.

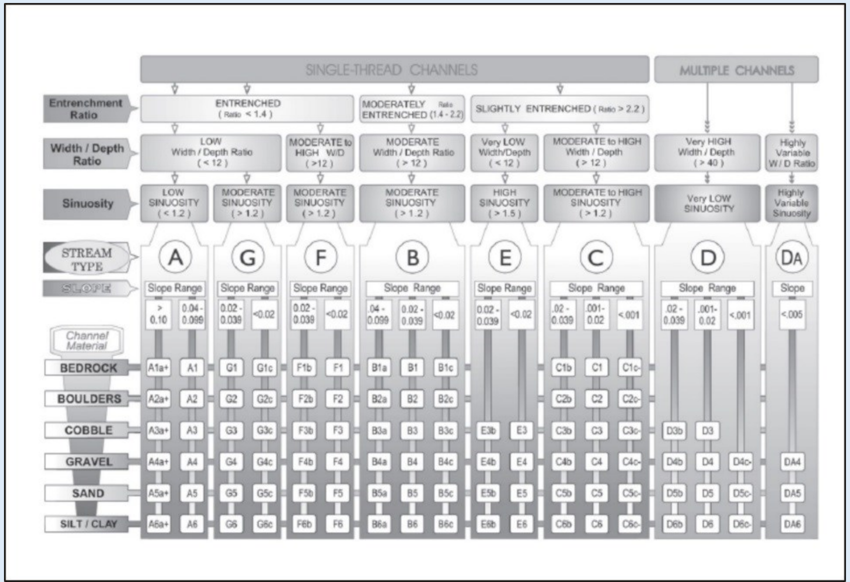
Species and common names of fish in the Whitemud River watershed.

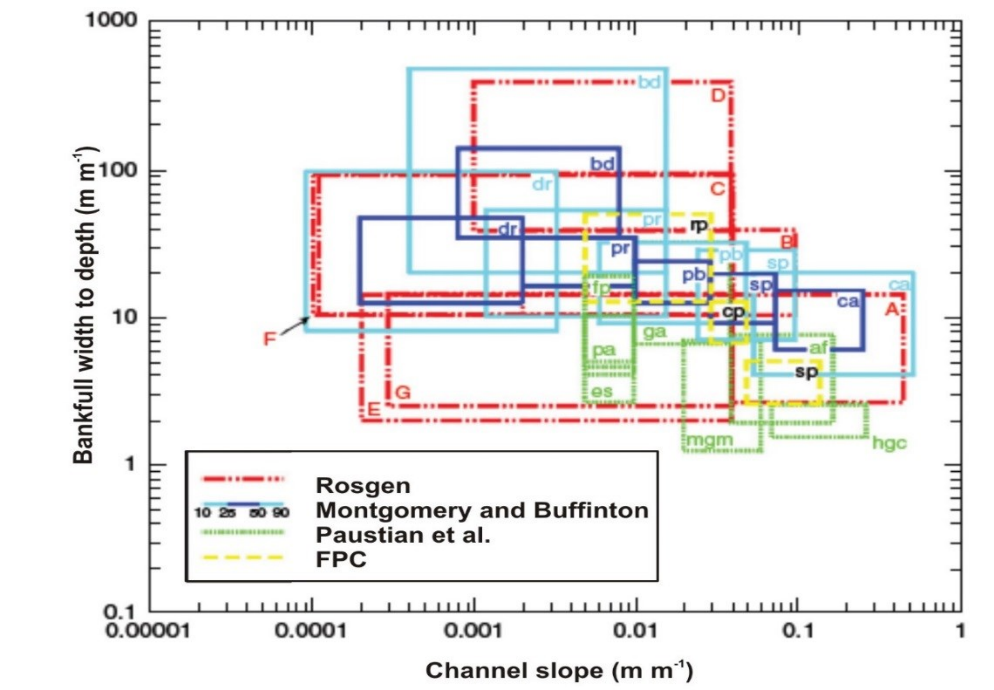
Species	ArcMap Field Name	Common Name	ArcMap Field Name
Arctic grayling	ARGR	Lakechub	LKCH
Brook stickleback	BRST	Longnose dace	LNDC
Burbot	BURB	Longnose sucker	LNSC
Emerald shiner	EMSH	Northern pike	NRPK
Flathead chub	FLCH	Redside shiner	RDSH
Finescale dace	FNDC	Trout perch	TRPR
Fathead minnow	FTMN	Walleye	WALL
Lakechub	LKCH	White sucker	WHSC

Opportunities to create channel classification systems



McCleary et al. 2011
- uplands
- swales
- seepage fed channels
- fluvial channels





Bankfull Channel Width

Bankfull channel width, depth and mean annual flow are predicted by statistical regression and modeled as a power function of mean annual flow, drainage area and or precipitation (e.g., Leopold and Maddock 1953 and Clarke et al. 2008). Statistical regressions for the Alberta Rocky Mountain Foothills (Hinton area) are used in this analysis but NetMap contains a tool to recalculate bankfull channel width.

Bankfull width (m) = a* (drainage area^b)* (Precip^c)   =0.966, b=0.5353, c=0

Bankfull Channel Depth

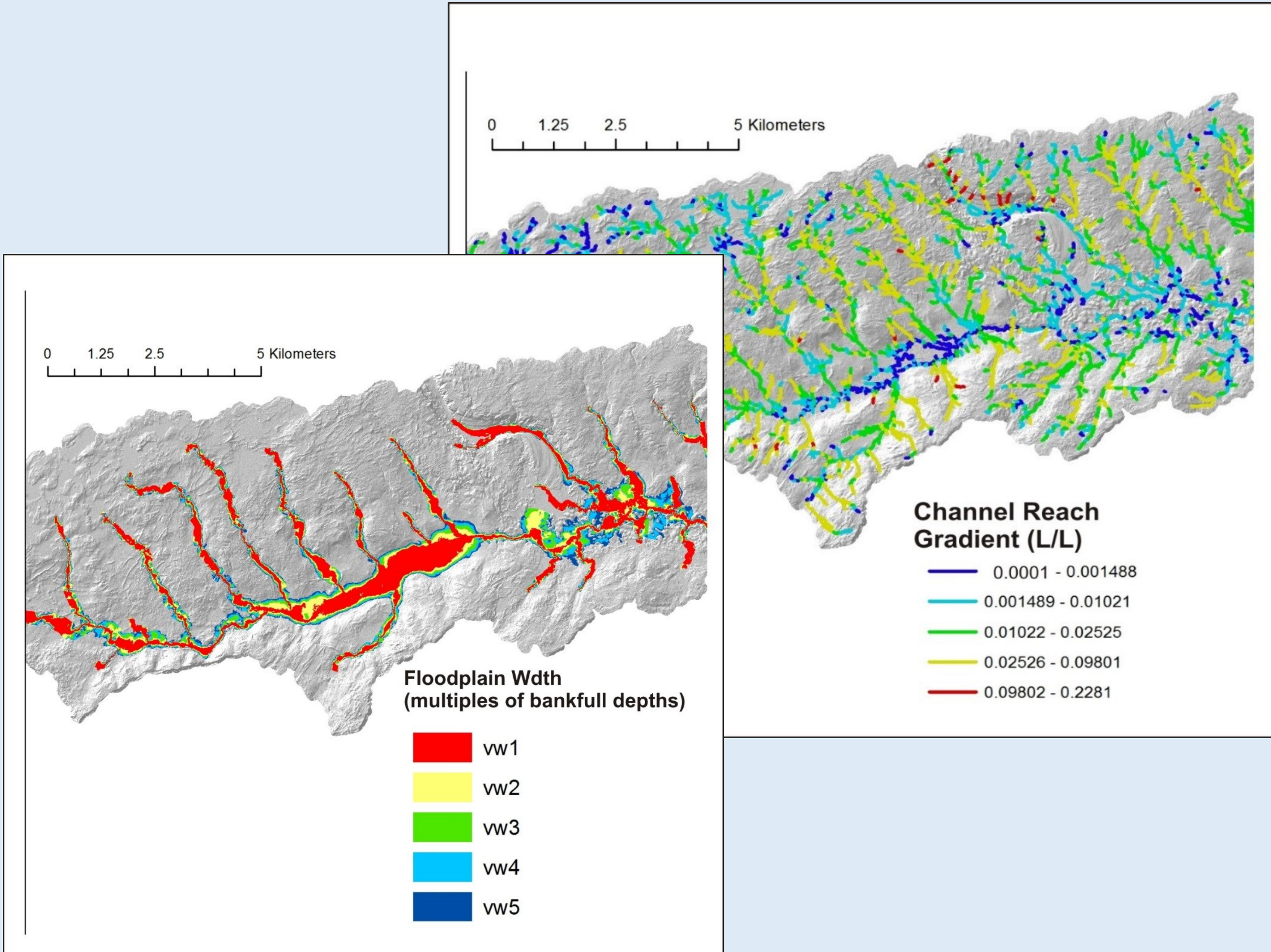
Bankfull channel depth is predicted by statistical regression and modeled as a power function of mean annual flow, drainage area and or precipitation. Statistical regressions for the Alberta Rocky Mountain Foothills (Hinton area) are used in this analysis but NetMap contains a tool to recalculate bankfull channel depth.

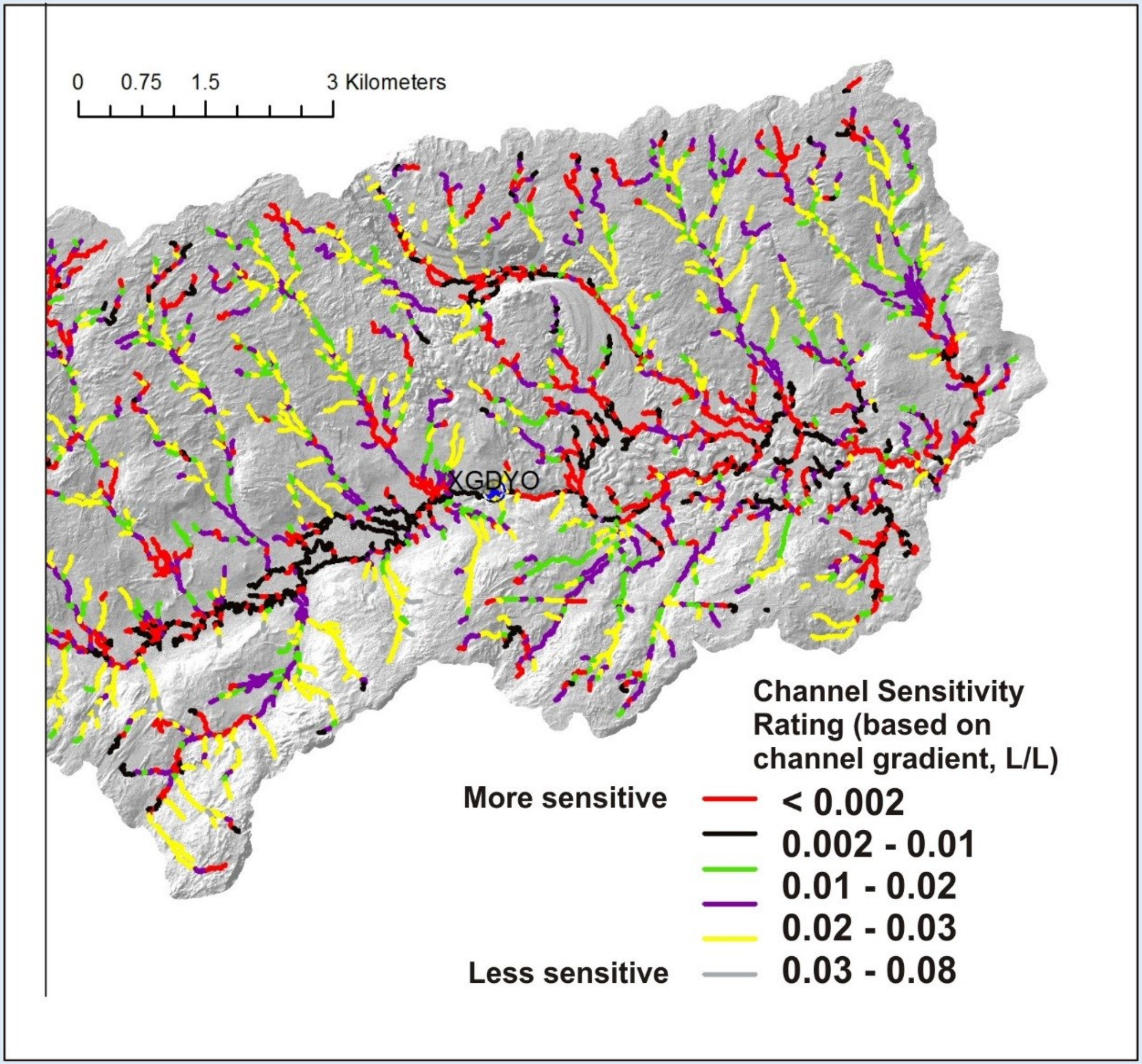
Bankfull depth (m) = a* (drainage area^b)* (Precip^c)   a=0.4427, b=0.2866, c=0

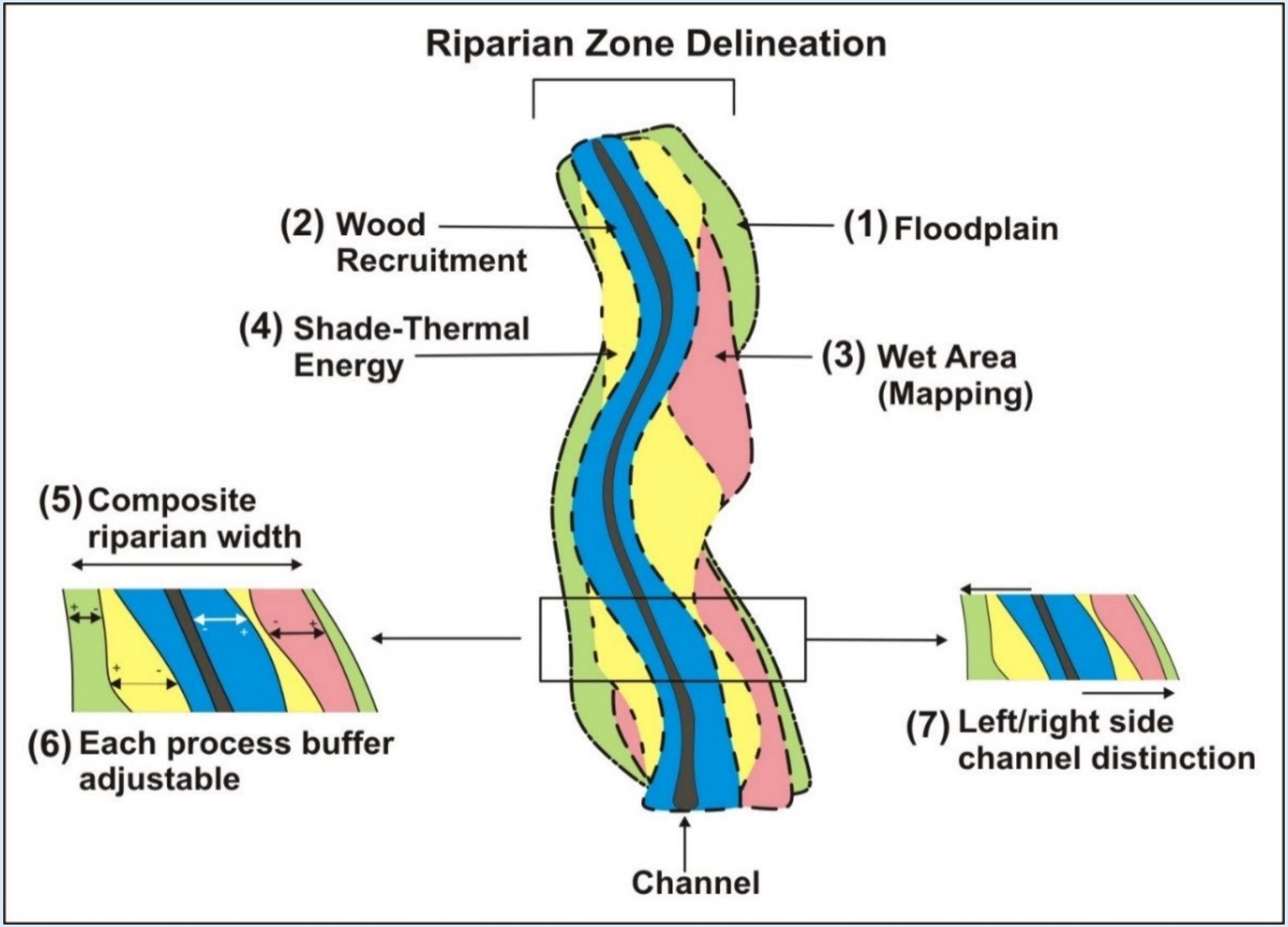
Mean Annual Flow

Mean annual flow is predicted based on the flow regression in Table 2. Analysts can use other statistical relationships to inform this parameter in the Integrated WAM-NetMap using this tool.

Mean Annual flow (m^3s-1) = a* (drainage area^b)* (Precip^c)   a=0.0216, b=0.933, c=0

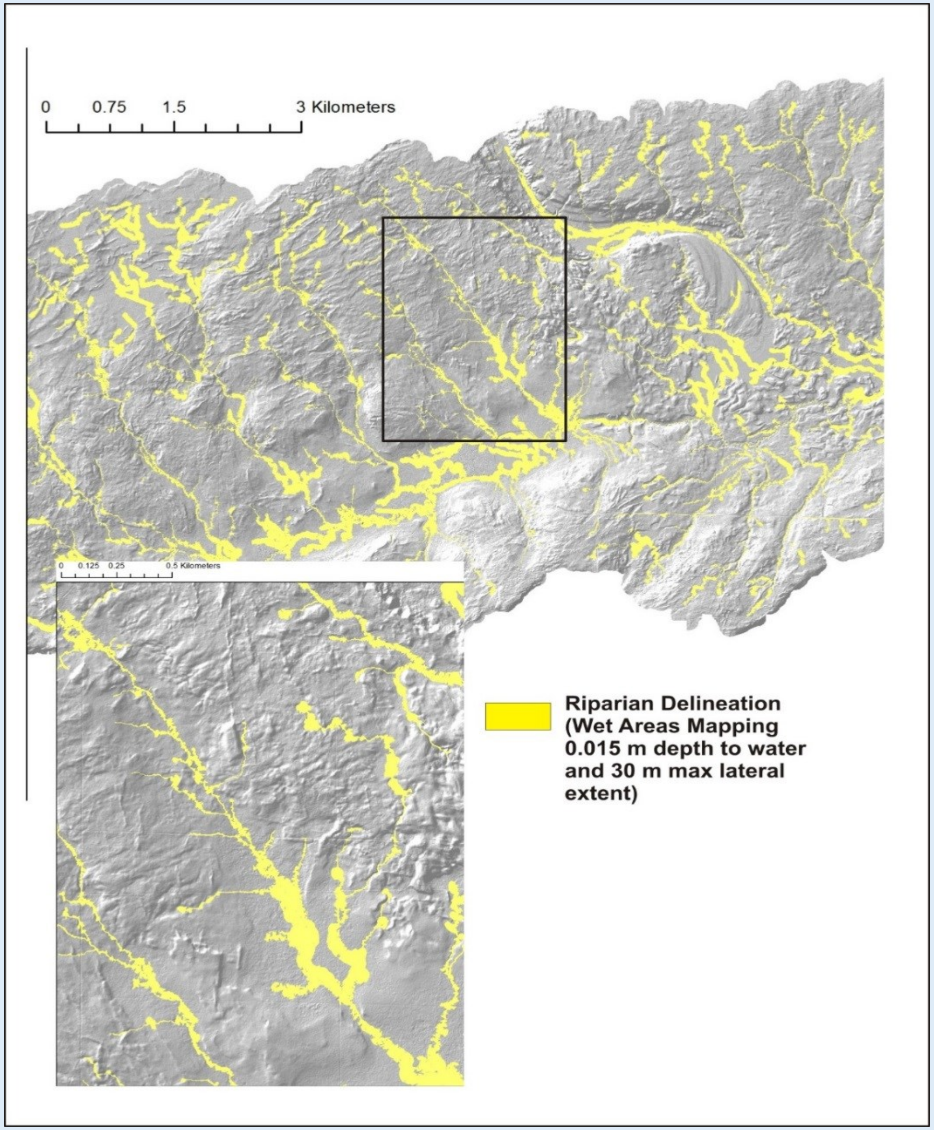

0
1.25
2.5
5 Kilometers
Channel Reach
Gradient (L/L)
0.0001 - 0.001488
0.001489 - 0.01021
0.01022 - 0.02525
0.02526 - 0.09801
0.09802 - 0.2281
0
1.25
2.5
5 Kilometers
Floodplain Wdth
(multiples of bankfull depths)
vw1
vw2
vw3
vw4
vw5

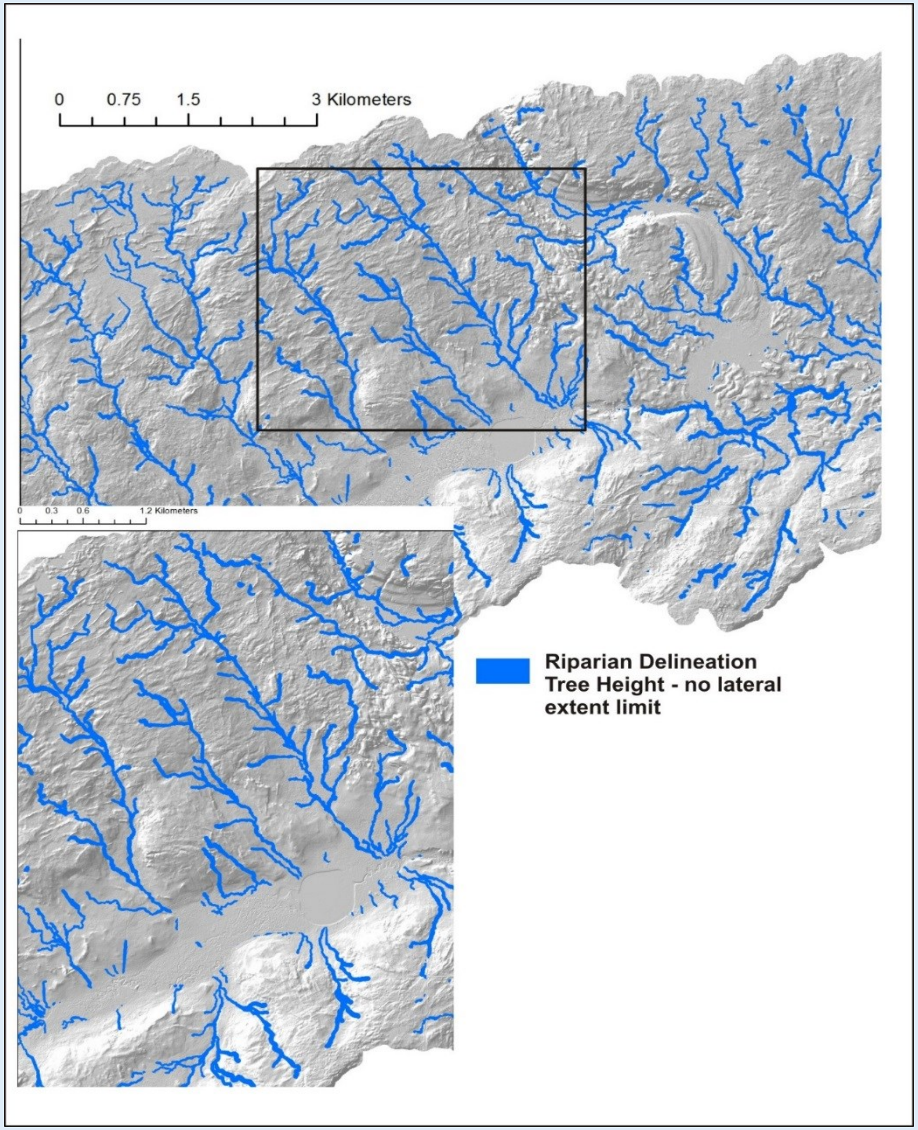

0 0.75 1.5 3 Kilometers
XGDYO
Channel Sensitivity Rating (based on channel gradient, L/L)
More sensitive
< 0.002
0.002 - 0.01
0.01 - 0.02
0.02 - 0.03
Less sensitive
0.03 - 0.08



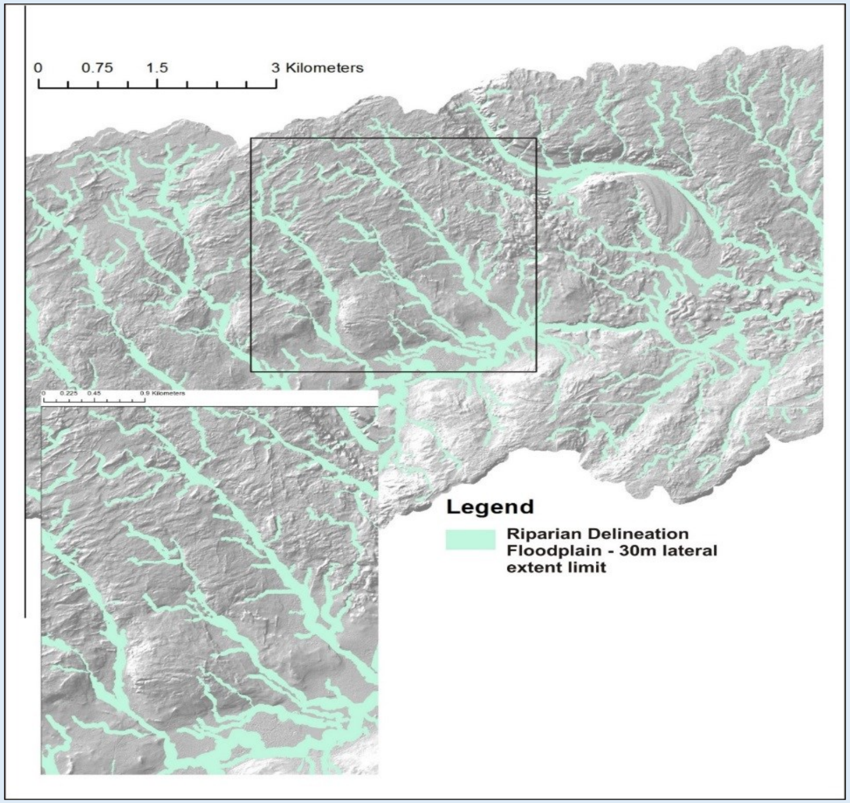
Riparian Zone Delineation
(2) Wood Recruitment
(1) Floodplain
(4) Shade-Thermal Energy
(3) Wet Area (Mapping)
(5) Composite riparian width
(6) Each process buffer adjustable
(7) Left/right side channel distinction
Channel

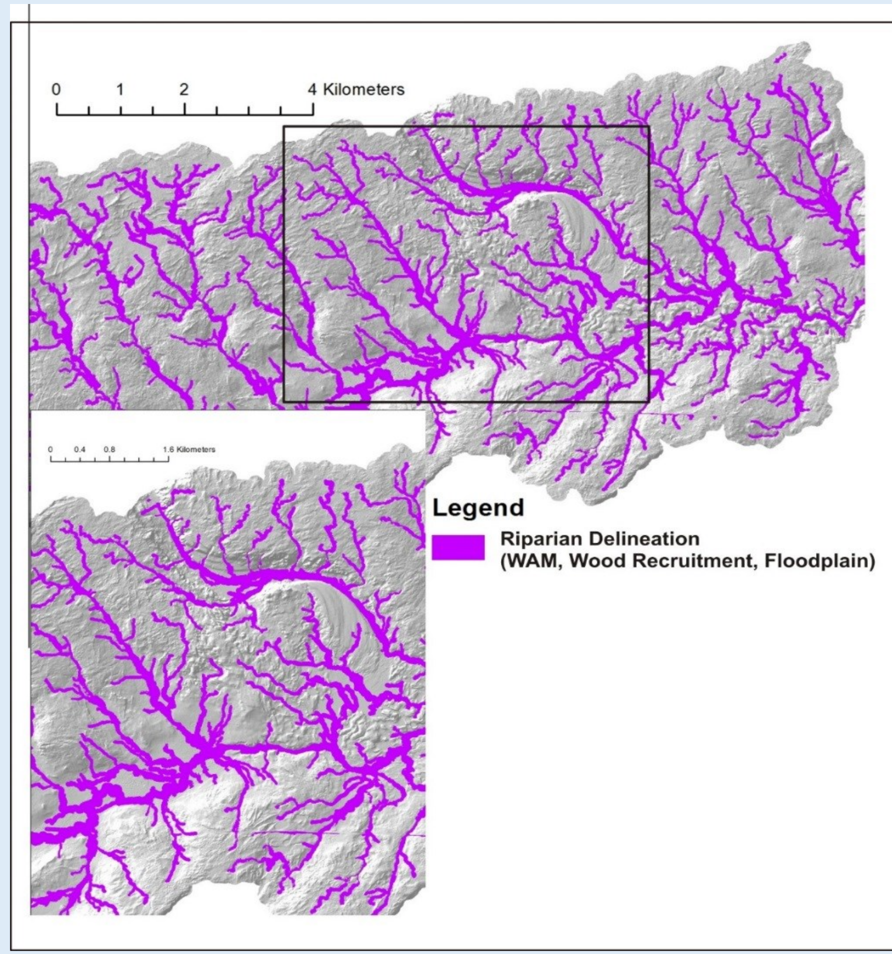
WAM and Tree Heights



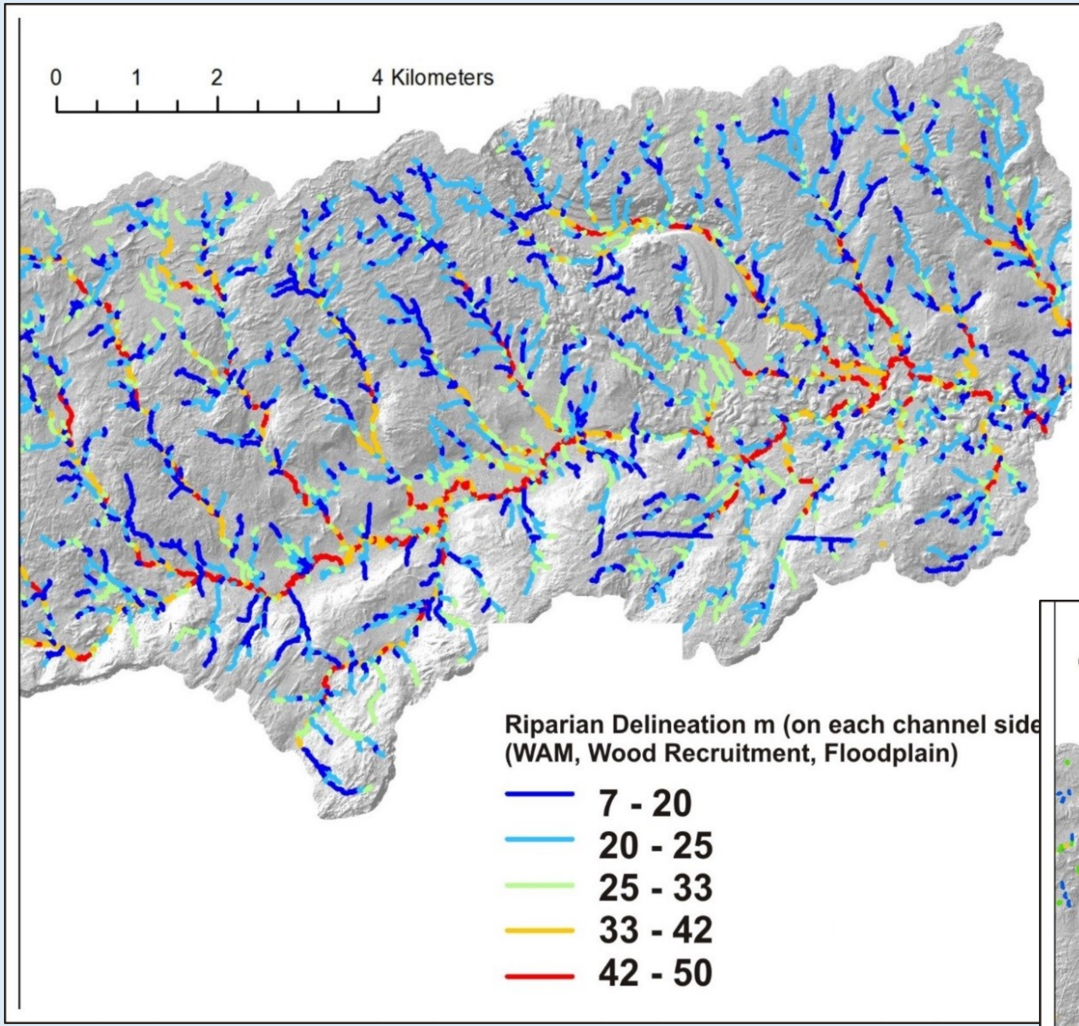


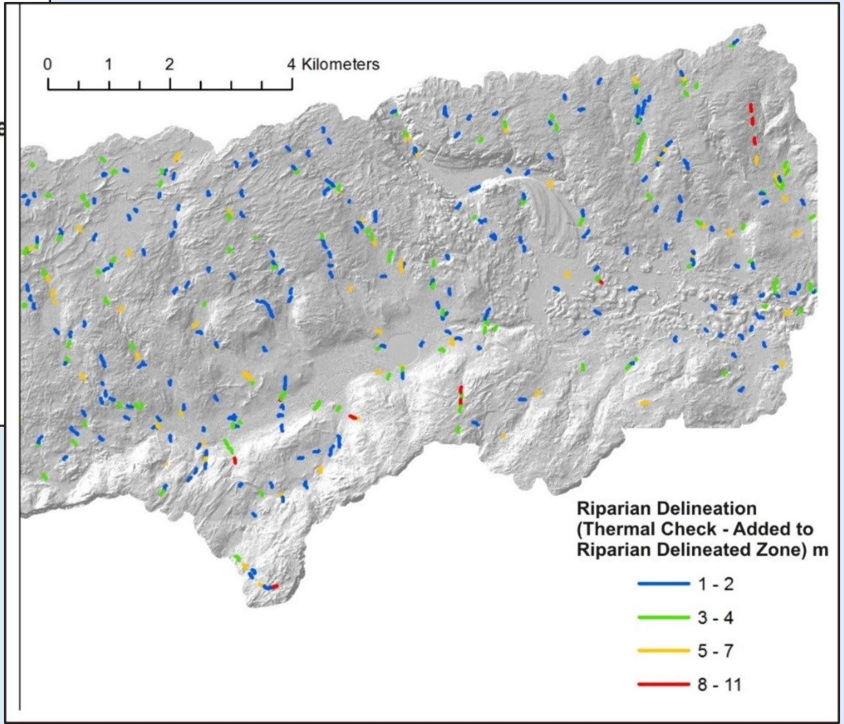
Floodplain and Riparian Delineation





Variable Width Riparian Zone Delineation



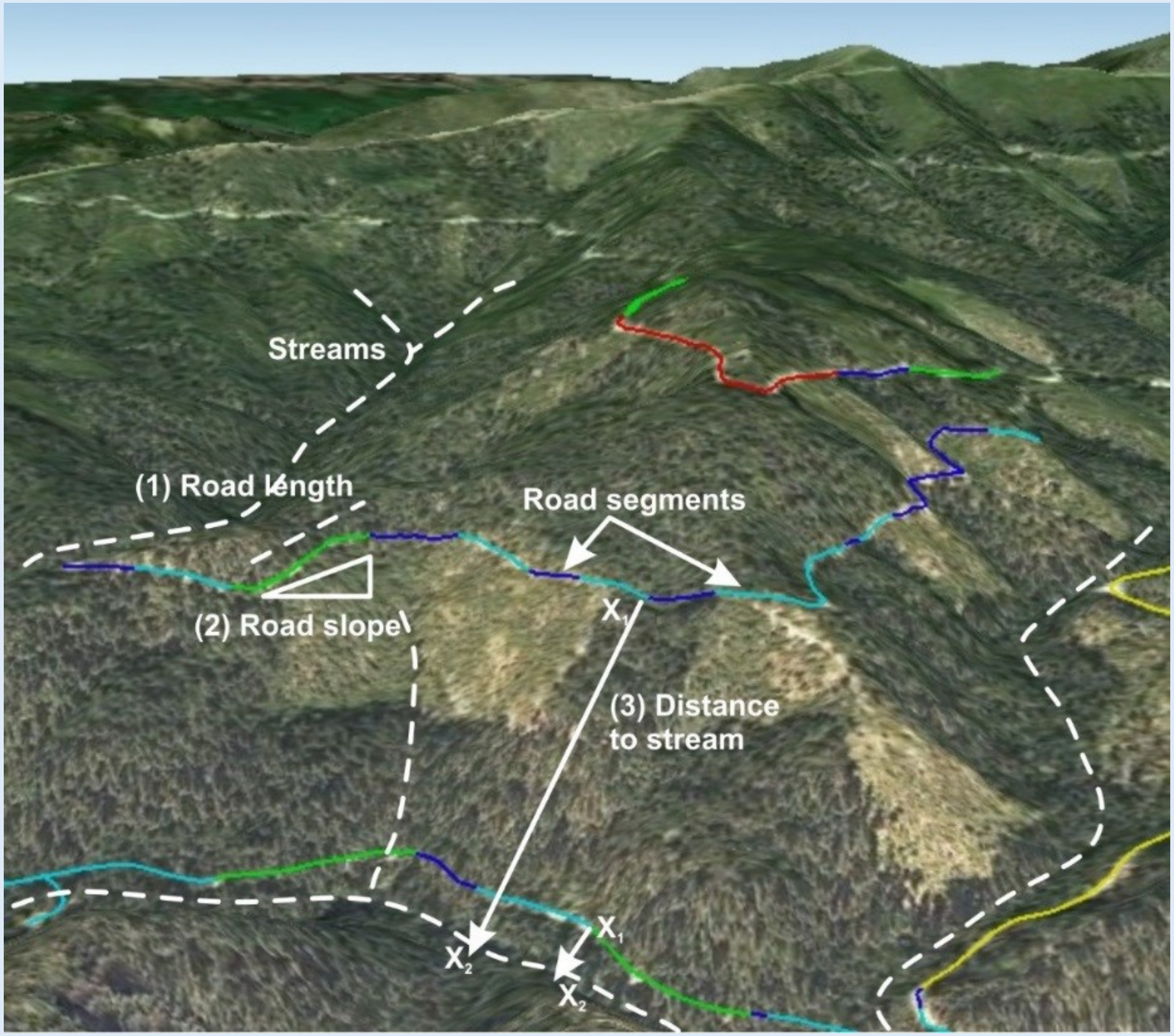


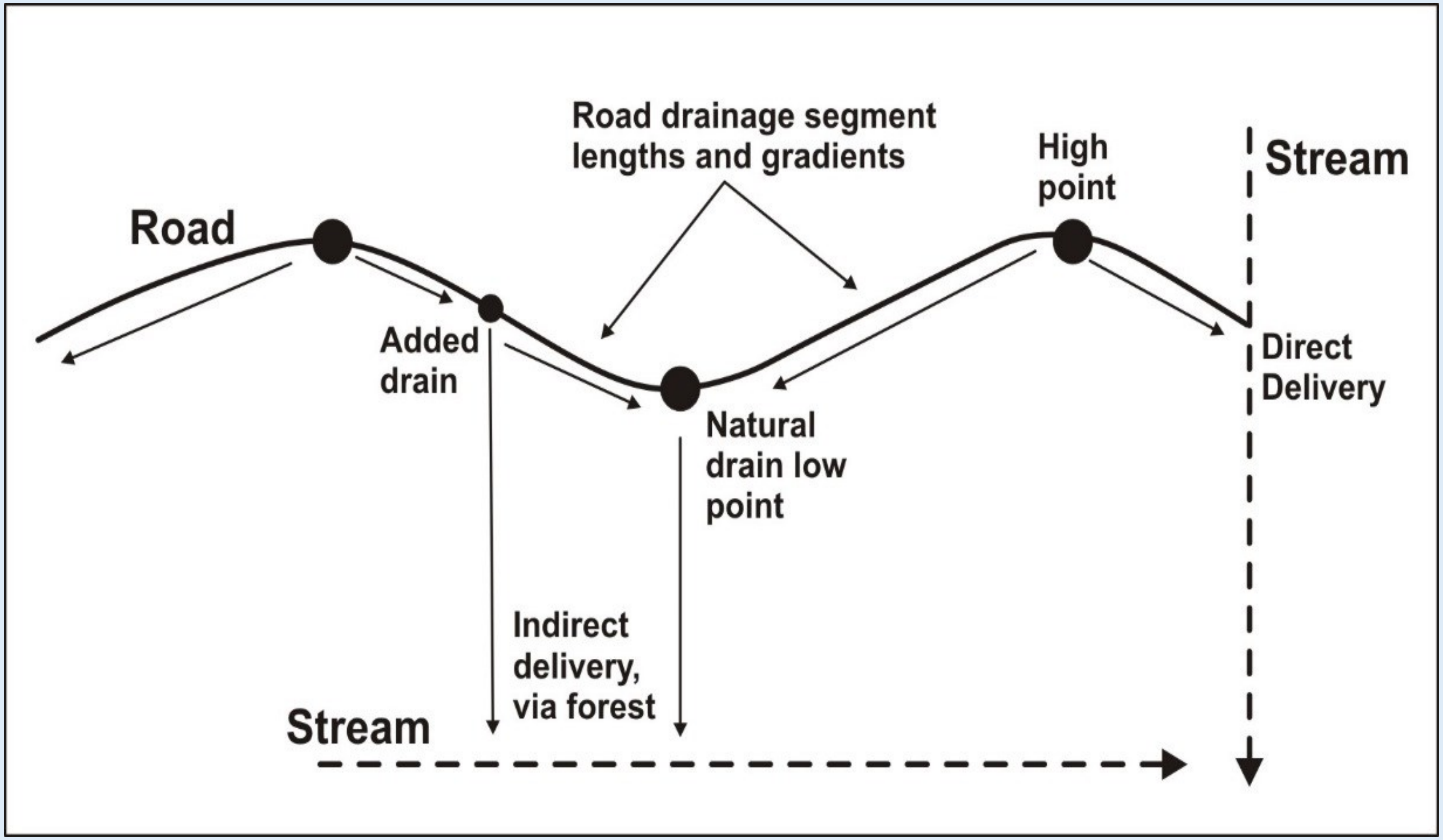
Road Erosion and Delivery Index

A variety of factors are observed to influence runoff and sediment yield from forest roads:

- Discharge rates of water and sediment are related to the surface area contributing runoff,
- sediment yield is related to the steepness of the road segment (Luce and Black, 1999),
- sediment yield varies with road surfacing material, road age, and road maintenance (Barrett et al., 2012; Luce and Black, 2001),
- sediment yield increases with increasing rainfall intensity (van Meerveld et al., 2014),
- log-truck traffic increases sediment production (Miller, 2014; van Meerveld et al., 2014),
- sediment concentrations in road runoff tend to be high at the beginning of a storm and to taper off over time (van Meerveld et al., 2014),
- the proportion of sediment delivered to streams decreases as the distance of the road from the stream increases (Croke et al., 2005; Ketcheson and Megahan, 1996).

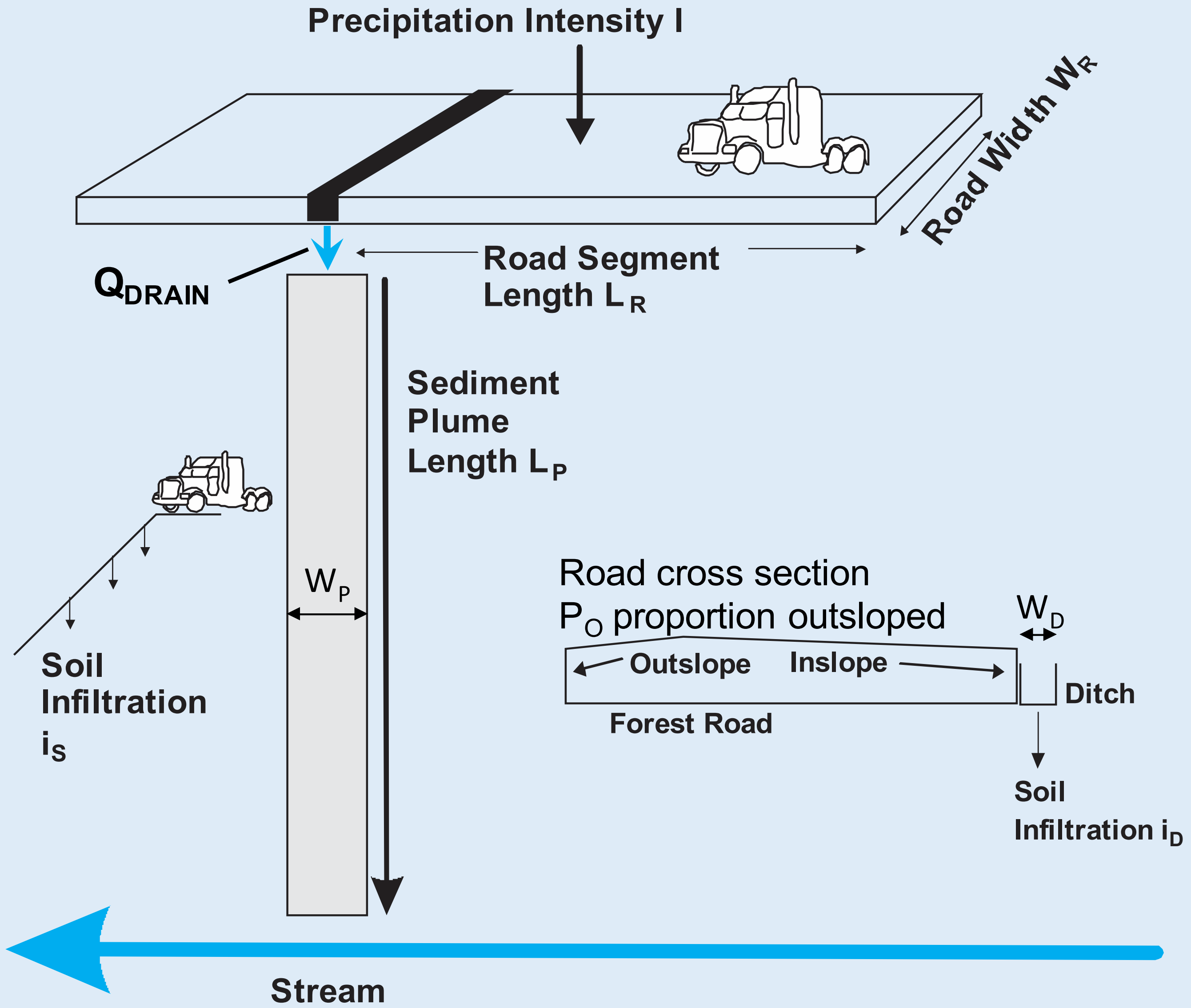
Road layer is draped onto the DEM

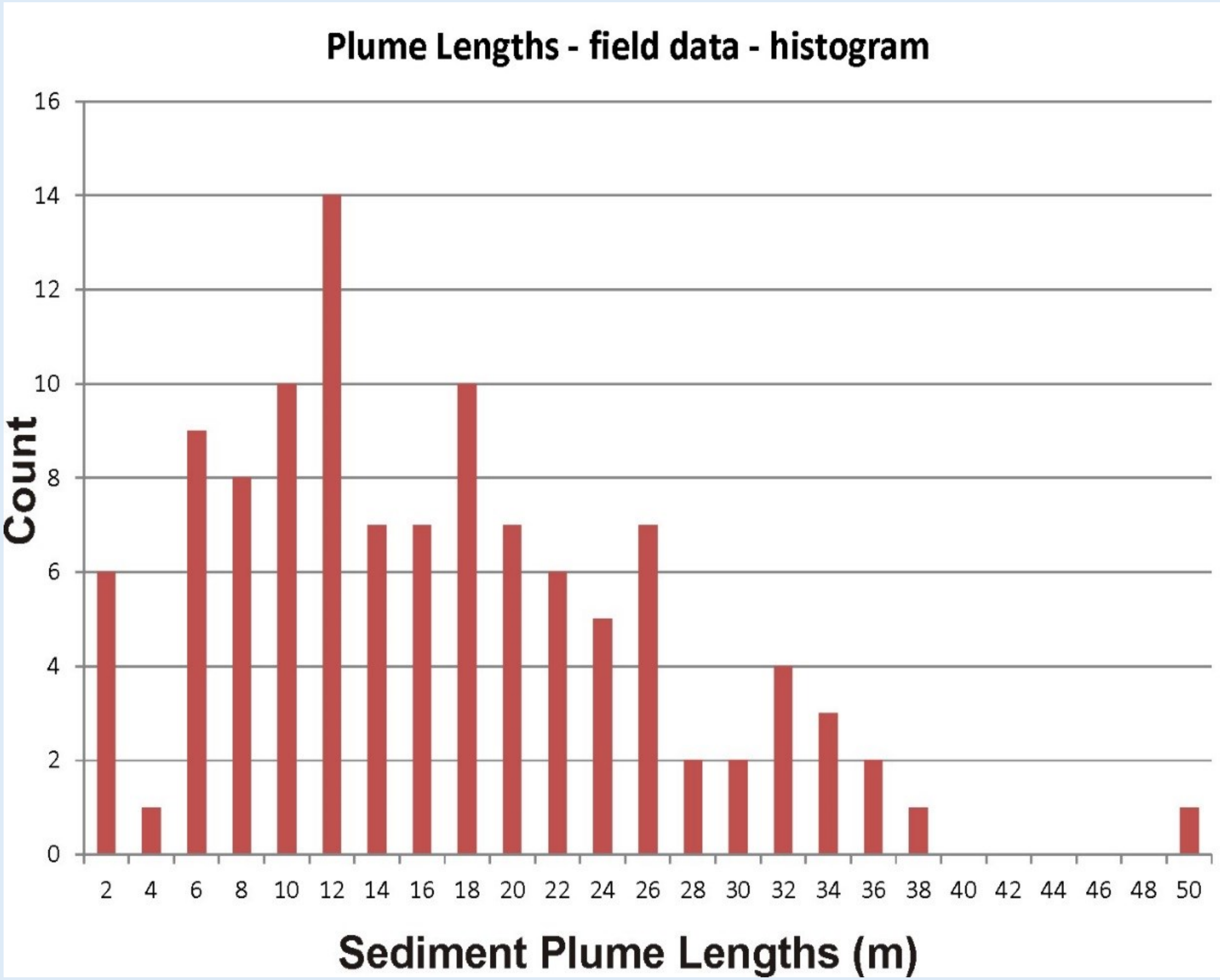


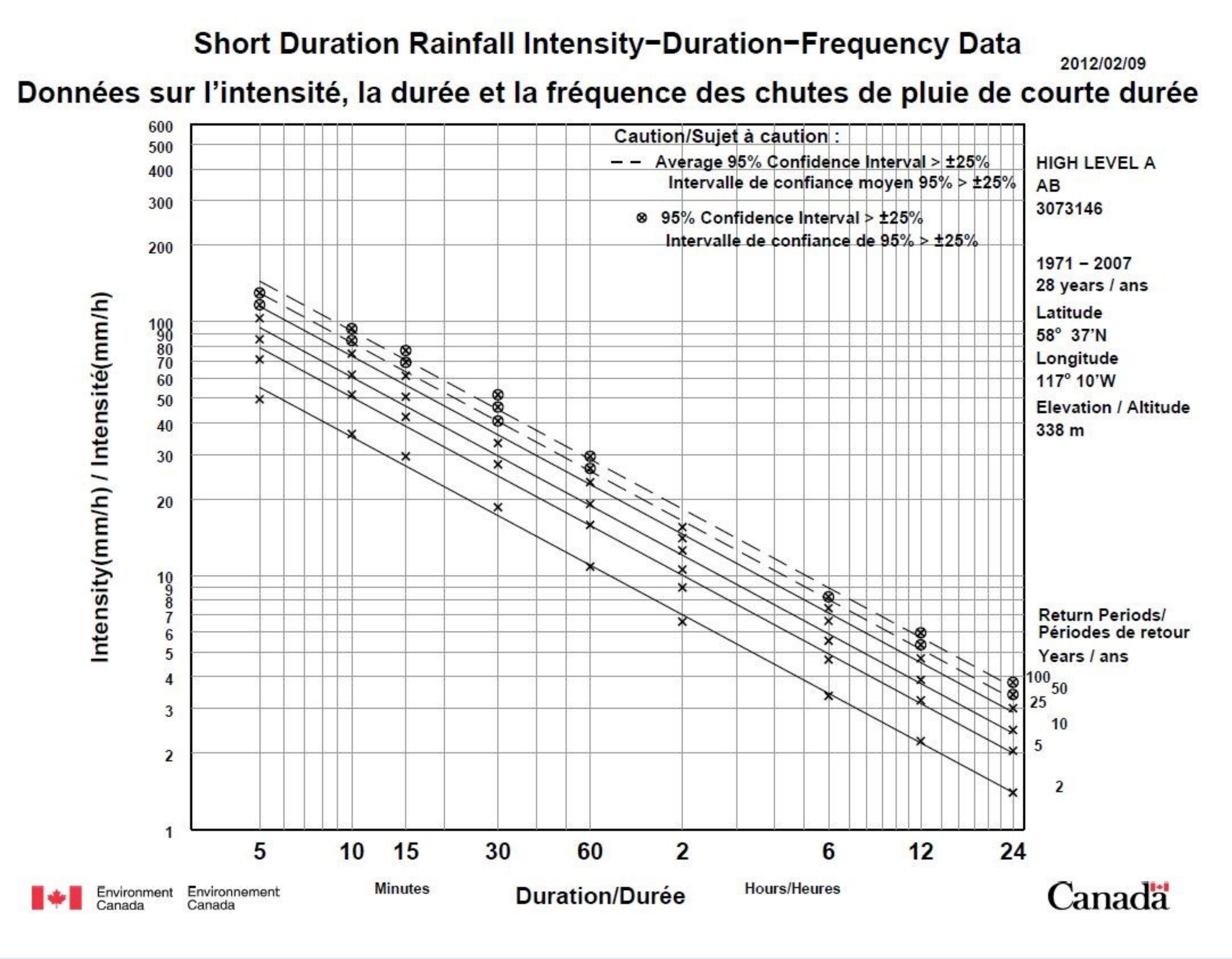


Road drainage segment lengths and gradients
High point
Stream
Road
Added drain
Direct Delivery
Natural drain low point
Indirect delivery, via forest
Stream

Numerical Framwork

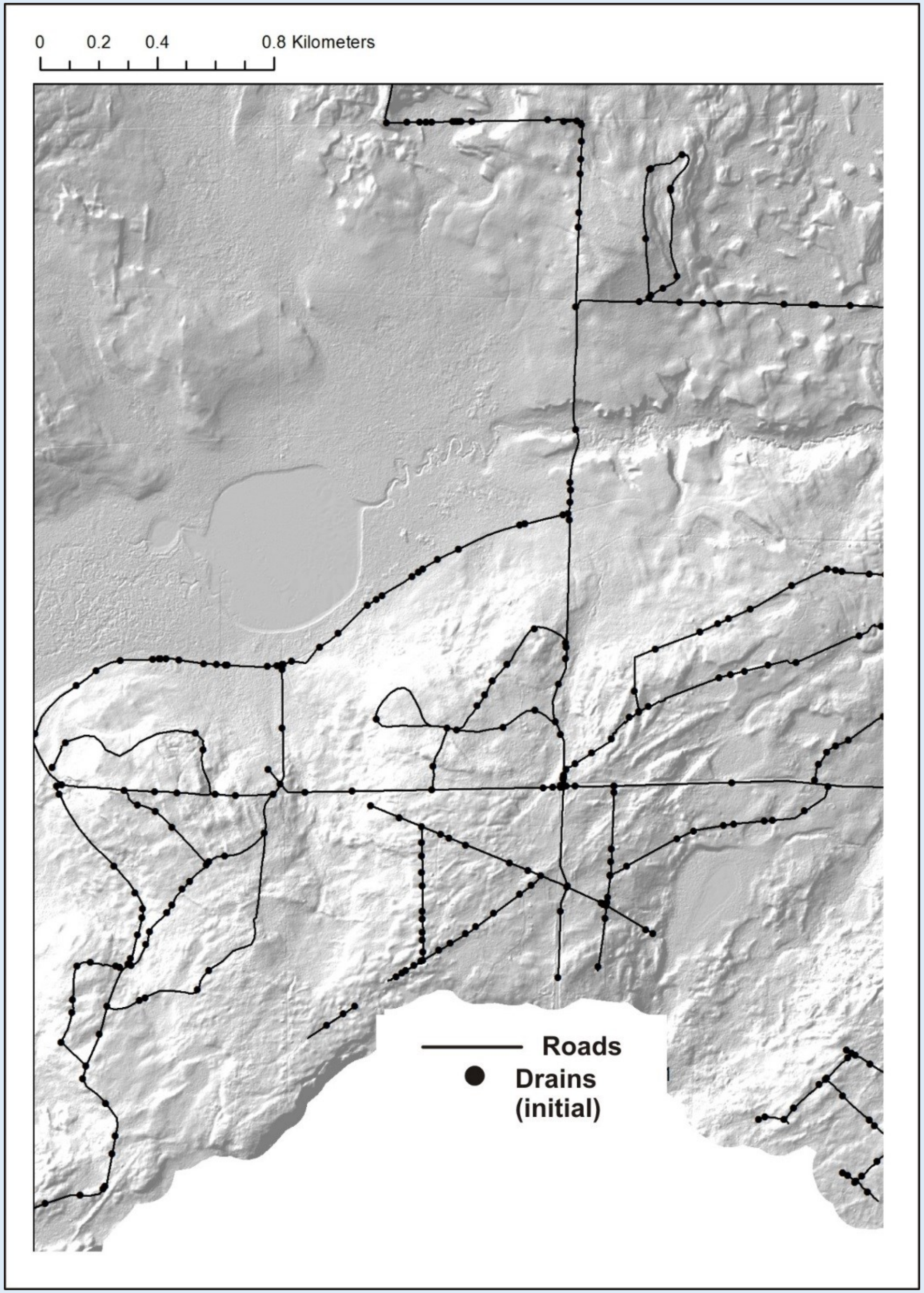


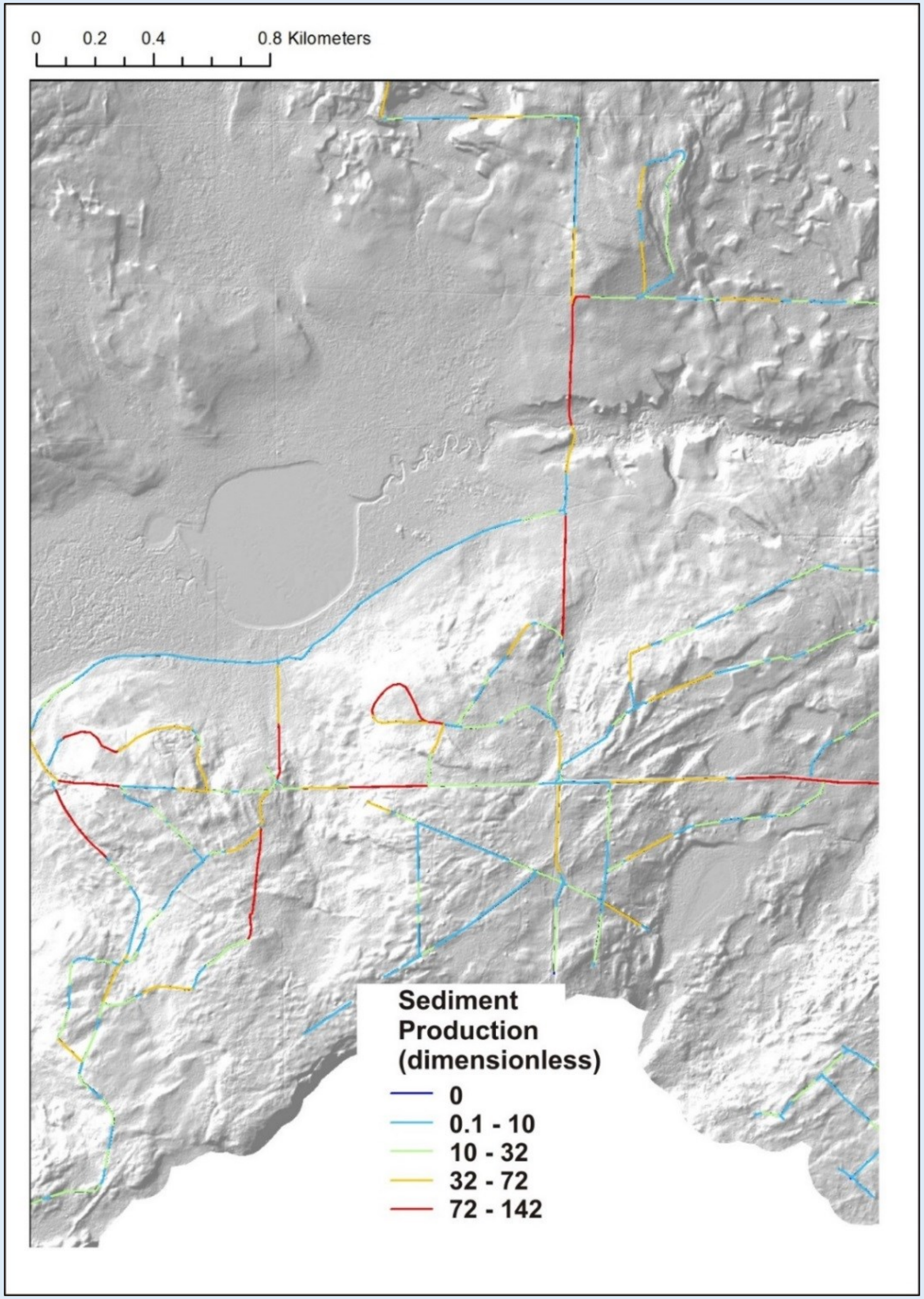

Plume Lengths - field data - histogram
Count
0
2
4
6
8
10
12
14
16
2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42 44 46 48 50
Sediment Plume Lengths (m)

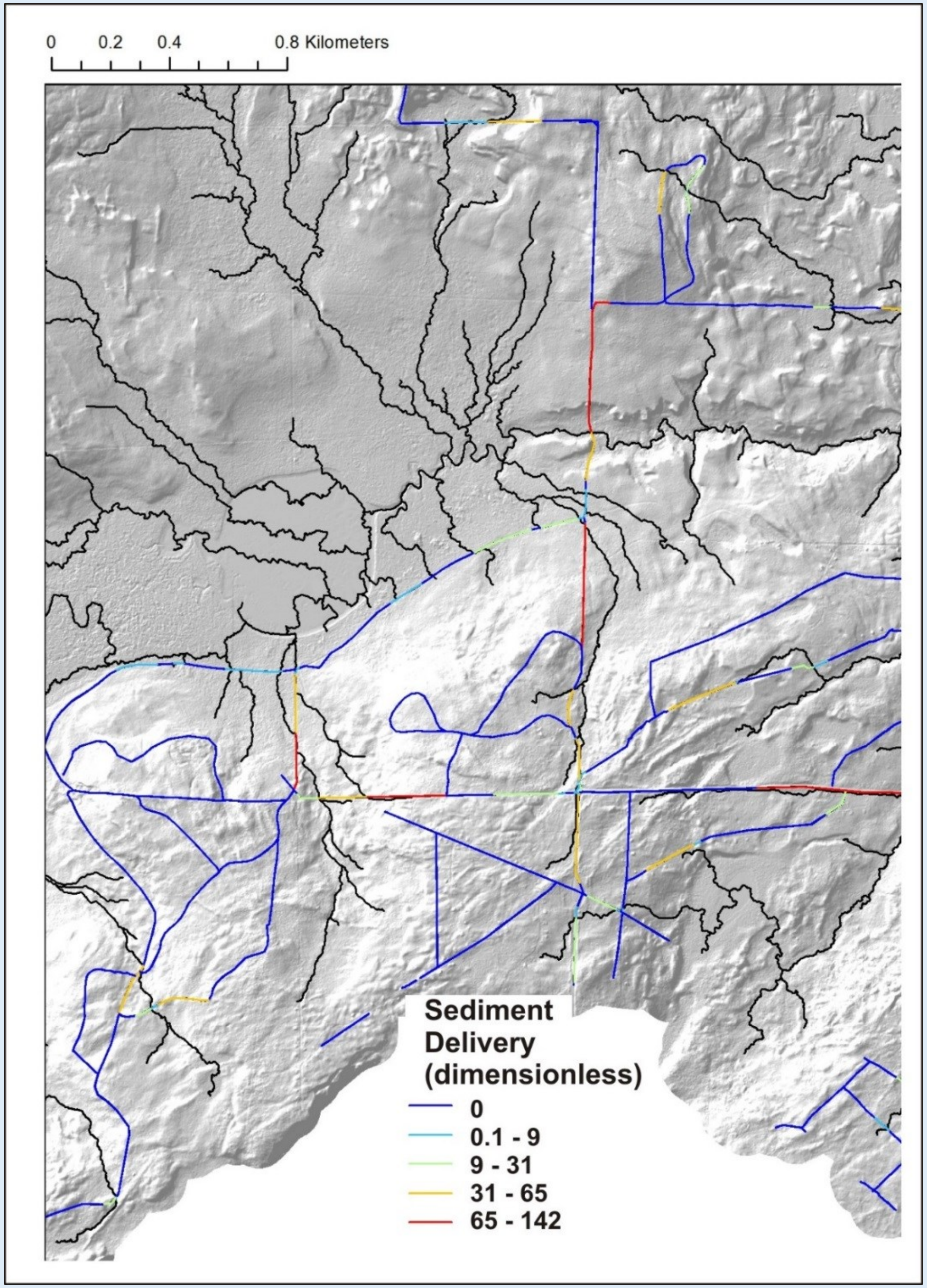

Short Duration Rainfall Intensity−Duration−Frequency Data
2012/02/09
Données sur l'intensité, la durée et la fréquence des chutes de pluie de courte durée
Caution/Sujet à caution :
Average 95% Confidence Interval > ±25%
Intervalle de confiance moyen 95% > ±25%
95% Confidence Interval > ±25%
Intervalle de confiance de 95% > ±25%
HIGH LEVEL A
AB
3073146
1971 − 2007
28 years / ans
Latitude
58° 37'N
Longitude
117° 10'W
Elevation / Altitude
338 m
Return Periods/
Périodes de retour
Years / ans
100
50
25
10
5
2
Intensity(mm/h) / Intensité(mm/h)
600
500
400
300
200
100
90
80
70
60
50
40
30
20
10
9
8
7
6
5
4
3
2
1
5
10
15
30
60
2
6
12
24
Minutes
Duration/Durée
Hours/Heures
Environment Canada
Environnement Canada
Canada

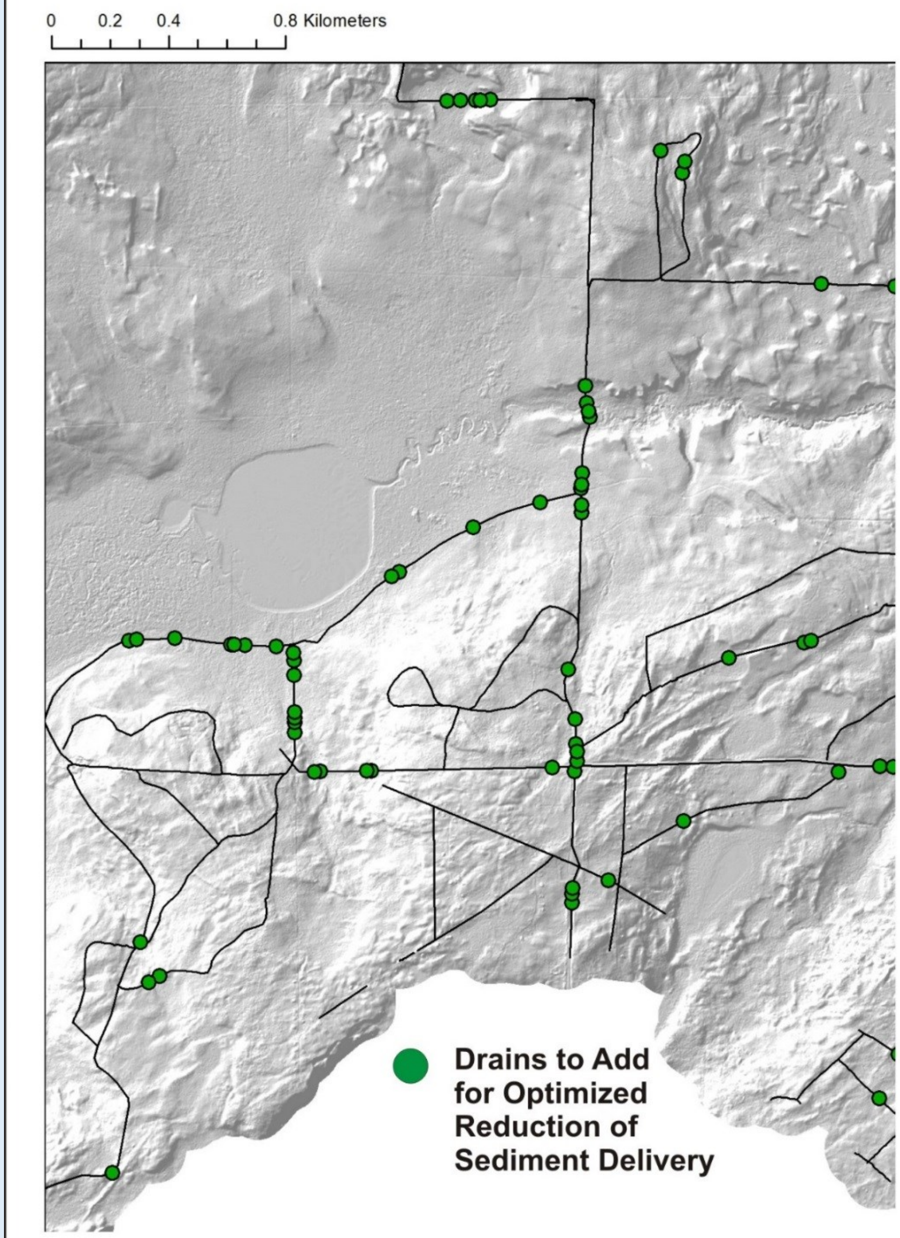
READI model parameters included: 1) minimum road segment length of 300 m, 2) minimum segment relief of 1 m, 3) maximum drain spacing of 300 m, 4) design storm duration 1 hour, 5) design storm intensity 0.02 m/hr (10 year event, **Figure 27**), 6) soil infiltration rate of 0.105 m/hr, 7) ditch infiltration rate of 0.073 m/hr, 8) outslope proportion 0.25, and 9) plume width of 1.5 m (rectangular plume).

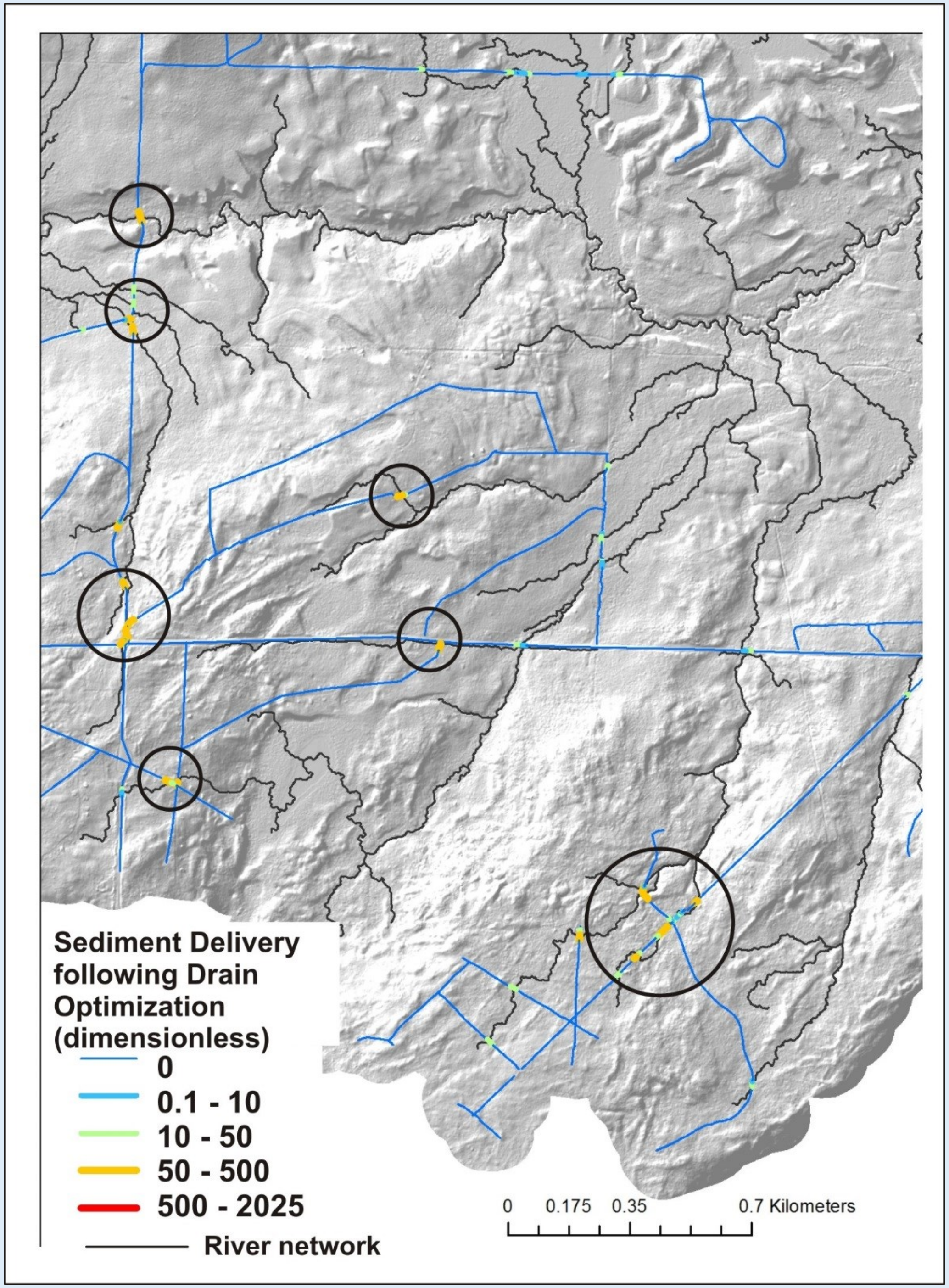
Parameter	Current Condition	After Adding Optimized Drains	Percent Change
Sediment Production (dimensionless)	497,000	497,000	0%
Sediment Delivery (dimensionless)	148,000	21,000	-86%
Fraction of Production Delivered to Streams	29.8%	4.3%	-84%
Percent Road Length Hydrologically Connected	30.5%	4.3%	-86%
Average Sediment Transport Length (plume length)	31 m	15 m	-52%

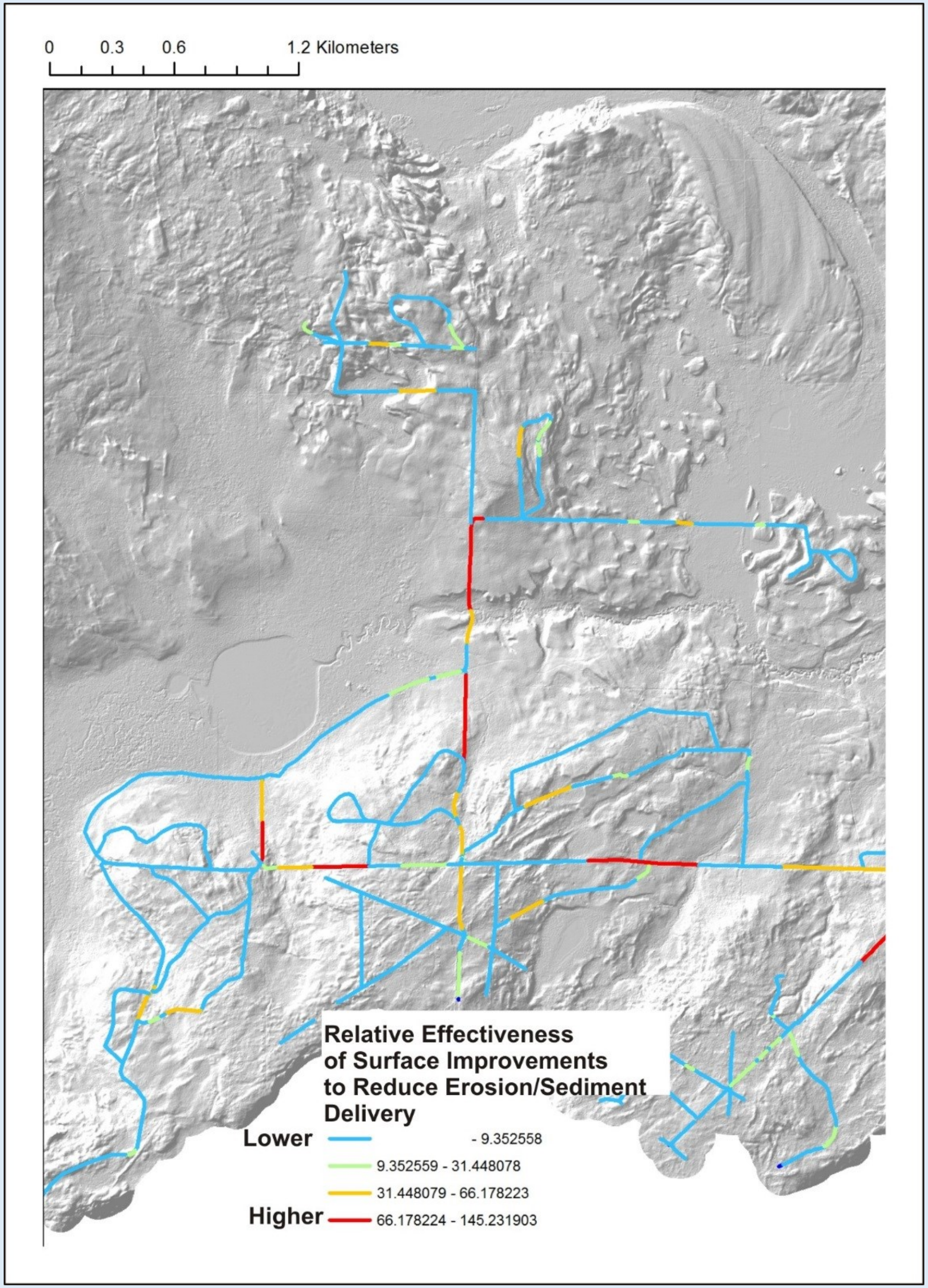

0
0.2
0.4
0.8 Kilometers
Roads
Drains
(initial)

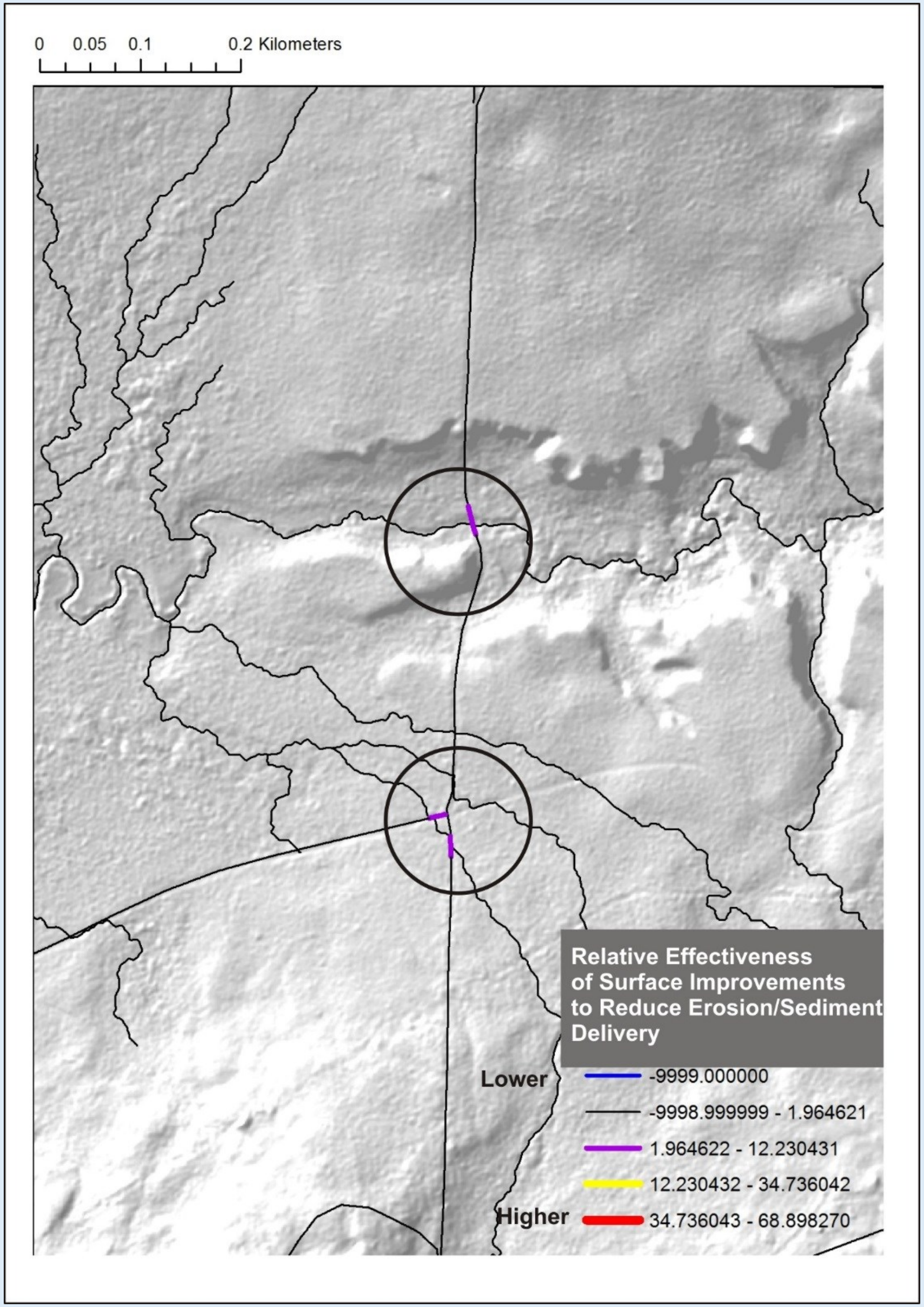

0 0.2 0.4 0.8 Kilometers
Sediment Production (dimensionless)
0
0.1 - 10
10 - 32
32 - 72
72 - 142

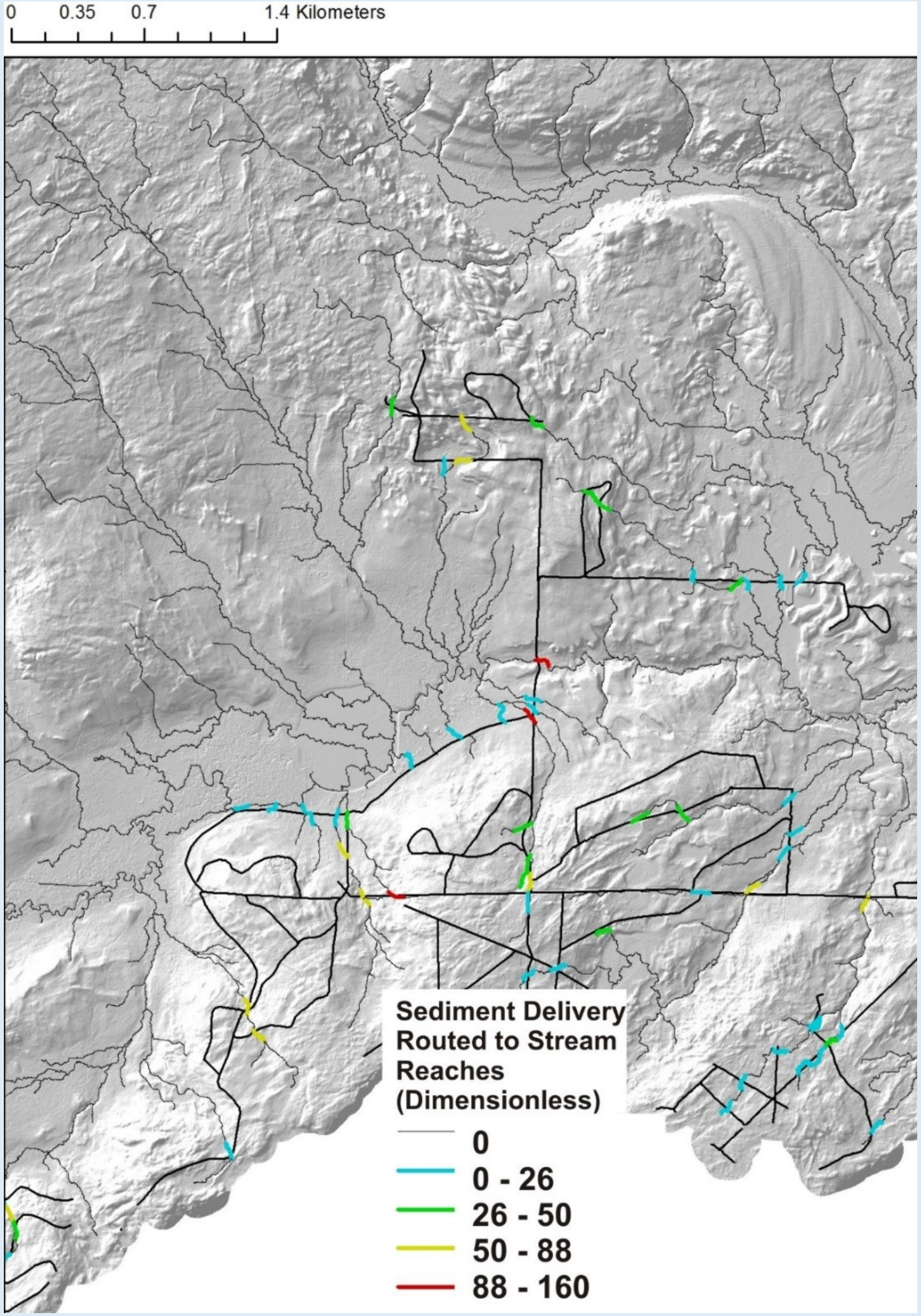

0
0.2
0.4
0.8 Kilometers
Sediment Delivery (dimensionless)
0
0.1 - 9
9 - 31
31 - 65
65 - 142


0 0.2 0.4 0.8 Kilometers
Drains to Add for Optimized Reduction of Sediment Delivery

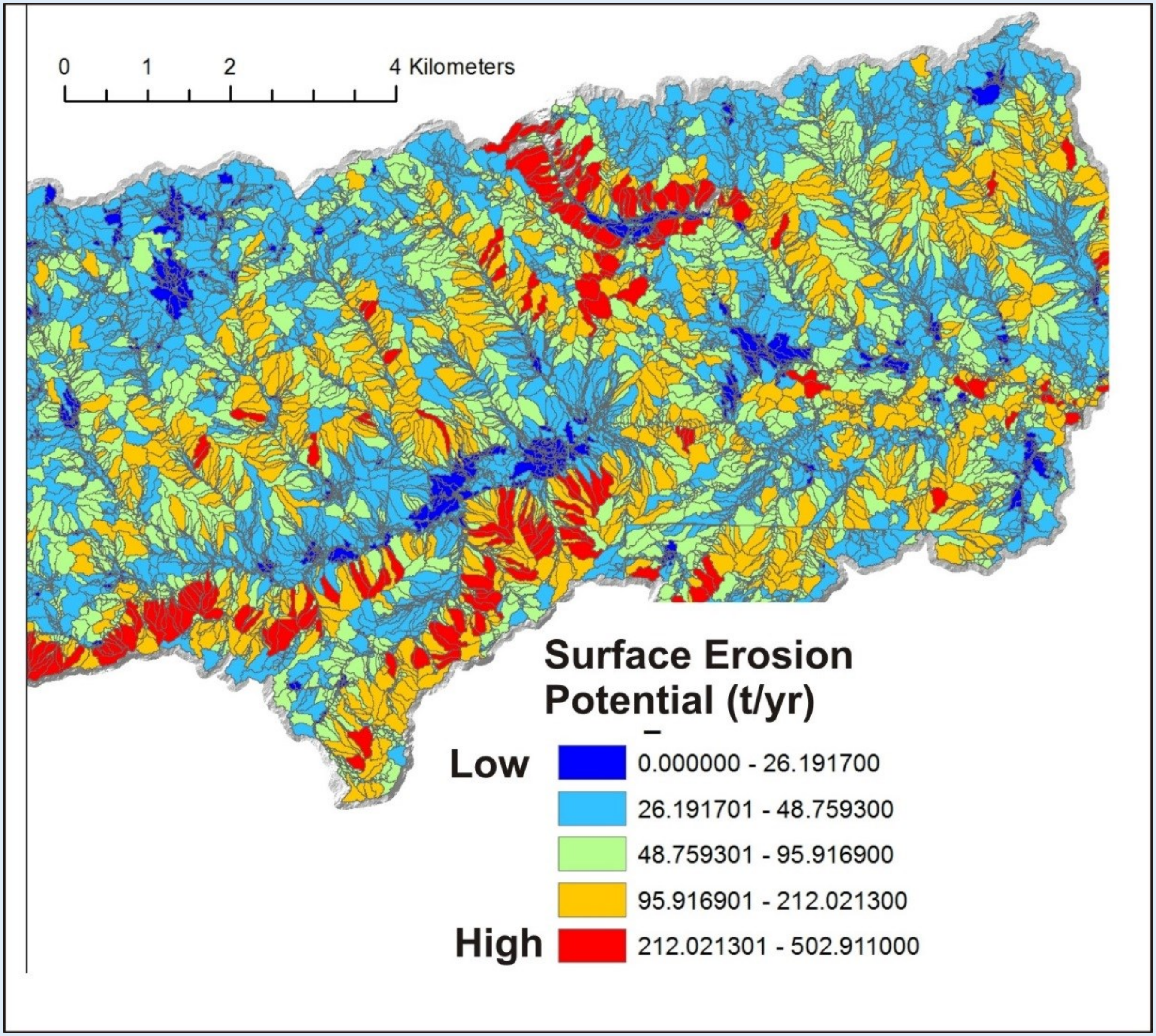

Sediment Delivery following Drain Optimization (dimensionless)
0
0.1 - 10
10 - 50
50 - 500
500 - 2025
River network
0 0.175 0.35 0.7 Kilometers

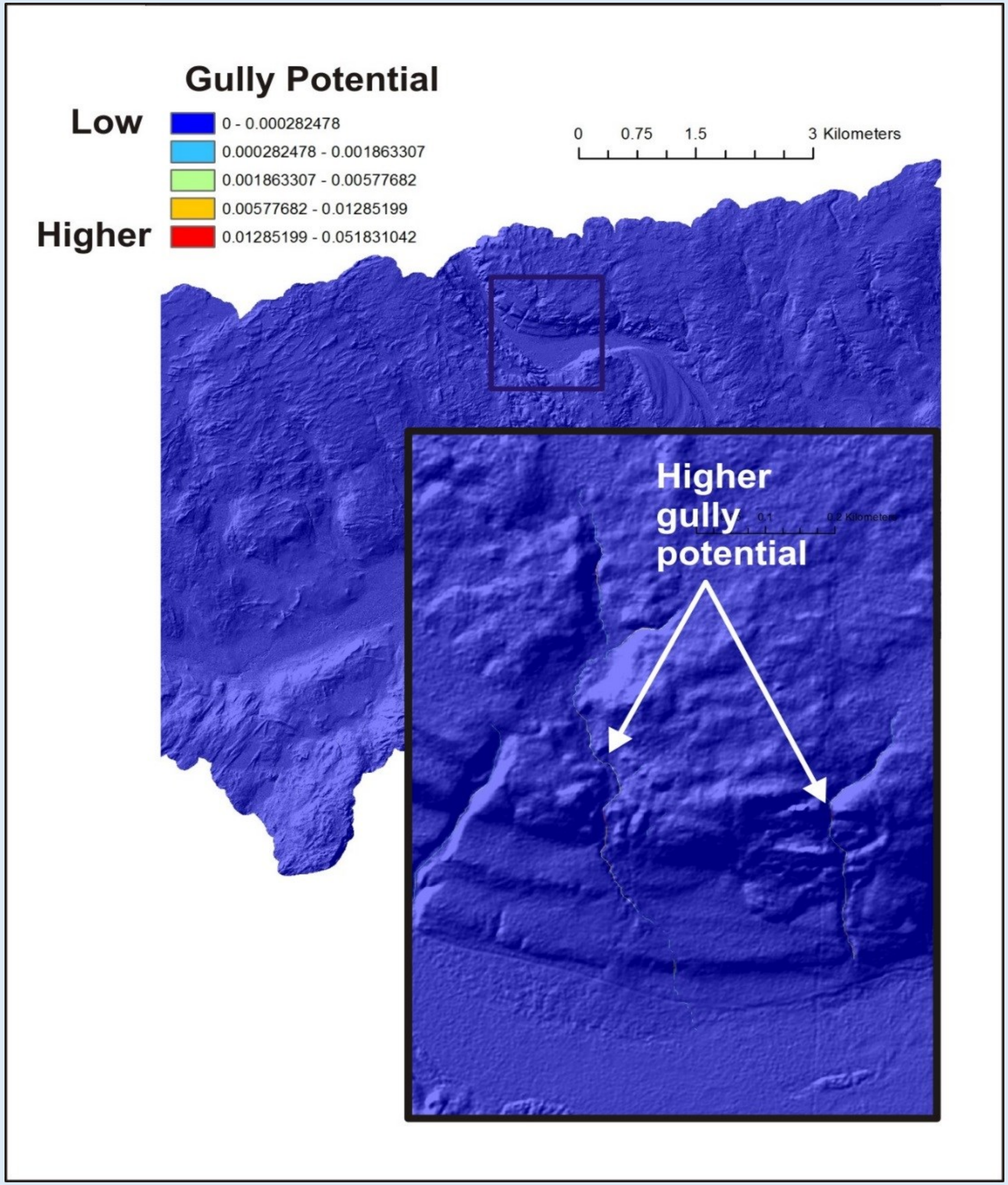

0 0.3 0.6 1.2 Kilometers
Relative Effectiveness of Surface Improvements to Reduce Erosion/Sediment Delivery
Lower
- 9.352558
9.352559 - 31.448078
31.448079 - 66.178223
Higher
66.178224 - 145.231903

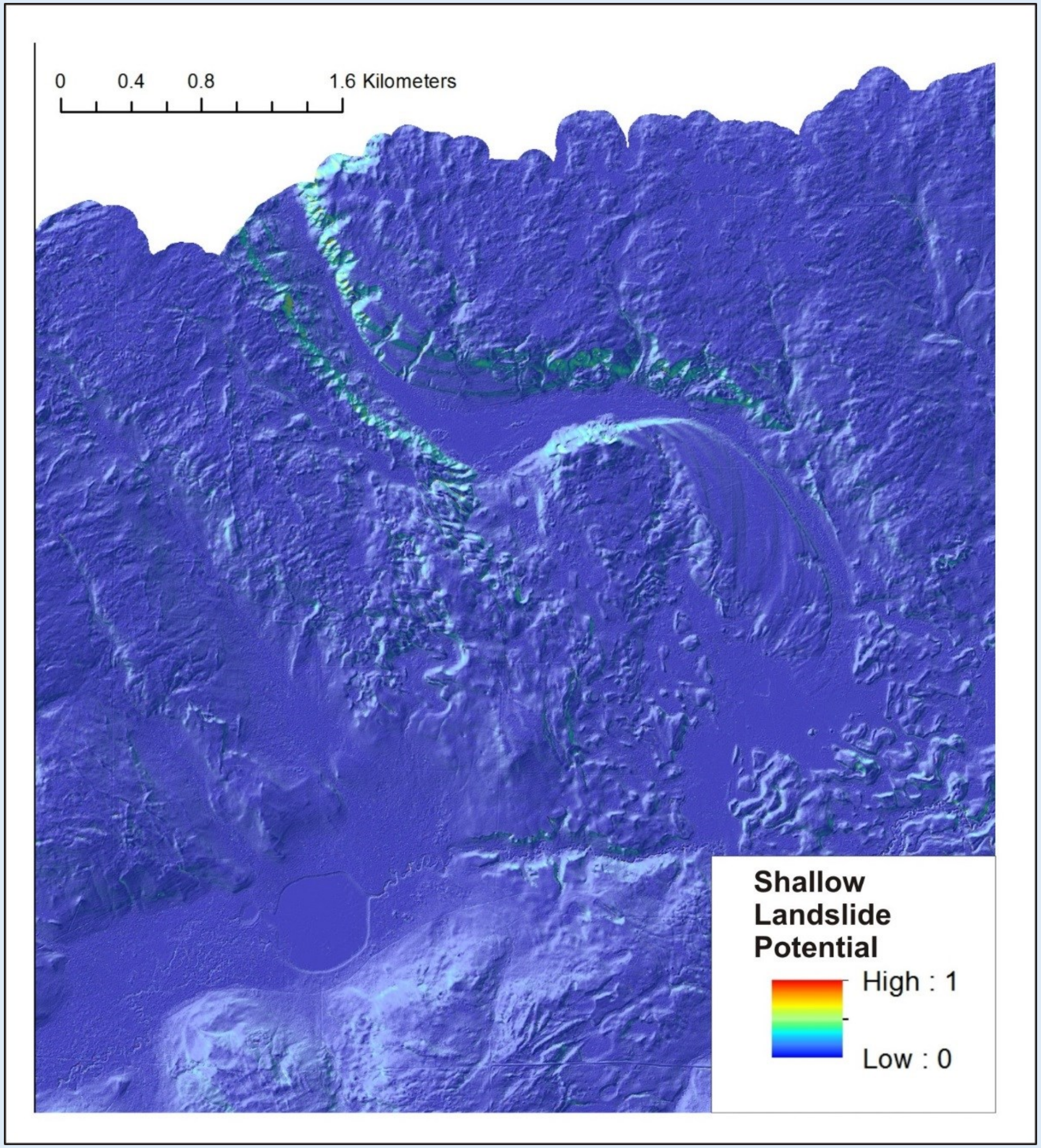

0 0.05 0.1 0.2 Kilometers
Relative Effectiveness of Surface Improvements to Reduce Erosion/Sediment Delivery
Lower
Higher
-9999.000000
-9998.999999 - 1.964621
1.964622 - 12.230431
12.230432 - 34.736042
34.736043 - 68.898270


0 0.35 0.7 1.4 Kilometers
Sediment Delivery Routed to Stream Reaches (Dimensionless)
0
0 - 26
26 - 50
50 - 88
88 - 160

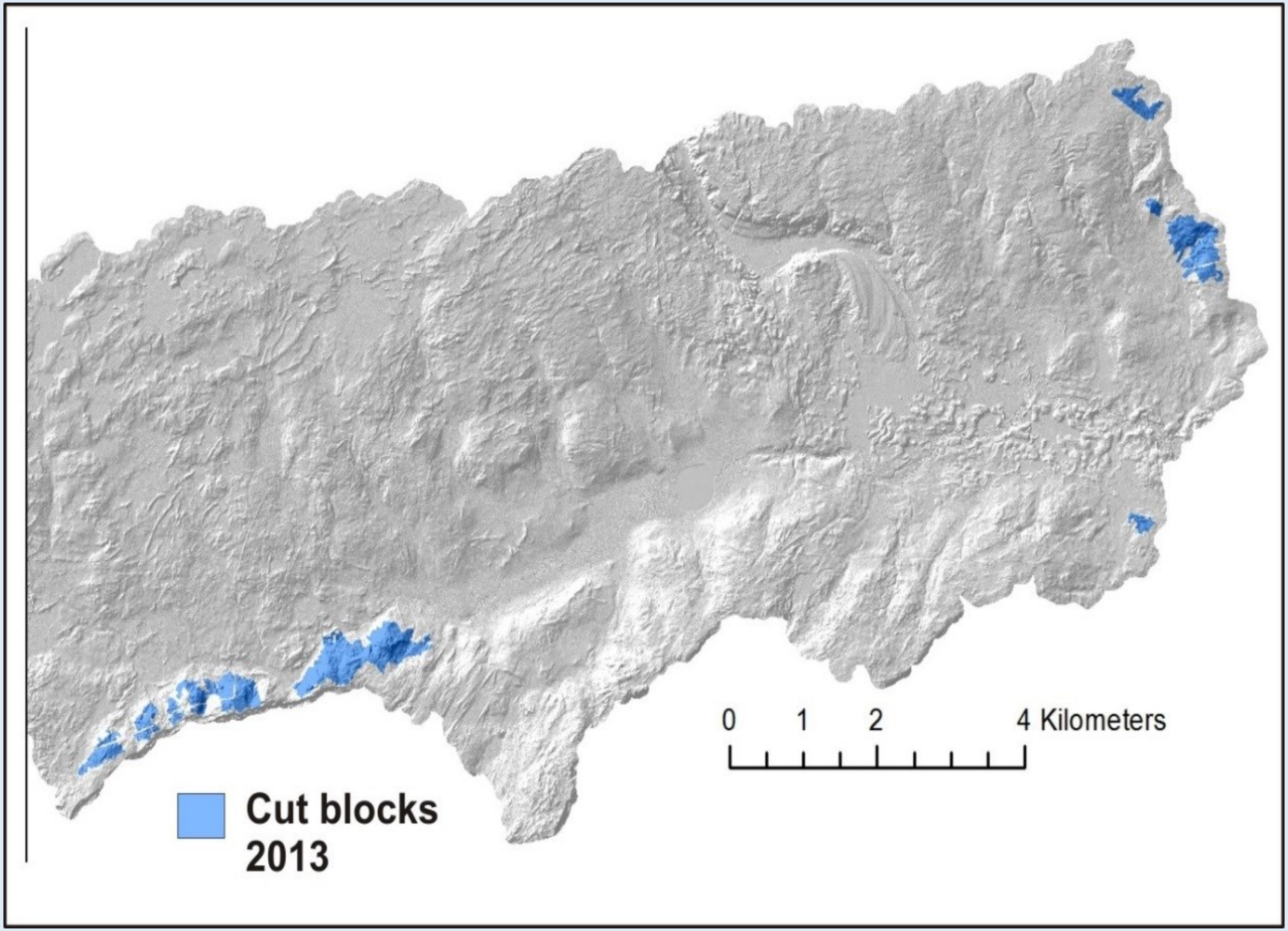
Predicted surface erosion potential using the WEPP model

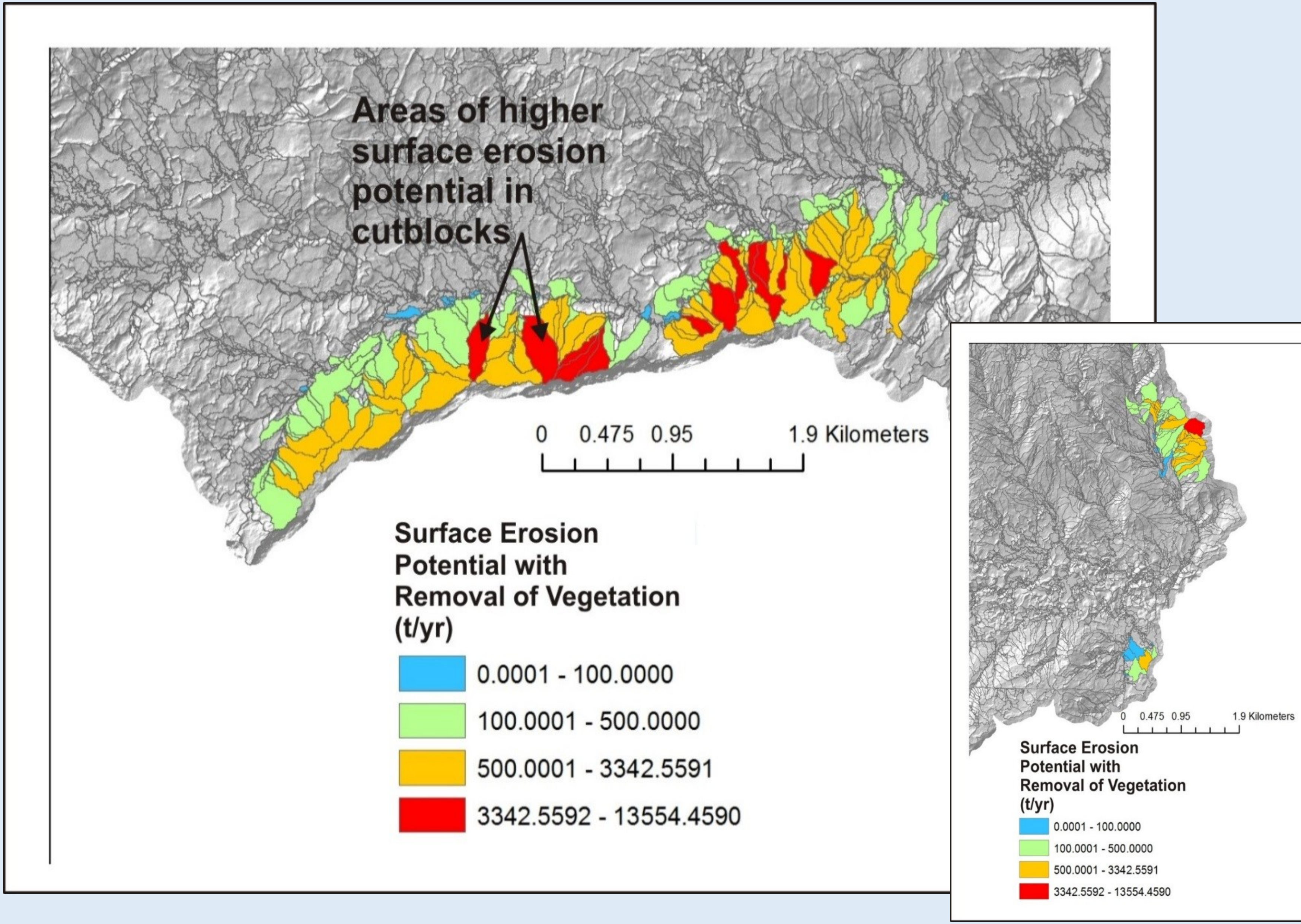



Gully Potential
Low
0 - 0.000282478
0.000282478 - 0.001863307
0.001863307 - 0.00577682
0.00577682 - 0.01285199
Higher
0.01285199 - 0.051831042
0 0.75 1.5 3 Kilometers
Higher gully potential

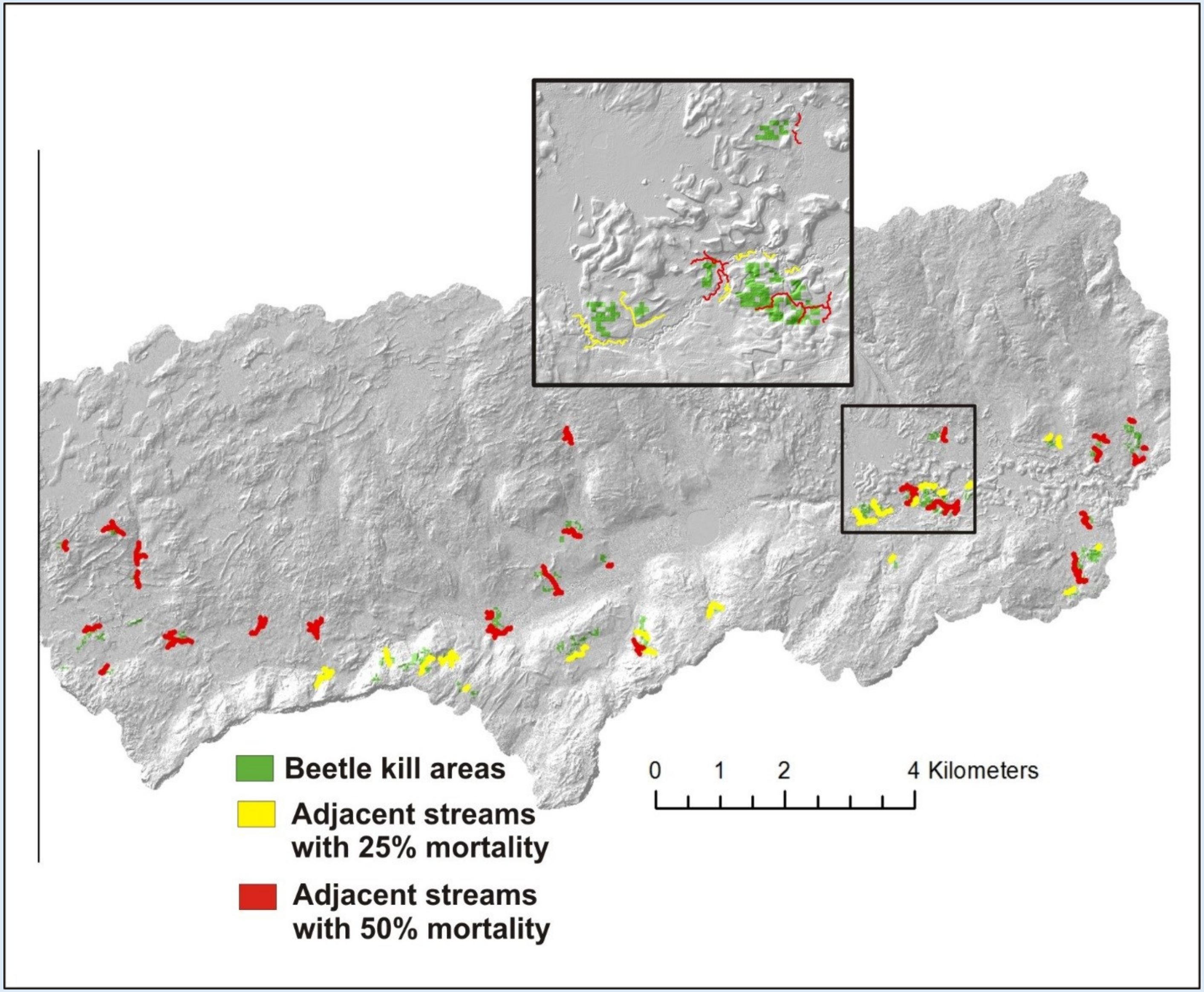

0 0.4 0.8 1.6 Kilometers
Shallow Landslide Potential
High : 1
Low : 0

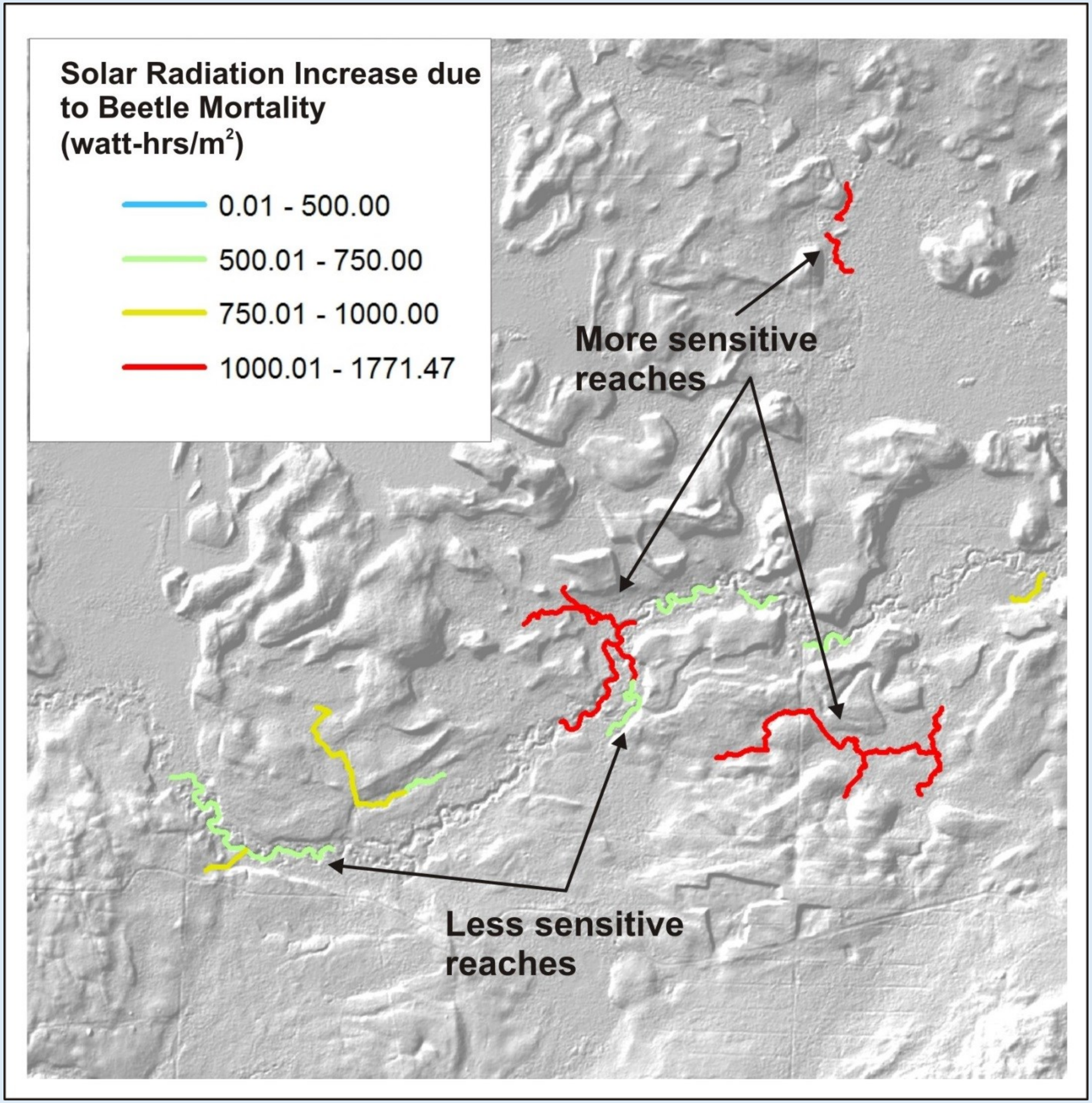
Forestry cut blocks and surface erosion potential (WEPP model)




Areas of higher surface erosion potential in cutblocks
0 0.475 0.95 1.9 Kilometers
Surface Erosion Potential with Removal of Vegetation (t/yr)
0.0001 - 100.0000
100.0001 - 500.0000
500.0001 - 3342.5591
3342.5592 - 13554.4590
0 0.475 0.95 1.9 Kilometers
Surface Erosion Potential with Removal of Vegetation (t/yr)
0.0001 - 100.0000
100.0001 - 500.0000
500.0001 - 3342.5591
3342.5592 - 13554.4590

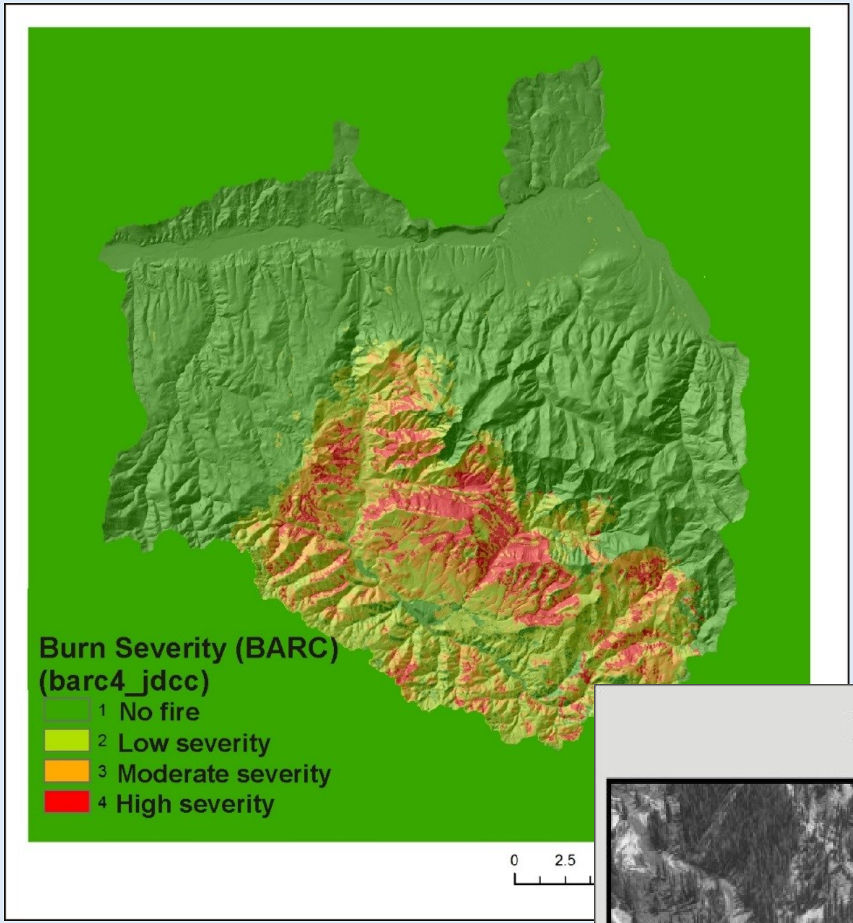
Bark Beetle Killed Trees and Shade – Thermal Impacts

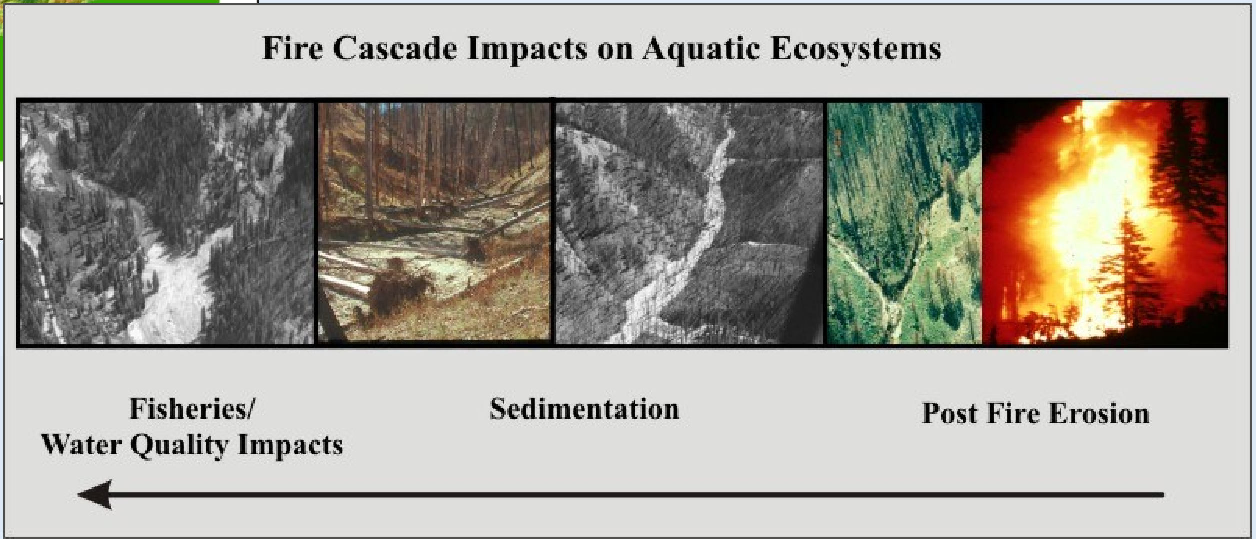




Solar Radiation Increase due to Beetle Mortality (watt-hrs/m²)
0.01 - 500.00
500.01 - 750.00
750.01 - 1000.00
1000.01 - 1771.47
More sensitive reaches
Less sensitive reaches

Post Wildfire and Pre Wildfire Analysis Capabilities (example provided from eastern Oregon) but tools and approach could be applied to Alberta





Evaluating Cumulative Effects in Alberta

1. Information on landforms, physical and biological processes, and land-use activities are linked directly to the specific parts of the channel network that they can influence. This is accomplished by the strategic use of flow direction and accumulation rasters, and discreet stream segment scale local contributing areas referred to as "drainage wings" and subbasin polygons.
2. Terrestrial information linked by flow paths to stream channels can be aggregated up and downstream, revealing spatial patterns of any watershed landform, streamform, process, disturbance or land-use activity at any spatial scale defined by the channel network. Data outputs include rasters, points, arcs, or polygons.
3. Watershed information (aquatic and terrestrial) is captured in frequency distributions and can be ranked at the scale of channel segments (approximately 100 m length scale), drainage wings, and subbasin polygons. Sorting and ranking can be used to examine aggregate patterns of any watershed feature or landform at the scale of entire management areas.
4. Within the *WIN-System*, frequency or cumulative distributions of any watershed attribute (landforms, processes, land uses) are used within the habitat-stressor overlap tool to search for locations (in the river network) where selected combinations of watershed and land use attributes overlap. The tool currently supports five levels of overlapping attributes. One can find, for example, where the highest 5% of road surface erosion intersects the highest 10% of fish habitat quality, or where the highest 10% of forest mortality due to beetles overlaps the highest 10% of thermally sensitive stream reaches, and where does that combination overlap with the highest 10% of fish habitat potential.
5. Habitat-stressor analyses can also be applied at the scale of subbasins, using another *WIN-System* tool. An example of how this would potentially work in Alberta can be viewed using TerrainWorks online TerrainViewer tool.
6. Intersections between watershed processes and land uses can also be viewed longitudinally along variable lengths of the channel network using the profiling tool. Any number of watershed and land use attributes can be selected and overlaid revealing along channel patterns of land uses and watershed processes.

Evaluating Cumulative Effects in Alberta

7. Cumulative effects often have a temporal component, including the history and time series of land use changes and natural disturbances in a watershed. The numerical structure of the *WIN-System* can support routing and mixing of materials downstream (such as flow, nutrients, sediment, wood, pollutants), with a stochastic time element. See numerical simulations that used this data structure in the form of simulation videos .
8. New analysis capabilities can be added to the *WIN-System* by TerrainWorks or by Alberta Province and others.

Acknowledgements

We gratefully acknowledge the financial and technical support provided by Forest Program Management Section/Forest Management Branch of Alberta Government. We also thank Barry White, John Diiwu, Chris Bater and Axel Anderson for technical support. We also thank Jae Ogilvie, Research Associate with University of New Brunswick, for help with data acquisition during the course of this project.