Railroad Gulch best management practices evaluation: A paired watershed study

Humboldt Redwood™

HUMBOLDT STATE UNIVERSITY

Supported by a grant from the California Board of Forestry Monitoring Study Group

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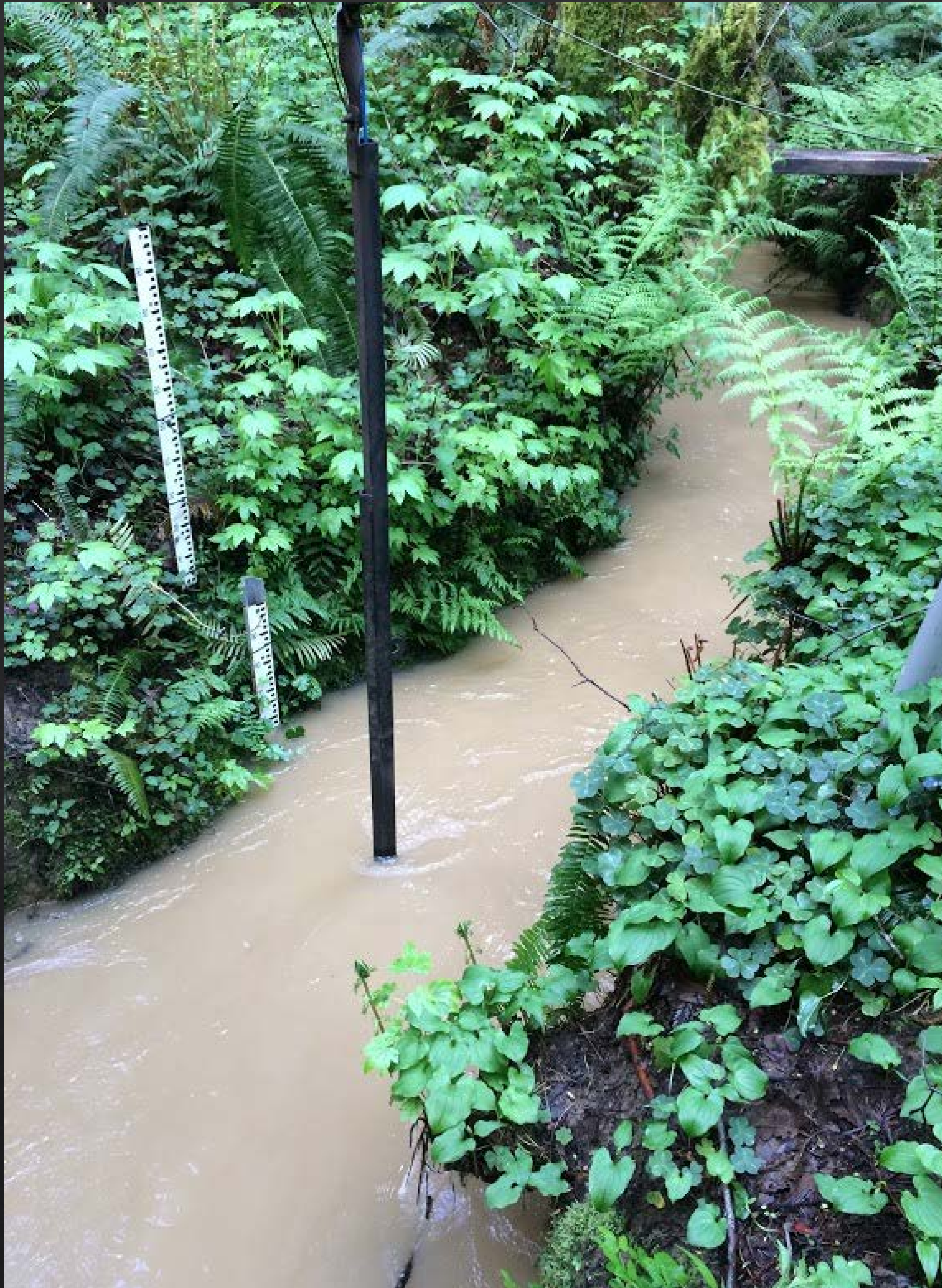
- Thanks for helpful suggestions and edits from Lee Macdonald, Mike Miles, Drew Coe, Pete Cafferata and others

Outline

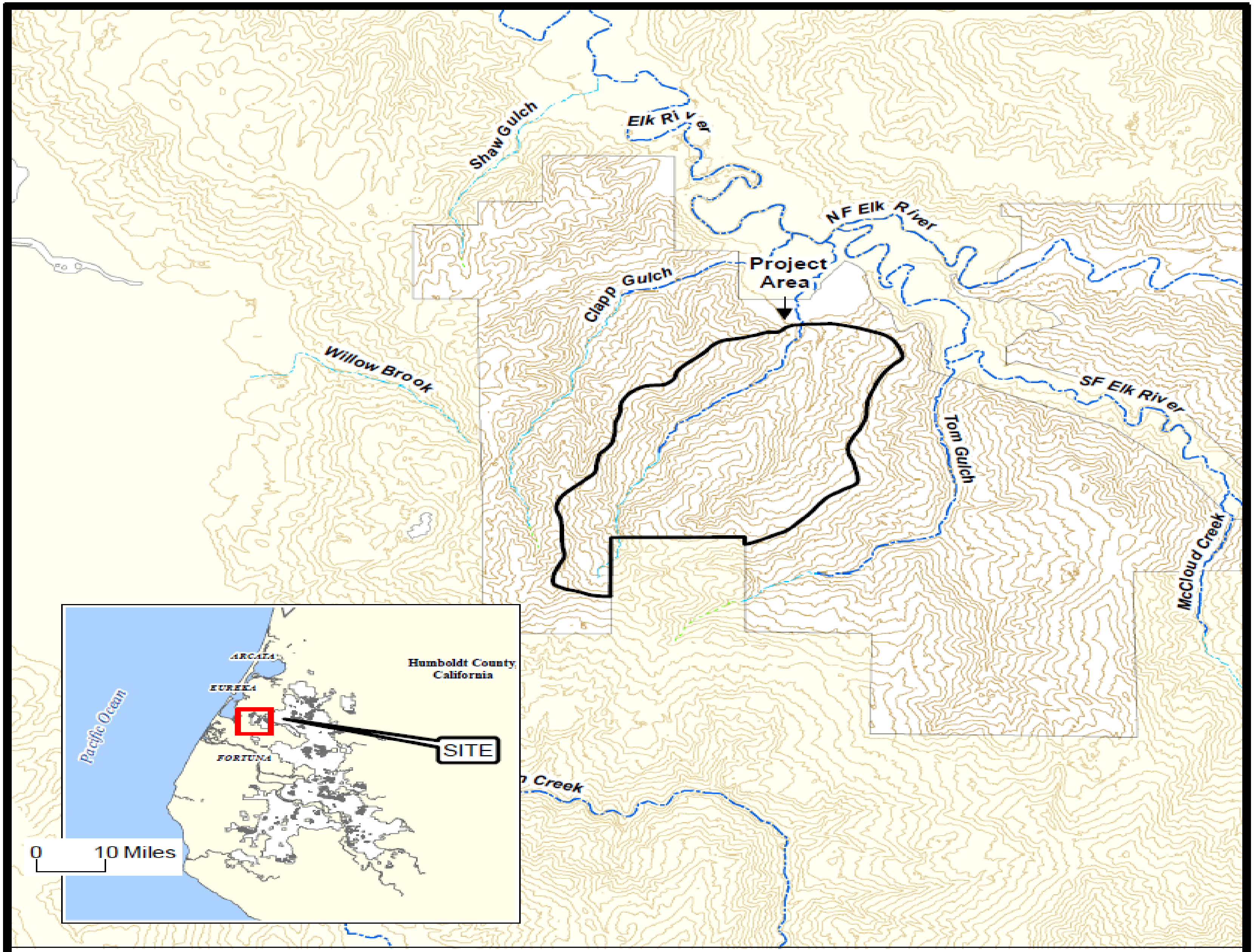
- Goals
- Project overview
- Methods
- Results
- Conclusions



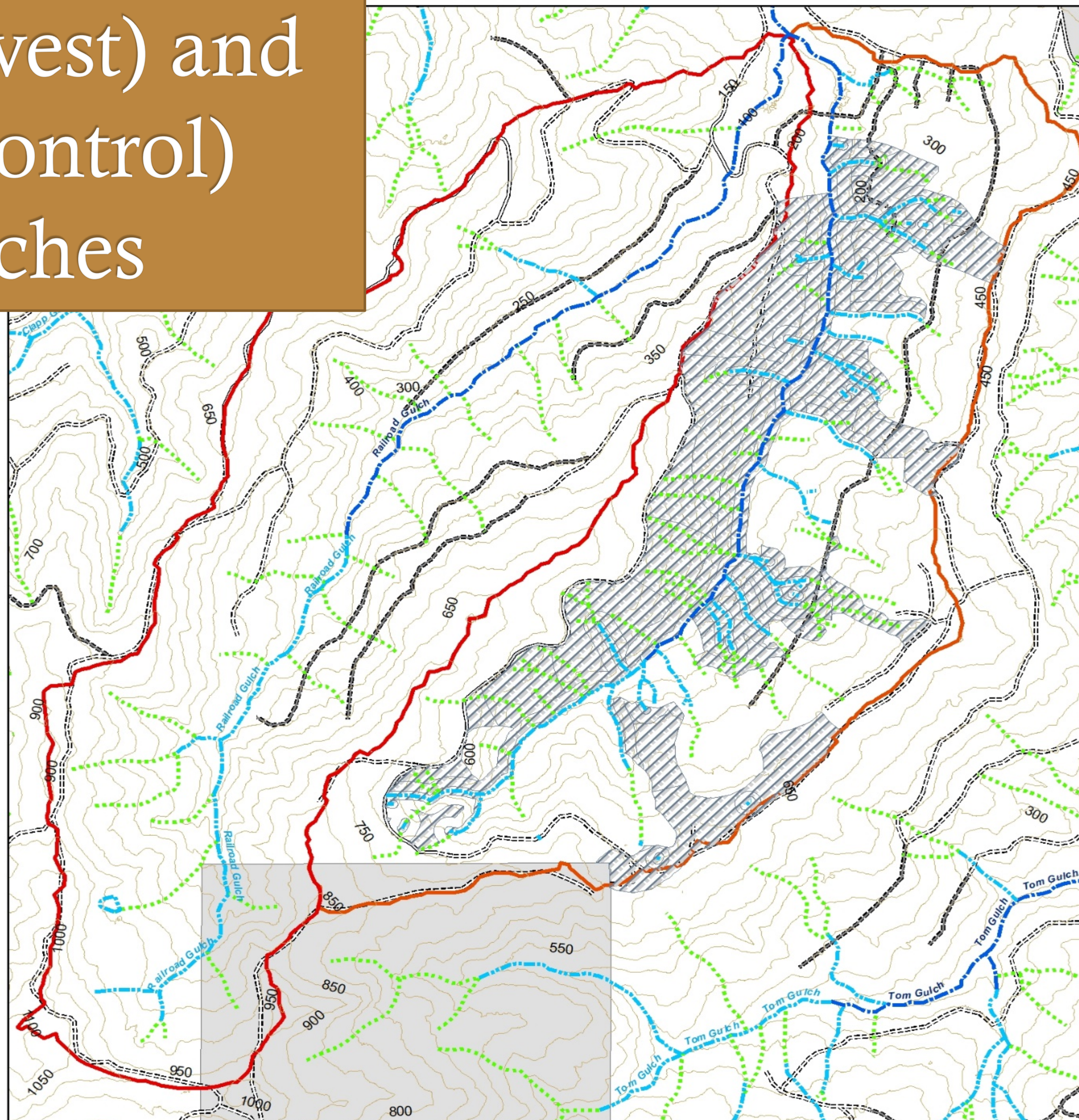
Goals

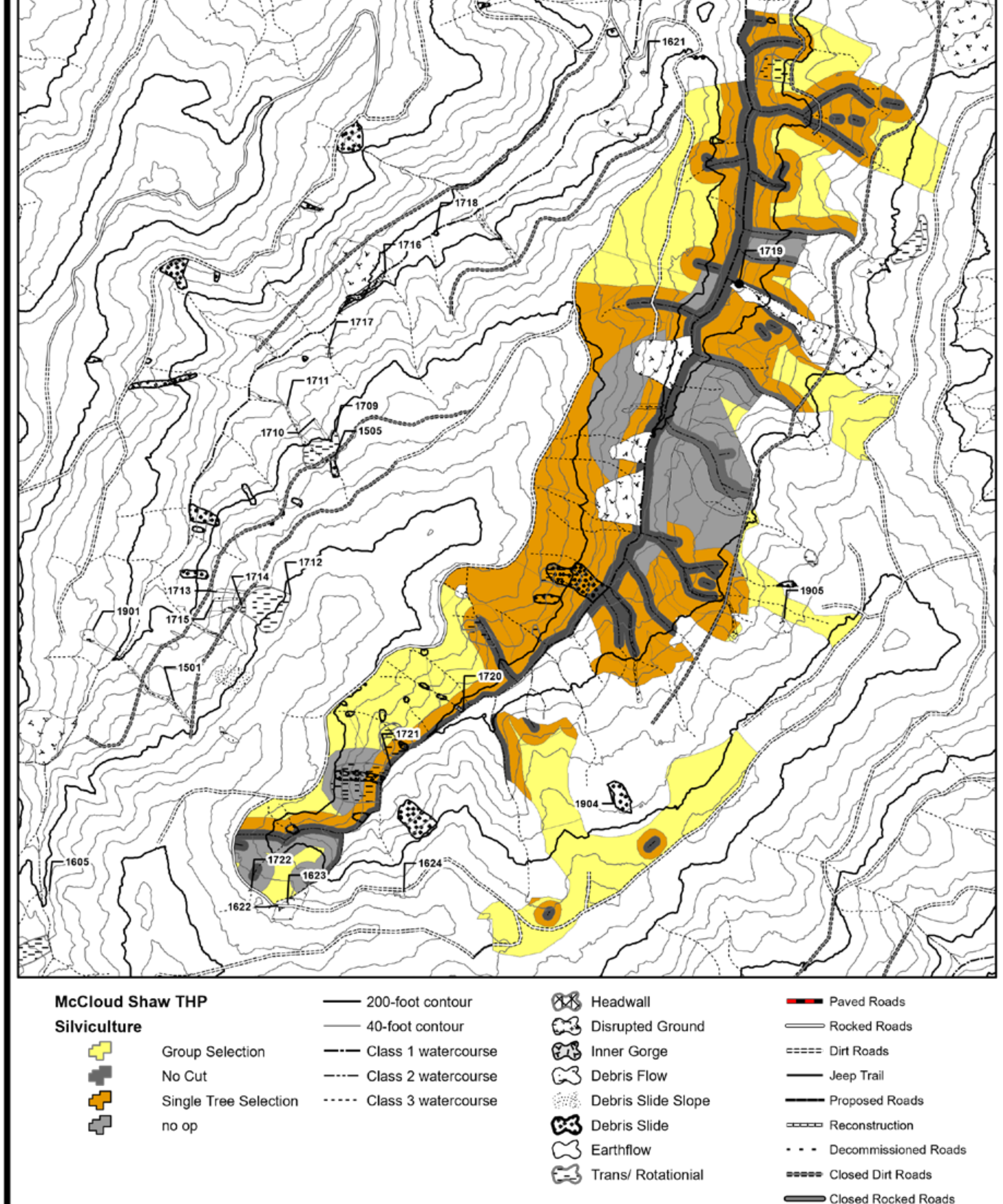
- Evaluate the effectiveness of:
  - Humboldt Redwood Company's (HRC) Habitat Conservation Plan (HCP)
  - California Forest Practice Rules
  - Elk River Watershed Analysis-derived prescriptions
- in minimizing sediment delivery to watercourses in response to timber harvest activities.
- Gain insight into dominant erosional processes within the watersheds

Study Site


Shaw Gulch
Elk River
NF Elk River
Project Area
Clapp Gulch
Willow Brook
SF Elk River
Tom Gulch
McCloud Creek
Creek
ARCATA
EUREKA
FORTUNA
Humboldt County
California
Pacific Ocean
SITE
0
10 Miles

East (harvest) and West (control) Branches

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McCloud Shaw THP
Silviculture
Group Selection
No Cut
Single Tree Selection
no op
200-foot contour
40-foot contour
Class 1 watercourse
Class 2 watercourse
Class 3 watercourse
Headwall
Disrupted Ground
Inner Gorge
Debris Flow
Debris Slide Slope
Debris Slide
Earthflow
Trans/ Rotational
Paved Roads
Rocked Roads
Dirt Roads
Jeep Trail
Proposed Roads
Reconstruction
Decommissioned Roads
Closed Dirt Roads
Closed Rocked Roads

Description: Railroad Gulch

- 85% redwood, 12% Douglas-fir. Stands are primarily single tiered and even aged
- Hookton formation (Pleistocene) and Wildcat (Miocene to Pleistocene) sediments
- Highly erodible and subject to both shallow and deep-seated mass movements

Harvest History

- West branch is 366 acres, East branch is 317 acres
- Initial clear-cutting and railroad harvesting including the use of 'steam donkeys' in the early 1900's
- Railroad line placed down the main channels – ties now visible
- Densely restocked
- Selection and even-aged harvest between 1987 and 2002

McCloud Shaw Timber Harvest Plan

- 122 acres of single tree selection
- ~2 acres of group selection
- 24 acres of no harvest
- 4 acres of ridge top harvest for construction of 2,750 feet of haul road
- Cable yarding
- Total harvest of 13MMBF/acre

Timeline

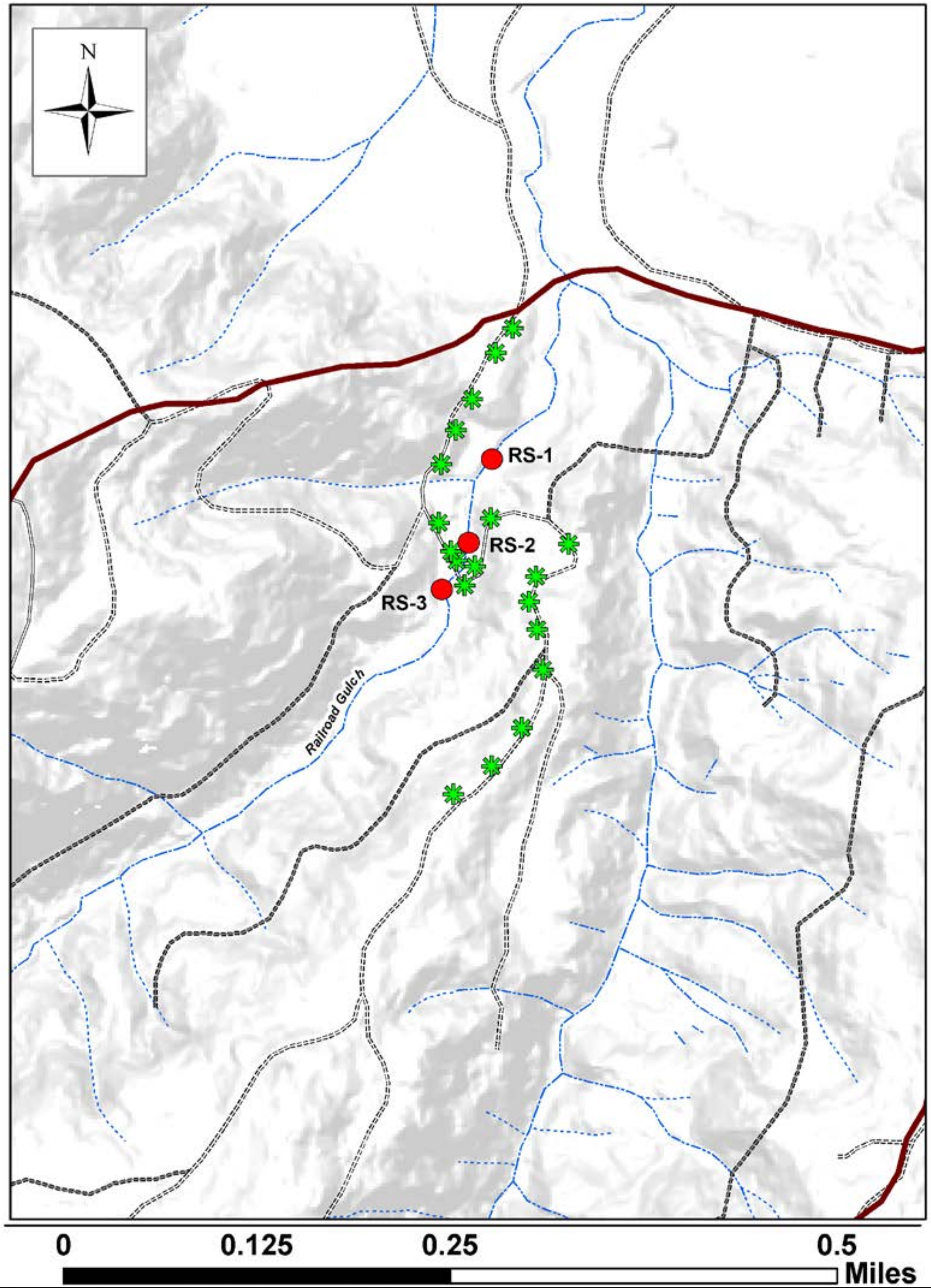
- Monitoring WY 2014 - 2020
- Road construction and upgrading -summer of 2015
- Harvest -summer of 2016

Sediment Yield at the Mouth

- Storm and Annual Sediment Loads
- Continuous Turbidity Monitoring
- Pump Sampler for Suspended Sediment Concentration
- Continuous Stage Monitoring
- Discharge Rating Curve from Field Measurements

Issue: Section of Haul Road Traverses Control Watershed

Impact minimized by rocking and erosion control wattles on water bars



Long Term Erosion Rates

Field samples analyzed by accelerator mass spectrometry for Be-10 at Purdue. Higher Be-10 correlated with lower catchment erosion rates.

Peak Flows

- Continuous discharge stations.
- Rainfall data.
- Analysis of peak flows, runoff coefficient (Q/P) and rainfall intensities.

Landslides

Annual aerial photography and field inspection

Landslide Map

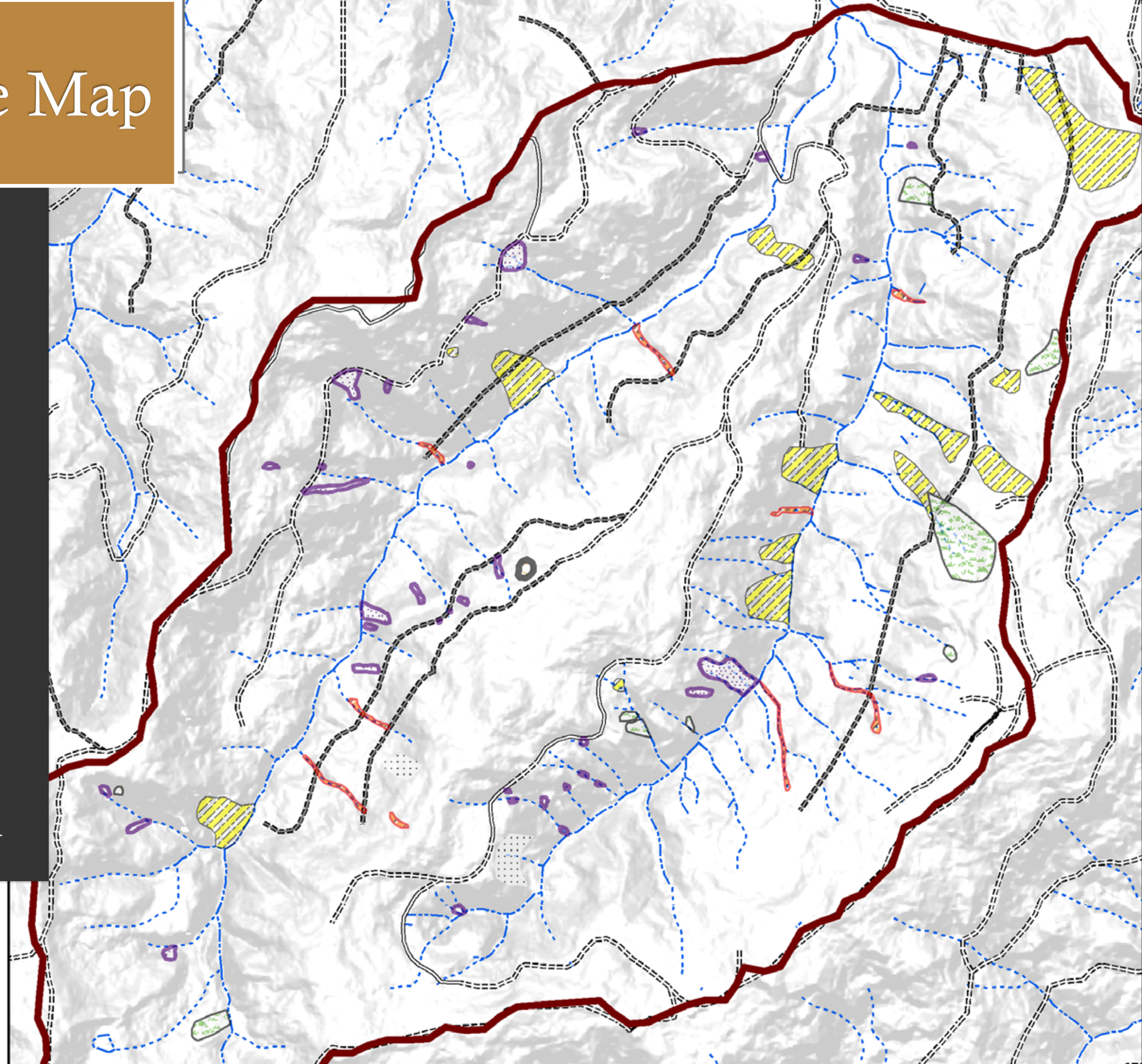
red outlines: debris flows;

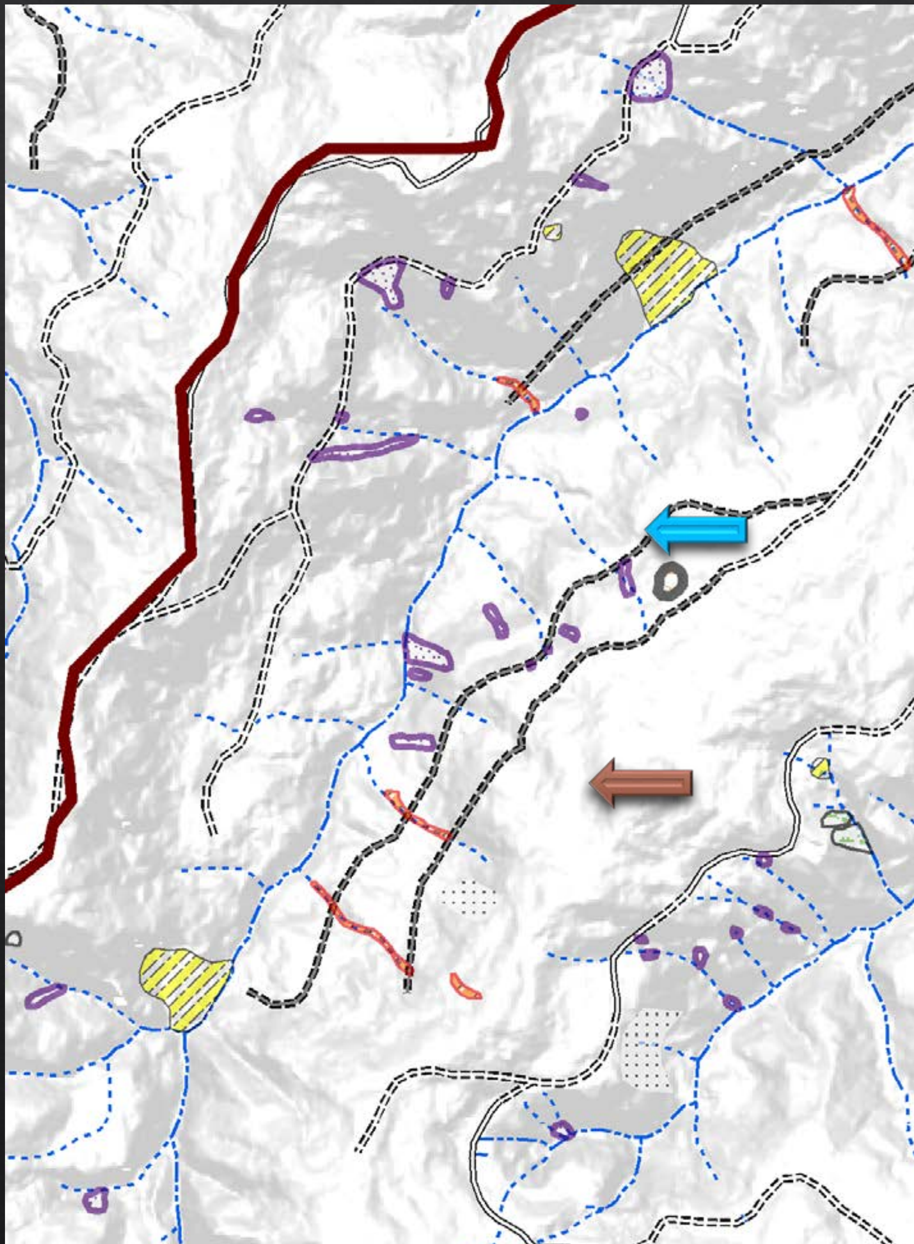
polka dots with purple outlines: debris slides;

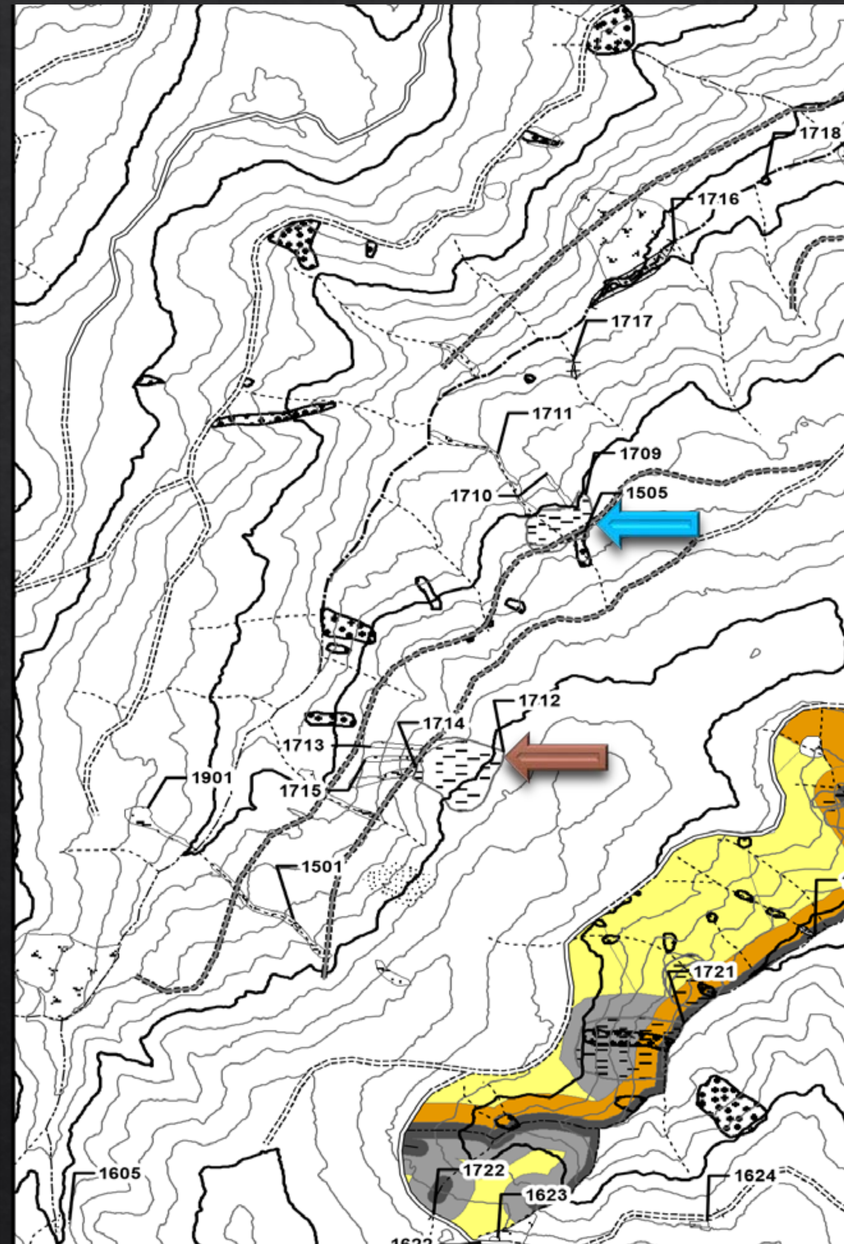
polka dots (no outline): debris slide slopes;

yellow patterns: earthflows;

green patterns: trans/rotational landslides.







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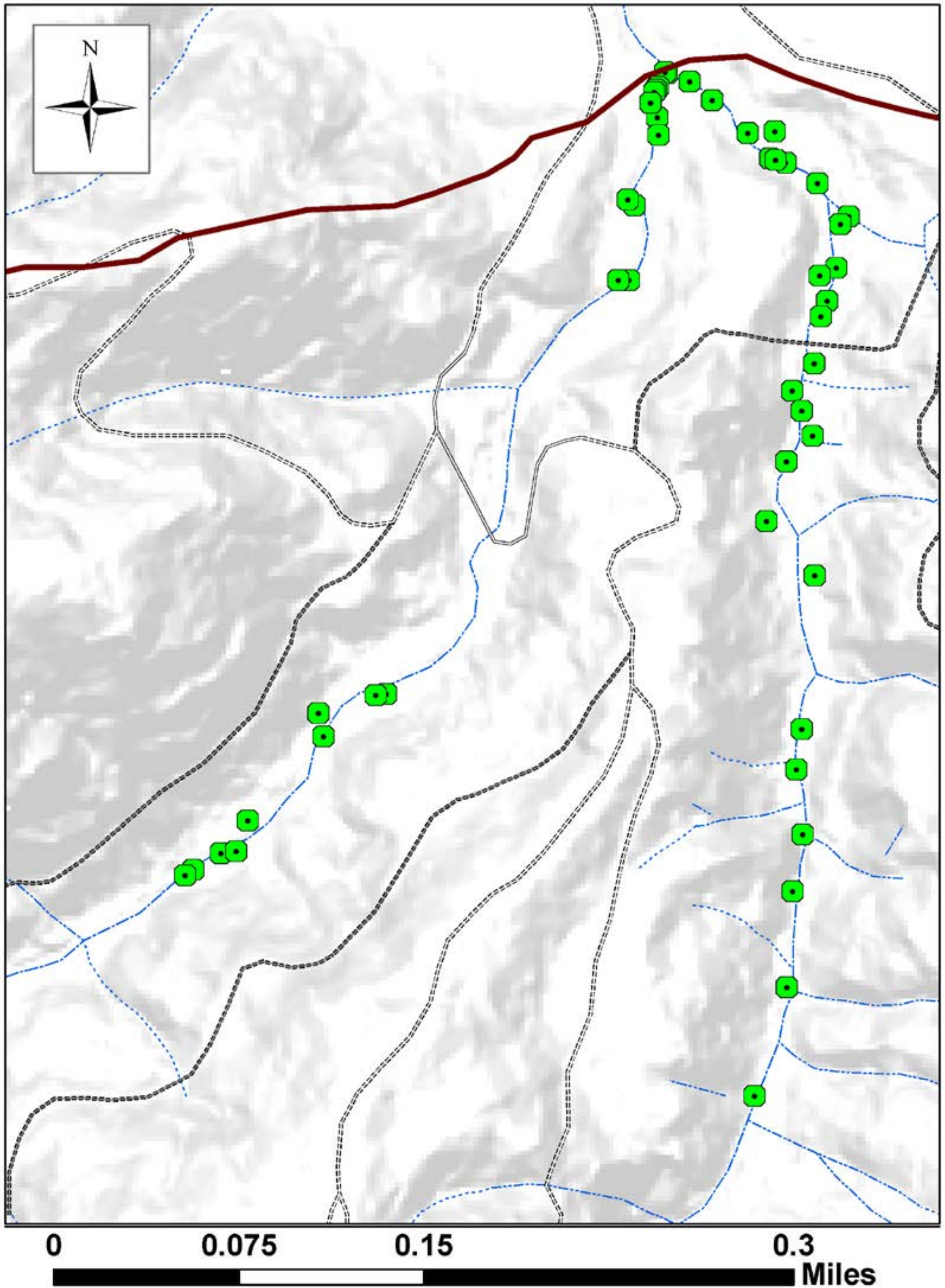
Earth flow on West Branch, Railroad Gulch.

Streamside Landslides

Streamside Landslides

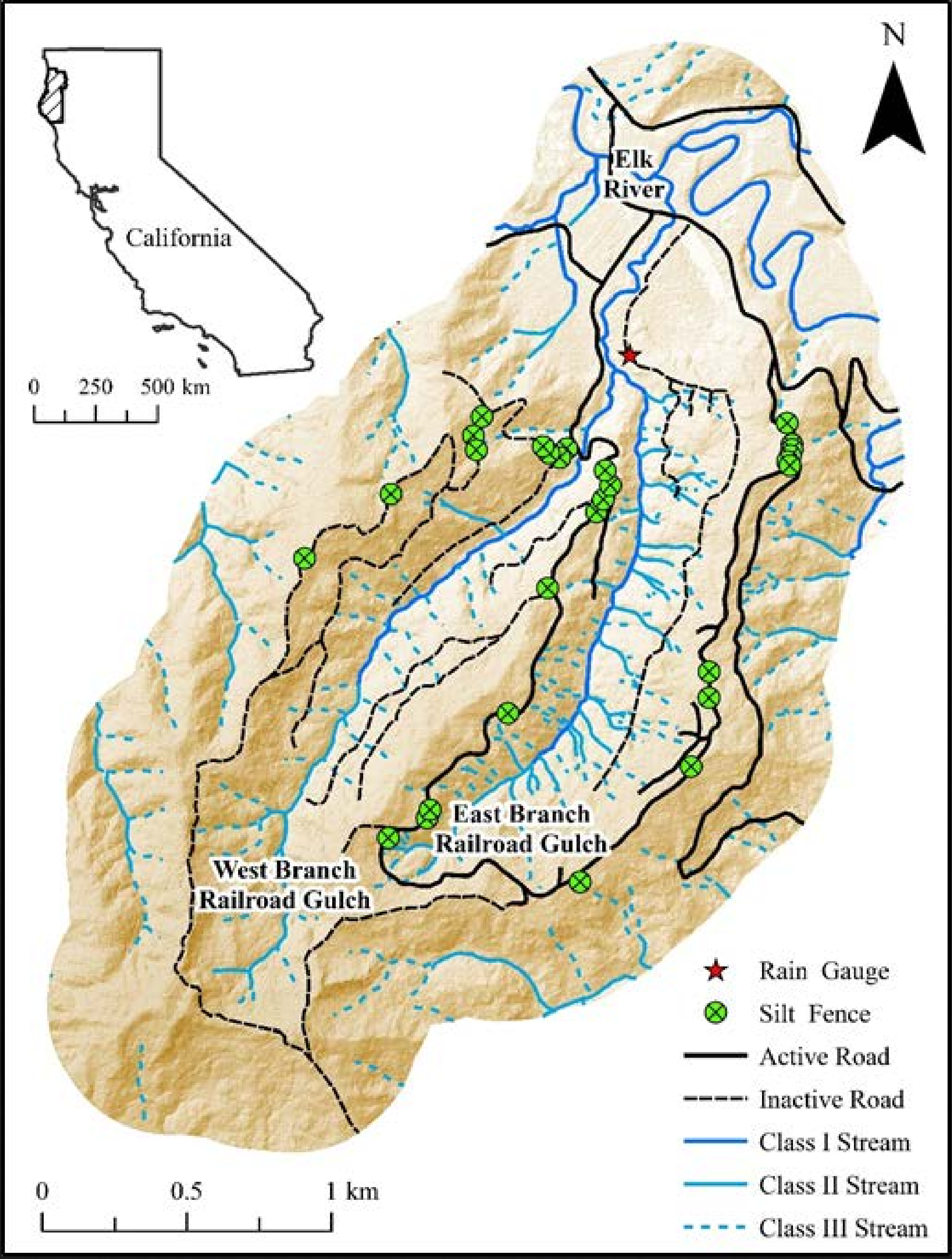
Methods: Annual field inspection of lower 2600 feet.

Painting Banks, Volume of void

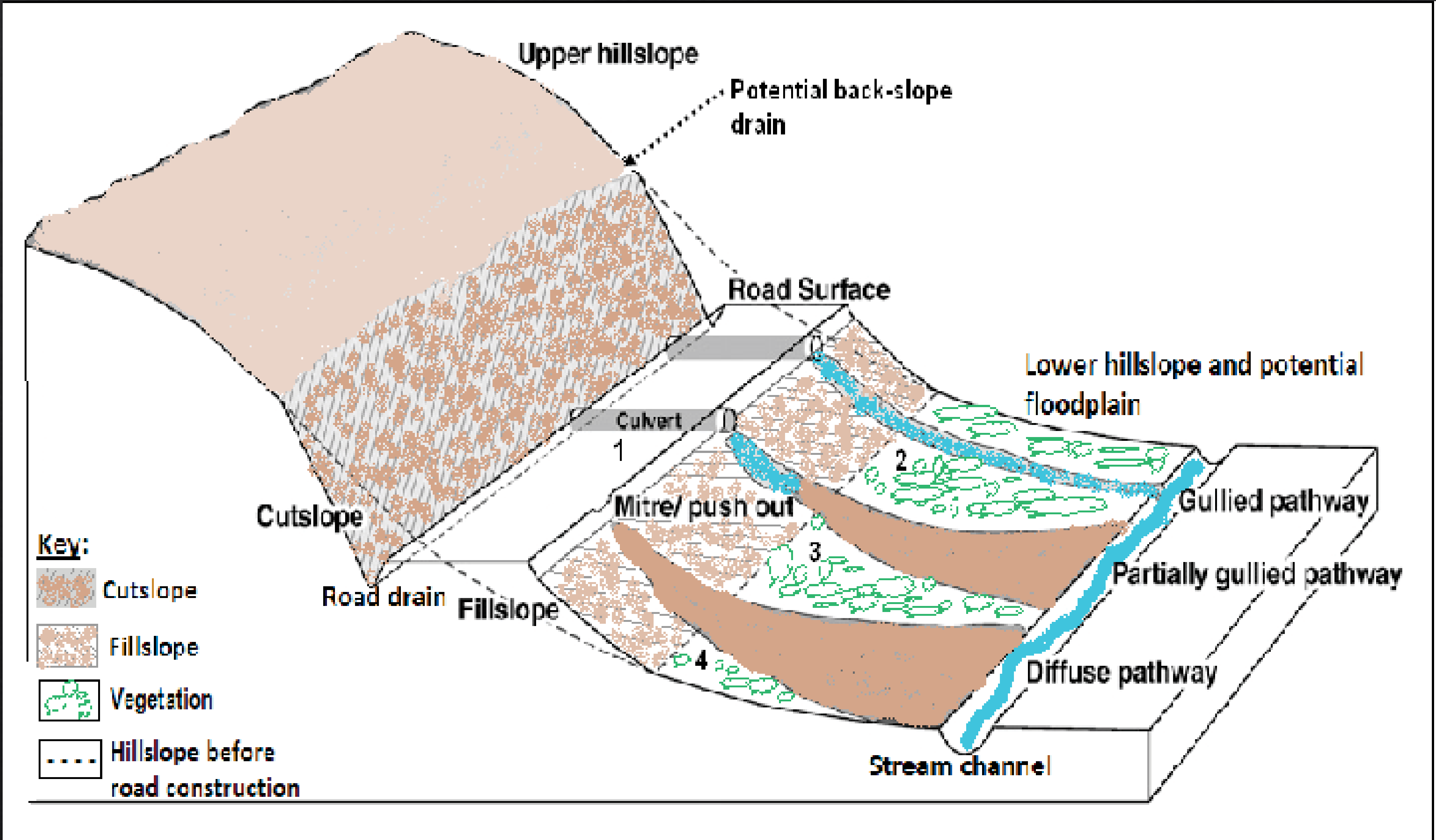


Road Erosion

- Annual road surveys to evaluate erosion and hydrologic connectivity on 363 road segments
- Sediment fences installed on 28 water bars to collect eroded material



Plume length



Road Crossings

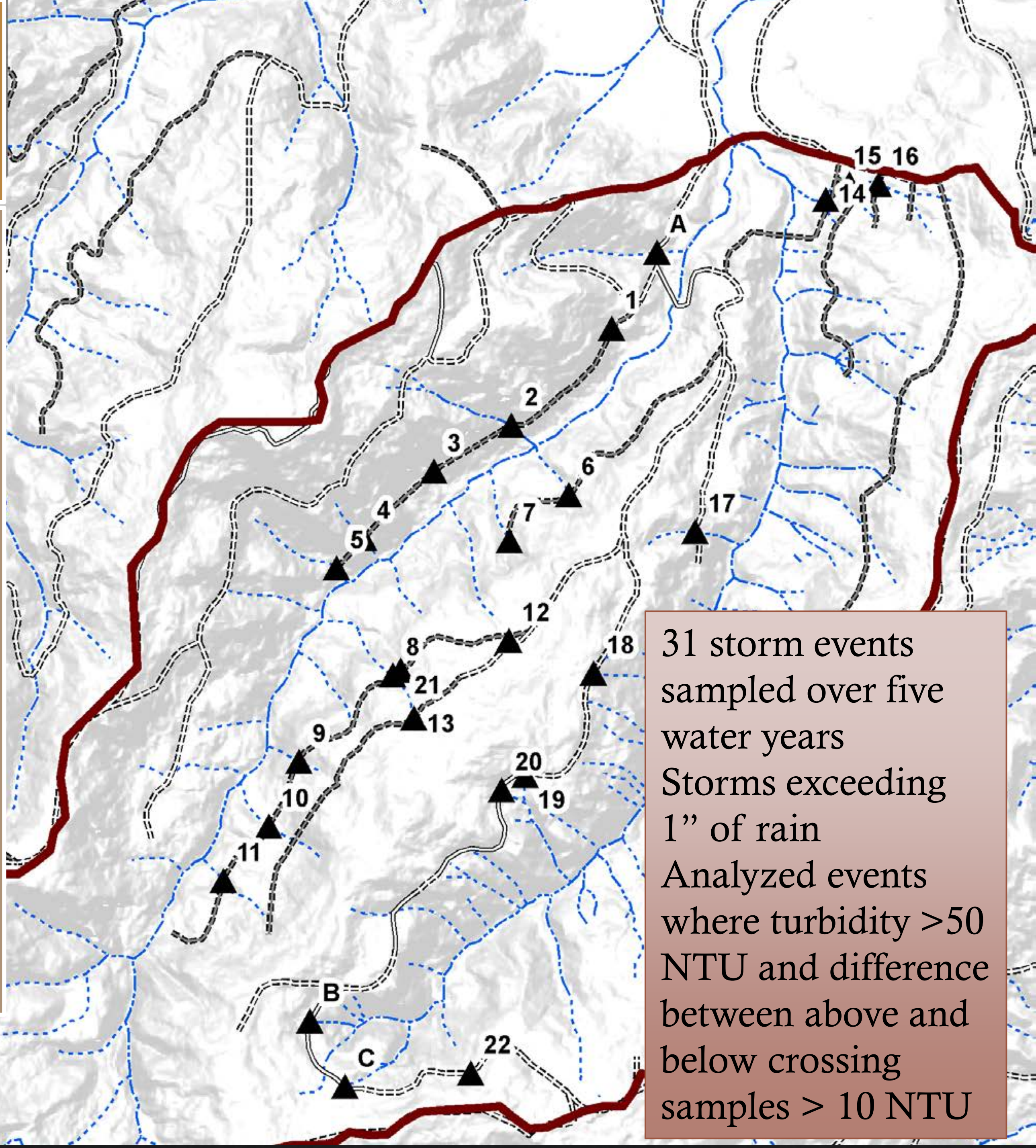
Method: Annual inspection and grab sampling for turbidity during storm events

Sites 1-16, 21

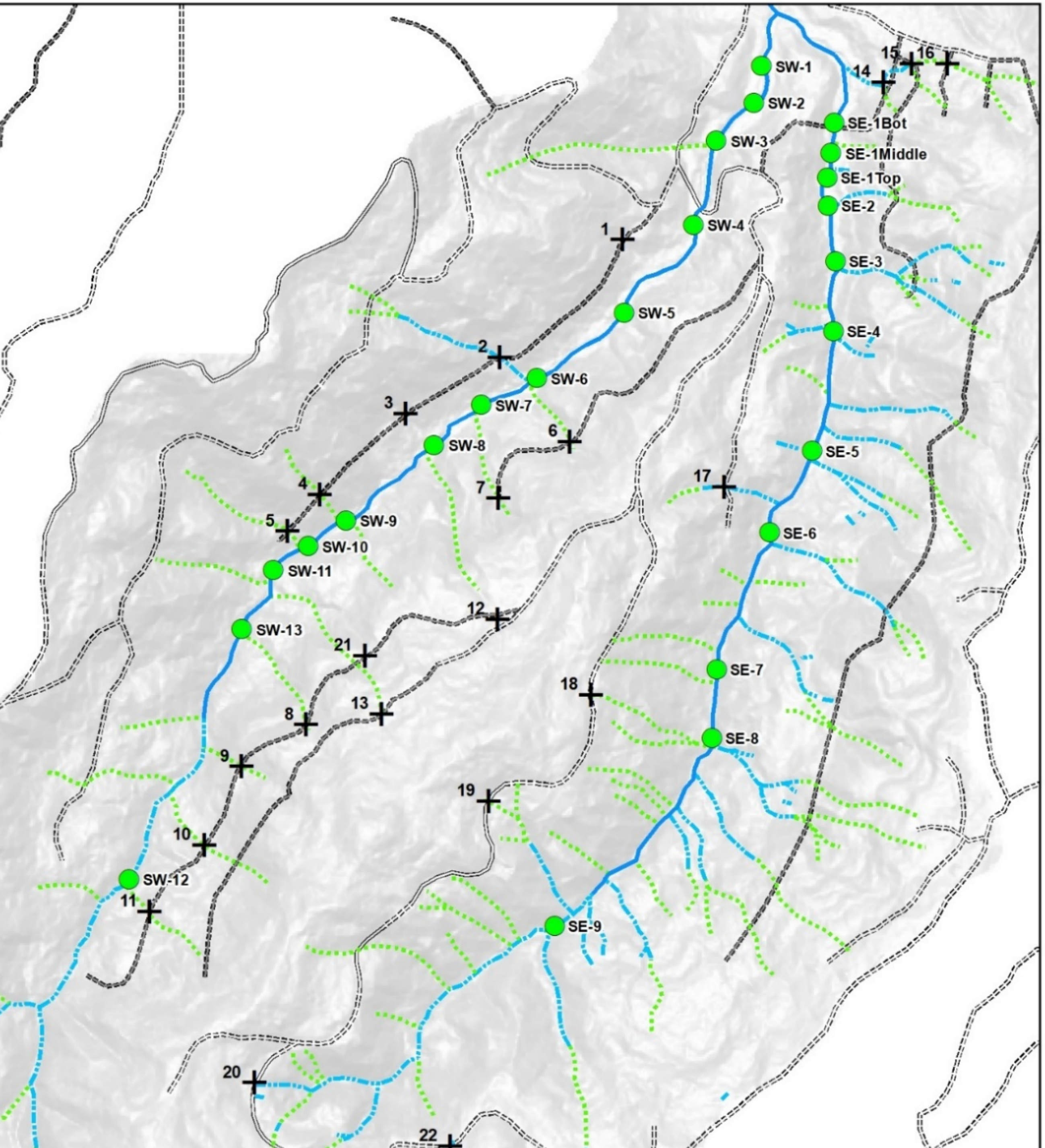
Debris torrent at #11 on 2/6/15

Humboldt Crossings: 6 treated and 14 untreated

New crossings: Sites 17-20,22 (A,B,C)



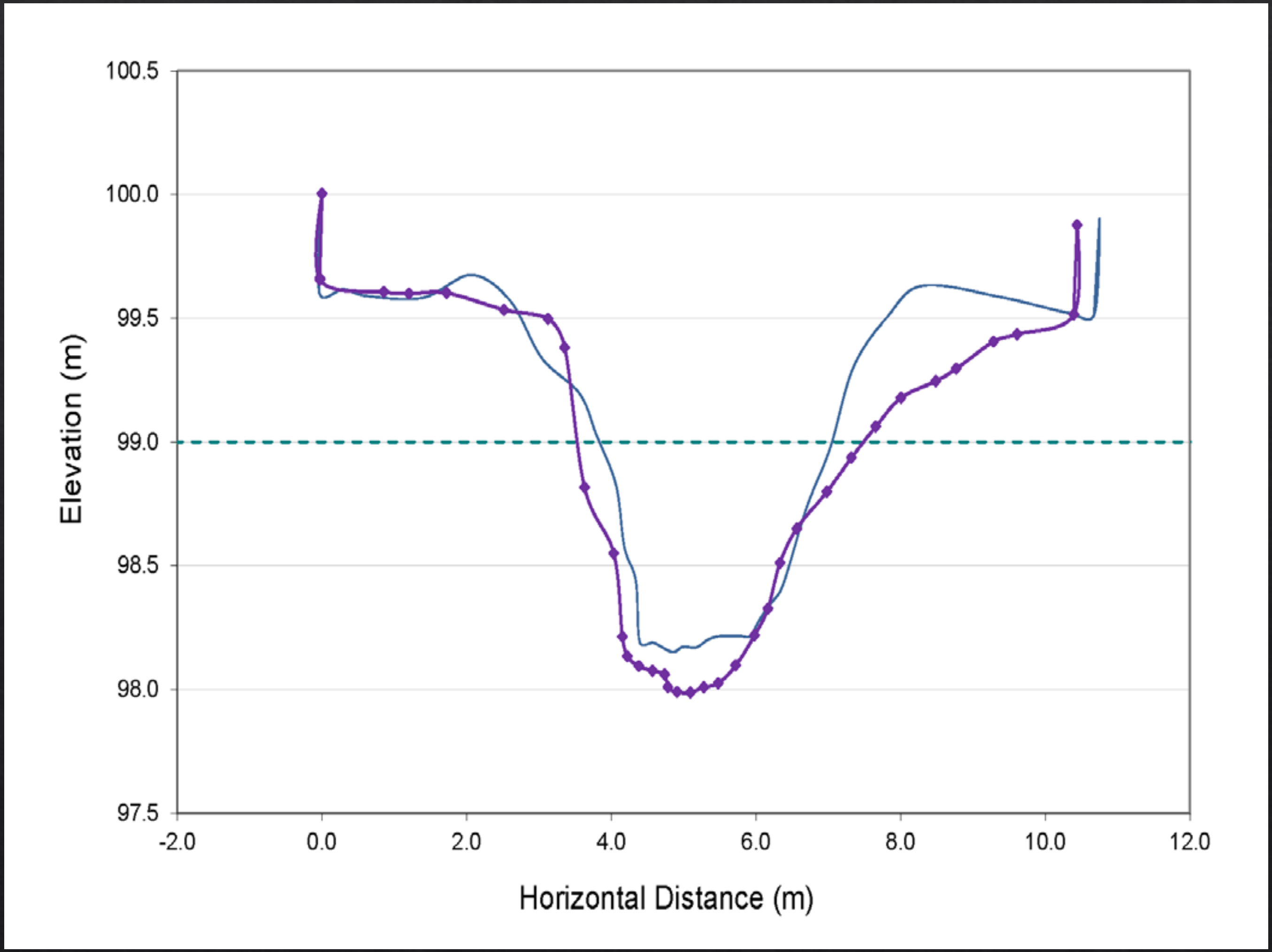
31 storm events sampled over five water years
Storms exceeding 1” of rain
Analyzed events where turbidity >50 NTU and difference between above and below crossing samples > 10 NTU



Tributary Storm Sampling

SW for West Branch and SE for East Branch.

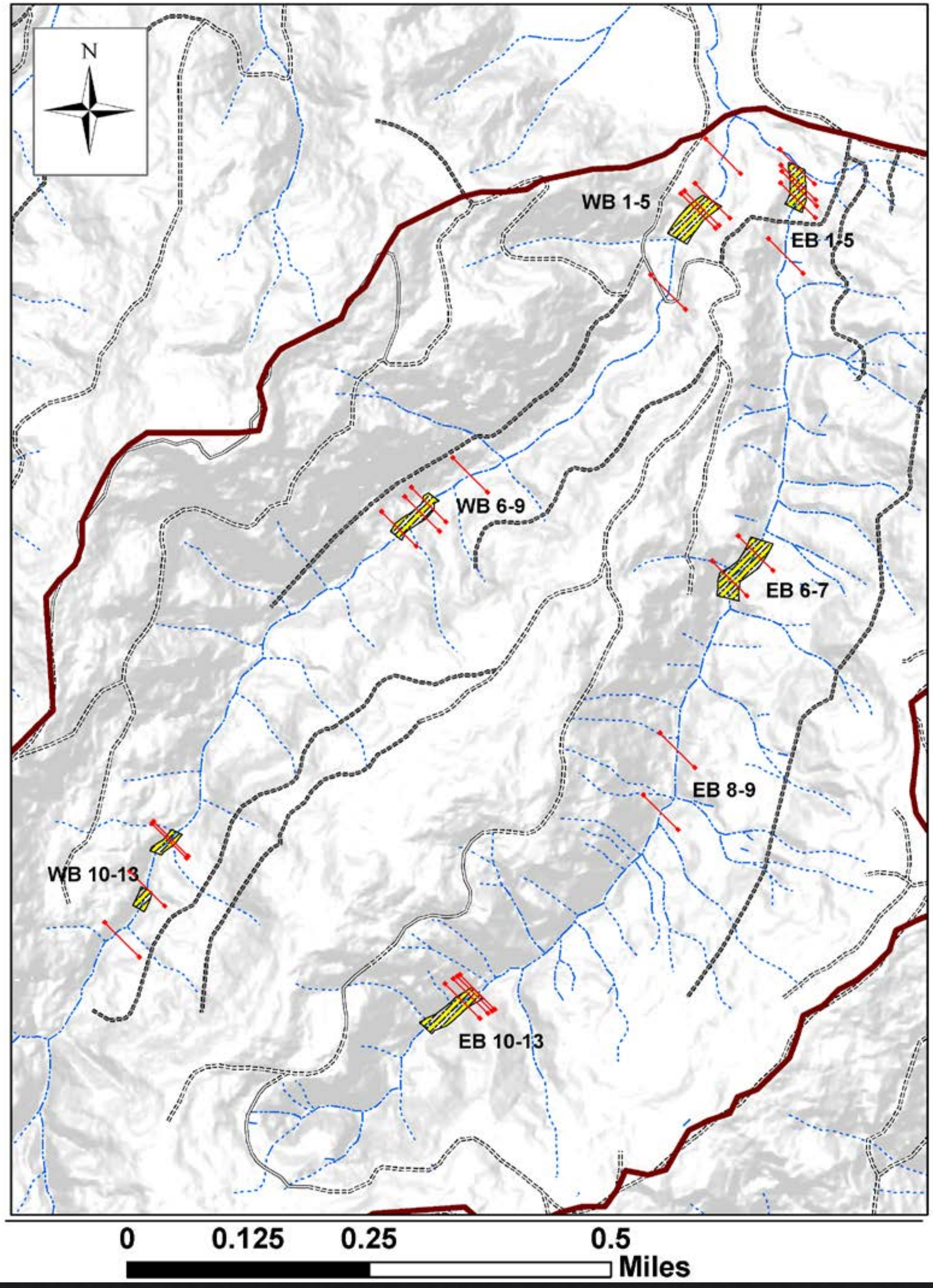
River Cross Sections and Bed Material



River Cross Sections

Methods: 13 cross sections established in each branch, surveyed annually.

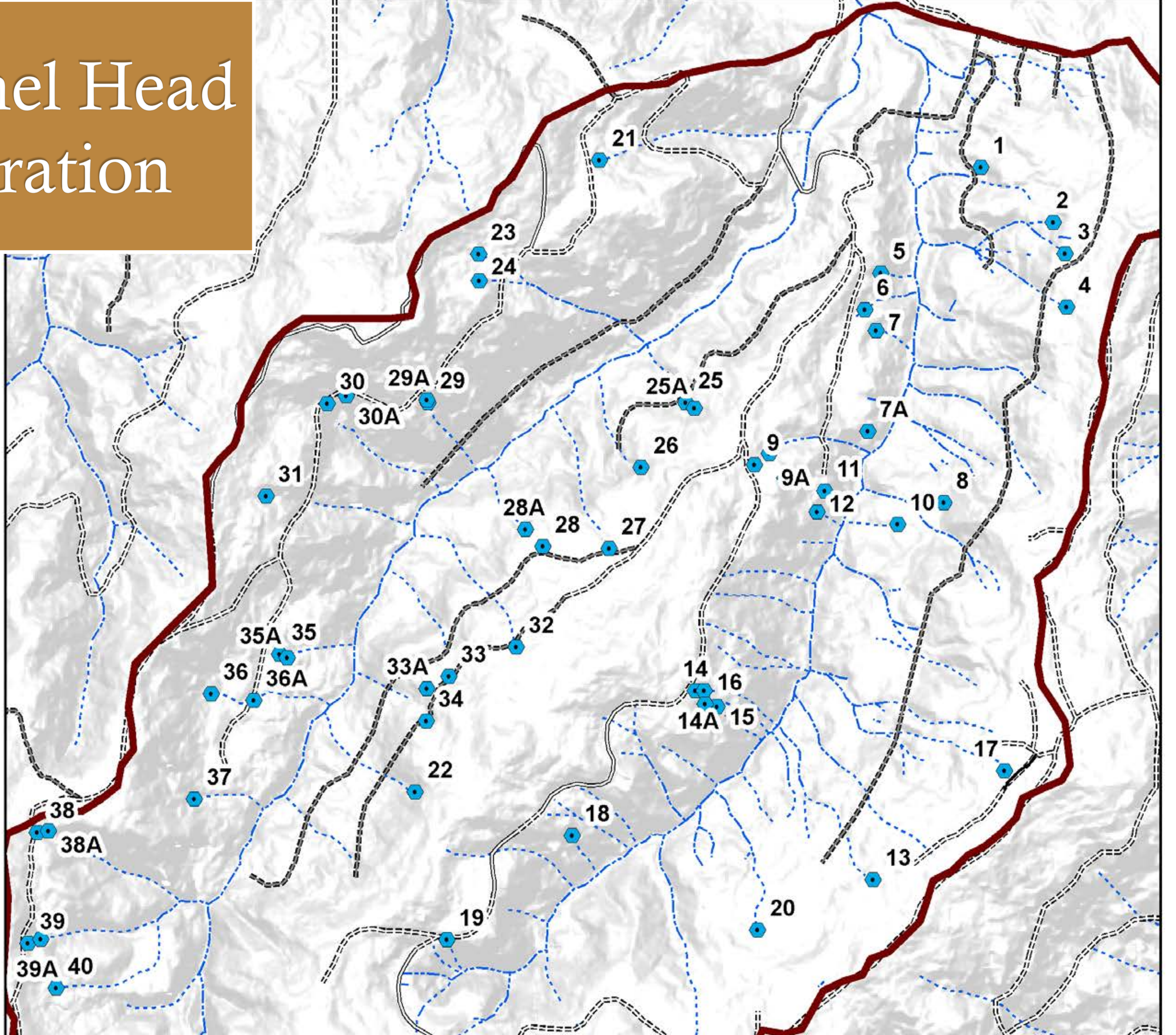
Annual Pebble counts.



Channel Head Migration

Channel initiation points monumented with rebar, examined annually for movement

Channel Head Migration



RESULTS

Rainfall and Runoff

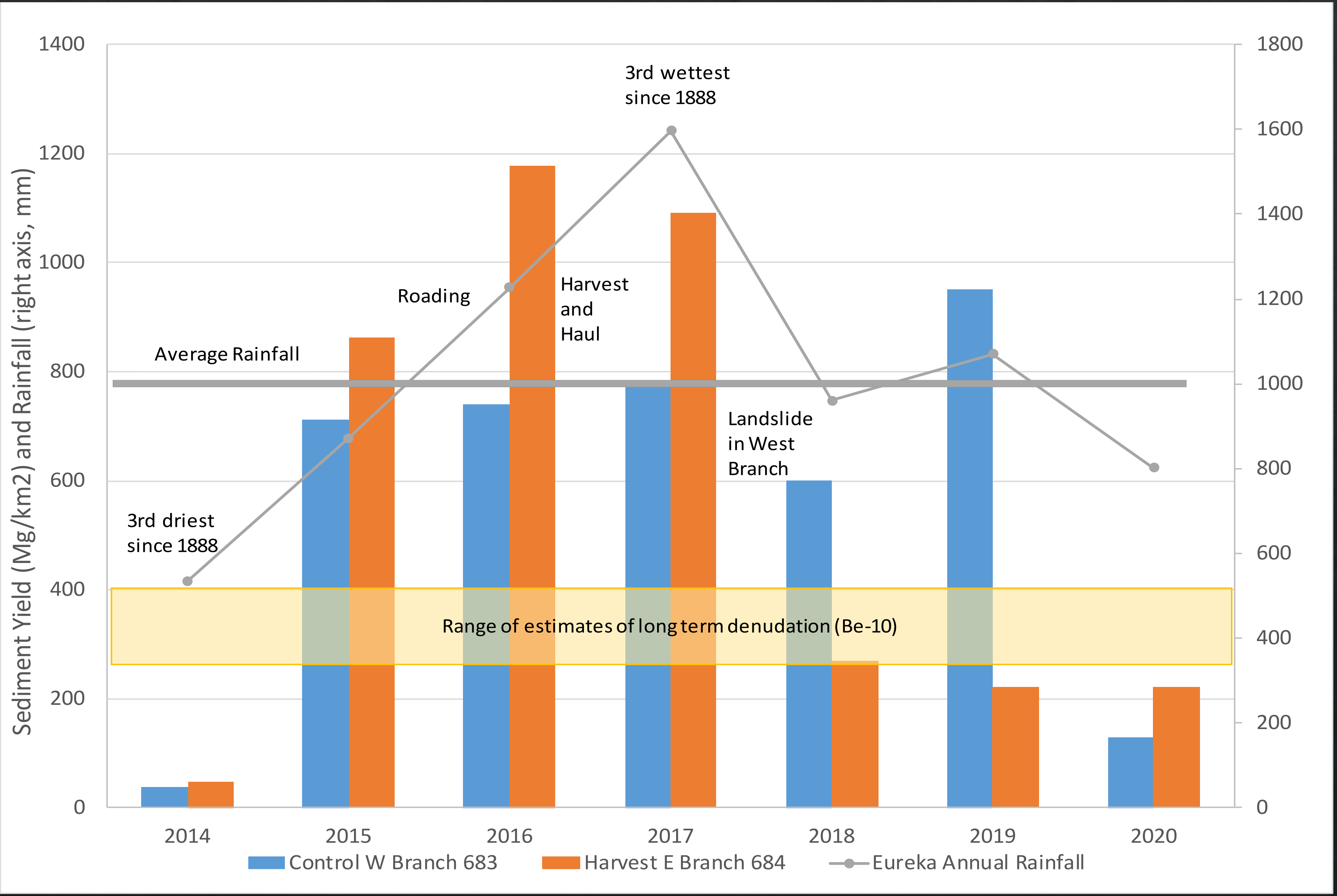
WY	Rainfall	East Branch (harvest) Cumulative discharge (Q)	West Branch, (control), Cumulative discharge (Q)
	mm	mm	mm
2014	560	148	118
2015	856	451	474
2016	1427	583	516
2017	1811	610	612
2018	950	367	236
2019	1211	312	520
2020	869	211	169

WY	Rainfall	East Branch (harvest) Runoff Coefficient	West Branch, (control) Runoff Coefficient
	mm	Q/Rainfall	Q/Rainfall
2014	560	0.26	0.21
2015	856	0.53	0.55
2016	1427	0.41	0.36
2017	1811	0.34	0.34
2018	950	0.39	0.25
2019	1211	0.26	0.43
2020	869	0.24	0.19

WY	Rainfall	East (harvest) Peak discharge	West (control) Peak discharge
	mm	$m^3/s/km^2$	$m^3/s/km^2$
2014	560	0.31	0.24
2015	856	1.25	1.35
2016	1427	1.56	1.62
2017	1811	0.7	0.81
2018	950	0.36	0.33
2019	1211	0.25	0.56
2020	869	0.45	0.27

WY	Rainfall	East (harvest) Peak daily average discharge	West Branch Peak daily average discharge
	mm	$m^3/s/km^2$	$m^3/s/km^2$
2014	560	0.13	0.1
2015	856	0.42	0.33
2016	1427	0.56	0.48
2017	1811	0.28	0.33
2018	950	0.27	0.29
2019	1211	0.13	0.43
2020	869	0.23	0.2

Annual Sediment Yield and Rainfall

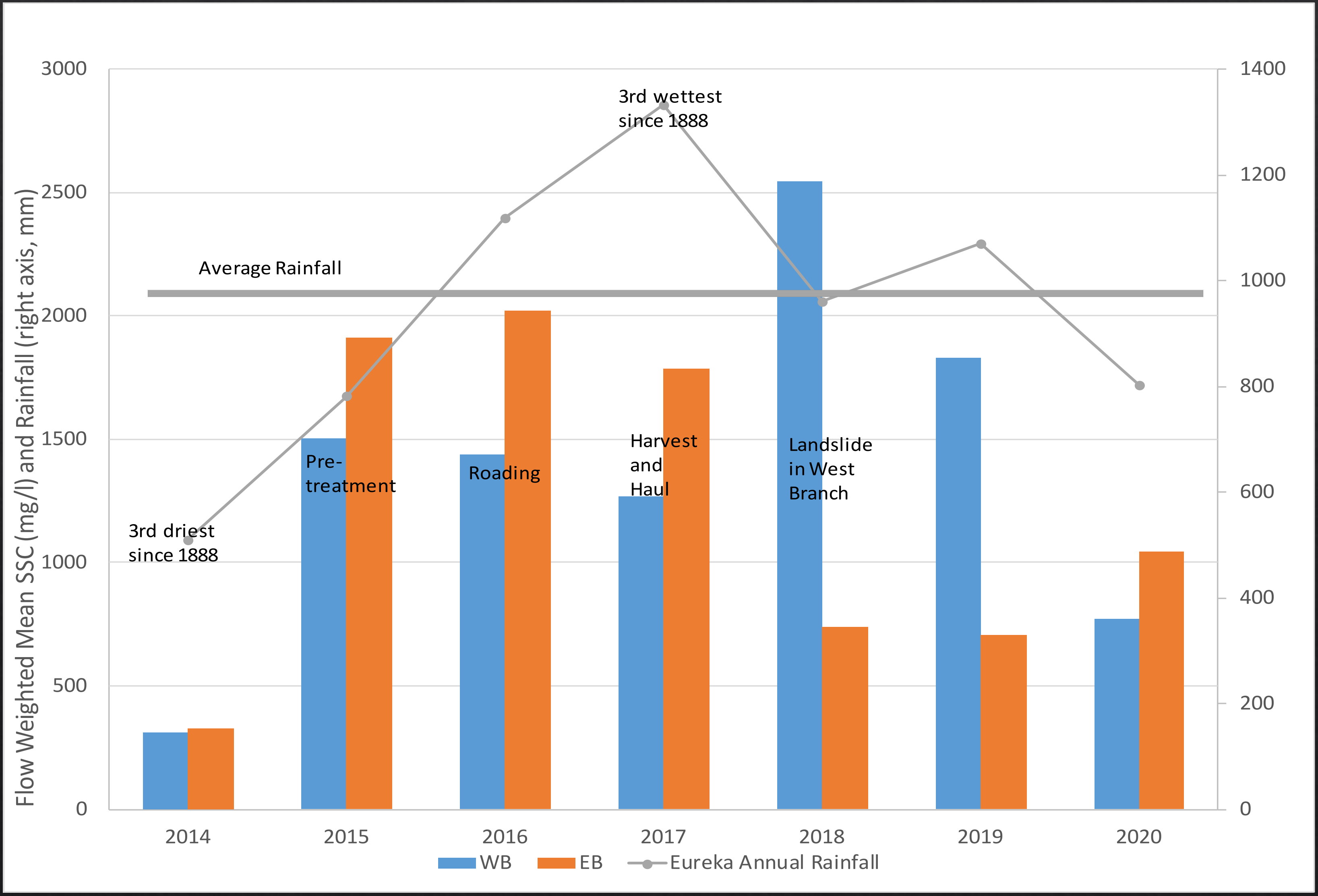


Drainage density

		East			West	
Class	Stream Length (km)	Drainage Density (km/km^2)	Avg Channel Width (m)	Length (km)	Drainage Density (km/km^2)	Avg Channel Width (m)
1	1.6	1.2	4.6	1.5	1.1	6.7
2	4.3	3.4	3.6	1.8	1.2	2.7
3	6.2	4.9		4.6	3.2	
Total	12.1	**9.5**		7.9	**5.5**	

Average channel widths derived from cross section surveys within each stream class. Cross sections 1-9 are in Class 1 reaches and cross-sections 10-13 are within class II reaches.

Flow weighted mean SSC



Current Erosion Rates and Long-term Erosion Rates

Year	W Branch Control	Comparison to Be-10 Value*	E Branch Harvest	Comparison to Be-10 Value	Eureka Annual Rainfall
	$Mg/km^2/yr$	%	$Mg/km^2/yr$	%	mm
2014	37	12%	49	16%	535
2015	713	236%	861	285%	872
2016	740	245%	1178	390%	1228
2017	774	256%	1090	361%	1596
2018	600	199%	270	89%	960
2019	950	315%	220	73%	1070
2020	130	43%	220	73%	802
Average 1888-2010					1002

* Long-term estimate derived from Be-10 is 302 $Mg/km^2/yr$.

Landslides

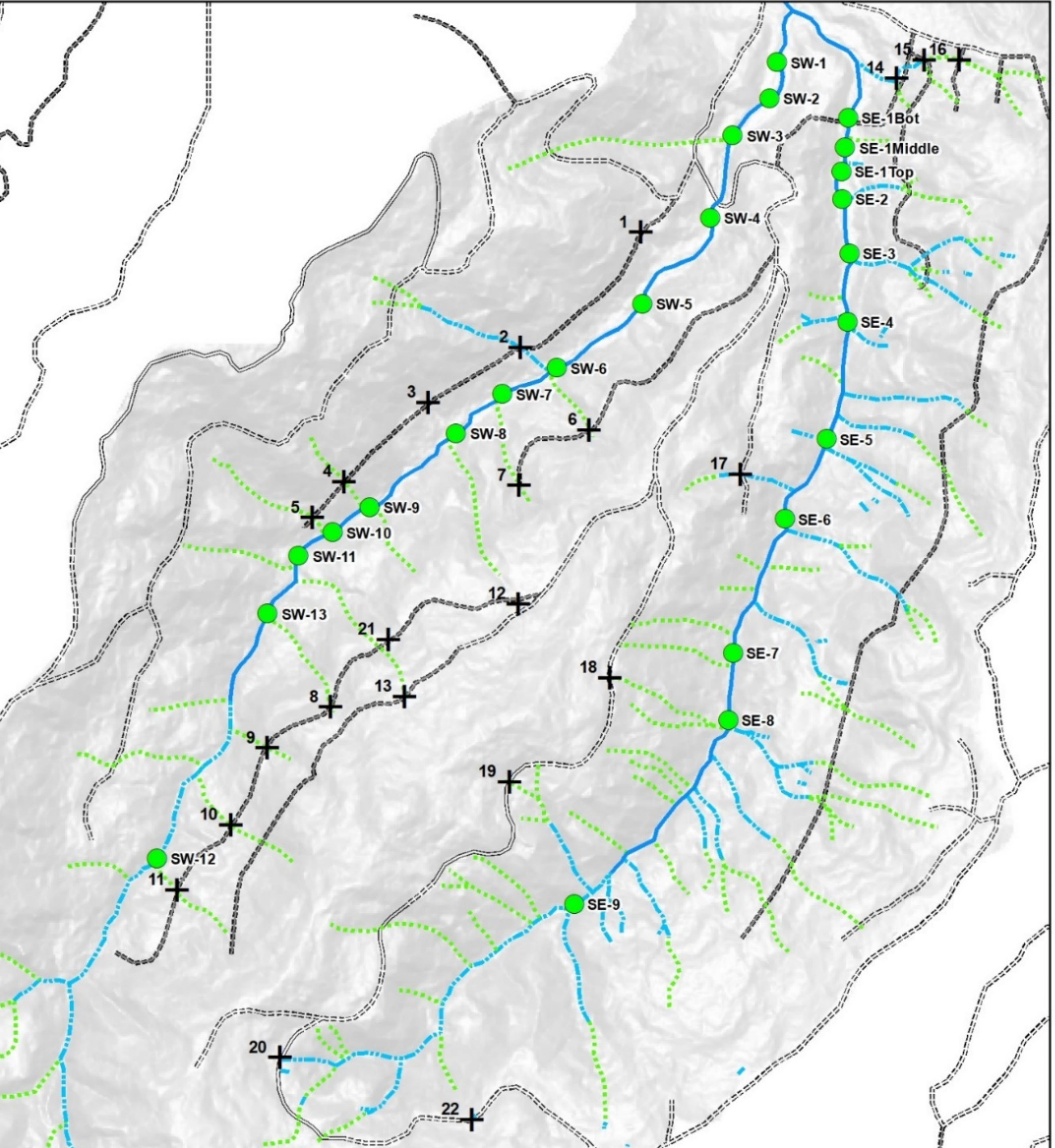
Water Year	West Branch (cubic yd)	East Branch (cubic yd)	Railroad Gulch Total (cubic yard)
2015	102	0	102
2016	66	.3	66
2017	562	0.5	562
2018	0	0	0.0
2019	12	0	12
Total	742	0.8	743

Small Streamside Landslides

	Water Year	2013	2014	2015	2016	2017	2018	2019
East Branch (39% harvested)	Displaced (yd^3)	6	0.3	8.8	21.8	15.9	17.2	27.6
	Delivered (yd^3)	6	0.3	8.8	13.3	15.5	12.6 One site	27.6 One site
West Branch (control)	Displaced (yd^3)	11.4	0.6	20.5	32.9	34.5	1.44	8.5
	Delivered (yd^3)	11.2	0.6	12.8	15.1	21.7	1.26	5.8
Ratio of Delivered Sediment EB/WB		0.5	0.5	0.7	0.9	0.7	10	4.8

Sediment Yield from Streamside Landslides

- Erosion estimates from the surveyed 800 m (2,625 ft) of each sub-basin were extended to the entire basin
- Similar sediment loads per km were assumed for the rest of the Class I channels, 50% of this loading from the smaller Class II channels and 10% from the Class III channels
- In WY 2016 streamside landsliding was 90 Mg (99 tons) or 6% of the total sediment load for the East Branch, and 67 Mg (74 tons) or 6% in the West Branch
- In WY 2017, streamside landsliding was 104 Mg (115 tons) or 7% of the East Branch sub-basin sediment load, and 96 Mg (106 tons) or 8% of the West Branch load



Storm Sampling

Road and stream sites for storm event sampling. SW for West Branch and SE for East Branch.

West Branch Tributary Turbidity

West Branch	2014	2015	2016	2017	2018	2019
SW-3 Larger subwatershed	Higher than main stem for 2/4	Higher than main stem for 4/9			Higher than other tribs, lower than main stem	
SW-4			Higher than main stem for 5/8		Higher than other tribs, lower than main stem	Higher than other tribs, lower than main stem
SW-12 Debris flow – Dec 2015 followed by larger landslide June 2017			Debris flow. Higher than main stem after 12/14/15	Debris flow. Higher than main stem for 5 of 10, less by end of season	Debris flow raises main stem turbidity	Debris flow raises main stem turbidity
# Events	4	9	8	10	5	4
Comments	Little influence of tribs on main stem		Little influence of tribs on main stem	Little influence of tribs on main stem	SW-12 turbid, effect on main stem	SW-12 turbid, effect on main stem

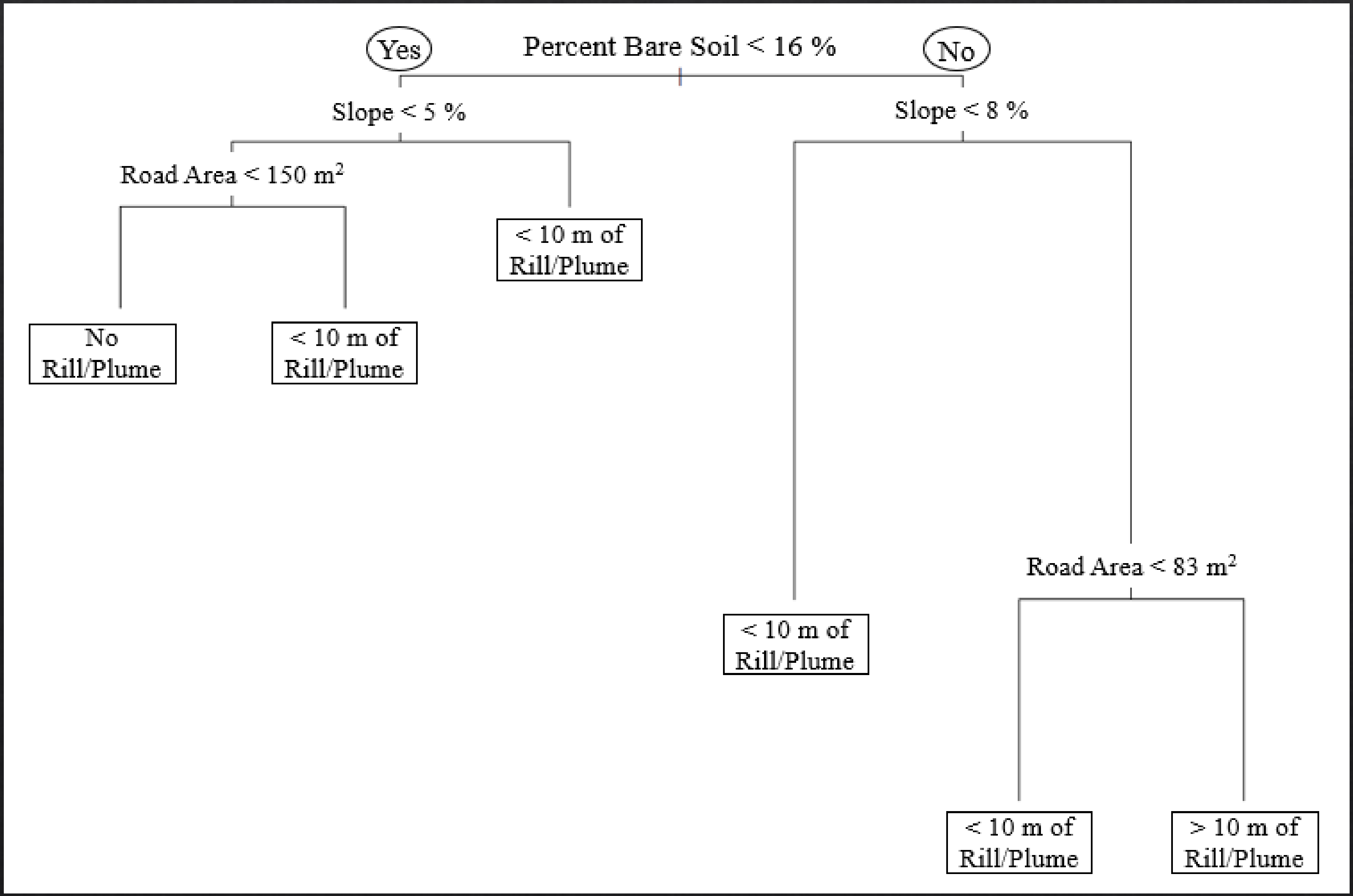
East Branch Tributary Turbidity

East Branch	2014	2015	2016	2017	2018	2019
SE-3 Two old spur road crossings				Higher than main stem for 3/10	Trib similar to main stem	Trib clearer than main stem
SE-5 Incising into earth flow	Higher than main stem for 7 of 9 dates		Higher than main stem on 8/8	Higher than main stem for 7/10	Trib much more turbid than main stem	Trib much more turbid than main stem
SE-6 intersects old spur road				Higher than main stem for 4/10	Trib much more turbid than main stem	Trib more turbid than main stem
SE-8 Old spur road crossings and debris flow			Higher than main stem for 6/8	Higher than main stem for 10/10	Trib clearer than main stem	Trib slightly less turbid than main stem
# Events	4	9	8	10	5	4
Comments	Tribs clearer than main stem			Clearer tributaries. In a few cases tributaries influence main stem		SE-5 & SE-6 highest. Main stem clearest at SE-9

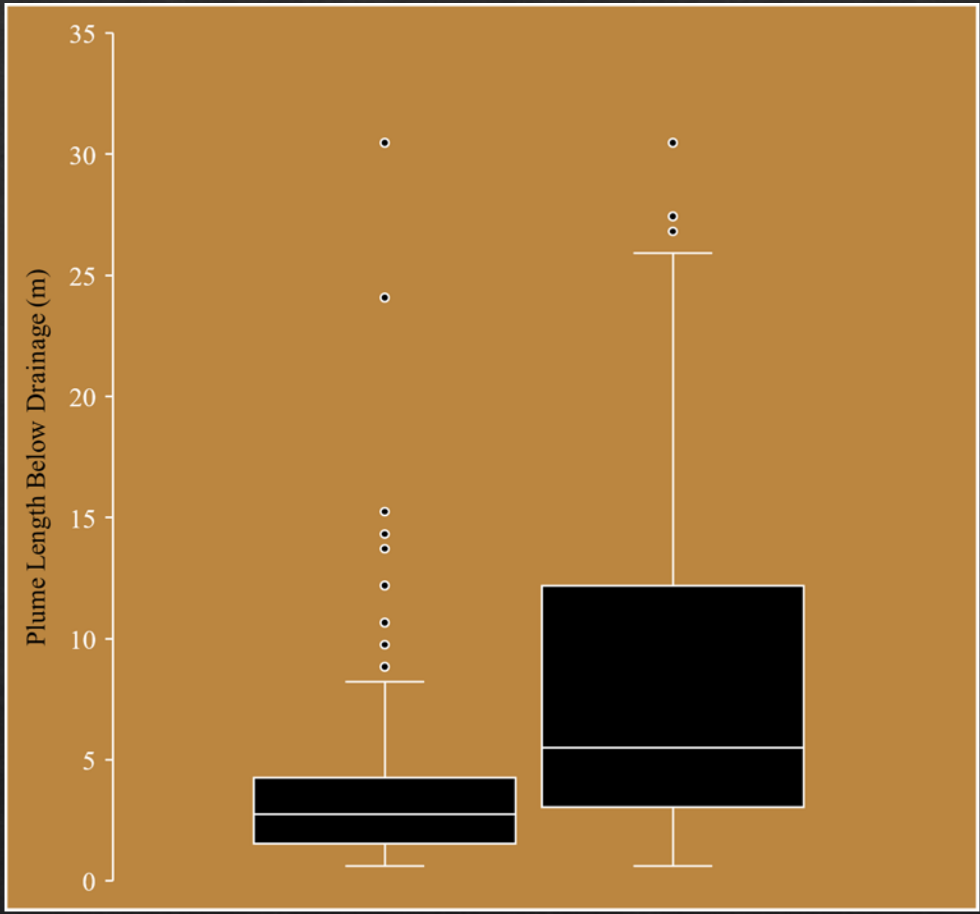
Road surface erosion and related sediment delivery to watercourses

East Branch (harvest)	Plume Length Below Drainage (m)	Plume Length on Road (m)	Rill on Road Length (m)
2014	1.7	0.0	0.1
2016	5.2	3.2	1.0
2017	6.4	5.0	2.0
2018	5.9	3.1	2.7
2019	5.9	3.1	2.8
West Branch (control)	-	-	-
2014	2.2	0.2	0.6
2016	2.3	0.5	1.2
2017	2.5	0.3	1.2
2018	2.7	2.0	5.2
2019	2.7	2.0	5.6

Road Erosion Decision Tree

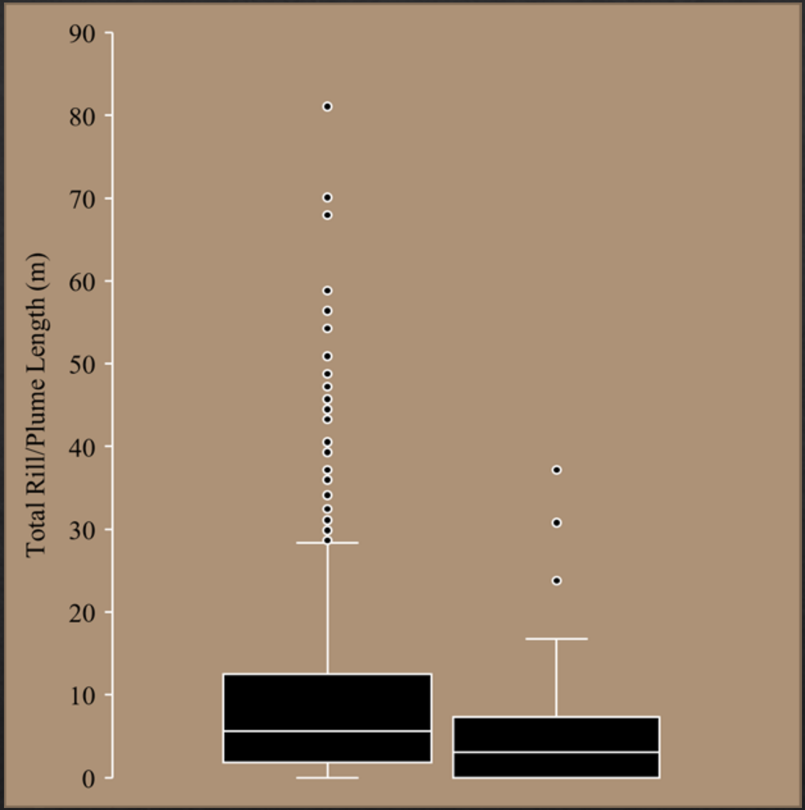


Plume length

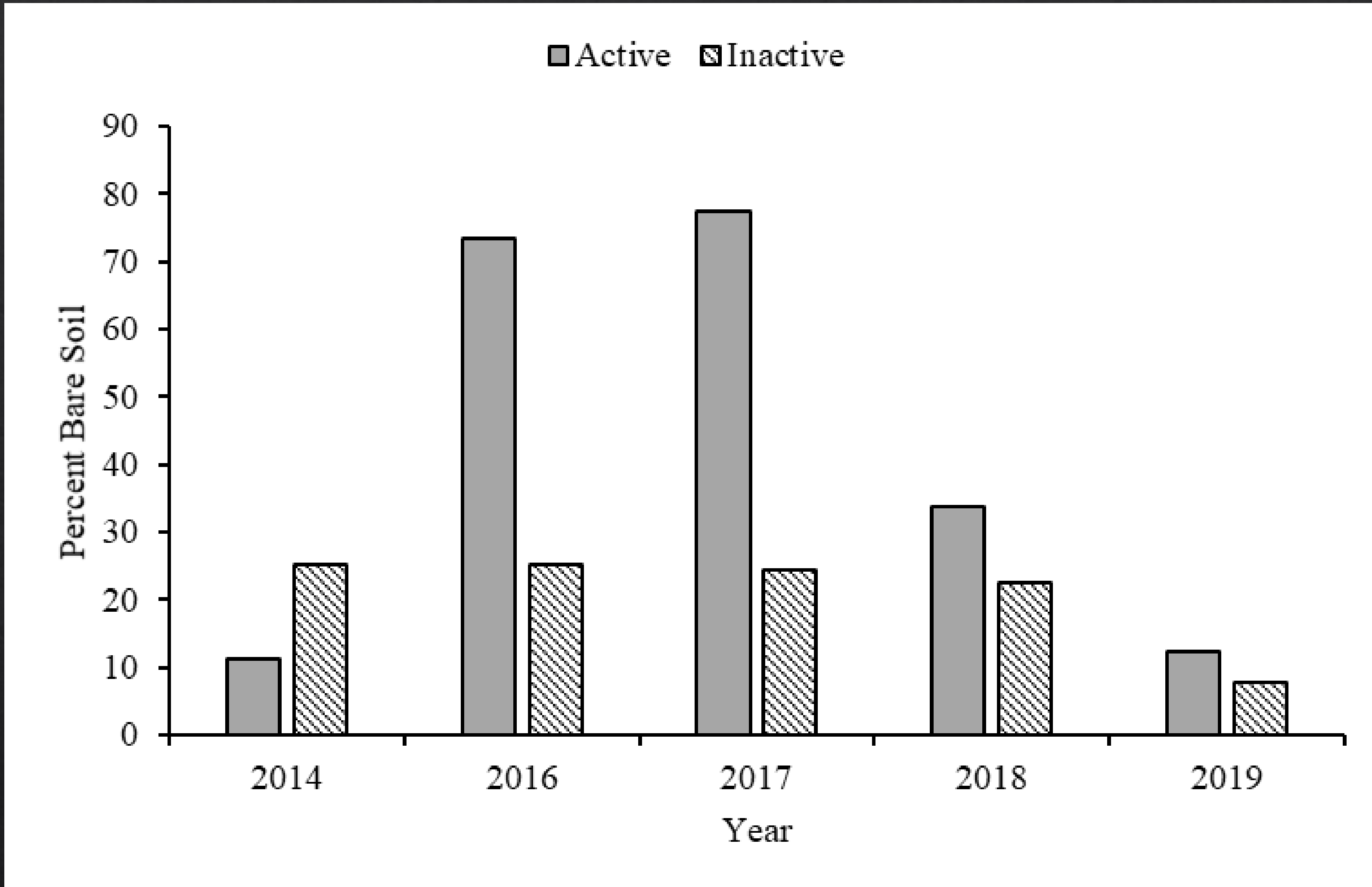


Box plot (a) shows the differences in plume lengths below drainages on road segments with rilling absent (left) and present ($\alpha < 0.01$; n=215).

Plume length



Differences in total rill and plume length on native (left) vs. rocked road surfaces ($\alpha < 0.01$; n=1273).



Percent bare soil on active and inactive road segments for years 2014-2019.

Road Sediment Production

- Measured sediment production rates for active and inactive roads were 0.0 kg m^2 yr^{-1} to 4.8 kg m^2 yr^{-1} (0.0 t ac^{-1} yr^{-1} to 21.4 t ac^{-1} yr^{-1}).
- 1 -2 percent of active road lengths and 4-9 percent of inactive road lengths were observed to be connected to watercourses between WY 2017 and 2019
- Thus we can estimate 5 Mg (5.5 t) and 9 Mg (9.9 t) of sediment delivered from roads to the East and West Branch Railroad Gulch, respectively.

Road Crossing Properties and Turbidity Observations

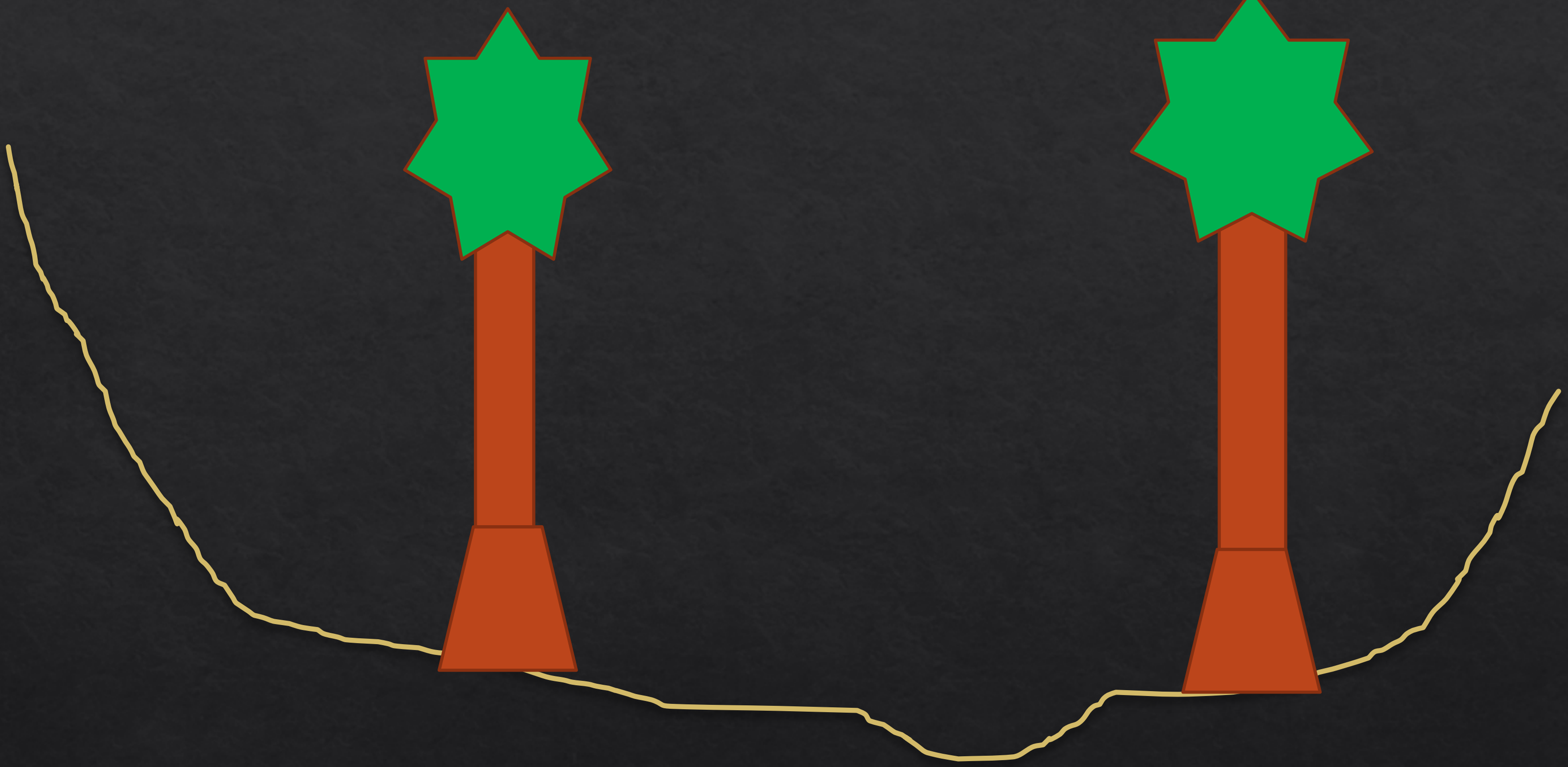
West Branch

Site #	Road Type	Location	Properties	Results
1-5	Spur	Lower West Branch, west slope	Untreated crossings.	Low turbidities, little effect of road. Site #5 had strong influence of road on turbidity.
6,7	Spur	West Branch, east slope	Untreated crossings.	Strong and consistent influence of road on turbidity.
8	Spur	Upper West Branch, east slope	Crossing overtaken by #1504 streamside bank failure.	Bank failure raised turbidity in stream.
21 (8)	Spur	Upper West Branch, east slope	New site created to evaluate road-related turbidity after #1504 event.	Road runoff much less turbid than impact of bank failure.
9,10,12,13	Spur	Upper West Branch, east slope	Partially treated crossings – surface fill removed, wood left in place.	#13 often high.
11	Spur	Upper West Branch, east slope	Crossing overtaken by #1501 debris flow.	High turbidities observed from debris flow, declined over time.

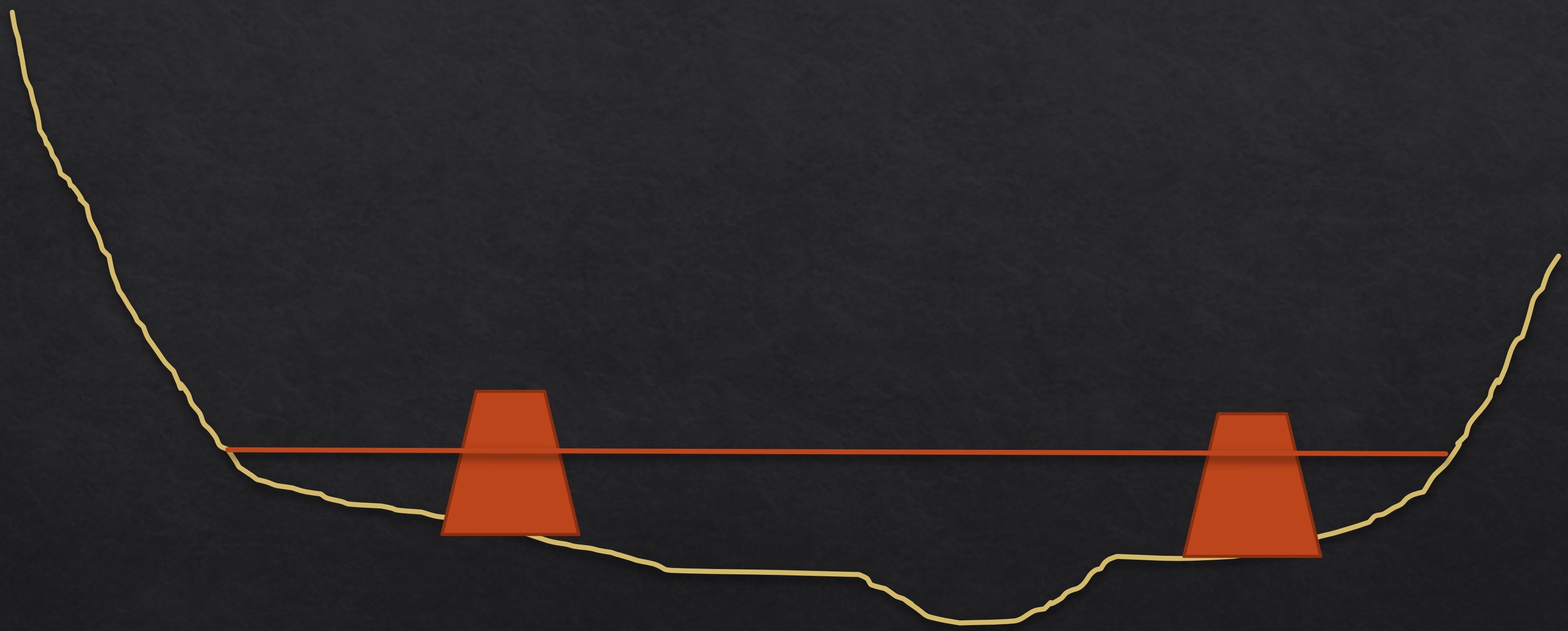
East Branch

Site #	Road Type	Location	Properties	Results
14-16	Spur	Lower East Branch, east slope	Untreated crossings.	Little to no effect of road.
17	Spur	East Branch, west slope	Partially treated crossing, – surface fill removed, wood left in place. Summer 2015.	Reduction in turbidity-elevating events after treatment. However road-related turbidity elevation, observed after WY 2016 hauling.
18	Haul	East Branch, west slope	Culvert, rocks placed to armor spillway. Summer 2015.	Often dry. Road-related turbidity elevation, particularly after WY 2016 hauling.
19	Haul	East Branch, west slope	Inboard ditch cross-drain. Graded and rocked summer 2015.	Reduction in turbidity-elevating events after treatment. However slight road-related turbidity elevation, observed after WY 2016 hauling.
20	Haul	Upper East Branch, west slope	Rocked ford. Graded and rocked summer 2015.	Only one sample date showed turbidity elevation below road crossing
22	Haul	Upper East Branch, east slope	Rocked ford. Graded and rocked summer 2015.	Often dry. Road-related turbidity elevation, particularly after WY 2016 hauling.

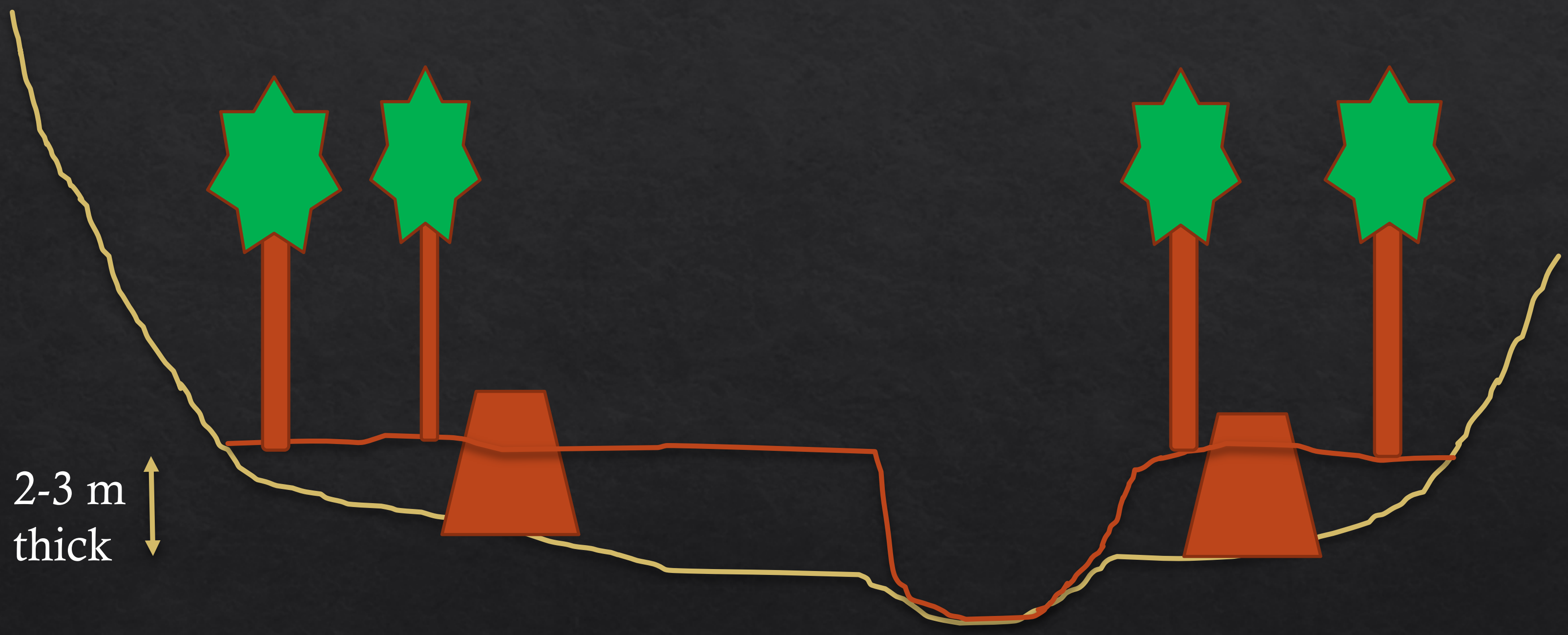
Cross Sections Historical Perspective



Cross Sections Historical Perspective



Cross Sections Historical Perspective



Cross Sections at Headwaters above all harvest units

		Cross section width (m)		Cross section area (m^2)		Area change from Previous* (m^2)		Result compared to previous	
	Year	East	West	East	West	East	West	East	West
Head-water (4 XS)	2014	3.69	2.7	1.14	1.05				
	2015	3.74	2.86	1.17	1.17	0.03	0.12	Scour	Scour
	2016	3.63	2.73	1.25	1.21	0.08	0.04	Scour	Scour
	2017	3.58	2.79	1.22	1.37	-0.03	0.16	Fill	Scour
	2018	3.59	2.92	1.26	1.58	0.05	0.21	Scour	Scour
	2019	3.58	3.60	1.26	1.97	0.00	0.40	-	Scour

Cross Sections Mid

		Cross section width (m)		Cross section area (m^2)		Area change from Previous* (m^2)		Result compared to previous	
	Year	East	West	East	West	East	West	East	West
Mid (4 XS)	2014	5.9	7.41	2.54	4.07				
	2015	6.15	7.72	2.87	4.17	0.33	0.1	Scour	Scour
	2016	5.86	7.61	2.94	4.11	0.07	-0.06	Scour	Fill
	2017	5.79	7.69	3.15	4.11	0.2	0	Scour	NC
	2018	6.25	7.83	3.25	4.11	0.1	0	Scour	NC
	2019	6.28	7.80	3.39	3.95	0.1	-0.17	Scour	Fill

Cross Sections at Mouth

Cross Section Survey Results, Width and area are averages of cross sections in the mouth (#1-5), middle (#6-9) and headwater (#10-13) reaches

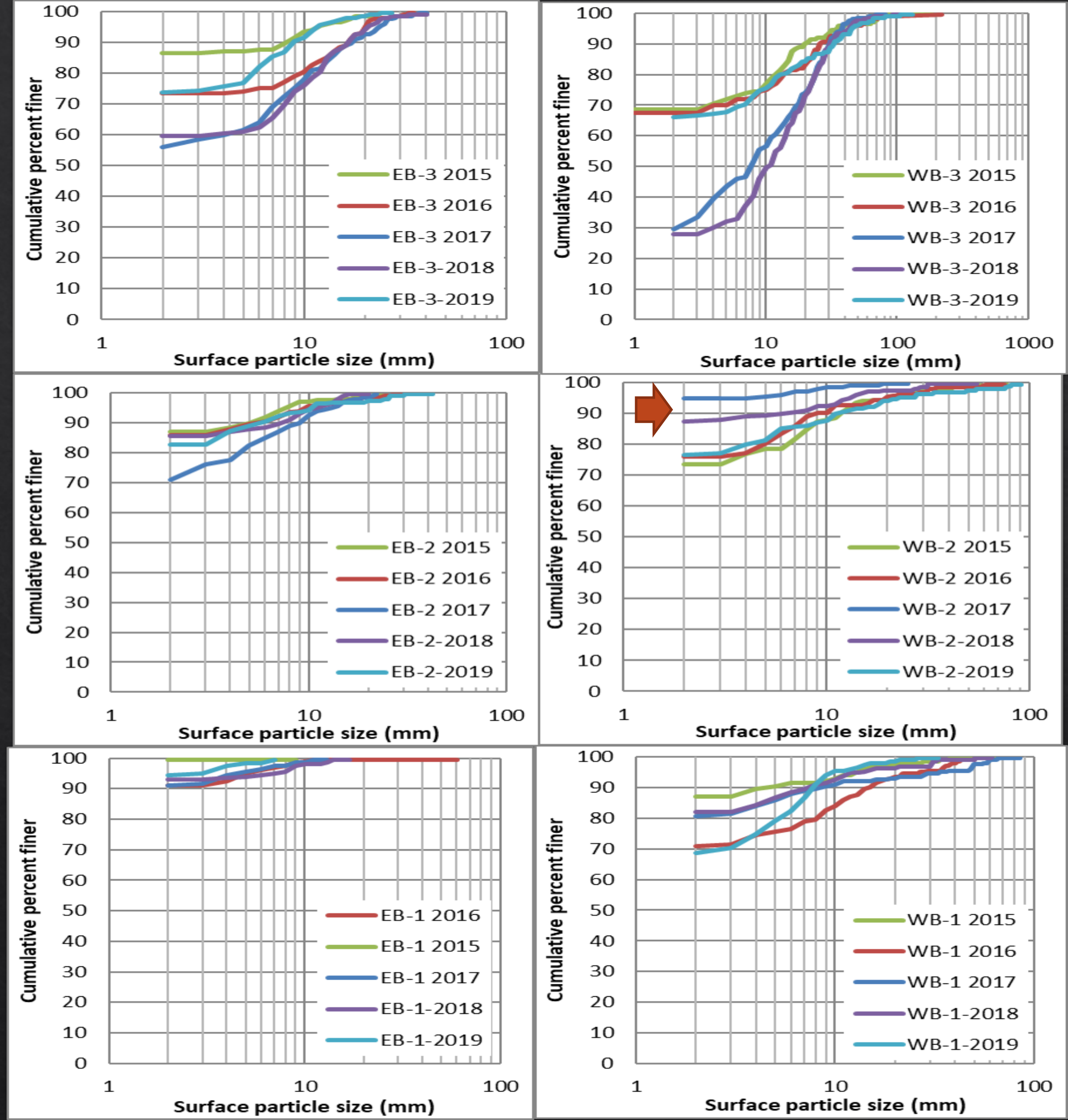
		Cross section width (m)		Cross section area (m^2)		Area change from Previous* (m^2)		Result compared to previous	
	Year	East	West	East	West	East	West	East	West
Mouth (5 XS)	2014	3.54	6.17	2.02	4.98				
	2015	3.63	6.05	2.14	5.01	0.12	0.03	Scour	Scour
	2016	3.67	6.04	2.27	5.11	0.13	0.1	Scour	Scour
	2017	3.69	5.89	2.32	5.03	0.05	-0.08	Scour	Fill
	2018	3.77	5.87	2.30	5.09	-0.02	0.06	Fill	Scour
	2019	3.73	6.26	2.25	5.18	-0.05	0.09	Fill	Scour

Cross Section Sediment Yield

- Cross-section data used to estimate sediment load from scour and channel bank erosion
- Scour and fill volumes averaged over three reaches, and the total Class I channel length of 1600 m was divided into thirds
- The mean area of scour or fill for each reach was multiplied by this length to obtain a volume, and this was converted to a mass using the same density value of 1.53 Mg/m^3. Masses were then summed
- 287 Mg of scour in WY 2016 and 254 Mg of scour in WY 2017. This was 11% and 10% of the total load for those years respectively

headwater

Bed Material



mouth

Rate of retreat of channel initiation points at the head of watercourses

- No changes, channels were stable throughout study period

Conclusions

Conclusions-Sediment Load

- Wide range of precipitation complicates interpretation
- Peak flows did not show consistent post-harvest increase
- Harvest branch showed sediment yield increases relative to control for two years after roading, harvest and hauling
- A portion of the increase may be due to greater drainage density in harvested basin – greater hydrologic response to wet years
- A major landslide dominated the sediment budget for control watershed in 2018 and 2019. Recovered quickly – low sediment loads in dry 2020.

Conclusions – Current and Long Term Erosion Rates

- Be-10 derived erosion rates, indicative of erosion rates over millennial time scales, are similar to present day rates
- Average rainfall years had erosion rates that were very similar to the long term average erosion rate
- Wetter years and landsliding elevated erosion rates above long term rates, while drier years were much lower

Conclusions - Landslides

- Landslides did not occur in or adjacent to harvest areas
- Small streamside landsliding increased with rainier years and higher peak flows
  - While streamside landsliding increased in the harvest unit in 2018 and 2019, this was only observed at single locations, with very little erosion overall
- Tributaries did not appear to affect turbidity in the main stem
  - Exceptions included tributaries draining the WB landslide, a tributary incising into an earth flow, and a tributary intersecting an old spur road

Conclusions - Roads

- Rills on roads, plume deposition on roads, and plume deposition below road drainage features all increased after the rainy 2016 and 2017.
- Plumes and rills on roads exceeded 10 m in length when percent bare soil >16%, road area > 82 m^2 and road slope > 8%
- If rilling was present on road surface, plume lengths were greater
- Native surface roads had consistently higher rill and plume lengths compared to rocked roads
- Rapid natural revegetation of road surfaces observed
- Road-related sediment delivery is very low – as estimated from observations of road connectivity and sediment fence data

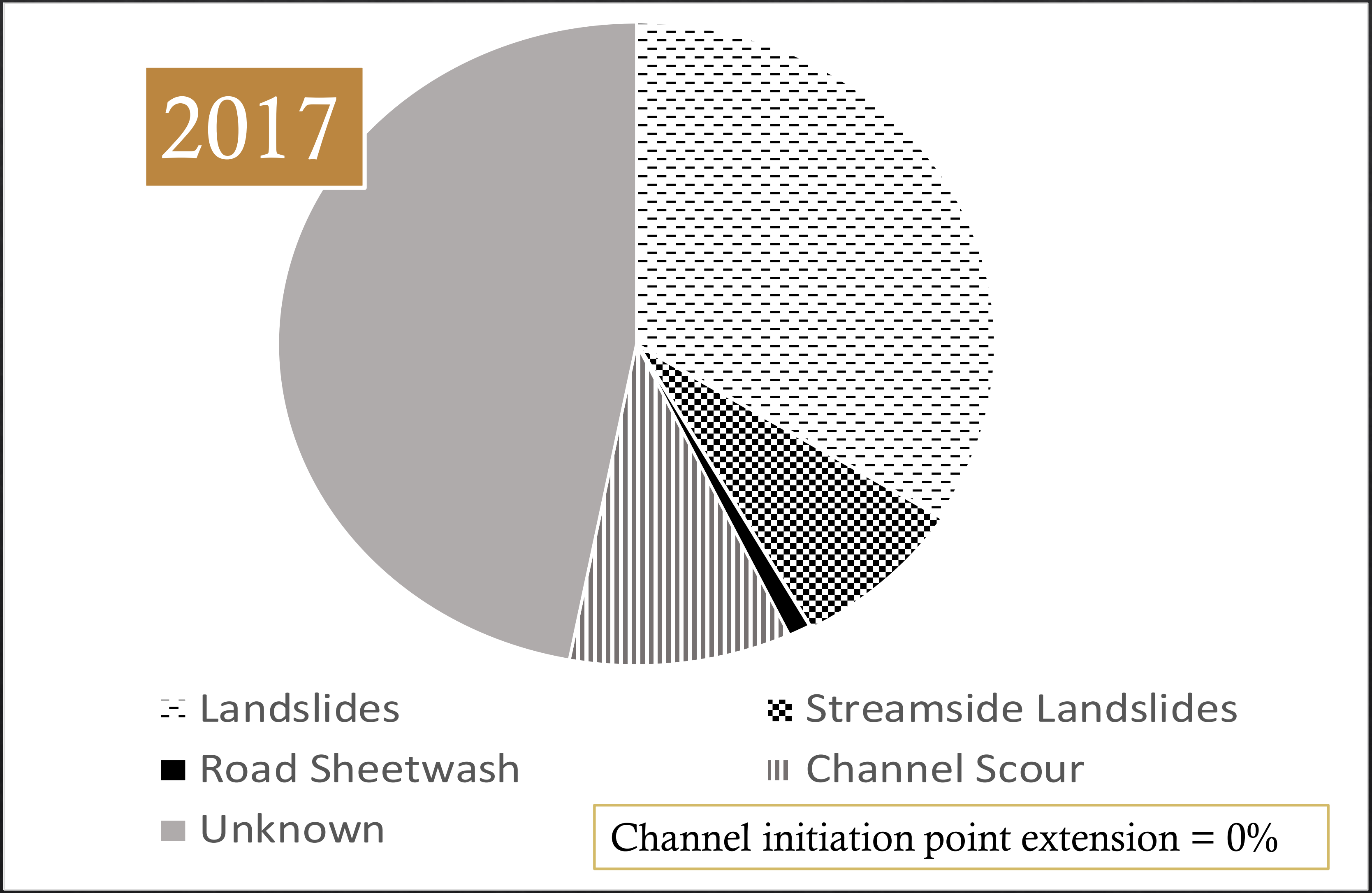
Conclusions – Road Crossings

- Influence of roads on turbidity was variable
- Road-related turbidity increases in tributary streams were observed, particularly during biggest rain events/ wettest time of year
- Some untreated crossings showed road-related turbidity increases
- In several cases turbidity improved after crossings partially removed or upgraded

Conclusions –Cross Sections and Bed Material

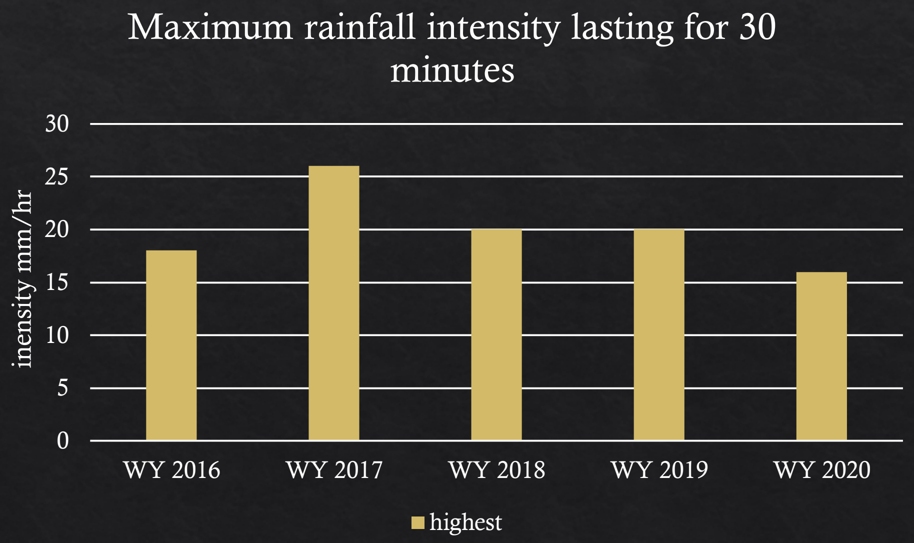
- General trend of bed scour, may reflect long-term adjustment to massive floodplain sedimentation after harvest of old-growth forest in 1900s
- Scour and coarsening are associated, as are the converse, fill and fining trends
- Greatest scour in wettest years, some fill in drier years
- Fill trend evident after WB landslide
- Changes to stream size and bed material from harvest not evident
- No changes to headwater channel initiation points observed over study

Annual Sediment Budgets (in progress)



Remaining Steps

- Sediment budget for each year
- Compare rainfall intensity and storm sediment yields
- Graphic showing spatial relationship of sediment sources
- Final edits



Questions?