Humboldt Redwood™

Freshwater Creek

Watershed Analysis Revisited

September 27, 2018

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Project Description

Title: Freshwater Creek Watershed Analysis Revisited

Purpose: Aquatic Habitat Conservation Plan Trends and Effectiveness Monitoring Report

Executive Summary:

Watershed analysis was conducted for the Freshwater Creek Watershed Analysis Unit (WAU) as required by the Pacific Lumber Company (PALCO) Habitat Conservation Plan (HCP) (PALCO 1999) on lands now owned and managed by the Humboldt Redwood Company (HRC). The original Freshwater Creek Watershed Analysis was completed in 2003. The HCP Watershed Analysis program is designed to analyze and monitor watershed conditions, assess effects of historic and contemporary forest management, and identify management prescriptions necessary to maintain, or achieve, over time, properly functioning aquatic habitat conditions for federal and state listed or sensitive salmonids, amphibians, and reptiles that are the HCP Covered Species. These species include the steelhead trout (*Oncorhynchus mykiss*), Chinook salmon (*Oncorhynchus tshawytscha*), coho salmon (*Oncorhynchus kisutch*), coastal cutthroat trout (*O. clarki clarki*), northern red-legged frog (*Rana aurora*), foothill yellow-legged frog (*Rana boylii*), tailed frog (*Ascaphus truei*), southern torrent salamander (*Rhyacotriton variegatus*), and the northwestern pond turtle (*Emys marmorata marmorata*). This Freshwater Creek Watershed Analysis Re-Visitation is a comparison of results and changes since the original watershed analysis report was completed.

The Freshwater Creek watershed is a 31-mi^2 drainage basin located approximately 5 miles east of Eureka, California in Humboldt County (Map 1). The watershed drains into Humboldt Bay through the Freshwater and Eureka Sloughs at the north end of Eureka. Major tributaries of Freshwater Creek include Cloney Gulch, South Fork Freshwater Creek, Little Freshwater Creek, McCready Gulch, and Graham Gulch (Map 2). Approximately 24 mi^2 (15,400 acres), or 77% of the designated WAU, is owned and managed for timber production by HRC (Table 2-1). Other ownerships in the WAU are comprised of mostly private residences and smaller working ranches and farmland.

The watershed is underlain by a series of bedrock types and sedimentary deposits from the Jurassic to Holocene periods including undifferentiated Wildcat formation, Central belt bedrock, and Yager terrane. Twenty-seven miles of Class I streams flow through HRC property providing habitat for all HCP covered fish species. Productive soils and Mediterranean climate support a coniferous lowland forest community comprised of coastal redwood (*Sequoia sempervirens*), western hemlock (*Tsuga herophylla*), Sitka spruce (*Picea sitchensis*), grand fir (*Abies grandis*) and Douglas-fir (*Pseudotsuga menziensii*). While conifers are the prevalent tree type, hardwoods including primarily red alder (*Alnus rubra*), tanoak (*Notholithocarpus densiflorus* var. *densiflorus*) (in drier sites), willow (*Salix spp.*), big-leaf maple (*Acer macrophyllum*), California bay laurel (*Umbellularia californica*) and wax myrtle (*Morella californica*) are also found in the watershed.

The Mediterranean climate of the Freshwater Creek basin is evident in mild, wet winters with varying rainfall and storm intensities. Precipitation totals are tracked at the National Oceanic and Atmospheric Administration (NOAA), National Weather Service (NWS) station on Woodley Island in Eureka, California (rain gage EKA01), located approximately 9 miles west of the Freshwater Creek watershed. Mean annual precipitation has been approximately 39 inches during the 1888 - 2015 128-year period of record (Figure 2-4) with roughly 90% of the annual precipitation falling as rain during the months of October through May[1]. Rainfall from WY2001 through 2015 ranged from the fourth highest annual rainfall of record (59 inches in WY 2006) to the sixth lowest rainfall of record (21 inches in WY 2014) and included the largest ever recorded maximum daily rainfall of 6.8 inches in December of WY 2003. Both WY 2003 and WY 2006 seasons ended with a prolonged and sometimes intense series of storms that occurred late in the season when hillslopes were already saturated. The average annual rainfall over the last 15 years (38.4 inches) is consistent with the 128 year long term average (39 inches).

Average annual harvest rates in the Freshwater Creek WAU (2001-2015) have dropped nearly in half since the 1990s going from 3% to 1.7% of total watershed area. Individual sub-basins have correspondingly experienced drops in average annual harvest rates compared to the 1990s with the only exception being the second largest sub-basin (6,436 acres), Upper Mainstem Freshwater Creek, where harvest rates have increased 26% (going from 134 acres per year to 169 acres per year). A significant change in the predominant silviculture applied during timber harvest occurred in 2008 with the transfer of ownership from PALCO to HRC when uneven-age selection management replaced even-age, typically clearcut, regeneration methods. Selection silviculture is believed to be beneficial to slope stability due to retention of mature forest canopy cover and root strength. Approximately 26% of the Riparian

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[1] California Date Exchange Center (http://cdec.water.ca.gov/cgi-progs/queryWY?staid=ERK&sensor_num=2&wy=2015&span=128)

Management Zone (RMZ) within Class I and Class II streams in Freshwater was harvested using low intensity single tree selection methods from 2001 – 2015, or approximately 2% of the total riparian area per year.

The watershed analysis compares an estimate of sediment delivery to streams from forest management land use (i.e. road and harvest unit landslide and surface erosion) to *background* delivery (i.e. landslides, bank erosion, and soil creep). Forest management land use is further broken down into two time periods: *pre-HCP* consisting of difficult to control ongoing chronic erosion sources originating from pre-1999 timber operations, and contemporary *post HCP* activities including harvest and road system management. *Background* Streamside landslides and bank erosion combined with soil creep account for an estimated 56 percent (262 tons/mi^2/yr) of total average annual delivery (2001-2011). Impacted stream channels from historic logging practices, and roads constructed prior to HCP standards and not yet decommissioned or upgraded to the HCP storm-proofed standard, represent the greatest sediment contributors from the *pre-HCP* category delivering a combined estimated 23 percent (110 tons/mi^2/yr). The contemporary road system is the most significant sediment contributor of the *post HCP* category with road-related landslides, washouts, and surface erosion combining to produce approximately 10 percent (50 tons/mi^2/yr) of the total annual sediment source budget. Current Mass Wasting prescriptions including site-specific licensed geologic review appear effective in avoiding timber harvest related landsliding.

Roads remain an important source of management-related sediment delivery. Ongoing sediment reduction efforts to address these sources include continual road system improvement and limitations on construction and re-construction on unstable areas and near streams. Road density (miles of road per square mile of watershed, HRC lands) has not changed significantly since 2003. New road construction has been mitigated with road decommissioning and closure resulting in a net reduction in total road miles of 1% from 2003 to 2015. As of 2015, a total of 146 miles (88%) of the 166-mile Freshwater Creek WAU road system (on HCP covered lands) has been upgraded to the HCP storm-proofed standard. A total of 30 miles of streamside and mid-slope road in the watershed have been treated for erosion control and decommissioned since 1999. Roads remain a primary point of focus for the control of anthropogenic sediment sources.

HRC maintains seven Aquatic Trends Monitoring (ATM) stations in Freshwater that have been monitored since 2003 (one site since 2005) to assess long-term conditions impacting streams. Parameters monitored include in-stream large woody debris, substrate size, pool dimensions, water temperature and stream canopy cover. An increase in both riparian and overstream canopy cover was reported for five of the seven stations (2003-2014). A decrease in overstream canopy cover was observed at the South Fork

Freshwater Station as was a decrease in riparian canopy cover at the Graham Gulch station. Stream temperature monitoring found that all seven ATM stations met the cold water in-stream temperature targets when averaged over the 12-year monitoring period (2003-2014). In-stream large woody debris (LWD) surveys suggest lower, larger drainage area stream reaches in Little Freshwater Creek and the Freshwater mainstem remain large wood deficient, while pool-forming 'key piece' large wood count is at or near target in major Class I tributaries including the South Fork, McCready Gulch, Cloney Gulch, and Graham Gulch. Riparian prescriptions appear to be effective in providing for maintenance of cold-water temperatures throughout the watershed, and in recruitment of large wood to streams except in the largest channels where further instream wood projects could benefit fish habitat in the near term.

Sediment yield, turbidity, and peak flow gaging stations were installed over a three-year period beginning in WY 2003. Since WY 2003, chronic turbidity, sediment yield, and peak flow have been generally consistent temporally but spatially variable across sub-basins in the Freshwater Creek watershed, a phenomenon commonly observed in drainages throughout the North Coast. Water quality parameters appear to be either favorable or trending towards more favorable conditions in Upper Freshwater Creek, Cloney Gulch, and McCready Gulch. Sediment yields have remained generally static in the South Fork and Little Freshwater Creek sub-basins despite recent increases in chronic turbidity in both drainages. The Beck's tributary continues to deliver a variable, yet moderate amount of sediment into the upper mainstem, as does Graham Gulch which, per unit area, produces the highest sediment yields on HRC lands in the watershed. A sediment source also appears to be present in the mainstem reach between HTM stations 526 and 502.

Data to assess channel geomorphology in low gradient (1-4%) depositional ('response') reaches are derived primarily from cross-section surveys conducted at the seven ATM reaches since 2003. Results of these surveys indicate relatively stable channel conditions. ATM survey data are limited by uneven monitoring records and the lack of repeatable measurements across sites. Cross-section locations changed sporadically throughout the monitoring period in many sub-basins, which hampered a thorough assessment of trends.

Freshwater Creek contains small populations of coho salmon (*O. kisutch*), and steelhead trout (*O. mykiss*). Adult coho escapement estimates have ranged from nearly 2000 adults returning from the sea in 2002 to less than 100 in 2009 with the most recent available data for 2015 estimating 450 adults. Chinook salmon (*Oncorhynchus tshawytscha*) are less common but also found in the watershed, as are Coastal cutthroat trout (*O. clarkii clarkii*). Population estimates for Chinook, coho, and steelhead have been monitored by the California Department of Fish and Wildlife (CDFW) since the year 2000 using life cycle monitoring techniques including weir counts, spawner surveys, and outmigrant trapping.

HCP covered amphibian and reptile species include the southern torrent salamander (*Rhyacotriton variegatus*); tailed frog (*Ascaphus truei*); northern red-legged frog (*Rana aurora aurora*); foothill yellow-legged frog (*Rana boylii*); and northwestern pond turtle (*Emys marmorata marmorata*). All HCP covered species, except northwestern pond turtles, continue to be encountered in the Freshwater Creek WAU either in surveys conducted for this WA revisit, or incidental to other surveys and monitoring. Given the location of the Freshwater Creek WAU within the fog belt, and closer to the coast than more southern and inland WAUs on HRC lands, habitat conditions favor cold water species such as the tailed frog and southern torrent salamander.

Reviewed:

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10%TU	10% exceedance probability or 10% turbidity exceedance (turbidity level that was exceeded 10% of the time)
ACP	Aquatic Conservation Plan
APFC	Aquatic Properly Functioning Condition
ARIP	Annual Road Inspection Program
ASTR	*Ascaphus truei* (tailed frog)
ATM	Aquatic Trends Monitoring
bis	break in slope
BMPEP	Best Management Practice Evaluation Program
C	Celsius
CDEC	California Data Exchange Center
CAL FIRE	California Department of Forestry and Fire Protection
cc	clearcut
CDFW	California Department of Fish and Wildlife
CESA	California Endangered Species Act
C/F	cascade/falls
CFPR	California Forest Practice Rules
CGS	California Geological Survey
CGU	Channel Geomorphic Unit
cms	cubic meter per second
CW	channel width
DEM	Digital Elevation Model
DITE	*Dicamptodon tenebrosus* (coastal giant salamander)
ELAP	Environmental Laboratory Accreditation Program
EMMA	*Emys marmorata marmorata* (northwestern pond turtle)
FPR	Forest Practice Rules
ft	feet or foot
GIS	Geographic Information System
HCP	Habitat Conservation Plan
HFAC	Humboldt Fish Action Council
HGR	high gradient riffle
HRC	Humboldt Redwood Company, LLC
HTM	Hydrologic Trends Monitoring
hw	headwall
HYRE	*Hyla regilla* (Pacific treefrog)
km	kilometer
KP	key piece
LCS	Life Cycle Monitoring Station
LGR	low gradient riffle
LMS	Lower Mainstem
LS	landslide
LWD	Large Woody Debris
mi	mile
mm	millimeter
mpc	mechanical partial cut
Mw	Magnitude (seismic moment)
MWAT	maximum weekly average temperature
MWP	Mass Wasting Potential

NCRWQCB	North Coast Regional Water Quality Control Board
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NTU	Nephelometric Turbidity Unit
NWS	National Weather Service
OMT	out-migrant trapping
P	pool
PAD	Passage Assessment Database
PALCO	The Pacific Lumber Company
PFC	Properly Functioning Condition
PIT	Passive Integrated Transponder
PVC	polyvinyl chloride
PWA	Pacific Watershed Associates
QAPP	Quality Assurance Project Plan
QA/QC	Quality Assurance/Quality Control
RAAU	*Rana aurora aurora* (northern red-legged frog)
RABO	*Rana boylii* (foothill yellow-legged frog)
RHVA	*Rhyacotriton variegatus* (southern torrent salamander)
RI	Return Interval
RMZ	Riparian Management Zone
RPF	Registered Professional Forester
rrf	road-related fill
rx	road crossing
SGS	spawning ground surveys
SP	step pool
ss	streamside slope
SSC	suspended sediment content
st	stream channel
sw	swale channel
THP	Timber Harvesting Plan
TMDL	Total Maximum Daily Load
tons/mi^2/year	tons per square mile per year
USDA	U.S. Department of Agriculture
USFWS	U.S. Fish and Wildlife Service
UTC	Coordinated Universal Time
WA	Watershed Analysis
WAU	Watershed Analysis Unit
WDNR	Washington Department of Natural Resources
WEPP	Water Erosion Prediction Project
WWDR	Watershed-Wide Waste Discharge Requirements
WY	water year
yd^2	square yards
yd^3	cubic yards
yr	year

1 INTRODUCTION

The goal of Humboldt Redwood Company's (HRC's) Aquatic Conservation Plan (ACP, HCP §6.3), developed in agreement with federal and state resource agencies, is to maintain or achieve, over time, a properly functioning aquatic habitat condition in streams and rivers affected by the landowner's forest management activities. The purpose of the Habitat Conservation Plan (HCP) watershed analysis (WA) process is to promote local understanding of linkage between aquatic habitat conditions and processes and forest management activities in order to establish best management practices for protecting, restoring, and enhancing the aquatic habitat of specified salmonids, amphibians, and reptiles. These species include Northern California steelhead (*Oncorhynchus mykiss*), Chinook salmon (*Oncorhynchus tshawytscha*), Coho salmon (*Oncorhynchus kisutch*), northern red-legged frog (*Rana aurora aurora*), foothill yellow-legged frog (*Rana boylii*), tailed frog (*Ascaphus truei*), southern torrent salamander (*Rhyacotriton variegatus*), and the northwestern pond turtle (*Emys marmorata marmorata*).

Watershed Analysis was initially completed for the Freshwater Creek Watershed Analysis Unit (WAU) in 2003. Following synthesis of baseline information gathered during this initial assessment and critical review by all parties which included California Department of Fish and Wildlife (CDFW), National Marine Fisheries Service (NMFS), U.S. Fish and Wildlife Service (USFWS), California Geological Survey (CGS), California Department of Forestry and Fire Protection (CAL FIRE), North Coast Regional Water Quality Control Board (NCRWQCB), and the public, watershed-specific HCP prescription modifications were developed and established. The HCP requires periodic review of trends and effectiveness monitoring studies, along with any relevant new science, for each of the eight WAUs. Conditions and processes related to mass wasting, surface erosion, riparian function, and stream channel/aquatic habitat are examined independently, and collectively, from both management and biological perspectives. The findings of this periodic, focused revisitation may result in the change of forestry prescriptions and/or monitoring protocols through an adaptive management process subject to review, and establishment, by the signatory HCP wildlife agencies.

The initial round of WA has been completed on all eight HCP WAUs, as follows: Van Duzen (2002), Freshwater (2003), Lower Eel/Eel Delta (2004), Elk River/Salmon Creek (2005), Upper Eel/Larabee (2007), Bear River (2008), Yager/Lawrence Creek (2009), and Mattole River (2012). Revisitation of the Elk River/Salmon Creek WAU was recently completed (2014).

2 WATERSHED CHARACTERISTICS

The Freshwater Creek watershed is a 31-mi^2 drainage basin located approximately 5 miles east of Eureka, California in Humboldt County (Map 1). The watershed drains into Humboldt Bay through the Freshwater and Eureka Sloughs at the north end of Eureka. Major tributaries of Freshwater Creek include Cloney Gulch, South Fork Freshwater Creek, Little Freshwater Creek, McCready Gulch, and Graham Gulch (Map 2). Approximately 24 mi^2 (15,400 acres), or 77% of the designated WAU, is owned and managed for timber production by HRC (Table 2-1). Other ownerships in the WAU are comprised of mostly private residences and smaller working ranches and farmland. Several private larger ranches occupy the eastern perimeter of the watershed in the Greenwood Heights and Kneeland areas. Major land uses in the watershed are forestry (91% of the watershed area), agricultural/ residential (8%), and power line right-of-way (1%).

Table 2-1. Freshwater Creek WAU area by ownership (2012 HRC GIS)

Sub-basin Name	Sub-basin Area (acres)	Area of HRC HCP Ownership (acres)	Non-HRC Ownership (Acres)	Percent of HRC HCP Ownership
Upper Mainstem Freshwater	6,435.6	4,410.9	2,024.7	68.5%
South Fork Freshwater	2,025.9	2,022.0	3.9	99.8%
Graham Gulch	1,596.1	1,419.5	176.6	88.9%
Cloney Gulch	2,992.1	2,624.5	367.7	87.7%
Little Freshwater	2,971.2	2,963.5	7.7	99.7%
McCready Gulch	1,304.9	1,092.7	212.2	83.7%
Lower Mainstem Freshwater	2,015.4	454.8	1,560.6	22.6%
School Forest	372.5	316.6	55.9	85.0%
Fay Slough	7,934.6	27.0	7,907.7	0.3%
Freshwater Watershed Total	***27,648.4***	***15,331.5***	***12,316.9***	**55.5%**

2.1 GEOLOGY, SEISMIC REGIME, AND TOPOGRAPHY

Maps produced by the CGS indicate that the Freshwater Creek watershed is underlain by a series of bedrock types and sedimentary deposits (Kelley 1984, Kilbourne 1985a and 1985b, Kelsey and Allwardt 1987, Falls 1999). These deposits range from Jurassic to Holocene in age with a similar variety in physical properties and weathering traits. The lithologies as differentiated by Falls (1999) are as follows:

- Jurassic age Central belt (KJfs, KJfm);
- Late Cretaceous to Pliocene age Coastal belt (specifically Yager terrane) (Ty);

- Miocene-Pliocene age undifferentiated Wildcat Group formation (Twl, Twu);
- Quaternary age river terrace deposits (Qrt); and
- Quaternary age alluvium (Q).

Approximately 40% of the basin is underlain by Central belt bedrock, 4% by Yager terrane, 55% undifferentiated Wildcat formation sediments, and less than 1% Quaternary aged surficial deposits. A detailed summary of these lithologic units is provided in Appendix A "Mass Wasting Assessment" in the initial Freshwater WAU (The Pacific Lumber Company [PALCO] 2003).

The geologic map produced by Falls (1999) was used as the base map for this assessment. The data source for geologic information provided in the initial analysis was based on the compilation of four CGS maps (Kelley 1984, Kilbourne 1985a and 1985b, and Kelsey and Allwardt 1987). The Falls (1999) geologic map was not available in digital format at the time Freshwater WAU Mass Wasting assessment was produced; consequently, there is some variation in acreage values between this and the initial Freshwater Creek WA.

Figure 2-1 and Table 2-2 show the distribution of lithologies within the HRC HCP covered lands within the Freshwater WAU; Figure 2-2 and Table 2-3 present slope class information for the HRC HCP covered lands; and Map 3 shows the spatial distribution of slope classifications.

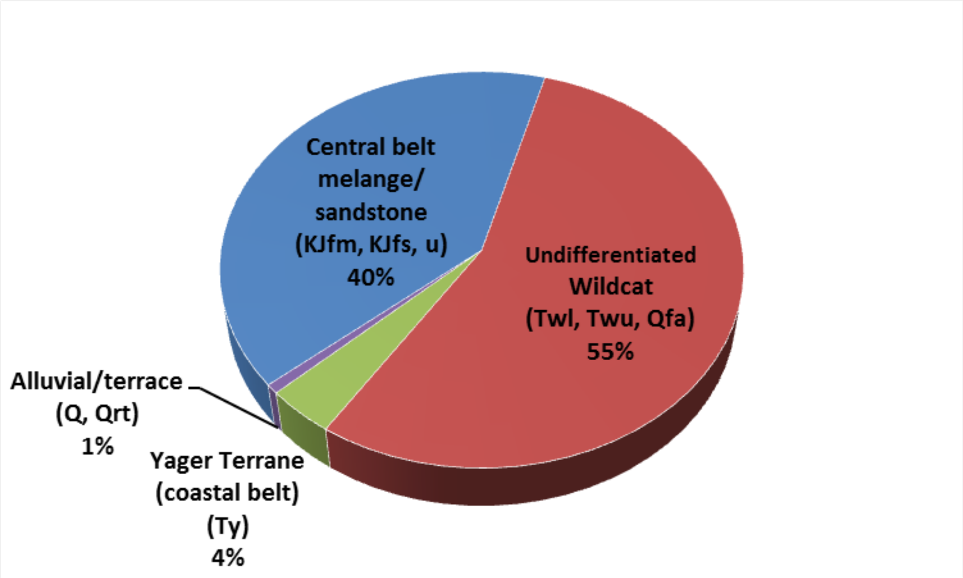

Figure 2-1. Lithologic units as percent of HRC Freshwater HCP area (2012 HRC GIS, from Falls 1999)

Table 2-2. Distribution of lithologic units on HRC HCP covered lands within the Freshwater WAU (based on Falls 1999)

	Undifferentiated Wildcat (Twl,Twu,Qfa)		**Central belt melange/sandstone (Kjfs,Kjfm,u)**		**Yager Terrane (coastal belt) (Ty)**		**Alluvial/terrace (Q,Qrt)**	
Sub-basin Name	**Area (Acres)**	**% of WAU Area**	**Area (Acres)**	**% of WAU Area**	**Area (Acres)**	**% of WAU Area**	**Area (Acres)**	**% of WAU Area**
Upper Mainstem Freshwater	1,396	31.7%	2,861	64.9%	80	1.8%	74	1.7%
South Fork Freshwater	1,070	52.9%	597	29.5%	344	17.0%	11	0.6%
Graham Gulch	524	36.9%	832	58.6%	62	4.4%	0	0%
Cloney Gulch	796	30.3%	1,812	69.1%	16	0.6%	0	0%
Little Freshwater	2,865	96.7%	0	0%	99	3.3%	0	0%
McCready Gulch	1,006	92.0%	87	8.0%	0	0%	0	0%
Lower Mainstem Freshwater	444	97.6%	0	0%	0	0%	11	2.4%
School Forest	298	94.1%	0	0%	0	0%	19	5.9%
Fay Slough	27	100.0%	0	0%	0	0%	0	0%
Freshwater Watershed Total	**8,425**	**55.0%**	**6,194**	**40.4%**	**597**	**3.9%**	**116**	**0.8%**

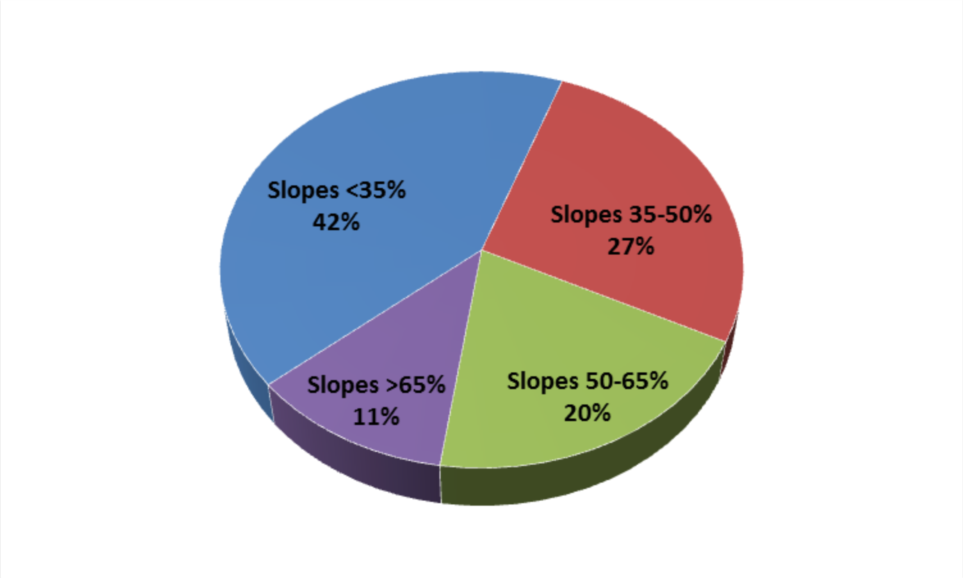

Figure 2-2. Topography as percent of HRC Freshwater HCP area (2012 HRC GIS)

Table 2-3. Slope class area by sub-watershed (HCP Covered Lands) (2012 HRC GIS)

Sub-basin Name	Total	Percent acres within Slope Class			
		0-35%	35-50%	50-65%	>65%
Upper Mainstem Freshwater	4411.0	47%	26%	16%	11%
South Fork Freshwater	2021.9	28%	28%	27%	16%
Graham Gulch	1419.7	47%	27%	16%	10%
Cloney Gulch	2624.5	57%	25%	12%	7%
Little Freshwater	2963.5	30%	28%	29%	13%
McCready Gulch	1092.7	35%	28%	22%	14%
Lower Mainstem Freshwater	455.0	45%	29%	17%	9%
School Forest	316.6	34%	28%	24%	15%
Fay Slough	27.0	16%	21%	38%	25%
Freshwater Watershed Total	***15331.7***	**42%**	**27%**	**20%**	**11%**

The principal structural feature in the Freshwater Creek watershed is the Freshwater fault. The Freshwater fault zone is composed of the Freshwater and Greenwood Heights faults (Knudsen 1993), which are inferred to be parallel northwest-trending, northeast-dipping, high angle thrust faults. These faults place undifferentiated Wildcat and Yager terrane (coastal belt) formation sediments into contact with Central belt bedrock. This series of faults is not considered active by the State of California under the provisions of the Alquist-Priolo Earthquake Fault Zoning Act.

The nearest on-land faults zoned by the State of California as active are the Little Salmon and Fickle Hill faults (Hart and Bryant 1997). These faults are subparallel, northwest trending thrust faults that are part of a broad, 25-kilometer (km) wide fold and thrust belt that accommodates onshore deformation associated with the Cascadia Subduction Zone. The Little Salmon fault is approximately 7 miles southwest of the watershed, and the Fickle Hill fault is approximately 3 miles north of the basin. For a more detailed discussion of regional seismicity, refer to Section 3.3 of the “Mass Wasting Assessment” appendix of the initial 2003 Freshwater Creek WA (PALCO 2003).

2.2 STREAM CLASS

Stream classes are described in the California Forest Practice Rules (CFPR) as Class I, II, III, or IV dependent upon watercourse characteristics and key indicator beneficial uses. CFPR Class I streams include stream reaches that supply domestic water (within 1,000 feet [ft]) and/or have fish that are always or seasonally present, and include habitat to sustain fish migration and spawning. CFPR Class II streams include streams that have fish always or seasonally present offsite within 1,000 ft downstream, and/or streams that support aquatic habitat for non-fish aquatic species. These streams typically flow year-round, or at minimum beyond the winter season. CFPR Class III streams include generally smaller watercourses that have no aquatic life present but show evidence of being capable of sediment transport to Class I or Class II streams. They are typically ephemeral in nature with flows limited to the winter period in response to extended rainfall. Class IV streams include man-made watercourses. Table 2-4 presents a summary of the Class I, II, and III channel lengths by sub-basin and Map 4 shows the spatial distribution of stream classes in the HCP area of the Freshwater Creek WAU.

Table 2-4. Stream class lengths on HRC HCP covered lands within the Freshwater WAU (2012 HRC GIS)

Sub-basin Name	Class I (miles)	Class II (miles)	Class III (miles)	Total (miles)
Upper Mainstem Freshwater	8.5	27.8	34.2	70.5
South Fork Freshwater	3.3	11.8	22.0	37.2
Graham Gulch	1.97	8.51	11.68	22.2
Cloney Gulch	3.38	13.64	18.70	35.7
Little Freshwater	6.17	17.27	33.54	57.0
McCready Gulch	2.45	6.49	9.08	18.0
Lower Mainstem Freshwater	0.11	1.20	4.15	5.5
School Forest	0.81	0.44	2.45	3.7
Fay Slough	0.00	0.02	0.22	0.2
Freshwater Watershed Total	***26.7***	***87.2***	***136.0***	***250.0***

2.3 FOREST TYPE

The Mediterranean climate supports a coniferous lowland forest community comprised of redwood (*Sequoia sempervirens*), western hemlock (*Tsuga herophylla*), Sitka spruce (*Picea sitchensis*), grand fir (*Abies grandis*) and Douglas-fir (*Pseudotsuga menziensii*). While conifers are the prevalent tree type, hardwoods including primarily red alder (*Alnus rubra*), tanoak (*Notholithocarpus densiflorus* var. *densiflorus*) (in drier sites), willow (*Salix spp.*), big-leaf maple (*Acer macrophyllum*), California bay laurel (*Umbellularia californica*) and wax myrtle (*Morella californica*) can be found in the watershed (see Table 2-5 and Figure 2-3).

Table 2-5. Forest type by sub-basin in the HRC HCP of the Freshwater Creek WAU (2012 HRC GIS)

	Vegetation Type (HCP Only) – Total Acres								
Sub-basin Name	**Redwood**	**Redwood/ Douglas-fir**	**Redwood/ Hardwood**	**Douglas-fir**	**Douglas-fir/ Redwood**	**Douglas-fir/ Hardwood**	**Conifer/ Hardwood**	**Hardwood**	**Non-timber**
Upper Mainstem Freshwater	1462.6	578.4	30.2	235.8	1790.0	5.6	40.4	213.4	54.5
South Fork Freshwater	739.3	680.9	24.3	42.2	430.5	0.0	54.5	33.5	16.7
Graham Gulch	744.9	536.9	0.0	17.2	54.7	0.0	6.1	15.5	44.3
Cloney Gulch	1593.3	694.7	0.0	47.5	191.9	0.0	0.0	0.0	97.1
Little Freshwater	2066.8	710.2	51.0	0.5	0.0	0.0	80.2	17.4	37.5
McCready Gulch	908.1	168.7	0.0	0.0	0.0	0.0	13.5	0.0	2.4
Lower Mainstem Freshwater	265.2	113.9	16.1	0.0	0.0	0.0	0.0	31.6	28.0
School Forest	297.5	0.3	0.0	0.0	0.0	0.0	0.0	18.3	0.5
Fay Slough	27.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Freshwater Watershed Total	***8104.7***	***3484.1***	***121.6***	***343.3***	***2467.1***	***5.6***	***194.7***	***329.6***	***280.9***

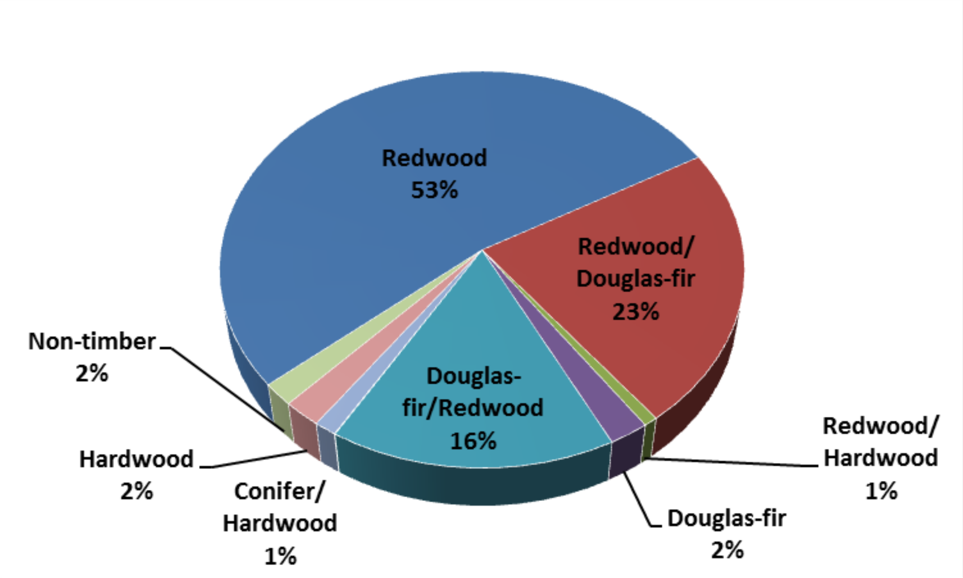

Figure 2-3. Composition of vegetation as percent of HRC Freshwater HCP area (2012 HRC GIS)

2.4 CLIMATE AND STORM HISTORY

The Mediterranean climate of the Freshwater Creek basin is evident in mild, wet winters with varying rainfall and storm intensities. Precipitation totals are tracked at the National Oceanic and Atmospheric Administration (NOAA), National Weather Service (NWS) station on Woodley Island in Eureka, California (rain gage EKA01), located approximately 9 miles west of the Freshwater Creek watershed. Mean annual precipitation has been approximately 39 inches during the 128-year period of record (Figure 2-4) with roughly 90% of the annual precipitation falling as rain during the months of October through May[2]. Annual rainfall during the recent 2003-2017 water year (WY) period (average of 39 inches) has been variable, as total precipitation was well above average in WY 2003 and WY 2006 (fifth and second highest on record, respectively) and well below average in WY 2014 (sixth lowest on record) and 2015 (Figure 2-5). The December 2002 storm set a number of rainfall records at the Woodley Island station including maximum daily rainfall (6.8 inches, Return Interval (RI) greater than 125 years). Maximum daily rainfall was also notably high in WY 2014 (2.6 inches, RI of approximately 3 years) despite the extremely low annual total (Figure 2-6). Both WY 2003 and WY 2006 seasons ended with a prolonged and sometimes intense series of storms that occurred late in the season when ground water levels were high and hillslopes were saturated.

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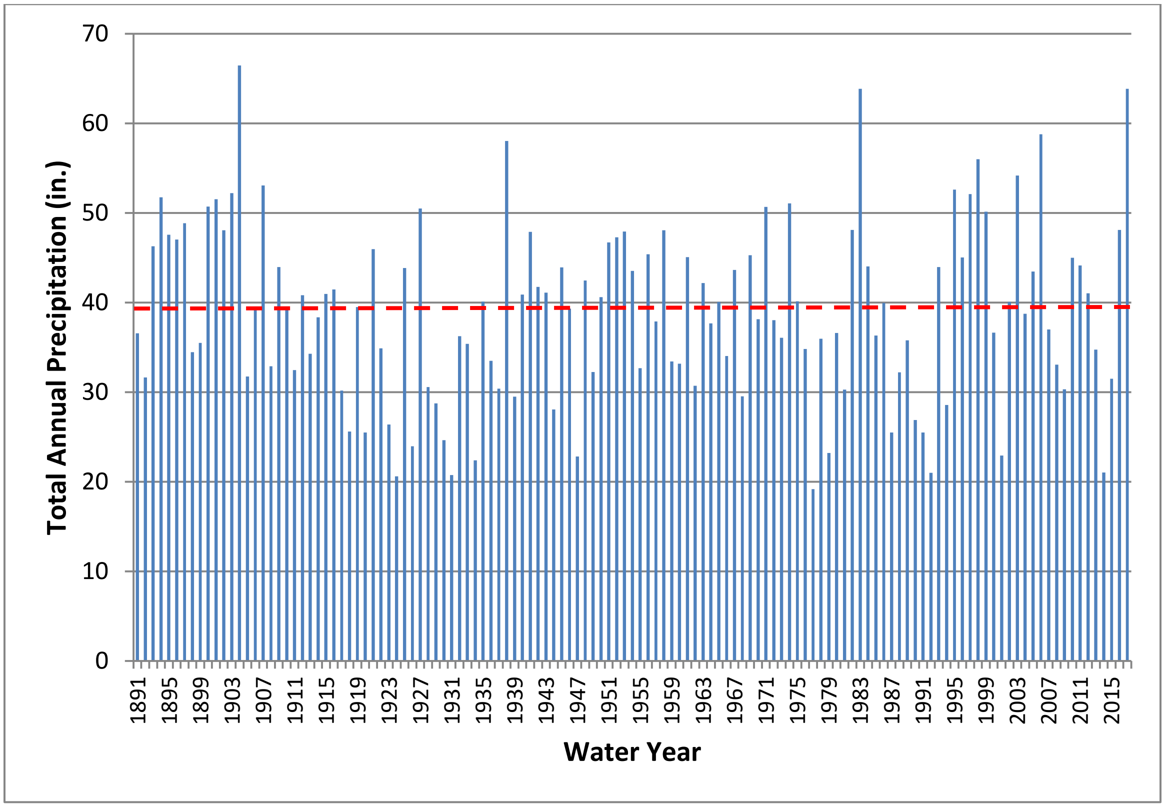
[2] California Date Exchange Center (http://cdec.water.ca.gov/cgi-progs/queryWY?staid=ERK&sensor_num=2&wy=2015&span=128)



Note: Dashed red line indicates average total annual precipitation for period of record (39 inches).

Figure 2-4. Total annual precipitation at Woodley Island, Eureka, CA, WY 1888-2015

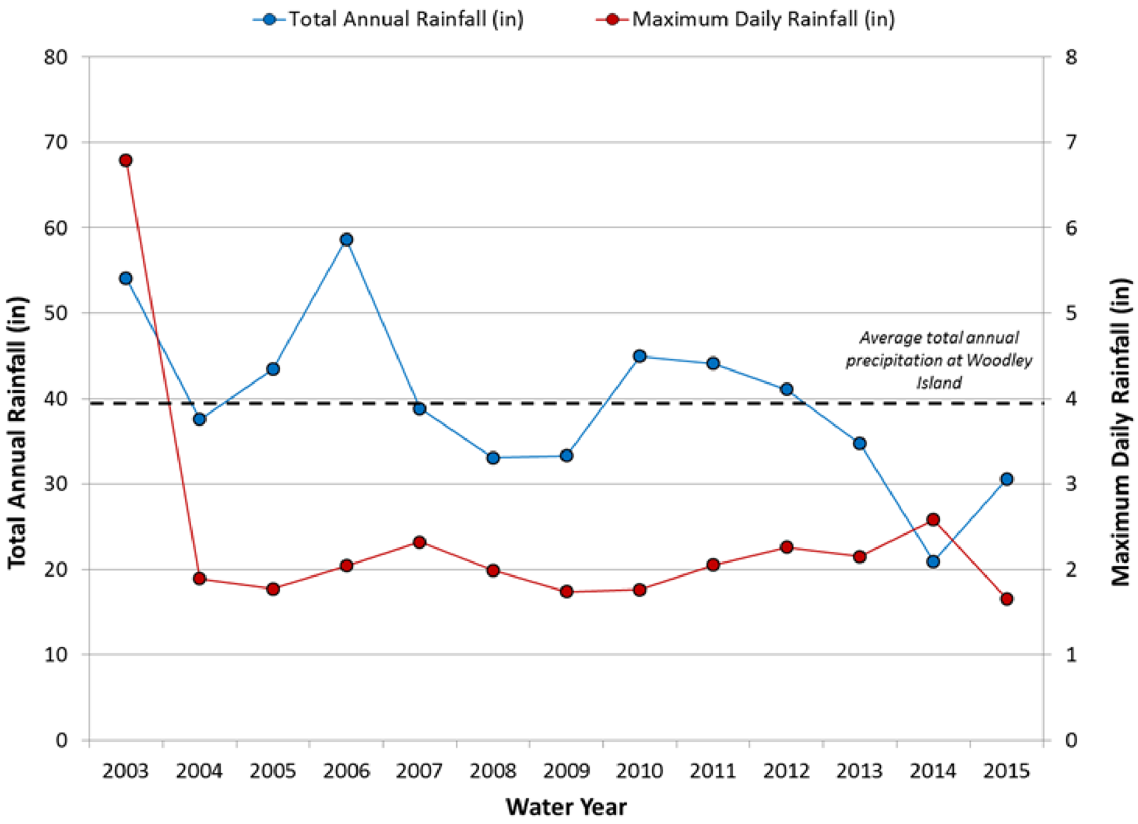


Figure 2-5. Total annual and maximum daily rainfall at Woodley Island, Eureka, CA, WY 2003-2015

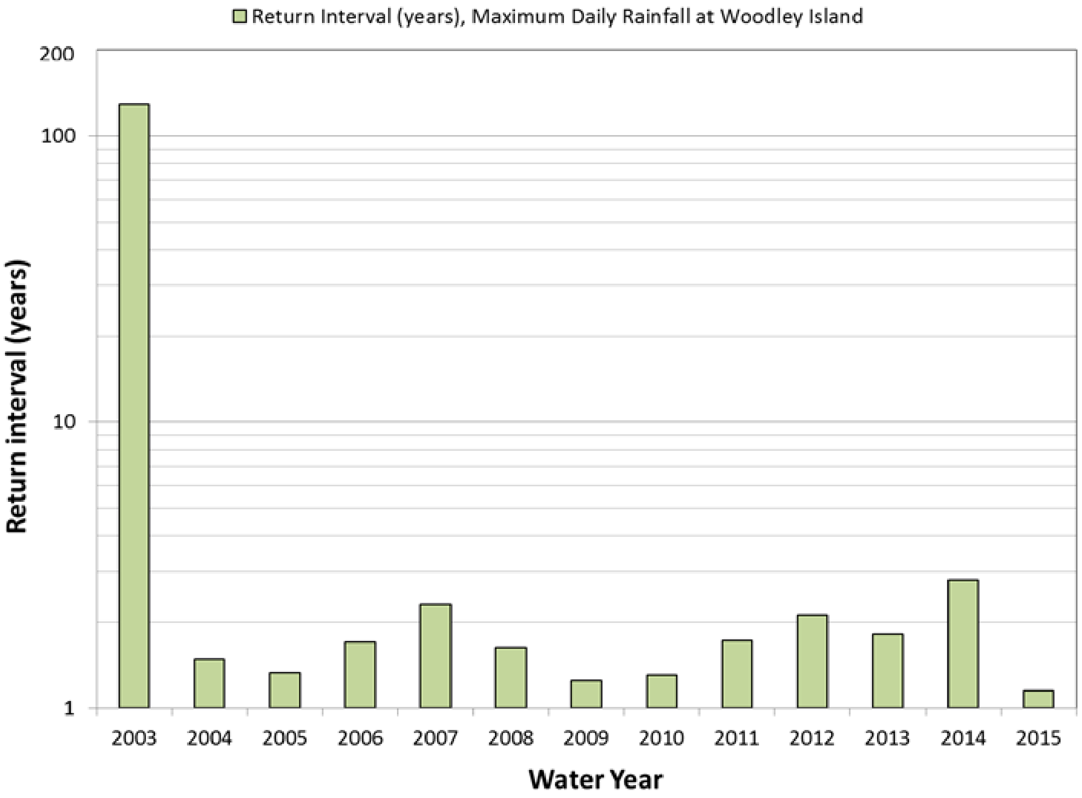


Figure 2-6. Return intervals (years) for maximum daily rainfall totals at Woodley Island, Eureka, CA, WY 2003-2015 (period of record = 128 years)

3 FOREST MANAGEMENT AND HARVEST HISTORY

Logging in the Freshwater basin began in the 1860s in the School Forest sub-basin of the lower watershed, not far from Humboldt Bay (Freshwater Creek Watershed Analysis, PALCO 2003). The initial timber harvest entries continued to move upstream into McCready Creek (1870s), lower Cloney Gulch (1880s and 1890s), Falls Gulch (1880s), Graham Gulch (1880s and 1890s), and lower Little Freshwater Creek (1870s and 1890s). Early logging was accomplished by a combination of railroad and “steam donkey”. Railroad grades were commonly placed within the riparian areas or up the stream channel in many of the sub-basins including McCready, Cloney, Graham, and portions of the South Fork. Railroad timbers and logging debris were used to fill crossings of small lateral tributaries and this fill still contributes to in-channel woody debris within some stream reaches. Virtually the entire watershed was logged by the 1950s, with overall harvesting and clearcutting rates for this period peaking in the 1930s at approximately 600 acres/year.

With the depletion of old-growth timber, harvesting rates declined in the 1940s and 1950s and then picked up again in the late 1960s as lower basin second-growth forests were commercially thinned. Between 1966 and 1974, the first truck haul roads were built in the lower basin, and widespread tractor logging was employed to selectively harvest portions of the maturing second-growth forest. Harvesting rates declined again to less than an annual average of 200 acres from 1975 to 1987 before increasing in response to a change in ownership and resurgence of second growth timber into commercial size classes (Freshwater Creek Watershed Analysis, PALCO 2003).

The Z’Berg-Nejedly Forest Practice Act of 1973 resulted in the establishment of State Forest Practice Rules (FPRs) in 1974, reducing watershed impacts. Continual revisions to the FPRs over the past 40 years have improved watershed protection over time as the scientific understanding of hillslope linkage to aquatic habitat conditions and processes has increased.

The nature of timber harvest operations in Freshwater Creek changed again significantly following implementation of the PALCO HCP in 1999, and yet again with the change of ownership from PALCO to HRC in August 2008. From 2001 through July 2008, PALCO used primarily even-age silviculture in harvesting mainly second growth redwood and Douglas-fir. Clearcut unit size and environmental impacts were reduced by HCP conservation measures restricting harvest adjacent to watercourses and on unstable areas. HCP wet weather road use limitations, new road construction standards, and requirements for “stormproofing” and road system monitoring were implemented. After July 2008, with the transition of ownership from PALCO to HRC, timber harvesting was converted to mainly uneven-aged selection silvicultural practices. HRC immediately ended traditional clearcutting, minimized the use of herbicides, and implemented an old growth tree retention policy. HRC continues to support, develop, and implement the HCP.

A total of 7,065 acres were harvested within the Freshwater Creek watershed from 2001 through 2015 (Table 3-1, Figure 3-1). Average annual acres logged during this 15-year time period was 471 acres per year. No harvest occurred within the Fay Slough sub-basin. Harvested acres account for *each entry* so that if the same acre is harvested twice during this time period it is represented as two acres in this summary.

Annual harvest rates by sub-basin were calculated using total acres harvested as a percentage of the entire watershed or sub-watershed area (including non-HRC ownership) and subsequently divided by 15 years. These rates ranged from 0 to 3.9% of total sub-basin acres per year. The highest rates of harvest within this time period occurred in South Fork Freshwater Creek (3.9% acres/year), and Little Freshwater Creek (3.3% acres/year). All other rates were less than 3% of the total sub-basin acres per year. Overall, the approximate rate of HRC harvest within the entire watershed was 1.7% acres/year during this time period (2001-2015). Cable and helicopter yarding were the primary logging methods, with tractor logging limited to lesser inclined slopes (i.e., <40%). Even-age and uneven-age cut proportions range widely from sub-basin to sub-basin but were 0.42 even-age and 0.58 uneven-age cut overall for the entire watershed.

Table 3-1. HRC Freshwater Creek annual harvest acres by mechanism and sub-watershed 2001-2015

Sub-basin Name	**Harvest Mechanism (acres)**				***Total***	***% of Total Sub-basin Area[1]***	***Annual Rate of Harvest***	***Even-age Harvest proportion***	***Uneven-age Harvest proportion***
	Tractor Yarding	**Tractor/ Cable Yarding**	**Cable Yarding**	**Helicopter Yarding**			(% sub-basin acres/years)[1]		
Upper Mainstem Freshwater	870.3	17.3	1529.6	116.2	2533.4	39.4%	2.6%	0.29	0.71
South Fork Freshwater	199.1	1.0	943.8	33.2	1177.1	58.1%	3.9%	0.32	0.68
Graham Gulch	357.0	1.4	280.0	48.6	687.0	43.0%	2.9%	0.47	0.53
Cloney Gulch	238.1	13.3	374.6	182.8	808.8	27.0%	1.8%	0.95	0.05
Little Freshwater	181.2	7.3	1239.2	46.5	1474.2	49.6%	3.3%	0.32	0.68
McCready Gulch	113.4	0	201.1	22.8	337.3	25.8%	1.7%	0.83	0.17
Lower Mainstem Freshwater	8.9	0	9.3	0	18.1	0.9%	0.1%	0.90	0.10
School Forest	0	0	29.2	0	29.2	7.8%	0.5%	0.86	0.14
Fay Slough	0	0	0	0	0	0.0%	0.0%	0	0
Freshwater Watershed Total	***1,968.0***	***40.3***	***4,606.7***	***450.1***	7065.1	25.6%	***1.7%***	***0.42***	***0.58***

1 – Percent of total area includes HRC and non-HRC ownerships

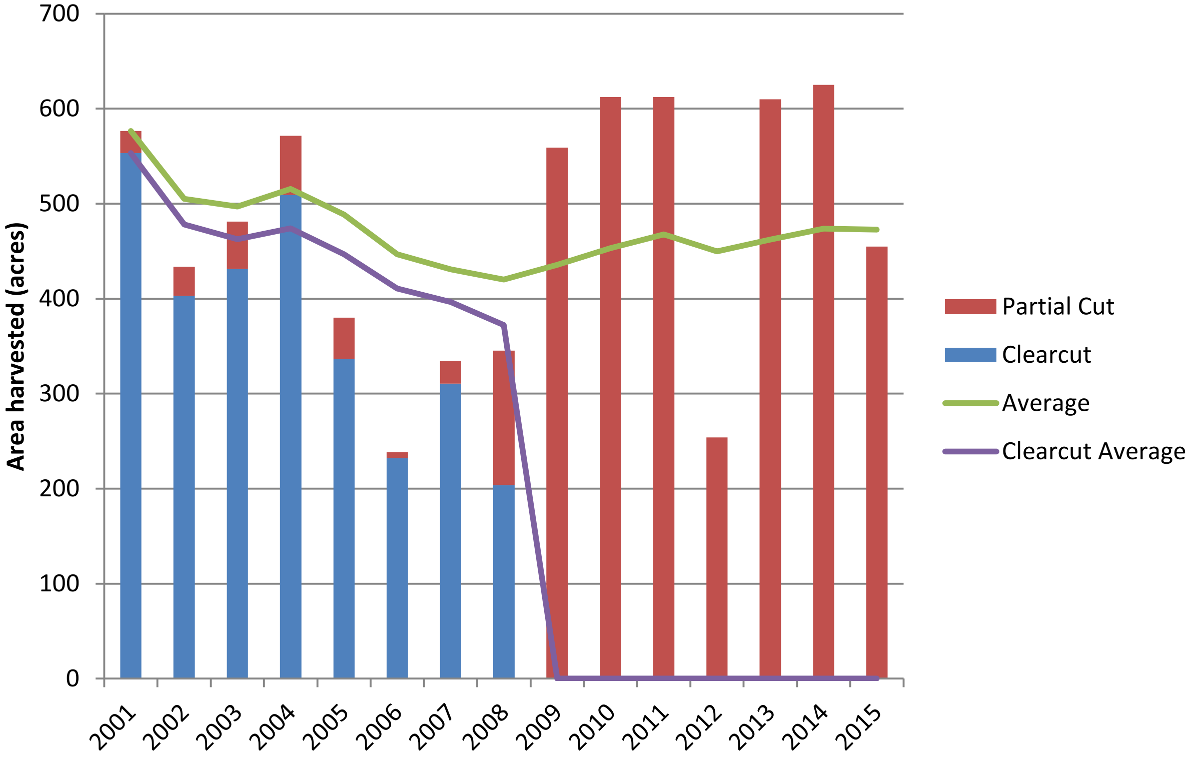
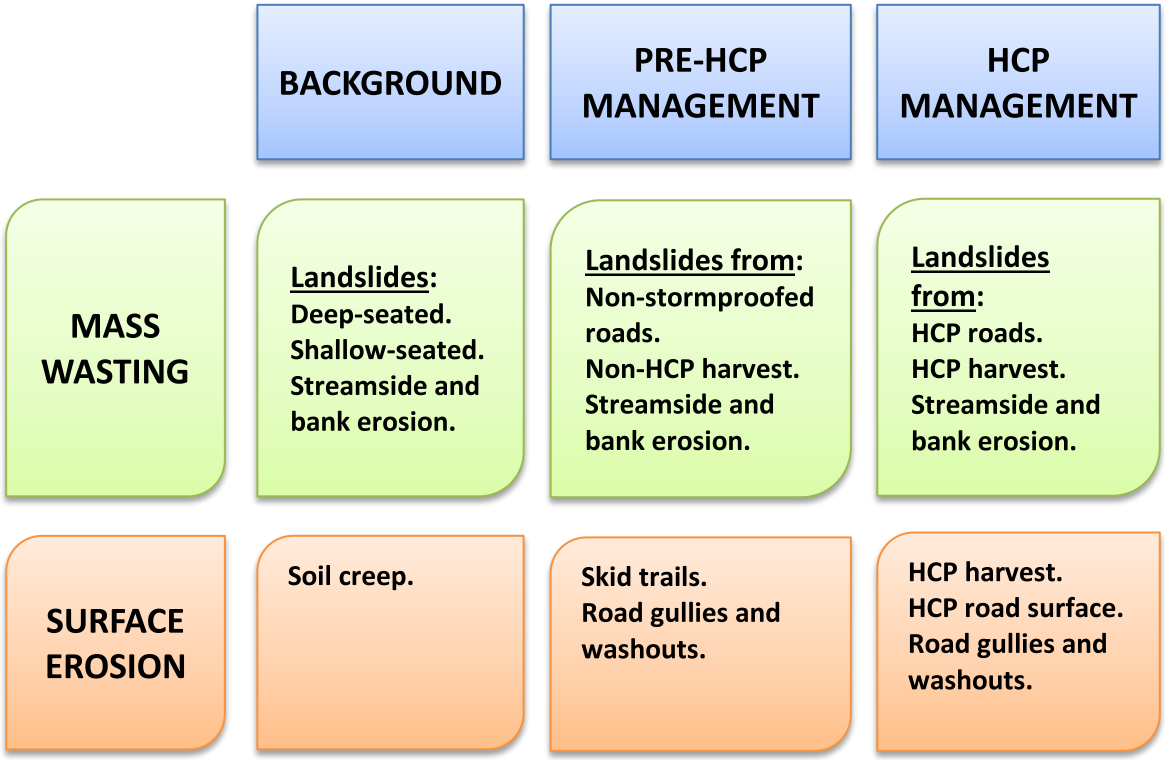


Figure 3-1. Acres harvested by year and method in HRC Freshwater HCP area

4 SEDIMENT

This report includes an updated sediment source budget for the Freshwater Creek WA revisit. This budget allows for comparison and analysis of sediment sources over time and at a spatially distributed scale (by sub-basin) across the watershed. Recognition of the relative importance of each sediment source allows for management to address identified areas of concern. Comparison of forest management-related sediment delivery to background delivery (i.e., on-going natural processes apart from land use activities) provides for an understanding of significance. Tracking delivery spatially, over a designated time period, is somewhat complicated and relies upon a suite of quantification measures from full inventories, to sample surveys, to modeled estimates. Methods used for estimating annualized rates of delivery (tons/mi^2/year) for the current (revisit) Freshwater Creek sediment budget period (2001-2011) are presented with the full sediment budget in Appendix 1.

For this analysis, sediment sources are divided into three general categories as presented in the following diagram:



	BACKGROUND	PRE-HCP MANAGEMENT	HCP MANAGEMENT
MASS WASTING	Landslides: Deep-seated. Shallow-seated. Streamside and bank erosion.	Landslides from: Non-stormproofed roads. Non-HCP harvest. Streamside and bank erosion.	Landslides from: HCP roads. HCP harvest. Streamside and bank erosion.
SURFACE EROSION	Soil creep.	Skid trails. Road gullies and washouts.	HCP harvest. HCP road surface. Road gullies and washouts.

Background sediment sources are those that are part of natural processes with little to no apparent linkage in causal mechanism to land use activities. These include open slope landslides and earthflows on hillslopes occupied by advanced forest regeneration (>15-30 years) and older forests, natural soil creep, and stream bank erosion. Management-related sediment sources are separated into two categories in order to assess contemporary HCP performance versus continuing sediment delivery from older sources caused by pre-HCP logging including historical unregulated (pre-1974) practices. **Pre-HCP** sources include landslides, smaller streamside landslides and bank erosion, gullies, and washouts from pre-HCP harvest settings, legacy abandoned roads, and portions of the maintained contemporary road system not yet upgraded to HCP stormproofed standards. Pre-HCP sediment sources also include an estimate of continued sediment delivery from older skid trails, particularly where such features intersect with watercourses (e.g., stream crossings and in-channel skidding corridors). Contemporary **HCP Management** sources include landslides, smaller streamside landslides/bank erosion, gullies and washouts, and surface erosion (sheet and rilling) associated with HCP harvesting, and delivery from roads following stormproofing treatments.

In the sediment budget timeframe of 2001 through 2011, the overall estimated unit rate for sediment yield to streams from HCP covered lands in the Freshwater WAU was 475 tons/mi^2/year. Natural processes and chronic (pre-HCP) legacy sediment sources are primary drivers of contemporary yield, with road-related erosion as the most significant contemporary (HCP) management influence. Figure 4-1 and Figure 4-2 illustrate the relative contribution of specific sources and processes.

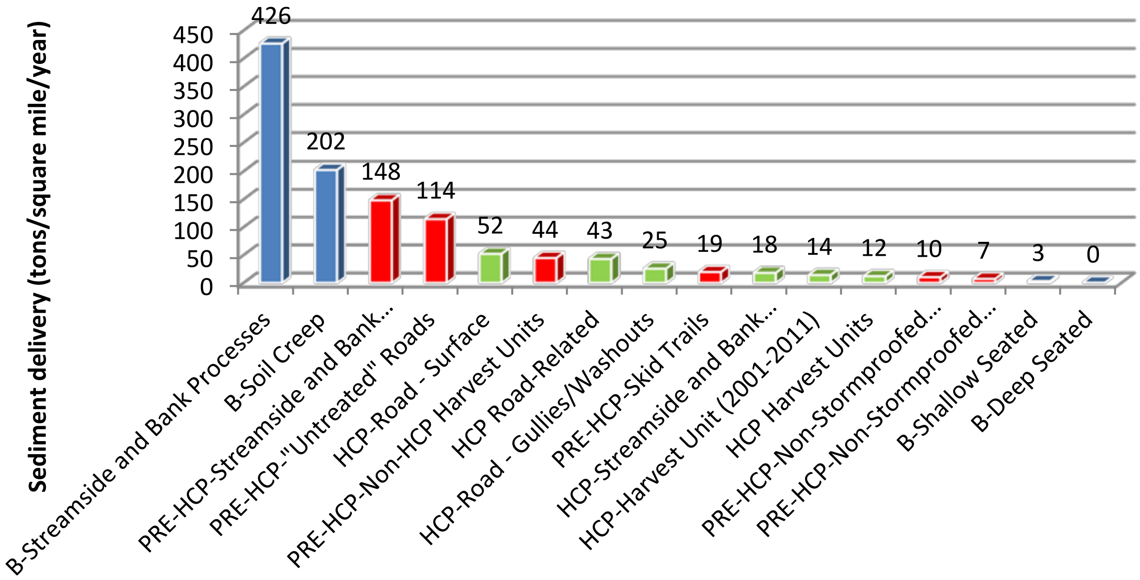
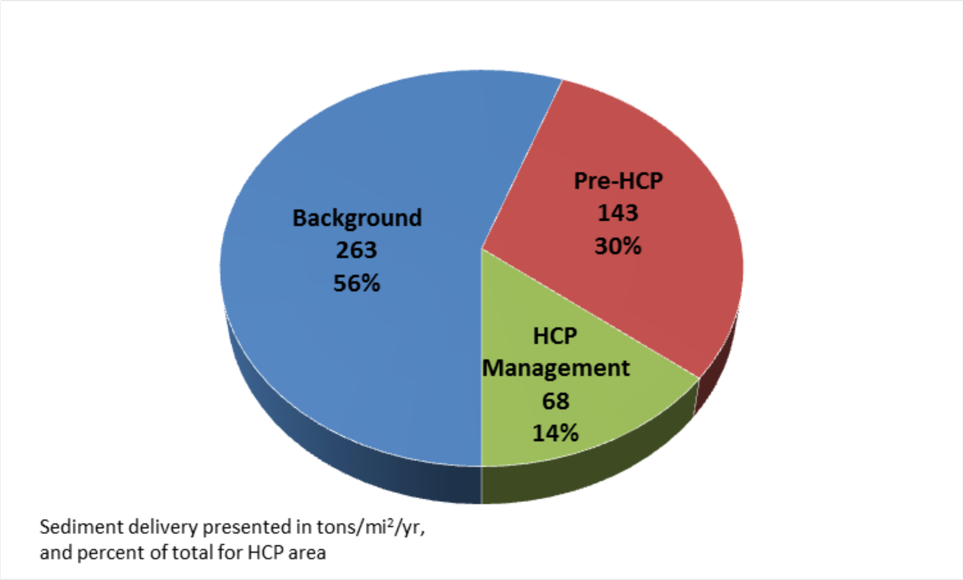


Figure 4-1. Freshwater estimated sediment delivery from HRC HCP ownership, 2001-2011



Sediment delivery presented in tons/mi^2/yr, and percent of total for HCP area

Figure 4-2. Freshwater estimated sediment delivery for all identified sources for HRC HCP land by source category, 2001-2011

4.1 MASS WASTING

4.1.1 Mass Wasting Avoidance Strategy

The overall strategy and enforceable prescriptions for controlling management-related mass wasting is outlined in the HCP (§6.3.3) and more specifically in the current Freshwater Creek Watershed Analysis Prescriptions (December 2003, HCP §6.3.3.7) (see Appendix 2).

In summary, specific hillslope and road-related prescriptions exist for identified potential mass wasting geomorphic conditions, such as inner gorge and headwall swales. Registered Professional Foresters (RPFs) are trained to identify active or potential unstable areas on the ground, and consult with Licensed Geologists in the management or avoidance of these areas. The use of existing slope stability hazard maps and models, along with review of recent and historical aerial photographs, are used in scoping for active or potential unstable slopes during timber harvest planning consistent with modern and state-of-the-art standards of geologic practice. Hillslope monitoring for the purpose of understanding the relationship between land management and landslide occurrence includes aerial photo review, field investigations, helicopter fly-overs, focused effectiveness monitoring projects, and post-event forensic analyses.

Road-related mass wasting sources are further addressed and minimized across the property by employing specific standards for constructing, stormproofing, and upgrading roads. Monitoring of road-related sources is completed through the Annual Road Inspection Program (ARIP) to proactively identify potential road-related mass wasting sources, and through the Roads Best Management Practice Evaluation Program (BMPEP) to review the quality and effectiveness of completed work. The most recent report for the Roads BMPEP is provided in Appendix 3.

4.1.2 Landslide Inventory WY 2001-2010 (Aerial Photographic Analysis)

A summary of landslide inventory information collected for the period from WY 2001 through WY 2010 is presented in this section. Triggering precipitation events are discussed, along with methods and results of the landslide inventory conducted for three aerial photograph sets (2003, 2006, and 2010). The sediment budget (Appendix 1) prepared for the Freshwater Creek WA revisit covers the period from 2001 through 2011, and utilizes the results of the landslide inventory for these three aerial photograph sets as discussed below.

4.1.2.1 Threshold Precipitation

Annual cumulative, monthly cumulative, and maximum daily precipitation volumes for WY 2003 and WY 2006 were considerable and, in several instances, record breaking. A series of frontal storms brought heavy and prolonged periods of rainfall to Humboldt County during portions of both water years. Annual totals were a minimum of 15 inches above the annual average of 39 inches, with WY 2003 ranked 9th and WY 2006 ranked 5th for the 128-year period of record (WY 1888-2015) at the Woodley Island station in Eureka. Several months within each season contained above average rainfall, particularly January, April, and December. These months experienced both prolonged and high-intensity storms which resulted in a maximum daily rainfall RI event of 125 years (ranked 1st) occurring in WY 2003. Although maximum daily rainfall totals for WY 2006 ranked relatively low (76th), annual/ monthly precipitation amounts contributed to the 6th highest stage recorded (53 ft) on the Eel River at the Scotia gage. December and January storm events in WY 2006 produced widespread flooding across lowlands as well as triggered numerous landslides throughout Humboldt County. On February 3, 2006, a Major Disaster (Presidential) was declared as a result of the flooding and landslide damage associated with these storms during the Incident Period from December 17, 2005 to January 3, 2006. Additionally, both WY 2003 and WY 2006 ended with a prolonged and sometimes intense series of storms that occurred late in the season when ground water levels were high and hillslopes were saturated.

Landslide occurrences in Humboldt County and on HRC ownership during these specific water years suggests that mass wasting hydrologic thresholds were surpassed. Precipitation events that result in the activation of landslides can be subdivided into four categories: intensity-duration threshold, cumulative rainfall threshold, event duration threshold, and event intensity threshold. Slopes within the Freshwater Creek watershed likely experienced at least two threshold events during WY 2003 (intensity-threshold) and WY 2006 (cumulative rainfall threshold/event duration threshold), which subsequently resulted in the occurrence of landslides. Oswald Geologic (2012) concluded that these conditions contributed to the precipitation-triggered landslide identified during the review of the 2003 and 2006 aerial photographs.

4.1.2.2 Overview

An analysis of stereo-paired aerial photographs covering the Freshwater Creek watershed was conducted in 2012 (Oswald Geologic, 2012). Three aerial photograph sets (2003, 2006, and 2010) were evaluated for the presence of active landslides. The study was conducted in accordance with parameters and methodologies developed to generate the landslide inventory for the Elk River watershed to the south.

Landslides were plotted on 10-ft Digital Elevation Model (DEM) topographic maps and dimensional attributes were recorded from the photographs using a 20:1 engineering scale (resolution of approximately 5 ft). The area-volume relation developed by Oswald Geologic (2012) was then used to generate landslide displacement volumes that are recorded in Table 4-1 and Table 4-2 (see Appendix 4). Landslide depths were modeled at 5 ft for shallow events and 12 ft for deep failures.

Seventy-seven active landslides (LS) are identified in the Oswald Geologic report (2012) (2003 = 44; 2006 = 30; 2010 = 3), with LS 110, 172, 268, 409, 411, and 763 experiencing reactivation during the investigated time period. Five of the failures documented in the Oswald Geologic inventory (LS 433, 446, 689, 690, and 692) were detected during daily duties (road inspections) and were not identified through the interpretation of aerial photographs. For consistency, these five sites have been excluded from the data set presented in this report (see Section 4.1.3 for details).

Although identified during the photo analysis, LS 410 was also eliminated from the data set. A ground survey revealed that the region of high albedo recognized on the aerial photographs corresponded to a large tree fall event that initiated on the face of an old scarp. Since ground movement at the site was not a direct by-product of landslide processes, but rather an erosional event, it was removed from the data set.

Table 4-1. Freshwater Creek hillslope landslides identified from aerial photographic analysis

	Total number of slides	Displaced volume (yd^3)	Number of slides delivered	Delivered volume (yd^3)
2003	44	22,334	29	4,218
2006	24	11,272	16	2,112
2010	3	1,091	3	329
Total observed	***71***	***34,697***	***48***	***6,659***

Table 4-2. Landslide delivery (2003, 2006, 2010 aerial photograph analysis) and estimated delivery rate (2001-2011 sediment budget) by sub-basin

Sub-basin	Area (acres)	Area (mi^2)	Number of landslides delivered for years 2003, 2006, and 2010[1]	Total volume delivered for years 2003, 2006, and 2010 (yd^3)[1]	Estimated total volume delivered for years 2001, 2002, 2004, 2005, 2007, 2008, 2009, and 2011 (yd^3)[2]	Calculated average annual streamside landslide delivery rate (tons/mi^2/yr)[3]	2001-2011 sediment budget estimated annual landslide delivery rate (tons/mi^2/yr)[4]
Upper Mainstem	4411	6.89	14	2360	933	231	292
South Fork	2022	3.16	4	1155	456	270	335
Graham Gulch	1420	2.22	6	779	308	221	284
Cloney Gulch	2624	4.10	4	516	204	187	210
Little Freshwater	2964	4.63	15	1578	624	320	381
McCready Gulch	1093	1.71	3	217	86	294	317
Lower Mainstem	455	0.71	1	4	2	178	179
School Forest	317	0.49	1	50	20	195	213
Fay Slough	27	0.04	0	0	0	122	122
Total	**15331**	**23.96**	**48**	**6659**	**2632**	**247**	**297**

[1] *Landslide delivery data are taken directly from the aerial photograph inventory years of 2003, 2006, and 2010.*

[2] *Estimated landslide delivery cumulative total volume over the 8 years not included in the aerial photograph inventory are based on the 2010 delivery volume which is used to represent average annual volume for each of the other years.*

[3] *Streamside landslides are estimated based on unit rates developed from a stream survey. Note that background, pre-HCP, and HCP management account for 72%, 25%, and 3%, respectively, of each sub-basin total.*

[4] *Total landslide delivery rates for 2001-2011 sediment budget period include landslides from aerial photograph years, estimated landslides in other years, and calculated streamside landslides.*

Additional data set modifications involved the re-calculation of the failure displacement volumes for the revised inventory (now N=71). Volume re-calculation was necessary due to the detection of formula errors in the original Oswald Geologic (2012) Excel data set. The volume re-calculation also involved the adjustment of volume mass conversion in the original study (1.53 tons/yd^3) to the one provided in the current sediment budget (1.4 tons/yd^3), for consistency with the conversion used for total maximum daily load (TMDL) work conducted in the area by the NCRWQCB. Consequently, as a by-product of these revisions, the data presented in this report (see Table 4-1, Table 4-2, and Map 5) are different than documented by Oswald Geologic (2012).

4.1.2.3 Revised Inventory

The Freshwater watershed revised landslide inventory for the 2001 through 2011 sediment budget period, based on aerial photograph years 2003, 2006, and 2010, consists of 71 failures (2003 = 44; 2006 = 24; 2010 = 3). The size of the landslides is relatively diverse, ranging from very small (188 yd^2) to covering over a half acre (23,562 yd^2). A majority of the failures (N=56) initiated on hillslopes adjoining watercourses (*Geomorphic Association* = streamside slope [ss], stream channel [st] or swale channel [sw], break in slope [bis], and headwall [hw]), with 53% (N=30) of them associated with pre-existing instabilities (classified as reactivations).

These near stream points of origin obviously result in a fairly high delivery rate, as 48 of the identified failures discharged sediment directly into a watercourse (Table 4-1). However, less than 20% of the total displaced volume associated with these slides actually entered a mapped watercourse (approximately 6,700 yd^3 delivered vs. approximately 34,700 yd^3 mobilized) with just over 3,264 yd^3 going into Class III watercourses (Figure 4-3). Sixty-eight percent (4,501 yd^3) of the total discharged volume came from slides that initiated on streamside slopes (ss) and headwall swales (hw). A significant percentage of this volume (2,400 yd^3) was contributed by slides that originated at stormproofed roadways, with another 2,500 yd^3 from slides originating from non-HCP (i.e., pre-HCP) harvest areas (Figure 4-4).

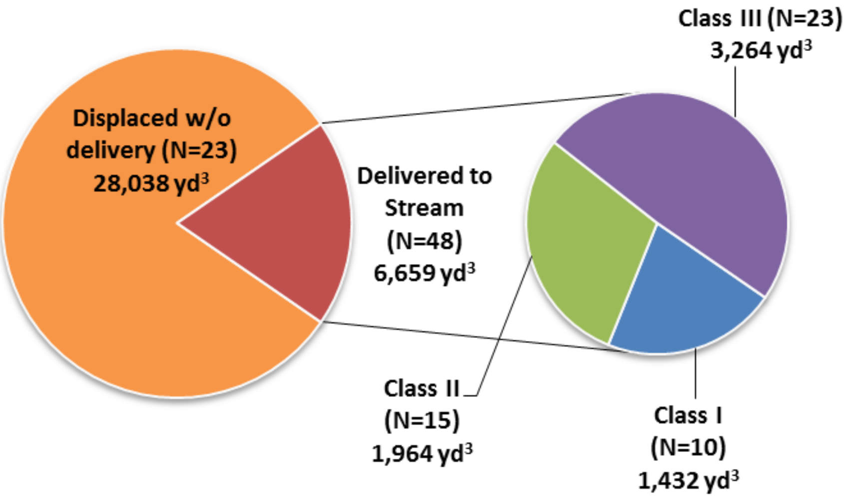


Figure 4-3. Freshwater Creek HRC HCP landslide volume displaced and delivered by stream class (2003, 2006, 2010 aerial photographic analysis)

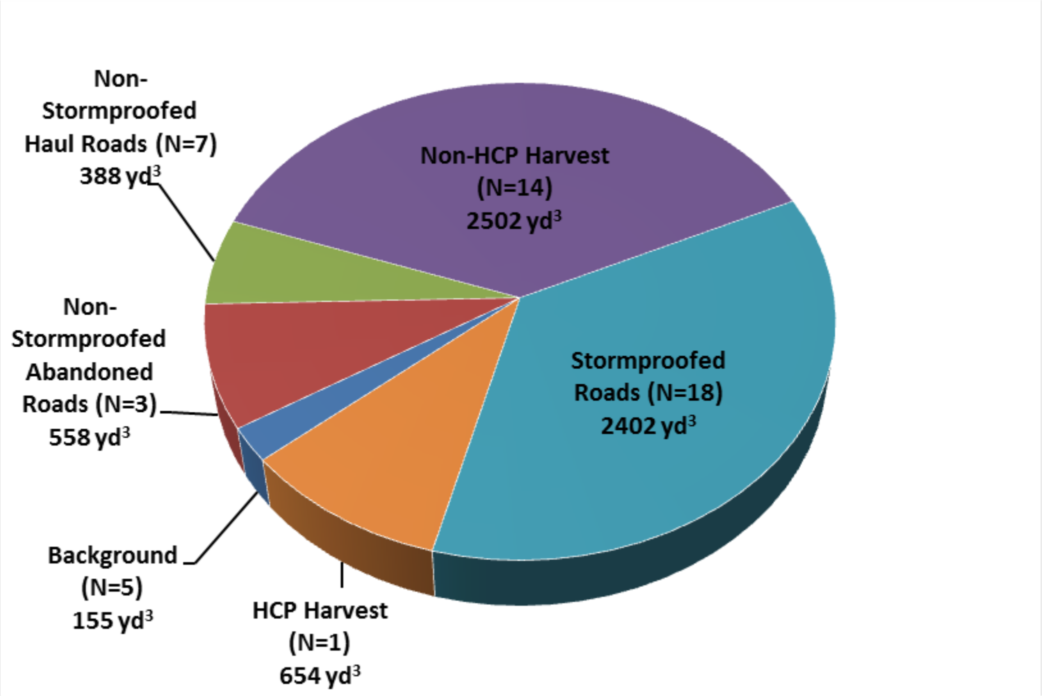


Figure 4-4. Freshwater Creek HRC HCP area watershed landslide inventory sediment source volume delivered

Two landslides (LS 266 and 747), which have *Geomorphic Associations* of “ss” and “hw” (retrospectively), delivered 17% of the total discharge volume calculated for the study period (approximately 1,160 yd^3 of approximately 6,700 yd^3). Neither slide is associated with road construction (*Landuse Association*: LS 266 = mechanical partial cut [mpc]; LS 747 = clearcut [cc]), however, LS 747 did occur on a hillside operated on under Timber Harvesting Plan (THP) 1-01-200 HUM (Freshwater South 23). This event is the largest sediment-delivering failure (654 yd^3) in the inventory and originated at what may be the top of a poorly expressed headwall swale. The slide appears to have failed along a joint/ bedding plane and subsequently graded into an extended debris torrent (200-ft long). Ninety percent of the sediment mobilized by this event entered the down slope Class III watercourse.

This open-slope debris flow is the only failure that occurred within a cut block laid out in accordance with HCP prescriptions (*HCP Harvest* slide) (Figure 4-4). The plan area underwent a geologic evaluation in accordance with the HCP interim prescriptions and a report detailing the investigator’s observations, conclusions, and recommendations is attached to Section 5 of the THP (Golder 2000). Several slope instabilities (LS-1 through LS-3) were identified and subsequently omitted from the operations by means of no-cut areas. A second supplemental evaluation was conducted by GeoEngineers (2001a; 2001b) to address concerns presented in Pre-Harvest Inspection reports produced by the CGS (formerly California Division of Mines and Geology), NCRWQCB, and NMFS staff. GeoEngineers (2001a; 2001b) responses are also attached to Section 5 of THP 1-01-200 HUM. The subject headwall and initiation point for LS 747 was not identified as an area of concern in these reports and was subsequently harvested.

Under current NCRWQCB permits, a series of maps must be reviewed by a State Licensed Geologist prior to conducting harvesting operations in the Freshwater Creek watershed. Maps produced by the Mass Wasting Potential (MWP) and SHALSTAB (Dietrich and Montgomery 1998) models identify the failed headwall as having a high landslide hazard potential, and thus would have undergone a focused evaluation. It is our opinion that, under the current standards of practice, this particular area of concern for LS 747 would have been identified and subsequently mitigated through harvest restrictions.

Landslide LS 266, which delivered 504 yd^3 of sediment, corresponds to a series of shallow landslides that initiated on a steep streamside slope (ss) along the mainstem of Freshwater Creek. This event only delivered 25% of its total volume to the adjoining watercourse. The remaining 75% is presently stored on slopes above the banks of the impacted reach.

The hillside on which LS 266 initiated has been categorized as both a debris slide slope and inner gorge (Kilbourne 1985a and 1985b, Falls 1999a, Oswald Geologic 2012, and HRC 2013a). These types of landslide-related landforms are inherently prone to mass-wasting events; therefore, it is reasonable to assume that the dynamic hillslope process affiliated with these geomorphic features will continue whether management activities occur or not. It has been demonstrated that unseasonably high intensity/long-duration rainfall events or large magnitude earthquakes can trigger landslides in these types of geologic environments, whether the ground is forested or not. Consequently, this landform is likely to continue to experience ground movement in the future.

This suspect slope, including LS 266, is encompassed by THP 1-13-070 HUM (Double Deuce). The plan area underwent a geologic evaluation in accordance with the Freshwater Creek WA and the NCRWQCB Tier 2 requirements. During this evaluation, LS 266 was observed and slopes around it classified as potentially unstable; subsequently, this area of concern was placed within an enhanced Class I Riparian Management Zone (RMZ) inner band (prescribed as no-cut zone). A CGS Note 45 (CGS 1999) compliant report (HRC, 2013a) detailing the results of this evaluation is attached to Section 5 of the plan.

Although neither of these large slides was associated with a road, 43 of the remaining delivering failures mapped by Oswald Geologic (2012) were categorized as having a *Landuse Association* attributable to roadways (rrf, rlf, rcb, rd, and rx) (61% of all mapped landslides). These failures occurred along both stormproofed (N=31) and untreated roads (N=12), with 77% of the slides initiating in fill prisms (rrf, rxf, and rlf).

LS 227 and LS 704 are fill embankment failures that occurred along stormproofed roadways. These two events represent 10% of the total volume discharge to waterways. Both sites have been repaired/ upgraded and have not experienced any post-treatment movement. The majority of the delivered material was reportedly removed and end-hauled to suitable storage sites during repair operations.

Regardless of the geomorphic setting or if anthropogenically influenced, 54 of the inventoried landslides (>75%) initiated on slopes underlain by undifferentiated Wildcat formation sediments. These events deposited over 4,400 yd^3 of sediment to down slope waterways, with nearly all the remaining sediment being input by failures that initiated on slopes that developed on Central belt hillslopes.

4.1.3 Landslide Inventory WY 2011-2015 (Daily Duties)

Results of landslide inventory work associated with ongoing forest management activities from WY 2011 through WY 2015, and in response to precipitation and earthquake threshold events, are discussed in this section. An analysis of stereo-paired aerial photographs was not conducted for this time interval. However, active landslides inventoried for this period were identified through the execution of daily duties including:

- Annual helicopter surveys;
- Plan lay out;
- ARIP; and
- Ground surveys instigated by triggering events as defined in the Watershed-Wide Waste Discharge Requirements (WWDR) Permit Order R-2006-004.

WWDR Permit Order R-2006-004 defines threshold events as:

- Two inches of precipitation in 12 hours, regardless of cumulative rainfall, as measured at the NWS station on Woodley Island in Eureka, California.
- Three inches of precipitation in 24 hours, following 10 inches of cumulative rainfall after October 1, as measured at the NWS Woodley Island station.
- An earthquake that has a zone of influence that overlaps any or all portions of the Freshwater Creek Watershed, in accordance with calculations presented in Keefer (1984). Details regarding

this relationship and it applicability to inspection triggers is detailed in Quality Assurance Project Plan (QAPP) Version 3.0 (HRC, 2009).

4.1.3.1 Precipitation

Although total annual precipitation was above normal in WY 2011 and WY 2012, none of the storms that occurred during these water years exceeded a WWDR-defined rainfall threshold. In WY 2013, just over 31 inches of precipitation were recorded at the NWS Woodley Island station from October 1, 2012 to May 30, 2013 (below normal). Although considered a dry winter, Freshwater Creek was impacted by a series of storms in late November and early December 2012. This set of storms delivered substantial precipitation over the basin, but did not surpass WWDR thresholds.

WY 2014 was also an unseasonably dry winter with just under 17.5 inches of precipitation recorded at the NWS Woodley Island station from Oct 1, 2013 to May 2014 (seasonal average rainfall totals through January commonly exceed 22 inches). Below-normal annual precipitation volumes were also recorded in WY 2015, although several brief stormy periods took place in February 2015 with the largest event occurring between February 5 and 9 (maximum daily RI of 2.1 years).

The general lack of landslide occurrences in Humboldt County and on HRC ownership during these specific water years suggests that mass wasting hydrologic thresholds were not exceeded.

4.1.3.2 Earthquake Threshold Events

A magnitude (seismic moment [Mw]) 5.6 earthquake occurred near Weitchipec, California on February 13, 2012. According to Keefer's (1984) model, this magnitude earthquake could potentially activate slides within a 49-km radius. This 49-km radius overlapped the northern half of the Freshwater Creek Watershed. Twenty THP units were inspected on February 14, 2012 in response to this earthquake. No landslides were reported during this inspection or subsequent helicopter surveys.

On March 10, 2014 at 18:13 Coordinated Universal Time (UTC), a Mw 6.8 earthquake occurred 81 km west (40.8290 North; 125.1340 West) of Eureka, California. This event was 16.6 km deep and occurred as the result of oblique strike slip motion within the Juan de Fuca plate. Ground motion from this event was felt along the northern California and southern Oregon coastlines, in particular in the City of Eureka, California. No significant damage was reported in the greater Eureka area.

In response to this event, HRC Forestry and Forest Science Department staffs conducted preliminary inspections of all Tier 2 harvest units from March 11 to 14, 2014. Subsequent to this assessment, HRC Forest Science staff carried out an aerial survey of all Tier 2 units within the Freshwater Creek drainages.

4.1.3.3 Inventory

During the WY 2011-2015 study period there were four ARIP inspections, four helicopter surveys, and two ground inspections prompted by the occurrence of threshold events (February 13, 2012 = Mw 5.6 earthquake; March 10, 2014 = Mw 6.8 earthquake). These inspections resulted in the identification of three failures (FW 1201, FW 1202, and FW 1301) (WY 2012 = 2; WY 2013 = 1). The landslides identified during this time period are equal to or less than 3 yd^3 in size. All of the failures initiated along roadways (*Landuse Association* = road-related fill [rrf], road crossing [rx]) that contoured across slopes adjoining watercourses (*Geomorphic Association* = streamside slope [ss], stream channel [st]). None were associated with HCP timber operations, but did occur along road alignments categorized as stormproofed. No landslides attributable to the February 13, 2012 or the March 10, 2014 seismic events were identified during ground-based or subsequent aerial surveys.

4.1.4 Small Streamside Landslide and Bank Erosion

Twenty-six miles of combined Class I, II, and III watercourses were field surveyed in 2012 for evidence of streamside landslides and significant bank erosion on HCP covered lands in the Elk River WAU which lies adjacent the Freshwater WAU to the southwest (SHN 2012). These sources are important elements in the development of refined sediment budgets, as these smaller features are typically not apparent on aerial photography because of the generally dense riparian canopy cover. Unit rates from this field survey were applied to Freshwater sub-basins in order to generate estimates of sediment delivery based on geology, stream density, and watercourse classification (Figure 4-5); use of unit rates developed from Elk River WAU data is expected to result in conservatively higher sediment delivery estimates in the Freshwater WAU, based on observations of more small streamside landslide activity in the Elk River WAU.

4.2 SURFACE EROSION

Surface erosion is considered to be the wearing away of soils from the land surface by wind or water. For the purposes of the Freshwater Creek WA, surface erosion sources are categorized by process/source of origin including: soil creep, harvested areas, legacy skid trails, road surface, road gullies, road crossings, and road fill failures (both pre- and post-treatment). Table 4-3, Figure 4-6, Figure 4-7, and Figure 4-8 present sediment delivery rate by general and specific surface erosion source categories. Overall, surface erosion processes accounted for approximately 38% of the total sediment delivery in the 2001-2011 sediment source budget.

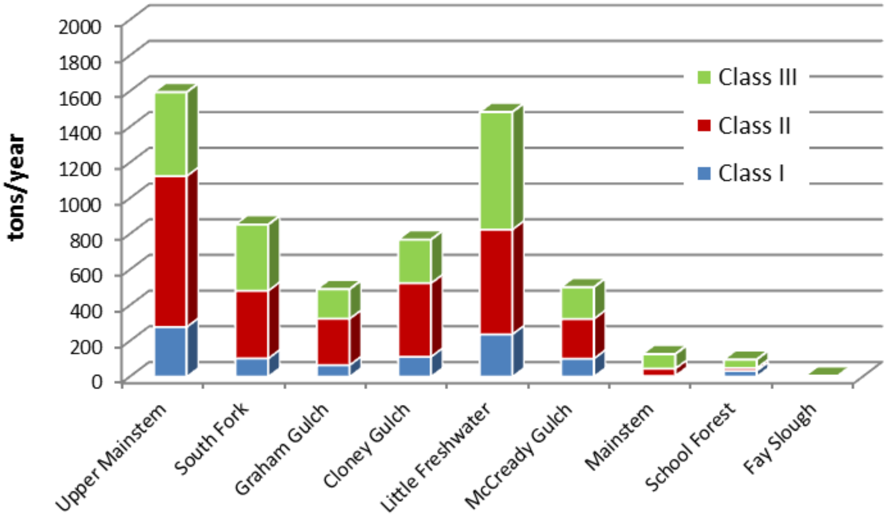
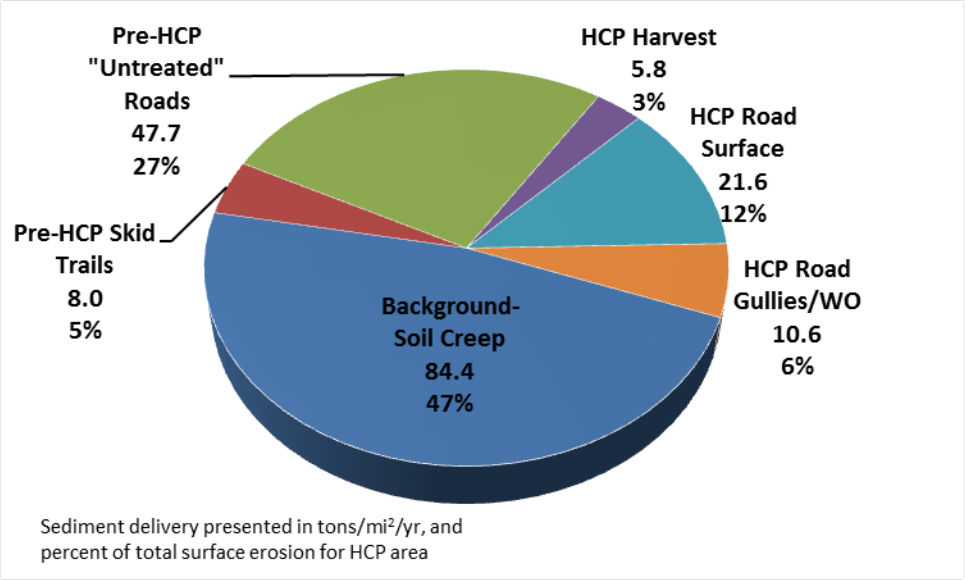


Figure 4-5. Freshwater HRC HCP area streamside landslide and bank erosion sediment delivery by stream class and sub-basin based on unit rate and cumulative length of each stream class, 2001-2011

Table 4-3. Surface erosion sediment delivery by source (2001-2011) HRC HCP area within the Freshwater Creek WAU

Surface Sediment Source	Sediment Delivered		
	Tons per Year	Tons per Square Mile per Year	Percent of Total
Soil Creep	2,021	84.4	47%
Timber Harvest Surface Erosion (average for 2001-2011)	138	5.8	3%
Road Surface Erosion (average for 2001-2011)	518	21.6	12%
Post HCP-Treated Stream Crossing Washouts and Road Gullies	253	10.6	6%
Pre-HCP Skid Trails	191	8.0	4%
Pre-HCP "Untreated" Roads	1,143	47.7	27%
Total HCP Lands (23.96 square miles)	***4,264***	***178.0***	***100%***



Sediment delivery presented in tons/mi²/yr, and percent of total surface erosion for HCP area

Figure 4-6. Freshwater HRC HCP area sources of sediment delivery from surface erosion, 2001-2011

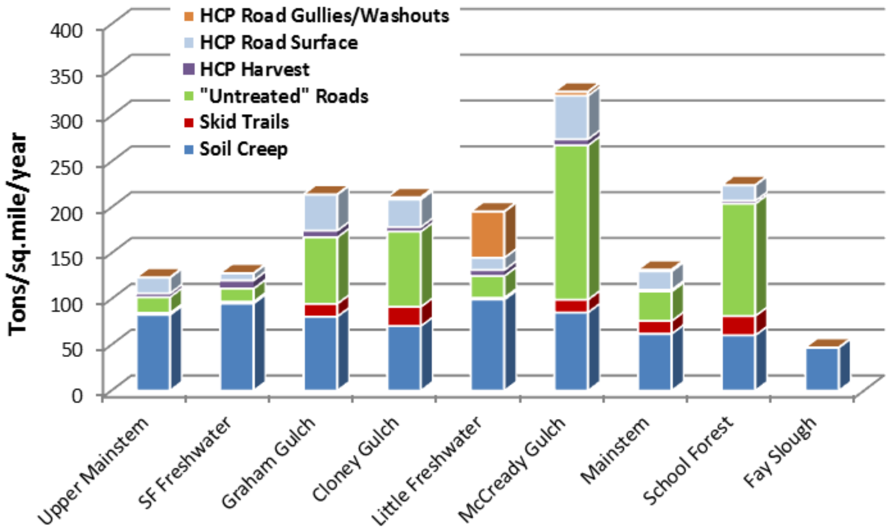


Figure 4-7. Freshwater HRC HCP covered lands surface erosion delivery rate sources by sub-basin 2001-2011

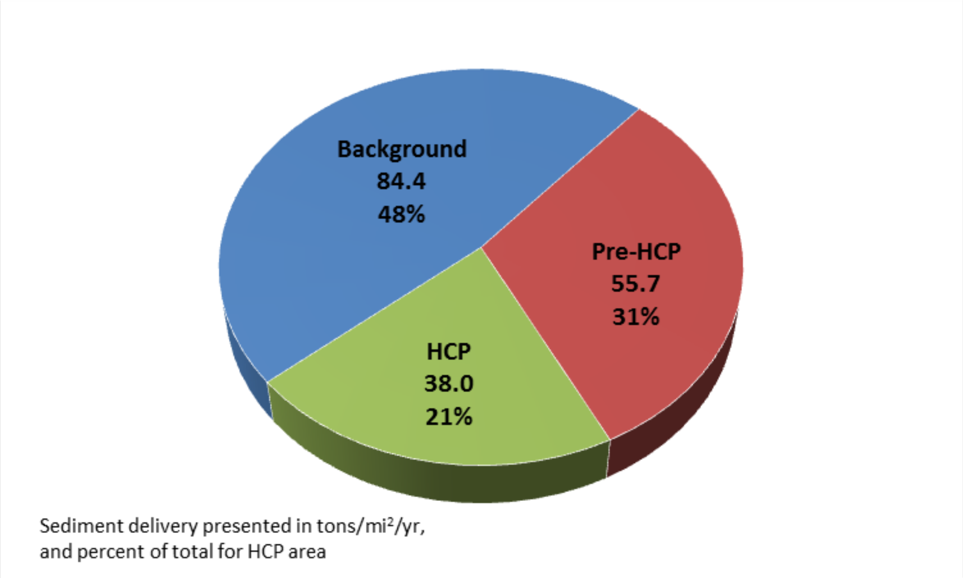


Figure 4-8. Source of sediment delivery from surface erosion for Freshwater HRC HCP area, 2001-2011

4.2.1 Soil Creep

Soil creep is defined as the slow, down slope movement of the soil mantle due to gravity. Soil creep rates were calculated with the following formula (Washington Department of Natural Resources [WDNR] 1997):

ANNUAL SEDIMENT YIELD FROM SOIL CREEP =
LENGTH OF STREAM CHANNEL X 2 BANKS X SOIL DEPTH X SOIL CREEP RATE X SOIL BULK DENSITY

A soil creep unit rate of 1.5 mm/year was used for calculations with a 3-ft soil depth and 1.4 tons/yd^3 soil bulk density. The unit rate was determined from an average of soil creep rates used in the initial Freshwater Creek WA following a scientific review of regional information. Soil creep accounted for an estimated 47% of the sediment delivery from surface erosion with a rate of 84.4 tons/mi^2/year. Because of the calculation method, differences between sub-basins throughout the watershed are a result of differences in stream lengths (Figure 4-7). Calculations within the initial Freshwater Creek WA used varying rates and soil thicknesses based on geology and slope and soil creep was estimated to be 90 tons/mi^2/year. The initial WA calculated values for all streams lengths within the watershed (HCP and non-HCP lands) and only calculated soil creep for stream banks not included in the streamside landslide and bank erosion estimates.

4.2.2 HCP Timber Harvest

All timber harvest operations in the Freshwater Creek watershed under HRC ownership are subject to the Freshwater Creek Watershed Analysis Prescriptions (December 2003; Appendix 2). These enforceable forestry prescriptions were established as part of the HCP WA process (HCP §6.3.2) in collaboration with state and federal HCP signatory wildlife agencies including CDFW, NMFS, and USFWS. The prescriptions are designed to prevent or minimize sediment delivery to streams through a combination of equipment exclusion zones, harvest restrictions, and other disturbance minimization measures applied adjacent to watercourses.

Key erosion control elements of the prescriptions include:

- 50- and 30-ft no-harvest zones adjacent Class I and Class II watercourses respectively, substantially minimizing or eliminating ground disturbance within the highest hazard area relative to sediment delivery.
- Slope dependent 75- to 150-ft wide RMZs adjacent Class I (fish-bearing) watercourses, and 50- to 100-ft RMZ width adjacent Class II watercourses, within which heavy ground-based skidding equipment use (e.g., tractors, skidders, forwarders, etc.) is excluded with minimal exception, and within which all pre-existing down wood (e.g., trees, logs, limbs) is retained, substantially minimizing ground disturbance within the highest hazard area relative to sediment delivery.
- A slope-dependent 50- to 100-ft RMZ for slopes adjacent and leading to Class III watercourses, within which heavy ground-based skidding equipment use (e.g., tractors, skidders, forwarders, etc.) is excluded with minimal exception, and within which all pre-existing down wood (e.g., trees, logs, limbs) is retained, substantially minimizing ground disturbance within the highest hazard area relative to sediment delivery.
- A multivariate hillslope management plan using a combination of models, landslide hazard maps, field investigation, licensed geologic input, and enforceable WA-based prescriptions for identified high hazard areas including inner gorges and steep streamside slopes, headwall swales, and areas of significant past ground disturbance resulting in local instability.

In addition to these prescriptions, HRC practices uneven-age selection silviculture forestry which maintains and grows mature forest cover. This transition from even-age to uneven-age management occurred in the summer of 2008 immediately following transfer of ownership to HRC.

Logging methods include cable and helicopter yarding on moderate to steep slopes, and a mixture of ground-based and cable yarding of down timber on slopes inclined less than 40 percent.

Estimates of sediment delivery rates from surface erosion as a result of ground disturbance during timber harvest activities were calculated for each sub-basin using the Water Erosion Prediction Project (WEPP) model (Elliot et al. 2000). The WEPP model was developed by a federal inter-agency team as a physically-based soil erosion model that provides an estimate of erosion and sediment delivery through a buffer based on site-specific soil, ground cover, and topographic conditions and the local climate. Application of the HRC WEPP model to this setting is explained in the initial Freshwater Creek WA conducted in the early 2000s (PALCO 2003). All management-slope-stream buffer combinations for areas harvested by HRC in the HCP area from 2001 through 2011 were analyzed. All units included in the calculations were harvested under HCP restrictions and, therefore, all sediment delivery is considered to be HCP harvest related. A delivery rate of 5.8 tons/mi^2/year was estimated to be associated with HCP harvest for 2001-2011. A breakdown of delivery by sub-basin is provided in the Sediment Source Budget (Appendix 1).

4.2.3 Legacy Skid Trails

Estimates for sediment delivery from legacy skid trails originate from the NCRWQCB draft TMDL for Elk River (NCRWQCB 2013). The NCRWQCB used Elk River studies conducted primarily or entirely on HRC ownership to arrive at an overall estimate of 21 tons/mi^2/year (15 yd^3/mi^2/year) for sub-basins where tractor logging was a prevalent harvesting method (1950s through the 1980s). HRC used the following sources of information to accept or adjust this full estimate for application to Freshwater sub-basins: documented sub-basin tractor harvest history and densities, Pacific Watershed Associates (PWA) skid trail potential sediment delivery volumes, locations of all HRC skid trail sites and surveyed areas in both Elk and Freshwater watersheds, and general knowledge of differences between the two watersheds. In general, the Elk River watershed had higher impacts and therefore more sediment delivery from skid trails than the Freshwater watershed, due to the timing and more than one round of tractor logging for sub-basins in the Elk River watershed. Based on these factors, sub-basins with the greatest impacts from tractor logging were assigned the full TMDL rate, and other sub-basins with relatively less impacts were adjusted to 65% or 10% of the full rate. Overall sediment delivery from legacy skid trails is estimated at a rate of 8.0 tons/mi^2/year, accounting for approximately 4% of the total surface erosion delivery. This source of sediment is typically associated with historical tractor stream crossings that were not removed, or only partially removed, upon completion of use. Remaining crossing fill in the channel is subject to erosion during high-flow events. Eroding remnants of historical skid trails up and down stream channels also fall under this category.

4.2.4 Road Surface

Sediment delivery as a result of road surface erosion was estimated using analysis from SEDMODL2 with inputs from HRC road inventory data adjusted for updated traffic factors developed by Dr. Kate Sullivan reflecting HCP wet weather road use restrictions applied to all roads (Sullivan et al. 2011: *Sediment Production from Stormproofed Roads on Humboldt Redwood Company Lands*). Other corrections were also made to account for the effect of stormproofing (rocking) on native roads at the stream crossings, as was also done in the initial Freshwater Creek WA (PALCO 2003). SEDMODL2 is a Geographic Information System (GIS) application based on an empirical model developed by the WDNR used throughout the Pacific Northwest, which uses the following equation:

TOTAL SEDIMENT DELIVERED = TREAD + CUTSLOPE, WHERE:

> ***TREAD = GEOLOGIC EROSION RATE × TREAD SURFACING FACTOR × <u>TRAFFIC FACTOR</u> × SEGMENT LENGTH × ROAD WIDTH × ROAD SLOPE FACTOR × PRECIPITATION FACTOR × DELIVERY FACTOR***
>
> ***CUTSLOPE = GEOLOGIC EROSION RATE × CUTSLOPE COVER FACTOR × SEGMENT LENGTH × CUTSLOPE HEIGHT × DELIVERY FACTOR***

The following revised traffic factors developed by Sullivan et al. (2011) were used:

- Heavy traffic/active mainline (main haul): 0.04
- Moderate traffic/active secondary (primary): 0.05
- Light traffic/not active (secondary, spur): 0.01
- No traffic/abandoned (abandoned): 0.1

Sediment delivery rates from road surfaces (2001 through 2011) were estimated, based on road conditions at the end of 2011, to be approximately 21.6 tons/mi^2/year (12% of all surface erosion) for HCP managed roads. The initial Freshwater Creek WA estimated a rate of 200 tons/mi^2/year based on similar SEDMODL calculations but without adjusted HCP traffic factors.

Three sub-basins stand out as having higher road surface erosion relative to other sub-basins. McCready Gulch had the highest road surface erosion delivery rate (47 tons/mi^2/year) due to overall road density, length and density of untreated abandoned or dirt roads, delivery factors (more road lengths closer to or with stream crossings), and higher number of cutslopes. Graham Gulch and Cloney Gulch sub-basins also had relatively high rates for some of the same reasons.

4.2.5 "Untreated" Roads

An annual sediment delivery estimate from untreated roads (i.e., roads not yet upgraded to HCP stormproofed standards), resulting from gullies and washouts of fill and/or cutbanks, including watercourse crossing failures, was calculated using the 1998-2003 ***management discharge site*** rate provided in the NCRWQCB's Draft TMDL for Upper Elk River (NCRWQCB 2013; Peer Review Draft – Table 4.32). This rate (55 tons/mi^2/year) was used by the NCRWQCB to adjust estimates of future yield from inventoried road-related sediment sources to correspond with actual past yield rates. The TMDL rate was applied without adjustment for the period of 2001-2005, and then reduced for the subsequent period of 2006-2011 to account for the treatment (erosion control) of sites implemented during the first period. The reduction in rate corresponded directly with the amount/percentage of future delivery controlled by treatment during the first period analyzed (2001-2005). An annual sediment delivery rate of 47.7 tons/mi^2/year (27% of all surface erosion) for the entire sediment budget period was calculated as the weighted average of the tons/year for each period (2001-2005, 2006-2011), and assumes both periods had failure-triggering events (i.e., 2003 and 2006).

This method for estimating annual delivery rate is somewhat crude as it relies on estimates of future sediment delivery (which are inherently uncertain) made during the initial road inventories, most of which were conducted over a decade ago. Thus, confidence is low in the precision of annual delivery rate estimates. However, being based upon actual field inventories, the approach does provide for a generally accurate representation of relative sub-basin delivery.

Individual sub-basin estimates were calculated as follows: For each period, the percentage of future yield for each sub-basin (based on spatially explicit field inventories) relative to the watershed total was calculated. The tons/year for each sub-basin was then calculated, for each period, based on the tons/year previously calculated for the entire watershed multiplied by the individual percentage (yield) for each sub-basin.

Based on the field inventories of future delivery, a significant portion of the estimated annual delivery originated directly from failing watercourse crossings including legacy culverts, log-fill, and fords. The McCready Gulch sub-basin had the highest rate of sediment delivery from pre-HCP untreated roads with 168 tons/mi^2/year. This sub-basin had older, extensive, poorly constructed road systems including mainline haul roads located parallel to Class I streams and a relatively high number of mid-slope stream crossings. Also, the McCready Gulch sub-basin has also experienced significant HCP stormproofing and road decommissioning in recent years to address this situation.

4.2.6 HCP “Treated” Roads

HRC monitors road construction and reconstruction practices closely. This is accomplished through a formal annual road auditing and inspection program which tracks performance and evaluates effectiveness. The program is patterned after the U.S. Forest Service BMPEP as required by the HCP and is similar to the approach used by CAL FIRE for assessing the effectiveness of forest practice rules in Cafferata and Munn (2002).

For the purpose of sediment budget estimates, post-treatment delivery has been quantified from discharge notifications submitted by HRC to the NCRWQCB based on observations during these road inspections and other general field visits. Estimated delivery from these sources occurred at a rate of 10.6 tons/mi^2/year and accounted for about 6% of all surface erosion from 2001-2011.

Confidence in delivery estimates for this source is moderate to high as the inventories from which rates originate are current and based on actual observed delivery.

4.3 CONTROL OF SEDIMENT FROM ROADS

HRC maintains a 166-mile contemporary road network across its Freshwater Creek ownership (HCP covered lands); approximately 6.9 miles per square mile. In addition to this maintained road system, a total of 30 miles of streamside and mid-slope road in the watershed have been treated for erosion control and decommissioned since 1999 (Table 4-4; Map 6).

Upgrading and stormproofing are HCP terms for proactively reducing road-related sediment delivery by disconnecting roads from the stream system through the installation of additional cross drains, removing or stabilizing unstable fills, replacing failing or undersized culverts with culverts and bridges sized to accommodate 100-year flood events, rocking or otherwise treating hydrologically-connected native road surfaces, and in some instances decommissioning roads altogether. As of 2015, HRC has storm-proofed and upgraded 146 miles (88%) of the 166-mile Freshwater Creek road system (HCP covered lands). Another 30 miles, as noted above, involved the decommissioning (i.e., removal from the contemporary road system) of legacy logging roads.

In addition to stormproofing, road use restrictions are implemented across HRC property. HCP §6.3.3.6 describes conditions under which various types of road use – from log hauling to light vehicle use – is permitted during the wet weather period (October 15 – May 1). Roads are required to meet and be maintained to a specific "permanent" standard designed to minimize sediment delivery if log hauling is to occur during dry periods of the wet weather period. Log hauling is prohibited during rainfall events sufficient to generate overland flow off the road surface in hydrologically-connected road segments. Use of the road for hauling is not allowed to resume following shut down due to rainfall until overland flow has abated and saturated soil conditions are not exhibited on the road surface in hydrologically-connected road segments.

Table 4-4. HRC HCP Road Conditions within the Freshwater Creek WAU in 2015 (2016 HRC GIS)

Sub-basin Name	**HCP Area Road Miles**		**Road Density- Treated[1] Miles/sq. mile**				**Road Density-Untreated Miles/sq. mile**				**Road Density[2] Miles/sq. mile**
	Treated	***Untreated***	***Paved***	***Gravel***	***Native "Dirt"***	***Decom***	***Paved***	***Gravel***	***Native "Dirt"***	***Legacy/ aband***	***Total***
Upper Mainstem (Upper FW)	46.97	3.39	0.00	2.76	3.64	0.42	0.03	0.05	0.29	0.12	6.89
South Fork Freshwater	18.70	1.27	0.00	4.28	1.48	0.16	0.00	0.15	0.25	0.00	6.16
Graham Gulch	16.68	3.19	0.00	1.79	3.44	2.28	0.01	0.02	1.06	0.34	6.68
Cloney Gulch	34.73	6.22	0.00	2.98	3.18	2.32	0.00	0.03	0.49	1.00	7.67
Little Freshwater	31.42	2.12	0.00	3.44	2.81	0.53	0.00	0.16	0.13	0.17	6.71
McCready Gulch	19.24	1.75	0.00	3.63	2.94	4.70	0.00	0.06	0.82	0.14	7.59
Mainstem (Lower Freshwater)	5.37	0.58	0.13	3.52	1.82	2.10	0.10	0.14	0.58	0.00	6.28
School Forest	2.75	1.23	0.00	1.31	3.88	0.36	0.00	0.04	2.45	0.00	7.68
Fay Slough	0.00	0.16	0.00	0.00	0.00	0.00	0.00	2.61	1.19	0.00	3.79
Total	175.86	19.91	0.00	3.09	2.99	1.26	0.01	0.09	0.45	0.28	6.92

[1] From 2012-2015, treatments were implemented on 26 miles of roads.

[2] Total road density does not include roads decommissioned to stormproofed standards.

HCP §6.3.3.5 outlines road inspection requirements to be conducted to ensure road maintenance needs are identified on an annual basis and in response to large storm events. These include an annual (April – October) road system inspection conducted for the purpose of identifying maintenance needs, as well as preventative winter season storm-triggered inspections following 3 inches or more of precipitation within a 24-hour period. Additional inspections are conducted under RPF purview.

4.3.1 Road-Related Sediment Source Inventory

HRC maintains an inventory of road-related sediment sources across its ownership including the Freshwater Creek WAU. This inventory serves as the basis for prioritizing and scheduling road upgrading and stormproofing activities.

Including decommissioned roads, 176 miles of the Freshwater haul road system have been upgraded and/or stormproofed since 1998. This includes the treatment of over 760 individual active or potential sediment road-related discharge sites, resulting in the prevention or removal of an estimated 154,400 cubic yards of sediment from entering the Freshwater Creek stream system (Figure 4-9). Road-related sediment control on HCP covered lands in the Freshwater watershed will continue to primarily focus on the maintenance of stormproofed roads.

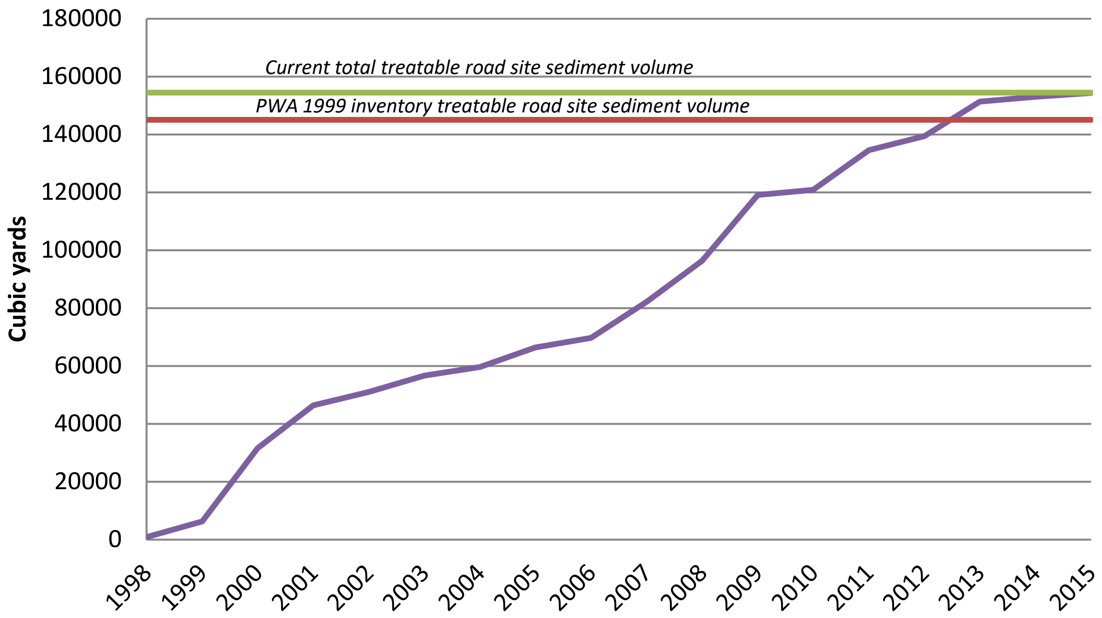


Figure 4-9. Freshwater treated road-related sediment source volume

4.3.2 Road Decommissioning

As previously discussed, 30 miles of historically constructed roads have been decommissioned on HRC Freshwater ownership since 1999 (see Map 6). Decommissioning is intended to permanently remove a designated road from the contemporary haul road system. It therefore requires adequate planning to ensure other access routes to the area, either existing or planned, are available for future forest management. Decommissioning attempts to make the targeted road “hydrologically invisible” by removing elements of the road that unnaturally reroute hillslope drainage or present slope stability hazards. Historical streamside and mid-slope roads constructed during the ground-based tractor logging era are often targeted for decommissioning as part of developing a contemporary road system that favors ridgetops and primarily serves areas utilizing cable yarding logging methods.

Pacific Watershed Associates has played a lead role in the assessment and supervision of much of the road decommissioning that has occurred on HRC timberlands in the Freshwater Creek watershed. Three particularly noteworthy PWA-HRC partnership projects include:

<u>Graham Gulch and School Forest Salmonid Enhancement Project:</u> Decommissioned 5.11 miles of mid-slope, streamside, and inner gorge roads including the treatment of road surface and 73 sediment source sites resulting in the control of over 14,000 cubic yards of sediment. This work was conducted from 2009 through 2011 in the Graham Gulch and School Forest Creek tributaries to Freshwater Creek. (PWA Report No. 11084101, March 2012)

<u>Cloney Gulch Road Decommissioning Project:</u> Decommissioned 7.18 miles of mid-slope, streamside, and inner gorge roads including the treatment of road surface and 58 sediment source sites resulting in the control of over 15,000 cubic yards of sediment. This work was conducted from 2009 through 2012 in the Cloney Gulch and Falls Gulch tributaries to Freshwater Creek (PWA 2012).

<u>McCready Gulch Road Decommissioning Project:</u> Decommissioned 3.5 miles of mid-slope, streamside, and inner gorge roads including the treatment of 39 discrete sediment source sites resulting in the control of over 33,000 cubic yards of sediment. This work was conducted from 2011 through 2013 in the McCready and Horse Gulch tributaries to Freshwater Creek (PWA 2014).

4.3.3 Erosion Control Effectiveness Studies

HRC, and its predecessor, have undertaken several scientific studies over the last decade in order to better understand the effectiveness of HCP stormproofing and wet weather restriction practices in preventing storm-triggered sediment delivery from roads. Two of these studies, designed and implemented under the supervision of Dr. Kate Sullivan, are summarized below.

4.3.3.1 Sediment Production from Stormproofed Roads on HRC Lands

The objectives of the study reported by Sullivan et al. (2011) (Appendix 5) were to quantify the amount of sediment generated from HRC stormproofed roads, determine the effect of vehicle use on sediment generation from different road surfaces, quantify the erosion rates from road surfaces managed according to HCP guidelines, and determine road locations and lengths that deliver sediment to streams. Combined, data from this study were used to validate sediment models and assumptions, mainly SEDMODL and SEDMODL2.

All road segments measured during this study represented common road conditions found on the property. Sites were primarily in the undifferentiated Wildcat geology located in the Freshwater and Elk River watersheds. The study methods produced highly repeatable results among sites and years. Study results have implications for a number of the HCP strategies including the effectiveness of wet weather hauling restrictions, road surfacing and construction, hydrologic disconnection at stream crossings, road sediment modeling, and sediment budgets.

Key findings from this report included:

- Sediment load produced during events was primarily related to total rainfall amount and runoff volume.
- Sediment concentrations during storms followed a “supply-limited” pattern as observed in previous studies such as Bilby et al. (1989) and Reid and Dunne (1984). Sediment concentration was highest at the initiation of runoff and declined sharply in the first hours of a rainfall event as sediment washed from the road surface. There was no relationship between discharge rate and suspended sediment concentration at any site.
- The effects of traffic before and/or during events were low but detectable at a few of the road segments. At others, traffic effects could not be detected despite very heavy traffic.
- The annual total sediment yield from rocked road segments was very low compared to previous studies and compared to SEDMODL estimates. Situations that appeared to lead to higher sediment yields included not fully stabilized cutslopes, very steep gradients, pit-run rocked surfaces with log truck traffic, and new construction.
- The relevance and importance of parameters used in the WDNR model and SEDMODL, including total precipitation, erosion, traffic levels, vegetative cover density, surfacing material, and time since construction, were validated in this study. The baseline erosion rate, based on geology provided in the WDNR manual, was consistent with observations within the context of model application, based on sediment measured from native surface roads.
- Both the WDNR (SEDMODL) and WEPP models significantly over-predict sediment relative to observations on HRC roads managed with HCP road management strategies.

- The traffic factor applied to heavily used mainline roads (log truck traffic) based on regional studies was originally 20 times greater than a base condition of light pickup use only. Changing the factor to just 0.04 times the base rate correctly models sediment for all mainline road segments. This essentially eliminates the traffic effect as a factor influencing sediment yield on roads managed with HCP construction and use standards.

This study was primarily designed to determine erosion rates for use in sediment budgeting. However, the study also directly assessed the effectiveness of some of the road management practices implemented under the HCP to minimize sediment generation, and results had implications for others. These further findings include:

- The very low sediment yields observed from heavily used roads confirmed the effectiveness of the wet weather hauling restrictions. Erosion rates were at least 10 times lower than observed in other similar studies in the coastal regions of the Pacific Northwest dominated by rainfall precipitation (e.g., Bilby et al. 1989).
- The lowest sediment yields were observed on road surfaces rocked with the most durable material. Strategic use of the best rock on the locations with the greatest potential for delivery of road surface runoff to streams, such as within the hydrologically connected segments, would further minimize sediment delivery.
- As expected, erosion rates were significantly higher on dirt roads. HCP requirements to hydrologically disconnect and effectively manage surface runoff, and rigid adherence to seasonal restrictions prevent/minimize discharge for native surfaced roads.
- Sediment yields were higher on newly constructed roads for the first year after construction. Yield declined to low levels the year following. Scheduling construction a year prior to use for log hauling would enable the road to harden and help minimize sediment input.
- Several study segments had cutslope issues that affected sediment yield. Incomplete vegetative cover resulted in visibly active erosion on one secondary road, illustrating the importance of achieving proper cutslope stability and vegetative cover.
- Allowing ditches to vegetate appears to have also helped minimize the sediment generated with road and ditch runoff on heavily used road segments.
- The low road erosion rates observed in this study have significant implications for sediment budgeting in HRC watersheds. Road surface sediment models were adjusted for the Freshwater Creek WA revisit based on some of the results of this study.

4.3.3.2 Effectiveness of Road Construction Practices in Preventing Sediment Delivery: Monitoring Report for 2006 to 2010

In 2005, HRC implemented a road auditing and inspection program to track performance and evaluate effectiveness of road projects at minimizing road-related sediment delivery to streams (Miles and Simpson 2013) (Appendix 3). This program is patterned after the U.S. Forest Service BMPEP as required by the HCP (§6.3.5.1.3).

The objective of the road construction/deconstruction specifications is to produce a road that is "storm-proofed," meaning it is capable of weathering all storms including large magnitude, infrequent events (defined as the 100-year storm) with little to no damage to water crossings and minimum sediment delivery. The HRC road monitoring program evaluates the effectiveness of stormproofing specifications in minimizing sediment delivery to streams. Field inspections focus on stream crossings and their contributing road segments during and after occasions when roads are vulnerable to erosion. Data collection is done in the form of an implementation audit immediately following construction, wet weather and post wet weather inspections, and erosion void monitoring.

Key findings from this report include:

- Post-construction sediment delivery volumes were found to have declined greatly from previous findings and substantially lower than reported from elsewhere in the region. Zero or small volumes (< 1 yd^3) of sediment were delivered following construction at 71% of crossings. Delivery was less than 10 yd^3 at 90% of sites.
- Each year, a few sites had large volumes of erosion. A number of these have been investigated to determine how to prevent such erosion in the future. Taking the population as a whole, generally about 0.6% of the sediment "saved" (i.e., removed or stabilized) each year by stormproofing projects delivers to the stream.
- HRC project design implementation rates are high. Despite the conservative decision rule used during the audit process in determining non-conformance, most aspects of road design are in conformance 90 to 100% of the time at the component level with even higher rates, when possible, at the subcomponent level.
- Less than half of audit non-conformances resulted in "problems" observed on the roads in the following winter. Further, not all problems led to erosion and not all erosion sites delivered sediment to streams. Out of the small number of sites failing one or more specifications, only about 15% eventually delivered sediment to streams. These results were taken under consideration and improvements were made to the audit process, specifically, to enable distinction between minor and major deviations to specifications in the future, such that a minor specification non-conformance does not necessarily mean the entire site fails to conform to specifications.

Overall, the HRC road auditing and inspection plan has shown that road work is being done effectively to minimize sediment delivery to watercourses. When activities do result in sediment discharge, HRC can identify why it occurred and adaptively manage future potentially similar situations.

5 RIPARIAN FUNCTION

Riparian function can be defined as the interaction of various hydrologic, geomorphic, and biotic processes within the riparian environment (WDNR 1997). Riparian areas are transition zones between terrestrial and aquatic ecosystems and provide important functions for stream ecology, including temperature regulation and input of large woody debris, organic matter, and nutrients (Gregory et al. 1987; Figure 5-1). Riparian forests both affect and can be affected by the active stream channel as well as by geologic and topographic features. Riparian forests influence stream channel complexity, bank cohesion, fish and wildlife habitat, thermal regulation of stream temperature and riparian microclimate, and support the aquatic and terrestrial food web in the form of insect and organic matter.

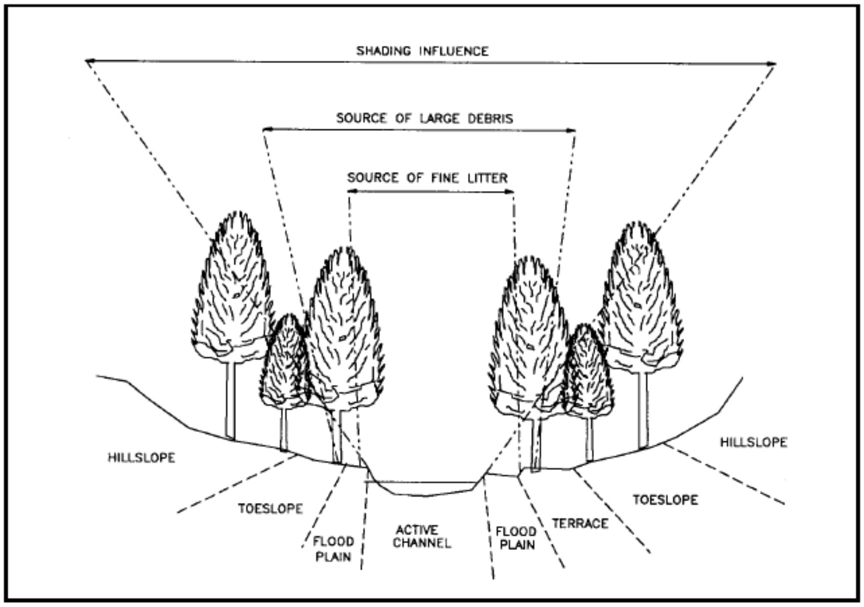


Figure 5-1. Diagrammatic representation of functional roles of riparian zones (Gregory et al. 1987)

These processes may be lost or degraded as riparian vegetation is altered in size, density, or species composition. Loss of riparian vegetation can also have detrimental effects on bank stability as root strength is lost or diminished.

5.1 CURRENT CONDITIONS

The initial Freshwater WA (PALCO 2003) found approximately 70 percent of Class I and II riparian zones to be dominated by dense (>90% canopy cover) second growth redwood approximately 70 years of age on average, with an increasing hardwood component (red alder, willow, and big leaf maple) along Class I (fish-bearing) valley floors. Other conifer species present include Douglas-fir, Sitka spruce, western hemlock, and red cedar.

Updated information on riparian stand conditions is limited to a review of contemporary harvest history and data collected at seven Aquatic Trends Monitoring (ATM) stations. The 2014 Class I Stream Aquatic Habitat Trends Monitoring Report provides recent ATM survey results (see Section 7.1). As a whole, HCP lands in Freshwater Creek met HCP Aquatic Properly Functioning Condition (APFC) targets for both overstream and riparian forest canopy cover in 2014.

5.2 RIPARIAN MANAGEMENT ZONE PRESCRIPTIONS

All Class I and II watercourses on the HRC HCP covered lands within the Freshwater Creek WAU have an RMZ divided into an inner and outer band. Timber harvest is prohibited from within the inner band immediately adjacent the watercourse. Timber harvest in the outer band is limited to single-tree selection pursuant additional specific requirements detailed in the Freshwater Creek Watershed Analysis Prescriptions (December 2003; Appendix 2).

5.3 RIPARIAN HARVEST

A cumulative total of approximately 117 acres of Class I RMZ Outer Band, and 468 acres of Class II RMZ Outer Band were harvested using single-tree selection pursuant HCP Freshwater Creek WA prescriptions from 2001 to 2015 (Table 5-1).

Table 5-1. Riparian harvest acres on HRC HCP land 2001-2015

	Freshwater HCP Covered Lands
Class I Outer Band	117
Class II Outer Band	468
Total	***585***
Estimated Total RMZ[1]	2240
Estimated RMZ Harvest	***26.1%***

[1] Estimate based on stream class miles and averaged RMZ widths: Class I streams buffered by 100 ft each side for a total width of 200 ft and Class II streams buffered by 75 ft each side for a total width of 150 ft.

5.4 PRESCRIPTION EFFECTIVENESS

5.4.1 Stream Temperature and Canopy Cover

Canopy cover is considered to be the percent of stream channel shaded by the natural spread of overstory canopy. While there are many other influences that affect stream temperature, canopy cover shields the watercourse from solar heating. Summer water temperatures can limit the success of juvenile salmonid growth and feeding. The APFC target value for a stream's maximum weekly average temperature (MWAT) is less than or equal to 16.8°C. Water temperature meeting the APFC target is considered to provide an optimum condition for Coho salmon.

The initial Freshwater Watershed Analysis (PALCO 2003) found that, with one exception, stream temperatures throughout the watershed were meeting this target. The exception was the station in the region referred to as Mainstem Freshwater, approximately 750 ft downstream of South Fork Freshwater where stream temperatures exceeding 16.8°C were recorded in 1997. It was also reported that stream canopy conditions throughout the watershed were adequate except for the middle reaches of Upper Freshwater and South Fork Freshwater as well as portions of Graham Gulch.

As part of the HCP ATM program, stream temperature values have been collected at seven monitoring stations every three years throughout the watershed (Map 7). Riparian and overstream mid-channel canopy cover is also measured at these locations. Section 7.1.4 discusses water temperature monitoring at all seven ATM stations in the Freshwater Creek WAU, and includes a summary of MWAT data for the 2003-2014 period. All of the sites meet the APFC MWAT target when averaged over the 12-year period. For canopy cover, all stations exhibited an increase in both riparian and overstream canopy cover except for Station 015 (South Fork Freshwater) which had a decrease in overstream canopy and 019 (Graham Gulch) which saw a decrease in riparian canopy cover.

5.4.2 LWD Recruitment

The initial Freshwater Creek WA examined recent recruitment of LWD to stream channels based on in-channel wood counts of LWD recruited within an estimated period of no more than two years. Twenty-three segments were sampled through the Freshwater watershed and instream densities (or recruitment) per year ranged from 13 to almost 300 m^3/km/yr. As stated in the Freshwater Creek Watershed Analysis Cumulative Effects Assessment (PALCO 2003), "large woody debris (LWD) is abundant through most of the watershed, with the exception of the lower mainstem." As for LWD recruitment, the initial assessment from 2003 states that "the majority of the riparian stands in the Freshwater Watershed (73% of stands along Class I and II streams and 54% of the stands along Class III streams) currently provide good near-term and long-term LWD recruitment per the definitions of functional wood described by Fox (1994)."

Section 7.1.1 below outlines current LWD conditions based on the 2003-2014 period. In general, average piece length is below the APFC target while average diameters are above target. Average LWD piece frequency is below target and average volume frequencies are generally above target. Average key piece frequencies were above target in South Fork Freshwater and McCready Gulch but below target elsewhere.

Section 7.2 below describes two extended LWD surveys completed in 2006 and revisited in 2013. As may be expected, APFC targets for LWD were achieved regularly in the upper stream reaches but deficiencies were apparent in the lower stream reaches. This may be due to high flows transporting away LWD within the lower reaches.

6 STREAM CHANNEL

The WA revisit includes evaluating changes in stream channel conditions in the Freshwater Creek watershed. Stream channel monitoring activities since 2002 have involved characterization of turbidity, suspended sediment, and flow at a maximum of nine stream Hydrologic Trends Monitoring (HTM) sites (Map 7). Additionally, trends in channel aggradation and degradation have involved conducting cross-sectional channel surveys within specific stream reaches. This section provides a summary of study sites and methods, and sediment monitoring results with time and by location. Detailed monitoring results are presented by individual sub-basin in Appendix 6.

6.1 STUDY SITES AND METHODS

Since 2002, a network of fully instrumented gaging stations has been maintained across the Freshwater Creek watershed by the former landowner, PALCO, and the current landowner, HRC. Nine run-of-the-river (i.e., no flumes) HTM stations are currently operated by HRC (Map 7) with contributing basin areas ranging from 2 to 23 km^2 (Table 6-1). Six HTM stations were installed in 2002, two in 2003, and one in 2005. Monitoring is conducted during the winter months (October-May) and produces an annual record of stream discharge and suspended sediment using continuous monitoring instruments. Continuous data (water depth and turbidity) are complemented by manual measurements of discharge in relation to stage and by suspended sediment samples collected via automatic water samplers over a range of flows. Cross-sectional surveys are conducted annually within each monitoring reach in order to detect trends in channel incision/aggradation and to assess any potential shifts observed in stage-discharge rating curves.

6.2 SEDIMENT MONITORING RESULTS

The following section provides an overview of water quality and channel dimensions throughout the Freshwater Creek watershed. Detailed channel monitoring data are presented and discussed, by sub-basin, in Appendix 6.

6.2.1 Sediment Yield, Turbidity, and Peak Flow

Gaging stations were installed over a three-year period beginning in WY 2003 (Table 6-1). Due to the uneven monitoring record among stations, only data from the HTM stations installed in WY 2003 are used to assess mean spatial patterns of sediment yield, turbidity, and peak flow. Detailed analysis of data collected at the remaining three stations is addressed in Appendix 6. Data from all gaging stations are included when assessing temporal trends.

Table 6-1. Summary of HRC water quality HTM gaging stations in the Freshwater Creek watershed

Station Number	Station Description	Drainage Area (km^2)	Begin Monitoring (Water Year*)	Total Years Monitored**
500	Unnamed tributary to upper mainstem Freshwater Creek, referred to as "Beck's"	2.2	2003	14
502	Middle reach of upper mainstem Freshwater Creek, referred to as “Upper Freshwater Creek”	17.1	2003	14
504	Cloney Gulch	12.0	2003	14
505	Graham Gulch	6.2	2003	14
506	South Fork Freshwater Creek	8.2	2003	14
523	Lower reach of upper mainstem Freshwater Creek at confluence of South Fork Freshwater Creek, referred to as “Lower Freshwater Creek”	22.8	2005	12
526	Upstream reach of upper mainstem Freshwater Creek above Road 15, referred to as Upper Freshwater Creek	5.1	2004	13
527	McCready Gulch	4.7	2003	14
528	Little Freshwater Creek	12.0	2004	13

**Water year (WY) period: October 1 - September 30; **Through WY 2016 (all stations currently active)*

Due to known differences in turbidity among different sensor types and makes (Davies-Colley and Smith 2001, Lewis and Eads 2009, and Sullivan et al. 2012), annual relationships are developed between each field turbidimeter (DTS-12 by Forest Technology Systems) and the bench turbidimeter used to process samples in the HRC sediment laboratory (HACH 2100 by HACH). Derived model equations are utilized to compute a parameter termed “lab turbidity” from the field reading in the 15-minute continuous record. The relationship is linear and very strong for each instrument ($R^2 \geq 0.9$). The standardized lab turbidity is used for comparisons of turbidity parameters among stations throughout this report. Sediment yields were developed using continuous field turbidity as it has been established as the preferred surrogate variable to predict instantaneous suspended sediment concentration (SSC) (Lewis and Eads 2009).

Turbidity datasets from each gaging station were truncated by the latest start date and the earliest end date throughout the total period of record in order to ensure that each annual dataset contained an equal number of intervals for comparative analysis. Turbidity exceedance analysis was performed based on methods detailed by Klein et al. (2011). A 10% exceedance probability or 10% turbidity exceedance (turbidity level that was exceeded 10% of the time being considered [10%TU]) was derived from the continuous data to represent chronic turbidity. Calculating the 10%TU captures stormflow turbidities that occur between storm peaks and winter baseflows, providing a single value to index chronic exposure to salmonids (Klein et al. 2011).

Chronic turbidity and suspended sediment yield are variable across sub-basins in the Freshwater Creek watershed (Figure 6-1). Since WY 2003, mean sediment yields have been highest at Graham Gulch (Station 505; 174 Mg km^{-1} yr^{-2}) and lowest at Cloney Gulch (Station 504; 112 Mg km^{-1} yr^{-2}). Mean 10%TU has been highest at Graham Gulch (Station 505; 61 Nephelometric Turbidity Units [NTU]) and lowest at McCready Gulch (Station 527; 38 NTU). Mean 10%TU at Graham Gulch has been approximately 30% higher than at Cloney Gulch where the second highest levels of chronic turbidity have been measured since WY 2003 (47 NTU).

Annual weather conditions have exerted a dominant influence on annual turbidity and sediment yield patterns. Across all stations throughout the period of record, turbidity and sediment yield trends have exhibited a relatively consistent temporal distribution with spikes observed during the wet winters of WY 2003, 2006, and 2011 and dips observed during drier winters of WY 2014 and WY 2009 (Figure 6-2). Overall, there has been greater annual variation among sites in terms of turbidity than sediment yield. For example, the upper extent of mainstem Freshwater Creek (Station 526) has been markedly less turbid than all other stations during all but one season since WY 2004.

Annual instantaneous peak flows have been somewhat less variable among sub-basins than sediment yield and turbidity (Figure 6-3). Since WY 2003, peak flows have been highest on average at Beck's tributary (Station 500; 1.2 cms km^{-2}) and lowest on average at McCready Gulch (1.1 cms km^{-2}). Across all stations, flow trends have been generally consistent temporally with the largest events occurring in WY 2003 and WY 2011 (Figure 6-4). WY 2006 contained the largest discrepancy between stations as peak flow measured at Beck's tributary was about 25% higher than the next highest measurement in the watershed (mid-upper Freshwater Creek; Station 502) and nearly 65% greater than at the lowest (Cloney Gulch). Trends observed at Cloney Gulch have been somewhat unique relative to other sub-basins particularly during the drier water years of 2008 and 2014.

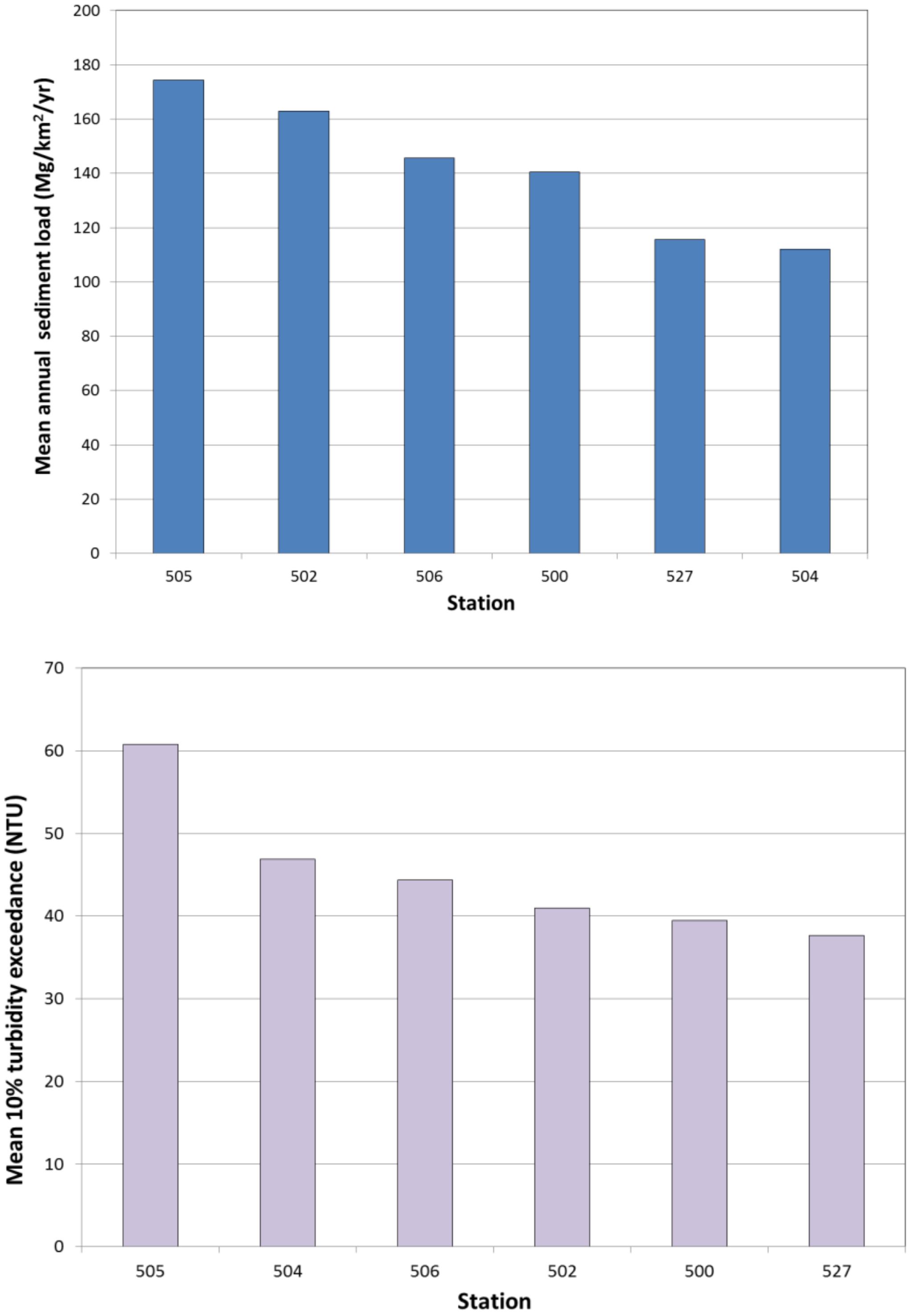
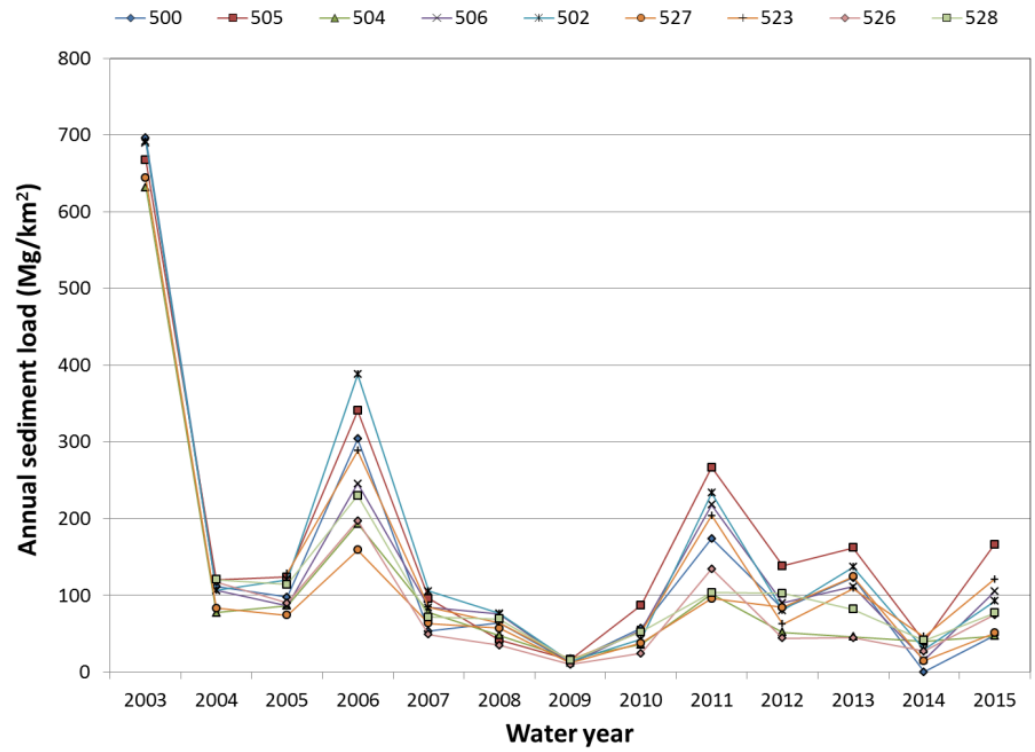


Figure 6-1. Mean annual suspended sediment load and mean annual 10%TU at Freshwater Creek gaging stations installed in WY 2003



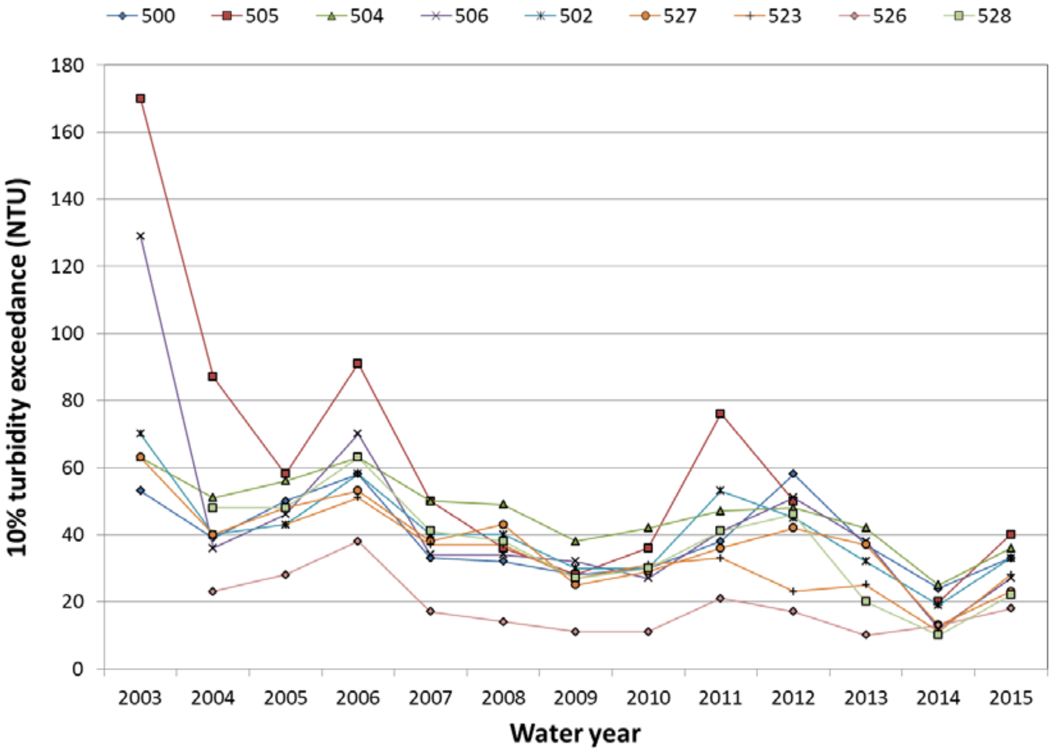


Figure 6-2. Annual suspended sediment yield and annual 10%TU at all Freshwater Creek gaging stations, WY 2003-2015

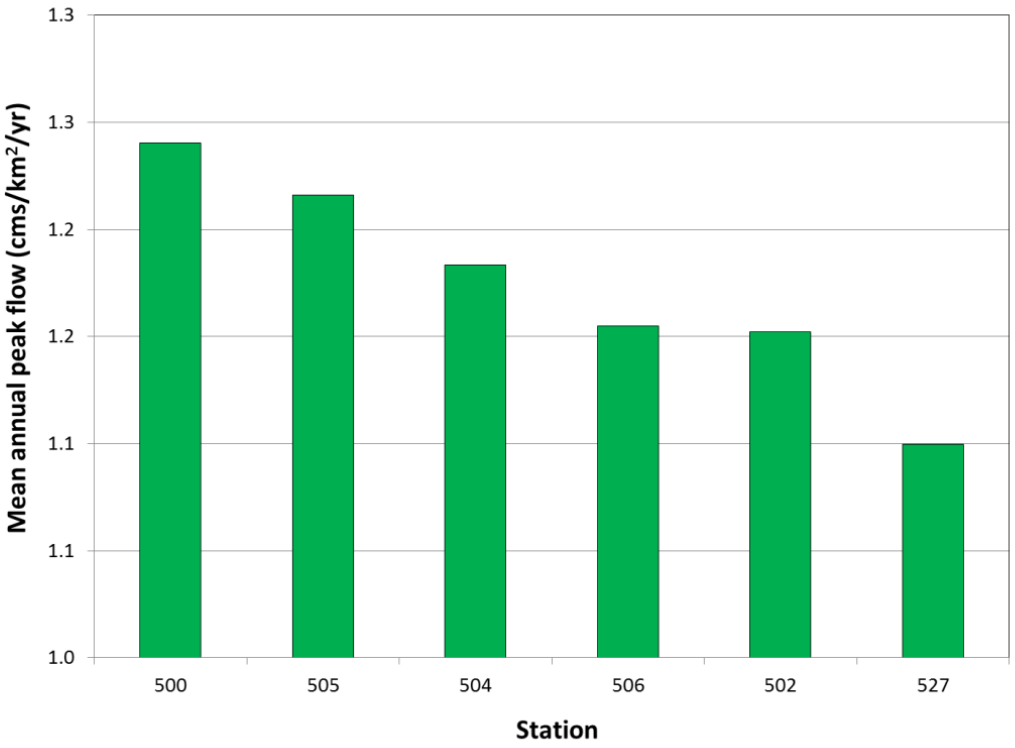


Figure 6-3. Mean annual instantaneous peak flow at Freshwater Creek gaging stations since WY 2003

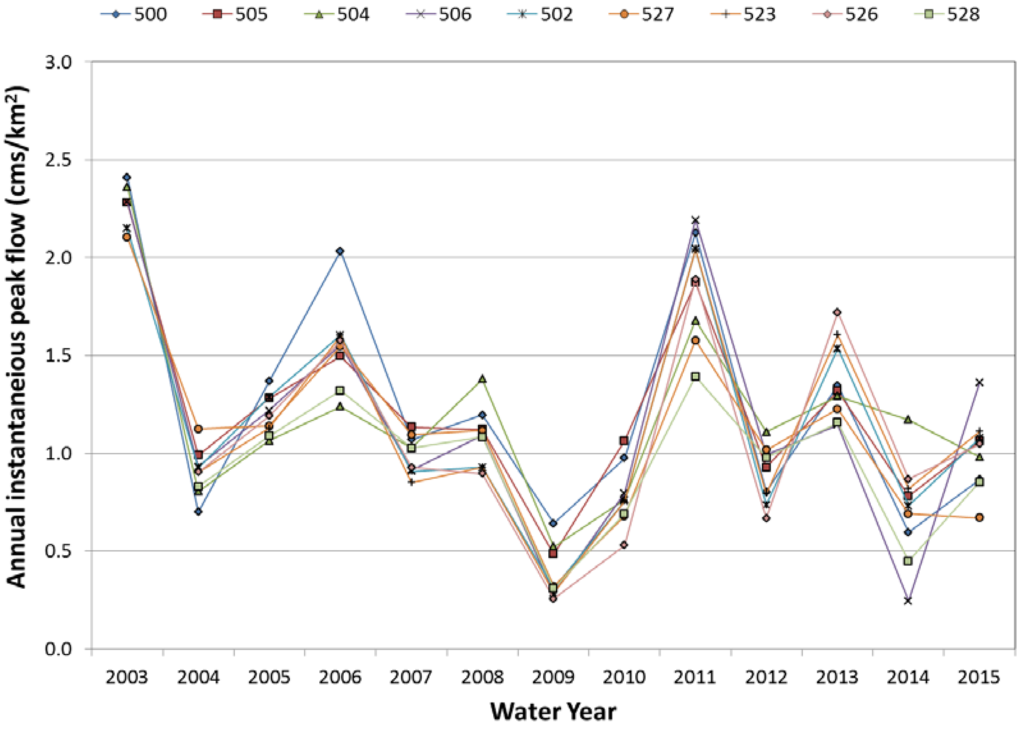


Figure 6-4. Annual instantaneous peak flow per all gaging stations in Freshwater Creek

Annual sediment yield has been highly correlated with peak flow at all stations ($R^2 = 0.55$ to 0.90). The relative strength of this relationship provides a useful metric to evaluate potential changes in watershed response to large streamflow events. In the five years from WY 2011 through WY 2015, sediment yield has been generally lower (i.e., ≥ 3 out of 5 years) relative to peak flows at three HTM stations (502, 504, and 523) and has remained generally unchanged or has been higher relative to peak flows at six HTM stations (506, 527, 505, 528, 526, and 500) (Table 6-2). More discussion regarding trends at individual stations is provided in Appendix 6.

Table 6-2. Sediment yield vs peak flow and annual precipitation vs 10%TU regression summary for Freshwater Creek gaging stations

Station Number	Peak Flow vs. Sediment Yield Coefficient of Determination [R^2]	Annual PTP vs. 10% TU Coefficient of Determination [R^2]	5-Year Sediment Yield Summary (WY 2011-2015)
506	0.90	0.57	Higher sediment loads relative to peak flows (3/5 years)
523	0.87	0.63	Lower sediment loads relative to peak flows (3/5 years)
502	0.85	0.73	Lower sediment loads relative to peak flows (4/5 years)
527	0.83	0.68	Higher sediment loads relative to peak flows (3/5 years)
505	0.80	0.54	Higher sediment loads relative to peak flows (3/5 years)
528	0.76	0.69	Higher sediment loads relative to peak flows (3/5 years)
526	0.66	0.52	Higher sediment loads relative to peak flows (3/5 years)
504	0.60	0.77	Lower sediment loads relative to peak flows (5/5 years)
500	0.51	0.22	Higher sediment loads relative to peak flows (4/5 years)

6.2.2 Channel Dimensions

Changes for in-stream channel dimensions can be assessed by cross-section survey data collected at the gaging (i.e., HTM) stations and at the seven ATM stations distributed throughout the watershed (Map 7).

A single high-density total station survey is conducted annually at each gaging station in Freshwater Creek. In 2012, survey locations were assessed and many cross-sections were re-located. As a result, all but two stations (526 and 500) contain multiple survey periods (i.e., more than one cross-section has been surveyed since the station was installed). Table 6-3 lists survey periods and provides a summary of channel conditions throughout the monitoring period. Figure 6-5 illustrates these conditions from 2012-2016, the most recent survey period during which the same cross-section location has been measured at each station. Survey data illustrate overall aggradation at six stations, overall scour at two stations, and negligible change at one station (see Appendix 6). These trends are consistent with observed shifts in rating data (i.e., at stations where aggradation has occurred, lower discharge has been measured relative to stage), particularly at Beck's tributary, Cloney Gulch, Graham Gulch, and Mid-Freshwater Creek. Channel area response to peak flow has been variable across sub-basins (Table 6-4). The strongest linear relationships have been observed in the upper mainstem of Freshwater Creek ($R^2 = 0.47$) where channel area has decreased as peak flow increases, and in South Fork Freshwater Creek where channel area has increased with decreasing peak flows ($R^2 = 0.35$). The relationship weakens but remains mixed at Beck's tributary and Lower Freshwater, and no correlation has been observed at the other stations.

Table 6-3. Summary of cross-sectional survey data collected at Freshwater Creek gaging stations, 2012-2016

Station Number	Survey Period(s)	5-Year Summary (2012-2016)
506	2002-2003; 2004-2009; 2010-2011; 2012-2016	General scour 2002-2011; Slight fill 2012-2016.
523	2006-2011; 2012-2016	Slight fill 2006-2011; Stable 2012-2016
502	2002-2003; 2006-2011; 2012-2016	Moderate scour 2002-2010; Moderate scour 2012-2016
527	2004-2011; 2012-2016	Slight fill 2004-2011; Moderate fill 2012-2016
505	2005-2011; 2012-2016	Slight fill 2005-2011; Moderate fill 2012-2016
528	2005-2011; 2012-2016	Stable 2005-2011; Stable 2012-2016
526	2005-2016	Moderate scour
504	2005-2011; 2012-2016	Moderate scour 2002-2010; Moderate fill 2012-2016
500	2003-2016	Substantial fill

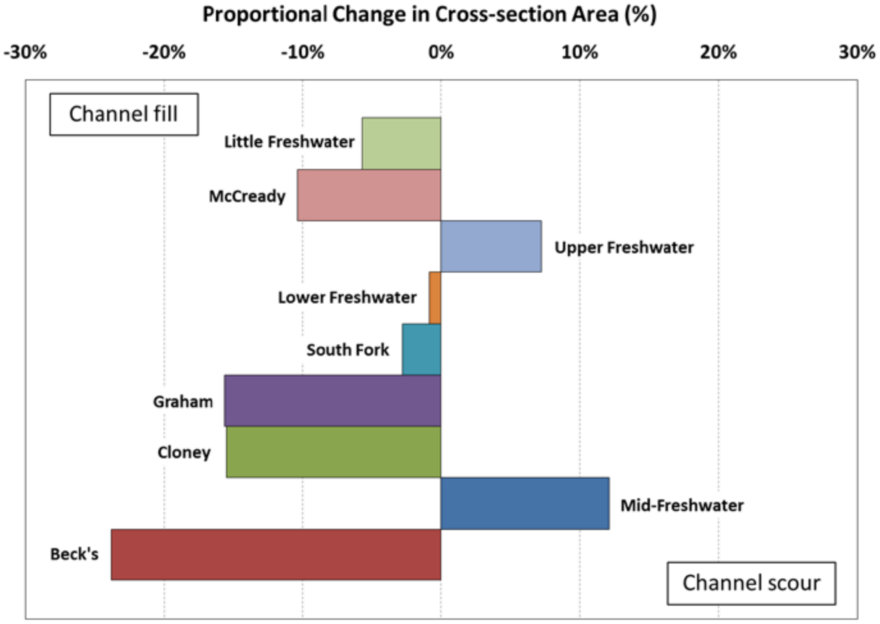


Figure 6-5. Net change in cross-section area expressed as proportion of starting area from 2012 to 2016 at each gaging station in the Freshwater Creek watershed

Table 6-4. Previous winter peak flow (cms) vs. channel area (square meter) regression statistics for Freshwater Creek gaging stations, WY 2003-2015

Station	Previous Winter Peak Flow vs. Change in Cross-section Area Regression Slope [m]	Coefficient of Determination [R^2]
526	-6.71	0.47
506	6.93	0.35
500	3.54	0.28
523	-6.28	0.27
502	-2.00	0.11
528	1.41	0.01
505	0.61	0.004
504	-0.36	0.003
527	-0.11	0.0001

Note: Negative slope values indicate that channel area decreases with increasing peak flows.

Reaches for ATM data collection were delineated between 1997 and 2008 and contain five cross-section locations that are spaced evenly throughout an approximately 1,000-ft-long monitoring reach. ATM stations originally contained three cross-sections but two additional surveys were added in 2002 to most sites in order to increase statistical power. From 1997-2000, surveys were conducted annually but transitioned to a three-year cycle beginning in 2005 as more stations were introduced into the monitoring program. Table 6-5 provides a general summary of cross-section data collected at each ATM station. Contrary to trends observed in the gaging station survey data (which contains only one cross-section per sub-basin), ATM survey data suggest that streambed elevations have been more stable within each sub-basin over time. Differences in upstream and downstream conditions within each monitoring reach are also evident. See Appendix 6 for a detailed synthesis of channel conditions at each sub-basin.

Table 6-5. Summary of cross-sectional survey data collected at Freshwater Creek ATM stations, 1997-2016

Station Number	Stream Name	Basin Area (km^2)	Reach Gradient (%)	Initial Survey Year	General Trend Throughout Monitoring Period
015	South Fork Freshwater Creek	8.17	1.7	1997	Generally stable with some aggradation in the mid-to-upper portions of the reach.
034	Freshwater Creek	22.7	0.9	1997	Aggradation in the lowest portion of the reach since 1997; middle and upper portions have scoured and remained generally stable, respectively, since 2005.
200	Freshwater Creek	32.01	0.4	2005	Generally stable since 2005 with slight aggradation in the lower reach.
019	Graham Gulch	6.43	1.4	1997	Lower reach has scoured since 1997, mid-to-upper portions generally stable since 2005.
202	McCready Gulch	4.39	2.3	2005	Slight aggradation in the top portion; scour in the lower portion since 2005.
092	Cloney Gulch	12.01	0.9	1998	Generally stable with slight scour in the lower portion since 1997; slight fill towards the upper portion since 2005.
018	Little Freshwater Creek	12.06	0.8	2008	Reach has been generally stable throughout since 2005.

6.3 DISCUSSION

Since WY 2003, chronic turbidity, sediment yield, and peak flow have been generally consistent temporally but spatially variable across sub-basins in the Freshwater Creek watershed, a phenomenon commonly observed in drainages throughout the North Coast. Water quality parameters appear to be either favorable or trending towards more favorable conditions in Upper Freshwater Creek, Cloney Gulch, and McCready Gulch. Sediment yields have remained generally static in the South Fork and Little Freshwater Creek sub-basins despite recent increases in chronic turbidity in both drainages. Conditions do not appear to be improving in the Beck's tributary, which continues to deliver a variable, yet moderate amount of sediment into the upper mainstem, nor in Graham Gulch which, per unit area, produces the highest sediment yields in the watershed. A sediment source also appears to be present in the mainstem reach between HTM stations 526 and 502. Each of these scenarios warrants further investigation.

A study was initiated in 2010 that examined sediment production resulting from harvest and road treatment practices in the Beck's tributary sub-basin. Preliminary results from the study suggest that road crossings increased downstream turbidity and SSC, particularly during the first storm event following new construction. Results are generally inconclusive regarding how sediment yields at the gaging station (Station 500) were affected by specific harvest plans due to (1) the large amount of harvesting that occurred within the sub-basin prior to the study; and (2) variable patterns in annual precipitation that occurred during the study.

High sediment yields and chronic turbidity levels in Graham Gulch may be due in part to short-term sediment inputs associated with the Graham Gulch and School Forest Salmonid Habitat Enhancement Project which decommissioned over 5 miles of streamside road (2009-2011). Mixed lithologies dissect numerous mapped traces of the Coastal Belt thrust fault which are likely exacerbating erosive processes. A focused sediment source investigation may be in order to better understand how natural and anthropogenic factors interrelate to influence water quality conditions in the sub-basin.

Average annual suspended sediment yield is 130% higher at Mid Freshwater Creek (Station 502) than measured two miles upstream at Upper Freshwater Creek (Station 526). This discrepancy may be a cumulative result of hillslope instability, increased transport capacity, and a higher proportion of contributing low-order watercourses between the two stations. The HRC landslide inventory denotes an increase in inherent hillslope instability upstream of Station 502 which is a consequence of the presence of deep-seated ground movement. The frequency and distribution of Class II watercourses dramatically increase downstream of Station 526. These drainages function as transport systems for landslide-derived sediments. Downstream of Station 526, the mainstem channel passes through a series of coherent and incoherent Central Belt lithologies which may also explain the increased sediment yields.

Estimates of natural or background erosion rates are extremely variable given the relatively short monitoring period and long history of anthropogenic influence in the Freshwater Creek watershed. Most of the tributary basins have experienced both harvest and road construction/decommissioning during the 13-year monitoring period, often in the same year. Forest management and restoration activities that potentially deliver sediment are ongoing and can exact both positive and negative effects on annual sediment yield. As a result, a great deal of uncertainty exists regarding the overall influence of management activities on current sediment-related water quality. Sullivan et al. (2012) addressed this question in a report that reviewed nine water years of monitoring data (WY 2003-2011) collected at Elk River and Freshwater Creek gaging and ATM stations. Pertinent conclusions from that study include:

- Spatial variability exists within Freshwater Creek sub-basins in terms of sediment yield and to a lesser extent turbidity.
- Sediment yield at the sub-basin scale is very responsive to locally accelerated erosion.
- Many sub-basins contain a mixture of lithologies and it is difficult to discern geologic effects among them.
- High sediment loads are only associated with undifferentiated Wildcat lithology.

- Legacy sediment sources are still active and may contribute as much as 20 to 30% of the current observed sediment yield.
- Channel cutting and bank erosion associated with first cycle logging is a significant source of contemporary sediment yield.
- Downward trending sediment yield largely reflected weather history, significantly reduced landsliding, and improved roads.
- A small, but statistically significant decline in sediment yield occurred with time. Background sediment yield rates could thus be reached by 2025-2045.
- Results confirmed the Klein et al. (2011) finding that basin area and annual rate of harvest 10-15 years prior to 2005 had a positive and highly statistically significant effect on 2005 10% turbidity exceedance data only. In all other individual years (WY 2003-2011) and for all data grouped, the statistical analysis had the opposite effect, with a decreasing trend in turbidity with harvest rate.
- Harvest rate does not significantly influence sediment yield or 10% turbidity exceedance from 2003-2011 when all Freshwater Creek and Elk River variables are grouped together in a single statistical model.

Lewis and Klein (2014) were critical of the statistical analysis and interpretation presented in Sullivan et al. (2012) and issued a series of arguments against the results of that study. The authors felt that in the analysis relating turbidity to harvest rates, and inclusion of a confounding random effect for site location, negated the effect of harvesting, which they interpreted as actually being positive in each of the nine years. The authors acknowledged that the effect (1) appeared to be in decline; and (2) had not been statistically significant since 2005. However, the authors maintained that this was likely due to it no longer being large enough in relation to the sample size. Lewis and Klein (2014) felt that differences in the decay coefficients for erosivity and sediment yield variables could not be interpreted as evidence of recovery but were to be expected as a consequence of the assumed relationships. Finally, the authors maintained that combining the two data sets (and splitting "event" and "non-event" years) hid the fact that the Elk River and Freshwater Creek watersheds were on two different trajectories. Simply put, in terms of sediment response to harvesting, Freshwater Creek was in decline but not Elk River.

Although the critical questions and level of analysis presented in Sullivan et al. (2012) differ from those presented in this report, some of the more generalized results from that study conform to those included here. Spatial variability in sediment yield continues to be evident in the Freshwater Creek watershed as is the capacity of sub-basins to respond to accelerated rates of local erosion. It is clear from the monitoring record that even typically low-yield sub-basins (i.e., Upper Freshwater and McCready Gulch) maintain the capacity to deliver major pulses of sediment in extreme winters like WY 2003 and, to a lesser extent, WY 2006.

Initiation of the monitoring program in an extreme event year like WY 2003 essentially ensures the presence of a downward trend in sediment yield across sub-basins. No "pre-treatment" monitoring data exist in which to accurately assess baseline conditions. Additional high-flow years will be helpful in evaluating high yield capacity and response relative to what was measured during the WY 2003 season. Five additional years of monitoring data have been collected since the Sullivan study, three of which contained winter seasons with below-average annual precipitation. Despite drier conditions through the recent 2015-2016 wet season, another rigorous analysis that incorporates recent data is necessary in order to fully assess the statistical significance of any trends present in the Freshwater Creek watershed. Such an analysis could examine all years of monitoring data as a stand-alone group using serial autocorrelation techniques suggested by Lewis and Klein (2014) and include predictor variables utilized in the Sullivan et al. (2012) model (harvest history, geology, road data, watershed characteristics, weather parameters, etc.).

The strong correlation observed across sub-basins between annual instantaneous peak flow and annual suspended sediment yield is useful in that it provides a fairly straightforward metric to evaluate changes in sediment response over time. This analysis could be strengthened further, however, in order to improve confidence in trend detection. For example, sediment yields could be evaluated on a per-storm (rather than annual) basis to compare storm event sediment yield to storm event peak flow. Mean discharge centered on the time of instantaneous peak flow might provide a stronger surrogate to characterize the magnitude of seasonal storm events. Site-specific precipitation data derived from HRC rain gages could provide antecedent precipitation indices that exert significant impacts on peak flow, soil erosion, and sediment transport. Incorporating these strategies in future analyses would strengthen statistical models by providing more sample points on the hydrograph for evaluation.

Data to assess channel conditions throughout the watershed are derived primarily from cross-section surveys conducted at gaging stations and ATM reaches within each sub-basin. Single cross-sections at each gaging station are useful to address changes in stage-discharge relationships but are less informative in describing channel bed conditions at larger scales. These survey data suggest recent aggradation in all but two sub-basins, which is generally consistent with trends observed in associated stage-discharge rating data. ATM reaches comprise longer stream lengths and contain more cross-sections which improve confidence in extrapolating results at larger scales. These surveys generally point to more stable conditions upstream of the gaging stations in most sub-basins. However, nearly all of the ATM stations are located in the lower reaches of the sub-basin which typically function as depositional zones. Little information is available regarding channel bed characteristics in the middle and upper reaches of each sub-basin. ATM survey data are further limited by uneven monitoring records and the lack of repeatable measurements across sites. Cross-section locations changed sporadically throughout the monitoring period in many sub-basins, which hampered a thorough assessment of trends.

6.4 MONITORING RECOMMENDATIONS

A more targeted approach to monitoring in the Freshwater Creek watershed will allow for more focused efforts to be conducted regarding data collection and analysis and help answer critical questions regarding land management effects on fluvial processes. To implement a more targeted approach, the number of gaging stations within the watershed could be decreased, with greater effort focused on collecting more meaningful data at the remaining locations. Such efforts could focus on improving confidence in estimates of sediment yield by incorporating bedload sampling techniques, testing water samples for organic content, and/or collecting more streamflow measurements, particularly at high flows.

Possible locations recommended for discontinuance of monitoring include HTM stations 526, 502, and 500, as the following observations were made: (1) favorable water quality and channel dimension conditions seem evident in the upper portion of Upper Freshwater Creek (Station 526); (2) improved water quality conditions and favorable channel dimension conditions seem evident in the middle portion of the upper reach (Station 502); (3) data collected in the lowest portion (Station 523) generally reflects upstream trends; and (4) the inherent difficulty in separating background vs. legacy vs. current management effects in the Beck’s tributary sub-basin. Water quality conditions in Upper Freshwater Creek can still be assessed based on monitoring data derived from Lower Freshwater Creek (Station 523) which has served as a representative indicator of processes in the upper watershed. The 14-year data record from HTM stations 526 and 502 offers a reasonable understanding of processes in the upper sub-basins, and a focused examination of the area between these locations should provide even more clarity. The Beck’s tributary sediment source study resulted in findings that were generally inconclusive regarding how sediment yields related to individual harvest plans. It is clear, however, that a variety of factors influence contemporary sediment loading in the sub-basin. A more nuanced, long-term, paired-basin study that examines the interplay between natural, legacy, and current management effects on water quality and hillslope processes is underway in Railroad Gulch, a tributary to mainstem Elk River. The results of this study, though derived under different conditions, may help frame some of the critical questions pertinent to processes observed in the Beck’s tributary sub-basin.

High resolution streambed elevation surveys can serve as an important surrogate to hydrology monitoring within the sub-basins where hydrology monitoring is recommended to be discontinued. If, over time, drastic changes in streambed conditions are observed (i.e., an unexplained and consistent shift towards aggradation), it may be necessary for hydrology monitoring to resume at the previously discontinued gaging station locations. Repeatable long-profile surveys could replace cross-section surveys in sub-basins where such fieldwork is feasible. These surveys would extend farther into the middle and upper reaches and thus provide the means for a more representative analysis of channel dimensions in the sub-basin. Combining long-profile survey data with ATM pebble counts would help relate changes in particle-size class distribution to those observed in thalweg elevation and pool characteristics.

It is recommended that hydrology monitoring continue at HTM stations 504, 505, 606, 523, 527, and 528 as these stations provide useful water quality information to inform conditions throughout the Freshwater Creek watershed. Including these data with results from ATM stations and topographic data derived from long-profile surveys into a more advanced and targeted analysis will allow for an improved understanding of hydrologic trends in the Freshwater Creek watershed.

7 FISHERIES ASSESSMENT

This fisheries assessment provides information pertaining to aquatic habitat conditions, salmonid population abundance, species distribution, and the location and physical composition of known migration barriers within the Freshwater Creek watershed. HCP listed species within the WAU include Chinook salmon (*Oncorhynchus tshawytscha*), coho salmon (*O. kisutch*), steelhead trout (*O. mykiss*), and coastal cutthroat trout (*O. clarki clarki*). Rare observations of chum salmon (*O. keta*) and pink salmon (*O. gorbuscha*) have also been documented by CDFW field survey crews. At least 22 species of fish have been known to reside in Freshwater Creek through recurring documentation and historical observations. The majority of these species, however, includes non-natives and those limited to estuarine regions downstream of HRC ownership.

Salmonids utilize the available habitats in Freshwater Creek according to their respective species, life history stages, and changing physiological requirements throughout the year. The lower mainstem stream reaches are typically underutilized by spawning adults, yet provide suitable habitats for summer rearing, overwintering, and out-migrating juveniles. The upper mainstem reaches and all major tributaries except School Forest are the most heavily utilized by spawning adults and also provide crucial rearing and overwintering habitats to juveniles. Currently, there are no known anthropogenic migration barriers on HRC ownership in Freshwater Creek, and annual spawning ground surveys (SGS) have recently documented salmonids in all major stream reaches downstream of naturally-occurring anadromous barriers. Over time, trends in populations are expected to become clearer and habitat usage will be better understood through continued habitat inventories, biological monitoring efforts, and emerging Passive Integrated Transponder (PIT) tag tracking technologies.

Annual salmonid population data have been collected by CDFW at the Freshwater Creek Salmonid Life Cycle Monitoring Station and results published annually since the fall of 2001. These salmonid population abundance trends are presented in subsections that follow, and may prove useful when attempting to corroborate the results of the HRC ATM program which tracks in-stream habitat conditions over the span of the HRC HCP (1999-2049).

7.1 AQUATIC TRENDS MONITORING

In-stream aquatic habitat conditions have been regularly monitored since 2003 at seven ATM stations distributed within the Freshwater Creek watershed, except ATM Station 202 (McCready Gulch) where monitoring began in 2005. Habitat data are collected to document long-term aquatic conditions as characterized by the following parameters:

- Large woody debris (LWD) dimension, volume, and piece frequency;
- Substrate particle size;
- Pool dimension;
- Water temperature; and
- Canopy cover.

These data are evaluated with the goal of determining whether salmonid habitat conditions are meeting, or are trending towards APFC targets established in 1997 by the signatory HCP wildlife agencies. Over time, these data may also provide useful information to help determine if APFC criteria are applicable to the individual ATM stream reaches, where inherent watershed characteristics may preclude any such habitat targets. Although there are no more than six survey years of ATM data for any individual ATM station in the Freshwater Creek watershed, HRC has constructed scatter plots for each habitat parameter that reveal the current direction of trends relative to APFC targets. These figures are presented and discussed in Appendix 7 by individual ATM station. Appendix 7 also presents results of Quality Assurance/Quality Control (QA/QC) activities conducting by revisiting monitoring sites, with the same field technicians switching roles of habitat data collection. Habitat parameter data from each monitoring event’s original visit and revisit were compared to identify if protocol adjustments were warranted to achieve greater consistency, and results show an improving degree of precision over the years.

For each habitat parameter, data collected at the ATM stations are presented and discussed below, allowing for comparison of habitat characteristics between monitoring sites over the period surveyed (2003-2014). Five tributary and two mainstem ATM stations were monitored in the Freshwater Creek watershed, scheduled on a three-year rotation; tributary stations were monitored in McCready Gulch (Station 202), Little Freshwater (Station 018), Cloney Gulch (Station 092), Graham Gulch (Station 019), and South Fork (Station 015). The two mainstem stations are Freshwater Creek (Station 034) and (Station 200). These permanent sites are located within “response reaches” of equal or less than 4% gradient that have historically provided habitat for anadromous salmonids. Most response reaches are between 200 and 400 meters (approximately 600 to 1,200 ft) in length. Table 7-1 provides basic information on physical watershed attributes and monitoring parameters at each Freshwater ATM station. Figure 7-1 provides an overview of the Freshwater Creek watershed and the locations of the ATM stations. Figure 7-2 provides representative photographs from 2014 taken at the beginning of each ATM station.

Table 7-1. Physical watershed attributes and general monitoring parameters at current Freshwater Creek ATM stations

ATM Station	Stream Name	Upstream Watershed Acreage	Upstream Area (mi^2)	Township Range Section	Underlying Geology	Upstream Lithology	Average Reach Gradient (%)	Elevation (ft)	Water Temperature (Annual)	Stream Habitat Parameters (3-Year Rotation)
034	Freshwater Creek	5,609	8.8	T04N R01E (15)	Yager terrane (Ty), Holocene aged alluvial deposits (Qrt)	Yager terrane (Ty), Central belt bedrock (KJfs/KJfm)	0.9	190	X (+Air)	X
015	South Fork Freshwater Creek	2,019	3.2	T04N R01E (15)	Yager terrane (Ty)	Central belt bedrock (KJfs/KJfm), Wildcat Group (Tlw), Yager terrane (Ty)	1.7	183	X	X
200	Freshwater Creek	7,911	12.4	T04N R01E (10)	Wildcat Group (Tlw), Holocene aged alluvial deposits (Qrt)	Yager terrane (Ty), Central belt bedrock (KJfs/KJfm)	0.4	134	X	X
019	Graham Gulch	1,588	2.5	T04N R01E (03)	Wildcat Group (Tlw), Yager terrane sandstone (Ty)	Central belt bedrock (KJfs/KJfm), Wildcat Group (Tlw)	1.4	95	X	X
092	Cloney Gulch	2,968	4.6	T04N R01E (03)	Wildcat Group (Tlw)	Central belt bedrock (KJfs/KJfm), Wildcat Group (Tlw)	0.9	85	X	X
202	McCready Gulch	1,084	1.7	T05N R01E (34)	Central belt sandstone (KJfs)	Wildcat Group (Tlw)	2.3	111	X	X
018	Little Freshwater Creek	2,980	4.7	T04N R01E (04)	Wildcat Group (Tlw)	Wildcat Group (Tlw)	0.8	65	X	X

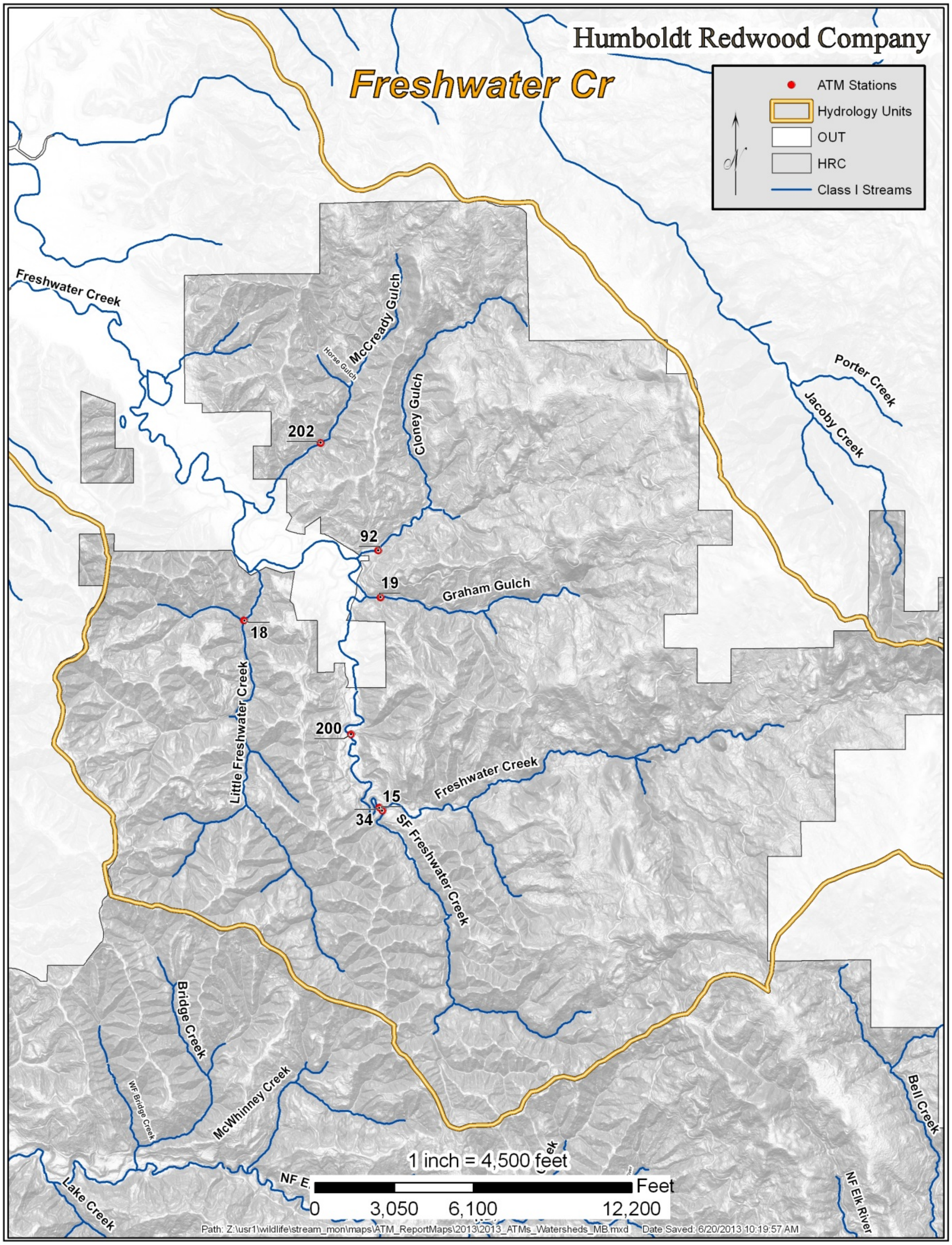


Figure 7-1. Map of the Freshwater Creek watershed and HRC ATM station locations

Freshwater Creek Station 034

SF Freshwater Creek Station 015

Freshwater Creek Station 200

Graham Gulch Station 019

Cloney Gulch Station 092

McCready Gulch Station 202

Little Freshwater Creek Station 018

Note: These photographs were taken in 2014.

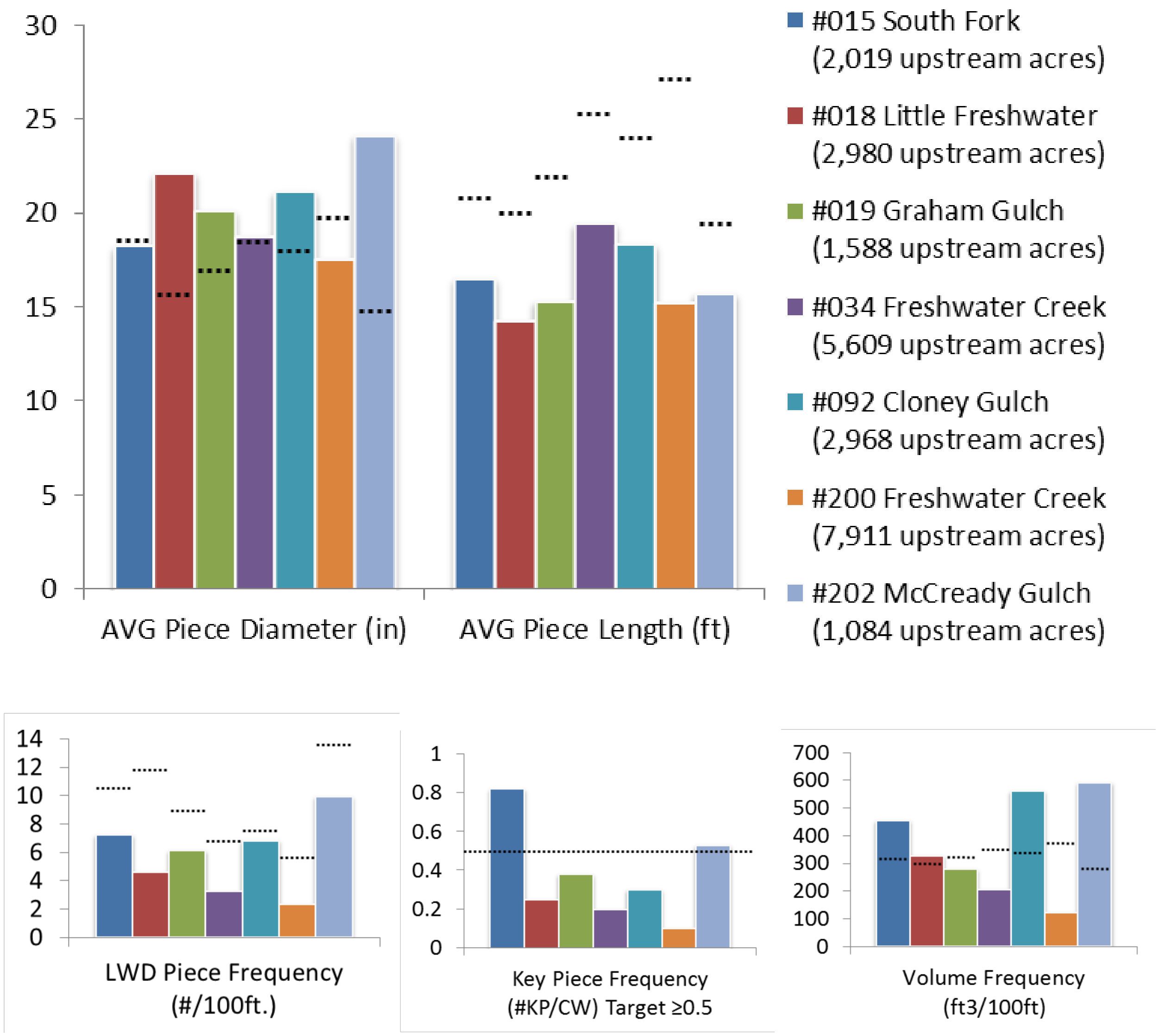
Figure 7-2. Freshwater Creek ATM stations

7.1.1 Mean LWD Parameters

Large woody debris plays a vital role in the development and maintenance of freshwater spawning and rearing habitats critical to salmonid survival. It is a major component that drives pool development during high-flow events, assists in the processes of metering and sorting spawning substrates, provides essential cover for spawning adults and rearing juveniles, and offers a medium on which a wide variety of aquatic invertebrates can persist. APFC criteria for LWD can vary by watershed, as they are a function of channel width. These criteria focus on the following five LWD parameters:

- Piece frequency (#/100 ft of channel);
- Key piece frequency [#KP/channel width (CW)];
- Average piece diameter (inches);
- Average piece length (ft); and
- Volume frequency (ft^3/100 ft of channel).

In order to qualify, individual LWD pieces must be at least partially within the bankfull channel and at least 6 ft (1.8 meters) in length and 6 inches (0.15 meters) wide at the midpoint. Figure 7-3 provides the mean results of LWD data collected at all seven Freshwater ATM stations from 2003-2014, and is intended to provide a general perspective of the LWD distributions within and between sites.



Note: APFC targets are represented by dotted line segments.

Figure 7-3. Freshwater Creek mean LWD results organized by ATM station, 2003-2014

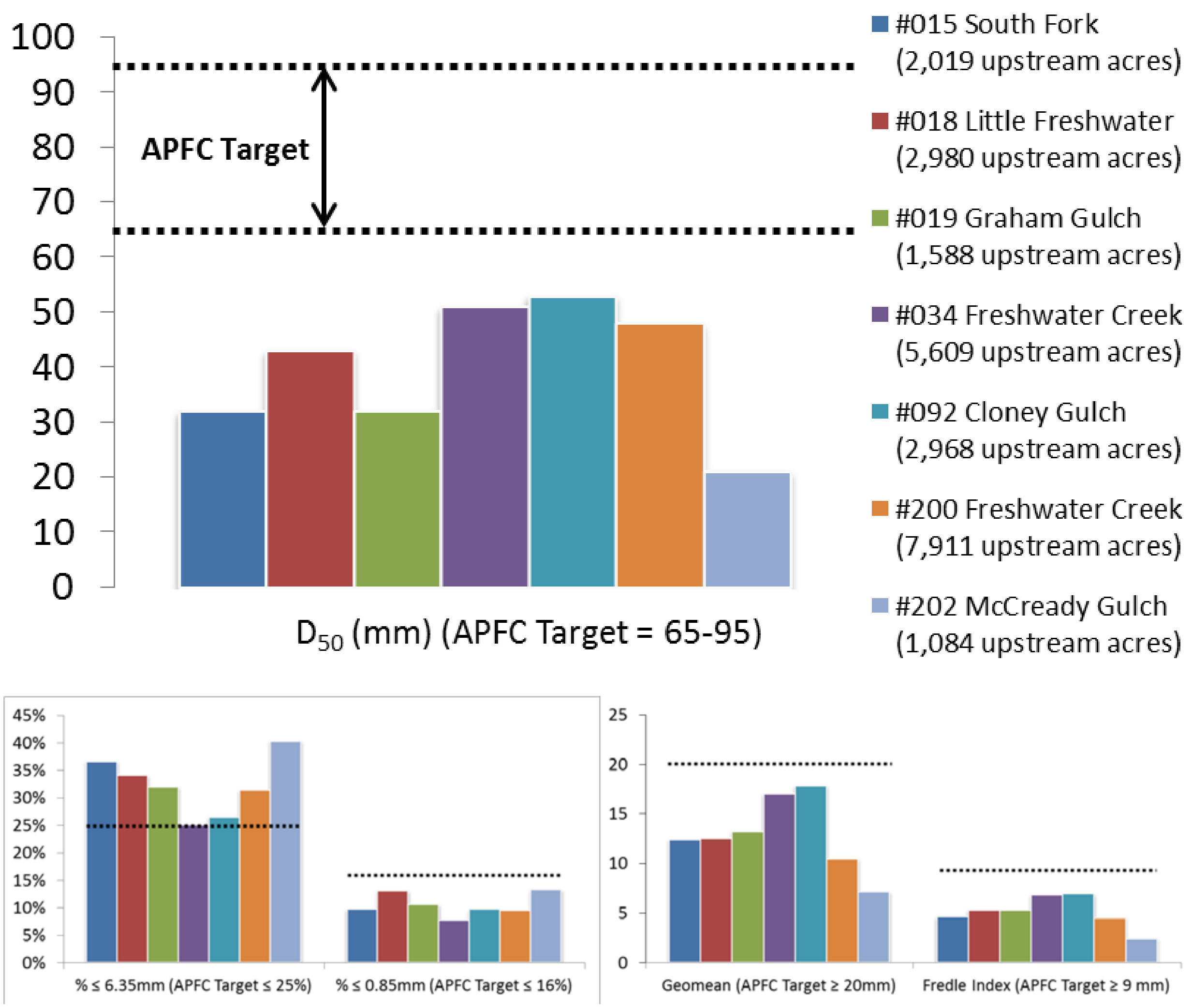
7.1.2 Mean Substrate Particle Size Parameters

The substrate particle size of a streambed can be a limiting factor for salmonid spawning success and egg-to-fry survival. While there is some degree of overlap in the preferred sizes of suitable spawning gravel amongst the salmonid species, salmonids typically do not spawn in substrates too fine (sand, silt, clay) or in substrates too coarse (large cobbles, boulders).

Streambed surface substrate particle size is determined using a standardized pebble count method of measuring the secondary axis of 200 individual pieces within each of the first three riffles (divided equally into ten transects) at each ATM station. The APFC target for D_{50} (the median [50th percentile] particle size) is defined as 65-95 millimeters (mm). Once the data collected from the three riffles have been sorted, those three D_{50} values are averaged to determine the mean D_{50} for each ATM station for that particular survey year. These D_{50} values are used as a general indicator of whether a streambed is fining or coarsening.

Streambed sub-surface sediment was measured using a shovel sampling method at three pool riffle crests within each sampling reach. Sediment volume had to be a minimum of 2,000 grams of particles less than 125 centimeters in size. Samples were dry sieved in HRC’s Environmental Laboratory Accreditation Program (ELAP) accredited sediment processing laboratory.

Mean measurements over the entire monitoring period (2003-2014) indicate all Freshwater ATM stations met APFC criteria for fine sediment less than 0.85 mm, while all but one site failed to meet targets for percent particles less than 6.35 mm. Geomean, bed surface D_{50}, and Fredle Index were all under target due to the large fraction of substrates less than 6.35 mm. Figure 7-4 provides the results of the mean substrate particle size distributions at all seven Freshwater Creek ATM stations from 2003-2014 relative to APFC target criteria, intended to provide a general perspective of the substrate size composition within and between sites.

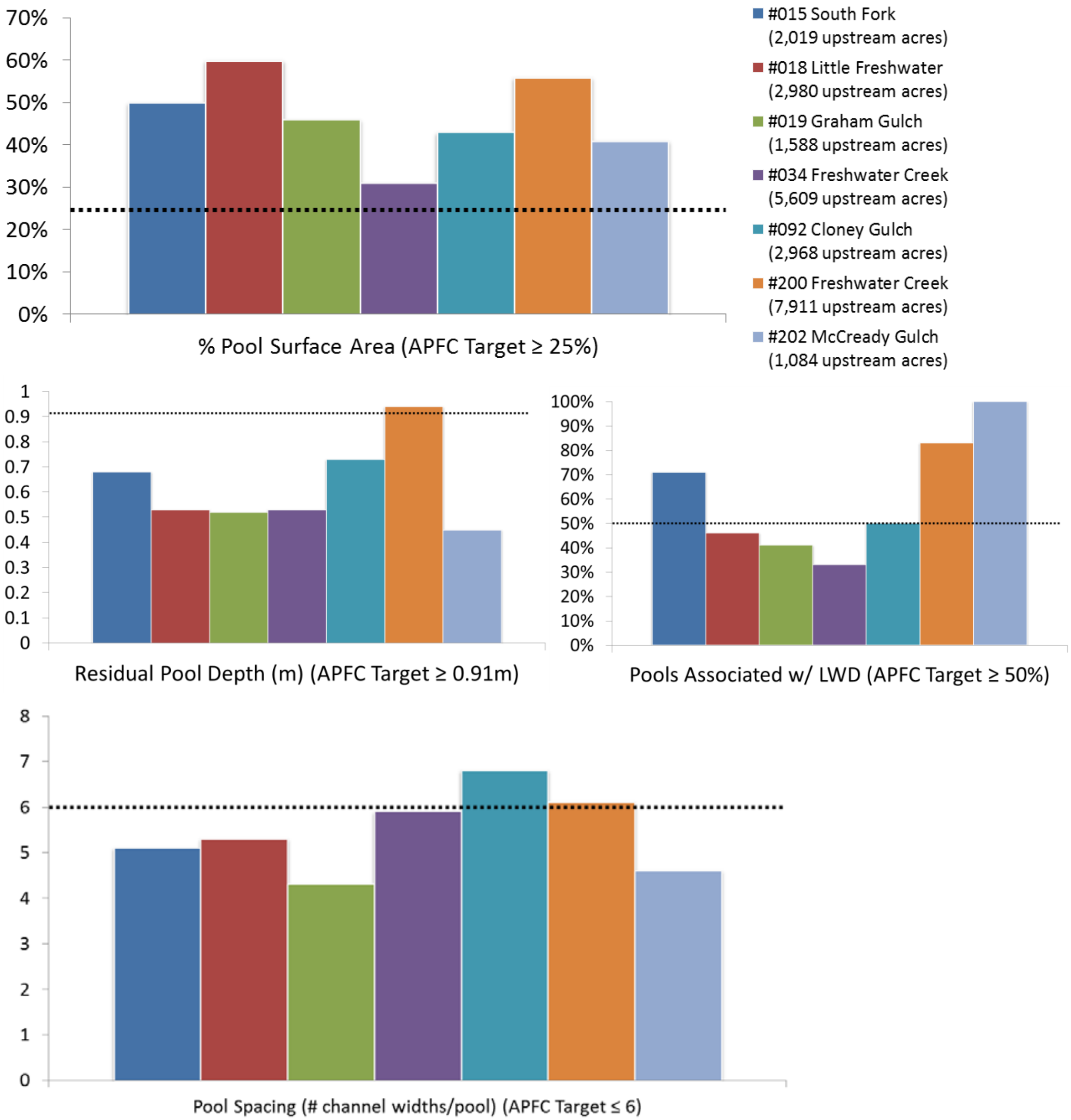


Note: APFC targets are represented by dotted line segments.

Figure 7-4. Freshwater Creek mean substrate particle size results, 2003-2014

7.1.3 Mean Pool Habitat Parameters

Pools are the primary summer rearing habitats used by salmonids within a stream. HRC conducts habitat measurements on stream reaches to determine the percentage of total channel length composed of pools, as well as their dimensions and residual depth (the difference between the maximum depth and the riffle crest depth). In addition to these physical measurements, observations are recorded on whether or not LWD (meeting size criteria) is influencing individual pools within the survey reach. All of these measurements address APFC targets of pool-to-pool spacing based on bankfull width, percent of surface area comprised of pool habitat, number of pools associated with LWD, and average residual pool depth. Figure 7-5 provides the mean results of pool habitat parameters at all seven Freshwater Creek ATM stations from 2003-2014 relative to APFC target criteria, intended to provide a general perspective of the pool habitat conditions within and between sites.

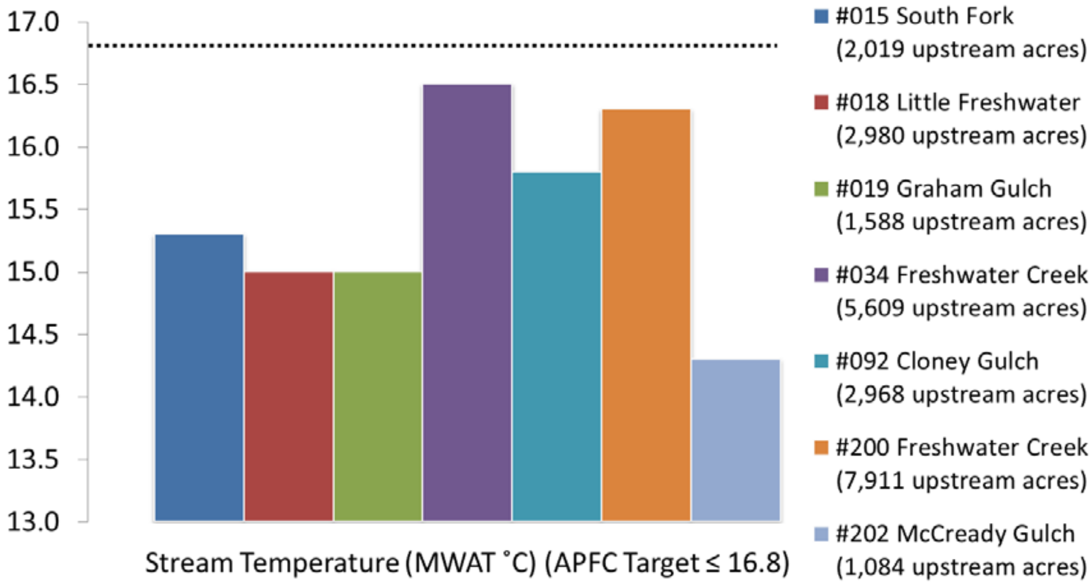


Note: APFC targets are represented by dotted line segments.

Figure 7-5. Freshwater Creek mean pool habitat parameter results by ATM station, 2003-2014

7.1.4 Maximum Weekly Average Temperature

Stream water temperature is tracked during the warmest months of the year (June 1st - October 1st). Temperature is monitored with continuous-recording data loggers (Onset HOBO® Water Temp Pro v2) placed in protective, perforated polyvinyl chloride (PVC) housings and secured firmly to the streambeds in a sufficiently-mixed unit (preferably a shallow pool or run). Temperature data are used to calculate the maximum weekly average temperature (MWAT), or, the average of the daily mean temperature measured during the warmest seven consecutive days each year. The APFC target for MWAT at all ATM stations is less than or equal to 16.8 ˚C. Figure 7-6 provides the mean results of MWAT records at all seven Freshwater Creek ATM stations from 2003-2014 relative to the APFC criteria target, intended to provide a general perspective of the maximum temperatures within and between sites.

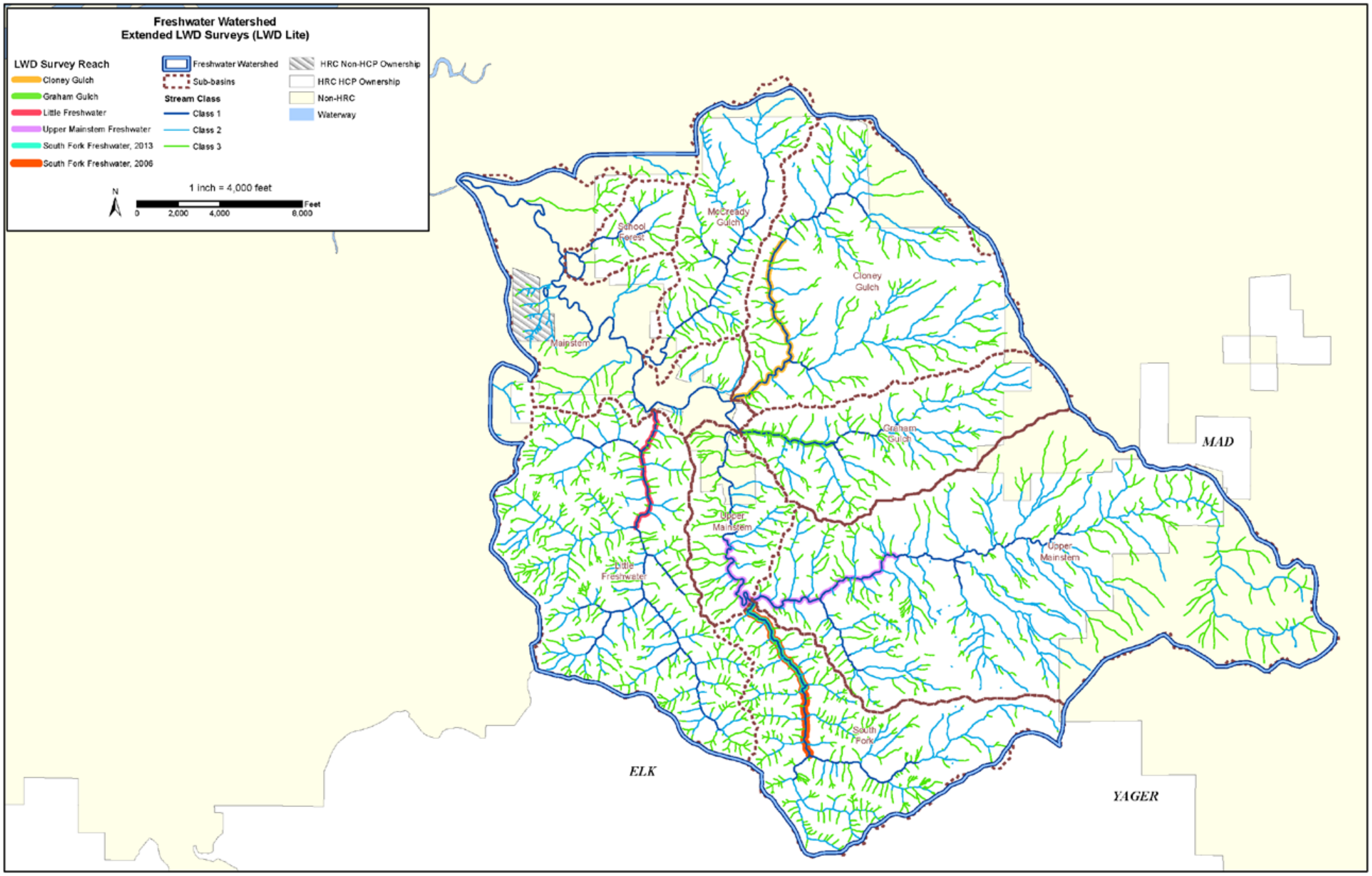


Note: The APFC target is represented by the dotted line segment.

Figure 7-6. Freshwater Creek mean MWAT results organized by ATM station, 2003-2014

7.2 EXTENDED LWD SURVEYS

Two extended LWD surveys, initially completed in 2006 and later revisited in 2013, provide data to quantify LWD piece density, volume, and distribution throughout the watershed beyond the spatial limitations of individual ATM reaches. The data collection process and results are documented in Appendix 7. Figure 7-7 shows the locations of the five extended LWD survey reaches, color coded for interpretation.



Note: Little Freshwater was surveyed in 2013 only, and South Fork Freshwater was surveyed approximately half the distance in 2013 compared to what had been surveyed in 2006. McCready Gulch was not surveyed in either of these years.

Figure 7-7. Locations of the five extended LWD surveys conducted in 2006 and 2013

Results of these two surveys suggest LWD deficiencies in the lower sub-basins, gradually increasing in both piece number and volume towards the upper stream reaches. However, this may not necessarily reflect a lower recruitment potential in those lower reaches. Rather, it may simply reflect the greater mobility potential of LWD in the lower reaches as a function of bankfull channel width and potential energy of the stream. In other words, the LWD in the lower reaches has a greater chance of being carried away by high-flow events and/or lifted out and deposited outside of the stream channel. Conversely, as the bankfull channel width and potential energy of the stream progressively decreases upstream, the LWD is less prone to mobilizing and has a greater chance of remaining within the bankfull width of the stream channel. As the APFC LWD targets are rarely achieved within the ATM reaches positioned lower in the sub-basins, it is reasonable to suggest that those locations should be targeted for future instream wood placement restoration projects utilizing pieces at least 1.5 times longer than the bankfull width. Furthermore, as the other ATM habitat parameter data suggest, LWD is a common driver of improving overall habitat characteristics including pool dimension/frequency, substrate coarseness, and overall channel complexity.

7.3 BIOLOGICAL MONITORING AND DISTRIBUTION

Extensive fisheries monitoring has been conducted in Freshwater Creek by CDFW including annual out-migrant trapping (OMT), summer juvenile population estimates, upstream adult salmonid trapping and PIT tagging at the Humboldt Fish Action Council (HFAC) weir, and winter SGS. These annual surveys are intended to satisfy four primary objectives:

- Define the relationship between SGS observations and adult escapement;
- Estimate juvenile and adult abundance;
- Provide a study framework to investigate habitat-productivity relationships; and
- Characterize the diversity of life history patterns.

Previously documented anadromous barriers are re-evaluated during SGS to determine their status as either permanent or temporary, and recently-formed barrier features are documented. Those data are used to regularly update the California Passage Assessment Database (PAD) and the HRC ArcGIS database.

Since the early 2000s, abundance estimates were made for multiple life history stages, and at multiple spatial scales for coho salmon, Chinook salmon, and steelhead trout. Several methods were used to characterize abundance including:

- Adult escapement: weir-carcass mark-recapture experiment;
- Spawning ground surveys; and
- Juvenile emigration trapping mark-recapture experiment.

Multi-year comparisons were used to generate escapement prediction models of the relationship between coho salmon redd counts and adult escapement.

7.3.1 Adult Escapement

Adult escapement is the portion of an anadromous fish population that escapes the commercial and recreational fisheries and reaches the freshwater spawning grounds. Estimating escapement on Freshwater Creek was conducted through a Petersen mark-recapture experiment. Adult salmonids were intercepted at the permanent HFAC weir approximately 8 river km upstream from the mouth of Freshwater Creek. Each captured fish was identified to species and sex, measured for length, scanned for previously-inserted PIT tags, and inspected for predation wounds. Prior to release, untagged steelhead and coho salmon received an individual identifying PIT tag, injected just beneath the skin adjacent to the dorsal fin. Coho salmon were also given a hole-punch to the operculum (gill plate) as a secondary mark to determine PIT tag loss. These “marked” fish were later “recaptured” by scanning the carcasses found during spawning ground surveys or recovering kelts (post-spawn steelhead) at the weir facility. All the data collected were used to form a Petersen estimate of abundance, or N(hat), for each spawning year shown below. Note that Chinook salmon were not included in the Petersen mark-recapture experiment due to their low abundance, except for one year in 2002. Tabular and graphical representations of the adult abundance of steelhead, coho, and Chinook salmon for the Freshwater Creek watershed are presented in Table 7-2, and Figure 7-8, Figure 7-9, and Figure 7-10 (Anderson and Ward 2016).

Table 7-2. Adult salmonid escapement for survey years 2000 to 2015

Year	Steelhead		Coho		Chinook	
	N(hat)	SD	N(hat)	SD	N(hat)	SD
2000	99	23	177*		154*	
2001	195	43	701*		122*	
2002	153	22	1807	213	135	32
2003	432	23	731	25	26*	
2004	254	17	974	37	14*	
2005	257	17	789	128	22*	
2006	235	23	396	47	18*	
2007	203	29	262	41	7*	
2008	51	7	399	71	2*	
2009	61	11	89	10	2*	
2010	132	32	455	38	19*	
2011	108	35	624	148	1*	
2012	149	60	318	75	2*	
2013	127	54	155	67	0*	
2014	87	23	718	68	8*	
2015	106	38	449	86	2*	

Escapement year includes Fall through Spring (e.g., Year 2000 is Fall 2000 through Spring 2001). Hatchery produced Chinook returns contributed to counts in years 2000-2003 (Anderson and Ward 2016). *Indicates weir count.

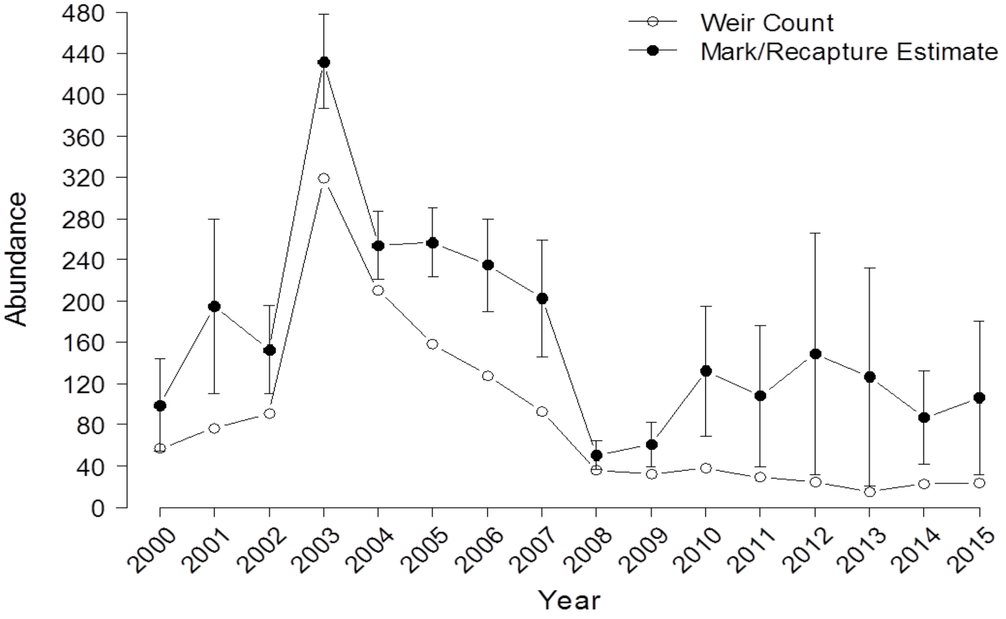


Figure 7-8. Adult steelhead trout weir counts and escapement estimates (± 95% confidence intervals) in Freshwater Creek for survey years 2000 through 2015 (Anderson and Ward 2016)

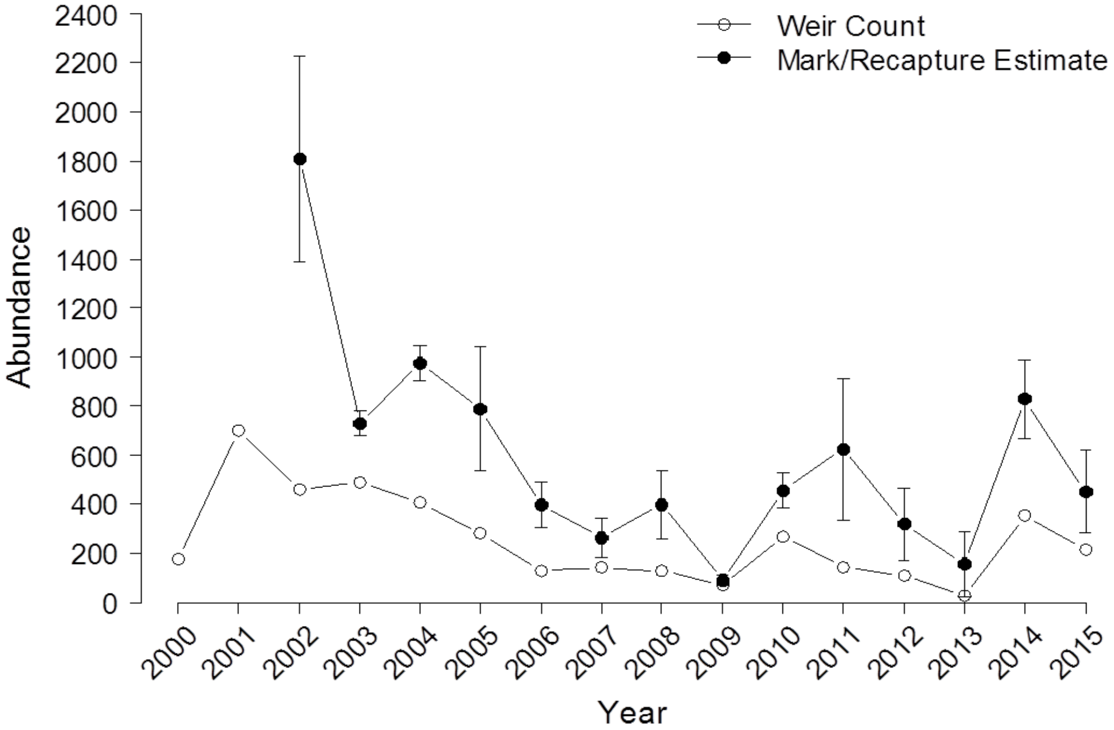


Figure 7-9. Adult coho salmon weir counts and escapement estimates (± 95% confidence intervals) in Freshwater Creek for survey years 2000 through 2015 (Anderson and Ward 2016)

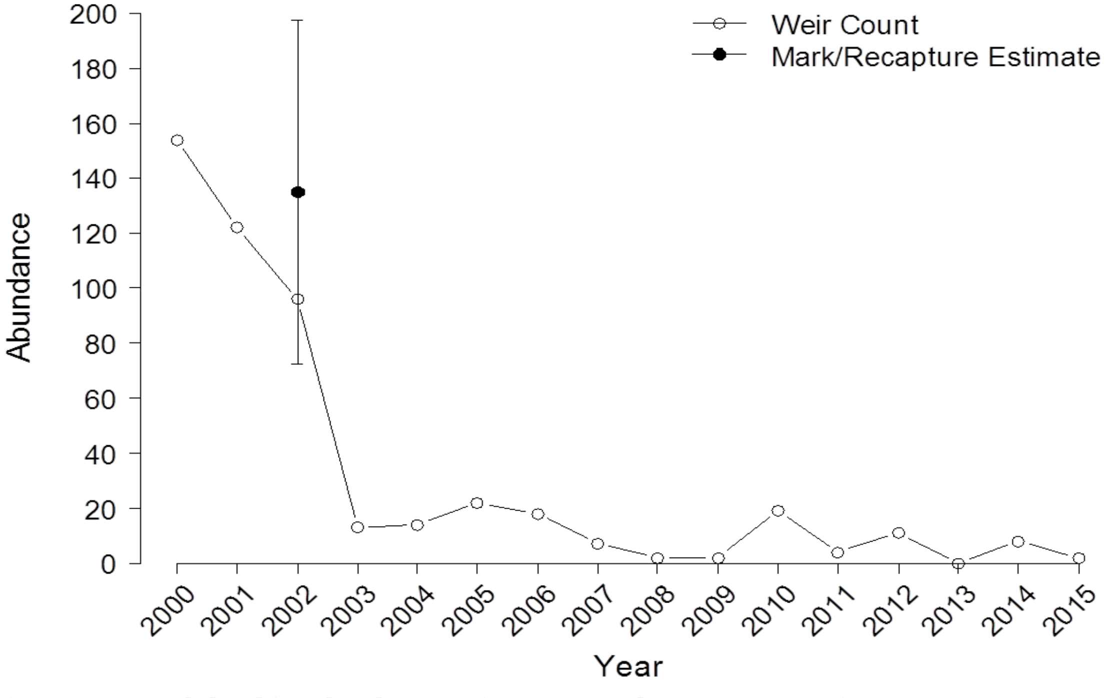


Figure 7-10. Adult Chinook salmon weir counts and escapement estimate (2002; ± 95% confidence intervals) in Freshwater Creek for survey years 2000 through 2015 (Anderson and Ward 2016)

7.3.2 Juvenile Salmonid Spring Emigrant Trapping

The abundance of out-migrating salmonid juveniles (smolts) in Freshwater Creek has been estimated through mark-recapture trapping techniques since 2001. Initially, seven out-migrant traps were installed in the Freshwater Creek watershed: McCready Gulch, Lower Mainstem (LMS), Little Freshwater, Cloney Gulch, Graham Gulch, South Fork, and Upper Mainstem. The LMS trap (situated approximately 5 km upstream of the HFAC weir) utilized an incline-plane trap, whereas pipe and pallet weir traps were installed at the remaining locations. In 2006, the HFAC weir was retrofitted to intercept out-migrating smolts to potentially explain the lower-than-expected ratio of tagged to untagged returning adults. The early trap design was not as efficient as was anticipated, but with slight modifications it began intercepting large numbers of fish the following spring. In 2008, only the LMS and HFAC traps were operated. Beginning in 2009, all were abandoned except the HFAC weir facility because it was clear to CDFW that they could efficiently generate an abundance estimate with only one trap situated low in the watershed. Furthermore, it led to the realization that smolt were not only using the lower reaches of the watershed in large numbers, but also emigrating before the out-migrant traps could be installed, leading to the idea of a “super-population” of smolts.

Super-Population of Smolts: The hypothetical “super-population” of smolts includes all of the smolt that would make up the returning adult run of coho salmon to Freshwater Creek. This includes those “unaccounted” fish that began emigrating in the fall, winter, and early spring before trap installation, those fish that evaded the traps during the trapping season, those that were captured during the trapping season, and those that emigrated after the traps had been dismantled. Estimates of a “super-population” are currently generated through back-calculating adult runs every 3rd year, based on ocean survival estimates and the general 3-year life history pattern of coho.

The importance of the lower mainstem and off-channel habitats for coho and steelhead smolts found in the lower basin (downstream of HRC) is reflected in the greater overall numbers of smolts trapped at the freshwater-saltwater interface (HFAC weir) compared to historical estimates when trapping occurred at and above the LMS (Table 7-3, Figure 7-11, and Figure 7-12).

Table 7-3. Emigrant juvenile salmonid catch and abundance estimates for 2001-2016 (Anderson and Ward 2016)

Year	Basin	Coho Salmon			Steelhead				Chinook	Cutthroat Trout			
		Age 0+Fry	Age 1+ Smolt		Parr	Pre-Smolt	Smolt		Age 0+Fry-Smolt	Parr	Pre-Smolt	Smolt	Resident
		Catch	N(hat)	95%CI	Catch	Catch	N(hat)	95%CI	Catch	Catch	Catch	Catch	Catch
2006													
	Tribs		**1891**	**365**	**72**	**175**	**39**	**N/A**	**493**	**8**	**107**	**10**	**43**
	LMS	**4843**	**3009**	**432**	**20**	**52**	**22**	**N/A**	**913**	**3**	**48**	**2**	**14**
	HFAC		**216**	**N/A**	**2**	**3**	**19**	**N/A**	**46***	**0**	**6**	**3**	**0**
2007													
	Tribs		**2111**	**294**	**154**	**280**	**22**	**N/A**	**865**	**47**	**150**	**24**	**22**
	LMS	**1752**	**3685**	**532**	**247**	**284**	**7**	**N/A**	**2298**	**10**	**62**	**11**	**3**
	HFAC		**5888**	**1006**	**123**	**136**	**1607**	**312**	**314***	**26**	**59**	**12**	**2**
	Super Pop		**22633**	**8399**									
2008													
	LMS	**1777**	**3096**	**308**	**156**	**124**	**142**	**44**	**988**	**21**	**190**	**0**	**9**
	HFAC		**4945**	**464**	**57**	**86**	**798**	**80**	**253***	**5**	**63**	**1**	**1**
	Super Pop		**9536**	**4365**									
2009													
	HFAC		**6543**	**724**	**424**	**383**	**1091**	**101**	**0***	**61**	**108**	**7**	**32**
	Super Pop		**11253**	**1817**									
2010													
	HFAC	**193***	**5138**	**221**	**78**	**90**	**829**	**176**	**104***	**15**	**99**	**4**	**53**
	Super Pop		**15444**	**2356**									
2011													
	HFAC	**150***	**4535**	**256**	**298**	**173**	**1161**	**192**	**2380***	**45**	**87**	**9**	**63**
	Super Pop		**11862**	**2755**									
2012													
	HFAC	**785***	**14835**	**1104**	**263**	**34**	**1391**	**454**	**20***	**31**	**32**	**7**	**160**
	Super Pop		**35788**	**20017**									
2013													
	HFAC	**125***	**16795**	**693**	**453**	**80**	**1561**	**89**	**306***	**20**	**25**	**8**	**336**
	Super Pop		**35712**	**6968**									
2014													
	HFAC	**3***	**15724**	**405**	**10**	**45**	**456**	**41**	**0**	**2**	**20**	**3**	**265**
	Super Pop		**25289**	**9641**									
2015													
	HFAC	**11***	**10470**	**980**	**20**	**29**	**331**	**36**	**463***	**8**	**16**	**2**	**206**
2016													
	HFAC	**3***	**8648**	**1043**	**166**	**14**	**1218**	**222**	**62***	**58**	**1**	**1**	**77**

*indicates catches where the HFAC trap was not designed to hold fry <50 mm fork length.

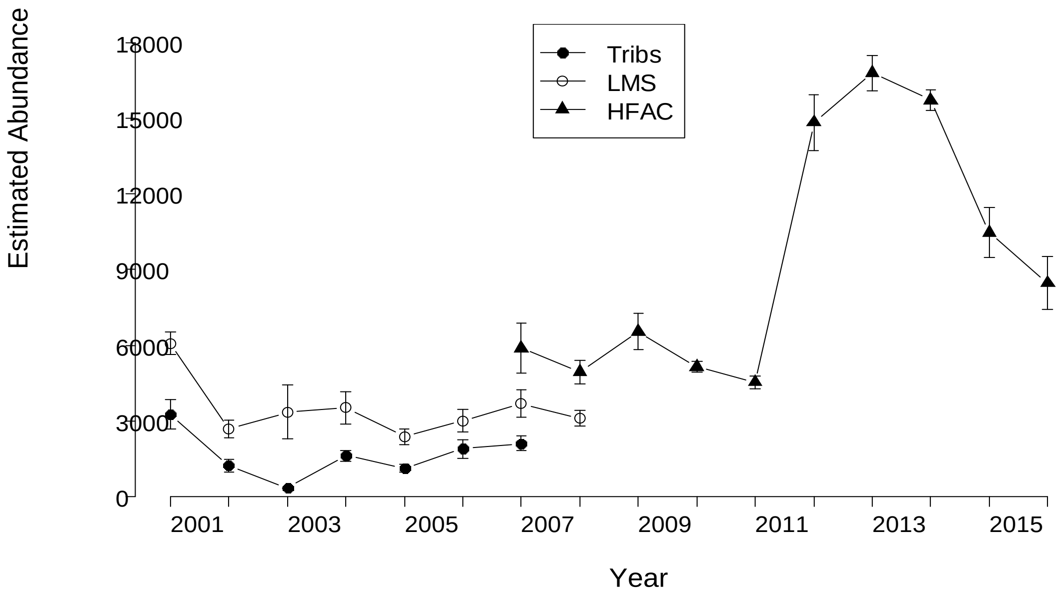


Figure 7-11. Time-series plot of juvenile coho salmon spring emigration estimates for all tributary reaches combined (Tribs), the Lower Main-Stem trap (LMS), and the adult weir (HFAC) trapping locations, 2001-2016 (Anderson and Ward 2016)

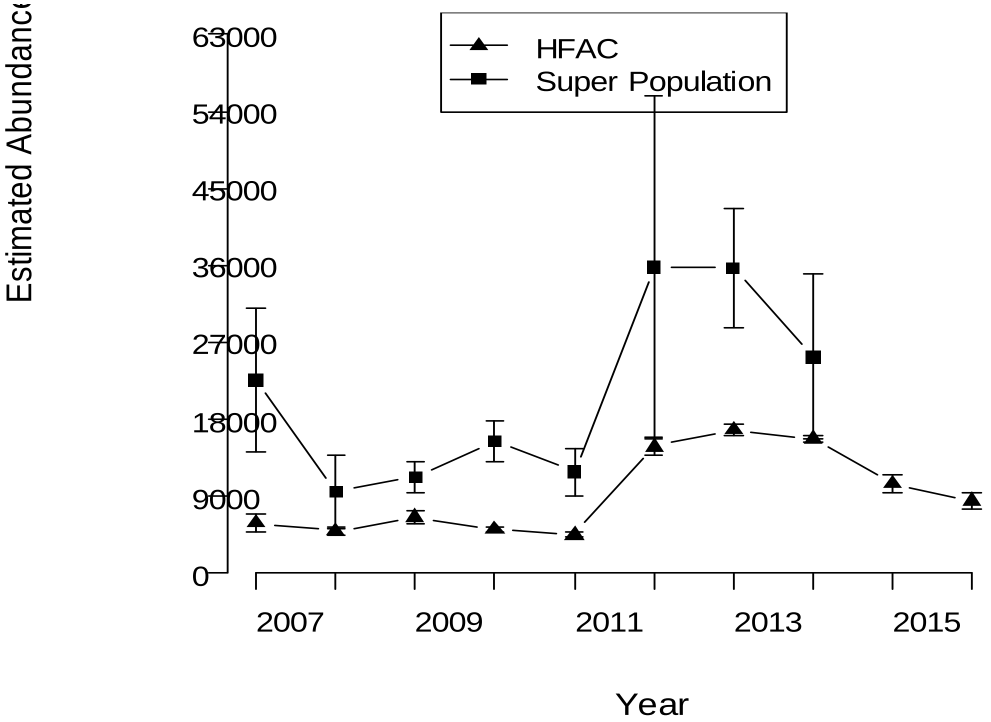


Figure 7-12. Time-series plot of juvenile coho spring emigration estimates (95% confidence intervals) at a downstream migrant trap (HFAC) and "super-population" estimates 2007-2015 (Anderson and Ward 2016)

7.3.3 Coho Salmon Redd Counts vs. Escapement

The relationship of observed redds and estimated coho escapement, by survey year (Anderson and Ward 2016), is shown in Figure 7-13. A significant empirical relationship was found between the ln-transformed escapement of adult coho salmon estimated with the weir-carcass mark-recapture experiment and the ln-transformed number of redds observed in Freshwater Creek ($F=28.18$, $P=0.0002$, $R^2=0.7$) (Figure 7-14). This suggests that it may be possible to generate a “ballpark” estimate of adult escapement based on the number of redds observed in a particular spawning season. However, with any prediction models, there are key assumptions that must be taken into consideration when interpreting this relationship:

- Male and female spawning fish occur in an equal 50:50 ratio; and
- The detection probability of redds is the same every time a SGS is conducted, regardless of personnel or weather conditions.

Based on these two key assumptions, biologists and fisheries managers understand that the prediction model is inherently imperfect. For example, it is unlikely that male and female fish *necessarily* occur in a perfect 50:50 ratio. On average, however, the male to female ratio is probably somewhere near 50:50 on any given spawning year. Likewise, it is unlikely that redd detection probability is *necessarily* the same each time field crews conduct spawning ground surveys. Detection probability likely increases with field experience. In other words, a veteran field technician with a skillfully-trained eye is likely going to be better at spotting fish and/or redds than a newly-trained crew member in his/her first field season. Detection probability is also a function of stream conditions, and it is unlikely that water clarity stays constant throughout the spawning season.

It is encouraging though, that a significant relationship between redd counts and adult escapement has been observed in Freshwater Creek since monitoring began over a decade ago. Ideally, biologists and fisheries managers alike would prefer to calculate the exact number of fish returning to spawn in any given year, in any given watershed based on the number of redds they observed. It is more realistic, however, to view this relationship as an “imperfect index” of how the number of redds relates to adult escapement.

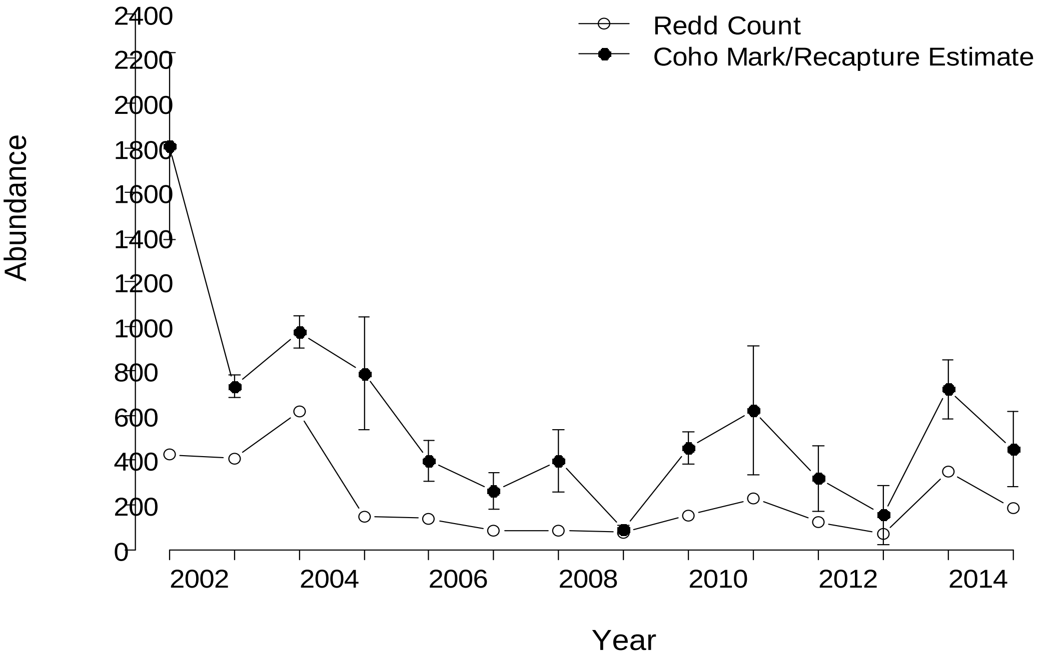
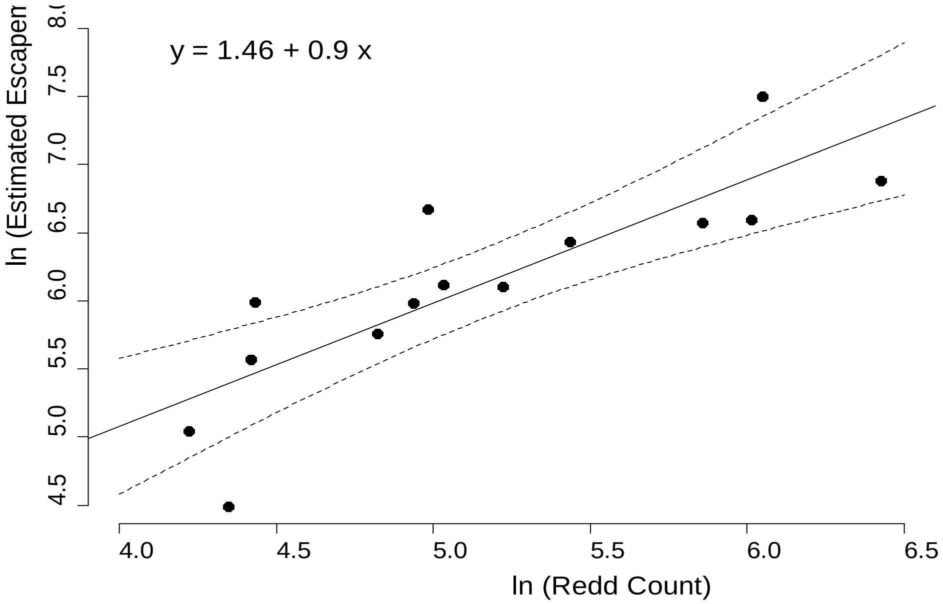


Figure 7-13. Time-series plot of coho salmon redd counts and estimated adult escapement (±95% confidence intervals), 2002-2015 (Anderson and Ward 2016)



Dotted lines indicate 95% confidence intervals for the fitted regression line.

Figure 7-14. Scatter plot with regression line of ln-transformed redd counts vs ln-transformed coho salmon estimated escapement, 2002-2015 (Anderson and Ward 2016)

7.4 RECOMMENDATIONS

We recommend that future population abundance, survival, and habitat utilization studies in Freshwater Creek take advantage of new development in PIT tag technology. This technology allows for the tracking of juvenile and adult fish as they move throughout the watershed. This information can provide insight into what specific habitat attributes contribute to higher survival rates and how juvenile fish utilize and emigrate to and from these habitats at various life stages.

Recently, much focus has been placed on restoration of off-channel and seasonal habitats in the lower basin for enhancing over-wintering capacity for juvenile coho salmon. Data presented from the CDFW OMT results justifies this approach. Important restoration opportunities include areas where off-channel rearing habitats can be created or enhanced such that fish can find refugia outside of the main channel during high discharge events, and then return to the main channel as flows recede. Recently, floodplain connectivity has been restored in the lower Freshwater Creek watershed through the Wood Creek Enhancement Project near Three Corners Grocery. These restored, tidally-influenced habitats provide critical resources to federally threatened species including coho salmon and steelhead trout, federally-endangered tidewater goby, and a variety of songbirds, shorebirds, and waterfowl.

The development of a population model utilizing stage to stage stock-recruit data requires years (15 years or more is desirable) of data at multiple spatial scales for one population. Therefore, we recommend that all the Life Cycle Monitoring Station (LCS) data collected in coastal California be evaluated, collectively, for potential use in a single generalized life cycle model. This model can be used to generate hypotheses of limiting factors and test restoration scenarios to guide restoration efforts for coho salmon.

Map 8 depicts known and presumed distributions of the four HCP listed salmonid species and the known migration barriers which limit them. Data used to generate this map were collected on field surveys conducted by CDFW, HFAC, and HRC. Field surveys included upstream (adult) migrant trapping, carcass/redd surveys, downstream (smolt) trapping, and presence/absence (snorkel/electrofishing) surveys.

Distribution is limited by geologic or anthropogenic barriers, increased gradient, sufficient habitats and available streamflow. Resident rainbow and/or cutthroat trout have been either observed or presumed upstream of natural anadromous barriers in the following tributaries: McCready Gulch, Little Freshwater Creek, Cloney Gulch, Graham Gulch, South Fork, and Upper Mainstem. The barriers on Cloney Falls and Upper Mainstem are geologic rock features (waterfalls). All other anadromous barriers in Freshwater Creek are either caused by log jams, gradient transitions, or diminishing habitats. Through data collection during winter spawning surveys and subsequent summer juvenile population abundance surveys, debris jams have been shown to restrict fish passage in Freshwater Creek. In some instances, these jams have mobilized and cleared out naturally during high-flow events. In other instances, field crews have manually removed key portions of some of these debris jams to accelerate the process for improved fish passage. As a result of HCP road upgrades and/or stormproofing, there are no known anthropogenic barriers remaining on HRC ownership.

Partial barriers, such as the swimming pool at the Freshwater Park and the HFAC weir, seasonally restrict fish passage. Fish access to adjacent habitats may be hampered by the juvenile fish ladder installed at the county park during the summer, while fish are passively directed into a trap at the HFAC weir to conduct adult and out-migrant estimates throughout the winter and spring. During winter high-flow events, the panels at the HFAC weir are dropped to allow unrestricted passage of fish and debris that could otherwise become pinned and cause fish mortality and structural damage to the facility.

Culverts at the county road crossings on Cloney Gulch and Graham Gulch have been upgraded to improve fish passage in recent years. A “bottomless” culvert was installed on Graham Gulch in 2005 and a baffled culvert was installed on Cloney Gulch several years prior. Step-pools were also constructed at the confluence of Cloney Gulch to reduce channel gradient and further improve fish access by reducing stream velocity.

8 AMPHIBIANS AND REPTILES

8.1 INTRODUCTION

Four amphibian and one reptile species are covered under the HRC HCP: the southern torrent salamander (*Rhyacotriton variegatus*, RHVA); tailed frog (*Ascaphus truei*, ASTR); northern red-legged frog (*Rana aurora aurora*, RAAU); foothill yellow-legged frog (*Rana boylii*, RABO); and northwestern pond turtle (*Emys marmorata marmorata*, EMMA). None of these species are currently listed under the federal or state endangered species acts, but all are listed as California Species of Special Concern (CDFW 2016), with the exception of the foothill yellow-legged frog. The foothill yellow-legged frog is a Candidate species petitioned for listing as threatened under the California Endangered Species Act (CESA). The California Fish and Game Commission voted to accept a listing petition for evaluation on June 21, 2017, and designated the foothill yellow-legged frog as a candidate species pursuant to Fish and Game Code 2074.2. During the candidacy period any take of foothill yellow-legged frog is prohibited except as authorized under CESA.

Surveys and habitat assessments for the covered species have been ongoing through implementation of HCP monitoring strategies. Sections of the HCP addressing amphibians and reptiles include: 6.3.2.1, 6.3.5.2.4, and 6.10. These HCP sections discuss the process by which both WA and effectiveness monitoring address the covered species' habitat needs. The initial WA for the Freshwater Creek WAU, completed in 2003, included an Amphibian and Reptile Module (Appendix G) (PALCO 2003) which described the life history requirements and habitat requirements of the covered species. Further discussion was subsequently provided in HRC Amphibian and Reptile HCP Annual Reports (e.g., HRC 2013b).

Key findings of the 2003 Freshwater Creek WAU Amphibian and Reptile Module included:

- All covered species, except northwestern pond turtles, were encountered in the Freshwater Creek WAU incidentally, in surveys conducted for the analysis, or in surveys previously conducted.
- Habitat and occurrences were identified for the southern torrent salamander and tailed frog in headwater streams through field surveys for the assessment. The upstream distribution of these headwater species was estimated based on drainage area. Seeps and springs that could provide habitat for the southern torrent salamander were not mapped for the analysis. However, these features were thought to be more commonly located along the interface of the undifferentiated Wildcat and Central belt mélange/sandstone geologies due to the availability of competent substrates. Identification and mapping of seeps and springs with potential habitat for these species during the THP process is important for their conservation.
- Potential habitat for the northern red-legged frog and the foothill yellow-legged frog was based on parameters identified through baseline data and literature, as well as consultation with local

and regional experts. Specific field surveys were not conducted for these two species; however, both species were observed in the Freshwater Creek WAU. (Surveys were done concurrent with fish habitat surveys.)

- Habitat for the northwestern pond turtle is not likely to occur because basking and nest sites are unavailable. This species was not observed in this watershed on HRC lands, but has been reported anecdotally downstream.
- Data on aquatic habitat conditions and amphibian and reptile life history and distribution patterns, obtained from field surveys and historical analysis, were extrapolated to segments in Channel Geomorphic Units (CGUs), based on underlying geology and channel gradient.
- The yellow-legged frog, southern torrent salamander, and tailed frog benefit from larger cobbles and other coarse sediment. The CGUs with unconsolidated geology (i.e., Wildcat) produce little or no coarse sediments and high volumes of fine sediments and result in highly embedded substrates. The CGUs with consolidated geologies (i.e., Central belt mélange/sandstone and Yager terrane [coastal belt]) produce more coarse sediments that provide interstitial spaces and are suspected to form better quality habitat for these three species.
- Those CGUs within the undifferentiated Wildcat geologies were considered to be areas of concern. The fine sediments typical of undifferentiated Wildcat geologies provide poor habitat for tailed frog tadpoles, yellow-legged frogs, and torrent salamanders. Red-legged frogs may breed off channel in very low gradient, low-flow backwaters and off streams in floodplain pools throughout this geology but not in the main channels. Torrent salamanders were not observed in any surveys within undifferentiated Wildcat geologies, and tailed frog tadpoles were observed at only one atypical survey site where LWD had trapped coarse sediments and provided available substrate, which was thought to have originated in the adjacent Yager formations.
- In general, habitat conditions in CGUs throughout the watershed included abundant LWD, good pool area, and high canopy closure. Substrate embeddedness was low in the consolidated geologies (i.e., Central belt mélange/sandstone), and high in the unconsolidated geologies (i.e., undifferentiated Wildcat).

No specific monitoring requirements were recommended as a result of the 2003 Freshwater Creek WA (PALCO 2003) or through riparian prescription development.

Surveys described above for the 2003 Freshwater Creek WA were subsequently used as baseline surveys from which to establish future monitoring sites. In addition, more records of covered species occurrence in the WAU have been gathered from incidental observations recorded during THP surveys, and from wildlife monitoring surveys, including protocol surveys of Class I and Class II waters (streams, watercourses, seeps, springs, lakes, ponds, and wetlands). The additional records have been used to establish new monitoring sites since the initial baseline surveys.

Since the 2003 Freshwater Creek WA and initial baseline surveys, HRC has implemented two changes in sampling strategies for the covered species: 1) distribution of surveys was focused on WAUs scheduled for upcoming WA revisit, and 2) surveys for the headwater species (tailed frog and southern torrent salamander) were changed to an “occupancy-level” survey. This second change was initiated because it was recognized that the vigorous sampling techniques originally used for the baseline surveys could potentially negatively impact sub-populations through manipulation of habitat. The change to an occupancy-level survey meant that the same techniques would be used, but that the survey would be terminated once the focus species was found. Alternately, an entire reach would be surveyed only if no specimens could be located. This technique allows monitoring for the persistence of sub-populations within WAUs without risking potential habitat damage. Northern red-legged frog surveys have consistently been conducted using a site occupancy-level approach, so no change in survey strategy was necessary for this species.

8.2 METHODS

The survey protocol for tailed frogs and southern torrent salamanders uses an area-constrained search method for Class II waters. The suggested sampling period for torrent salamanders is after the first winter rains (e.g., October-November) through May, depending on weather and watercourse conditions. For tailed frogs the suggested sampling period is March through June. Based on the results of previous surveys, it appears that the survey season for both species can be extended when favorable water conditions exist, although drought conditions that prevailed prior to the 2015-2016 winter rainfall have in some cases required that surveys be conducted earlier in the season.

Survey reaches for tailed frogs and southern torrent salamanders are sub-divided into survey belts. In addition to site occupancy, the habitat type, gradient, substrate, embeddedness, and canopy at the belt level are recorded (Table 8-1). During the 2016 survey period, one water temperature measurement (°C) was taken in the first survey belt at the beginning of each survey. This was intended as a quick look at water temperatures at the survey locations, and not related to more intensive survey monitoring such as is conducted at the Class I stream ATM program sites.

For tailed frogs, site occupancy and habitat conditions were monitored at 11 sites in 2013, 2015, and 2016 based on verified locations from the 2003 WA in the Freshwater Creek WAU, with 10 of the 11 sites located in consolidated geologies (i.e., Central belt mélange/sandstone and Yager terrane). The sites are distributed by sub-basin as follows (Map 9):

- Cloney Gulch (n = 1)
- Graham Gulch (n = 1)
- Upper Mainstem (n = 4)
- South Fork (n = 4)
- Little Freshwater (n = 1)

Table 8-1. Habitat codes for tailed frog and southern torrent salamander survey summaries

Parameter	Explanation		
Habitat Type	**P**=Pool **R**=Run **LGR**=Low Gradient Riffle		**HGR**=High Gradient Riffle **C/F**=Cascade/Falls **SP**=Step Pool
Substrate C/I	Competent (**C**) hard and does not break in the hand it is competent. Incompetent (**I**) Readily crumbles or has plasticity it is incompetent.		
Embeddedness (1-4)	**1**=0-25%, **2**=26-50%	**3**=51-75% **4**=76-100%	
Species ID	**RHVA** = southern torrent salamander **ASTR** = tailed frog		**DITE** = coastal giant salamander **RAAU** = northern red-legged frog

For southern torrent salamanders, site occupancy and habitat conditions were monitored at eight sites from 2013 through 2016 based on verified locations from the 2003 WA in the Freshwater Creek WAU. All monitoring sites are in consolidated geologies (i.e., Central belt mélange/sandstone and Yager terrane). The sites are distributed by sub-basin as follows (Map 9):

- Cloney Gulch (n = 1)
- Graham Gulch (n = 1)
- Upper Mainstem (n = 4)
- South Fork (n = 2)

For northern red-legged frogs, known breeding sites are inspected for evidence of adults, juveniles, and egg masses. In addition to site occupancy, water source and formation are recorded. Northern red-legged frogs prefer a variety of slow-moving waters or ponds for breeding, including lakes, ponds, stream backwaters, sloughs, and roadside ditches (Nussbaum et al. 1983). Habitats of this type are limited in the Freshwater Creek WAU. During the 2003 WA, this species was observed incidentally during fish habitat (i.e., stream) surveys, and breeding sites were not located and verified.

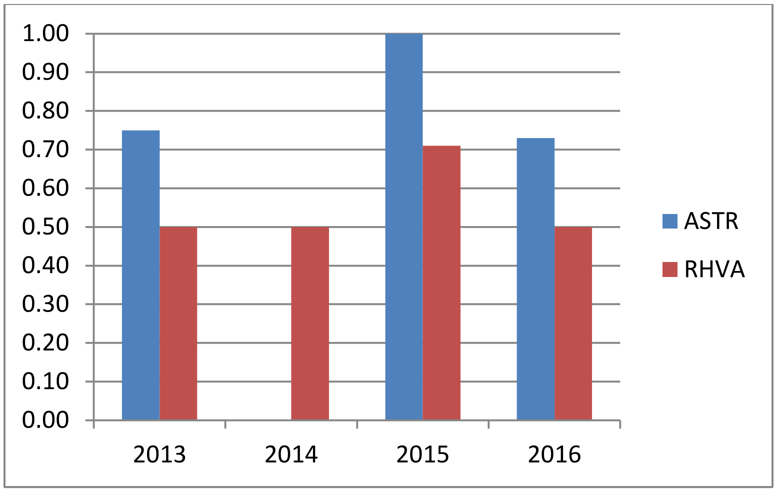
Red-legged frog occupancy in WAUs can readily be established by observing evidence of breeding (e.g., egg masses or tadpoles) in ponded waters. In the years since the baseline surveys, northern red-legged frogs have been observed using ponded waters for breeding in the Freshwater Creek WAU on various surveys and incidental observations, as discussed above. Although breeding habitat is limited and often ephemeral, three sites have been used to monitor northern red-legged frog occupancy from 2011 through 2016. Levels of effort for monitoring have not been consistent from year to year. Two of the three monitoring sites are in consolidated geologies (i.e., Central belt mélange/sandstone and Yager terrane). The sites are distributed by sub-basin as follows (Map 9):

- McCready Gulch (n = 1)
- Cloney Gulch (n = 1)
- Upper Mainstem (n = 1)

8.3 RESULTS

8.3.1 Tailed Frog and Southern Torrent Salamander Site Occupancy

Occupancy rates for tailed frog and southern torrent salamander in the Freshwater Creek WAU during the period 2013 through 2016 are shown in Figure 8-1. There were no tailed frog surveys in this WAU in 2014. Occupancy rates for tailed frog ranged from 0.73 to 1.00. For southern torrent salamander the rates were from 0.50 to 0.71. Complete survey results for tailed frog and southern torrent salamander are shown in Table 8-2 and Table 8-3, respectively.



Note: No tailed frog surveys were done in 2014.

Figure 8-1. Occupancy rates for tailed frog (ASTR) and southern torrent salamander (RHVA) in the Freshwater Creek WAU, 2013-2016

Table 8-2. Complete results for tailed frog (ASTR) surveys, 2013 and 2015–2016

Site #	Date	Belt #	Belt Habitat Type	Belt Gradient (%)	Belt Substrate	Belt Embed	Belt Canopy	Species ID	Age ID	Count	Water Temp °C
165	16-Jul-13	1	LGR	3	C	2	82.0%	NA	NA	NA	NA
165	16-Jul-13	2	LGR	0.5	C	2	53.0%	ASTR	T	2	NA
175	16-Jul-13	1	LGR	2	C	2	88.0%	ASTR	A	1	NA
175	16-Jul-13	1	LGR	2	C	2	88.0%	DITE	L	1	NA
170	06-Aug-13	1	C/F	45	C	2	53.0%	ASTR	T	2	NA
179	13-Aug-13	1	LGR	1	C	2	89.5%	DITE	L	5	NA
179	13-Aug-13	2	HGR	15	C	2	92.5%	DITE	L	1	NA
179	13-Aug-13	1	LGR	5	C	1	65.5%	DITE	L	2	NA
179	13-Aug-13	2	LGR	3	C	2	70.0%	NA	NA	NA	NA
179	13-Aug-13	1	C/F	85	C	1	85.0%	DITE	L	2	NA
179	13-Aug-13	2	C/F	60	C	1	85.0%	DITE	L	1	NA
170	09-Jan-15	1	SP	20	C	1	41.0%	ASTR	T	4	NA
165	01-Jun-15	1	LGR	1	C	2	89.5%	ASTR	T	1	NA
165	01-Jun-15	1	LGR	1	C	2	89.5%	DITE	L	1	NA
175	01-Jun-15	1	LGR	3	C	2	79.0%	NA	NA	NA	NA
175	01-Jun-15	2	LGR	1.5	C	2	86.5%	ASTR	T	1	NA
175	01-Jun-15	2	LGR	1.5	C	2	86.5%	DITE	L	2	NA
179	01-Jun-15	1	LGR	4	C	1	89.5%	ASTR	A	1	NA
179	01-Jun-15	1	LGR	4	C	1	89.5%	DITE	L	2	NA
170	19-Apr-16	1	SP	45	C	2	64.0%	ASTR	T	4	11.5°
170	19-Apr-16	1	SP	45	C	2	64.0%	DITE	L	0	NA
166	31-May-16	1	LGR	7	C	2	91.0%	ASTR	T	2	12°
165	01-Jun-16	1	LGR	1	C	2	98.5%	ASTR	T	3	11.5°
175	01-Jun-16	1	P	0	C	3	76.0%	ASTR	A	2	11°
179	02-Jun-16	1	LGR	6	C	2	95.5%	DITE	L	1	11°
179	02-Jun-16	2	LGR	3	C	1	94.0%	ASTR	T	1	NA
206	02-Jun-16	1	LGR	2	C	1	80.5%	ASTR	T	1	14°
206	02-Jun-16	1	LGR	2	C	1	80.5%	DITE	L	1	NA
186	06-Jun-16	1	LGR	5	C	2	91.0%	NA	NA	NA	11.5°
186	06-Jun-16	2	HGR	13	C	2	94.0%	DITE	L	1	NA
186	06-Jun-16	1	HGR	32	C	2	91.0%	ASTR	T	2	NA
200	06-Jun-16	1	C/F	70	C	2	70.0%	NA	NA	NA	11°
200	06-Jun-16	2	C/F	75	C	2	92.5%	NA	NA	NA	NA
200	06-Jun-16	1	LGR	3	C	3	91.0%	NA	NA	NA	NA
200	06-Jun-16	2	HGR	23	C	2	88.0%	NA	NA	NA	NA
210	06-Jun-16	1	HGR	10	C	1	47.0%	DITE	L	5	10°
210	06-Jun-16	2	HGR	15	C	1	47.0%	DITE	L	4	NA
210	06-Jun-16	1	LGR	3	C	3	83.5%	DITE	L	5	NA
210	06-Jun-16	2	LGR	6	C	3	91.0%	DITE	L	2	NA
183	06-Jun-16	1	HGR	40	C	2	68.5%	NA	NA	NA	11°
183	06-Jun-16	2	HGR	40	C	2	74.5%	DITE	L	2	NA
183	06-Jun-16	1	HGR	30	C	2	79.0%	NA	NA	NA	NA
183	06-Jun-16	2	SP	40	C	2	59.5%	DITE	L	2	NA
1175	07-Jun-16	1	HGR	17	C	1	76.0%	ASTR	T	2	13°

A = adult, L = larvae, T = tadpole, NA = not available
LGR = low gradient riffle, C/F = cascade/falls, HGR = high gradient riffle, P = pool, SP = step pool
ASTR = *Ascaphus truei* (tailed frog), DITE = *Dicamptodon tenebrosus* (coastal giant salamander)

Table 8-3. Complete results for southern torrent salamander (RHVA) surveys, 2013–2016

Site #	Date	Belt #	Belt Habitat Type	Belt Gradient (%)	Belt Substrate	Belt Embed	Belt Canopy	Species ID	Age ID	Count	Water Temp °C
182	24-Jan-13	1	HGR	17	C	2	95.50%	NA	NA	NA	NA
182	24-Jan-13	2	C/F	20	C	1	95.50%	RHVA	L	1	NA
182	24-Jan-13	2	C/F	20	C	1	95.50%	RHVA	J	1	NA
180	24-Jan-13	1	SP	5	C	2	97.00%	DITE	L	1	NA
180	24-Jan-13	2	SP	10	C	2	98.50%	DITE	L	2	NA
192	01-Feb-13	1	C/F	35	C	3	98.50%	NA	NA	NA	NA
192	01-Feb-13	2	C/F	60	C	3	91.00%	NA	NA	NA	NA
192	01-Feb-13	1	HGR	30	C	2	100.00%	DITE	L	1	NA
3	04-Feb-13	1	C/F	42	C	2	96.00%	ASTR	T	1	NA
3	04-Feb-13	1	C/F	42	C	2	96.00%	DITE	L	1	NA
3	04-Feb-13	2	C/F	35	C	2	95.50%	RHVA	A	1	NA
177	05-Feb-13	1	C/F	55	C	2	92.50%	RHVA	L	1	NA
177	05-Feb-13	1	C/F	55	C	2	92.50%	DITE	L	2	NA
201	05-Feb-13	1	C/F	50	C	2	97.00%	DITE	L	1	NA
201	05-Feb-13	2	HGR	25	C	2	94.00%	NA	NA	NA	NA
201	05-Feb-13	1	HGR	25	C	2	95.50%	NA	NA	NA	NA
201	05-Feb-13	2	C/F	40	C	2	92.50%	NA	NA	NA	NA
1	06-Feb-13	1	C/F	22	C	2	92.50%	DITE	L	5	NA
1	06-Feb-13	2	HGR	22	C	2	92.50%	RHVA	L	1	NA
6	07-Feb-13	1	HGR	23	C	3	92.50%	NA	NA	NA	NA
6	07-Feb-13	2	C/F	30	C	2	97.00%	NA	NA	NA	NA
6	07-Feb-13	1	C/F	30	C	2	100.00%	DITE	L	1	NA
6	07-Feb-13	2	HGR	28	C	2	100.00%	DITE	L	1	NA
180	25-Feb-13	1	C/F	60	C	3	85.00%	NA	NA	NA	NA
180	25-Feb-13	1	HGR	6	C	2	83.50%	RHVA	A	1	NA
201	26-Feb-13	1	LGR	7	C	2	82.00%	NA	NA	NA	NA
201	26-Feb-13	2	C/F	33	C	2	94.00%	NA	NA	NA	NA
201	26-Feb-13	2	C/F	33	C	2	98.50%	NA	NA	NA	NA
201	26-Feb-13	2	C/F	25	C	3	97.00%	NA	NA	NA	NA
6	23-Jan-14	1	HGR	23	C	2	95.50%	RHVA	A	1	NA
3	23-Jan-14	1	C/F	42	C	2	95.50%	RHVA	A	1	NA
201	23-Jan-14	1	C/F	50	C	2	97.00%	NA	NA	NA	NA
201	23-Jan-14	2	HGR	25	C	2	94.00%	NA	NA	NA	NA
201	23-Jan-14	1	HGR	25	C	2	95.50%	NA	NA	NA	NA
201	23-Jan-14	2	C/F	40	C	2	92.50%	NA	NA	NA	NA
177	23-Jan-14	1	C/F	55	C	2	92.50%	NA	NA	NA	NA
177	23-Jan-14	2	C/F	45	C	2	94.00%	NA	NA	NA	NA
177	23-Jan-14	1	C/F	60	C	2	91.00%	NA	NA	NA	NA
177	23-Jan-14	2	C/F	50	C	2	94.00%	NA	NA	NA	NA
182	24-Jan-14	1	HGR	17	C	2	92.50%	RHVA	J	1	NA
182	24-Jan-14	2	C/F	20	C	1	95.50%	NA	NA	NA	NA
180	24-Jan-14	1	HGR	5	C	2	97.00%	NA	NA	NA	NA
180	24-Jan-14	2	SP	10	C	3	98.50%	NA	NA	NA	NA
180	24-Jan-14	1	C/F	45	C	3	85.00%	DITE	L	2	NA
180	24-Jan-14	2	C/F	20	C	2	82.00%	DITE	L	1	NA
180	24-Jan-14	2	C/F	20	C	2	82.00%	RHVA	L	1	NA
192	24-Jan-14	1	C/F	35	C	3	98.50%	NA	NA	NA	NA
192	24-Jan-14	2	C/F	60	C	3	89.50%	NA	NA	NA	NA
192	24-Jan-14	1	C/F	40	C	3	95.50%	NA	NA	NA	NA
192	24-Jan-14	2	C/F	40	C	3	95.50%	NA	NA	NA	NA
1	27-Jan-14	1	LGR	5	C	3	39.50%	ASTR	T	1	NA
1	27-Jan-14	2	HGR	20	C	2	47.00%	ASTR	T	1	NA
1	27-Jan-14	1	C/F	25	C	2	95.50%	ASTR	T	2	NA
1	27-Jan-14	1	C/F	25	C	2	95.50%	DITE	L	1	NA
1	27-Jan-14	2	HGR	20	C	2	85.00%	ASTR	T	1	NA
180	18-Dec-14	1	HGR	25	C	2	79.00%	DITE	L	1	NA
180	18-Dec-14	1	HGR	25	C	2	79.00%	RHVA	L	1	NA
182	05-Jan-15	1	C/F	55	C	3	95.50%	NA	NA	NA	NA

Site #	Date	Belt #	Belt Habitat Type	Belt Gradient (%)	Belt Substrate	Belt Embed	Belt Canopy	Species ID	Age ID	Count	Water Temp °C
182	05-Jan-15	2	HGR	32	C	2	88.00%	NA	NA	NA	NA
182	05-Jan-15	1	C/F	60	C	2	89.50%	RHVA	L	1	NA
201	06-Jan-15	1	C/F	75	C	1	62.50%	NA	NA	NA	NA
201	06-Jan-15	2	HGR	25	C	2	74.50%	NA	NA	NA	NA
201	06-Jan-15	1	SP	65	C	1	91.00%	NA	NA	NA	NA
201	06-Jan-15	2	C/F	80	C	1	95.50%	NA	NA	NA	NA
177	07-Jan-15	1	SP	23	C	1	79.00%	RHVA	A	1	NA
192	07-Jan-15	1	C/F	90	C	1	56.00%	RHVA	A	1	NA
3	08-Jan-15	1	C/F	30	C	1	97.00%	NA	NA	NA	NA
3	08-Jan-15	2	C/F	35	C	1	89.50%	RHVA	L	1	NA
1	09-Jan-15	1	C/F	40	C	2	70.00%	DITE	L	1	NA
1	09-Jan-15	2	C/F	120	C	1	74.50%	DITE	L	1	NA
1	09-Jan-15	2	C/F	120	C	1	74.50%	RHVA	L	1	NA
6	13-Jan-15	1	SP	25	C	1	88.00%	DITE	L	1	NA
6	13-Jan-15	2	HGR	18	C	1	80.50%	DITE	L	1	NA
6	13-Jan-15	1	C/F	27	C	1	74.50%	DITE	L	1	NA
6	13-Jan-15	2	C/F	50	C	1	83.50%	NA	NA	NA	NA
1	31-May-16	1	C/F	90	C	2	86.50%	DITE	L	1	11
1	31-May-16	2	C/F	120	C	1	82.00%	RHVA	L	1	NA
3	31-May-16	1	C/F	35	C	1	89.50%	DITE	L	2	12
3	31-May-16	2	C/F	47	C	1	91.00%	DITE	L	1	NA
3	31-May-16	2	C/F	47	C	1	91.00%	RHVA	L	1	NA
177	31-May-16	1	SP	25	C	2	80.50%	NA	NA	NA	7
177	31-May-16	2	SP	40	C	2	83.50%	RHVA	A	1	NA
177	31-May-16	2	SP	40	C	2	83.50%	DITE	L	1	NA
192	31-May-16	1	SP	30	C	2	57.50%	NA	NA	NA	9
192	31-May-16	2	SP	30	C	2	91.00%	NA	NA	NA	NA
192	31-May-16	1	HGR	13	C	2	100.00%	NA	NA	NA	NA
192	31-May-16	2	HGR	16	C	2	100.00%	NA	NA	NA	NA
182	01-Jun-16	1	HGR	10	C	2	97.00%	DITE	L	3	10
182	01-Jun-16	2	HGR	15	C	2	98.50%	DITE	L	2	NA
182	01-Jun-16	1	SP	20	C	2	92.50%	DITE	L	2	NA
182	01-Jun-16	2	SP	20	C	2	91.00%	DITE	L	1	NA
201	01-Jun-16	1	C/F	60	C	1	62.50%	NA	NA	NA	9
201	01-Jun-16	2	HGR	25	C	2	75.00%	DITE	L	1	NA
201	01-Jun-16	2	HGR	25	C	2	75.00%	RAAU	A	1	NA
201	01-Jun-16	1	SP	30	C	2	91.00%	NA	NA	NA	NA
201	01-Jun-16	2	SP	30	C	2	97.00%	NA	NA	NA	NA
180	01-Jun-16	1	LGR	10	C	1	91.00%	RHVA	L	1	NA
180	01-Jun-16	1	LGR	10	C	1	91.00%	DITE	L	1	8
6	02-Jun-16	1	SP	25	C	2	89.50%	NA	NA	NA	9
6	02-Jun-16	2	HGR	16	C	2	80.50%	NA	NA	NA	NA
6	02-Jun-16	1	C/F	27	C	3	74.50%	NA	NA	NA	NA
6	02-Jun-16	2	C/F	45	C	3	83.50%	NA	NA	NA	NA

A = adult, L = larvae, T = tadpole, J = juvenile, NA = not available
LGR = low gradient riffle, C/F = cascade/falls, HGR = high gradient riffle, SP = step pool
ASTR = *Ascaphus truei* (tailed frog), DITE = *Dicamptodon tenebrosus* (coastal giant salamander), RHVA = *Rhyacotriton variegatus* (southern torrent salamander), RAAU = *Rana aurora aurora* (northern red-legged frog)

Tailed frog detections were primarily of tadpoles (80%) with their distinctive tail marking and habit of using the suction-like mouthparts to forage on stream cobble (Figure 8-2). This would be expected, given the timing of the surveys and the location of the detections primarily in the low gradient riffles in areas with competent rock.

Photo credit: M. Dunkelberger, HRC

Figure 8-2. Tailed frog tadpole, Site 170

Coastal giant salamanders (*Dicamptodon tenebrosus*, DITE) were observed at 8 of the 11 monitoring sites (73%).

In 2013, surveys were conducted in July and August (not during the suggested sampling period of March through June) but were opportunistically done in conjunction with torrent salamander surveys at or near the tailed frog sites.

The tailed frog surveys in 2015 and 2016 were done during the preferred sampling period for this species and with good flow conditions. During the survey period reported here (2013, 2015, and 2016), all tailed frog monitoring sites had occupancy on at least one survey, with the exception of sites 183, 200, and 210. Underground flow, low flow, or difficulties of search due to abundance of large wood in the channel have been noted as problems at these sites relative to observing the target species.

Detections of southern torrent salamander adults and larvae were roughly equal, with detections of larvae making up slightly more than half (55%) (Figure 8-3). Coastal giant salamanders have been observed at all eight of the southern torrent salamander monitoring sites.

Photo credit: M. Dunkelberger, HRC

Figure 8-3. Adult male southern torrent salamander, Freshwater Site 1

Southern torrent salamander surveys from 2013 through 2016 were conducted during the suggested sampling period (November through May). Drought conditions during this period may have aided surveys by concentrating animals within available habitat.

All southern torrent salamander monitoring sites were found to be occupied during the survey period (2013 through 2016) with the exception of site 201.

8.3.2 Northern Red-legged Frog Site Occupancy

As discussed above, during the 2003 Freshwater Creek WA northern red-legged frogs were observed on fish habitat surveys. Lentic breeding habitat for the species was not identified at that time. Although habitat appears limited and ephemeral in this WAU, three sites found since the baseline surveys have been used in an attempt to monitor northern red-legged frog occupancy from 2011 through 2016. The level of effort for monitoring has not been consistent from year to year during this period. Complete survey results are shown in Table 8-4.

Table 8-4. Complete results for northern red-legged frog (RAAU) surveys, 2011–2016

Site ID	Date	Water Source	Formation	Species	Age Desc	Count
1	16-Feb-11	Stream	Basin	NA	NA	NA
133	19-Apr-11	Spring	Roadside Ditch	RAAU	Egg Mass	1
133	19-Apr-11	Spring	Roadside Ditch	RAAU	Tadpole	200
133	19-Apr-11	Spring	Roadside Ditch	HYRE	Tadpole	70
1	07-Dec-11	Stream	Basin	NA	NA	NA
54	07-Dec-11	Spring	Equipment	NA	NA	NA
133	22-Dec-11	Spring	Roadside Ditch	RAAU	Egg Mass	3
54	06-Nov-12	Spring	Equipment	NA	NA	NA
133	06-Nov-12	Spring	Roadside Ditch	RAAU	Egg Mass	5
1	12-Nov-12	Stream	Basin	NA	NA	NA
2	12-Nov-12	Rain Pooling	Equipment	NA	NA	NA
67	12-Nov-12	Rain Pooling	Equipment	NA	NA	NA
1	03-Jan-13	Stream	Basin	NA	NA	NA
1	06-Nov-14	Stream	Basin	NA	NA	NA
2	06-Nov-14	Rain Pooling	Equipment	NA	NA	NA
67	06-Nov-14	Rain Pooling	Equipment	NA	NA	NA
133	06-Nov-14	Spring	Roadside Ditch	RAAU	Egg Mass	2
1	17-Feb-15	Stream	Basin	NA	NA	NA
2	17-Feb-15	Rain Pooling	Equipment	NA	NA	NA
54	17-Feb-15	Spring	Equipment	NA	NA	NA
67	17-Feb-15	Rain Pooling	Equipment	HYRE	Egg Mass	10
67	17-Feb-15	Rain Pooling	Equipment	HYRE	Tadpole	15
1	19-Apr-16	Stream	Basin	NA	NA	NA
133	19-Apr-16	Spring	Roadside Ditch	RAAU	Egg Mass	1
2	07-Jun-16	Rain Pooling	Equipment	NA	NA	NA
67	07-Jun-16	Rain Pooling	Equipment	NA	NA	NA

NA = not available, RAAU = *Rana aurora aurora* (northern red-legged frog), HYRE = *Hyla regilla* (Pacific treefrog)

The preferred sampling period for observing adults, juveniles, or egg masses of this species is generally November through March, following rainfall events that stimulate adults to breed and for females to deposit eggs at breeding sites. The survey period can be expanded in the local region depending on the duration and intensity of the rainy period, which in turn influences the hydroperiod of wetlands and ponds (e.g., HRC 2013b). In a study of northern California coastal wetlands, Sendak (2008) found that ponds with an average maximum depth of 6 inches or greater exhibited hydroperiods longer than 4 months. Red-legged frogs require lentic breeding sites (ponds, wetlands) with a hydroperiod of 4 to 6 months to allow eggs and juveniles to metamorphose (Sendak 2008).

Keeping in mind the very small sample size, occupancy of the monitored sites in the Freshwater Creek WAU from 2011 through 2016 by northern red-legged frogs has been very low. None of the monitored sites were occupied by red-legged frogs during two of the sampling periods (2013 and 2015). Only one of the sites (133, Cloney Gulch sub-basin) was occupied by this species during the survey period (in 2011, 2012, 2014, and 2016) (Figure 8-4). Other species observed at these locations include Pacific treefrog (*Hyla regilla*, HYRE).

Photo credit: M. Dunkelberger, HRC

Figure 8-4. Northern red-legged frog egg masses, Site 133

Red-legged frog monitoring sites were classified by water source (i.e., stream, rain pooling, spring, or road runoff) and formation (i.e., basin, roadside ditch or equipment origin). Maximum length, width, and depth have been measured to obtain an index of suitability. For example, the only occupied site during this survey period, site 133, is a spring-fed roadside ditch (formed by heavy equipment) that has been found to maintain a depth of approximately seven inches throughout the breeding period.

8.3.3 Habitat Conditions at Tailed Frog Monitoring Sites

Belt habitat type at the Freshwater Creek WAU tailed frog monitoring sites is primarily low gradient riffle (LGR) and high gradient riffle (HGR) at 40% and 33%, respectively (Figure 8-5).

Belt gradient ranged from 0 to 85%, with a mean of 18%. This channel habitat characteristic is consistent with survey results for LGR.

For belt substrate, all of the sites were of competent rock. This result is consistent with the location of the monitoring sites in the Central belt mélange/sandstone and Yager terrane (coastal belt) formations.

Belt embeddedness ranged from Class I to Class III (0 to 75%), and was primarily (64%) Class II (26 to 50% embeddedness). When compared to the Properly Functioning Conditions (PFC) Matrix used for habitat condition evaluation in the 2003 WA, Class II embeddedness falls within the Fair to Poor category.

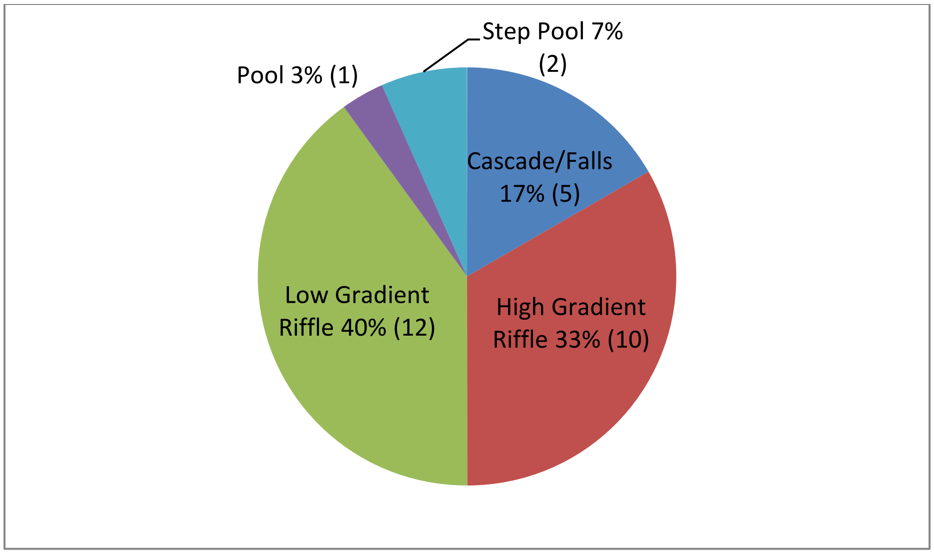


Figure 8-5. Belt habitat types at Freshwater Creek WAU tailed frog monitoring sites, 2013-2016

Belt canopy cover had a range of 41.0 to 98.5%, with a mean of 79.3%. PFC targets for canopy cover considered beneficial for tailed frog and southern torrent salamander are > 85% and > 80%, respectively.

On the 2016 surveys, one water temperature measurement (°C) was taken in the first survey belt at the beginning of the survey. Water temperatures were cold, and within a range generally considered beneficial for tailed frogs (range 10-14° C, mean 11.6° C) (Brown 1975, Claussen 1973).

No changes in belt habitat conditions (e.g., habitat type, gradient, substrate, or canopy) were noted between years. There were no changes in RMZ prescriptions since watershed-specific prescriptions were established by the 2003 WA. No degraded habitats were noted. Although some surveys were done outside the preferred sampling period, flow conditions were generally adequate for observing ASTR tadpoles attached to rocks. However, flexibility in survey timing is needed during years with variation in rainfall and streamflow.

8.3.4 Habitat Conditions at Southern Torrent Salamander Monitoring Sites

Belt habitat types at the Freshwater Creek WAU southern torrent salamander monitoring sites are composed primarily of cascade/falls (C/F), step pool (SP), and HGR, at 40%, 28%, and 25%, respectively (Figure 8-6).

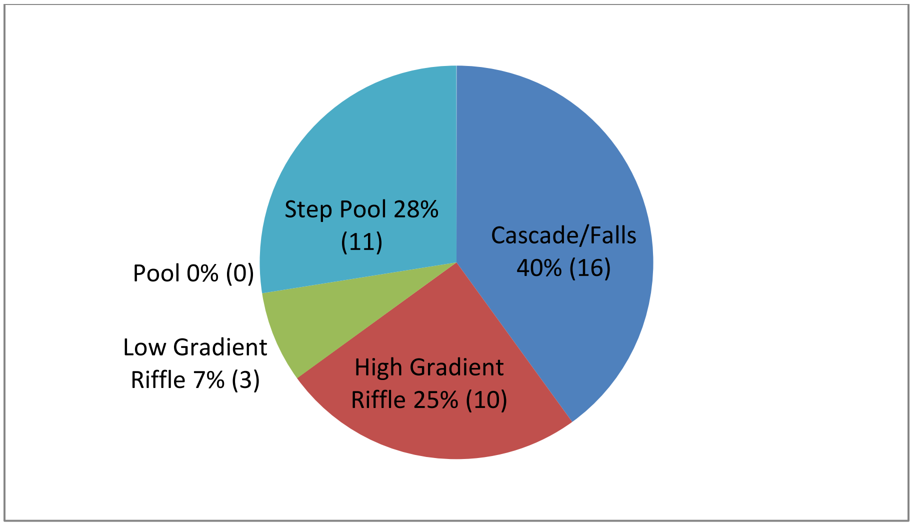


Figure 8-6. Belt habitat types at Freshwater Creek WAU southern torrent salamander monitoring sites, 2013-2016

Belt gradient ranged from 5 to 120%, with a mean of 35.5%. Similar to tailed frog habitat characteristics, high gradient C/F and SP habitat for southern torrent salamanders is consistent with survey results from other channel types in the watershed when channels are in consolidated geologies (Figure 8-7).

For belt substrate, 100% of the sites were underlain with competent rock. Again, this is consistent with the location of the monitoring sites in the Central belt mélange/sandstone and Yager terrane (coastal belt) formations.

Belt embeddedness ranged from Class I to Class III (0 to 75%), and was primarily (76%) Class I and II (0 to 50% embeddedness). When compared to the PFC Matrix used for habitat condition evaluation in the 2003 WA, Class I and II embeddedness is generally Good to Fair, although 24% of the sites were in Class III, or Poor category.

Belt canopy ranged from 39.5 to 100%, with a mean of 88.2%. PFC targets for canopy cover considered beneficial for tailed frog and southern torrent salamander are > 85% and > 80%, respectively.

No changes in belt habitat conditions (e.g., habitat type, gradient, substrate, or canopy) were noted between years. Similarly, there were no changes in RMZ prescriptions since they were established by the 2003 WA. No degraded habitats were noted.

Photo credit: M. Dunkelberger, HRC

Figure 8-7. Example of southern torrent salamander habitat, Site 1

During the 2016 survey period in the Freshwater WAU, one water temperature measurement was taken in the first survey belt at the beginning of the survey. This was intended as a quick look at water temperatures at the survey locations, and not related to more intensive survey monitoring such as is conducted at the Class I stream ATM program sites. Water temperatures were cold, and within a range generally considered beneficial for southern torrent salamanders (7 to 12° C, mean of 9.4°) (Diller and Wallace 1996, Welsh and Lind 1996).

8.3.5 Habitat Conditions at Northern Red-legged Frog Monitoring Sites

As discussed previously, given the lack of northern red-legged frog verified breeding sites resulting from surveys for the 2003 Freshwater Creek WA, three sites with documented breeding (i.e., egg masses or tadpoles) were subsequently located. The three sites (sites 1, 54, and 133) have been visited from 2011 to 2016 to check for northern red-legged frog breeding activity and to monitor habitat conditions.

All three sites resulted from heavy equipment use:

- Site 1 is a settling basin at the bottom of a steep road grade, designed to intercept any flow off the road and allow settling of fines.
- Site 54 is a pond that was created when heavy equipment inadvertently dammed flow from a spring.
- Site 133 is a roadside ditch that intercepts flow from a spring and has created ponded water (Figure 8-8).

Photo credit: M. Dunkelberger, HRC

Figure 8-8. Northern red-legged frog Site 133 breeding habitat in roadside ditch

Water source, formation, and dimensions of the monitored ponds are shown in Table 8-5. The ponds average 38.5 ft long, 17.9 ft wide, and 18.9 inches deep. All sites have emergent vegetation that is adequate for attachment of egg masses. Depth of the sites appears adequate to allow hatching of eggs and metamorphosis of tadpoles, depending on the hydroperiod (e.g., Sendak 2008). However, drought conditions have impacted some of the sites during 2012 through 2016, when they were found to not have sufficient depth, or to be completely dry. In addition, since the sites were originally documented as breeding sites, sites 1 and 54 have been found to be increasingly overgrown with willow and alder and may no longer be suitable for breeding. Site 133 is the exception and is the most consistently used of the sites.

Table 8-5. Water source, formation, and dimensions for northern red-legged frog ponds

Site ID	Water Source	Formation	Max Length (ft)	Max Width (ft)	Max Depth (in)
1	Stream	Basin	35.0	19.0	37.8
54	Spring	Equipment	59.1	23.0	11.8
133	Spring	Roadside Ditch	21.3	11.8	7.1

8.4 DISCUSSION

All HCP covered species, except northwestern pond turtles, continue to be encountered in the Freshwater Creek WAU either in surveys conducted for this WA revisit, or incidental to other surveys and monitoring. However, monitoring efforts have focused on the tailed frog and southern torrent salamander due to their association with headwater stream habitats.

The initial Freshwater Creek WA of 2003, including the Amphibian and Reptile Habitat Assessment (Appendix G) (PALCO 2003), recognized that underlying geology influences the stream substrate, which in turn influences the habitat available for the covered species. The yellow-legged frog (Hayes and Jennings 1988, Kupferberg 1996), southern torrent salamander, and tailed frog (Diller and Wallace 1996 and 1999) benefit from larger cobbles and other coarse sediment.

Those sub-basins in predominantly Central belt mélange/sandstone and Yager terrane geologic formations, including in the Cloney Gulch, Graham Gulch, Upper Mainstem, and South Fork sub-basins, provide coarse sediments characteristic of tailed frog and southern torrent salamander habitat. The canopy cover over streams in these units continues to be high, and embeddedness varies with gradient.

Northern red-legged frogs may breed off channel in low-gradient, low-flow backwaters and in a variety of other spring or rain fed pools, ponds or ditches, but not in the main channels, although adults may be encountered in mesic areas. Foothill yellow-legged frog habitat is generally unavailable due to high canopy cover over the streams.

Channels with moderate to high gradient step-pool and cascade/falls habitat, with high canopy cover and the cobble/gravel substrates, provide habitat for tailed frog tadpoles throughout, while instream torrent salamander habitat is typically found in Class II headwater streams and off-channel seeps. The coarse sediments available in these streams provide interstitial spaces and thus good habitat for headwater amphibians.

In contrast, those sub-basins with unconsolidated geology (i.e., Wildcat), including in the School Forest, McCready Gulch, Little Freshwater, and portions of the Mainstem sub-basins, produce little or no coarse sediments and high volumes of fine sediments and can result in highly embedded substrates. This reduces the habitat quality for the headwater species by eliminating available coarse sediments and interstitial spaces. Exceptions include those portions of the Mainstem, Little Freshwater, and South Fork sub-basins that are underlain by the Yager formation. The western pond turtle and northern red-legged frog do not appear to require coarse substrate, and they prefer canopy openings.

A period of 10 to 13 years elapsed between surveys for the analyses. While site occupancy was fair to high for tailed frogs and southern torrent salamanders, some of the sites had not been visited for 10 years or more, and surveying some of what are very small seep features and confined stream reaches with low flow and abundant LWD can possibly lead to false negatives. The year 2016 was the fourth consecutive year of drought conditions in California, leading to low or underground flows, and leaving some sites dry.

Species occupancy can "blink on and off" over the years. Although all sites monitored have been occupied in some years of the survey period, data indicate that sites may not be occupied again while habitat conditions remain virtually unchanged. Survey intensity, for example the level of effort used in searching small habitat areas, can vary by surveyor. In addition, belt habitat and belt gradient calls can be slightly different between years and may indicate differences in observers rather than actual changes in habitat.

Coastal giant salamanders have been observed at 8 of the 11 tailed frog monitoring sites, and at all 8 of the southern torrent salamander monitoring sites. Coastal giant salamanders are potential predators of southern torrent salamanders (e.g., Brode 1995), and are also known to prey on tailed frog tadpoles (e.g., Nussbaum et al. 1983).

HRC property-wide surveys have indicated that northern red-legged frogs deposit eggs from October through February, considerably earlier than suggested in the literature for other regions of the west coast (Storm 1960, Brown 1975, and Licht 1969). Sites with ponded water have been utilized for egg deposition. The surveys were not able to locate backwater pools within watercourses that are utilized. Egg masses were generally deposited in shallow water, or the shallow regions of larger ponds, allowing for easy observation and enumeration of egg masses in most cases. In addition, egg masses also persisted for extensive periods of time, (e.g., four to six weeks), allowing for flexibility in a sampling schedule.

HRC northern red-legged frog pond sites generally fall into one of three categories: 1) relatively small in size, resulting from heavy equipment use during past logging operations and the building of associated logging roads; 2) roadside settling basins used to prevent sediment from getting into rivers and streams; and 3) naturally occurring ponds and wetlands in low-lying areas. Use of the ponds in the Freshwater Creek WAU by northern red-legged frogs has declined as the ponds have become overgrown with riparian vegetation and it may be necessary to clear vegetation to increase suitability.

Maintenance of good habitat and recovery of degraded habitat is dependent upon the appropriate application of riparian management prescriptions and proper implementation of management zones during timber harvesting operations and road construction and maintenance. Thus, continued identification and mapping of watercourses, seeps, and springs with potential habitat for these species during the THP process is important for their conservation.

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APPENDICES

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APPENDICES

APPENDIX 1

Sediment Source Budget

Sediment Budget (Tons/square mile/yr)

2001-2011	3/22/2014		Module	Upper Mainstem (Upper Freshwater)	South Fork Freshwater	Graham Gulch	Cloney Gulch	Little Freshwater	McCready Gulch	Mainstem (Lower Freshwater)	School Forest	Fay Slough	TOTAL	% OF TOTAL	total tons/yr
				6.89	3.16	2.22	4.10	4.63	1.71	0.71	0.49	0.04	**23.96**		
BACKGROUND		Deep Seated	MW	0	0	0	0	0	0	0	0	0	0	0.0%	0
		Shallow Seated	MW	2.8	0	0	0	1.6	0	1.1	0	0	1.1	0.2%	27
	Streamside Landslides	Streamside and Bank Processes	MW	167	194	159	135	231	212	128	140	88	178.0	38%	4263
	Surface Erosion	Soil Creep	SE	83	95	81	70	99	85	62	60	47	84.4	18%	2021
PRE-HCP	Landslides	Non-Stormproofed Abandoned Roads	MW	1.8	0	0	21	0	0	0	0	0	4.1	0.9%	99
		Non-Stormproofed Haul Roads	MW	6.0	0	4.3	0	0	5.2	0	18	0	2.9	0.6%	69
		Non-HCP Harvest Units	MW	41	0	44	0.7	13	1.1	0	0	0	18.5	3.9%	444
	Streamside Landslides	Streamside and Bank Processes	MW	58	67	55	47	80	73	45	49	31	61.8	13%	1480
	Surface Erosion	Skid Trails	SE	2	2	14	21	2	14	14	21	0	8.0	1.7%	191
		"Untreated" Roads	SE	17	14	72	82	24	168	32	123	0	47.7	10%	1143
HCP MGMT	Landslides	HCP Road-Related	MW	9.4	28	14	0.6	46	16	0	0	0	17.8	3.8%	427
		HCP Harvest Units	MW	0	37	0	0	0	0	0	0	0	4.9	1.0%	116
	Streamside Landslides	Streamside and Bank Processes	MW	6.9	8.1	6.6	5.6	9.6	8.8	5.3	5.9	3.7	7.4	1.6%	178
	Surface Erosion	Harvest Unit (2001-2011)	SE	4.1	9.0	7.3	5.0	6.5	6.7	1.9	3.2	0	5.8	1.2%	138
		Road - Surface	SE	17	7.6	39	30	13	47	20	17	0	21.6	4.6%	518
		Road - Gullies/Washouts	SE	0.2	0	0.2	2.3	50	4.3	1.6	0	0	10.6	2.2%	253
				416	**463**	**498**	**421**	**576**	**643**	**311**	**437**	**169**	**475**	**100%**	11367
SUMMARY															
	Background	Landslides		169	194	159	135	232	212	129	140	88	179	38%	
		Surface Erosion		82.7	95.1	80.8	70.4	99.5	85.3	62.0	60.4	47.0	84.4	17.8%	
	Pre-HCP	Landslides		106	67	104	69	93	80	45	67	31	87	18%	
		Surface Erosion		19	16	86	103	26	182	46	144	0	56	12%	
	HCP Management	Landslides		16	73	21	6	55	25	5	6	4	30	6%	
		Surface Erosion		21	17	47	37	70	59	24	20	0	38	8%	
Annual Sediment Yield		**Background**		252	289	240	205	332	297	191	201	135	263	56%	
	tons/mi^2/yr	**Pre-HCP**		126	84	190	172	119	262	91	210	31	143	30%	
		HCP Management		38	90	67	44	126	84	29	26	4	68	14%	
Annual Sediment Yield		**Background**		61%	63%	48%	49%	58%	46%	62%	46%	80%	56%		
	% of sub-basin total	**Pre-HCP**		30%	18%	38%	41%	21%	41%	29%	48%	18%	30%		
	tons/mi^2/yr	**HCP Management**		9%	19%	14%	10%	22%	13%	9%	6%	2%	14%		
		Total (tons/sq mi/yr)		**416**	**463**	**498**	**421**	**576**	**643**	**311**	**437**	**169**	**475**		
		Disturbance Index		**0.65**	**0.60**	**1.07**	**1.05**	**0.74**	**1.16**	**0.63**	**1.18**	**0.25**			
													HCP total		
		Total (tons/yr)		2865	1462	1104	1725	2669	1097	221	216	7	11367		

APPENDIX 2

Freshwater Creek Watershed Analysis Predictions

PRESCRIPTIONS

The prescriptions for the Freshwater watershed, as agreed upon by the prescription team, are detailed in the following sections.

Changes to HCP language:

The following provides the detailed prescriptions written to address the issues identified in the causal mechanism reports. The numbered headings refer to the numbering in the original HCP language.

6.3.4.1.2 Class I RMZs

All fish bearing (or restorable) Class I watercourses will have an RMZ. The RMZ for Class I watercourses is divided into two bands, the inner band and the outer band. The bands are measured, based on slope distance, from 0 to 50 feet and 50 to 75, 100, or 150 feet, depending on slope as shown on Table 1, respectively, from the watercourse transition line as defined by the FPRs (Title 14 California Code of Regulations [CCR] Section 895.1), or the outer edge of the CMZ (see below). Class I RMZ prescriptions may be modified as a result of watershed analysis revisitation.

	Riparian					
	Class I			Class II		
Slope	<20%	20-50%	>50%	<20%	20-50%	>50%
No cut buffer width (feet, slope distance)	0 - 50	0 - 50	0 - 50	0 - 30	0 - 30	0 - 30
Outer band 60% overstory canopy retention (feet, slope distance)	na	na	na	30 - 50	30 - 75	30 - 100
Outer band 50% overstory canopy retention (feet, slope distance)	50 -75	50 -100	50 -150	na	na	na
Outer band 50% understory canopy retention (feet, slope distance)	50 -75	50 -100	50 -150	30 - 50	30 - 75	30 - 100
Cable yarding required	no	yes > 30%	yes	no	yes > 30%	yes
Total EEZ width (feet, slope distance)	75	100	150	50	75	100
Retain the 18 largest trees within 100' of watercourse	yes	yes	yes	no	no	no
Full suspension yarding used when feasible	yes	yes	yes	yes	yes	yes
Harvest re-entry interval	20 years	20 years	20 years	20 years	20 years	20 years
Retain downed wood in RMZ	yes	yes	yes	yes	yes	yes

Table 1. Summary of Class I and Class II prescriptions.

Prescriptions for the Entire Class I RMZ

1. The RMZ width shall be measured from the watercourse transition line or the outer Channel Migration Zone (CMZ) edge (if present) on each side of the watercourse. Young willow and alders (less than 25 years old) shall not be used as the lone criterion for determining the watercourse transition line.
2. No sanitation salvage, exemption harvest, or emergency timber operations (as defined and allowed in the FPRs) shall occur in the RMZ except as per prior agreement with the Wildlife Agencies in accordance with the approved HCP.
3. All portions of downed wood (i.e., LWD), except as defined as slash in the FPRs, will be retained. Slash will be retained at those sites where it will contribute to soil stabilization and sediment filtration. Exceptions may be proposed in a THP and approved by the Wildlife Agencies.

4. Trees felled during current harvesting operations and THP-approved road construction are not considered downed wood for purposes of retention.
5. Felled hazard trees or snags not associated with a THP are considered downed wood and are to be retained in the general vicinity.
6. Trees that fall naturally onto roads, landings, or harvest units within the RMZ are considered downed wood and are to be retained in the general vicinity.
7. All nonhazard snags will be retained, as per the snag policy in the HCP.
8. The RMZ is an EEZ for timber operations, except for permitted roads and equipment crossings.
9. Full suspension yarding will be used when feasible. Full suspension yarding is not feasible on flat ground, in other sites with limited deflection, where an adjacent landowner will not provide permission to secure a cable, or where a full suspension yarding system would jeopardize the safety of field personnel. For the purposes of this prescription, the expanded definition of feasibility according to the FPRs does not apply as an additional determination beyond that described above. For these conditions, yarding will be conducted in a manner that avoids ground disturbance that might deliver sediment to waters to the maximum extent practicable. Where ground disturbance occurs, PALCO will treat (e.g., through seeding, mulching, etc.) all sites with exposed mineral soil that can reasonably be expected to deliver sediment to waters (e.g., gullies, ruts).
10. Trees not marked for harvest may be felled within the RMZ to provide safety clearance for cable yarding corridors. Such felling will be done only as needed to ensure worker safety. In such cases, to the extent possible given site conditions and the FPRs, trees will be felled toward the waters to provide LWD and will be identified in THPs as an in lieu practice (Title 14 CCR Section 916.1). Regardless, trees felled within the RMZ for safety purposes will be retained as downed wood.
11. Trees not marked for harvest which are damaged in the cable yarding corridors must be retained in place either standing or as downed wood.
12. There will be a maximum of one entry every 20 years.
13. If any area within the RMZ falls within the boundary of a mass-wasting area of concern, then the more restrictive prescription applies for that area.
14. Burning will be conducted according to Section 6.3.4.2.

Prescriptions for Class I Inner Band, 0 to 50 Feet

1. Unless otherwise approved by the Wildlife Agencies, timber harvest will not occur within the inner band. This restriction includes sanitation salvage, exemption harvest, or emergency timber operations. For the purpose of adding

LWD to the stream, or for the release of riparian stands for LWD recruitment, felling trees from within the 30-50 feet portion of the inner band will be allowed when approved by the Wildlife Agencies on a THP-by-THP basis. Trees felled for these purposes are considered downed wood.

2. Road segments within the first 30 feet of the inner band must be mitigated by extending the inner band on the opposite side of the waters from the existing road an equivalent distance of that portion of the road prism within the inner band. In the case of RMZ road crossings, the first 50 feet of road extending inland from the watercourse transition line is exempt from this mitigation.

Prescriptions for Class I watercourses 0 to 100 Feet

1. The 18 largest conifer trees per acre (i.e., in the area measured by 435 feet of watercourse length and within 100 feet of the watercourse and lake transition line) shall be retained on each side of the watercourse per each harvest entry (i.e., the largest 18 trees preharvest shall be retained at the end of each harvest).

Prescriptions for the Class I Outer Band, 50 to 75, 100, or 150 Feet[5]

1. The RMZ shall be clearly identified on the ground by the RPF who prepared the THP, or a supervised designee, with paint, flagging, or other suitable means prior to the preharvest inspection.
2. A base mark below the cut line of residual or harvest trees within the outer band shall be placed in advance of the preharvest inspection by the RPF or supervised designee.
3. At least 50% overstory and 50% understory canopy covering the ground shall be retained postharvest in a well-distributed multistoried stand composed of a diversity of species similar to that found before the start of operations. Postharvest conifer canopy closure will not be reduced below an absolute value of 25%.
4. Exclusive of the 18 largest trees per acre on each side of the Class I watercourses, any additional trees left for outer band canopy retention (or inner band if there is limited harvest) shall include those with the highest probability of recruitment to watercourses.

6.3.4.1.3 Class II RMZs

All nonfish bearing Class II waters and watercourses will have an RMZ. The RMZ for Class II watercourses is divided into two bands, the inner band and outer band. The bands are measured, based on slope distance, from 0 to 30 feet, and 30 to 50, 75, or 100 feet, depending on slope, respectively, from the watercourse transition line or the outer edge of the CMZ (see below). Class II RMZ prescriptions may be modified as a result of watershed analysis revisitation.

Prescriptions for the Entire Class II RMZ on watercourses, streams, and lakes

1. The RMZ width shall be measured from the watercourse transition line or the outer Channel Migration Zone (CMZ) edge (if present) on each side of the watercourses. Young willows and alders (less than 25 years old) shall not be used as the lone criterion for determining the watercourse transition line.
2. No sanitation salvage, exemption harvest, or emergency timber operations (as defined and allowed in the FPRs) shall occur in the RMZ except as per prior agreement with the Wildlife Agencies in accordance with the approved HCP.
3. All portions of downed wood (i.e., LWD), except as defined as slash in the FPRs, will be retained. Slash will be retained at those sites where it will contribute to soil stabilization and sediment filtration. Exceptions may be proposed in a THP and approved by the Wildlife Agencies.
4. Trees felled during current harvesting operations and THP-approved road construction are not considered downed wood for purposes of retention.
5. Felled hazard trees or snags not associated with a THP are considered downed wood and are to be retained near the location of the removal.
6. Trees that fall naturally onto roads, landings, or harvest units within the RMZ are considered downed wood and are to be retained near the location of the removal.
7. All nonhazard snags will be retained, as per the snag policy in the HCP.
8. The RMZ is an EEZ for timber operations except for permitted roads and equipment crossings.
9. Full suspension yarding will be used when feasible. Full suspension yarding is not feasible on flat ground, in other sites with limited deflection, where an adjacent landowner will not provide permission to secure a cable, or where a full suspension yarding system would jeopardize the safety of field personnel. For the purposes of this prescription, the expanded definition of feasibility according to the FPRs does not apply as an additional determination beyond that described above. For these conditions, yarding will be conducted in a manner that avoids ground disturbance that might deliver sediment to waters to the maximum extent practicable. Where ground disturbance occurs, PALCO will treat (e.g., through seeding, mulching, etc.) all sites with exposed mineral soil that can reasonably be expected to deliver sediment to waters (e.g., gullies, ruts).
10. Trees not marked for harvest may be felled within the RMZ to provide safety clearance for cable yarding corridors. Such felling will be done only as needed to ensure worker safety. In such cases, to the extent possible given site conditions

and the FPRs, trees will be felled toward the waters to provide LWD and will be identified in THPs as an in lieu practice (Title 14 CCR Section 916.1). Regardless, trees felled within the RMZ for safety purposes will be retained as downed wood.

11. Trees not marked for harvest which are damaged in the cable yarding corridors must be retained in place, either standing or as downed wood.
12. There will be a maximum of one entry every 20 years.
13. If any area within the RMZ falls within the boundary of a mass-wasting area of concern, then the more restrictive prescription applies for that area.
14. Burning will be conducted according to Section 6.3.4.2.

Prescriptions for Class II Inner Band, 0 to 30 Feet on Watercourses, Streams, and Lakes

1. Unless otherwise approved by the Wildlife Agencies, timber harvest will not occur within the inner band. This restriction includes sanitation salvage, exemption harvest, or emergency timber operations. For the purpose of adding LWD to the stream or for the release of riparian stands for LWD recruitment, felling trees from within the 10-30 feet portion of the inner band will be allowed when approved by the Wildlife Agencies on a THP-by-THP basis in accordance with section 6.3.2.2 #7. Trees felled for these purposes are considered downed wood.
2. Road segments within the no-harvest band must be mitigated by extending the no-harvest band on the opposite side of the waters from the existing road an equivalent distance of that portion of the road prism within the no-harvest band. In the case of RMZ road crossings, the first 50 feet of road extending inland from the watercourse transition line is exempt from this mitigation.

Prescriptions for the Class II Outer Band, 30 to 50, 75, or 100 Feet[6] on Watercourses, Streams, and Lakes

1. The RMZ shall be clearly identified on the ground by the RPF who prepared the THP, or a supervised designee, with paint, flagging, or other suitable means prior to the preharvest inspection.
2. A base mark below the cut line of residual or harvest trees within the outer band shall be placed in advance of the preharvest inspection by the RPF or supervised designee.
3. At least 60% overstory and 50% understory canopy covering the ground shall be retained postharvest in a well-distributed multistoried stand composed of a diversity of species similar to that found before the start of operations.

Postharvest conifer canopy closure will not be reduced below an absolute value of 25%.

4. Trees left for outer band canopy shall include those with the highest probability of recruitment to watercourses.

Alternative Prescription for the Entire RMZ of all Class II waters which are hydrologically disconnected from watercourses (e.g., isolated seeps, springs, lakes, ponds and wetlands) which do not provide either water or habitat for Southern Torrent Salamander or Tailed Frog). The U.S. Fish and Wildlife Service and Department of Fish and Game shall provide criteria to be employed in the field to identify Southern Torrent Salamander and Tailed Frog habitat. If, after a field review, one or more of the Wildlife Agencies does not concur with PALCO's determination that a Class II water does not provide habitat or water for Southern Torrent Salamanders or Tailed Frogs, the default Class II prescription for watercourses, streams and lakes shall apply.

Alternative prescriptions for Class II waters will have an RMZ. The RMZ for these Class II waters is divided into two bands, the inner band and the outer band. RMZ width set for inner band and outer band will not vary with slope:

Inner Band = 0-30 feet (slope distance).
Outer Band = 30-50 feet (slope distance).

Prescriptions for Alternative Class II Inner Band:

1. Timber harvest will not occur within the inner band. This restriction includes sanitation salvage, exemption harvest, or emergency timber operations.

Prescriptions for Alternative Class II Outer Band:

1. The RMZ shall be clearly identified on the ground by the RPF who prepared the plan, or supervised designee, with paint, flagging, or other suitable means prior to the preharvest inspection.

2. A base mark below the cut line of residual or harvest trees within the outer band shall be done in advance of the preharvest inspection by the RPF or supervised designee.

3. At least 50% overstory covering the ground shall be retained postharvest. Postharvest conifer canopy closure will not be reduced below an absolute value of 25%.

6.3.4.1.4 Class III RMZs

All Class III waters will have an RMZ. Class III RMZ prescriptions may be modified as a result of watershed analysis revisitation.

A single RMZ band will be developed. Width of RMZ will vary depending upon slope:

- 0-50 feet (slope distance) for slopes 0-20% (0-25 feet for cable or helicopter yarding)
- 0-75 feet (slope distance) for slopes 20-50% (0-50 feet for cable or helicopter yarding)
- 0-100 feet (slope distance) for slopes greater than 50% (0-75 feet for cable or helicopter yarding)

Prescriptions for all Class III RMZs

1. If any area within the RMZ falls within the definition of a mass-wasting area of concern, then the more restrictive prescription applies.
2. All RMZ width requirements stop at the hydrologic divide.
3. All RMZs are EEZs for timber operations except for permitted roads and equipment crossings. All tractor road crossings must be flagged on the ground prior to the preharvest inspection and shown on the THP map for the purposes of evaluating potential sediment delivery to watercourses.
4. Skid trails shall be stabilized as per the 1998 FPRs per an approved THP in accordance with the Class I/II watercourse standard.
5. All downed wood and debris shall be retained within the EEZs except for cases of emergency as per agreement with the Wildlife Agencies.
6. All downed wood and debris in the channel shall be retained.
7. Trees felled during current harvesting operations and THP-approved road construction are not considered downed wood for purposes of retention.
8. Felled hazard trees or snags not associated with a THP are considered downed wood and are to be retained in the nearest safe location.
9. Trees that fall naturally onto roads, landings, or harvest units within the EEZs shall be treated as downed wood and are to be retained in the nearest safe location.
10. Full suspension yarding will be used when feasible. Full suspension yarding is not feasible on flat ground, in other sites with limited deflection, where an adjacent landowner will not provide permission to secure a cable, or where a full suspension yarding system would jeopardize the safety of field personnel. For the

purposes of this prescription, the expanded definition of feasibility according to the FPRs does not apply as an additional determination beyond that described above. For these conditions, yarding will be conducted in a manner that avoids ground disturbance that might deliver sediment to waters to the maximum extent practicable. Where ground disturbance occurs, PALCO will treat (e.g., through seeding, mulching, etc.) all sites with exposed mineral soil that can reasonably be expected to deliver sediment to a water (e.g., gullies, ruts).

11. Trees not marked for harvest may be felled within the RMZ to provide safety clearance for cable yarding corridors or faller safety. Such felling will be done only as needed to ensure worker safety. In such cases, to the extent possible given site conditions and the FPRs, trees will be felled toward the waters to provide LWD and will be identified in THPs as an in lieu practice (Title 14 CCR Section 916.1). Regardless, trees felled within the RMZ for safety purposes will be retained as downed wood.
12. Trees not marked for harvest which are damaged in the cable yarding corridors or site preparation, must be retained in place, either standing or as downed wood.
13. To the extent feasible, directionally fell harvest trees away from Class III watercourses.
14. Retain all ground cover vegetation, other submerchantable vegetation, and slash that provides sediment filter strip function post harvest within RMZs.
15. Retain 90% of all trees less than or equal to eight inches DBH within 15 feet (slope distance) of the bankfull edge of the channel.
16. Retain all trees a) situated within the bankfull channel, and b) those trees that have boles in contact with the bankfull channel. Bole in contact with the bankfull channel means that the vertical line of the bole overlaps with the bankfull channel.
17. Some class III channels are located at the base of small, steep, erosional features immediately adjacent to the channel. These features may or may not be vegetated. In these situations, retain trees within 10 feet (slope distance) from the bankfull edge of the channel that are in the portion of the topographic cross section extending from the bankfull width up to the first break-in-slope (including those trees whose bole is in contact with the break-in-slope). Bole in contact with the break-in-slope means that the vertical line of the bole overlaps with the break-in-slope. Break-in-slope for the Class III prescription is defined as any change in the slope (no minimum distance is required).
18. Burning will be conducted according to Section 6.3.4.2.

6.3.3.7 Hillslope Management

The hillslope management mass-wasting strategy applies to all portions of PALCO's ownership including the RMZs. The prescriptions in the RMZs for mass wasting will not be less restrictive than the riparian prescription developed as part of watershed analysis as appropriate and applicable to this Plan. The hillslope management prescriptions may be modified as a result of watershed analysis.

1. PALCO shall use the “Freshwater Creek Hillslope Management Checklist” for identifying areas at very high risk of mass wasting to which the appropriate mass wasting prescription will be applied when building roads and harvesting timber. If a very high prescription is not indicated through this, the registered professional forester (RPF) determines the appropriate prescription to be applied to the area consistent with the California Forest Practice Rules.
2. PALCO will develop an office and field based training course for foresters to educate them on the general geology, geologic processes, specific slope stability issues, and identifying unstable features on PALCO lands. The training will also include education on proper use of The Freshwater Creek Hillslope Management Checklist and will include the information contained in CGS Notes 45 and 50.

The Freshwater Creek Hillslope Management Checklist

Modified from the CALIFORNIA LICENSED FORESTERS ASSOCIATION GUIDE TO DETERMINING THE NEED FOR INPUT FROM A LICENSED GEOLOGIST DURING THP PREPARATION

In order to identify areas of very high risk of mass wasting, the following questions should be addressed by the RPF during Timber Harvesting Plan (THP) preparation.

1. *Are there unstable areas located within or adjacent to the proposed THP area?*

    a. *Were active features indicated on the maps available for the watershed? The RPF will review Freshwater WA maps A-5, A-6 and A-7 and CGS map 99-10, aerial photos, and previous THPs in the area to identify areas of concern. Areas identified as shallow landslides or active deep-seated landslides on these maps will receive the very high prescription.*
    b. *Were unstable areas observed in the field?*
        i. *Is an inner gorge (as defined in this section) present? If the answer is yes, the appropriate inner gorge prescription is to be applied. If the answer is no, proceed with the evaluation.*
        ii. *Is an headwall swale (as defined in this section) present? If the answer is yes, the appropriate headwall swale prescription is to be applied. If the answer is no, proceed with the evaluation.*
        iii. *If the area being reviewed is not underlain by previously mapped deep seated mass wasting features then the RPF should look for indicators of unstable areas that may include:*
            ③ *Hillslopes greater than 60%*
            ③ *Loose, unconsolidated soils*
            ③ *U-shaped swales*

    - *Irregular topography*
    - *Scarps*
    - *Benches*
    - *Hummocky ground*
    - *Surface cracks*
- ③ *Vegetative indicators*
    - *Leaning trees*
    - *Hydrophytes*
    - *Isolated patches of homogeneous vegetation*
- ③ *Disorganized drainage*
    - *Sag ponds*
    - *Seeps*
    - *Diverted watercourse*
- ③ *Road cut-bank failure*
- ③ *Road or landing fill failure*

If any of the features listed above is observed, consider part C and answer question 2.

iv. If the area being reviewed is underlain by previously mapped deep-seated mass wasting features, then the RPF should look for indicators of unstable areas that may include:

- ③ *Hillslopes greater than 60%*
- ③ *Ground cracks*
- ③ *Sharp, fresh, or unvegetated scarps or grabens*
- ③ *Debris slides or debris flows on the surface of the deep-seated feature*
- ③ *Recent rock fall or rock slides on the surface of the deep-seated feature*
- ③ *Fresh/recent ground, road, or landing displacement*
- ③ *Ponded or disrupted drainage (e.g., displaced steam channels, sag ponds, hydrophytes)*
- ③ *Displaced/stressed/missing forest cover, frequent leaning and/or recurved (bent) trees*
- ③ *Steep toes of deep-seated landslides or earthflows along stream edges or stream escarpments*

If any of the features listed above is observed, consider part C and answer question 2.

c. If unstable areas were identified in the THP area as listed in iii and iv, proposed timber operations on, adjacent to, upslope, or downslope of these features may have the potential to affect slope stability through:

- *Displacement of soil*
- *Division or concentration of drainage*
- *Reduction in interception or transpiration, and/or*
- *Reduction in root strength*

Examples of timber operations that may produce these effects are:

- *Timber cutting*
- *Construction and maintenance of:*
  - ③ *Roads*
  - ③ *Stream Watercourse Crossings*
  - ③ *Skid trails*
  - ③ *Beds for felling of trees (layouts)*
  - ③ *Fire breaks*
- *Mechanical site preparation*
- *Prescribed burning*

2. *Do the proposed timber operations have a reasonable potential to affect slope stability, and a potential for materials from landslides or unstable areas to affect public safety, water quality, fish habitat or other environmental resources? If the answer is yes, the area will receive the very high prescription. If the answer is no, the RPF determines the appropriate prescription to be applied to the area consistent with the California Forest Practice Rules.*

Very high prescription:

(1.) Inner Gorges on Class I Watercourses –

(a). **Harvest** – No harvest to the break in slope (a break-in-slope is defined as a slope less than that of the feature for a distance of 100 feet or more) above the watercourse or 400 feet (slope distance) from the watercourse, whichever is less. The distance is measured from the watercourse transition line or the edge of the CMZ whichever is appropriate. If harvesting is proposed within the inner gorge, beyond 400 feet (slope distance) from the watercourse, then an on-site geologic assessment shall be conducted by a California licensed geologist working with the RPF and the appropriate prescription developed with due consideration of the risk of the resource. The on-site geologic assessment will follow the procedures outlined in the CGS “Note 45”.

(b). **Roads** - If road construction is proposed, on-site geologic assessment is required and will follow the procedures outlined in the CGS “Note 45”. No new road construction will occur on any Class I inner gorge without review and approval by NMFS and CDF and G.

(2). Inner Gorges on Class II or III watercourses -

(a). **Harvest** - No timber harvest will be permitted unless on-site geologic assessment is conducted by a California licensed geologist working with the RPF and the appropriate prescription developed with due consideration of risk to the resource. The final prescription developed must include at least 50% canopy retention postharvest. Prescription development will include input from a fisheries biologist on potential biological impacts if a landslide were to occur. The on-site geologic assessment will follow the procedures outlined in the CGS “Note 45”. Other appropriate reference documents such as US Forest Service Slope Stability Guide for engineering geologic assessments may be used as necessary and determined by the geologist.

(b). **Roads** - If road construction is proposed, on-site geologic assessment is required and will follow the procedures outlined in the CGS “Note 45”. No new road construction will occur on any Class I inner gorge without review and approval by NMFS and CDF and G.

(3). Headwall Swales –

(a). **Harvest** - No timber harvest will be permitted unless on-site geologic assessment is conducted by a California licensed geologist working with the RPF and the appropriate prescription developed with due consideration of risk to the resource. The final prescription developed must include at least 50% canopy retention postharvest. Where appropriate, prescription development may include input from a fisheries biologist on potential biological impacts if a landslide were to occur. The on-site geologic assessment will follow the procedures outlined in the CGS “Note 45”. Other appropriate reference documents such as US Forest Service Slope Stability Guide for engineering geologic assessments may be used as necessary and determined by the geologist.

(b). **Roads** - No road construction or reconstruction will be permitted unless on-site geologic assessment is conducted by a California licensed geologist working with the RPF and the appropriate prescription developed with due consideration of risk to the resource. Where appropriate, prescription development may include input from a fisheries biologist on potential biological impacts if a landslide were to occur. The on-site geologic assessment will follow the procedures outlined in the CGS “Note 45”. Other appropriate reference documents such as US Forest Service Slope Stability Guide for engineering geologic assessments may be used as necessary and determined by the geologist. Road stormproofing activities required by the HCP are not restricted under this prescription.

(4). Harvest on other identified very high hazard areas - no timber harvest will be permitted unless on-site geologic assessment is conducted by a California licensed geologist working with the RPF and the appropriate prescription developed with due consideration of risk to the resource. Where appropriate, prescription development may include input from a fisheries biologist on potential biological impacts if a landslide were to occur. The on-site geologic assessment will follow the procedures outlined in the CGS "Note 45." Other appropriate reference documents such as US Forest Service Slope Stability Guide for engineering geologic assessments may be used as necessary and determined by the geologist.

(5). Road construction and reconstruction on other identified very high hazard areas - no road construction or reconstruction will be permitted unless on-site geologic assessment is conducted by a California licensed geologist working with the RPF and the appropriate prescription developed with due consideration of risk to the resource. Where appropriate, prescription development may include input from a fisheries biologist on potential biological impacts if a landslide were to occur. The on-site geologic assessment will follow the procedures outlined in the CGS "Note 45." Other appropriate reference documents such as US Forest Service Slope Stability Guide for engineering geologic assessments may be used as necessary and determined by the geologist. Road stormproofing activities required by the HCP are not restricted under this prescription.

(6) Road stormproofing, road closure, and road decommissioning of existing roads are acceptable and encouraged on the mass-wasting areas of concern.

Definitions for this section:

Inner Gorge-

A geomorphic feature formed by coalescing scars originating from landsliding and erosional processes caused by active stream erosion. The feature is identified as that area beginning immediately adjacent to the stream channel below the first break in slope.

Headwall Swale-

A concave depression, with convergent slopes of 60 percent or greater, that is connected to waters via a continuous linear depression (a linear depression interrupted by a landslide deposit is considered continuous for this definition).

6.3.4.3 Disturbance Index

1. The disturbance index and its elements may be modified as a result of watershed analysis revisitation, subject to approval by the Wildlife Agencies.

2. The disturbance index will be calculated at the subbasin scale.

3. With submittal of each THP in the Freshwater Watershed PALCO shall calculate and present the Disturbance Index in the relevant subbasin and identify the net change in the Disturbance Index resulting from proposed covered activities in the subject THP.

4. In subbasins where the Disturbance Index is equal to or greater than 150% above the estimate of background level, PALCO shall not conduct any covered activities in the subject THP which would result in a net increase of the index value.

5. In subbasins where the Disturbance Index is less than 150% above background levels PALCO may conduct covered activities in the subject THP with the limitation that such operations will not result in a net increase in the Disturbance Index above 150% over background threshold.

6. In all subbasins where timber operations are conducted, PALCO shall, in addition to other road related measures in the HCP, rock road surfaces within 100 feet of each THP watercourse crossing including those on appurtenant roads.

APPENDIX 3

Road BMPEP Program

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Effectiveness of Road Construction Practices in Preventing Sediment Delivery

Monitoring Report for 2011
Humboldt Redwood Company

June 2013

EXECUTIVE SUMMARY

Humboldt Redwood Company (HRC) has implemented a property wide road auditing and inspection program to track performance and evaluate effectiveness of road projects in meeting sediment delivery goals. HRC's road monitoring program is patterned after the U.S. Forest Service Best Management Practice Evaluation Program (BMPEP) as required by the Habitat Conservation Plan (HCP, section 6.3.5.1.3) and similar to the approach used by CALFIRE for assessing the effectiveness of forest practice rules in Cafferata and Munn (2002). This report summarizes the effectiveness of crossings constructed or closed in 2011.

In 2011, 186 closed and upgraded crossings were audited immediately following construction. Most of the upgraded and all closed crossing components met the conformance goal of 90% correct implementation. No major deviations to specifications were recorded; 23% recorded minor deviations. The most common component non-conformances occurred at culvert crossings where 25% of sites had minor deviations to standards relating to culvert extensions and downspout specifications.

Mitigated alternative prescriptions (MAPs) were implemented and tracked in 2011. Examples of MAPs implemented include the use of slash and rock to minimize sediment delivery at the terminus of hydrologically-connected inboard ditches, use of LWD as armoring on steep fillslopes, and under-excavated stream channels treated with LWD chunks and check dams.

The majority (93%) of crossings did not deliver any sediment in 2011. Delivery from standard crossings in 2011 was less than the 2006 to 2010 sampling period. In 2011, erosion volumes averaged 0.07 and 0.05 cubic yards per standard closed and upgraded crossing respectively. The pattern of site erosion in 2011 was similar to the 2006 to 2009 sampling period. Maximum void volume increased in 2010 when HRC completed extensive road decommissioning projects in the Lake Creek sub basins. In 2011, there was a lesser occurrence of large volume sediment delivery compared to the previous years.

Closed crossing erosion rates decreased significantly in 2011 compared to the 2006 to 2010 sampling period. This includes a 24% decrease in bank erosion, a 10% decrease in sloughing, and a 20% decrease in slope failure. Erosion from closed crossings was related to channel bed downcutting (4% of sites), channel bank erosion (2% of sites) and side slope sloughing (4% of sites).

Upgraded crossing erosion rates for all categories decreased in 2011 as well, with the exception of fill slope sloughing (25% increase). Erosion from upgraded crossings was primarily related to outlet fillslope sloughing (18% of sites) and stream bank sloughing (12% of sites). Only 3% of sites with outlet fillslope sloughing led to delivery (all less than 1 cubic yard), while all sites with streambank sloughing led to delivery ranging from less than 1 to 5 cubic yards.

The high implementation rate of specifications coupled with a low percentage of sites with sediment delivery indicates that HRC's construction/deconstructions standards are effective. More study on stream channel components would help evaluate erosion and delivery mechanics. Effectiveness case studies are planned on fillslope construction, the use of slash vs. straw in stream channels, and shallow excavations in 2012 to more fully understand these crossing component relationships with erosion and sediment delivery.

Director Forest Science

Mike Miles

Project Manager/ Primary Author

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OVERVIEW

Humboldt Redwood Company (HRC) owns and maintains an extensive road network to provide access to the property for the purposes of hauling timber, conducting silvicultural and scientific activities, and fire protection. Adoption of the Habitat Conservation Plan (HCP) by The Pacific Lumber Company (PALCO) in 1999 marked a major commitment to reduce road impacts and improve habitat for federally listed threatened and endangered fish species with new road management policies. A major focus of the HCP is to improve salmon habitat and water quality that had been degraded by erosion, much of which could be tied to forest roads. Improving the road system was recognized as central to achieving restoration goals.

When the HCP was adopted, the existing roads had been built to various construction standards over the past 50 years. Many had deteriorated from initial construction and were less effective at sediment prevention than the stormproofing standard adopted with the HCP. With the HCP, PALCO committed to upgrade the entire road system to a low impact standard within 20 years. HRC has maintained that commitment after acquiring PALCO lands in 2008.

The general standard for new construction, reconstruction, or closing roads, is to "stormproof" them to weather all storms including large magnitude, infrequent events (defined as the 100-year storm) without damage to water crossings and with minimum sediment delivery. Many characteristics of a road determine its potential to deliver sediment to streams. These elements and the general qualities of a stormproofed road are highlighted in Table 1. Roads built before adoption of the HCP often fail to have some or all of these qualities. Since 1999, PALCO and HRC have constructed, reconstructed or closed roads according to the stormproofing specifications. HRC has developed a manual with specific construction standards for all aspects of road design to support operations and the monitoring program. The manual integrates agency guidance, permitting documents, and other relevant sources of design specifications. Construction standards that achieve stormproofing objectives vary by road type.

Road inspections and maintenance ensure that roads remain at a high standard. HRC has implemented a road auditing and inspection program to track performance and evaluate effectiveness of road projects in meeting low impact goals. HRC's road monitoring program is patterned after the U.S. Forest Service Best Management Practice Evaluation Program (BMPEP) as required by HCP §6.3.5.1.3. This monitoring program has also been developed in cooperation with the North Coast Regional Water Quality Control Board for confirming that sediment sources are controlled in the Elk River and Freshwater Creek watersheds. A similar approach was used by the California Department of Forestry in evaluating the effectiveness of the Forest Practice Regulations (Cafferata and Munn, 2002; Board of Forestry 2006).

Sullivan and Simpson (2012) summarized road BMPEP results from sites constructed or closed from 2006 through 2010 in Elk River and Freshwater Creek. This report analyzes post construction audit and first winter erosion data from road sites constructed/closed in 2011 property-wide.

Study Area

HRC timberlands are located in Humboldt County on the northern coast of California. The timberlands are in deeply dissected mountainous topography underlain by poorly consolidated and incompetent sedimentary rocks that weather to very fine grained and highly erosive soils.

The climate is Mediterranean with warm to hot dry summers and mild wet winters. Two long-term National Weather Service rainfall records are available at local cities near sea level elevation. Roughly 90% of the average annual rainfall of 40 inches (1100 mm) falls between October and May. Road projects are worked during the summer dry period and monitored in the following winter's rainy months. Rainfall on the property increases in proportion to elevation from these stations. Storm rainfall is of moderate intensity.

Weather

Weather has been moderate during the monitoring period from 2006 to 2012. Sullivan (2011) introduced an "erosivity index" based on rainfall at the long-term National Weather Station located in Eureka, CA. The weather index is calculated as:

$$\textit{Erosivity Index} = \textit{Annual Rainfall (in.)} \times \textit{Maximum Daily Rainfall (in.)}$$

This simple index based on rainfall is highly correlated with the annual peak flow and stream sediment load observed each year and is a more effective indicator of the erosivity of storms than average rainfall alone. The erosivity index for the past 20 years is shown in Figure 1.

Erosivity during the first winter after 2011 construction (hydrologic year 2012) was moderate and near the long-term median. The erosivity (and rainfall characteristics) in 2003 exceeded a 100-year return interval.

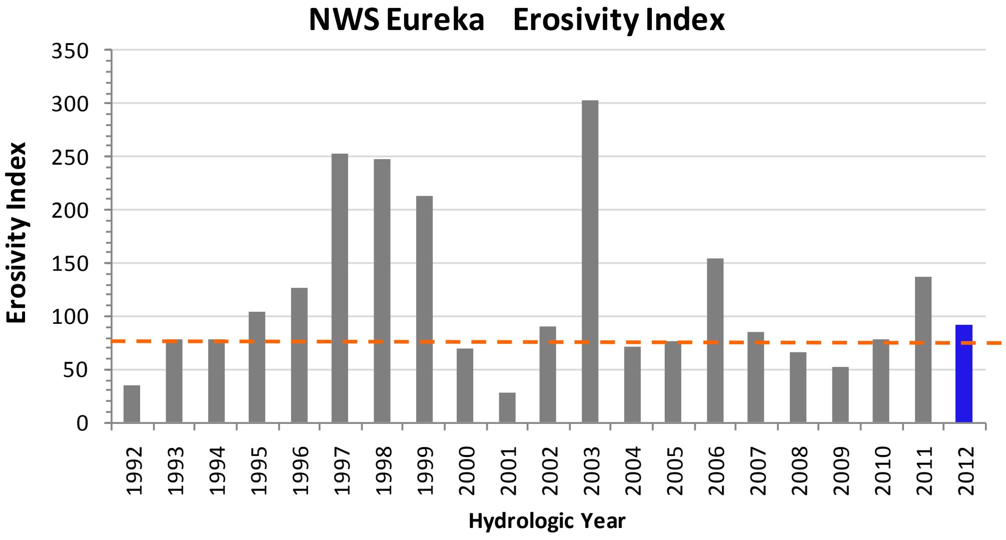


Figure 1. Erosivity index based on rainfall at the NWS station in Eureka, CA from 1992 to 2012. The long-term (124 year) median erosivity index is 79, shown by the orange line.

Monitoring Program Organization

Figure 2. Newly excavated closed crossing adjacent to Graham Gulch, Freshwater Creek.

The road monitoring program applies a programmatic level analysis of the effectiveness of road construction practices in preventing sediment delivery. Results are reported at the site, watershed and property level. The program also provides real-time information to HRC's forest operations staff to identify maintenance or repair needs.

Types of Projects Monitored. The effectiveness monitoring program focuses on road upgrading and decommissioning (closing) projects that construct or deconstruct the stream crossing to a stormproofed standard. Both project types require equipment operation and construction activity within the stream riparian zone with disturbance to channel bed and banks. Other non-stream related projects such as road fill pullbacks or road segment construction are also evaluated in this report.

Data and Evaluation. There are several types of information collected to determine road construction effectiveness. These include:

1) Audit to determine construction site conformed to specifications (Post Construction Audit).
2) Inspections for functionality of the construction practices after winter rainfall and stressor events (Wet Weather Inspection).
3) Measurement of erosion and sediment delivery after one or more winter seasons (Erosion Void Study).

Observations and measurements from the respective inspection are linked to determine the effectiveness of road construction/deconstruction practices. Practices are considered effective when correctly applied specifications prevent sediment delivery.

Information Organization. The key to accomplishing the effectiveness evaluation is that the road information is systematically organized in a similar manner in audits and inspections via the field forms developed for each. The basic structure of information is shown in Table 1. We use the term "components" to refer to the basic function or feature integrated into all roads, e.g. surface drainage or road fill. Each road component has one or more subcomponents and each subcomponent has one or more specifications. Information to the specification level is collected at each site. Within this report we will primarily summarize information at the component and subcomponent level.

Candidate Sites. Sites that had been previously identified as having future sediment delivery potential ("sed site"), as determined by in-house or third-party inspectors, and planned to be constructed/ deconstructed during the summer in 2011 were included in the pool. Of those sites, 25% were selected for the both the wet weather and erosion void project through a stratified random selection process. An additional 25% were selected for a wet weather inspection only. Maps are provided in Appendix A to show the location of all sites inspected in 2011.

Table 1. Components, Subcomponents and Construction Standards (Specifications) of road features. These categories are used in inspection and audit field forms to organize information.

COMPONENT	SUBCOMPONENT	CONSTRUCTION STANDARD
Excavation area in RMZ	Erosion Control Slash ☐ Straw ☐	○ All bare soil areas within RMZ are treated (exceptions: road surfaces, inside ditches, areas 100 sq. ft. or less on slopes 30% or less, and cutbanks exceeding 65%)
	Imminent Failure	○ Unstable earth on fillslopes and cutbanks are stabilized or removed at sites showing signs of imminent failure that could deliver sediment to a Water
	House-keeping	○ All rubbish removed from riparian area ○ All hazardous material removed from riparian area
Stream Channel	Slopes	○ Excavated side slopes 2:1 (50%) or if steeper, to natural slope ○ Fill completely removed to 100-year flood ○ Unstable sidecast is removed
	Channel Bed Characteristics	○ Excavated to original channel bed ○ Excavated at or wider than natural channel (100-yr high water mark) ○ Excavated channel bed mimics natural channel steps
	Channel Grade & Orientation	○ Gradient is at even grade or concave ○ Orientation (alignment) mimics natural channel (within 15°)
	Transition	○ Not over-excavated at upstream/downstream transition ○ Nick points are armored if present
	Banks and Slopes in High Water Mark	○ Lower slopes are stabilized to withstand flow ○ Armoring is present where unstable areas exist ○ Armoring is present where stream banks may be undermined by flow
Road Prism	Hydrologic Disconnect	○ Left approach: Disconnect installed 125' from culvert centerline ○ Right approach: Disconnect installed 125' from culvert centerline
	Diversion Prevention	○ Critical dip present ○ Downhill inboard ditch is blocked at the inlet basin
	Road Surfacing	○ Permanent road is rocked ○ Seasonal road is rocked, slash-packed or mulched ○ Entire hydro-connect area treated
Culvert Size_______ Meets size specified in work order above☐ Metal ☐ Plastic ☐	Alignment	○ Aligned with and parallel to channel centerline (within 15°) ○ Inlet even or below grade
	Inlet Basin	○ All floatable wood upstream of inlet, below high water mark removed
	Extension	○ Extends 3' past fill on inlet side ○ Extends 5' past fill on outlet side
	Armoring	○ Inlet and outlet armored with rip rap or LWD to top of culvert ○ Inlet wing wall armor extends around to the excavated cutbanks
	Dissipation	○ Energy dissipation at culvert outlet
	Downspout	○ Downspouts are securely coupled, staked and anchored at intervals no greater than 10 feet with bolt and chain ○ Half round downspouts are one size larger than primary culvert
Ford General ☐ Vented ☐	Road Surface	○ Road surfaced with minimum 2 to 3-inch diameter angular rock to a minimum thickness of6 inches at least 5 times the channel width ○ Approaches are surfaced with clean rock ○ Surface is not saturated (summer period)
	Material	○ Contains a mixture of rock size to fill voids within base rock

METHODS

Post Construction Conformance Audit

Newly constructed or deconstructed sed sites are the focus of the annual road effectiveness monitoring project. The audit is a field inspection of a construction site that verifies that specifications were implemented correctly. In 2011, HRC implemented a number of changes to the audit form to clarify specifications and to avoid errors in determination of nonconformance to specifications.

From 2006 through 2010, implementation was evaluated in just two categories: specification meets or does not meet in a strict pass/fail approach. Minor and major deviation ratings were added in 2011 to attempt to identify those deviations that are more likely to result in sediment delivery (Lewis and Baldwin 1997). This provided us with a greater ability to determine relative effectiveness of construction specifications, and to achieve erosion prevention objectives.

It is necessary for foresters and roads operators to interpret conditions requiring them to exercise professional judgment in site-specific decisions. We use the term "mitigated alternative prescription" or MAP for a prescription that deviates from our standardized specification. In 2011 we began tracking the MAPs, and auditors rated actual implementation against MAP design when they were applied.

Construction Specifications

HRC has compiled specifications for all features of roads that guide construction in the field. Some of these construction criteria are mandated in permits and regulations, but many specifications are developed through experience and knowledge gained by HRC managers and operators. Sources of information used as a basis for the specification lists include the California Forest Practice Rules, HRC Habitat Conservation Plan, CDFG Master Treatment Harvest Operation Lake and Streambed Alteration Agreement, PALCO road guidelines, Mendocino Redwood Company HCP Appendix E, Weaver and Hagans (1994) and National Marine Fisheries Service Salmon passage guidelines (2004).

Conformance auditors must be thoroughly familiar with the specifications in HRC's road specification modules (Appendix C). Specifications are a mix of quantitative specifications that lend themselves to measurement and more subjective evaluations that require judgment. The auditor must be very familiar with all specifications as well as the design of each specific road site to ensure they evaluate each site accurately and consistently. For instance, upgraded crossings are required to be treated with competent road surfacing material. The auditor must know the correct road surfacing material to be applied at a site depending on planned road use. Is the road designed for seasonal or all weather use? Is it a mainline or secondary road?

Audit Forms and Field Audit

The field form assists the auditor in consistently evaluating all appropriate specifications. Audit forms for upgraded and closed crossings, as well as road segments, are provided in Appendix B. Watershed operating protocol (WOP-36) has been developed which describes methods for conducting the post construction audit in detail. The audit forms are continuing to evolve as we improve both audit methods and construction specifications.

In the field, the auditor selects the appropriate field sheet for the type of crossing (Upgraded or Closed). The forms require the auditor to systematically examine each road feature within the hydrologically-connected segments, and make observations and measurements as they traverse and examine the hydro-connected segments, excavated stream channel and adjacent slopes. As the auditor examines each construction specification, a box is checked indicating whether the specification was met, a deviation to specification was encountered, or whether an alternative prescription (MAP) was applied. Deviations are categorized into "Minor" and "Major." Major deviations are those which the auditor assumes will result in delivery. Minor deviations are those which the auditor assumes will not lead to delivery. All major deviations are required to be reported to the road manager or area forester immediately so the site can be corrected while the equipment is nearby. A comment field is provided to describe minor and major deviations, general observations, or mitigated alternative prescriptions.

The audit is organized by the Physical Sciences Department and executed by trained personnel in the Forestry, Roads, or Physical Sciences Departments. The audit is preferably conducted as the project is completed so corrections can be applied if needed, but no more than 45 days following completion of the project and prior to winter rains.

Wet Weather Inspection

Project sites are inspected following the first winter after construction/ deconstruction to observe if the road is functioning as designed or whether problems develop resulting in sediment delivery. A Watershed operating protocol (WOP-35) has been developed which describes methods for conducting the wet weather inspection in detail. The wet weather inspection is organized by the Physical Sciences Department and executed by the Forestry and Roads Departments.

Figure 3. Wet weather Inspection of culvert crossing

The wet weather field form facilitates a systematic examination of the site for any structural problems, erosion and delivery that may have developed on the road since the project was completed. Field forms used to inspect sites are included in Appendix B.

Erosion and Delivery Observations: Inspectors are trained to recognize erosion types. There are 10 distinct types of erosion features for closed and upgraded crossing types, respectively. Each site may have one or more erosion features. All erosion observations are recorded regardless of size, delivery, or activity. The inspector may approximate the erosion volume on a continuous scale or estimate it in categories provided on the form. Precise erosion measurements are made at a sample of sites in the erosion void project, described in the next section.

Wet Weather Inspection Timing: Roads are most vulnerable to erosion after the first winter following construction and immediately after large storm events. Recently constructed sites that disturb soils are "soft" and prone to erosion until they harden with natural compaction and settling. Sites completed during the summer dry period make up the candidate pool for sites selected for observation and measurement the next winter. A stratified sample of 50% of the year's completed sites is inspected between April 1 and June 1, after the sites have overwintered.

To assess performance after large rain events, HRC has begun creating a pool of sites that will be reevaluated on a long term basis. Starting in 2011, sites that met all specifications in the conformance audit exclusive of minor and major deviations but including MAPs, are placed in queue within specific categories such as site type, geology and prescription type (Table 2). Inspections of these sites are triggered based on 24-hour rainfall intensity, using the long term rainfall data set from the Scotia and Eureka gages. Sites occurring in the Freshwater Creek, Elk River and Yager Creek watersheds will be triggered by the Eureka gauge on Woodley Island. Sites on the rest of the property will be triggered by rainfall events measured at the Scotia gauge. Triggering inspections will occur during the spring following 3, 5, 10, 25, 50 and 100 year storm events.

Table 2. Number of crossing types required to test effectiveness of construction specifications against stressor events.

Crossing Type	Geology Type	Sample size required for each triggering event			
		Meets all standards	Alternative Prescription 1	Alternative Prescription 2	Alternative Prescription 3
Culvert	Wildcat (QTw)	10	10	10	10
	Hookton (Qt)	10	10	10	10
	Franciscan Coastal Yager (y1)	10	10	10	10
	Franciscan Coastal/Central Melange (co1-4)(Cm2))	10	10	10	10
Ford	Wildcat (QTw)	10	10	10	10
	Hookton (Qt)	10	10	10	10
	Franciscan Coastal Yager (y1)	10	10	10	10
	Franciscan Coastal/Central Melange (co1-4)(Cm2))	10	10	10	10
Closed	Wildcat (QTw)	10	10	10	10
	Hookton (Qt)	10	10	10	10
	Franciscan Coastal Yager (y1)	10	10	10	10
	Franciscan Coastal/Central Melange (co1-4)(Cm2))	10	10	10	10

Erosion Void Quantification Project

Erosion volume and sediment delivery from road project sites are quantified in the erosion void project. The method involves detailed measurement of voids and deposits resulting from observed erosion. Field procedures are described in Watershed Operating Protocol (WOP-35).

The surveyor looks for voids left by bank erosion, rilling, gullying, sloughing, streamside land sliding, channel incision, or head-cutting. This requires a systematic examination of the entire project area. The voids are three-dimensional shapes with length, width, and depth dimensions that are measured to calculate volume.

Aluminum survey stakes, flags, or pins are used to mark the locations and perimeters of the erosion they observe (Figure 4). The surveyor divides the erosion feature into as many distinct shapes as necessary to achieve standard geometric shapes, and creates as many as needed to reduce the variability in depth or horizontal dimensions as much as possible. The void volume is calculated from a minimum of 9 depth measurements distributed within each subarea. The surveyor increases the number of measurements for highly irregular depths. Sites may have more than one erosion feature. The total erosion in the construction area is the sum of all of the voids measured.

Observed erosion may or may not deliver to the channel. All erosion voids or deposits within the flood-prone depth (taken to represent the 100-year flood level estimated as 2 times bankfull depth) are assumed to be 100% delivered. The surveyor does not include any “future” erosion. The surveyor records delivery as the proportion of the void.

The surveyor also estimates erosion “activity level.” The surveyor subjectively assesses whether the erosion appears to be complete and inactive, is likely to continue into the future, or is imminent. Site maintenance by the roads department is triggered if sediment delivery is imminent.

Figure 4. Erosion void measurement of bank slough

The erosion void study is conducted by HRC’s Physical Sciences Department.

Site Selection and Sampling Scheme

All sed site road projects completed between May and November, 2011, are the candidate pool for the conformance audit, wet weather inspections the following winter 2011-2012, and erosion void measurement the following summer 2012. One hundred percent of these road projects were audited to specifications (conformance audit). Of these, 25 % are selected for the erosion void study and wet weather inspection through a stratified random selection process. This enables a standard selection of large, medium and small sites of varying type (culvert crossing, closed crossing, etc.) and watershed to be sampled, to avoid over- or under-sampling any category. To bring the number of wet weather inspections up to 50% of the sites, an additional 25% of sites from the stratified pool are added. These additions are needed for statistical purposes. Table 3 provides the sample numbers for road project and measurement project types. All 2011 site locations are shown in Appendix A.

Table 3. Number of sites monitored by various methods each year.

Activity Year	Upgraded Sites (Crossings and Road Segments)			Closed Sites (Crossings and Road Segments)		
	Conformance	Following Rainfall Inspections		Conformance	Following Rainfall Inspections	
	Implementation Audit	Wet Weather Inspection	Erosion Void	Implementation Audit	Wet Weather Inspection	Erosion Void
2006	48	0	12	35	0	16
2007	41	34	9	57	40	29
2008	109	28	20	85	39	31
2009	61	26	12	53	43	32
2010	69	58	24	113	49	20
2011	108	51	26	115	57	27
TOTAL	436	197	103	458	228	155

RESULTS

Information from the various audits and inspections is presented as follows:

- Rate of conformance to specifications
- Post-construction sediment delivery
- Effectiveness of practices

Conformance to Specifications (Post Construction Audit)

Post-construction conformance audits document compliance with road construction specifications to assure that low-impact practices have been correctly implemented. Data are used to:

> Cross reference with erosion results to interpret the effectiveness of specific construction practices.
>
> Provide both immediate site-specific and long term feedback to the construction operators and forestry operations staff for corrective actions and improvement of practices.

Construction Specifications

The primary objective of the effectiveness monitoring project is to determine whether construction practices meet the stormproofing and HRC effectiveness goals. When sediment delivery is observed, it is first important to know whether the specification was applied correctly before effectiveness can be interpreted.

This section of the report focuses on conformance audit results for upgraded and closed road crossings. The sample includes 88 upgraded crossings, 98 closed crossings and 37 upgraded and closed isolated road segments. Findings are presented at two organizational levels: components and subcomponents. Major components represent a key element of road design that includes a group of specifications. The rule for determining conformance rate at the component level is if one specification within the group was not met, then the component as a whole did not meet specifications. Therefore, results summarized at the component level are especially conservative.

In 2011, 186 closed and upgraded crossings were audited immediately following construction (Figure 5). Figure 6 illustrates inspection of a culvert component. Figure 7 shows no major deviations (non-conformances) to specifications remained post construction. This is the result of the auditor communicating to the operator or HRC road supervisor immediately after a potential major deviation was encountered. Multiple site corrections were made by the equipment operator based on the auditor's immediate feedback. Twenty three (23) percent of sites had minor deviations to specifications, where the auditor determined that sediment delivery to the stream would not occur in spite of the presence of a deviation. One railcar bridge was installed in South Fork Elk River in 2011 and met all specifications during the post construction audit. Analysis of bridge installations cannot be done due to the small sample size. MAP's were applied at 18 percent of all constructed/deconstructed sites in 2011 (Figure 7).

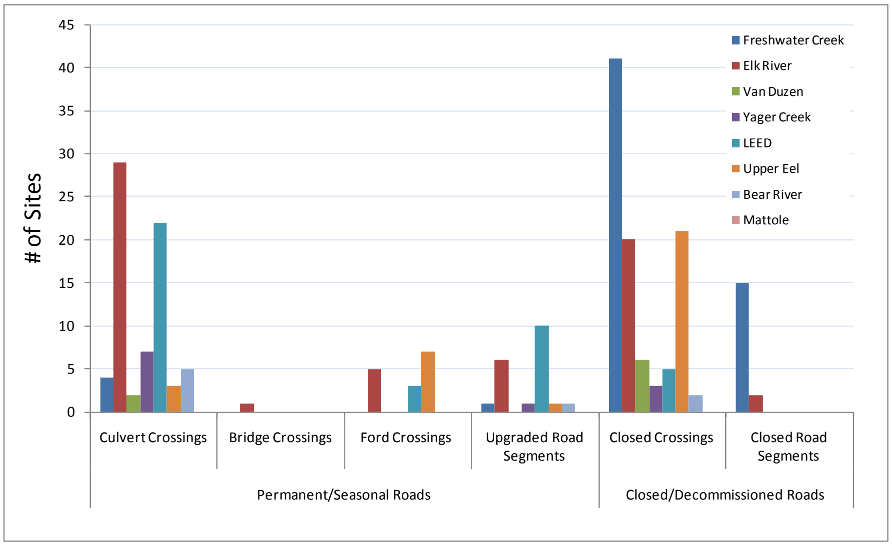


Figure 5. Number of sites audited in 2011 by site type and watershed analysis area.

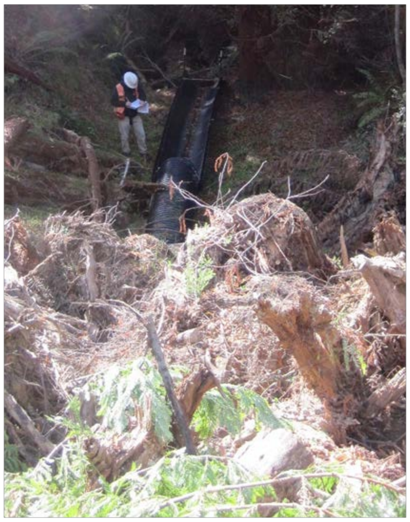


Figure 6. Culvert downspout specification inspection

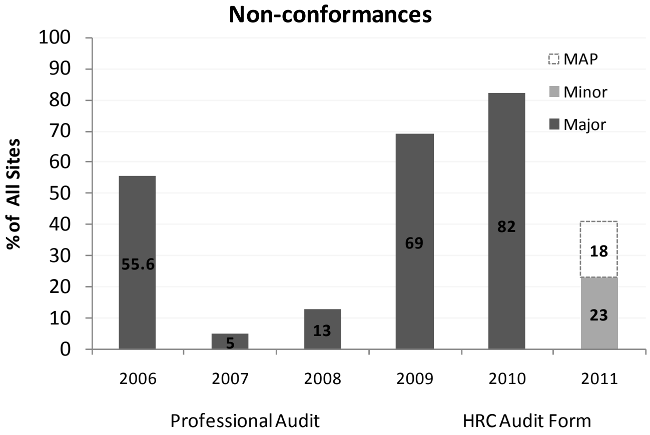


Figure 7. Percent of sites which did not conform to road construction specifications between 2006 and 2011.

UPGRADED ROADS

Culvert Crossings

In 2011, 72 culvert crossings were audited immediately after construction to determine if specifications were implemented correctly. No major deviations remained at any culvert crossing after auditor feedback, and relatively few minor deviations were recorded (Figure 8). Most of the minor deviations recorded at the culvert subcomponent level were related to culvert extension and downspout length specifications (Figures 9-11). In some cases, the culvert was not placed at channel grade. At a few sites, the hydrologic disconnect along the road surface was constructed beyond 100 feet from the centerline; however, the auditor determined the deviation was “minor” considering there was enough filter strip receiving surface runoff to avoid delivery from road surface. At 9% of the sites, fillslope armoring did not extend to the top of the culvert and/or the wingwall did not extend to excavated cutbanks.

Mitigated alternative prescriptions (MAP's) were applied 8% of the time for culvert downspouts and extensions specifications. MAP's were also occasionally used for diversion prevention, relief culvert, and hydrologic disconnect specifications.

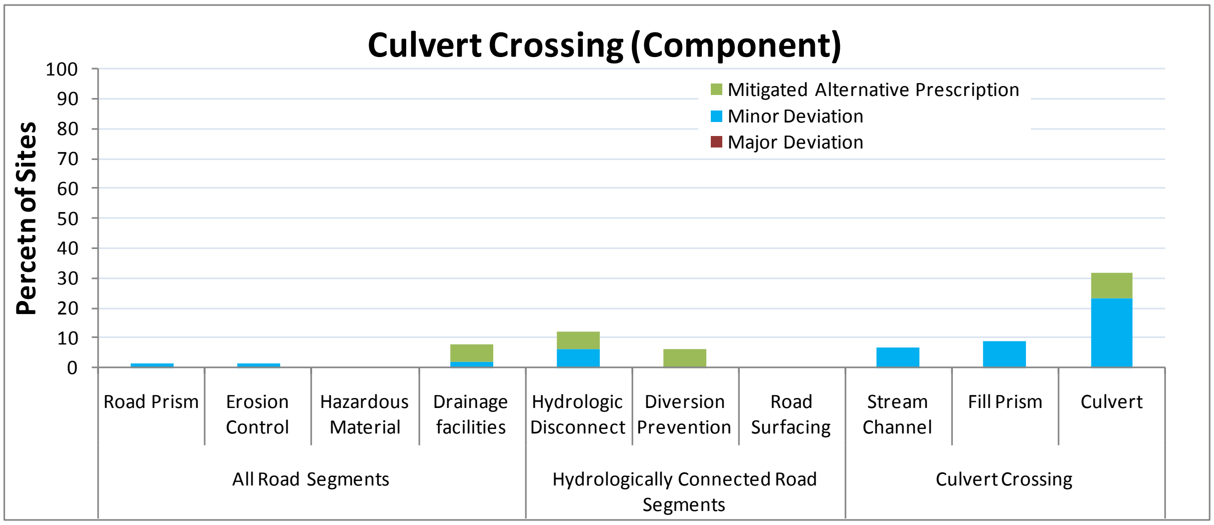


Figure 8. Percent of sites with major deviations, minor deviations, and/or mitigated alternative prescriptions applied in 2011. Data presented at the component level.

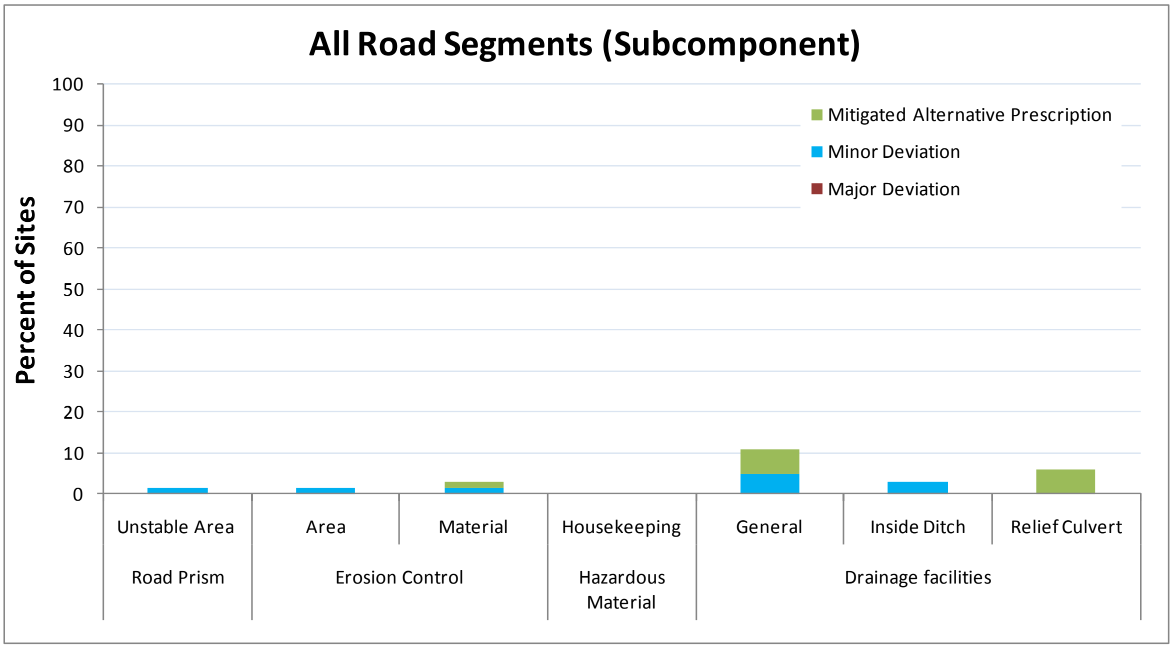


Figure 9. Percent of upgraded culvert crossings with major deviations, minor deviations, and or mitigated alternative prescriptions applied in 2011. Data is presented at the "All Road Segments" subcomponent level.

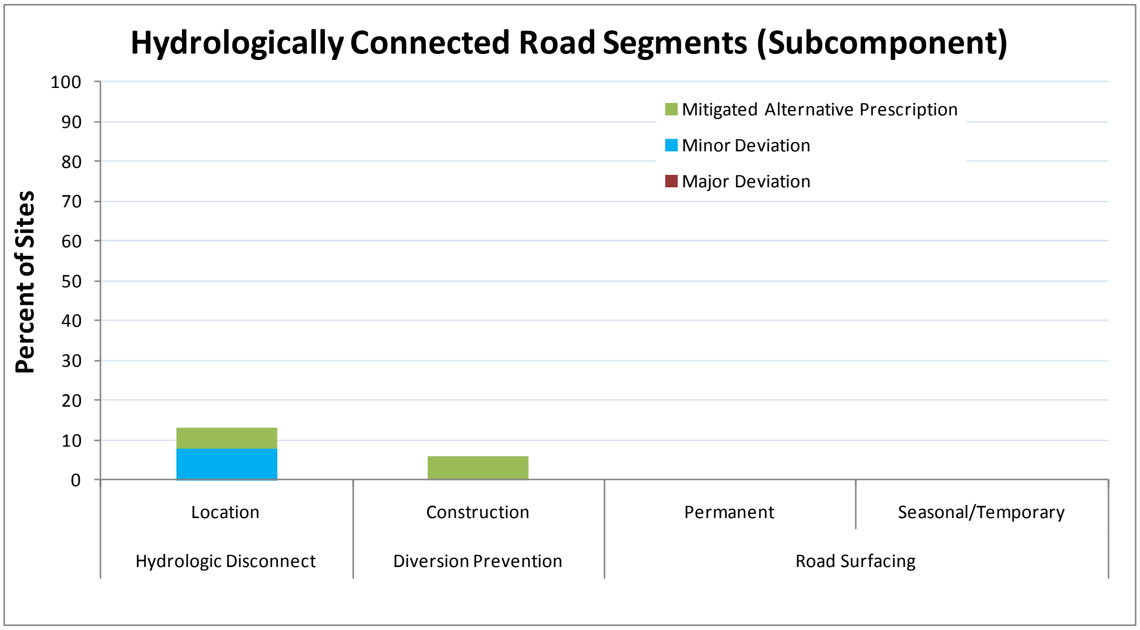


Figure 10. Percent of upgraded culvert crossings with major deviations, minor deviations, and or mitigated alternative prescriptions applied in 2011. Data is presented at the "Hydrologically-Connected Road Segments" subcomponent level.

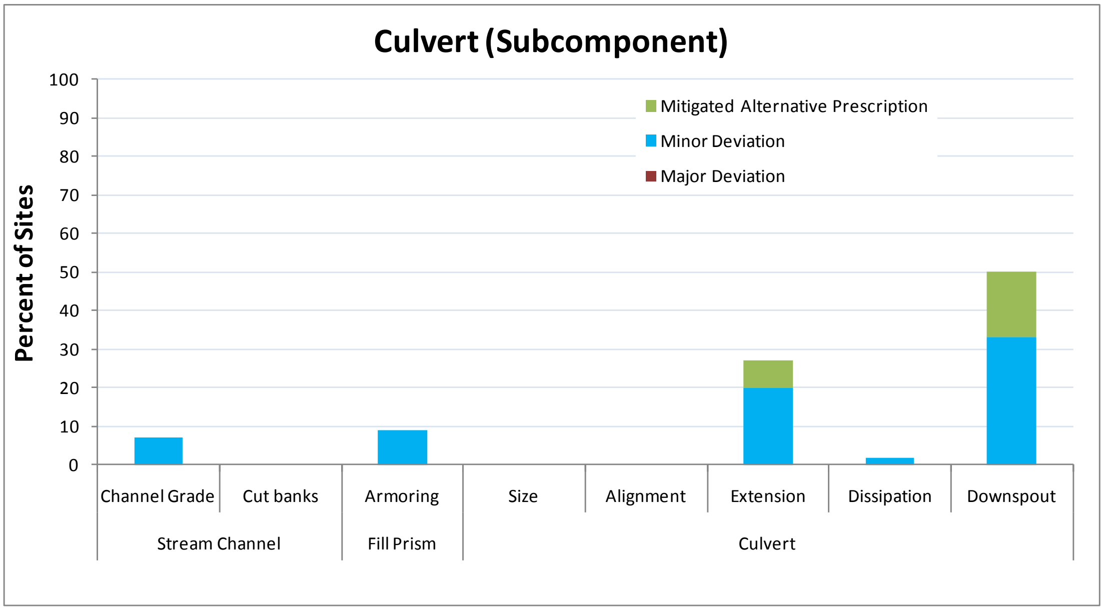


Figure 11. Percent of upgraded culvert crossings with major deviations, minor deviations, and or mitigated alternative prescriptions applied in 2011. Data is presented at the "Culvert" subcomponent level.

Ford Crossings

In 2011, 15 newly constructed fords crossings (Figure12) were audited across HRC property. No major deviations remained at any ford crossing after auditor feedback, and relatively few minor deviations were recorded (Figure 13). Minor deviations were associated with flow from disconnects reaching streams and a lack of rock size diversity on the running surface and spillway (Figure 14-16). Alternative prescriptions were applied at the hydrologic disconnect, fill face, road surface and drainage facilities.

Figure 12. Newly constructed Class III rocked ford.

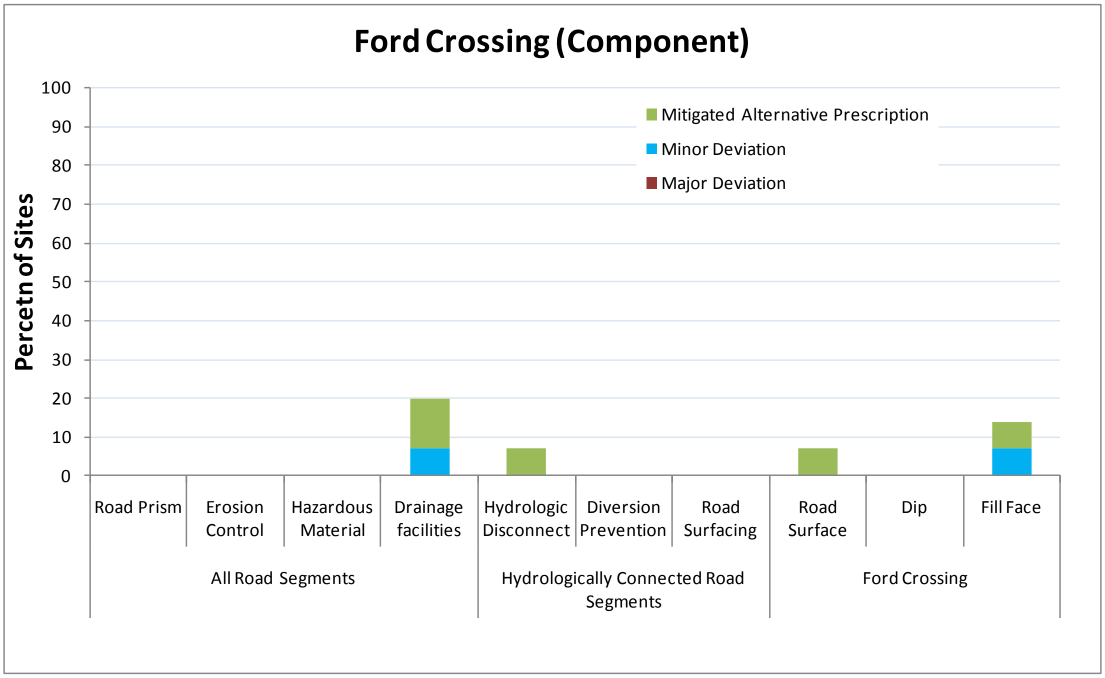


Figure 13. Percent of upgraded ford crossings with major deviations, minor deviations, and or mitigated alternative prescriptions applied in 2011. Data is presented at the component level.

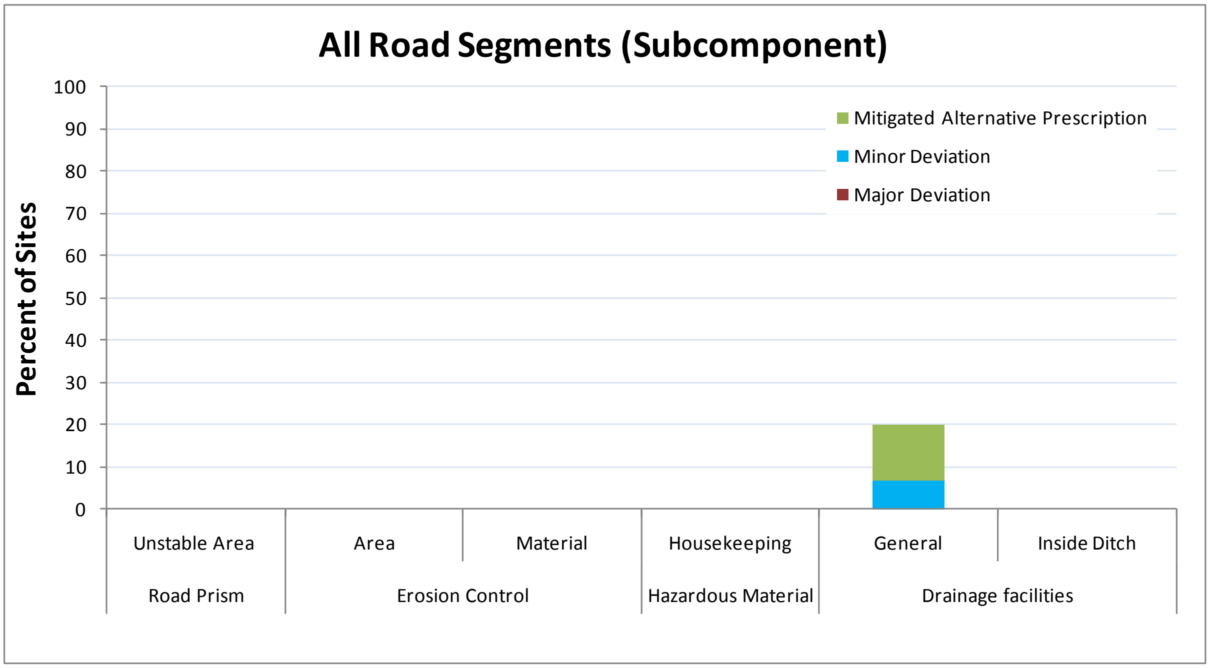


Figure 14. Percent of upgraded ford crossings with major deviations, minor deviations, and or mitigated alternative prescriptions applied in 2011. Data is presented at the "All Road Segments" subcomponent level.

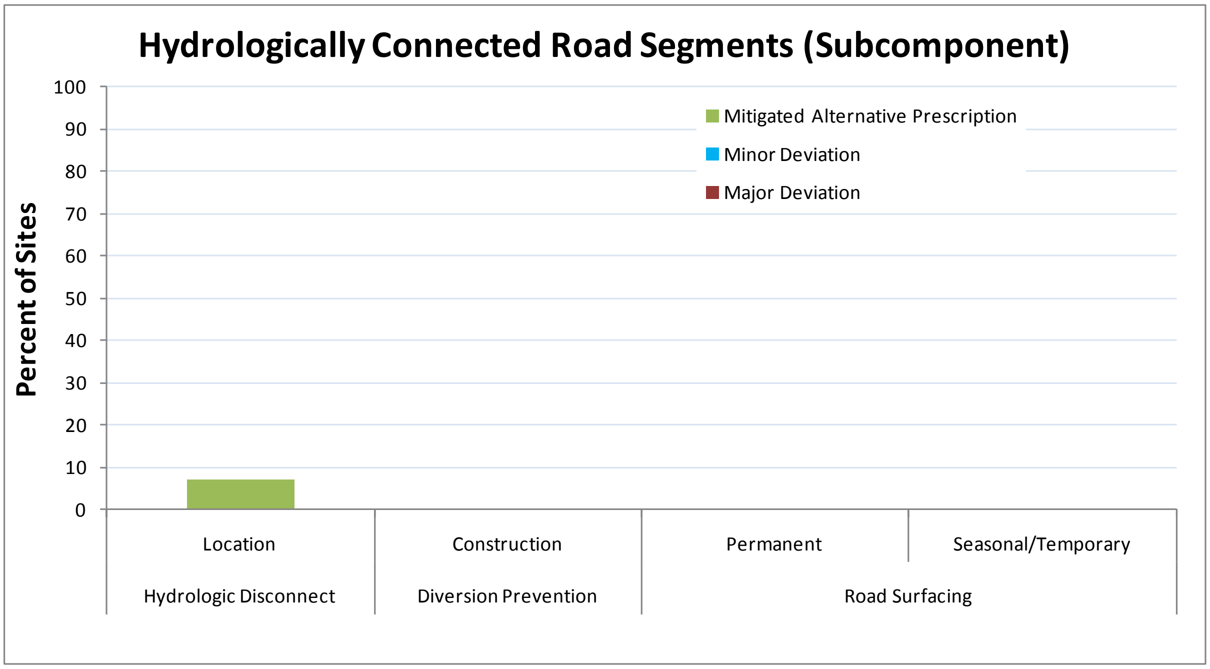


Figure 15. Percent of upgraded ford crossings with major deviations, minor deviations, and or mitigated alternative prescriptions applied in 2011. Data is presented at the "Hydrologically-Connected Road Segments" subcomponent level.

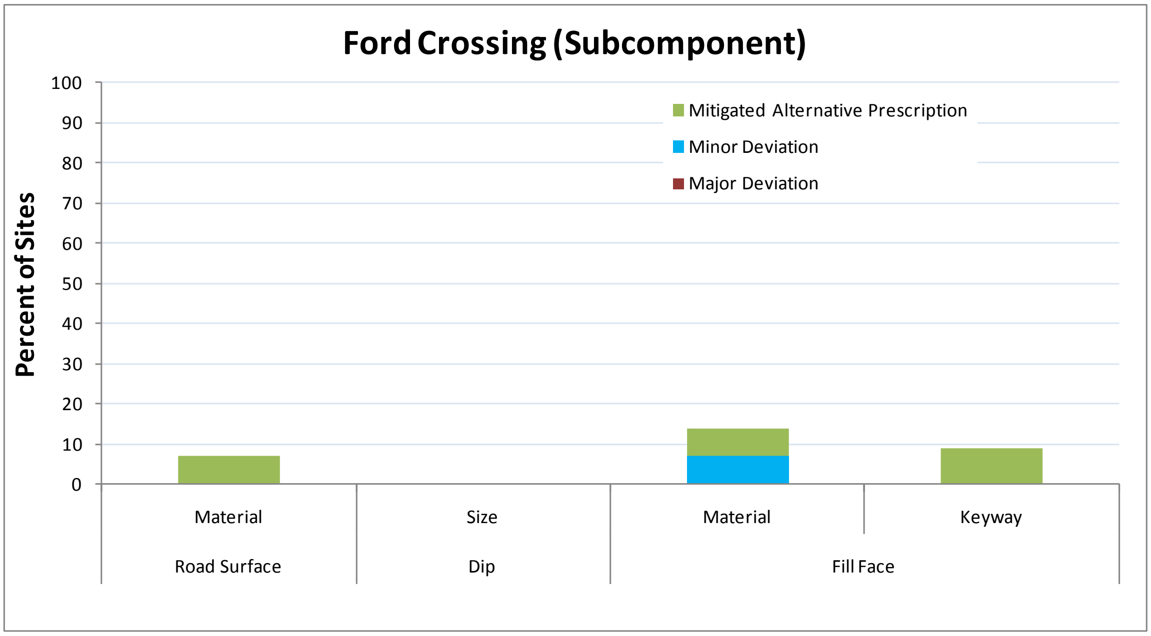


Figure 16. Percent of upgraded ford crossings with major deviations, minor deviations, and or mitigated alternative prescriptions applied in 2011. Data is presented at the "Ford Crossing" subcomponent level.

Upgraded Isolated Road Segments

Twenty (20) constructed/reconstructed upgraded isolated road segments were audited in 2011, with no major deviations remaining following auditor feedback (Figure 17). Two sites had minor deviations and mitigated alternative prescriptions relating to drainage spacing and ditch capacity.

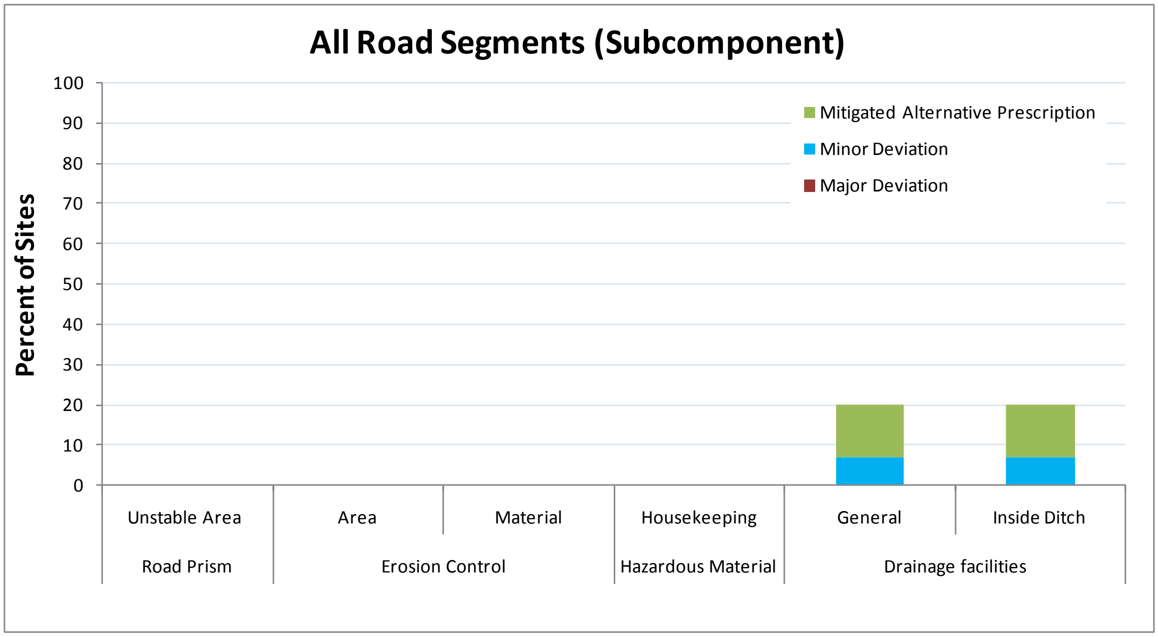


Figure 17. Percent of isolated road segments with major deviations, minor deviations, and or mitigated alternative prescriptions applied in 2011. Data is presented at the subcomponent level.

Upgraded Crossing Mitigated Alternative Prescriptions

Table 4 highlights alternative prescriptions applied to ford and culvert crossings in 2011. Alternative prescriptions were applied primarily at the culvert and road segment level. Alternatives included shortened sections of culvert extending from the fill face, increased downspout stake intervals, connected inboard ditch mitigations, and alternative placement and construction of diversion prevention structures.

Table 4. Mitigated alternative prescriptions applied to ford and culvert crossings in 2011.

Component	Subcomponent	Specification	Alternative Prescription
Culvert	Extension	Extends 3' past fill on upstream side	Installed culvert so that exposed inlet is 1 to 2 foot from fill face. Shallow fill, extra culvert length will cause erosion around culvert
	Downspout	Downspouts are securely coupled, staked, and anchored at intervals no greater than 10 feet.	The downspout was installed on flat grade and staked greater than 10' intervals.
All Road Segments	Drainage Facilities	Flow from drainage facilites can not reach a water	• Inboard ditch connects to inlet; however ditch is armored with rock. • Inboard ditch connects to inlet; however slash filter strip installed.
Hydrologically Connected Road Segments	Hydrodisconnect	Hydrologic disconnect installed between crossing hinge and 100' from centerline	Sufficient filter strip to avoid road runoff to watercourse.
	Diversion Prevention	Critical Dip Present	• Relief culvert directly down road. • Culvert oversized. • Rolling dip directly down road.

Upgraded Crossing New Prescriptions

Although not required and formally tracked as a construction specification alternative, HRC tested the incorporation of large wood debris in large culvert crossing fillslopes. In particular geology types, HRC has learned long, steep fillslopes are prone to erosion and failure after the first winter following construction. This adaptive practice is relatively unconventional in terms of standardized fillslope armoring specifications used in the past. When LWD is available, HRC plans to continue using this strategy to armor fillslopes prone to failure (Figures 18-19).

Figure 18. LWD cribbing along outlet fillslope of culvert crossing.

Figure 19. LWD chunks keyed into culvert outlet fillslope.

CLOSED ROADS

Closed Crossings

In 2011, 98 closed crossings were audited immediately after construction to determine if specifications were implemented correctly. No major deviations remained at any closed crossing after auditor feedback, and relatively few minor deviations were observed (Figures 20-23). Alternative prescriptions were applied primarily in association with road drainage and stream channel (Table 5).

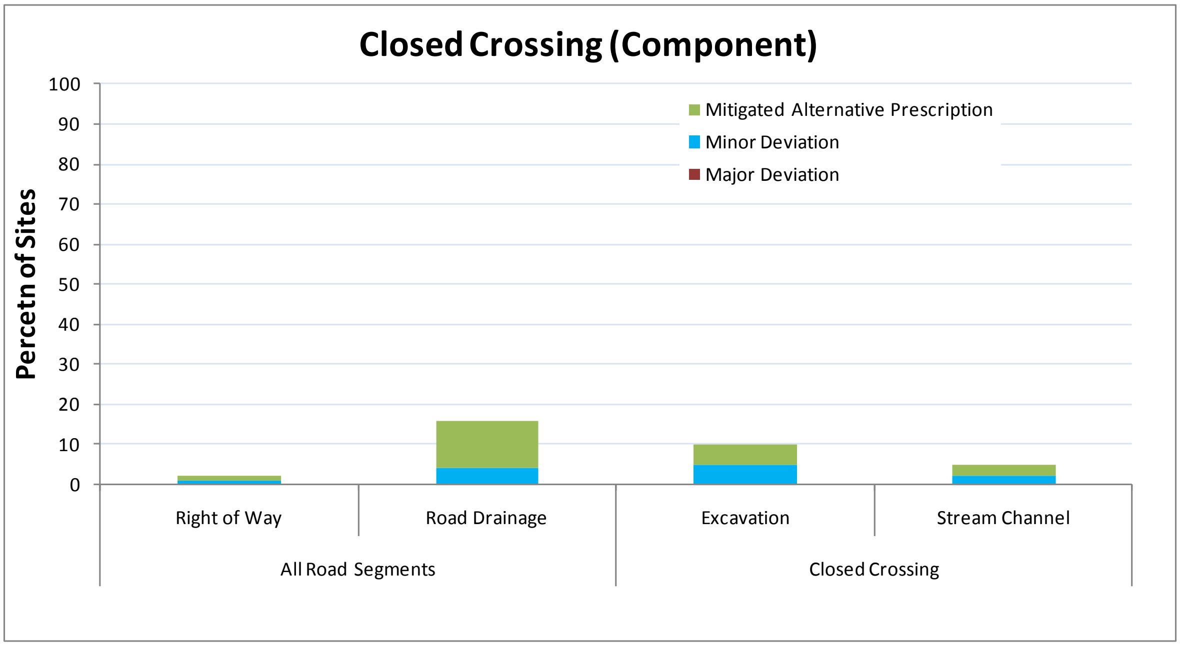


Figure 20. Percent of closed crossings with major deviations, minor deviations, and or mitigated alternative prescriptions applied in 2011. Data is presented component level.

Figure 21. Newly pulled Class III closed crossing

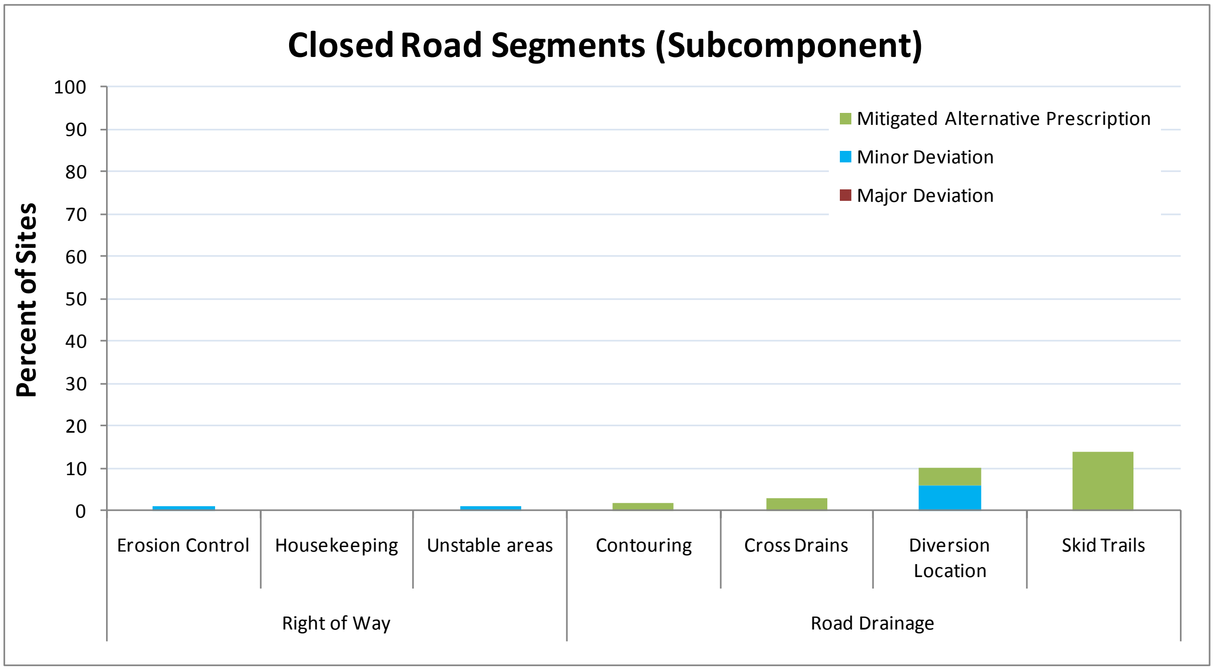


Figure 22. Percent of closed crossings with major deviations, minor deviations, and or mitigated alternative prescriptions applied in 2011. Data is presented subcomponent level.

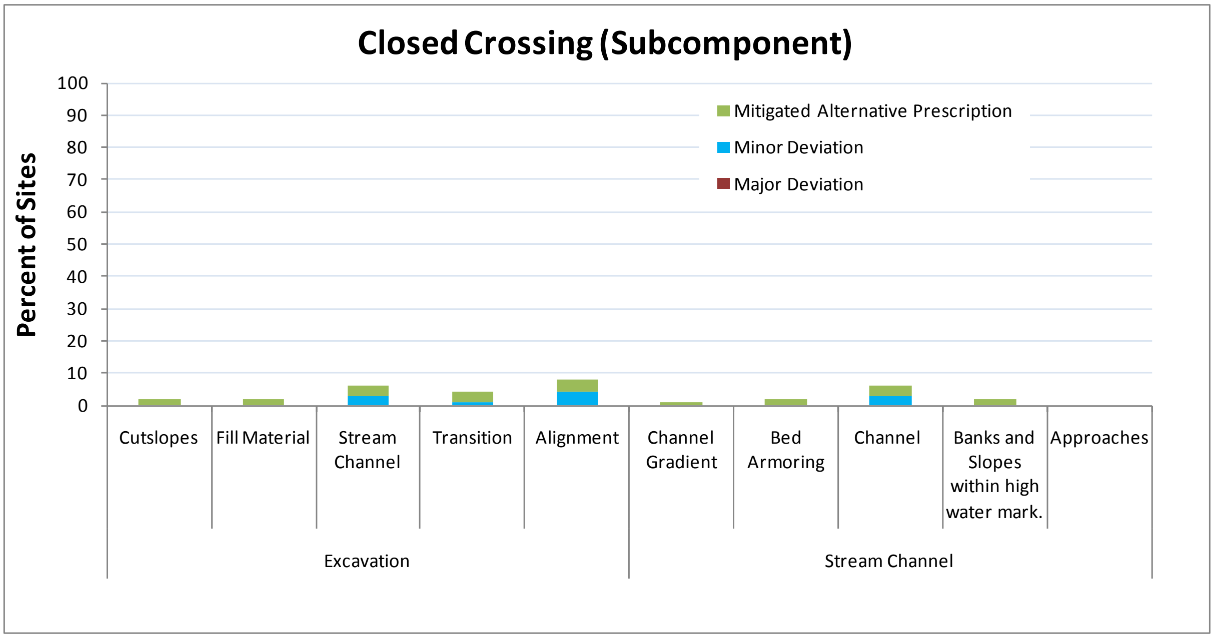


Figure 23. Percent of closed crossings with major deviations, minor deviations, and or mitigated alternative prescriptions applied in 2011. Data is presented at the subcomponent level.

Table 5. Mitigated alternative prescriptions applied to closed crossings in 2011.

Component	Subcomponent	Specification	Alternative Prescription
Road Drainage	Diversion Location	Flow from cross drains can not reach a water.	Slash packed and filter strip below drain
	Skid Trails	Skid trails disconnected above road	Old skid trail at top is part of Class III. LWD placed to disperse flow.
Excavation	Transition	Not overexcavated at upstream transition	Used LWD to compensate for overexcavation at head of crossing
	Stream Channel	Excavated to original channel bed	• Low stream power, site treated with LWD chunks • Three check dams in stream channel

Closed Road Segments

In 2011, 17 isolated closed road segments were audited immediately after construction to determine if specifications were implemented correctly. No major deviations or alternative prescriptions were recorded for any of these segments, with relatively few minor deviations (Figure 24). Ten (10) percent of the sites had cross drains which could reach a watercourse during high flow events; however all of the sites were mitigated with slash and or straw to avoid sediment delivery.

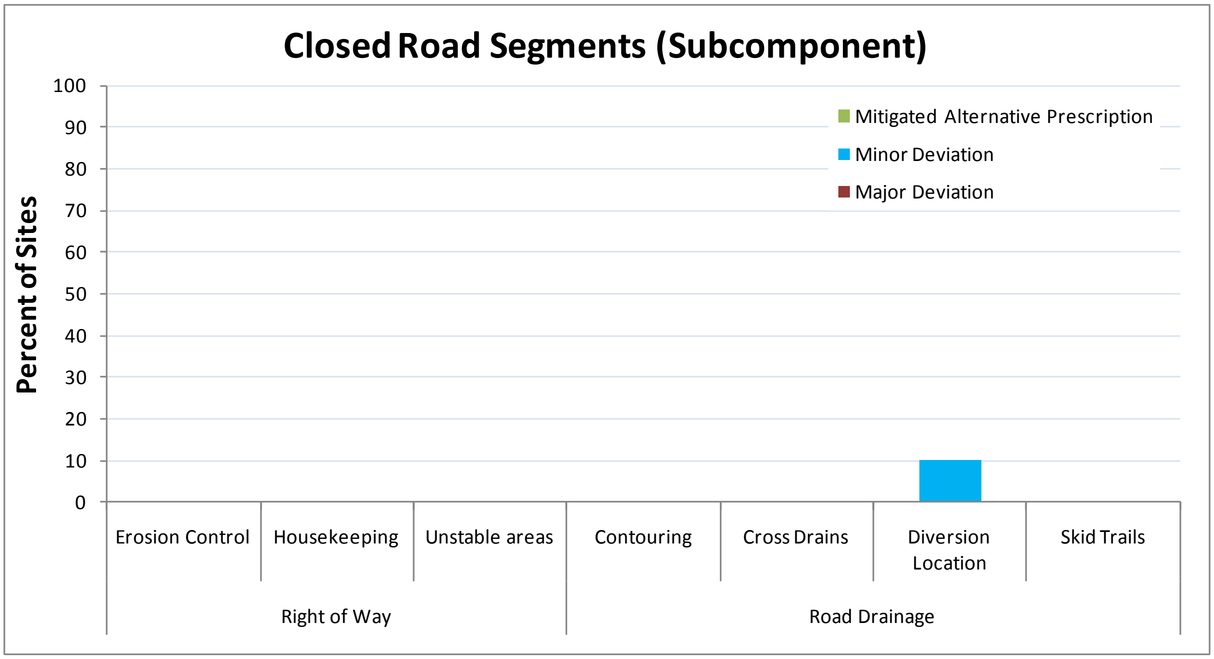


Figure 24. Percent of closed road segments with major deviations, minor deviations, and or mitigated alternative prescriptions applied in 2011. Data is presented at the subcomponent level.

Closed Mitigated Alternative Prescriptions

Table 5 (above) highlights alternative prescriptions applied to closed crossings in 2011. In some cases, Humboldt crossings were not excavated to the original channel bed where the stream power was low. Mitigating prescriptions primarily included the use of LWD chunks and check dams to stabilize the channel bed of those sites. LWD was also used to stabilize the head of the excavated channel to minimize the development of nickpoints.

Figure 25. LWD placed in pulled stream channel.

Post-Activity Erosion

Sediment delivery reported in this section is quantified by the erosion void project. The numbers reported are sediment volume (yd^3) delivered to the flood prone zone. Sediment delivery from newly constructed/deconstructed road crossings from 2011 (n=53) is compared to the 2005-2010 sampling period in Figure 26.

The majority of crossings (93%) did not deliver any sediment in 2011. Of the remaining sites, (4%) delivered between 0.1 and 1.0 cubic yard of sediment. Only 2% of sites had greater than 1 and less than 10 yd^3 delivered volume. One site (30837) from the Lake Creek subbasin in NF Elk River delivered 18.26 cubic yards of sediment. Delivery of sediment in 2011 was always less than the estimated sediment saved by the project.

The distribution of delivered sediment is shown in Figure 27. The purpose of this figure is to highlight the frequency of the larger delivered volumes. The pattern of site erosion in 2011 was similar to the 2006 through 2009 data set. Erosion volume was small in 2009 consistent with low winter flow that year. Maximum void volume increased in 2010 when HRC took on extensive decommissioning projects in Lake Creek. In 2011, there was less large delivery volumes compared to the previous years. Post-activity erosion volume is shown in relation to estimated sediment saved in Table 6.

In 2011, 0.2% of the sediment “saved” entered the stream the following winter (Table 6). This value is low compared to the previous 6 years. The only year in which percent sediment delivered was lower occurred during a drought year (2009).

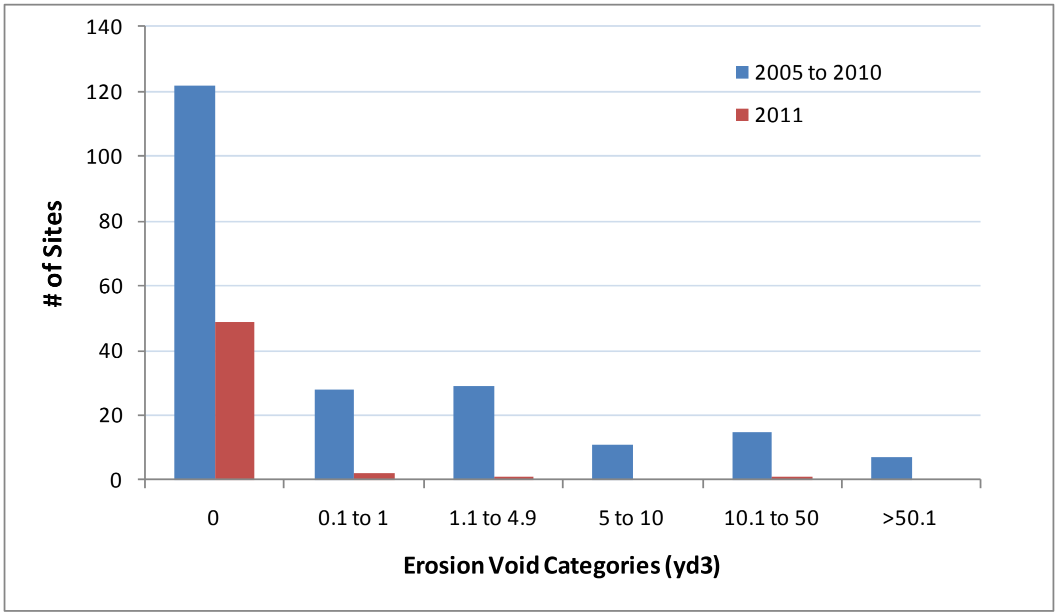


Figure 26. **Frequency distribution of overall sediment delivery volume frequency of upgraded and closed crossings measured using the erosion void methodology between 2005 to 2010 and 2011.**

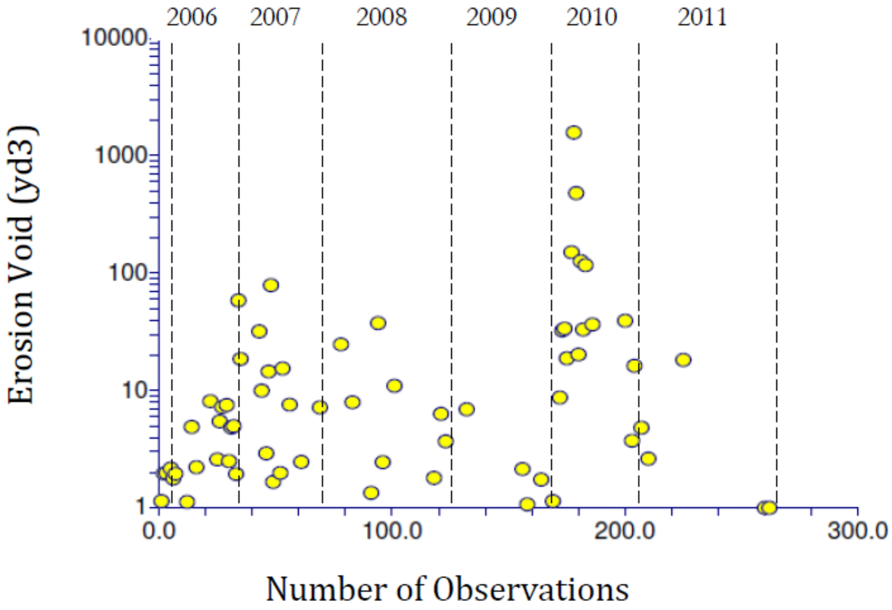


Figure 27. **Overall sediment delivery volume distributions of 258 upgraded and closed crossings measured between 2005 and 2011. Only values equal to or greater than 1 cubic yard are plotted.**

Table 6. Annual volume of sediment saved and post activity erosion at all erosion void sites.

Year	n	Total Sediment Saved (Yd^3)	Total Sediment Delivery (Yd^3)	Proportion
2005	7	1,030	11	1.1%
2006	28	6,770	59	0.9%
2007	38	20,964	177	0.8%
2008	51	14,054	102	0.7%
2009	44	10,734	14	0.1%
2010	33	21,683	2725	12.6%
2011	53	14,181	21	0.2%

SPECIAL CASES

Sullivan and Simpson (2012) described two sub-basins in the Elk River watershed where practices that have been routinely successful in preventing sediment delivery in other areas, were not successful there. Sites in the Tom Gulch and Lake Creek sub-basins where shown to have greater post activity erosion volumes than other parts of the property. Large delivery volumes were due to erosive Hookton geology in Tom's Gulch, and the large excavation volumes required for decommissioning crossings in Lake Creek. These sites are considered "special" or "non-standard" because standard best management practices and road construction specifications are not effective in minimizing the delivery of fine sediment in these locations. To measure trends in road construction practices, we have categorized sites into standard and "special cases" throughout the remainder of the report.

Little work was conducted in Lake Creek, and no work was conducted in Tom's Gulch in 2011. A Lake Creek "Big Dig" site (30847) was included in the 2011 erosion void study, with high post activity delivery volume (18.26 cubic yards) measured after the first winter. This site was by far the largest void measured in 2012 from 2011 site work.

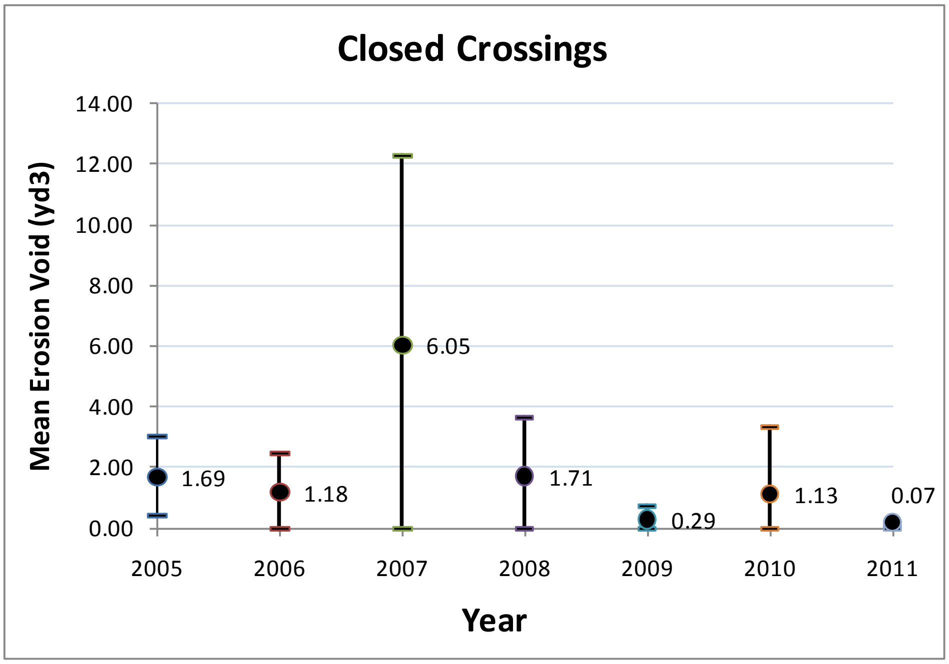
Figure 28. Slope failure at "Big Dig" site.

STANDARD SITE EROSION STATISTICS

The mean and 95% confidence interval of delivered volume from standard sites is shown by year in Figure 29. We present the average because this has been the metric reported from other studies in the region (e.g. PWA 2006, NCRWQCB 2011). We caution that the site erosion volume is not normally distributed (e.g. Figure 26 above). Because the sample distribution is highly skewed to the left, the mean overstates the central tendency of the data. In these cases, other nonparametric statistics such as median or percentiles are more appropriate. Percentiles of the distribution are provided in Table 7 as a preferred representation of the data distribution.

Both measures of central tendency (mean and percentile) show similar patterns. The mean and median (50th percentile) delivery volume has declined since measurements began in 2005. Closed crossings have a somewhat higher mean delivery volume compared to culvert crossings. Erosion volume was 7.36 yd^3 at the 85th percentile of the distribution in 2006 when sampling of a substantial number of sites began, and has declined to 0 yd^3 in 2011 (Figure 30). The median value has been zero since 2007.

Table 8 summarizes overall erosion estimates in upgraded and closed sites in various watersheds across HRC property. Outside the Freshwater Creek and Elk River watersheds, the sample size is currently too small to make a comparison between watersheds.



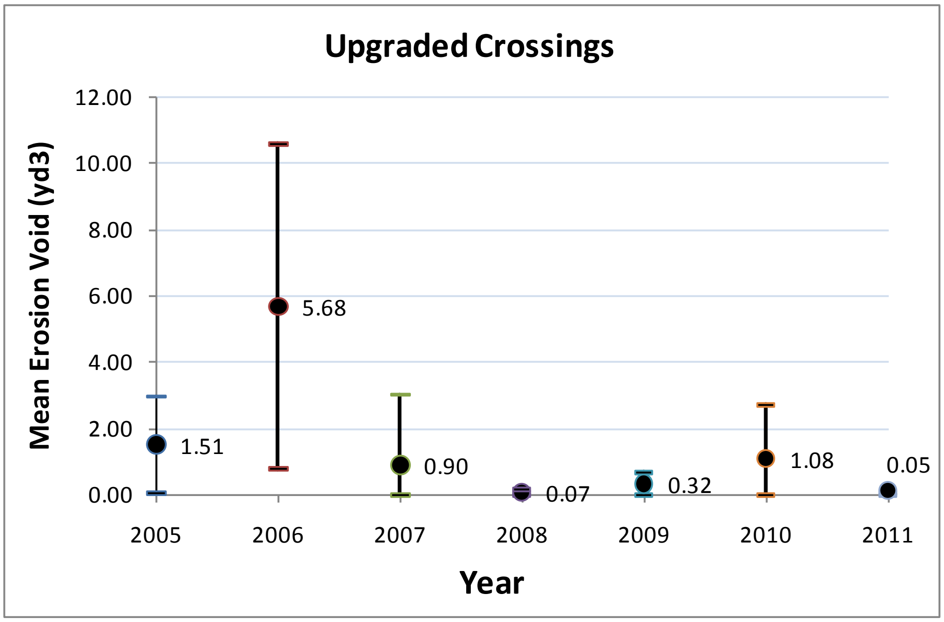


Figure 29. Average site post-activity erosion for standard closed and upgraded crossings. Error bars are 95% confidence limits.

Table 7. Cumulative percentile distribution of erosion void measurements (cubic yards) for standard sites by year (upgraded and closed sites are combined).

Year	n	50 Percentile	75 Percentile	80 Percentile	85 Percentile	90 Percentile	95 Percentile
2005	7	1.95	1.98	2.05	2.12	--	--
2006	23	0.63	4.90	5.82	7.36	7.88	16.52
2007	36	0.00	2.34	5.48	8.67	14.80	39.17
2008	41	0.00	0.31	0.42	0.77	2.23	10.70
2009	44	0.00	0.00	0.02	0.20	0.83	2.04
2010	30	0.00	0.00	0.25	1.66	3.63	12.13
2011	52	0.00	0.00	0.00	0.00	0.00	0.49

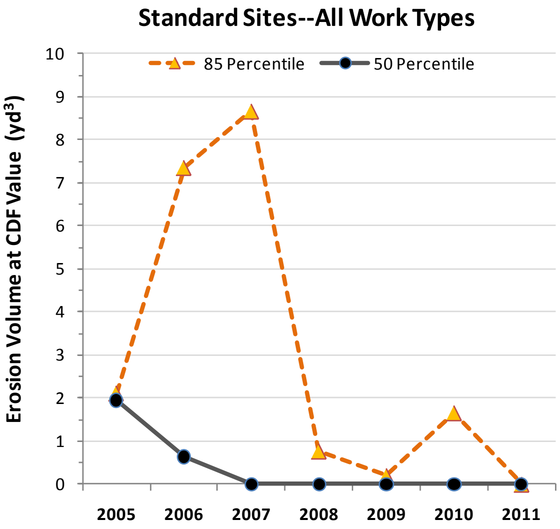


Figure 30. Erosion volume values at the 50th and 85th percentiles of the cumulative distribution function (% less than). The 50th percentile is the median value.

Table 8. Cumulative Distribution of erosion volume (yd^3) of standard sites by work type and watershed.

Closed Standard

Watershed	n	Mean	50 Percentile (Median)	75 Percentile	80 Percentile	85 Percentile	90 Percentile	95 Percentile
Freshwater Creek	61	2.75	0.00	0.00	0.41	1.50	6.13	15.34
NF Elk River	48	1.31	0.00	0.36	0.63	1.86	5.17	8.38
SF Elk River	25	1.23	0.00	1.55	1.98	2.45	4.72	10.14
Upper Eel River	4	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Van Duzen River	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Yager Lawrence	3	0.64	0.00	1.92	1.92	1.92	1.92	1.92

Upgraded Standard

Watershed	n	Mean	50 Percentile (Median)	75 Percentile	80 Percentile	85 Percentile	90 Percentile	95 Percentile
Bear River	3	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Freshwater Creek	25	1.07	0.00	0.74	1.03	2.88	6.18	7.44
Lower Eel/Eel Delta	5	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NF Elk River	21	0.54	0.00	0.00	0.00	1.22	2.35	6.72
SF Elk River	31	1.58	0.00	0.98	1.88	2.25	3.52	17.22
Upper Eel River	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Yager Lawrence	3	0.08	0.00	0.23	0.23	0.23	0.23	0.23

TYPES OF EROSION

Closed Crossings

In 2011, less erosion was observed at closed crossings compared to 2006-2010 (Figure 31). Sediment delivery in 2011 originated from the excavated channel bed, channel banks and sideslopes (Figures 32 and 33). The most common types of erosion included channel bed downcutting, channel bank erosion, and sidelslope sloughing. Bank erosion, sloughing and slope failure were down approximately 92% compared to 2006-2010. A small improvement in channel downcutting was also observed in 2011.

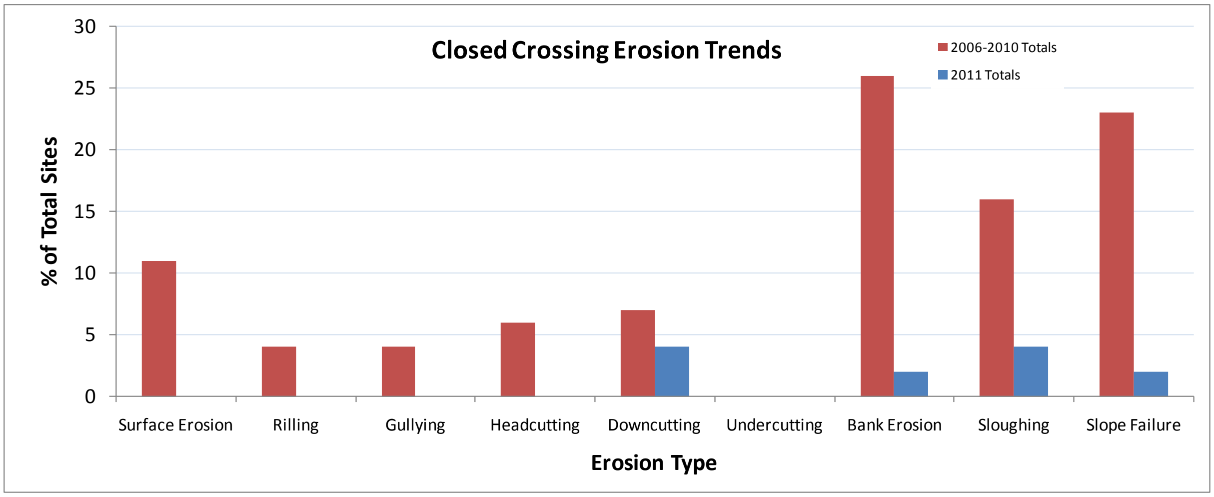
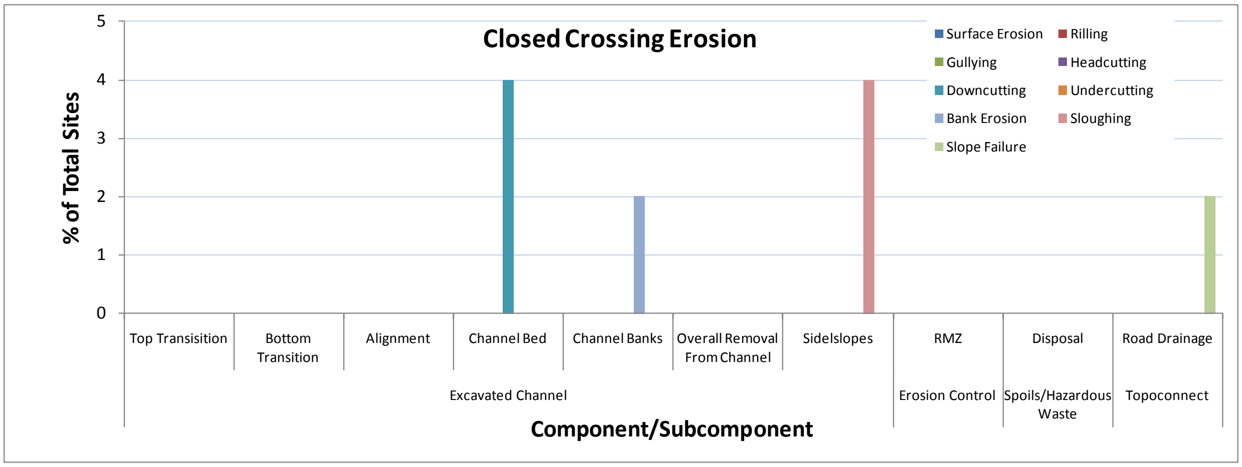


Figure 31. Percent of closed crossings with specific erosion types completed in 2011, compared to closed crossings treated between 2006 and 2010.

Figure 32. Slope failure adjacent to newly excavated channel.



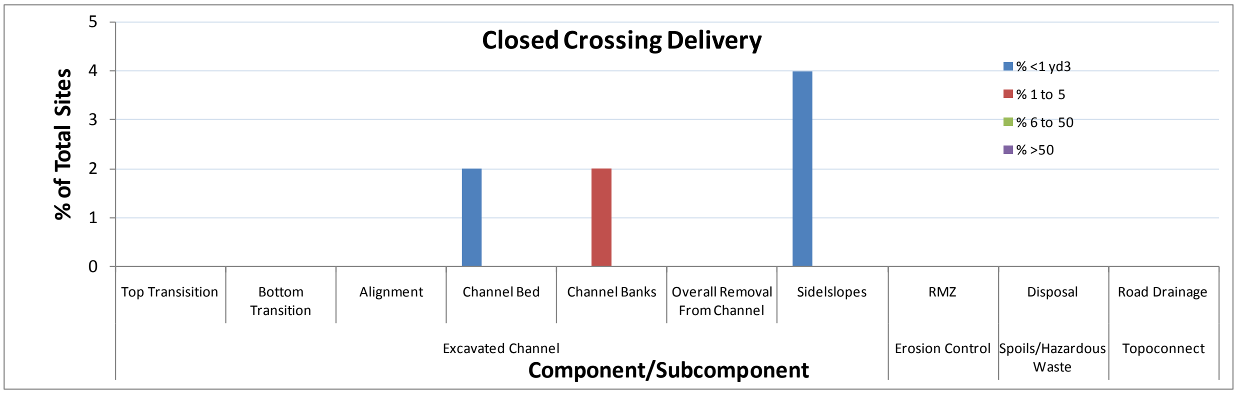


Figure 33. 2011 Closed crossing components/subcomponents with erosion and delivery

Upgraded Crossings

In 2011, 38 culvert crossings, 1 bridge crossing, and 8 ford crossings were constructed and inspected for erosion and delivery. No evidence of erosion or delivery was recorded from the bridge or ford sites. Delivery from upgraded culvert crossings was much less compared to the previous year's results (Figure 29 above). We observed less types of erosion in 2011 in most categories, most notably a 9% decrease in slope failure (Figure 34). The exception was culvert crossing fillslopes and streambanks, where observed sloughing was significantly higher in 2011 than from 2006-2010. Despite the relatively high rate of outlet fillslope sloughing (19%), only 4% of sites delivered sediment, with all delivery volumes less than 1 cubic yard (Figure 35). At sites where stream channel sloughing did occur, all delivered sediment to the stream. Delivery from the crossing features appear to be relative to the proximity to the stream channel. The lack of delivery resulting from fillslope delivery is likely due to the effectiveness of fail safe/soft armoring incorporated around the culvert inlet and outlet.

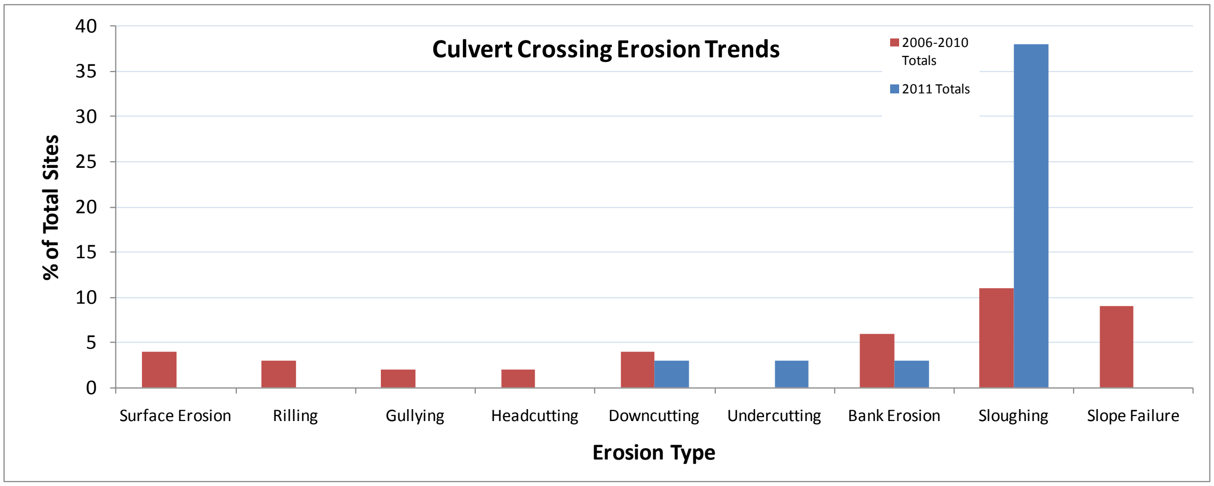


Figure 34. Percent of culvert crossings with specific erosion types completed in 2011, compared to closed crossings treated between 2006 and 2010.

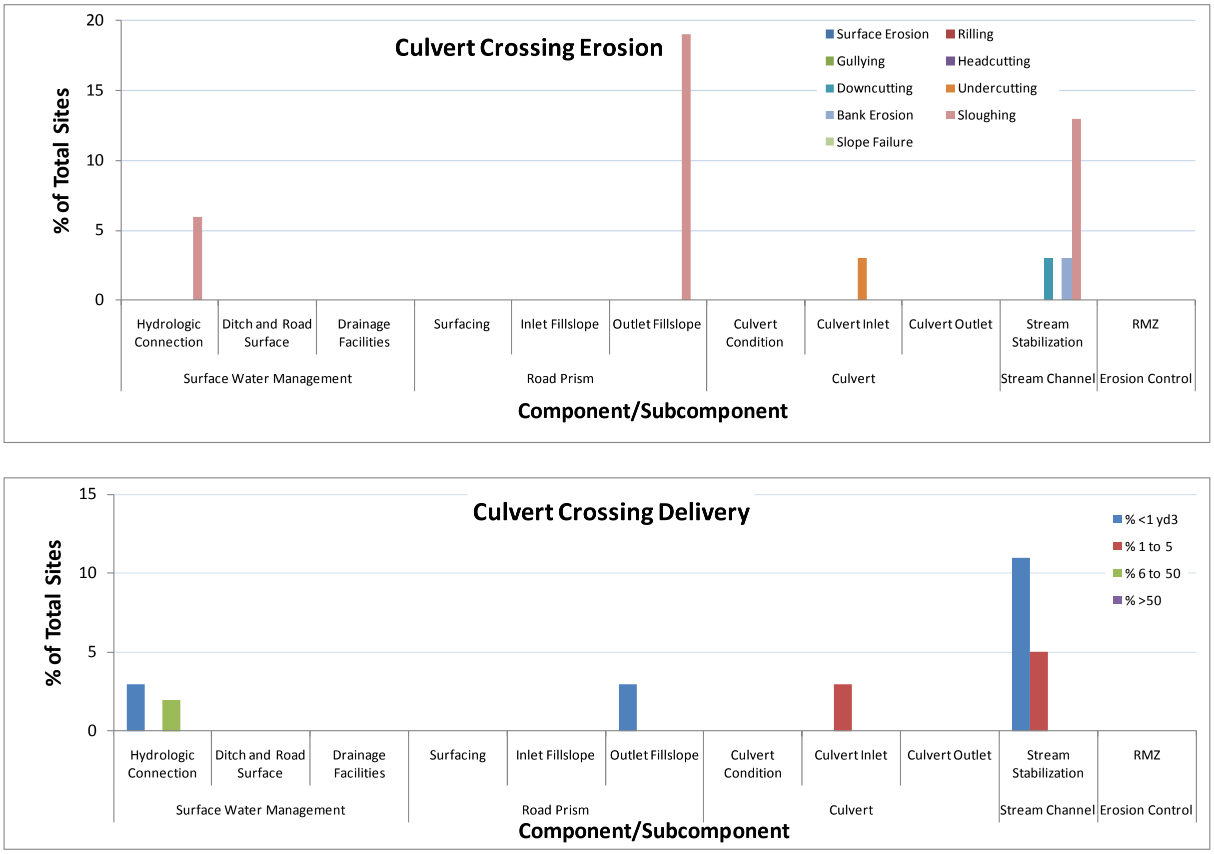


Figure 35. 2011 Culvert crossing components/subcomponents with erosion and delivery

ROAD EFFECTIVENESS EVALUATION

So far we have presented sediment delivery data as an indicator of aquatic resource protection, and operational compliance data as a measure of operating performance. Effectiveness evaluation requires connecting the observations to associate specific practices with success or failure in preventing sediment delivery. Figure 36 shows trends in conformance, erosion and sediment delivery over time.

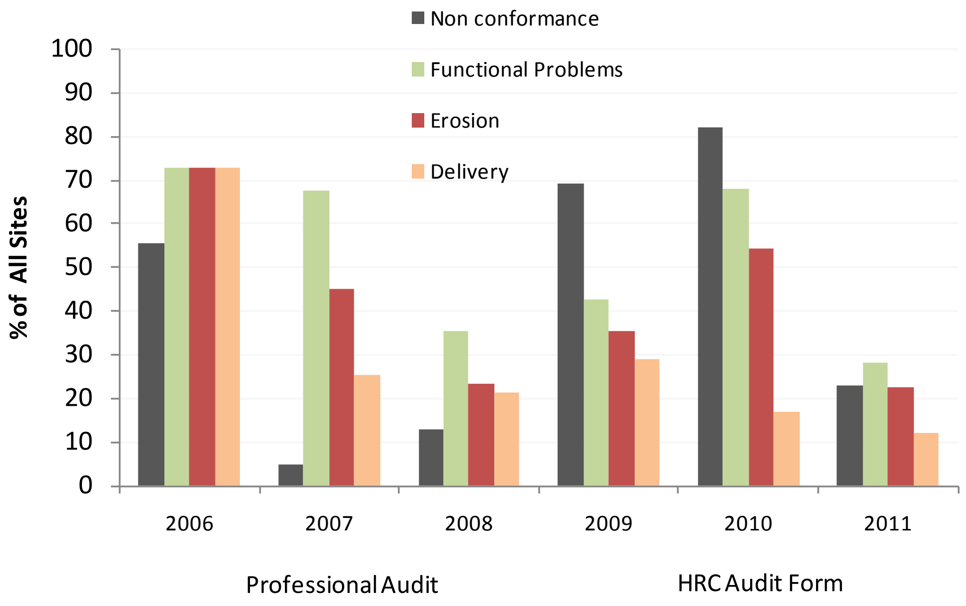


Figure 36. Percent of all crossings with non-conformances, functional problems, erosion and sediment delivery (pooled samples).

Appendix C (Effectiveness Figures) and Table 9 show upgraded and closed crossing components were implemented at very high rates in 2011, with little sediment delivery after the first winter following construction. All delivery events, but one, were associated with sites that had met construction specifications. In the one exception, a minor deviation relating to the culvert extension from the fillslope led to sediment delivery (0.5 cubic yard). If the culvert had extended the full 5 feet from the outlet fillslope, the sloughing fillslope would have been less likely to deliver sediment. There was no delivery associated with any of the mitigated alternative prescriptions (MAPs) applied at upgraded or closed crossings; however sample sizes were generally too small to conclude effectiveness of the MAPs that would lead to changing specifications. Metrics of performance can be computed from the count data in the contingency tables shown in Appendix D. We suggest target values for these measures. Table 8 provides the evaluation results.

Conformance = ——————   Target = 90%

Effectiveness = ——————   Target = 95%

Table 9. Effectiveness evaluation metrics of performance for standard sites in 2011.

Work Type	Component	Conformance	Effectiveness Measure
Upgraded	Erosion Control	99	100
	Drainage Facilities	97	98
	Hydro disconnect	93	100
	Diversion Prevention	100	100
	Road Surface	100	100
	Fill Prism	90	98
	Stream Channel	90	97
	Culvert	75	100
Closed	Right of Way	99	100
	Road Drainage	95	100
	Excavation	92	98
	Stream channel	98	96

At this stage in the road monitoring project, we can draw inferences about effectiveness of road management practices, even if results are not yet fully conclusive. The low percentage of sites with delivered sediment in the "implemented correctly" group indicates that HRC's construction/ deconstruction standards are effective. A few particular culvert crossing road design subcomponents stand out as having lower conformance rates. These include culvert extension and downspout standards.

The incidence and volume of post-activity sediment delivery is low. In fact, HRC has been quite successful in producing no erosion at all after construction activity with improvements since 2006. The notion that some sites "adjust" after construction is supported by observations in this monitoring program. Also supported is that adjustments rarely lead to delivery. The audit process we are using is conservative in determining non-conformance with specifications.

After six (6) years of monitoring, it is important to note that the data from audits, inspections, and measurements shows that most non-conformances do not lead to road problems or erosion, and that if erosion occurs it doesn't always deliver sediment to streams.

Road construction practices that need attention to improve performance include road fills, and stream channel excavations. Specific investigations are warranted to link mechanism of failure and site construction in greater detail. HRC is currently conducting a fillslope investigation exploring effectiveness of these specifications in the Bear River watershed. The audit form has been adjusted in 2013 to more accurately measure the application of straw and slash.

Improvements in 2011 are due to a combination of factors. Auditors now use explicit criteria and rules for determining if a site met or deviated from a specification, or whether an alternative mitigation was applied. Little to no work was conducted in the Tom Gulch and Lake Creek sub-basins in the Elk River watershed, where standard construction practices led to high post-activity erosion and delivery rates in the near past.

STUDY PLAN MOVING FORWARD

To fully assess the effectiveness of standard and alternative prescriptions, we will need to improve sample sizes over time. In accordance with recommendations from Lewis and Baldwin (1997), HRC has utilized a stratified random sample approach to select wet weather inspection sites in order to increase sample sizes of MAPs and minor/major deviations, as currently sample sizes in those categories are small. To address this, we are queuing sites into the long-term, weather-triggered inspection program described above.

The monitoring program has so far assessed the effectiveness of road management practices in preventing sediment delivery during the period immediately after major construction. The road must also withstand erosion during the large, infrequent storm events. Evaluating effectiveness during the larger storms is key component of the program. The same techniques will be used to assess erosion following large storm events. HRC is prepared to exercise the “storm verification” element of the monitoring program, triggered by benchmark storm sizes, as large storms occur.

LONG TERM PERFORMANCE ASSESSMENT

Ninety six (96) sites constructed/deconstructed in 2011 have been placed in a queue to be tested for stability against storm events across various geology types. On December 2, 2012, a 3-year recurrence rain event generating 3.28 inches in 24 hours was recorded in Scotia. Nine (9) of the queued sites occurring within the southern portion of HRC property will be inspected during the spring of 2013. These same sites as well as the remaining sites in queue will be inspected when large magnitude storms trigger 5, 10, 15, 25, 50 and 100 year storm events. Sites will be added as new prescriptions developed and tested (see Table 2, Methods, pg. 14).

SHORT TERM PERFORMANCE ASSESSMENT

During the 2012 and 2013 construction years, short term effectiveness of stream crossings will continue to be evaluated by auditing 100% of all constructed/deconstructed crossings (not just identified potential sediment delivery sites), wet weather inspecting 50%, and conducting an erosion void study on 25%. By 2014, short term effectiveness of standard crossings will be established by the large sample size evaluating short term performance. Starting in 2014, 100% of crossings will be audited; however, annual wet weather inspections and an erosion void study will no longer be required. The inspections will shift from short term performance to the long performance as described above.

QUALITY ASSURANCE/QUALITY CONTROL

In 2011, quality assurance/quality control (QAQC) wet weather inspections were conducted on 8 closed crossings, 2 ford crossings and 1 culvert crossing by different personnel. Inspections were made within eight days of each other. All upgraded crossings and 6 of the closed crossings showed no sign of erosion or problems, and were confirmed by the QAQC inspection. A closed crossing with side slope failure was characterized equally, in terms of erosion and delivery estimates, by both auditors. Another closed crossing was originally evaluated as having no problems, while the QAQC inspection encountered minor channel bed incision.

There was no QAQC conducted on post construction audits in 2011. Moving forward, the QAQC program will verify the ability of auditors to inspect consistently.

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APPENDICES

Appendix A. Site Locations

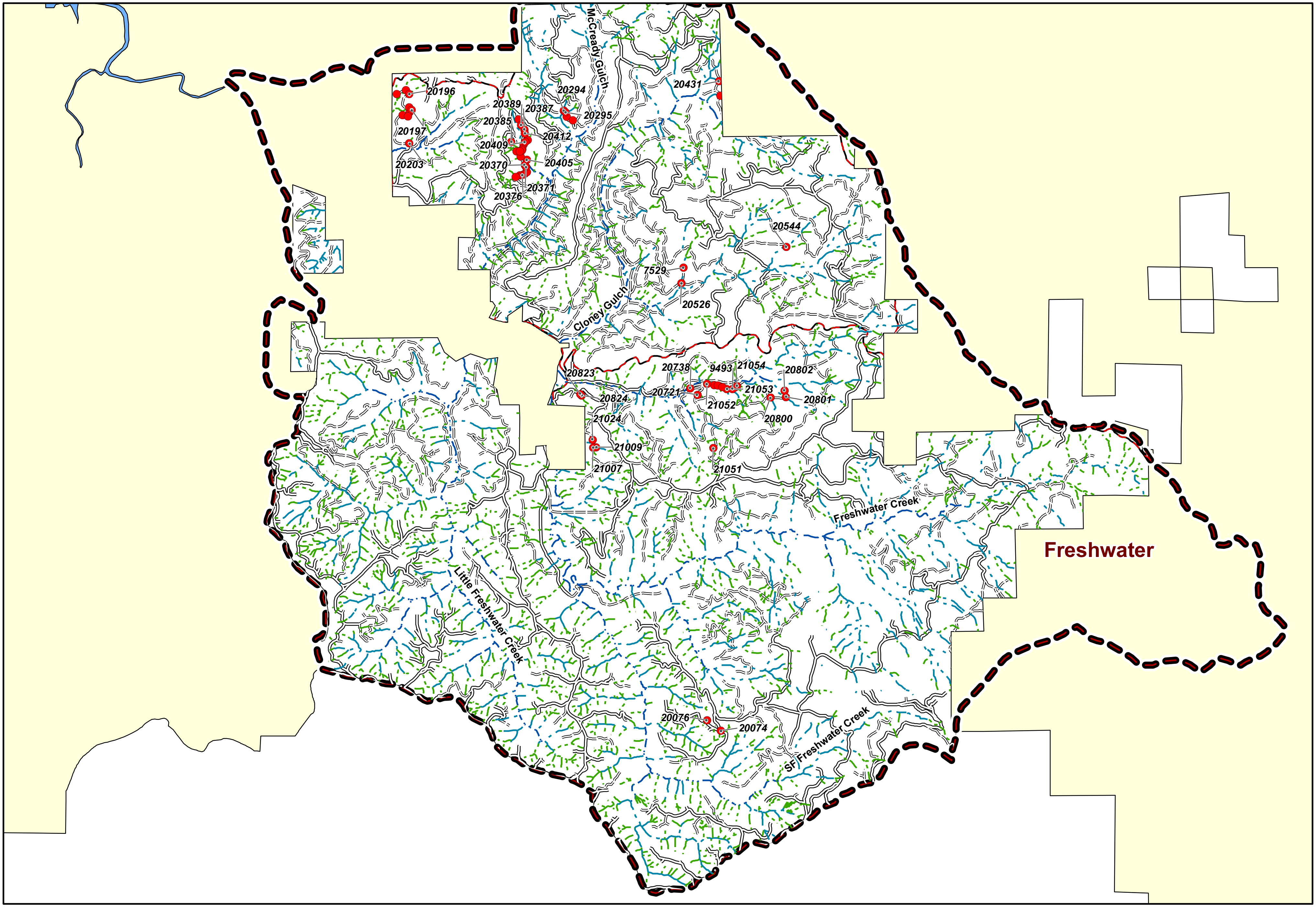
2011 Roads BMPEP Report

1 **Freshwater**

Legend

● 2011 Sites
Watersheds
Class 1
Class 2
Class 3
Paved Road
Rocked Road
Dirt Road
HRC
Off Property
River

1 inch = 5,000 feet



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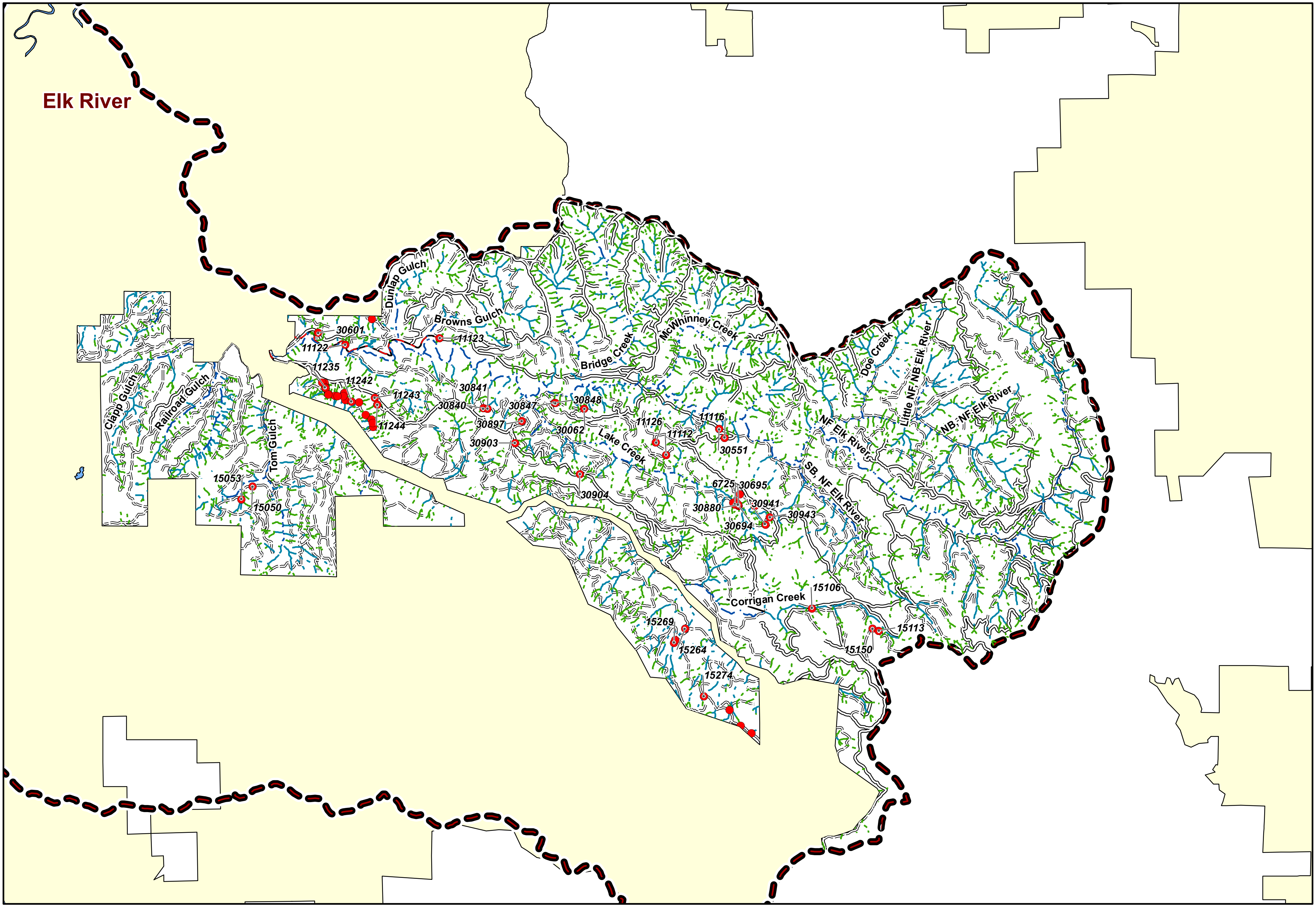
2011 Roads BMPEP Report

2 Elk River

Legend

- ● 2011 Sites
- Watersheds
- Class 1
- Class 2
- Class 3
- Paved Road
- Rocked Road
- Dirt Road
- HRC
- Off Property
- River

1 inch = 7,000 feet



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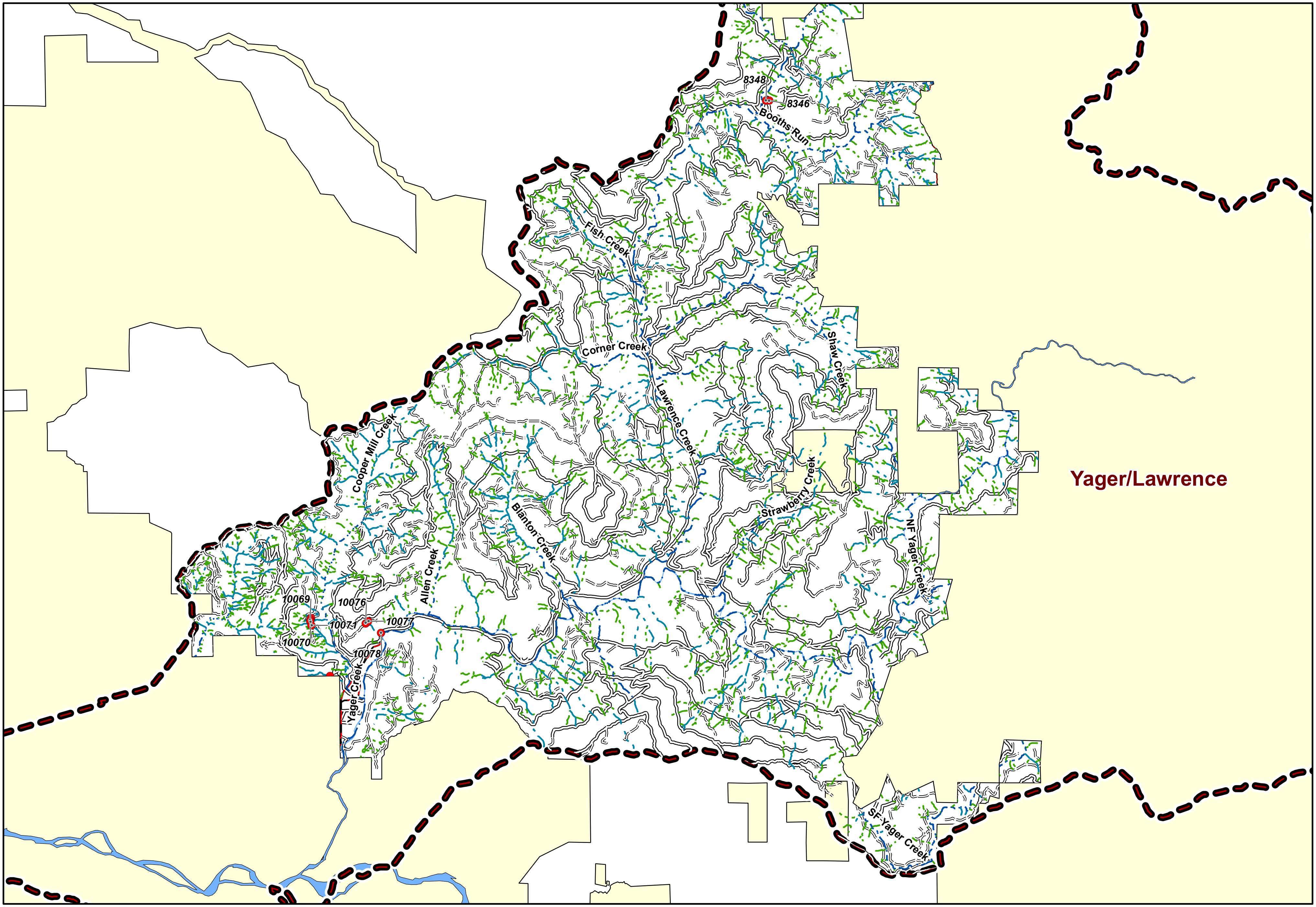
2011 Roads BMPEP Report

3 Yager/Lawrence

Legend

● 2011 Sites
Watersheds
Class 1
Class 2
Class 3
Paved Road
Rocked Road
Dirt Road
HRC
Off Property
River

1 inch = 8,000 feet



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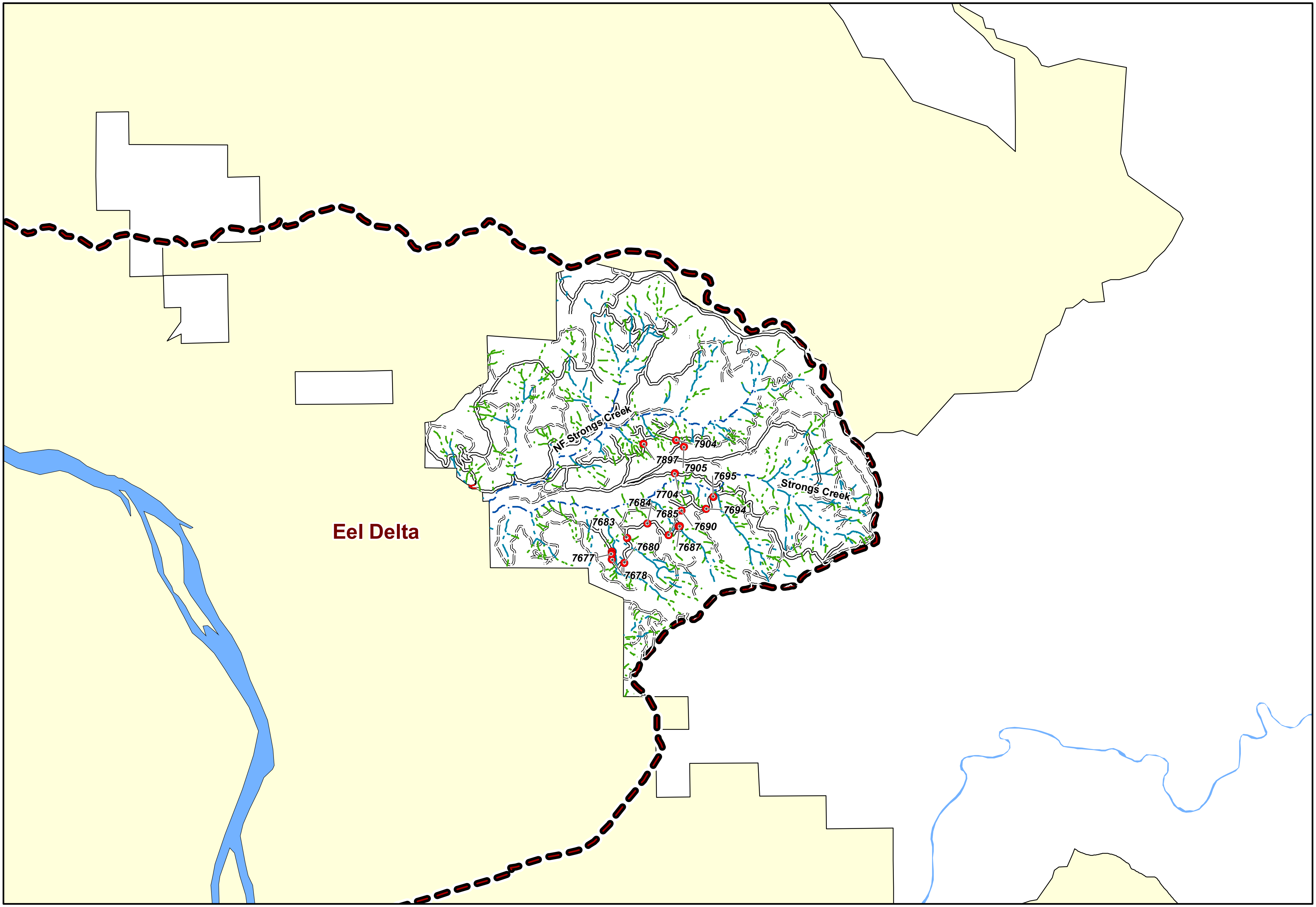
2011 Roads BMPEP Report

4 **Eel Delta**

Legend

- ● 2011 Sites
- Watersheds
- Class 1
- Class 2
- Class 3
- Paved Road
- Rocked Road
- Dirt Road
- ☐ HRC
- Off Property
- River

1 inch = 5,000 feet



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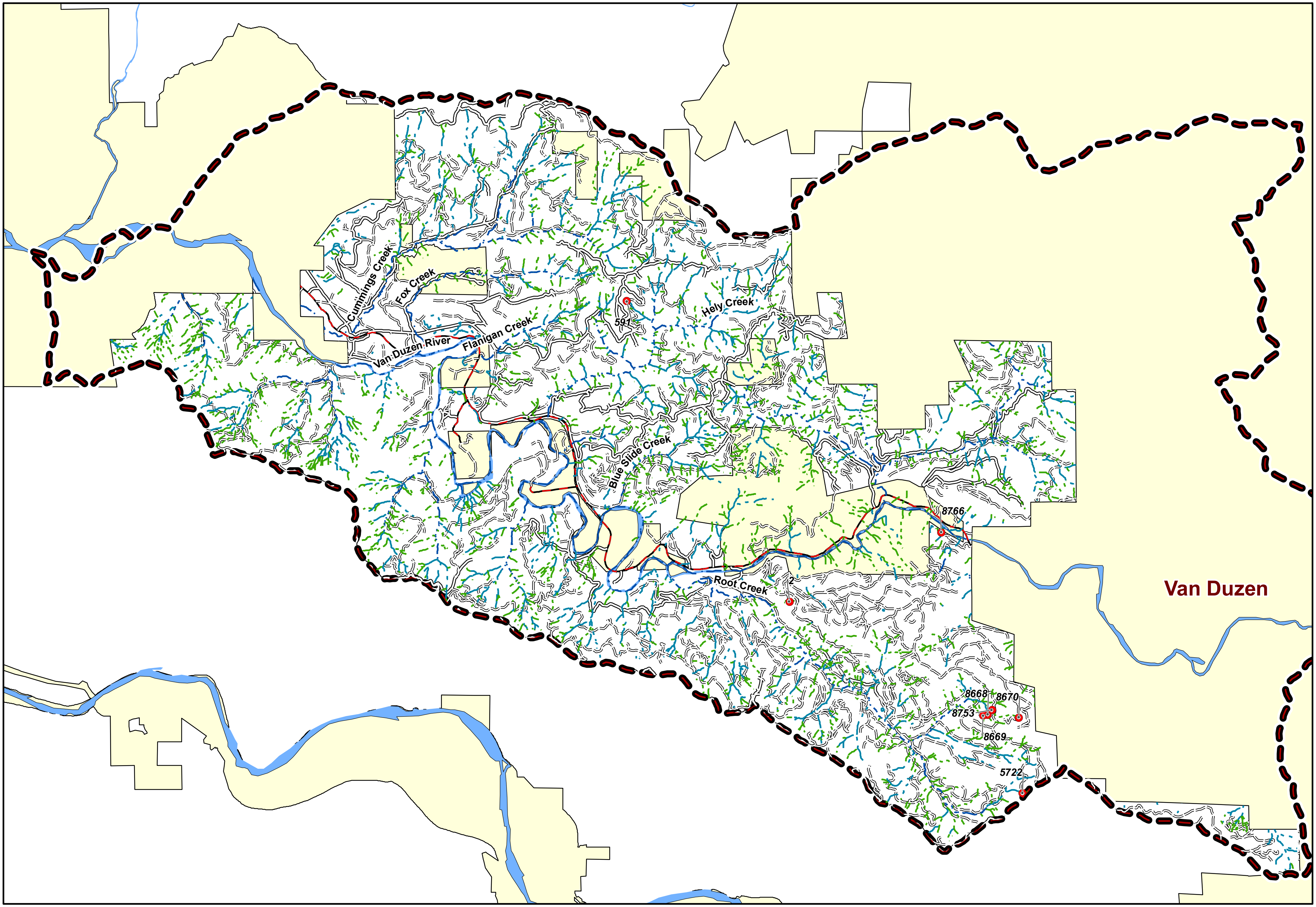
2011 Roads BMPEP Report

5 Van Duzen

Legend

●	2011 Sites	-·-·	Class 1	▬	Paved Road	☐	HRC
▬ ▬	Watersheds	- - -	Class 2	═	Rocked Road	🟨	Off Property
		- - -	Class 3	═ ═	Dirt Road	🟦	River

1 inch = 7,000 feet



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2011 Roads BMPEP Report

6

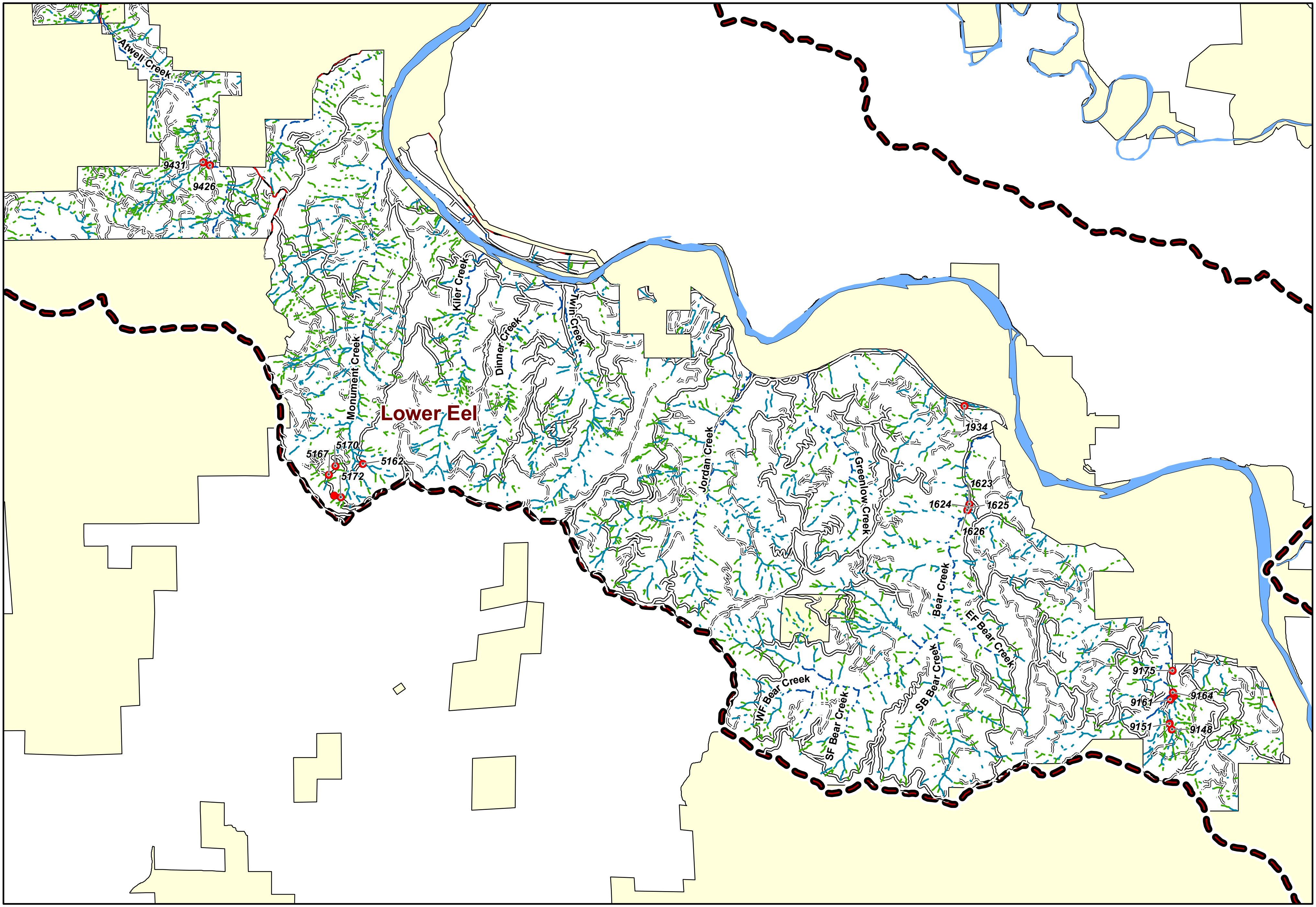
Lower Eel

Legend

- ● 2011 Sites
- Watersheds
- Class 1
- Class 2
- Class 3
- Paved Road
- Rocked Road
- Dirt Road
- HRC
- Off Property
- River

N W E S

1 inch = 7,000 feet



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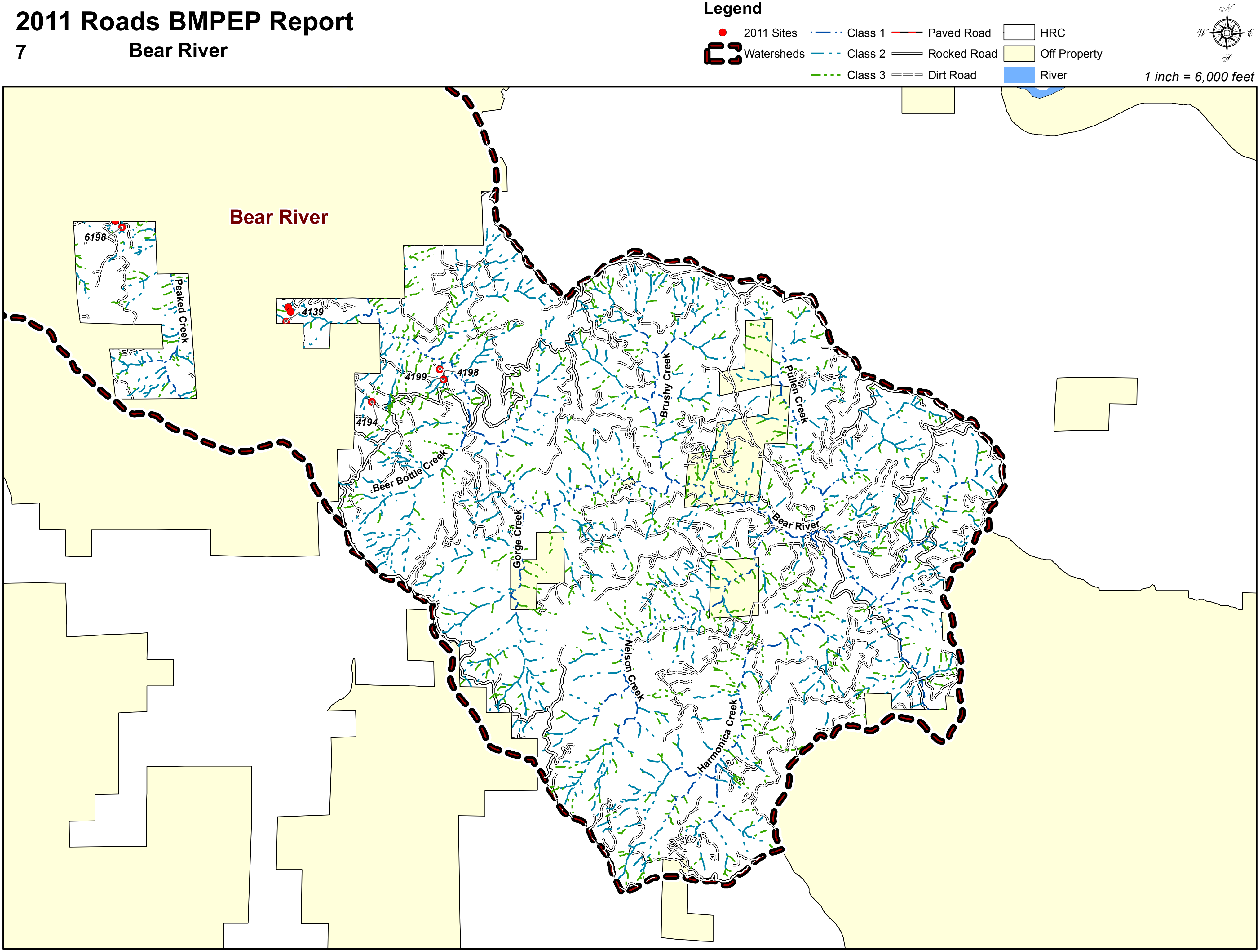
2011 Roads BMPEP Report

7 **Bear River**

Legend

- ● 2011 Sites
- Watersheds
- Class 1
- Class 2
- Class 3
- Paved Road
- Rocked Road
- Dirt Road
- HRC
- Off Property
- River

1 inch = 6,000 feet



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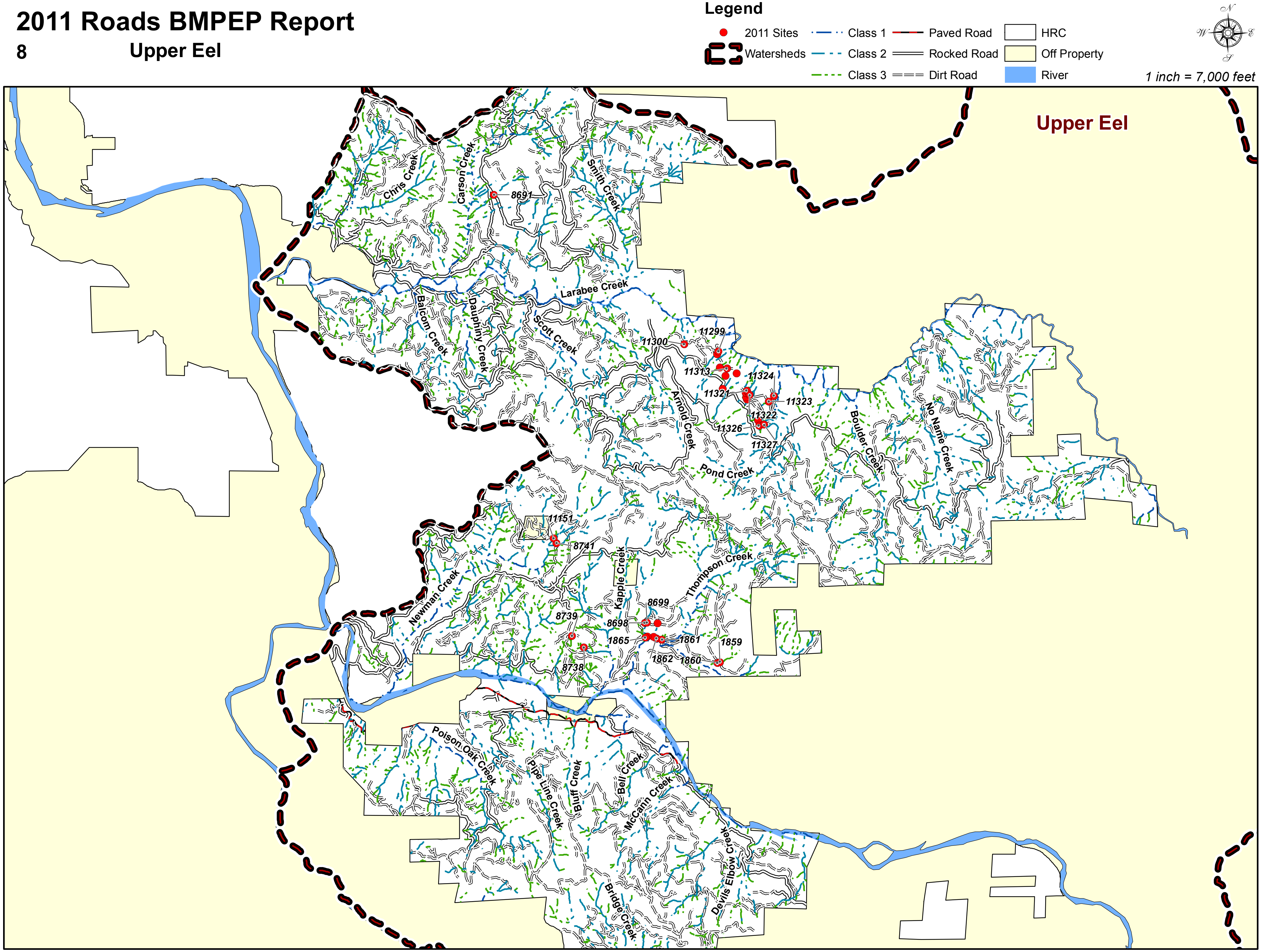
2011 Roads BMPEP Report

8

Upper Eel



1 inch = 7,000 feet

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Appendix B. Field Forms

DS-35-01-UPGRADED CROSSING **BMPEP Wet Weather Inspection Form** **UPGRADED CROSSING**

Site ID#		Field Crew:			
Road		Date:			
Watershed		Weather: Rain Int Rain Part Cloudy Clear		Photos: Y/N	
Road Type:	Permanent Seasonal Temporary		GPS Device:		
Location:	Lat:		Long:		

For office use only

	Initials	Date
Field Crew		
Rec.Agt		
Data Entry		
QA/QC		

Followup: ○ Crew performed repair ○ Notify Roads Dept ○ Notify NCRWQCB

COMPONENT	SUBCOMPONENT	PROBLEMS	EROSION TYPE CODE	ACTIVITY CODE	ESTIMATED DELIVERY VOLUME (YD3) CODE
SURFACE WATER MANAGEMENT	HYDROLOGIC CONNECTION	○ No problem ○ Water delivering via ditch ○ Water delivering via fillslope ○ Water delivering via road surface ○ Soil pipes ○ Ineffective rolling dip ○ Ineffective waterbar ○ Ineffective ditch out ○ Other			
	DITCH AND ROAD SURFACE	○ No problem ○ Ditch blocked ○ Discharging onto erodible fill ○ Discharging onto unstable area ○ DR culvert damaged or/blocked ○ Other			
	DRAINAGE FACILITIES	○ No problem ○ Damaged ○ Blocked ○ Other			
ROAD PRISM	SURFACING	○ No problem ○ Rutting ○ Standing water ○ Soft ○ Tension Cracks ○ Other			
	INLET FILLSLOPE	○ No problem ○ Tension cracks or eroding fill ○ Armoring not functioning ○ Other			
	OUTLET FILLSLOPE	○ No problem ○ Tension cracks or eroding fill ○ Armoring not functioning ○ Other			
CULVERT	CULVERT CONDITION	○ No problem ○ Crushed ○ Rust holes ○ Other			
	CULVERT INLET	○ No problem ○ Capacity exceeded, undersized ○ Blockage ○ Undercutting/flow ○ Other			
	CULVERT OUTLET	○ No problem ○ Downspout damaged or altered ○ Erosion below outfall ○ Other			
STREAM CHANNEL	STREAM STABILIZATION	○ No problem ○ Insufficient channel armoring ○ Nickpoint failing ○ Banks eroding ○ Floatable material ○ Other			
EROSION CONTROL	RMZ (All areas except for road surfaces and cutslopes >65%)	○ No problem ○ Bare soil in hydro connect ○ Bare soil in topo connect ○ Bare soil outside topo connect ○ Other			

Erosion

<u>EROSION TYPE CODE</u>

None (1)
Surface erosion (2)
Rilling (3)
Gullying (4)
Headcutting (5)
Downcutting (6)
Undercutting (7)
Bank Erosion (8)
Sloughing (9)
Slope failure (10)

<u>ACTIVITY CODE</u>

None (1)
Active (2)
Imminent (3)

<u>ESTIMATED DELIVERY VOLUME (yd^3)</u>

None (1)
<1 (2)
1-5 (3)
6-50 (4)
>50 (5)

<u>TOTAL DELIVERY VOLUME (yd^3)</u>

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Use back of form for c comments.

Effective Date: December 27, 2011

Humboldt Redwood
COMPANY, LLC

DS-35-02-CLOSED XING **BMPEP Wet Weather Inspection Form**

CLOSED CROSSING

Site ID#		Field Crew:	
Road		Date:	
Watershed		Weather: Rain Int Rain Part Cloudy Clear	Photos: Y/N
Road Type:	Closed Decommissioned Temporary	GPS Device:	
Location:	Lat:	Long:	

For office use only

	Initials	**Date**
Field Crew		
Rec.Agt		
Data Entry		
QA/QC		

Followup: ○ Crew performed repair ○ Notify Roads Dept ○ Notify NCRWQCB

COMPONENT	SUBCOMPONENT	PROBLEMS	EROSION TYPE CODE	ACTIVITY CODE	ESTIMATED DELIVERY VOLUME (YD3) CODE
EXCAVATED CHANNEL	TOP TRANSITION	○ No problem ○ Oversteepend transition ○ Lack of armoring ○ Other			
	BOTTOM TRANSITION	○ No problem ○ Oversteepend transition ○ Lack of armoring ○ Other			
	ALIGNMENT	○ No problem ○ Channel not at natural grade ○ Oversteepend segment within project area. ○ Excavation does not achieve natural channel width. ○ Stream diverted into erodible banks ○ Other			
	CHANNEL BED	○ No problem ○ Channel bed erosion ○ Lack of armoring along channel ○ Other			
	CHANNEL BANKS	○ No problem ○ Lack of armoring where required ○ Other			
	OVERALL REMOVAL FROM CHANNEL	○ No problem ○ Not enough fill removed ○ Too much fill removed ○ Other			
	SIDESLOPES	○ No problem ○ Over steepened slopes ○ Insufficient slope support ○ Lack of armoring ○ Mass wasting feature present ○ Other			
EROSION CONTROL	RMZ (All areas except for road surfaces and cutslopes >65%)	○ No problem ○ Bare soil in hydro connect ○ Bare soil in topo connect ○ Other			
SPOILS/ HAZARDOUS WASTE	DISPOSAL	○ No problem ○ Spoils/Waste in RMZ ○ Spoils/Waste delivering ○ Spoils/Waste perched near stream. ○ Other			
TOPO-CONNECT	ROAD DRAINAGE	○ No problem ○ Drainage facilities delivering to unstable areas ○ Ditches delivering water into project area ○ Other			

Erosion

EROSION TYPE CODE

None (1)
Surface erosion (2)
Rilling (3)
Gullying (4)
Headcutting (5)
Downcutting (6)
Undercutting (7)
Bank Erosion (8)
Sloughing (9)
Slope failure (10)

ACTIVITY CODE

None (1)
Active (2)
Imminent (3)

ESTIMATED DELIVERY VOLUME (yd^3)

None (1)
<1 (2)
1-5 (3)
6-50 (4)
>50 (5)

TOTAL DELIVERY VOLUME (yd^3)

____

Use back of form for comments.

Effective Date: December 27, 2011

Humboldt Redwood
COMPANY, LLC

DS-35-03-ALL ROAD SEGMENTS **BMPEP Wet Weather Inspection Form** **ALL ROAD SEGMENTS**

Site ID#		Field Crew:	
Road		Date:	
Watershed		Weather: Rain Int Rain Part Cloudy Clear	Photos: Y/N
Road Type:	Permanent Seasonal Temporary Closed Decommissioned		
Location:	Lat:	Long:	GPS Device:

For office use only

	Initials	Date
Field Crew		
Rec.Agt		
Data Entry		
QA/QC		

Followup: ○ Crew performed repair ○ Notify Roads Dept ○ Notify NCRWQCB

COMPONENT	SUBCOMPONENT	PROBLEMS	EROSION TYPE CODE	ACTIVITY CODE	ESTIMATED DELIVERY VOLUME (YD3) CODE
DRAINAGE	DRAINAGE FACILITIES	○ No problem ○ Soil pipes ○ Ineffective rolling dip ○ Ineffective waterbar ○ Ineffective ditch out ○ Ineffective relief culvert ○ Ditch blocked ○ Gullying within ditch. ○ Damaged ○ Blocked ○ Other			
	DRAINAGE LOCATION	○ No problem ○ Discharging onto erodible fill ○ Gully along fill or road prism ○ Gully extending beyond fill ○ Channel leading to watercourse. ○ Discharging onto unstable area ○ Other			
ROAD PRISM	STABILITY	○ No problem ○ Tension cracks or eroding fill ○ Failing road prism ○ Other			
HYDRO-CONNECTED ROADS	DELIVERY	○ Water delivering via ditch ○ Water delivering via fillslope ○ Water delivering via road surface			
	SURFACING	○ No problem ○ Rutting ○ Standing water ○ Soft ○ Untreated ○ Other			
SPOILS/ HAZARDOUS WASTE	RMZ	○ No problem ○ Spoils/waste delivering ○ Spoils/waste in RMZ. ○ Other			
EROSION CONTROL	RMZ (All areas except for road surfaces and cutslopes >65%)	○ No problem ○ Bare Soil ○ Other			

Erosion

EROSION TYPE CODE
None (1)
Surface erosion (2)
Rilling (3)
Gullying (4)
Sloughing (5)
Slope failure (6)

ACTIVITY CODE
None (1)
Active (2)
Imminent (3)

ESTIMATED DELIVERY VOLUME (yd$^{3)}$
None (1)
<1 (2)
1-5 (3)
6-50 (4)
>50 (5)

TOTAL DELIVERY VOLUME (yd$^{3)}$

____

Humboldt Redwood
COMPANY, LLC

Humboldt Redwood
COMPANY, LLC

Road Inventory/ Audit Form To Standard Permanent and Seasonal Road

Road:	Start-End:	Site Marker:	Audit Date:	Auditor:	Operator:
GPS Location	Lat:	Long:	Watershed:	Age at Audit: Newly Constructed/Reconstructed ☐ Existing ☐	
Road Type: Permanent ☐ Seasonal ☐	Site Type: Culvert Crossing ☐ Ford Crossing ☐ Road Segment ☐ Drainage facility ☐			Photos: Yes ☐ No ☐	

For office use only

	Initials	Date
Receiving Agent		
Data Entry		

COMPONENT	SUBCOMPONENT	CONSTRUCTION STANDARD	Standard Met?		Deviation				MAP Description/Comment
			Exceeds	Yes	Minor	Major	NA	MAP	
All Road Segments			Standard Met?		Deviation				
			Exceeds	Yes	Minor	Major	NA	MAP	MAP Description/Comment
Road Prism	Unstable Areas	○ No untreated unstable areas that can deliver to a water.	☐	☐	☐	☐	☐	☐	
Erosion Control	Area	○ All bare soil areas within RMZ are treated (Exception: Road surfaces and cutbanks) Bare Soil Area (L x W in feet) _______	☐	☐	☐	☐	☐	☐	
	Material	○ If straw mulch: complete coverage	☐	☐	☐	☐	☐	☐	
		○ If slash: packed or mashed into soil.	☐	☐	☐	☐	☐	☐	
Hazardous Material	House-keeping	○ No rubbish anywhere within riparian area	☐	☐	☐	☐	☐	☐	
		○ No hazardous material anywhere within riparian area	☐	☐	☐	☐	☐	☐	
Drainage Facilities	General	○ Permanent facilities are spaced according to Table 1	☐	☐	☐	☐	☐	☐	
		○ Flow from drainage facilities discharged to stable slopes	☐	☐	☐	☐	☐	☐	
		○ Flow from drainage facilities cannot reach a water	☐	☐	☐	☐	☐	☐	
	Inside Ditch	○ No diversion potential out of ditch	☐	☐	☐	☐	☐	☐	
	Ditch Relief Culvert	○ 18” diameter culvert or larger	☐	☐	☐	☐	☐	☐	
		○ Slope stabilized where discharged	☐	☐	☐	☐	☐	☐	
Hydrologically Connected Road Segments			Standard Met?		Deviation				
			Exceeds	Yes	Minor	Major	NA	MAP	MAP Description/Comment
Hydrologic Disconnect	Location	○ Left: Between crossing hinge and 100’ from culvert centerline	☐	☐	☐	☐	☐	☐	
		○ Right: Between crossing hinge and 100’ from culvert centerline	☐	☐	☐	☐	☐	☐	
	Type	Left: ☐ Rolling Dip ☐ Relief Culvert ☐ Waterbar	☐	☐	☐	☐	☐	☐	
		Right: ☐ Rolling Dip ☐ Relief Culvert ☐ Waterbar	☐	☐	☐	☐	☐	☐	
Diversion Prevention	Construction	○ Critical dip present	☐	☐	☐	☐	☐	☐	
		○ Inboard ditches draining away from inlet basin if culvert becomes plugged are blocked.	☐	☐	☐	☐	☐	☐	
Road Surfacing	Permanent	○ Constructed with competent material (rock)	☐	☐	☐	☐	☐	☐	
		○ Entire hydro connect area treated.	☐	☐	☐	☐	☐	☐	
	Seasonal/ Temporary	○ Road is rocked, slash-packed or mulched	☐	☐	☐	☐	☐	☐	
		○ Entire hydro connect area treated.	☐	☐	☐	☐	☐	☐	

Culvert Crossing ☐ Size: ______in. Type: ☐ Steel ☐ Aluminum ☐ Single Walled Plastic ☐ Double Walled Plastic ☐ Other_________ Design: ☐ Standard ☐ Arch

Trash Rack: ☐ Yes ☐ No

			Standard Met?		Deviation				
			Exceeds	**Yes**	**Minor**	**Major**	**NA**	**MAP**	**MAP Description/Comment**
Stream channel	Channel Grade	○ If upstream nickpoint, armored	☐	☐	☐	☐	☐	☐	
		○ If downstream nickpoint, armored	☐	☐	☐	☐	☐	☐	
		○ Equal or greater than upstream channel width entering ROW	☐	☐	☐	☐	☐	☐	
		○ Channel bed material stable	☐	☐	☐	☐	☐	☐	
		○ All floatable wood upstream of culvert inlet, below high water mark removed	☐	☐	☐	☐	☐	☐	
	Cut Banks	○ Slopes less than 2:1 (50%) or natural grade.	☐	☐	☐	☐	☐	☐	
		○ If armored, material large enough to remain in place in design storm is used	☐	☐	☐	☐	☐	☐	
Road Prism	Armoring	○ Inlet and outlet armored with rip rap or LWD to top of culvert	☐	☐	☐	☐	☐	☐	
		○ Inlet wing wall armor extends around to the excavated cutbanks	☐	☐	☐	☐	☐	☐	
Culvert	Size	○ Can accommodate 100-year storm flow	☐	☐	☐	☐	☐	☐	
	Alignment	○ Aligned with center of road prism and parallel (within 15°) with channel midline	☐	☐	☐	☐	☐	☐	
		○ Upstream end even or below grade	☐	☐	☐	☐	☐	☐	
	Fish Passage	○ Fish passage is allowed at all flows	☐	☐	☐	☐	☐	☐	
		○ Culvert is either embedded 40% inlet or an arch type	☐	☐	☐	☐	☐	☐	
		○ Slope is less than 0%	☐	☐	☐	☐	☐	☐	
		○ The minimum culvert width is > than 1.5 times the active channel width	☐	☐	☐	☐	☐	☐	
	Extension	○ Extends 3' past fill on upstream side	☐	☐	☐	☐	☐	☐	
		○ Extends 5' past fill on downstream side	☐	☐	☐	☐	☐	☐	
	Dissipation	○ Sufficient dissipation at culvert outlet	☐	☐	☐	☐	☐	☐	
	Downspout	○ Downspouts are securely coupled, staked and anchored at intervals no greater than 10 feet	☐	☐	☐	☐	☐	☐	
		○ Half round downspouts are one size larger than the culvert	☐	☐	☐	☐	☐	☐	
		○ Downspout couple is attached to culvert by bolting and chaining.	☐	☐	☐	☐	☐	☐	

Ford Crossing ☐ General ☐ Vented ☐

			Standard Met?		Deviation				
			Exceeds	**Yes**	**Minor**	**Major**	**NA**	**MAP**	**MA Description/Comment**
Road Surface	Material and extent	○ Surface the road with at least 4-inch rock to at least 6 in depth and at least 5 times the channel width	☐	☐	☐	☐	☐	☐	
		○ Surface hydrologically connected approaches with clean, screened gravel.	☐	☐	☐	☐	☐	☐	
		○ Surface is not saturated	☐	☐	☐	☐	☐	☐	
Dip	Size	○ Critical dips can accommodate 100-year storm flow	☐	☐	☐	☐	☐	☐	
Fill face	Material	○ Base rock is 6-24 inch with a mean diameter of 12 inches	☐	☐	☐	☐	☐	☐	
		○ Contains a mixture of rock size to fill voids within base rock	☐	☐	☐	☐	☐	☐	
	Keyway	○ If slope greater than 50%, keyway constructed at bottom of fill	☐	☐	☐	☐	☐	☐	
		○ Keyway constructed at least 24 in. below the outfall stream grade	☐	☐	☐	☐	☐	☐	

Bridge Crossing ☐ Railcar ☐ Prefabricated ☐ Log Stringer ☐ Length: ______ ft Width _______ ft Bridge Decking: Wood ☐ Steel ☐

			Standard Met? Exceeds	Yes	Deviation Minor	Major	NA	MAP	MA Description/Comment
Span and Abutments	Fill	Armoring up to 100-yr flood or edge of the terrace or bench the bridge rests on: ○ Present for bridge abutments and piers	☐	☐	☐	☐	☐	☐	
	Abutment grade	○ Does not exceed 1:1 grade unless the abutment is bedrock.	☐	☐	☐	☐	☐	☐	
Approaches	Freeboard	○ Exceeds 100-year flood levels.	☐	☐	☐	☐	☐	☐	
	Grade	○ When approaches are less than 5% slope, bridge is lifted above road grade, so that approaches drain away from bridge surface.	☐	☐	☐	☐	☐	☐	
Safety	Guard Rails	○ Present along entire bridge	☐	☐	☐	☐	☐	☐	

Table 1. Maximum suggested spacing for permanent drainage facilities (ft)

Road Grade %	Spacing (ft)
2	600-800
4	530
6	355
8	265
10	160
12	180
14	155
16	135
18	118

Humboldt Redwood
COMPANY, LLC

Road Inventory/ Audit Form To Standard Temporary, Closed and Decommissioned Road

Road:	Start-End:	Site Marker:	Audit Date:	Auditor:	Operator:
GPS Location	Lat:	Long:	Watershed:	Age at Audit: Newly constructed/Reconstructed ☐ Existing ☐	
Road Type: Temporary☐ Closed ☐ Decommissioned ☐	Site Type: Closed Crossing ☐ Road Segment ☐	Photos: Yes ☐ No ☐			

For office use only

	Initials	Date
Receiving Agent		
Data Entry		

COMPONENT	SUBCOMPONENT	CONSTRUCTION STANDARD	Standard Met?		Deviation				MAP Description/Comment
			Exceeds	Yes	Minor	Major	NA	MAP	
All Road Segments			**Standard Met?**		**Deviation**				**MAP Description/Comment**
			Exceeds	**Yes**	**Minor**	**Major**	**NA**	**MAP**	
Right of Way	Erosion Control	○ All bare soil areas within RMZ are treated	☐	☐	☐	☐	☐	☐	
		○ If straw mulch: 2-4” thick	☐	☐	☐	☐	☐	☐	
		○ If slash: packed or mashed into soil	☐	☐	☐	☐	☐	☐	
	House Keeping	○ Rubbish, debris, soil, cement or concrete washings	☐	☐	☐	☐	☐	☐	
		○ Hazardous material	☐	☐	☐	☐	☐	☐	
	Unstable Areas	○ No unstable areas which could deliver sediment to a water are present	☐	☐	☐	☐	☐	☐	
Road Drainage	Contouring	○ Drainage patterns are reestablished	☐	☐	☐	☐	☐	☐	
		○ Roads outsloped (Decommissioned Roads Only)	☐	☐	☐	☐	☐	☐	
	Spacing	○ Water is dispersed off road every 100 feet or less.	☐	☐	☐	☐	☐	☐	
	Cross Drains	○ No relief culverts	☐	☐	☐	☐	☐	☐	
		○ No berms	☐	☐	☐	☐	☐	☐	
		○ No inside ditches	☐	☐	☐	☐	☐	☐	
		○ Drains extend from the cut bank to outboard edge	☐	☐	☐	☐	☐	☐	
		○ Cross drains are skewed	☐	☐	☐	☐	☐	☐	
	Diversion Location	○ Flow from cross drains do not channelize to unstable area.	☐	☐	☐	☐	☐	☐	
		○ Flow from cross drains cannot reach a water.	☐	☐	☐	☐	☐	☐	
		○ If flow from drainage facilities is unavoidable isolation measures are used.	☐	☐	☐	☐	☐	☐	
	Skid Trails	○ Flow drains across skid trails below road.	☐	☐	☐	☐	☐	☐	
		○ Skid trails above road are disconnected	☐	☐	☐	☐	☐	☐	

Humboldt Redwood
COMPANY, LLC

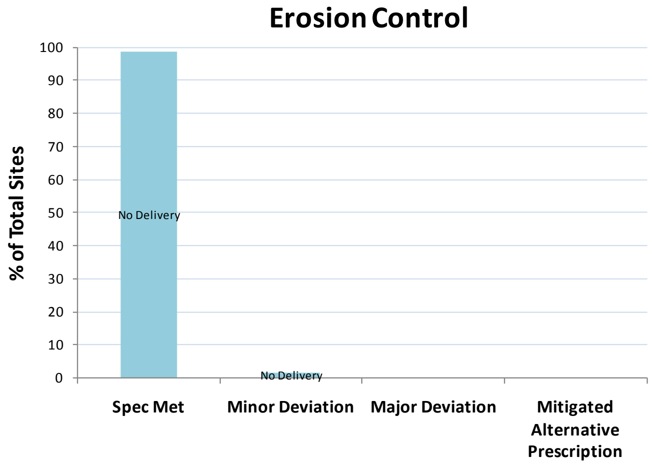
Road Inventory/ Audit Form To Standard Temporary, Closed and Decommissioned Road

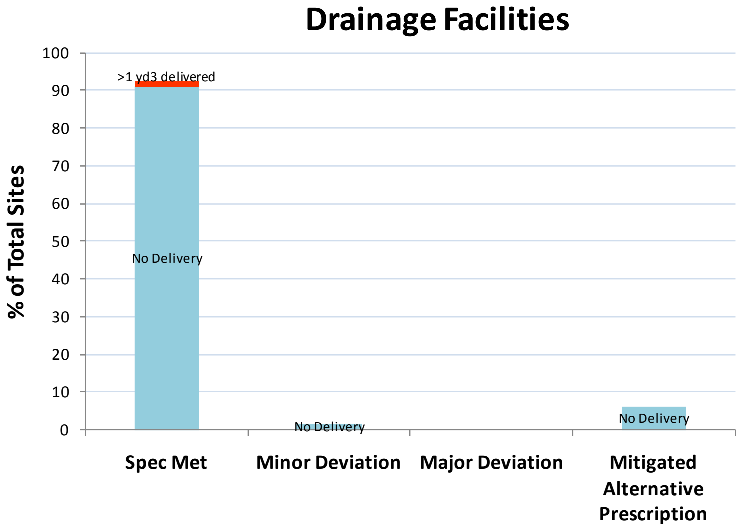
Closed Crossing ☐

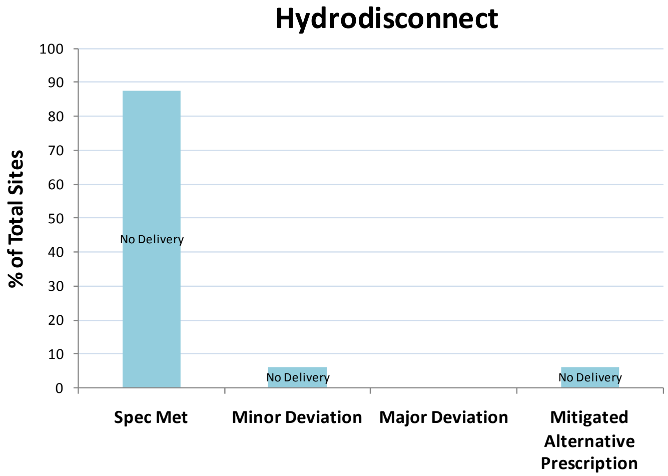
			Standard Met?		Deviation				
			Exceeds	**Yes**	**Minor**	**Major**	**NA**	**MAP**	**MAP Description/Comment**
Excavation	Cut Slopes	○ Slopes less than 2:1 (50%) or natural grade.	☐	☐	☐	☐	☐	☐	
	Fill Material	○ Slopes completely removed to 100-year flood ○ Unstable sidecast is removed.	☐ ☐	☐ ☐	☐ ☐	☐ ☐	☐ ☐	☐ ☐	
	Stream Channel	○ Excavated to original channel bed ○ Excavated at or wider than natural channel (100-yr High water mark)	☐ ☐	☐ ☐	☐ ☐	☐ ☐	☐ ☐	☐ ☐	
	Transition	○ Not overexcavated at upstream transition ○ No overexcavated at downstream transition	☐ ☐	☐ ☐	☐ ☐	☐ ☐	☐ ☐	☐ ☐	
	Alignment	○ Mimics natural channel	☐	☐	☐	☐	☐	☐	
Stream Channel	Channel Gradient	○ Gradient is at even grade or concave	☐	☐	☐	☐	☐	☐	
	Channel bed	○ Excavated channel bed stable	☐	☐	☐	☐	☐	☐	
	Channel	○ Nick points upstream and downstream of the channel are armored. ○ In areas where the channel bed is not defined, wood chunks are buried below stream grade to prevent down cutting.	☐ ☐	☐ ☐	☐ ☐	☐ ☐	☐ ☐	☐ ☐	
	Banks and Slopes Within High Water Mark	○ Lower slopes are stabilized from flow ○ Armoring is present where banks and slopes are greater than 2:1 or natural, or unstable areas exist. ○ Armoring is present where stream banks may be undermined by flow.	☐ ☐ ☐	☐ ☐ ☐	☐ ☐ ☐	☐ ☐ ☐	☐ ☐ ☐	☐ ☐ ☐	
	Approaches	○ Where ATV's will use excavated water crossings, ATV log bridges or approaches are rocked	☐	☐	☐	☐	☐	☐	

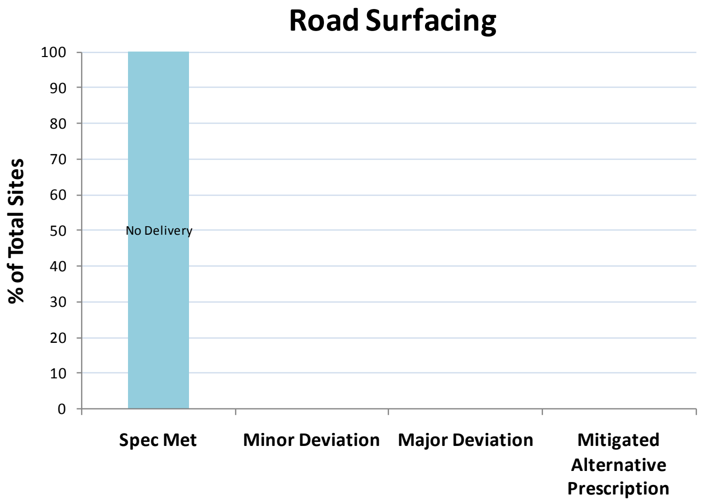
Appendix C. Road Effectiveness Figure

Appendix C. Percent implementation of UPGRADED CULVERT crossings specifications grouped by component in relation to % of sites which delivered sediment during the first winter following construction.

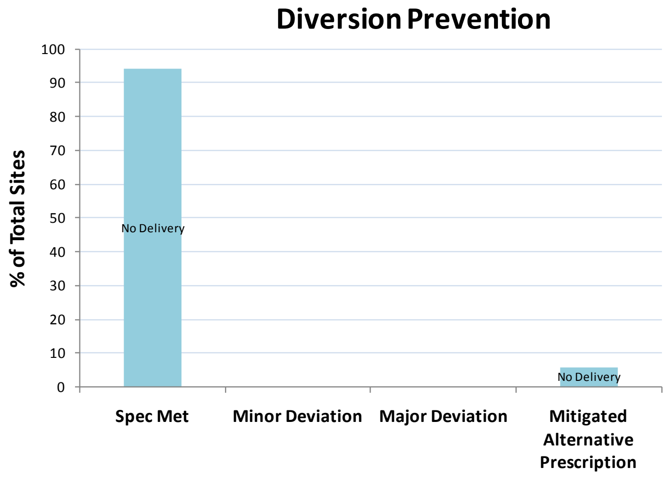


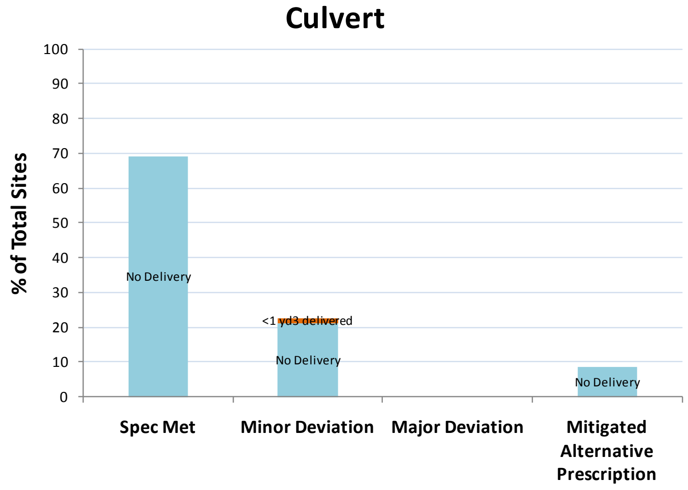


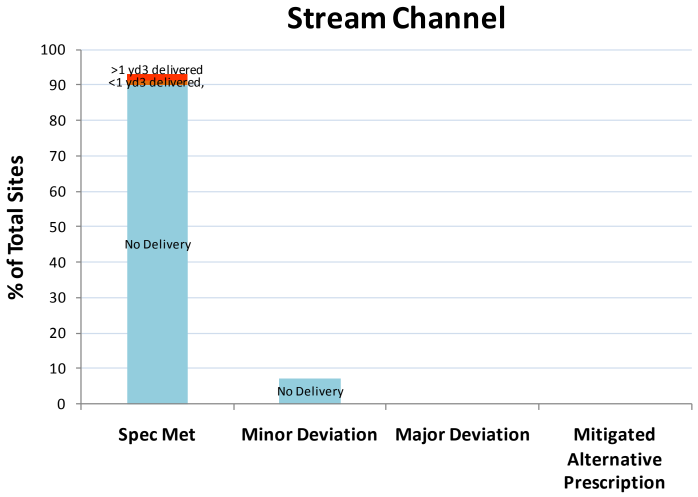


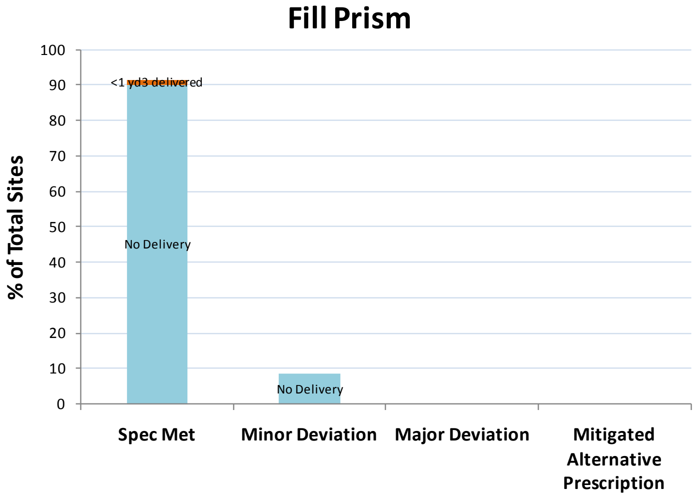


Appendix C. Continued – Upgraded crossings.



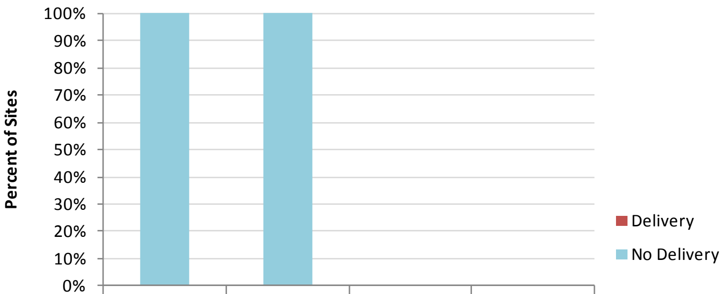






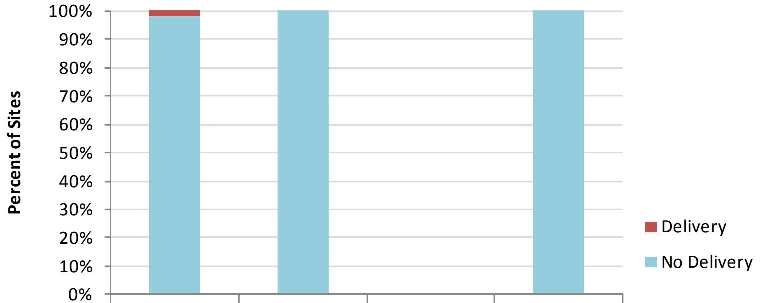
Appendix C. Marginal probabilities by implementation status for four construction components of UPGRADED CULVERT crossings.

Erosion Control



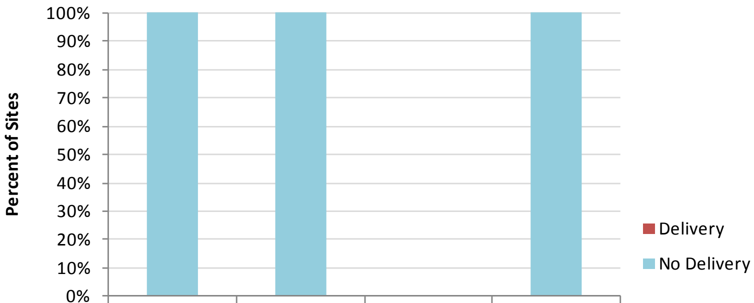
	Spec Met	Minor Deviation	Major Deviation	Mitigated Alternative Prescription
Delivery	0	0	0	0
No Delivery	69	1	0	0

Drainage Facilities



	Spec Met	Minor Deviation	Major Deviation	Mitigated Alternative Prescription
Delivery	1	0	0	0
No Delivery	60	1	0	4

Hydrodisconnect

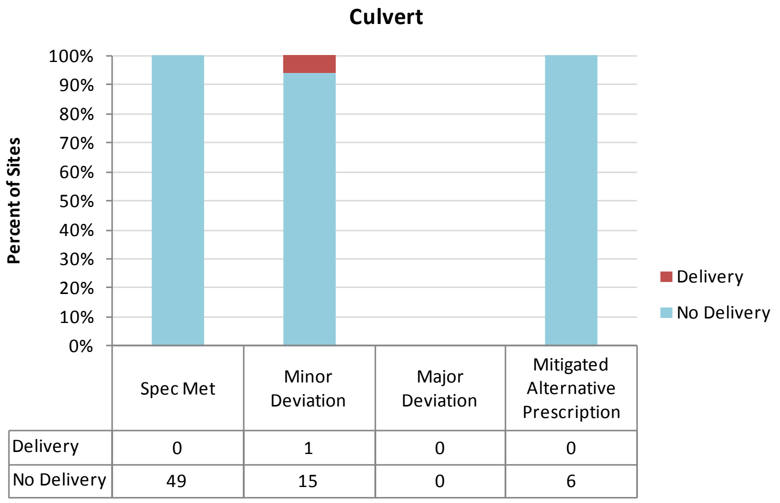


	Spec Met	Minor Deviation	Major Deviation	Mitigated Alternative Prescription
Delivery	0	0	0	0
No Delivery	57	4	0	4

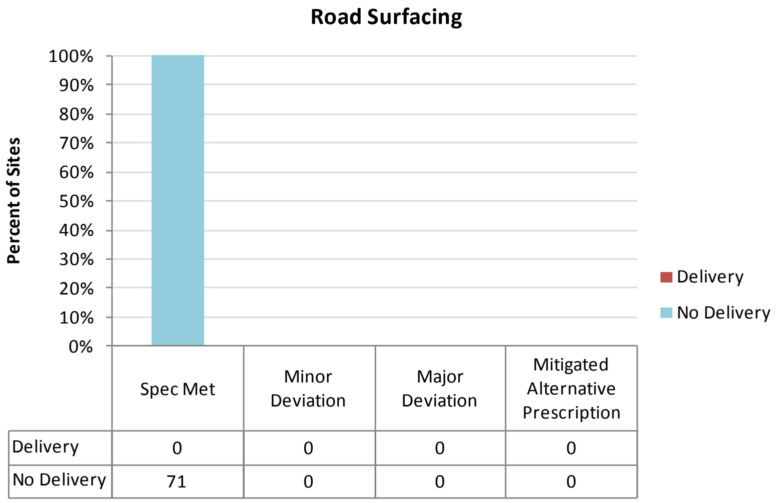
Diversion Prevention

	Spec Met	Minor Deviation	Major Deviation	Mitigated Alternative Prescription
Delivery	0	0	0	0
No Delivery	64	0	0	4

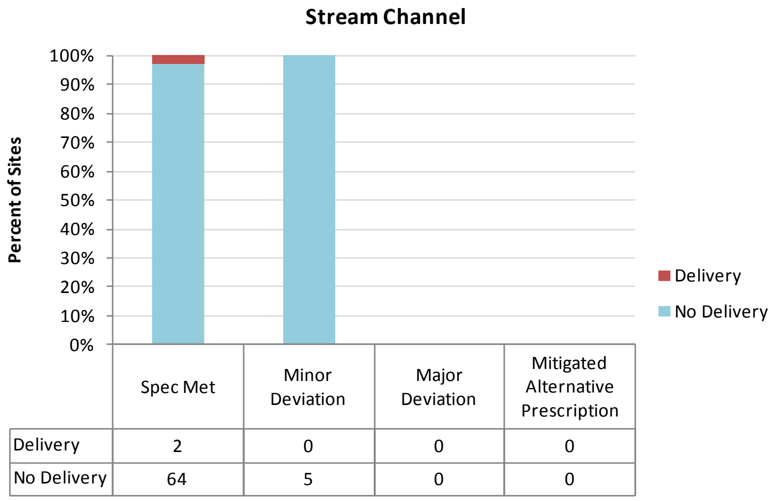
Appendix C. Continued – Upgraded crossings.



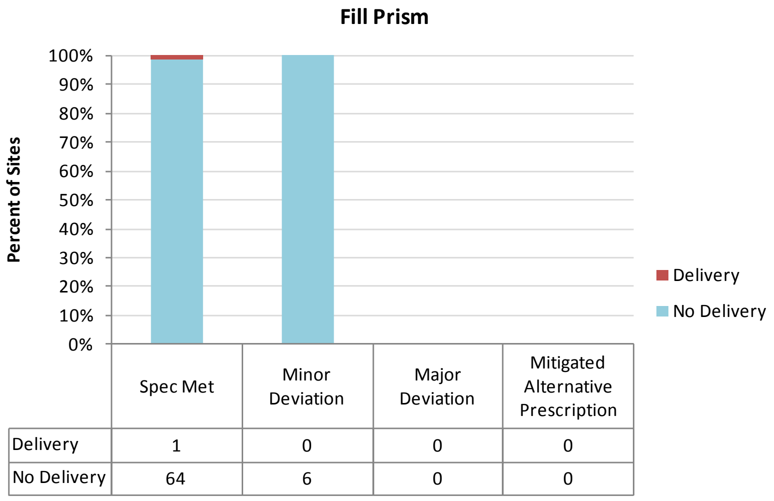
	Spec Met	Minor Deviation	Major Deviation	Mitigated Alternative Prescription
Delivery	0	1	0	0
No Delivery	49	15	0	6



	Spec Met	Minor Deviation	Major Deviation	Mitigated Alternative Prescription
Delivery	0	0	0	0
No Delivery	71	0	0	0

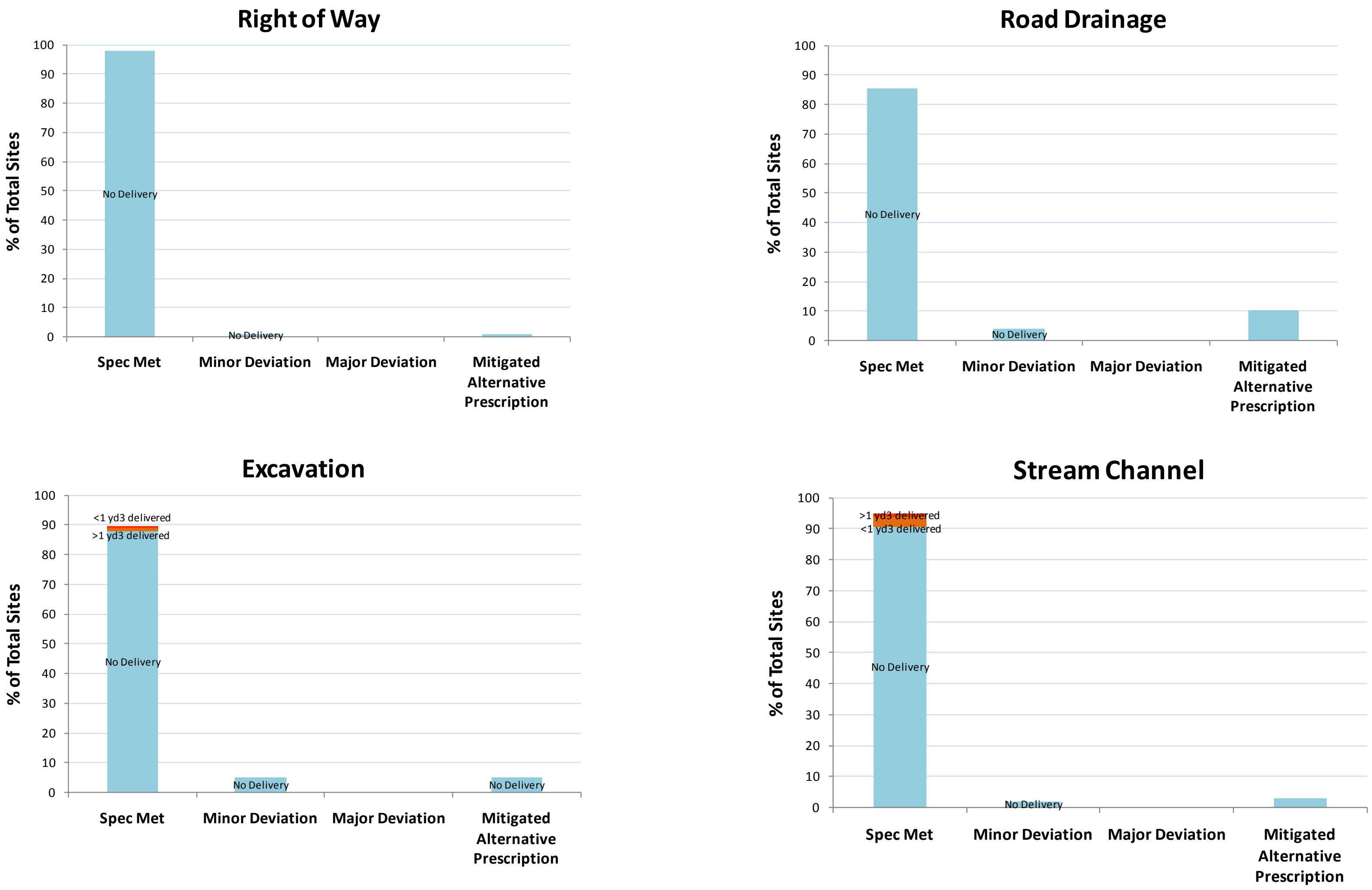


	Spec Met	Minor Deviation	Major Deviation	Mitigated Alternative Prescription
Delivery	2	0	0	0
No Delivery	64	5	0	0

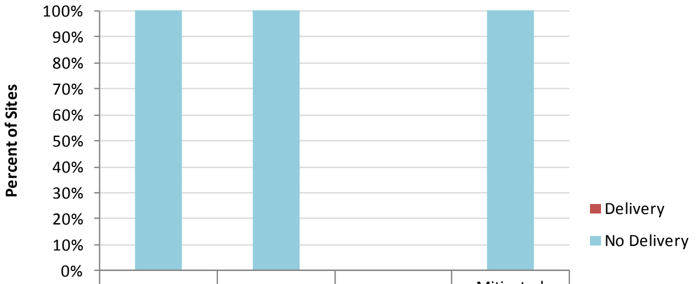


	Spec Met	Minor Deviation	Major Deviation	Mitigated Alternative Prescription
Delivery	1	0	0	0
No Delivery	64	6	0	0

Appendix C. Percent implementation of CLOSED CROSSINGS specifications grouped by component in relation to % of sites which delivered sediment during the first winter following construction.

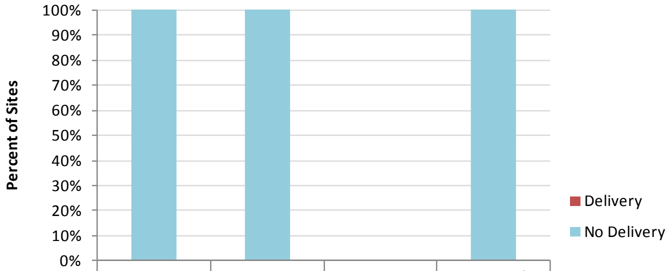


Appendix C. Marginal probabilities by implementation status for four construction components of CLOSED crossings.



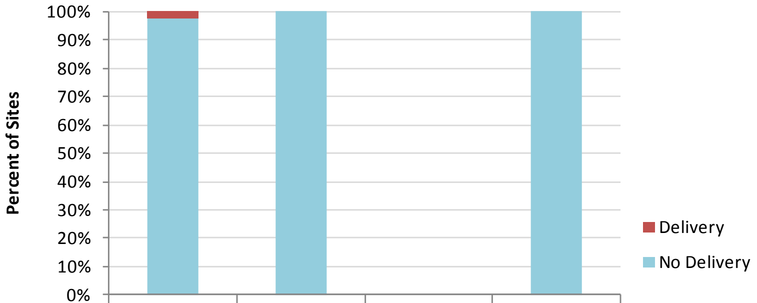
Right of Way

	Spec Met	Minor Deviation	Major Deviation	Mitigated Alternative Prescription
Delivery	0	0	0	0
No Delivery	95	1	0	1



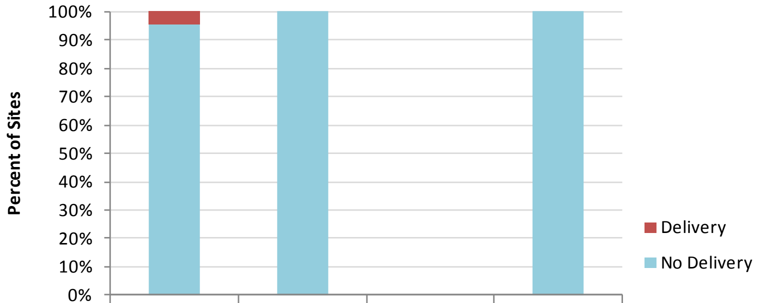
Road Drainage

	Spec Met	Minor Deviation	Major Deviation	Mitigated Alternative Prescription
Delivery	0	0	0	0
No Delivery	83	4	0	10



Excavation

	Spec Met	Minor Deviation	Major Deviation	Mitigated Alternative Prescription
Delivery	2	0	0	0
No Delivery	86	5	0	5



Stream Channel

	Spec Met	Minor Deviation	Major Deviation	Mitigated Alternative Prescription
Delivery	4	0	0	0
No Delivery	89	2	0	3

APPENDIX 4

Oswald Landslide Report

				ds=Debris Slide df=Debris flow tr=translational/rotational ef=earthflow	0=No 1=Yes	bis=break in slope ds=deep seated dss=debris slide slope hw= headwall pl=planar ss=streamside slope sw=swale channel				D=deep (12ft) S=shallow (5ft)		Yes/No	1,2,3 or NA (not applic.)	ah=abandoned haul as=abandoned skid trail ph=primary haul sh=secondary haul na=not applicable	Year banked NA=not applicable (not rd related) 0=not stormproofed	Y,N or NA	cc=cable clearcut mpc=moderate partial cut cable os=open slope rcb=rd location cutbank rd=road, no differentiation rrf=road location fill rlf=road location landing fill rxf=road crossing fill sk=skid related tc=tractor clearcut no=no management	<10 years 10-20 years >20 years		fld=field verified			Oswald regression formula calc.	Convert to cubic yards	OFFICIAL DELIVERY VOLUME (from formula or field verification)
SLIDEID	**Photo Year**	**AP #**	**Subbasin**	**Failure Mode**	**Reactivation Status**	**Geomorphic Association**	**AP Width (ft)**	**AP Length (ft)**	**AP Slide Area (ft^2)**	**Depth**	**runout (ft)**	**Delivery**	**stream class**	**road type**	**SPR banked**	**SPR fail**	**Landuse Association**	**Aerial Est. Stand Age**	**Volume Displaced (yd^3)**	**% del est.**	**Calc. % delivery**	**Prelim. Volume Delivered (yd^3)**	**area-volume Calc**	**convert vol cu. yds**	**Delivery Amt. (cu.yds)**
79	2003	13:58,59	Cloney Gulch	tr	0	hw	50	200	7854	S	100	Y	3	ah	2007	N	rd	>20	1047	fld	30%	314	33377	1236	314
232	2003	12-58	Cloney Gulch	ds	0	sw	25	50	982	S	25	N	na	sh	0	N	rrf	<10	310	fld	0%	0	2709	100	0
233	2003	12-58	Cloney Gulch	ds	0	ss	25	50	982	S	0	Y	3	na	NA	NA	mpc	<10	121	15%	15%	18	2709	100	15
234	2003	12-58	Cloney Gulch	tr	0	ds	25	25	491	S	0	Y	3	sh	2000	Y	rcb	<10	265	fld	5%	13	1173	43	13
754	2006	13-55	Cloney Gulch	ds	1	ss	50	50	1963	S	50	Y	2	ah	0	N	rrf	>20	242	75%	75%	182	6257	232	174
228	2003	12-56	Graham Gulch	ds	0	ss	25	50	982	S	50	Y	3	sh	2002	Y	rrf	<10	233	fld	75%	175	2709	100	175
230	2003	12-57	Graham Gulch	tr	0	ss	75	50	2945	D	0	Y	1	sh	0	N	rd	>20	35	fld	11%	4	10209	378	4
231	2003	12-57	Graham Gulch	ds	1	hw	25	50	982	S	25	Y	3	ph	0	N	rrf	10-20	121	25%	25%	30	2709	100	25
268	2003	13-46	Graham Gulch	ef	1	ds	50	400	15708	D	200	Y	2	na	NA	NA	tc	<10	4654	10%	10%	465	77090	2855	465
269	2003	13-46	Graham Gulch	ds	1	dss	25	50	982	S	0	N	na	ph	0	N	rrf	<10	121	0%	0%	0	2709	100	0
270	2003	13-46	Graham Gulch	ds	1	dss	25	50	982	S	0	N	na	ph	0	N	rcb	10-20	121	0%	0%	0	2709	100	0
268	2006	14-52	Graham Gulch	ds	1	ds	25	50	982	S	0	Y	3	na	NA	NA	os	10-20	121	85%	85%	103	2709	100	85
691	2006	13-53	Graham Gulch	df	1	bis	25	50	982	S	200	Y	1	sh	0	N	rrf	>20	121	25%	25%	30	2709	100	25
26	2003	12:53,54	Little Freshwater	tr	1	ss	100	175	13744	D	0	Y	3	na	NA	NA	cc	10-20	109	fld	100%	109	65609	2430	109
78	2003	10-52,53	Little Freshwater	ds	1	ss	12	20	188	S	0	N	3	as	NA	NA	mpc	<10	18	fld	0%	0	369	14	0
122	2003	12:52, 53	Little Freshwater	df	0	hw	40	200	6283	S	150	N	na	ph	1998	Y	rlf	10-20	1005	fld	0%	0	25492	944	0
168	2003	10-54	Little Freshwater	ds	1	ss	75	50	2945	S	50	Y	3	ph	2000	Y	rrf	>20	2212	fld	10%	221	10209	378	221
169	2003	10-54	Little Freshwater	df	0	ss	75	50	2945	S	150	Y	3	ah	2001	Y	rxf	<10	201	fld	75%	151	10209	378	151
170	2003	10-54	Little Freshwater	tr	0	hw	25	50	982	S	0	Y	3	sh	1997	Y	rcb	>20	74	fld	9%	7	2709	100	7
171	2003	10-54	Little Freshwater	ds	1	bis	25	50	982	S	50	N	na	as	1997	Y	rcb	>20	97	fld	0%	0	2709	100	0
172	2003	10-56	Little Freshwater	ds	1	bis	75	100	5890	S	200	Y	2	as	NA	NA	mpc	<10	727	25%	25%	182	23581	873	218
205	2003	11-54	Little Freshwater	ds	1	ss	25	25	491	S	0	N	3	na	NA	NA	cc	<10	61	0%	0%	0	1173	43	0
206	2003	11-54	Little Freshwater	ds	1	hw	25	25	491	S	0	N	na	na	NA	NA	cc	<10	244	fld	0%	0	1173	43	0
207	2003	11-55	Little Freshwater	ds	1	hw	25	25	491	S	50	Y	3	sh	1997	Y	rrf	10-20	140	fld	10%	14	1173	43	14
209	2003	11-57	Little Freshwater	ds	1	bis	25	25	491	S	0	Y	3	sh	1997	Y	rxf	<10	42	fld	100%	42	1173	43	42
210	2003	11-57	Little Freshwater	tr	0	pl	25	25	491	S	0	N	na	sh	1997	Y	rcb	<10	67	fld	0%	0	1173	43	0
212	2003	11-57	Little Freshwater	ds	1	pl	25	25	491	S	0	N	na	na	NA	NA	cc	10-20	61	0%	0%	0	1173	43	0
213	2003	11-57	Little Freshwater	ds	1	ss	25	50	982	S	25	Y	2	na	NA	NA	cc	10-20	121	15%	15%	18	2709	100	15
214	2003	11-58	Little Freshwater	ds	1	ds	50	75	2945	S	200	Y	2	na	NA	NA	tc	<10	364	10%	10%	36	10209	378	38
323	2003	11-56,57	Little Freshwater	ds	0	sw	40	50	1571	S	50	Y	3	ah	1997	Y	rxf	<10	194	85%	85%	165	4779	177	150
172	2006	11-52	Little Freshwater	ds	1	sw	50	25	982	S	0	N	na	as	NA	NA	rd	10-20	121	0%	0%	0	2709	100	0
409	2006	13-50	Little Freshwater	ds	0	bis	50	75	2945	S	100	Y	3	sh	1997	Y	rlf	<10	364	50%	50%	182	10209	378	189
743	2006	11-52	Little Freshwater	ds	0	pl	50	25	982	S	0	N	na	na	NA	NA	tc	<10	121	0%	0%	0	2709	100	0
745	2006	13-49	Little Freshwater	tr	1	bis	25	25	491	S	0	N	na	sh	1997	Y	rcb	<10	61	0%	0%	0	1173	43	0
746	2006	13-49	Little Freshwater	ds	0	bis	10	50	393	S	100	N	na	as	NA	NA	sk	<10	48	0%	0%	0	896	33	0
748	2006	13-50	Little Freshwater	ds	1	hw	25	25	491	S	75	N	na	ph	1997	Y	rrf	10-20	61	0%	0%	0	1173	43	0
751	2006	13-53	Little Freshwater	tr	0	bis	50	50	1963	S	0	N	na	ah	1998	Y	rrf	10-20	242	0%	0%	0	6257	232	0
762	2006	13-49	Little Freshwater	df	1	bis	50	75	2945	S	100	Y	2	as	1997	Y	rlf	<10	364	25%	25%	91	10208	378	95
704	2010	13-51	Little Freshwater	df	0	ss	100	100	7854	S	100	Y	3	sh	2000	Y	rrf	>20	970	fld	33%	320	33377	1236	320
705	2010	13-52	Little Freshwater	ds	1	ss	25	25	491	S	0	Y	2	na	NA	NA	no	>20	61	10%	10%	6	1173	43	4
409	2010	15-49	Little Freshwater	ds	1	bis	25	25	491	S	0	Y	3	sh	1997	Y	rlf	10-20	61	10%	10%	6	1173	43	4
752	2006	13-53	Mainstem	ds	1	ss	25	25	491	S	75	Y	1	na	NA	NA	os	>20	61	10%	10%	6	1173	43	4
753	2006	13-55	McCready Gulch	ds	0	ss	25	50	982	S	0	Y	3	sh	0	N	rrf	<10	121	50%	50%	61	2709	100	50
215	2003	11-59	McCready Gulch	ds	1	ss	25	25	491	S	0	Y	2	na	NA	NA	cc	<10	61	25%	25%	15	1173	43	11
216	2003	11-60	McCready Gulch	ds	1	ss	50	75	2945	S	25	Y	1	ah	1997	Y	rrf	<10	519	fld	30%	156	10209	378	156
76	2003	13:40-41	South Fork	ds	0	bis	30	60	1414	S	0	N	na	ph	1998	Y	rrf	<10	47	fld	0%	0	4208	156	0
77	2003	13:40,41	South Fork	tr	1	hw	100	140	10996	S	300	Y	3	ph	2000	Y	rrf	<10	433	fld	10%	43	50110	1856	43
264	2003	13-41	South Fork	tr	0	ds	50	75	2945	S	0	N	na	na	NA	NA	mpc	>20	364	0%	0%	0	10209	378	0
265	2003	13-41	South Fork	tr	0	bis	50	75	2945	S	0	N	na	sh	2000	Y	rcb	<10	67	fld	0%	0	10209	378	0
747	2006	13-50	South Fork	ds	0	hw	75	100	5890	S	200	Y	3	na	NA	NA	cc	<10	727	90%	90%	654	23581	873	654
749	2006	13-50	South Fork	ds	0	bis	50	50	1963	S	50	N	na	sh	1998	Y	rlf	10-20	242	0%	0%	0	6257	232	0
755	2006	14-47	South Fork	ds	0	ss	50	50	1963	S	50	Y	2	sh	2000	Y	rrf	>20	242	75%	75%	182	6257	232	174
756	2006	14-47	South Fork	ds	0	bis	25	25	491	S	25	N	na	sh	2000	Y	rrf	<10	61	0%	0%	0	1173	43	0
757	2006	14-49	South Fork	ds	0	hw	50	75	2945	S	150	Y	3	ph	1998	Y	rrf	>20	364	75%	75%	273	10209	378	284

				ds=Debris Slide df=Debris flow tr=translational/rotational ef=earthflow	*0=No 1=Yes*	*bis=break in slope ds=deep seated dss=debris slide slope hw= headwall pl=planar ss=streamside slope sw=swale channel*				*D=deep (12ft) S=shallow (5ft)*		*Yes/No*	*1,2,3 or NA (not applic.)*	*ah=abandoned haul as=abandoned skid trail ph=primary haul sh=secondary haul na=not applicable*	*Year banked NA=not applicable (not rd related) 0=not stormproofed*	*Y,N or NA*	*cc=cable clearcut mpc=moderate partial cut cable os=open slope rcb=rd location cutbank rd=road, no differentiation rrf=road location fill rlf=road location landing fill rxf=road crossing fill sk=skid related tc=tractor clearcut no=no management*	*<10 years 10-20 years >20 years*		*fld=field verified*			*Oswald regression formula calc.*	*Convert to cubic yards*	*OFFICIAL DELIVERY VOLUME (from formula or field verification)*
SLIDEID	**Photo Year**	**AP #**	**Subbasin**	**Failure Mode**	**Reactivation Status**	**Geomorphic Association**	**AP Width (ft)**	**AP Length (ft)**	**AP Slide Area (ft^2)**	**Depth**	**runout (ft)**	**Delivery**	**stream class**	**road type**	**SPR banked**	**SPR fail**	**Landuse Association**	**Aerial Est. Stand Age**	**Volume Displaced (yd^3)**	**% del est.**	**Calc. % delivery**	**Prelim. Volume Delivered (yd^3)**	**area-volume Calc**	**convert vol cu. yds**	**Delivery Amt. (cu.yds)**
227	2003	12-54	Upper Mainstem	ds	0	bis	75	75	4418	S	0	Y	3	ph	1998	Y	rrf	>20	679	fld	*50%*	339	16660	617	339
110	2003	14:44,45	Upper Mainstem	ds	1	ds	40	40	1257	S	0	Y	2	ah	0	N	rxf	<10	698	fld	*10%*	70	3650	135	70
208	2003	11-56	Upper Mainstem	ds	1	ss	50	25	982	S	0	Y	2	sh	2005	N	rxf	>20	144	fld	*65%*	94	2709	100	94
211	2003	11-57	Upper Mainstem	ds	1	pl	50	25	982	S	0	N	na	sh	1997	Y	rrf	>20	87	fld	*0%*	0	2709	100	0
229	2003	12-56	Upper Mainstem	ds	1	ds	25	25	491	S	100	Y	3	na	NA	NA	tc	>20	76	fld	*11%*	8	1173	43	8
266	2003	13-45	Upper Mainstem	ds	1	ss	200	75	11781	S	25	Y	1	na	NA	NA	mpc	>20	1454	25%	*25%*	364	54464	2017	504
267	2003	13-45	Upper Mainstem	tr	1	ss	50	50	1963	S	50	Y	1	na	NA	NA	mpc	<10	242	25%	*25%*	61	6257	232	58
290	2003	14-46	Upper Mainstem	ds	0	ds	25	25	491	S	0	N	na	na	NA	NA	mpc	>20	61	0%	*0%*	0	1173	43	0
322	2003	14,44,45	Upper Mainstem	tr	1	ds	120	140	13195	D	160	Y	2	na	NA	NA	cc	<10	3910	10%	*10%*	391	62453	2313	391
411	2003	13-43,44,45	Upper Mainstem	ds	0	ss	50	75	2945	S	0	Y	1	na	NA	NA	mpc	>20	364	75%	*75%*	273	10209	378	284
763	2003	13-43,44,45	Upper Mainstem	ds	1	ss	50	75	2945	S	0	Y	1	na	NA	NA	mpc	>20	364	75%	*75%*	273	10209	378	284
110	2006	15-42	Upper Mainstem	tr	1	ss	150	200	23562	D	0	Y	2	sh	0	N	rxf	10-20	6981	2%	*2%*	140	125796	4659	140
411	2006	15-41	Upper Mainstem	ds	1	ss	25	50	982	S	0	Y	1	na	NA	NA	mpc	>20	121	80%	*80%*	97	2709	100	80
750	2006	13-51	Upper Mainstem	ds	0	bis	25	50	982	S	75	Y	2	as	2000	Y	rrf	10-20	121	25%	*25%*	30	2709	100	25
758	2006	15-40	Upper Mainstem	tr	0	ss	50	25	982	S	0	Y	2	na	NA	NA	no	>20	121	50%	*50%*	61	2709	100	50
763	2006	13-43,44,45	Upper Mainstem	ds	1	ss	25	25	491	S	0	Y	1	na	NA	NA	mpc	>20	121	75%	*75%*	91	1173	43	33
744	2006	12-55	School Forest	ds	0	ss	25	50	982	S	50	Y	3	sh	0	N	rlf	10-20	121	50%	*50%*	61	2709	100	50
																									6659

APPENDIX 5

Sediment Production from Storm-proofed Roads

Humboldt Redwood
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Phone (707) 764-4392
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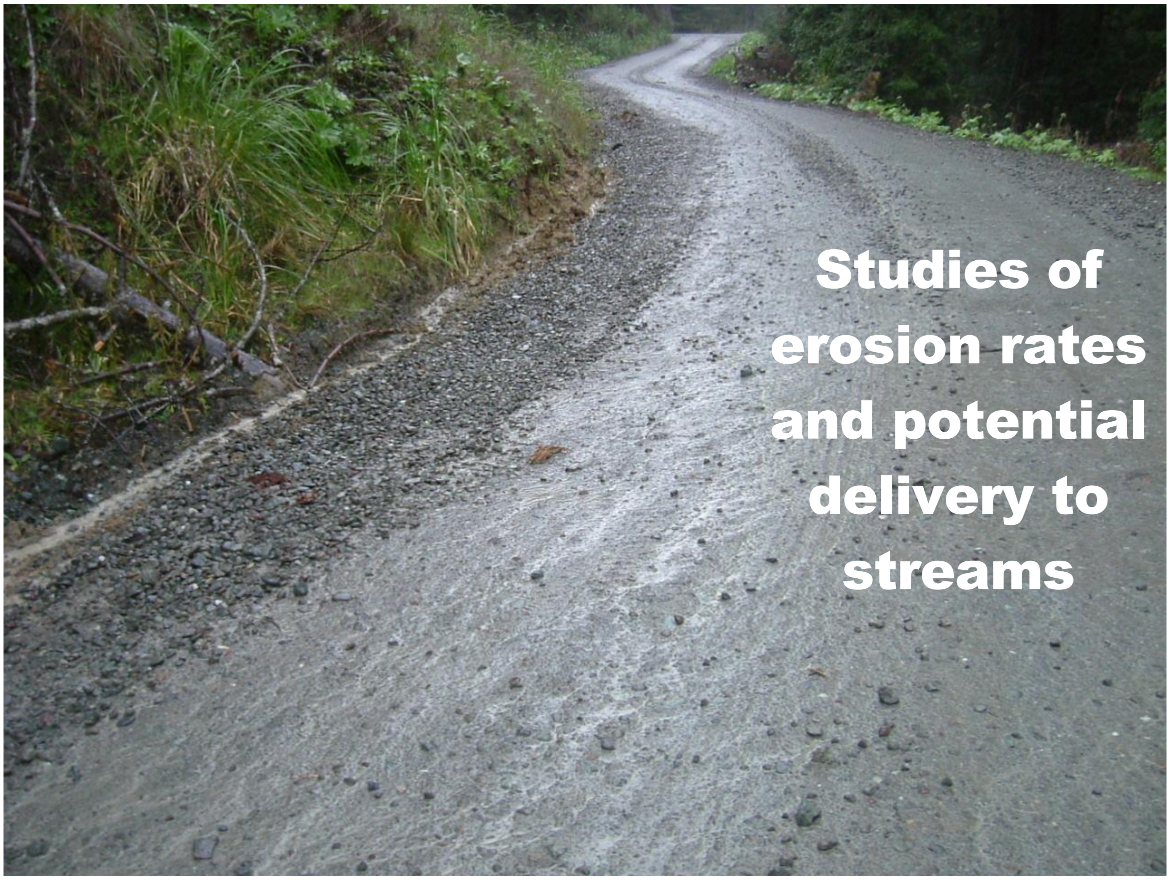
Sediment Production from Stormproofed Roads on Humboldt Redwood Company Lands



Studies of erosion rates and potential delivery to streams

October 2011

Humboldt Redwood
COMPANY, LLC

Sediment Production from Forest Roads on Humboldt Redwood Company Lands: Studies of Erosion rates and Potential Delivery to Streams

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Manual J. Kunz
Michael Medlin
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Kirsten Williams

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EXECUTIVE SUMMARY

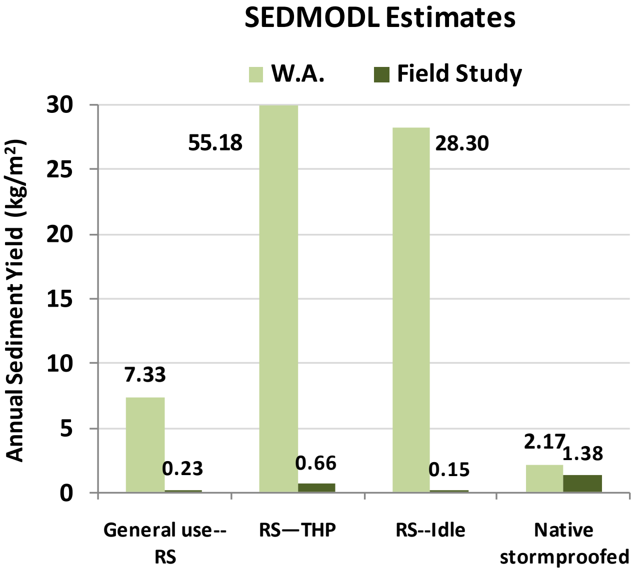
Forest roads are an important source of sediment on HRC property and a major focus of Habitat Conservation Plan strategies aimed at reducing timber management impacts on water quality and aquatic biota. The erosion rate from the road surfaces and the amount of road that is hydrologically connected to watercourses determines the how much sediment is delivered to streams from road surfaces locally and at the landscape scale. Both of these factors were considered in estimating the effect of the road network in Watershed Analysis of HRC property using a modeling approach. SEDMODL is a GIS application that finds road crossings in the existing road layers and estimates the length of road delivered to each. The road surface erosion engine within the GIS application is an empirical model developed by the Washington Department of Natural Resources that synthesized results from studies conducted throughout the Pacific Northwest over the past 30 years. The model estimates annual erosion for roads as a function of road characteristics including geologic substrate, traffic use, surfacing and cutslope conditions, all of which have been shown to influence the amount of sediment produced from a forest road. SEDMODL identifies the road segments that lie within 200 feet distance from a stream, and assumes that all road sediment generated within that area is delivered. The sediment model results are used in watershed sediment budgeting. Modeling of the "as is" roads on HRC lands as they existed prior to new stormproofing standards initiated with the HCP determined that road surface erosion is an important source of sediment in most watersheds and a dominant source in some. The studies described in this report were conducted to validate the sediment models and assumptions.

The objective of this project was to quantify the amount of sediment generated from HRC stormproofed roads by detailed measurement of the sediment content and volume of flow from road segments during the winter rainy season. Eight road segments located on mainline haul routes and secondary roads with gravel and native soil surfaces and a range of gradients, road features, and traffic were measured during either or both of the two year period of study. Installations were equipped with instruments that continuously measured flow and collected physical samples for laboratory analysis of sediment content. Data allowed analysis of sediment during rainstorms and annually. Traffic was monitored to determine the effect of vehicle use on sediment generation from the road surfaces. The study methods produced highly repeatable results among sites and years.

A second aspect of the study was an extensive road survey of road characteristics and direct entry stream length on stormproofed roads on HRC property conducted during the same period. Together, the two studies quantified the erosion rates from road surfaces managed according to HCP guidelines and determined the road locations and length that delivers sediment to streams. Study results have implications for a number of the HCP strategies including the effectiveness of wet weather hauling restrictions, road surfacing and construction, hydrologic disconnection at stream crossings, road sediment modeling, and sediment budgets.

All road segments measured during this study represented common road conditions found on the property. Sites were primarily in the wildcat geology located in the Freshwater and Elk River watersheds. Sites included heavily used mainline roads, lightly used and newly constructed secondary roads, and a native surface road. Gradients ranged from flat to steep, traffic varied from none to high daily use by log trucks.

Sediment concentration during storms followed a "supply-limited" pattern as observed in previous studies such as Bilby et al. (1989) and Reid and Dunne (1984). Sediment concentration was highest at the initiation of runoff and declined sharply in the first hours of a rainfall event as sediment washed from the road surface. Sediment load produced during rain events was primarily related to total rainfall amount and runoff volume. The effects of traffic before and/or during rain events were very low and could only be detected at one of the road segments in some storms. At others, traffic effects were undetected despite very heavy traffic use.



The annual total sediment yield from rocked road segments was very low compared to previous studies and compared to SEDMODL estimates, including the heavily used mainline roads. Situations that appeared to lead to higher sediment yields included:

- Cutslopes not fully stabilized
- Very steep gradients
- Pit-run rocked surfaces with log truck traffic (pitrun indicates a lower quality rock, not as resistant to abrasion)
- New construction

Annual sediment yield from road segments was predicted with high R^2 and could be explained statistically by road characteristics of road slope, surfacing factor, time since construction, and vegetation density on the cutslopes. Multivariate analysis of measured yield found that no traffic factors were needed to accurately predict observed erosion even though a number of the roads were heavily used by log truck traffic.

The road flume study validated the relevance and importance of parameters used in the WDNR model and SEDMODL. The same parameters important to model erosion prediction such as total precipitation, erosion, traffic levels, vegetative cover density, surfacing material, and time since construction were statistically confirmed in this study. However, both the WDNR (SEDMODL) and WEPP models significantly over predict sediment relative to observed on HRC roads managed with HCP road management strategies. Updating the sediment models will require adjustment to traffic factors in particular. The traffic use factors have the greatest influence on sediment generation in current models.

A major component of HRC's Habitat Conservation Plan is to control road-related erosion and minimize sediment delivery through state-of-of the art construction practices (collectively termed stormproofing) and seasonal and storm-based restrictions on use of roads. Stormproof construction practices, road drainage design to minimize the connectivity of the ditches to the streams, and ongoing maintenance are all important to minimize sediment generation and delivery from the road system. HRC also prevents road surface erosion and damage to roads by log truck traffic by matching the timing of use to the resistance of the road surfacing. Some roads can be used year round whiles others can only be used only during the summer dry season. Wet weather restrictions apply to log hauling during rainstorms. Truck traffic must cease operating when surface runoff is visible on road surfaces. Truck traffic can only resume after visible runoff ends.

This study was primarily designed to determine erosion rates for use in sediment budgeting. However, the study also directly assessed the effectiveness of some of the road management practices to minimize sediment generation, and results had implications for others.

Wet Weather Hauling Restrictions. The study design allowed direct evaluation of the effectiveness of the wet weather hauling restrictions. Studied road segments represented mainline roads with heavy use by log trucks and secondary roads periodically used for log hauling. Traffic during the winter months was significant and normal for these watersheds. Roads were operated according to wet weather restrictions. Previous studies had periods of no hauling as a consequence of normal operation, but none has measured a deliberately applied strategy to restrict log truck traffic during wet weather on all roads. The very low sediment yields observed from heavily used roads confirmed the effectiveness of the wet weather hauling restrictions. Erosion rates were at least 10 times lower than observed in other similar studies in the coastal regions of the Pacific Northwest dominated by rainfall precipitation s (e.g. Bilby et al. 1989). The sensitivity of soils to erosion is as high on HRC lands as anywhere road sediment has been studied.

Ditch Vegetation: Another unique management element on HRC roads is the practice of allowing ditches to vegetate. This practice appears to have also helped minimize the sediment generated with road and ditch runoff on heavily used road segments.

Surfacing Material: Rock surfacing materials available in the area vary in durability and resistance to abrasion. The lowest sediment yields were observed on road surfaces rocked with the most durable material. Sediment yields from pitrun materials were very low but were relatively higher than those surfaced with the most resistant rock. This result suggests that strategic use of the best rock on the locations with the greatest potential for delivery of road surface runoff to streams, such as within the hydrologically connected segments, would further minimize sediment delivery.

New Construction: Sediment yields were higher on newly constructed roads for the first year after construction. Yield declined to low levels the year following. This recovery period is shorter than the 2-yr period suggested in the Watershed Analysis surface erosion module. Scheduling construction a year prior to use for log hauling would enable the road to harden and help minimize sediment input.

Cutslope vegetation and stability: Several study segments had cutslope issues that affected sediment yield. Incomplete vegetative cover resulted in visibly active erosion on one secondary road illustrating the importance of achieving proper cutslope stability and vegetative cover.

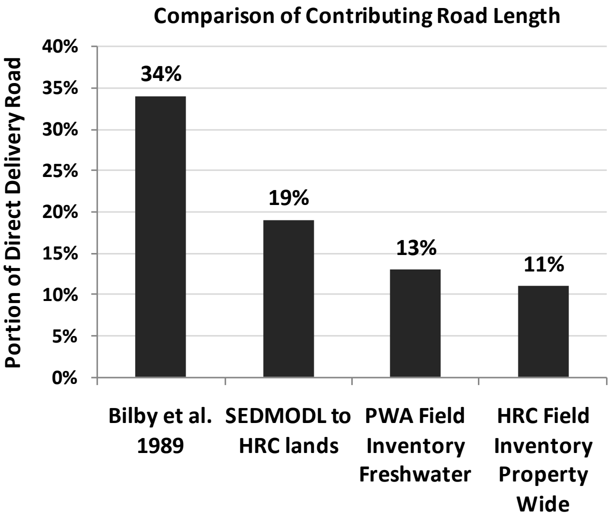
Native Surface (Dirt Roads). Erosion rates were significantly higher on dirt roads. These results emphasize the importance of a number of management practices for this road type which is common on HRC property. These include care to hydrologically disconnect and effectively manage surface runoff, rigid adherence to seasonal restrictions. Erosion control measures beyond what was done on the measured road segment would reduce erosion from what was measured. The native surface study segment had a bare soil surface. Establishing vegetative cover on the surface of these roads would undoubtedly reduce erosion from what was observed in this study.

Sediment Budgets and Modeling. The low road erosion rates observed in this study have significant implications for sediment budgeting in HRC watersheds. Road surface sediment models should be adjusted to reflect the HRC stormproofing and construction standards. Study results provide the basic information to do so.

Sediment Delivery. A survey project of stormproofed roads was performed to assess the characteristics of roads to better inform sediment modeling parameters and to determine the amount of direct entry road length on storm proofed roads to better inform delivery assumptions used to determine watershed scale sediment input. Roads included in HRC's long-term plan for active management of the property were surveyed in this project. A total of 472 miles of stormproofed road well distributed across the property with the exception of Bear and Mattole Rivers were surveyed using a protocol provided by K. Dube of Geodynamics who performed the surface erosion module in several Watershed Analyses.

Road characteristics were measured on 1,649 individual hydrologically connected segments during the survey. The study found the proportion of direct delivery segments varied somewhat between watersheds and subbasins depending on road layout at the landscape scale. The average delivery was 11.1%. This value is lower than previous studies. For example, the Freshwater Creek Watershed Analysis assumed 19% of the road system directly delivers to streams.

The study results characterize the average and distributions of stormproofed road conditions found on HRC property. Summarized results can be used to inform application of Sediment Models in Watershed Analysis. Most of the parameters used in previous applications are reasonably close to those found in the survey but all could use some adjustment. On average, cutslopes are shorter, vegetation density is greater, and connected segments are shorter than assumed. These conditions would tend to lower sediment delivery estimate from previous applications of road sediment modeling.



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OVERVIEW

Forest roads can be an important source of sediment to streams. Traffic use and maintenance of semi-permeable gravel or native soil road surfaces produces fine sediments that can be easily transported to the stream system by surface runoff depending on the connectivity of drainage to water courses. Increase in both coarse and fine sediments to streams is of ecological concern because elevated concentrations of sediments may adversely impact the aquatic biota and salmonid fishes. Even relatively low levels of suspended sediment and turbidity have been reported to cause changes in the feeding behavior of fish population in the stream (Bilby et al. 1989).

A number of studies have quantified sediment generated from gravel and dirt road surfaces generation in the Pacific Northwest region. Reid and Dunne (1984) measured discharge and collected sediment samples manually to derive relationships between precipitation, storm hyetographs, discharge, and sediment concentrations. Using these relationships and rainfall records, an annual record of sediment yield was constructed. Reid and Dunne (1984) reported that sediment yield varied with the level of truck traffic use with sediment yield ranging from 0.1 kg m^{-2} (unused road) to 125 kg m^{-2} (heavily used by log trucks). Bilby et al. (1989) continuously measured ditch flow and collected sediment samples at intervals during storms to determine the annual road surface sediment yield of 2.14 kg m^{-2}. These investigators also found that road construction and traffic influenced sediment yield. Both studies were conducted in the state of Washington. Luce and Black (1999) measured the sediment production from 75 road sections in Oregon using sediment traps that collected sediment over a 4-month period. They found that most road segments produced a little sediment while a few produced a great deal. Coe (2006) measured sediment runoff from forest roads in the Sierra Mountains of Nevada and California. Luce and Black (1999) and Coe (2000) emphasized the prediction of yield based on road surface characteristics such as contributing area and road gradient.

Studies have demonstrated that the most critical variables determining the amount of sediment production on a road surface are the material forming the road, characteristics of construction, and amount and type of vehicle use. Specific parameters controlling sediment production on a road surface may be divided into three categories: 1) characteristics of the road including drainage area, slope, and ditch conditions, 2) construction methods for drainage control; 3) the geographical setting of the road that determines the climate, soil substrate, and geologic materials that establish the basic road materials and flow characteristics; and 4), wear of the road surface with type and amount of use and maintenance.

The Watershed Analysis methodology used to assess sediment sources on Humboldt Redwood Company lands contains a simple empirical model developed by the Washington Department of Natural Resources (1992) to assess potential road erosion input to streams for purposes of sediment budgeting. The model was developed by Dr. Walt Megahan who synthesized results from many of the road studies conducted in coastal and interior regions of the Pacific Northwest. Basic erosion rates for a unit area of road surface for a variety of geologic types were empirically derived from the published studies. The basic rate applies to a native surface road with non-vegetated cut and fillslopes with a “normal” level of traffic defined as light pickup use only. The model then revises the basic erosion rate by factors grounded in the field studies based on surfacing material, age of road, level of use (especially by log trucks), vegetative cover of ditches and slopes, and expected average rainfall. This model has been applied on all HRC roads in “as is” condition prior to stormproofing during Watershed Analyses and was the basis for road surface erosion estimates in sediment budgets.

Control of erosion from road surfaces is a major component of HRC’s Habitat Conservation Plan. The general standard for new construction or reconstruction is to “stormproof” each road to weather all storms including large magnitude, infrequent events without damage to water crossings and with minimum sediment delivery. Roads can be disconnected from watercourses by crowning the running surface, decreasing the distance between cross culverts and water bars, and various means of safely shunting drainage onto the forest floor. Sediment minimization is also accomplished by matching the timing of use to the resistance of the road surfacing. Roads used during wet weather must have durable surfaces and are constructed to manage road drainage away from streams through a variety of construction techniques. Roads constructed of native soil only with no rocked surface can only be used during the summer dry season. Log truck use is restricted during rainstorms when road surfaces are actively shedding water. Log truck traffic is restricted during the winter on all roads during rainstorms when surface runoff is observed. All of these measures are designed to minimize sediment generation and delivery from road surfaces.

The purpose of the studies presented in this report are twofold: 1) to measure the sediment yield from storm-proofed roads on HRC property to validate erosion rates for improving sediment budget estimates, 2) to evaluate the effectiveness of seasonal and wet weather road use restrictions. Erosion rates and delivery reflect both construction and road use. The study consists of two parts: 1) measurement of sediment delivered from storm-proofed road segments over the winter period with typical road use patterns, and 2) inventory of stormproofed roads throughout the property to determine the amount of road surface delivering sediment to the streams at the watershed scale. These projects are described individually.

ROAD SEDIMENT GENERATION – A FLUME STUDY

The objective of this study was to quantify the amount of sediment delivery from stormproofed roads over the course of a winter with typical Company traffic use including log hauling. Hydrologically discrete road segments were instrumented to measure flow and the sediment concentration of ditch runoff on a continuous basis during the rainy season. Data are used to assess the interaction between rainfall, runoff, and traffic in determining the volume of sediment produced per unit area of road surface.

Study Area and Methods

Fieldwork was conducted on road segments located in the Elk River and Freshwater Creek watersheds. Both of these watersheds drain into the Humboldt Bay on the northern coast of California. The climate in the area is Mediterranean; summers are dry followed by wet winters with roughly 90% of average annual rainfall precipitating between October and March. Sites were measured for two winters in hydrologic years 2004 and 2005. The study got underway in January 2004 and ended in May 2005. Average annual rainfall for the 125-year record measured at the NWS Eureka weather station is about 990 mm (39.11 inches) and about 1100 mm (43.3 inches) within the watersheds. Annual rainfall at Eureka was 939 mm (37.57 inches) in 2004 and 1100 mm (43.45 inches) in 2005. Therefore, rainfall was close to the long-term average in both years.

The geology of the watersheds consists of the Wildcat Group, the Franciscan Central Belt Group, and the Yager Formation. The Wildcat Group – a thick transgressive-regressive sequence of late Miocene to Middle Quaternary – consists primarily of mudstone, siltstone, claystone, fine-grained sandstone, and minor conglomerate. Wildcat sediments are primarily silt- and sand-sized and geologically young making them both loosely consolidated and erodible by nature. Their silty and sandy composition results in rapid weathering and the development of granular, non-cohesive soil materials. The gravels that are derived from the Wildcat are typically very soft and abrade rapidly into fine materials. Figure 2 shows site locations relative to the general geologic map of the area. Most sites are in the Wildcat geology. Site 854 is near the border and appears to fall in the Franciscan formation. However, based on our familiarity with the soils at this site, it should also be considered Wildcat.

The Franciscan Central Belt is a late Jurassic to Cretaceous accretionary mélange consisting of pervasively sheared matrix of fine sediments surrounding exotic blocks of greenstone, blue schist, serpentinite, graywacke, metagraywacke, and chert ranging from several meters up to hundreds of meters in size. Rocks in this group consist of a matrix of fine sediments with included blocks of harder metamorphic rocks (Freshwater Creek Watershed Analysis). Although this group has larger rocks, they are still poorly consolidated with low durability. The Yager Formation – formed in the Paleocene – consists of dark gray indurated mudstones, shales, graywackes, siltstones, and conglomerates, with interbedded limey siltstones. Rocks in the Yager group are much harder and generate larger classes of gravel and cobble (Freshwater Creek Watershed Analysis, 2003). The monitored sites represent the Wildcat Group and may include the Franciscan Central Belt Formation dependent on the accuracy of the geologic maps.

Roads in the watershed are generally rocked with material quarried from nearby borrow pits or river run gravel obtained from off property that may be of mixed geologic materials including some not found in the watershed. The cutslopes and substrate of the road represent the local geology.

Figure 1. Road sediment generation study sites.

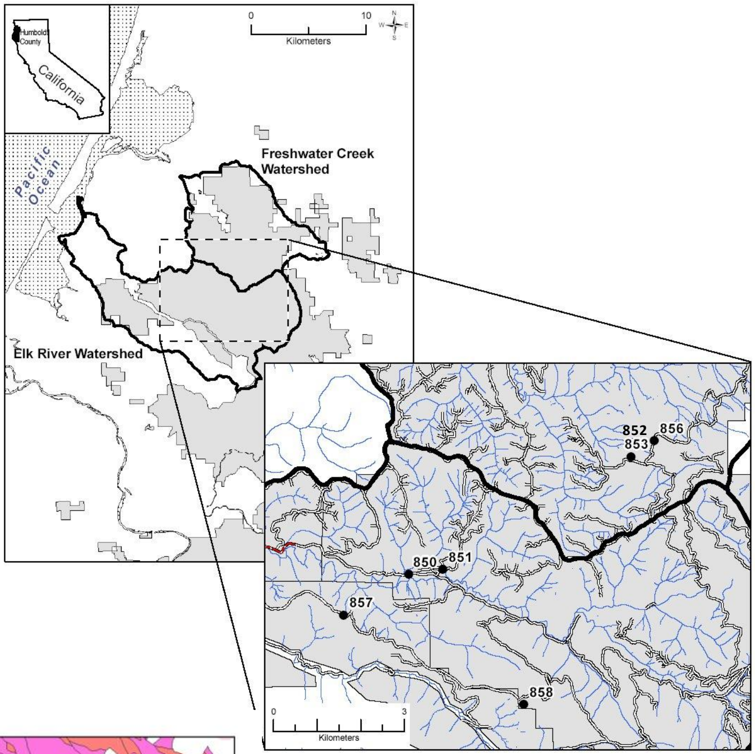
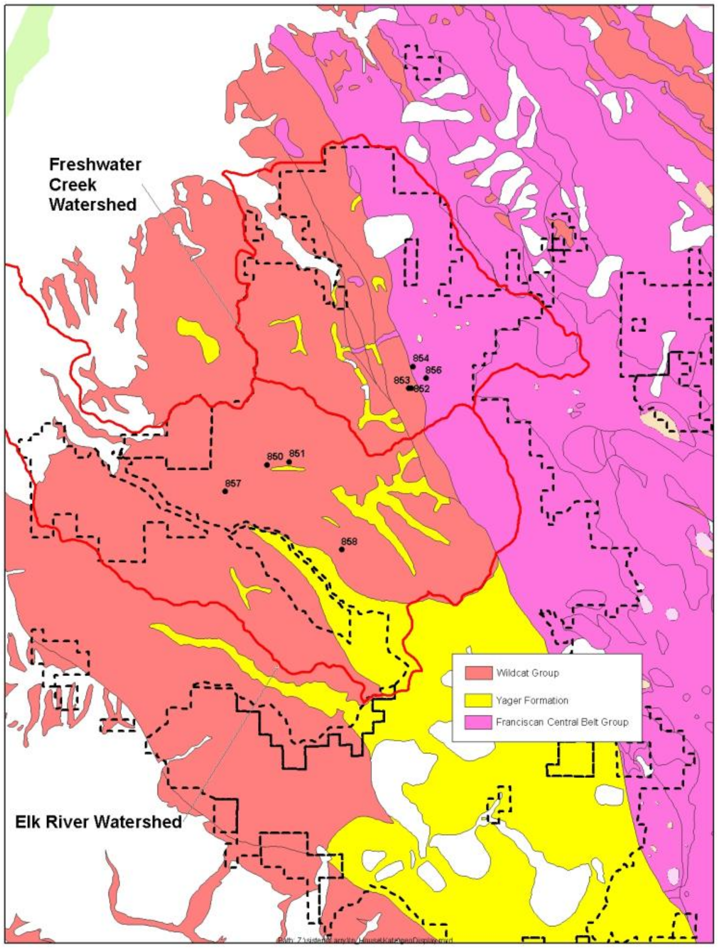


Figure 2. Sites in relation to geologic formations.



This study was designed to examine discharge and sediment (in the form of turbidity and suspended sediment concentration (SSC)) from roads surfaced with either gravel or native soil materials, which we refer to as “seasonal” roads. Truck traffic, including pickups, is excluded from these roads during the wet months of the year.

During the 2-year study, a total of 8 road segments on various types of road surfacing and use levels were measured for at least one year. Locations of sites are shown in Figures 1 and 2 and site characteristics are provided in Table 1. Segments ranged from 60 to 220 meters in length. Four sites were measured for 2 years. Two sites (sites 850 and 851) were located in the N. Fork Elk River watershed near Bridge Creek, within section 28 of T4N and R1E. We refer to this road as the “Elk River Main Line” or the ER road. This is a main haul road that funnels traffic to the County Road from the headwaters of the N. Fork Elk River as well as many areas of Freshwater Creek. This road was rocked with competent surfacing material and was stormproofed. Traffic was significant during measurement in both years due to active winter logging.

Two sites were located on rocked segments sites representing secondary roads or feeders to the main truck routes in Freshwater Creek (sites 852 and 853, Table 1, Figures 1 and 2). Road segments 852 and 853 were newly constructed in 2004. There was limited light pickup traffic in 2004 at both sites. Site 853 was measured again in 2005 and had active log hauling from several timber harvest units. Site 852 was measured only in 2004. Site 854 was located in the Incline area of Freshwater Creek and was a seasonal dirt road. The segment was newly built in 2004 and was used for truck hauling during the summer prior to measurement but not during the winter. The site was not measured in 2005. Three additional rocked road segments were instrumented for measurement in 2005. One site was located on the main haul road in Freshwater Creek (Rd 15) (856) and one was located on the mainline haul road of S. Fork Elk River known as the “Ridge Road” (857) (Figure 1). The final segment was located in the upper reaches of the S. Fork Elk River (858). This segment was rocked with pit run material and was attached to an actively used landing. Photographs of the road segments are provided in Figures 3, 4, and 5.

All of the roads were constructed as partial bench roads (road is partly cut into the hillslope and the cut material was sidecast). Rocked roads were built on a compacted base and surfaces were crowned. The seasonal road was outsloped. Segments were crowned or insloped with ditches draining through relief culverts. We used the disconnecting structures to capture the road runoff for study. Width and vegetative cover in the ditches varied. There was either exposed soil or grass for all or part of the ditch length. The cut- and hillslopes along the road segments were vegetated with grass, shrubs, and/or trees for the most part, although newly built roads had less vegetation on the cut- and fillslopes. Some had slash coverage. The seasonal roads were outsloped with no ditches and with no cutslopes due to the relatively flat terrain where they were constructed. Table 1 provides characteristics of the road segments.

PALCO was the owner/operator during the study period.

Table 1. General characteristics related to location, geology and road characteristics.

	Road Segment ID							
Road ID	**ER1**	**ER1**	**U91.26**	**U91.24**	**U91.24**	**Rd 15**	**U08**	**U08.55**
Site Number	**850**	**851**	**852**	**853**	**854**	**856**	**857**	**858**
Location								
Watershed	Elk River	Elk River	Freshwater	Freshwater	Freshwater	Freshwater	Elk River	Elk River
Geology	Wildcat	Wildcat	Wildcat	Wildcat	Wildcat	Franciscan Belt	Wildcat	Wildcat
Road surface								
Gradient, %	7.5	17.0	5.7; 8.8 1)	11.7	15.0	1.0; 1.0 1)	2.0	14.0
Length, m	219	102	38; 91 1)	59	61	100; 80 1)	104	108
Road surface area contributing to ditch , m^2	671.13	256.24	404.97	107.15	440.32	252 2)	145.6 2)	151/2 2)
Proportion of road surface area contributing to ditch (%)	40	31	42	24	72	35 2)	35 2)	35 2)
Surfacing	Competent Rock	Competent Rock	Competent Rock	Competent Rock	Native soil	Pit Run Rock	Competent rock	Pit run rock
Construction	crowned	crowned	crowned	crowned	outsloped	crowned	crowned	crowned
Years Measured	2004, 2005	2004, 2005	2004	2004, 2005	2004	2005	2005	2005
Road Type	Mainline haul	Mainline haul	Second. spur	Second. spur	Seasonal	Mainline haul	Mainline haul	Landing, road
Traffic use	Heavy 2004 2005	Heavy 2004 2005	Newly constructed, no use	Newly constructed 2004 no use 2004 hauling 2005	None	Heavy	Heavy	None
Ditch								
Width, m	0.5 – 2.0	0.5 – 3.5	0.5 – 2.5	0.5 – 2.5	0	0.5 – 1.0	0.5 – 1.5	0.5 – 2.0
Vegetation	Grass, 85%	Grass/brush	Grass/none	Grass/none	None	Grass	Grass	None
Cutslope								
Height, m	2.3	2.6	2.0	3.7	1.2	3.0	5.0	2.5
Gradient, %	70	100	100	100	30	45	70	70
Vegetation, Density %	Grass, 85%	Grass, 85%	None	Grass/ 20% year 1 60% year 2	Slash, 40%	Grass, 90%	Brush, 90%	Grass, 70%

1) Road at 856 consists of two separate segments.
2) No surface survey was conducted on roads at 856, 857 and 858. Contributing areas estimated using average of surveyed sites.

Figure 3. Photographs of road sites on the N. Fork Elk River (ER) mainline road, measured in 2004 and 2005. Site 850 was 7.5% gradient and 851 was 17% gradient.

Figure 4. Photographs of sites 856 and 857.

Site 856

Mainline rocked Road 15

Gradient average 1.0%

Site 857

Elk River mainline rocked Road U08

Gradient average 2.0%

Figure 4 continued. **Photographs of sites 858 and 854.**

Site 858

Secondary pitrun rocked Road U08.55

Gradient average 14.0%

Site 854

Secondary native surface road U91.24

Gradient 15.0%

Figure 5. Photographs of secondary road sites in Freshwater.

Site 852

Secondary rocked road U91.26

Gradient average 7.5%

Site 853

Secondary rocked road U91.24

Gradient 11.7%

WATER DEPTH AND FLUME DISCHARGE

The instrumentation installed at each site was designed to measure the flow delivered from the road surface and ditch on a continuous basis throughout the winter season. Sediment concentration of flow was also measured on frequent intervals during stormflow.

Figure 6. Photos of the flume installations.

Flow was isolated and collected at the downstream end of a ditch relief at the bottom of a road segment with an inside ditch or at the water bars on the seasonal road. Flow through the culvert was funneled into a flume. Figure 6 shows the site instrumentation and construction. Flow was first channeled into a catch basin where the larger sediment sizes could deposit. The approximate dimensions of the catch basin were 1.5 × 1.5 × 1.2 meters. Flow then proceeded through an H-flume mounted to the catch basin. Significant sediment was captured at a several sites in the first year. The catch basins were redesigned in 2005 to minimize deposition and to encourage mixing so sediment was sampled by the ISCO during the storm event.

Each installation was equipped with a float and stilling well manufactured by Unidata. Depth was translated to flow with the flume's depth/discharge relationship (U.S.D.A. handbook number 224). Data was recorded in 5-minute intervals. The data logger was downloaded regularly using a handheld computer (model: PSION Workabout) and directly entered to the corresponding station working file. At every field visit, the UNIDATA Water Level Instrument was calibrated by comparing the instrument's offset with the measured depth in the flume. If necessary, the offset could be adjusted. The flume's rating curve was verified by measuring discharge in the field over a range of flow depths.

Instruments were first deployed in January of 2004 and removed around April 25 that year. The first year of the study was a learning experience as staff mastered the instrumentation and adjusted to observed flow conditions. There were gaps in the records at some time at a number of the stations. Sampling was more complete in hydrologic year 2005. Most of the instruments were installed by Oct 22 and were removed by May 20. Most storms were measured, but all sites had some gaps in either flow or sediment.

TURBIDITY AND SUSPENDED SEDIMENT CONCENTRATION

Water samples were drawn by the ISCO sampler or manually grabbed from the water flowing through the throat of the flume where it should be well mixed (Figure 6). The ISCO sampler was initially triggered by water depth in the flume and then pumped at regular intervals until its 24 bottles were filled. Various sample timings were used. Initially the interval was 30 minutes but was later reset after typical flow duration patterns were established. Generally, sampling was 1 per hour in the first 15 hours of the storm and every 2 hours thereafter for a total of 33 hours. Field crews serviced sites frequently and replenished bottles. Any sediment that was deposited in the flume itself was collected and weighed.

Samples were returned to HRC's Sediment Lab where they were analyzed for turbidity (NTU) and suspended sediment concentration (SSC, mg/L) following HRC's WOP-4 and WOP-5, respectively. A total of 2,800 sediment samples were collected and processed during the 2 year study. The data was entered into HRC's Hydrologic Monitoring database, and from there, it was downloaded to the corresponding station working file.

BULK SEDIMENT SAMPLING

The catch basins were constructed with plywood and lined with plastic to prevent leaking. Sediment deposited in the box was shoveled into buckets and weighed at the end of the hydrologic season or at more frequent intervals if necessary. This was the case with the seasonal roads with dirt surfaces. The total wet-weight of the captured sediment was measured in the field using a tripod and a fish scale (d = 0.5 kg) if volume was significant.

One single bucket with a representative sediment sample was brought to HRC's sediment lab, where the particle size distribution was examined, following Standard Operating Procedure WOP-07. The moisture content of the sampled sediment was determined. Soil cans containing sediment samples were wet-weighed, baked at 105°C for at least 24 hours and dry-weighed. The percentage of moisture of the corresponding sediment sample resulted from the average moisture content of the soil can samples. During this process, approximately 0.5 liter of sediment was dried (24 hours at 105°C) and sieved using United States Standard Testing Sieves (125 to 0.075 mm). Due to the very fine character of the captured sediment, the dried material formed clumps during the sieving process. These clumps were broken down manually in order to achieve analysis of the particle size distribution.

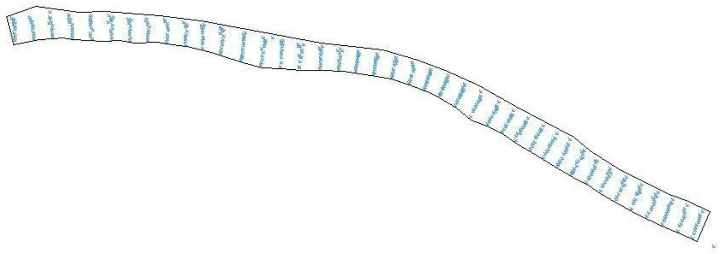
PRECIPITATION

Two tipping bucket rain gauges were placed in each of the two key site areas. One rain gauge station (site 718) was located in Elk River at Bridge Creek approximately 100 meters west of site 850 (elevation 43 m, 141 feet msl), Another rain gage (site 719) was placed in Freshwater Creek between sites 852 and 853 (elevation 384 m; 1,260 ft msl, Figure 3). The rain gauges at stations 718 and 719 were downloaded about once a month. Gaps in the record resulting from technical problems were filled by interpolation from one or more of the many rain gauges located in these two watersheds.

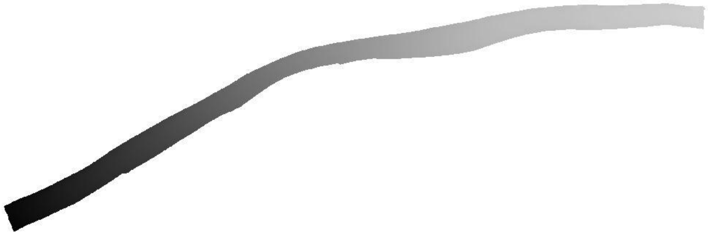
ROAD SURFACE SURVEY

Each road segment was carefully surveyed to determine the surface area contributing to the ditch discharge. The survey was executed using an electronic total station surveying instrument. The survey was the basis for a hydrologic model, which showed flow patterns of the road surface (Figure 7). By treating the road surface as a watershed, the model distinguished between contributing parts of the road surface, and areas where the runoff bypassed the corresponding sites and flowed onto the forest floor. The contributing area and other characteristics are listed in Table 1 and illustrated in Figure 8. This detailed survey was only conducted on segments 850, 851, 853 and 854 in 2004. Contributing area characteristics of segments added in 2005 (segments 856, 857 and 858) were estimated based on length, width, and average contributing area from the surveyed segments.

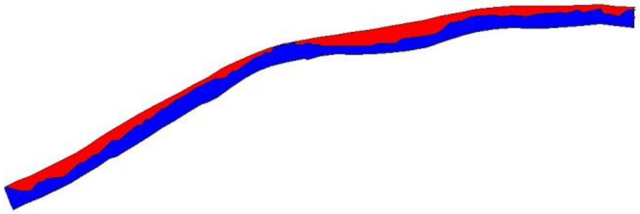
Figure 7. Survey and digital elevation modeling of road segment. Site 850 is shown.



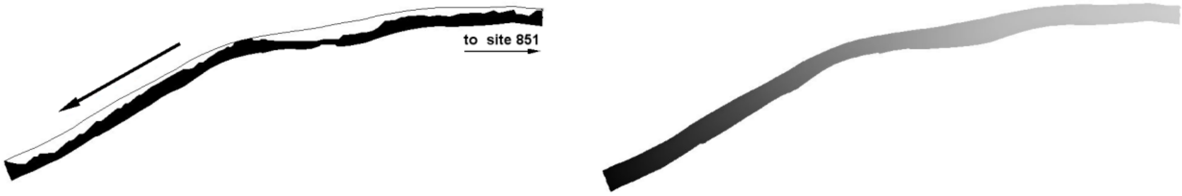
Raw Data



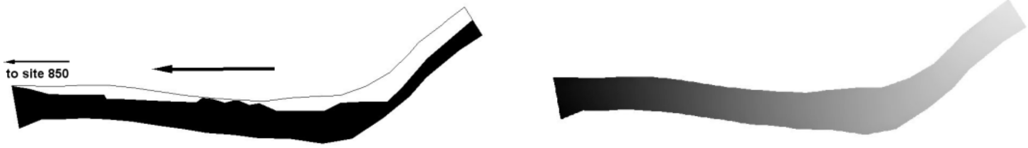
Digital Elevation Model (DEM)



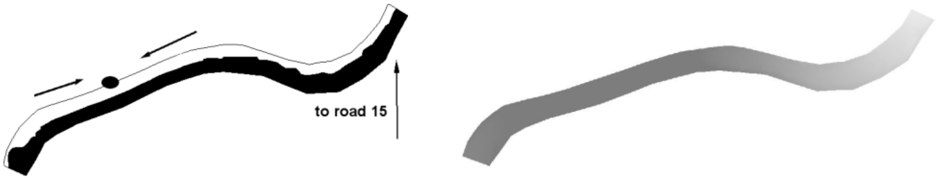
Contributing Road Area (red)



(A) Site 850 Mainline rocked road. Contributing area = 617 m^2

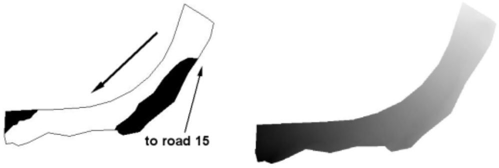


(B) Site 851 Mainline rocked road. Contributing area = 256 m^2



(C) Site 852 Mainline rocked road. Contributing area = 405 m^2

(D) Site 853 Secondary rocked road. Contributing area = 107 m^2



(E) Site 854 Native surface road. Contributing area = 440 m^2

Figure 8. In the left column, road areas contributing to the ditch (white), and digital elevation models (DEM, right column) are shown for site 850 (A), 851 (B), 852 (C), 853 (D); as well as road areas, where surface runoff contributes to the flume: 854 (E). The arrows indicate the flow direction of the runoff; the inlet of the culvert is at the lower end of the road segment, except in 852, where the inlet is illustrated by a point. Darker areas in the DEM are of lower elevation. The images also illustrate the type of surface design: roads 850 and 853 were crowned, the road at 854 was outsloped.

TRAFFIC

Traffic was not measured during the first year of the study (2004). We assume that the standard practices were followed and that average patterns of traffic use occurred. Logging in both watersheds primarily occurred during the winter because the roads were stormproofed and each received about the same amount of harvest each year. The mainline road (sites 850 and 851) experienced winter truck hauling as PALCO conducted logging activities in the watershed. Traffic use reflected the range of traffic from light to heavy that is typical of PALCO operations. Traffic on HRC roads is highly regulated on a seasonal and stormflow basis. Log truck and light pickup traffic is barred from using seasonal roads from October 15 to June 1 each year. During the winter rainy season, log truck traffic is only allowed on dry days when there is no observable surface runoff from road surfaces. The wet weather restrictions were in force. None of the other road segments experienced traffic during the winter and there was no THP activity on the secondary rocked roads. There was no truck use of the seasonal roads but ATVs did use the road at several times.

Traffic counters were installed in 2005 on the rocked road segments. We used a relatively low cost instrument manufactured by SICK Inc (model WL2000-B1302). The instrument uses a photoelectric sensor and an infrared beam sent between the sensor and target and counts when the beam is broken. The instrument records the number of vehicles (rather than axles) and pickups could not be distinguished from log trucks. The instrument also recorded wildlife or humans that may have broken the beam. This instrument proved to be less exact than a standard axle counter, although it was effective in showing relative high use periods with active logging and to established base traffic rates. Vehicle passage was recorded every 5 minutes.

Figure 9. Photograph of traffic counter installation.

Vehicles used the mainline roads throughout the season, with periods of more intense activity during logging operations. Figure 10 shows vehicle use by day for the five sites where traffic was measured in 2005. Four mainline haul routes and one secondary road were monitored for traffic.

All four of the mainline sites experienced similar maximum traffic volume at some time during the season. Daily traffic on the mainline roads fluctuated from a few vehicles on weekends to as many as 225 per day, depending on logging activity, day of the week, and daily rainfall. Maximum traffic on the secondary road was about 25 vehicles per day. Up to 200 vehicles per day were observed when multiple logging sides were active in areas accessed by each road. No road sustained the same level of use all winter as logging moved around the North and South Fork Elk River and Freshwater watersheds. Traffic at the mainline sites peaked at different times. Log truck traffic use at Site 856 in Freshwater Creek increased in January as soon as the new calendar year began. Site 857 on the S. Fork Elk River mainline was most intensive during March, while traffic on the N. Fork mainline peaked in April.

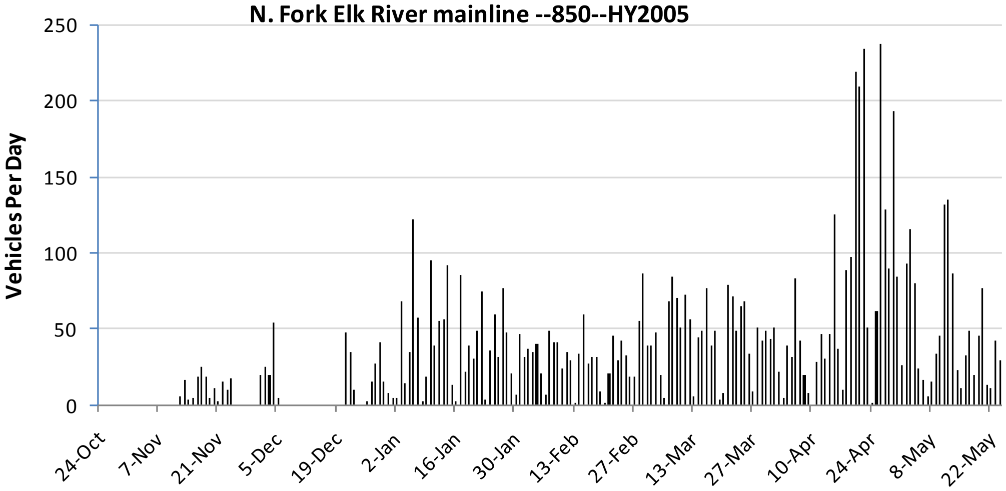
Sites 850 and 851 had similar patterns and numbers of vehicles. The segments were located near each other on the N. Fork Elk river mainline (road ER). Site 850 lies closer to the public road. Vehicles traveling into the watershed (inbound) on rd ER pass site 850 located near Bridge Creek. Vehicles can travel into the Freshwater Creek watershed by staying on rd ER and traveling up the hill. A significant portion of Freshwater Creek can be accessed through this route and it is commonly used by Company personnel and loggers. Rd 851 is on this route about ½ mile further inland. Rd ER junctions with Rd 16 before 851 inbound. This road accesses the south side of the upper N. Fork Elk River watershed and eventually traverses into Lawrence Creek. Vehicles using this route pass 850 but bypass 851.

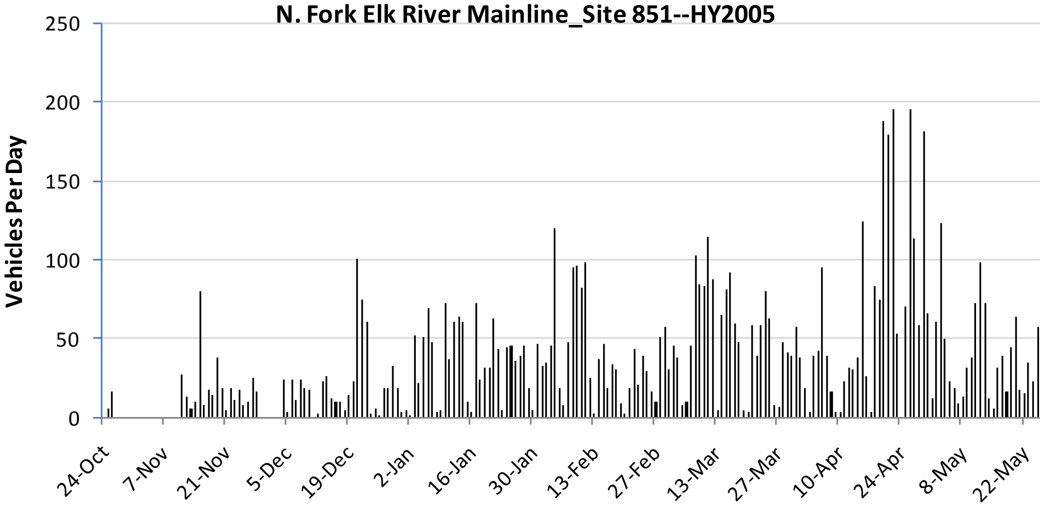
Through the entire winter season, traffic on the mainline roads totaled from 6,000 to 7,500 vehicles, depending on site (Figure 11). The total number of vehicles using the secondary road 853 was 610.

The average weekly pattern of traffic on each road is shown in Figure 12. The median value of daily traffic use is shown to eliminate the intensive periods and represent the routine use by Company personnel. The baseline weekday traffic use on the N. Fork Elk and Freshwater mainline was about 40 vehicles per day with minimum use during the weekend. That was about 20 vehicles inbound and outbound. Average daily use was about 20 vehicles per day in the S. Fork Elk River. The Freshwater secondary road site accesses the Incline area of Freshwater Creek. This road was periodically used for road construction in 2005. Average daily use on this road was 3 vehicles per day.

During weekdays, vehicle use of the mainline trunk roads nearly always began at about 5:30 A.M. and ended about 18:00. We note that our instruments often counted vehicles at night on either a random or regular basis. These counts were likely wildlife. All records were scrutinized for these types of occurrences. The apparent wildlife ticks were corrected occasionally but not systematically. We found that that log trucks could also be counted more than once at some sites depending on subtle differences in the height of the instrument, in that when set high, the vehicle could break the light beam more than once. This was apparent when there was excessive number of vehicles counted in a 5-minute period based on experience with road use. Traffic was corrected when individual 5-minute records were excessive indicating multiple counts of the same vehicle. Field notes assisted in calibrating interpretation of the vehicle record.

Figure 10. Vehicle counts by day at each study site.





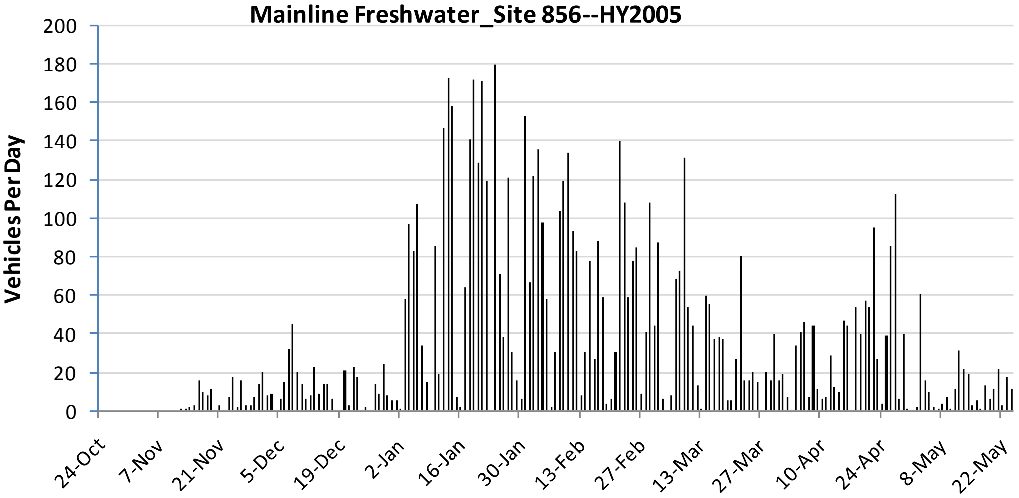
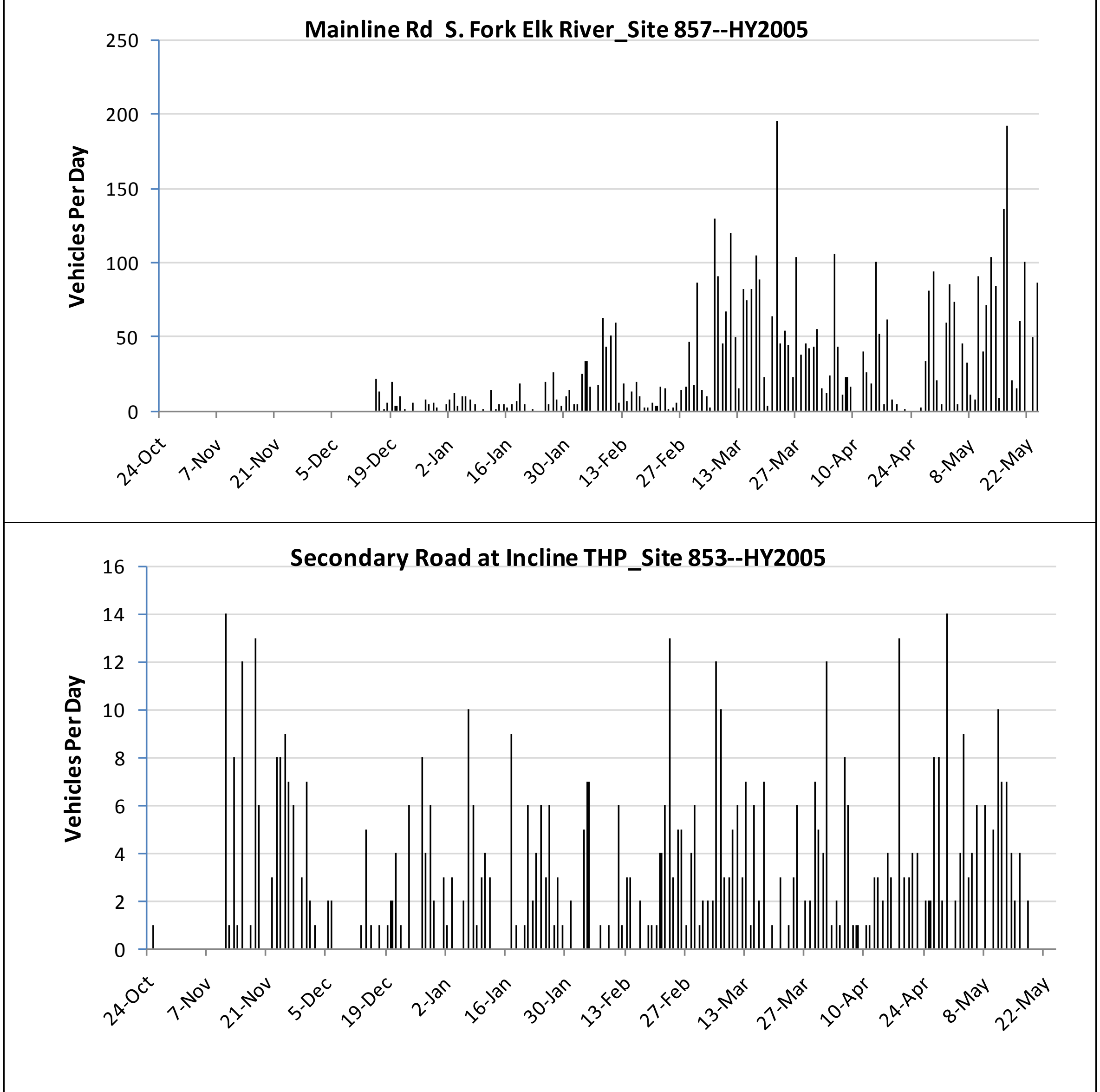


Figure 10. Continued. Vehicle counts by day.



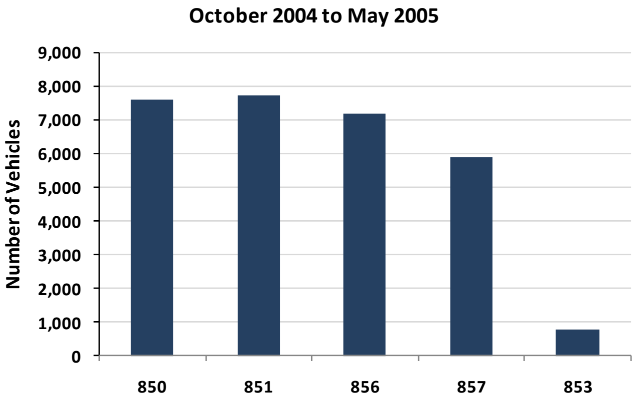
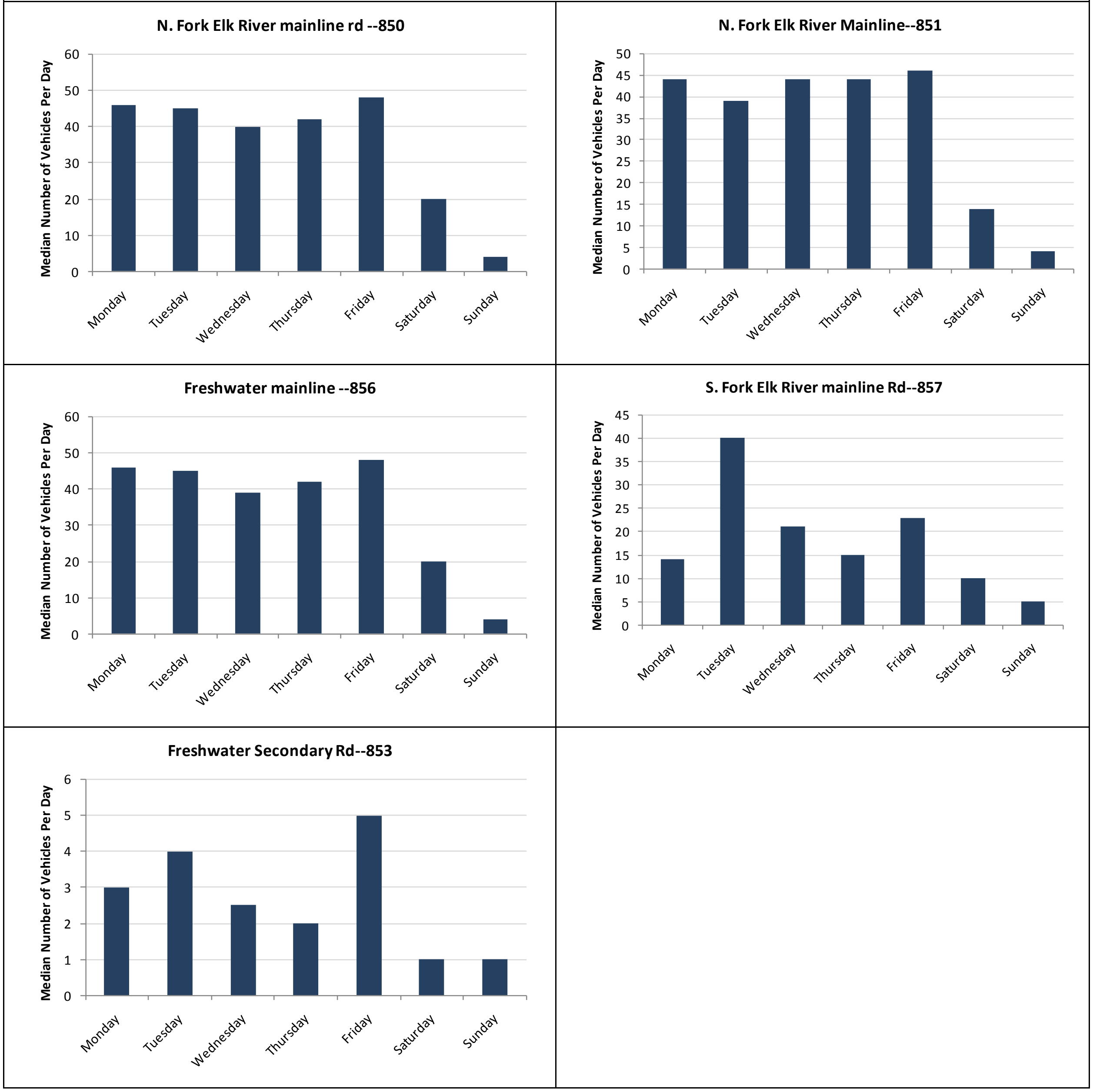


Figure 11. Total number of vehicles counted during hydrologic year 2005.

Figure 12. General baseline vehicle use of road segments by day of the week. Median values are shown.



Results and Discussion

The study design allows analysis of the hydrologic and sediment characteristics of road runoff within storms and seasonally. In this section we examine the relationships between:

- Seasonal road surface flow
- Rainfall and runoff during storm events
- Runoff and the physical characteristics of the road
- Sediment transport characteristics of road runoff during storms
- Traffic influence on sediment during storms
- Annual sediment generation from the road surfaces.

All statistics in this report were calculated with SPSS 19.0 statistical software.

GENERAL PATTERNS OF FLOW FROM ROAD SURFACES DURING THE WINTER SEASON

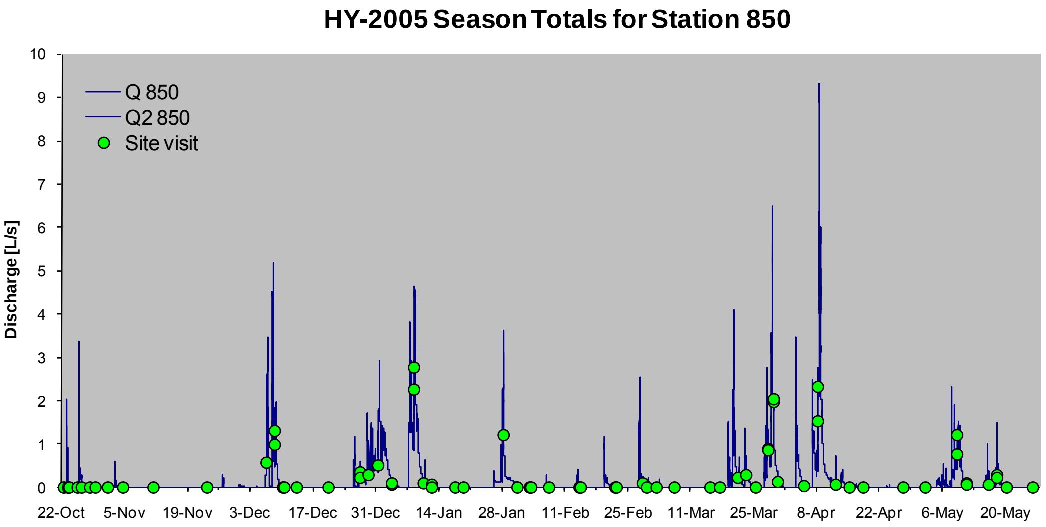
The seasonal record of 15-minute rainfall and flume depth for the hydrologic year 2005 at Site 850 on the N. Fork Elk River mainline is shown in Figure 13. Site visits are shown as dots. Discharge normally followed a standard pattern: rainfall intensity increased rapidly at the beginning of the storm and decreased slowly after the peak.

The hydrograph for the 2005 winter for all 5 sites with precipitation superimposed is shown in Figure 14. Although gravel and dirt road surfaces are hard, they are still permeable. Rainfall infiltrates into the road at low intensity rainfall. Low intensity rain generated no runoff at all. Generally, at least 2 to 3 mm (0.04 to 0.05 inches) of rainfall was needed to generate flow. However, once minimum rainfall amounts were exceeded, road runoff was highly responsive to the rainfall at each site and peaked near the maximum rainfall intensity. Often rainstorm intensity reached several peaks in a specific event.

Although there was a general pattern of hydrograph response, discharge from the road surface peaked within different lag times, varying from one storm to another and differing among sites. In addition, large peaks in the hydrograph did not always correspond to the largest rain storms and some smaller storms without sharp peaks in rainfall created larger than expected peaks in runoff. The road segment at 850 had larger road surface area and length (219 meters) as this road cut into the hillslope as it traversed down a steep grade. Runoff from this road site generally flowed for longer durations. In contrast, site 853 was located on a secondary road near the top of a ridge with only a small cutslope and short road length (59 meters). This site flowed only during the larger storm events and during some fairly significant storms there was no runoff at all.

Figure 13. Annual hydrograph of runoff at site 850 (A) on the N. Fork Elk River mainline, and daily rainfall (B). Green dots indicate site visits.

A.



B.

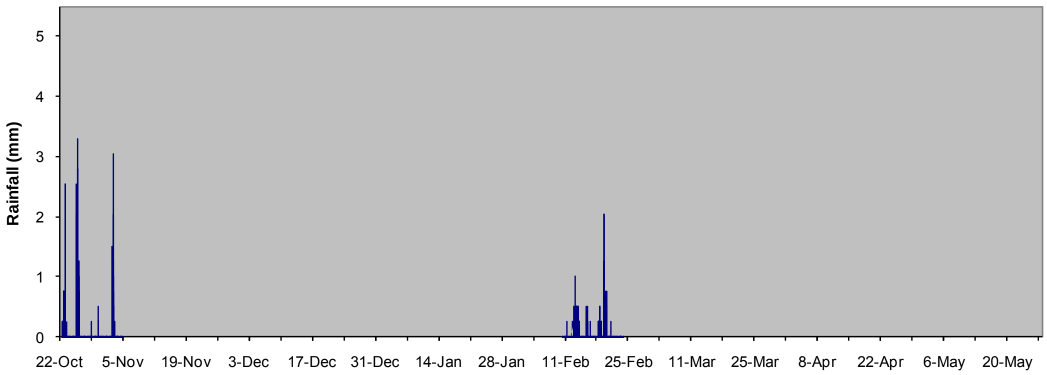
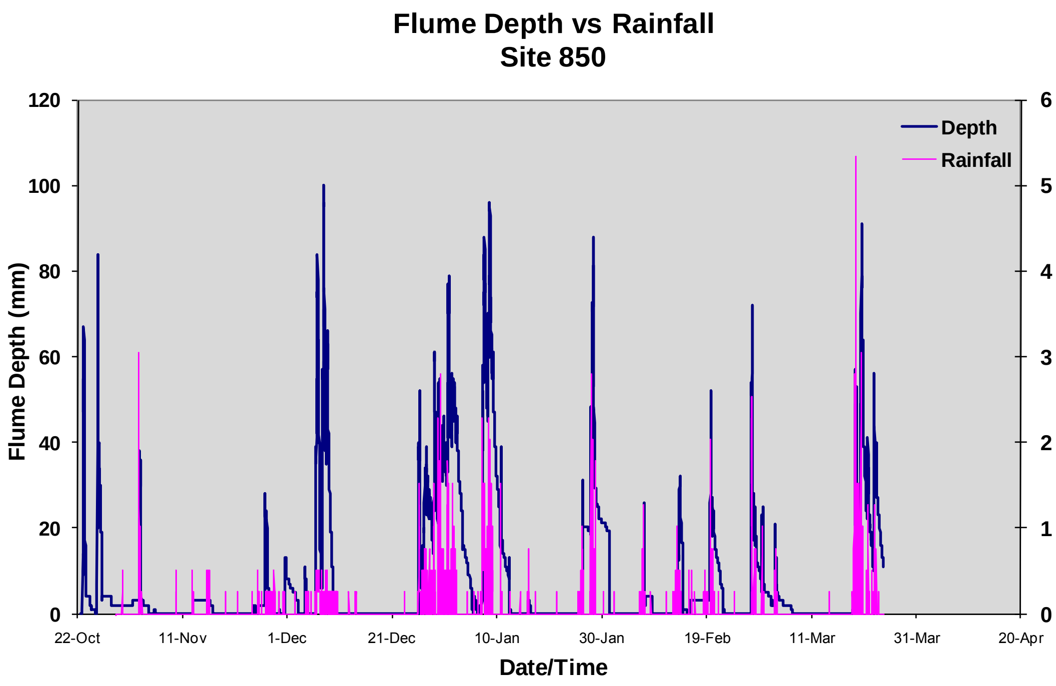


Figure 14. Flume flow depth and rainfall in 15-minute intervals at sites 850 and 851 on the N. Fork Elk River mainline road, site 853 on the secondary road in Freshwater, and sites 857 and 858 in S. Fork Elk River.



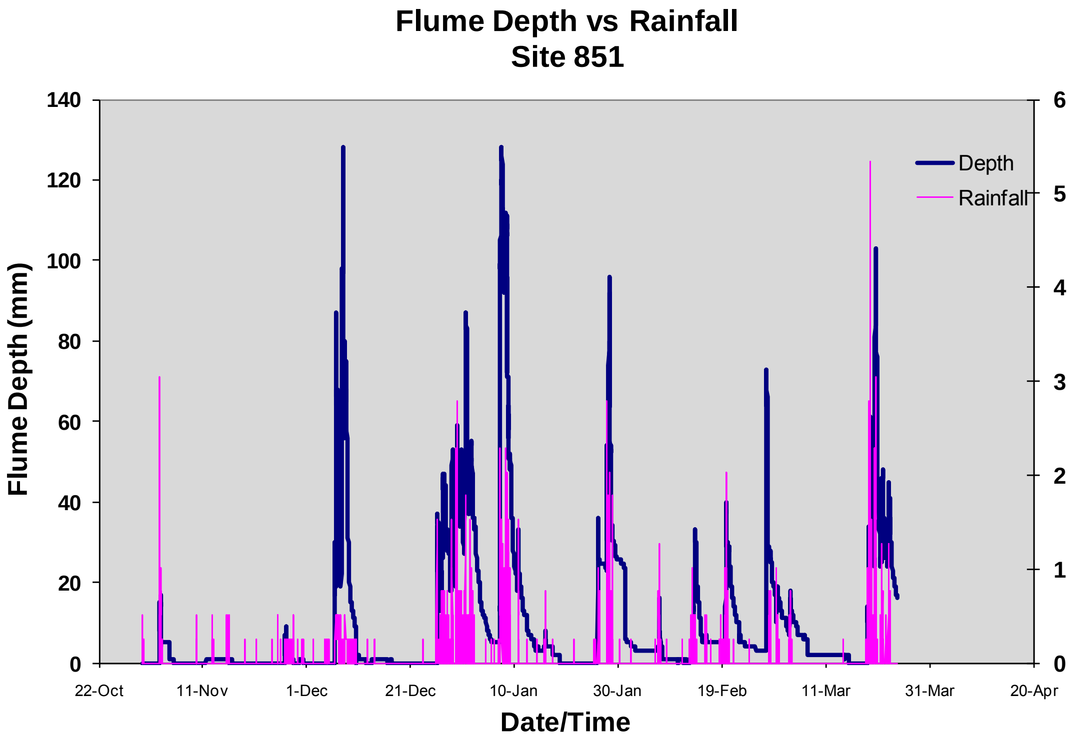
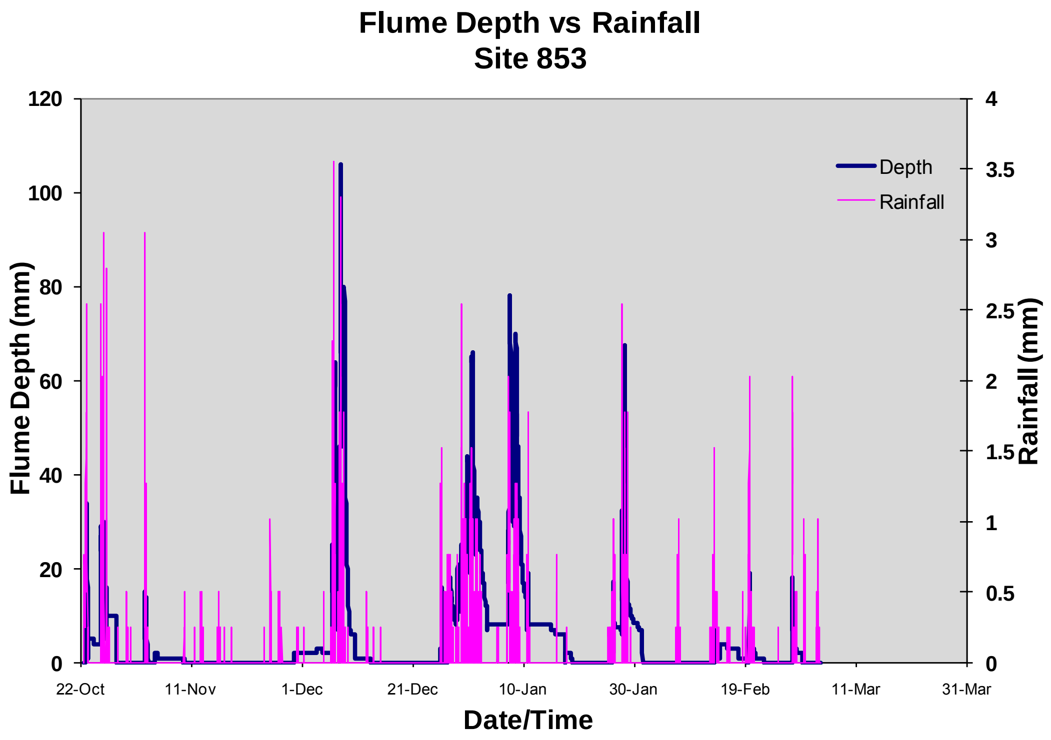


Figure 14. Continued



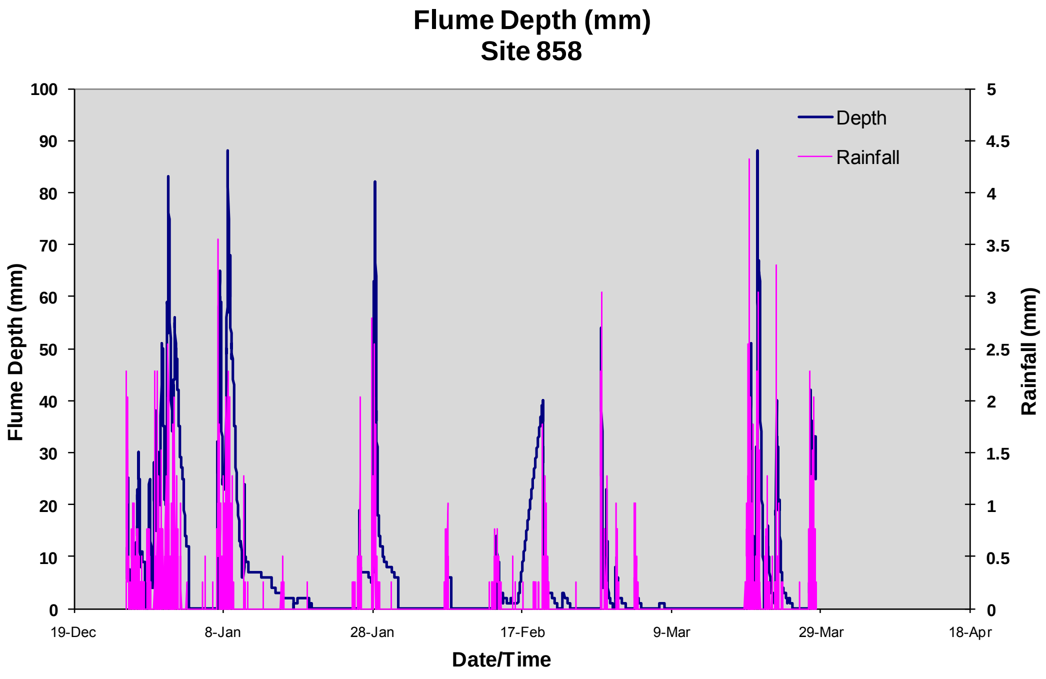
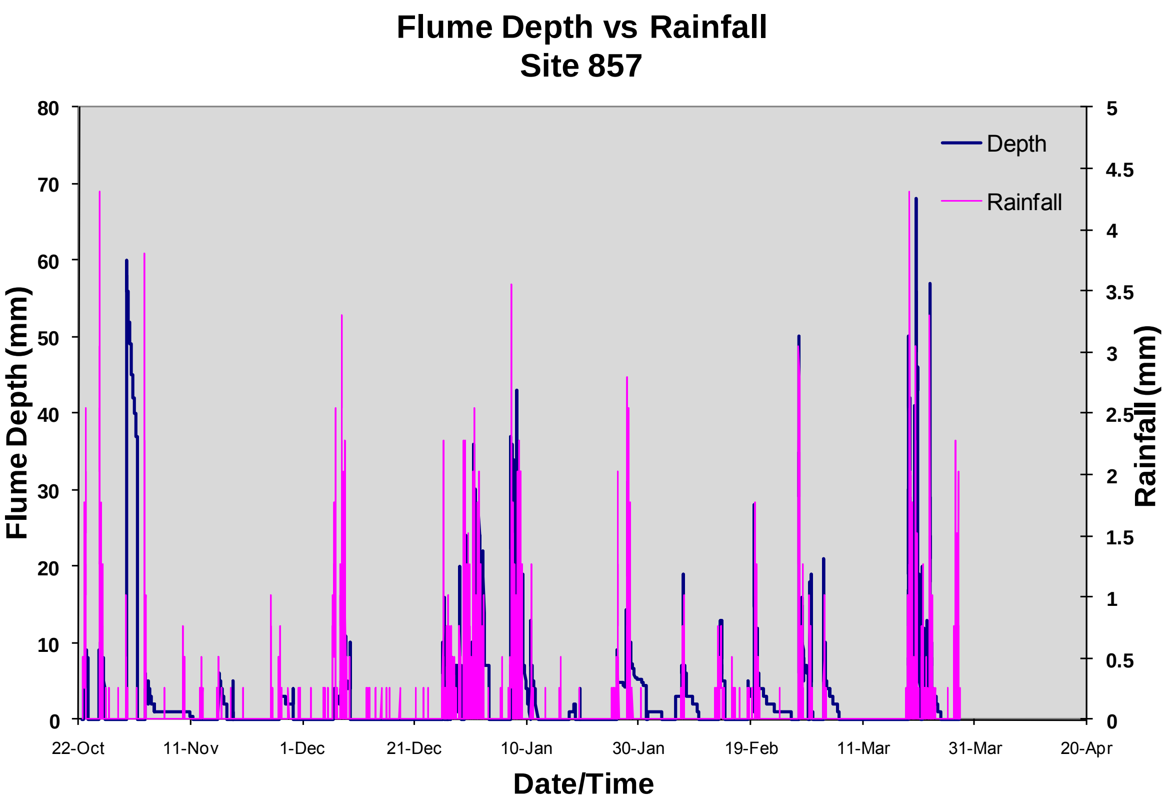


Figure 14 continued.



RAINFALL AND RUNOFF DURING STORM EVENTS

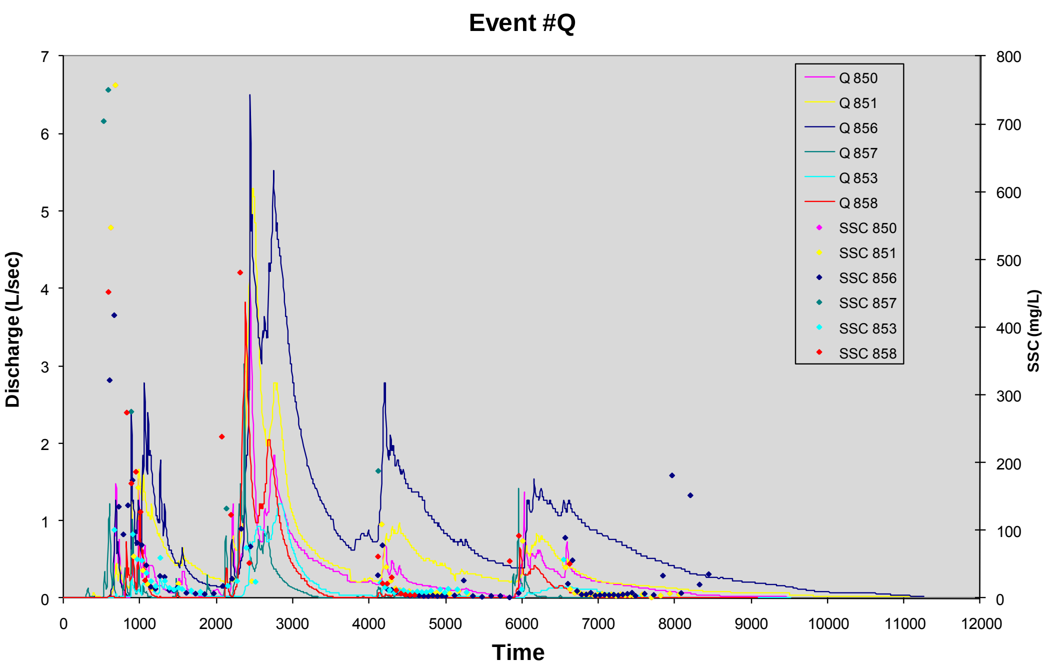
The annual discharge record was segregated into storm events. An event was defined as positive depth of water in the flume. An event began with onset of water depth and ended when no depth was observed. Discharge from the road surface initiated concurrent with sufficient rainfall volume and intensity. The ditches often continued to flow after runoff ended on the road surface as subsurface flow from the hillslope was captured by the ditch. Thus, some events were much longer than an actual rainstorm.

Only rainstorm events were included in the event record where the sediment data was inclusive, complete, and representative for that particular site. Sampling began in January in 2004. There were 13 discrete events in the first year of study. Table 2 provides rainfall and sediment characteristics of these events at each site. Instruments were installed at different times and not every site captured sediments during all rainstorm events that occurred throughout the monitoring period. In hydrologic year 2005, sampling began at the beginning of the rainy season in mid October. There were 26 discrete events in 2005. Sampling was more complete at each site during hydrologic year 2005, although there are still some gaps at each site.

Total rainfall amount, rainfall intensities, and antecedent rainfall varied between rainstorm events providing different conditions for both ditch discharge and sediment production (Tables 2 and 3). The events covered a wide range of rainfall and traffic conditions and produced a range of sediment throughout the season. Average storm duration was 26 h, ranging from 14 to as high as 300 h. Mean rainfall intensity ranged from 0.7 to 2.6 mmh^{-1} (average 1.6 mmh^{-1}) and maximum hourly intensity from 2.8 to 12.4 mmh^{-1} (average 6.4 mmh^{-1}). Total rainfall for these rainstorms varied from 24 mm to 150 mm (about 1 inch to 5.5 inches). Events often included one or more peaks in closely spaced storms and some were of quite long duration (5+days). Rain was not continuous during events.

Individual road segments and their associated hillslope areas reacted differently to rainstorms. As an example, the hydrologic response of the road segments is illustrated for storm Q in Figure 15. The hydrographs show that the roads reacted to the same amount of rainfall with similar initiation of runoff and timing of the peak, but that the peak volume and duration of runoff varied significantly among the sites.

Figure 15. Flume discharge (L/sec) during event Q at 6 road segments.



ble 2. Characteristics of rainstorm events that occurred during the 2004 monitoring period by site.

Event	Dates	Duration min (h)	TRA mm	MRI (mm/h)	MXRI mm/h	ADP days	24hAR mm	1wAR mm	2wAR mm	4wAR mm	Q surf m^3	Q flume m^3	Q_f/Q_s
Site 850													
C	1/23/04	615 (10)	24	2.2	4.8	3	0	15	33	n/a	16	27	1.69
D	1/27/04	560 (9)	20	2.0	5.1	3	2	34	51	n/a	14	13	0.06
E	1/30 - 1/31/04	1440 (24)	23	0.6	2.0	2	1	59	75	n/a	15	26	1.73
F	2/2 - 2/4/04	2895 (48)	28	0.7	6.1	1	1	52	86	n/a	23	68	2.96
H	2/16 - 2/18/04	3760 (63)	124	1.9	7.4	9	4	9	60	150	83	534	6.43
K	3/25 - 3/27/04	2365 (39)	47	1.1	8.1	30	1	6	6	38	31	15	0.48
L	3/29 - 3/30/04	885 (15)	21	1.3	4.3	1	0	53	54	55	14	11	0.79
N	4/20 - 4/21/04	1245 (21)	14	1.0	3.0	4	4	30	32	102	14	8	0.57
Site 851													
C	1/23/04	615 (10)	24	2.2	4.8	3	0	15	33	n/a	6	25	4.17
D	1/27/04	560 (9)	20	2.0	5.1	3	2	34	51	n/a	5	22	4.40
E	1/30 - 1/31/04	1440 (24)	23	0.6	2.0	2	1	59	75	n/a	6	41	6.83
F	2/2 - 2/4/04	2895 (48)	28	0.7	6.1	1	1	52	86	n/a	7	116	16.57
H	2/16 - 2/18/04	3760 (63)	124	1.9	7.4	9	4	9	60	150	32	555	17.34
K	3/25 - 3/27/04	2365 (39)	47	1.1	8.1	30	1	6	6	38	12	33	2.75
L	3/29 - 3/30/04	885 (15)	21	1.3	4.3	1	0	53	54	55	5	22	4.40
Site 852													
D	1/27/04	455 (8)	20	2.0	5.8	3	4	30	32	n/a	8	136	17.00
F	2/2 - 2/4/04	2840 (47)	30	0.9	6.6	1	1	48	93	n/a	18	392	21.78
I	2/25 - 2/27/04	4000 (67)	96	1.4	6.6	6	1	22	163	258	39	806	20.67
K	3/25 - 3/27/04	2435 (41)	45	1.0	7.6	30	1	10	10	58	18	185	10.28
L	3/29 - 3/30/04	895 (15)	30	1.9	5.1	1	0	55	55	57	12	183	15.25
N	4/20 - 4/21/04	1295 (22)	22	0.9	2.8	4	5	36	38	116	9	53	5.89
Site 853													
F	2/2 - 2/4/04	2840 (47)	30	0.9	6.6	1	1	48	93	n/a	5	21	4.20
I	2/25 - 2/27/04	4000 (67)	96	1.4	6.6	6	1	22	163	258	10	126	12.60
L	3/29 - 3/30/04	895 (15)	30	1.9	5.1	1	0	55	55	57	3	24	8.00
Site 854													
E	1/30 - 1/31/04	1480 (25)	20	0.9	12.4	2	0	70	85	n/a	9	7	0.78
L	3/29 - 3/30/04	895 (15)	30	1.9	5.1	1	0	55	55	57	13	5	0.39
N	4/20 - 4/21/04	1295 (22)	22	0.9	2.8	4	5	36	38	116	10	4	0.40

TRA: Total rainfall amount; MRI: Mean rainfall intensity, MXRI: Maximum rainfall intensity, ADP: Antecedent dry period, AR: Antecedent rainfall, Q surf: Runoff volume from contributing road area, Q flume: Ditch discharge.

Table 3. Characteristics of rainstorm events and sediment data collected during the monitoring period.

Event No.	Start Date	End Date	Duration min	Duration hour	TRA mm	15min MXRI mm/hr	MXRI mm/h	ADP days	2w AR mm	Q surf m^3	Q flume m^3	Qf/Qs	T Sed kg	MSED y g/h	PSSC mg/l	MSED c mg/l	SEDAREA g/m^2
Site 850																	
A	10/22/04 18:15	10/23/04 12:40	1105	18	47	10.2	7.6	n/a	74	31.9	28.8	0.90	0.56	31	108	36	1
E	11/26/04 17:00	11/28/04 12:35	2615	44	11	2.0	1.3	34	15	7.7	4.4	0.58	0.08	2	68	16	0
F	12/6/04 9:30	12/10/04 10:00	5790	96	81	2.0	2.0	8	23	54.5	225.2	4.13	9.85	102	934	101	15
G	12/25/04 22:45	1/5/05 9:30	15045	251	152	11.2	5.8	16	2	102.2	413.3	4.04	14.65	58	182	22	22
H	1/7/05 2:30	1/10/05 17:25	5215	87	88	9.1	6.1	2	153	59.1	401.4	6.79	5.628	65	139	20	8
I	1/10/05 17:30	1/12/05 10:55	2485	41	6	6.1	3.8	0	193	4.1	9.7	2.38	0.23	6	95	14	0
J	1/26/05 0:55	1/31/05 11:45	7850	131	54	11.2	5.8	14	4	36.3	131.5	3.62	4.80	37	255	36	7
K	2/6/05 18:45	2/7/05 3:45	540	9	7	5.1	2.3	6	56	4.8	0.9	0.19	0.03	3	50	35	0
L	2/13/05 7:15	2/14/05 11:35	1700	28	22	4.1	2.0	6	10	14.5	12.6	0.87	0.15	5	68	18	0
M	2/19/05 16:30	2/22/05 3:15	3525	59	20	8.1	4.6	5	37	13.1	23.5	1.79	0.824	14	409	46	1
N	2/27/05 13:45	3/1/05 10:15	2670	45	29	10.2	7.9	5	40	19.3	30.6	1.59	2.513	56	429	48	4
Q	3/18/05 21:00	3/25/05 10:45	9465	158	114	21.3	8.6	17	0	76.7	160.4	2.09	11.690	74	757	47	17
R	3/27/05 9:15	4/1/05 7:15	7080	118	71	16.2	6.6	2	115	47.5	303.2	6.38	11.810	100	520	53	18
S	4/3/05 5:30	4/6/05 7:20	4430	74	36	13.2	9.1	2	139	24.2	91.6	3.79	4.836	65	581	90	7
T	4/6/05 23:45	4/12/05 5:05	7520	125	96	10.2	8.1	1	108	64.4	405.9	6.30	10.261	82	348	40	15
U	4/12/05 5:10	4/15/05 11:30	4700	78	22	7.1	2.8	0	135	14.8	24.1	1.62	0.964	12	365	75	1
V	4/16/05 13:30	4/18/05 10:15	2685	45	10	3.0	2.0	1	154	7.0	4.0	0.57	0.035	1	127	23	0
W	5/4/05 13:45	5/13/05 14:35	13010	217	95	12.2	8.4	16	14	63.9	171.6	2.68	14.130	65	872	59	21
X	5/15/05 15:15	5/20/05 9:35	6860	114	45	8.1	4.1	2	100	30.3	34.1	1.12	2.794	24	994	135	4

TRA: Total rainfall amount; MXRI: Maximum rainfall intensity, ADP antecedent dry period, AR: Antecedent rainfall, Q surf: Runoff volume from contributing road area; Q flume: Ditch discharge; T sed: Total sediment yield during an event, MSED y: Mean sediment yield during an event; MSED c: Mean sediment concentration during an event; PSSC: Peak sediment concentration during an event; SEDAREA: Sediment yield per unit area of road surface.

Table 3. Characteristics of rainstorm events and sediment data collected during the monitoring period, continued.

Event No.	Start Date	End Date	Duration min	Duration hour	TRA mm	15min MXRI mm/hr	MXRI mm/h	ADP days	2w AR mm	Q surf m^3	Q flume m^3	Qf/Qs	T Sed kg	MSED y g/h	PSSC mg/l	MSED c mg/l	SEDAREA g/m^2
851																	
A	10/22/04 18:15	10/23/04 22:25	1690	28	47	10.2	7.6	n/a	66	12	5	0.38	0.21	8	222	76	1
B	10/25/04 16:00	10/26/04 23:00	1860	31	36	13.2	8.9	2	113	9	9	0.94	0.25	8	57	45	1
C	11/2/04 16:30	11/4/04 13:45	2715	45	17	12.2	7.9	7	87	4.2	1.5	0.36	0.24	5	943	124	1
D	11/15/04 17:45	11/16/04 16:40	1375	23	5	2.0	1.0	11	23	1.2	0.0	0.01	0.00	0	27	14	0
E	11/26/04 17:00	11/28/04 12:35	2615	44	11	2.0	1.3	10	15	2.9	0.3	0.10	0.01	0	83	29	0
F	12/6/04 9:30	12/10/04 11:20	5870	98	82	2.0	2.0	8	23	20.9	367.4	17.54	14.63	150	734	94	57
G	12/25/04 22:45	1/5/05 12:15	15210	254	152	11.2	5.8	15	2	39.0	443.0	11.35	18.53	73	168	31	72
H	1/7/05 2:30	1/10/05 17:25	5215	87	88	9.1	6.1	2	153	22.6	775.2	34.34	26.80	308	1132	72	105
I	1/10/05 17:30	1/14/05 5:00	5010	84	6	6.1	3.8	0	193	1.6	16.6	10.63	0.43	5	200	24	2
L	2/13/05 7:15	2/15/05 5:15	2760	46	22	4.1	2.0	30	10	5.5	16.3	2.95	0.93	20	431	75	4
N	2/27/05 13:45	3/1/05 10:45	2700	45	29	10.2	7.9	12	40	7.4	52.3	7.12	4.01	89	2014	157	16
O	3/1/05 13:00	3/4/05 0:00	3540	59	6	4.1	3.0	0	54	1.6	10.0	6.18	0.32	5	491	58	1
P	3/4/05 0:30	3/5/05 15:25	2335	39	5	3.0	1.5	0	59	1.4	5.2	3.79	0.39	10	388	85	2
Q	3/18/05 21:00	3/25/05 15:55	9775	163	114	21.3	8.6	13	0	29.3	291.6	9.96	17	101	1147	127	64
R	3/27/05 9:15	4/1/05 13:20	7445	124	71	16.2	6.6	2	115	18.2	307.0	16.91	10.784	87	316	52	42
S	4/3/05 5:30	4/6/05 14:00	4830	80	36	13.2	9.1	2	139	9.2	127.1	13.76	3.309	41	333	58	13
T	4/6/05 23:45	4/11/05 16:45	6780	113	96	10.2	8.1	0	108	24.6	464.6	18.89	11.837	105	83	23	46
U	4/11/05 16:50	4/15/05 15:00	5650	94	22	7.1	3.0	0	165	5.7	59.8	10.56	4.612	49	148	22	18
W	5/4/05 13:45	5/13/05 19:05	13280	221	95	12.2	8.4	19	14	24.4	168.9	6.92	3.979	18	313	22	16
X	5/15/05 15:15	5/21/05 16:25	8710	145	45	8.1	4.1	2	100	11.6	84.7	7.32	1.352	9	28.2	9	5

TRA: Total rainfall amount; MXRI: Maximum rainfall intensity, ADP antecedent dry period, AR: Antecedent rainfall, Q surf: Runoff volume from contributing road area; Q flume: Ditch discharge; T sed: Total sediment yield during an event, MSED y: Mean sediment yield during an event; MSED c: Mean sediment concentration during an event; PSSC: Peak sediment concentration during an event; SEDAREA: Sediment yield per unit area of road surface.

Table 3. Characteristics of rainstorm events and sediment data collected during the monitoring period, continued.

Event	Start Date	End Date	Duration	Duration	TRA	MXRI	MXRI	ADP	2w AR	Q surf	Q flume	Qf/Qs	T Sed	MSED y	PSSC	MSED c	SEDAREA
No.			min	hour	mm	mm/hr	mm/h	days	mm	m^3	m^3		kg	g/h	mg/l	mg/l	g/m^2
Site 853																	
A	10/22/04 18:00	10/24/04 12:05	2525	42	52	10.2	8.1	n/a	92	5.5	5.1	0.93	0.16	4	686	100	1.50
B	10/25/04 16:00	10/28/04 11:40	4060	68	44	12.2	8.6	1	125	4.7	11.0	2.34	0.16	2	170	54	1.52
C	11/2/04 17:30	11/3/04 7:20	830	14	16	12.2	7.4	5	102	1.7	0.6	0.34	0.03	2	152	36	0.28
F	12/6/04 9:15	12/10/04 12:25	5950	99	137	14.2	7.6	33	22	14.7	239.7	16.29	3.44	35	152	25	32.12
G	12/25/04 23:00	1/3/05 12:30	12330	206	142	10.2	5.3	15	3	15.3	146.9	9.62	2.30	11	134	21	21.45
H	1/7/05 2:45	1/10/05 14:55	5050	84	83	8.1	5.1	4	143	8.9	185.4	20.78	1.49	18	75	13	13.94
I	1/10/05 17:45	1/15/05 1:55	6250	104	7	7.1	5.1	0	188	0.8	7.1	9.37	0.02	0	31	8	0.21
J	1/26/05 1:00	1/31/05 12:55	7915	132	50	10.2	4.6	11	4	5.3	39.8	7.49	1.90	14	134	31	17.69
L	2/13/05 7:00	2/14/05 7:15	1455	24	26	6.1	2.5	13	10	2.7	0.4	0.14	0.01	0	35	19	0.06
M	2/19/05 16:15	2/22/05 11:40	4045	67	18	8.1	6.3	5	40	1.9	0.5	0.27	0.029	0	130	32	0.27
N	2/27/05 13:45	3/1/05 12:10	2785	46	22	8.1	6.6	5	39	2.4	0.8	0.32	0.040	1	127	70	0.37
Q	3/18/05 21:15	3/25/05 12:00	9525	159	118	17.3	8.4	17	0	12.6	62.1	4.92	1.43	9	101	28	13.39
R	3/27/05 9:00	3/30/05 12:45	4545	76	92	18.3	6.9	2	118	9.8	150.1	15.25	2.293	30	59	16	21.40
S	4/3/05 5:15	4/5/05 12:25	3310	55	36	15.2	7.1	4	160	3.9	38.7	9.94	0.341	6	92	15	3.19
T	4/6/05 23:00	4/12/05 13:50	8090	135	111	10.2	7.6	1	129	11.9	228.9	19.30	2.802	21	109	14	26.15
V	4/16/05 12:45	4/18/05 5:00	2415	40	16	4.1	3.0	4	160	1.7	5.1	2.94	0.018	0	10	3	0.17
W	5/4/05 13:00	5/11/05 11:35	9995	167	104	13.2	8.9	16	19	11.1	58.8	5.29	0.449	3	19	7	4.19
X	5/15/05 15:00	5/21/05 11:20	8420	140	55	9.1	5.1	4	111	5.9	13.9	2.36	0.071	1	43	7	0.66

Event	Start Date	End Date	Duration	Duration	TRA	MXRI	MXRI	ADP	2w AR	Q surf	Q flume	Qf/Qs	T Sed	MSED y	PSSC	MSED c	SEDAREA
No.			min	hour	mm	mm/hr	mm/h	days	mm	m^3	m^3		kg	g/h	mg/l	mg/l	g/m^2
Site 857																	
A	10/22/04 18:15	10/23/04 15:40	1285	21	45	30.5	8.4	n/a	92	9	1	0.12	0.03	1	88	43	0.14
C	11/2/04 16:30	11/4/04 14:55	2785	46	19	45.7	8.9	10	87	4	0	0.13	0.00	0	44	26	0.02
D	11/15/04 17:00	11/17/04 10:45	2505	42	6	6.1	1.5	11	27	1	0	0.38	0.00	0	77	28	0.02
G	12/25/04 22:45	1/3/05 9:40	12175	203	196	30.5	7.9	39	4	41	21	0.52	1.31	6	131	50	6.30
H	1/7/05 1:45	1/10/05 14:05	5060	84	99	42.7	7.1	4	197	20	27	1.29	0.53	6	32	19	2.55
J	1/26/05 1:00	1/31/05 10:40	7780	130	57	33.5	7.1	15	4	12	8	0.71	0.93	7	383	141	4.46
M	2/19/05 16:30	2/21/05 22:10	3220	54	21	21.3	4.6	19	37	4	2	0.54	0.04	1	378	378	0.18
N	2/27/05 13:45	3/1/05 9:05	2600	43	33	36.6	8.6	6	43	7	10	1.42	0.83	19	308	235	3.97
Q	3/18/05 22:15	3/24/05 21:25	8590	143	118	51.8	7.6	18	1	24	44	1.78	8.10	57	750	409	38.94
R	3/27/05 9:00	3/30/05 9:20	4340	72	75	33.5	6.3	2	118	16	25	1.59	2.03	28	267	87	9.76
S	4/3/05 4:45	4/5/05 9:40	3175	53	36	45.7	8.9	4	145	7	3	0.38	0.09	2	371	194	0.44
T	4/6/05 23:30	4/10/05 21:00	5610	94	93	30.5	7.1	2	111	19	4	0.23	0.10	1	117	87	0.47

TRA: Total rainfall amount; MXRI: Maximum rainfall intensity, ADP antecedent dry period, AR: Antecedent rainfall, Q surf: Runoff volume from contributing road area; Q flume: Ditch discharge; T sed: Total sediment yield during an event, MSED y: Mean sediment yield during an event; MSED c: Mean sediment concentration during an event; PSSC: Peak sediment concentration during an event; SEDAREA: Sediment yield per unit area of road surface

Table 3. Characteristics of rainstorm events and sediment data collected during the monitoring period, continued.

Event No.	Start Date	End Date	Duration min	Duration hour	TRA mm	15min MXRI mm/hr	MXRI mm/h	ADP days	2w AR mm	Q surf m^3	Q flume m^3	Qf/Qs	T Sed kg	MSED y g/h	PSSC mg/l	MSED c mg/l	SEDAREA g/m^2
Site 856																	
A	10/22/04 18:00	10/23/04 22:00	1680	28	52	10.2	8.1	n/a	92	14	27	1.96	0.92	33	34	11	3.42
B	10/25/04 16:00	10/28/04 13:35	4175	70	44	12.2	8.6	2	125	12	108	9.13	6.73	97	421	83	24.91
C	11/2/04 17:30	11/4/04 10:45	2475	41	16	12.2	7.4	5	102	4	24	5.62	0.81	20	509	46	3.00
E	11/26/04 17:15	11/29/04 16:25	4270	71	11	2.0	1.8	22	17	3	5	1.63	0.23	3	70	34	0.87
F	12/6/04 9:15	12/14/04 6:30	11355	189	140	14.2	7.6	7	22	38	1653	43.77	27.94	148	680	36	103.47
G	12/25/04 23:00	1/7/2005 2:40	17500	292	143	10.2	5.3	12	3	39	1458	37.78	26.99	93	410	32	99.96
H	1/7/05 2:45	1/10/05 17:10	5185	86	83	8.1	5.1	0	143	22	1037	46.13	18.56	215	984	72	68.74
J	1/26/05 0:00	1/31/05 10:35	7835	131	50	10.2	4.6	15	4	13	240	17.87	14.15	108	857	112	52.41
K	2/6/05 18:30	2/8/05 3:45	1995	33	8	4.1	1.8	6	52	2	4	1.86	0.23	7	300	72	0.85
L	2/13/05 7:00	2/15/05 14:00	3300	55	26	6.1	2.5	5	10	7	48	6.99	1.46	26	336	72	5.39
M	2/19/05 16:15	2/22/05 12:00	4065	68	18	8.1	6.3	4	40	5	24	4.98	1.39	20	815	55	5.14
N	2/27/05 13:45	3/1/05 11:35	2750	46	22	8.1	6.6	5	39	6	28	4.65	3.025	66	678	83	11.20
O	3/1/05 13:00	3/3/05 22:05	3425	57	6	4.1	2.0	0	44	2	4	2.35	0.352	6	311	60	1.30
P	3/4/05 0:15	3/5/05 10:40	2065	34	6	4.1	1.5	0	50	2	1	0.80	0.097	3	235	76	0.36
Q	3/18/05 21:15	3/25/05 16:10	9775	163	118	17.3	8.4	13	0	32	526	16.53	17.714	109	417	39	65.61
R	3/27/05 9:00	4/2/05 22:00	9420	157	92	18.3	6.9	2	118	25	1210	48.51	10.150	65	78	16	37.59
S	4/3/05 5:15	4/6/05 20:40	5245	87	36	15.2	7.1	0	160	10	300	30.57	2.875	33	150	22	10.65
T	4/6/05 23:00	4/12/05 6:55	7675	128	104	10.2	7.6	0	129	28	1659	59.19	15.806	124	222	19	58.54
U	4/12/05 7:00	4/16/05 6:30	5730	96	20	8.1	3.0	0	143	5	90	16.68	1.979	21	40.2	3	7.33
V	4/16/05 12:45	4/21/05 13:10	7225	120	16	4.1	3.0	0	160	4	122	27.91	0.274	2	25	5	1.02
W	5/4/05 13:00	5/14/05 16:40	14620	244	104	13.2	8.9	13	19	28	1022	36.43	3.589	15	217	11	13.29
X	5/15/05 0:00	5/25/05 12:10	15130	252	65	9.1	5.1	0	105	17	401	22.93	2.762	11	80	8	10.23

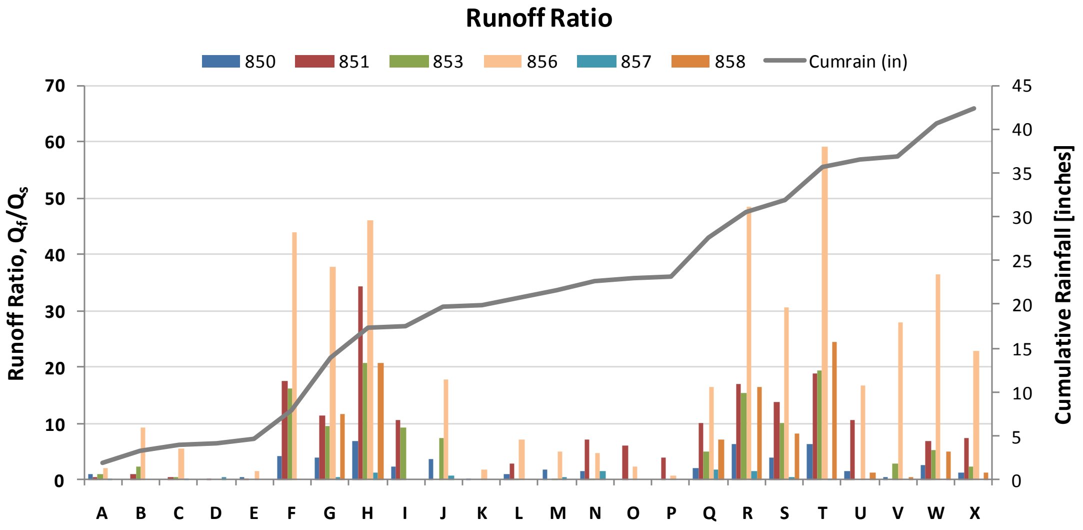
TRA: Total rainfall amount; MXRI: Maximum rainfall intensity, ADP antecedent dry period, AR: Antecedent rainfall, Q surf: Runoff volume from contributing road area; Q flume: Ditch discharge; T sed: Total sediment yield during an event, MSED y: Mean sediment yield during an event; MSED c: Mean sediment concentration during an event; PSSC: Peak sediment concentration during an event; SEDAREA: Sediment yield per unit area of road surface.

Table 3. Characteristics of rainstorm events and sediment data collected during the monitoring period, continued.

Event No.	Start Date	End Date	Duration min	Duration hour	TRA mm	MXRI mm/hr	MXRI mm/h	ADP days	2w AR mm	Q surf m^3	Q flume m^3	Qf/Qs	T Sed kg	MSED y g/h	PSSC mg/l	MSED c mg/l	SEDAREA g/m^2
Site 858																	
G	12/25/04 22:45	1/3/05 10:30	12225	204	196	30.5	7.9	n/a	4	21	244	11.56	0.98	5	696	179	9.03
H	1/7/05 1:45	1/10/05 13:05	5000	83	99	42.7	7.1	4	197	11	221	20.73	1.91	23	33	15	17.69
Q	3/18/05 22:15	3/25/05 5:45	9090	152	118	51.8	7.6	67	1	13	89	6.99	6.50	43	480	114	60.21
R	3/27/05 9:00	3/30/05 10:20	4400	73	75	33.5	6.3	2	118	8	133	16.44	10.87	148	899	83	100.60
S	4/3/05 4:45	4/5/05 10:10	3205	53	36	45.7	8.9	4	145	4	32	8.29	0.49	9	52	17	4.51
T	4/6/05 23:30	4/12/05 4:00	7470	125	94	30.5	7.1	2	111	10	248	24.51	41.31	332	748	118	382.48
U	4/12/05 6:45	4/15/05 10:35	4550	76	20	21.3	3.0	0	132	2	3	1.19	0.12	2	105	85	1.14
V	4/16/05 14:15	4/18/05 9:25	2590	43	11	9.1	1.5	1	150	1	0	0.37	0.00	0	15	15	0.01
W	5/4/05 12:45	5/11/05 9:55	9910	165	102	30.5	8.4	16	10	11	54	4.91	1.22	7	531	41	11.31
X	5/17/05 6:30	5/19/05 14:15	3345	56	39	27.4	5.3	6	117	4	6	1.33	0.23	4	164	72	2.12

TRA: Total rainfall amount; MXRI: Maximum rainfall intensity, ADP antecedent dry period, AR: Antecedent rainfall, Q surf: Runoff volume from contributing road area; Q flume: Ditch discharge; T sed: Total sediment yield during an event, MSED y: Mean sediment yield during an event; MSED c: Mean sediment concentration during an event; PSSC: Peak sediment concentration during an event; SEDAREA: Sediment yield per unit area of road surface.

Figure 16. Seasonal pattern of runoff ratio (Qf/Qs) at sites in relation to cumulative rainfall.



At the initiation of a storm, the rainfall infiltrates through the dry surfaces of the road and ditch. Discharge peaked approximately one hour after rainfall reached its maximum intensity. After some time, the road surface and ditch saturate and a larger portion of the rainfall runs off. After significant wetting by cumulative rainfall, the hillslope adjacent to the ditch contributes subsurface flow to the ditch as soils on the hillslopes partially saturate and downslope subsurface runoff occurs. The ratio between Q_f (discharge measured at the mouth of the culvert) and Q_s (discharge contributed by the road surface based on the amount of rain) changed during periods of wet weather as more flow was registered than rainfall could account for. The seasonal pattern of the ratio Qf/Qs is shown in Figure 16. There was little intercepted flow (large values of Qf/Qs) until cumulative rainfall reached about 6 inches (150 mm). The ratio also declined during the mid-winter dry period (events K to P). During these relatively dry periods, nearly all the flow was from the road surface (low values of Qf/Qs). Site 856 was particularly responsive with a high rate of flow from hillslopes during rainy periods.

Figure 17. Total storm runoff per unit area of contributing road surface (m^3/m^2) in relation to total event rainfall.

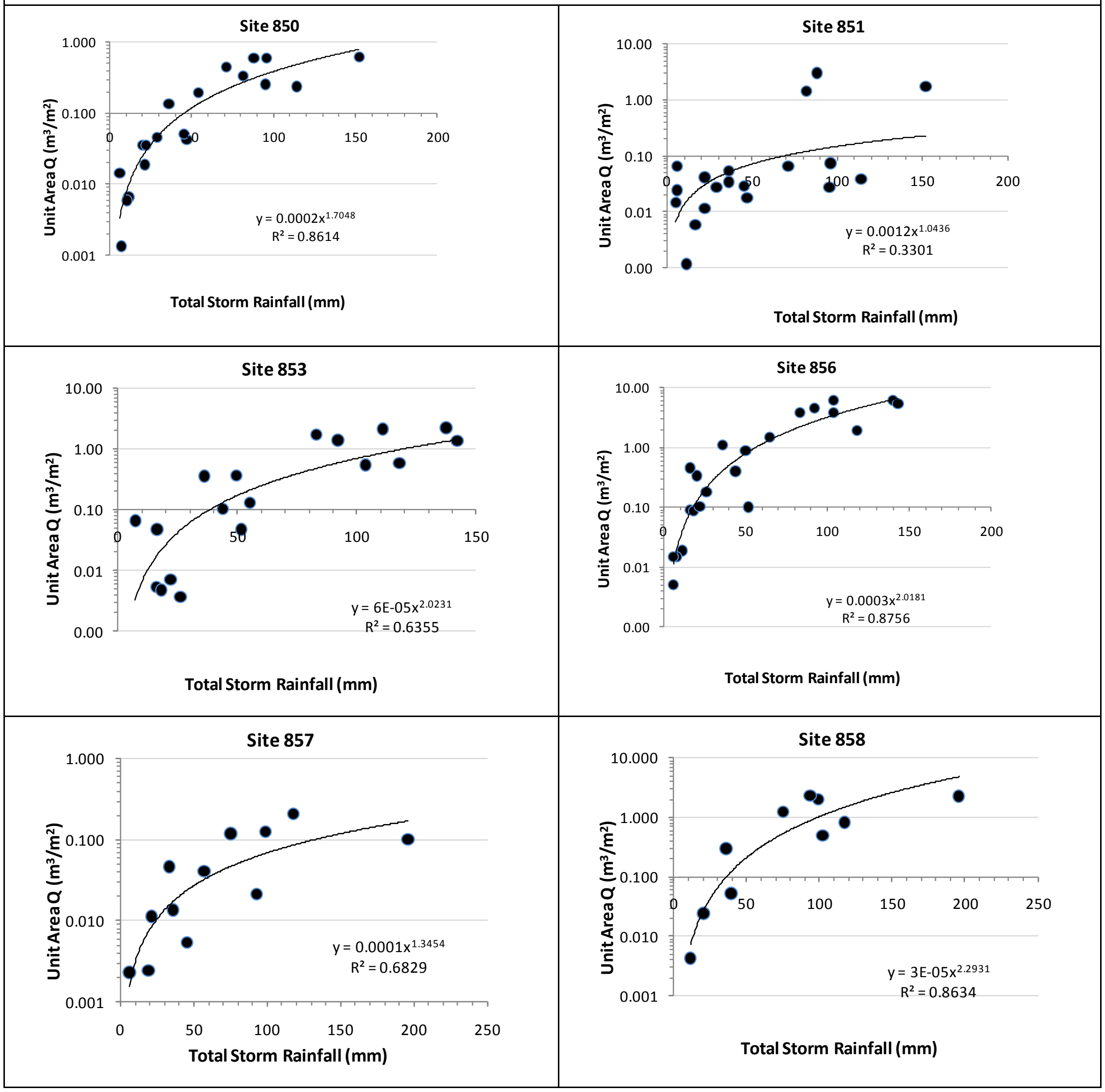
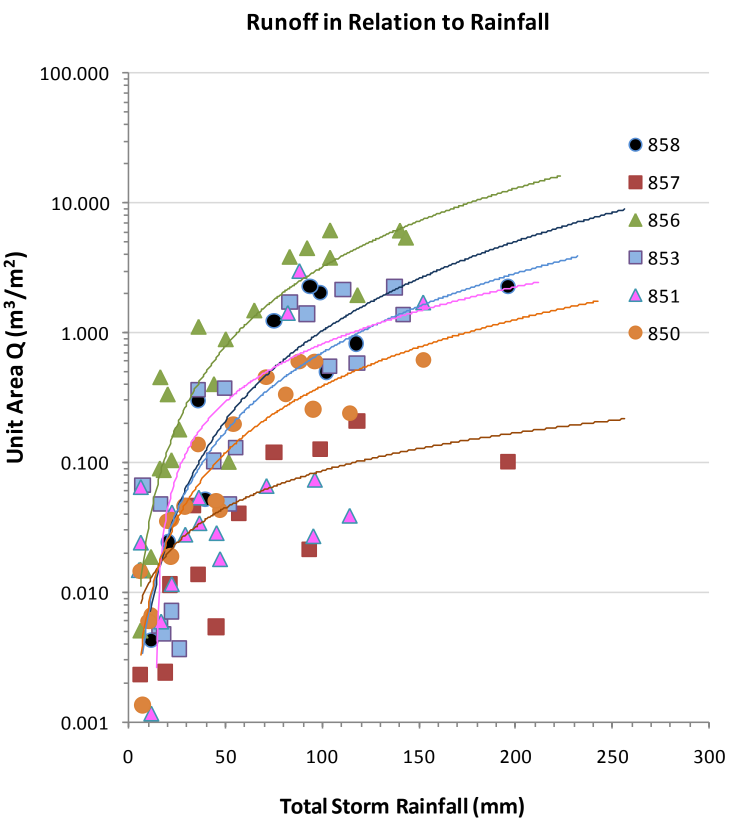


Figure 18. Total storm runoff per unit area of contributing road surface (m^3/m^2) as a function of total event rainfall for all sites.



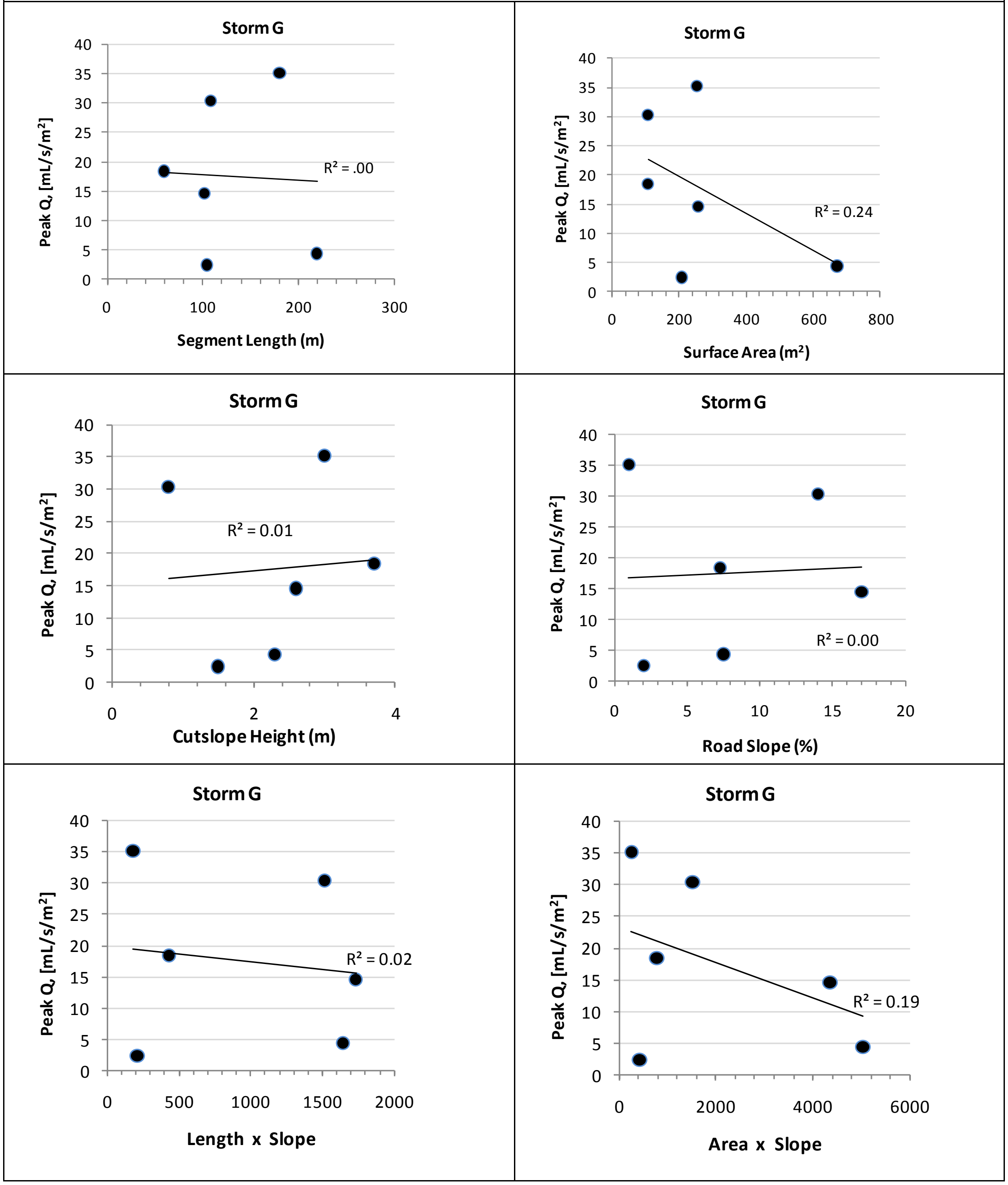
The total volume of runoff from each road was dependent on the total rainfall of the storm (TRA, mm). Figure 17 shows the total runoff volume per unit area of contributing road surface area in relation to total rainfall for all the events at each road site. TRA was highly correlated with discharge at all sites but 851 (the steep mainline road segment). It would be expected that the runoff volume would relate to rainfall volume, but there is a very large difference between events in the volume of runoff for the same amount of rainfall, as evident in Figure 18 where all sites are plotted together, and Q is expressed as total event discharge per unit area of road surface (m^3/m^2).

We hypothesize that the physical characteristics each of the road segments such as area, slope, and cutbank conditions determine important characteristics of runoff and storm hydrographs (Figure 18). To evaluate the effect of road characteristics, we focus on how the segments reacted during the same event so rainfall can be ignored. Two events in 2005 were selected when data was available for all 6 sites measured. One occurred early in the winter season (event G, 12/25/2004 to 1/5/2005) and one occurred at the end of the season (event T, 4/6/2005 to 4/10/2005.) We examine peak flow runoff and total storm runoff, both expressed per unit area of road surface.

The relationship between peak discharge per unit area of each road segment is shown in relation to physical site characteristics for event G in Figure 19. Peak flow is expressed as mL/s/m^2 of road surface so different segments can be directly compared. The physical characteristics included slope, contributing surface area, segment length, cutbank height, and combining terms suggested by Coe (2006) and Luce and Black (1999) including Area x Slope and Length x Slope. It is clear in Figure 19 that there was almost no relationship between peak flow during this storm and any of the individual physical characteristics. The strongest parameter was area, although the R^2 of a line fit through the data is only 0.24.

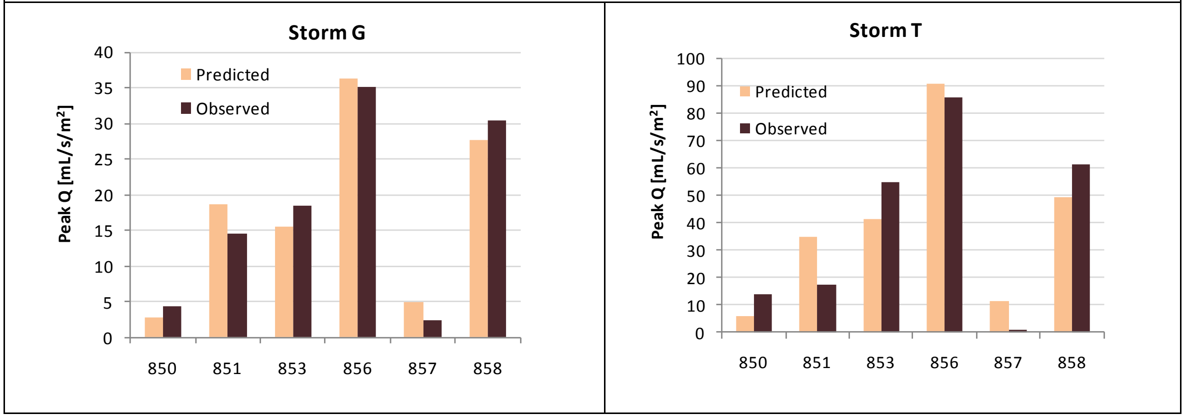
Prediction of peak flow was considerably improved by combining the characteristics. A multivariate regression was fit to the characteristics of road slope, segment length, surface area and cutslope height to explain the unit area Peak Q of segments during Storm G and Storm T. A backward stepping multivariate linear regression left all parameters in the model. An equation was produced for each storm that predicted Peak Q of each segment with an R^2 of 0.95 (event G) and 0.85 (event T). The equations differed slightly between storms. The regression predictions for events G and T are shown relative to observed in Figure 20. The multivariate equation with a combination of site characteristics produced predicted values of peak flows close to observed and replicated the variation in yield among the sites.

Figure 19. Peak flow per unit area of contributing road surface (mL/s/m^2) from road segments during event G in relation to physical road characteristics.



We also examined the relationship between the total storm runoff per unit area of road surface and the physical characteristics of the road. Though not shown, the same variability in peak flow with individual road characteristics observed in Figure 19 was apparent with total flow as well.

Figure 20. Results of a multivariate linear regression of peak flow relative to physical road characteristics during storm events.



SEDIMENT CHARACTERISTICS OF ROAD RUNOFF

The concentration of sediment (SSC, mg/L) in the road surface runoff showed a very similar pattern at all stations in all rain events. Figures 21 to 25 show the flow, rainfall, sediment concentration and traffic for two events at each station where traffic was measured. (Similar figures for 2004 are provided in Appendix A). To the extent possible, the two examples at each site were selected during the highest traffic periods. Weekend-centered storms were avoided, although this eliminated many events. Events not shown are similar to the examples in all cases.

Sediment concentration was highest at the initiation of rainfall and the storm hydrograph and decreased rapidly as the storm progressed. The highest sediment concentrations were always within the first hours of the event. Many of the events had two or more peaks in discharge. Later peaks, even if larger than the initial peak, showed some increase in sediment concentration from low levels but rarely achieved the higher values at the beginning of the event. Peak sediment concentration did not correspond to peak discharge.

Other road studies have also observed strong patterns of high initial values of sediment with rapidly decreasing concentrations (Bilby et al. 1989; Reid and Dunne 1984), which they interpreted as limitation on sediment supply as runoff washed sediment from the road surface. Observations in this study were consistent with this interpretation. Use of the road between storms produced some sediment on the road surface. The next surface runoff event cleaned the road surface rapidly. Without additional log truck traffic per HCP operating restrictions, the surface runoff maintained a very low level of sediment concentration. We note that the sediment concentrations observed from the road surfaces after the peaks were similar or lower than suspended sediment concentrations we have collected from the streams during many of these same events in other projects.

Note in Figures 21 through 25 that traffic patterns changed during the runoff events. More intense periods of traffic use indicating log hauling did not coincide with the storm hydrograph and did not appear to produce a significant increase in sediment concentration. Vehicle traffic that did occur during the main portion of the events when flow was elevated and presumably road surface runoff could be observed. Note that the duration of flow into the flumes exceeded the duration of flow on the road surface. This was confirmed by visually examining the 5-minute records of rainfall and traffic. When rainfall occurred during daytime hours, traffic was low and appeared to be limited to normal daily pickup use.

The maximum SSC observed varied among the sites ranging from 750 to 1147 mg/L in 2005 (Table 3). Sites 850 and 851 on the N. Fork Elk mainline were measured two years. In 2004, peak SSC was about 2950 mg/L at each site (Tables 2 and 3). We do not know why the sediment concentration was higher in 2004. The secondary road site (853) in Freshwater was also measured both years. The maximum SSC increased from 306 to 686 mg/L in 2005. Nevertheless, these sediment concentrations were far lower than observed by Bilby et al. (1989) and Reid and Dunne (1984) in earlier studies where sediment concentrations from active haul roads were as high as 15,000 mg/L.

Figure 21. Site 850 event hydrograph with rainfall, traffic, and sediment concentration.

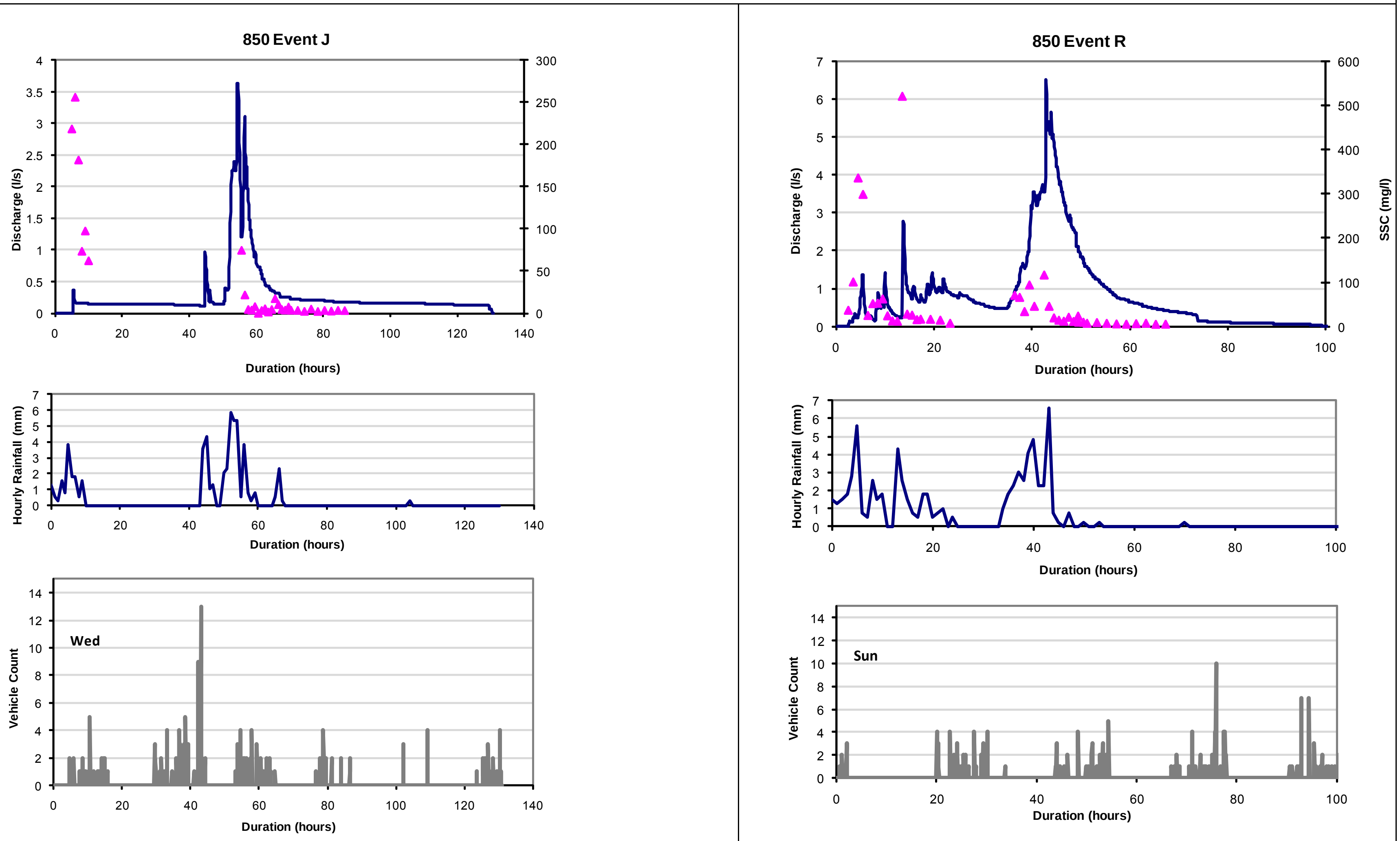


Figure 22. Site 851 event hydrograph with rainfall, traffic, and sediment concentration.

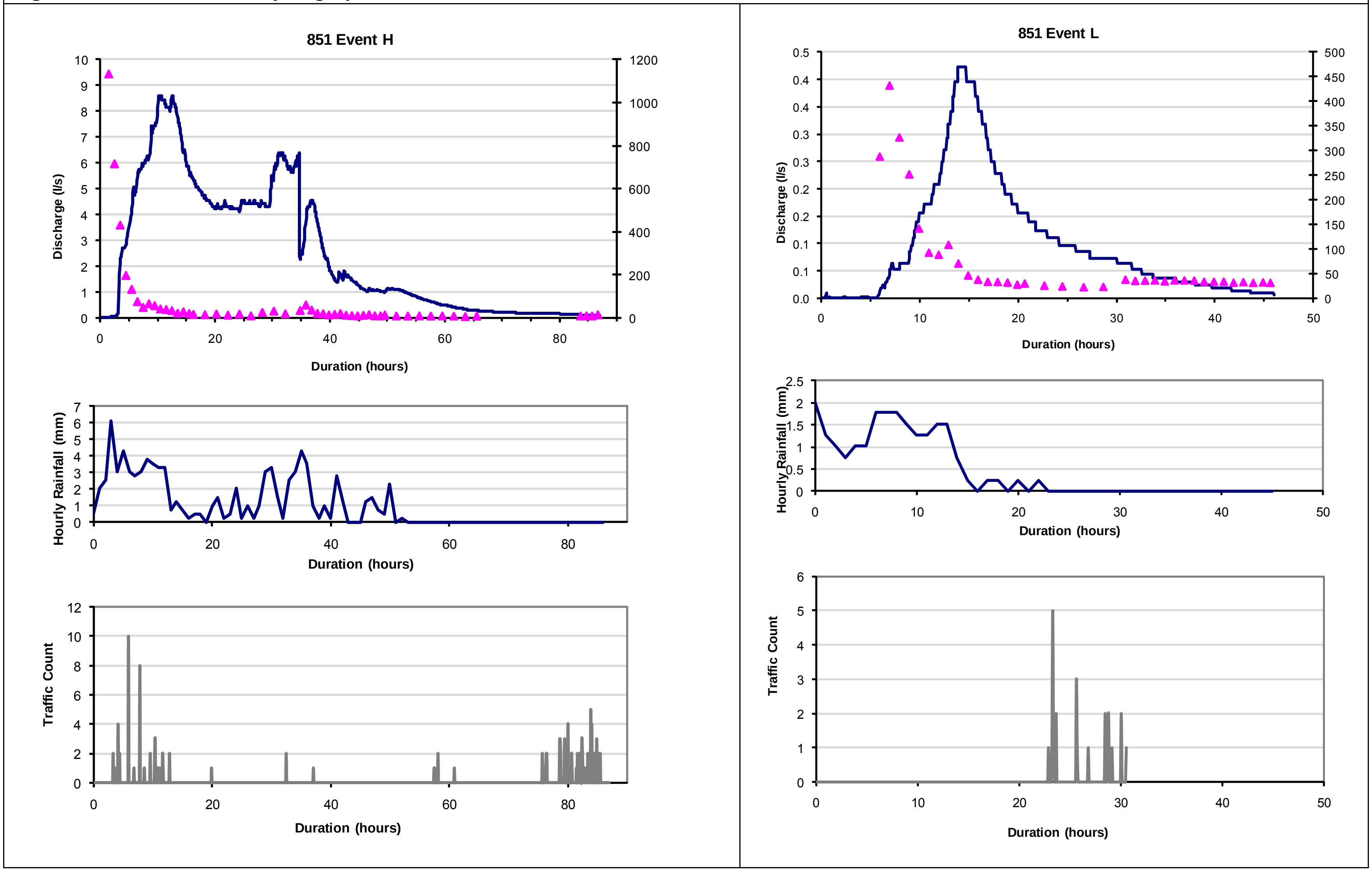


Figure 23. Site 857 event hydrograph with rainfall, traffic, and sediment concentration.

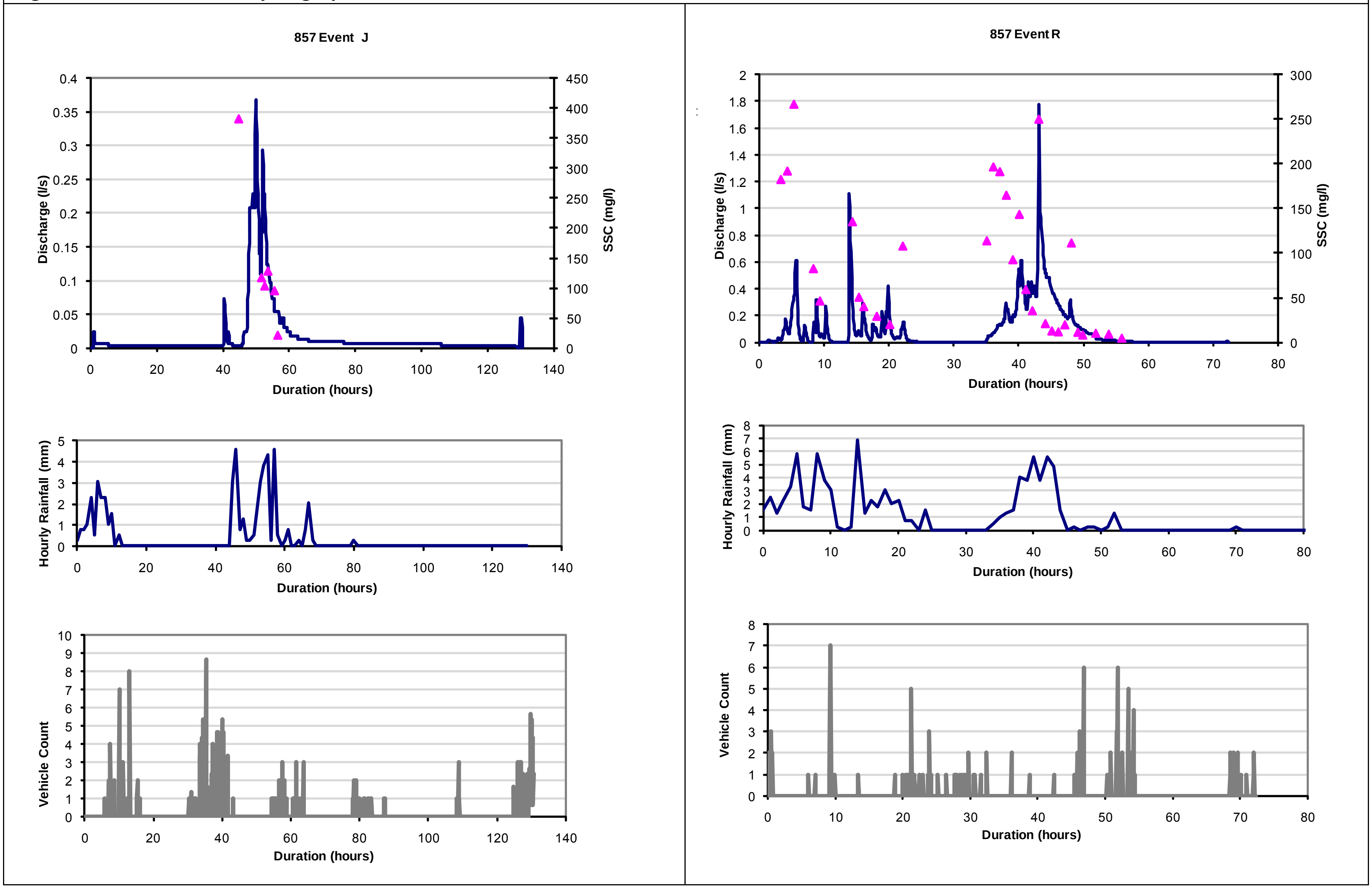


Figure 24. Site 856 event hydrograph with rainfall, traffic, and sediment concentration.

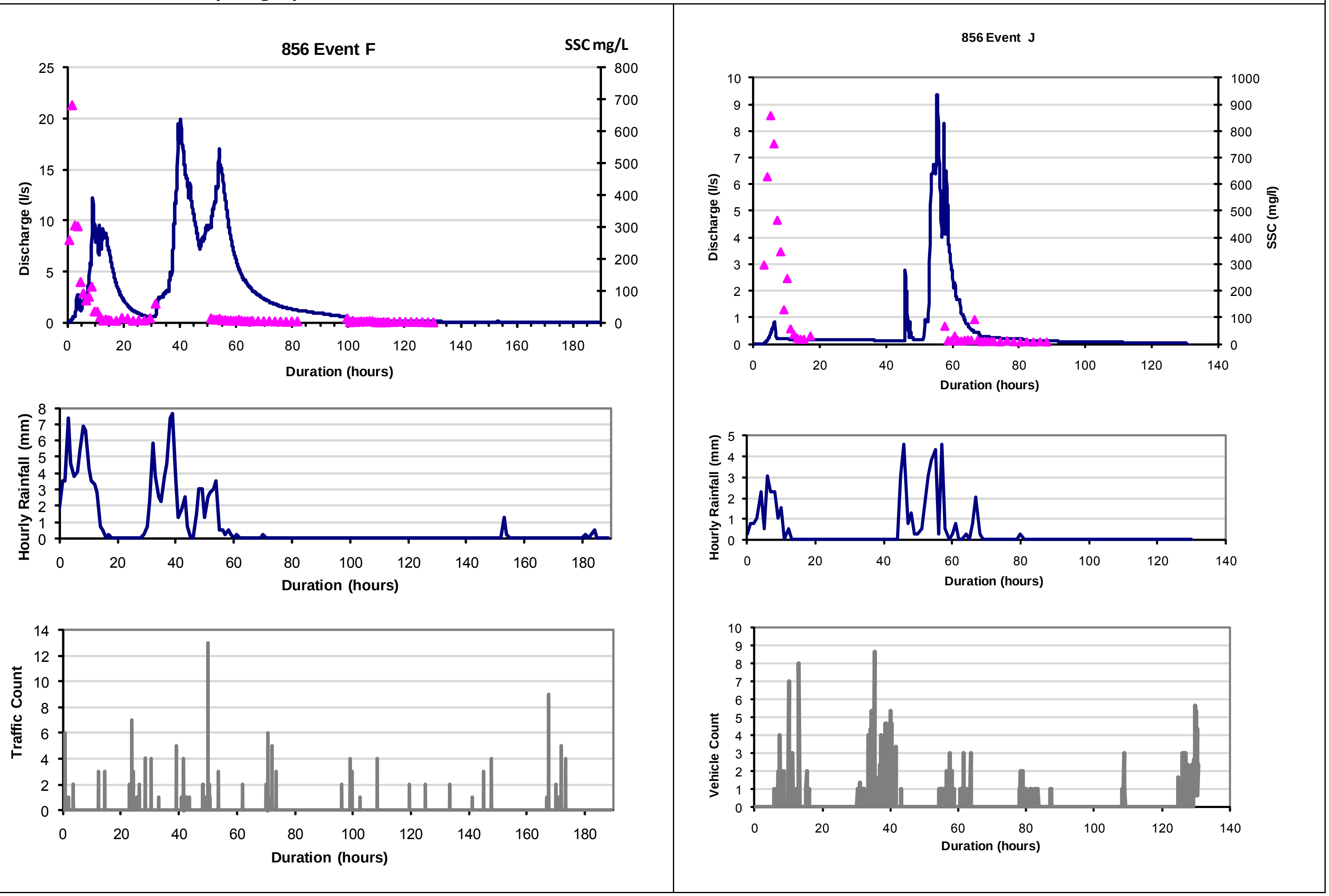
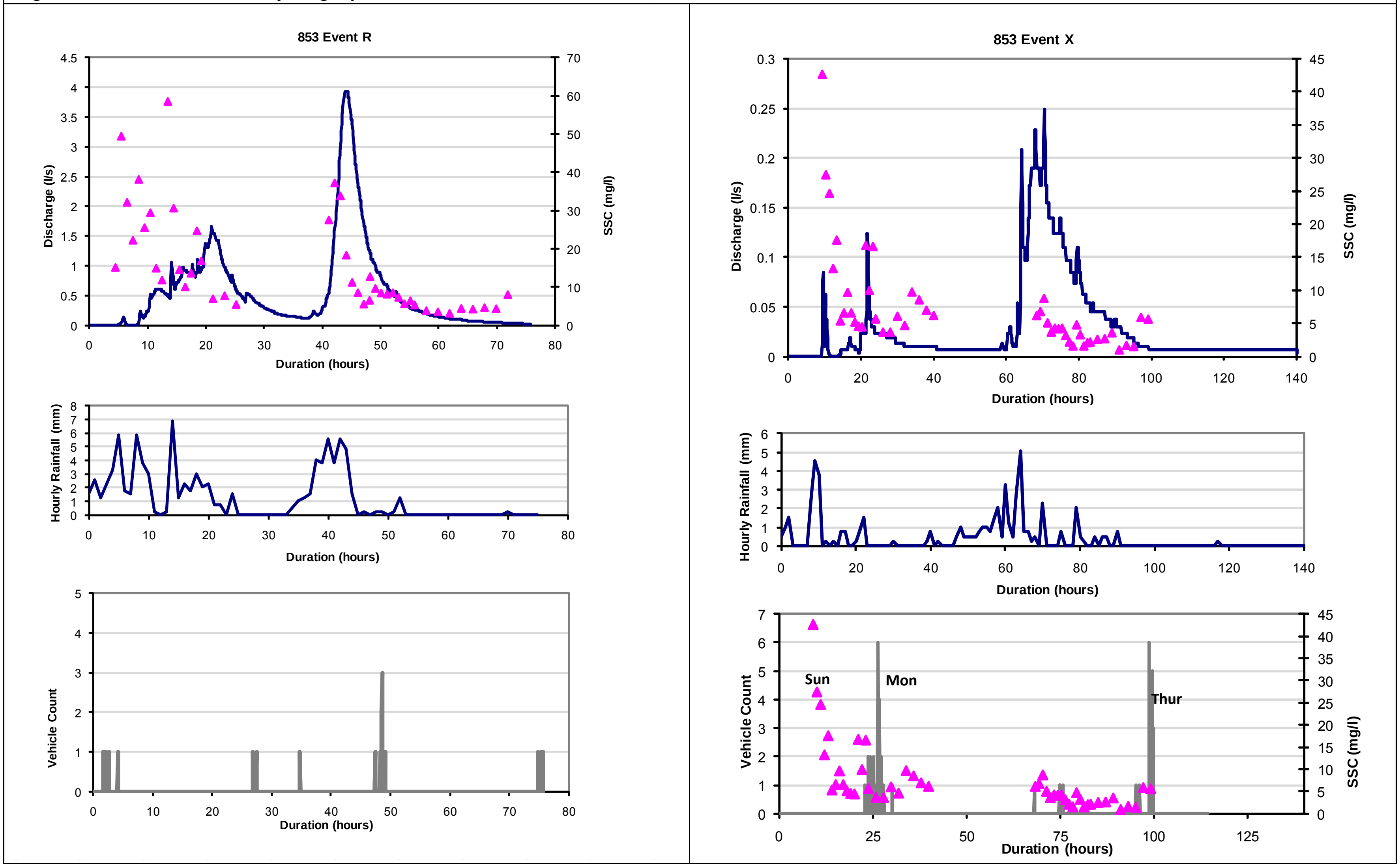


Figure 25. Site 853 event hydrograph with rainfall, traffic, and sediment concentration.



Unlike streamflow where these is a strong relationship between flow (Q, mL/s) and sediment concentration (SSC, mg/L), there was virtually no relationship between Q and SSC of the road runoff. Figure 26 shows the relationship between suspended sediment concentration and flume discharge for all samples collected during the year at each site in 2005. SSC and Q have been Ln-transformed to normalize the distribution. The range in SSC was wide, but discharge explained virtually none of the variation at any site at any level of flow.

Figure 26. Suspended sediment concentration (SSC, mg/L) in relationship to flume runoff (Q, L/s).

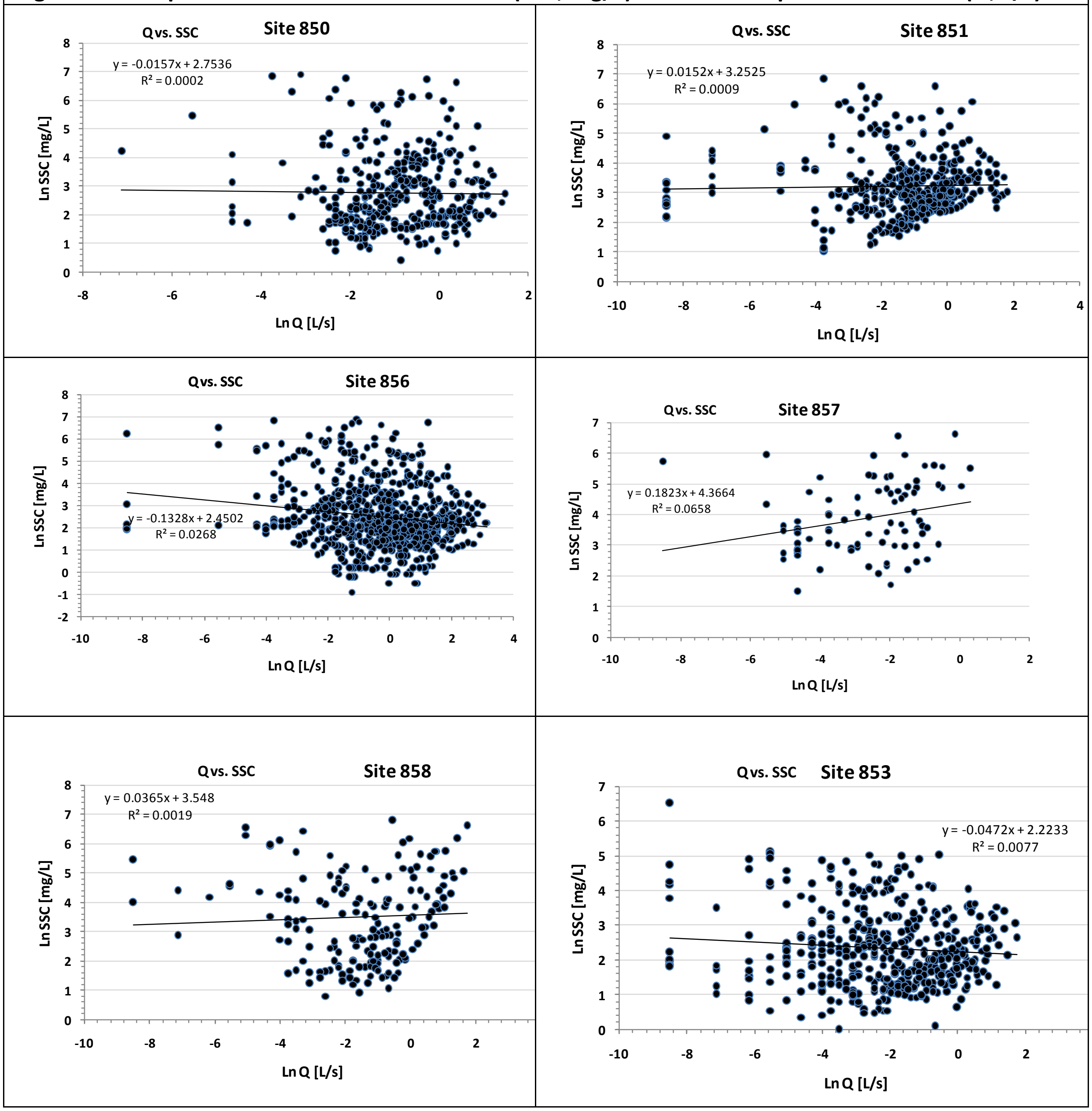
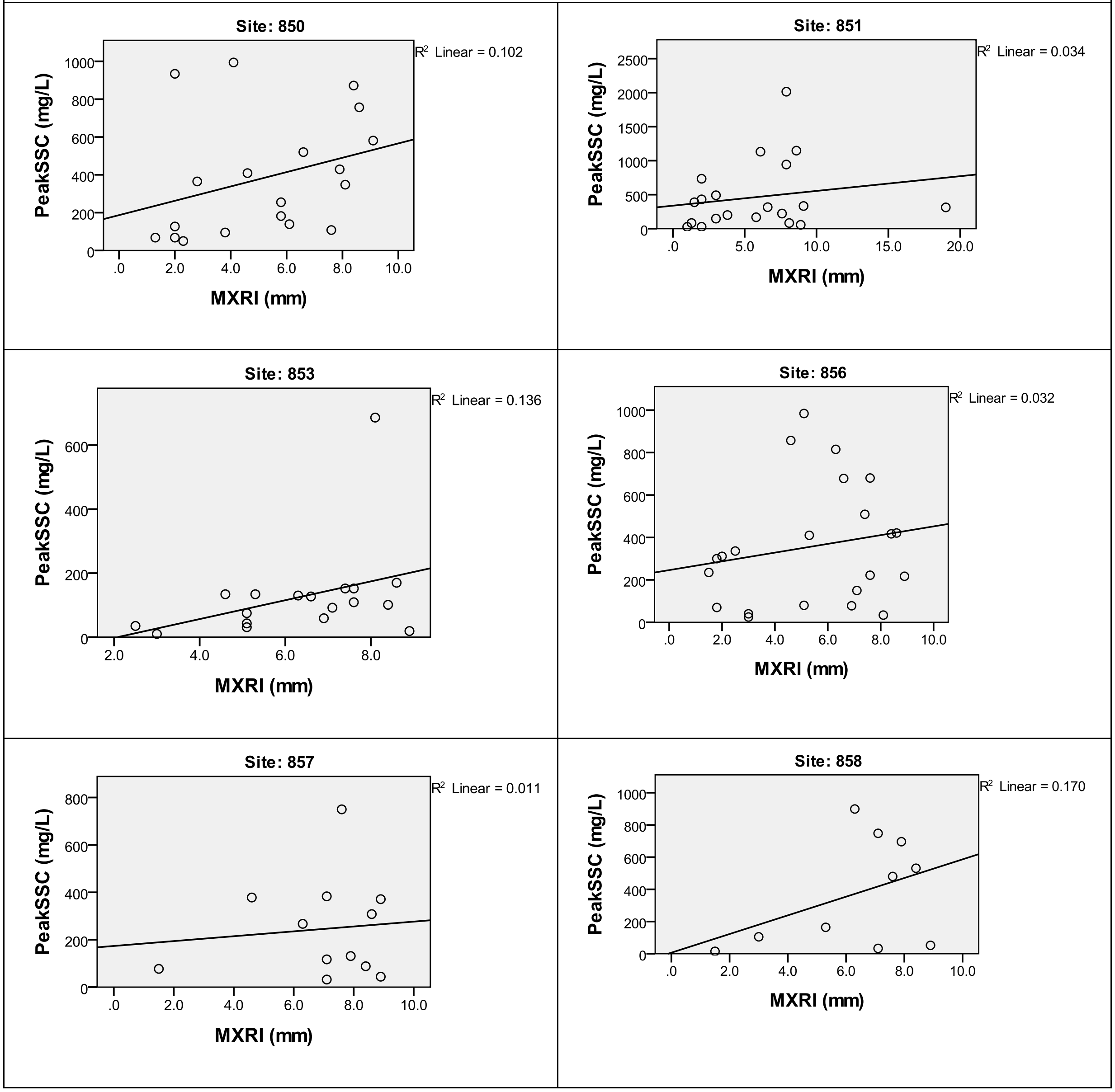


Figure 27. Relationship of event peak suspended sediment concentration [mg/L] in relation to maximum rainfall intensity [MXRI, mm/hr] in 2005.



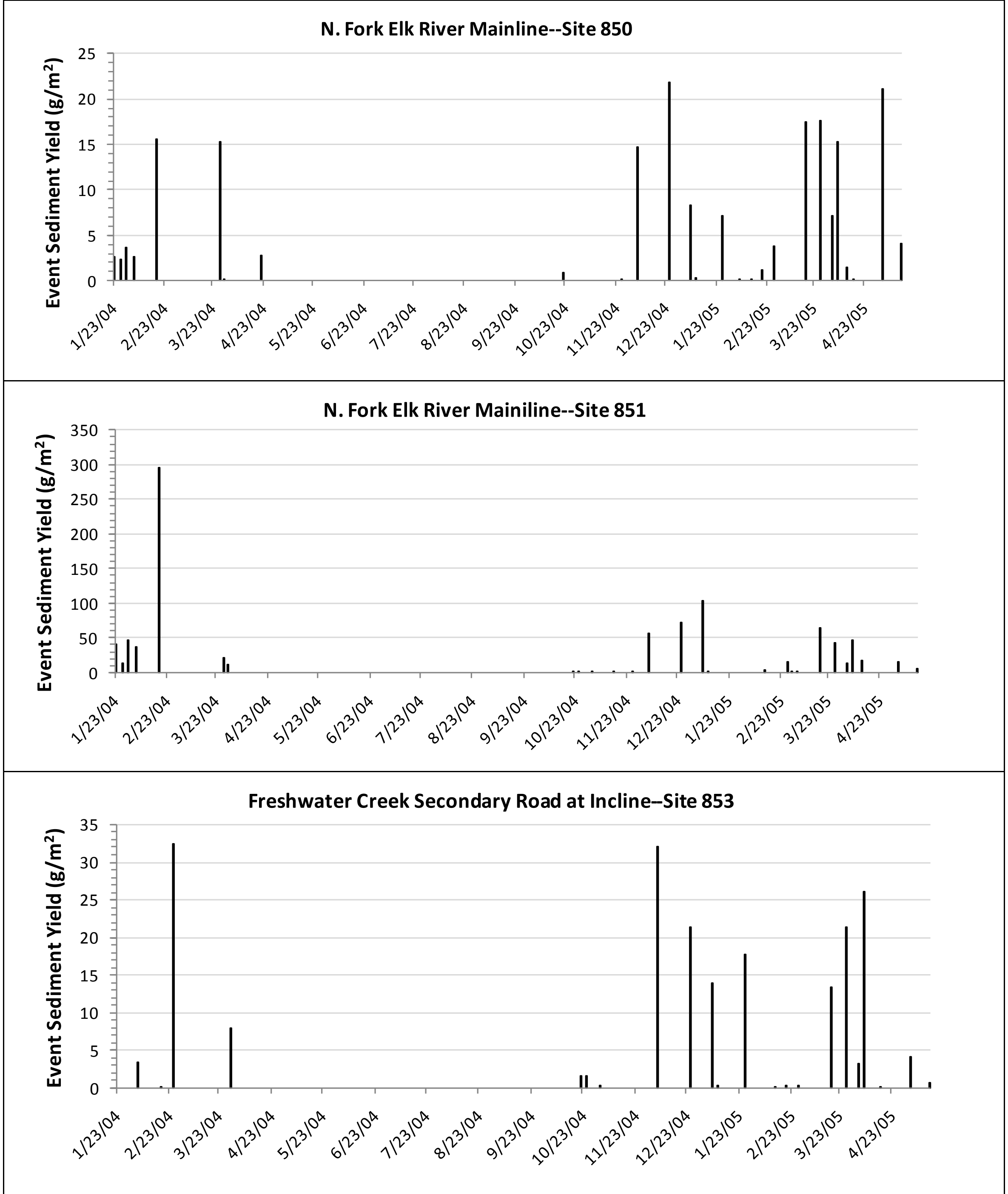
On the event level, there was somewhat more pattern to the sediment characteristics in relation to hydrologic parameters. The peak sediment concentration in each event was positively but weakly related to maximum rainfall intensity of the event (Figure 27).

SEDIMENT YIELD BY RAINFALL EVENT

Sediment yield was computed for each storm from the measured suspended sediment concentration (mg/L). Measured sediment data were added to the 5-minute continuous discharge record, and the sediment concentration between samples was interpolated between the measured values. Event sediment characteristics of peak SSC and total sediment yield are provided in Tables 2 and 3. The event total sediment is the sum of 5-min values in the defined period.

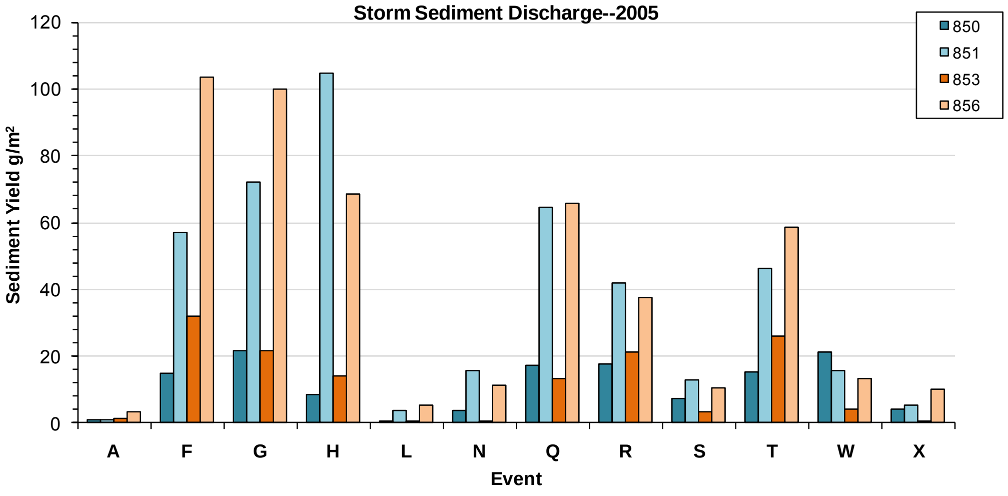
Event sediment yield at sites measured for two years is shown in Figure 28 (sites 850, 851 and 853). These results show that data was generally quite similar from year to year. The exception is site 851 where one storm produced much higher sediment than others. This paper has emphasized presentation of results from 2005 because more storms were sampled at more sites.

Figure 28. Event sediment yield [g/m^2] for sites measured for two years.



In both years and at all sites, sediment yield tended to be highest at the start of the rainy season and tapered off as the season progressed (Figure 29). The site on the very steep segment of the N. Fork Elk River mainline (851) experienced very high sediment yield during one event in 2004. This site had a maintenance issue when the cutslope slumped due to subsurface piping during a large storm. The road segment was maintained and sediment returned to normal levels. Nevertheless, this very steep road segment generally produced more sediment than the nearby lower gradient segment at site 850. Bilby et al. (1989) found higher sediment yields from steeper sloped roads. Weaver and Hagans (1994) advise that very steep sections of road are prone to deterioration from truck wear and require frequent maintenance and best construction practices to maintain good condition.

Figure 29. Event sediment yield by site for 2005 and 2004.



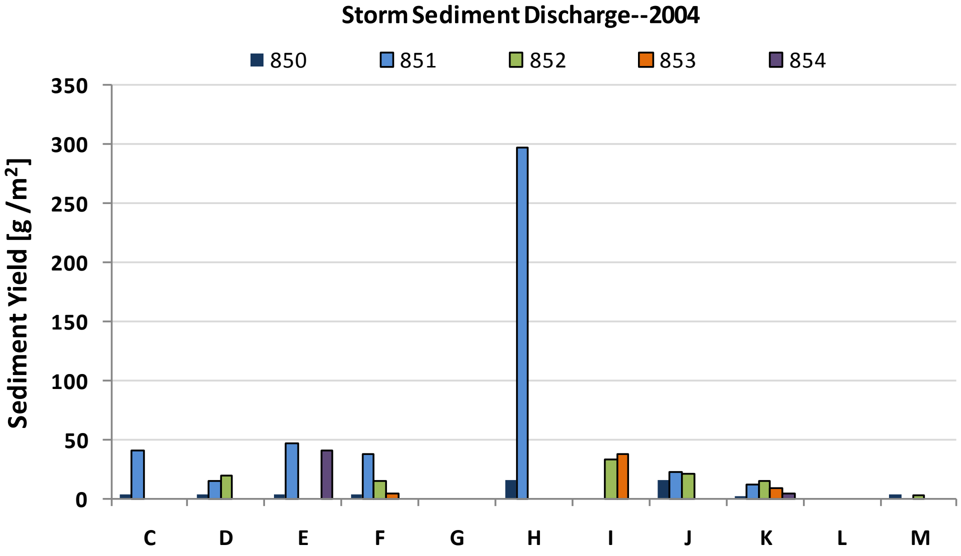
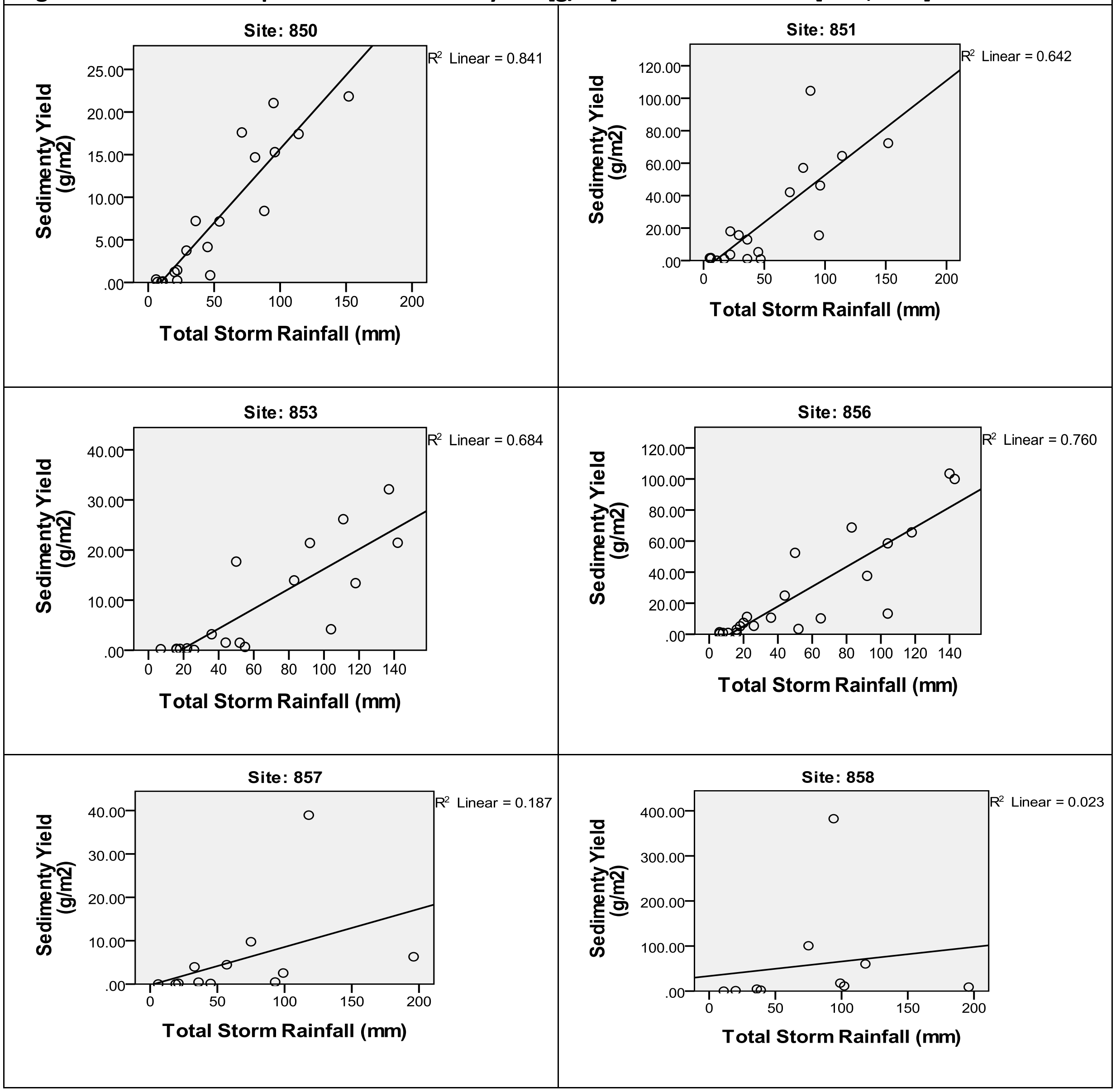


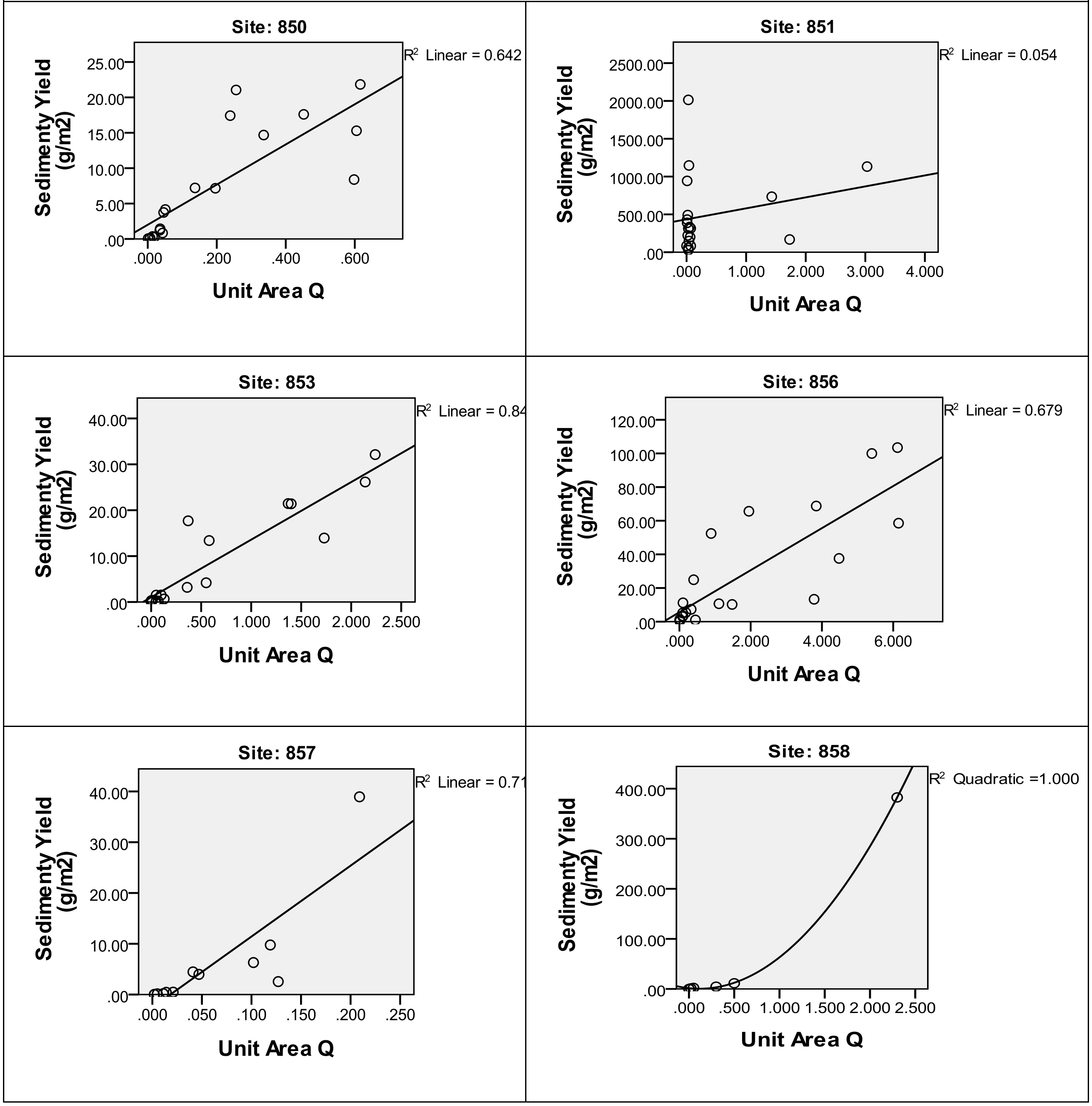
Figure 30. Relationship of event sediment yield [g/m^2] and total rainfall [TRA, mm] in 2005.



The strongest relationship between rainfall or hydrologic variables and event sediment characteristics was between sediment yield and total storm rainfall (Figure 30). Event sediment yield was positively and relatively strongly related to total storm rainfall at most of the sites. Sites 857 and 858 showed only a small increase in sediment yield at high rainfall. Each of these sites had one large event not well explained by rainfall alone.

This is a useful result because it confirms that rainfall can be a surrogate for discharge for estimating road sediment yield for many road segments, as is the assumption of the sediment models.

Figure 31. Relationship between event sediment yield (g/m²) and unit area Q [m³/m²] by event in 2005.



Total rainfall was shown to have a high correlation with unit area discharge (m³/m²) (Figure 17) and sediment yield (Figure 30). As would be expected, sediment yield was also strongly related to total runoff (unit area Q) at each site. This hydrologic variable was an even stronger predictor than total rainfall for sites 857 and 858 (Figure 31).

The relationships between sediment yield and road characteristics are discussed with annual results in a later section of this report.

TRAFFIC INFLUENCE ON SEDIMENT YIELD

All studies of sediment production from forest roads surfaced with gravel or soil have found that traffic, especially log hauling, increases sediment generation and potentially delivery to streams depending on the connectivity of the road surfaces and ditches to water courses and construction methods. The effects can come from traffic use during storm runoff or from the accumulated traffic between events (Bilby et al. 1989). PALCO limited truck use of rocked roads to light pickups after surface runoff was visible on the road surface in accordance with HCP requirements. This prescription is designed to prevent wear and tear on the road surfaces during wet weather when the road surface is more prone to degradation (Weaver and Hagans 1994). It also limits ongoing sediment generation from the passage of vehicles when runoff can deliver it to streams.

The amount of traffic before an event (number of accumulated vehicles since the end of the last event), and during an event are listed in Table 4. Figure 32 shows the seasonal pattern of sediment yield per event as well as traffic and rainfall. Higher sediment yields almost always coincided with higher rainfall. Sometimes traffic was higher during these events, sometimes it was not. Visually discerning any effect of traffic is difficult. Just one instance of higher yield appears to be associated with traffic primarily (Site 856 in event J.) If traffic influenced event sediment yield, the effect was subtle in the larger rainfall effects.

Linear regression was used to determine the relationship between traffic characteristics before and during events and the sediment yield per event (g/m^2). The regression for the total traffic combining counts before and during was also computed. The results are shown for total traffic (Figure 33), traffic during the event (Figure 34), and traffic before the event (Figure 35). The regression statistics R^2 and significance level are provided in Table 5.

Sediment yield was unrelated to traffic parameters at most sites and weakly related at a few. However, at site 857 on the S. Fork Elk River mainline, there was a strong and statistically significant relationship between event sediment yield and all of the traffic parameters. Sediment yield at site 850 was related to several traffic parameters but was statistically significant only with traffic between events.

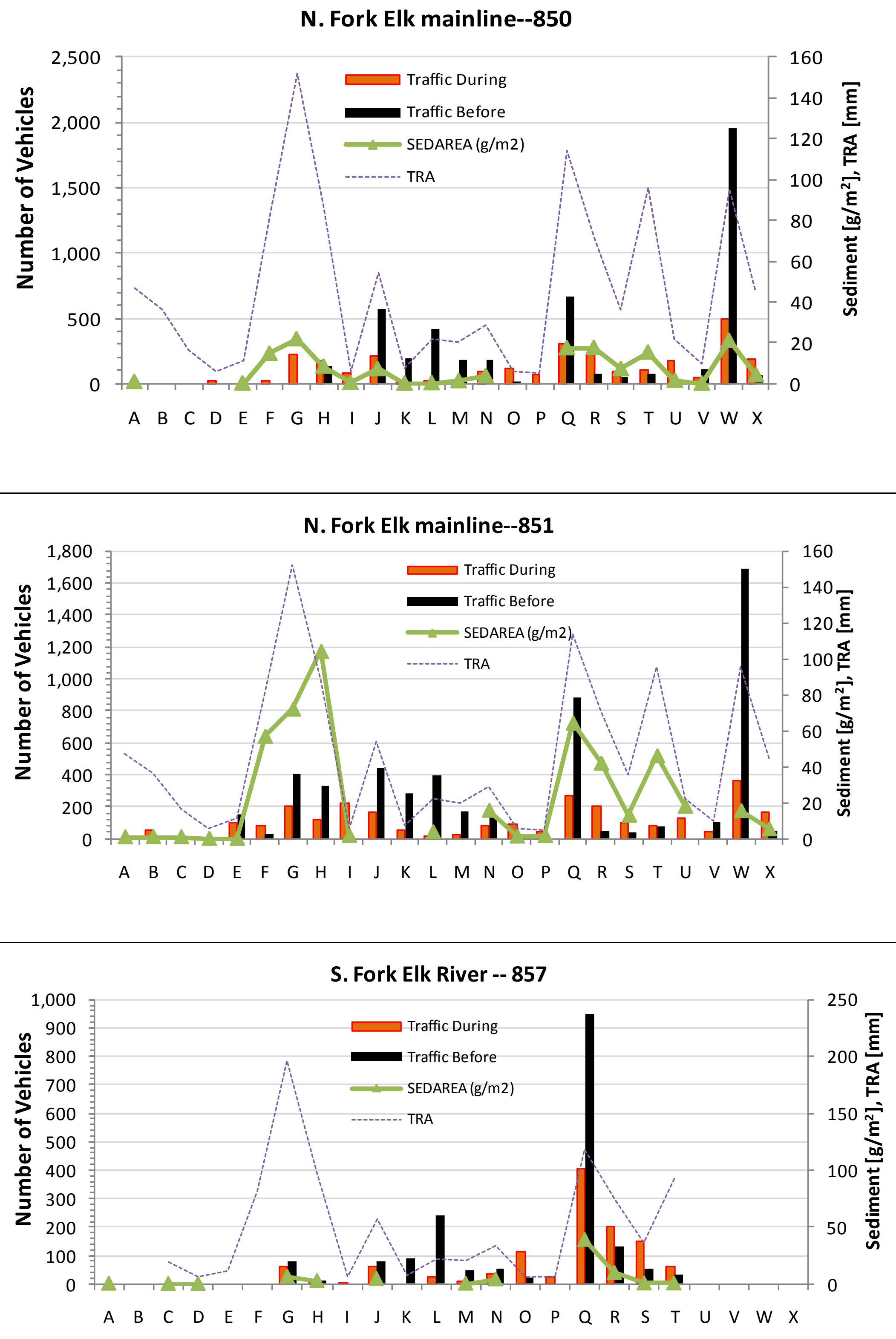
Earlier multivariate regression analysis showed that total event rainfall explained much of the variability in event sediment yield. It is also clearly evident in the event characteristics shown in Figure 29 that sediment yields were generally higher during large rainfall. With the exception of site 857, traffic explained little of the variability in sediment yield when taken alone. A backward stepping multivariate linear regression was applied to the event sediment yield as the dependent variable and traffic before, traffic during, and total rainfall amount (TRA) as the independent variables to assess the traffic factors in the context of rainfall. The model kept all variables at each site. Table 6 provides regression results including unstandardized and standardized regression coefficients. The standardized coefficients express the relative predictive importance of that parameter in explaining variation within the regression.

The adjusted R^2 of the multivariate regression was high for four of the five segments (.77 to .97). R^2 at Site 851 was only 0.05 indicating that virtually none of the variation was explained by any of the three factors. Rainfall accounted for more than 80% of the variation in the sediment yield at sites 850, 856, and 853 (the secondary road), and was statistically significant at $P<0.05$. The multivariate relationship confirmed the importance of traffic at site 857 evident with the simple regressions (Table 6). Rainfall had little influence on sediment yield at this site. It is probably noteworthy that the ratio Qf/Qs was consistently much lower at this site than the others indicating that most of the flow originated on the road surface only. Traffic effects indicated with simple linear regression disappeared within the overriding effect of rainfall at sites 850 and 856.

Table 4. Number of vehicles before a rain event (since previous event) and during event at each site.

			Site 850		Site 851		Site 853		Site 856		Site 857	
Event #	Start Date	End Date	Before	During	Before	During	Before	During	Before	During	Before	During
A	10/22/04 18:00	10/24/04 12:05										
B	10/25/04 16:00	10/28/04 11:40				54						
C	11/2/04 17:30	11/3/04 7:20										
D	11/15/04 17:45	11/16/04 16:40		18		6						
E	11/26/04 17:00	11/28/04 12:35			154	101	60		75	112		
F	12/6/04 9:15	12/10/04 12:25		18	29	81	15		68	4		
G	12/25/04 23:00	1/3/05 12:30		218	405	202	22	33	158	278	78	62
H	1/7/05 2:45	1/10/05 14:55	138	173	332	119	2	20	133	120	12	13
I	1/10/05 17:45	1/15/05 1:55	0	83	0	223	0	5	0	85	0	2
J	1/26/05 1:00	1/31/05 12:55	573	208	445	168	35	12	1467	312	80	62
K	2/6/05 18:30	2/8/05 3:45	192	3	282	50	14	0	536	0	89	0
L	2/13/05 7:00	2/14/05 7:15	414	17	400	15	10	3	574	24	240	24
M	2/19/05 16:15	2/22/05 11:40	176	22	174	25	6	6	271	36	48	10
N	2/27/05 13:45	3/1/05 12:10	185	96	130	85	32	5	474	105	56	35
O	3/1/05 13:00	3/3/05 22:05	6	120	6	95	4	5	0	160	24	111
P	3/4/05 0:15	3/5/05 10:40	0	66	0	46	0	2	0	13	0	23
Q	3/18/05 21:15	3/25/05 12:00	671	308	882	271	66	11	628	157	951	407
R	3/27/05 9:00	3/30/05 12:45	72	217	45	206	3	20	133	113	133	204
S	4/3/05 5:15	4/5/05 12:25	50	87	39	97	13	11	22	96	56	152
T	4/6/05 23:00	4/12/05 13:50	70	99	82	85	6	4	25	75	31	61
U	4/12/05 7:00	4/16/05 6:30	0	170	0	126	0	7	0	72	0	154
V	4/16/05 12:45	4/18/05 5:00	109	44	109	42	4	3	68	42	82	33
W	5/4/05 13:00	5/11/05 11:35	1960	489	1688	360	77	40	673	83	496	404
X	5/15/05 15:00	5/21/05 11:20	61	182	49	169	11	54	28	29	101	380

Figure 32. Sediment yield, traffic and total rainfall (TRA) during events at each site.



N. Fork Elk mainline--850

N. Fork Elk mainline--851

S. Fork Elk River -- 857

Figure 32. Continued.

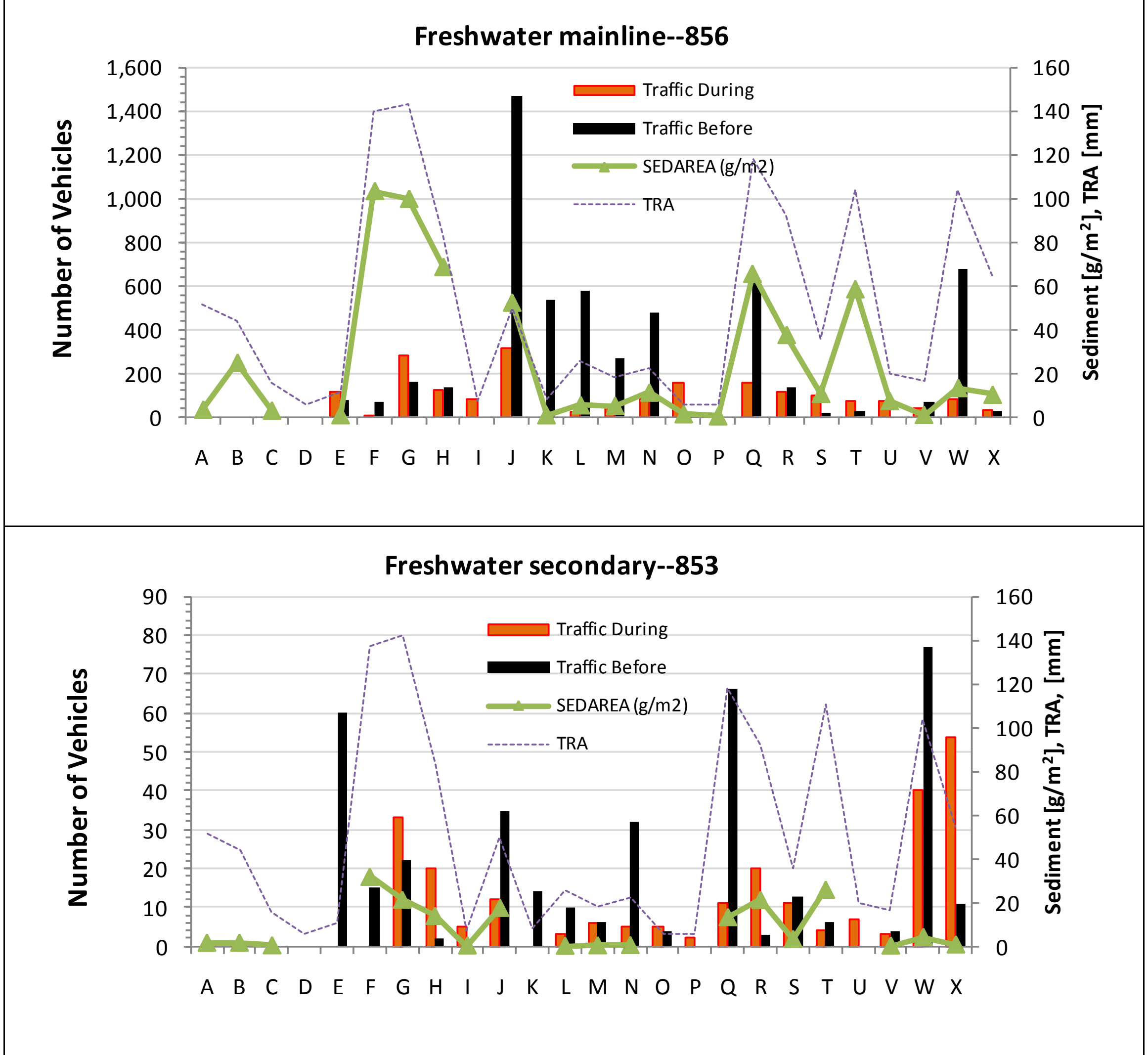


Table 5. Regression statistics for simple linear relationships between traffic characteristics and event sediment yield (g/m^2).

	Traffic During		Traffic Before		All Traffic	
Site	R^2 (Adj R^2)	Sig. (p)	R^2 (Adj R^2)	Sig. (p)	R^2 (Adj R^2)	Sig. (p)
850	.153 (.100)	0.109	.417(.381)	0.004	.215 (.166)	0.052
851	.108 (.058)	0.158	.001 (-.061)	0.902	.019 (-.042)	0.587
853	.000 (-.067)	0.972	.006 (-.061)	0.773	.049(-.019)	0.409
856	.188 (.140)	0.064	.008 (-.050)	0.715	.028 (-.029)	0.492
857	0.814 (.788)	0.001	0.969 (.965)	0.000	.961(.955)	0.000

Figure 33. Linear regression of event sediment yield in relation to total traffic use preceding and during the event by site.

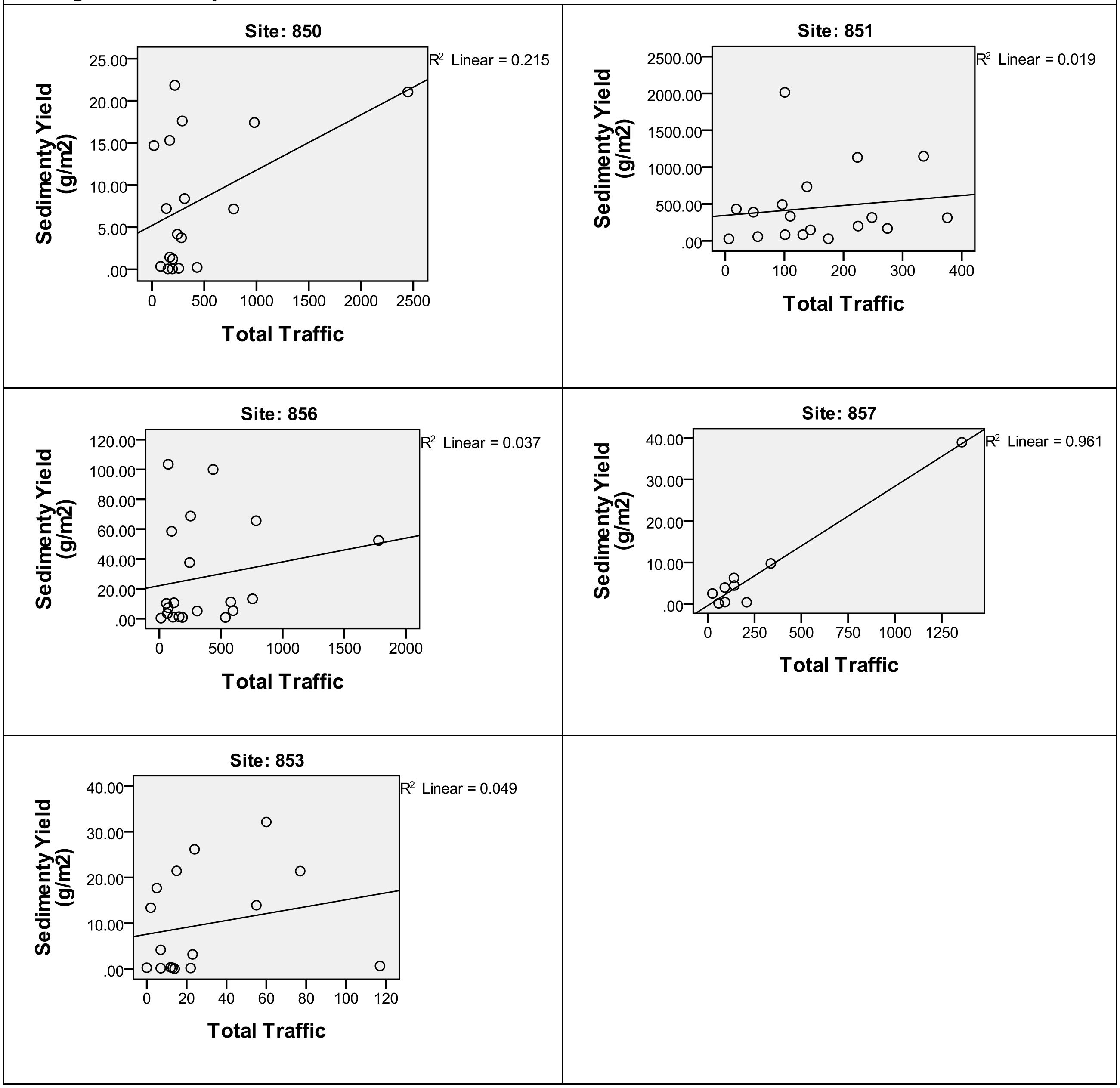


Figure 34. Linear regression of event sediment yield in relation to traffic use during the event by site.

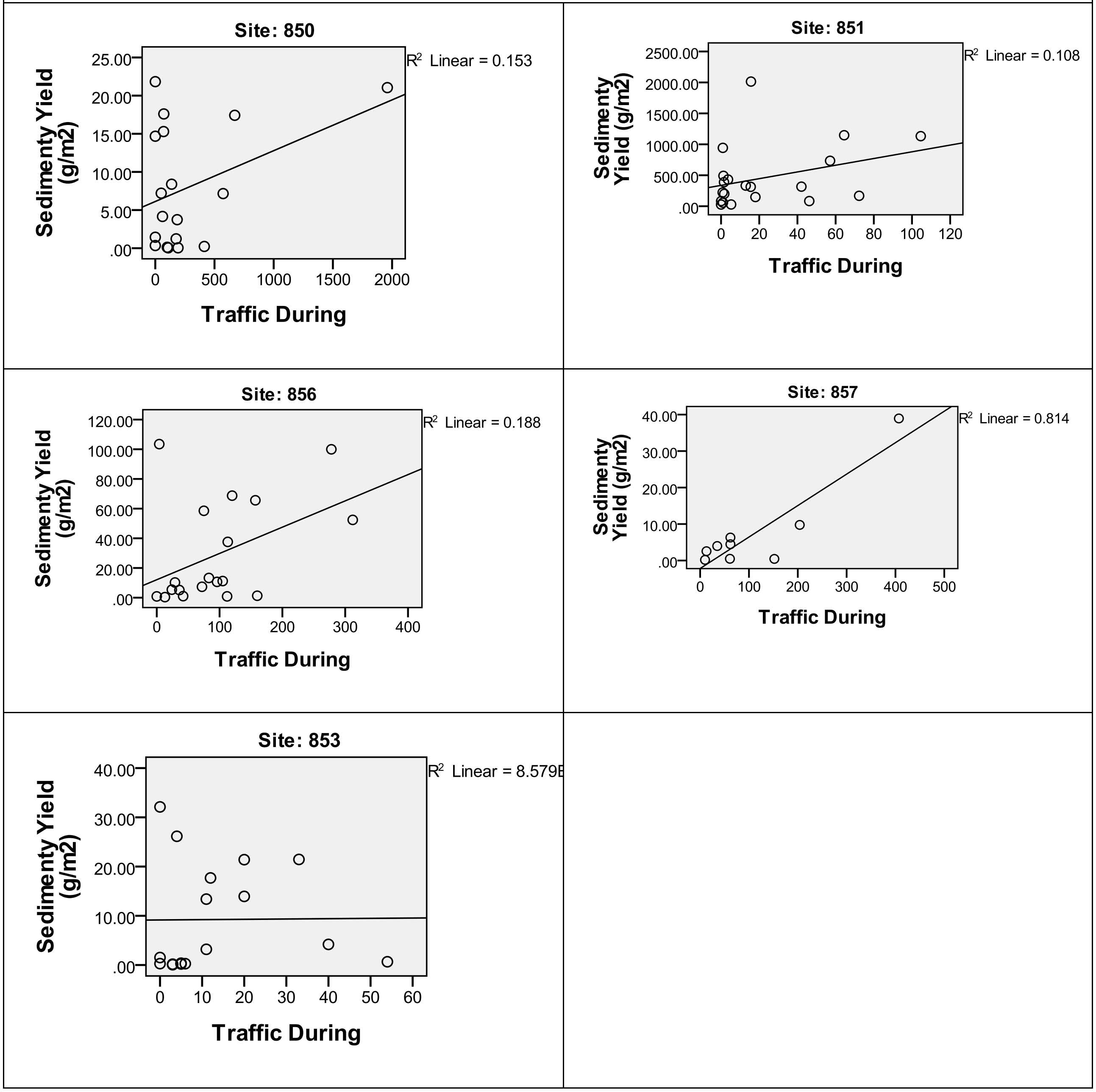


Figure 35. Linear regression of event sediment yield in relation to traffic use preceding the event by site.

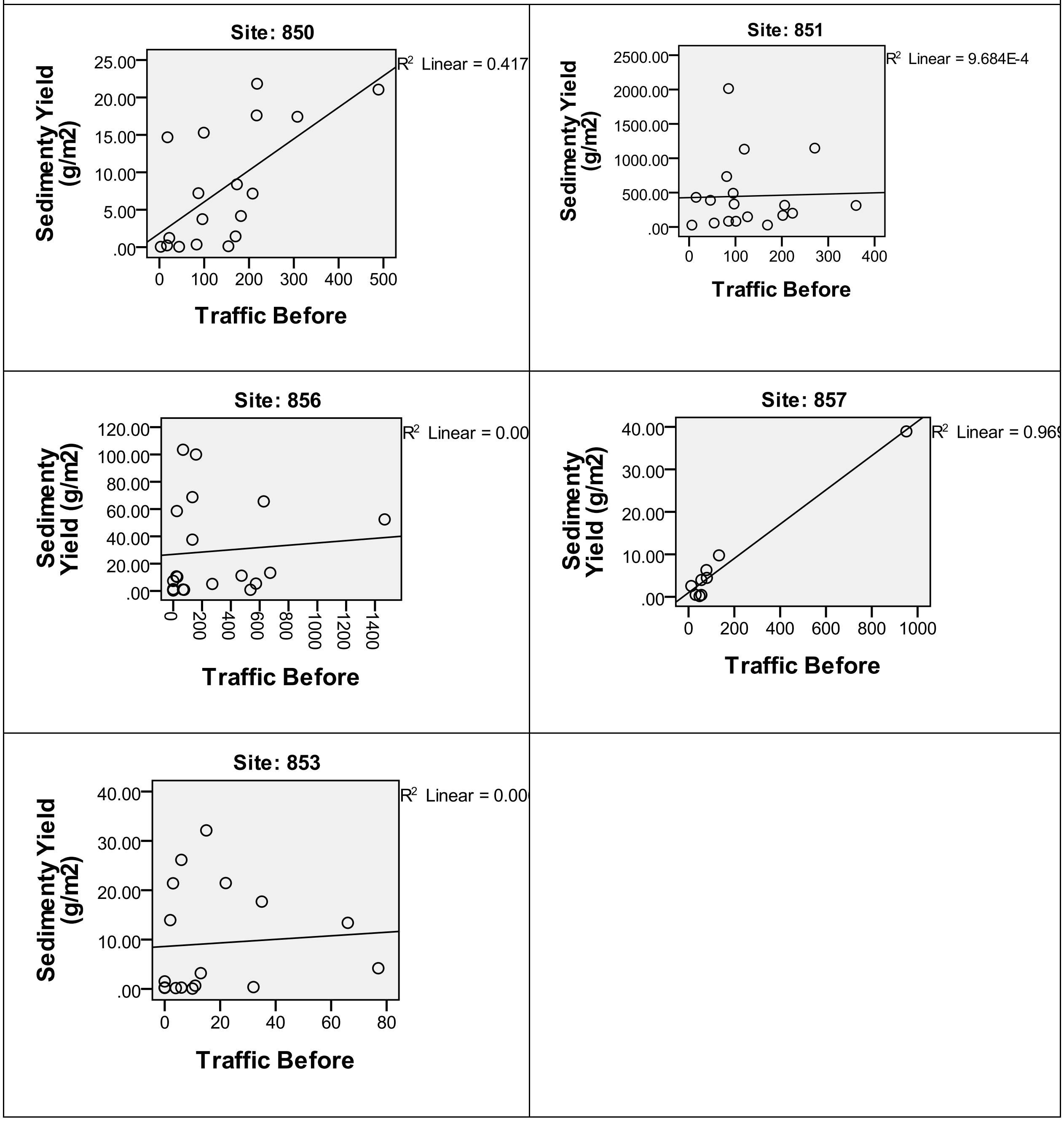


Table 6. Regression statistics: Sediment Yield = f(total storm rainfall, traffic before the event, and traffic during the event.

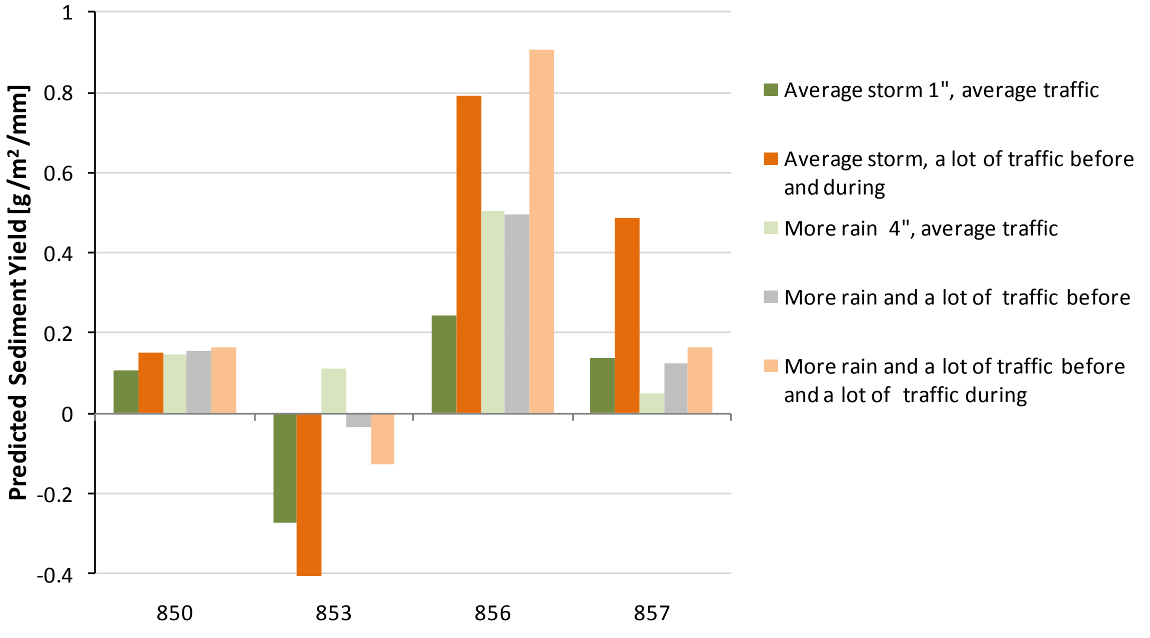
Dependent Variable: Sediment Yield (g/m^2)

		Unstandardized Coefficients				Standardized Coefficients		
Site	Adj. R^2	Constant	TRA	Traffic Before	Traffic During	TRA	Traffic Before	Traffic During
850	0.87	-1.7646	0.159	0.004	0.002	0.86*	0.07	0.11
851	0.05	361.576	-6.788	0.696	13.398	-0.58	0.12	0.81
853	0.84	-0.635	0.239	-0.073	-0.14	1.01*	-0.26	-0.31*
856	0.77	-11.421	0.593	-0.004	0.088	0.82*	-0.05	0.22
857	0.97	-1.051	0.022	0.036	0.009	0.10	0.88*	0.09

*statistically significant at $p<0.05$

To help visualize the effect of traffic on sediment yield, the multivariate regression was computed for 5 scenarios of event rainfall and traffic for the 4 sites with significant R^2. Sediment yield was normalized to rainfall amount to highlight the traffic influence within the regression. Rainfall ranged from an average 1" storm to a 4" event. Traffic ranged from the daily average with no log truck traffic to some of the highest values observed during the season (300 to 500 hundred vehicles per event). Results are shown in Figure 36. Most of the sites had relatively narrow range in sediment yield, even with these extreme cases. Yield at site 853 did not change with escalating rainfall or traffic. Site 856 on the Freshwater mainline road responded to all of the parameters. Site 856 also consistently produced much more runoff per unit area than the other sites (Figure 16).

Figure 36. Regression equation of Table 6 computed for scenarios of rainfall and traffic. Sediment yield is expressed as g/m^2/mm rainfall to normalize for rainfall effects.



PARTICLE SIZE OF ROAD SEDIMENT

Most of the sediment that passed through the flume was sampled by the ISCO pumping sampler. Samples were returned to the laboratory and processed for sediment content. These samples contained predominantly clay sized sediment. The silt content increased when suspended sediment concentration was high during a few storms.

Sediment caught in the catch basin in 2004 was processed for particle size distribution (Table 7). Results from 2004 are provided because more sediment was deposited in the catch basin. The installations were redesigned in 2005 to minimize deposition. As expected, the catch basin generally captured silt and sand sized material as the finer fractions generally remained in suspension and were sampled in the flume. Nevertheless, 15% or more of the catch basin sediment was clay-sized. The proportion of annual sediment made up of the catch basin sediment is provided in Table 7. The proportion of sediment that settled in the catch basin at site 854 was quite high. This site was the steep, newly constructed, native surface road. A fairly high proportion of the annual load was in the sand fraction from 0.075 to 2 mm grain size (35%). The newly constructed secondary road at 853 also produced a high proportion of the sand fraction in its first year (43%).

Table 7. Particle size characteristics of sediment collected in the catch basin in 2004.

	850	851	853	854
Sand	72.4%	58.8%	74.9%	42.0%
Silt	12.6%	6.8%	11.5%	20.9%
Clay	15.0%	34.4%	13.6%	37.2%
Catch basin proportion of annual load	2.4%	4.5%	58.0%	82.7%

ANNUAL SEDIMENT YIELD FROM ROAD SEGMENTS

The annual sediment yield of each road segment was determined by summing the event totals each year. The sediment captured in the catch basin was added to the total. Each site included a different set of events in each year (Tables 2 and 3) and accounted for different amounts of annual rainfall. The sites were not installed until January in 2004 and nearly one third of the rainfall was missed that year. To make data comparable, the measured total sediment from each year was prorated to the mean annual rainfall of the watershed (1100 mm, 43 inches). Calculations are provided in Table 8. Only the annual prorated values are discussed further.

Figure 37 shows the annual sediment yield for all sites measured in 2004 and 2005, expressed in kg/m^2. Sites measured in two years are included twice so there are a total of 11 segment observations. There were clearly groups with common values so Figure 37 was ordered that way. There were three general levels of sediment yield, with remarkable consistency in sediment yield within those groups even though road situations varied within each group.

Figure 37. Annual sediment yield per unit area of contributing road segment area prorated to mean annual rainfall of 1100 mm. Units are kg/m^2.

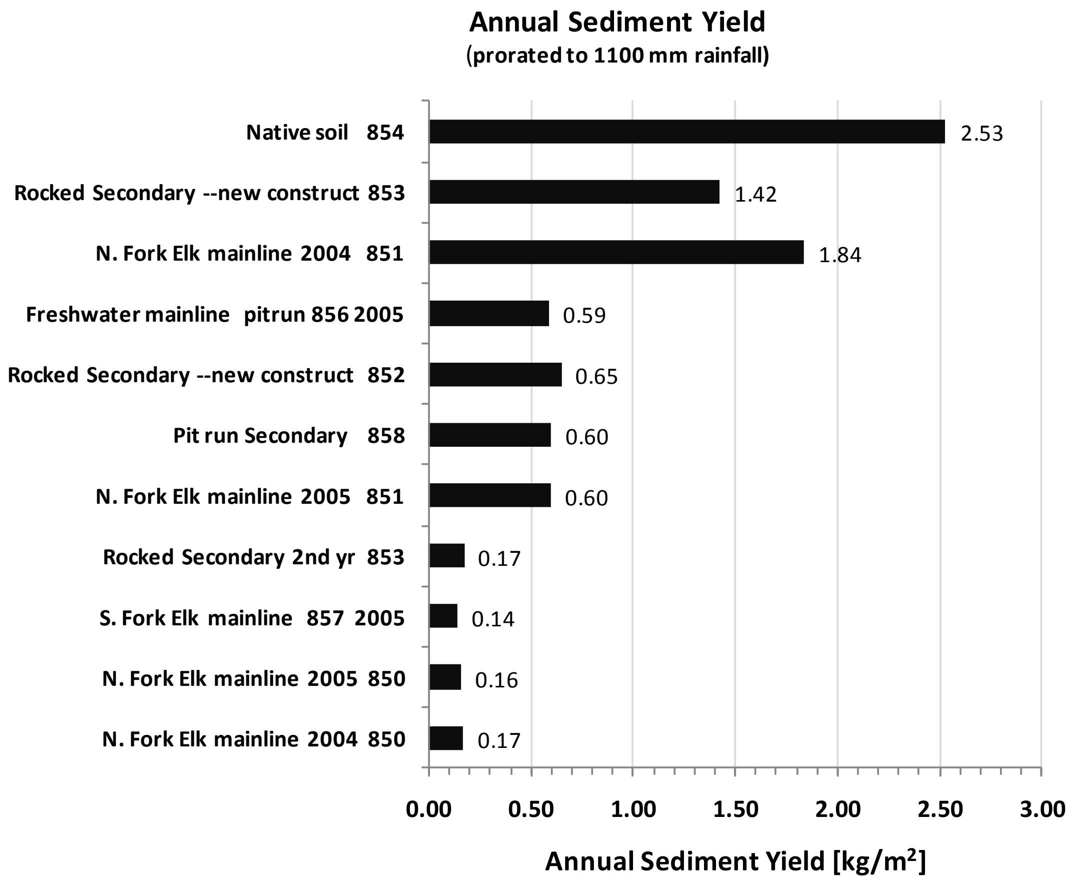


Table 8. Annual sediment yield computations.

2004 Season Total Measured Sediment Load

Site	Area (m2)	TRA (mm)	Rain on surface (m^3)	Qflume (m^3)	Total Sed (kg)	Sed Per Area (kg/m^2)	Sed in Box (kg)	Catch basin kg/m^2	Prorate Season Catch basin to Annual Ppt Total (51.8%) kg/m^2	Sed per Area Prorated to Ave Annual PPT (kg/m^2)	Total Sediment Prorated to Ave Annual PPT (kg/m^2)
850	671	301	211	702	30.25	0.046	0.734	0.001	0.002	0.168	0.170
851	256	287	73.8	814	120.03	0.468	5.6	0.022	0.042	1.794	1.836
852	405	243	104	1756	41.7	0.103	37.9	0.094	0.181	0.466	0.647
853	107	265	71	294	22.16	0.21	30.6	0.286	0.552	0.872	1.424
854	440	284	105	105	85.8	0.19	409	0.930	1.794	0.736	2.530

2005 Season Total

Site	Area (m2)	TRA (mm)	Rain on surface (m^3)	Qflume (m^3)	Total Sed (kg)	Sed Per Area (kg/m^2)	Sed in Box (kg)	Catch basin kg/m^2	Prorate season catch basin to Annual Ppt Total (kg/m^2)	Sed per Area Prorated to Ave Annual PPT (kg/m^2)	Total Sediment Prorated to Ave Annual PPT (kg/m^2)
850	671	1008	676.8	2477	95.86	0.143	1.11	0.002	0.002	0.156	0.158
851	256	986	252.59	3205	119.16	0.465	20.00	0.078	0.078	0.519	0.597
853	107	1128	120.85	1195	16.99	0.159	1.79	0.017	0.017	0.155	0.172
856	252	1179	254.75	9994	158.03	0.627	0.42	0.002	0.002	0.585	0.587
857	146	797	173.83	165	13.99	0.096	1.27	0.009	0.009	0.132	0.141
858	151	791	173.9	1029	63.62	0.421	2.10	0.014	0.014	0.585	0.599

Low Sediment Yield Group

The group with the lowest sediment yields averaged about 0.16 kg/m^2 per year. All were rocked storm proofed roads with both high and low levels of traffic.

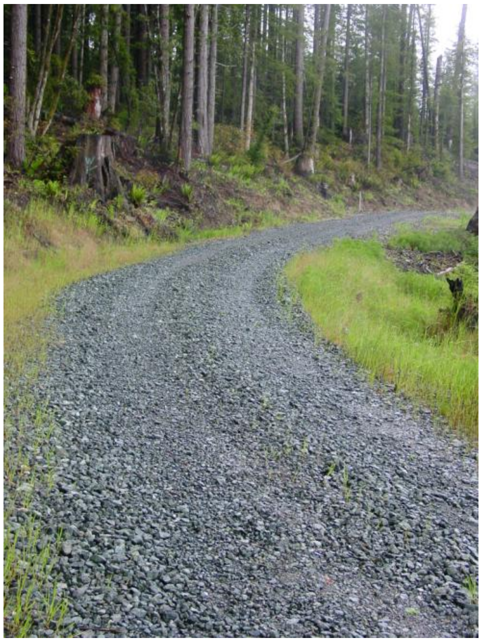
This group included both years at N. Fork Elk ER mainline (**site 850**). This segment was surfaced with durable rock, in good condition throughout both years, moderately sloped (about 7.5%), and received the largest volume of traffic in both years. There was a large contributing area. Ditches, cutslopes and fillslopes were well-vegetated. The segment produced an almost identical amount of sediment each year.

0.16 kg/m^2 per year

The South Fork Elk River (**site 857**) mainline road U08 was surfaced with durable rock, in good condition throughout the study, gently sloped (2.0%) with heavy traffic. There was a moderate sized contributing area. Ditches and cutslopes were well-vegetated.

0.14 kg/m^2 per year

The rocked secondary road U91.24 in the Incline area of Freshwater Creek (**site 853**) in year 2005. This road was in its 2nd winter following construction. Gradient was 11.7% with small contributing area. At this time, the cutslopes and ditches were well-vegetated. There was no log hauling in 2005 but the road was periodically used for THP layout and by construction crews on route to sites accessed by the road.



0.17 kg/m^2 per year

Moderate Group

The moderate group had sediment yields of about 0.6 kg/km^2, about 3 times higher than the low group and included roads with heavy traffic and no traffic.

Rocked stormproofed road on Freshwater Creek mainline Rd 15 **(Site 856)**. Gradient was low (1%) with moderately large contributing area. The road was routinely used for log hauling and traffic was heavy. Ditches were well vegetated. This was the only segment on the Franciscan geologic formation.

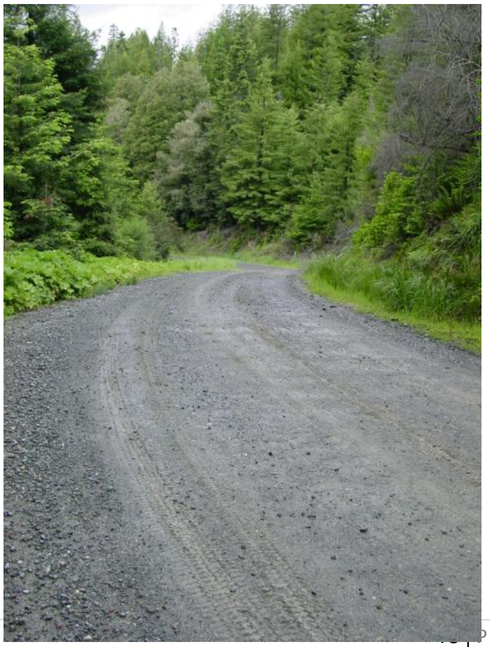
0.59 kg/m^2 per year

Secondary haul road U08.55 located in the upper reaches of the S. Fork Elk River (**Site 858**). The road was connected to a landing at the top of the segment just out of sight on the photo. The road was steep with gradient of 14% with moderate sized contributing area. The road surface was pit run, less durable, rock with well vegetated cutslopes and partially vegetated ditches. Traffic was not counted, but the road and landing were used for log hauling for periods during the measurement interval.

0.60 kg/m^2 per year

N. Fork Elk River (ER road) **site 851** in 2005. This segment was surfaced with durable rock, in good condition throughout the winter, very steeply sloped (17%), and was heavily used by log truck traffic throughout the winter. There was a moderate sized contributing area. Ditches, cutslopes and fillslopes were well-vegetated.

0.60 kg/m^2 per year



The rocked secondary road U91.26 in the Incline area of Freshwater Creek (**site 852**). The road was newly constructed to stormproofed standards just prior to measurement. The gradient was 8.8% in the steeper reach and 5.7% in the lower reach with a large contributing area. The cutslopes and ditches had bare soil and were poorly vegetated for a significant length of the segment. The road was used for logging activities in the summer prior to measurement. The road dead-ended just below the measurement site and was not routinely used by PALCO traffic other than hydrology technicians servicing the site during the winter.

0.65 kg/m^2 per year

Sediment yield at site 852 was affected by an exposed and failing cutslope visible on the left cutslope in the upper photo and shown during a rainstorm in the lower photo. Sediment delivered from the cutslope was a contributor to measured sediment at this site. The road surface was well constructed and durable.

Higher Sediment Group

Three sites in the higher sediment group produced about 1.8 kg/m^2 of sediment. This group includes heavily used, secondary, and native surface roads.

The rocked secondary road U91.24 in the Incline area of Freshwater Creek (**site 853**) in year 2004. The road was newly constructed to stormproofed standards in the summer of 2004 just prior to measurement. The road was rocked with durable material with steep gradient (11.7%). The cutslopes and ditches were not well vegetated along significant portions of the segment. The road had been used for log hauling during the summer prior to measurement.

1.42 kg/m^2 per year

N. Fork Elk River (ER road) mainline **site 851** in 2004. This segment was surfaced with durable rock, steeply sloped (17%), and received heavy traffic. There was a moderate sized contributing area. Ditches, cutslopes and fillslopes were well-vegetated. There was a cutslope failure at a subsurface seep that failed during storm event H when 124 mm of rain (4.8 inches) fell within a 2-day period (See Figure 31). The road was repaired immediately.

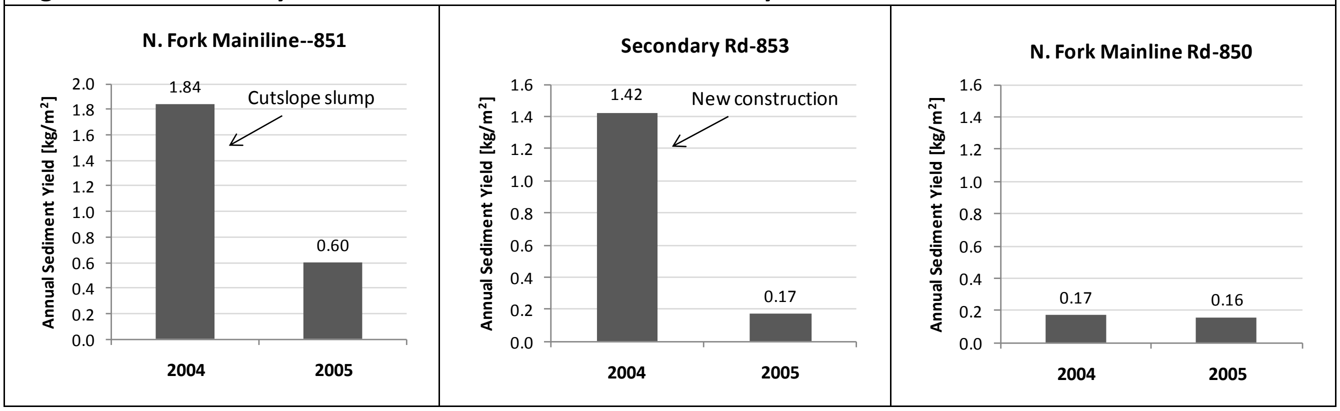
1.84 kg/m^2 per year

Freshwater Creek secondary road U91.24 site 854. This outsloped seasonal road segment had a native soil surface (wildcat geology). The road was steeply sloped (15.0%) with small contributing area. The road was newly constructed and used for log hauling from one THP unit in the summer prior to measurement. There was no truck traffic during the measurement period, although ATV’s used the road early in the winter season. The road surface did not have any vegetative cover.

2.53 kg/m^2 per year

Two segments in the relatively high group were among the three road segments that were measured in both years of the study (Figure 38). Circumstances at these sites are illustrative of factors that influence sediment yield. The steep section of the N. Fork mainline (segment 851) experienced a cutslope failure that significantly increased sediment yield in the event in which it occurred (Figure 29) as well as the annual total (Figure 37). The slump appeared to contribute about 0.26 yd^3 (317 kg) of material measured at the flume, although the original slump was larger. PALCO's road crew repaired the site immediately. This site indicates the importance of building and maintaining stable cutslopes as they can be a significant source of sediment. Quick response limited the adverse impacts of the cutslope failure.

Figure 38. Sediment yield rates at the 3 sites measured for 2 years.

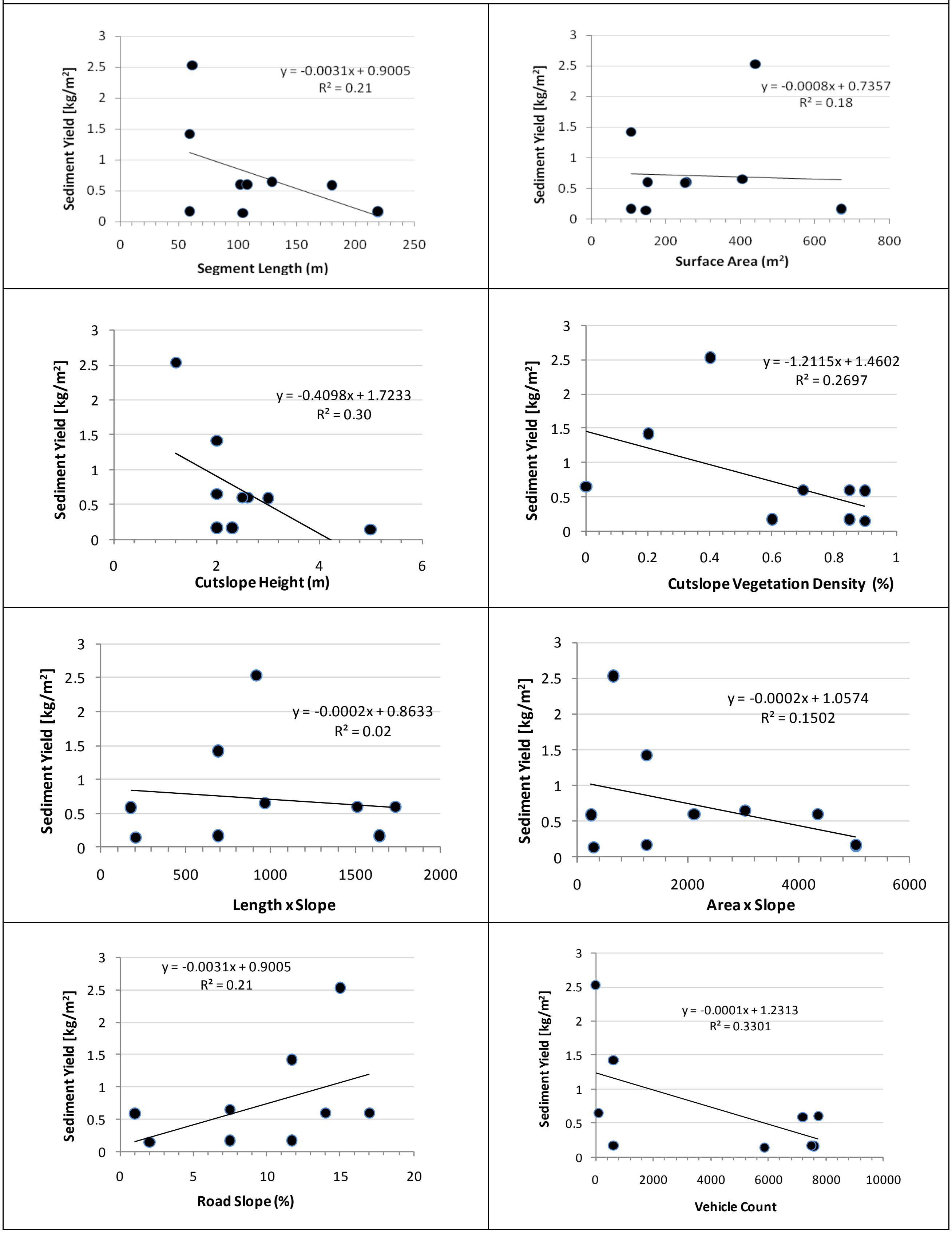


The secondary road (853) had higher erosion rates in the first year of construction. Roads and the disturbed areas within the road right-of-way are "soft" after they are first constructed and compact or harden after a winter season. The second year sediment yield at site 853 appears to reflect this settling. In addition, cutslopes had not yet fully vegetated although they were treated with erosion control. This also emphasizes the need for thorough and successful erosion control treatment. Finally, the N. Fork mainline site 850 showed no construction, erosion control, or maintenance issues in either year of the study and it produced consistently low sediment yields each year. The secondary road achieved these same low values in its second year after construction. The two mainline sites have different baseline erosion rates in 2005, possibly reflecting the very steep road gradient at site 851.

All road segments measured during this study represented common road conditions found on the property. Sites were primarily in the wildcat geology. Sites included heavily used mainline roads, lightly used and newly constructed secondary roads, and a native surface road. Gradients ranged from flat to steep, traffic varied over 10 times from none to high daily use by log trucks. Sediment yield on the 11 road segments ranged over 14 times from the lowest to the highest. Most of the road segments had very low sediment yield including the heavily used mainline roads. Situations that appeared to lead to higher sediment yields included:

- Cutslopes not fully stabilized
- Very steep gradients
- Pit-run rocked surfaces with log truck traffic (pitrun indicates a lower quality rock, not as resistant to abrasion)
- New construction

Figure 39. Annual sediment yield [kg/m^2] of road segments in relation to physical road characteristics.



ANNUAL SEDIMENT YIELD IN RELATION TO ROAD CHARACTERISTICS AND TRAFFIC

Next, we explore the relationships between the variability in sediment yield shown in Figure 37 and road characteristics.

Simple linear regression relationships between annual yield and individual road characteristics are shown in Figure 39. Sediment yield was weakly related to several of the road characteristics. Sediment yield had a negative relationship (declined) with segment length, cutslope height, and cutslope vegetative density, and increased with road slope. Sediment yield was not influenced by the road surface area. The combining variables of Length x Slope and Area x Slope as suggested by Luce and Black (1999) and Coe (2006) did not explain variation in sediment yield and are dropped from further analysis.

Multivariate regression analysis was performed to determine the relationship of sediment yield to the combination of road characteristics. With this analysis, we are evaluating the same principles incorporated into the WDNR sediment prediction model. The WDNR model starts computations from a baseline erosion rate that is raised or lowered by surfacing, traffic, and vegetative cover factors in a novel multivariate approach. The model synthesizes results from studies of gravel and soil surfaced logging roads conducted over the past 30 years throughout the Pacific Northwest region. Observations in this study indicated that surfacing and road age were important. The age of the road is incorporated in the WDNR model in the baseline erosion rate, essentially doubling the rate in the first 2 years after construction. We addressed new construction by assigning an age factor of 1 to well established roads and a value of 2 for new roads. To address road surfacing durability, we assigned the appropriate surfacing factor from the WDNR model. Traffic was evaluated both as total vehicle count and using the traffic factors as would be assigned by the WDNR model. No traffic data were available for 3 of the sites measured in 2004. 2005 values were used for site 850. We believe the estimate of road use on the ER main haul road was reasonable since the road carries about the same amount of winter log hauling traffic each year. Site 851 in 2004 was left out because it had a maintenance issue that was known to elevate sediment yield but was not reflected in the road characteristics or factors. The other 2004 segments had no traffic to speak of. Both vegetation density as measured and the WDNR vegetation factor were evaluated.

A backward stepping multivariate regression was fit to sediment yield as the dependent variable and various road and traffic characteristics as independent variables. Having only 10 sites limited the number of parameters that could be entered into the multivariate regression to maintain sufficient degrees of freedom for a valid test. After trial and error, the set of parameters that produced the highest R^2 included surfacing factor, age factor, vegetation factor, road slope, and the traffic factor. The traffic factor was found to better represent vehicle use than the actual vehicle count, possibly because the range in the factor is much narrower. The vegetation cover factor from the WDNR model was found to be a better predictor than vegetation density. Note that rainfall was not included in the regression because the annual sediment yields have already been normalized to a common rainfall datum.

The complete regression statistics are provided in Table 9. The backward stepping regression produced 2 models. Model 1 kept all of the entered parameters. Model 1 found the traffic factor to be marginally influential compared to the other parameters (sig. = 0.104). Model 2 eliminated the traffic factor. However, neither the R^2 nor the ANOVA significance level were improved by eliminating the traffic factor, so results for the models with and without traffic are included in Table 9. Predicted versus observed sediment yield by study segment computed from the equations for both models is shown in Figure 40. Generally the predicted values were close to the observed. Each model estimated some sites better than the other. Neither model predicted site 852 well. This was the secondary road with cutslope erosion issues.

Table 9. Complete regression statistics for multivariate regression of annual sediment yield in relation to road characteristics and traffic.

Coefficients

		Coefficients		Coefficients			Interval for B	
Model		B	Std. Error	Beta	t	Sig.	Bound	Bound
1	(Constant)	-4.456	.995		-4.481	.021	-7.621	-1.291
	Surfacing Factor	2.715	.660	.745	4.114	.026	.615	4.814
	Age Factor	6.823	1.849	7.302	3.690	.035	.938	12.709
	Vegetation Factor	-12.101	3.755	-6.979	-3.223	.048	-24.050	-.151
	Road Slope (%)	.052	.012	.668	4.184	.025	.012	.092
	TrafficFactor	-.055	.024	-1.121	-2.307	.104	-.131	.021
2	(Constant)	-2.337	.550		-4.248	.013	-3.865	-.810
	Surfacing Factor	1.490	.565	.409	2.637	.058	-.079	3.058
	Age Factor	2.696	.674	2.885	3.999	.016	.824	4.568
	Vegetation Factor	-3.673	1.250	-2.118	-2.938	.042	-7.143	-.202
	Road Slope (%)	.031	.012	.397	2.545	.064	-.003	.065

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.984	.968	.916	.11947
2	.955	.913	.825	.17231

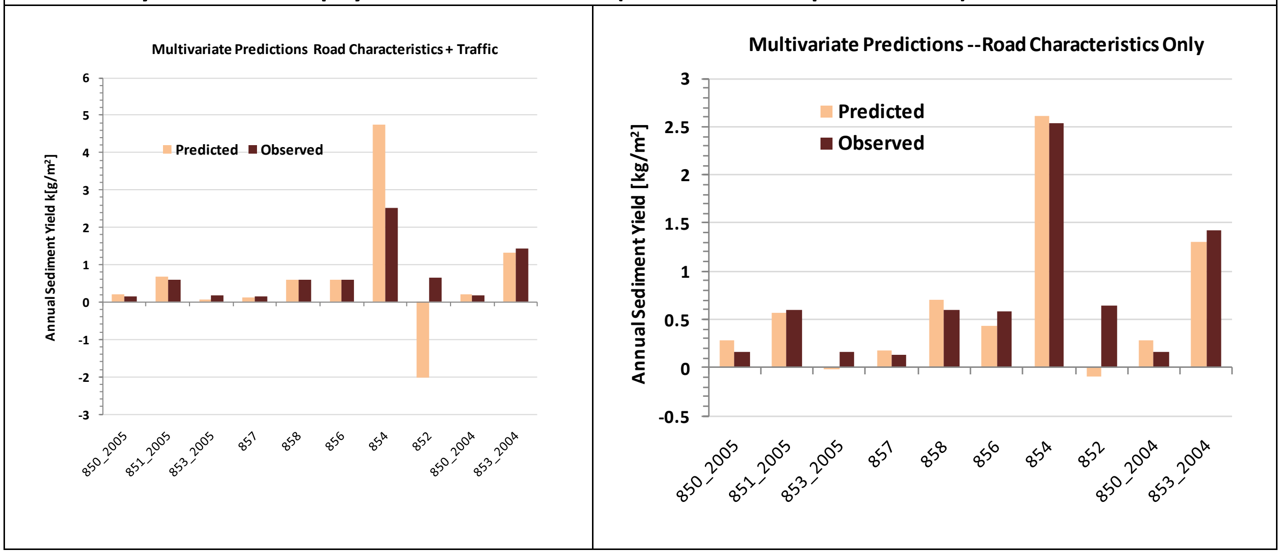
ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1.315	5	.263	18.432	.018
	Residual	.043	3	.014		
	Total	1.358	8			
2	Regression	1.239	4	.310	10.436	.022
	Residual	.119	4	.030		
	Total	1.358	8			

Correlations

		Sediment Yield (kg/m2)	Surfacing Factor	Age Factor	Vegetation Factor	Road Slope (%)	Traffic Factor
Pearson Correlation	Sediment Yield (kg/m2)	1.000	.128	.735	.653	.314	.125
	Surfacing Factor	.128	1.000	-.279	-.249	-.008	.279
	Age Factor	.735	-.279	1.000	.976	.078	-.357
	Vegetation Factor	.653	-.249	.976	1.000	.143	-.530
	Road Slope (%)	.314	-.008	.078	.143	1.000	-.078
	TrafficFactor	.125	.279	-.357	-.530	-.078	1.000
Sig. (1-tailed)	Sediment Yield	.	.371	.012	.028	.205	.374
	Surfacing Factor	.371	.	.234	.259	.492	.234
	Age Factor	.012	.234	.	.000	.421	.173
	Vegetation Factor	.028	.259	.000	.	.356	.071
	Road Slope (%)	.205	.492	.421	.356	.	.421
	TrafficFactor	.374	.234	.173	.071	.421	.

Figure 40. Multivariate prediction equation results expressing the relationship between annual sediment yield and road physical characteristics. (See Table 9 for parameters.)



The road factors account for virtually all of the 10-fold order of magnitude variability in annual sediment yield (Figure 37). Several observations are important regarding these results. The goodness of fit of the regression and the high significance of each of the variables confirms that the road factors accounted for in the WDNR sediment model are fundamentally important in determining sediment yield from HRC roads, validating the approach if not the model itself. We added road gradient to the equation which is not included in the WNDR model.

Although the variables statistically selected by the multivariate statistical analysis agreed with those included in the WDNR model, the influence on measured sediment yield was opposite to that of the WDNR model for two of the parameters. Traffic is positively but weakly correlated with sediment yield (Table 9). However, in the regression equation, the traffic coefficient is negative so that sediment yield declines with increasing traffic. It was previously shown that the traffic effect was negligible for individual rain events scale where variability in traffic use during the season would have facilitated discerning its effect. The negligible influence of traffic holds true at the annual level as well considering the single factor analysis in Figure 39 and the multiple regression results. We conclude that traffic use of stormproofed rocked roads following wet weather restrictions has an insignificant effect on the yield of sediment from the road surfaces.

Also counterintuitive was the influence of the vegetation factor in the multivariate regression. Sediment yield statistically increased with increasing vegetation factor, implying more sediment from well vegetated cutslopes than from unvegetated slopes. (The same result occurred with vegetation density). Note that the vegetation factor equals 1 at minimum vegetation density and declines with increasing density (see Table 12). Thus, yield should decrease with increasing factor. The negative influence of vegetation does not match what was observed in the relationship between vegetation density and sediment yield in Figure 39. The multivariate result may be an artifact of the small sample size or the dominance of other parameters at these particular sites. Both multivariate models 1 and 2 tend to compute negative values for sediment yield for some combinations of input parameters when the vegetation factor is greater than 0.5 (vegetation cover < 50%). All of the other parameters behave well throughout the likely range of the input parameters, always producing positive and reasonable estimates of sediment yield. Thus, although the multivariate models predict sediment yield at the study segments quite well, we don’t believe the equations can be applied universally to conditions outside the range of conditions found in the study segments.

MEASURED SEDIMENT YIELD RELATIVE TO WATERSHED ANALYSIS AND SEDMODL

A primary objective of this study was to measure sediment yield from road surfaces representative of HRC property in order to validate the various models used to determine road surface erosion. This is important because modeling results are used in sediment budgets for the watersheds that in turn influence management strategies for reducing sediment yields at the watershed and THP spatial scales. Road sediment yield is modeled using several approaches for different planning activities. At the watershed scale, sediment delivered to streams from road surfaces is quantified using the Washington Department of Natural Resources (WDNR) Watershed Analysis Surface Erosion module. As previously described, erosion is modeled based on geologic substrate, annual precipitation, road gradient, cutslope vegetative cover, age of construction, and traffic use. The combination of these factors produces an estimate of sediment yield per unit area of road surface. The WDNR erosion model was incorporated as the engine of a GIS application called SEDMODL that estimates road sediment delivery at the watershed scale.

To validate the WDNR erosion model, the sediment yield from the flume study road segments was computed using the WDNR model as described in the Watershed Analysis Surface Erosion module. It is important to note that the model was applied to “as is” roads and not HCP managed stormproofed roads as measured in this study. We set the calculations to compute the sediment yield per unit area of road surface. Two model runs were performed with results provided in Table 10. In the first model run (top table), the WDNR factors from the manual were applied to the segment characteristics. Measured sediment yield for the segments is shown in the rightmost column.

Sediment yield predicted by the WDNR model and observed measured in the flume study are visually compared in Figure 41A. The WDNR model significantly over-predicted sediment yield in 8 of the 10 cases. Modeled sediment yield was up to 330 times greater than the observed sediment yield. Predicted yields were so much higher than observed that results had to be depicted on a logarithmic scale in Figure 41A. Observed was close to modeled only for segment 854 (the newly constructed native surface road.) Modeled yield for segment 852 (the newly constructed secondary road with problem cutslopes) was much closer but still two times greater than observed.

As was shown in the preceding regression analysis of road factors and sediment yield, the flume study has confirmed the relevance of the factors included in the WDNR model on HRC roads and even used several of the factors directly from, or in a manner consistent, with the WDNR model. However, to bring SEDMODL into alignment with observed sediment yield, some model factors must be adjusted. This could involve the base erosion rate or the road characteristic adjustment factors. We start with the assumption that the baseline erosion rate recommended by the WDNR manual was correct for this area, as suggested by the reasonably close prediction of the native surfaced road modified for the particulars of the site. Native surface roads are probably most indicative of soil erosion rates.

Traffic Factor. The traffic factor has the greatest influence on modeled sediment yield, varying over 4 orders of magnitude with traffic intensity (Table 11). It is important to recognize that the studies that informed the WDNR model measured roads with the pattern of use by log trucks standard to the industry. For the most part, this meant active log truck use during all weather conditions (e.g. Bilby et al. 1989). The most significant difference with previous studies is that log trucks do not operate on HRC roads during observable road surface runoff. This practice significantly and consistently stops traffic when roads are most vulnerable to erosion and deterioration and is likely the primary factor determining the low amount of sediment delivery observed in this study.

Table 10. Prediction of sediment yield from flume study road segments using WDNR model. Top table uses recommended factors in WA manual, bottom table shows calculations with revised factors (changed factors indicated with red type).

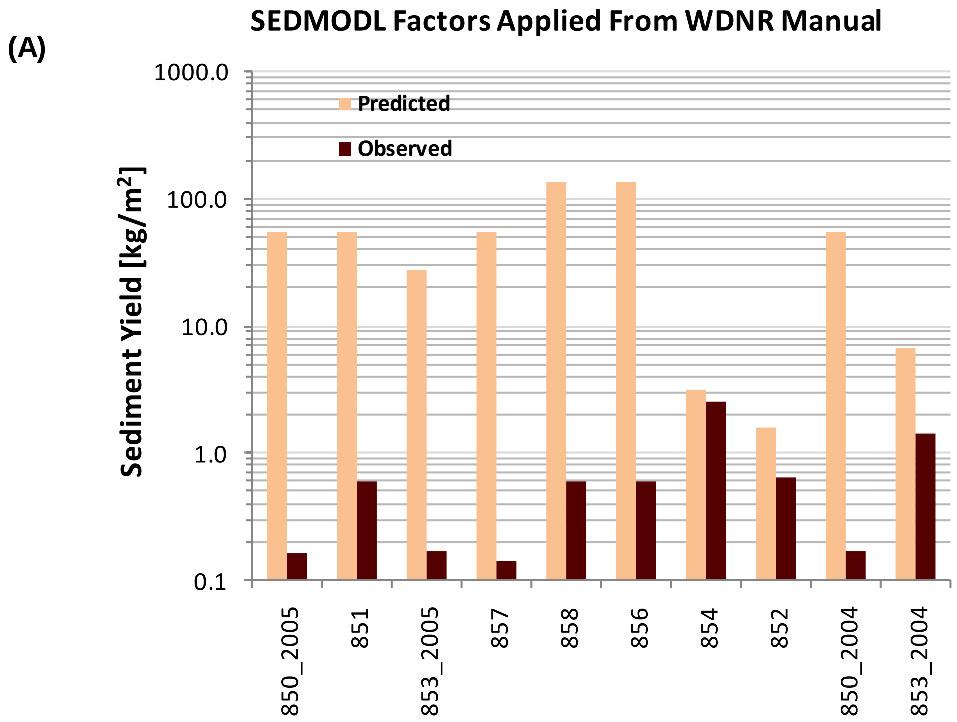
STUDY SEGMENTS **Wildcat Erosion Rate** **Recommended Factors in WDNR Model**

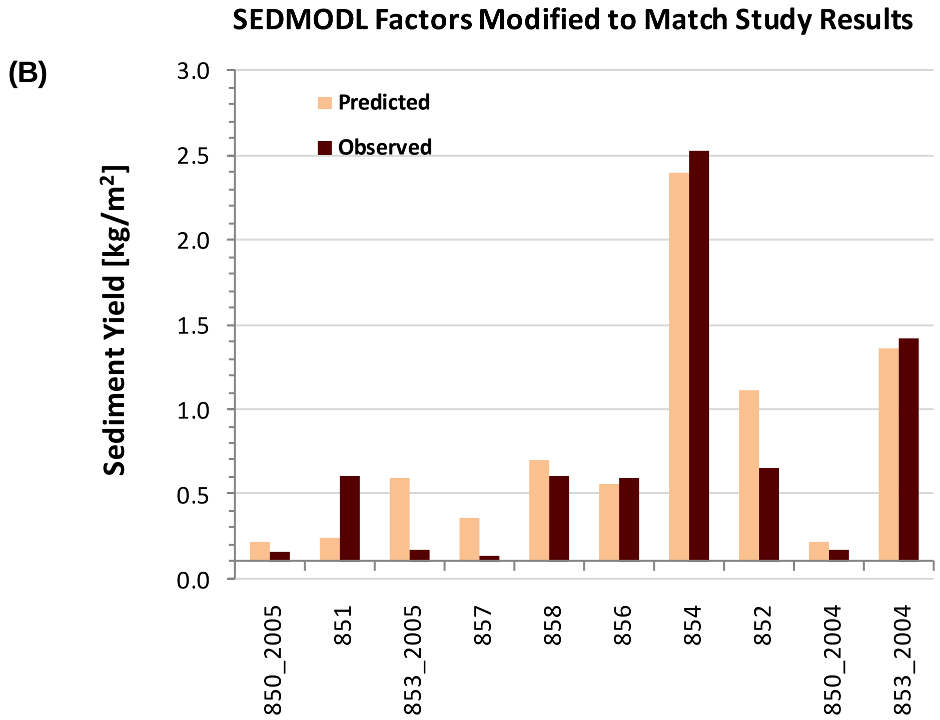
	SEDMODL										FLUME STUDY
	BASELINE EROSION RATE		ROAD SURFACE EROSION			CUTSLOPE EROSION				MODEL TOTAL	MEASURED
Road Segment	Erosion Rate (tons/ac)	Erosion Rate (kg/m^2)	Surfacing Factor	Traffic Factor	Surface Unit Area Erosion (kg/m^2)	Cutslope Height (m)	Unit Area (m^2)	Vegetation Factor	Cutslope Unit Area Erosion (kg/m^2)	Total Erosion (kg/m^2)	Total Erosion (kg/m^2)
850_2005	60	13.44	0.2	20	53.76	2.3	2.3	0.05	0.12	53.88	0.16
851	60	13.44	0.2	20	53.76	2.6	2.6	0.05	0.13	53.89	0.6
853_2005	60	13.44	0.2	10	26.88	2	2	0.28	0.56	27.44	0.17
857	60	13.44	0.2	20	53.76	5	5	0.15	0.75	54.51	0.14
858	60	13.44	0.5	20	134.40	2.5	2.5	0.23	0.57	134.97	0.6
856	60	13.44	0.5	20	134.40	3	3	0.15	0.45	134.85	0.59
854	110	26.88	1	0.1	2.69	1.2	1.2	0.43	0.52	3.20	2.53
852	110	26.88	0.2	0.1	0.54	2	2	0.53	1.06	1.60	0.65
850_2004	60	13.44	0.2	20	53.76	2.3	2.3	0.17	0.38	54.14	0.17
853_2004	110	26.88	0.2	1	5.38	2	2	0.66	1.31	6.69	1.42

STUDY SEGMENTS **Wildcat Erosion Rate** **Factors Revised with Flume Study Results**

	SEDMODL										FLUME STUDY
	BASELINE EROSION RATE		ROAD SURFACE EROSION			CUTSLOPE EROSION				MODEL TOTAL	MEASURED
Road Segment	Erosion Rate (tons/ac)	Erosion Rate (kg/m^2)	Surfacing Factor	Traffic Factor	Surface Unit Area Erosion (kg/m^2)	Cutslope Height (m)	Unit Area (m^2)	Vegetation Factor	Cutslope Unit Area Erosion (kg/m^2)	Total Erosion (kg/m^2)	Total Erosion (kg/m^2)
850_2005	60	13.44	0.2	0.04	0.11	2.3	2.3	0.05	0.12	0.22	0.16
851	60	13.44	0.2	0.04	0.11	2.6	2.6	0.05	0.13	0.24	0.6
853_2005	60	13.44	0.2	0.01	0.03	2	2	0.28	0.56	0.59	0.17
857	60	13.44	0.2	0.04	0.11	5	5	0.05	0.25	0.36	0.14
858	60	13.44	0.2	0.05	0.13	2.5	2.5	0.23	0.57	0.70	0.6
856	60	13.44	0.2	0.04	0.11	3	3	0.15	0.45	0.55	0.59
854	110	26.88	1	0.07	1.88	1.2	1.2	0.43	0.52	2.40	2.53
852	110	26.88	0.2	0.01	0.05	2	2	0.53	1.06	1.11	0.65
850_2004	60	13.44	0.2	0.04	0.11	2.3	2.3	0.05	0.12	0.22	0.17
853_2004	110	26.88	0.2	0.01	0.05	2	2	0.66	1.31	1.36	1.42

Figure 41. Observed vs. predicted sediment yield of flume study segments using WDNR module factors (A) and revised factors recommended by this study (B).





The observed low sediment yields from the road surfaces can only be replicated by the WDNR model if the traffic factors are adjusted downward by a significant amount. We tried to maintain the relative relationship among traffic use when adjusting, but even this was difficult. The traffic factor must be adjusted to virtually 0 to match observed erosion rates for all segments. Original traffic factors and those suggested by this study are provided in Table 11.

Table 11. Recommended traffic factors for SEDMODL as applied to stormproofed road on HRC property under HCP management.

	WA Manual	Recommended based on study
Heavy traffic/active mainline:	20 x	0.04
Moderate traffic/active secondary:	2 x	0.05
Light traffic/not active	1 x	0.01
No traffic/abandoned	.02	.1

The adjustment is large change for unused roads where the factor was already low, but adjustments were dramatic for the heavier traffic categories. Because of the way the model works, the traffic factor must remain in the equation. However, such a small effect even with heavy traffic is consistent with the multivariate regression results presented in the previous section.

Model calculations with adjusted factors are provided on the bottom of Table 10. We also made some minor adjustments in some of the other factors as follows.

Vegetation Factor. Ground cover on cutslopes and fillslopes reduces sediment generation. Factors for ground cover from the WDNR model are provided in Table 12. Generally, a factor reflecting about 50% coverage has been applied on HRC property during Watershed Analysis. The segments involved in this study had vegetative coverage of more than 80%, although at least one did not and sediment yield was higher from that site. The fact that ditches on HRC property are so heavily vegetated suggests that the vegetation factor can be reduced even further. Allowing ditches to vegetate was not standard practice in earlier studies. In this case, we have added a lower factor of 0.05 for roads with dense vegetation on both cutslopes and ditches.

Table 12. Recommended vegetation factors for SEDMODL as applied to stormproofed road on HRC property under HCP management.

Ground Cover Density	WA Manual
Cut + Ditch >80%	0.05 (new)
>80%	0.18
50%	0.37
30%	0.53
20%	0.63
10%	0.77
0%	1.00

Table 13. Surfacing factors for SEDMODL as applied to stormproofed road on HRC property under HCP management.

Surfacing Material	WA Manual
Paved	0.03
Dust-oil	0.15
Gravel, > 6” deep	0.20
Gravel, 2-4” deep	0.50
Native soil/rock	1.0

Surfacing Factor for Road Tread. Resistant road surfacing materials lower the erosion rate relative to the native surface road. Generally a factor of 0.2 has been applied to rocked storm proofed roads during Watershed Analysis applications (Table 13). This study produced no additional information to alter the surfacing factor, so no change is suggested. Pitrun gravel was expected to have lower durability and there was some evidence of higher erosion due to this factor. For this application the factors were used as supplied by the WDNR model.

New Construction. The WDNR model doubles the rate of erosion from new roads. Results from this study suggest that a surcharge for new construction is appropriate. No changes were made to the WDNR model approach, although we handled the factor with a multiplier in the multivariate regression.

Results from the second model iteration using revised factors are provided on the bottom of Table 10. Observed sediment yield is shown relative to predicted computed with the revised factors is shown in Figure 41B. Predicted modeled yield was close to observed with the revised factors.

There are other ways to revise the WDNR computations, such as changing the baseline erosion rate or the surfacing factors. We opted to revise the factors we could support from the statistical analysis of road factors. Most factors supplied in the WDNR module appear to produce results that are reasonably consistent with this study. It is clear that the WDNR traffic factors are not valid for stormproofed roads as managed under wet weather restrictions on HRC property.

SEDMODL APPLICATION in WATERSHED ANALYSIS

To apply SEDMODL to HRC property, roads have been classified according to surfacing and traffic categories and the erosion factors assigned to the categories. HRC has not modeled each existing road segment based on its unique characteristics, although SEDMODL could do this if informed with site specific information. Road types and length were determined by GIS. The factors were selected by the watershed analyst based on field observations made during the Watershed Analysis process and best professional judgment.

We evaluate the WDNR model and proposed revision of its application in Watershed Analysis by applying factors to road types. We repeat the model calculations as shown for segments in Table 10 by first applying the factors as done in the Freshwater Creek in Watershed Analysis (PALCO 2003), and then using the recommended new factors. The factors as applied in Watershed Analysis and results are provided on the top portion of Table 14. The revised traffic and vegetation factors and computations are provided in the lower portion of Table 14.

Table 14. Baseline erosion rate and factors applied to road types on HRC lands in the Freshwater Creek Watershed Analysis (2003) and recommended by this study with computed effects on unit road surface area sediment yield. Red typeface in lower table indicates suggested factors to match modeling to study results.

Wildcat Erosion Rate 2002 Watershed Analysis Estimate

	SEDMODL									
	BASELINE EROSION RATE		ROAD SURFACE EROSION			CUTSLOPE EROSION				MODEL TOTAL
Road Classification	Erosion Rate (tons/ac)	Erosion Rate (kg/m^2)	Surfacing Factor	Traffic Factor	Surfacing Unit Area Erosion (kg/m^2)	Assumed Height (ft)	Unit Area (m^2)	Vegetation Factor	Cutslope Unit Area Erosion (kg/m^2)	Total Erosion (kg/m^2)
General use--RS	60	13.44	0.2	2.2	5.91	15	4.57	0.31	1.42	7.33
RS—THP	60	13.44	0.2	20	53.76	15	4.57	0.31	1.42	55.18
RS--Idle	60	13.44	0.2	10	26.88	15	4.57	0.31	1.42	28.30
Paved	60	13.44	0.03	20	8.06	15	4.57	0.31	1.42	9.48
Dirt stormproofed	60	13.44	1	0.1	1.34	15	4.57	0.18	0.82	2.17
Rocked	60	13.44	0.2	10	26.88	20	6.10	0.44	2.68	29.56
Dirt	60	13.44	1	0.05	0.67	18	5.49	0.37	2.03	2.70
Abandoned	60	13.44	1	0.1	1.34	10	3.05	0.37	1.13	2.47

Wildcat Erosion Rate Revised with Flume Study Results

	SEDMODL									
	BASELINE EROSION RATE		ROAD SURFACE EROSION			CUTSLOPE EROSION				MODEL TOTAL
Road Classification	Erosion Rate (tons/ac)	Erosion Rate (kg/m^2)	Surfacing Factor	Traffic Factor	Surfacing Unit Area Erosion (kg/m^2)	Assumed Height (ft)	Unit Area (m^2)	Vegetation Factor	Cutslope Unit Area Erosion (kg/m^2)	Total Erosion (kg/m^2)
General use--RS	60	13.44	0.2	**0.04**	0.11	15	4.57	0.05	0.23	0.34
RS—THP	60	13.44	0.2	**0.05**	0.13	15	4.57	0.05	0.23	0.36
RS--Idle	60	13.44	0.2	**0.01**	0.03	15	4.57	0.05	0.23	0.26
Paved	60	13.44	0.03	**0.04**	0.02	15	4.57	0.1	0.46	0.47
Dirt stormproofed	60	13.44	1	**0.07**	0.94	15	4.57	0.18	0.82	1.76
Rocked	60	13.44	0.2	**0.04**	0.11	15	4.57	0.44	2.01	2.12
Dirt	60	13.44	1	**0.1**	1.34	15	4.57	0.37	1.69	3.04
Abandoned	60	13.44	1	**0.1**	1.34	15	4.57	0.37	1.69	3.04

Results from the field study confirmed the importance and validity of the basic factors and relationships in SEDMODL and the WDNR model. We therefore have no reason to reject the model estimates for pre-HCP road management practices. However, we note that “as is” road erosion rates in the upper half of Table 14 were high relative to similar studies on comparable logging roads (e.g. Bilby et al., 1989). The revised factors produced sediment yields within the range observed in this study.

Some of the improvements in erosion rates can be associated with stormproofed construction practices. The nature of the flume study, however, makes it most suitable for assessing road surfacing and wet weather hauling practices. This study carefully measured the sediment yield from road surfaces during the winter season when hauling was active and wet weather restrictions were operative. Results indicate that the traffic factor has essentially been eliminated from the erosion equation. Enough road segments were examined, runoff measured, and traffic counted to confirm this result was consistent across all stormproofed road types.

This study measured only stormproofed roads. However, non-stormproofed rocked roads are not used at all by any log truck traffic during the entire winter season and traffic factors should be reduced to match stormproofed roads when applied in the WDNR model.

COMPARISON TO THE WEPP MODEL

The WEPP model is also applied to estimate sediment from hillslopes and road surfaces during Timber Harvest Planning. WEPP is a process based model developed at the USFS Rocky Mountain Research Station (WEPP 1999). Results from the flume study were compared to modeled estimates for the road segments measured in 2005 in Figure 42. Two WEPP methods were used. First, the characteristics of this study’s road segments were entered into WEPP model available online. Second, W. Conroy, hydrologist for PALCO, developed a modified WEPP-based model by running the model a number of times using the input factors selected for the PALCOs property. Running the model requires some professional judgment so this tool was developed to ensure proper model use by HRC foresters. He created a set of empirical tables for use in PALCO THPs. Results of both WEPP based approaches are shown in Figure 42.

WEPP also substantially overestimated sediment yield from the road surfaces, typically by a factor of 3 to 10 times. The PALCO modified WEPP improved estimates relative to observed for several cases, but not as a general rule. WEPP may have performed poorly for the same reasons as SEDMODL.

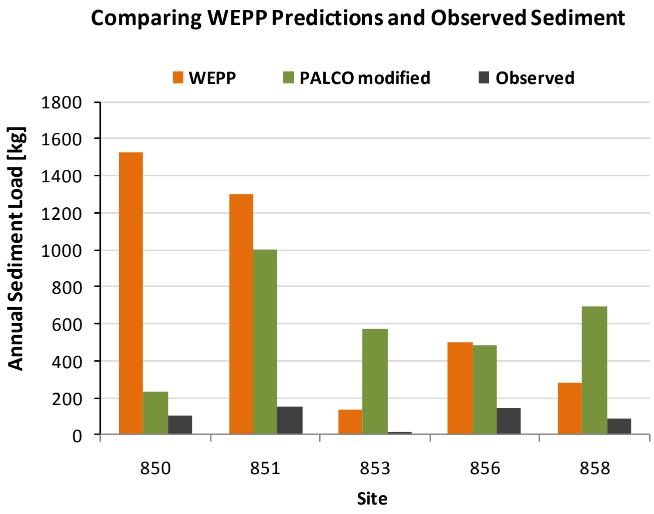


Figure 42. Comparison of WEPP model results applied to measured road segments and observed sediment yield.

Summary and Study Conclusions

Key findings of the road sediment generation flume study are briefly reviewed.

ROAD SURFACE FLOW AND SEDIMENT RUNOFF

- All rain did not generate runoff. Once sufficient rainfall occurred, road surfaces were highly responsive to rainfall.
- Ditches often continued to drain hillslopes after road surface runoff ceased as water moved downslope through soils and seeped through the cutslopes. The extent of ditch runoff varied by site, with some clearly receiving considerable upslope water seepage while others had very little. These observations were consistent with Wemple (1998). Hillslope dominated runoff is generally not heavily sediment laden when cutbanks and ditches were well vegetated and stable.
- Road segments produced different amounts of runoff normalized to unit area for the same amount of rainfall. Differences among sites were explained by multivariate regression using a combination of segment slope, contributing area, length and cutslope height with high R^2. Combining variables such as length x slope, area x slope, etc. as suggested by Luce and Black (1999) and Coe (2006) did not improve estimates of discharge.
- Sediment concentration during storms followed a “supply-limited” pattern as observed in previous studies such as Bilby et al. (1989) and Reid and Dunne (1984). Sediment concentration was highest at the initiation of runoff and declined sharply in the first hours of a rainfall event as sediment washed from the road surface. There was no relationship between discharge rate (Q, mL/s) and suspended sediment concentration (mg/L) at any site.
- Sediment load produced during events was primarily related to total rainfall amount and runoff volume.
- Sediment yield of individual rainfall events tended to be greatest early in the winter wet season and declined through the winter, even as traffic typically increased in the Freshwater and Elk River watersheds in the new calendar year.
- The effects of traffic before and/or during events were low but detectable at a few of the road segments. At others traffic effects could not be detected despite very heavy traffic.
- The annual total sediment yield from rocked road segments was very low compared to previous studies and compared to SEDMODL estimates. The geology of the study area has highly erosive soils so lowered erosion rates from the roads appears to management strategies.
- Consistent erosion and discharge results were achieved among road segments, and from year to year.
- Annual sediment yield from road segments was predicted with high R^2 using road characteristics of road slope, surfacing factor, age factor, and vegetation density. Multivariate

analysis of measured yield found that no traffic factors were needed to accurately predict observed erosion even though a number of the roads were heavily used by log truck traffic.

FLUME STUDY RESULTS COMPARED TO ROAD SEDIMENT MODELS

- The relevance and importance of parameters used in the WDNR model and SEDMODL, including total precipitation, erosion, traffic levels, vegetative cover density, surfacing material, and time since construction were validated in this study.
- The baseline erosion rate based on geology provided in the WDNR manual was consistent with observed within the context of model application based on sediment measured from native surface roads.
- Both the WDNR (SEDMODL) and WEPP models significantly over predict sediment relative to observed on HRC roads managed with HCP road management strategies.
- Significantly lowering the traffic factor aligned predicted sediment to that observed. The traffic factor applied to heavily used mainline roads (log truck traffic) based on regional studies was originally 20 times greater than a base condition of light pickup use only. Changing the factor to just 0.04 times the base rate correctly models sediment for all mainline road segments. This essentially eliminates the traffic effect as a factor influencing sediment yield on roads managed with HCP construction and use standards.

Management implications

HRC manages its roads to minimize the delivery of sediment to water courses in accordance with voluntary agreements and permits with various federal and state agencies. The Habitat Conservation Plan prescribes forest road construction, maintenance, and use strategies. Stormproof construction practices, road drainage design to minimize the connectivity of the ditches to the streams, and ongoing maintenance are all important to minimize sediment generation and delivery from the road system. HRC also prevents road surface erosion and damage to roads by log truck traffic by matching the timing of use to the resistance of the road surfacing. Some roads can be used year round whiles others can only be used only during the summer dry season. Wet weather restrictions apply to log hauling and use of the roads by heavy trucks during rainstorms. Truck traffic must cease operating when surface runoff is visible on road surfaces. Truck traffic can only resume after visible runoff ends.

This study was primarily designed to determine erosion rates for use in sediment budgeting. However, results also address the effectiveness of some road management practices designed to minimize sediment generation, with implications for others.

Wet Weather Hauling Restrictions. Study observations directly evaluated the effectiveness of the wet weather hauling restrictions. Studied road segments represented mainline roads with heavy use by log trucks and secondary roads periodically used for log hauling. Traffic during the winter months was significant and normal for these watersheds. Roads were operated according to wet weather restrictions. No previous studies that we are aware of have studied heavily used roads where traffic was stopped during periods of observable road runoff. Other studies had periods of no hauling as a consequence of normal operations (e.g. Bilby et al. 1989), but none has measured a deliberately applied strategy to restrict log truck traffic during wet weather on all roads.

The very low sediment yields observed from heavily used roads confirmed the effectiveness of the wet weather hauling restrictions. Erosion rates were at least 10 times lower than observed in other similar studies in the coastal regions of the Pacific Northwest dominated by rainfall precipitation. The sensitivity of soils to erosion is as high in this area as anywhere road sediment has been studied.

Ditch Vegetation: Another unique management element on HRC roads is the practice of allowing ditches to vegetate. This practice appears to have also helped minimize the sediment generated with road and ditch runoff on heavily used road segments.

Surfacing Material: Rock surfacing materials available in the area vary in durability and resistance to abrasion. The lowest sediment yields were observed on road surfaces rocked with the most durable material. Sediment yields from pitrun materials were very low but were still higher than the most resistant rock. This result suggests that strategic use of the best rock on the locations with the greatest potential for delivery of road surface runoff to streams, such as within the hydrologically connected segments, would further minimize sediment delivery.

New Construction: Sediment yields were higher on newly constructed roads for the first year after construction. Yield declined to low levels the year following. This recovery period is shorter than the 2-yr period suggested in the Watershed Analysis surface erosion module. Scheduling construction a year prior to use for log hauling would enable the road to harden and help minimize sediment input.

Cutslope vegetation and stability: There were cutslope issues that affected sediment yield at several sites. Incomplete vegetative cover resulted in visibly active erosion on one secondary road illustrating the importance of achieving proper cutslope stability and vegetative cover. Another segment experienced a slump from soil piping during a high rainfall event. This problem may have been difficult to prevent, but rapid response by maintenance crews limited sediment problems for the rest of the storm season. Even the small size of the slump significantly increased sediment yield from the segment that year.

Native Surface (Dirt Roads). Erosion rates were significantly higher on dirt roads. These results emphasize the importance of a number of management practices for these types of roads that are common on HRC property. These include care to hydrologically disconnect and effectively manage surface runoff, rigid adherence to seasonal restrictions and careful maintenance with ATV use. Erosion control measures beyond what was done on the measured road segment would reduce erosion from what was measured. Establishing vegetation on the road surfaces and cutslopes would undoubtedly reduce erosion from what was observed in this study.

Sediment Budgets and Modeling: The low road erosion rates observed in this study have significant implications for sediment budgeting in HRC watersheds. Road surface sediment models should be adjusted to reflect the HRC stormproofing and construction standards. Study results provide the basic information to do so.

INVENTORY OF ROAD CHARACTERISTICS RELEVANT TO SEDIMENT ESTIMATION ON HRC STORMPROOFED ROADS

The first section of this report described a detailed field study that quantified road sediment generation from a unit area of road surface in relation to rainfall, traffic and road characteristics. To assess delivery of sediment from road surfaces to streams at the local or watershed scale requires quantification of the relevant road conditions that determine sediment generation and delivery at these spatial scales. A road survey was conducted to characterize road features that factor in erosion and delivery of sediment to streams.

Objective

The objectives of this study were to inventory stormproofed roads on HRC property to:

- Characterize road features that influence erosion rates from road surfaces and ditches,
- Develop data for sediment modeling to use with SEDMODL in sediment budgeting in Watershed Analysis and TMDLs,
- Quantify potential sediment delivery from the road system as a whole.

Roads included in the long-term plan for active management of the property were surveyed in this project. Closed and decommissioned roads were not surveyed.

Study Area and Survey Methods

The survey assessed road characteristics included in SEDMODL on stormproofed roads. The inventory methods were developed by Kathy Dube of GeoDynamics, who was the Surface Erosion Module analyst for the Freshwater and Elk River Watershed Analyses. The road survey protocol included the parameters listed in Table 15. The survey protocol is provided in Appendix C. PALCO did not measure all parameters provided in the Dube manual, but surveyors did measure each parameter consistent with manual instructions. A few characteristics of cut-and fillbanks were collected within the crossing area.

The survey crew surveyed the entire road length. Initial segment distance was started at the road junction with another road. The surveyors progressed along the road on ATVs. Distance was carefully measured with a distance wheel attached to the ATV. The road was segregated into segments according to delivery or non-delivery through surface or ditch runoff to streams. The surveyor visually elected break points that segregated the portion of the road network that deliver sediment directly to the stream (hydrologically connected) from those that did not. The break was identified as a hydrologic disconnection feature or topographically defined surface. A direct entry segment would include the segment, crossing, and any segment draining to the crossing from the other direction when present.

Table 15. Road features surveyed on stormproofed roads in Elk River and Freshwater Creek.

Location	Attribute	Measures
Road	Start distance	measured in ft from road start point
	End distance	measured in ft from road start point
	Segment delivery	Direct, no delivery
	Surfacing	asphalt, gravel, native, pitrun, /with ruts, /w grass
	Road configuration	Insloped, outsloped, crowned, out w/ditch
	Road drainage	full, half, none, split
	Average tread width	record in ft
	Ditch width	record in ft
	Ditch vegetation	grass, brush, trees, none
	Ditch depth	<1ft, 1-3 ft, 3-5 ft, >5 ft
	Road gradient	record in %
	Cutslope average height	None, 2.5 ft, 5 ft, 10 ft, 25 ft
	Cutslope gradient (degrees)	<15, 15-45 >45
	Cutslope cover	record in %
	Portion within segment directly draining	record in %
Stream crossing	Cutbank length	record in ft
	Cutbank cover	record in %
	Fillbank length (ft)	record in ft
	Fillbank cover	record in %

Drainage to streams was added to the survey protocol in 2005 so all segments do not have a value for this parameter. The portion of the road surface within the hydrologically connected zone that delivered to the stream was visually estimated by the surveyor.

Stormproofed roads existing throughout HRC property were inventoried in 2004 and 2005. The survey included most of the road length that had been stormproofed to that time. A total of 472 miles (2,492,466 ft) of stormproofed roads were surveyed throughout the property, with some road length surveyed in each Watershed Analysis Area except the Bear and Mattole Rivers.

In the years following adoption of the HCP, PALCO concentrated road stormproofing activities in the Freshwater Creek watershed and the Elk River mainline road to allow winter logging. A significant portion of the Freshwater roads were already stormproofed at the time of the road. Surveyed roads in these two watersheds are shown in Figures 43 and 44. Upper Eel and Yager/Lawrence WAAs were also more extensively surveyed than others.

Figure 43. Stormproofed roads in the Freshwater Creek watershed inventoried for delivery and road characteristics.

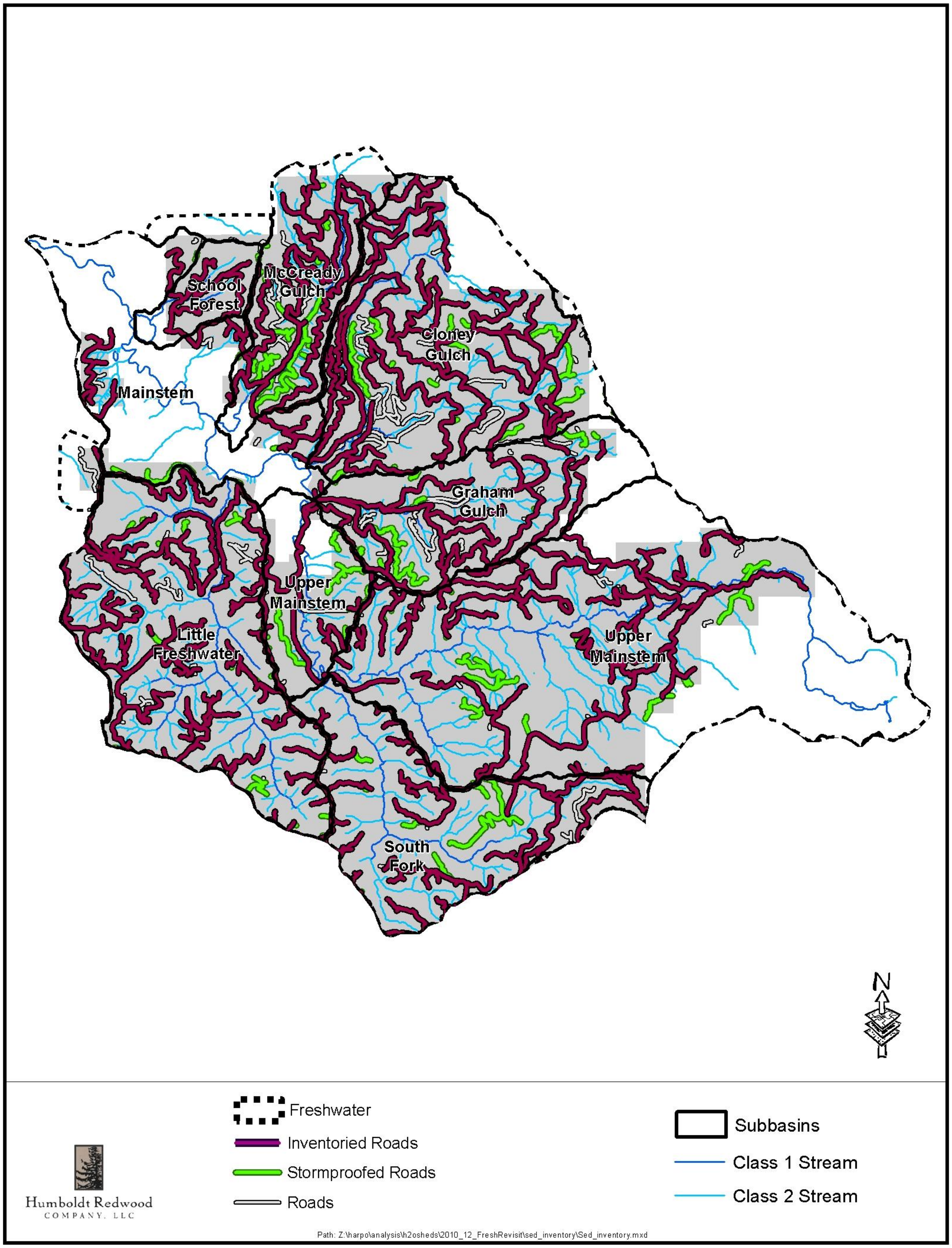
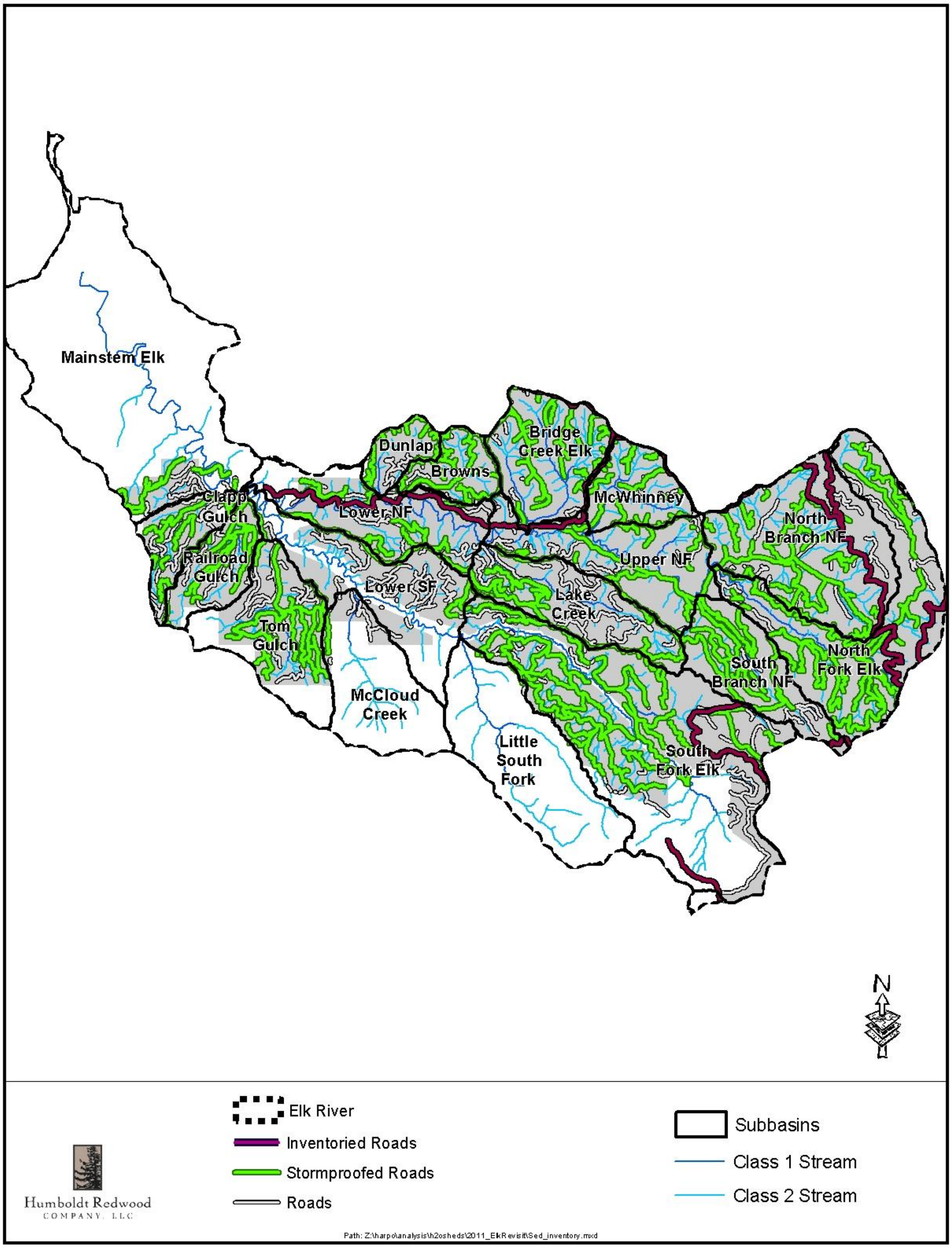


Figure 44. Stormproofed roads in the Elk river watershed inventoried for delivery and road characteristics.



Results

The objective of this report is to provide road characteristics statistics that can be used to inform models estimating road erosion and delivery from HRC roads. Characteristics of the connected road segments are primarily summarized by road types: gravel, pitrun (less durable gravel), native surface, and asphalt. Statistics are computed with SPSS® statistical software 19.0.

DIRECT DELIVERY ROAD LENGTH

Figure 45 shows the total length by general road use category and road surfacing type. Most of the road length is secondary roads with relatively limited traffic use except when serving as a haul road for a THP. The so called “mainline” roads are only a small portion of the total road length. Generally these are roads named with letters in the GIS database. Mainline indicates a heavily used trunk road that serves as a feeder from many smaller secondary roads, or is a main route from one watershed to the next. Asphalt use as a surfacing material is limited to the lower segments of the mainline in the North Fork Elk River where the road travels along the river.

Direct entry (hydrologically connected) road length statistics are provided by Watershed Analysis Area (WAA) and subbasins in Tables 16 (English units) and 17 (metric units). The tables provide the length of direct entry road by road type, the total surveyed length, and the direct entry proportion of the surveyed.

There was considerable variability in proportion of direct entry length to total road length at the subbasin level. This reflects real differences in road location relative to streams. Road placement strategies in earlier decades were not concerned with sediment delivery. Some subbasins have riparian corridor roads that travel for significant distances along streams, while others have very little intersection with streams due to ridgetop locations. HRC’s long term goal is to eliminate riparian corridor roads as much as possible. Some of the variability is also an artifact of the survey. Some subbasins with very small survey length have a high proportion of direct entry roads. What roads were surveyed was determined by what had been stormproofed at the time and only a short distance may have been completed. Screening with a one mile minimum survey length to exclude problems from unrepresentative road length, the direct entry portion varied from a low of 1.0% to a high of 20.1% among subbasins. The average delivery at the watershed scale was 11.1% (Tables 16/17).

Figure 45. Hydrologically connected length by road use category and road surfacing material. Top figure is in ft, bottom is in meters.

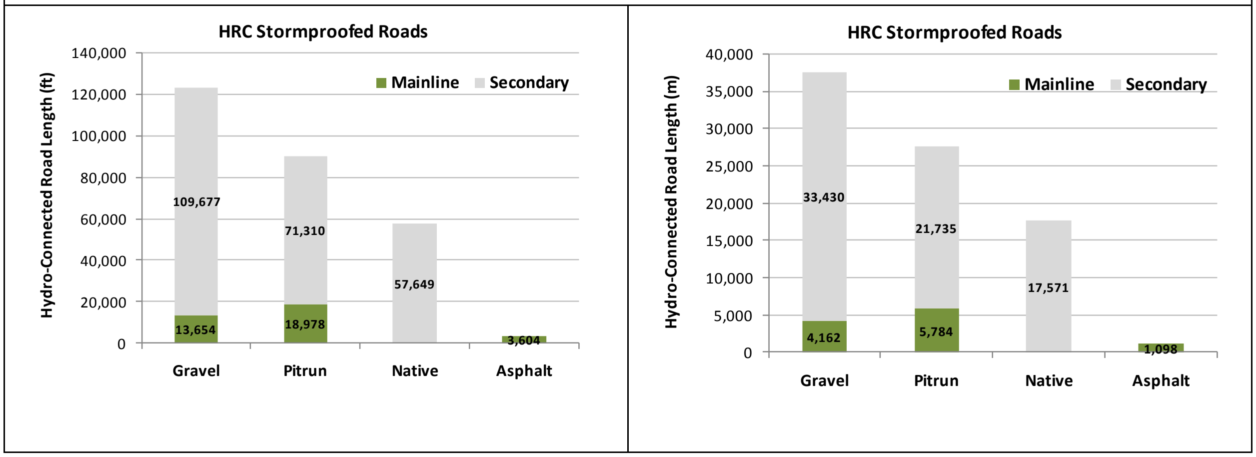


Table 16. Total length (ft) of hydrologically connected stormproofed roads by WAA and subbasin. ENGLISH UNITS

		Hydrologically Connected Segment Length (ft)				Total Survey	Proportion
HYU_NAME	**SUBBASINS**	**Gravel**	**Pitrun Gravel**	**Native Surface**	**Asphalt**	**Length Surveyed (ft)**	**% Length Surveyed Direct Delivery**
Elk River	Bridge Creek Elk	0	365	0	0	9,030	4.0%
	Browns	290	0	0	0	294	98.6%
	Dunlap	0	0	0	37	181	20.4%
	Lower NF	217	678	0	3,093	19,521	20.4%
	McWhinney	0	0	0	0	6,919	0.0%
	South Branch N. Fork	0	0	0	0	2,472	0.0%
	North Branch NF	0	298	0	0	10,337	2.9%
	Upper NF	0	1,172	0	0	4,413	26.6%
	South Fork Elk River	0	0	0	0	39	0.0%
	North Fork Elk	0	0	0	0	11,911	0.0%
	TOTAL	507	2,513	0	3,130	65,117	9.4%
Freshwater	Cloney Gulch	4,822	858	4,489	0	113,073	9.0%
	Graham Gulch	2,807	1,109	3,554	126	59,864	12.7%
	Little Freshwater	313	7,099	2,175	0	121,323	7.9%
	Mainstem	1,851	945	1,207	119	27,947	14.7%
	McCready Gulch	6,192	0	4,228	0	73,757	14.1%
	School Forest	0	0	761	0	15,166	5.0%
	South Fork	1,501	2,823	131	0	78,616	5.7%
	Upper Mainstem	15,597	4,715	3,322	0	117,788	20.1%
	Ryan Slough	0	216	0	0	10,956	2.0%
	TOTAL	33,083	17,765	19,867	245	618,490	11.5%
Upper Eel	Balcom Creek Complex	2,756	1,076	686	0	58,023	7.8%
WAA	Boulder Creek	657	0	1,282	0	33,991	5.7%
Larabee Creek	Carson Creek Complex	4,442	1,429	2,433	0	84,482	9.8%
	Chris Creek	0	1,195	1,138	0	32,980	7.1%
	Main Stem Larabee I	2,215	874	1,564	0	44,907	10.4%
	Mid Larabee Creek Complex	4,314	334	1,587	0	60,430	10.3%
	Mill Creek	477	0	356	0	18,885	4.4%
	No Name Creek Complex	711	224	5,305	0	61,827	10.1%
	Scott Creek Complex	3,433	754	2,127	0	82,195	7.7%
	Smith Creek	298	90	2,391	0	44,472	6.2%
Sequoia	Cameron Creek	88	0	459	0	17,646	3.1%
	Kapple Creek Complex	3,388	514	1,430	0	61,859	8.6%
	McCann Creek Complex	20	905	166	0	10,645	10.2%
	Newman Creek	1,201	3,022	1,464	0	73,562	7.7%
	Poison Oak Creek Complex	4,486	551	75	0	39,806	12.8%
	Thompson Creek	420	0	2,513	0	36,015	8.1%
	TOTAL	28,906	10,968	24,976	0	761,725	8.5%
Lower Eel/	Allen	0	598	0	0	2,237	26.7%
Eel Delta WAA	Lower Eel	0	912	0	0	4,807	19.0%
Lower Eel	Perrott	0	896	0	0	5,820	15.4%
	Weber	0	1,147	219	0	17,299	7.9%
	Elk Creek	945	106	1,095	0	21,043	10.2%
Eel Delta	Strongs			384		8,310	4.6%
	TOTAL	945	3,659	1,314	0	51,206	11.6%
Yager/Lawrence	Blanton Creek	22,511	11,083	4,486	83	278,621	13.7%
Yager	Cooper Mill Creek	9,454	8,637	4,242	396	188,834	12.0%
	South Fork Yager Creek	1,157	2,156	787	0	57,539	7.1%
	North Fork Yager Creek	131	5,829	1,162	0	57,405	12.4%
Lawrence	Bell Creek	2,570	1,756	0	0	28,259	15.3%
	Booths Run	9,428	1,766	363	0	109,681	10.5%
	Corner Creek	13,498	13,396	647	0	173,309	15.9%
	Lawrence Creek	0	1,049	0	0	10,730	9.8%
	Shaw Creek	1,032	9,349	674	0	76,094	14.5%
	TOTAL	59,781	55,021	12,361	479	980,472	13.0%
Van Duzen WAA	Wolverton Gulch	48	0	25	88	15,456	1.0%
	TOTAL	48	0	25	88	15,456	1.0%
Grand Total		123,270	89,926	58,543	3,942	2,492,466	11.1%

Table 17. Total length (m) of hydrologically connected stormproofed roads by WAA and subbasin. METRIC UNITS

		Hydrologically Connected Segment Length (m)				Total Survey	Proportion
HYU_NAME	**SUBBASINS**	**Gravel**	**Pitrun Gravel**	**Native Surface**	**Asphalt**	**Length Surveyed (m)**	**% Length Surveyed Direct Delivery**
Elk River	Bridge Creek Elk	0	111	0	0	2,752	4.0%
	Browns	88	0	0	0	90	98.6%
	Dunlap	0	0	0	11	55	20.4%
	Lower NF	66	207	0	943	5,950	20.4%
	McWhinney	0	0	0	0	2,109	0.0%
	South Branch N. Fork	0	0	0	0	753	0.0%
	North Branch NF	0	91	0	0	3,151	2.9%
	Upper NF	0	357	0	0	1,345	26.6%
	South Fork Elk River	0	0	0	0	12	0.0%
	North Fork Elk	0	0	0	0	3,630	0.0%
	TOTAL	155	766	0	954	19,848	9.4%
Freshwater	Cloney Gulch	1,470	262	1,368	0	34,465	9.0%
	Graham Gulch	856	338	1,083	38	18,247	12.7%
	Little Freshwater	95	2,164	663	0	36,979	7.9%
	Mainstem	564	288	368	36	8,518	14.7%
	McCready Gulch	1,887	0	1,289	0	22,481	14.1%
	School Forest	0	0	232	0	4,623	5.0%
	South Fork	458	860	40	0	23,962	5.7%
	Upper Mainstem	4,754	1,437	1,013	0	35,902	20.1%
	Ryan Slough	0	66	0	0	3,339	2.0%
	TOTAL	10,084	5,415	6,055	75	188,516	11.5%
Upper Eel WAA	Balcom Creek Complex	840	328	209	0	17,685	7.8%
	Boulder Creek	200	0	391	0	10,360	5.7%
Larabee Creek	Carson Creek Complex	1,354	436	742	0	25,750	9.8%
	Chris Creek	0	364	347	0	10,052	7.1%
	Main Stem Larabee I	675	266	477	0	13,688	10.4%
	Mid Larabee Creek Complex	1,315	102	484	0	18,419	10.3%
	Mill Creek	145	0	109	0	5,756	4.4%
	No Name Creek Complex	217	68	1,617	0	18,845	10.1%
	Scott Creek Complex	1,046	230	648	0	25,053	7.7%
	Smith Creek	91	27	729	0	13,555	6.2%
Sequoia	Cameron Creek	27	0	140	0	5,379	3.1%
	Kapple Creek Complex	1,033	157	436	0	18,855	8.6%
	McCann Creek Complex	6	276	51	0	3,245	10.2%
	Newman Creek	366	921	446	0	22,422	7.7%
	Poison Oak Creek Complex	1,367	168	23	0	12,133	12.8%
	Thompson Creek	128	0	766	0	10,977	8.1%
	TOTAL	8,811	3,343	7,613	0	232,174	8.5%
Lower Eel/ Eel Delta WAA	Allen	0	182	0	0	682	26.7%
	Lower Eel	0	278	0	0	1,465	19.0%
Lower Eel	Perrott	0	273	0	0	1,774	15.4%
	Weber	0	350	67	0	5,273	7.9%
	Elk Creek	288	32	334	0	6,414	10.2%
Eel Delta	Strongs	0	0	117	0	2,533	4.6%
	TOTAL	288	1,115	401	0	15,608	11.6%
Yager/Lawrence	Blanton Creek	6,861	3,378	1,367	25	84,924	13.7%
Yager	Cooper Mill Creek	2,882	2,633	1,293	121	57,557	12.0%
	South Fork Yager Creek	353	657	240	0	17,538	7.1%
	North Fork Yager Creek	40	1,777	354	0	17,497	12.4%
Lawrence	Bell Creek	783	535	0	0	8,613	15.3%
	Booths Run	2,874	538	111	0	33,431	10.5%
	Corner Creek	4,114	4,083	197	0	52,825	15.9%
	Lawrence Creek	0	320	0	0	3,271	9.8%
	Shaw Creek	315	2,850	205	0	23,193	14.5%
	TOTAL	18,221	16,770	3,768	146	298,848	13.0%
Van Duzen WAA	Wolverton Gulch	15	0	8	27	4,711	1.0%
	TOTAL	15	0	8	27	4,711	1.0%
Grand Total		37,573	27,409	17,844	1,202	759,704	11.1%

ROAD FEATURES

There were 1,649 individual hydrologically connected segments surveyed throughout the property. Descriptive statistics are provided for:

- Segment length
- Road width
- Ditch width
- Road gradient
- Percent of road segment draining to streams
- Cutslope height
- Cutslope vegetative cover

These characteristics are emphasized because they are used to estimate sediment in sediment models or determine total road delivery at the local and watershed scale. Statistics are calculated grouping sites by road surfacing material.

SEGMENT LENGTH

Descriptive statistics for segment length of individual hydrologically connected segments is provided by surfacing material in Table 18 and by surfacing material and road surface configuration in Table 19. Median length by surfacing and configuration is shown in Figure 46.

Table 18. Segment length (ft) descriptive statistics by road surfacing type.

Surfacing Material	Mean (ft)	N	Std. Deviation	S.E.	Sum (ft)	Median (ft)
ASPHALT	236.0	17	146.44	35.517	4,012	210
GRAVEL	181.7	680	149.29	5.725	123,579	140
NATIVE	116.9	505	86.32	3.841	59,052	100
PIT RUN	202.7	446	168.66	7.986	90,408	160

Figure 46. Proportion and median length of road segments by road surface material and configuration (ft).

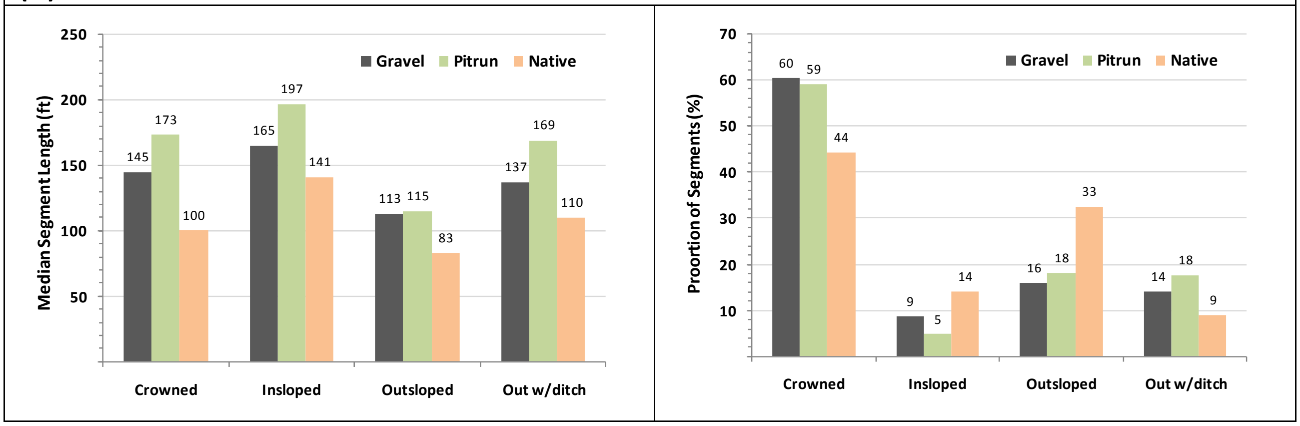


Table 19. Segment length (ft) descriptive statistics by road surfacing type and surface configuration.

Surfacing Material	Configuration	Mean (ft)	N	Std. Deviation	S.E.	Sum (ft)	Median (ft)
ASPHALT	CROWNED	278.7	12	150.86	43.55	3,344	285
	INSLOPED	131.3	3	94.37	54.48	394	84
	OutwDitch	155.0	1	.	.	155	155
GRAVEL	CROWNED	188.7	410	139.96	6.91	77,376	145
	INSLOPED	237.3	59	251.79	32.78	13,999	165
	OUTSLOPED	133.8	109	99.43	9.52	14,589	113
	OutwDitch	157.6	96	100.67	10.27	15,132	137
NATIVE	CROWNED	117.2	223	84.77	5.68	26,125	100
	INSLOPED	144.0	71	77.65	9.22	10,223	141
	OUTSLOPED	98.6	164	80.54	6.29	16,166	83
	OutwDitch	136.7	46	109.32	16.12	6,290	110
PIT RUN	CROWNED	210.6	263	154.49	9.53	55,397	173
	INSLOPED	234.0	22	222.69	47.48	5,147	197
	OUTSLOPED	155.1	81	178.04	19.78	12,561	115
	OutwDitch	206.8	79	161.15	18.13	16,339	169

Hydrologically connected road segments tended to be longer on pitrun gravel surfaced roads and shortest on native surface roads, with hard gravel roads in between. Outsloped roads tended to have shorter connected segment lengths and insloped roads tended to have longer connected sediment lengths. Crowned road segments were in between. Note that at many sites, the connected segment extends on both sides of a crossing.

Descriptive statistics of road features are presented as follows:

Surfacing	Data Distribution	Descriptive Statistics
Gravel	Figure 47	Table 20
Pitrun	Figure 48	Table 21
Native	Figure 49	Table 22
Asphalt	not shown	Table 23

Table 20. Descriptive statistics of road characteristics for segments surfaced with gravel.

Surfacing Material			Road Width (ft)	Ditch Width (ft)	Cutslope Height (ft)	Cutslope Vegetation %	Gradient (%)	Draining to Stream %
GRAVEL	N	Valid	680	680	680	680	680	367
		Missing	0	0	0	0	0	313
	Mean		14.0	2.4	9.5	82.1	6.3	66.3
	Std. Error of Mean		0.12	0.102	0.293	0.922	0.167	1.55
	Median		14	2	10	90	5	70
	Mode		15	0	10	100	3	100
	Std. Deviation		3.133	2.651	7.652	24.051	4.349	29.7
	Variance		9.816	7.026	58.559	578.463	18.914	882.092
	Minimum		0	0	0	0	0	0
	Maximum		40	40	25	100	28	100
	Percentiles	25	12	0	5	70	3	40
		50	14	2	10	90	5	70
		75	15	3	10	100	9	90

Table 21. Descriptive statistics of road characteristics for segments surfaced with pitrun rock.

Surfacing Material			Road Width (ft)	Ditch Width (ft)	Cutslope Height (ft)	Cutslope Vegetation %	Gradient (%)	Draining to Stream %
PIT RUN	N	Valid	446	446	446	446	446	353
		Missing	0	0	0	0	0	93
	Mean		14.5	2.5	10.8	87.9	5.2	68.7
	Std. Error of Mean		0.245	0.105	0.405	0.865	0.206	1.542
	Median		14	2	10	95	4	80
	Mode		12	0	10	100	2	100
	Std. Deviation		5.18	2.21	8.555	18.268	4.356	28.973
	Variance		26.833	4.882	73.195	333.713	18.972	839.415
	Minimum		0	0	0	0	0	0
	Maximum		100	11	25	100	20	100
	Percentiles	25	12	0	5	80	2	50
		50	14	2	10	95	4	80
		75	16	4	10	100	7	90

Figure 47. Data distribution of road characteristics of gravel surfaced roads.

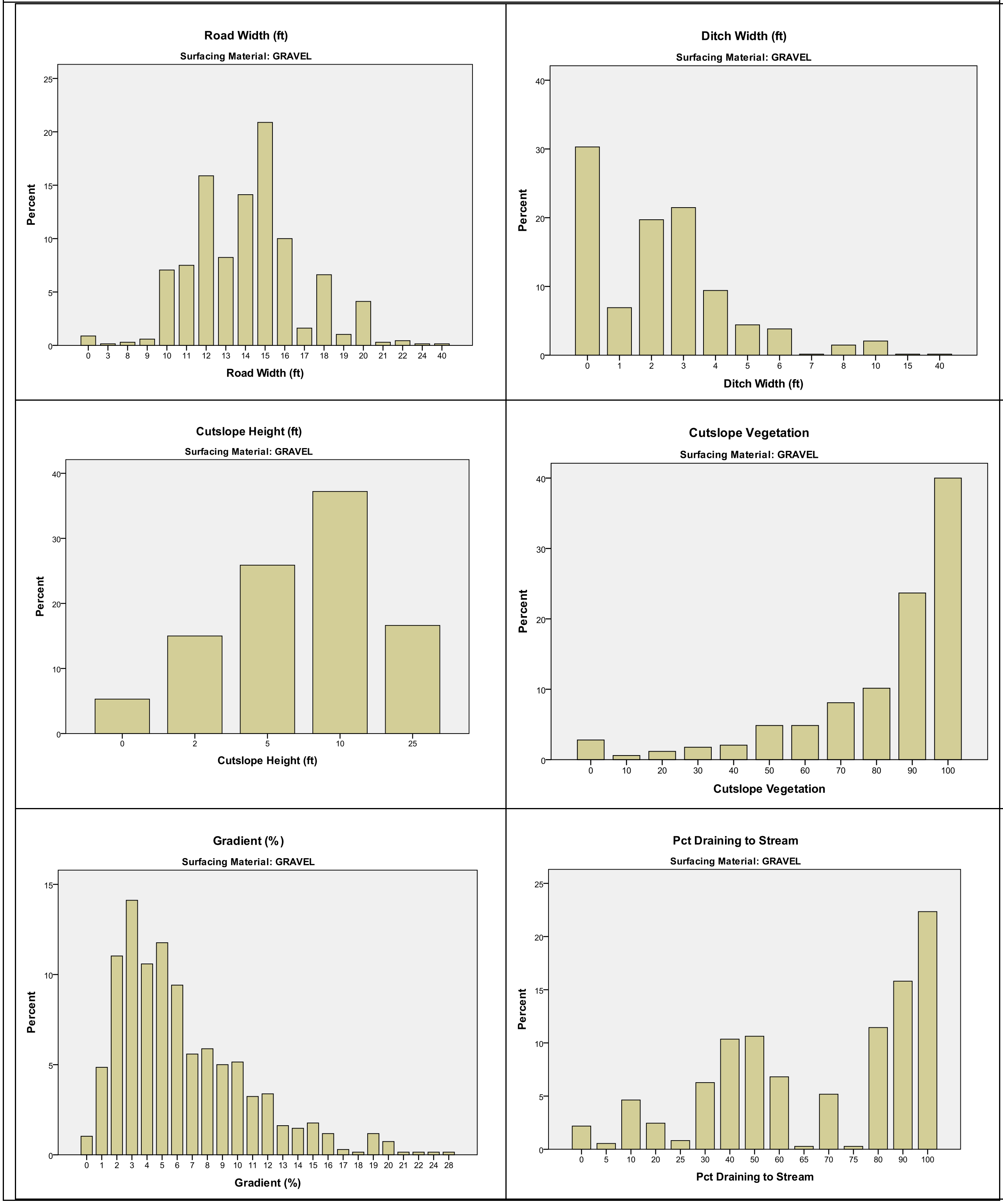


Figure 48. Data distribution of road characteristics of pitrun rock surfaced roads.

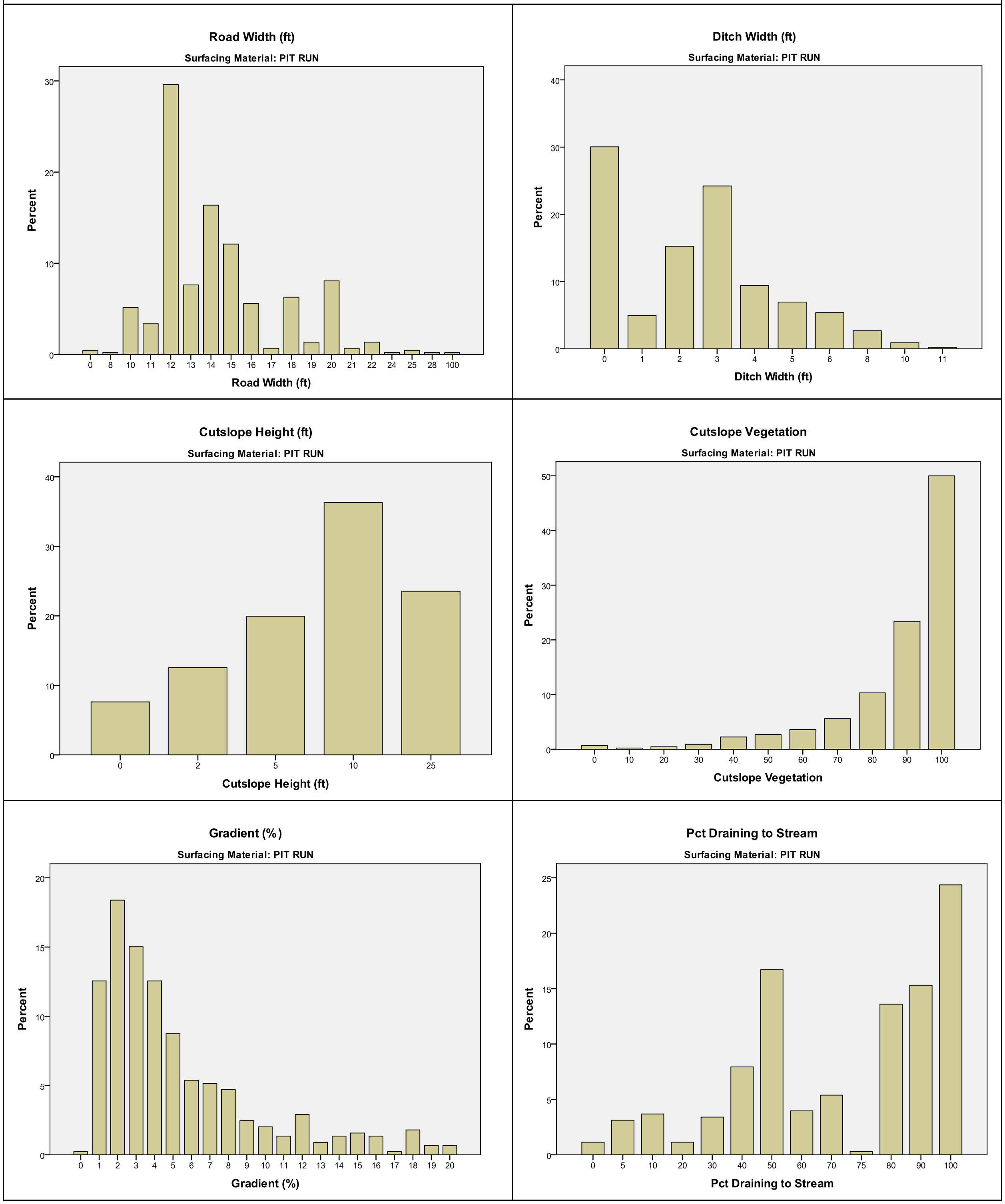


Table 22. Descriptive statistics of road characteristics for native soil surfaced segments.

Surfacing Material			Road Width (ft)	Ditch Width (ft)	Cutslope Height (ft)	Cutslope Vegetation %	Gradient (%)	Draining to Stream %
NATIVE SOIL	N	Valid	505	505	505	505	505	209
		Missing	0	0	0	0	0	296
	Mean		11.8	1.0	9.6	77.8	6.9	83.5
	Std. Error of Mean		0.116	0.078	0.359	1.169	0.213	1.933
	Median		12	0	10	90	6	100
	Mode		12	0	10	100	2	100
	Std. Deviation		2.616	1.745	8.059	26.266	4.781	27.951
	Variance		6.845	3.045	64.944	689.913	22.859	781.251
	Minimum		0	0	0	0	0	0
	Maximum		21	15	25	100	24	100
	Percentiles	25	10	0	5	70	3	80
		50	12	0	10	90	6	100
		75	13	2	10	100	10	100

Table 23. Descriptive statistics of road characteristics for asphalt surfaced segments.

Surfacing Material			Road Width (ft)	Ditch Width (ft)	Cutslope Height (ft)	Cutslope Vegetation %	Gradient (%)	Draining to Stream %
ASPHALT	N	Valid	17	17	17	17	17	16
		Missing	0	0	0	0	0	1
	Mean		13.7	2.7	3.9	87.7	2.2	80.6
	Std. Error of Mean		1.06	0.549	1.564	8.022	0.654	4.697
	Median		14	3	0	100	1	85
	Mode		14	0	0	100	1	100
	Std. Deviation		4.372	2.262	6.447	33.077	2.698	18.786
	Variance		19.118	5.118	41.559	1094.118	7.279	352.917
	Minimum		0	0	0	0	0	50
	Maximum		20	6	25	100	10	100
	Percentiles	25	12	0	0	100	1	70
		50	14	3	0	100	1	85
		75	15	4	5	100	2	100

Figure 49. Data distribution of road characteristics of native soil surfaced roads.

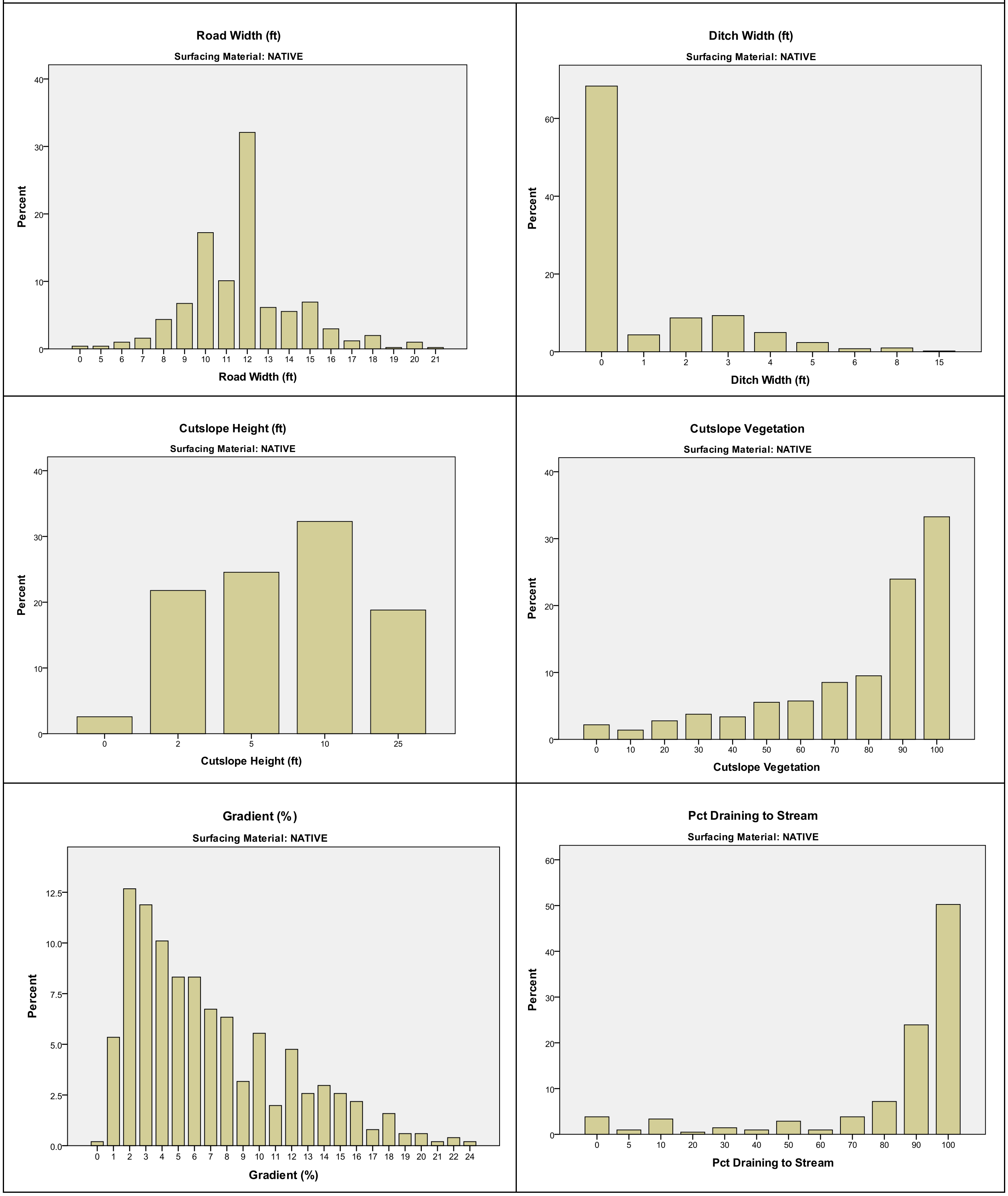


Figure 50. Central tendency statistics for road characteristics by surfacing type—MEDIAN values.

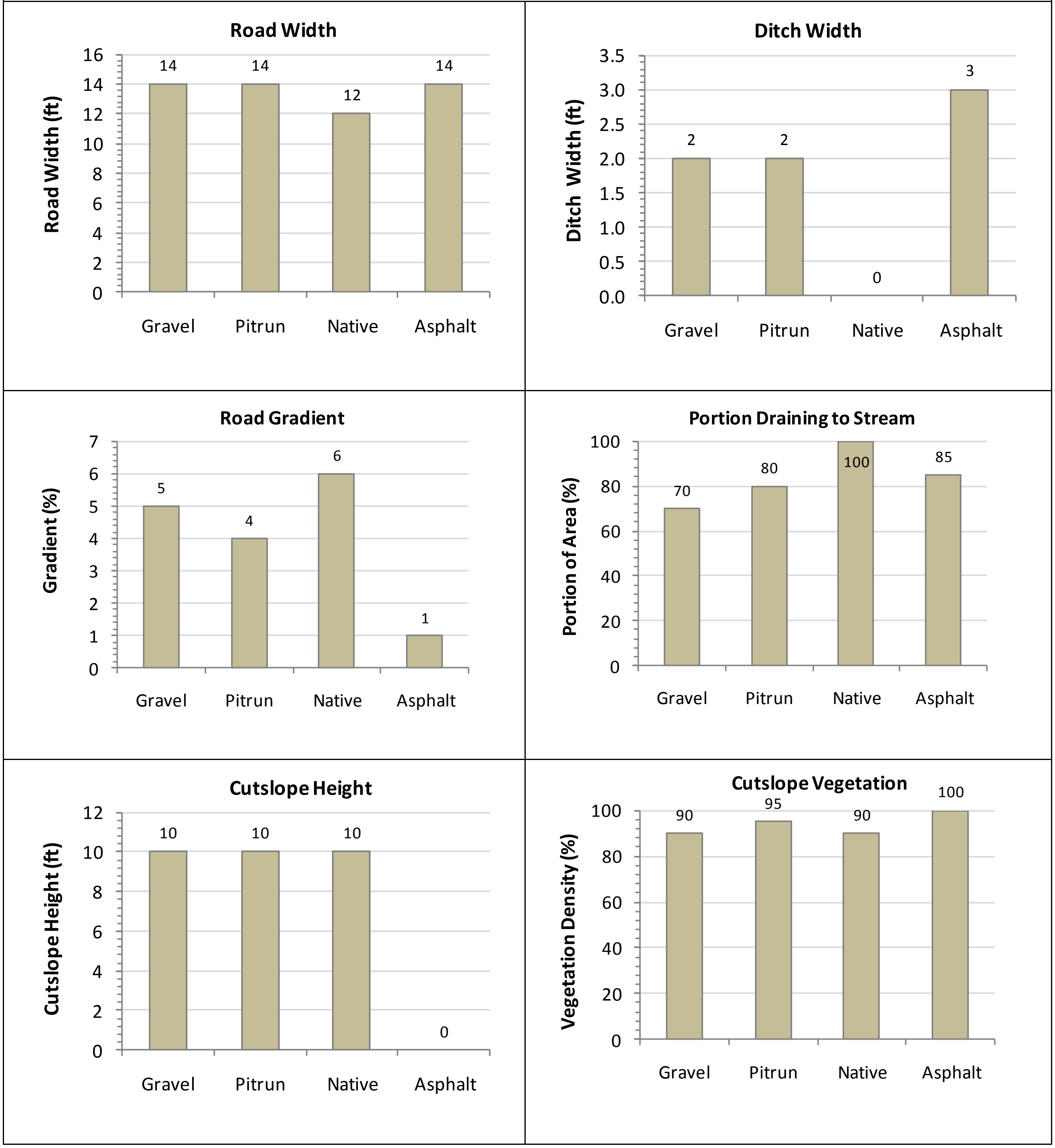
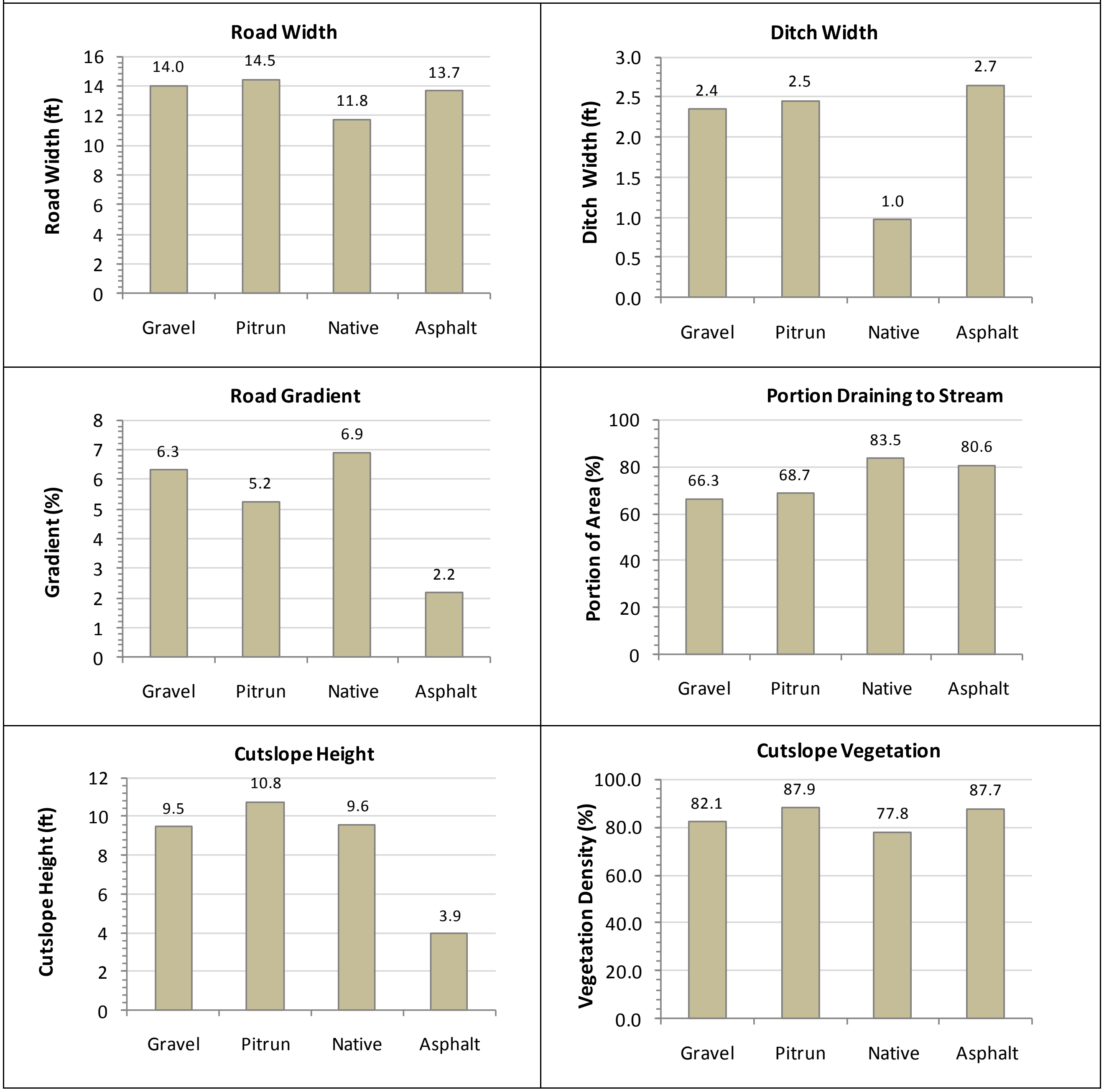


Figure 51. Central tendency statistics for road characteristics by surfacing type—MEAN values



CHARACTERISTICS USED FOR ESTIMATING SEDIMENT YIELD WITH SEDMODL

SEDMOLD as applied on HRC roads assigns erosion rates to road types, then computes delivery total by road length to estimate road sediment generation and delivery, rather than modeling individual segments based on their unique characteristics. Average values of road characteristics are applied to each road type. Descriptive statistics were calculated for road sediment characteristics of the 1649 hydrologically connected segments. The central tendency of those characteristics is discussed here. Table 24 provides the mean, median, and modal values for these parameters. Depending on the choice of statistics, these are the characteristics of the "typical" stormproofed road on HRC property.

Relationship to the Road Flume Study

The road flume study described earlier in this report measured sediment from individual road segments representing gravel, pitrun and native surface roads. The study segments were not hydrologically connected to enable the sites to be instrumented. However, these segments appear to be representative of the roads on HRC property as indicated by survey results from the hydrologically connected segments. The gravel surfaced segments covered a wide range of gradients, although the study segments tended to be steeper than average. Most of the study segments were similar in length and total area as the typical road (Table 22), although several were much longer. Cutslopes tended to be slightly shorter than the typical roads with typical vegetative density within the range commonly observed. The proportion of road drainage entering the stream estimated by the road surveyors (60 to 100%) tended to be higher than that determined at the study segments (30 to 40%). This could be the difference between visual estimates and highly precise total station surveys. It could also reflect that roads close to the streams may have higher proportion of surface area draining to them. Overall, the flume study roads were very representative of the typical road conditions found on HRC property as verified in the road survey. The flume study probably oversampled the highly trafficked roads relative to the infrequently used secondary road network.

Finally, the road surveyors noted when roads were grassed over, and when they were rutted indicating some surface damage (Figure 52). About 5.9% of the total surveyed length had rutted road surfaces. These are likely to produce sediment at a greater rate than determined in the flume study. Conversely, 20% of the roads, and a significant 46% of the native surface roads had grass cover on the road surface. Grass cover on dirt roads should substantially lower erosion from this road type relative to what was measured in the road study. This should be considered in the surfacing factor used in the WDNR model.

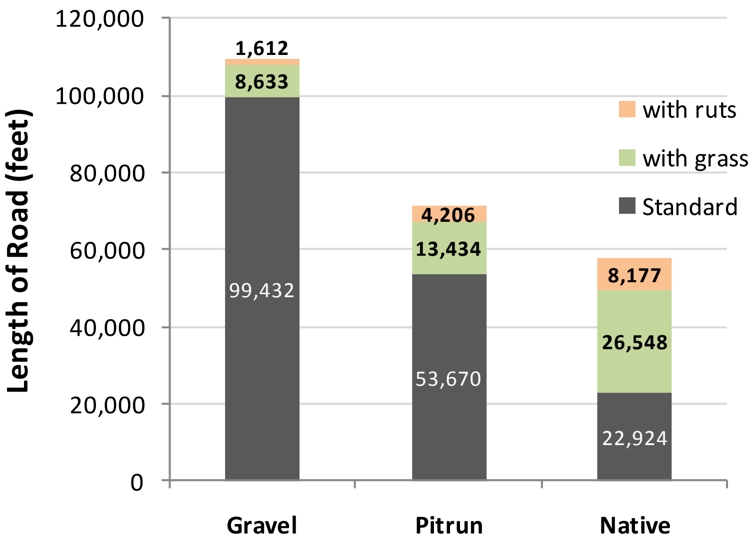


Figure 52. Portion of each road type with grass or ruts.

Table 24. Mean, median, and modal characteristics of road characteristics by road type.

Mean Values of Road Characteristics From Survey

Road Type	Configuration	Segment Length (ft)	Road Width (ft)	Ditch Width (ft)	Gradient %	Cutslope Ht (ft)	Cutslope Veg Density %	% Segment Draining	Road Area ft^2	Road Area (m^2)
Gravel	Crowned	189	14	2.4	6.3	9.5	82.1	66.3	1,754	163.0
Pitrun	Crowned	211	14.5	2.5	5.2	10.8	87.9	68.7	2,102	195.3
Native	Crowned	117	11.8	1	6.9	9.6	77.8	83.5	1,153	107.1

Median Values of Road Characteristics From Survey

Road Type	Configuration	Segment Length (ft)	Road Width (ft)	Ditch Width (ft)	Gradient %	Cutslope Ht (ft)	Cutslope Veg Density %	% Segment Draining	Road Area ft^2	Road Area (m^2)
Gravel	Crowned	145	14	2	5	10	90	70	1,421	132.0
Pitrun	Crowned	173	14	2	4	10	95	80	1,938	180.0
Native	Crowned	100	12	0	6	10	90	100	1,200	111.5

Modal Values of Road Characteristics From Survey

Road Type	Configuration	Segment Length (ft)	Road Width (ft)	Ditch Width (ft)	Gradient %	Cutslope Ht (ft)	Cutslope Veg Density %	% Segment Draining	Road Area ft^2	Road Area (m^2)
Gravel	Crowned	125	15	0	3	10	100	100	1,875	174.2
Pitrun	Crowned	60	12	0	2	10	100	100	720	66.9
Native	Crowned	100	12	0	2	10	100	100	1,200	111.5

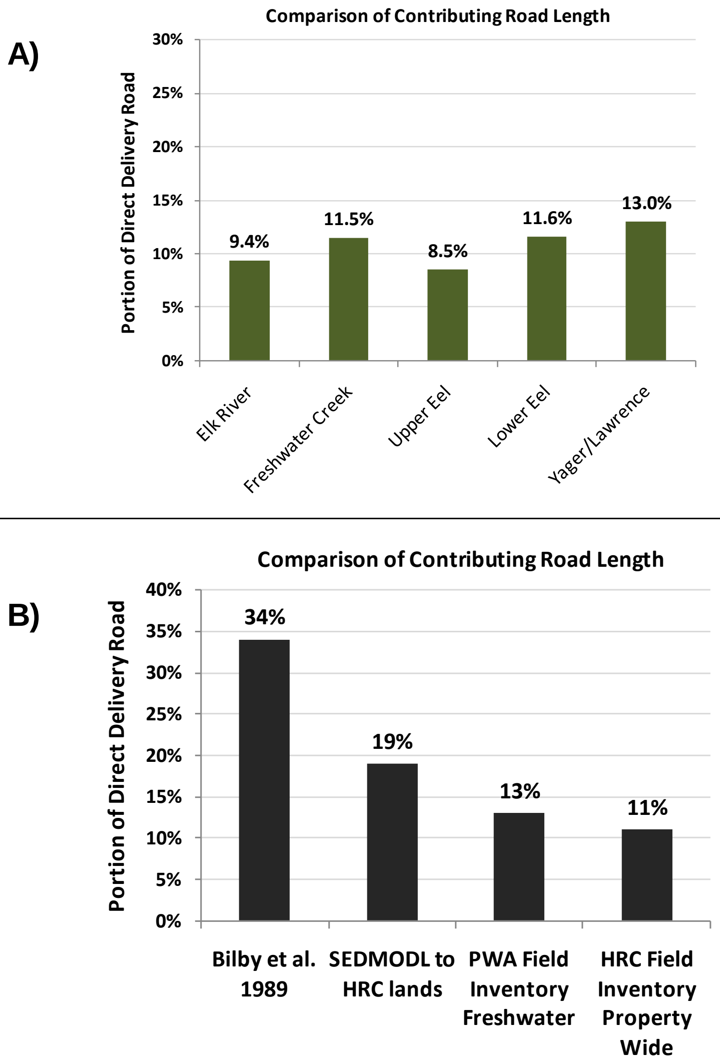
Management Implications of the Road Survey Project

A large portion of the HRC road network that had been stormproofed by 2005 distributed throughout the property was surveyed for road characteristics important to the generation from road surfaces and delivery to streams. Road survey data is characterized in this report.

Data on average road characteristics should be useful to future sediment budget work at the watershed scale and application of sediment models.

The survey results document the proportion of road length that drains to streams. The average direct delivery for the entire 472 miles of road surveyed was 11.1%. This proportion varied with road configuration in watersheds and subbasins. This proportion was lower than estimated in Watershed Analysis in applying SEDMODL and by a PWA after road survey in Freshwater Creek (Figure 53). Direct delivery in an industrial forest ownership in the 1980's was reported in Bilby et al. (1989) and is also shown to indicate the overall progress of modern construction practices.

Figure 53. Direct delivery proportion of stormproofed road length by basin (A), and compared to previous estimates (B).



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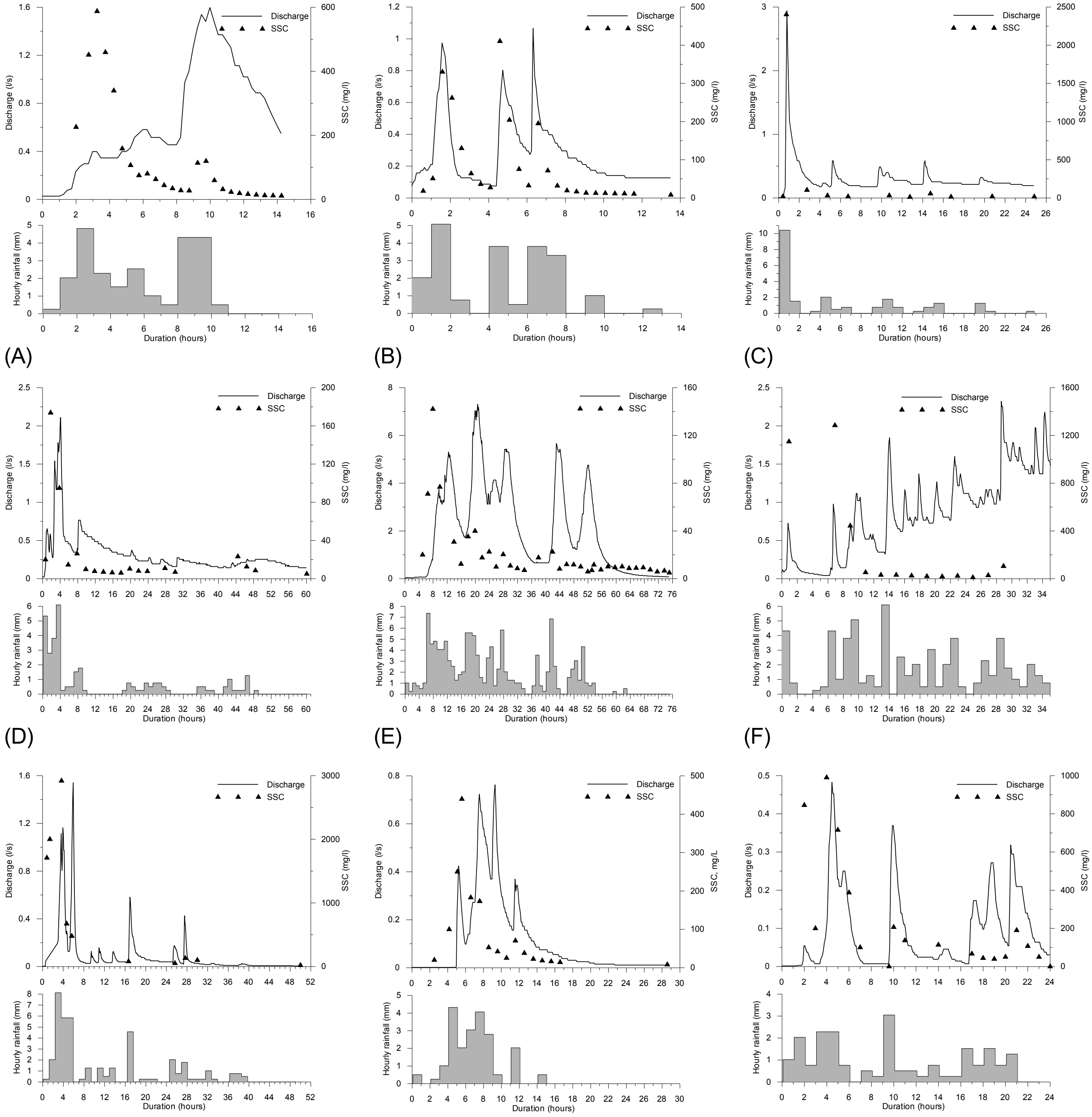
Wemple, B.C. 1998. Investigations of runoff production and sedimentation on forest roads. Ph.D. Dissertation, Oregon State University.

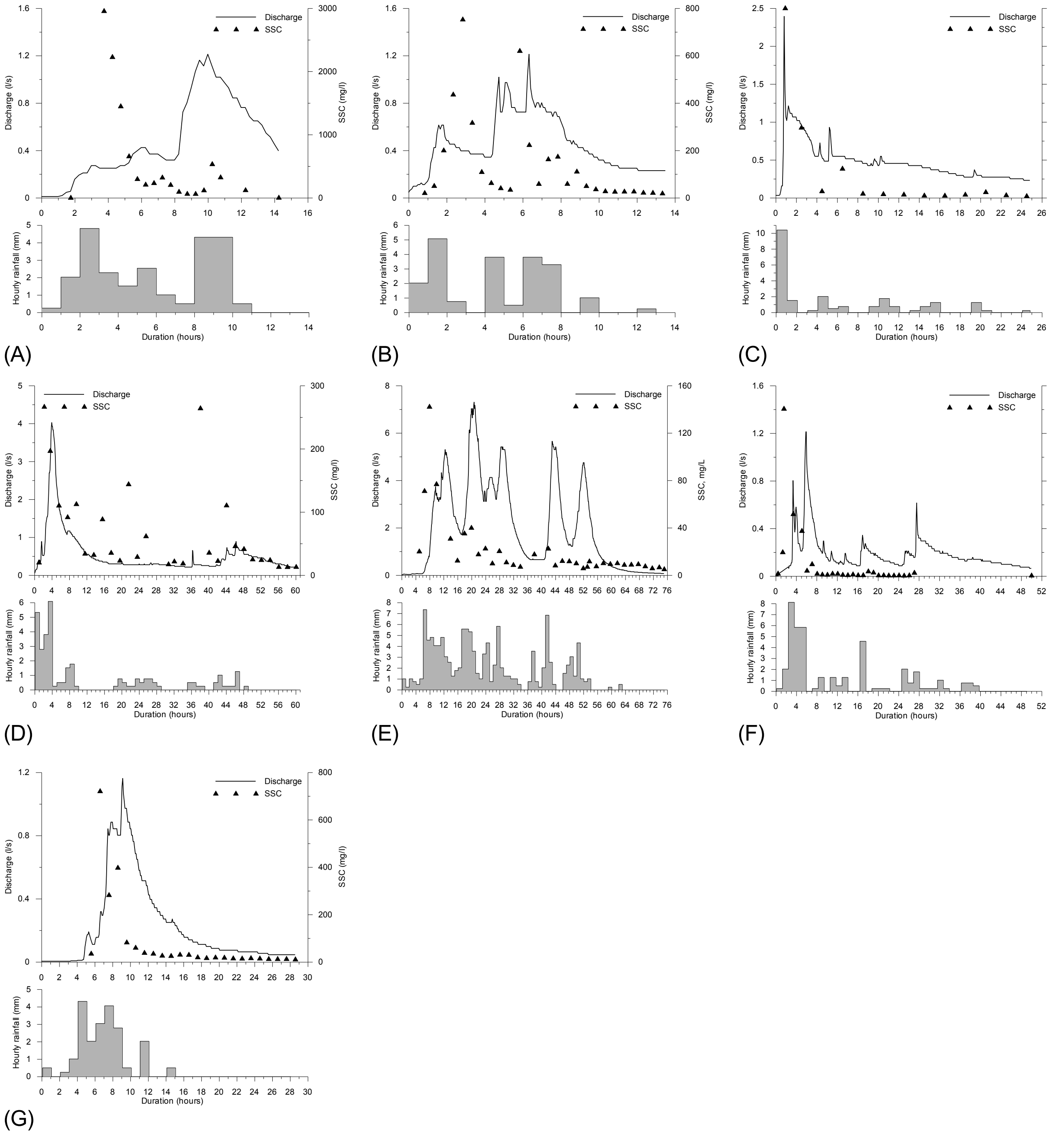
APPENDICES

Appendix A. Storm hydrographs for sites measured in 2004



(A)
(B)
(C)
(D)
(E)
(F)
(G)
(H)
(I)

Figure A.1 **Storm hydrographs, discharge, and the measured suspended sediment concentration (SSC) at 850 during 2004 events: (A): 3, (B): 4, (C): 5, (D): 6, (E): 8, (F): 9, (G): 10, (H): 11, and (I): 13.**



(A)

(B)

(C)

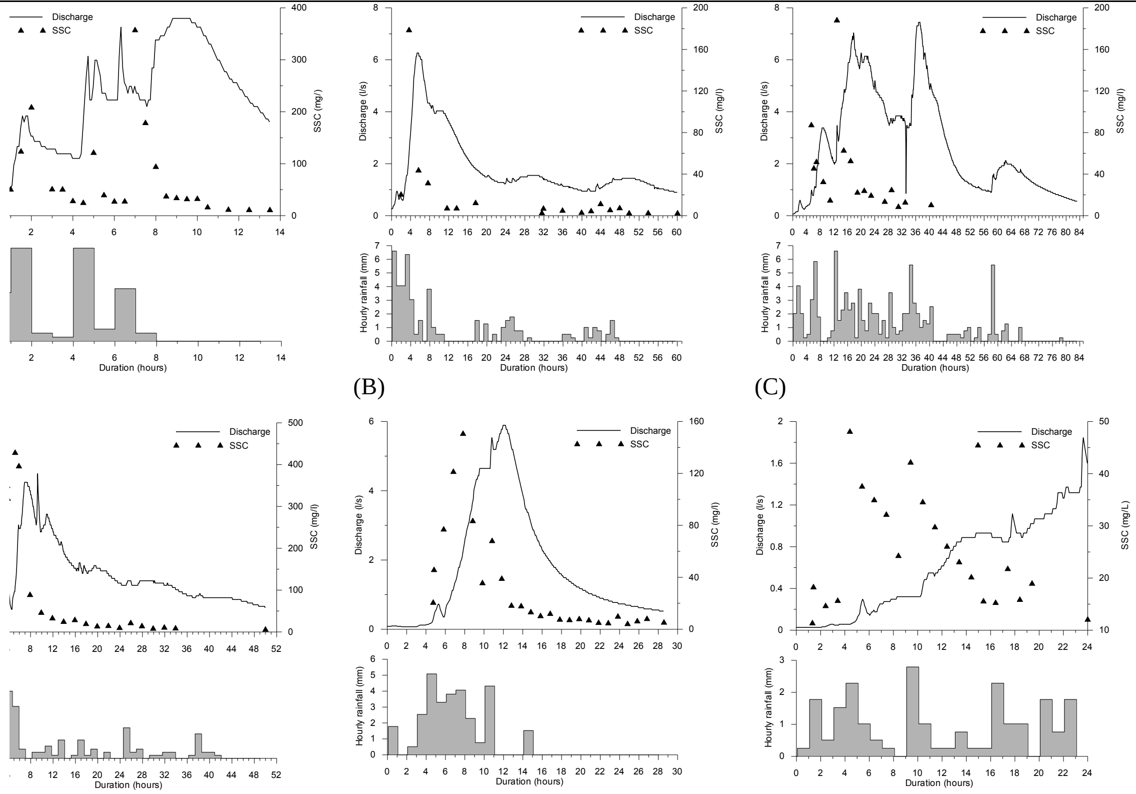
(D)

(E)

(F)

(G)

Figure A-2: Storm hydrographs, discharge, and the measured suspended sediment concentration (SSC) at 851during events: (A): 3, (B): 4, (C): 5, (D): 6, (E): 8, (F): 10, (G): 11.



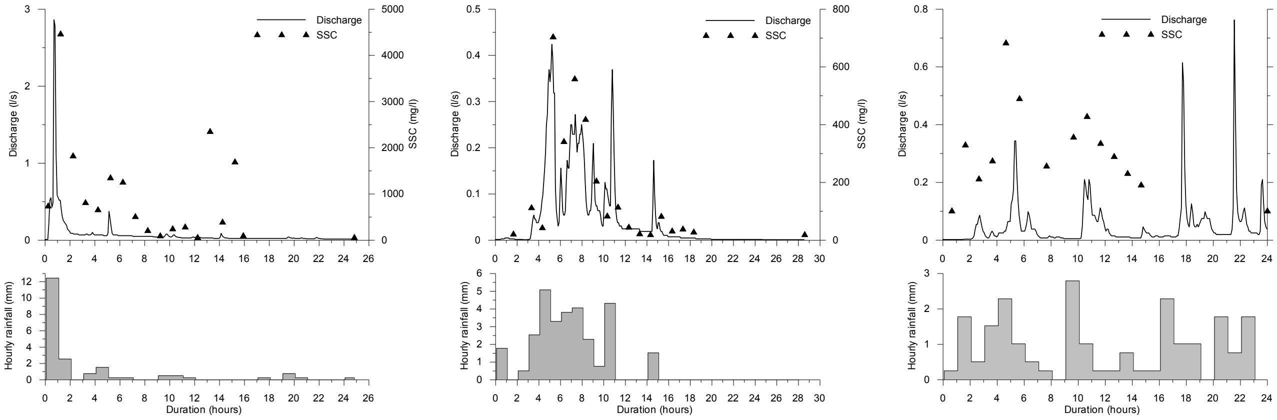
(B)

(C)

(E)

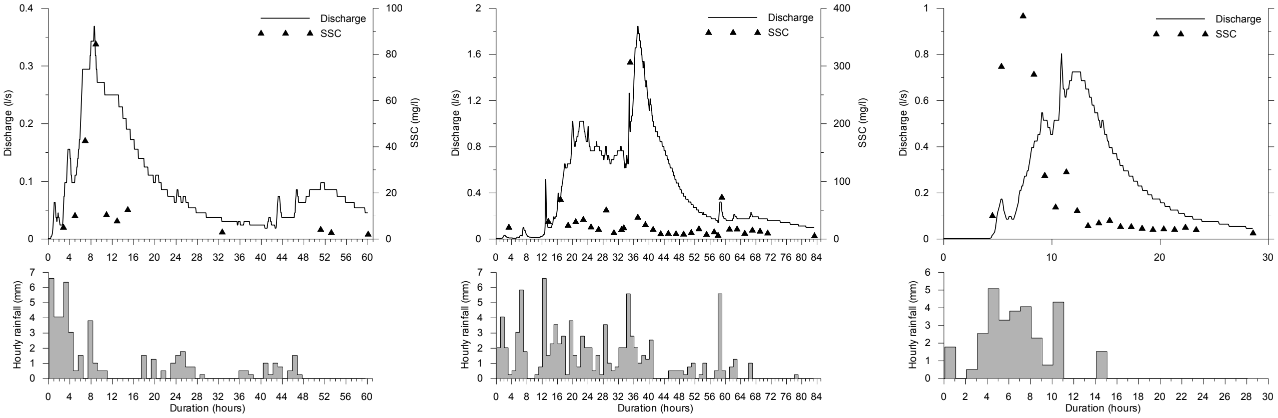
(F)

Figure A-3: Storm hydrographs, discharge, and the measured suspended sediment concentration (SSC) at 852 during events: (A): 4, (B): 6, (C): 9, (D): 10, (E): 11, (F): 13.



(A) (B) (C)

Figure A-3: Storm hydrographs, discharge, and the measured suspended sediment concentration (SSC) at 854 during events: (A): 5, (B): 11, (C): 13.

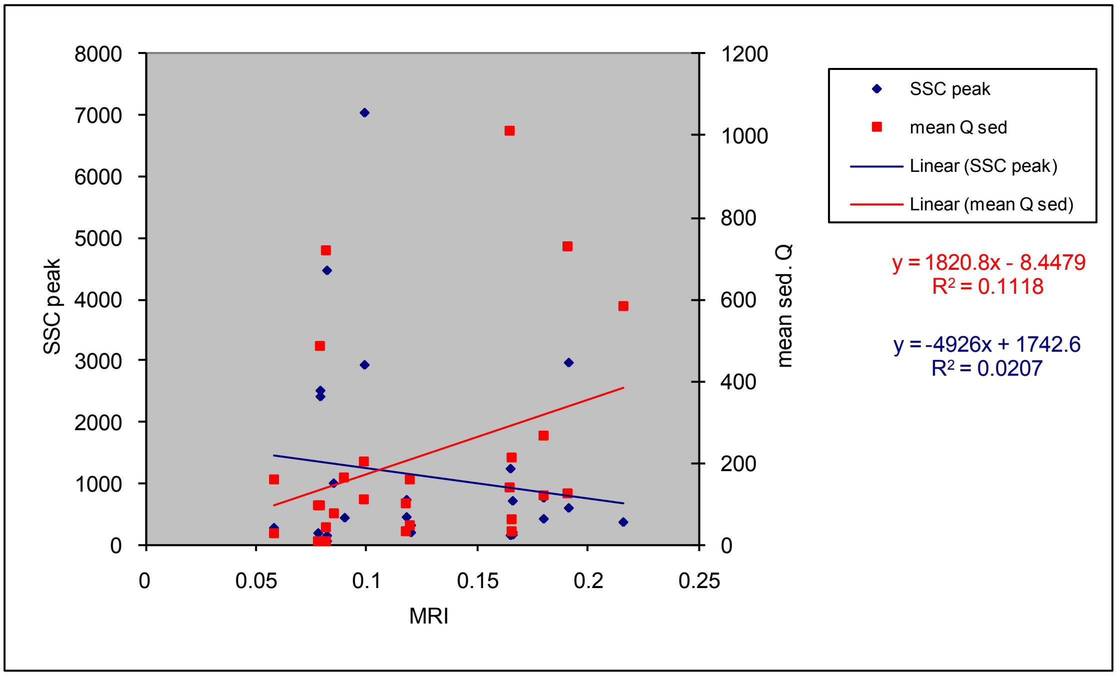


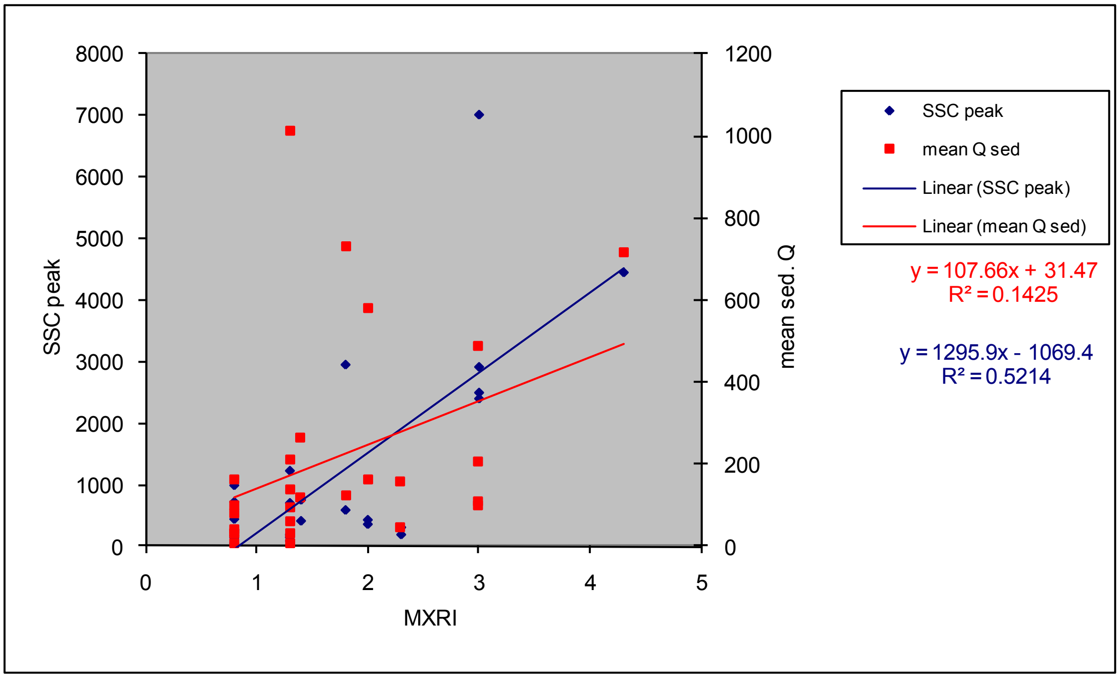
(A) (B) (C)

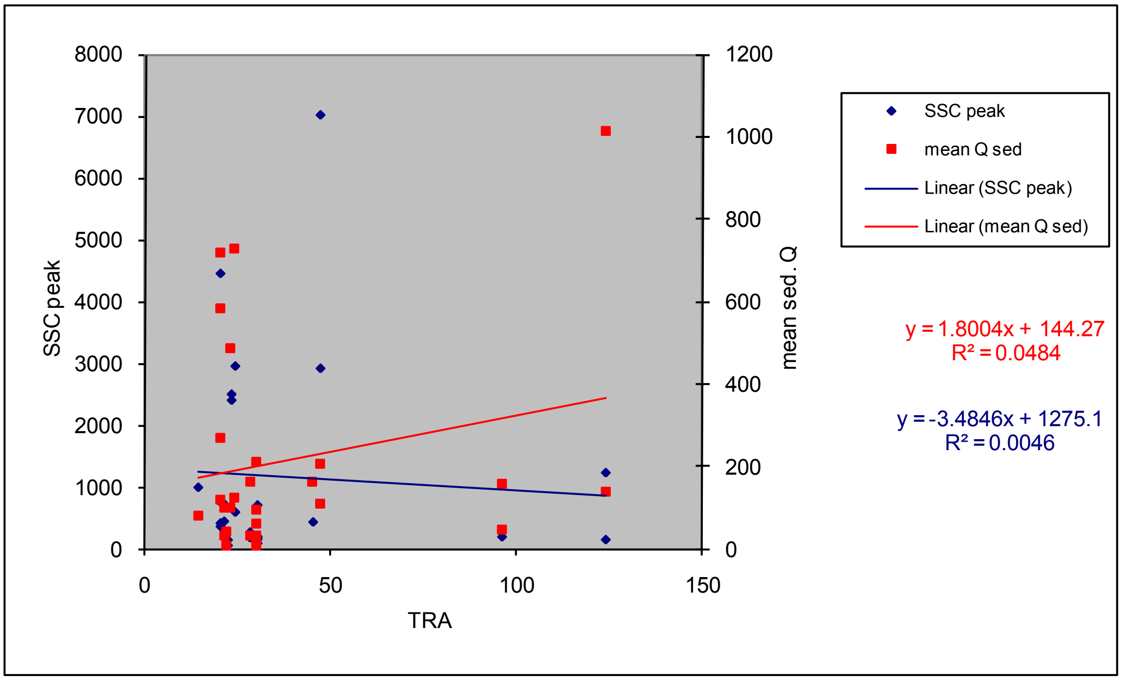
Figure A-4: Storm hydrographs, discharge, and the measured suspended sediment concentration (SSC) at 853 during events: (A): 6, (B): 9, (C): 11.

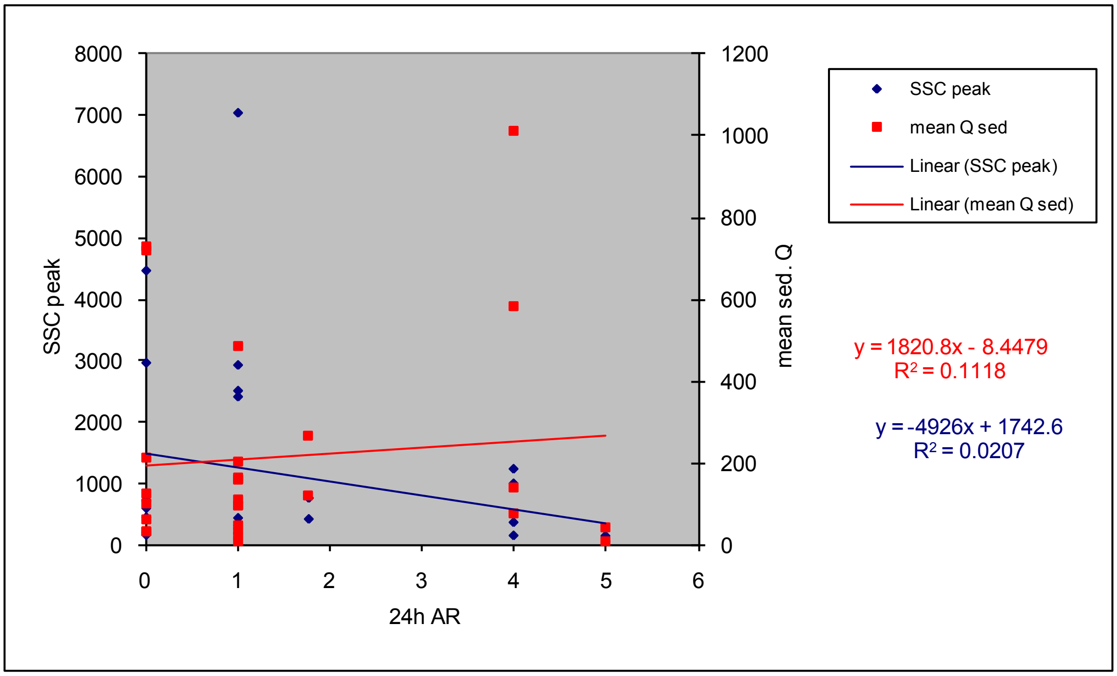
Appendix B. Relationship of sediment and flow characteristics –2004 data

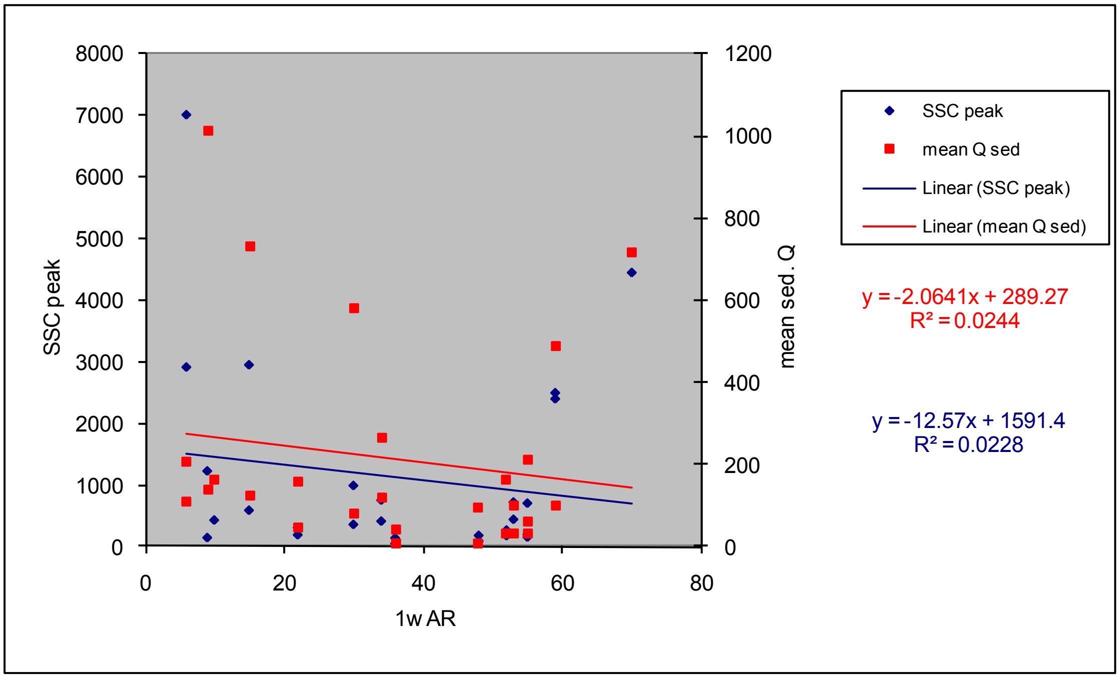
Sediment characteristics in relation to rainfall parameters--2004

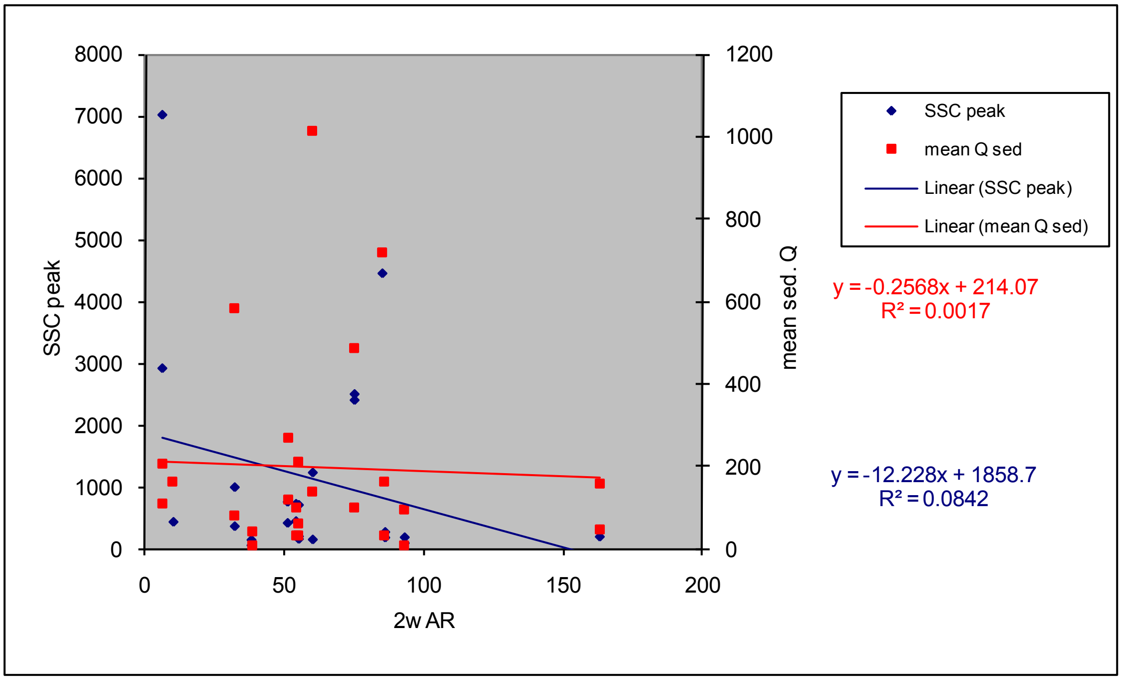




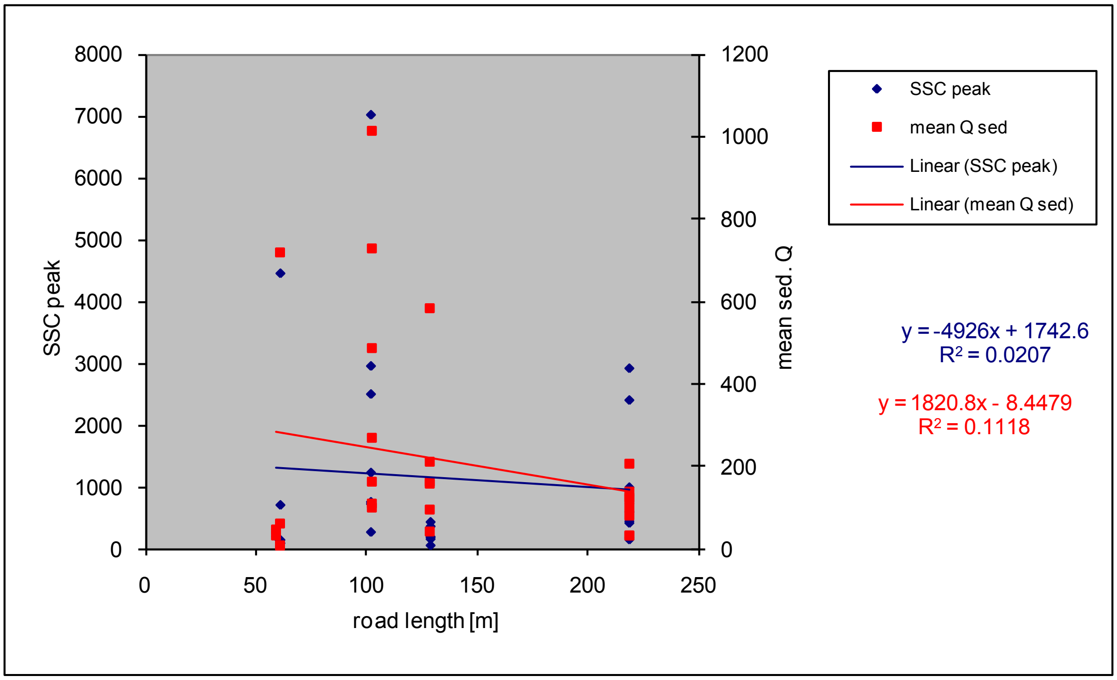

8000
7000
6000
5000
4000
3000
2000
1000
0
SSC peak
1200
1000
800
600
400
200
0
mean sed. Q
0
50
100
150
TRA
SSC peak
mean Q sed
Linear (SSC peak)
Linear (mean Q sed)
y = 1.8004x + 144.27
R² = 0.0484
y = -3.4846x + 1275.1
R² = 0.0046

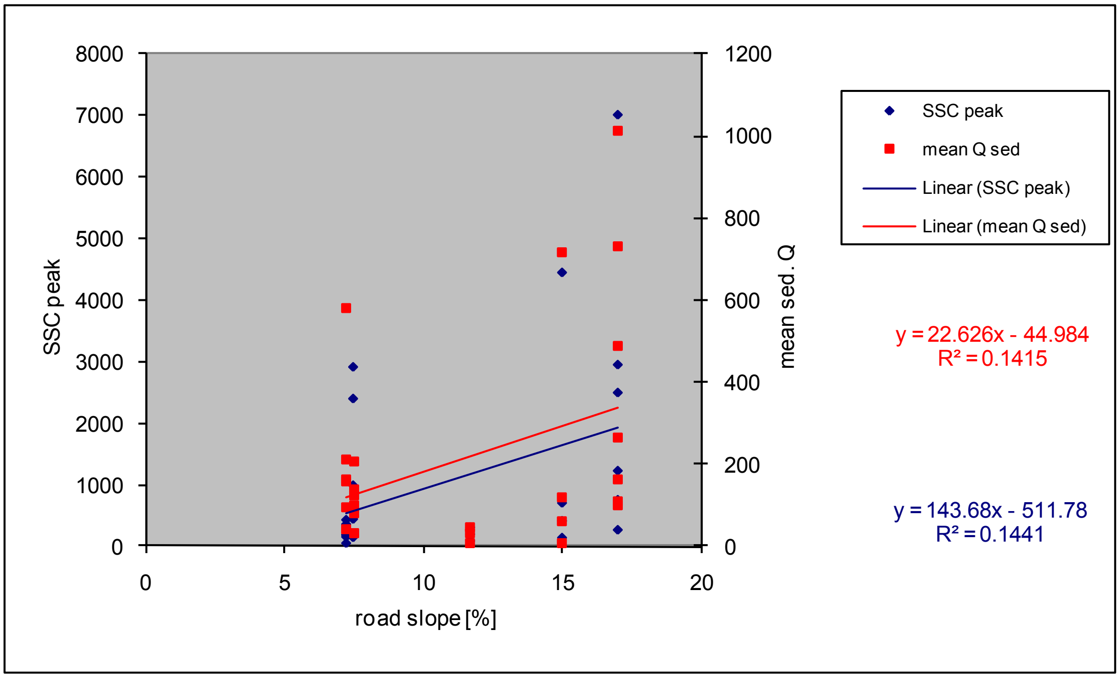

8000
7000
6000
5000
4000
3000
2000
1000
0
SSC peak
1200
1000
800
600
400
200
0
mean sed. Q
0
1
2
3
4
5
6
24h AR
SSC peak
mean Q sed
Linear (SSC peak)
Linear (mean Q sed)
y = 1820.8x - 8.4479
R² = 0.1118
y = -4926x + 1742.6
R² = 0.0207


8000
7000
6000
5000
4000
3000
2000
1000
0
SSC peak
1200
1000
800
600
400
200
0
mean sed. Q
0
20
40
60
80
1w AR
SSC peak
mean Q sed
Linear (SSC peak)
Linear (mean Q sed)
y = -2.0641x + 289.27
R² = 0.0244
y = -12.57x + 1591.4
R² = 0.0228


8000
7000
6000
5000
4000
3000
2000
1000
0
SSC peak
1200
1000
800
600
400
200
0
mean sed. Q
0
50
100
150
200
2w AR
SSC peak
mean Q sed
Linear (SSC peak)
Linear (mean Q sed)
y = -0.2568x + 214.07
R² = 0.0017
y = -12.228x + 1858.7
R² = 0.0842

Suspended sediment relationships to road characteristics--2004





Appendix C. PALCO Road Surface Erosion and Culvert Inventory Manual

Electronic PDF file attached.

Appendix D. Electronic Data Files

APPENDIX 6

Stream Channel Monitoring Data

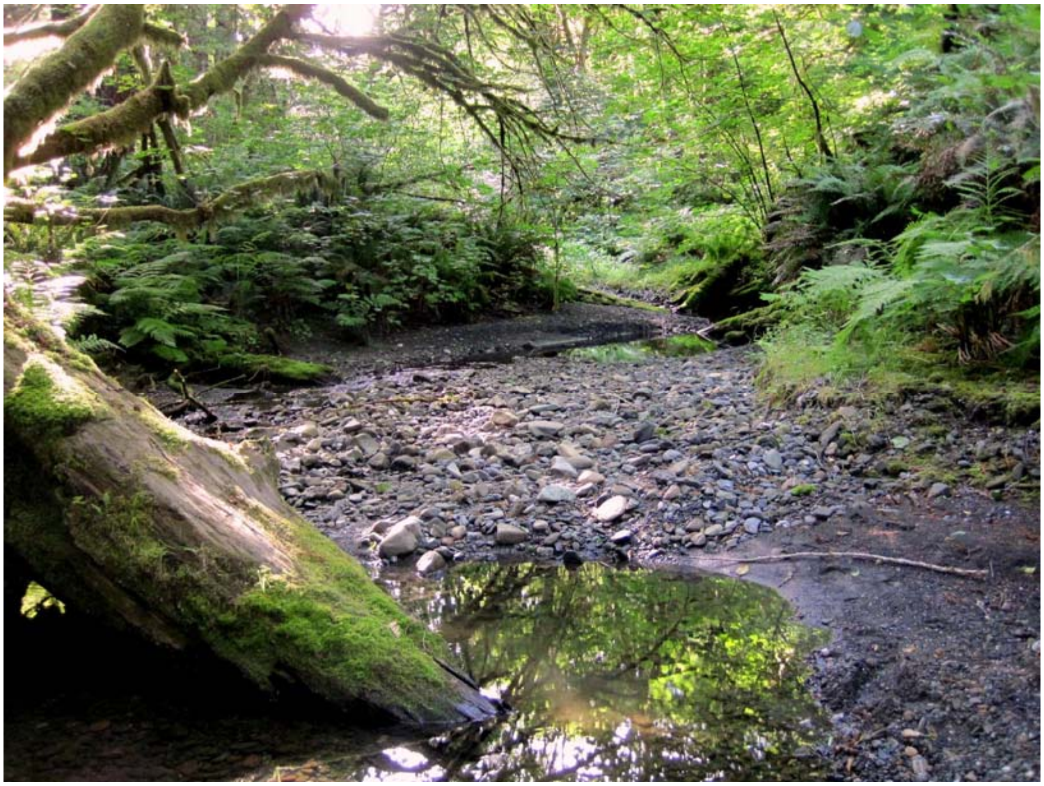
Humboldt Redwood™

Freshwater Creek

Watershed Analysis Revisited

Appendix 6 – Stream Channel Monitoring Data

June 8, 2018



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LIST OF ACRONYMS

10%TU	10% exceedance probability or 10% turbidity exceedance (turbidity level that was exceeded 10% of the time)
ATM	Aquatic Trends Monitoring
cms	cubic meter per second
ft	feet or foot
HRC	Humboldt Redwood Company, LLC
km	kilometer
Mg	megagram
NTU	Nephelometric Turbidity Unit
WY	water year
XS	cross-section
yr	year

1 STREAM CHANNEL MONITORING DATA BY SUB-BASIN

In support of the stream channel assessment for the Freshwater Creek Watershed Analysis revisit, the Humboldt Redwood Company, LLC (HRC) evaluated water quality and channel dimension data specific to each of the nine Freshwater Creek sub-basins in which monitoring has occurred, as discussed below. Locations of Aquatic Trends Monitoring (ATM) and Hydrologic Trends Monitoring (HTM) stations are shown in Figure 1.

1.1 UPPER FRESHWATER CREEK

Within the Freshwater Creek watershed, Upper Freshwater Creek comprises the drainage area upstream of the confluence of South Fork and the mainstem of Freshwater Creek. Four gaging stations are located in this area – HTM stations 523 (Lower Freshwater Creek, at the South Fork confluence), 500 (Beck's tributary, tributary to the mainstem upstream of 523), 502 (Mid-Freshwater Creek, upstream of Beck's), and 526 (Upper Freshwater Creek, in the upper extent of the mainstem). Water quality and channel dimension conditions are listed below for each sub-basin. Only one ATM station exists in this portion of the watershed, Station 015, which begins at the confluence of the mainstem and South Fork. Survey data from Station 015 complement data derived at the single cross-section at Station 523 but does not inform on conditions in the middle to upper portions of Upper Freshwater Creek.

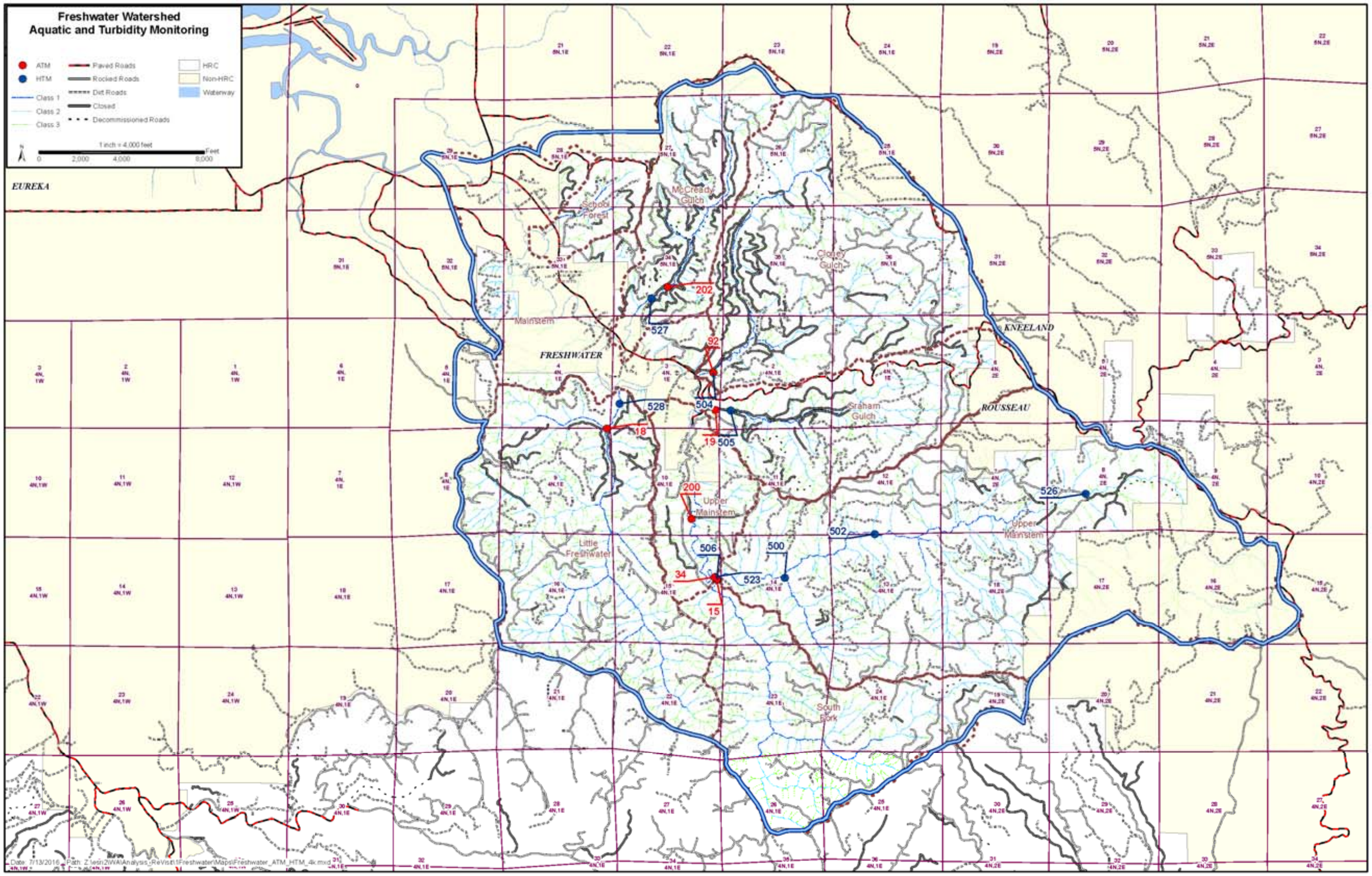


Figure 1. Freshwater Watershed HRC Aquatic Trends Monitoring (ATM) and Hydrologic Trends Monitoring (HTM) Stations

1.2 UPPER FRESHWATER CREEK (STATION 526)

1.2.1 Sediment Yield, Turbidity, and Peak Flow

Monitoring began at the Upper Freshwater Creek gaging station (Station 526) in Water Year (WY) 2004; one year following a winter in which the highest suspended sediment yields to date were measured at other gaging stations due to record-breaking precipitation totals. All currently active stations in the watershed were installed by WY 2005. From WY 20052015, mean annual sediment yield (Mg km^{-2} yr^{-1}) and mean 10%TU have been lower at Station 526 than all other stations in the Freshwater Creek watershed; 10%TU is defined as the turbidity level that was exceeded 10% of the time. The highest suspended sediment yield was measured in WY 2006 (approximately 200 Mg km^{-2} yr^{-1}) which was the third lowest yield measured that season (behind Cloney Gulch and McCready Gulch, respectively). Annual peak flow and total annual suspended sediment yield appear to be correlated ($R^2 = 0.66$). Loads have generally remained static relative to annual peak flow during the monitoring period with the exceptions of WY 2004 and WY 2006 (where yields were high relative to peak flow) and WY 2013 and WY 2014 (where yields were low relative to peak flow) (Figure 2). It is unlikely that there is a statistically significant decrease in annual 10%TU since WY 2004 ($R^2 = 0.30$), but, on average, chronic turbidity is relatively low (18 Nephelometric Turbidity Units [NTU]) and is nearly within the 3 to 16 NTU range of “pristine” sites reported by Klein, et al. (2011). A semi-moderate relationship exists between 10%TU and total annual precipitation ($R^2 = 0.52$) (Figure 3) and illustrates that turbidity has been lower relative to total precipitation in seven out of the ten seasons (WY 2006-2015).

1.2.2 Channel Dimensions

Survey data at the gaging station provide the only metric to assess channel dimensions in the upstream extent of Upper Freshwater Creek. Since 2005, the channel cross-sectional area has been generally stable, increasing by approximately 10% (Figure 4). Across all stations, the strongest relationship between channel response to peak flow has been observed at Station 526 ($R^2 = 0.47$). Relatively high channel scour was measured following the lowest peak flow on record (WY 2009) and relatively high aggradation was measured following the highest measured peak flow during the monitoring period (WY 2011). Increase in channel area in 2009 appears to be due to the release of a large sediment wedge that was present in the cross-section in 2008.

1.2.3 Summary and Conclusions

On average, Station 526 has contributed about 13% of the total sediment load measured at the farthest downstream Station 523. Given the location of this gaging station, data collected from the upper extent of Upper Freshwater Creek offer a projection of sediment loading that enters the system from off-property sources. As a result, trends in water quality observed within this portion of the watershed are not expected to be strongly influenced by any change in HRC management practices. Sediment yield, turbidity, and cross-section data suggest this is a headwater reach that contains generally favorable water quality conditions as well as the capacity to produce high sediment yields during extreme water years. Sediment yield, despite being the lowest in the watershed on average, is still relatively high given that the source is a headwater reach. It is possible that legacy skid trails (which are abundant in the upper sub-basin) have increased hydraulic conductivity to a large network of high-gradient (>25%) Class II watercourses that deliver sediment into the mainstem channel. A potential fault gouge is also present in this portion of the watershed which has deformed over time resulting in a higher propensity towards erosive processes.

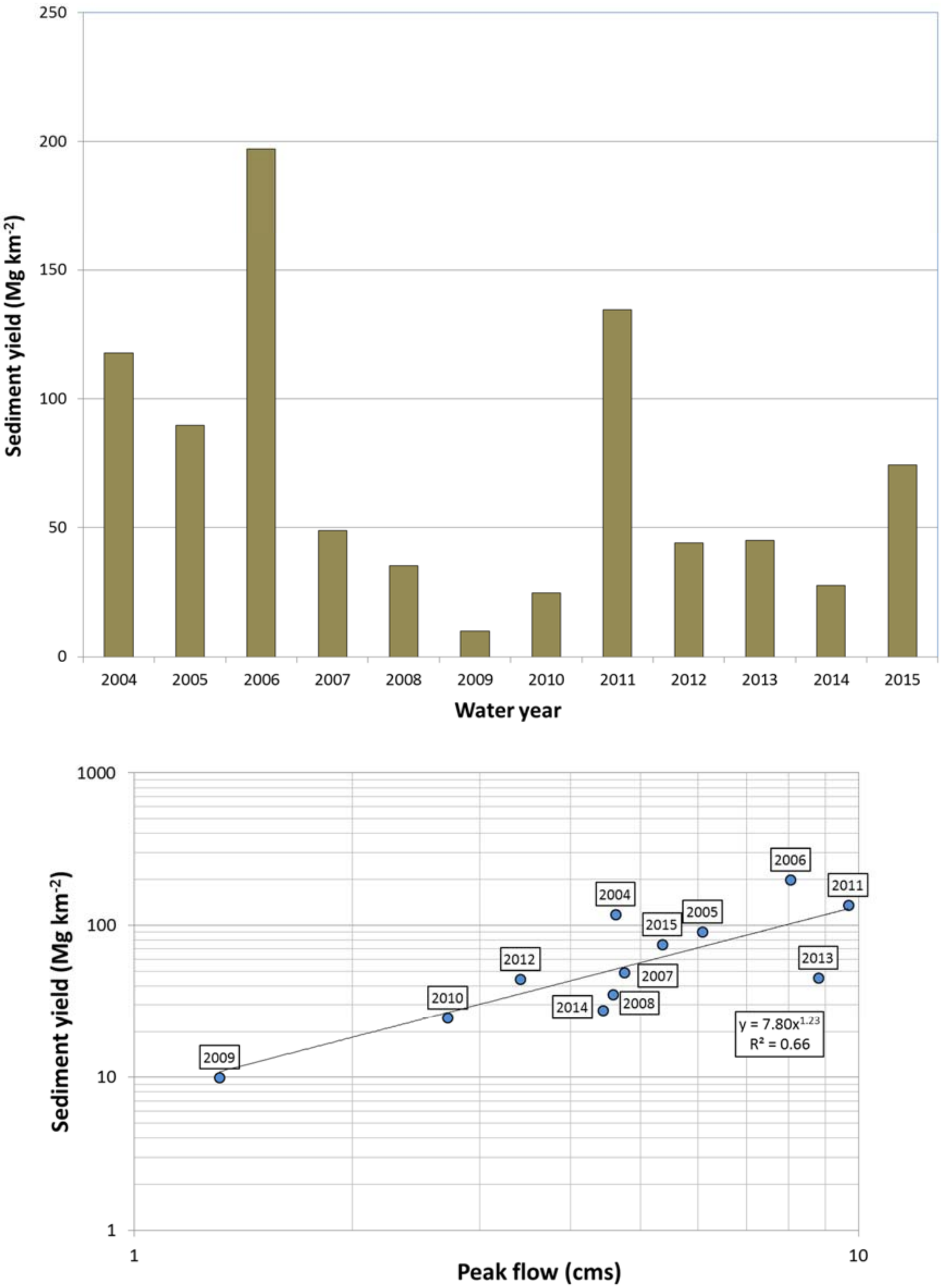


Figure 2. Suspended sediment yield and peak flow data measured at Upper Freshwater Creek (Station 526), WY 2004-2015

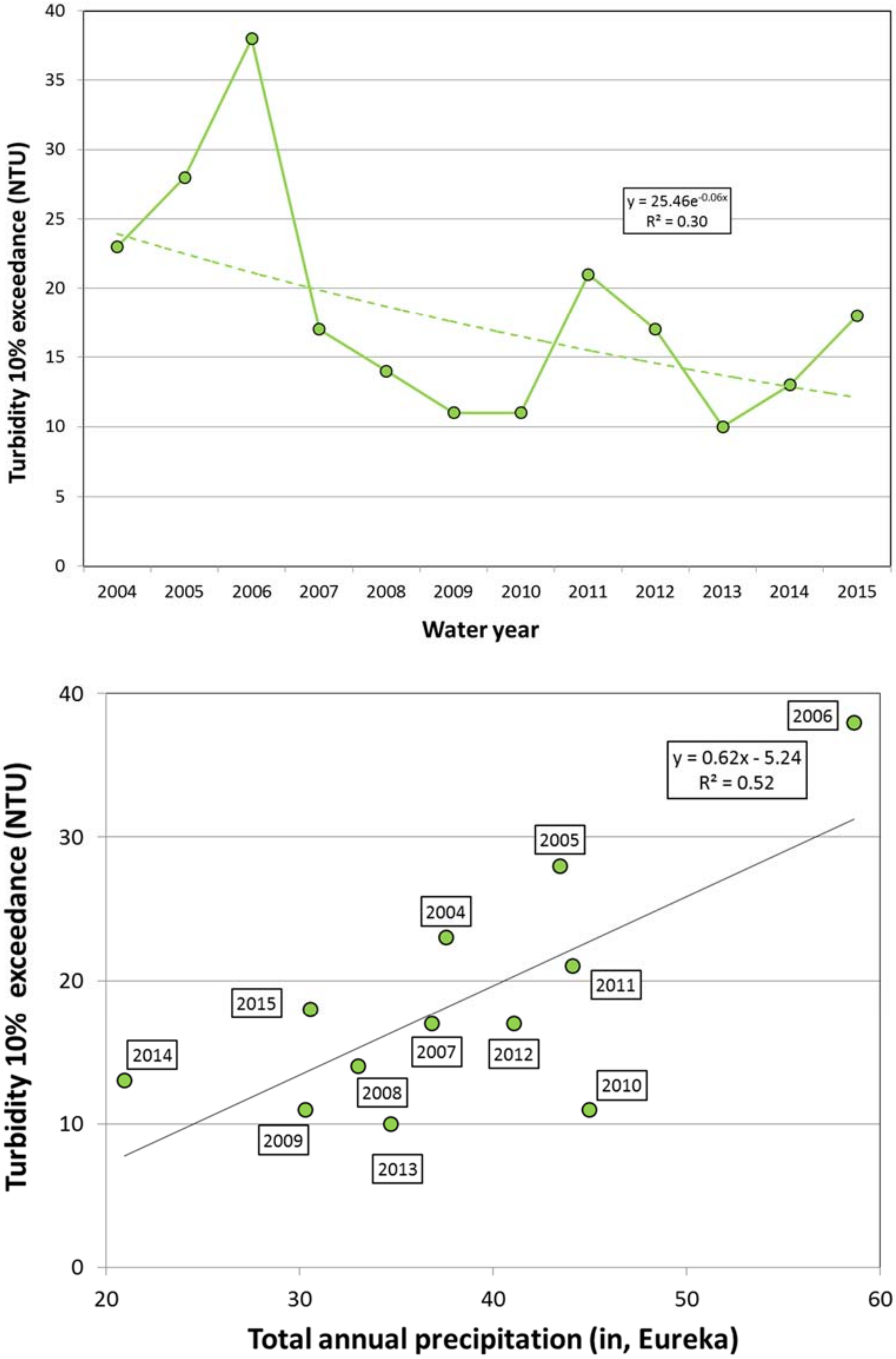
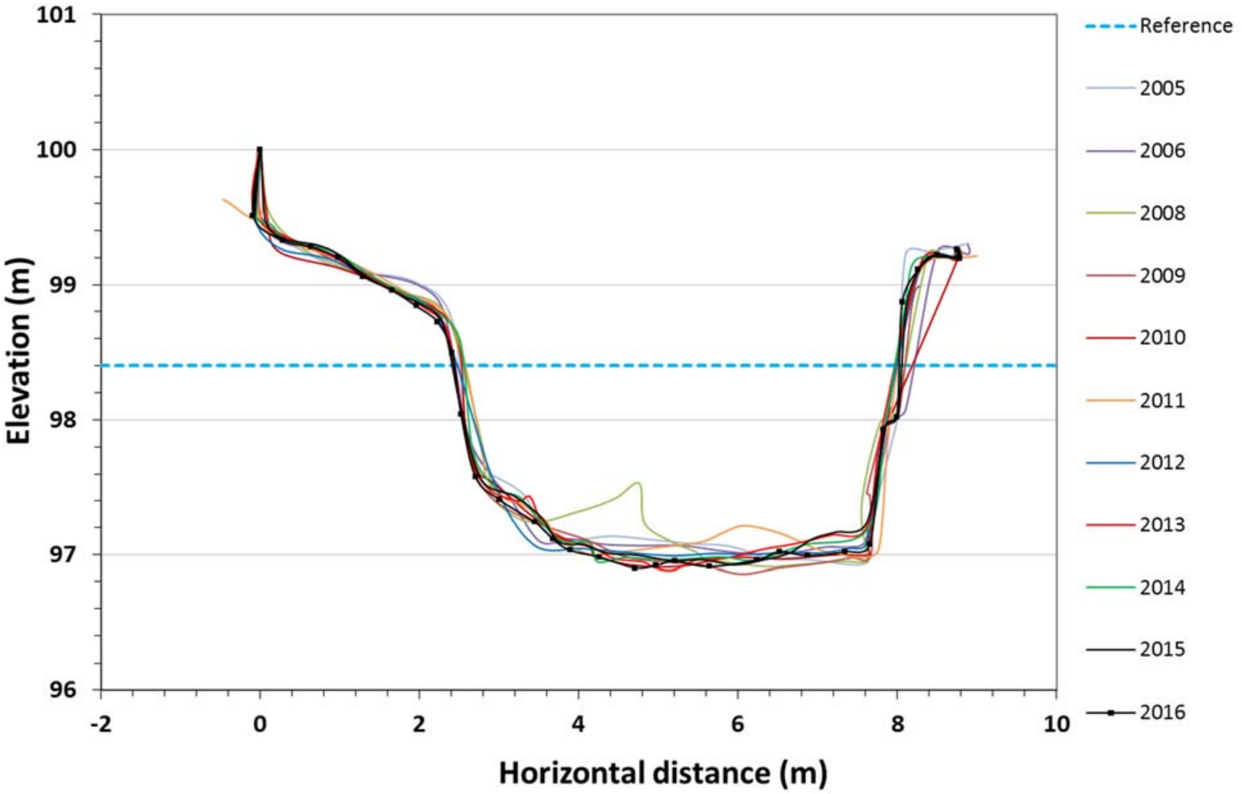


Figure 3. Turbidity data measured at Upper Freshwater Creek (Station 526), WY 2004-2015



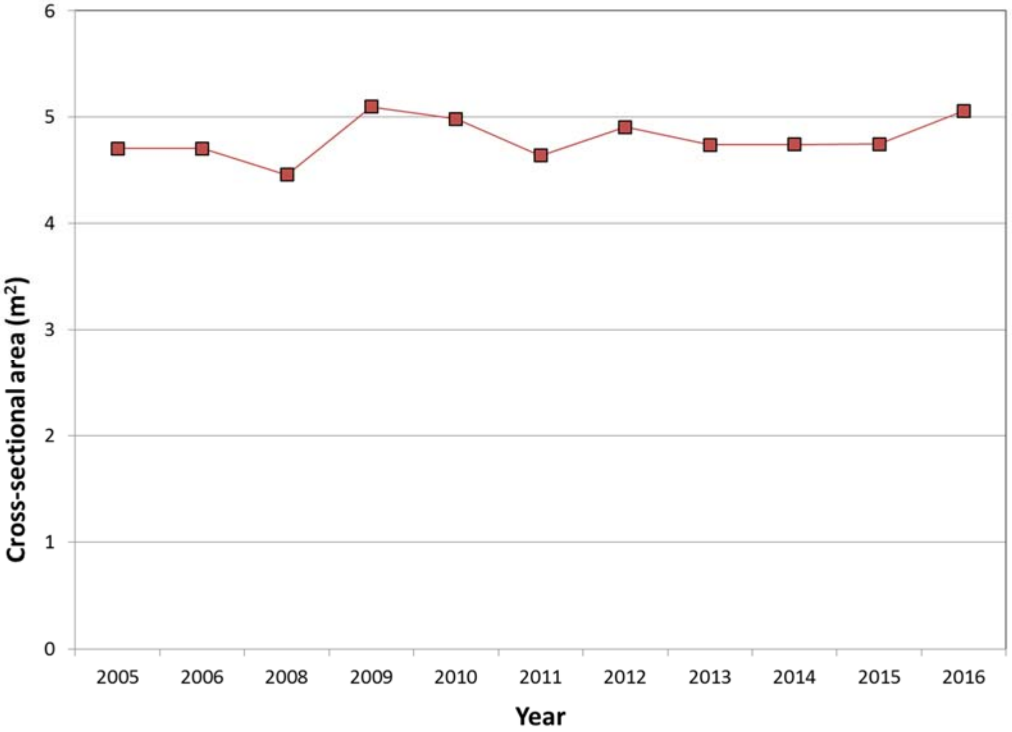


Figure 4. Cross-section survey data measured at Upper Freshwater Creek (Station 526), 2004-2016

1.3 MID-FRESHWATER CREEK (STATION 502)

1.3.1 Sediment Yield, Turbidity, and Peak Flow

Among the six gaging stations installed in WY 2003, mean annual sediment yield (Mg km^{-2} yr^{-1}) and mean 10%TU have been the second and fourth highest, respectively, at the Mid-Freshwater Creek gaging station (Station 502). Suspended sediment yield measured in WY 2003 (approximately 700 Mg km^{-2} yr^{-1}) was 75% greater than the next highest yield measured in WY 2006 (600 Mg km^{-2} yr^{-1}). There is a strong correlation between annual peak flow and suspended sediment yield ($R^2 = 0.85$). Loads have been lower relative to annual peak flow in five out of the last six years (WY 2010-2015) (Figure 5). Additional analysis is necessary to determine whether there is a statistically significant decrease in annual 10%TU ($R^2 = 0.40$), but turbidity exceedance is reasonably well-correlated to total annual precipitation ($R^2 = 0.73$) (Figure 6). Lower turbidity was observed relative to total precipitation in four out of the last six years (WY 2010-2015), which, along with trends observed in sediment yield, suggests water quality conditions may be improving in this portion of the Freshwater Creek watershed despite large overall annual suspended sediment loads.

1.3.2 Channel Dimensions

Survey data at the gaging station provide the only metric to assess channel dimensions in this sub-basin. Unique cross-sections were measured in 2002-2003, 2006-2011, and 2012-2016 monitoring periods (Figure 7. Cross-section survey data measured at Mid-Freshwater Creek (Station 502), 2002-2016). No survey data exist for 2004-2005. Channel response to peak flow has been highly variable. Slight aggradation was measured in 2003 following the largest peak flow on record the previous winter. Substantial scour was measured in 2006 following the third largest peak flow on record. Scour was also measured in 2009 and 2010 following low winter flows. The channel has been relatively stable from 2012-2016 with a trend toward increased scour observed each year despite varying levels of winter precipitation.

1.3.3 Summary and Conclusions

On average, Station 526 has contributed nearly 80% of the total sediment load measured at the most downstream Station 523. Per unit area, the second highest sediment loads in the Freshwater Creek watershed have been measured at Station 502. Average annual loading is 130% higher at Station 502 than measured two miles upstream at Station 526, which may warrant a more detailed analysis. Despite the high sediment loads, recent conditions in this reach are encouraging as water quality and channel dimensions appear to be showing the strongest signs of recovery relative to the other two mainstem gaging stations.

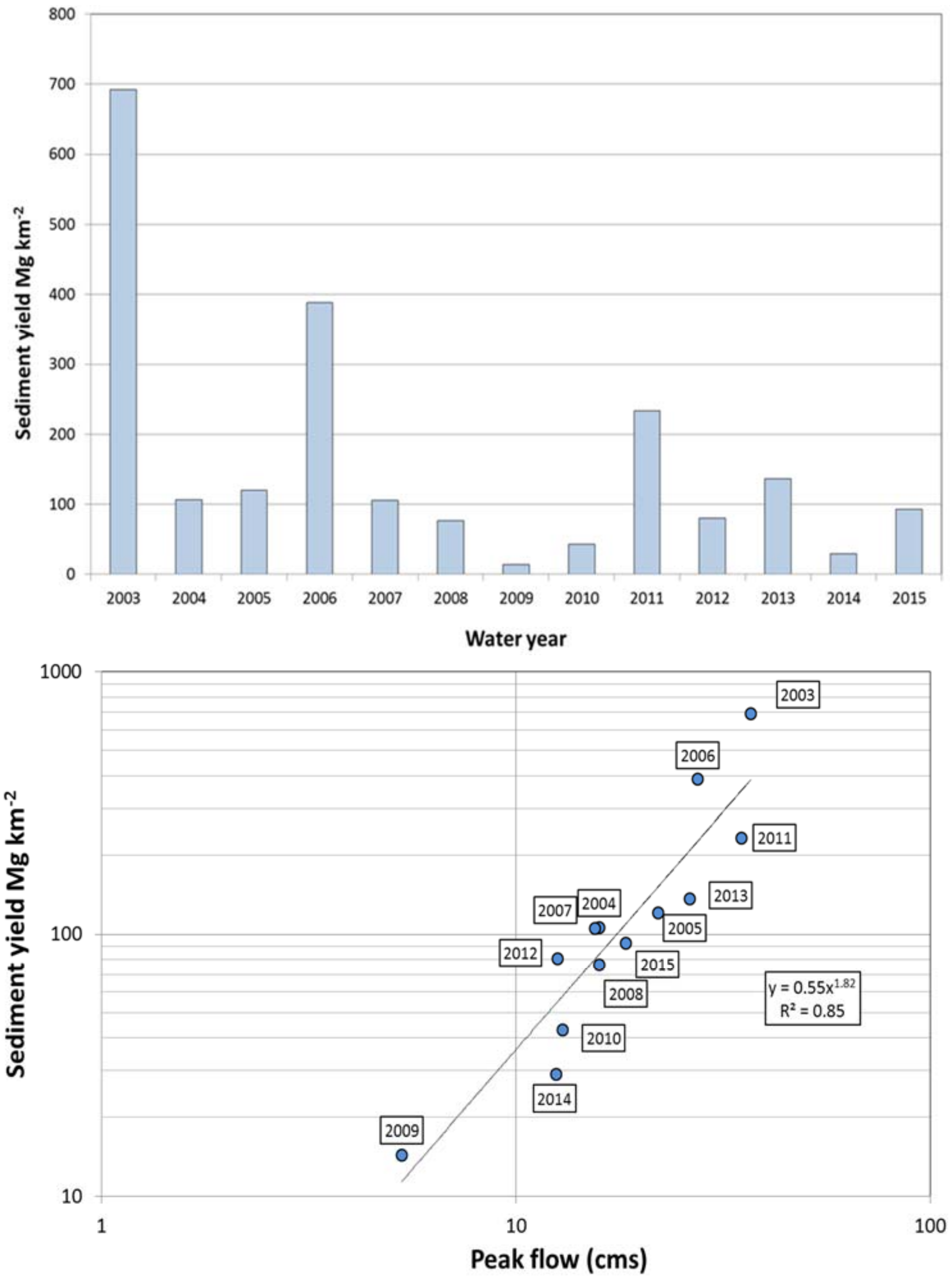


Figure 5. Suspended sediment yield and peak flow data measured at Mid-Freshwater Creek (Station 502), WY 2003-2015

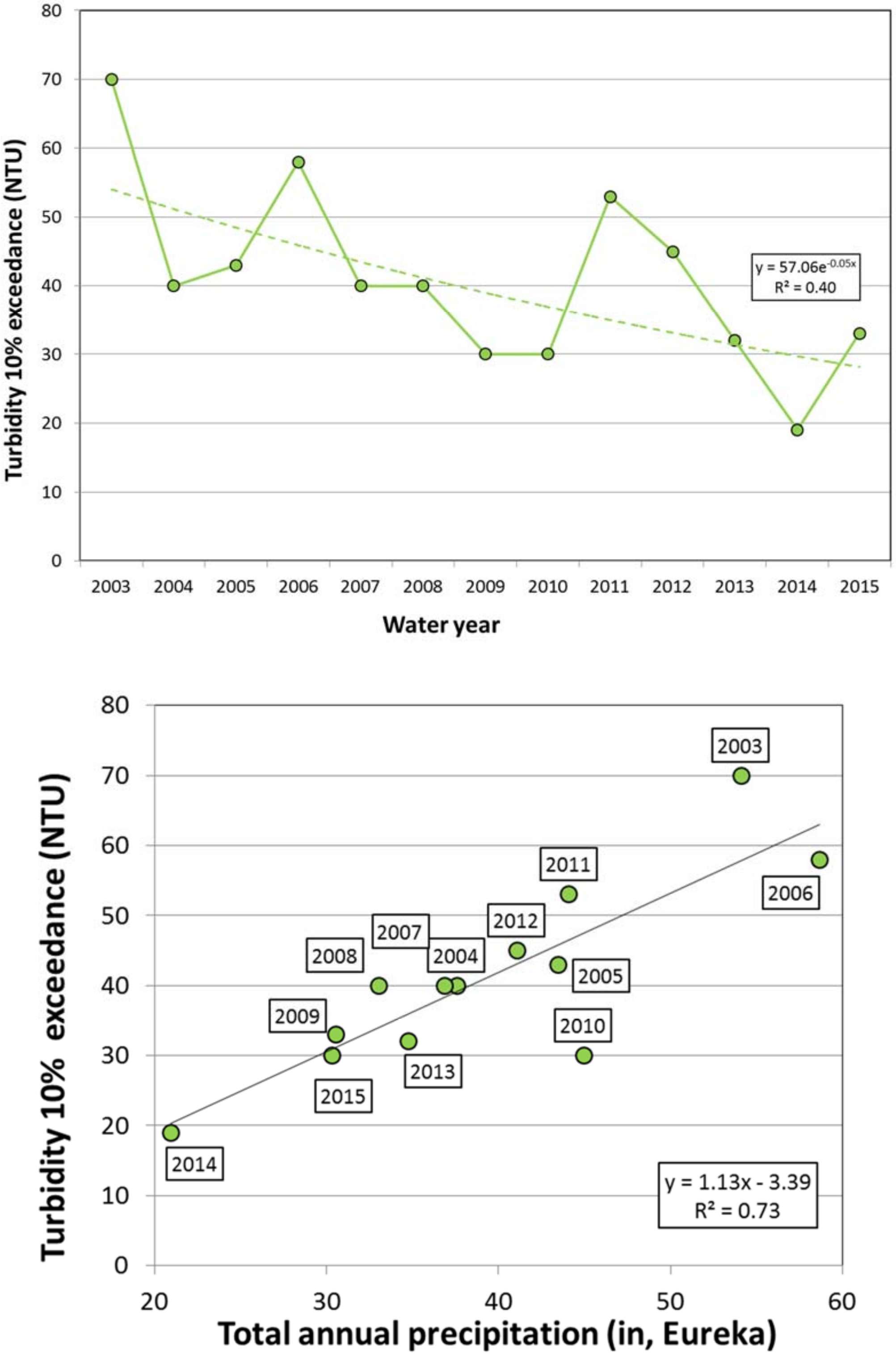


Figure 6. Turbidity data measured at Mid-Freshwater Creek (Station 502), WY 2003-2015

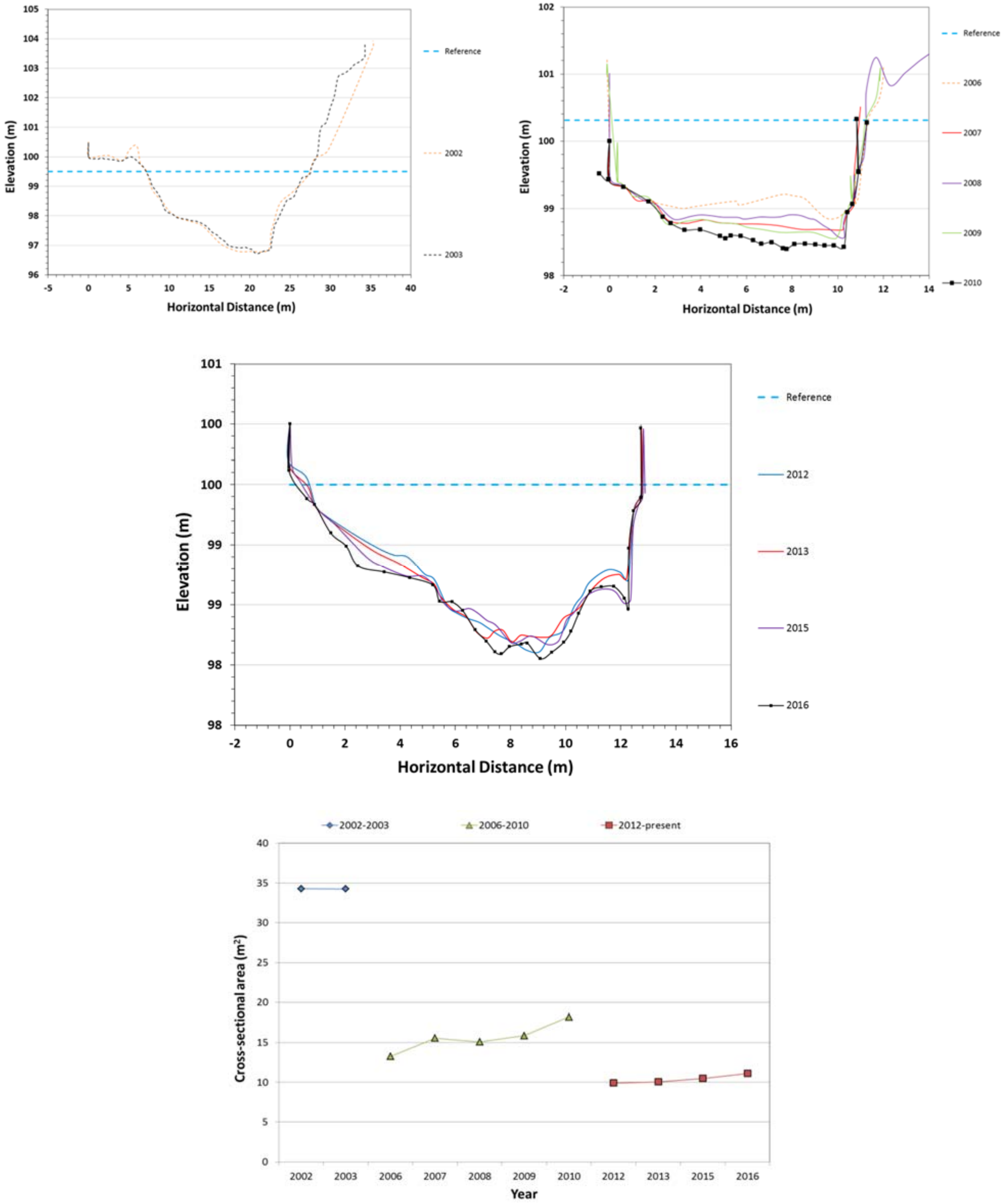


Figure 7. Cross-section survey data measured at Mid-Freshwater Creek (Station 502), 2002-2016

1.4 BECK'S TRIBUTARY (STATION 500)

1.4.1 Sediment Yield, Turbidity, and Peak Flow

Among the six gaging stations installed in WY 2003, mean annual sediment yield and mean 10%TU have been the fourth and fifth highest, respectively, in the Beck's tributary sub-basin (Station 500). A large sediment yield was measured in WY 2003 (approximately 1500 Mg km^{-2} yr^{-1}), approximately 125% greater than the next highest yield measured in WY 2006 (600 Mg km^{-2} yr^{-1}) (Figure 8). Sediment yield has not decreased relative to annual peak flow. Annual peak flow has been higher on average at Station 500 than at any other sub-basin in the watershed. Loads were high in WY 2004 relative to peak flow which may indicate lingering effects (i.e., residual sediment storage or instability) from large storms that occurred the previous winter. 10%TU has been found to be moderately correlated to total annual precipitation ($R^2 = 0.61$). Lower turbidity was observed relative to total precipitation during WY 2007-2011 but has increased since, particularly in WY 2012 during which levels were particularly high (Figure 9).

1.4.2 Channel Dimensions

Currently, there are no ATM stations present in the Beck's tributary sub-basin. As such, the single cross-section at the gaging provides the only metric to assess channel dimensions in the sub-basin. Channel cross-sectional area has decreased in this location by approximately 20% (Figure 10) since measurements began in 2003. This trend has supported rating data where lower stream discharge has been measured relative to stage.

1.4.3 Summary and Conclusions

On average, Station 500 has contributed slightly less than 10% of the total sediment load measured at the most downstream Station 523. Sediment yield and turbidity data suggest that water quality conditions have remained generally static since WY 2013. Streambed survey data are limited to a single cross-section which may or may not be indicative of conditions at larger scales. The Beck's tributary sub-basin is relatively small and has undergone substantial harvesting and road construction prior to and during the monitoring period. These practices have undoubtedly influenced water quality conditions – yet the degree of which is not currently quantified. Additional analysis is necessary to evaluate monitoring trends and examine how natural processes in the sub-basin relate to legacy and current management practices.

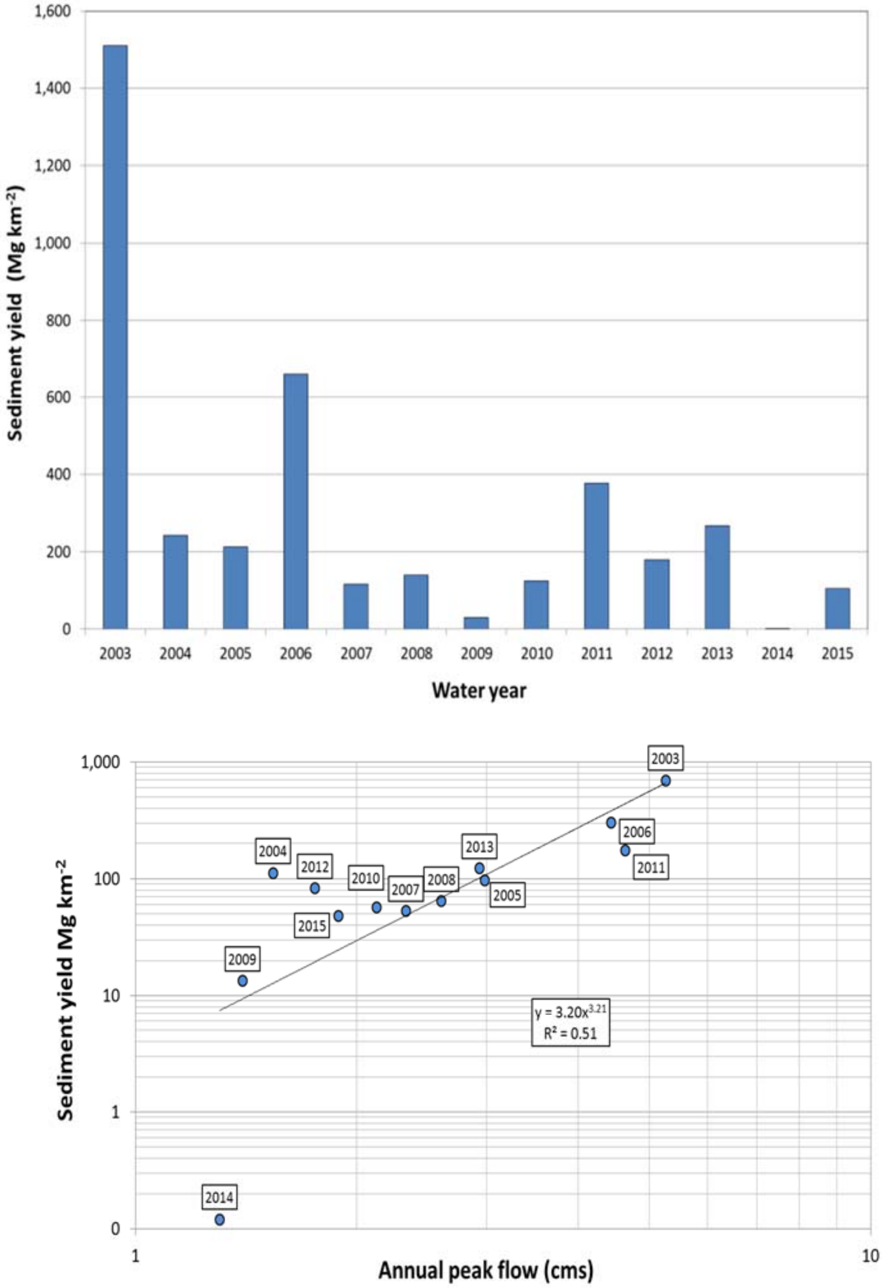
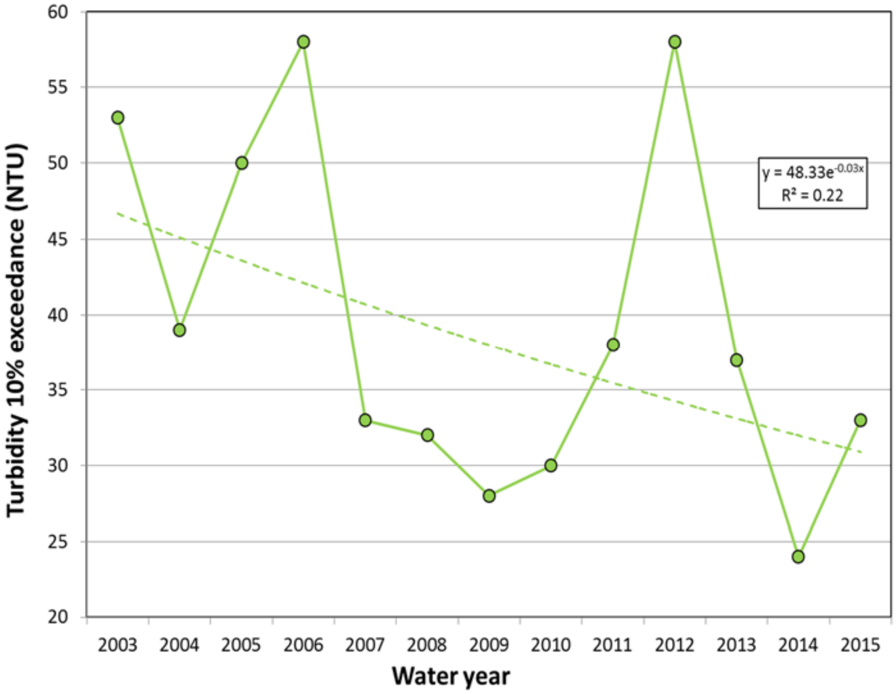


Figure 8. Suspended sediment yield and peak flow data measured at Beck's tributary (Station 500), WY 2003-2015



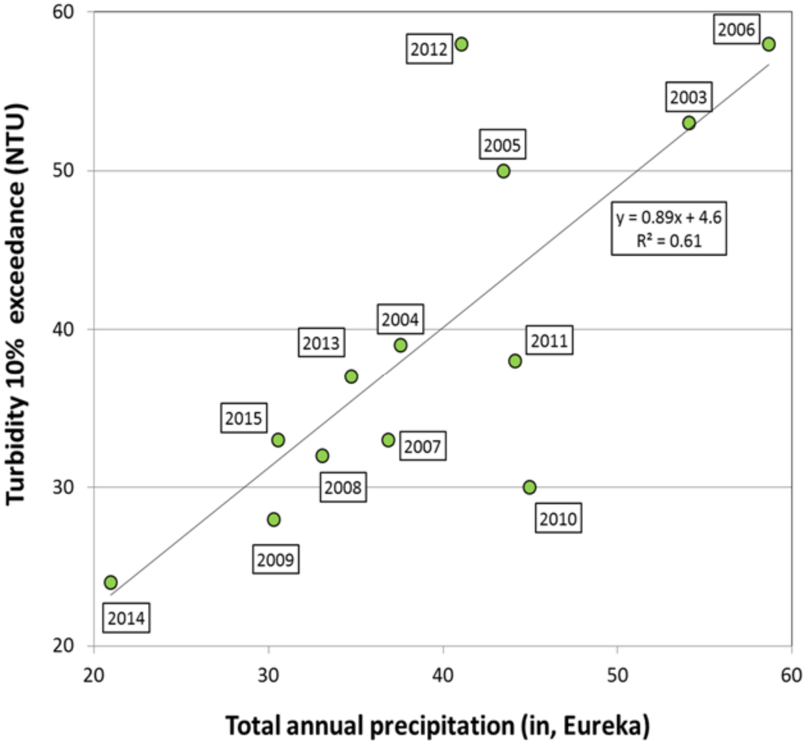


Figure 9. Turbidity data measured at Beck's tributary (Station 500), WY 2003-2015

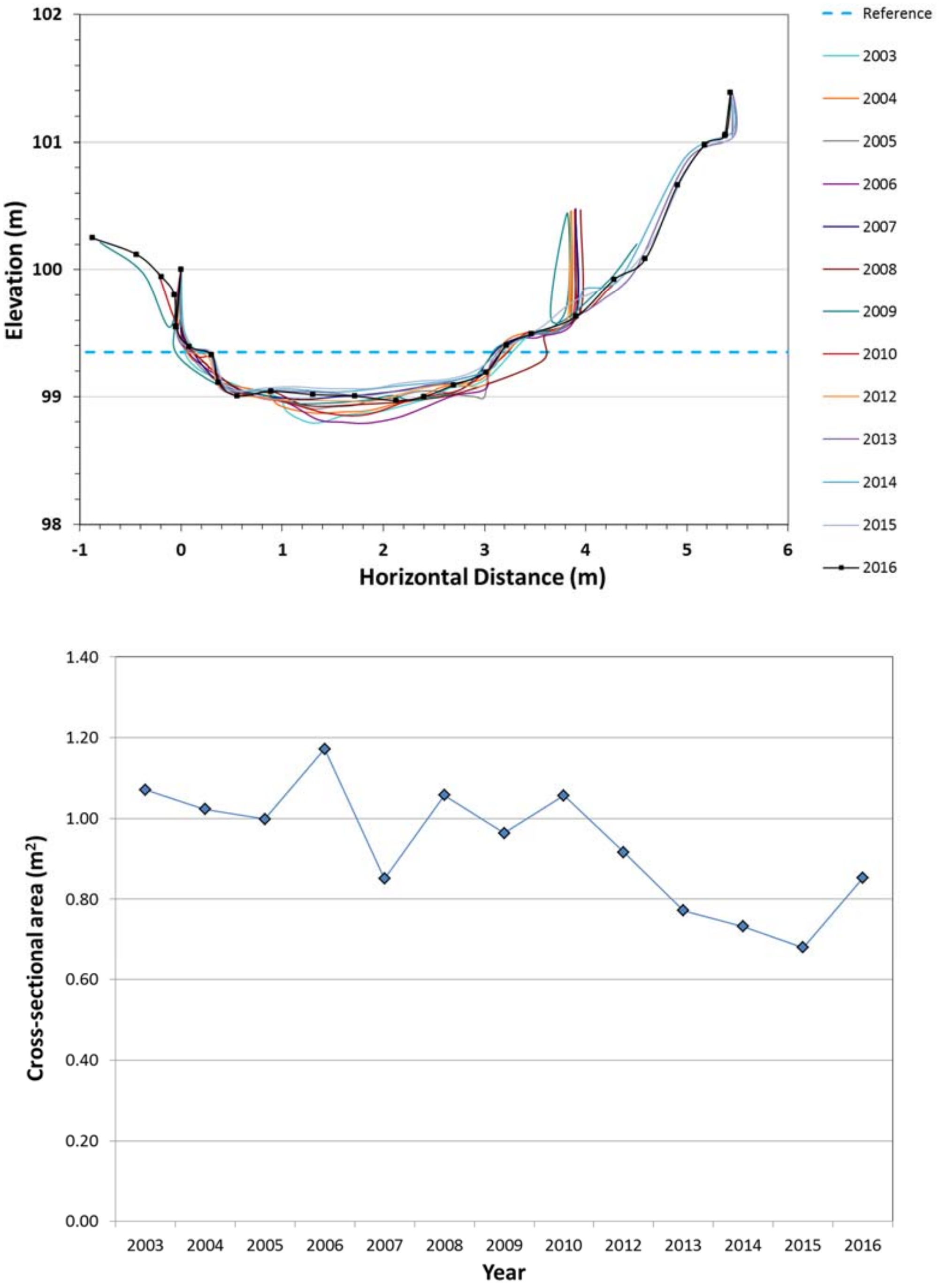


Figure 10. Cross-section survey data measured at Beck's tributary (Station 500), 2003-2016

1.5 LOWER FRESHWATER CREEK (STATION 523)

1.5.1 Sediment Yield, Turbidity, and Peak Flow

Monitoring began at the Lower Freshwater Creek gaging station (Station 523) in WY 2005. From WY 2005-2015, mean annual sediment yield (Mg km^{-2} yr^{-1}) and mean 10%TU at Station 523 is the third highest and second lowest in the Freshwater Creek watershed, respectively. The highest suspended sediment yield was measured in WY 2006 (approximately 290 Mg km^{-2} yr^{-1}). A strong correlation exists between annual peak flow and total annual suspended sediment yield ($R^2 = 0.87$). Loads have been lower relative to annual peak flow in four out of the last six years (WY 2010-2015) (Figure 11). Annually, Station 523 is capturing a variable percentage (approximately 60-110%) of the total loads measured at upstream Station 502 (Mid-Freshwater Creek) and Station 500 (Beck's tributary) (Figure 12). This suggests annual variability in sediment transport and/or the presence of additional sediment sources in the reaches between Station 502 and 523. Years where proportions are less than 100% indicate storage, and years where proportions exceed 100% suggest additional sediment sources contributing between Stations 502 and 523, possibly from Class II watercourses between the two stations. On average since WY 2005, 86% of the sediment yield measured upstream is accounted for annually at Station 523 which seems plausible given the inherent uncertainty in load estimates. Annual 10%TU values appear to be trending downward since WY 2005 ($R^2 = 0.58$), but increased in WY 2015 along with suspended sediment yield, so the downward trend may not be statistically significant. However, a moderate relationship exists between 10%TU and total annual precipitation ($R^2 = 0.63$) (Figure 13) and illustrates that turbidity has been lower relative to total precipitation in five out of the last six seasons (WY 2010-2015).

1.5.2 Channel Dimensions

The ATM Station 034 monitoring reach begins just downstream of Station 523 and, along with the gaging station cross-section, is used to evaluate channel conditions in the lower extent of Upper Freshwater Creek. At the gaging station, total cross-sectional area decreased slightly during the 2006-2011 survey period and was generally stable from 2012-2016 (Figure 14). ATM data indicate some aggradation at the most downstream cross-section (XS-1) and relative stability in the upstream extent. In the middle of the reach, the XS-3 cross-sectional area has increased by nearly 50% since 2000 (Figure 15).

1.5.3 Summary and Conclusions

Conditions may be improving in the lower portions of Upper Freshwater Creek. Additional monitoring data will allow for a stronger assessment of recent trends and help illustrate whether the increased yields and higher turbidity exceedance values measured in WY 2015 were an anomaly. Temporal trends in sediment yield measured at Station 523 generally match those measured at the upstream gaging stations and the majority of the upstream load is generally captured each season. These results indicate that the station is effective in monitoring water quality conditions in Upper Freshwater Creek.

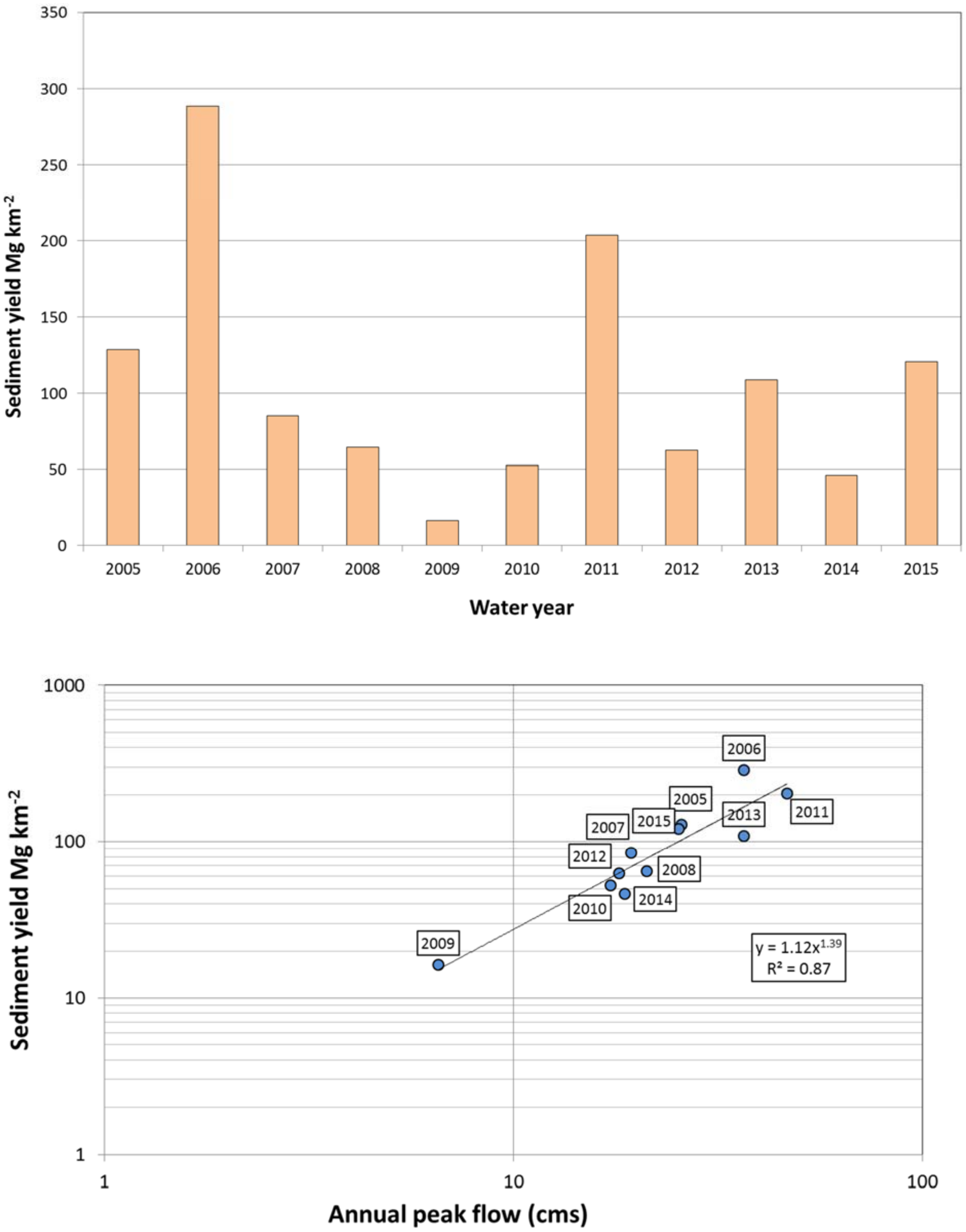
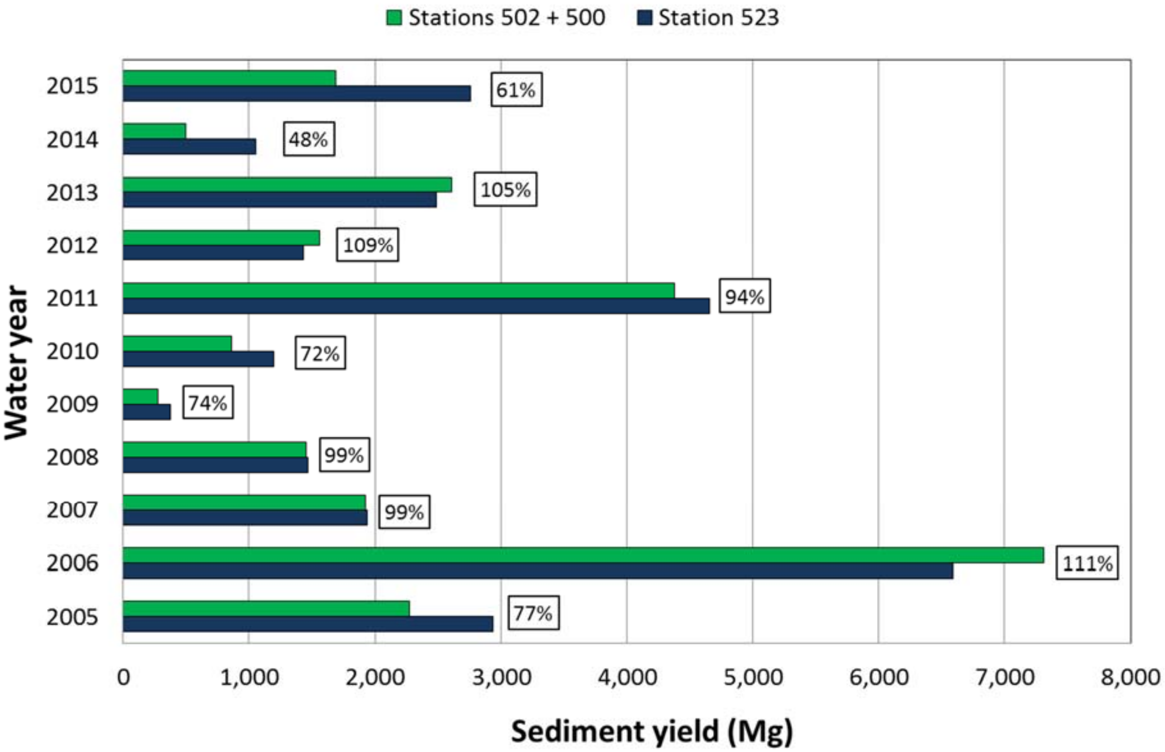
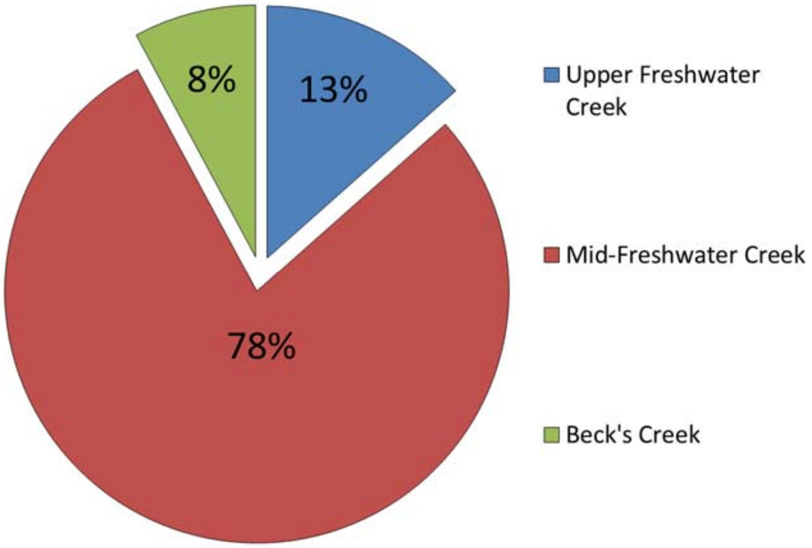


Figure 11. Suspended sediment yield and peak flow data measured at Lower Freshwater Creek (Station 523), WY 2005-2015

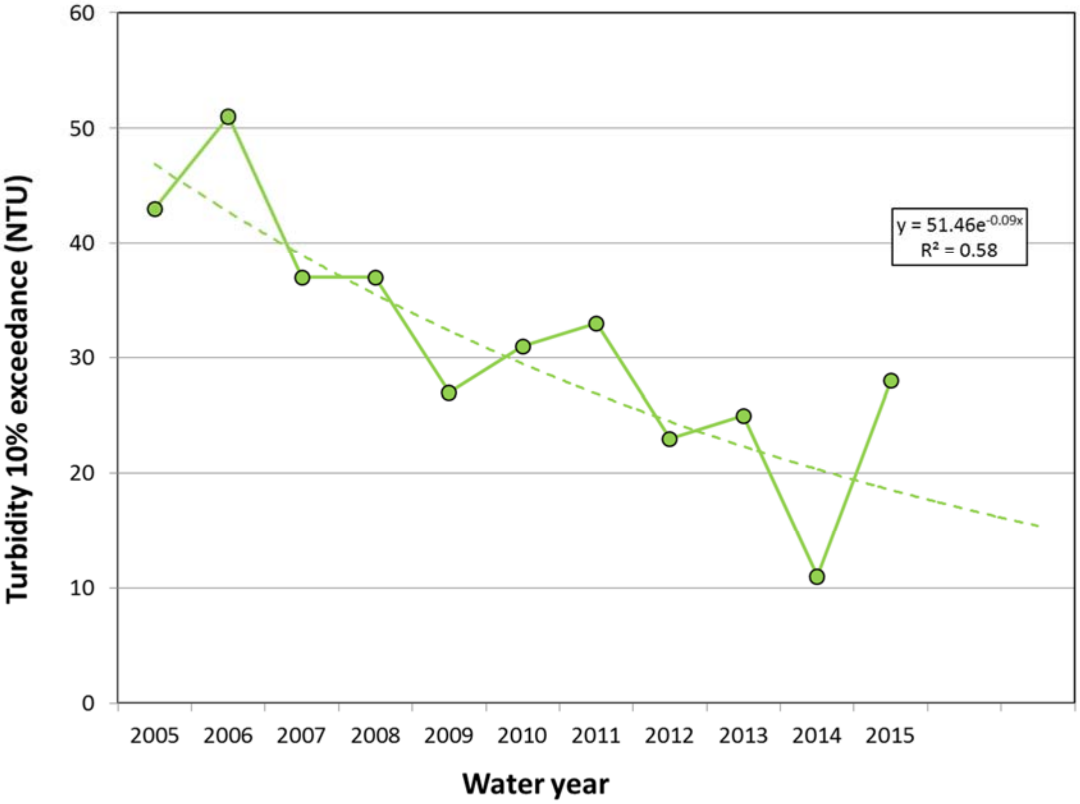


Note: Percentages indicate annual proportion of sediment yield measured at Station 523 (Lower Freshwater Creek) that is accounted for at upstream Stations 502 (Mid-Freshwater) and 500 (Beck's).



Note: Percentages indicate average annual contribution in sediment yield from upstream basins to total yield measured at Station 523.

Figure 12. Suspended sediment yield measured at Station 523 (Lower Freshwater Creek) relative to upstream stations, WY 2005-2015



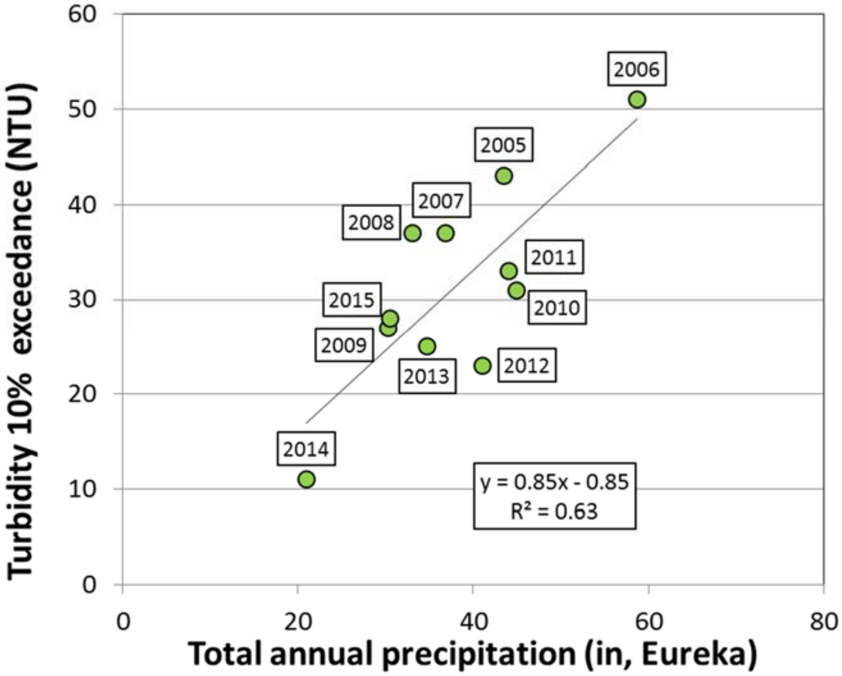


Figure 13. Turbidity data measured at Lower Freshwater Creek (Station 523), WY 2005-2015

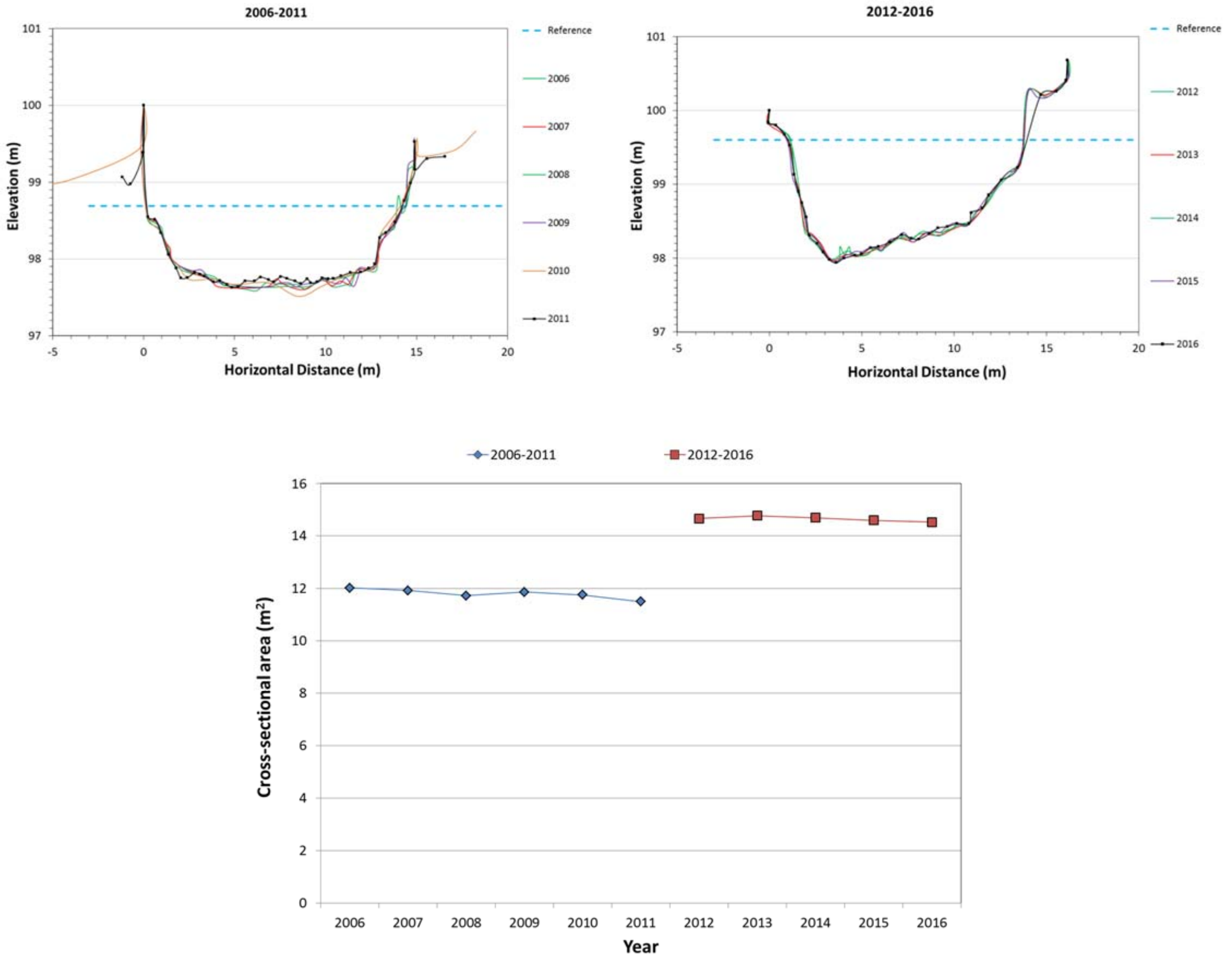
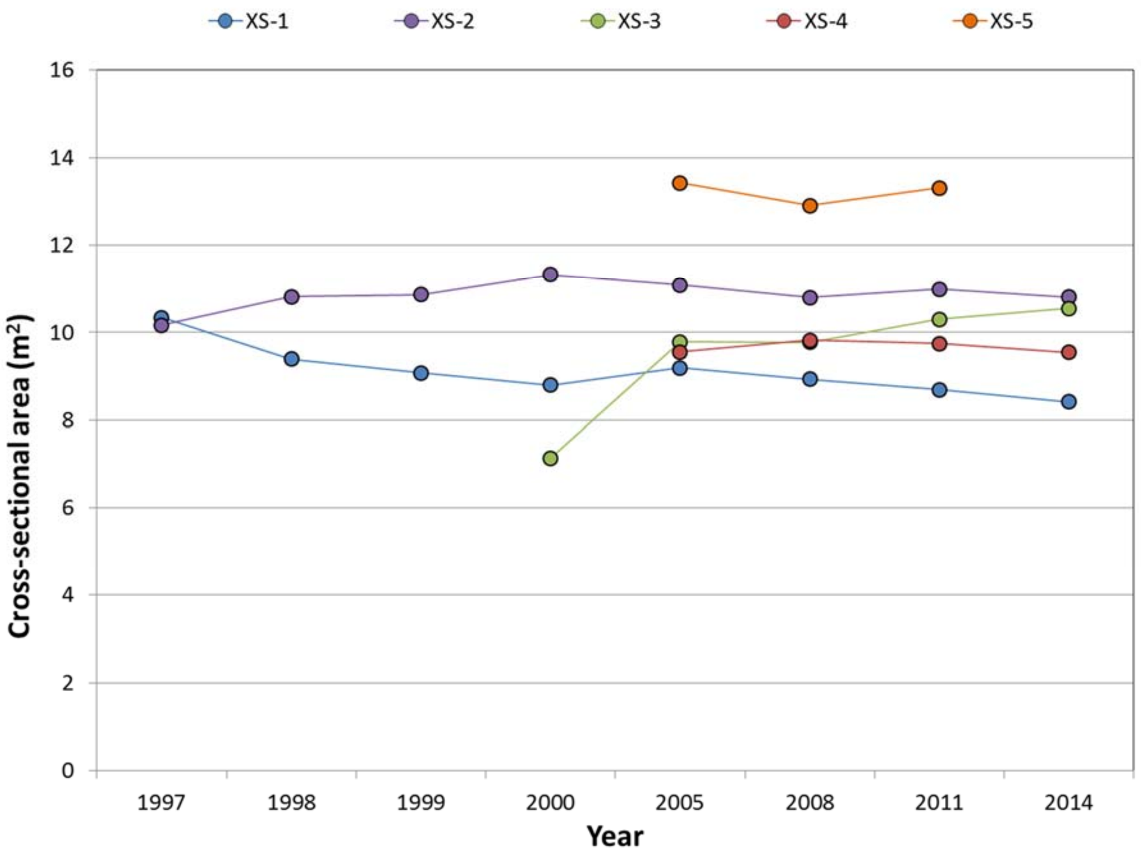


Figure 14. Cross-section survey data measured at Lower Freshwater Creek (Station 523), 2006-2016



Note: XS-1 is the most downstream cross-section in the monitoring reach (approximately 1,000 ft) and XS-5 is the most upstream.

Figure 15. Total cross-sectional area at ATM Station 034 cross-sections located along the downstream extent of Lower Freshwater Creek, 1997-2014

1.6 SOUTH FORK FRESHWATER CREEK (STATION 506)

1.6.1 Sediment Yield, Turbidity, and Peak Flow

Among the six gaging stations installed in WY 2003, mean annual suspended sediment yield and mean 10%TU have each been the third highest in the South Fork Freshwater Creek sub-basin (Station 506). A high sediment yield was measured in WY 2003 (690 Mg km^{-2} yr^{-1}), nearly 300% greater than the next highest which was measured in WY 2006 (235 Mg km^{-2} yr^{-1}) (Figure 16). Annual peak flow and total annual sediment yield have the strongest correlation of any sub-basin in the watershed ($R^2 = 0.90$).

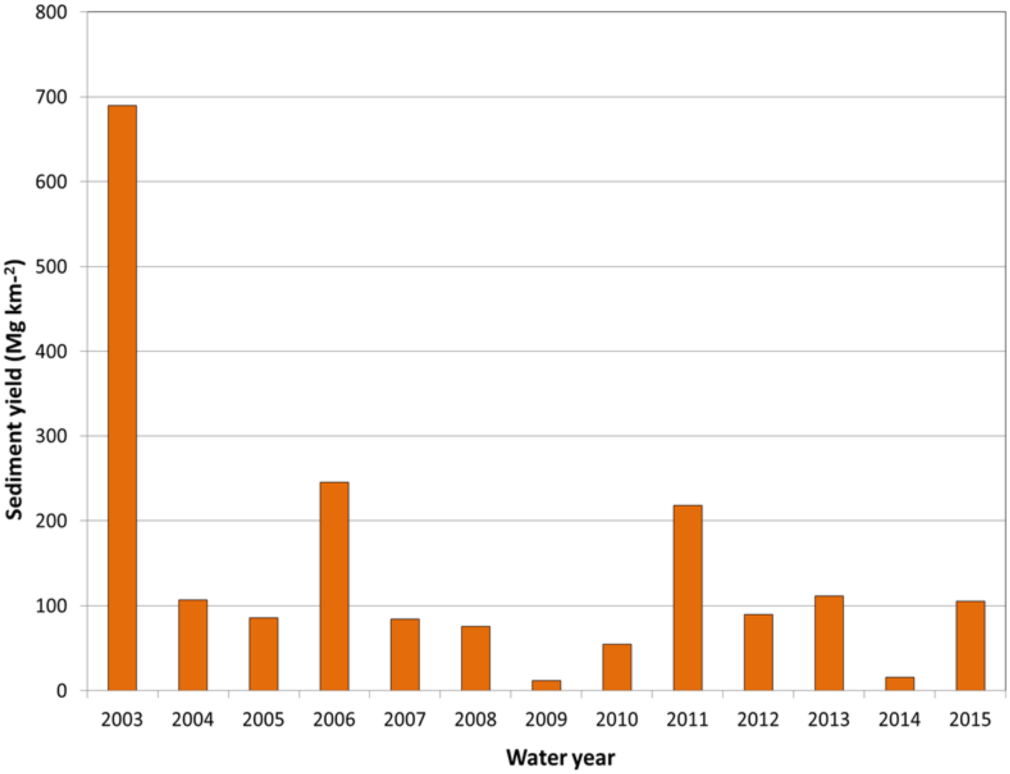
Lower sediment yields were measured relative to peak flow in WY 2008-2011 but have since remained generally static. 10%TU has been moderately correlated to total annual precipitation ($R^2 = 0.57$) and illustrates higher levels of chronic turbidity in four out of the last five years (WY 2011-2015) (Figure 17).

1.6.2 Channel Dimensions

The ATM Station 015 monitoring reach begins at Station 523 and, along with the gaging station cross-section, can be used to evaluate channel conditions in the lower extent of South Fork Freshwater Creek. At the gaging station, there have been four survey periods during which unique cross-sections were measured within the same monitoring reach. Total cross-sectional area increased substantially in 2003 (approximately 30%) and to lesser degrees in 2011 and 2013. Slight aggradation was measured in 2007 and 2014 (Figure 18 and Figure 19). ATM data indicate general downstream stability since 1997. Since 2005, scour has been measured in the middle reaches and aggradation towards the upstream extent (Figure 20).

1.6.3 Summary and Conclusions

Water quality trends appear to be generally static in the South Fork sub-basin. A more robust analysis of available data would likely provide a more definitive indication of an increasing or decreasing trend. Such an analysis will be aided by data collected during future monitoring. The strong correlation between peak flow and suspended sediment yield should continue to serve as a useful metric with which to track changing conditions within the sub-basin.



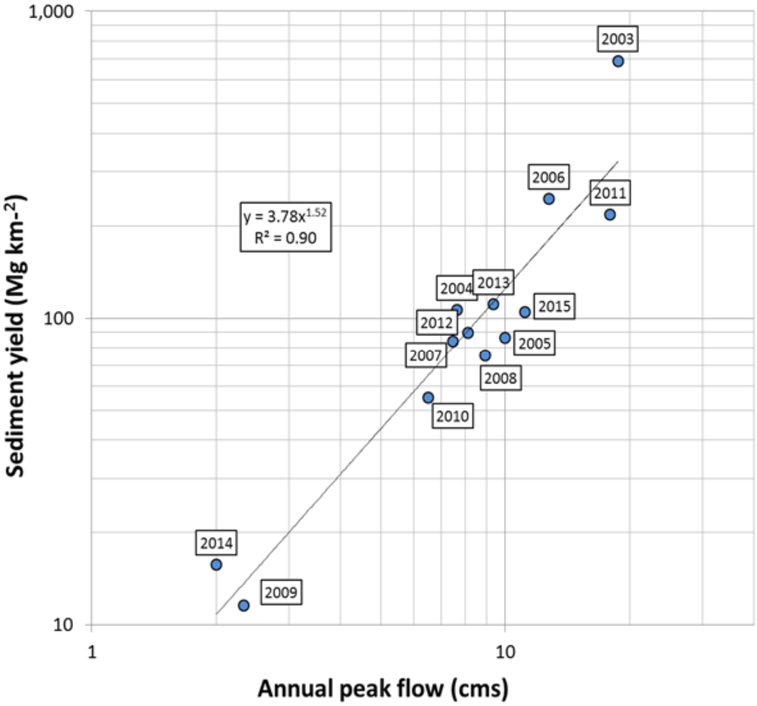
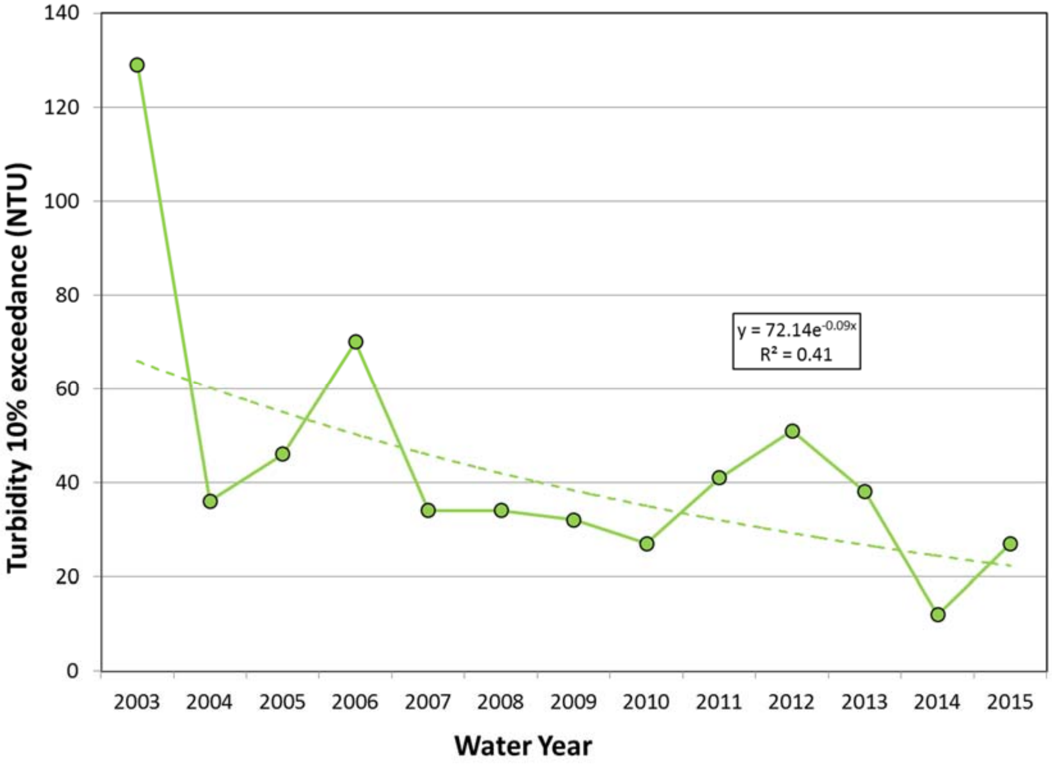


Figure 16. Suspended sediment yield and peak flow data measured at South Freshwater Creek (Station 506), WY 2003-2015



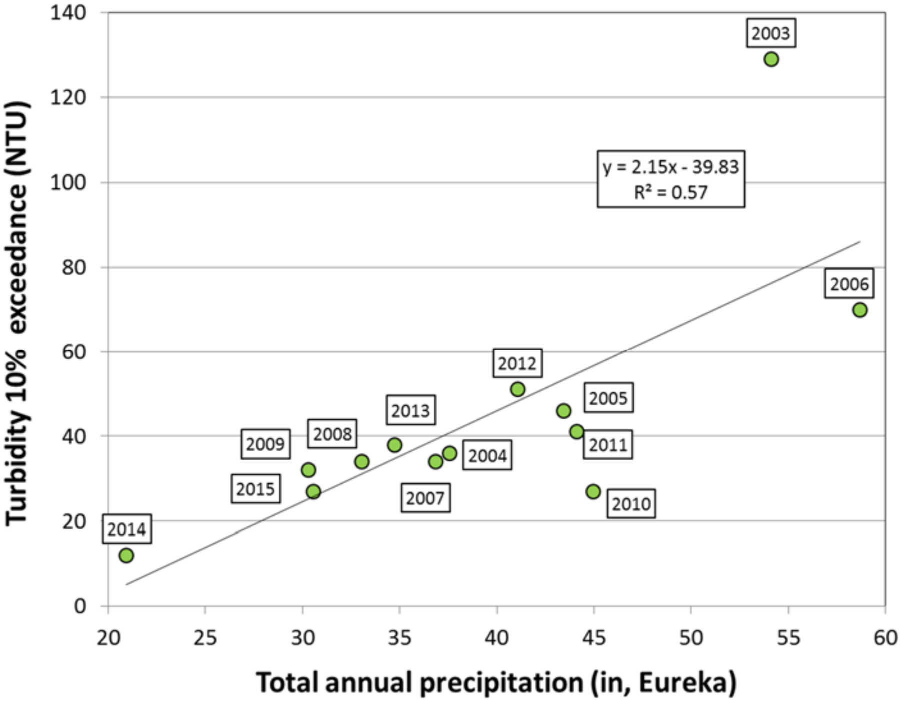


Figure 17. Turbidity data measured at South Fork Freshwater Creek (Station 506), WY 2003-2015

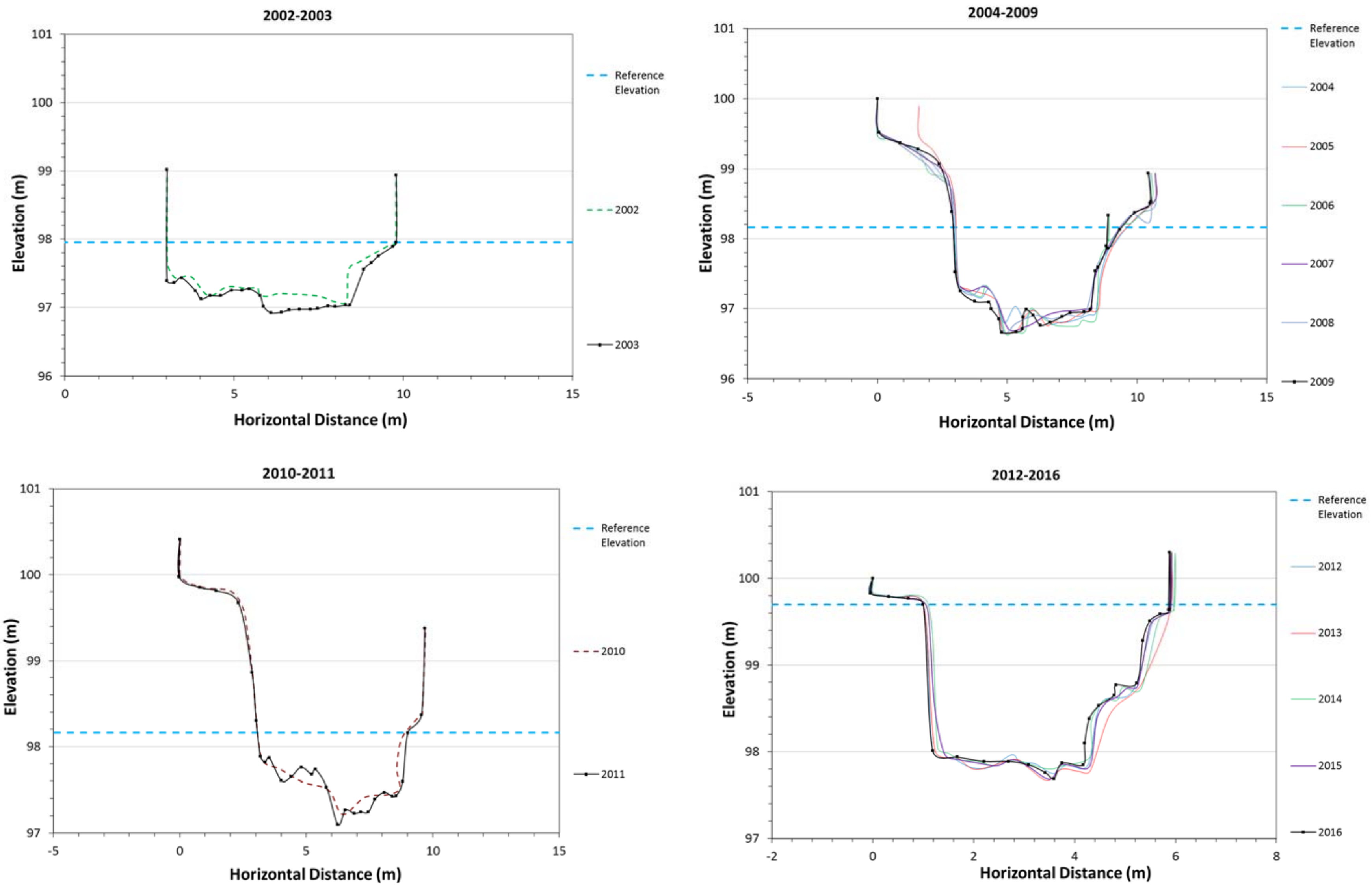


Figure 18. Cross-section measurements per year at South Fork Freshwater Creek (Station 506), 2002-2016

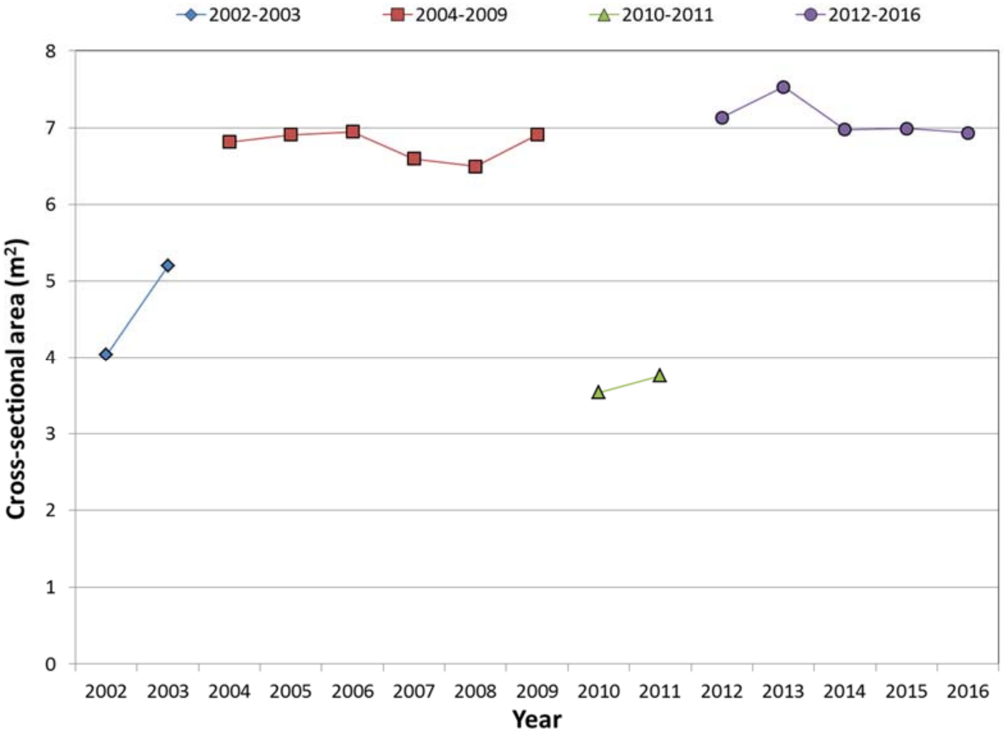
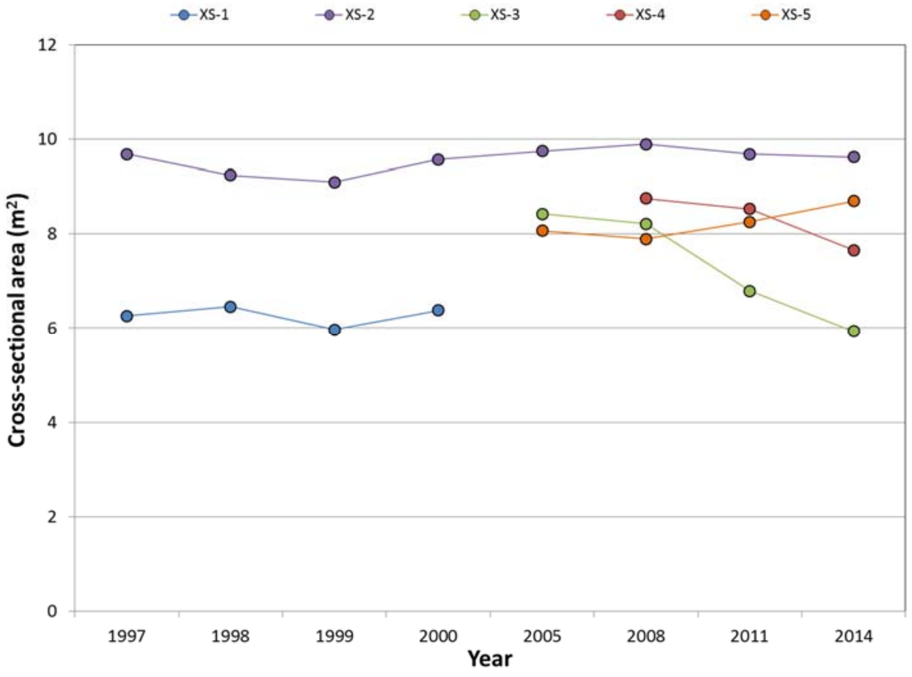


Figure 19. Total cross-sectional area per year measured at South Fork Freshwater Creek (Station 506), 2002-2016



Note: XS-1 is the most downstream cross-section in the monitoring reach (approximately 1,000 ft) and XS-5 is the most upstream.

Figure 20. Total cross-sectional area at ATM Station 015 cross-sections located along the downstream extent of South Fork Freshwater Creek, 1997-2014

1.7 GRAHAM GULCH (STATION 505)

1.7.1 Sediment Yield, Turbidity, and Peak Flow

Among the six gaging stations installed in WY 2003, mean annual suspended sediment yield (Mg km^{-2} yr^{-1}) and mean 10%TU have both been the highest in the Graham Gulch sub-basin (Station 505). A high sediment yield was measured in WY 2003 (approximately 670 Mg km^{-2} yr^{-1}), approximately 95% greater than the next highest yield measured in WY 2006 (approximately 340 Mg km^{-2} yr^{-1}) (Figure 21). Annual peak flow and total annual sediment yield are well correlated ($R^2 = 0.80$). Sediment yield does not appear to have decreased relative to annual peak flow, the latter of which has been the second highest on average compared to all other sub-basins in the watershed since WY 2003. 10%TU has been moderately correlated to total annual precipitation ($R^2 = 0.54$). Chronic turbidity decreased in WY 2005-2010, following very high levels in WY 2004 and 2003, but has fluctuated in recent years (Figure 22).

1.7.2 Channel Dimensions

The ATM Station 019 monitoring reach begins downstream of Station 523 and, along with the gaging station cross-section, can be used to evaluate channel conditions in the lower extent of Graham Gulch. At the gaging station, total cross-sectional area fluctuated widely during the 2005-2011 survey period with intermittent periods of scour and aggradation. From 2012-2014 the channel was relatively stable, until 2015 when substantial aggradation occurred (Figure 23). ATM data indicate an overall increase in channel area within the downstream portions of the reach with general stability upstream since 1997. Notable downstream scour was measured during the 2008 survey relative to 2005 measurements (Figure 24).

1.7.3 Summary and Conclusions

High sediment yields and increased levels of chronic turbidity may be in part due to the geologic conditions. A focused sediment source investigation may be in order to better understand factors driving water quality conditions in this sub-basin.

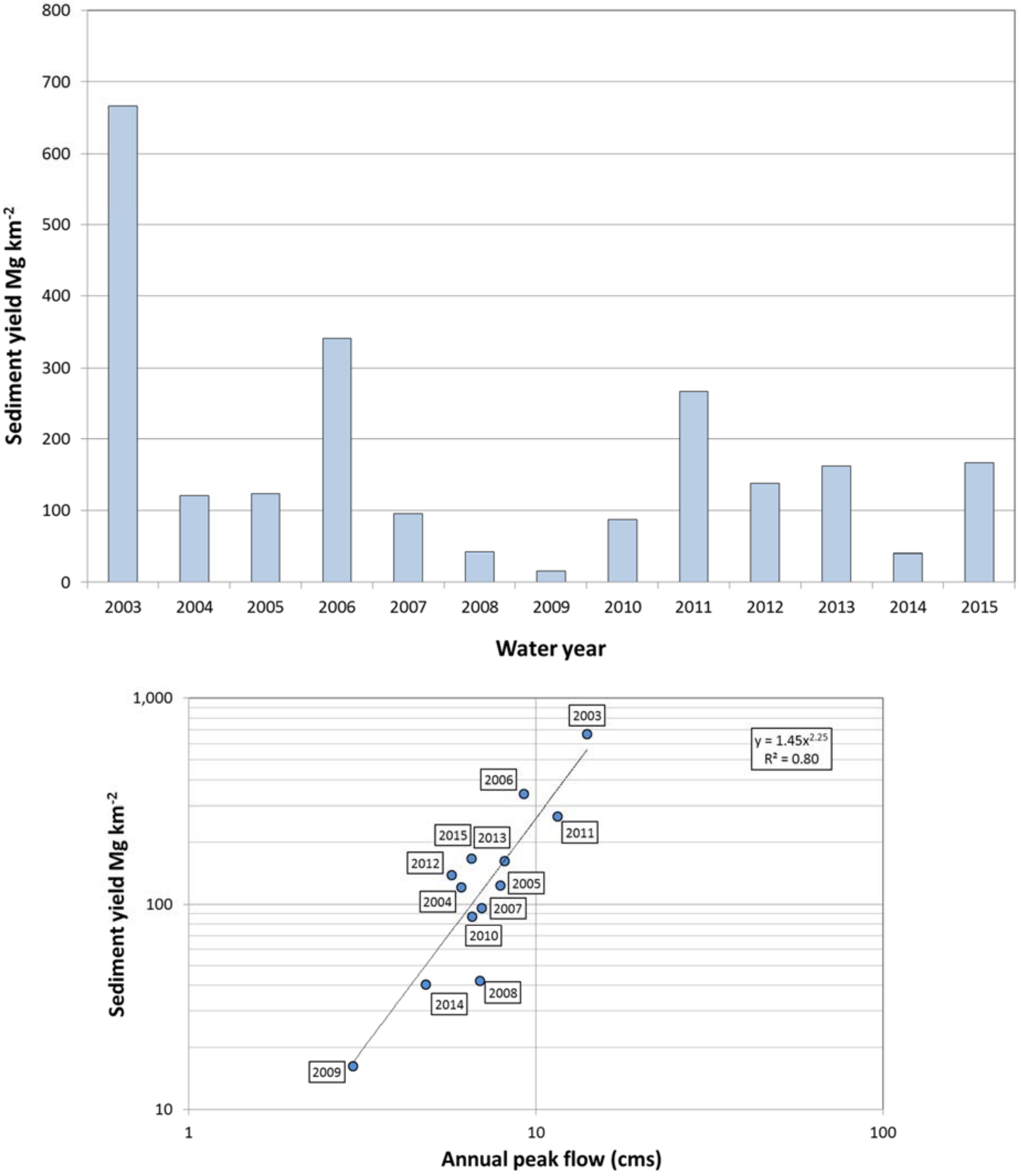


Figure 21. Suspended sediment yield and peak flow data measured at Graham Gulch (Station 505), WY 2003-2015

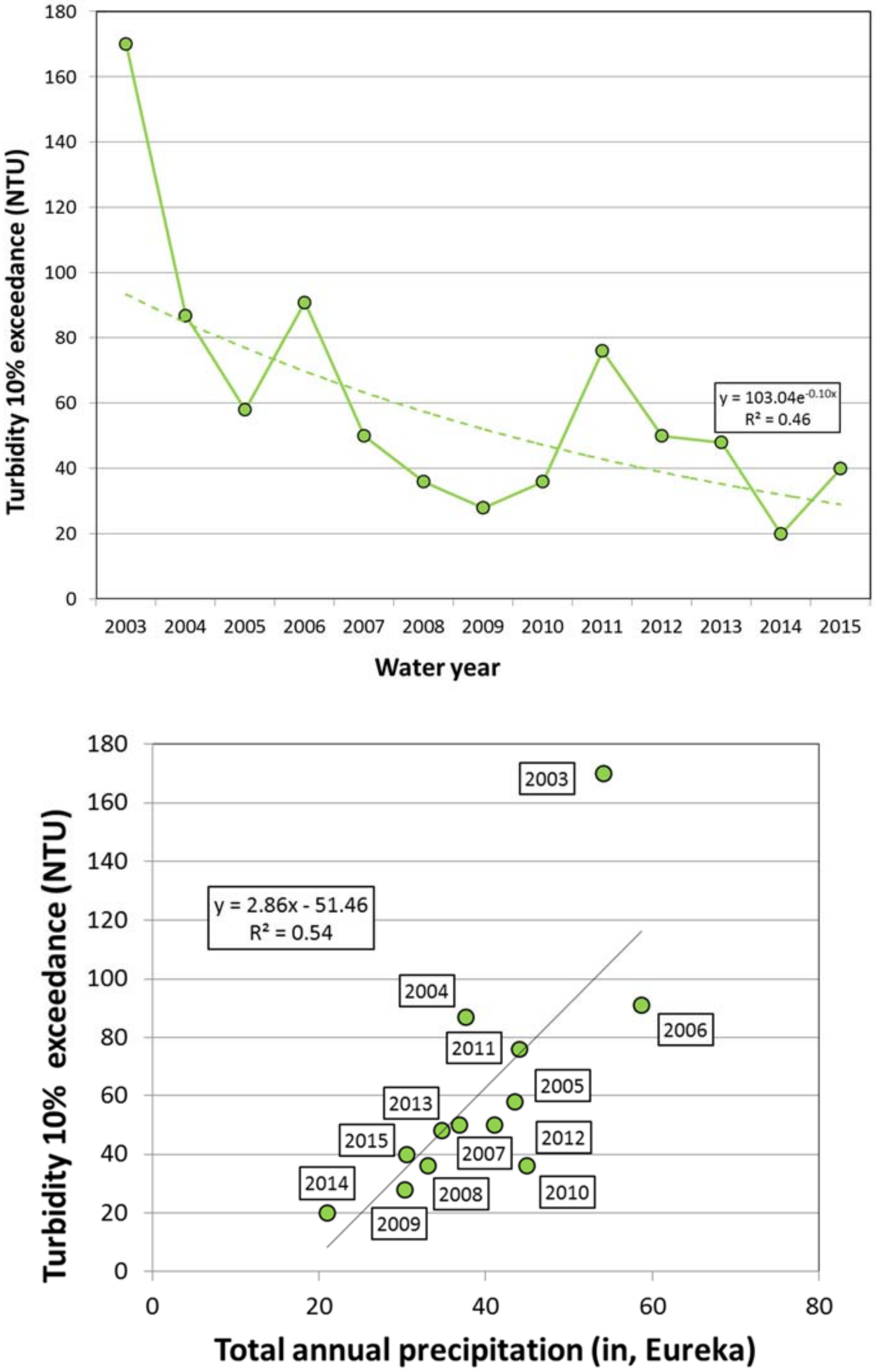


Figure 22. Turbidity data measured at Graham Gulch (Station 505), WY 2003-2015

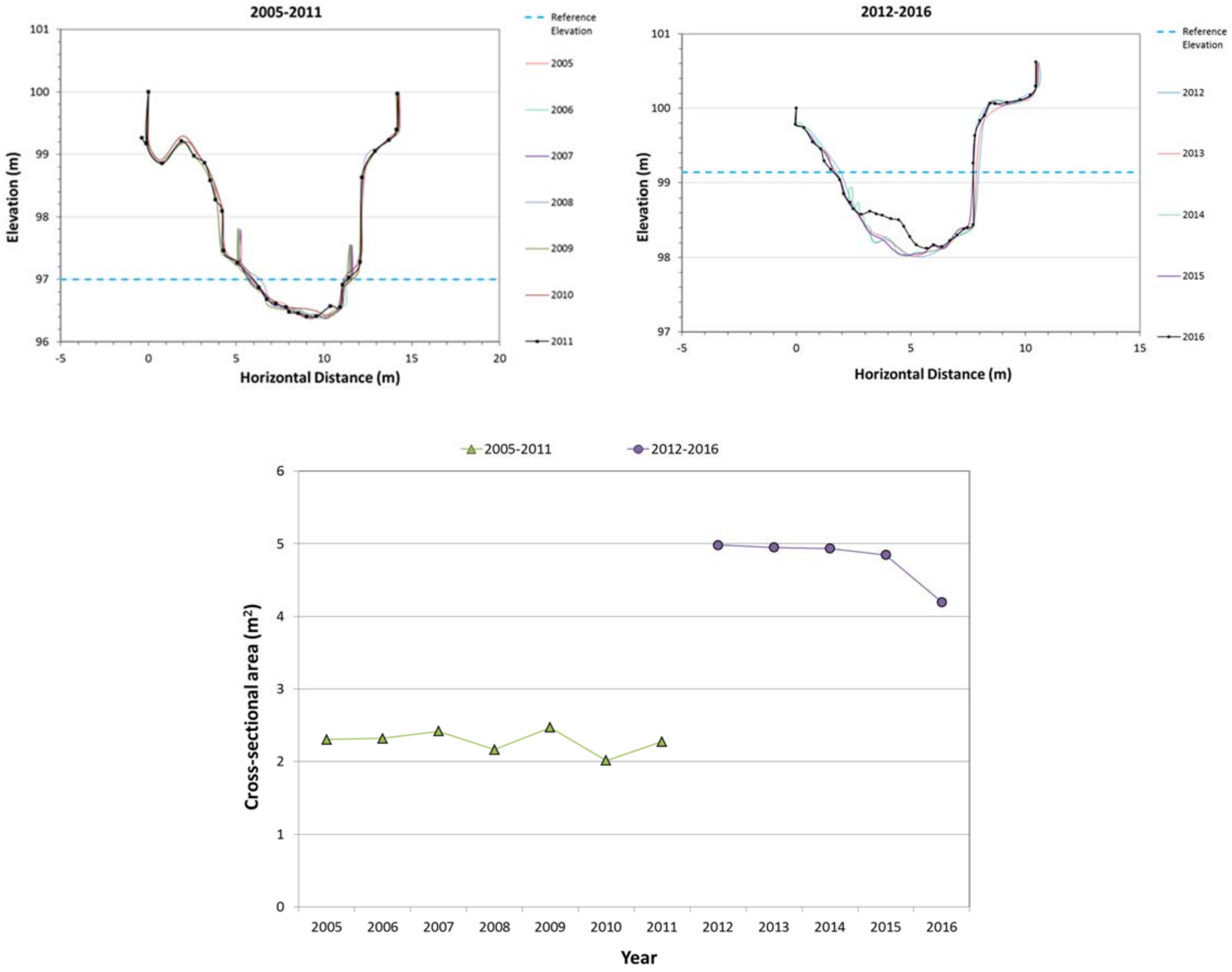
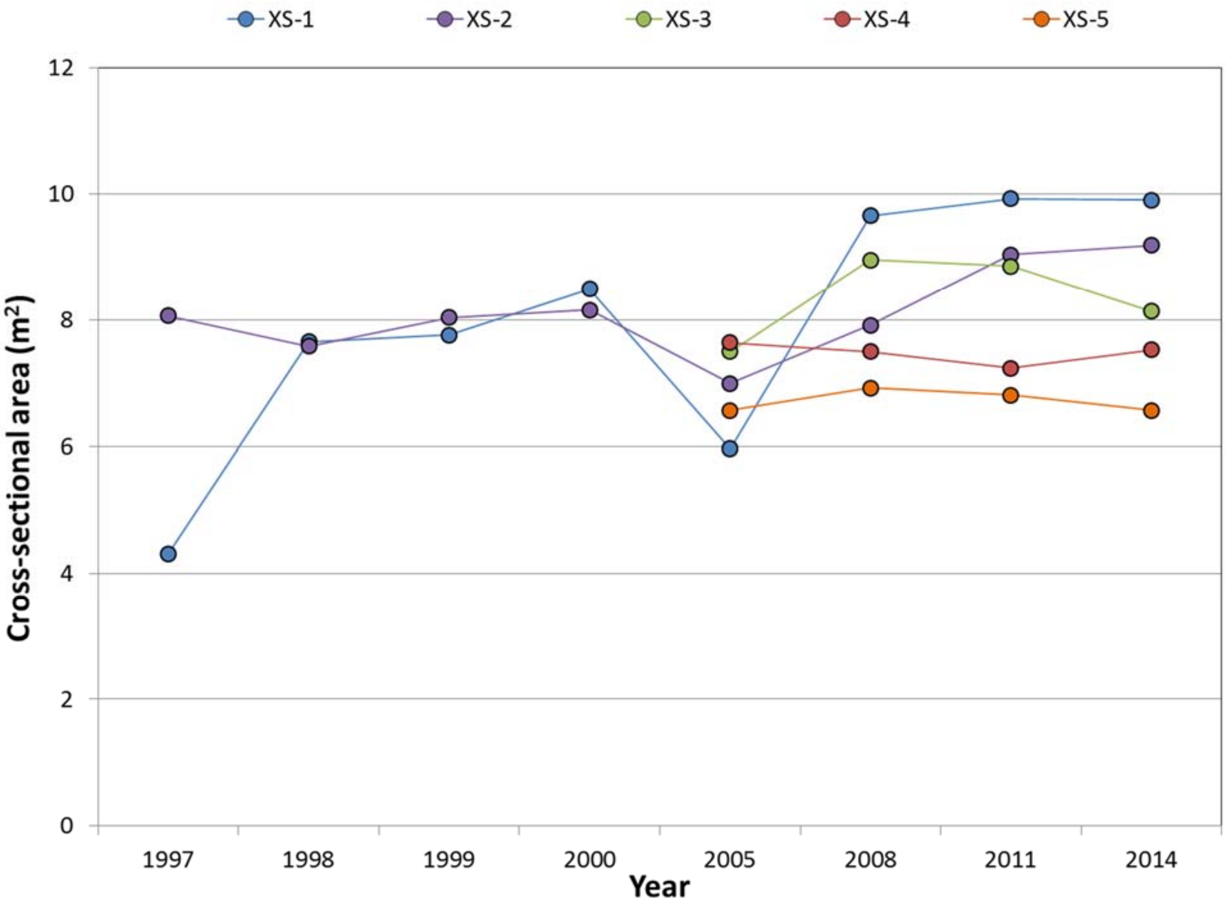


Figure 23. Cross-section survey data measured at Graham Gulch (Station 505), 2005-2016



Note: XS-1 is the most downstream cross-section in the monitoring reach (approximately 1,000 ft) and XS-5 is the most upstream.

Figure 24. Total cross-sectional area at ATM Station 019 cross-sections located along the downstream extent of Graham Gulch, 1997-2014

1.8 CLONEY GULCH (STATION 504)

1.8.1 Sediment Yield, Turbidity, and Peak Flow

Among the six gaging stations installed in WY 2003, mean annual suspended sediment yield (Mg km^{-2} yr^{-1}) and mean 10%TU have been the lowest and second highest, respectively, in the Cloney Gulch sub-basin (Station 504). A high sediment yield was measured in WY 2003 (approximately 630 Mg km^{-2} yr^{-1}), approximately 225% greater than the next highest yield measured in WY 2006 (approximately 195 Mg km^{-2} yr^{-1}) (Figure 25). A moderate correlation exists between annual peak flow and total annual sediment yield ($R^2 = 0.60$). Loads have been lower relative to annual peak flow in each of the last five seasons (WY 2011-2015). 10%TU is well correlated to total annual precipitation ($R^2 = 0.77$). Chronic turbidity is high in Cloney Gulch but appears to be declining as 10%TU has been lower relative to annual rainfall during each of the last seven seasons (Figure 26).

1.8.2 Channel Dimensions

The ATM Station 092 monitoring reach begins just downstream of Station 504 and, along with the gaging station cross-section, can be used to evaluate channel conditions in the lower extent of Cloney Gulch. At the gaging station, total cross-sectional area increased steadily during the 2005-2011 survey period. Aggradation occurred from 2012 to 2013. The channel has been generally stable since (Figure 27). ATM data indicate an overall increase in channel cross-sectional area within the downstream-to-middle portions of the reach with general stability upstream since 1998 (Figure 28).

1.8.3 Summary and Conclusions

The strongest indications of decreasing suspended sediment loads and levels of chronic turbidity have been measured in the Cloney Gulch sub-basin. This is encouraging given that large portions of the drainage consist of undifferentiated Wildcat lithology, a geologic group often associated with high sediment yields due in part to a relatively low capacity for infiltration. Harvesting is scheduled to continue in the upper portions of the sub-basin in 2017. Data collected through continued monitoring will be critical to test water quality response to future management activities in the sub-basin.

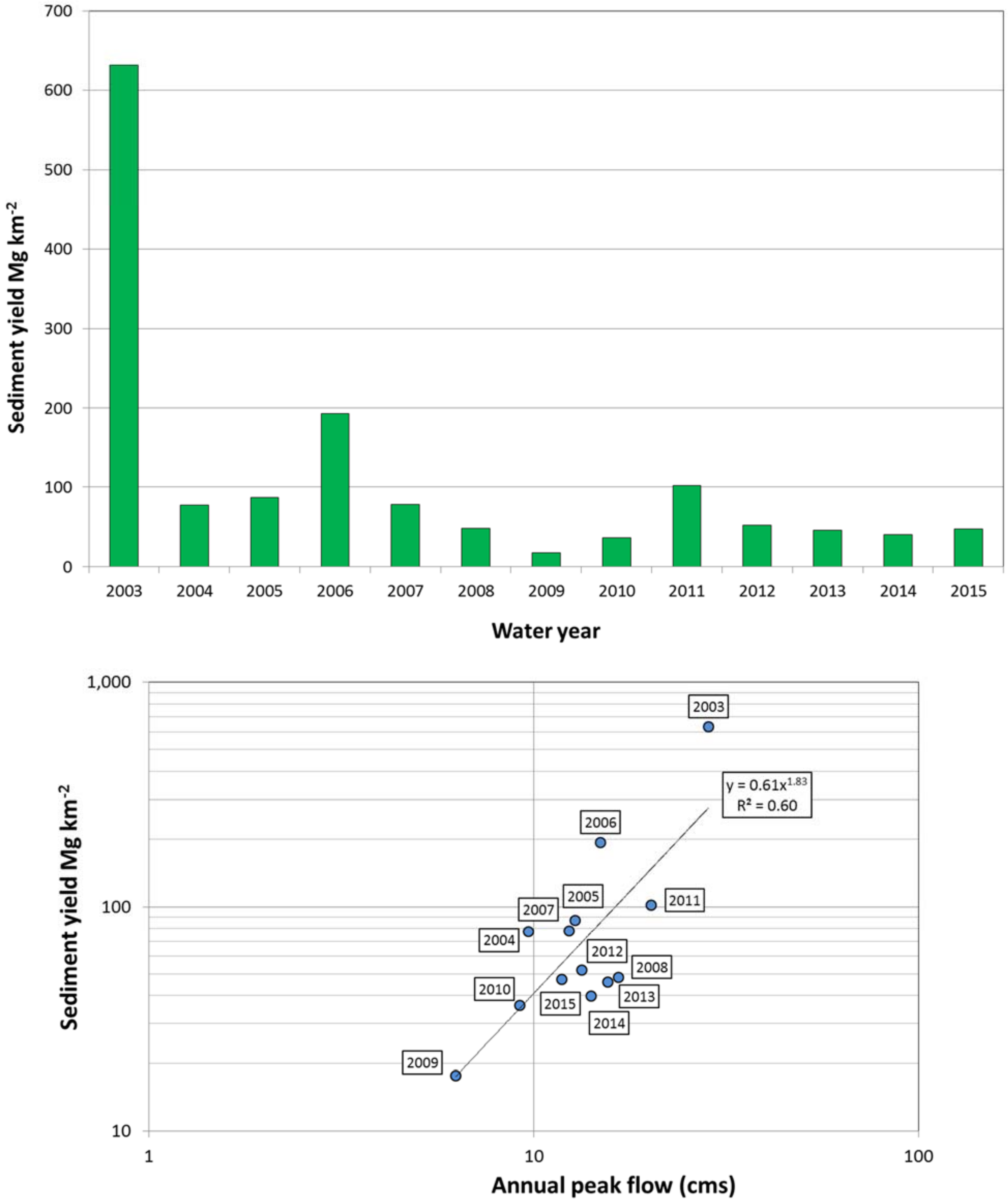
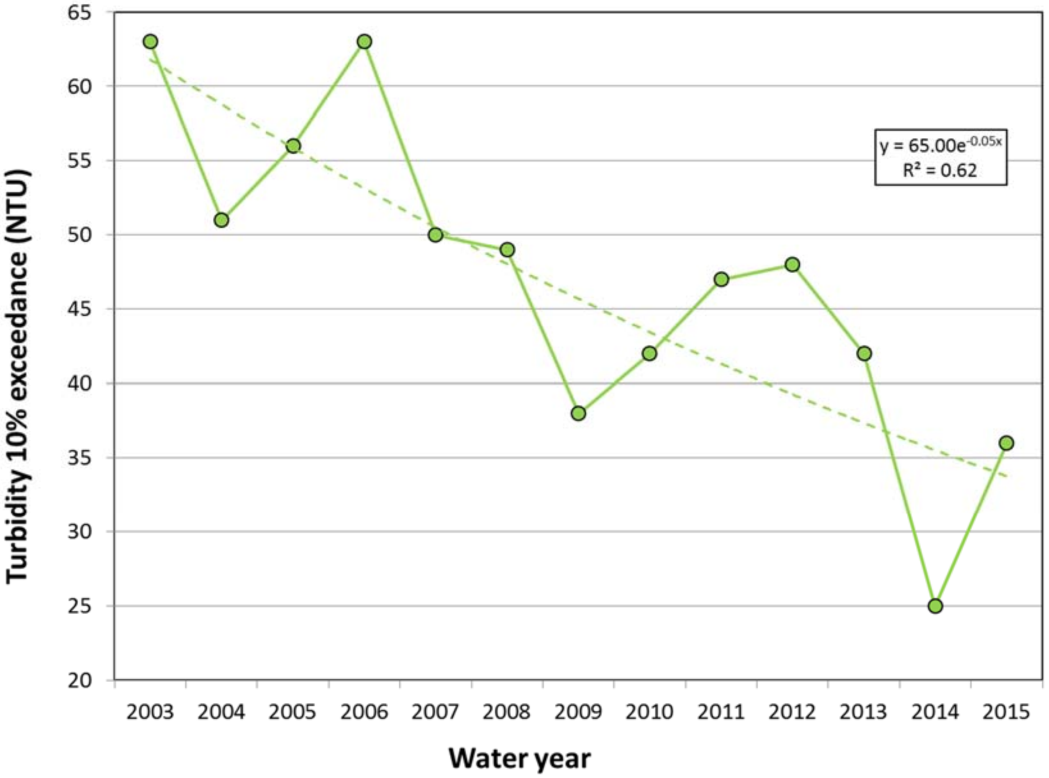


Figure 25. Suspended sediment yield and peak flow data measured at Cloney Gulch (Station 504), WY 2003-2015



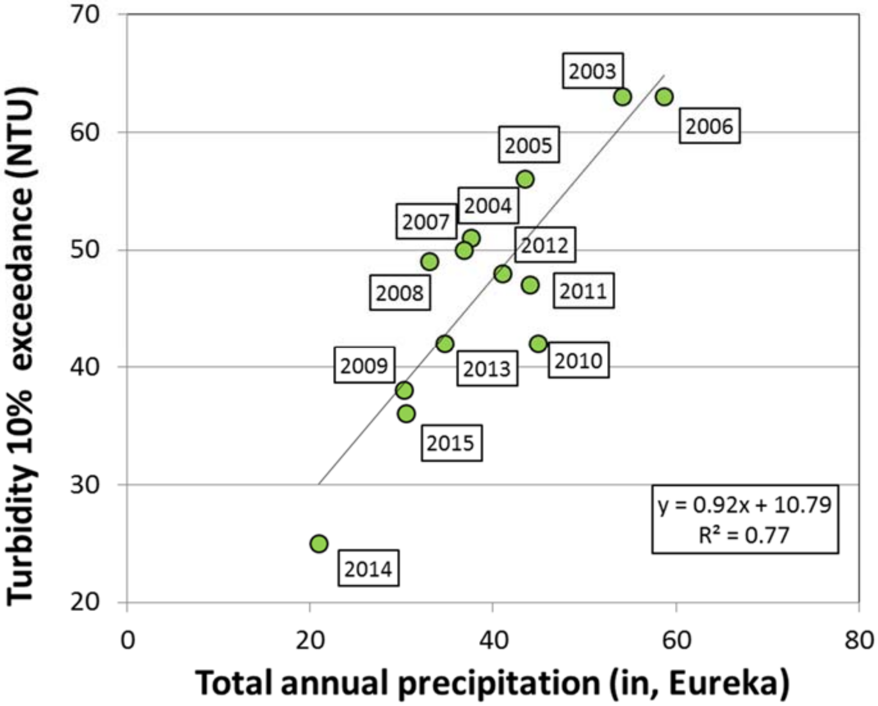


Figure 26. Turbidity data measured at Cloney Gulch (Station 504), WY 2003-2015

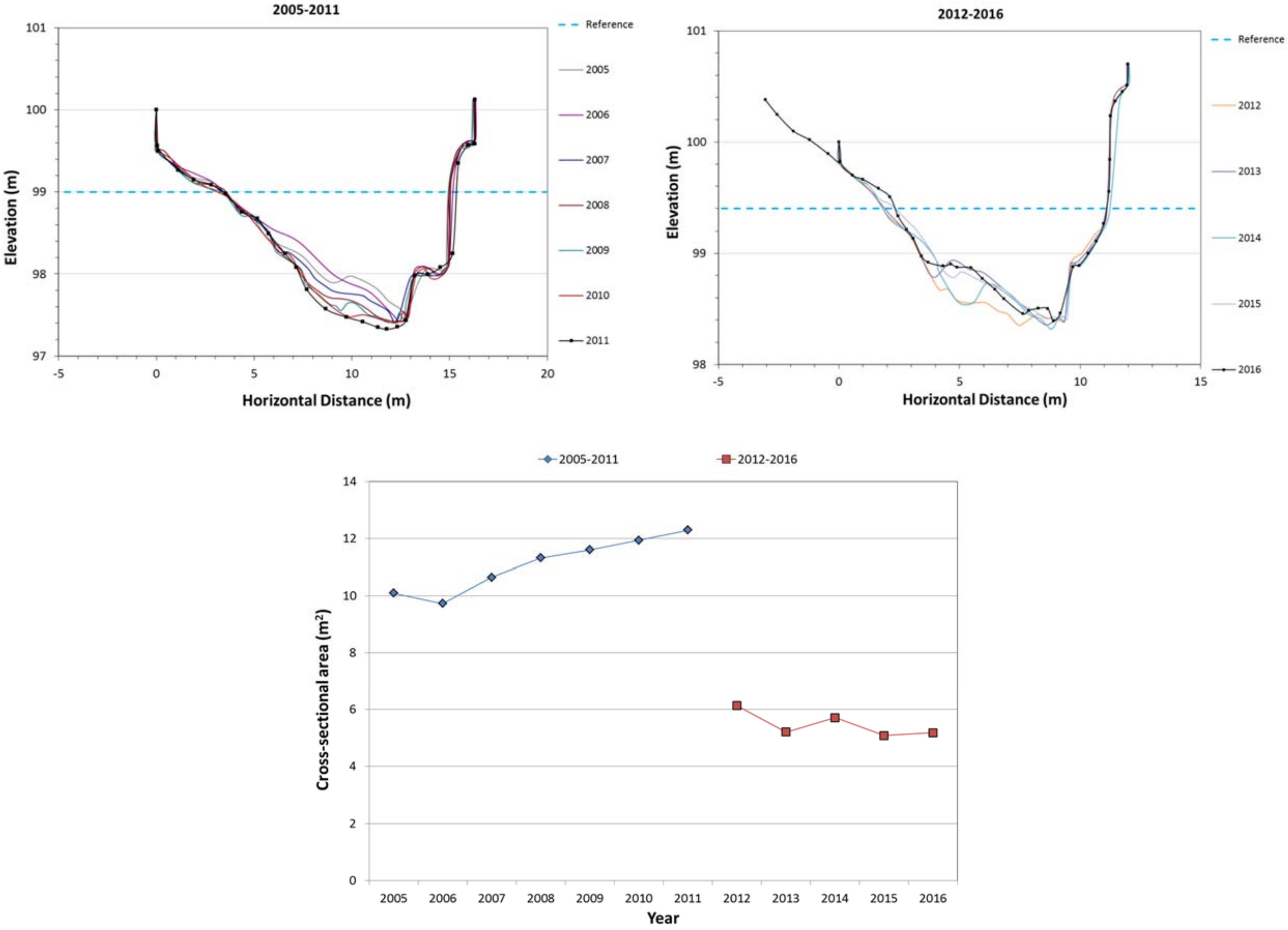
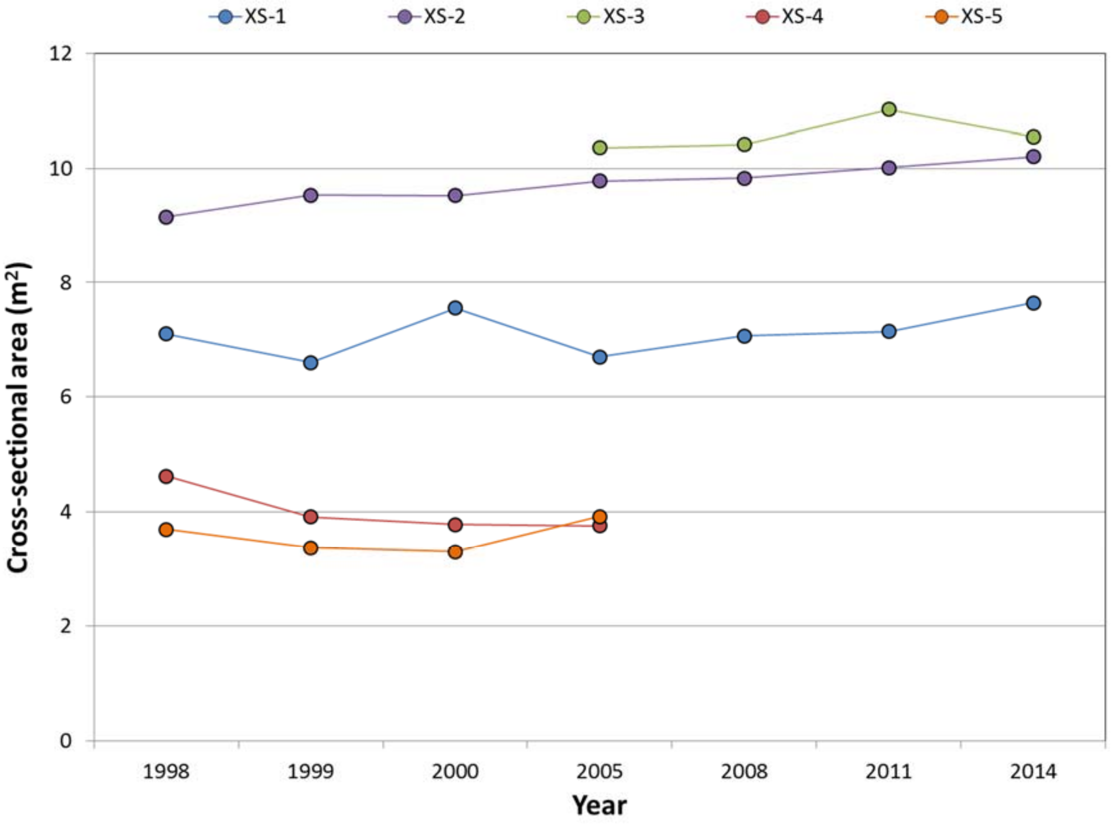


Figure 27. Cross-section survey data measured at Cloney Gulch (Station 504), 2005-2016



Note: XS-1 is the most downstream cross-section in the monitoring reach (approximately 1,000 ft) and XS-5 is the most upstream.

Figure 28. Total cross-sectional area at ATM Station 092 cross-sections located along the downstream extent of Cloney Gulch, 1997-2014

1.9 LITTLE FRESHWATER CREEK (STATION 528)

1.9.1 Sediment Yield, Turbidity, and Peak Flow

Monitoring began at the Little Freshwater Creek gaging station (Station 528) in WY 2004. From WY 2004-2015, both mean annual sediment yield (Mg km^{-2} yr^{-1}) and mean 10%TU at Station 523 are the sixth highest in the Freshwater Creek watershed. The highest suspended sediment yield was measured in WY 2006 (approximately 230 Mg km^{-2} yr^{-1}). Per unit area, mean annual peak flows have been the lowest at this station since WY 2004 (0.9 cms km^{-2}). A strong correlation exists between annual peak flow and total annual suspended sediment yield ($R^2 = 0.76$). From WY 2007-2011, sediment yields were lower relative to peak flow but have increased in recent years (Figure 29). A moderate relationship exists between 10%TU and total annual precipitation ($R^2 = 0.69$) (Figure 30) and illustrates that turbidity has been lower relative to total precipitation in five out of the last six seasons (WY 2010-2015).

1.9.2 Channel Dimensions

The ATM Station 018 monitoring reach begins about 1,500 ft upstream of Station 523 and, along with the gaging station cross-section, is used to evaluate channel conditions in the lower-middle extent of Little Freshwater Creek. At the gaging station, total cross-sectional area was generally stable during the 2005-2011 survey period and has been slowly aggrading (approximately 6% decrease in cross-sectional area) from 2012-2016 (Figure 31). ATM data indicate relative stability throughout the monitoring reach since 2008 (Figure 32).

1.9.3 Summary and Conclusions

Large portions of the Little Freshwater Creek sub-basin were harvested in the early 2000s which, along with the dominant presence of undifferentiated Wildcat geology, may explain high sediment yields relative to peak flow measured during the first three years of monitoring (WY 2004-2006). Sediment yields have been somewhat lower since that time but have remained generally static for the past five years. Chronic turbidity, however, appears to be decreasing. Harvesting is scheduled to continue in the lower portions of the sub-basin. As is the case in Cloney Gulch, results derived from continued monitoring will be useful in evaluating watershed response to contemporary management practices.

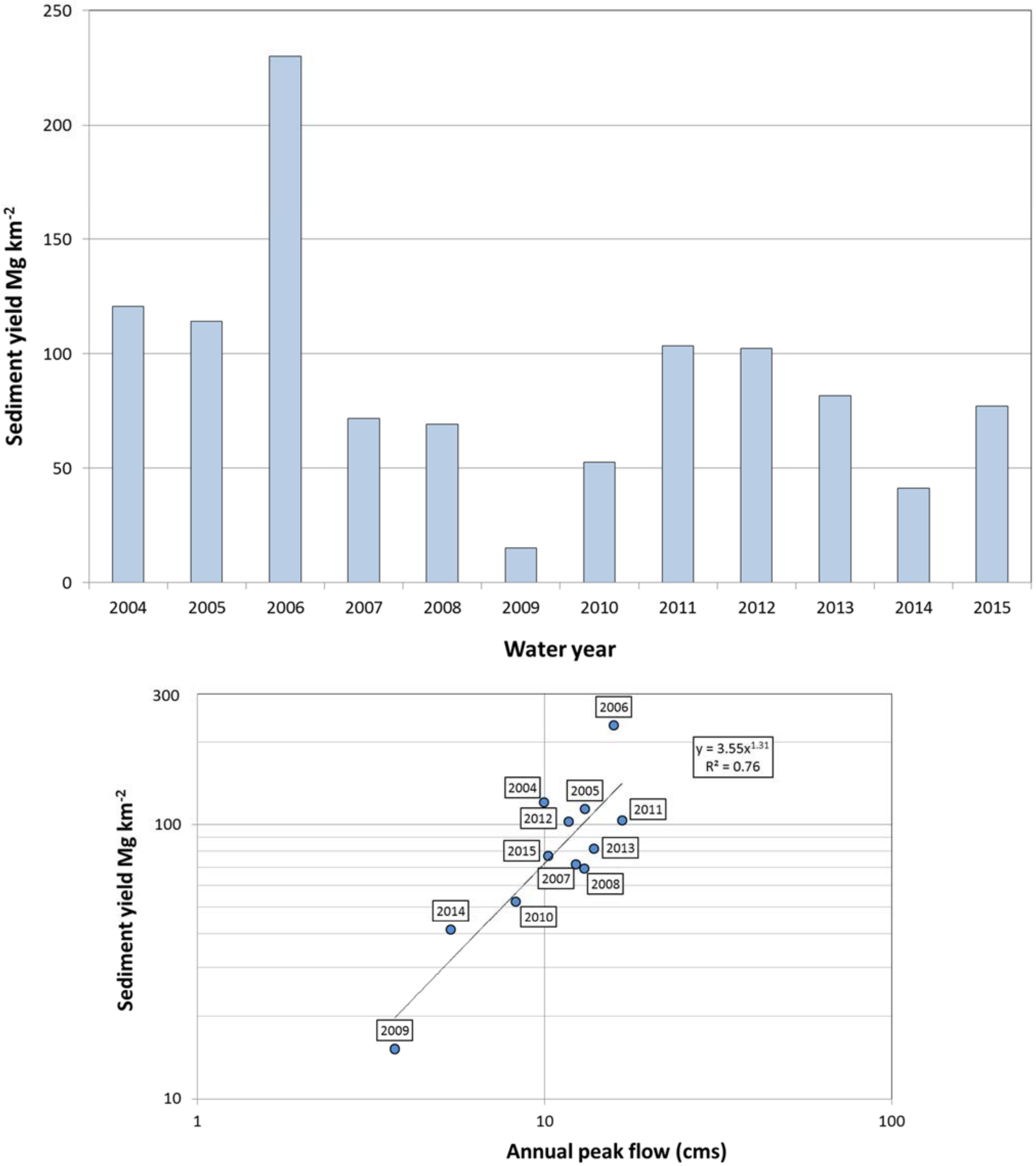
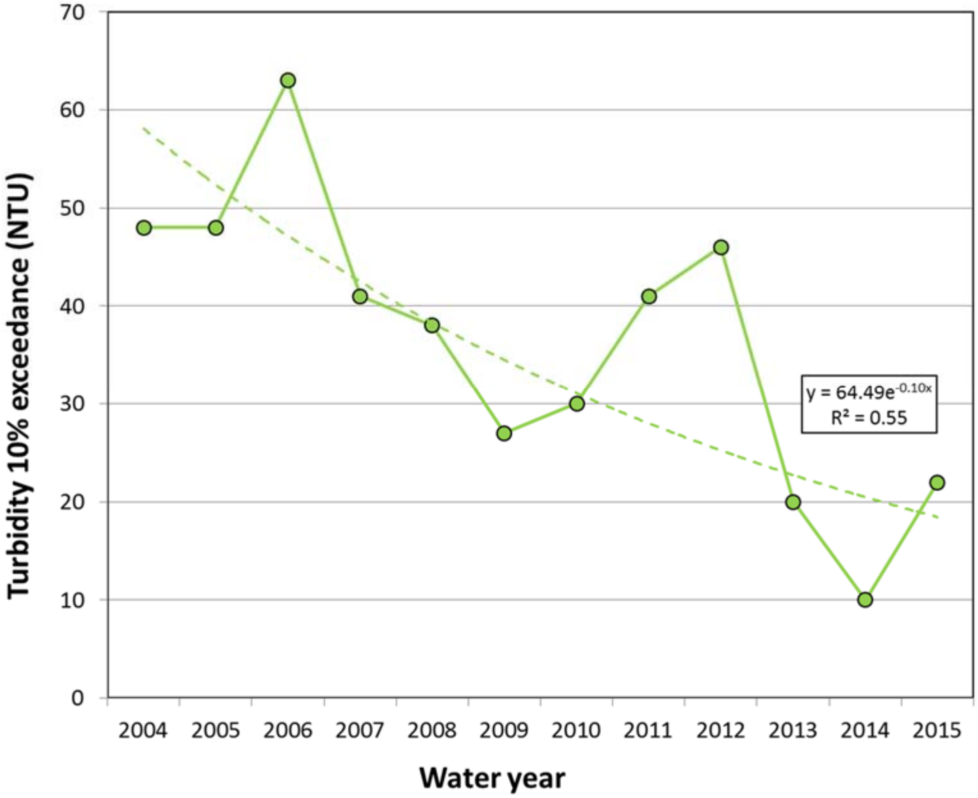


Figure 29. Suspended sediment yield and peak flow data measured at Little Freshwater Creek (Station 528), WY 2004-2015



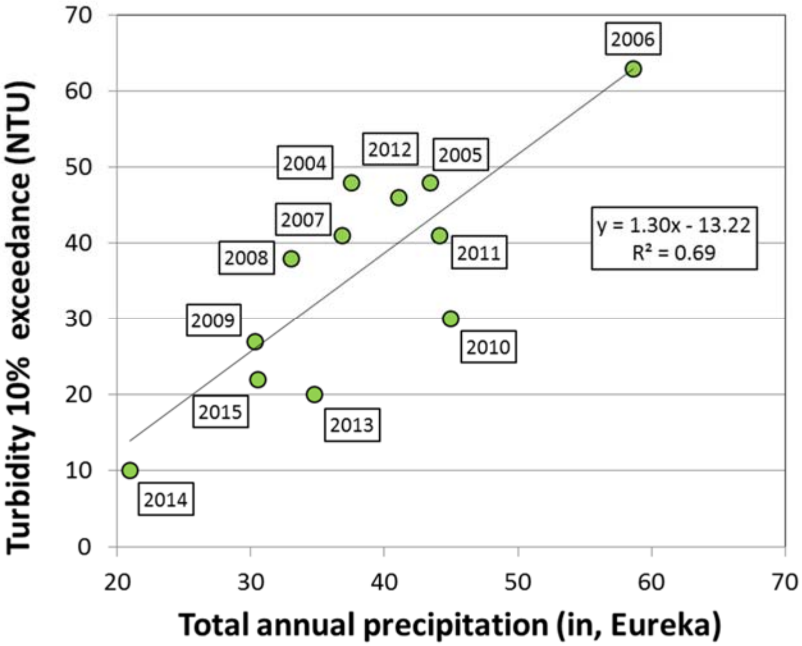


Figure 30. Turbidity data measured at Little Freshwater Creek (Station 528), WY 2003-2015

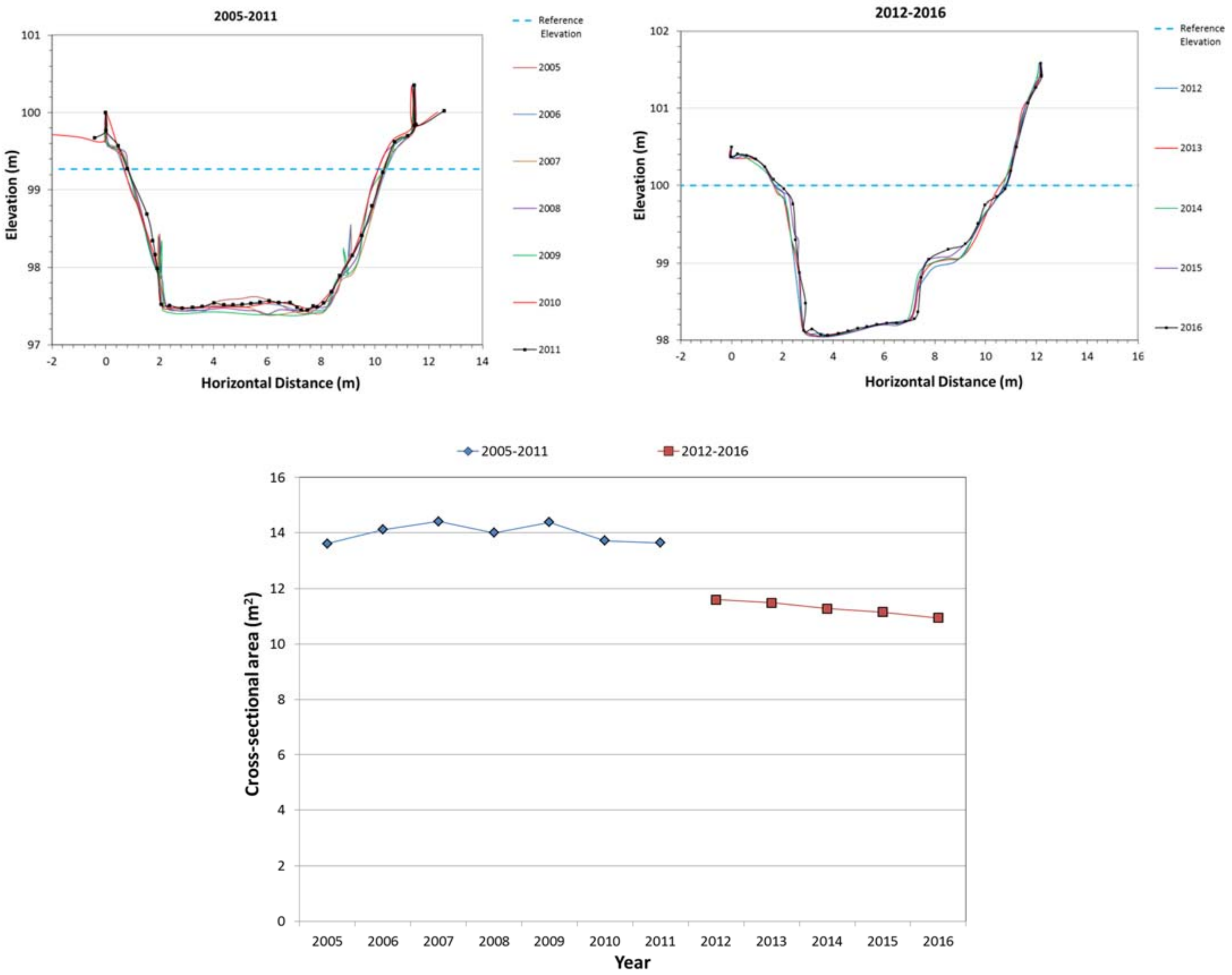
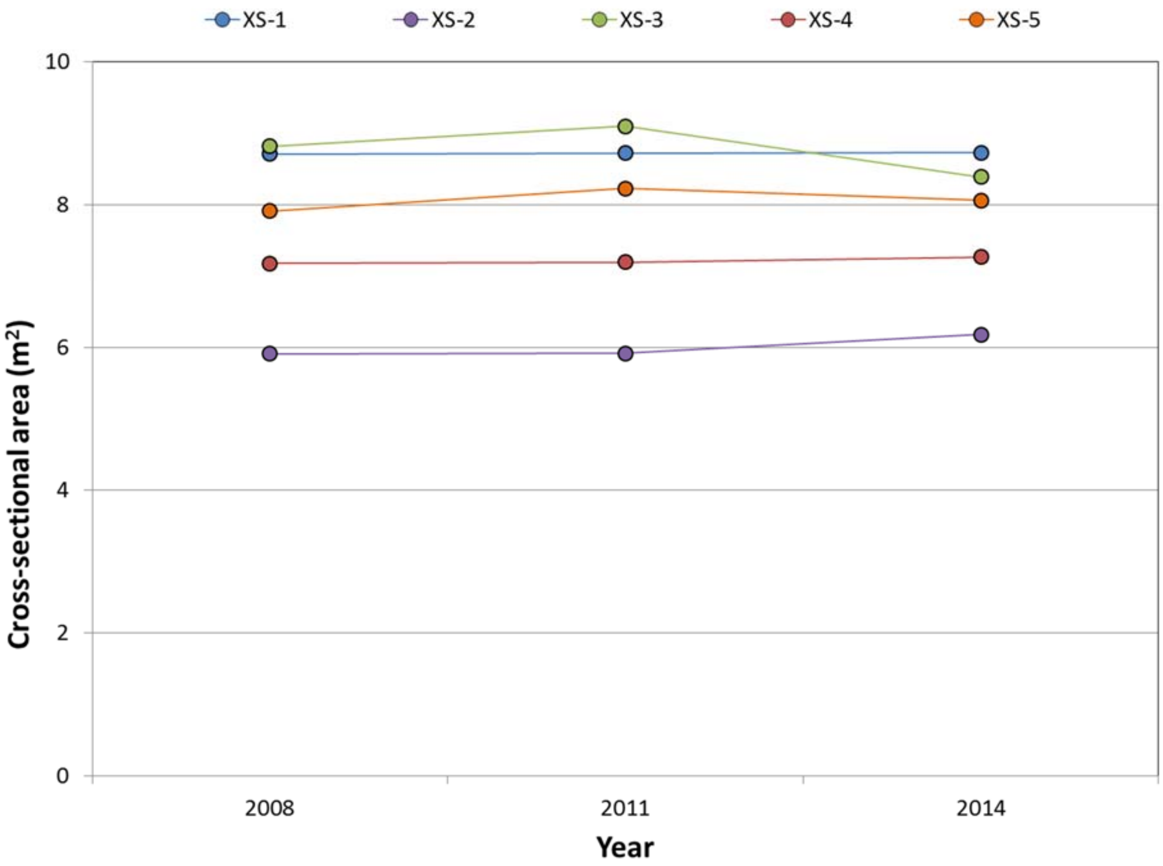


Figure 31. Cross-section survey data measured at Little Freshwater Creek (Station 528), 2005-2016



Note: XS-1 is the most downstream cross-section in the monitoring reach (approximately 1,000 ft) and XS-5 is the most upstream.

Figure 32. Total cross-sectional area at ATM Station 018 cross-sections located along the downstream extent of Little Freshwater Creek, 2008-2014

1.10 MCCREADY GULCH (STATION 527)

1.10.1 Sediment Yield, Turbidity, and Peak Flow

Among the six gaging stations installed in WY 2003, mean annual suspended sediment yield (Mg km^{-2} yr^{-1}) and mean 10%TU have been the second lowest and lowest, respectively, in the McCready Gulch sub-basin (Station 527). A high sediment yield was measured in WY 2003 (approximately 645 Mg km^{-2} yr^{-1}), approximately 300% greater than the next highest yield measured in WY 2006 (approximately 160 Mg km^{-2} yr^{-1}) (Figure 33). Data collected in WY 2003 are incomplete as the station was located slightly downstream of its present location and monitoring did not begin until the second half of the winter in

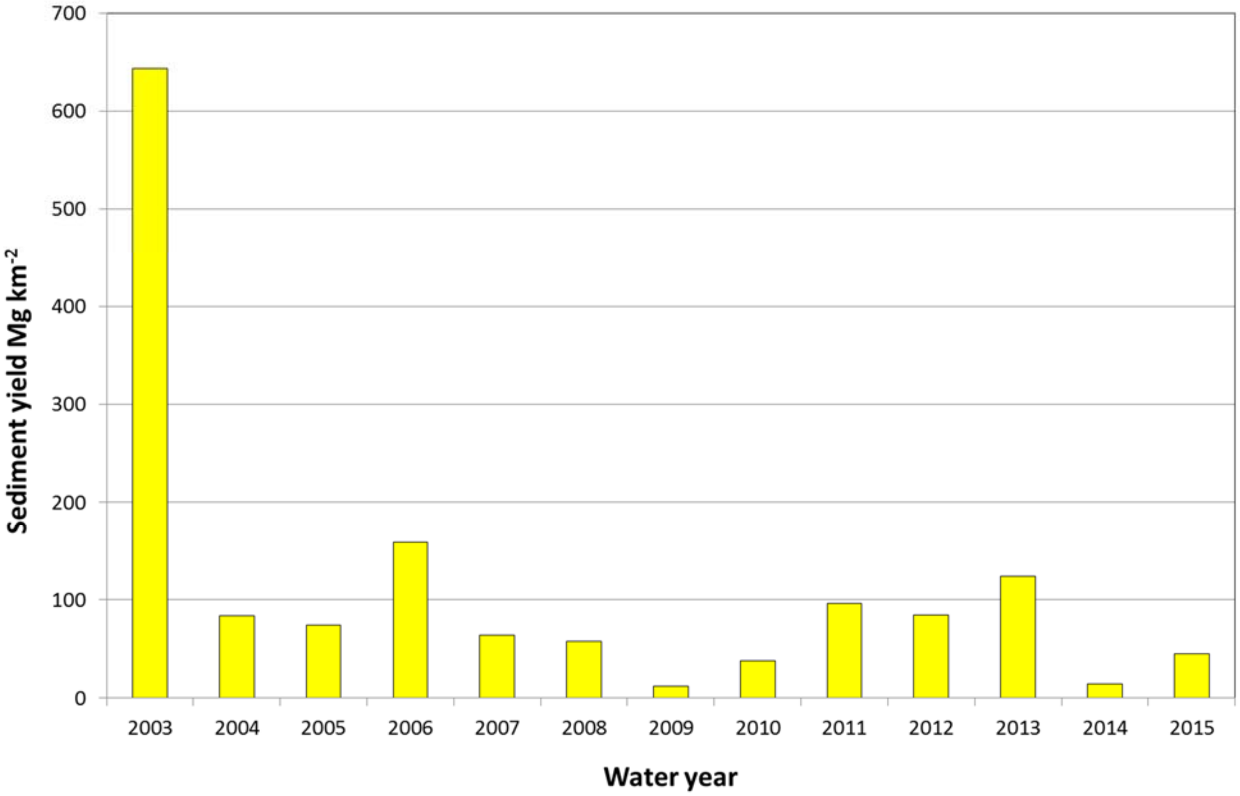
December 2002. Despite these uncertainties, it is clear, however, that sediment yield was very high in the sub-basin that season. A strong correlation exists between annual peak flow and total annual sediment yield ($R^2 = 0.83$). Loads dipped slightly relative to peak flow during WY 2005-2008 but have remained generally static and suggest no clear increasing or decreasing trend throughout the monitoring record. 10%TU is moderately correlated to total annual precipitation ($R^2 = 0.68$). Chronic turbidity may be showing some signs of decline as 10%TU has been lower relative to precipitation during the last two seasons (WY 2014-2015) (Figure 34).

1.10.2 Channel Dimensions

The ATM Station 202 monitoring reach begins about 1,000 ft upstream of Station 527 and, along with the gaging station cross-section, can be used to evaluate channel conditions in the lower-to-middle extent of McCready Gulch. At the gaging station, total cross-sectional area fluctuated during the 2004-2011 survey period with intermittent periods of scour and aggradation. Channel cross-sectional area has decreased by about 10% in the 2012-2016 survey period largely due to aggradation measured in 2016 (Figure 35). ATM data indicate general stability in the upper and lower extents of the reach and substantial fluctuation in the middle reach (XS-3) (Figure 36).

1.10.3 Summary and Conclusions

Due to HRC property boundary (and access) limitations, the McCready Gulch gaging station is located slightly farther upstream of the Freshwater Creek confluence than other stations in the watershed. Station 526 also captures the effects of the Horse Gulch tributary, a watercourse where conditions are not currently being monitored. Sediment yields are generally quite low in this sub-basin and chronic turbidity levels appear to be decreasing over time. Continued hydrology monitoring may not be necessary given that no future harvesting is scheduled within this drainage in the immediate future. Channel dimensions retain the capacity for annual fluctuation which stresses the importance of continued streambed surveys in the sub-basin.



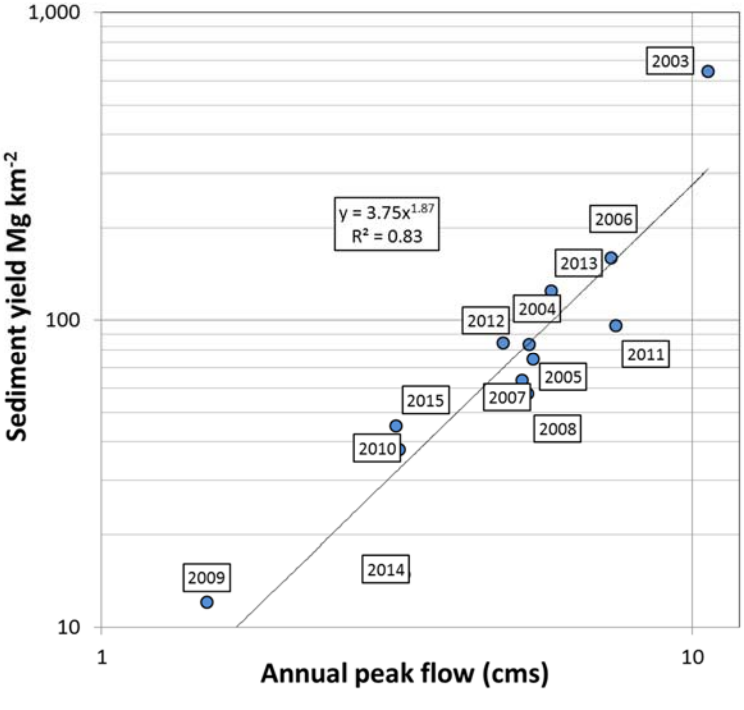


Figure 33. Suspended sediment yield and peak flow data measured at McCready Gulch (Station 527), WY 2003-2015

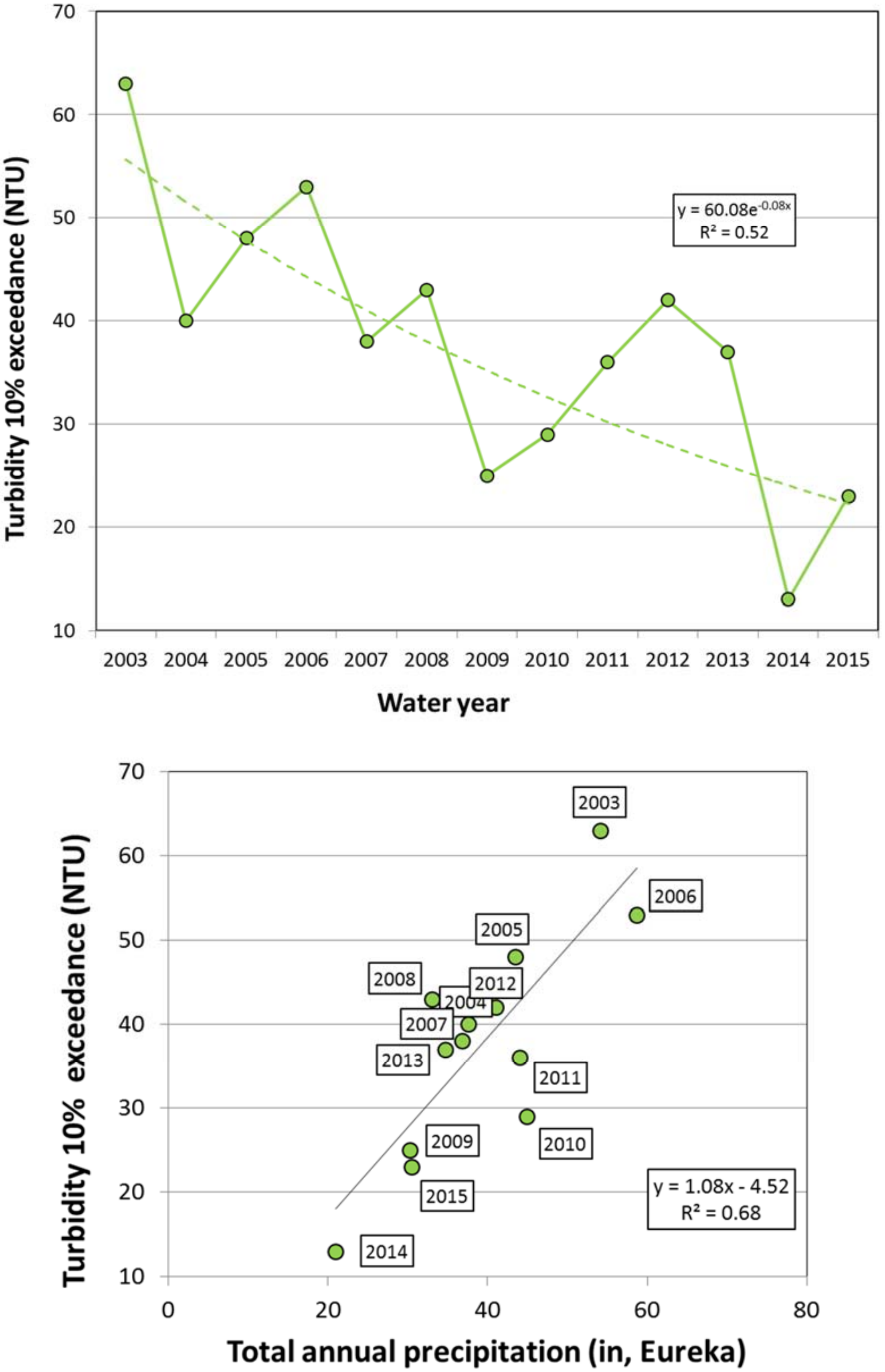


Figure 34. Turbidity data measured at McCready Gulch (Station 527), WY 2003-2015

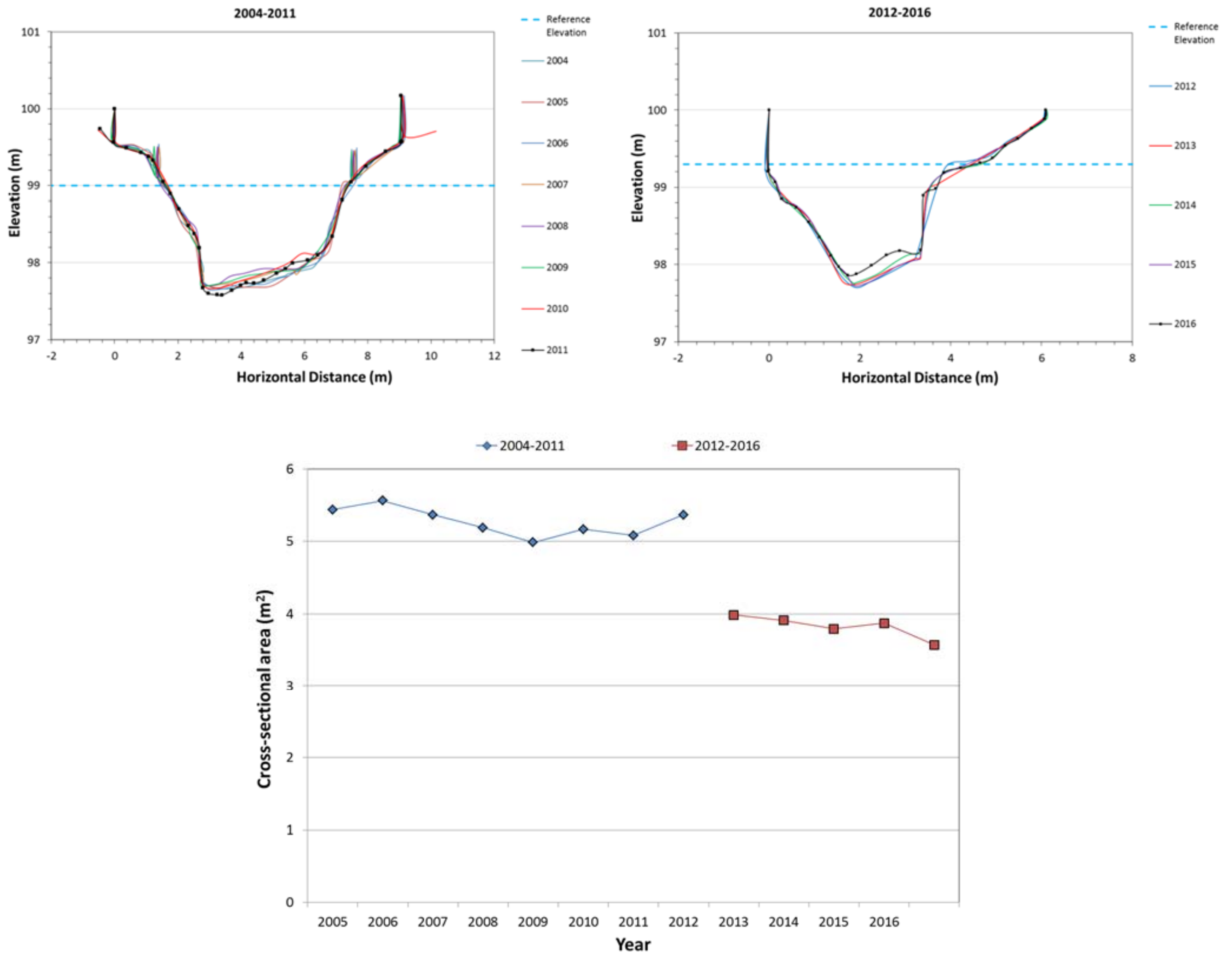
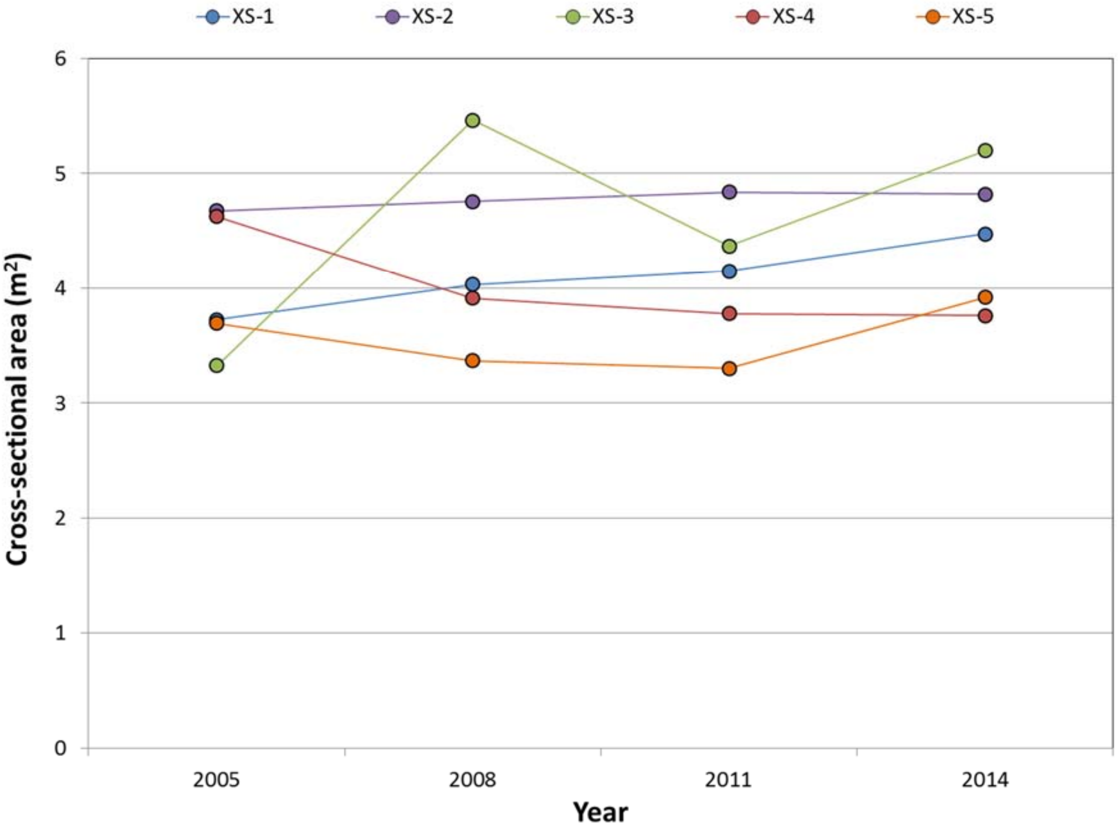


Figure 35. Cross-section survey data measured at McCready Gulch (Station 527), 2005-2016



Note: XS-1 is the most downstream cross-section in the monitoring reach (approximately 1,000 ft) and XS-5 is the most upstream.

Figure 36. Total cross-sectional area at ATM Station 202 cross-sections located near the middle extent of McCready Gulch, 2005-2014

2 REFERENCES

Klein, R., Lewis, J., & Buffleben, M. (2011). Logging and turbidity in the coastal watersheds of northern California. *Geomorphology*, doi:10.1016/j.geomorph.2011.10.011.

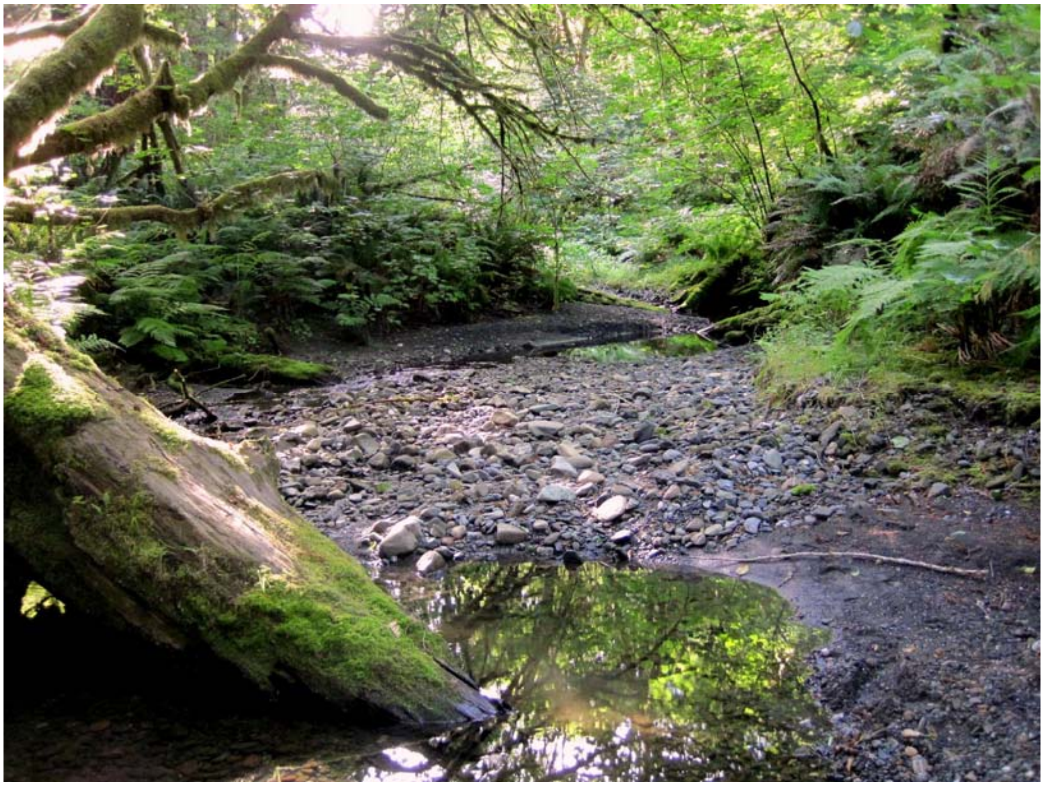
APPENDIX 7

Fish Habitat Monitoring Data

Freshwater Creek
Watershed Analysis Revisited

Appendix 7 – Fish Habitat Monitoring Data

June 8, 2018



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LIST OF ACRONYMS

APFC	Aquatic Properly Functioning Condition
ATM	Aquatic Trends Monitoring
ft	feet or foot
GPS	Global Positioning System
HRC	Humboldt Redwood Company, LLC
LWD	large woody debris
QA/QC	Quality Assurance/Quality Control
SDOM	standard deviation of the mean

1 AQUATIC TRENDS MONITORING

In support of the fisheries assessment for the Freshwater Creek Watershed Analysis revisit, the Humboldt Redwood Company, LLC (HRC) evaluated habitat trends at Aquatic Trends Monitoring (ATM) stations in the Freshwater Creek watershed. Results for individual sub-basins are discussed below. Locations of ATM stations are shown in Figure 1.

1.1 INDIVIDUAL SUB-BASIN RESULTS

1.1.1 ATM Station 034 (Freshwater Creek)

Habitat trends at ATM Station 034 vary in both the magnitude and direction of change (Figure 2). The most notable improvements towards Aquatic Properly Functioning Condition (APFC) targets were observed in pool area percentage, pool spacing, key large woody debris (LWD) piece frequency, average LWD diameter, total LWD volume, water temperature, and both overstream and riparian canopy cover. Habitat parameters that appear to be trending away from APFC targets include surface particle size (D_{50}), percentage of pools associated with wood and total LWD piece frequency. There have been virtually no changes in residual pool depth and average LWD piece length.

These trends may imply relationships between the habitat parameters that have shown improvements. As LWD key pieces, volume, and diameter increase, it would be reasonable to expect an increase in pool area and frequency. Likewise, as canopy cover increased, one could expect to observe a steady decrease in water temperature. However, there may be other confounding factors that could be responsible for the apparent fining of the D_{50} surface particle size and the minimal changes in residual pool depth; habitat parameters which were expected to respond positively to an increase in LWD key pieces, average diameter, and volume.

As data collection continues, the strength and direction of these trends is expected to become clearer, lending insight to land managers attempting to maximize their resources for habitat restoration. ATM trends suggest that the mainstem reaches within the proximity of ATM Station 034 could benefit from instream wood placement restoration projects to improve overall pool frequency and habitat complexity, which in turn may contribute to an increase in the biological carrying capacity of the stream reach.

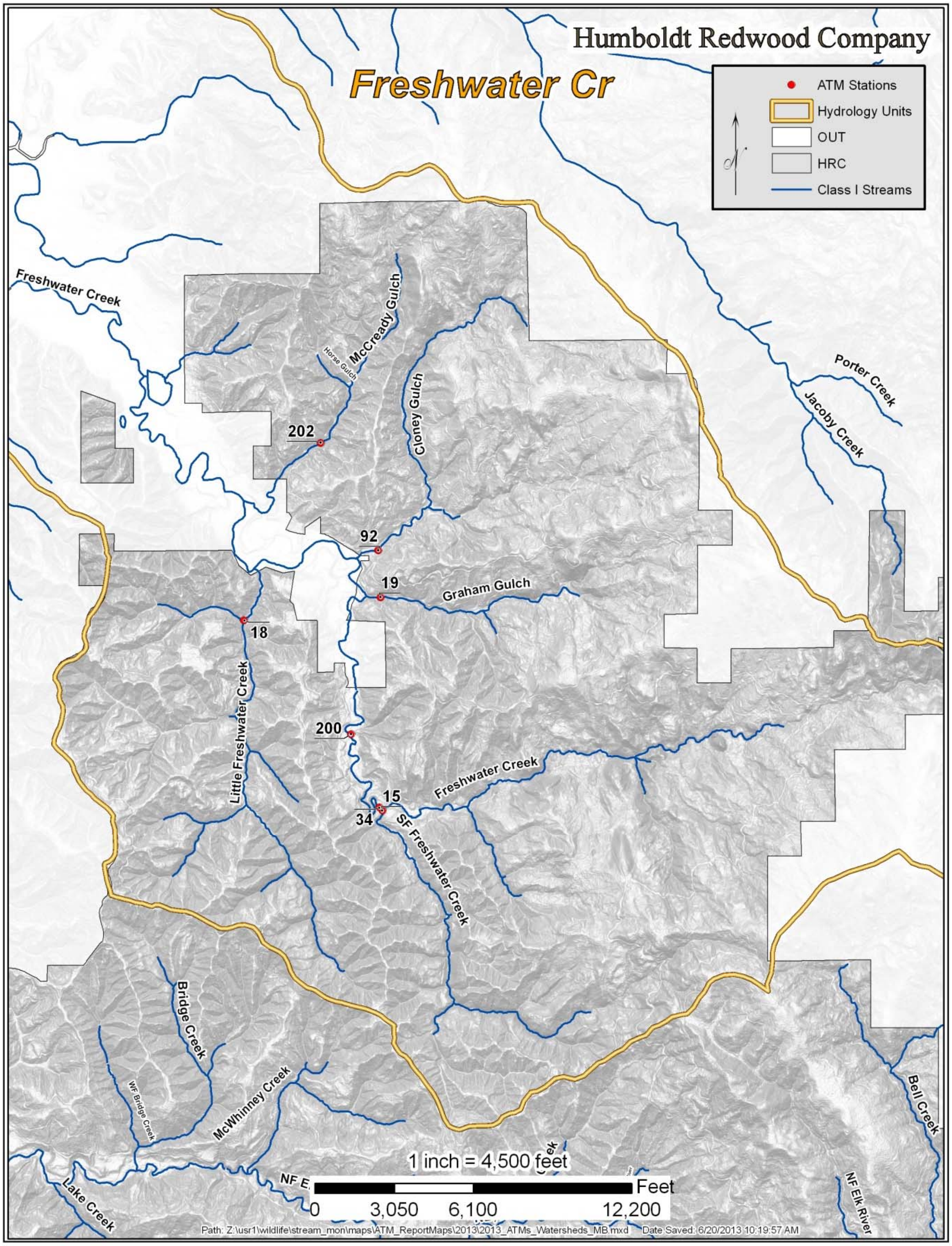
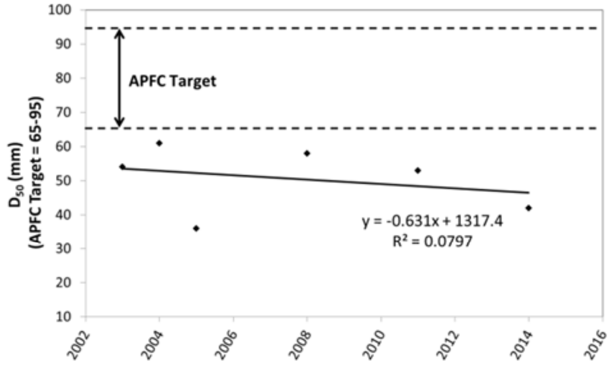
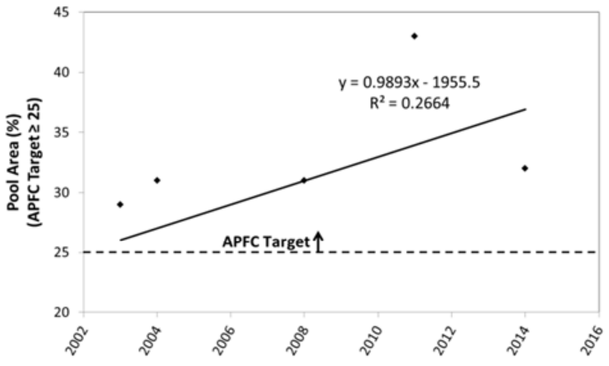
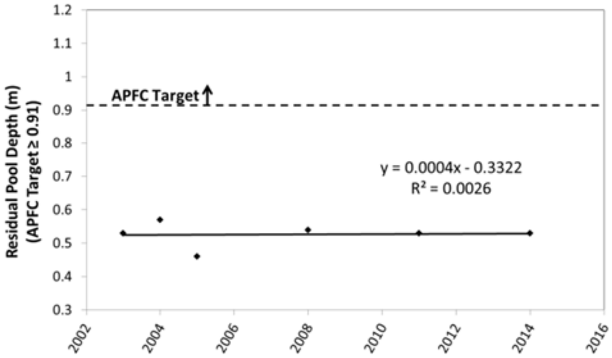
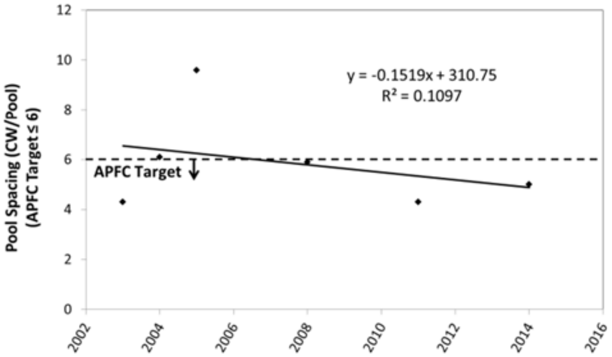


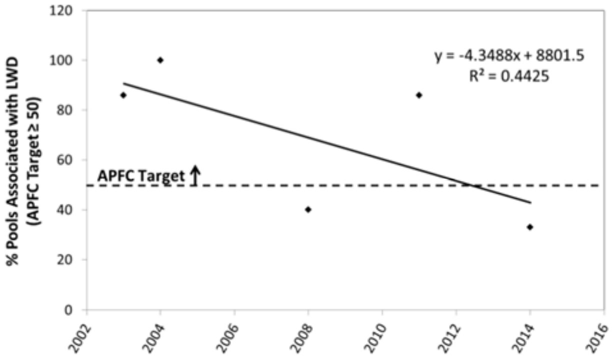
Figure 1. Map of the Freshwater Creek watershed and HRC ATM station locations

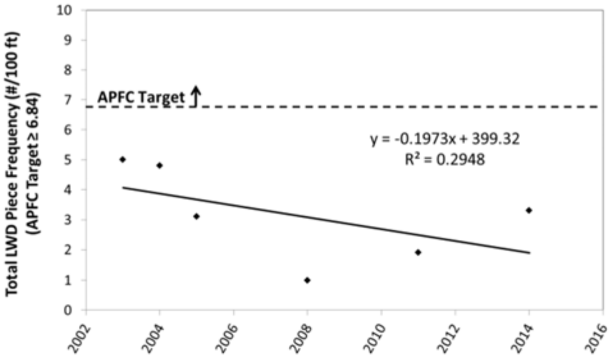

D_{50} (mm)
(APFC Target = 65-95)
APFC Target
y = -0.631x + 1317.4
R² = 0.0797
100
90
80
70
60
50
40
30
20
10
2002
2004
2006
2008
2010
2012
2014
2016

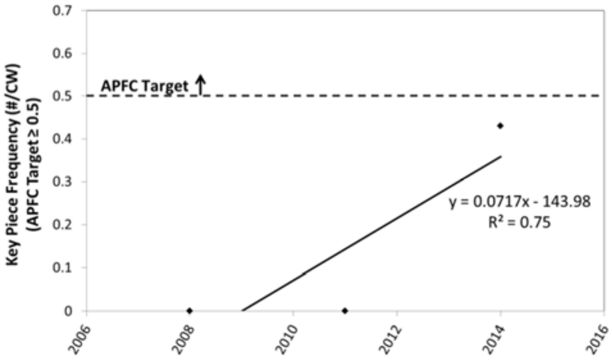

Pool Area (%)
(APFC Target ≥ 25)
y = 0.9893x - 1955.5
R² = 0.2664
APFC Target ↑
45
40
35
30
25
20
2002
2004
2006
2008
2010
2012
2014
2016

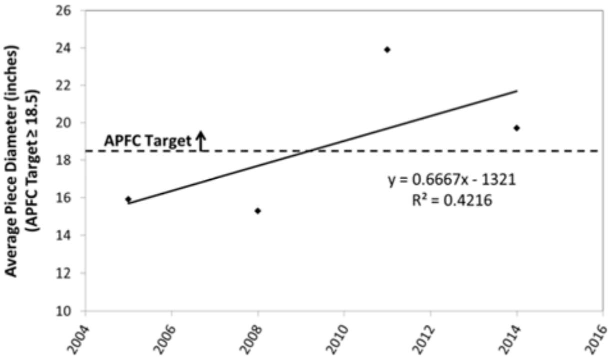

Residual Pool Depth (m)
(APFC Target ≥ 0.91)
APFC Target ↑
y = 0.0004x - 0.3322
R² = 0.0026
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
2002
2004
2006
2008
2010
2012
2014
2016


Pool Spacing (CW/Pool)
(APFC Target ≤ 6)
y = -0.1519x + 310.75
R² = 0.1097
APFC Target ↓
12
10
8
6
4
2
0
2002
2004
2006
2008
2010
2012
2014
2016


% Pools Associated with LWD
(APFC Target ≥ 50)
y = -4.3488x + 8801.5
R² = 0.4425
APFC Target ↑
120
100
80
60
40
20
0
2002
2004
2006
2008
2010
2012
2014
2016


Total LWD Piece Frequency (#/100 ft)
(APFC Target ≥ 6.84)
APFC Target ↑
y = -0.1973x + 399.32
R² = 0.2948
10
9
8
7
6
5
4
3
2
1
0
2002
2004
2006
2008
2010
2012
2014
2016


Key Piece Frequency (#/CW)
(APFC Target ≥ 0.5)
APFC Target ↑
y = 0.0717x - 143.98
R² = 0.75
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
2006
2008
2010
2012
2014
2016


Average Piece Diameter (inches)
(APFC Target ≥ 18.5)
APFC Target ↑
y = 0.6667x - 1321
R² = 0.4216
26
24
22
20
18
16
14
12
10
2004
2006
2008
2010
2012
2014
2016

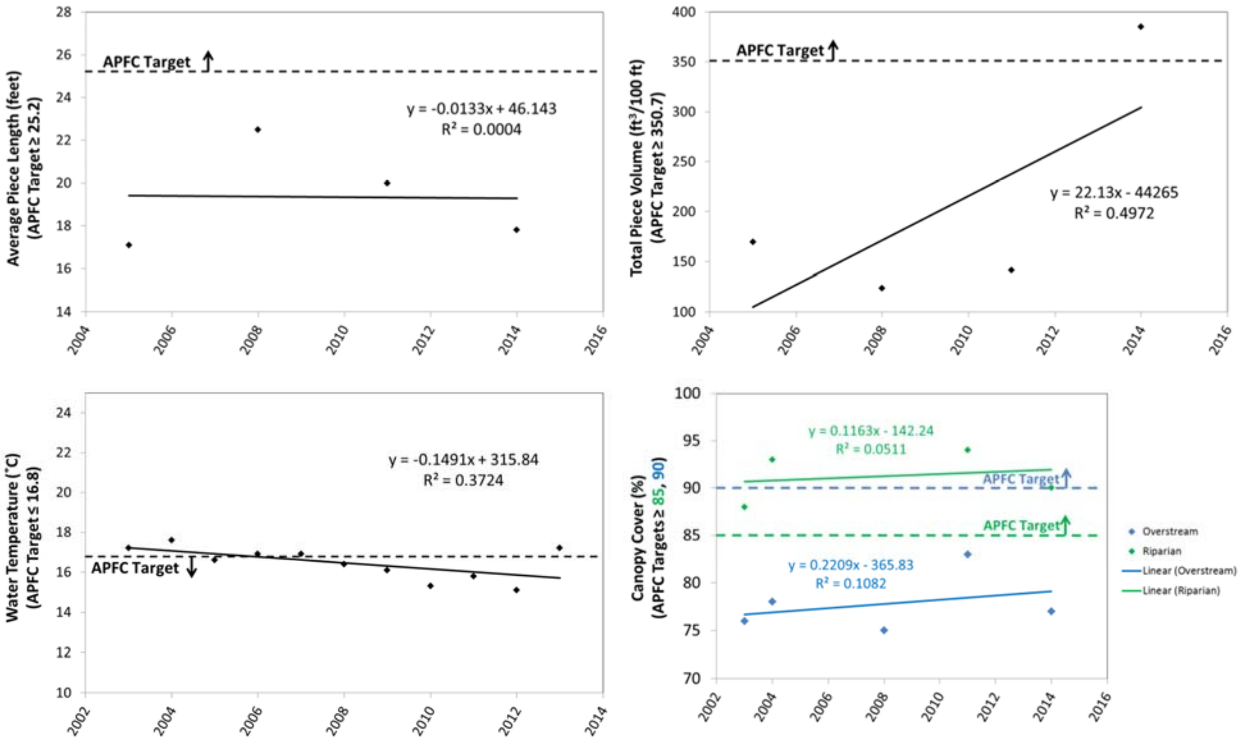
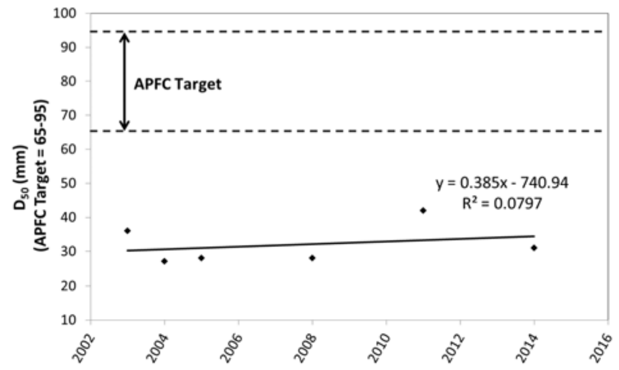


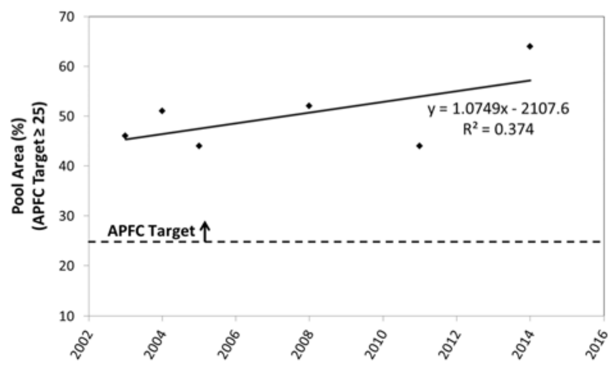
Figure 2. Habitat trend results relative to APFC target criteria at ATM Station 034 (Freshwater Creek) from 2003-2014

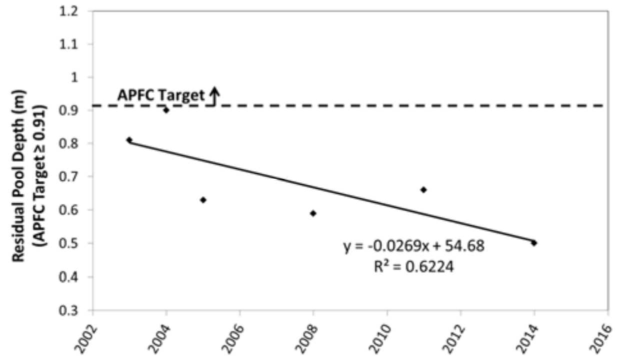
1.1.2 ATM Station 015 (South Fork)

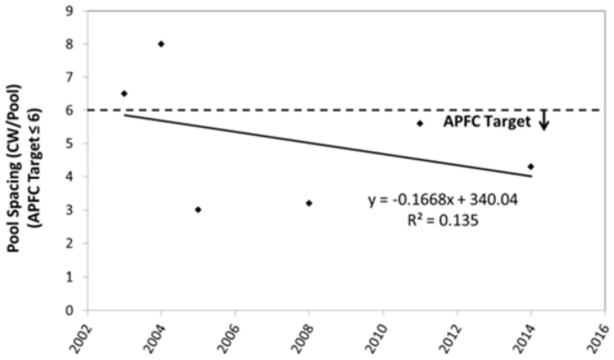
Habitat trends at ATM Station 015 vary in both the magnitude and direction of change (Figure 3). The most notable improvements towards APFC targets were observed in pool area percentage, pool spacing, total LWD piece frequency, key LWD piece frequency, average LWD diameter, average LWD piece length, total LWD volume, water temperature, and riparian canopy cover. Habitat parameters that appear to be trending away from APFC targets include residual pool depth, percentage of pools associated with wood, and overstream canopy cover. There has been virtually no change in surface particle size (D_{50}).

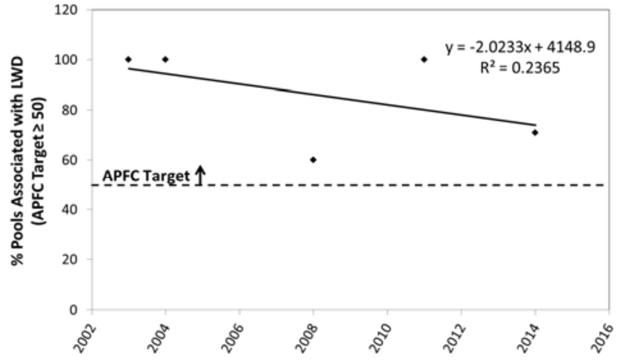
These trends may imply relationships between the habitat parameters that have shown improvements. For example, as multiple LWD parameters trend in a positive direction, it seems reasonable to expect a positive increase in pool area and frequency. Likewise, as riparian canopy cover increased, one could expect to observe a steady decrease in water temperature. There may be other confounding factors that could be influencing relationships between LWD and D_{50} surface particle size, and water temperature and overstream canopy cover. More extensive correlation analyses may be warranted so that any relationships between habitat parameters can be determined with a greater degree of certainty.

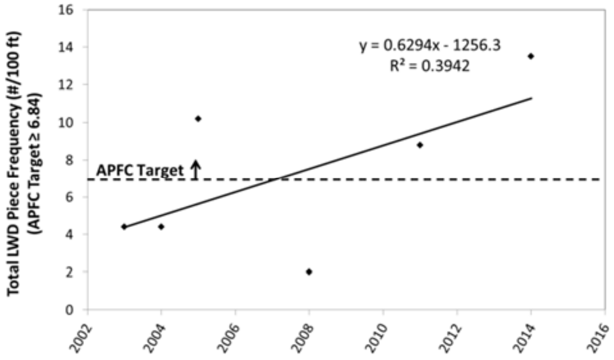

D50 (mm)
(APFC Target = 65-95)
APFC Target
y = 0.385x - 740.94
R² = 0.0797
10
20
30
40
50
60
70
80
90
100
2002
2004
2006
2008
2010
2012
2014
2016

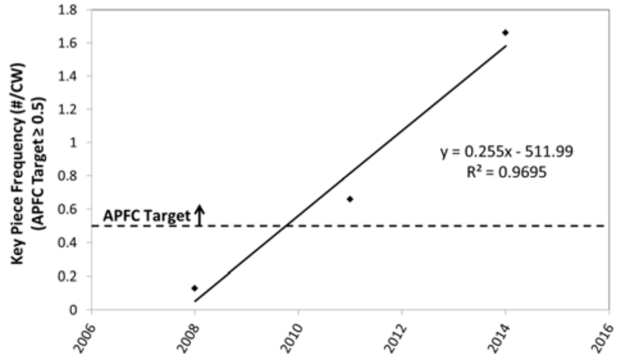

Pool Area (%)
(APFC Target ≥ 25)
APFC Target ↑
y = 1.0749x - 2107.6
R² = 0.374
10
20
30
40
50
60
70
2002
2004
2006
2008
2010
2012
2014
2016

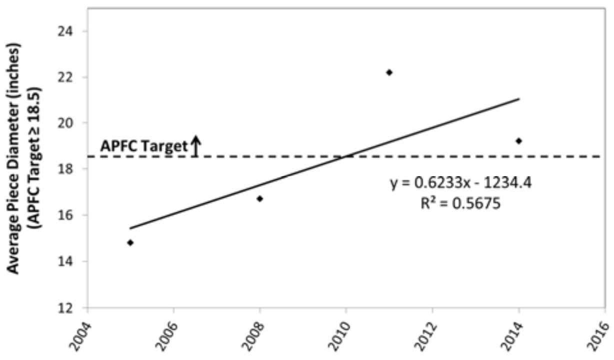

Residual Pool Depth (m)
(APFC Target ≥ 0.91)
APFC Target ↑
y = -0.0269x + 54.68
R² = 0.6224
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
1.1
1.2
2002
2004
2006
2008
2010
2012
2014
2016


Pool Spacing (CW/Pool)
(APFC Target ≤ 6)
APFC Target ↓
y = -0.1668x + 340.04
R² = 0.135
0
1
2
3
4
5
6
7
8
9
2002
2004
2006
2008
2010
2012
2014
2016


% Pools Associated with LWD
(APFC Target ≥ 50)
APFC Target ↑
y = -2.0233x + 4148.9
R² = 0.2365
0
20
40
60
80
100
120
2002
2004
2006
2008
2010
2012
2014
2016


Total LWD Piece Frequency (#/100 ft)
(APFC Target ≥ 6.84)
APFC Target ↑
y = 0.6294x - 1256.3
R² = 0.3942
0
2
4
6
8
10
12
14
16
2002
2004
2006
2008
2010
2012
2014
2016


Key Piece Frequency (#/CW)
(APFC Target ≥ 0.5)
APFC Target ↑
y = 0.255x - 511.99
R² = 0.9695
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2006
2008
2010
2012
2014
2016


Average Piece Diameter (inches)
(APFC Target ≥ 18.5)
APFC Target ↑
y = 0.6233x - 1234.4
R² = 0.5675
12
14
16
18
20
22
24
2004
2006
2008
2010
2012
2014
2016

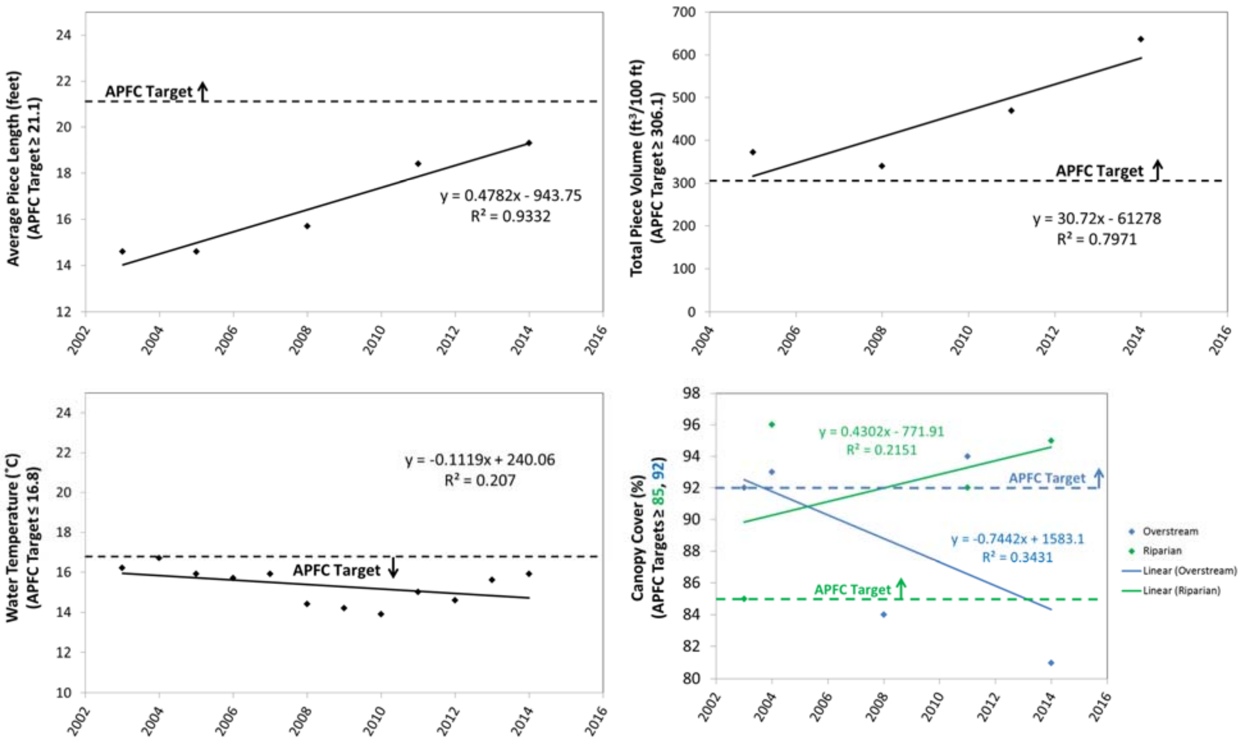
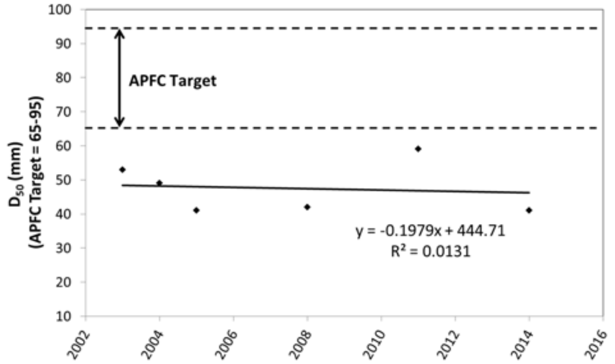


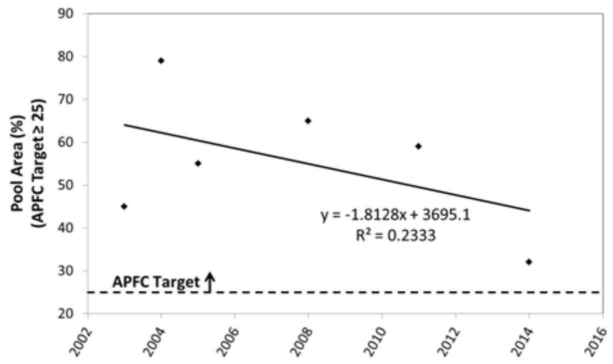
Figure 3. Habitat trend results relative to APFC target criteria at ATM Station 015 (South Fork) from 2003-2014

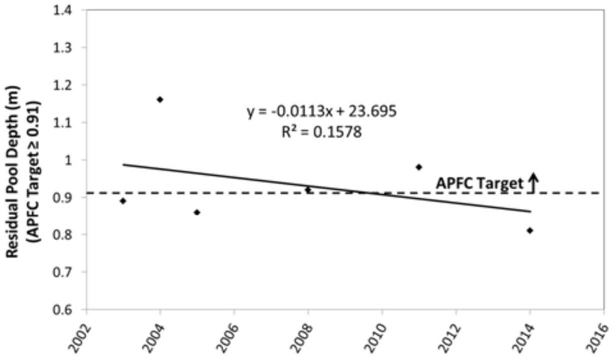
1.1.3 ATM Station 200 (Freshwater Creek)

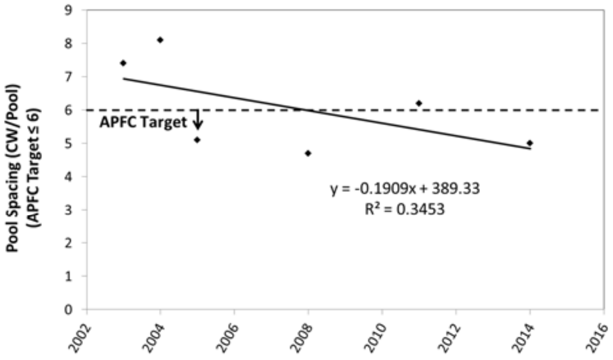
Habitat trends at ATM Station 200 vary in both the magnitude and direction of change (Figure 4). The most notable improvements towards APFC targets were observed in pool spacing, average LWD piece diameter, average LWD piece length, water temperature, and both overstream and riparian canopy cover. Habitat parameters that appear to be trending away from APFC targets include pool area percentage, residual pool depth, percentage of pools associated with wood and total LWD piece frequency. There have been only slight changes in surface particle size (D_{50}), LWD key piece frequency, and total LWD volume.

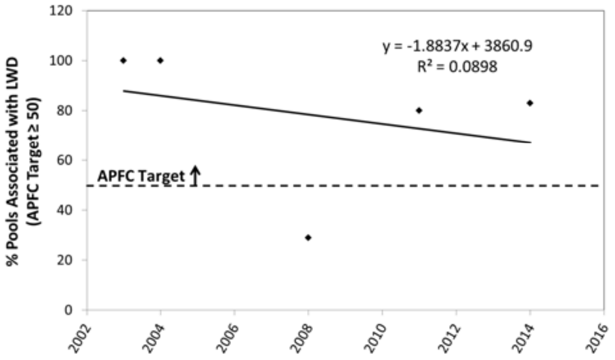
The current ATM trends in LWD and pool parameters suggest that further analyses may be warranted to explain the concurrent declines in these habitat conditions. ATM Station 200 is located in the mainstem of Freshwater Creek, and the trends suggest that this segment of stream channel could benefit from focused efforts of restoration in the form of instream wood augmentation as a primary driver to ultimately increase adult salmonid spawning potential and juvenile salmonid carrying capacity through pool development. The relatively wide bankfull channel may be contributing to the LWD deficiencies within this stream reach. Over time, as riparian forests mature and larger pieces become available for natural recruitment, other habitat parameters such as substrate particle size (D_{50}) are expected to improve.

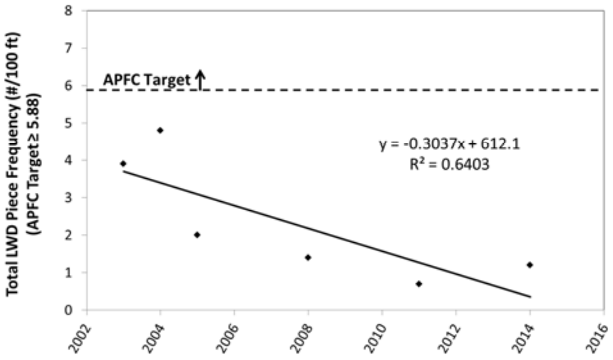


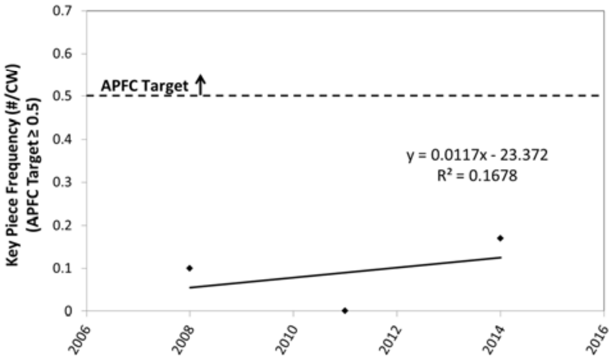


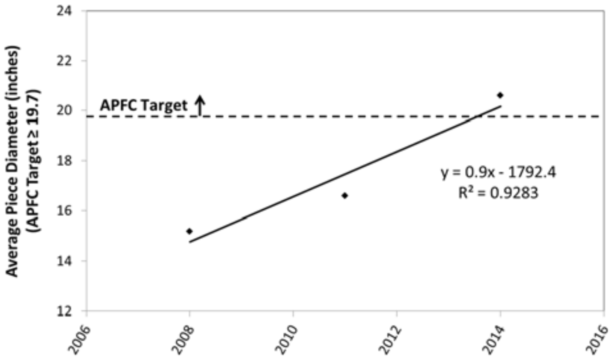












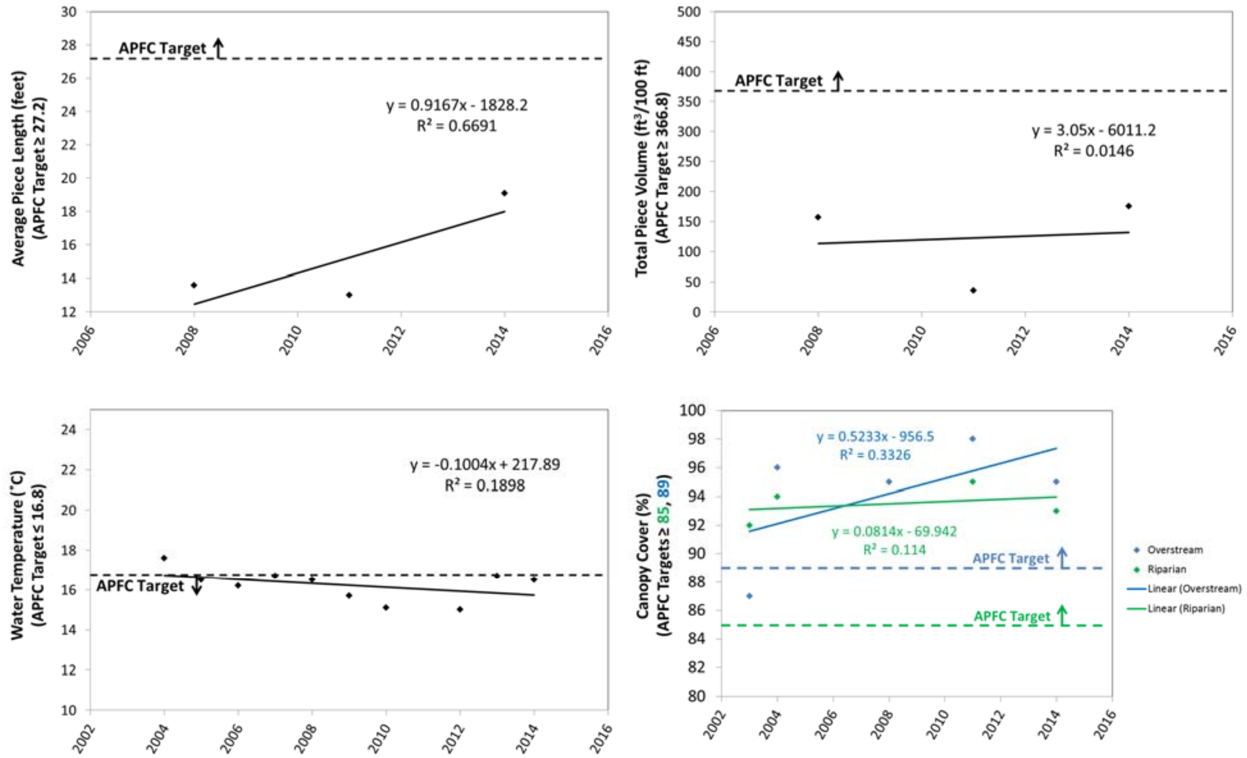
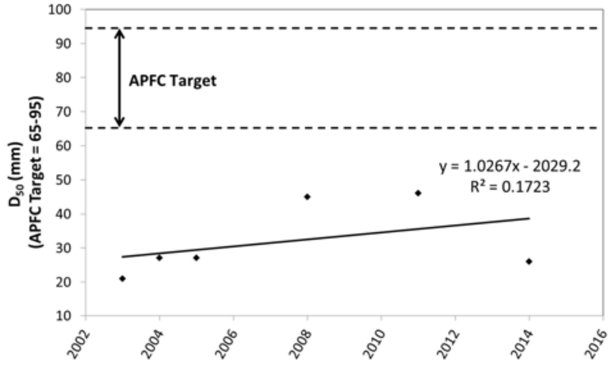


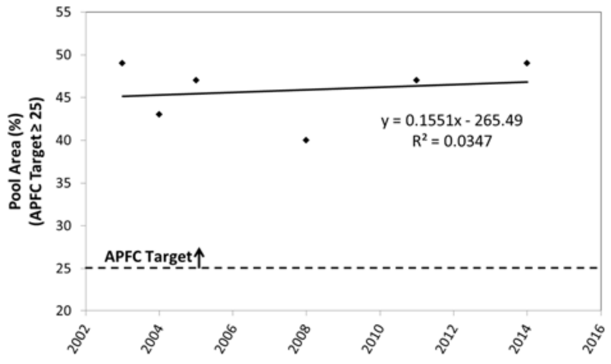
Figure 4. Habitat trend results relative to APFC target criteria at ATM Station 200 (Freshwater Creek) from 2003-2014

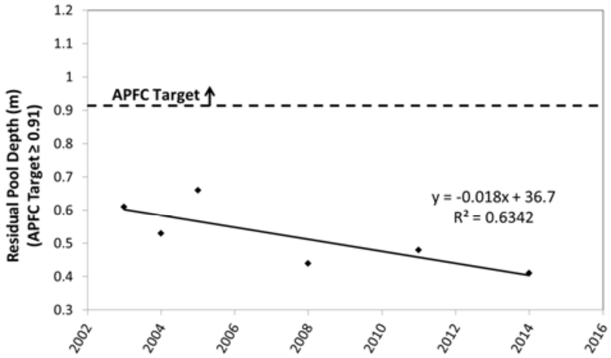
1.1.4 ATM Station 019 (Graham Gulch)

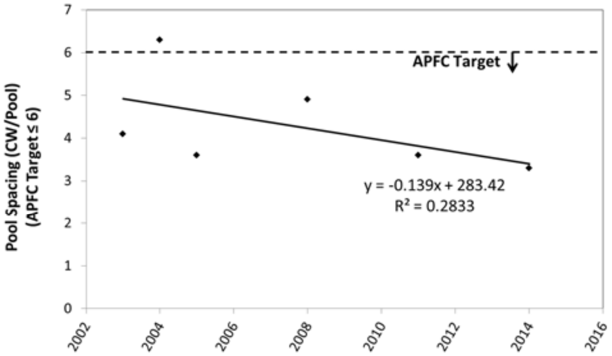
Habitat trends at ATM Station 019 vary in both the magnitude and direction of change (Figure 5). The most notable improvements towards APFC targets were observed in surface particle size (D_{50}), pool spacing, LWD key piece frequency, average LWD piece diameter, water temperature, and overstream canopy cover. Habitat parameters that appear to be trending away from APFC targets include residual pool depth, percentage of pools associated with wood, total LWD piece frequency, and riparian canopy cover. There have been only slight changes in pool area percentage, average LWD piece length, and total LWD volume.

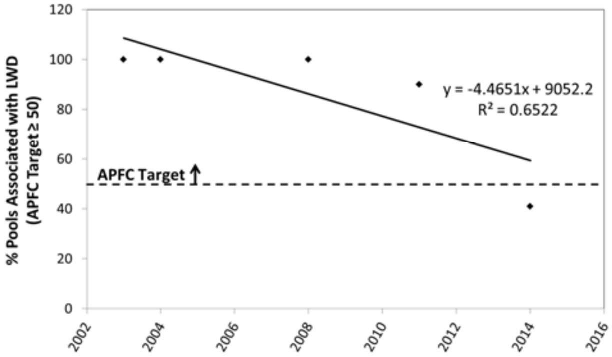
The current ATM trends in LWD and pool parameters suggest that this tributary may benefit from in-stream wood augmentation projects. However, trends in LWD may be potentially misleading or appear somewhat contrary to what other habitat trends such as pool spacing may suggest. It appears that while total LWD piece frequency is in decline, LWD key piece frequency is improving. Likewise, average LWD piece diameter appears to be improving while piece length and total volume appear to be static.

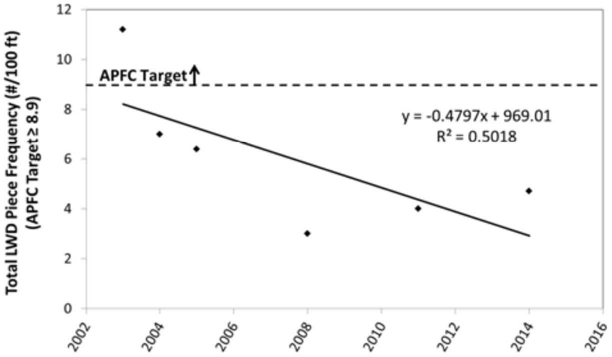

100
90
80
70
60
50
40
30
20
10
D_{50} (mm)
(APFC Target = 65-95)
APFC Target
y = 1.0267x - 2029.2
R² = 0.1723
2002
2004
2006
2008
2010
2012
2014
2016

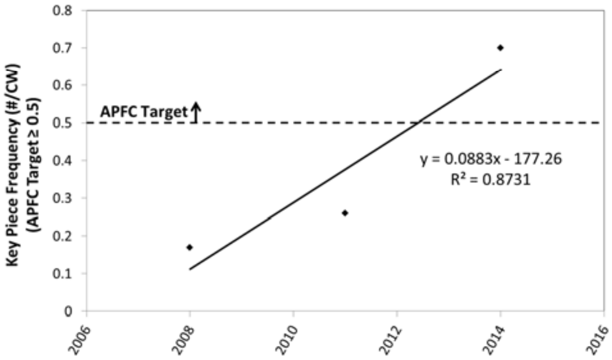

55
50
45
40
35
30
25
20
Pool Area (%)
(APFC Target ≥ 25)
y = 0.1551x - 265.49
R² = 0.0347
APFC Target ↑
2002
2004
2006
2008
2010
2012
2014
2016

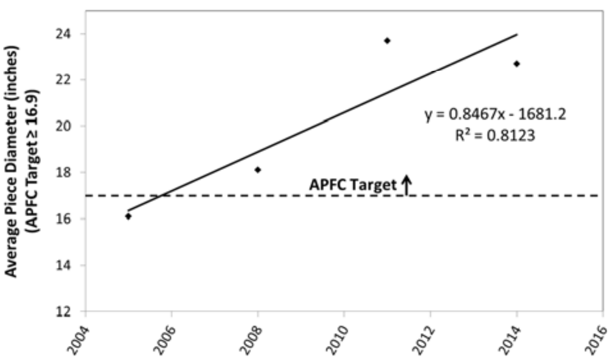

1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
Residual Pool Depth (m)
(APFC Target ≥ 0.91)
APFC Target ↑
y = -0.018x + 36.7
R² = 0.6342
2002
2004
2006
2008
2010
2012
2014
2016


7
6
5
4
3
2
1
0
Pool Spacing (CW/Pool)
(APFC Target ≤ 6)
APFC Target ↓
y = -0.139x + 283.42
R² = 0.2833
2002
2004
2006
2008
2010
2012
2014
2016


120
100
80
60
40
20
0
% Pools Associated with LWD
(APFC Target ≥ 50)
y = -4.4651x + 9052.2
R² = 0.6522
APFC Target ↑
2002
2004
2006
2008
2010
2012
2014
2016


12
10
8
6
4
2
0
Total LWD Piece Frequency (#/100 ft)
(APFC Target ≥ 8.9)
APFC Target ↑
y = -0.4797x + 969.01
R² = 0.5018
2002
2004
2006
2008
2010
2012
2014
2016


0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Key Piece Frequency (#/CW)
(APFC Target ≥ 0.5)
APFC Target ↑
y = 0.0883x - 177.26
R² = 0.8731
2006
2008
2010
2012
2014
2016


24
22
20
18
16
14
12
Average Piece Diameter (inches)
(APFC Target ≥ 16.9)
y = 0.8467x - 1681.2
R² = 0.8123
APFC Target ↑
2004
2006
2008
2010
2012
2014
2016

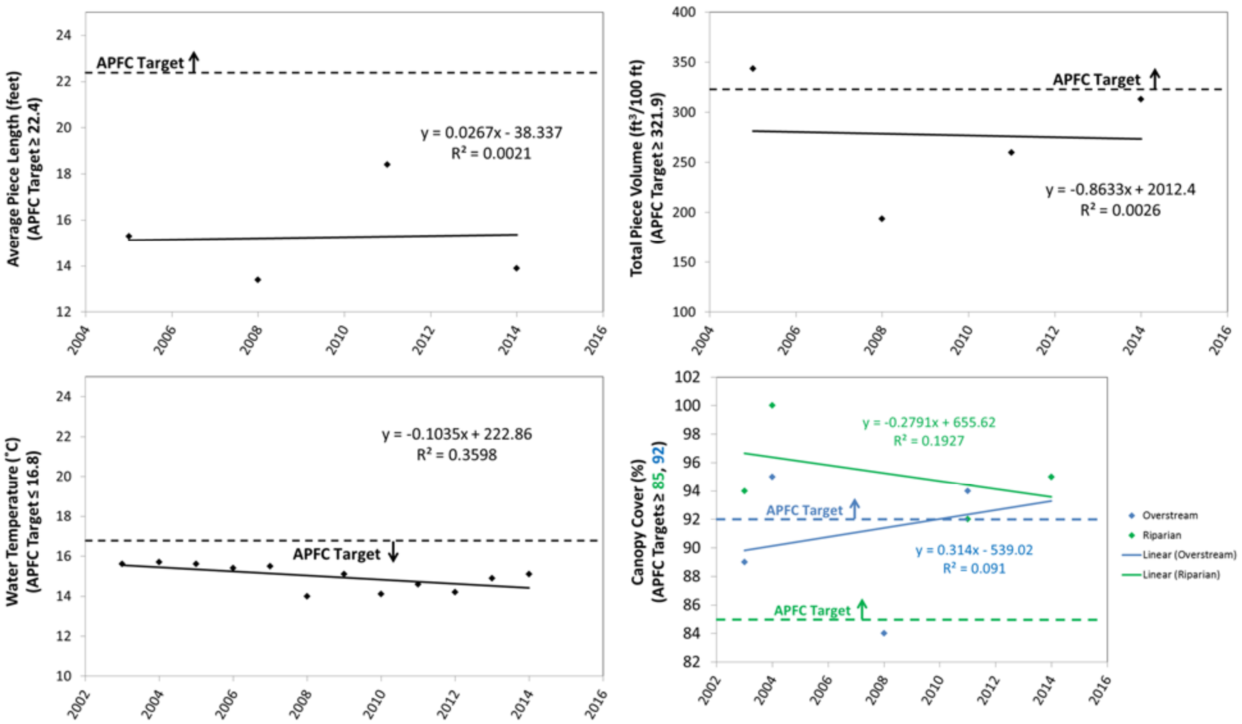


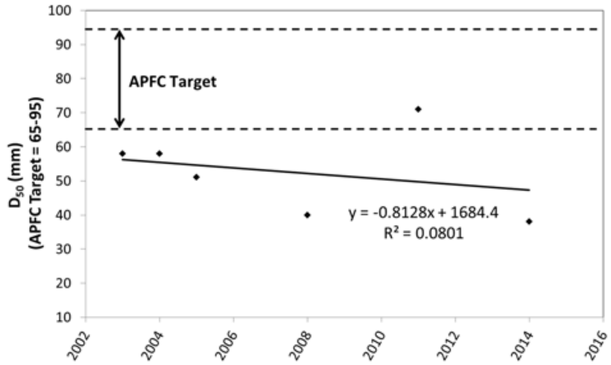
Figure 5. Habitat trend results relative to APFC target criteria at ATM Station 019 (Graham Gulch) from 2003-2014

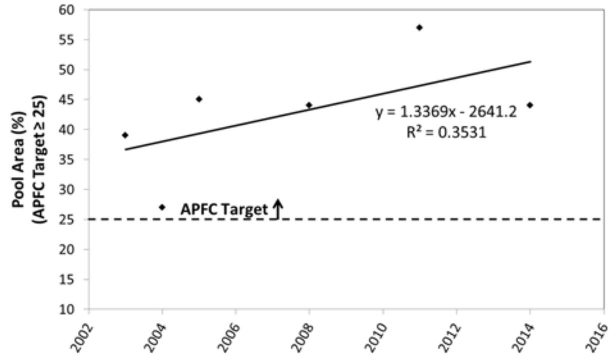
1.1.5 ATM Station 092 (Cloney Gulch)

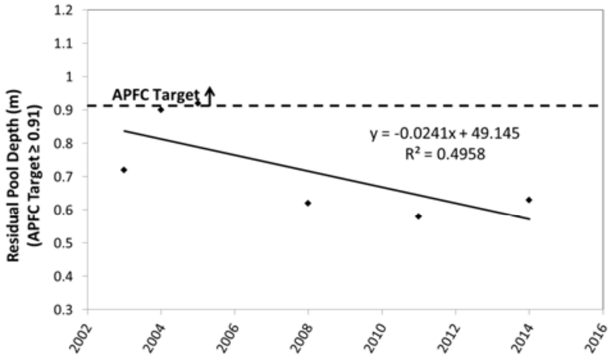
Habitat trends at ATM Station 092 vary in both the magnitude and direction of change (Figure 6). The most notable improvements towards APFC targets were observed in pool area percentage, pool spacing, LWD key piece frequency, average piece diameter, average piece length, water temperature, and both overstream and riparian canopy cover. Habitat parameters that appear to be trending away from APFC targets include surface particle size (D_{50}), residual pool depth, pools associated with wood, total LWD piece frequency, and total piece volume.

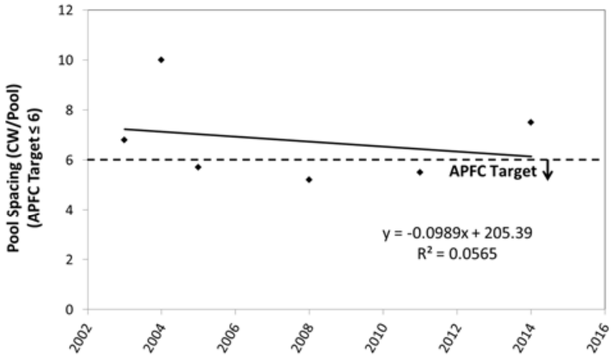
Ample overstream and riparian canopy cover appear to be contributing to the consistently cool water temperatures observed in this tributary. LWD trend analysis appears somewhat contrary, with average piece dimensions increasing as total piece volume is declining. Pool habitat conditions and surface particle size (D_{50}) appear to be currently in regression. Considering the apparent decline in total LWD piece frequency, residual pool depth, and pool spacing, this tributary is a strong candidate for future in-stream wood augmentation projects to create new pools and enhance existing pool function while increasing the biological carrying capacity of the stream. A reversal in both surface particle size (D_{50})

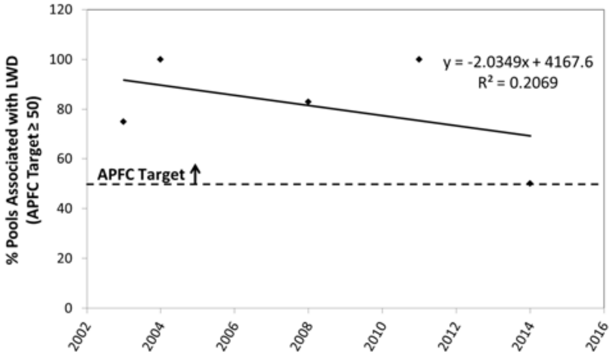
and residual pool depth trends is likely to increase salmonid spawning potential while simultaneously improving conditions for summer-rearing juveniles.

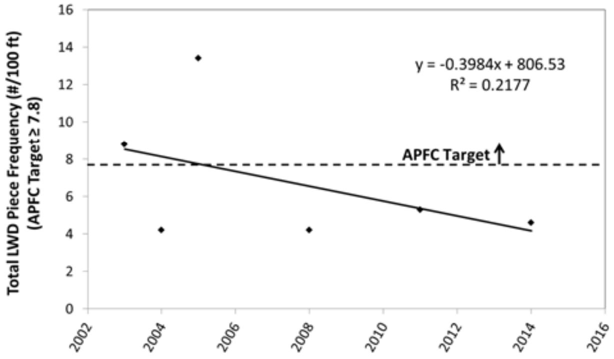


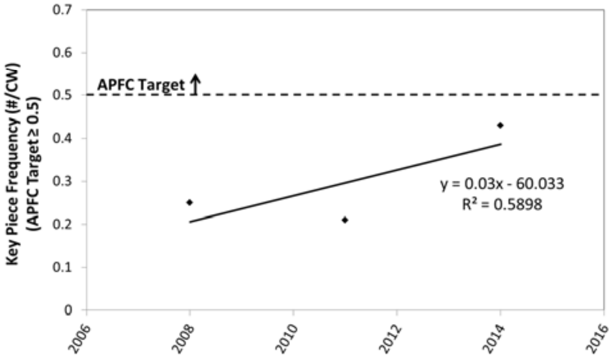


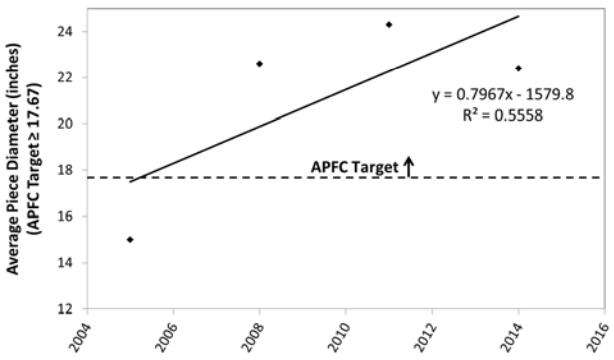












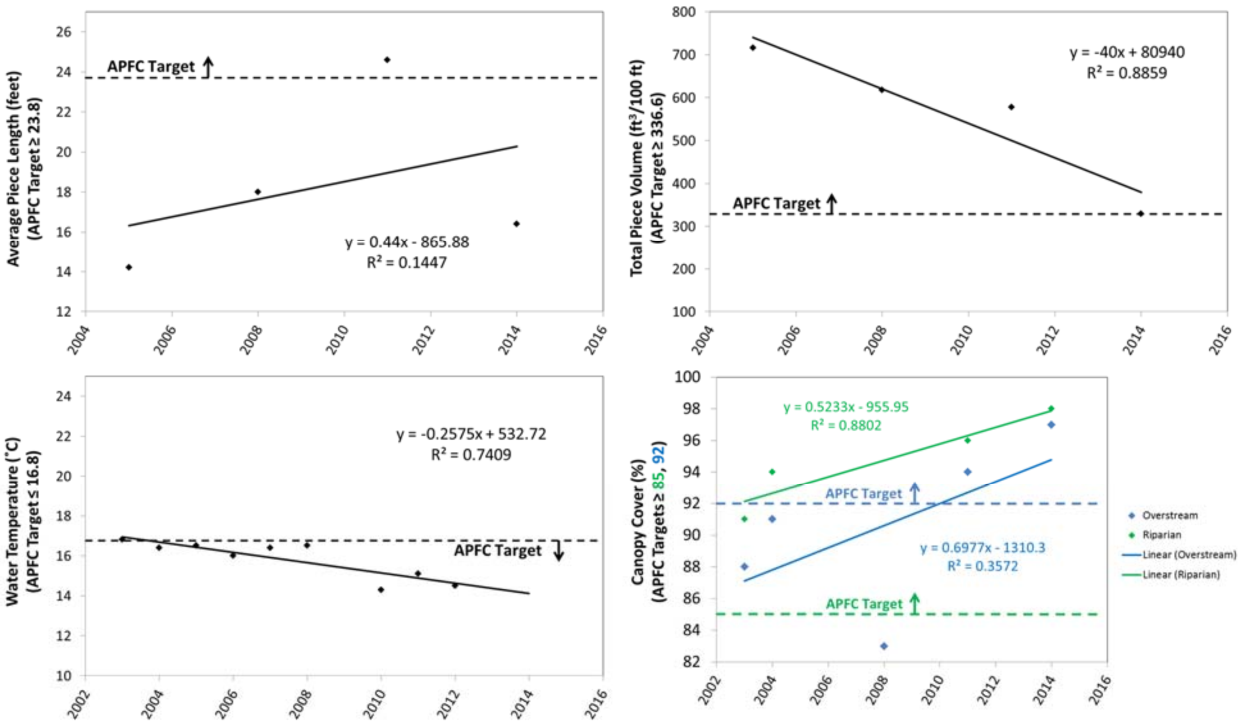
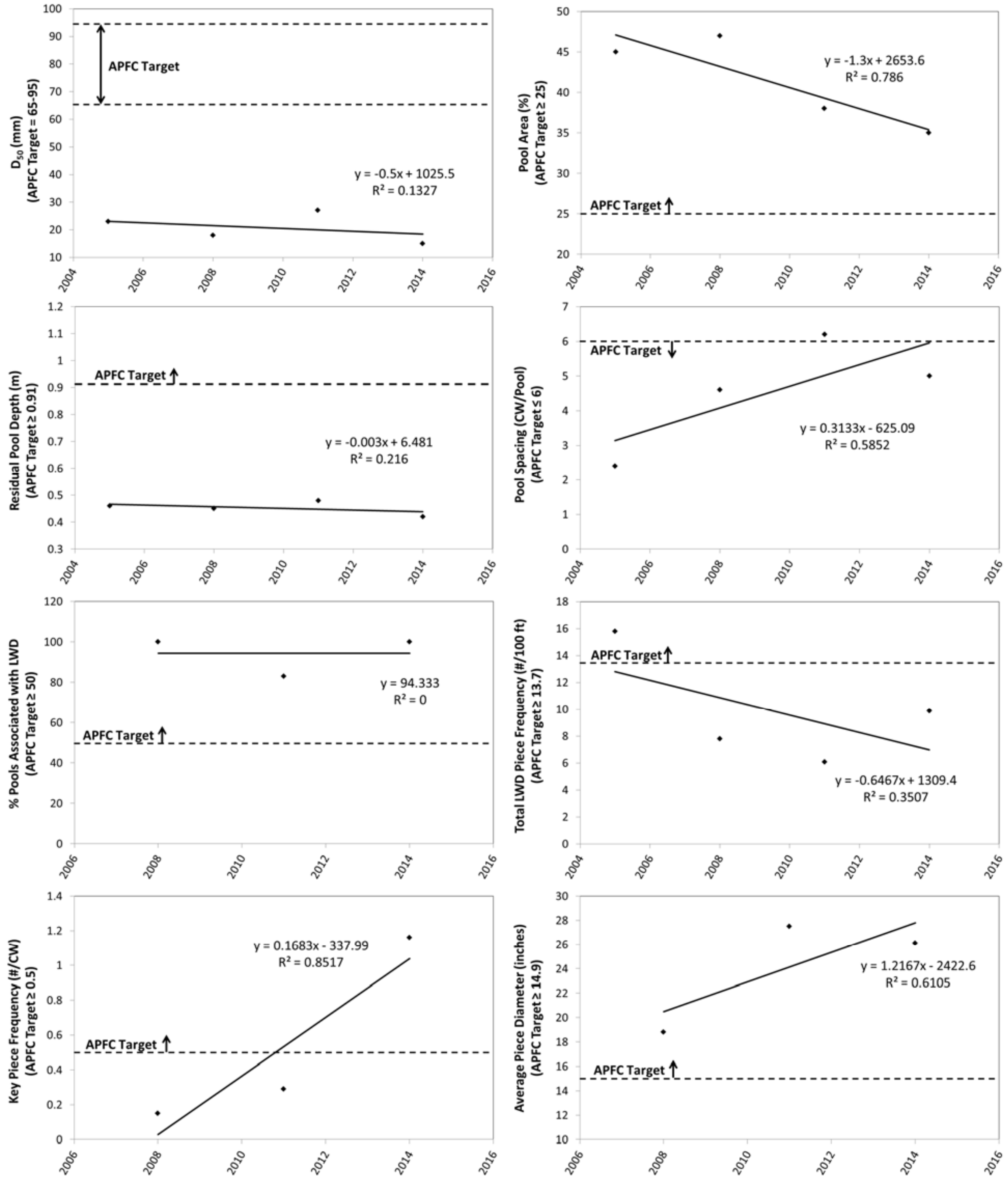


Figure 6. Habitat trend results relative to APFC target criteria at ATM Station 092 (Cloney Gulch) from 2003-2014

1.1.6 ATM Station 202 (McCready Gulch)

Habitat trends at ATM Station 202 vary in both the magnitude and direction of change (Figure 7). The most notable improvements towards APFC targets were observed in LWD key piece frequency, average LWD piece diameter, and both overstream and riparian canopy cover. Habitat parameters that appear to be trending away from APFC targets include pool area percentage, pool spacing, total LWD piece frequency, average LWD piece length, and total LWD volume. There have been only slight changes in surface particle size (D_{50}), residual pool depth, percentage of pools associated with wood, and water temperature.

While trends suggest declines in some habitat parameters, other habitat trends suggest stability in this relatively small sub-basin. LWD trends suggest that there is an increasing frequency of key pieces accumulating within the bankfull stream channels. However, overall declines in total piece frequency may be the driving factor influencing the decline in size, depth, and frequency of pool habitats. The narrow channel width of this tributary may play a role in the limited mobilization and distribution of woody debris deposited in the upper watershed. It is expected, however, as riparian forests mature and recruitment of LWD resumes along the entire stream reach, long term improvements in habitat conditions will be achieved across all parameters.



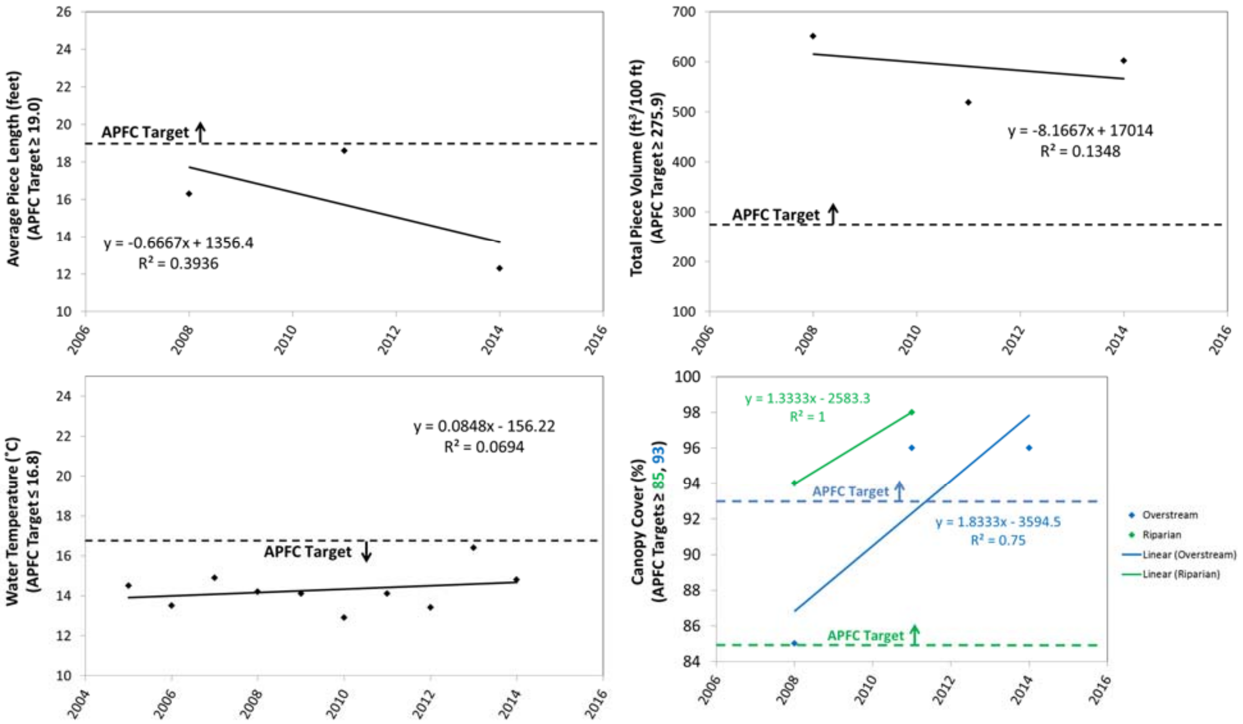
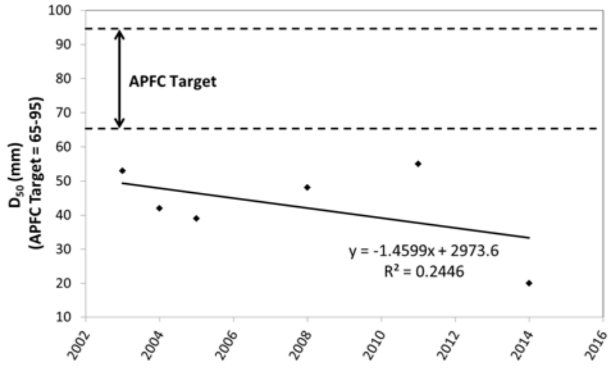


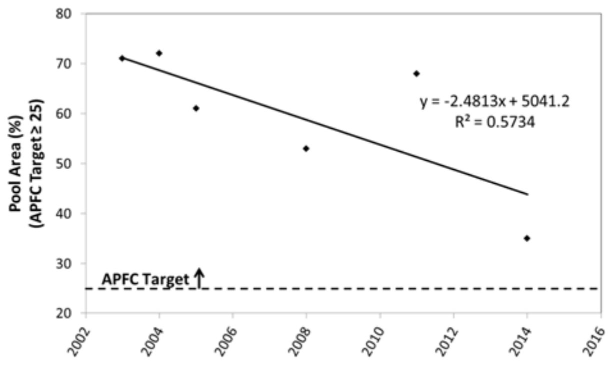
Figure 7. Habitat trend results relative to APFC target criteria at ATM Station 202 (McCready Gulch) from 2003-2014

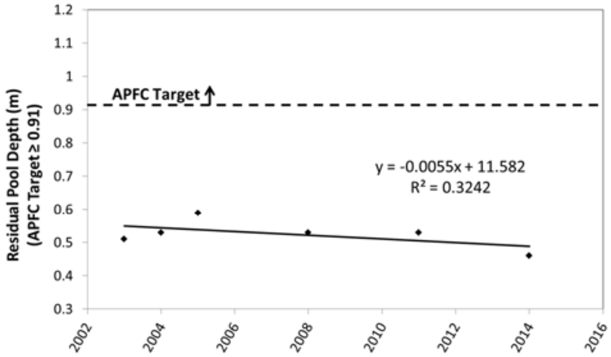
1.1.7 ATM Station 018 (Little Freshwater)

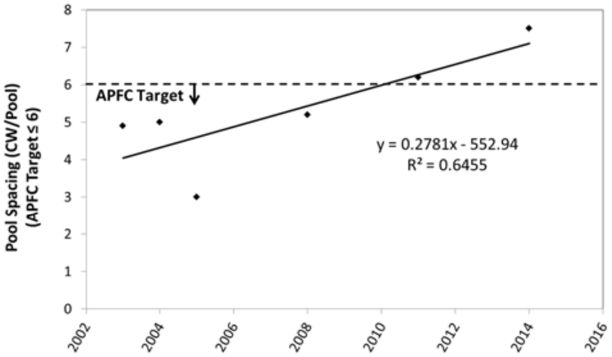
Habitat trends at ATM Station 018 vary in both the magnitude and direction of change (Figure 8). The most notable improvements towards APFC targets were observed in LWD key piece frequency, average LWD piece diameter, average LWD piece length, water temperature, and both overstream and riparian canopy cover. Habitat parameters that appear to be trending away from APFC targets include surface particle size (D_{50}), pool area percentage, residual pool depth, pool spacing, percentage of pools associated with wood, total LWD piece frequency, and total LWD volume.

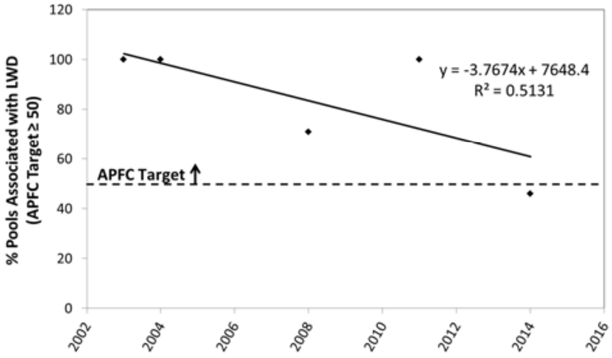
LWD data suggest a wood deficiency within this survey reach, although individual pieces appear to be increasing in size and diameter. Pool dimensions and surface substrate sizes are strongly influenced by woody debris within the channel. This stream would likely benefit from wood augmentation projects to facilitate the sorting of spawning gravels and increase the size, frequency, and complexity of pool habitats which may increase biological carrying capacity. Water temperature is unlikely to increase as percentage of canopy cover continues to exceed target values. Furthermore, as riparian forests mature and natural recruitment occurs more frequently, overall habitat conditions are expected to become more favorable to spawning adult and rearing juvenile salmonids.

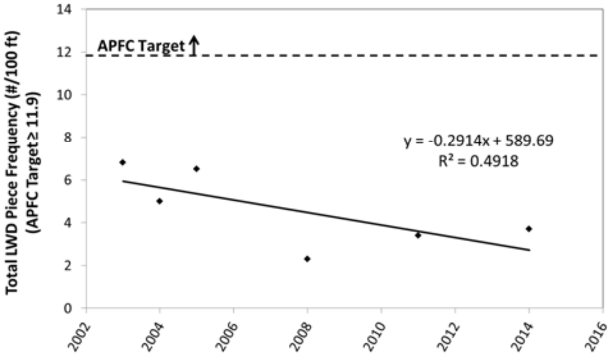

D_{50} (mm)
(APFC Target = 65-95)
APFC Target
y = -1.4599x + 2973.6
R^2 = 0.2446
100
90
80
70
60
50
40
30
20
10
2002
2004
2006
2008
2010
2012
2014
2016

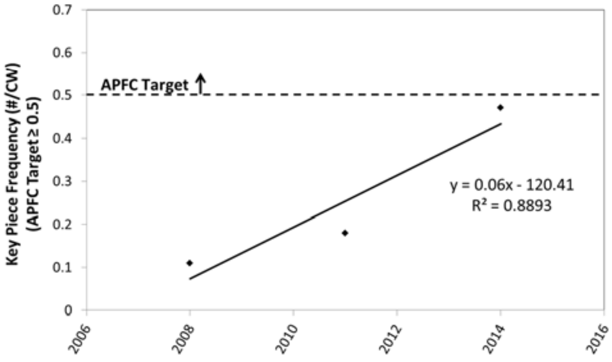

Pool Area (%)
(APFC Target ≥ 25)
y = -2.4813x + 5041.2
R^2 = 0.5734
APFC Target ↑
80
70
60
50
40
30
20
2002
2004
2006
2008
2010
2012
2014
2016

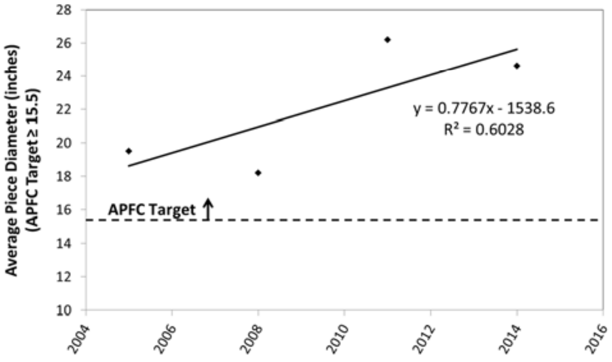

Residual Pool Depth (m)
(APFC Target ≥ 0.91)
APFC Target ↑
y = -0.0055x + 11.582
R^2 = 0.3242
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
2002
2004
2006
2008
2010
2012
2014
2016


Pool Spacing (CW/Pool)
(APFC Target ≤ 6)
APFC Target ↓
y = 0.2781x - 552.94
R^2 = 0.6455
8
7
6
5
4
3
2
1
0
2002
2004
2006
2008
2010
2012
2014
2016


% Pools Associated with LWD
(APFC Target ≥ 50)
y = -3.7674x + 7648.4
R^2 = 0.5131
APFC Target ↑
120
100
80
60
40
20
0
2002
2004
2006
2008
2010
2012
2014
2016


Total LWD Piece Frequency (#/100 ft)
(APFC Target≥ 11.9)
APFC Target ↑
y = -0.2914x + 589.69
R^2 = 0.4918
14
12
10
8
6
4
2
0
2002
2004
2006
2008
2010
2012
2014
2016


Key Piece Frequency (#/CW)
(APFC Target ≥ 0.5)
APFC Target ↑
y = 0.06x - 120.41
R^2 = 0.8893
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
2006
2008
2010
2012
2014
2016


Average Piece Diameter (inches)
(APFC Target ≥ 15.5)
y = 0.7767x - 1538.6
R^2 = 0.6028
APFC Target ↑
28
26
24
22
20
18
16
14
12
10
2004
2006
2008
2010
2012
2014
2016

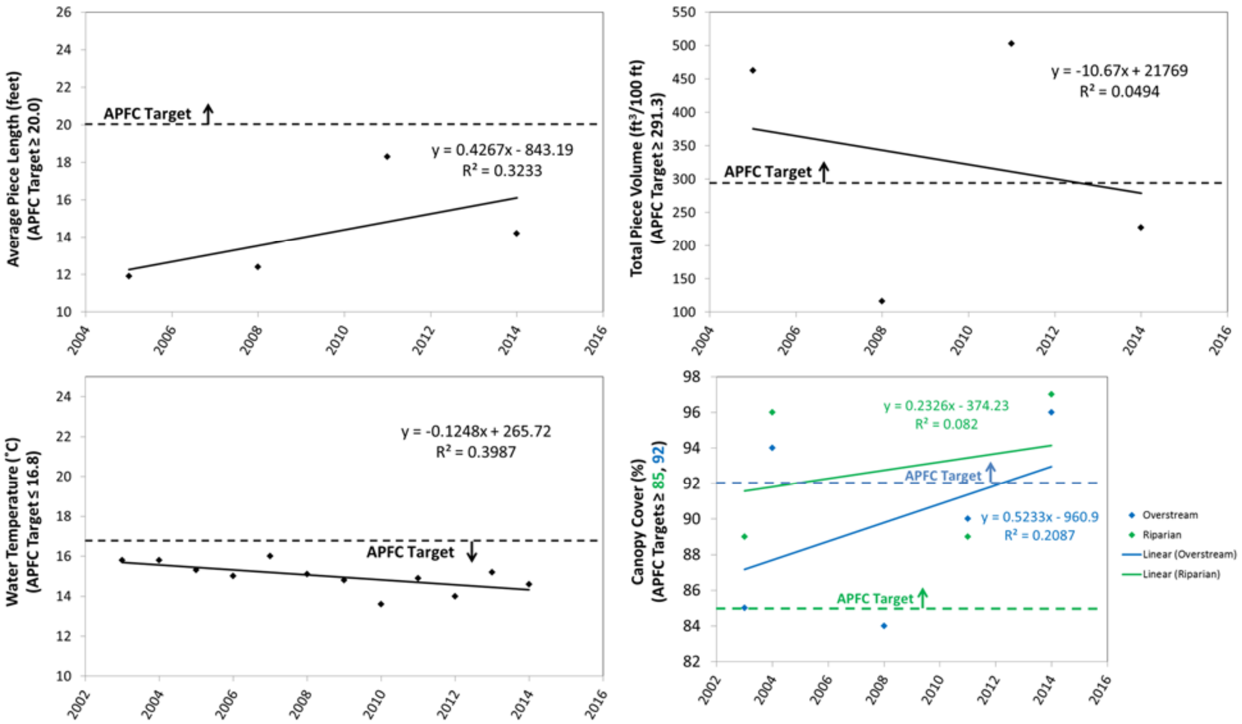
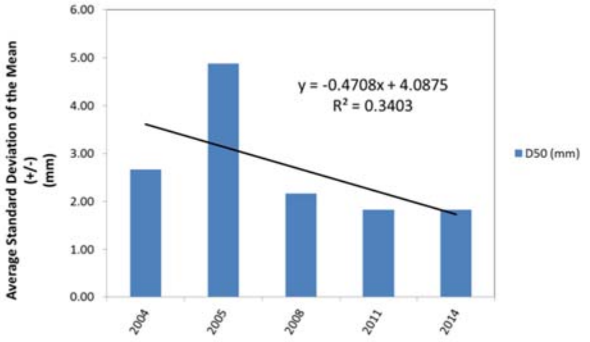
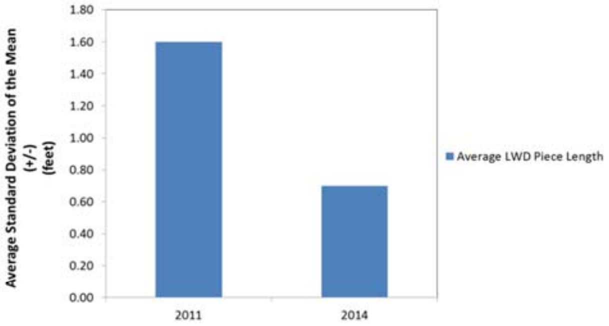


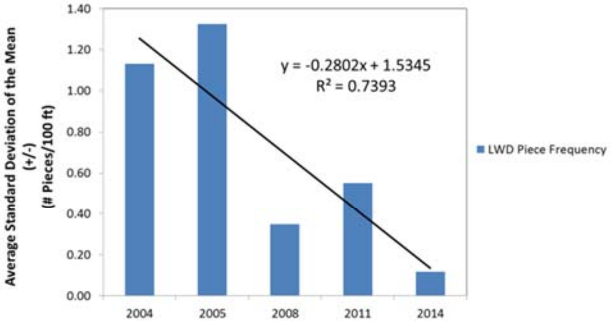
Figure 8. Habitat trend results relative to APFC target criteria at ATM Station 018 (Little Freshwater) from 2003-2014

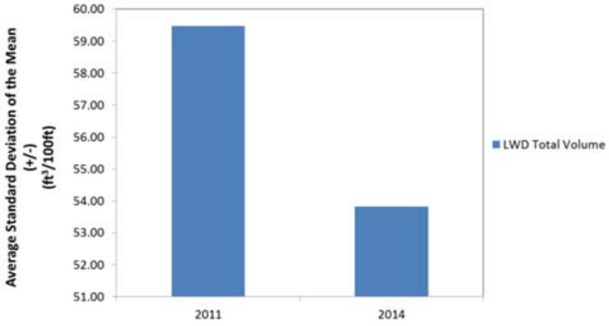
1.2 ATM QA/QC SUMMARY

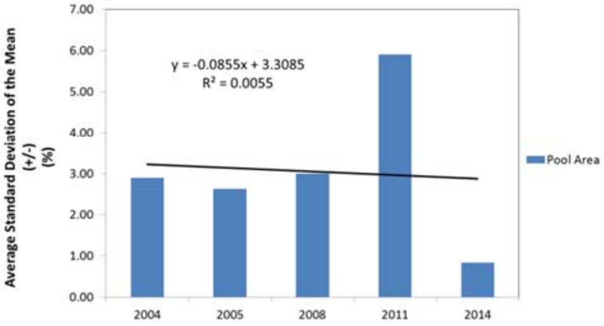
Quality assurance/quality control (QA/QC) trends suggest varying degrees of repeatability and consistency in implementation of the ATM survey methodology (Figure 9). This is reflected in the average standard deviation of the mean (SDOM), derived from the data of the initial vs. revisit field observations at two to five stations during each survey cycle from 2004-2014. Overall, these QA/QC trend analyses suggest that the ATM data collection methodologies have been improved upon in recent years with an increasing degree of precision. All trends are shown to be declining to some degree, suggesting an improvement in the efficiency of the field crews and/or repeatability of the ATM methods employed. As QA/QC measures continue to be conducted annually, the strength of these conclusions will likely increase with a greater degree of certainty. Water temperature is not included in the QA/QC process. However, individual temperature loggers undergo pre-season calibration screenings that check for consistency, accuracy, and factory defects.

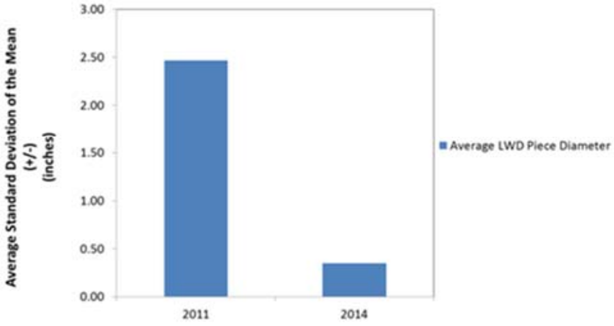

Average Standard Deviation of the Mean (+/-) (mm)
6.00
5.00
4.00
3.00
2.00
1.00
0.00
y = -0.4708x + 4.0875
R² = 0.3403
D50 (mm)
2004
2005
2008
2011
2014

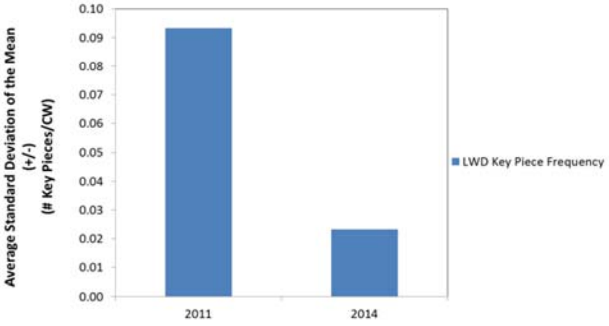

Average Standard Deviation of the Mean (+/-) (feet)
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
Average LWD Piece Length
2011
2014

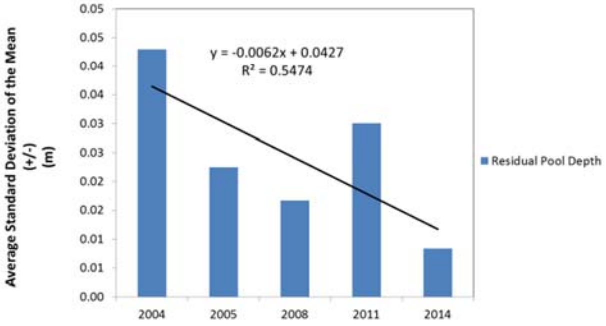

Average Standard Deviation of the Mean (+/-) (# Pieces/100 ft)
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
y = -0.2802x + 1.5345
R² = 0.7393
LWD Piece Frequency
2004
2005
2008
2011
2014


Average Standard Deviation of the Mean (+/-) (ft³/100ft)
60.00
59.00
58.00
57.00
56.00
55.00
54.00
53.00
52.00
51.00
LWD Total Volume
2011
2014


Average Standard Deviation of the Mean (+/-) (%)
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
y = -0.0855x + 3.3085
R² = 0.0055
Pool Area
2004
2005
2008
2011
2014


Average Standard Deviation of the Mean (+/-) (inches)
3.00
2.50
2.00
1.50
1.00
0.50
0.00
Average LWD Piece Diameter
2011
2014


Average Standard Deviation of the Mean (+/-) (# Key Pieces/CW)
0.10
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
LWD Key Piece Frequency
2011
2014


Average Standard Deviation of the Mean (+/-) (m)
0.05
0.05
0.04
0.04
0.03
0.03
0.02
0.02
0.01
0.01
0.00
y = -0.0062x + 0.0427
R² = 0.5474
Residual Pool Depth
2004
2005
2008
2011
2014

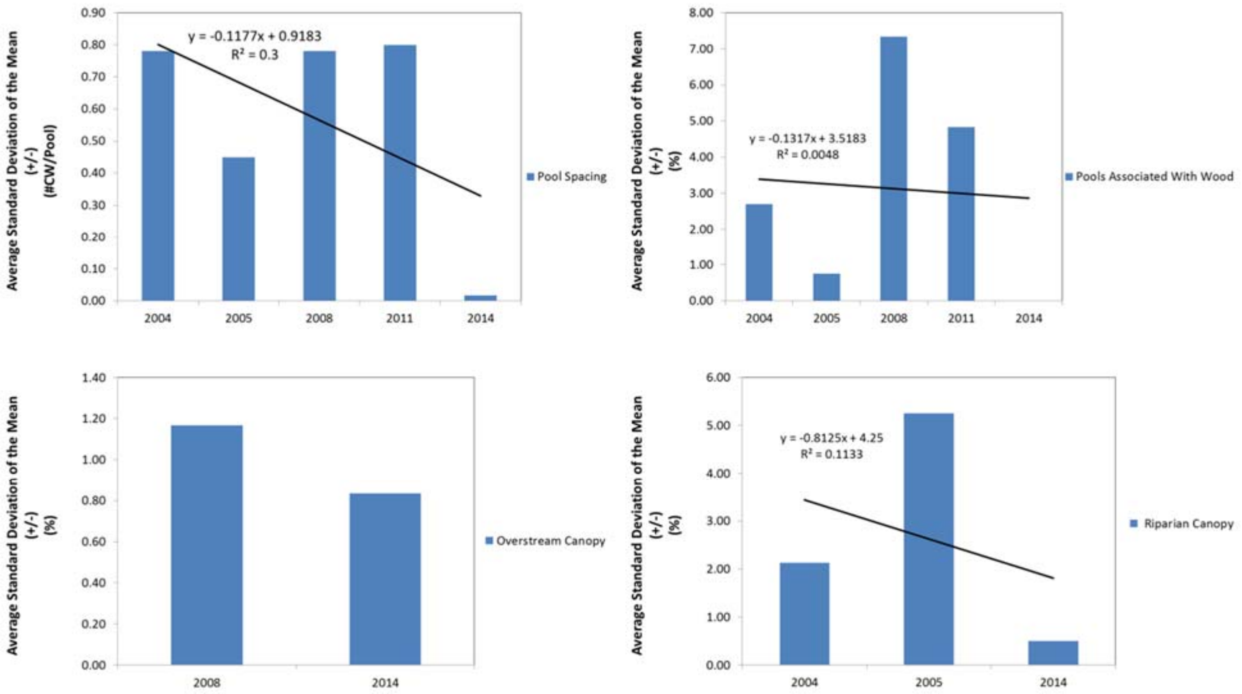


Figure 9. Mean HRC ATM QA/QC precision results (+/-) presented in individual habitat parameters and their respective metrics, 2003-2014

2 EXTENDED LWD SURVEYS

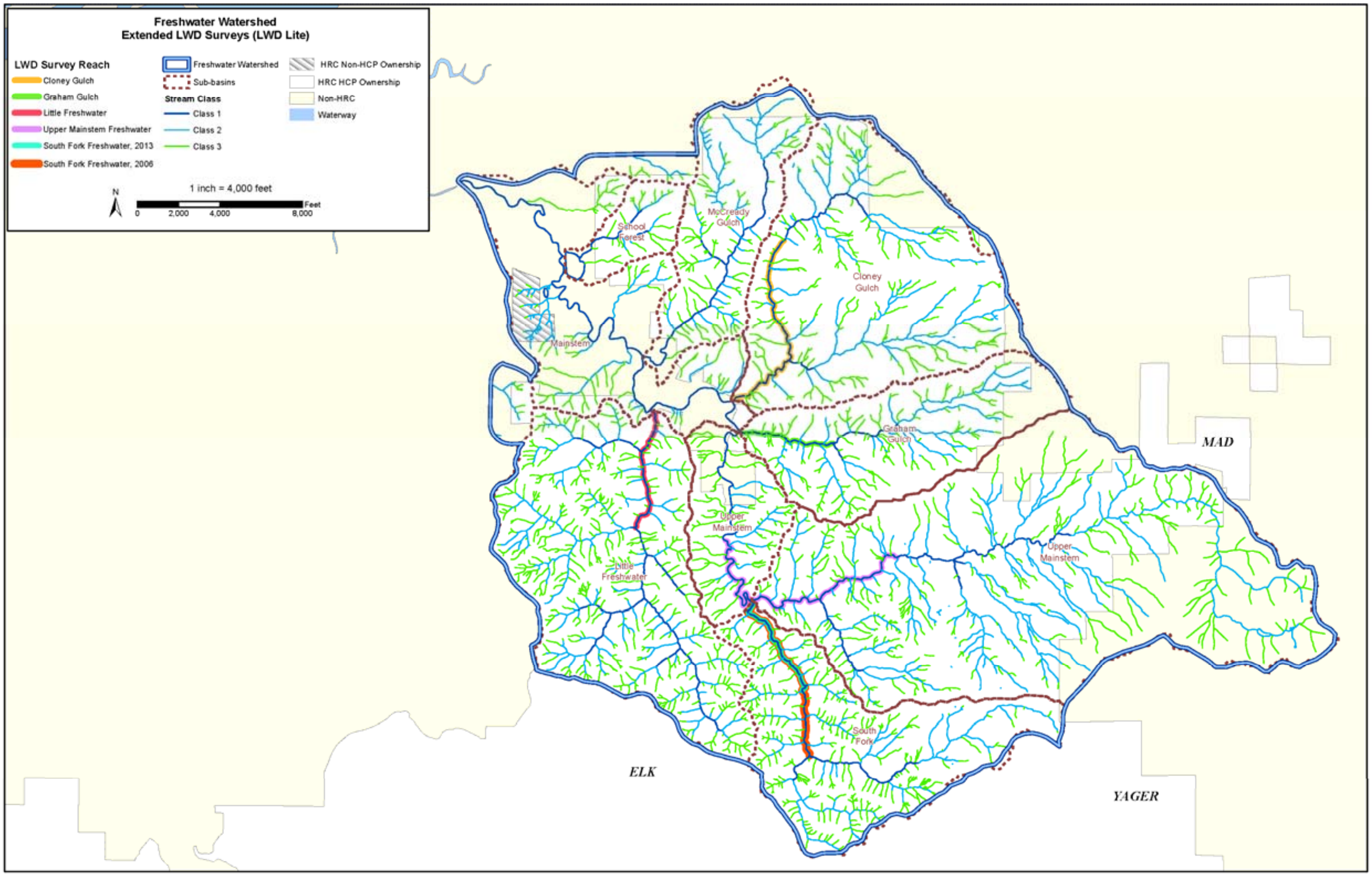
In support of the fisheries assessment for the Freshwater Creek Watershed Analysis revisit, HRC conducted extended LWD surveys in the Freshwater Creek watershed. Locations of the five extended LWD survey reaches, color coded for interpretation, are shown in Figure 10. Results for these extended surveys, initially completed in 2006 and revisited in 2013, are presented below (Figure 11, Figure 12, Figure 13, Figure 14, and Figure 15). These comprehensive surveys, conducted by moving upstream from a downstream starting point, were intended to quantify LWD piece density, volume, and distribution throughout the watershed beyond the spatial limitations of individual ATM reaches. Included within the figures are the approximate locations of the ATM sites (darker bars) and their corresponding site-specific APFC target. Note: Little Freshwater was surveyed only in 2013, and South Fork Freshwater was surveyed approximately half the distance in 2013 compared to what had been surveyed in 2006. McCready Gulch was not surveyed in either of these years. The 2006 and 2013 surveys were conducted by different field crews.

The methodology in 2006 utilized a string box (hip chain) to record the upstream distance of the LWD pieces within the surveyed reaches, while upstream distance was recorded using a hand-held Global Positioning System (GPS) unit in 2013. To standardize these two surveys for comparative purposes, the LWD data from each survey were broken out into roughly 500-ft intervals to spatially align each reach between both survey years. LWD pieces in both 2006 and 2013 must have met these same criteria to be counted:

- Pieces must have been ≥0.15 m (0.5 ft) in diameter;
- Pieces must have been ≥1.8 m (6 ft) in length;
- Pieces must have occurred within the bankfull width of the stream channel; and
- Only the portions of wood which occurred within the bankfull channel were measured, but included the entire piece if more than 50% of the volume resided within the bankfull channel.

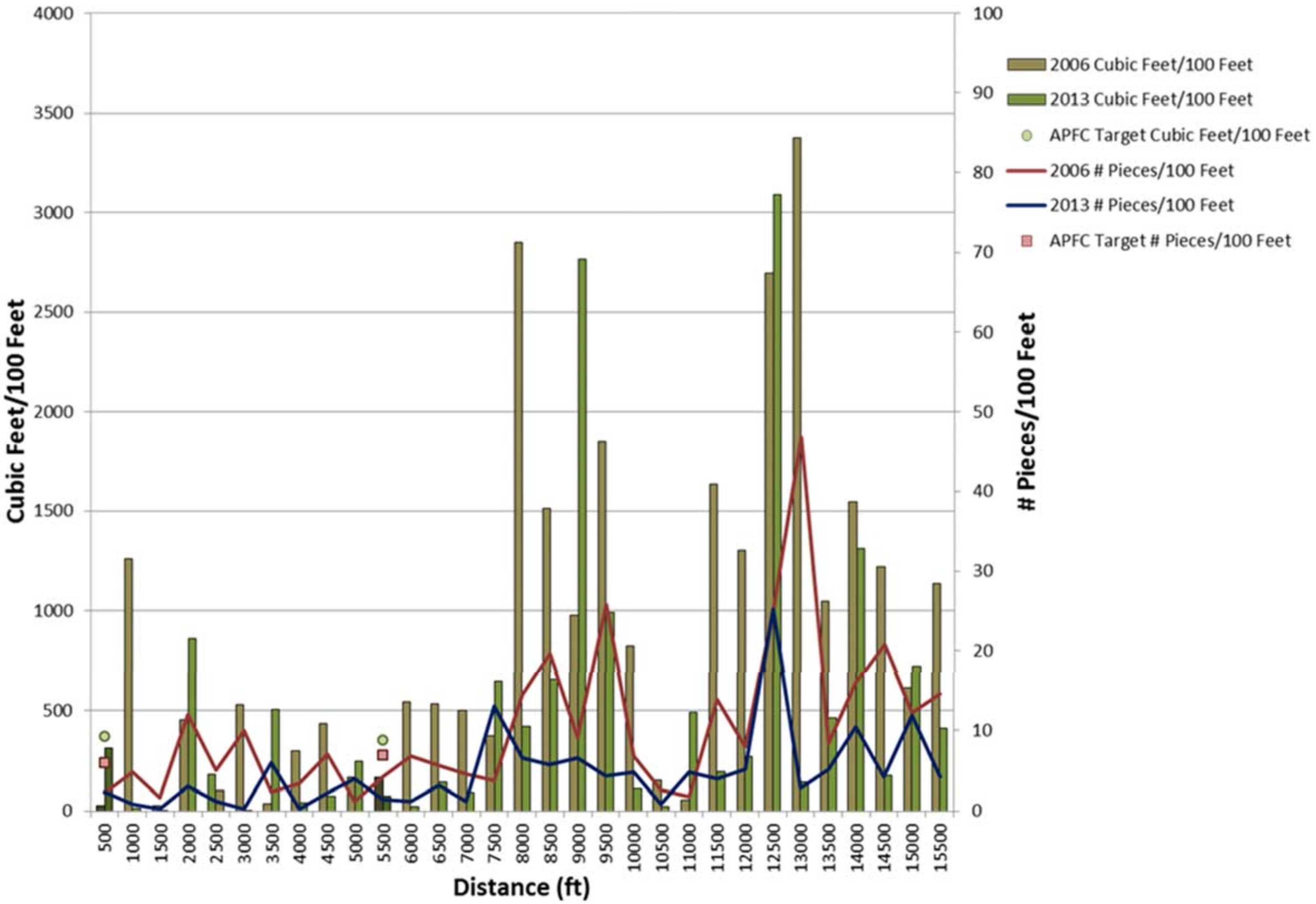
Results of these two surveys suggest LWD deficiencies in the lower sub-basins, gradually increasing in both piece number and volume towards the upper stream reaches. However, this may not necessarily reflect a lower recruitment potential in those lower reaches. Rather, it may simply reflect the greater mobility potential of LWD in the lower reaches as a function of bankfull channel width and potential energy of the stream. In other words, the LWD in the lower reaches has a greater chance of being carried away by high flow events and/or lifted out and deposited outside of the stream channel. Conversely, as the bankfull channel width and potential energy of the stream progressively decreases upstream, the

LWD is less prone to mobilizing and has a greater chance of remaining within the bankfull width of the stream channel. As the APFC LWD targets are rarely achieved within the ATM reaches positioned lower in the sub-basins, it is reasonable to suggest that those locations should be targeted for future instream wood placement restoration projects utilizing pieces at least 1.5 times longer than the bankfull width. Furthermore, as the other ATM habitat parameter data suggest, LWD is a common driver of improving overall habitat characteristics including pool dimension/frequency, substrate coarseness, and overall channel complexity.



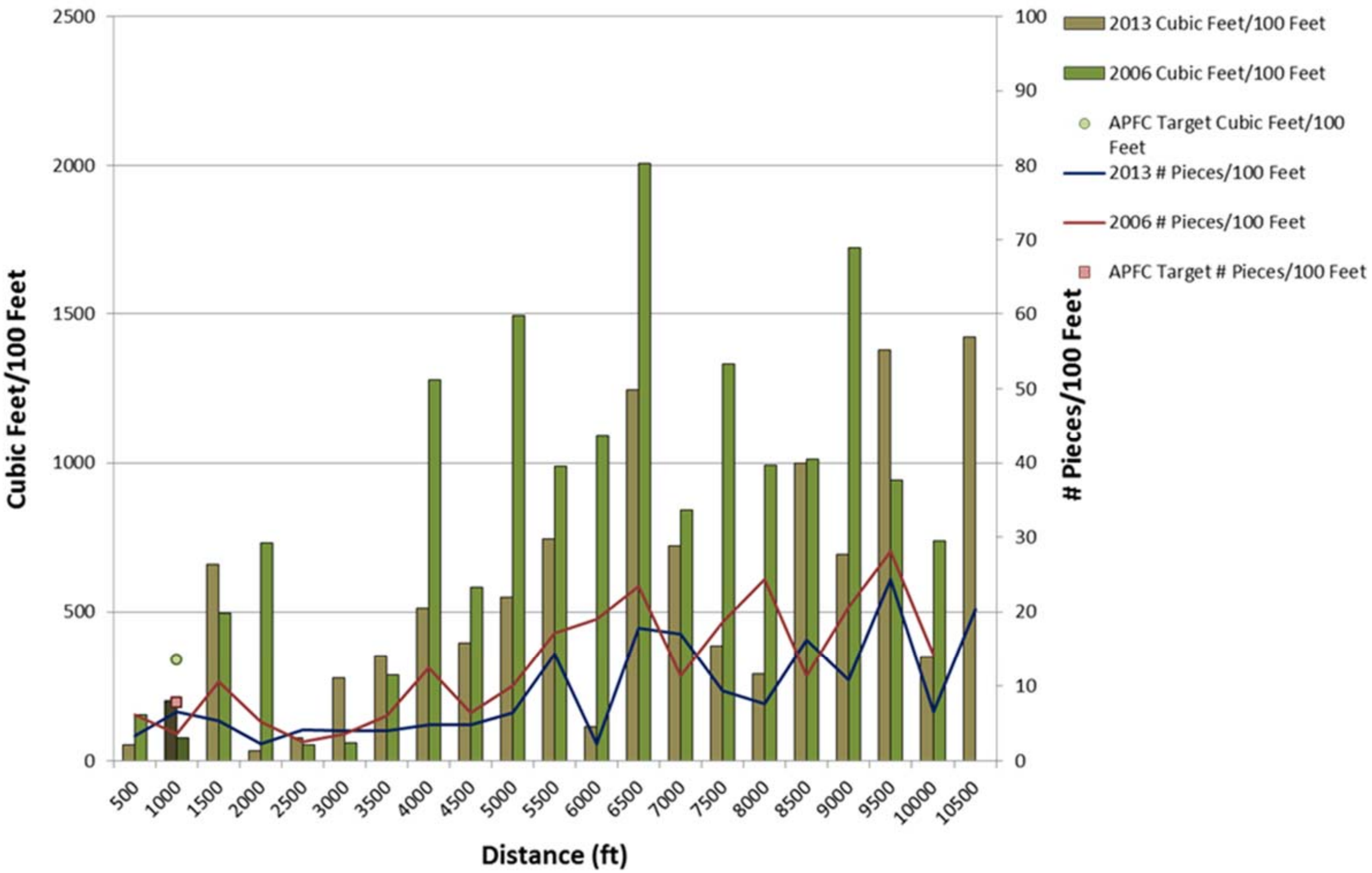
Little Freshwater was surveyed in 2013 only, and South Fork Freshwater was surveyed approximately half the distance in 2013 compared to what had been surveyed in 2006. McCready Gulch was not surveyed in either of these years.

Figure 10. Locations of the five extended LWD surveys conducted in 2006 and 2013



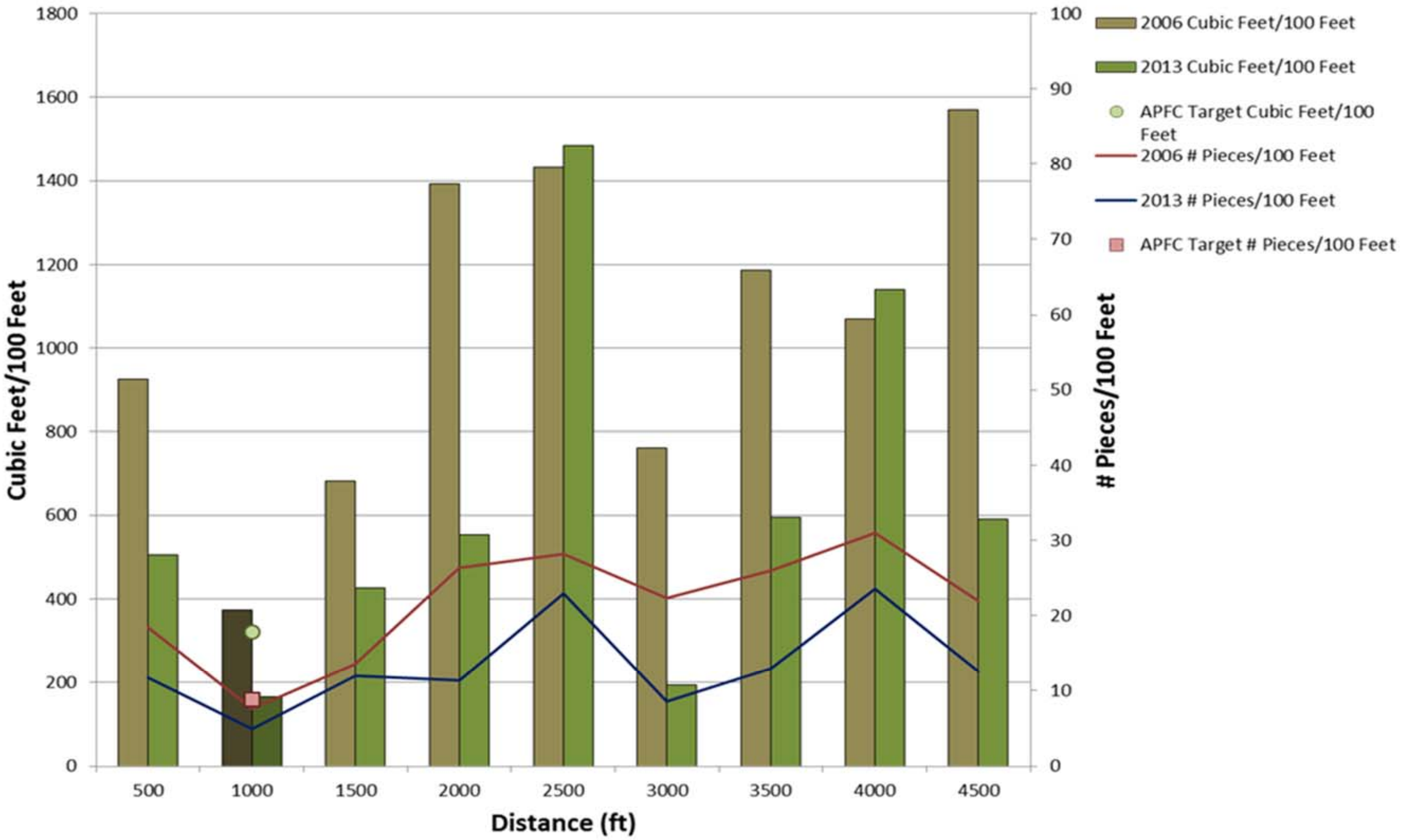
Approximate ATM station locations indicated by slightly darker bars at 500 ft (ATM Station 200) and 5,500 ft (ATM Station 034) and their corresponding APFC targets.

Figure 11. Results of the 2006 and 2013 LWD Lite Surveys on Mainstem Freshwater Creek



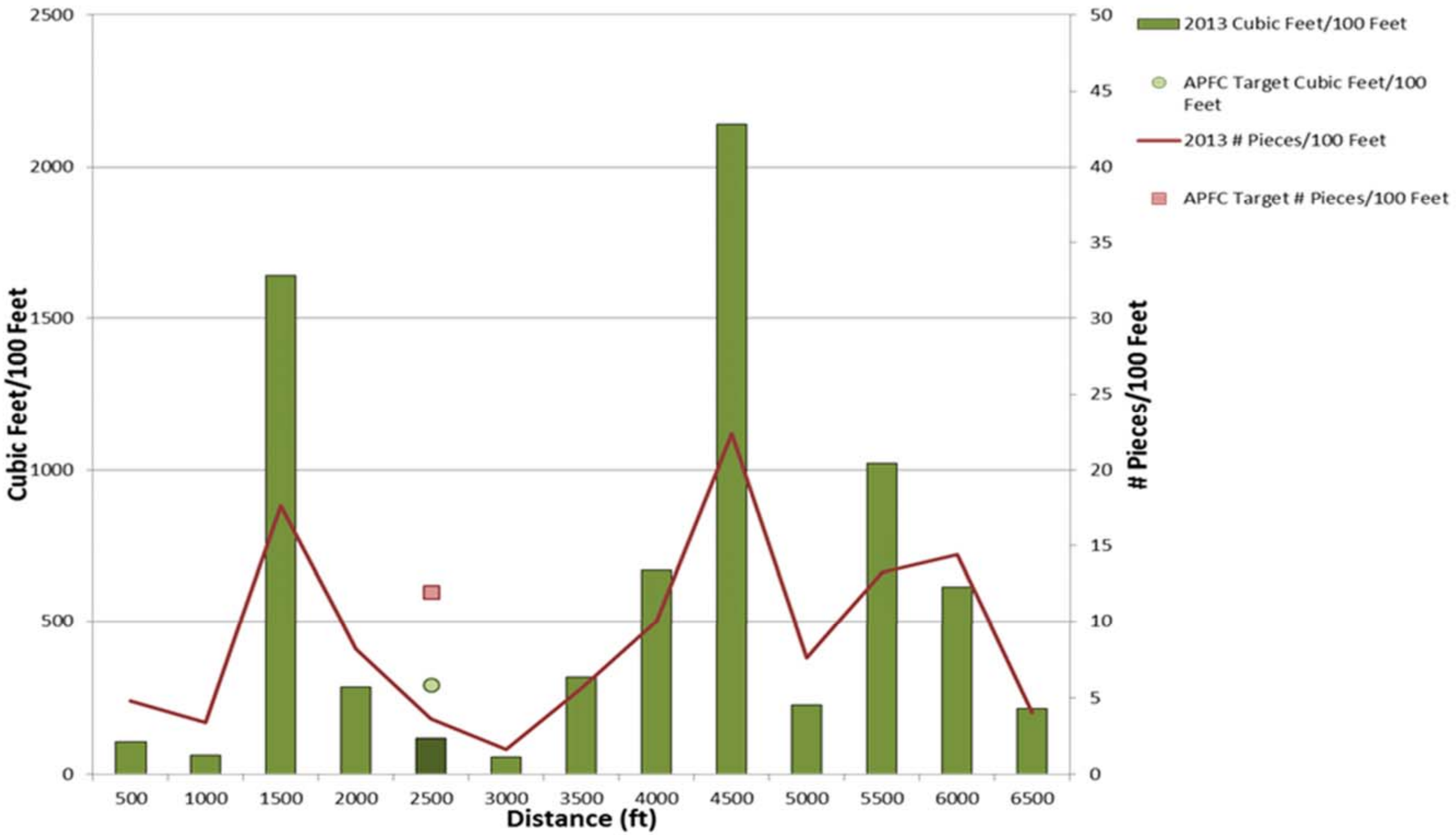
The approximate location of ATM Station 092 and corresponding APFC targets are indicated by slightly darker bars (approximately 1000 ft).

Figure 12. Results of the 2006 and 2013 LWD Lite Surveys on Cloney Gulch



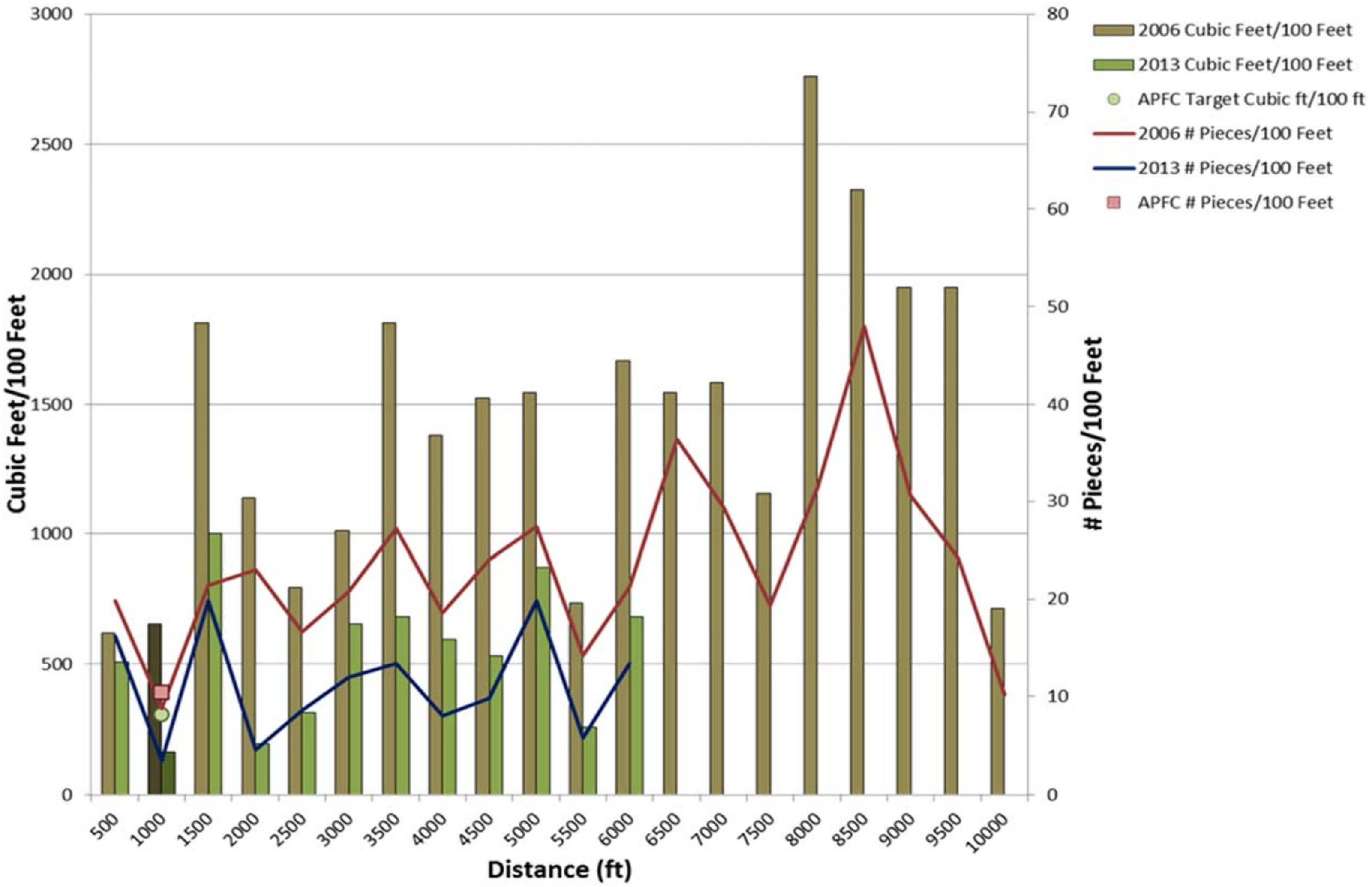
The approximate location of ATM Station 019 and corresponding APFC targets are indicated by slightly darker bars (approximately 1000 ft).

Figure 13. Results of the 2006 and 2013 LWD Lite Surveys on Graham Gulch



The approximate location of ATM Station 018 and corresponding APFC targets are indicated by a slightly darker bar (approximately 2500 ft)

Figure 14. Results of the 2013 LWD Lite Survey on Little Freshwater Creek



The approximate location of ATM Station 015 and corresponding APFC targets are indicated by slightly darker bars (approximately 1000 ft). Note that roughly twice the distance was surveyed in 2006 than in 2013.

Figure 15. Results of the 2006 and 2013 LWD Lite Surveys on SF Freshwater Creek