Fresno River Watershed Assessment Project

Draft Final Report

Prepared for

California State Department of Water Resources
County of Madera

By

California State University, Fresno

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1. INTRODUCTION

The Fresno River is located in Madera County, California and is the most southerly of major east-side tributaries of the San Joaquin River (**Figure 1.1**). It rises on the western slopes of the Sierra Nevada and flows in a southwesterly direction through the mountains and foothills and across the valley floor (via the Eastside Bypass) to the San Joaquin River.

The Upper Fresno River watershed covers the drainage area above Hidden Dam and Hensley Lake. It consists of 234 square miles of mountain and foothill terrain and is approximately 33 miles in length and 7 miles in width. Elevation ranges from about 7,000 feet at the headwaters to about 400 feet at the dam. Streams flow in relatively steep, narrow canyons having slopes ranging from 300 feet per mile in the headwaters areas to about 20 feet per mile near the reservoir (United State Army Corps of Engineers 1975).

The Fresno River Basin has a temperate semiarid climate characterized by cool wet winters and warm dry summers. Soils in the area are predominantly decomposed granite and range in depth from shallow at high elevations to moderate at low elevations. Vegetation ranges from relatively dense coniferous forests to open grasslands. Precipitation characteristics of the Fresno River Basin are significantly affected by topography. Normal annual precipitation varies from 50 inches in the headwater areas to about 15 inches at Hidden Dam. About 90% of runoff-producing precipitation occurs during the period from November to April.

Tributaries that feed the Fresno River include Lewis Creek, Nelder Creek (including Redwood Creek), China Creek, Miami Creek (including Petersen and Carter Creeks), Crook Creek and Coarsegold Creek (**Figure 1.2**). Hidden Dam and Hensley Lake (southwest corner of map) occupy the lowest point of the area, and the community of Sugar Pine (north edge of map) is the highest point of the area. As also indicated by road density in **Figure 1.2**, the human population is mainly distributed along the river’s main tributaries. According to the U.S. Geological Survey's (USGS) National Water Information System (NWIS), the Upper Fresno River Watershed can be further divided into 16 sub-watersheds (**Figure 1.3**), representing the smallest basins with 12-digit hydrologic unit code (HUC).

Project Objectives and Tasks

The Upper Fresno River Watershed Assessment Project was intended to assess the overall health of the watershed through field surveys, on-site measurements, laboratory tests, and data analysis. The following specific tasks were prescribed:

1. Impacts of the first flood (storm) event on water quality,
2. Sedimentation study to quantify soil erosion and sediment transport,
3. Impacts of septic systems on water quality,
4. Macroinvertebrate study to identify the health indices of the watershed, and
5. Baseline studies in areas of proposed developments.

Due to budget cuts and time constraints, Task 5 was not pursued by agreement.

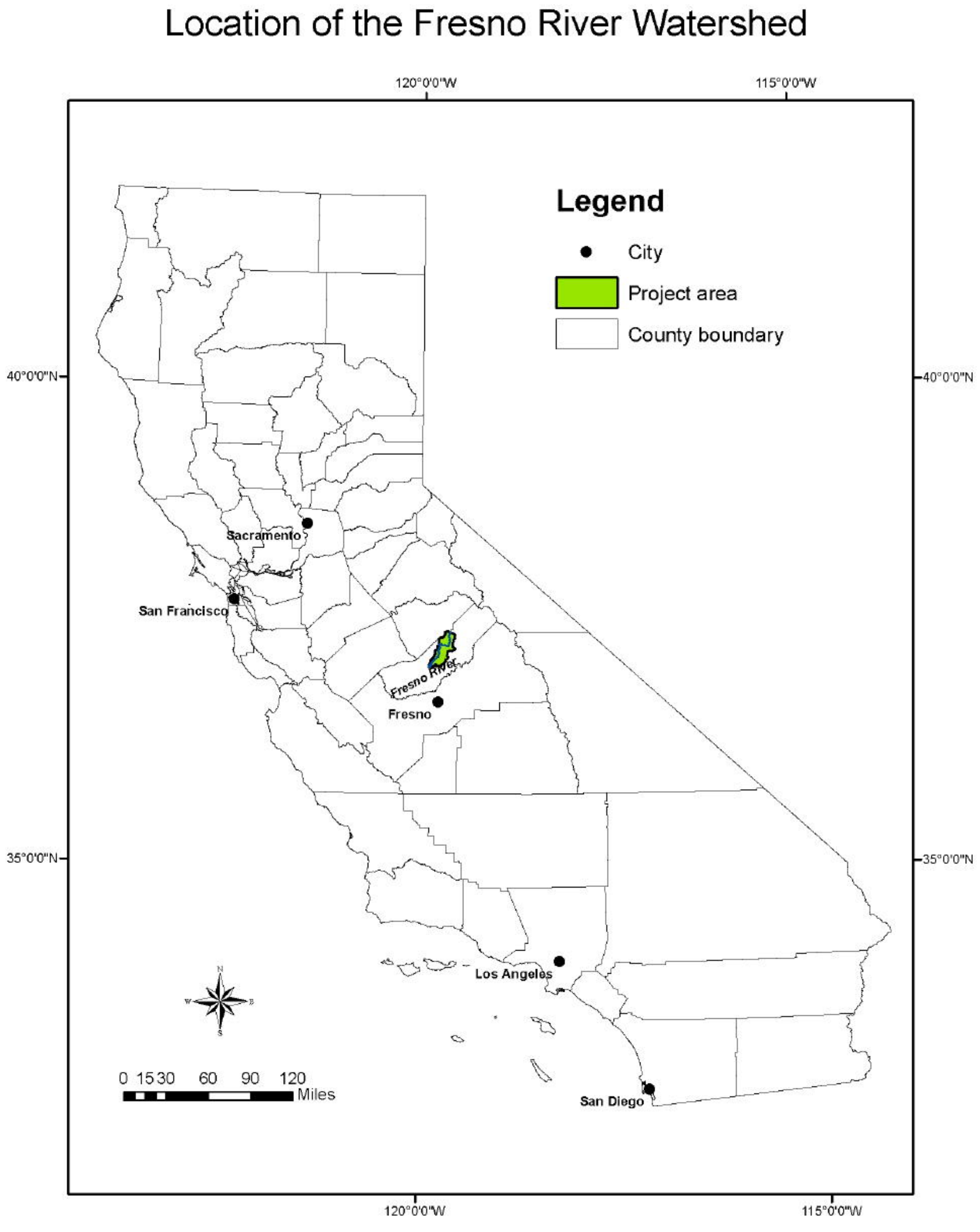


Figure 1.1. The Fresno River Watershed Assessment project area

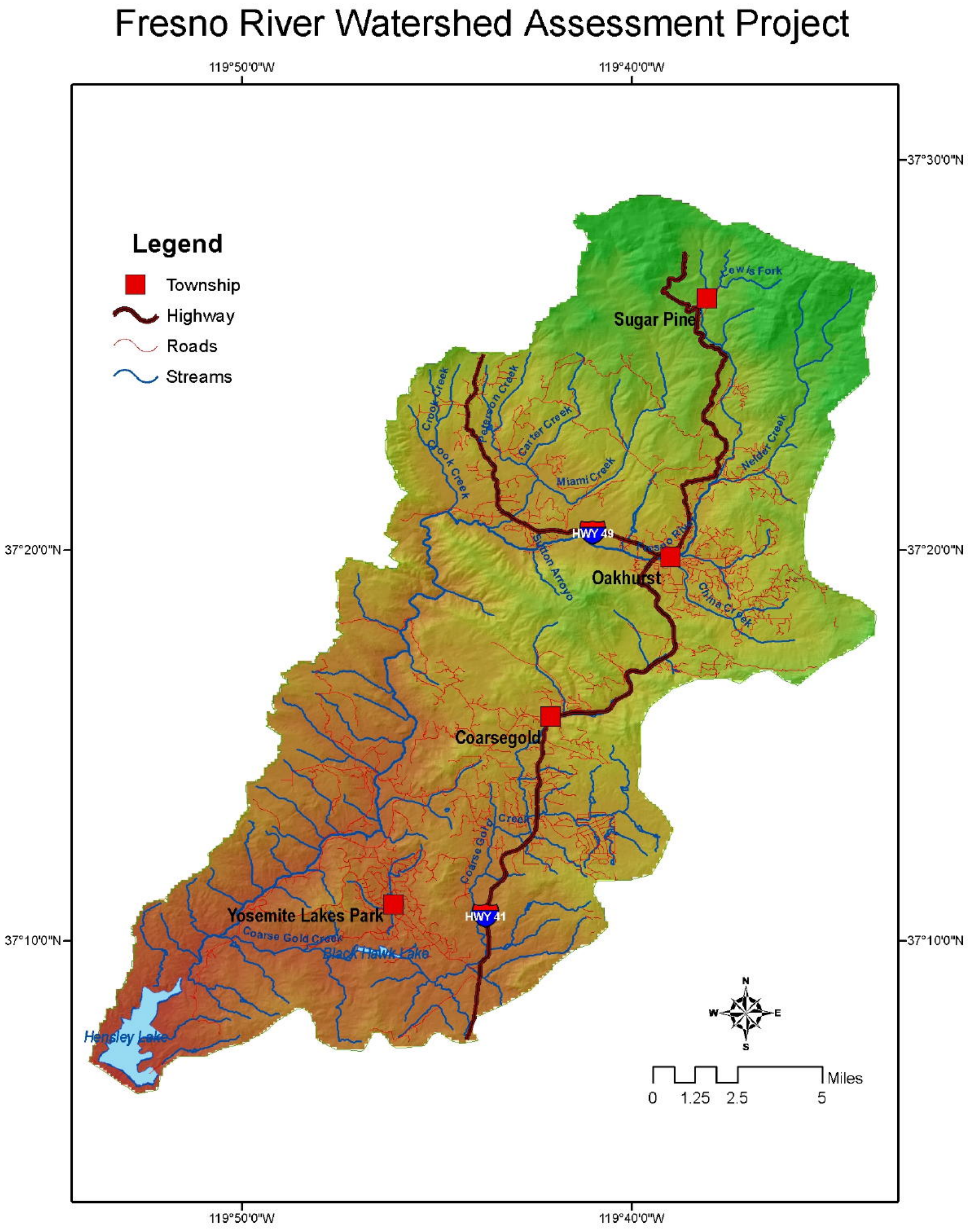


Figure 1.2. The Fresno River, its tributaries and the road system in the watershed

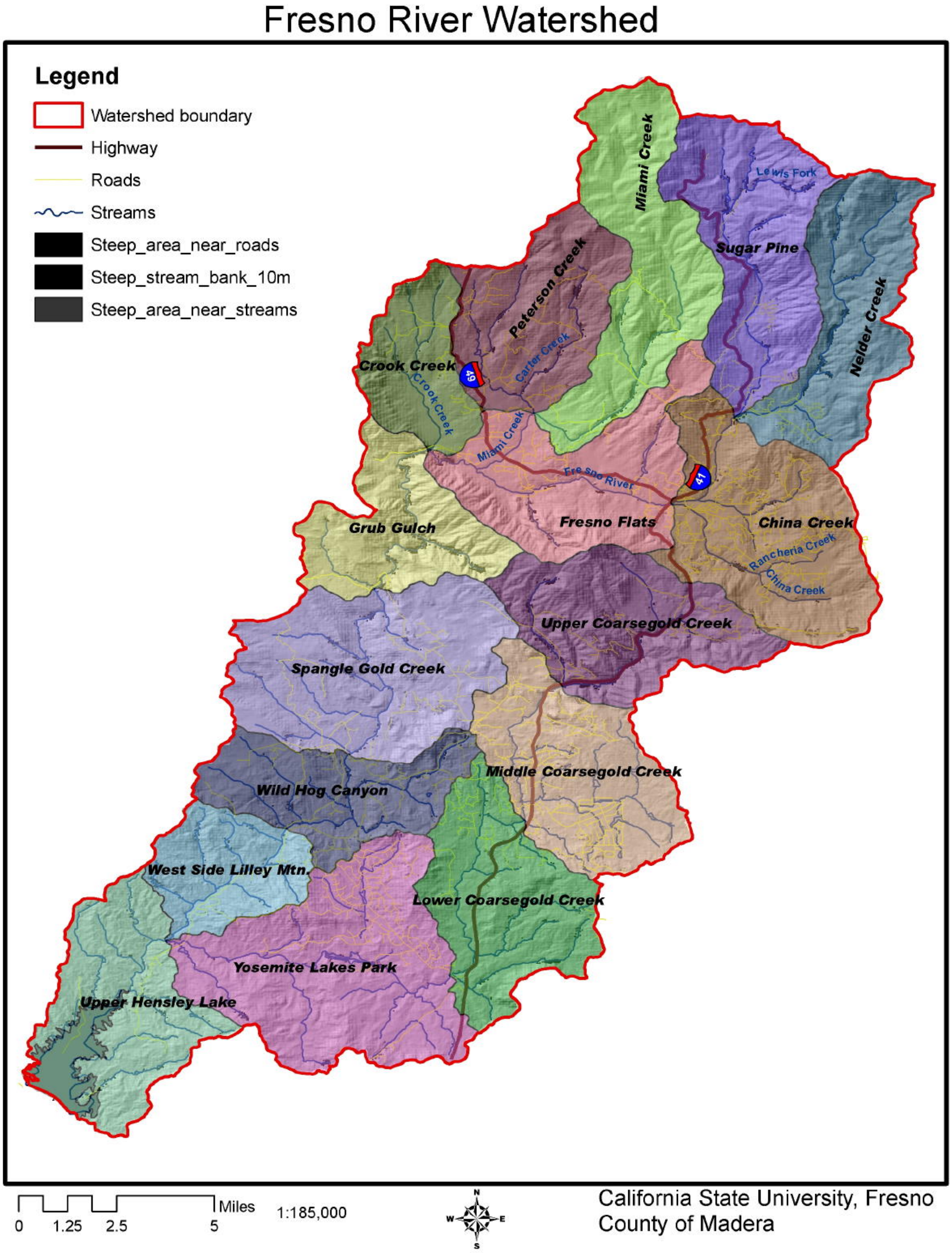


Figure 1.3. Fresno River subwatersheds.

2. MONITORING PLAN AND METHODS

2.1. Background

The population of Madera County was one of the fastest growing in the state of California (20.5% vs. 8.5%) from 2000-2008 (US Census Bureau). This puts an increasing strain on scarce water resources, especially in an area such as eastern Madera County which lacks water storage projects. Increasing population also rapidly alters land use in ways that may significantly impair water retention and quality within watersheds.

To monitor water quality in Fresno River and Hensley Lake, the Madera County Engineering Department, the Fresno office of the California Regional Water Quality Control Board (RWQCB) and the HYDROQUAL consulting company first conducted a field survey in 2001. They selected 25 sampling sites along the main stem of Fresno River, the mouths of its major tributaries, and on Hensley Lake (RWQCB, 2003). Twelve of these sites were sampled by the Regional Water Quality Control Board in 2001. This study provided a basic understanding of water quality status in the watershed.

In 2003-04 water year from October to September, the California Water Institute at Fresno State (2004, led by Steve Blumenshine and Zhi Wang) conducted the second field study to further understand the causes of water quality impairment in the watershed. The above mentioned sampling locations at several sites were modified for better hydraulic and access conditions. **Figure 2.1** shows the geographic locations of all sites and **Table 2.1** shows the access roads and global positioning of each monitoring site. Six sampling events were conducted to collect data at critical times in the water year based on the precipitation and runoff patterns in the Fresno River watershed. It took up to 4 days to collect the samples for each event. The first three events were conducted in the dry seasons (May/June, August and December) and the other three in the wet season (January/Feb, March and April). It was concluded from this study that: (1) the total flow into the Hensley Lake was dominated by baseflow (seepage from groundwater) and the total amount of water released into the lake was trending downward; (2) the nutrient concentration in the Fresno River was lower than that in the lake, thus the river was diluting the lake; and (3) the bacterium counts varied in different sections along the river, which was roughly correlated to the geographic locations of the human population centers.

In the 2008-09 water year from October to September, the California State University Foundation (led by Steve Blumenshine and Zhi Wang) conducted the third field study. The above mentioned tasks in Chapter 1 were carried out. The first task was on the impacts of the first few storm or flood events on the amount of sediment and nutrient transport into the Fresno River and Hensley Lake system, which happened in very short periods of time and were missed in the previous studies.. The second task on sedimentation study was to quantify the soil erosion status and its effects on stream water quality. The third task was to understand the impacts of the septic systems in the surface waters. Septic systems can cause surface water impairment in two major ways. First, leaking septic systems can leach nitrogenous (nitrogen-based) nutrients into the groundwater where they may be carried to the surface as baseflow. Second, and more relevant to human health, pathogenic bacteria and other microbes may be carried by overland flow or leaching from septic systems and transport to surface waters. The Madera IRWMP Sec 6.3 further describes potential impacts and mechanisms of impacts from failing septic systems. And the fourth task was a bioassessment using macroinvertebrates to evaluate the overall health of the watershed.

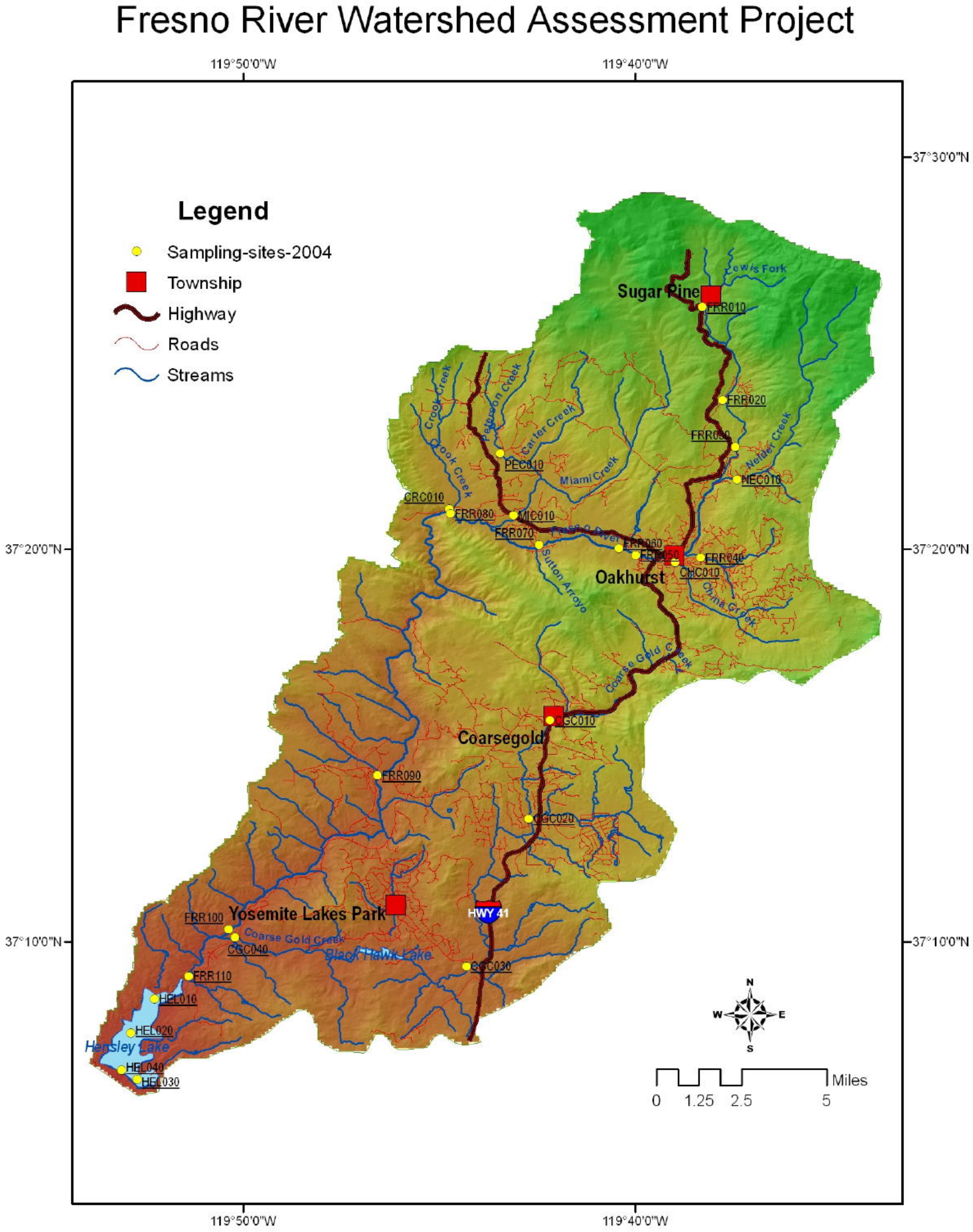


Figure 2.1. Sampling locations for 2003-04 water year

Table 2.1. Sampling locations accessed for the study of 2003-04 water year.

Sites	Station ID	Place: access roads	GPS		Elevation approx-ft
			Longitude	Latitude	
Fresno River	FRR010	Sugar Pine: Lewis Fork below the community of Sugar Pine, Freeway 41, Road 630	-119.63702	37.4364	4231
	FRR020	Cedar Valley: Lewis Fork below the community of Cedar Valley	-119.62843	37.396828	3303
	FRR030	Sky Ranch Road: Lewis Fork of the Fresno River at Sky Ranch Road	-119.62296	37.376756	2984
	FRR050	Oakhurst WWTF: Fresno River above WWTF below the confluence of China Creek	-119.66547	37.330856	2240
	FRR060	Downstream of WWTF: Fresno River downstream of Oakhurst WWTF	-119.67244	37.333633	2215
	FRR070	Fresno River - Miami Creek: Fresno River above the confluence of Miami Creek	-119.70653	37.335192	2092
	FRR080	Fresno River - Miami Creek: below the confluence of Miami Creek near Ahwahnee	-119.74513	37.349753	1890
	FRR090	Fresno River - Spangle Gold Creek: below the confluence of Spangle Gold Creek	-119.77528	37.237169	1101
	FRR100	Fresno River - Coarse Gold Creek: above confluence of Coarse Gold Creek near Rd 400	-119.83859	37.171786	758
	FRR110	Fresno River - below the confluence of Coarse Gold Creek before the inflow to Hensley Lake	-119.85555	37.151881	591
Hensley Lake	HEL010	Hensley Lake: near the inflow	-119.86997	37.142092	540
	HEL020	Hensley Lake: midpoint	-119.87996	37.12765	540
	HEL030	Hensley Lake: near Andy's cove	-119.87748	37.108067	540
	HEL040	Hensley Lake: at the outflow tower	-119.88400	37.112014	540
Tributaries	NEC010	Nelder Creek - Lewis Fork: Nelder Creek just upstream from the confluence with Lewis Fork	-119.62231	37.362953	2910
	FRR040	Cheapo Saddle: Cheapo Saddle drainage on Road 427 in the town of Oakhurst	-119.63769	37.329731	2288
	CHC010	China Creek - Fresno River: China Creek upstream from the confluence	-119.64855	37.327719	2272
	PEC010	Peterson Creek - Miami Creek: Peterson Creek just above the confluence with Miami Creek	-119.72300	37.374042	2262
	MIC010	Miami Creek - Peterson Creek: Miami Creek just below confluence with Peterson Creek	-119.71726	37.347697	2214
	CRC010	Crooks Creek - Fresno River: Crooks Creek above the confluence	-119.74519	37.350164	2063
	CGC010	Coarse Gold Creek - Highway 41: Bridge just south of Coarsegold	-119.70176	37.260583	1901
	CGC020	Coarse Gold Creek - Meadow Ridge Lane Bridge: approximately ¼ mile west of Hwy 41	-119.71091	37.218792	1799
	CGC030	Coarse Gold Creek at Yosemite Springs Parkway Bridge: one mile west of Hwy 41	-119.73731	37.156081	1156
	CGC040	Coarse Gold Creek near Fresno River: Coarse Gold Creek upstream from the confluence	-119.83577	37.168319	771

2.2. Selection of Sample Locations and Frequency

The siting rationale and sampling frequency was determined through a prioritization of hydrology and watershed conditions that are most likely to lead to impairment of surface waters. Application of these priorities is limited by the scope of the project as determined in the project tasks, timelines, and budget. Overall, we sought to capture variability in the system caused by rainfall accumulation and subsequent water distribution over the water year.

Figure 2.2 and **Table 2.2** show the sampling locations for this study which is more focused on the upper part of the watershed where the sources of watershed impact (and sediments) are generated.

2.2.1. *Sediment transport and accumulation*

In order to estimate the amount of soil erosion and sediment transport in the watershed, as well as to validate a GIS-aided soil erosion computer model, four sites were selected to set up sediment fences or traps (**Table 2.2, Fig. 2.2**) to measure the actual amount of erosion.

2.2.2. *Septic influences on indicator bacteria*

Monitoring for evidence of septic contamination of surface waters focused on concentrations of failing/repaired septic systems. These designations were proved by the Madera County Department of Resources Management Agency's Code 4219: Septic System Fepair Permit; Code 4214: Code Septic System.

In cooperation with the Madera County Department of Planning & Resource Management Agency, we identified clusters of septic parcels in which most were designated as older and/or in need of repair. We also applied criteria of proximity to surface water, at least 4% slope, and permeable soils. Through this process we identified 10 sample locations (**Table 2.3**), most of which are comprised of paired sites representing locations up and down stream of the septic clusters (example in **Fig. 2.3**). This configuration also includes sample sites above and below the Oakhurst WWTP. Despite large clusters of people and septic systems, we did not use the last two pairs in this assessment. The Coarsegold Creek channel draining the Indian Lakes region is often dry and thus disconnected from the Fresno River system, at least by surface waters. The drainage of the Yosemite Lakes Park region is received by Black Hawk Lake. The residence time of water in Black Hawk Lake may be such that it is acting as a filter to the Fresno River, although this may require more study and/or consultation with the YLP water manager.

Sampling points at each station were established during reconnaissance prior to the 2008-2009 water year using mapping software, GIS tools, and field inspection and verification of surface water channels and conditions. Representative transects were marked with field flagging located with a handheld GPS receiver, and described in field data sheets. This marking ensured sampling from an exact and repeatable position over subsequent sampling events.

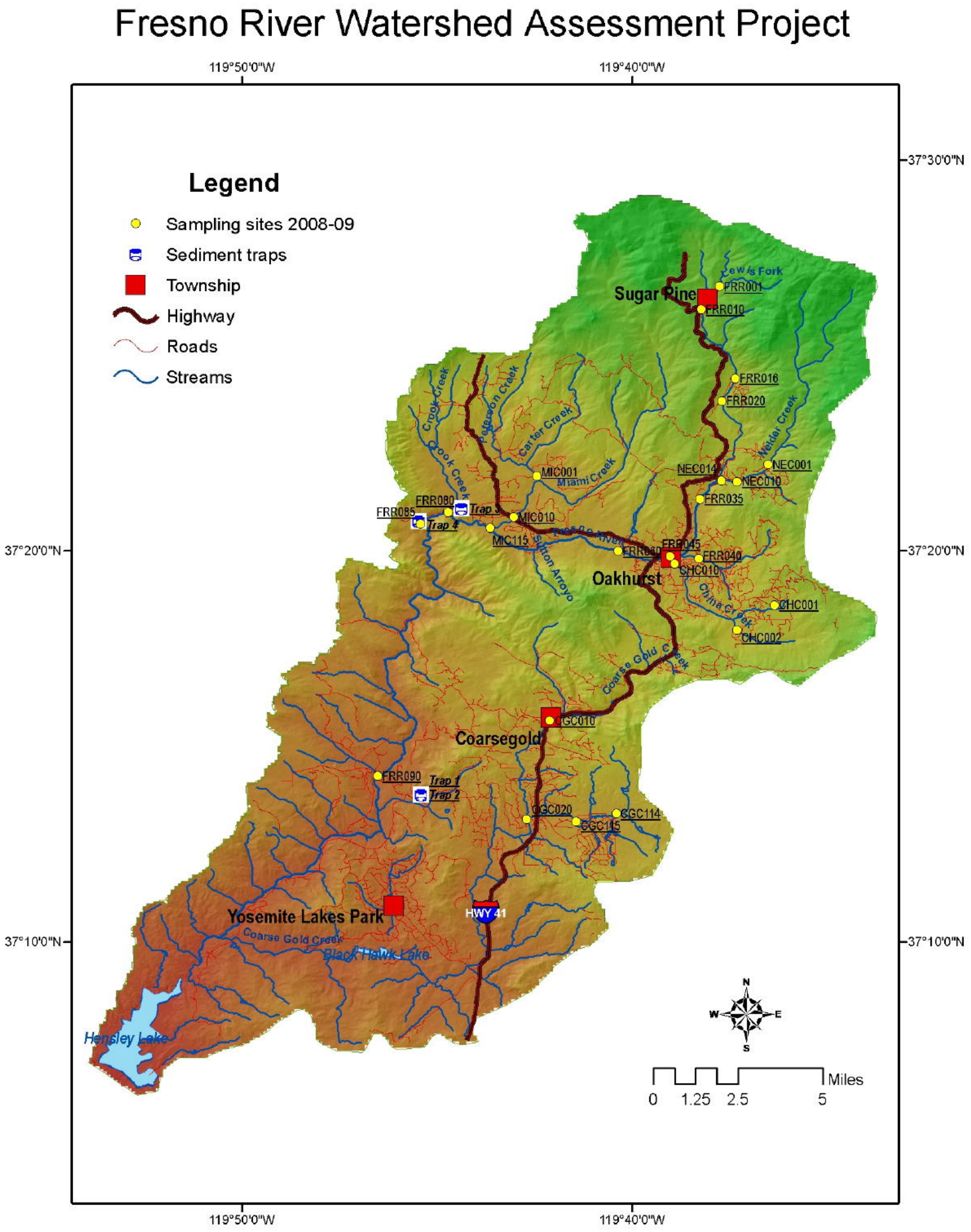


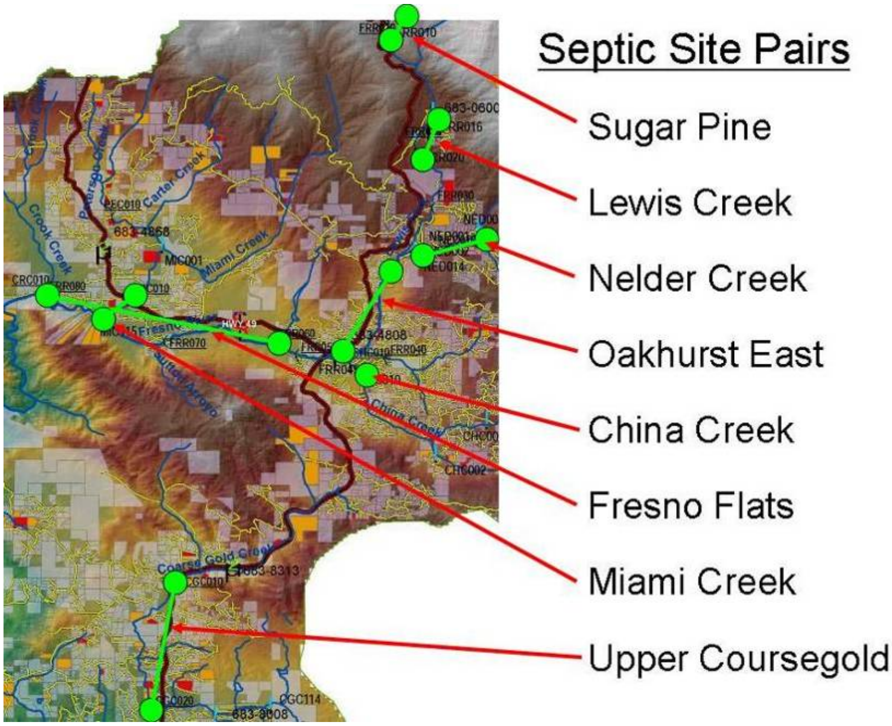
Figure 2.2. Sampling locations used for 2008-09 water year

Table 2.2: Sampling locations accessed in the 2008-09 water year (the bold-faced are new sites).

Sites	Station ID	Place: access roads	GPS		Elevation approx-ft
			Longitude	Latitude	
Fresno River	**FRR001**	Sugar Pine: Lewis Fork below the community of Sugar Pine, Hwy 41, Road 630, end	-119.62914	37.44613	4383
	FRR010	Sugar Pine: Lewis Fork below the community of Sugar Pine, Hwy 41, Road 630	-119.63702	37.4364	4231
	FRR016	Cedar Valley Dr, Cedar Spring Rd (end)	-119.62262	37.40689	3367
	FRR020	Cedar Valley: Lewis Fork below the community of Cedar Valley	-119.62843	37.396828	3303
	FRR030	Sky Ranch Road: Lewis Fork of the Fresno River at Sky Ranch Road	-119.62296	37.376756	2984
	FRR035	Hwy 41 below Cedar Valley, Riverfalls Rd	-119.637475	37.3554167	2723
	FRR045	Hwy 41, Rd 426	-119.6504222	37.3309694	2609
	FRR060	Downstream of WWTF: Fresno River downstream of Oakhurst WWTF	-119.67244	37.333633	2215
	FRR080	Fresno River - Miami Creek: below the confluence of Miami Creek near Ahwahnee	-119.74513	37.349753	1890
	FRR090	Fresno River - Spangle Gold Creek: below the confluence of Spangle Gold Creek	-119.77528	37.237169	1101
Tributaries	**NEC001**	Nelder Creek – Rd 222, Dorstan Dr, Bridge Rd, Hillside Dr (north end)	-119.60849	37.37014	3017
	NEC010	Nelder Creek - Lewis Fork: Nelder Creek just upstream from the confluence with Lewis Fork	-119.62231	37.362953	2910
	NEC014	Nelder Creek - Hwy 41, Rd 222, Deer Run Trail Rd, Lazy Oak Dr	-119.62838	37.36321	2850
	FRR040	Cheapo Saddle: Cheapo Saddle drainage on Road 427 in the town of Oakhurst	-119.63769	37.329731	2288
	CHC001	China Creek – Hwy 41, Rd 426, Bea Sore Rd	-119.60582	37.31012	2959
	CHC002	China Creek - Hwy 41, Rd 426 , Rd 423, China Creek Rd	-119.62181	37.2995	2656
	CHC010	China Creek - Fresno River: China Creek upstream from the confluence	-119.64855	37.327719	2272
	MIC001	Miami Creek - - Hwy 49, Rd 621	-119.7072361	37.36511944	2139
	MIC010	Miami Creek - Peterson Creek: Miami Creek just below confluence with Peterson Creek	-119.71726	37.347697	2214
	MIC115	Miami Creek - Hwy 41, Indian Rock Rd, Shandee Ln	-119.7272028	37.342925	2015
	CRC010	Crooks Creek - Fresno River: Crooks Creek above the confluence	-119.74519	37.350164	2063
	CGC010	Coarse Gold Creek - Hwy 41: Bridge just south of Coarsegold	-119.70176	37.260583	1901
	CGC020	Coarse Gold Creek - Meadow Ridge Lane Bridge: approximately ¼ mile west of Hwy 41	-119.71091	37.218792	1799
	CGC030	Coarse Gold Creek at Yosemite Springs Parkway Bridge: one mile west of Hwy 41	-119.73731	37.156081	1156
	CGC034	Lower Coarse Gold Creek – not sampled	-119.76865	37.17272	1107
	CGC035	Lower Coarse Gold Creek – not sampled	-119.8092333	37.1636444	962
	CGC040	Coarse Gold Creek near Fresno River: Coarse Gold Creek upstream from the confluence	-119.83577	37.168319	771
	CGC114	Coarse Gold Creek - Hwy 41, Rd 417 (end)	-119.67338	37.22108	2212
	CGC115	Coarse Gold Creek - Hwy 41, Rd 417, Modoc Rd, Delaware Rd, Ottawa Ave, Chinook Rd	-119.69055	37.21765	2073
Sediment Traps	**Trap 1**	Road 415 west of Sesame Street	-119.75675	37.229166	1501
	Trap 2	Road 415 west of Sesame Street, below Trap 1	-119.7567	37.22917	1500
	Trap 3	Road 600 before bridge over Crook Creek	-119.7394	37.35139	1930
	Trap 4	Road 600, on Lary Bellaw's property	-119.75767	37.345883	1852

Table 2.3. Sampling sitting pairs for monitoring septic system clusters (bold-faced are new sites).

Pair #	Region	Upper site	Lower site	Site status Oct 08	PE4214, 4219 Parcels	Comments
1	Sugar Pine	**FRR001**	FRR010	Some flow	9	Consist flow, Far, High impact
2	Cedar Valley	**FRR016**	FRR020	Wet	35	Consist flow, Far, High impact
3	Nelder and Redwood creeks	**NED001**	NED014	Wet	105	Fairly dense
4	China Creek	**CHC002**	CHC010	Dry	170	Discharge into Fresno River The upper area is mostly dry
5	Oakhurst-Hwy41	**FRR035**	**FRR045**	Wet	213	Rapid flow in deep canyon
6	Miami Creek	MIC010	**MIC115**	Wet from golf course	30	Mainly golf course effect
7	Oakhurst-Hwy49	FRR060	FRR080	Wet	93	Normal flow
8	Coarsegold	CGC010	CGC020	Dry	215	Coarsegold and south
9	Indian Lakes	**CGC114**	**CGC115**	Dry	265	Small channel, mostly dry
10	Yosemite Lakes Park	**CGC034**	**CGC035**	Dry	Not used	Flow into the Black Hawk Lake no discharge into Fresno River



(a). Sampling sites located up- and down-stream of the septic clusters

(b). Example septic cluster with color coded parcels

Figure 2.3. Example map illustrating septic parcels in the Fresno River watershed. Parcels are color coded according to criteria of the septic systems (e.g. age, needing repair, etc.) by the Madera County Department of Public Health.

2.3. General Field Measurements and Sample Collection

Field measurements and sample collection, preservation, and transport were conducted in accordance with the Fresno River System Sampling Plan (March 2003), which was based on California Surface Water Ambient Monitoring Plan (SWAMP) procedures. Sampling was conducted by students and faculty from the Biology and the Earth & Environmental Sciences Departments at California State University, Fresno. All sampling was conducted by a crew of 3-4 persons. Field crews were lead by one of the project's principle investigators (PI) or Biology graduate student Brett Moore. The assistants were all California State University, Fresno students who had taken advanced coursework in stream and lake ecology, and were trained by the PIs.

Table 2.4 shows the sampling dates. A total of 16 field tours were conducted in 2008 and 2009.

Table 2.5 shows nutrient and microbiological parameters measured in the field and laboratories. The field parameters—water temperature, dissolved oxygen (mg/L & % saturation), total dissolved solids, oxygen reduction potential, electrical conductivity and pH— were measured with an YSI 85 multi-meter. Stream turbidity was measured using a portable turbidity meter (Turner Designs Aquafluor). Discharge was calculated using an electromagnetic velocity meter (Marsh-McBirney, Inc. MODEL 2000-51). Six or more individual measurements of stream velocity and depth were taken across each transect.

Determination of nutrient and bacterial levels were determined from grab samples collected in sterile Whirlpak bags. Samples were immediately placed in an ice-filled cooler and kept at 4 degrees Celsius for transfer to the appropriate laboratory. Sample for nitrogenous compounds (Total Kjeldahl Nitrogen, Ammonia, and Nitrate) were analyzed at the Fresno County Public Health Laboratory. Levels of fecal indicator bacteria (FIB) were determined in the Microbiology Lab, headed by Dr. Alice Wright in the Biology Department at CSU-Fresno. Specific analyses are further described in the relevant report chapters.

2.4. Field QA/QC

Field meters were calibrated the day before a sampling round with laboratory standards for pH, conductivity, and turbidity measurements, and against 100% saturated air in the case of dissolved oxygen (DO). Meters were turned on and allowed to warm up for at least 10 minutes and were placed in the stream channel at least 10 minutes to ensure stable readings before values were read to allow for stable readings. Before leaving the site, the PI checked all recorded metered values. Parameters with questionable values were re-measured for confirmation.

All grab samples were collected in cleaned vessels that were rinsed three times with water from the site. Tiles used for quantifying stream bed organic matter (periphyton) accumulations were placed in labeled 4 oz. Whirl-Pak bags and kept on ice. Tap water and a soft nylon brush were used to remove material from tiles within 24 hours of collection (US EPA 1997).

The field data were entered into Excel spreadsheets and checked for accuracy by a project PI. Suspect values were checked against field data sheets and corrected if necessary. All original data sheets have been archived.

Table 2.4. Sampling Dates

	Year	2008								2009							
	Site ID\date	4/25	5/26	10/2	10/16	11/1	11/2	11/6	11/21	1/6	1/8	1/30	2/20	3/20	4/3	5/22	5/29
Fresno River	FRR001			X				X	X	X		X		X	X	X	
	FRR010		X	X				X						X		X	
	FRR016			X				X		X				X			
	FRR020		X					X		X				X			
	FRR030	X						X	X			X			X		
	FRR035				X	X	X	X		X				X		X	
	FRR045				X	X	X	X		X				X		X	
	FRR060					X	X	X		X				X			
	FRR080							X		X						X	
	FRR085							X	X			X			X		
	FRR090	X	X					X	X			X			X		
Tributaries	NEC001			X				X	X	X		X		X			
	NEC002			X												X	
	NEC003			X													
	NEC010	X															
	NEC014			X				X		X				X			
	FRR040			X		X	X										
	CHC001			X													
	CHC002			X													
	CHC010									X							
	MIC001							Dry		Dry							
	MIC010									X				X	X	X	
	MIC115									X				X			
	CRC010													X	X	X	
	CGC010	X				X	X	X		X		X		X	X	X	
	CGC020	x								X		X		X	X	X	
	CGC030	x															
	CGC034																
	CGC035				X			Dry		Dry							
	CGC040																
	CGC114			Dry				Dry		Dry							
	CGC115			Dry				Dry		Dry							
Sediment	Trap A										X		X		X		X
	Trap B										X		X		X		X
	Trap C										X		X		X		X
	Trap D										X		X		X		X

Table 2.5. Measured water quality parameters.

	Parameters	Unit
Field parameters	Water temperature	^oC
	Dissolved oxygen (DO)	mg/L
	Dissolved oxygen saturation	%
	Electric conductivity (EC)	µS/cm
	pH	
	Water turbidity	NTU (Nephelometric Turbidity Units, particle size and density)
	Water discharge (Q)	ft^3/s or m^3/s
	Total dissolved solids (TDS)	mg/L
	Oxygen reduction potential (ORP)	Millivolts
Nutrients (Fresno County Public Health Laboratory)	Total Nitrogen (TN)	mg/L
	Ammonia Nitrogen (NH_3-N)	mg/L
	Nitrite Nitrogen (NO_2-N)	mg/L
Microbiological Organisms (CSU Fresno Microbiology Lab)	Total coliform	MPN (most probable number of bacteria in 100ml of water)
	E. coli	MPN
	Enterococcus	MPN

2.5. Particle Size Analysis

The Particle size analysis was conducted using sieving and laser particle diffraction methods. The larger particles of the samples (> 250 microns) were separated by the wet- and dry-sieving methods. The small particles (1.5 - 250 microns) were separated using the LISST-PORTABLE laser diffraction particle size analyzer (Sequoia Inc, 2004).

2.5.1. Wet sieving:

Stream sediment samples were chemically and physically prepared for particle size analysis. For each sample, approximately 200 grams of the sediment and 300 ml of a five percent (%) sodium hexametaphosphate solution were placed in a 1000 millimeter (ml) beaker (Jacob and Topp, 2002). Then, the beaker was placed on a mechanical mixer and mixed for about 5 minutes. The soil solution was then passed through United States Department of Agriculture (USDA) individual sized sieves. Beginning with the larger sieve (4 mm or 5.6 mm), the soil solution was poured over the partially submerged sieve. To prevent the larger sieved particles from floating out into the container, care was taken to prevent the water from submerging to the top of the sieve. The sieve was vibrated in the water against the sides of the container until all the smaller size particles passed through the sieve. The sieved sediments were placed in empty aluminum foil drying dish. To rinse out lodged sediments, the sieve was placed upside down in a beaker with about 200 ml of distilled water. The beaker was shacked to ensure that the sediments on the sieve were fully washed out. Excess water from the beaker was poured out and the remaining liquid and sediment were transferred with a syringe to an aluminum foil drying dish. The procedure was repeated for all the remaining sieves. The fine sediments that passed through all of the sieves were placed in a 500 ml poly bottle and saved for particle size analysis using the Sequoia's LISST-Portable Laser Diffraction Particle Size Analyzer.

The smaller aluminum foil containers with the coarser sieved sediments were allowed to air dry for approximately two weeks prior to calculating organic matter content. To prepare the dried samples for organic content and dry mass content analysis, approximately 200 grams (g) of air dried sample were oven dried for 12 hours at 105 degrees Centigrade in a Fisher Scientific Isotemp oven. The samples were then weighted using a Metler AE 240 weight scale. To evaluate the percentage of organic matter, approximately 20 grams of the oven-dried, sieved material were placed in ceramic crucibles. The crucibles were placed in a 6000 Thermolyne furnace oven at 550-600 degrees Centigrade for two hours. The oven was allowed to cool down for several hours until approximately 200 degrees Centigrade. The oven was allowed to cool while keeping the door closed to prevent shattering of the insulating walls. The samples were then placed in glass desiccators and allowed to cool down to about 25 degrees Centigrade. The samples were then weighed using the Metler AE 240 weight scale. The weight ratio of furnace sample to oven dried sample were then calculated.

2.5.2. Dry Sieving

Stream volumetric samples were allowed to air dry for two weeks at room temperature before dry sieving. The drying process can be accelerated by placing the sediment in an oven at 105 degrees Centigrade overnight. Dry sieving was conducted using stainless steel sieves ranging in size from US Sieve No. 4 to No. 270 (0.1870 inch to 0.0021 inch). The samples were sieved by stacking five sieves and using a mechanical shaker. Sieving times averaged approximately 10 minutes. The sieved samples were weighted using the Metler AE 240 weight scale.

2.5.3. Laser Diffraction Method

For selected samples, particle size distribution (PSD) were generated using the Sequoia LISST Portable Laser Size Analyser (LISST-Portable, **Fig. 2.4**). The LISST-Portable applies the full Mie theory in its calculations. The Mie theory is an analytical solution of Maxwell's equations for the scattering of electromagnetic radiation by spherical particles. Samples were prepared and added to the mixing chamber of the LISST-Portable. The LISST-Portable generates PSD data for particles ranging from 1.25 to 250 microns.

Samples analyzed by laser diffraction were prepared by wet sieving sediments to particles less than 250 microns. The LISST-Portable was prepared by cleaning the mixing chamber with deionized water and setting a background reading. The mixing chamber was then filled with the sediment sample. When the mixer is turned, it swirls the sediment solution, and the LISST-Portable program generates a continuous particle size graph. Readings were acquired from the LISST-Portable interface connected to a computer.

Figure 2.4. LISST-Portable Laser Diffraction Particle Size Analyzer (Sequoia Inc. 2004)

2.6. Fine Sediments and Macroinvertebrates

Fine sediment was sampled using a bottomless 5 gallon bucket. One fine sediment sample was taken from riffles in close proximity to each macroinvertebrate transect. Since there were three macroinvertebrate transects, three fine sediment samples were also taken per site for each sampling event. The bucket was placed down in the riffle, large cobbles were removed, and the sampling depth was taken. Then, the fine sediment was suspended inside the cylinder for approximately one minute by digging and spinning the top 5 cm of substrate. After suspension of the fine sediment, a grab sample was taken. In the lab, 100 ml of the samples were filtered onto pre ashed Whatman GF/D glass fiber filters (pore size = 2.7 µm), dried at 70°C for at least 24 hours, and weighed to the nearest 0.1 mg. After obtaining the dry weight, the samples were then placed in a muffle furnace at 400°C for at least four hours, cooled, and reweighed in order to determine % organic matter from loss of weight by ignition. A portion of the remaining grab sample was analyzed using a Sequoia Scientific LISST-PORTABLE laser particle analyzer, which produced a size distribution of particles from 1.5 to 250 µm.

Benthic macroinvertebrate assemblages were sampled at the seven sediment sites bimonthly throughout the 2008-09 water year. The exceptions were the two sites on the intermittent tributary Coarsegold Creek. These sites were only sampled during the January and April sampling events when there was streamflow present. Sampling throughout the water year allowed us to observe and quantify the temporal shifts in assemblages at the sites. Macroinvertebrate sampling and handling followed the detailed procedures outlined by the California SWAMP (CDFG 2007). The sample design combined the reachwide benthos and targeted riffle composite procedures because sampling sites were limited in access and habitat types. Three riffles at each site were targeted. Riffles were chosen because they often contain the highest macroinvertebrate diversity in streams, and were the predominant habitat type at our sample reaches. Transects across each riffle were then sampled at 25%, 50%, and 75% of the wetted width with a 30.5 cm D-frame kicknet with 250 µm mesh. The three transect samples then formed a riffle composite sample with a total sample area of 0.3 m^2 per riffle.

Samples were brought back to the CSUF lab, placed in 70% ethanol, and sorted for organisms. Invertebrates were later identified to genus or lowest possible level otherwise using Merritt and Cummins (1996). Chironomidae were identified to the subfamily level, and non insects were identified to family or order. Twenty five common macroinvertebrate metrics from previous works were calculated to provide the variables used to examine assemblages across sites (Rosenberg and Resh 1993, Zweig and Rabeni 2001, Klemm et al. 2002, Roy et al. 2003). Tolerance metrics were calculated using published tolerance values (Lenat 1993, Zweig and Rabeni 2001, Klemm et al. 2002). Taxa were assigned to functional feeding groups (FFGs) from designations in Merritt and Cummins (1996). Metrics were screened for scope and redundancy. If a metric contained no range between sites, or had a linear relationship with another more interpretable metric with a Pearson pairwise correlation coefficient >0.70 it was removed from further analysis (Klemm et al. 2002). Screening produced 11 metrics to examine assemblages across sites (**Table 5.3**). Due to the importance of clingers in urbanization studies, a twelfth metric % clinger was also added for interpretation. Also, indicator species analysis (ISA) was performed using abundance data to investigate general patterns of occurrence, indicate environmental conditions of the sampling sites, and describe the longitudinal structure of macroinvertebrate assemblages in the watershed. Indicator values were based on 1000 randomizations. Only genera with p-values < 0.100 and with indicator values >30 were considered significant. The final step in analysis used weighted averaging was used to score sites based on water quality tolerance values from literature (Lenat 1993, Klemm et al. 2002) and generated fine sediment tolerance values in order to determine the most important source of impairment to macroinvertebrate assemblages in the watershed.

2.7. GIS-aided Analysis and Modeling

A Geographic Information System (GIS) was used to integrate and analyze spatial data for the project. The latest version of GIS software, ArcGiS 9.2 from ESRI (Environmental System Research Institute, Redland, California) was used to delineate watershed boundaries and produce analytical data. The Fresno River watershed and regional maps were obtained from multiple sources. The digital elevation map (DEM) and data on streams, water bodies, population, and transportation were obtained from public domain internet sources (e.g., MapMart http://www.mapmart.com/, GIS Data Depot http://data.geocomm.com/). The Madera County Engineering and Environmental Offices provided digital maps of roads, septic systems and land uses in the project area. The Interdisciplinary Spatial Information Systems (ISIS) GIS center at California State University, Fresno provided aerial photos of the project area.

GIS tools were also used to develop the input maps to run a computer model called RUSEL that calculates the soil erosion and sediment transport volumes in the watershed (Baca, 2009). The objectives of this study were to evaluate soil erosion within the Upper Fresno River Watershed using GIS and the Revised Universal Soil Loss Equation (RUSLE) model to develop soil erosion risk assessment.

2.8. Additional Data

Additional hydrologic and nutrient loading data were obtained from the following sources:

- California Department of Water Resources (http://cdec.water.ca.gov/reservoir.html): Hensley Lake and Oakhurst area historical meteorological and hydro data;
- Madera County Engineering and General Services: Oakhurst Waste Water Treatment Facility – effluent discharge data (2003); and
- RWQCB: Lewis Creek Waste Water Treatment Facility – upstream and downstream discharge and microbiological data (2003).

3. HYDROLOGY, WATER QUALITY AND FIRST FLUSH STUDY

3.1. Hydrology of Fresno River Basin

The graph in **Figure 3.1** illustrates the temporal distribution and amount of rainfall in the upper Fresno River watershed (California DWR, 2010: http://cdec.water.ca.gov/reservoir.html). It can be seen that the monitoring year of 2008-09 was very close to the average for the decade.

Fig. 3.2a shows daily discharge into Hensley Lake and precipitation in Oakhurst during the past 15 years (1994-2009). A typical Water Year starts in October when the river discharge begins to increase. The first few rainfalls of the season are absorbed by the typically dry soil in the watershed; thereafter, the rainfall events produce overland flows into the river. Depending on the year, the flow can peak in February, March or April; the discharge drops quickly in June and the river is then fed mainly by subsurface seepage through soil and fractured rocks. **Fig. 3.2b** shows the hydrograph during the project period from May 2008 to October 2009.

The 15-year hydrograph (**Fig. 3.2a**) shows that the upper Fresno River watershed experienced very wet years from 1994 to 2000 with abundant rainfall and runoff. The following years from 2000 to 2004 were relatively dry with minimal runoff into the Hensley Lake. This was followed by two moderate wet years (2004-05 and 2005-06) when both the amounts of rainfall and runoff increased to the medium levels. The past four water-years are again dry. Due to the extended draughts in later 2006-07 and 2007-08, rainfall in the 2008-09 water year was largely absorbed by soil and undulating relief of the watershed, thus producing limited amount of runoff discharge into the Hensley Lake. Increased amount of water interception and transfer in the upper areas of the watershed also caused the decrease in stream flow in the lower part of the watershed.

During the monitoring water year of 2008-09 (**Fig. 3.2b**), the early rainfall events in October, November and December of 2008 did not produce significant runoff discharge into the Hensley Lake. However, according to our observation, large rainfalls in the upper watershed produced local floods in the Oakhurst area (e.g., the first flood on November 1st). Inflow record at the Hidden Dam showed near-zero discharge into the Hensley Lake. Significant discharge came in the first five months of 2009. Afterward, the rainfall almost diminished resulting in near-zero runoff discharge into the Hensley Lake.

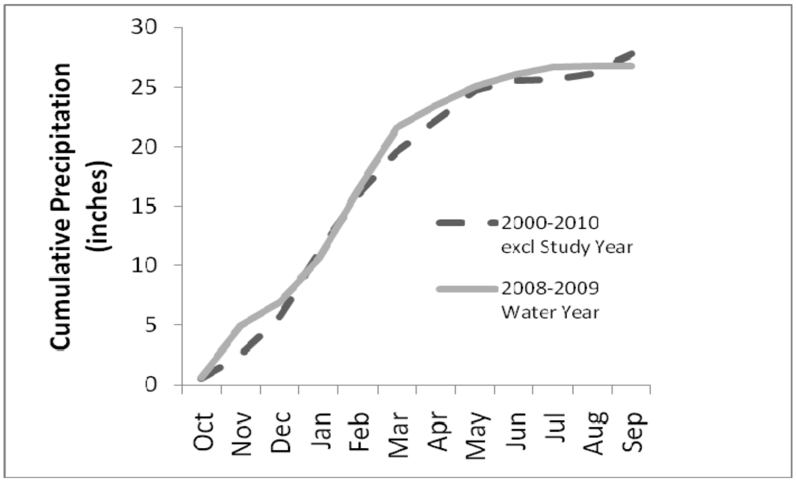
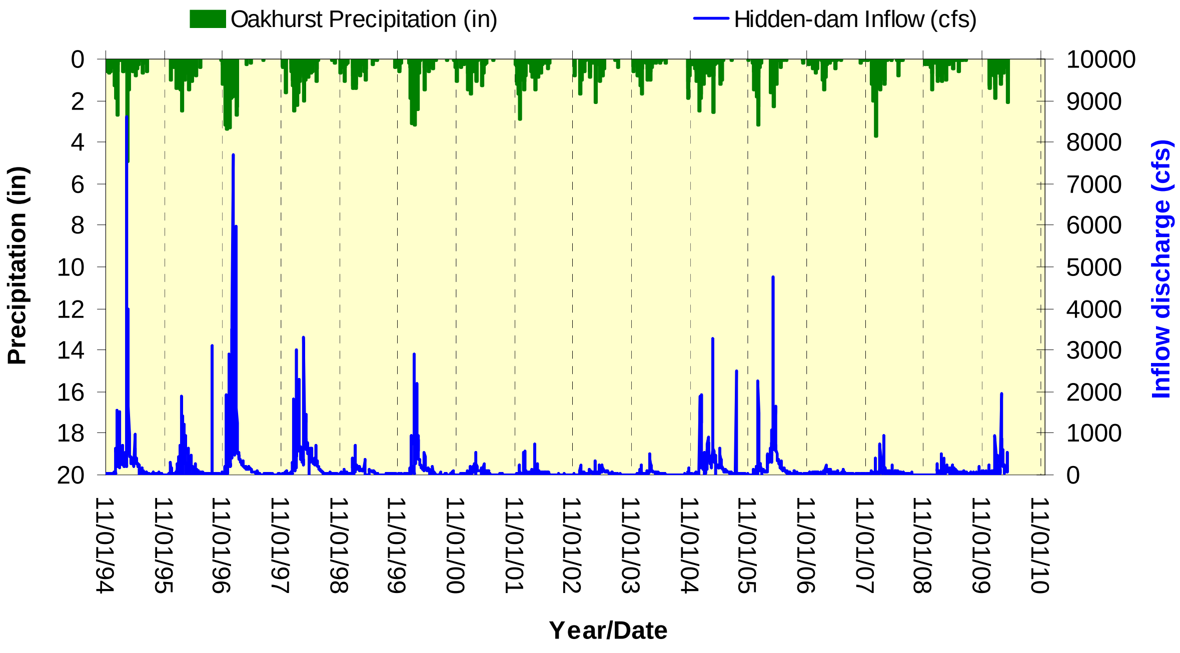
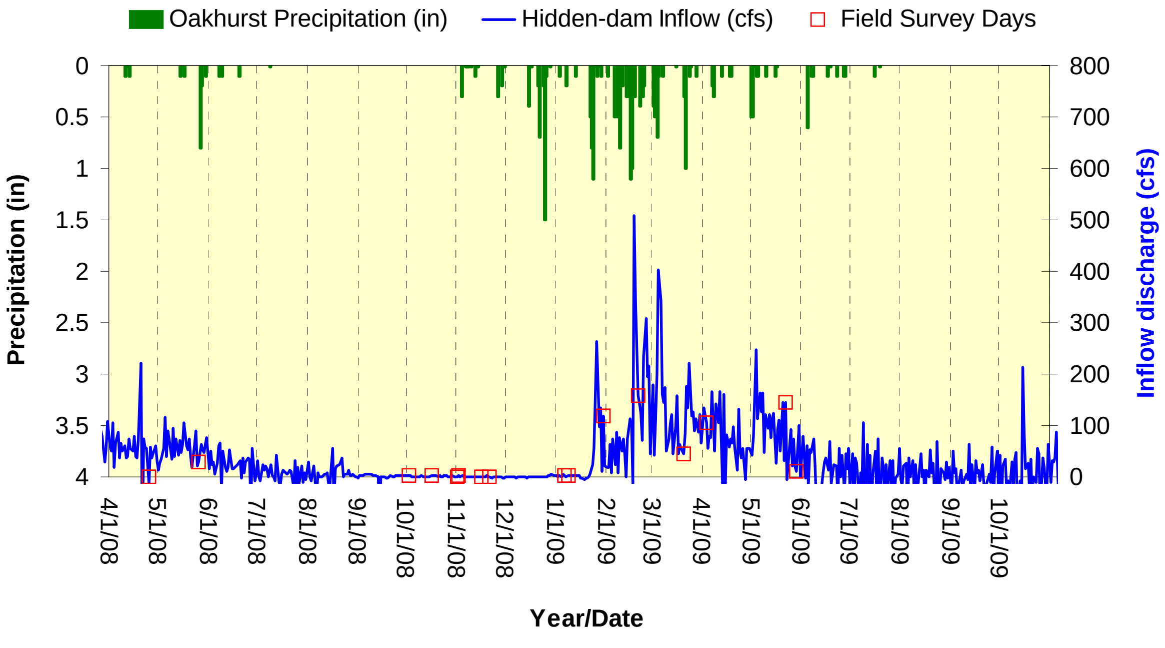


Figure 3.1. Temporal distribution of rainfall in inches in the Upper Fresno River Watershed in 2008-09 water year (solid line) as compared to the decadal average (dashed line)



a). Hydrograph for 1994-2009 hydrologic years



b). Hydrograph for April 2008 – October 2009 and the dates of sampling

Figure 3.2. Fresno River hydrograph - discharge into Hensley Lake and precipitation in Oakhurst area.

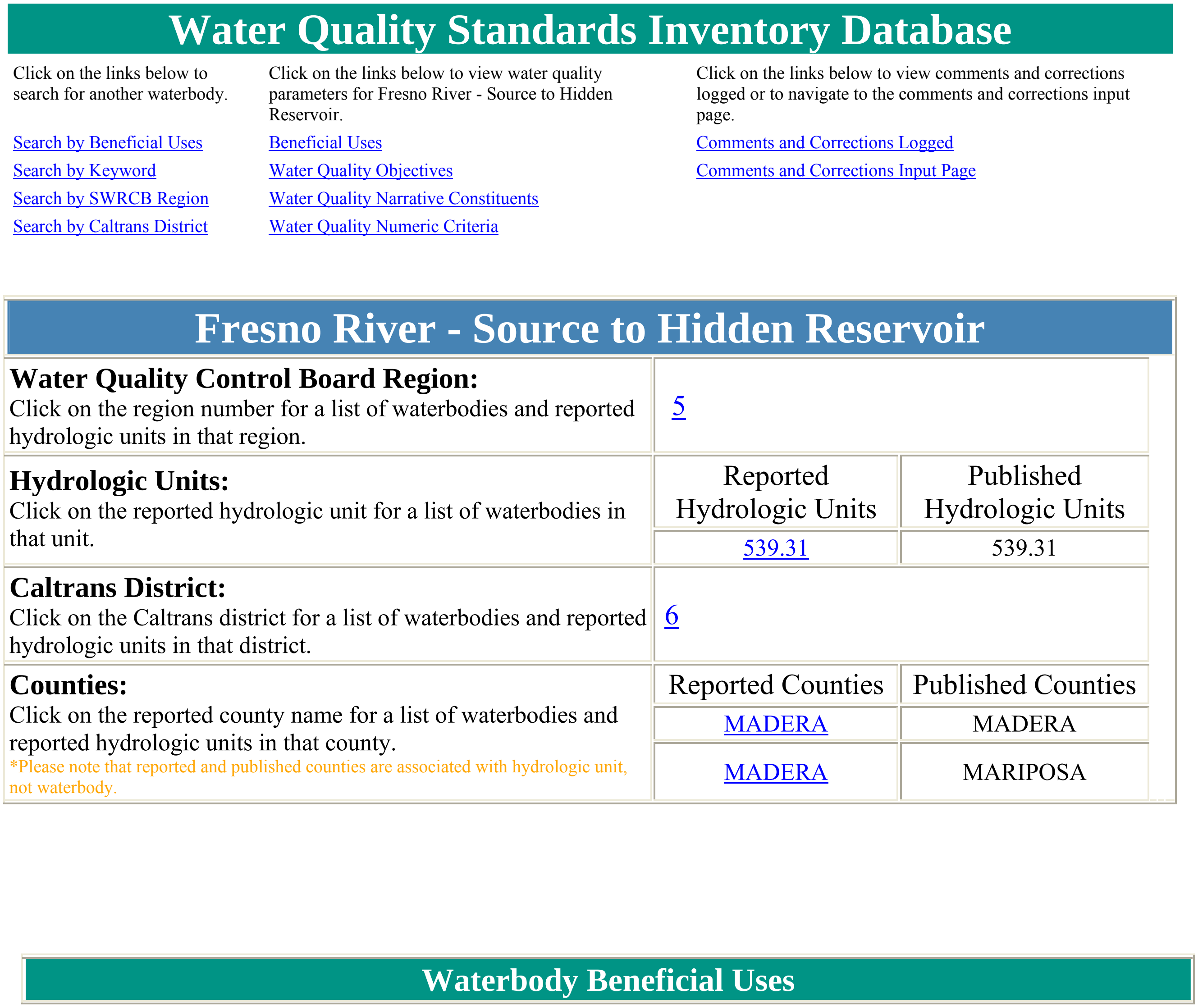
3.2. Water Quality Measurements

3.2.1 Water Quality Criteria

Evaluation of field measured parameters of water quality is based on RWQCB narrative descriptions (**Table 3.1**) for beneficial uses of Fresno River from the source to Hensley Reservoir. The Water Quality Standards Inventory Database for the upper Fresno River (http://endeavor.des.ucdavis.edu/wqsid/) reflects information in the Central Valley RWQCB Basin Plan.

The database shows that there are no specific water quality objectives for the upper Fresno River surface waters. We therefore address our results in the context of the general objectives for relevant parameters. We retained only those constituents that could be observed or measured in our site visits or through subsequent sample processing. Water quality bacterial parameters are extensively addressed in Chapter 6.

Table 3.1. Overview of Water Quality Standards from CA SWQCB & RWQCB information compiled at http://endeavor.des.ucdavis.edu/wqsid/



Water Quality Standards Inventory Database

Click on the links below to search for another waterbody.	Click on the links below to view water quality parameters for Fresno River - Source to Hidden Reservoir.	Click on the links below to view comments and corrections logged or to navigate to the comments and corrections input page.
Search by Beneficial Uses	Beneficial Uses	Comments and Corrections Logged
Search by Keyword	Water Quality Objectives	Comments and Corrections Input Page
Search by SWRCB Region	Water Quality Narrative Constituents	
Search by Caltrans District	Water Quality Numeric Criteria	

Fresno River - Source to Hidden Reservoir

Water Quality Control Board Region: Click on the region number for a list of waterbodies and reported hydrologic units in that region.	5	
Hydrologic Units: Click on the reported hydrologic unit for a list of waterbodies in that unit.	Reported Hydrologic Units	Published Hydrologic Units
	539.31	539.31
Caltrans District: Click on the Caltrans district for a list of waterbodies and reported hydrologic units in that district.	6	
Counties: Click on the reported county name for a list of waterbodies and reported hydrologic units in that county. *Please note that reported and published counties are associated with hydrologic unit, not waterbody.	Reported Counties	Published Counties
	MADERA	MADERA
	MADERA	MARIPOSA

Waterbody Beneficial Uses

RWQCB Beneficial Use Click on the beneficial use for the beneficial use code and description.	**Use Status** Potential or Existing
Agricultural Supply	Existing
Cold Freshwater Habitat	Existing
Municipal and Domestic Supply	Existing
Water Contact Recreation	Existing
Non-Contact Water Recreation	Existing
Warm Freshwater Habitat	Existing
Wildlife Habitat	Existing

Water Quality Objectives

Waterbody Reach	Beneficial Use	Constituent	Constituent Concentration	Constituent Units	Constituent Details	Constituent Comments
*No WQOs Available						

Water Quality Ammonia Criteria

Beneficial Use	Constituent Name	Constituent pH	Constituent Temperature	Constituent Time Duration	Constituent Concentration	Constituent Units
*No NH3 Criteria Available						

Water Quality Bacteria Criteria

Beneficial Use	Constituent Name	Constituent Concentration Details	Constituent Concentration	Constituent Units	Constituent Comments	Constituent Reference
REC1	Fecal Coliform	Geometric Mean-10% of Samples for 30 day	400	Count per 100 ml	Geometric mean value. Based on more than 10 percent of the total number of samples taken during any 30-day period.	
REC1	Fecal Coliform	Geometric Mean-5 Samples for 30 day	200	Count per 100 ml	Geometric mean value. Based on minimum of not less than five samples for any 30-day period.	

Constituent Name	**Constituent Description**	**Observations/Data**
Color	Water shall be free of discoloration that causes nuisance or adversely affects beneficial uses.	No discoloration noted
DO (dissolved Oxygen)	**5.0 mg/l** in all other Delta waters except for those bodies of water which are constructed for special purposes and from which fish have been excluded or where the fishery is not important as a beneficial use. For surface water bodies outside the legal boundaries of the Delta, the monthly median of the mean daily dissolved oxygen (D)) concentration shall not fall below 85 percent of saturation in the main water mass, and 95 percentile concentration shall not fall below 75 percent of saturation.	Several DO readings <5.0 during first flush in November. See Fig. 3.3 and following text.
Floating Material	Water shall not contain floating material in amounts that cause nuisance or adversely affect beneficial uses.	None noted

Oil and Grease	Waters shall not contain oils, greases, waxes, or other materials in concentrations that cause nuisance, result in a visible film or coating on the surface of the water or on objects in the water, or otherwise adversely affect beneficial uses.	None noted
pH	The pH shall not be depressed below 6.5 nor raised above 8.5.	At septic sites, 6 of 49 values were <6.5. These measures were high in the watershed from FRR 001 through FRR 020. At sediment sites, 5 of 24 values were <6.5. Two values were high elevation, three were lower (FRR 085, 090)
Sediment	The suspended sediment load and suspended sediment discharge rate of surface waters shall not be altered in such a manner as to cause nuisance or adversely affect beneficial uses.	See Chapters 4 & 5.
Settleable Material	Waters shall not contain substances in concentrations that result in the deposition of material that causes nuisance or adversely affects beneficial uses.	See Chapters 4 & 5.
Suspended Solids	Waters shall not contain suspended material in concentrations that cause nuisance or adversely affect beneficial uses.	See Chapters 4 & 5.
Toxicity	All waters shall be maintained free of toxic substances in concentrations that produce detrimental physiological responses in human, plant, animal, or aquatic life. This objective applies regardless of whether the toxicity is caused by a single substance or the interactive effect of multiple substances. Compliance's with this objective will be determined by analyses of indicator organisms, species diversity, population density, growth anomalies, and biotoxicity tests of appropriate duration or other methods as specified by the Regional Water Board.	See Chapter 6. Some high levels of Fecal Indicator Bacteria.
Temperature	The natural receiving water temperature of intrastate waters shall not be altered unless it can be demonstrated to the satisfaction of the Regional Water Board that such alteration in temperature does not adversely affect beneficial uses.	Water temperature may be altered by local water diversions
Taste and Odor	Water shall not contain taste or odor producing substances in concentrations that impart undesirable tastes or odors to domestic or municipal water supplies or to fish flesh or other edible products of aquatic origin, or that cause nuisance, or otherwise adversely affect beneficial uses.	None noted
Turbidity	Waters shall be free of changes in turbidity that cause nuisance or adversely affect beneficial uses. Increases in turbidity attributable to controllable water quality factors shall not exceed the following limits: 1) Where natural turbidity is between 0 and 5 Nephelometric Turbidity Units (NTUs), increases shall not exceed 1 NTU. 2) Where natural turbidity is between 5 and 50 NTUs, increases shall not exceed 20 percent. Where natural turbidity is between 50 and 100 NTUs, increases shall not exceed 10 NTUs. Where natural turgidity is greater than 100 NTUs, increases shall not exceed 10 percent. In determining compliance with the above limits, appropriate averaging periods may be	Turbidity is generally low in the watershed. Difficult to assess impacts because no ‘natural turbidity’ is defined for this watershed.

	applied provided that beneficial uses will be fully protected. Exceptions to the above limits will be considered when a dredging operation can cause an increase in turbidity. In those cases, an allowable zone of dilution within which turbidity in excess of the limits may be tolerated will be defined for the operation and prescribed in a discharge permit. For Folsom Lake (50) and American River (Folsom Dam to Sacramento River)(51), except for periods of storm runoff, the turbidity shall be less than or equal 10 NTUs. To the extent of any conflict with the general turbidity objective, the more stringent applies. For Delta waters, the general objectives for turbidity apply subject to the following: except for periods of storm runoff, the turbidity of Delta waters shall not exceed 50 NTUs in the waters of the Central Delta and 150 NTUs in other Delta waters. Exceptions to the Delta specific objectives will be considered when a dredging operation can cause an increase in turbidity. In this case, an allowable zone of dilution within which turbidity in excess of limits can be tolerated will be defined for the operation and prescribed in a discharge permit.	

3.2.2 Clean Water Act Section 303(d) listing for Dissolved Oxygen

In January 2009 the Central Vallery RWQCB circulated a Draft Integrated Report which included a recommendation to include a portion of the upper Fresno River in the Clean Water Act (CWA) Section 303(d) list of impaired waterbodies. Specifically:

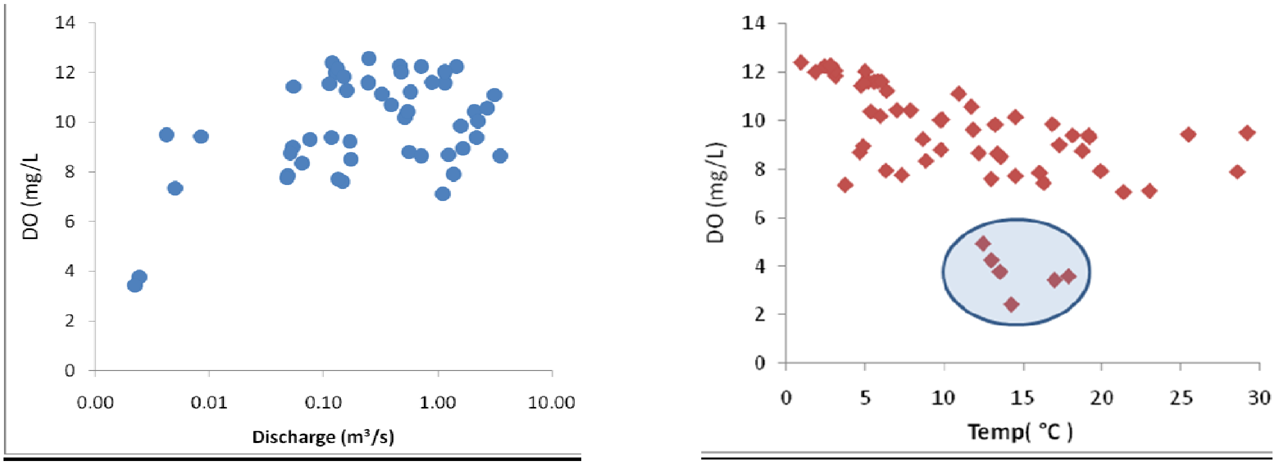
'Decision ID 8636 – listing of the Fresno River (above Hensley Reservoir to confluence with Nelder Creek and Lewis Fork) on the 303(d) list due to low Dissolved Oxygen'.

This finding was based on 15 data points collected by the RWQCB during 2001-2002. Seven of the 15 data points were deemed to be below the threshold criteria for dissolved oxygen as per designated use of the upper Fresno River. We note that most of the seven samples were taken during August and October, when conditions of low flow and warm water will naturally lead to low dissolved oxygen levels. In general, low flow reduces water turbulance and thus gas exchange with the atmosphere, and the solubility of gases decreases with temperature. The 2008-2009 data from both septic and sediment sites reflect these relationships; dissolved oxygen (DO) relationships with water discharge and temperature are both highly significant ($P<0.001$)(**Fig. 3.3**).

The listing decision cites Beneficial Use as 'Warm Freshwater Habitat', and states the Water Quality Objective/Criterion as: "The Basin Plan Objective sets the minimum Dissolved Oxygen content at 8 mg/L". **However, the lastest version of the Basin Plan (revised Sept 2009) for the Central Valley RWQCB lists the DO threshold for Warm Freshwater Habitat as 5.0 mg/L (Water Quality Objectives III-5.00).** By this criteria, only five of the 15 samples in question would be below the threshold, and according to 303(d) TMDL criteria, 5 or more samples is the threshold for listing for sample sizes ranging from 5-30.

This recent listing brings into question the validity of samples now 8-9 years old and whether new data would allay the listing process or be adequate to meet guidelines for 'delisting'. In the

2008-2009 assessement, we found that five of 27 samples were below even the 5.0 mg/L DO threshold, which is the *minimum* number of exceedances for this sample size. However, the range of sample sites in the 2001-2002 data were fairly narrow, as the stations included as per the criteria included only FRR050. FRR060, FRR080, FRR090. If we include the same range of sample sites from the 2008-2009 data, the result is two of 17 samples below 5.0 mg/L, which is not a sufficient proportion of samples for 303(d) listing.



(a) **(b)**

Figure 3.3. Dissoved Oxygen versus discharge (a) and water temperature (b) from both sediment and septic sampling events. Both relationships are highly significant. Points in oval in (b) are all from the November storm sampling event. Discharge measurements were not possible in all circumstances, resulting in fewer data points in panel (a).

Table 3.2. Mean values for measured environmental variables of water quality. (*) denotes < 0.10 significance in post hoc multiple comparison tests.

Environmental Variables	**Sites**							
	FRR001	**NED001**	**FRR030**	**FRR085**	**FRR090**	**CGC010**	**CGC020**	***p*-value**
Physical								
Elevation (ft)	4383	3017	2986	1699	1000	2089	1696	–
Drain Area (km²)	9.3	28.6	41.0	264.5	344.6	38.1	74.9	–
Impervious Area (km²)	0.07	0.15	1.50	10.03	10.46	0.40	1.47	–
% Impervious	0.8	0.5	3.7	3.8	3.0	1.1	2.0	–
Water Quality								
Temperature (°C)	4.3	8.2	7.6	11.7	12.8	13.3	12.1	0.106
DO (mg/L)	10.17	9.66	10.00	9.84	9.66	10.06	9.27	0.999
Conductivity	0.024	0.075	0.041	0.092	0.121	0.175	0.131	0.547
pH	6.56	6.73	7.10	6.55	6.18	7.95	8.20	0.308
TDS	0.015*	0.047	0.026	0.077	0.079	0.204	0.164	0.002
Discharge (cfs)	11.26	13.37	18.84	47.79	45.21	1.11*	1.05*	0.040

3.3. The Effects of the First Flood

The typical Mediterranean climate of California (i.e., wet winter and spring, and dry summer and fall) makes it important to monitor the runoff process of the first few major floods in early November or December, because the accumulated surface matters in the precedent rainless months would be suddenly flushed into the streams and water bodies causing a quick impairment of water quality in the watershed (Wang 2006).

3.4. Field Measurement of the First Flood

In order to evaluate the effects of the first flood on water quality and sediment transport in the watershed, two storm water collectors were installed at two stations: one at CGC010 on the Coarsegold Creek and the other at FRR060 on the main stem of the Fresno River (**Fig. 3.4**). The storm water collector (Global Water Stormwater Sampler, type SS201) is an automated sampling device that collects two different samples during a storm event. The "first flush" sample is collected at the beginning of a storm event and consists of the initial runoff from the storm event. The "time weighted" composite sample is collected at selected intervals during the storm event and consists of all the runoff collected at different intervals during the flood. The Global Stormwater Sampler is triggered when the attached water sensor (located at the end of the black cable) detects storm water during a storm event. The water sensor can be used with the rain gauge or by itself to trigger the automatic sampler. The water sensor, by itself, can also be used to detect storm water when placed at a predetermined height above a storm water channel.

On November 1st of 2008, a large storm was forecasted to produce a significant flood in the Oakhurst area. Thus, monitoring and sampling of this first flood was conducted. Grab samples of the river water were taken before and after the flood at stations CGC010 on Coarsegold creek, FRR035, FRR045 and FRR060 on the main stem of the Fresno River (**Fig. 2.2**). Two storm water collectors (**Fig. 3.4**) were installed at CGC 010 and FRR060. The "first flush" sample was collected when the flood water level rose for 10 cm to reach the "first flush" sensor and consisted of the initial runoff from the storm event. The "time weighted" composite sample was since collected at two-hour intervals during the flood, each time collecting 200 ml of flood water, and thus consisted of all the runoff samples collected during the entire flood period.

(a) (b)

Figure 3.4. Installation of Global Stormwater samplers at: (a) station CGC010 on Coarsegold Creek and (b) station FRR060 on the main stem of the Fresno River below Oakhurst.

3.5. Changes in water color and sediment content due to first flood

Photographs of water color and sediment traces were made to show the effects of the first flood. As shown in **Table 3.3**, the initial water quality was low by the dark color of the water. The Fresno River discharge was mainly composed of effluents from the waste water treatment facilities. After the storm, the water color became brown due to sediment addition. Large amount of surface debris and sediment were swept into the stream during the flood.

3.6. Measured nutrient concentration changes due to first flood

Table 3.4 shows the nutrient contents in water samples taken before and after the flood as well as during the flood (by "first flush" and "time weighted" samples). The instrument detectable values are shown in **Fig. 3.6**. It can be seen that the first flood caused a slight increase in nutrient content (KN) at the upstream station FRR035 (steep channel) and a slight decrease at FRR045 (end of the steep channel). At CGC010, a tributary station on Coarsegold creek, the total nitrogen (KN) and Nitrate (NO_3-N) levels were initially very high indicating accumulation of the nutrients. The "first flush" and the "time weighted" flood process caused lower concentrations although post-storm level was slightly higher than the "time weighted". This indicates that the tributary is the **nutrient losing stream** which mainly cleans the local area and transports the nutrients to the downstream areas. At station FRR060 on the main stem of the Fresno River, the pre-storm nutrient level was low, at the same level as that of the "first flush", but it steadily increased throughout the flooding period (**Fig. 3.6**). This clearly indicates that the main Fresno River is the **nutrient gaining stream**, collecting nutrients from all upstream tributaries. The Hensley Lake is the eventual repository.

3.7. Changes in sediment concentration and particle size distribution due to first flood

The first flood carries a large amount of sediments which facilitate the transport of nutrients especially phosphorous that are attached to the sediment particles. The deposited fine sediment particles also affect biota in the substrate. **Table 3.5** shows changes in particle size distribution before and after the first flood. At FRR035 on the steep channel of Fresno River, the pre-flood particles were broadly distributed between 1.5 and 250 micron meters with the weighted mean particle size of 48 microns and the total sediment concentration of 87 ppm (see **Table 3.7**). The post-flood distribution (histogram) is slimmer, with the weighted mean particle size of 32 microns and the total sediment concentration of 86 ppm (see **Table 3.7**). In other words, finer particles (<2 microns) and coarser ones (>150 microns) were largely carried away by the first flood, leaving the more uniform particles centered at 32 microns in the post-flood water. A similar pattern is observed for FRR045 where the average size decreased from 50 microns to 32 microns after the flood and the total concentration increased from 59 ppm to 202 ppm (**Table 3.7**, **Fig. 3.6**). Nevertheless, it can be concluded from this study that **the overall sediment loads in the upper streams of the Fresno River is relatively low during the flood event**.

Table 3.6 shows the dynamic scenarios of particle size distribution during the first flood at station CGC010 and FRR060 with storm water samplers. It can be seen that the coarser and finer particles were initially washed away before "first flush". The histogram became slimmer with a slightly increased average particle size at CGC010 and a slightly decreased average particle size at FRR060 (also see **Table 3.7**). After the "first flush", the extremely coarser and finer particles were loaded again in the post-flood water. The final histograms are severely skewed toward smaller particles, indicating **siltation of the river channel following the first flood**. The total sediment concentration increased ten fold from 85 to 859 ppm at FRR060 (**Fig. 3.6**), indicating that the lower Fresno River channel below Oakhurst becomes a **repository of sediments with extremely fine and coarse particle sizes**. Effects of sedimentation on the stream beds and its' biota are covered in Chapter 5.

Table 3.3. Observation of changes in water color and sediment transport due to first flood

Station	Pre-flood water color	Post-flood water color	Post-flood erosion trace
FRR035			
FRR045			
CHC010			
CGC010			
FRR060			

Table 3.4. Measured changes in the contents of Kjeldahi Nitrogen (KN), Nitrate(No$_3$-N) and ammonia (NH$_3$) in water samples taken before and after the first storm event. The “first flush” and “time weighted” samples were taken during the flood using storm water samplers.

Site	Date	Sample Type	KN(mg/L)	NO$_3$-N(mg/L)	NH$_3$(mg/L)
FRR035	**11/1/2008**	Grab before flood	**0.45**	<0.45	<0.5
	11/2/2008	Grab after flood	0.58	<0.45	<0.5
FRR045	**11/1/2008**	Grab before flood	**1.00**	<0.45	<0.5
	11/2/2008	Grab after flood	0.80	<0.45	<0.5
CGC010	**11/1/2008**	Grab before flood	**2.60**	3.50	<0.5
	11/2/2008	First Flush	1.60	1.10	<0.5
	11/2/2008	Time Weighted	1.30	0.90	<0.5
	11/2/2008	Grab after flood	1.40	1.00	<0.5
FRR060	**11/1/2008**	Grab before flood	**0.47**	<0.45	<0.5
	11/2/2008	First Flush	0.47	<0.45	<0.5
	11/2/2008	Time Weighted	1.10	<0.45	<0.5
	11/2/2008	Grab after flood	1.60	<0.45	<0.5

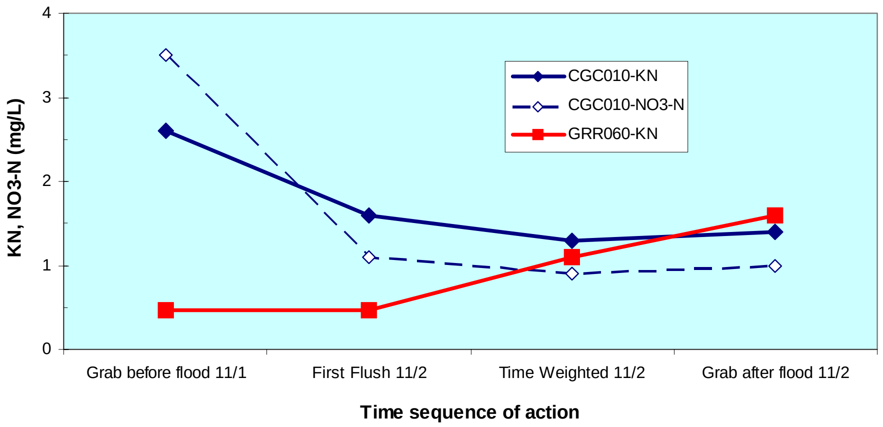


Figure 3.5. Measured changes of detectable Kjeldahi Nitrogen (KN) and Nitrate(NO$_3$-N) in water samples taken before and after the first storm event. The “first flush” and “time weighted” samples were taken during the flood event using storm water samplers.

Table 3.5. Particle size distribution of sediments in the first-flood water samples

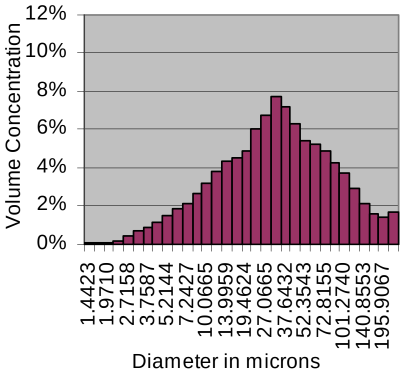
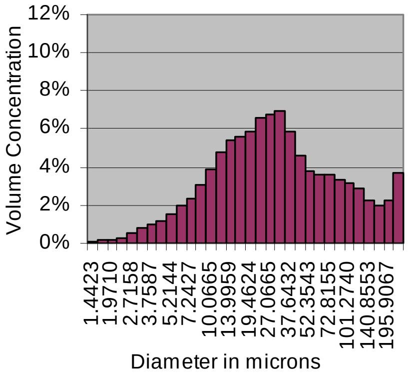
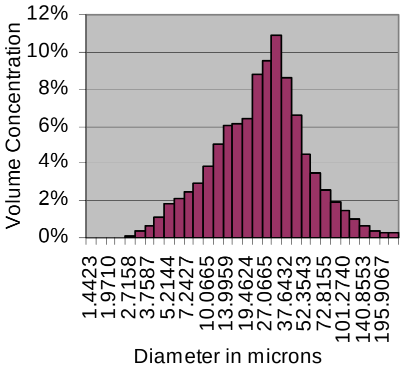
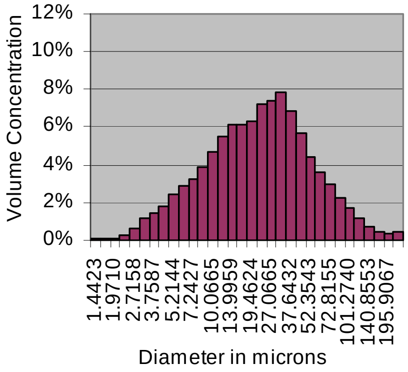
Station	FRR035	FRR045
Pre-flood		
Post-flood		

Table 3.6. Particle size distribution of sediments in the first-flood water samples

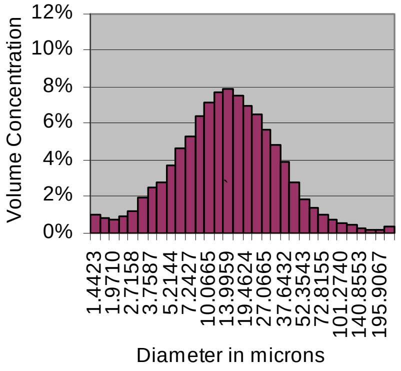
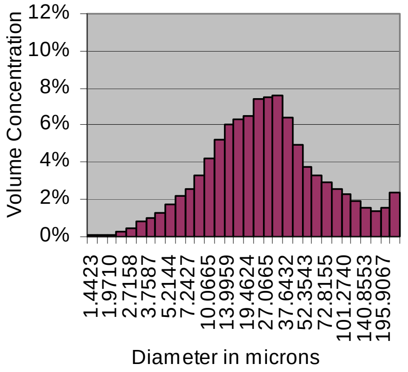
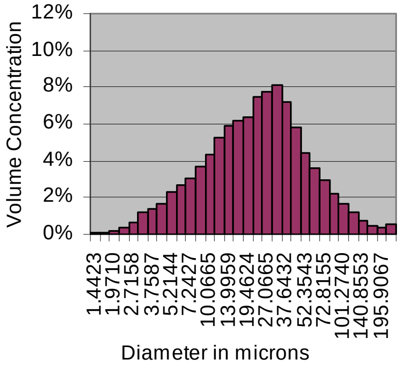
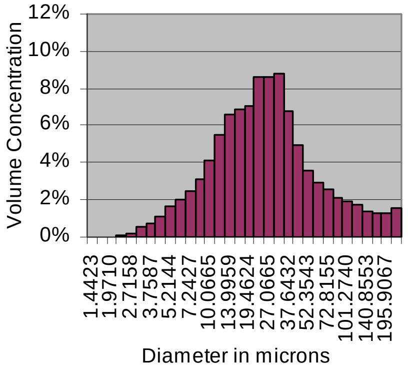
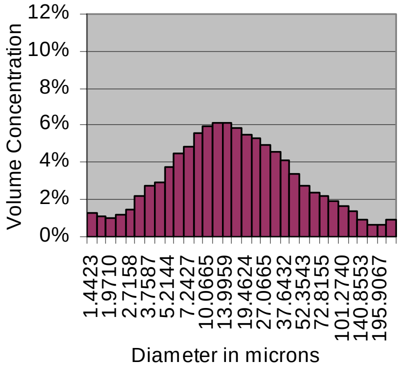
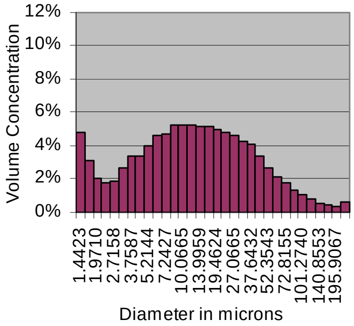
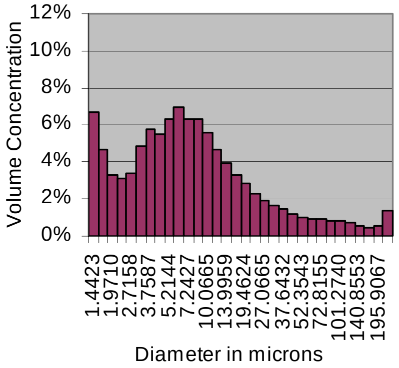
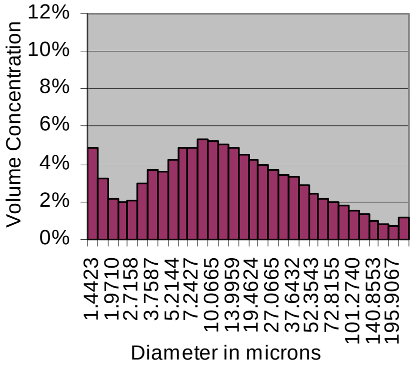
Station	CGC010	FRR060
Pre-flood		
First flush		
Time weighted		
Post-flood		

Table 3.7. Typical particle diameters (D at 10, 50 and 90 percent cumulative histogram) and the total sediment concentration in water samples from the first flood.

Station ID	Sampling Time	D10 (μm)	D50 (μm)	D90 (μm)	Weighted Average D (μm)	Total Concentration (μl/l)
FRR035	pre-flood	7.24	27.07	85.87	48.02	86.93
	post-flood	7.24	22.95	52.35	32.38	85.76
FRR045	pre-flood	6.14	22.95	119.44	50.28	58.72
	post-flood	5.21	19.46	61.74	32.05	201.75
CGC010	pre-flood	3.76	11.87	31.92	20.75	355.39
	first-flush	5.21	19.46	61.74	32.40	183.90
	time weighted	3.19	11.87	61.74	28.42	332.20
	post-flood	1.44	5.21	31.92	17.93	234.79
FRR060	pre-flood	6.14	22.95	85.87	41.97	82.19
	first-flush	7.24	19.46	72.82	38.56	91.84
	time weighted	1.97	10.07	44.39	23.19	779.52
	post-flood	1.68	10.07	61.74	26.63	858.74

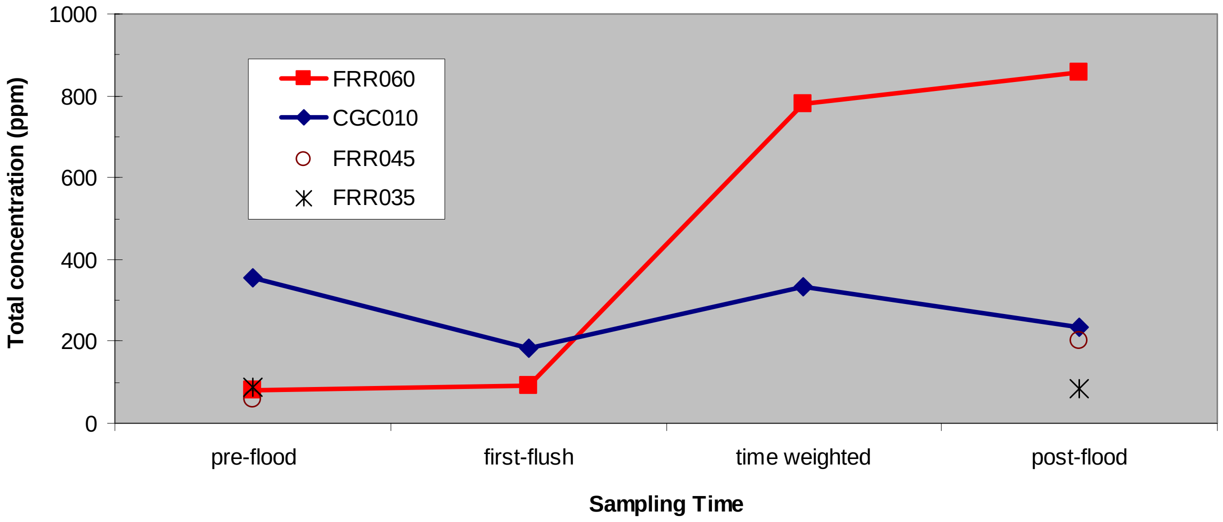


Figure 3.6. Diagrammatic of the total sediment concentrations (ppm-part per million) in water samples taken from the first flood.

3.8. General conclusions on hydrology, water quality and the effects of first flood

The following conclusions can be made based on the foregoing results:

- The long term Fresno River discharge into the Hensley Lake is trending downward, with less snow-dominated precipitation available and more interceptions in the upper areas of the watershed.
- The overall water quality in the watershed is worsening due to nutrient and sediment loading into the river.
- The effects of the first flush are strong: it cleans the tributary (nutrient losing) streams and cumulatively loading nutrients in the main stem of the Fresno River.

- The sediment load during the first flush is generally low in the upper areas of the watershed; However, it can increased ten folds during the flood in the lower part of the River sections. Thus, large amounts of sediments are loaded into the lower channel or the Hensley Lake during the flood events.
- After the first flush, the river channel is typically deposited with increased amounts of very fine and very coarse particles, causing substrate siltation that will affect habitat quality for stream biota.

4. SEDIMENTATION STUDY TO QUANTIFY SOIL EROSION AND SEDIMENT TRANSPORT

Excess sediments entering surface waters act as pollutants by physical and chemical means. The eroded sediments tend to have a higher concentration of nutrients such as phosphorus and organic nitrogen, pesticides, and other organic residue contaminants. These eroded sediments entering surface waters have the potential to adversely impact benthic organics and surface water quality. The objectives of this study were to evaluate soil erosion within the Upper Fresno River Watershed using geographic information systems (GIS) and the Revised Universal Soil Loss Equation (RUSLE) model to develop soil erosion risk assessment. Field experiments at selected sites were conducted to verify the modeling results.

This study was conducted through a thesis work by Baca (2009) for his Master of Science degree in Geology with Dr. Zhi Wang. The specific tasks were to estimate: 1) soil loss from sheet and rill erosion, 2) soil loss from gully and channel erosion, and 3) soil erosion risks of the entire watershed.

4.1. Field Measurement of Soil Erosion using Sediment Fences

Sediment erosion rates were measured from sediment fences installed during the 2008-2009 raining season. The sediment fences are made of Lumite, a black woven polypropylene geotextile with a tensile strength of 175 x 115 lbs and a permeability of 15 gal/ft^2/min (**Fig. 4.1**). The fences were installed by driving rebar sections of about 1 m depth into the ground and attaching the sediment fences with cable ties. The extra fabric was spread out in front of the fence to serve as an "apron" and secured with fabric staples, 6 in x 2 in. This apron facilitated the identification and removal of the sediment trapped by the fence.

Figure 4.1. Installation of geotextile sediment trap and apron.

Four sediment fences were installed at three different locations (**Fig. 2.2, Table 2.2**). Sediment Traps 1 and 2 were installed alongside Road 415. These sediment traps were used to measure the sediments from roadside gully erosion and from a rural residential development. This location is approximately 2,000 ft from a tributary stream of the Fresno River. Sediment Trap 3 was installed alongside Road 600 in order to evaluate hillslope sediment erosion from unpaved roads and rural development. Sediment Trap 4 was installed at the property of a resident (Mr. Larry Ballew, next to the main Fresno River) in order to measure hillside sheet erosion from a site with minimal gully erosion. The drainage areas for the sediment traps were estimated in the field and verified using aerial photographs.

Road slope was estimated using a tape and global positioning system (GPS) unit. Sediment production rates from the sediment fences were determined by weighting the amount of sediment trapped by the sediment fences. A soil sample from each site was collected and analyzed for moisture content in order to determine the soil loss rates on a dry-mass basis. Soil samples were analyzed for particle size distribution using soil sieves and a laser diffraction particle size analyzer, see Lab measurements below. Annual sediment production rates were determined by dividing the mass of the sediment by the drainage area contributing sediments.

After the rainy season, at each sediment trap, sediments were weighted and composite soil samples collected. The soil samples were taken to the Hydrology laboratory (with Dr. Zhi Wang) at California State University and were analyzed for moisture contents and grain size distributions.

4.2. The Development and Application of RUSLE Model

The development of soil loss equations began in the 1940s in the midwestern area of the United States known as the Corn-belt (Wischmeier and Smith, 1965). The Agricultural Research Service (ARS) of the United States Department of Agriculture (USDA) developed the Universal Soil Loss Equation (USLE) from numerous available erosion studies at the National Runoff and Soil Loss Data Center at Purdue University in 1954. The USLE equation was published in Agricultural Handbook No. 282 (Wischmeier and Smith, 1965). USLE was then revised to include additional techniques for estimating site specific values of its factors for additional land uses, climatic conditions, and management practices. These additional techniques included the following: a soil erodibility nomograph for farmland and construction areas; topographic factors for irregular slopes; cover factors for range and woodland; cover and management effects of conservation tillage practices; erosion prediction in construction sites; estimated erosion index values for western states and Hawaii; soil erodibility factors for benchmark Hawaiian soils; and improved design and evaluation of control support practices (Wischmeier and Smith, 1978). The USLE model has been widely applied to different farming areas and validated by numerous studies conducted at the field scale (Wischmeier and Smith, 1978). However, the application of USLE to landscape-scale erosion modeling was determined to be inappropriate (Foster and Wischmeier, 1974).

The Universal Soil Loss Equation (USLE) was later modified into the Revised Universal Soil Loss Equation (RUSLE) by Wischmeier and Smith (1978). RUSLE became the most frequently used empirical soil erosion model worldwide (Renard et al., 1997). The RUSLE model included techniques for determining the rainfall-runoff erosivity factor (R), soil erodibility factor (K), cover-management factor (C), and support practice factor (P) (Renard et al., 1997). The RUSLE model predicts annual average erosion (tons/acre/yr) resulting from sheet and rill erosion as a result of raindrop impact and surface runoff. The equation has been validated by more than 10,000 plot-years of data from natural rainfall plots, and numerous rainfall-simulation plots (Renard et al., 1997). However, RUSLE cannot be used to estimate gully or stream-channel erosion. The RUSLE model is designed to predict long term average annual soil loss primarily from cropland and rangeland under specified management systems (Renard et al., 1997). Modeling using RUSLE has expanded to larger areas such as watersheds and forestlands (Cox and Mandramootoo, 1998; Millward and Mersey, 1999). In addition, the RUSLE model has also been used in conjunction with GIS to determine the role of individual variables on the overall soil loss rates (Millward and Mersey, 1999).

Numerous methods have been derived to determine values of the six RUSLE parameters (Renard et al., 1997; Lu et al., 2004). The traditional field methods using soil erosion plots are difficult to apply because of methodology restrictions and the cost of replicating the parameter values (Lu et al., 2004). Many of the newer methods are now based on spatial determination and analysis using GIS (Cox and Madramootoo, 1998; Mitasova, 1996). The basic equation used to determine soil erosion in the RUSLE model is listed below

$$A = R \bullet K \bullet L \bullet S \bullet C \bullet P \qquad (4\text{-}1)$$

where,

A = Average annual soil loss (tons/acre/yr) resulting from sheet and rill erosion.
R = Rainfall and runoff factor - the number of rainfall erosion index units, plus a factor for runoff from snowmelt or applied water where such runoff is significant (100 ft×tonf×acre^{-1}×yr^{-1}).
K = Soil erodibility factor - the soil loss rate per erosion index unit for a specified soil as measured on a standard plot of 72.6-ft (22.1-m) length of uniform 9 percent slope in continuous clean-tilled fallow (dimensionless).
L = Slope length factor – the ratio of soil loss from the field slope length to soil loss from a 72.6-ft length under identical conditions (dimensionless).
S = Slope steepness factor – the ratio of soil loss from the field slope gradient to soil loss from a 9 percent slope under otherwise identical conditions (dimensionless).
C = Cover and management factor – the ratio of soil loss from an area with specified cover and management to soil loss from an identical area in tilled continuous fallow (dimensionless).
P = Support practice factor – the ratio of soil loss with a support practice like contouring, strip-cropping, or terracing to soil loss with straight-row farming up and down the slope (dimensionless).

The values of the above six independent factors (R, K, L, S, C, P) at every point of the watershed can be pre-determined and represented in individual GIS maps which can then be multiplied in GIS to arrive at the final total amount of erosion (A) in the entire watershed.

The rainfall and runoff factor (R) has been mapped for the entire United States. Thus the R factor can be determined by locating the drainage basin on a map and identifying the R value (Wischmeier and Smith, 1978). Alternatively for more precise calculation, site specific R factor values can be computed by obtaining continuous rainfall intensity data from recording-raingage data. This method may be more appropriate for this project because it can provide more detailed data, provided that sufficient rainfall data is available from nearby stations. Details for calculating the R factor are given in Appendix B of Agricultural Handbook No. 703 (Renard et al., 1997). To estimate the R factor accurately, the rain-gage records for all the storms in each year for many years (if available, at least 20 yrs) are required.

The soil erodibility factor (K) is the rate of soil loss per rainfall erosion index unit as measured on a unit plot length of 72.6 ft (22.1 m) and a minimum width of 6 ft with a 9 percent slope (Wischmeier and Smith, 1978). It measures the resistance of the soil to detachment and transportation by raindrop impact and surface runoff. Soil erodibility is a function of the soil properties including organic matter content, texture, particle size, and permeability. Because these properties vary within a given soil, erodibility (K values) also varies. Erodibility values of the major soils in the United States can be obtained from county Soil Survey Reports. The K values can also be estimated through the experimental equation listed below or nomographs to solve the equation (Wischmeier and Smith, 1978).

$$K = 2.1 \times 10^{-6} \times M^{1.14} \times (12 - OM) + 0.0325 \times (S - 2) + 0.025 \times (P - 3) \qquad (4\text{-}2)$$

where, M = (%silt + %very fine sand)(100 - %clay); OM = % organic matter; P = permeability class; and S = structure class.

Slope (S) and length (L) can be determined individually or jointly as the slope length and steepness factor (LS). The LS factor is an expression of the effect of topography, specifically, the joint effects of hillslope length and steepness on erosion rates at a particular site. Higher LS values mean higher risks of erosion. The value of LS increases as hillslope length and steepness increase, under the assumption that the runoff accumulates and accelerates in the downslope direction. This assumption is usually valid for lands experiencing overland flow but may not be true for forest and other densely vegetated areas (Mitasova, 1996).

Slope length is the horizontal distance from the beginning of overland flow to the point where deposition begins or runoff becomes concentrated in a channel (Renard et al., 1997). The slope length (L) factor was derived from plot studies and for field studies where slope is calculated as follows:

$$L = (\lambda / 72.6)^{m} \qquad (4\text{-}3)$$

where, 72.6 ft is equal to the RUSLE unit plot length, λ = is slope length, and
m is the slope length exponent (Wischmeier and Smith, 1978), which can be calculated using:

$$m = \beta / (1 + \beta) \qquad (4\text{-}4)$$

where, β is the ratio of rill to inter-rill erosion. β can be estimated using the following equation:

$$\beta = (\sin\theta / 0.0896) / \left[3.0(\sin\theta)^{0.8} + 0.56\right] \qquad (4\text{-}5)$$

where, θ is the angle of slope (McCool et al., 1989).

In field studies, slope is estimated using a clinometer or similar device. For field sites where slope lengths are greater than 15 ft, the slope steepness factor (S) can be calculated using the following equations (McCool et al., 1987).

$$S = 10.8 \sin\theta + 0.03 \qquad S < 9\%, \qquad (4\text{-}6A)$$

$$S = 10.8 \sin\theta - 0.50 \qquad S \geq 9\%, \qquad (4\text{-}6B)$$

The cover and management factor (C) is used in RUSLE to account for the effect of cropping and management practices on the rates of erosion (Renard et al., 1997). The nine major subfactors that affect the C factor in forests include the following: the amount of ground cover, canopy, soil reconsolidation, high organic matter content, fine roots, residual binding effects, onsite storage, steps, and contour tillage (Dissmeyer and Foster, 1980). The C factor is typically determined using a series of equations to compute soil loss ratios during actual events to standard conditions (Renard et al., 1997).

The support practice factor (P) is defined as the ratio of soil loss with a specific support practice to the corresponding soil loss with straight row upslope and downslope tillage (Renard et al., 1997). A higher P factor means soil conservation practice is less effective, leading to more erosion. The P factor is often not used in erosion studies (Lu et al., 2004; Breiby, 2006) and if used, the P factor has limited influence on the RUSLE modeling results (Millward and Mersey, 1999).

The RUSLE model can be run repeatedly using different C and P values to simulate erosion under various land management, geologic and ecological conditions.

4.3. Regional Geology

The study area is within the foothills of western Sierra Nevada with diverse geological and ecological settings. The oldest bedrock units of the Sierra Nevada are primarily metamorphic rocks that formed as a result of a series of complex plate interactions starting in the early Paleozoic (Moores, 1970; Schweickert, 1981; Saleeby, 1983; Sharp, 1988). These metamorphic rocks are intruded by granitic plutons, most of which comprise the Sierra Nevada batholith that formed as part of a late Jurassic to late Cretaceous continental margin magmatic arc, associated with east-dipping subduction of the Farallon Plate beneath the North America Plate.

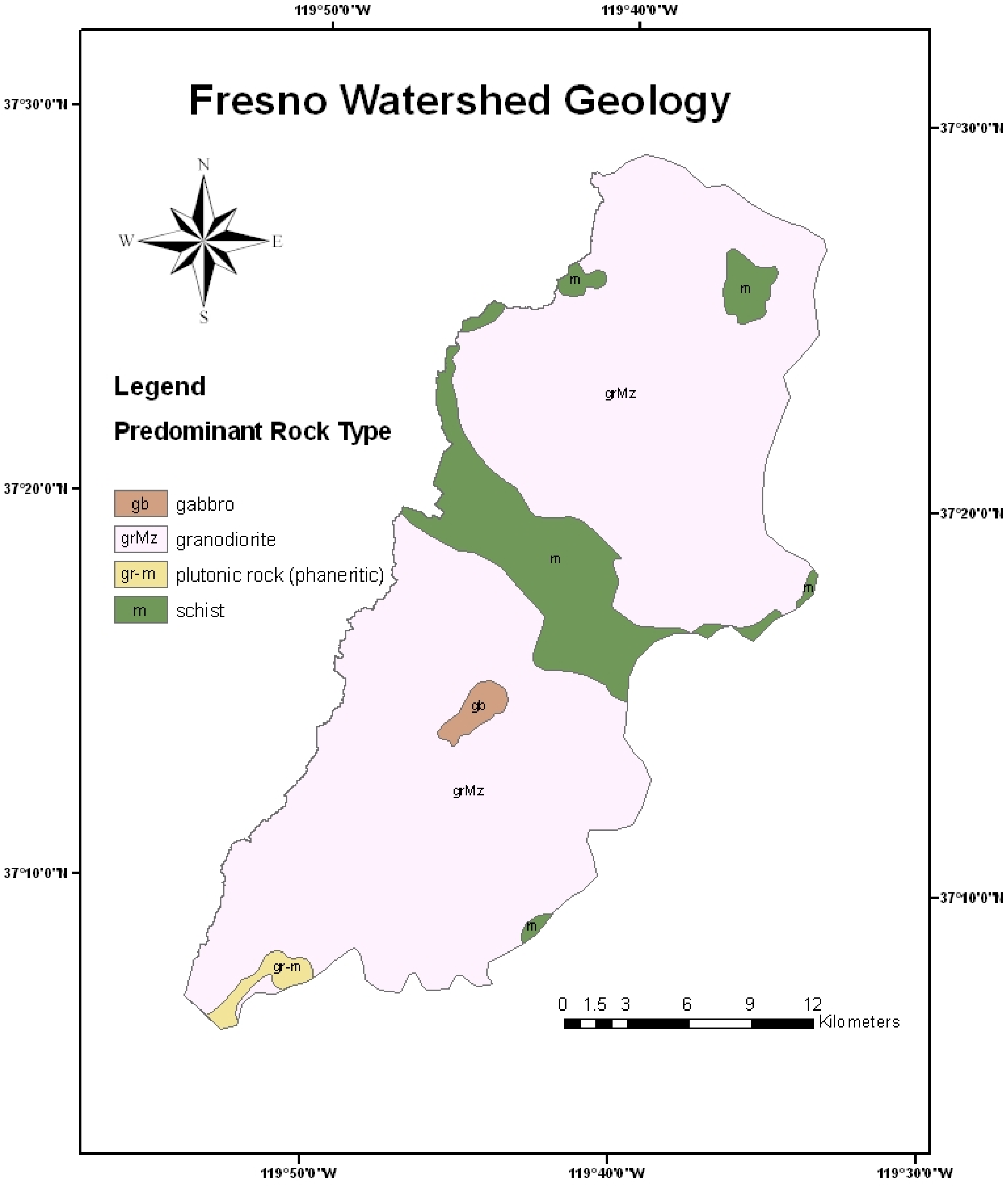
Most of the parent material of the soils within the Fresno River Watershed consists of granitic rocks (**Fig. 4.2**). However, some of the steepest terrains within the Fresno River Watershed consist of metamorphic rocks (roof pendants). In particular, some of the steepest terrain is associated with a belt of metamorphic rocks (consisting predominantly of amphibolites) crossing the middle of the Fresno River Watershed (Bateman, 1989).

4.4. Digital Elevation Model (DEM)

The slope length and steepness (LS) factor was calculated using a slope map derived from a clipped Digital Elevation Model (DEM) – a grid file at 10x10 m pixel resolution of the Fresno River Watershed (**Fig. 4.3**) and a mathematical expression relating LS with the input data. Data collection and computational procedures for generating the LS factor are described by Baca (2009).

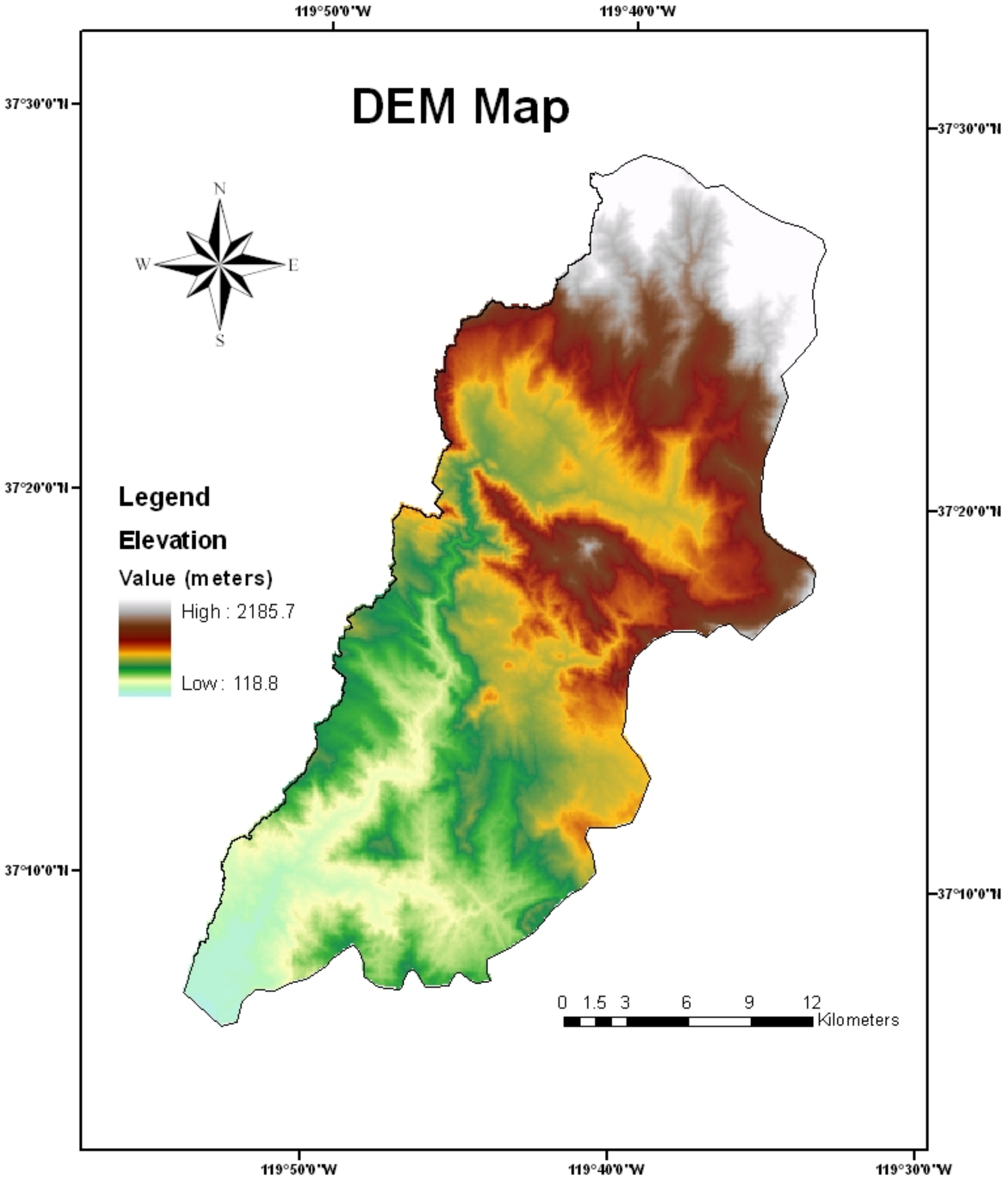
4.5. Watershed Slope and Steepness Maps

In ArcMap of the GIS software, the *Spatial Analyst* was enabled to do *Surface Analysis* and *Raster Calculation*. A slope map (**Fig. 4.4**) was generated from the DEM grid file of the Fresno River Watershed (**Fig. 4.3**). The LS factor map (**Fig. 4.5**) was generated using the DEM map and the slope map. Hillshade and contour maps were also created using "S*urface-Analysis*" and the DEM grid file in GIS to facilitate visual analyses.



Source: Online geology database obtained at
URL: http://tin.er.usgs.gov/geology/state/state.php?state=CA

Figure 4.2. Generalized geology of the Upper Fresno River Watershed (Ludington et al., 2005).



10 meter DEM - online at URL http://www.mapmart.com
Universal Transverse Mercator projection, Zone 11
North American Datum - 1927

Figure 4.3. Digital Elevation Model (DEM) map of the Upper Fresno River Watershed.

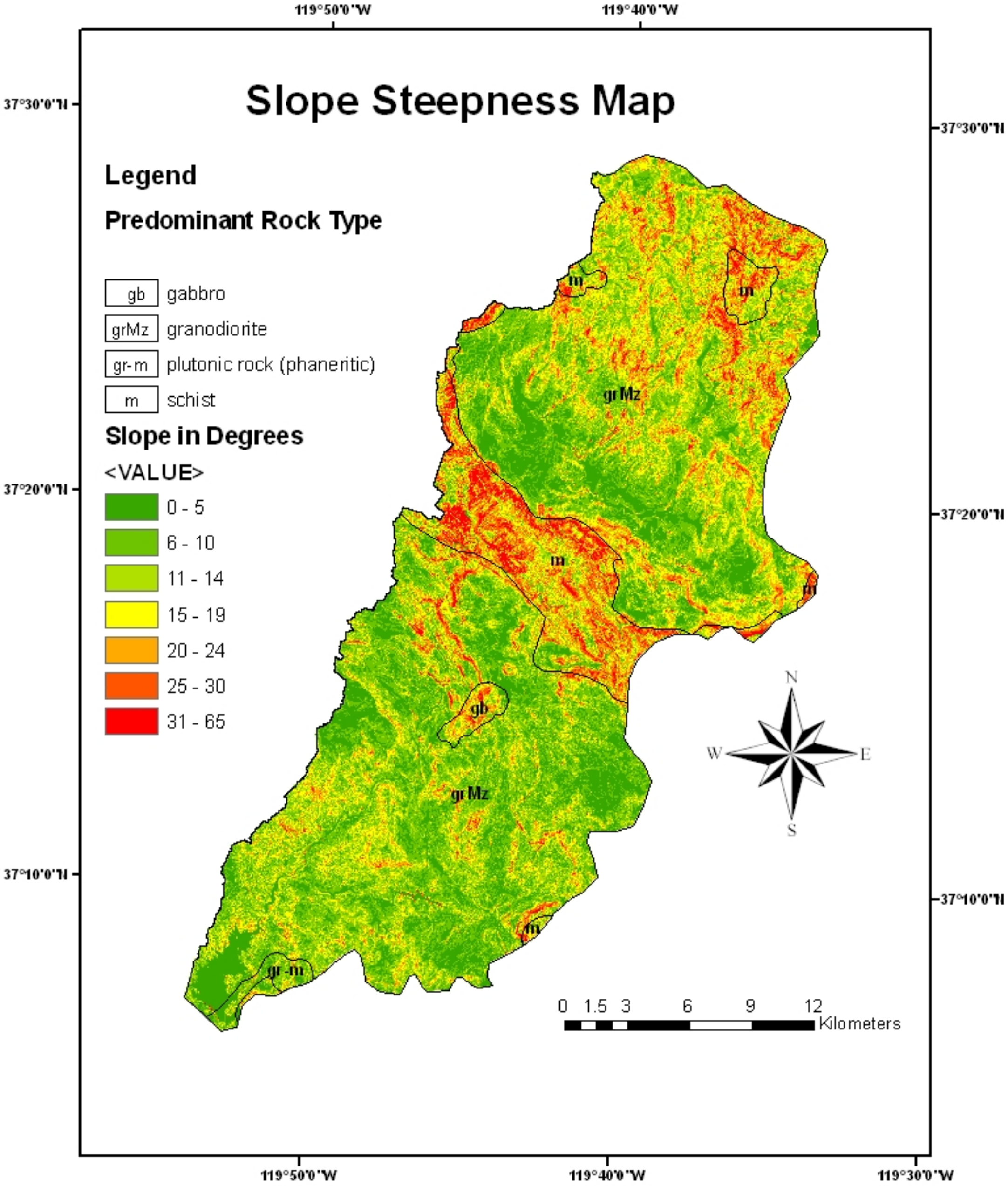


Figure 4.4. Slope steepness map and associated geology of the Upper Fresno River Watershed.

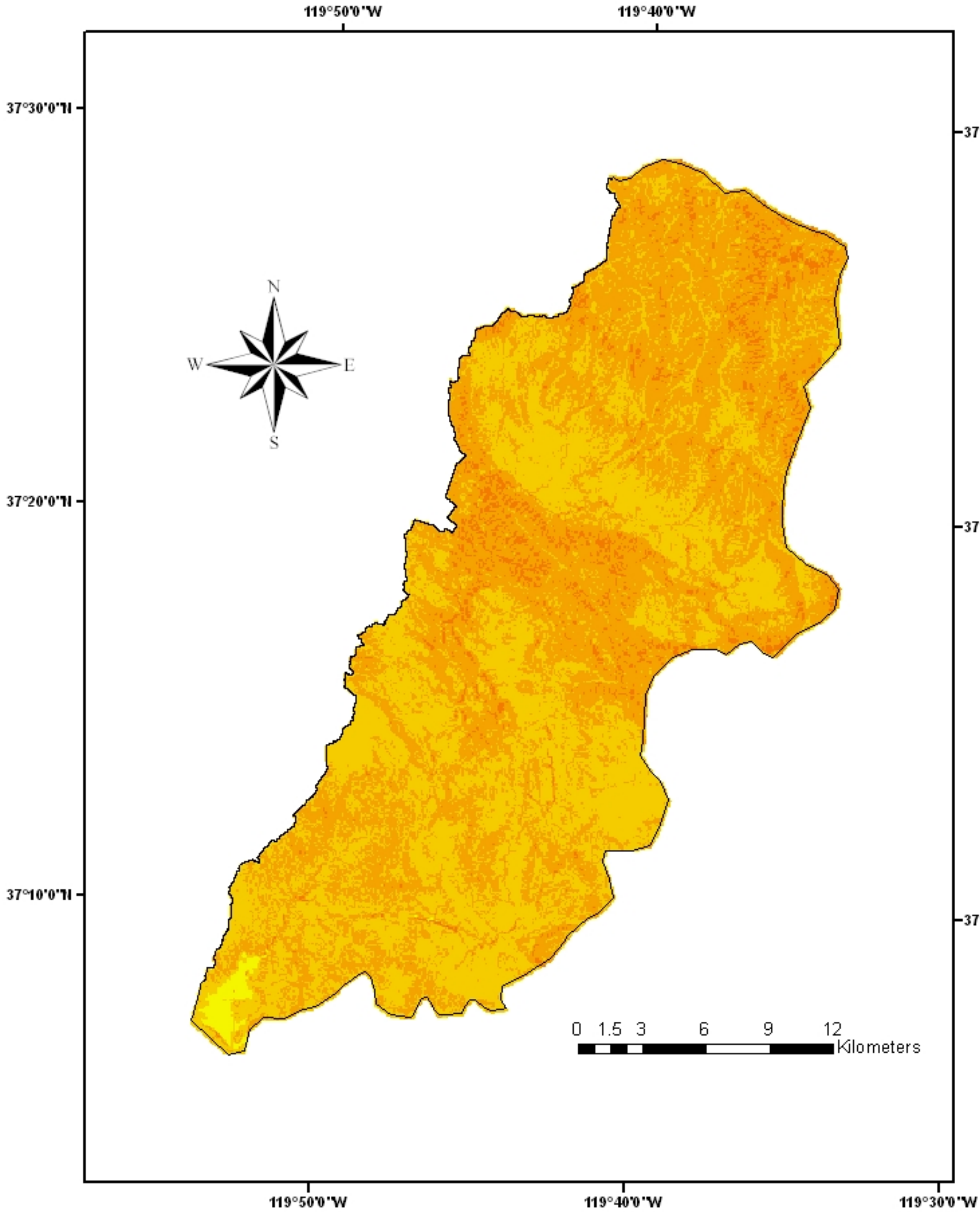


Figure 4.5. Slope length and steepness factor (LS) for the Upper Fresno River Watershed.

4.6. The Rainfall and Runoff Factor (R)

The R factor ranged from 7.4 to 31.3 within the Fresno River Watershed and correlated strongly to elevation. Results show that the R factor (**Fig. 4.6**) is greater in areas with higher elevation and greater topographic relief. The results are consistent with that of Wischmeier and Smith (1958), which state that soil loss is proportional to a rainfall factor composed of total storm kinetic energy (E) times the maximum 30-min intensity (I_{30}). Values of E and I_{30} for this study were calculated using the real historical rainfall data from rain-gage stations located within and around the Fresno River Watershed (see **Fig. 4.6**).

4.7. The Soil Erodibility Factor (K)

Soil K values can be accurately obtained from natural runoff plot experiments (Renard et al., 1997). However, due to insufficient resources it is impossible to conduct the experiment for the entire Fresno River Watershed. It is also technically impossible to conduct a statistically sufficient number of plots to extrapolate the soil erodibility results. Thus, the generalized Soil K values provided by the USDA were used for this study.

Within the Fresno River Watershed, soil K values range from 0 to 0.4 (**Fig. 4.7**). However, the majority of soils within the Fresno River Watershed have a K value of 0.3. Soils derived from metamorphic rocks have K values of mostly 0.4.

4.8. Cover and Management Factor (C)

Due to the limited information available and large study area of the Fresno River Watershed, the C factor was evaluated using suggested values in the literature and vegetation land use survey data (Wischmeier and Smith, 1958; Dissmeyer and Foster, 1980; Cal-Atlas, 2003). This was determined using data from a soil vegetation survey presented in the Cal-Atlas website http://www.atlas.ca.gov and then by selecting appropriate values from the literature. The C factor in undisturbed forest areas is noted to range from 0.0001 to 0.009 (Wischmeier and Smith, 1978).

Low and High C factor values were selected to simulate erosion under potential best case and worst case erosion scenarios, respectively. Based on the above criteria and assumptions, corresponding C values ranging from 0.001 to 0.009 were selected for the following types of land use: hardwood forest, hardwood woodland, herbaceous plants, conifer forests, conifer woodland, and urban development. **Table 4.1** shows the different C factor values assigned to the land use categories of the Fresno River Watershed.

The attributes table of the Sierra Vegetation shapefile was exported into Excel 2007 and modified to include a column with the assigned C factor values. The Excel file was then joined back to the attributes table of the Sierra Vegetation shapefile. The modified Sierra Vegetation shapefile was converted to a Grid map of the C factor (**Fig. 4.8**).

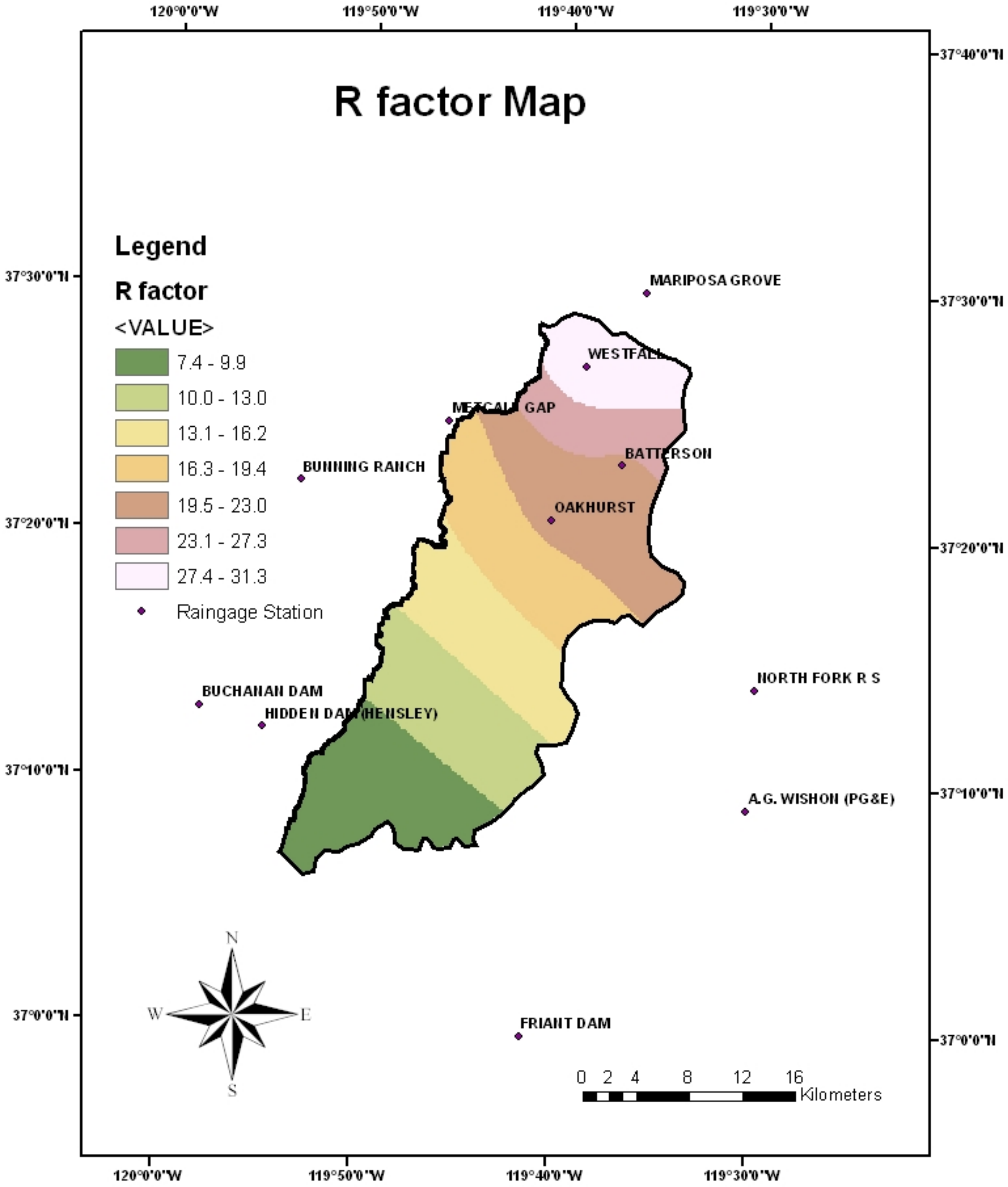
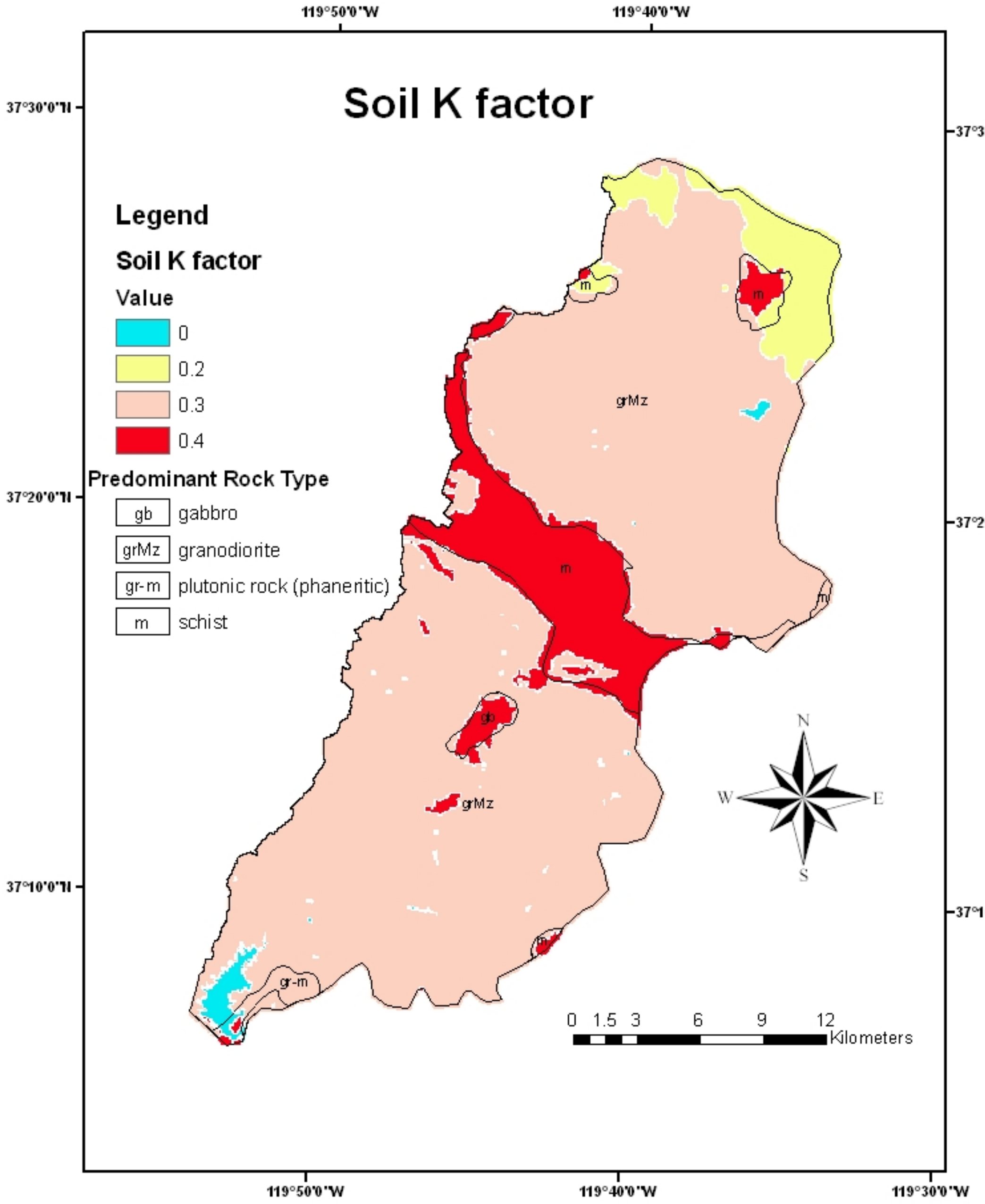


Figure 4.6. Rainfall and runoff erosivity factor (R) map for the Upper Fresno River Watershed.



Source: Online geology database obtained at
URL: http://tin.er.usgs.gov/geology/state/state.php?state=CA

Figure 4.7. Soil erodibility factor (K) and associated geology for the Upper Fresno River Watershed.

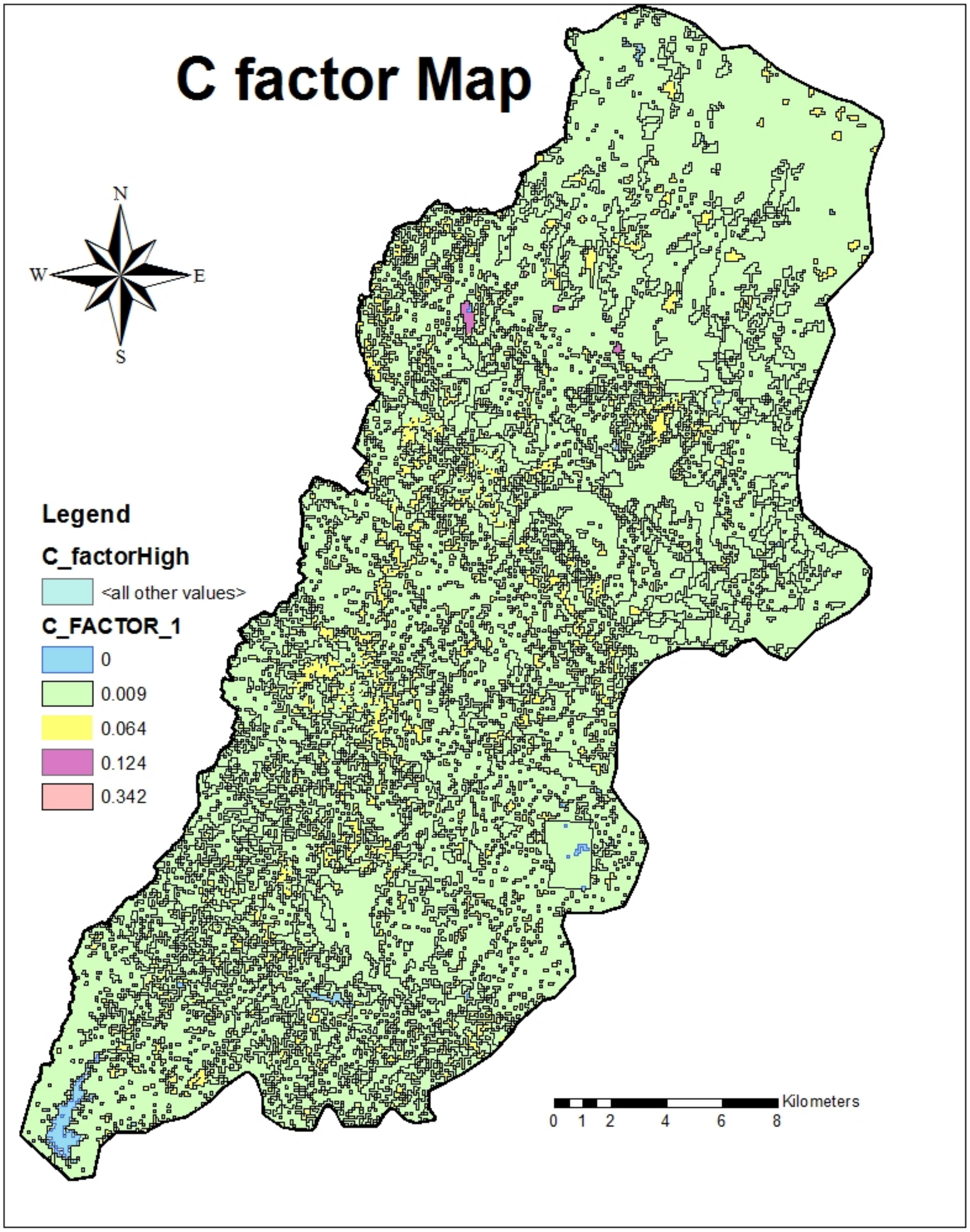


Figure 4.8. Cover and management factor (C) under less than favorable conditions.

Table 4.1. Cover and management factors (C) for different land use classes.

Land Use	Cover Management Factor		Method Source
	Low	High	
Shrub	0.014	0.064	Dissmeyer and Foster, 1980
Agriculture	0.124	0.124	Dissmeyer and Foster, 1980
Herbaceous	0.001	0.009	Wischmeier and Smith, 1958
Hardwood forest	0.001	0.009	Wischmeier and Smith, 1958
Barren – other	0.342	0.342	Dissmeyer and Foster, 1980
Hardwood woodland	0.001	0.009	Wischmeier and Smith, 1958
Conifer forest	0.001	0.009	Wischmeier and Smith, 1958
Water	0	0	Renard et al., 1997
Wetland	0	0	Renard et al., 1997
Urban	0.001	0.009	Wischmeier and Smith, 1958

4.9. Support and Management Factor (P)

There is almost no agriculture within the Fresno River Watershed. The support practices that are applied to agriculture such as contouring and terracing are not applicable to this study (Angima et al., 2003). Because this study focused on evaluating soil risk erosion, the P factor was not evaluated and kept at a constant value. The P factor is typically not evaluated or has limited influence on the RUSLE model (Lu et al., 2004).

4.10. Modeling Results

Once the RUSLE parameters were evaluated, soil risk assessment maps depicting potential annual soil loss (tons/acre/yr) for the Fresno River Watershed were generated by building the expression **[A] = [R]*[K]*[C]*[LS]** in GIS *Spatial Analyst >Raster Calculator*, where each of the RUSLE factors (R, K, C, LS) corresponds to a Grid file developed earlier. [A] is the resulting new grid file corresponding to one of the two sets of C values in **Table 4.1**.

Under low C factor values (better vegetation cover and land use management), the resulting soil erosion map is shown in **Fig. 4.9**. The estimated soil loss within the Fresno Watershed was generally low; the maximum was up to 43 tons/acre/yr. Under high C factor values (**Fig. 4.10**, poor cover and land use management); the soil loss rate could reach 200 tons/acre/yr.

The highest erosion risk potential area evaluated by the RUSLE model is located between Oakhurst and Coarsegold (**Figs. 4.9 and 4.10**). The steep topography between Oakhurst and Coarsegold is associated with a belt of metamorphic bedrocks that traverses the middle of the Fresno River Watershed **(Fig. 4.2)**.

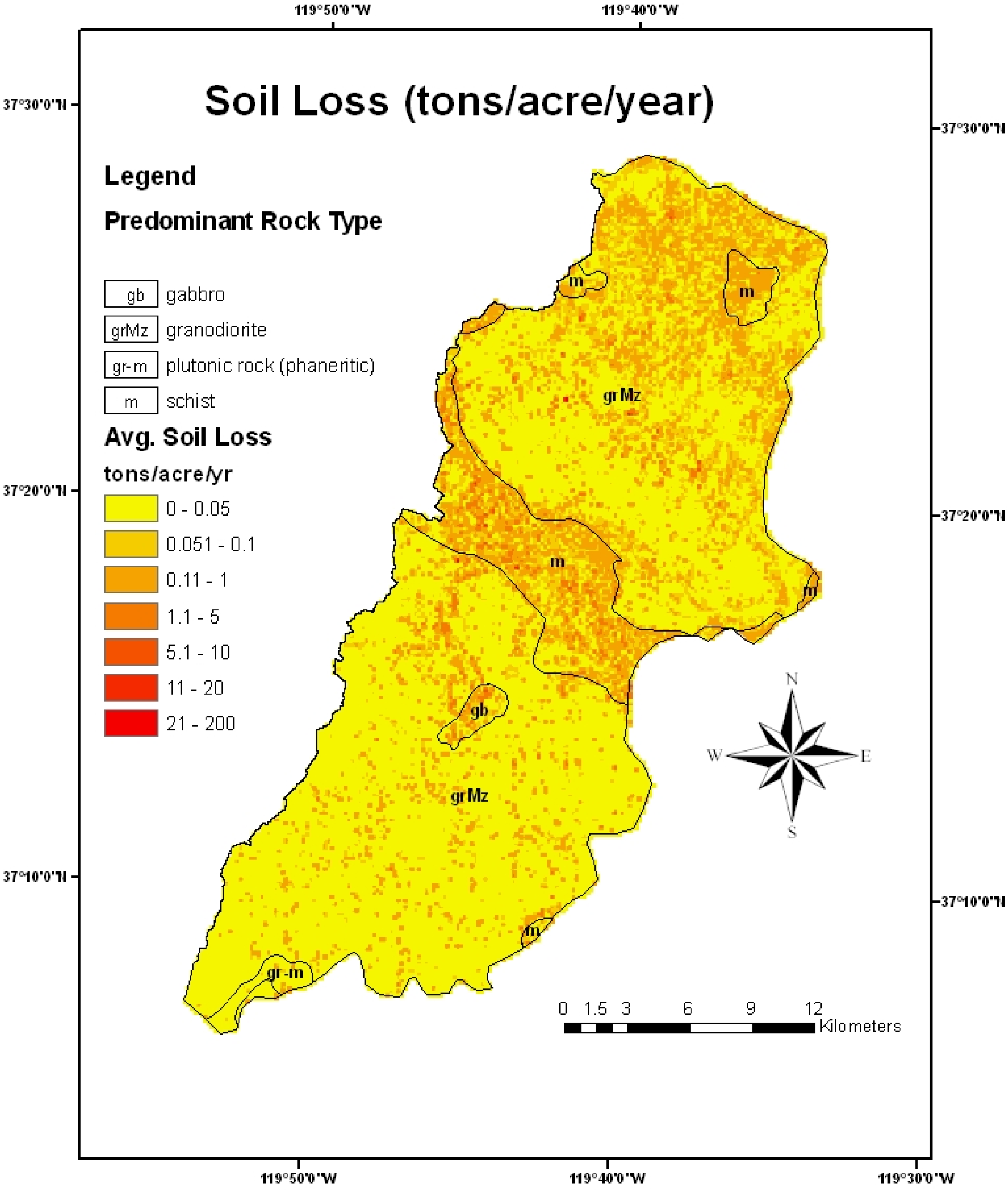


Figure 4.9. Simulated soil erosion using RUSEL under low C factor values, which are representative of good cover and management conditions.

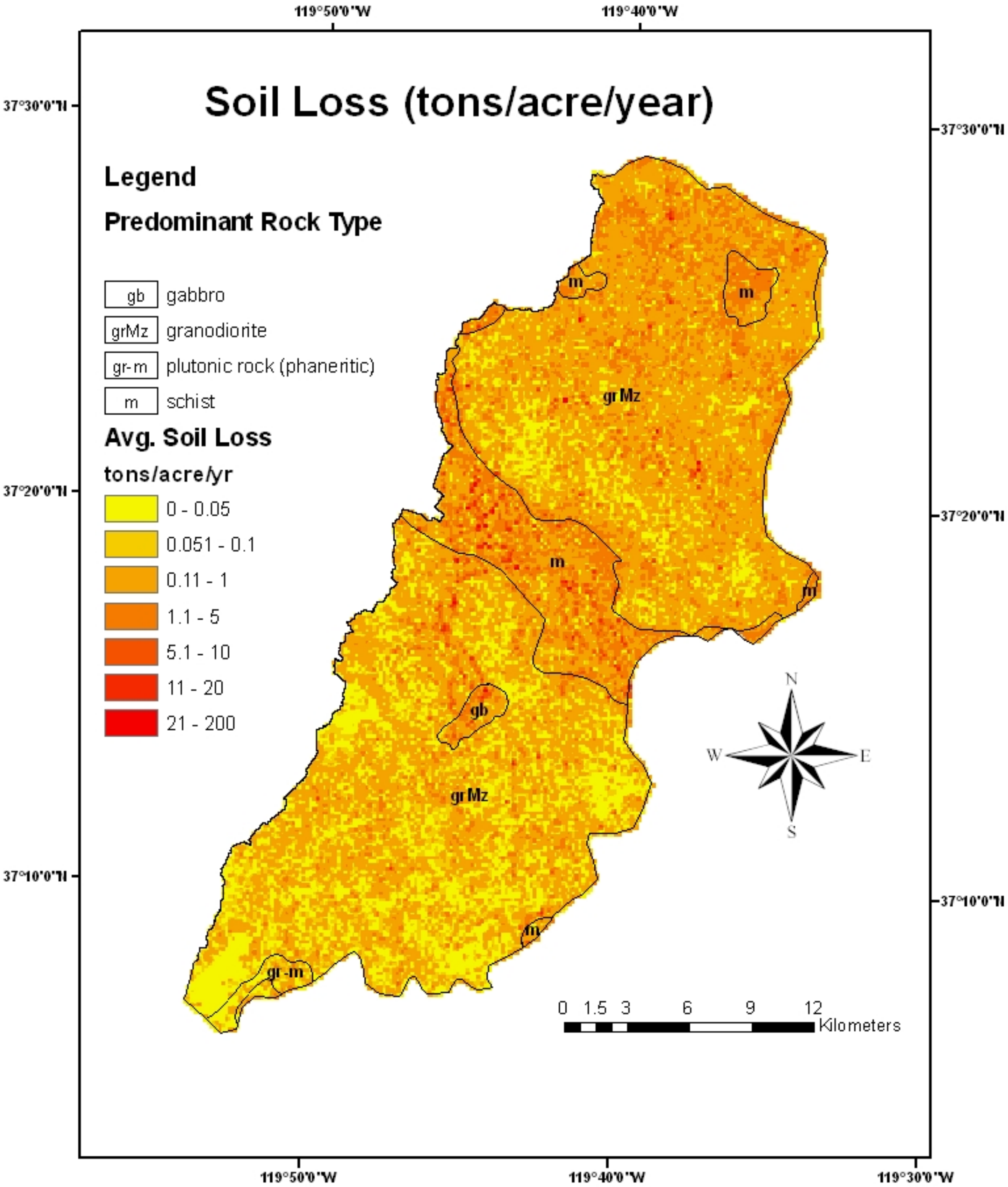


Figure 4.10. Simulated soil erosion under higher C factor values, which are representative of low percentage of ground and canopy cover and poor management conditions.

4.11. Experimental Validation

The RUSLE model indicates that under favorable cover and management conditions (Fig. 18), soil loss is less than 0.1 tons/acre/yr for the majority of the watershed. Our field experiment at Sediment Trap 4 (**Fig. 4.11**) shoed that the gross erosion was 0.12 tons/acre/yr. The hillslope drainage area of this area appears to be representative of the modeling results for most of the Fresno Watershed. Thus, the overall RUSLE model results indicate that under favorable cover and management conditions, soil loss for most of the watershed is less than 0.1 tons/acre/yr.

(a). Image modified from Google aerial photographic map.

(b). Trapped sediments

Figure 4.11. Trapped sediments in Sediment Trap #4 representing the more favorable vegetation cover and management conditions.

Areas around Sediment Traps 1 and 2 (beside Rd 415) and 3 (beside Rd 600) are more representative of erosion under less favorable cover and management conditions, such as steep slopes and highly erodible soils. Our field experiments at Sediment Traps 1 and 2 yielded a gross erosion rate of 1.31 tons/acre/yr, and at Sediment Trap 3 the yield was 1.34 tons/acre/yr (**Fig. 4.12**). As shown in **Fig. 4.13**, the RUSLE model predicted more or less (on average) the same erosion rates in the vicinity of Sediment Traps 1 and 2. However, as shown in **Fig. 4.10**, the majority of the watershed areas should have less than 1.0 tons/acre/yr of soil loss for the less favorable cover and management conditions.

(a). Trapped sediments in Sediment Traps 1 and 2 (beside Rd 415).

(b). Trapped sediments in Sediment Trap 3 (beside Rd 600).

Figure 4.12. Trapped sediments in Sediment Traps 1, 2 and 3 representing the less favorable vegetation cover and management conditions.

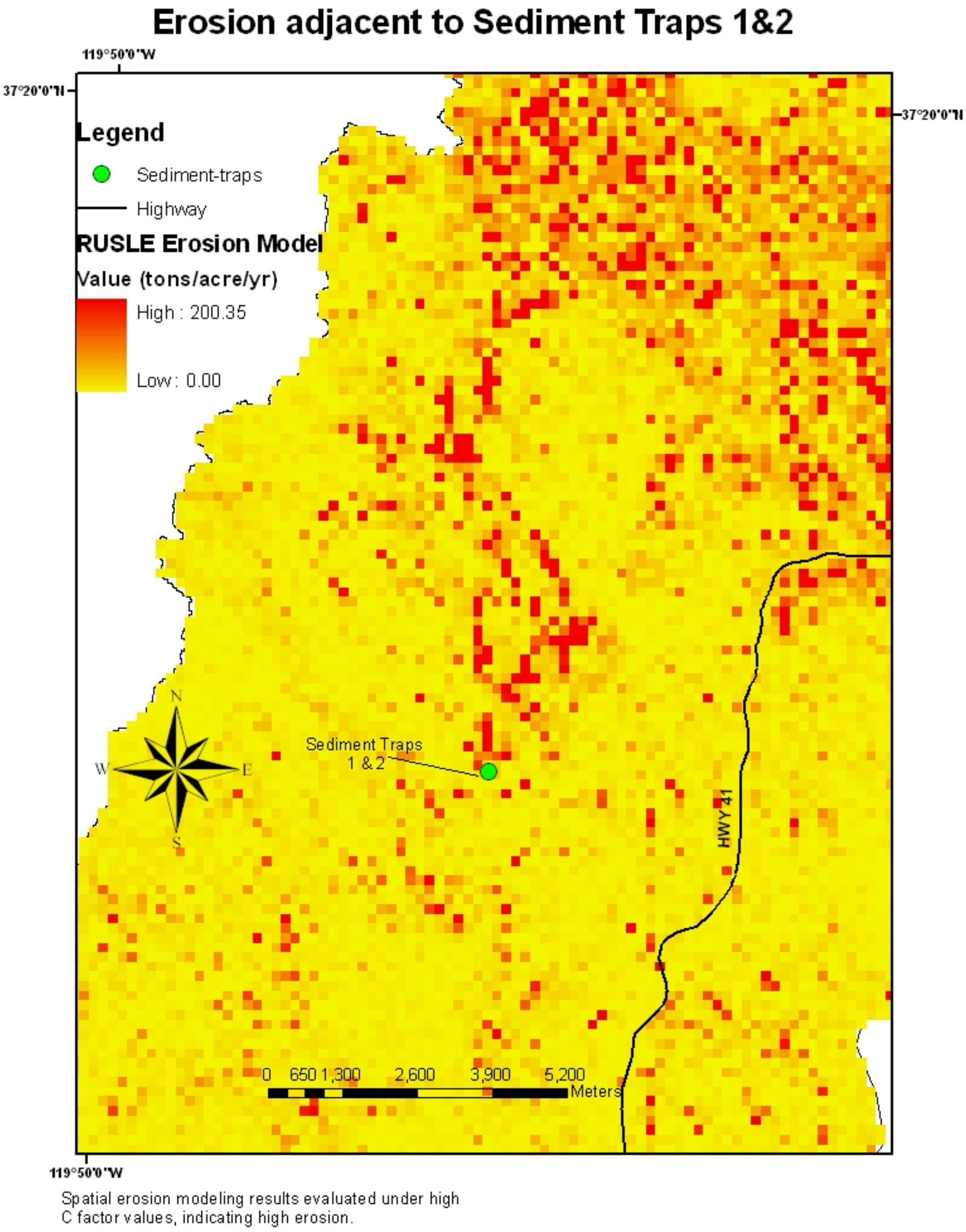


Figure 4.13. The RUSEL predicted soil loss rate around the area of Sediment Traps 1and 2, under less favorable vegetation cover and management conditions

4.12. Sediment Grain Size Distribution along the Fresno River

According to the USDA Particle size classification (**Table 4.2**), the sediment grain size distribution along the Fresno River, as shown in **Table 4.3**, is predominately skewed toward coarse sand.

On the tributary Coarsegold Creek (CGC), the grain size distribution is relatively similar between May 2008 and May 2009, suggesting insignificant annual change in fine sediment grain distribution. However, considerable coarser sediments appeared on April 3, 2009, which could be the result of the first few large storm events in the early season of 2008-2009 water year (**Fig. 8b**). On the tributary Nelder Creek (NEC), there were lesser amounts of fine silts and clay in the water; However, a large amount appeared on Nov. 6 of 2008, after the first flood on Nov. 1st.

For the main stem of Fresno River, **Fig. 4.14** shows the Pre 2008-2009 storm season cumulative grain size distribution while **Fig. 4.15** shows the post season cumulative grain size distribution. The pre season grain sizes at most of the stations were relatively homogenous. Approximately 70 percent of the stream sediments were coarse and very coarse sand, with the coarsest at Stations FRR85 and FRR90, and finest at Station FRR020 (**Fig. 4.14**). The post 2008-2009 storm season grain size distribution data (**Fig. 4.15**) show that sediments were coarsest at stations FFR060 and FRR080 and finest at Station FRR090, partially reversing the pre-season pattern.

The reduced percentage of coarse sands and very coarse sands at the Upper Fresno River sampling stations suggests that fine sediments are transported relatively easily within the watershed. Data from the lower Fresno River stations indicate that coarse sands are transported in pulses. The stations with the highest percentage of fines were found at the highest station site, Station FRR020, and also at the lowest Fresno River station, FRR090. This suggests that fines are transported longer distances relatively quickly or can increase at localized zones as fines wedge in between large gravel and boulder size rocks.

Grain size distribution data indicate that sediments entering the watershed are mostly coarse sands and may not be impacting water quality as a result of grain size. This sediment study does not reveal whether nutrients and other contaminants that may be transported with the sediment are impacting water quality. Thus, for further investigation (see next sections), a full grain size distribution ranging from clays and silts to boulders were conducted for gravel-cobble bed streams. This will provide more important information regarding the bed complexity of the stream.

Table 4.2. USDA Particle Size Classification.

Classification	Particle Size Range (mm)	
Clay	0	0.002
Silt	0.002	0.045
Very fine sand	0.045	0.1
Fine sand	0.1	0.25
Medium sand	0.25	0.5
Coarse sand	0.5	1
Very coarse sand	1	2
Fine gravel	2	10
Coarse gravel	10	750
Cobbles	> 750	

Table 4.13. Cumulative grain size distribution for sediment samples collected from selected stream sites within the Upper Fresno River Watershed.

Site Name	Date	< 0.25 mm Fine sand	< 0.5 mm Medium sand	< 1 mm Coarse sand	< 2 mm Very coarse sand	< 4 mm Fine gravel
CGC030	4/25/2008	11.35%	20.98%	64.75%	88.96%	100.00%
CGC010	5/28/2008	6.26%	11.99%	57.02%	90.25%	100.00%
CGC020	5/28/2008	12.51%	21.54%	60.43%	87.79%	100.00%
CGC010	11/6/2008	9.46%	17.30%	58.78%	84.23%	100.00%
CGC010	1/30/2009	12.32%	26.87%	61.41%	81.58%	100.00%
CGC020	1/30/2009	7.99%	16.66%	51.11%	79.66%	100.00%
CGC020	4/3/2009	1.61%	7.64%	64.04%	90.93%	100.00%
CGC020	5/22/2009	20.45%	33.86%	63.81%	82.95%	100.00%
FRR030	4/25/2008	22.03%	32.99%	68.32%	91.57%	100.00%
FRR090	5/28/2008	18.21%	28.98%	69.77%	92.86%	100.00%
FRR010	11/6/2008	21.18%	34.52%	76.17%	94.79%	100.00%
FRR016	11/6/2008	5.79%	14.09%	55.48%	87.48%	100.00%
FRR020	11/6/2008	18.39%	31.42%	70.39%	91.73%	100.00%
FRR035	11/6/2008	11.78%	28.94%	82.71%	97.63%	100.00%
FRR060	11/6/2008	17.53%	27.12%	59.03%	87.30%	100.00%
FRR080	11/6/2008	6.02%	13.44%	58.52%	92.19%	100.00%
FRR030	11/21/2008	10.46%	17.44%	54.49%	87.89%	100.00%
FRR085	11/21/2008	3.35%	9.78%	68.36%	97.07%	100.00%
FRR090	11/21/2008	3.95%	12.23%	66.81%	94.70%	100.00%
FRR030	1/30/2009	5.71%	13.27%	59.83%	90.13%	100.00%
FRR001	4/3/2009	5.87%	16.12%	80.07%	90.15%	100.00%
FRR085	4/3/2009	9.93%	26.08%	98.32%	100.00%	100.00%
FRR060	5/22/2009	2.52%	4.79%	39.02%	97.18%	100.00%
FRR080	5/22/2009	3.89%	8.17%	57.08%	92.63%	100.00%
FRR090	5/22/2009	8.59%	19.96%	74.51%	90.52%	100.00%
FRR020	5/23/2009	20.64%	35.92%	74.32%	90.63%	100.00%
FRR001	5/29/2009	21.34%	33.26%	70.19%	90.00%	100.00%
FRR030	5/29/2009	15.50%	27.94%	62.82%	86.76%	100.00%
FRR085	5/29/2009	13.09%	29.06%	91.32%	98.27%	100.00%
FRR090	5/29/2009	33.22%	52.28%	86.15%	95.10%	100.00%
NED014	11/6/2008	20.84%	35.92%	81.01%	96.71%	100.00%
NED001	11/21/2008	4.43%	8.83%	41.02%	74.67%	100.00%
NED001	1/30/2009	5.76%	15.33%	89.37%	98.01%	100.00%
NED001	4/3/2009	7.71%	20.32%	96.12%	98.64%	100.00%
NED001	5/29/2009	9.68%	16.32%	50.24%	79.69%	100.00%

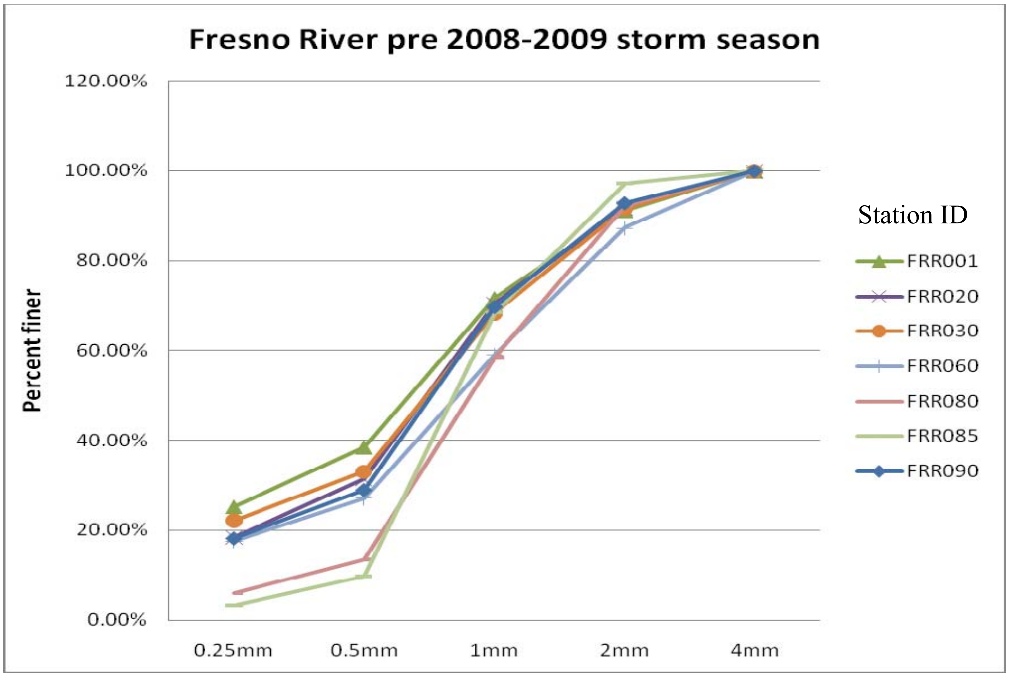


Figure 4.14. Pre 2008-2009 storm season cumulative grain size distribution for volumetric sediment samples collected from selected stream sites.

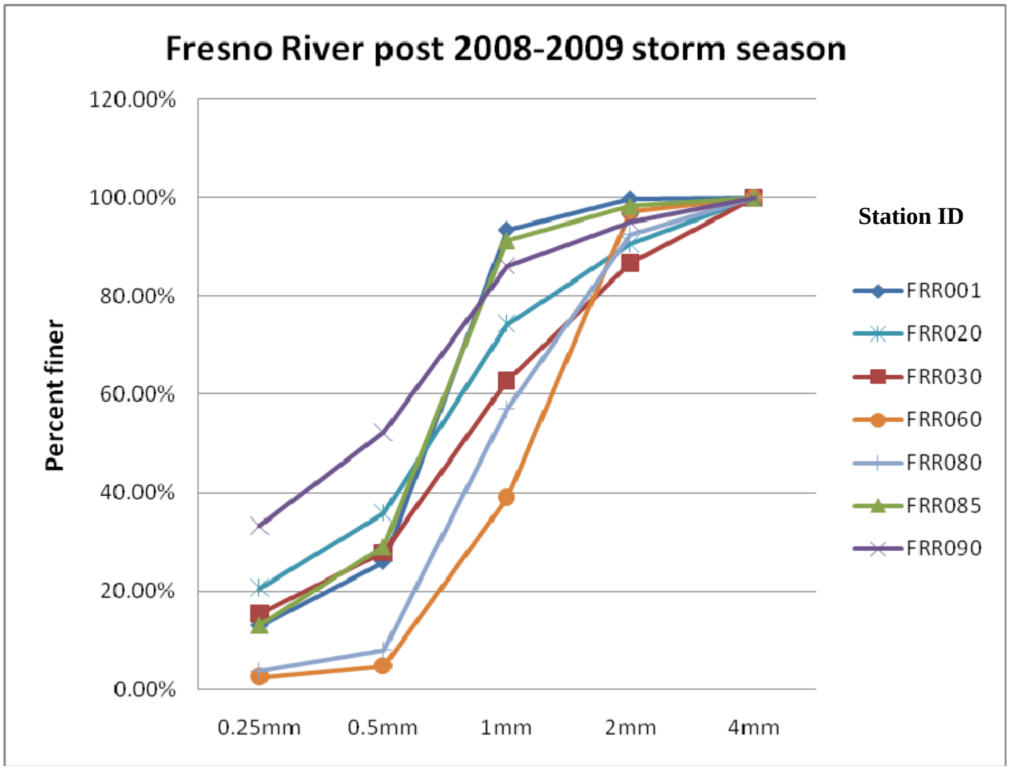


Figure 4.15. Post 2008-2009 storm season cumulative grain size distribution for volumetric sediment samples collected from selected stream sites.

4.13. Sediment Study Conclusions

1. The RUSLE model results indicate that sheet and rill erosion is minimal for most of the watershed. High erosion rates are mostly associated with specific areas with steep topography and poor land management conditions. The cover and management (C) factor was homogeneous throughout most of the watershed, suggesting that erosion within the watershed is affected more by soil types, climatic conditions, and topography.
2. Impacts to water quality within the Fresno Watershed do not appear to be a result of fine sediments entering the watershed. Grain size data indicated that the majority of the river-bed sediments were coarse sands. The majority of the very fine (clay and silt) particles were transported down to the Hensley Lake.