FINAL REPORT

Volunteer Monitoring
of
Suspended Sediment Concentration and Turbidity
and
Watershed Monitoring
of
Road Remediation in Annadel State Park

Sonoma Creek Watershed
Sonoma County, California

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Executive Summary

Between December 15, 2000, and September 30, 2002, the Sonoma Ecology Center worked with the California Department of Parks and Recreation on a project entitled Sediment Reduction in Sonoma Creek. Work for the project included:

- Analyzing road-related erosion in Annadel State Park (Annadel) near Santa Rosa, California
- Implementing remediation of old roads in the Sonoma Creek watershed portion of Annadel to address sediment delivery to Sonoma Valley's fish-bearing streams, minimize road and trail erosion, and eliminate unwanted roads and trails
- Photographing road and trail conditions before and after remediation work in Annadel
- Monitoring the effectiveness of road remediation through field estimates of erosion rates before and after project implementation
- Modeling predicted annual soil loss in the park using methods based on the Universal Soil Loss Equation, accounting for slope, vegetative cover, soil type, and subwatershed area
- Sampling Sonoma Creek and tributaries for turbidity (i.e., water clarity) and suspended sediment concentrations (SSC).

Results of each portion of the project were as follows:

- Estimated natural soil erosion rates for Annadel range from approximately 1 to 5 ton(s)/acre/year depending on soil type, soil depth, slope exposure, and topography. Erosion rates for nonvegetated road surfaces on which rill and gullies formed in Annadel are closer to 10 or 15 tons/acre/year.
- Approximately 4.8 miles of trail in Annadel were treated with equipment by road to trail conversion or full recontour. Of the trails evaluated for treatment, 3 miles (of 12-foot-wide trail) were on Schultz and Lawndale (roads on the Sonoma Creek side of the park), totaling 4.36 acres. Total remaining trail surface for Schultz and Lawndale after remediation equaled 1.95 acres, a 55 percent reduction over original nonvegetated trail surface.
- During the project period, 62 photopoints were established on four separate trails in Annadel. Fifteen photopoints were established on North Burma, fifteen on Two Quarry, eighteen on Schultz, and fourteen on Lawndale. Photopoint locations were selected to document areas with visible erosion and areas believed to be erosion prone (e.g., stream crossings and steep slopes). Photographs show that trails were rerouted, outsloped, narrowed, and closed as planned; erosion control material had been applied and had remained in place; rockwork had been done to line new water crossings and shore up trail edges. Work was completed as proposed and on time.
- For our quick estimate of soil loss, SEC collected erosion data from the North Burma and Two Quarry subwatersheds because of their similar geographic orientation and their comparable geologic and soil profiles. We also chose them for comparison with regard to pre- and post-project monitoring: the North Burma Trail had been remediated in 1998, and Two Quarry had not been completed when we examined it. Our quick estimate indicated that, at the time we made our assessment in spring 2001, less than 5 percent of North Burma Trail's surface had been affected by visible erosion. In contrast, 43 percent of Two Quarry's surface had been visibly affected at the time of our assessment.

- Results of field measuring were combined with watershed information in a sediment-production model to estimate potential soil erosivity of park areas independent of land uses. The model calculation produced a map of predicted annual soil loss for each 10-meter grid cell in Annadel. North Burma trail has undergone considerable restoration work, but some eroding segments of the trail are located in areas of high predicted soil loss. Two Quarry Trail is in very poor condition, and our quick estimate of soil loss from the trail corridor is high. However, the model did not predict high soil loss in this area, leading us to conclude that Two Quarry's poor condition probably reflects the poorly designed road. In general, our soil loss estimates may support the hypothesis that, even in relatively stable areas with little background erosion potential, a poorly sited road and history of intensive land-use impacts can cause severe erosion problems.
- SEC developed methods of water-quality monitoring to characterize existing levels of turbidity and SSC in Sonoma Creek and selected tributaries. Monitoring conducted for this project consisted of stage monitoring, grab sampling, automated data collection, depth-integrated sampling, and laboratory analysis. Sampling locations included two ongoing monitoring stations on Sonoma Creek (one of which is equipped with an automated data collection system) and 13 occasional grab-sampling sites. Grab sampling consisted of the simultaneous filling of one HACH cell and one SSC bottle. Sampling was primarily done during and directly following wet storms. Turbidity samples were analyzed in the field; SSC samples were analyzed at the Sonoma Ecology Center's M.U. D. Laboratory in Eldridge, California.

  Estimated turbidity exposure times for the five storms, the number of hours that turbidity was recorded at or above a given value, ranged from 18.17 to 109.83 hours at $\geq$0 NTU to 10 to 80.66 hours at $\geq$100 NTU. Extended times of elevated turbidity exposure resulted in severity indices (measures of deleterious effects on salmonids) associated with minor physiological stress, increased coughing rates, and increased respiration rates. Severity indices for the longer or more intense storm events were associated with moderate physiological stress and moderate habitat degradation and/or impaired homing for salmonids.

Work was supported in part by a 319(h) implementation grant awarded by the California Regional Water Quality Control Board, San Francisco Bay Region and administered by the State Water Resources Control Board, from funds provided by the U.S. Environmental Protection Agency. Other support came from a grant from the San Francisco Foundation, San Francisco Bay Fund. This document serves as a final report for 319(h) Contract 00-125-252-0 between SEC and the State Water Resources Control Board, dated April 13, 2001. The contract term began on December 15, 2000, and ended on December 31, 2002.

1.0 Introduction

This report presents results of Sediment Reduction in Sonoma Creek, a project conducted between December 15, 2000, and September 30, 2002, by the Sonoma Ecology Center (SEC) and the California Department of Parks and Recreation (DPR). Work was supported in part by a 319(h) implementation grant awarded by the California Regional Water Quality Control Board, San Francisco Bay Region (RWQCB) and administered by the State Water Resources Control Board (SWRCB), from funds provided by the U.S. Environmental Protection Agency (USEPA). Other support came from a grant from the San Francisco Foundation, San Francisco Bay Fund. This document serves as a final report for 319(h) Contract 00-125-252-0 between SEC and SWRCB, dated April 13, 2001. The contract term began on December 15, 2000, and ended on December 31, 2002.

1.1 Project Purpose and Scope

The purpose of our project was to analyze road-related erosion in Annadel State Park (Annadel), near Santa Rosa, California (Plate 1). Believed to contribute sediment to nearby streams, several degraded roadways were decommissioned (i.e., crossings removed, road surfaces graded to slope downhill [outsloped]), recontoured (i.e., roads removed and topography restored), or converted to narrow trails. In this report, all of these road-construction actions will be referred to as remediation.

1.1.1 Purpose and Scope of Road Remediation

California Department of Parks and Recreation (DPR), managers of Annadel, implemented road remediation for the project. DPR conducted two planning phases before performing on-the-ground work, as follows:

- In 1993, DPR officials documented sediment-caused damage from Annadel's backcountry roads in the Road Closure Plan (DPR 1998). (This plan closed roads to use by vehicles but not hikers, bikers, and equestrians.)
- In 1997, DPR produced Annadel's watershed planning document, the Trails Master Plan (DPR 1998).

The planning phases achieved the following:

- Identified road-related and upland sediment sources most likely to impact fish-bearing streams
- Developed implementation phases aimed at reducing road and trail erosion
- Identified a long-term objective of greatly reducing the number of roads and trails crisscrossing the park while still accommodating the needs of nearly 200,000 visitors annually.

Road remediation performed under this contract was conducted only in the Sonoma Creek watershed portion of Annadel. Specifically, work sought to address sediment delivery to Sonoma Valley's fish-bearing streams, minimize road and trail erosion, and eliminate unwanted roads and trails.

1.1.2 Purpose and Scope of Project Monitoring

SEC, the project contractor, conducted project monitoring to measure the success of road remediation in meeting the above-stated objectives. Questions addressed by each monitoring method were as follows:

- Did the DPR planning phases correctly identify the road-related and upland sediment sources most likely to impact fish-bearing streams?
- Did remediation work decrease road and trail erosion?
- Did remediation work reduce the number of roads and trails crisscrossing Annadel while accommodating park visitor needs?

Monitoring performed under this contract was conducted only in the Sonoma Creek watershed portion of Annadel.

1.2 Project Background

Annadel State Park is a 5,000-acre natural area east of Santa Rosa, California (Plate 1). The park is in Township 7 North, Range 7 West, in the United States Geological Survey (USGS) 7.5-minute Kenwood and Santa Rosa quadrangles. Project latitude and longitude are 38º25'14" North, 122º36'30" West. The site is approximately 5 miles long by 1.5 miles wide, with the long axis trending northwest-southeast. Elevations within Annadel range from 295 to 1,804 feet above mean sea level (MSL).

Project activities affected roads and trails and immediately adjacent land in multiple subwatersheds within park boundaries (Plate 2). Subwatersheds are defined for this report as the land areas discharging to the separate major perennial, intermittent, and ephemeral drainages in the park. For reference, subwatersheds have been named for the major trails that traverse them (Plates 2 and 3). In some cases, smaller subwatersheds have been combined to simplify discussion of topography and drainage. Project activities focused on Lawndale, Schultz, North Burma, and Two Quarry Trails (Plates 4a and 4b).

1.2.1 Topography and Drainage

Surface water originating within the park flows (1) as sheetflow running overland, (2) as perennial, intermittent, and ephemeral streams within first-, second-, and third-order drainages, and (3) as runoff conveyed along linear features such as roads, trails, ditches, and gullies. Flow is discharged out of the park at various points where drainages cross the park boundary. Because Annadel is contained within both the Sonoma Creek and Santa Rosa Creek watersheds, surface water draining the park potentially affects both creeks (Plate 2). Surface water leaving the eastern third of Annadel drains to Sonoma Creek and south to San Pablo Bay. Surface water leaving the western two-thirds flows to Santa Rosa Creek, west to the Russian River, and to the Pacific Ocean.

The Sonoma Creek watershed portion of Annadel is drained primarily by Schultz Creek in the Schultz subwatershed, Frey Creek in the Ridge subwatershed, and unnamed intermittent streams in the Lawndale subwatershed (Plate 2). Schultz and Frey Creeks are intermittent streams that drain plateau land at approximately 1,200 feet MSL. Schultz subwatershed also contains a smaller, ephemeral drainage in the park's southeast corner. At the head of Schultz Creek is Ledson Marsh, a reservoir with an earthen dam at its eastern end. The marsh overflows into Frey Creek in the wet season and dries up in the dry season. At the head of Frey Creek are wet meadows and Madrone Spring, a perennial spring at the base of Bennett Mountain. Surface water in the Lawndale subwatershed flows overland from higher-elevation areas to drainages in the northeast corner of the park and offsite as intermittent streamflow. The heads of two subwatersheds draining south to Yulupa Creek, a tributary of Sonoma Creek, are also within park boundaries.

The Santa Rosa Creek watershed area drains either side of a ridge that begins near the south park boundary at Bennett Mountain and extends to the northwest corner of the park. Two principal intermittent creeks drain the area northeast of the ridge. The first is an unnamed creek originating on the northeast flank of Bennett Mountain in the Two Quarry subwatershed. The creek flows northeast through Buick Meadow, turns west near the northern park boundary, along which it generally continues until leaving the park near the Oakmont community. Ephemeral flow in north-trending drainages contributes surface runoff to the unnamed creek near the park's northern boundary. The second intermittent creek drains False Lake Meadow in the North Burma subwatershed, flowing north into Santa Rosa Creek near Channel Drive. False Lake Meadow becomes wet during the rainy season and dries up in the dry months. Ephemeral drainages within the Orchard, Lower Steve's, and Warren Richardson subwatersheds drain north toward the northern park boundary and Santa Rosa Creek.

Southwest of the Bennett Mountain ridge, Spring Creek drains west to Lake Ilsanjo through the South Burma subwatershed. Spring Creek is a perennial stream, fed by year-round flow from Hunter Spring. Lake Ilsanjo is a reservoir at approximately 800 feet MSL, with impoundment at its southwest end and spillage at its west end. Ephemeral and intermittent flow also drains the ridge toward Lake Ilsanjo from the Upper Steve's, Steve's, and Marsh subwatersheds. Lake Ilsanjo spillwater continues west to the western park boundary through Spring Creek Canyon in the Spring Creek and Rough Go subwatersheds. At the western park boundary, surface water is directed north along ditches toward Spring Lake and Santa Rosa Creek. Intermittent and ephemeral drainages within Canyon and Cobblestone subwatersheds drain west and north toward the park boundary and Spring Lake and Santa Rosa Creek.

1.2.1.1 North Burma and Two Quarry Subwatersheds

Two subwatersheds analyzed in this study, North Burma and Two Quarry, are on the northeast border of Annadel, oriented and draining roughly north-northeast to Santa Rosa Creek. Exposures are generally east-northeast, with slopes vegetated by oak- and fir-dominated woodland. Because of their similar geographic orientation, North Burma and Two Quarry subwatersheds are affected by similar weather patterns. Both are exposed to Pacific storms moving generally from the northwest but are buffered from rain and wind by mountains of the Coast Ranges lying farther west and north. Rainfall within Annadel in the area of the North Burma and Two Quarry subwatersheds averages 40 inches annually (SCWA 1966).

North Burma and Two Quarry subwatersheds are underlain chiefly by Mio-Pliocene units of the Tertiary-age Sonoma Volcanics (Plate 5; Higgins 1983). These approximately 5.5- to 7.1-million-year-old volcanics are composed mostly of rhyolite, perlite, and basaltic andesite, with some obsidian, and minor deposits of silicic tuff. These rocks commonly form as lava falls, ash flows, and ash falls. Speculation about the locations of vents for the volcanic eruptions associated with the Annadel units places them anywhere from within current park boundaries to many kilometers distant (Higgins 1983). The rhyolitic flows especially, because of their viscosity upon formation, are not likely to have traveled far from their vents. The volcanoes linked to these Mio-Pliocene rocks were active for only a few million years. Exposures of volcanic rocks within Annadel indicate unit thicknesses of at least 200 meters, with the underground depths of lower contacts uncertain (Higgins 1983).

One notable difference between the geology of the two subwatersheds is the presence in the upper Two Quarry drainage of mappable beds of ash-fall and ash-flow tuff (near the South Burma subwatershed boundary). These tuffs are light tan in color and generally soft, potentially contributing fine, light-colored sediment to runoff traversing the upper slopes. Soils overlying bedrock in the North Burma and Two Quarry subwatersheds are discussed further below.

Both subwatersheds contain drainages that contribute flow to Santa Rosa Creek. As stated previously, the Two Quarry drainage originates on the northeast flank of Bennett Mountain and continues northeast through Buick Meadow, turns west near the northern park boundary, stays generally along the boundary, and leaves the site near the Oakmont community. The North Burma drainage heads in False Lake Meadow in the North Burma subwatershed, continuing north into Santa Rosa Creek near Channel Drive. Each drainage is fed by seasonal surface flow in ephemeral channels that drain upslope portions of each subwatershed.

1.2.2 Soil and Erosion

Except in the low-lying valleys and meadows where deeper clay soils are formed, Annadel's soils are rocky, shallow, and slightly acidic (SCS 1972). The Soil Conservation Service (SCS) survey of Sonoma County describes Annadel's soils as belonging largely to the Goulding series, which consists of well-drained clay loams underlain at a depth of 1 to 2 feet by metamorphosed basic igneous and weathered andesitic basalt. Other soil series, present at Annadel in minor amounts, include the Kidd, Laniger, Laughlin, Manzanita, Pleasanton, Posita, Spreckels, and Toomes soil series (SCS 1972). More information about Annadel soils and their erosivity is provided in Section 2.2.2 of this report.

In general, three major types of erosion occur naturally: sheet erosion, rill and gully formation, and mass wasting. Sheet erosion removes an approximately even and sometimes microscopically thin layer of soil from the ground surface. Rills are grooves that parallel the direction of runoff and are up to 1 square foot in cross section. Gullies are linear erosional features cut deeper and wider than 1 square foot in cross section. Gullies occur in areas losing at least 15 tons of soil per acre per year (tons/acre/year). Mass wasting is the large-scale soil movement in and on hillslopes through processes such as landslides and soil creep. Although neither quantified herein nor attributed to specific human activities in Sonoma Creek watershed, mass wasting accounts for large amounts of sediment movement in certain subbasins (e.g., Bear Creek subwatershed).

Soil eroded at a natural rate is replaced quickly through soil-building processes (Sheffer 2000). Natural soil erosion rates can more than double, however, due to anthropogenic effects. The following information has been compiled by the Napa County Resource Conservation District (Napa County RCD) regarding the impact of human activity on erosion (Napa County RCD 1994):

- Sheet erosion, rill and gully formation, and mass wasting can be accelerated by certain agricultural practices, increase of impermeable and hardened surfaces, and water diversions and other changes in watershed hydrology
- Accelerated sheet erosion can account for the removal of up to 10 tons of soil per acre per year (tons/acre/year) without significant visual effect
- When gullies and rills form, the estimated rate of soil removal is at least 15 tons/acre/year
- Accelerated streambank erosion, caused by intensified stream flows because of unnatural channel changes, can account for 300 or more tons/acre/year of soil loss.

In Sonoma Valley and Annadel State Park, estimated natural soil erosion rates range from approximately 1 to 5 ton(s)/acre/year depending on soil type, soil depth, slope exposure, and topography (Sheffer 2000). Past land uses in Annadel still believed to impact erosion potential include grazing, poorly designed road construction, and basalt quarrying activities (Hastings 2001).

2.0 Road Remediation

On-the-ground road remediation in Annadel State Park, begun by DPR in 1995 (Hastings 1998), resumed under this contract on April 1, 2001, and was completed on September 1, 2001. Lawndale and Schultz, the affected trails in the Sonoma Creek watershed, are shown on Plates 3 and 4a.

2.1 Methods of Road Remediation

Experienced DPR personnel supervised road remediation. Using topographic maps and a surveyor's wheel, DPR road experts evaluated 3 miles of Lawndale and Schultz Roads (trails) for unstable and sediment-causing conditions. Causes for concern on the road surfaces were noted and road prescriptions written to repair problem areas.

Tasks included using heavy equipment to (1) loosen compacted soil; (2) grade roadways to slope downhill (outslope) to allow water to run off trail surfaces in sheets rather than in concentrated rills; (3) remove culverts and recontour drainage crossings to create rolling dips; and (4) place sidecast material (material cast to the side of the roadways) on the uphill cut banks. Wherever they were available, rocks and large downed wood were placed at strategic locations on the reworked roadway to control visitor traffic.

Where road-to-trail stabilization and conversion could occur, the downslope berm (ridge of soil on downhill side of the road) was pulled, and the trail surface was outsloped. Topographic swales, which are very gentle topographic drainage features, were constructed to dewater the trail at regular intervals.

Hand crews placed weed-free sterile rice straw for erosion control on the newly reworked roadbeds. In the fall of 2001, seed of a non-invasive annual grass was broadcast along the edges of the road disturbance areas. During the following spring (March 2002), pre-emergent herbicide was used to treat all areas disturbed from the previous year of roadwork (removal and new trails) to reduce exotic thistle invasion.

In addition, DPR personnel monitored archeological sites before, during, and after trail crews performed road remediation. DPR archeologists were onsite every day of work to prescribe treatments, catalogue sites, and oversee road crews with regard to archeological resources.

2.2 Results of Road Remediation

Before remediation began, specific causes for concern on the evaluated 3 miles of Lawndale and Schultz Roads included:

- Along the steeper reaches of the roadways, inboard ditches acted as gullies, which when filled with water overwhelmed the undersized culverts that carry away the inboard runoff.
- During the rainy season, direct sediment-laden runoff flowed directly down the degraded roads. The amount of sediment washing off the roads with the runoff was enough to uncover large bedrock formations and tree roots and to leave the trail littered with large gravels and cobbles too large for transport. Runoff cut incised gullies into meadows and deposited large quantities of fine sediment into the creeks.
- Unstable portions of the roadway were excessively wide. Excessive width was caused by both water undermining the roadway and by visitors who were going around rough, deeply incised or muddy areas.

After remediation, the new trails avoid fragmenting open space, are limited in width (e.g., where road-to-trail conversion occurred, the trail was narrowed to a width of 4 feet), maintain grades of 5 percent or less, avoid hydrologic connectivity of roads with drainages, and are finished with erosion control material placed by hand crews. The erosion control material (1) protects the surface from raindrop impact, (2) encourages rain and runoff to infiltrate the soil, and (3) increases the soil's water-holding capacity. New trails are also outsloped, compacted, and change grade frequently, with swales about every 10 feet to dewater the surface. Frequent directional changes also discourage high visitor traffic speeds. Approximately 4.8 miles of trail were treated with equipment by road to trail conversion or full recontour.

Specific remediated trail segments under this contract included the following:

- Marsh Trail: Decommissioned and converted to a multi-use trail. Approximately 2.3 miles of degraded road were converted to 5-foot-wide trail, and .7 mile was fully recontoured and the trail re-routed. The recontoured section includes full topographic restoration of the road and outflow of the creek feeding Buick Meadow.
- Ridge Trail: Decommissioned and fully recontoured 1.5 miles of degraded road. A hand-constructed replacement trail was completed in August 2000. Total new trail distance: Approximately 1.5 miles.
- Lawndale Trail: Made drainage improvements parking lot off of Lawndale Road. Old road partially removed where new trails were installed and partially converted to

trail. The newly constructed Lawndale Trail was open to hikers only during the winter months was open to all visitors starting September 1, 2001.

- Schultz Trail: Partially converted to trail and partially removed. Newly constructed trail was open to hikers only during the winter months and open to all visitors starting August 1, 2001.

2.3 Discussion of Road Remediation

The DPR planning phases identified Annadel's roads as upland sediment sources within the park most likely to impact fish-bearing streams. This conclusion is supported by results of project monitoring (Section 3.0). We can also say that remediation work decreased road and trail erosion: when simply considering that road remediation reduced the amount of nonvegetated surface area exposed to raindrop impact, the project was successful in reducing trail erosion potential. Within the Sonoma Creek watershed portion of the park, Schultz and Lawndale Trails originally totaled 3 miles in length and averaged 12 feet wide, totaling 190,080 square feet or 4.36 acres. Two miles of these trails were completely removed (10,560 feet x 12 feet wide = 126,720 square feet or 2.9 acres) and 1 mile was converted to a 4-foot-wide trail (5,280 feet x 12 feet wide = 63,360 square feet or 1.46 acre converted to 0.49 acre of trail). Total remaining trail surface for Schultz and Lawndale therefore equals 1.46 plus 0.49 acres, or 1.95 acres, a 55 percent reduction over original nonvegetated trail surface.

Trail surface was reduced while accommodating park visitor needs. Work was staggered such that areas accessible by trails closed for curing during the winter months were also accessible by trails left open (e.g., when Lawndale and Schultz closed in winter, Two Quarry remained open for visitor access).

In DPR's experience, decommissioned roads are often aggressively invaded by weedy species. The sites will be monitored, and weeds will be removed as necessary. DPR experience also shows that visitors are sometimes slow to change their trail-use habits. DPR excluded mountain bikes and horses from using the newly constructed trails through the first wet season; however, in some instances, visitor used closed trails even when they were well marked. Bicycle and equestrian use on new, wet trails, more than hiker use, necessitates a substantial amount of tread repair the first and second seasons. The DPR maintenance experts and volunteers will continually monitor the trail for drainage problems and will repair them where necessary.

3.0 Project Monitoring

SEC monitored project success in consultation with staff at RWQCB (Hurley 2000; Napolitano 2000). Project monitoring included the following:

- Photopoint Analysis
- Quick Estimate
- Sediment Production Analysis
- Water-Quality Sampling.

3.1 Photopoint Analysis

SEC staff established monumented locations (i.e., locations mapped with respect to permanent landmarks) to photograph trail conditions in Annadel. The monumented locations, known as photopoints, were selected at areas of visible erosion along the trails. Photographs were taken at each photopoint before construction began and at construction completion to provide a graphic record of remediation impacts.

3.1.1 Methods of Photopoint Analysis

During the project period, 62 photopoints were established on four separate trails in Annadel. Fifteen photopoints were established on North Burma, fifteen on Two Quarry, eighteen on Schultz, and fourteen on Lawndale. (Note: North Burma and Two Quarry are in the Santa Rosa Creek [Russian River] watershed, but were studied for comparison. DPR remediated roads in the Santa Rosa Creek watershed under a separate contract.) One of the trails in the Santa Rosa Creek watershed, North Burma, was remediated in 1998 but was selected for comparison with trails still to be remediated. Photopoint locations were selected to document areas with visible erosion and areas believed to be erosion prone (e.g., stream crossings and steep slopes).

Distance to photopoints from each trailhead was measured using a surveyor's wheel. Four-inch-long wooden stakes marked with fluorescent paint were driven into the ground at the photopoint locations. Surveyor's flagging marked the approximate location of the wooden stake, and tape and compass were used to measure the distance and azimuth from the surveyor's flagging to the photopoint stake. The azimuth of the photographic shot also was noted. These details were logged in a field notebook and transferred subsequently to a computer database at the Sonoma Ecology Center's Sonoma Valley Watershed Station in Eldridge. Photopoint locations, along with erosion locations and trail alignments, were also documented using GPS (Plates 4a and 4b). The GPS photopoint database includes the photo number, photo code, and location descriptors so that every photopoint has a unique descriptor. This information was entered into the existing Annadel GIS database maintained by SEC.

One vertical and one horizontal photograph were taken for each azimuth at each location. In most cases, downtrail and uptrail azimuths were shot at each location (i.e., downtrail being the direction looking back down toward the trailhead). In some locations where gullies or rills had formed adjacent to the trail, an offtrail photograph also was shot. The photographic record for Annadel is stored in binders and on electronic discs available for public viewing at the Sonoma Valley Watershed Station. Examples of pre- and post-project photographs comparing before and after conditions of the trails are in Figure 1.

3.1.2 Results of Photopoint Analysis

Photographs show that trails were rerouted, outsloped, narrowed, and closed as planned; erosion control material had been applied and had remained in place; rockwork had been done to line new water crossings and shore up trail edges. Work was completed as proposed and on time.

Other specific changes included the following:

- Inboard ditches, which channel runoff along the inside of trails, were eliminated and replaced with outsloped surfaces that have regularly spaced swales for effective dewatering
- Trail surfaces were narrowed and minimized
- Boulders were placed trailside to dissuade users from straying onto and impacting vegetated areas
- Obvious gullying and direct sediment delivery to streams was eliminated by rerouting trails away from wet crossings
- New trails were rerouted onto gentle grades, minimizing headward erosion on steep slopes.

3.1.3 Discussion of Photopoint Analysis

The photopoint analysis was a valuable tool for recording pre- and post-project conditions along the remediated trails. Selecting areas of known erosion mandated assessment and stratification of all trail surfaces. Establishing photopoints with regard to permanent monuments and using GPS proved useful for drawing GIS-based maps of trail conditions. Evidence of trail surface improvements, as shown in the photographs, proved to be valuable background material for the project's education and outreach components.

3.2 Quick Estimate

SEC staff counted and measured erosional features in Annadel for a "quick estimate" of soil loss from the road and trail surfaces (Reid 2000). In a quick estimate, staff measure square footage of gullies and rills on the trails to estimate soil lost from each feature. Staff also measure square footage of areas obviously stripped by surface erosion (e.g., obvious because of exposed boulders, tree roots, trail downcut) for an estimate of soil lost from nonvegetated surfaces. Total measured areas are then extrapolated over the total length of the trail for an erosion rate for the overall trail surface.

3.2.1 Methods of Quick Estimate

SEC collected erosion data from two subwatersheds in Annadel. We selected the North Burma and Two Quarry subwatersheds for analysis because of their similar geographic orientation and their comparable geologic and soil profiles. We also chose them for comparison with regard to pre- and post-project monitoring: the North Burma Trail had been remediated in 1998, and Two Quarry had not been completed when we examined it.

Following the study's start date in January 2000, staff recorded observations of erosional features on North Burma and Two Quarry Trails. The lengths of both trails were walked with a surveyor's wheel while staff made qualitative evaluations of trail condition following the criteria listed in Figure 2, Trail Evaluation Worksheet. Trail condition was described as excellent, good, fair, and poor (Figure 2; Plate 2). Trail segments observed as falling within each category were measured with the surveyor's wheel. To be conservative in our study results and discussion, only segments listed as having "poor" trail condition were considered subject to past or present surface erosion. Rills and gullies, where observed, were measured using tape and ruler. Results were entered into a field notebook and stored on computer in an electronic summary of observable trail conditions.

3.2.2 Results of Quick Estimate

Observations and measurements made along North Burma and Two Quarry Trails during the spring 2000 and 2001 field seasons indicated the following:

3.2.2.1 North Burma

- User-caused rutting or visible erosion on the trail surface ("poor" trail condition on Plate 2) for approximately 414 linear feet (<5%) of the total measured trail length of 8,760 feet
- Approximately 23 isolated locations where surface or subsurface water flow crosses the trail and causes wet areas apparently susceptible to user-caused rutting
- Incipient rill formation (rills less than 1 square inch in cross section) in one of the wet areas noted above
- Gully formation in another wet area at the intersection with Warren Richardson Trail where surface flow crosses the North Burma Trail and causes gullying downslope toward Lake Ilsanjo (gully more than 1 square foot in cross section offtrail).

3.2.2.2 Two Quarry

- Visible erosion on the trail surface ("poor" trail condition on Plate 2) for approximately 4,494 linear feet (43%) of the total measured trail length of 10,642 feet. On the upper trail, between the Two Quarry bathroom and the Frey Canyon overlook, 616 linear feet (19%) of the total 3,304 feet are in poor condition. The lower trail, between the Frey Canyon overlook and the trailhead at the Warren Richardson intersection, has 3,878 (54%) of 7,158 linear feet in poor condition
- Approximately nine isolated locations where surface or subsurface water flow crosses the trail and causes gullies ranging in cross section from 27 square inches to 12 feet
- Major gully formation in the outboard edge of the trail at least two additional locations, not coincident with water crossings.

Table 1 summarizes results from our Quick Estimate of North Burma and Two Quarry trails.

Table 1. Summary of Results, North Burma and Two Quarry Trails

Trail	Total Length (linear feet)	Trail in "Poor" Condition (linear feet)	Trail in "Poor" Condition (percentage of total)	Gully Formation
North Burma	8,760	414	<5%	Minimal
Two Quarry				
Upper Trail (upslope from Warren Richardson)	3,304	616	19%	Major
Lower Trail (downslope from Warren Richardson)	7,158	3,878	43%	Minimal

3.2.3 Discussion of Quick Estimate

Much of Annadel has shallow surface soil underlain by hard bedrock. Visible erosional features are rare except where old quarries, roadcuts, roadbeds, and steep trails channel captured water, thereby focusing its erosive power (DPR 1998). Notably, gullies form where drainages cross trails and roads, so that flow is conveyed across outboard fill. The gullies extend and enlarge downslope from the outboard fill areas as downcutting continues. Mass wasting along roadcuts in Annadel is evident but rare.

Our quick estimate indicated that, at the time we made our assessment in spring 2001, less than 5 percent of North Burma Trail's surface had been affected by visible erosion. Additionally, the new North Burma had virtually no gully formation along its 8,760-foot length between the time of its completion in 1998 and our evaluation in 2001. Sediment had moved from North Burma's surface in 23 wet areas during the 2000-2001 season, but in these cases it appeared to have mobilized short distances (50 feet or less) to nearby level areas rather than long distances to drainages. With an average trail width of approximately 5 feet and an affected area of approximately 414 square feet (0.01 acre), an estimate of the amount of sediment eroded from the new North Burma trail can be written as follows:

North Burma ton/year = 0.01 acre x 15 tons/acre/year = 0.15 ton/year

Where 15 tons/acre/year is an estimated rate of soil removal where gullies and rills form (Napa County RCD, 1994).

Therefore North Burma at the time of our assessment appeared to be yielding considerably less than 1 ton of sediment per year, with only a small percentage of this amount being directly delivered to waterways.

In contrast, 43 percent of Two Quarry's surface had been visibly affected at the time of our assessment. Several sites of established gullying were observed, where surface flow was still being channeled along and off the trail during the wet season. If erosional forces that stripped Two Quarry and cut gullies were still at work on the 4,494 feet of trail observed to be in poor condition during this study, and assuming an average trail width of 10 feet (for an affected area of 44,940 square feet or 1.03 acre), annual sediment production from the old Two Quarry Trail can be estimated as follows:

Two Quarry ton/year = 1.03 acre x 15 tons/acre/year = 15.45 tons/year

Where 15 tons/acre/year is an estimated rate of soil removal where gullies and rills form (Napa County RCD, 1994).

If gullies were no longer actively forming on Two Quarry, but soil was still being stripped away as our field observations of sediment mobilization indicate, a conservative estimate for the old trail would be:

Two Quarry tons/year = 1.03 acre x 10 tons/acre/year = 10.3 tons/year

Where 10 tons/acre/year is an estimated rate of soil removal by sheet erosion without significant visual effect (Napa County RCD, 1994).

3.3 Sediment Production Analysis

Results of field measuring were combined with watershed information in a sediment-production model developed by staff in SEC's Global Positioning Systems/Geographic Information Systems (GPS/GIS) project to estimate potential soil erosivity of park areas independent of land uses.

3.3.1 Methods of Sediment Production Analysis

SEC staff developed a GIS model that implements the Universal Soil Loss Equation (USLE), a model developed by the U.S. Department of Agriculture in the 1950s to predict erosion of soil from agricultural fields. This model was chosen because it incorporates the major factors contributing to background sediment production in the Annadel area. Because the equation was designed for use in simple landscape conditions of Midwestern agricultural fields, various modifications of this equation are often used when applied to complex terrain and natural settings. It is understood that the use of USLE for these purposes is an approximation and may provide only a relative view of erosion potential with low reliability. The Modified and Revised Universal Soil Loss Equations (MUSLE and RUSLE) use the same empirical principles as USLE, but they also include improvements such as monthly rainfall factors, incorporation of the influence of profile convexity/concavity using segmentation of irregular slopes, and improved empirical equations for the computation of the LS factor (described below; Foster and Wischmeier 1974, Renard et al. 1997).

The RUSLE model accounts for the observation that soil loss through overland processes is a natural process, the rate of which is dependent on a series of interlocking factors, including rainfall erosivity, soil erodibility, the length and slope of the eroding surface, and vegetative cover. The annual erosion rate can be accentuated or reduced by anthropogenic influences, such as poor or improved land management practices, construction, or road building. This model strives to estimate the nonanthropogenic surface erosion (i.e., baseline erosion, or erosion not caused by human impacts) on a subwatershed basis. The interlocking factors are weighted and combined to predict the level of sediment production across the landscape. For our study, the predicted sediment production is calculated for raster grid cells with 10-meter sides (100 m^2) and can be aggregated over subwatersheds. The resulting maps indicate areas most prone to sediment production based on physical and biological landscape features.

The basic USLE equation (Wischmeir and Smith 1978) is expressed as:

$$A = R\ K\ L\ S\ C\ P$$

where

A = average annual soil loss (t/ac/yr);
R = rainfall and runoff erosivity index (ft-t/ac-in);
K = soil erodibility factor (t/ac);
L = slope length factor;
S = slope gradient factor;
C = cropping or vegetation management factor; and
P = conservation practice factor.

The equation factors are discussed below.

3.3.1.1 Rainfall-Runoff Erosivity Factor (R)

The rainfall-runoff erosivity factor (Wischmeier 1959, Wischmeier and Smith 1958) is a measure of how raindrop impact (rainfall intensity) and total storm energy contribute to soil erosion. This factor represents the mechanism responsible for detachment of soil particles by rainfall. The value for R is calculated on a storm-by-storm basis at individual rainfall gage stations and averaged over many years of data. In our model, we used a locally derived isoerodent map (NRCS 1998) to determine the value. The value for Annadel was determined from this map and applied uniformly to the whole park. Because Annadel receives has a moderately-high amount of annual precipitation almost all as rainfall, the R value is relatively high when compared to the state of California as a whole, but not as high as some areas further north along the coast.

3.3.1.2 Soil Erodibility (K)

Soil erodibility is a lumped parameter that represents an integrated average annual value of the total soil and soil profile reaction to a large number of erosional and hydrologic processes (Renard et al 1997). The soil erodibility factor is determined from long-term measurements at standard soil plots, and we have employed values that were developed locally (NRCS 1998). From these plots, scientists have derived relationships between the K factor and soil properties: values for the K factor were assigned to a map of soil types developed at 1:24,000 by the Soil Conservation Service (1972) (Plates 6a and 6b).

3.3.1.3 Slope Length and Steepness (LS)

The slope length and steepness factors are represented as a combined topographic factor, the LS factor. The LS factor in the original formulation of the USLE is derived in reference to the standard soil plot. These derivations are based on the slope gradient and length of the field plot and, for many reasons, are not suited to values determined from GIS elevation data (digital elevation model or DEM). DEM data is a satellite rendering of elevation values assigned to a 10-meter raster grid. The landscape of Annadel consists of many complex slopes, those with multiple segments when compared to the standard soil plot. Its hillslopes include concave and convex shapes, and these types are not easily transferable into the USLE format. For this reason, we considered a MUSLE approach that considers the upslope contributing area to surface flow. The upslope contributing area is the catchment area above any given point on the hillslope. Therefore, we replaced the hillslope length factor with upslope contributing area A (Moore and Burch 1986; Mitasova et al. 1995, 1996; Desmet and Govers 1996). This approach incorporates the impact of flow convergence on the erosion process. Moore and Burch (1986) described a formulation of the LS factor based on upslope contributing area that can be calculated from a DEM:

LS = (a/22.13)0.4 (s/0.0896)1.3

where
a = upslope catchment area; and
s = slope.

Slope and specific catchment area were calculated from the 10-meter DEM of the Red Creek basin using the Spatial Analyst extension for ArcView and the TARDEM program, respectively (ESRI 1998; Tarboton 1999). The LS factor is most strongly weighted by slope as shown by comparison between maps of slope (Plates 7a and 7b) and the LS factor (Plate 8).

3.3.1.4 Land Cover Factor (C)

The land cover factor is the ratio of soil loss under specified field conditions to the corresponding loss from the standard soil plot. This technique is modified by Leflen et al. (1985) and Mutchler et al. (1982) to incorporate the protection offered the soil surface by the vegetative canopy. Using the NRCS guide (1998), we determined the C factor for the different classifications contained in the vegetation type GIS for Annadel. This coverage was created from field data collected during the last 5 years (Plate 9a). C factor values were assigned to each vegetative type (Plate 9b).

3.3.1.5 Calculation of Sediment Production

Sediment production per hectare was calculated by multiplying the above-described factors using the map calculator in ArcView. The P factor for soil conservation practices was assumed to be 1, which is common for nonagricultural applications of the USLE (Molnar and Julien, 1997). The result was multiplied by 0.09 hectares per grid cell to obtain the result in sediment production per grid cell (Plate 10).

Several caveats and assumptions must be understood when interpreting the data. First, and most importantly, the USLE ignores sediment deposition. Because we employ the model as a relative scale of sediment production risk, maintaining a simple hillslope sediment production equation is efficient for our purposes. Second, the rainfall term is uniform for the entire park. The Annadel area probably experiences a variety of rainfall amounts increasing generally with elevation, but there is not adequate monitoring of rainfall to justify using a map surface with varying amounts. Some of the other data have imperfections; for example, the land cover map is dated to the mid-1990s. However, the vegetation information was collected from an intensive field survey of the park and closely matches current conditions at its scale of detail. Finally, it must be stressed that the USLE was designed for agricultural applications, but many have suggested modifications for applications like ours that we have incorporated herein.

3.3.2 Results of Sediment Production Analysis

The model calculation produced a map of predicted annual soil loss for each 10-meter grid cell in Annadel (Plate 10). The values range from 0 to 22.4 tons/acre. The areas predicted to yield the largest amount of sediment are shown in dark red, and areas with little erosion potential are shown in blue. Many of the areas with high predicted soil loss are known anecdotally to be sensitive to erosion.

Two Quarry and North Burma trails are depicted on the map. Trail condition as visually assessed in the field (Section 3.2.2) is shown for each trail reach. North Burma's trail condition shows good correlation with the predicted soil loss values. The poor-condition reaches are mainly found in areas of darker red and higher predicted soil loss. Much of Two Quarry is rated in poor or fair condition, but the soil loss predicted by the model is low in this area when compared to other areas of the park.

3.3.3 Discussion of Sediment Production Analysis

The RUSLE model appears to be a valuable and accurate tool for assessing the relative sensitivity of Annadel's landscape to soil loss. Clearly, many areas predicted to have high soil loss are known to be erosion hazards. For instance, the Schultz subwatershed ranks among the highest areas for erosion in the park and is known from field observations to display signs of severe erosion. North Burma trail has undergone considerable restoration work, but some eroding segments of the trail are located in areas of high predicted soil loss. Because the model is predicting high background soil loss in these areas, these reaches of the trail may need additional and consistent work to prevent excessive erosion.

Two Quarry Trail is in very poor condition, and our quick estimate of soil loss from the trail corridor is high (Section 3.2.2). There is considerable evidence of extreme soil loss in the trail corridor. However, the model did not predict high soil loss in this area. In designing the model to predict baseline soil loss, we ignored the P factor, which represents "practice," or land-use impacts. Consequently, the model's predictions are aimed at understanding the landscape's intrinsic erosion potential (background soil loss) based on near-pristine conditions.

Because the model did not predict high soil loss for roads sited in the places that we recorded field observations and estimates, we concluded that Two Quarry's poor condition probably reflects the poorly designed road. Two Quarry has had a long history of mining, and the original road was poorly sited with regard to erosion control. In general, our soil loss estimates may support the hypothesis that, even in relatively stable areas with little background erosion potential, a poorly sited road and history of intensive land-use impacts can cause severe erosion problems.

3.4 Water-Quality Monitoring

The Clean Water Act (CWA) requires protection of beneficial uses in surface waters through policy such as the Water Quality Control Plan (Basin Plan) for the San Francisco Bay Region. The Basin Plan states that surface waters (except ocean waters) shall be free of changes in turbidity that could cause nuisance or adversely affect beneficial uses associated with salmonids and the cold water fishery (RWQCB, 1995). In the Sonoma Creek watershed, salmonids of concern are chinook salmon *(Oncorhynchus tshawytscha)* and steelhead trout *(Oncorhynchus mykiss),* both listed as threatened species under the Endangered Species Act (ESA).

To understand changes that could cause nuisance or adversely affect beneficial uses, SEC reviewed studies aimed at establishing numeric water quality objectives (WQOs) for turbidity with regard to salmonids. Turbidity is associated in part with sediment in water, or suspended sediment concentration (SSC): water that contains SSC greater than 27 mg/L has been defined as "turbid"; above 27 mg/L, water has been characterized as "not drinkable," results in a 50 percent drop in the catch of fish, and leads to a 10 percent drop in fish production (Anderson, 1975). Research has connected elevated turbidity and SSC with observed effects on sampled salmonid populations, such as reduced feeding and growth rates, avoidance of turbid waters, or death: Newcombe and Jensen (1996) developed a severity index for ranking and analyzing the effects of excess turbidity or SSC on salmonids.

Table 2. Severity Index (Newcombe and Jensen, 1996)

Rank	Description of Effect due to Excess Turbidity or SSC
0	No effect
1	Alarm reaction
2	Abandonment of Cover
3	Avoidance response
4	Short-term reduction in feeding rates and/or feeding success
5	Minor physiological stress, increased coughing rate, and/or increased respiration rate
6	Moderate physiological stress
7	Moderate habitat degradation and/or impaired homing
8	Major physiological stress, poor condition, and/or long-term reduction in feeding rates and/or feeding success
9	Reduced growth rate, delayed hatching, and/or reduced fish density
10	0 to 20% mortality, increased predation, and/or moderate to severe habitat degradation
11	>20 to 40% mortality
12	>40 to 60% mortality
13	>60 to 80% mortality
14	>80 to 100% mortality

Using this severity index, Trush (2001) proposed that long-term reduction of feeding rates and success (severity index ranking of 8 or greater) directly results in smaller salmonids with higher mortality rates; therefore, a severity ranking of 8 has been demonstrated to be harmful to salmonids through compromise of the cold water fishery (Trush, 2001).

To arrive at a ranking in the severity index, Newcombe and Jensen (1996) first developed a suspended sediment dose index based on hours of fish exposure to SSC:

Suspended Sediment Dose Index = natural log (SSC x Hours Exposed)

(Examples: Using this equation, the suspended sediment dose index is 8 if fish are exposed to 65.86 mg/L SSC [the mean SSC value for Sonoma Creek watershed] for 48 hours. Alternately the suspended sediment dose index is 8 if fish are exposed to 625.97 mg/L SSC [the maximum SSC value for Sonoma Creek watershed] for 5 hours.)

Newcombe and Jensen (1996) next correlated the suspended sediment dose index to their observations of salmonid species in the Russian River watershed (chinook salmon, steelhead trout, and coho salmon *[Oncorhynchus kisutch]*). As the SSC dose index increased, so did the symptoms observed and ranked in the severity index. For all species studied, the severity index ranking correlates to the SSC dose index as follows:

Severity Index Ranking = 0.7491(SSC dose index) + 0.7625

Using this relationship, an SSC dose index of 8 correlates to a severity index ranking of 6.75.

SEC developed methods of water-quality monitoring to characterize existing levels of turbidity and SSC in Sonoma Creek and selected tributaries. Consultation with RWQCB staff indicated the difficulties involved in linking turbidity and SSC data directly to nonpoint sources such as roads and trails: noncontinuous sampling can give an inaccurate picture of when sediment pulses occur in runoff during a storm; sampling points are hard to locate so that samples reflect only the sediment contribution from roads; observed erosion on roads does not tell how much sediment is being delivered to waterways (Napolitano, 2000). Additionally, literature from previous road-related studies had already related poorly designed roads in parklands to negative effects on water quality (Weaver and Hagans, 1994). Therefore, SEC designed a sampling scheme to measure ambient turbidity and SSC in Sonoma Creek subwatersheds, understanding that subwatersheds with poorly designed roads have the potential for greater amounts of road-caused sediment to be delivered to its streams. Our sampling design is explained in the QAPP (Appendix A of this report).

In the sections below, we discuss SEC's water-quality monitoring conducted to date in the Sonoma Creek watershed and how our results for turbidity and SSC relate to the severity index ranking of Newcombe and Jensen. Water-quality monitoring conducted for this project consisted of the following:

- Stage monitoring
- Grab sampling
- Automated data collection
- Depth-integrated sampling
- Laboratory analysis.

3.4.1 Stage Monitoring

As part of water-quality monitoring, SEC measured stage (creek level) to gain an understanding of how stream stage relates to levels of turbidity and SSC.

3.4.1.1 Methods of Stage Monitoring

SEC measured stage at Station A (STA) and Station B (STB), two ongoing monitoring locations on Sonoma Creek (Plate 11). We started our program by establishing these two locations for the following reasons:

- Centrality in the Sonoma Creek watershed (i.e., they provide information about a number of upvalley subwatersheds, potentially important to assessing parkland roads)
- Accessibility
- Proximity to the Sonoma Valley Watershed Station where our equipment is housed
- Functionality as good demonstration sites for training volunteers.

Station locations are listed in Table 3. Station selection criteria are discussed further in the QAPP (Appendix A). Photographs of each station are in Figure 3.

Table 3. Ongoing Monitoring Stations on Sonoma Creek

Site Code	Site Name	Stage Gauge	Number of Samples Collected in HY 2002	Type of Samples Collected in HY 2002	Site Description
STA	Sonoma Creek at Station A	Staff gauge on concrete bank	78	Grab	On creek right at old damsite at SDC
STB	Sonoma Creek at Station B	Wire-weight gauge lowered from bridge	9	Depth Integrated	On bridge over Sonoma Creek, Harney Drive, SDC

A photograph of the staff gauge on the concrete bank used to measure stage at STA is shown in Figure 4. A sketch of the type of wire-weight gauge used to measure creek depth at STB is shown on Figure 5. Stage was measured at STA and STB at the time of turbidity and SSC sampling. Stage was not measured at any other sampling sites (see Section 3.4.2.1 for a list of sites). Protocols for stage monitoring are in the QAPP (Appendix A).

When taking stage readings at STB, samplers often estimated stream velocity readings using the orange-peel method. In this method, an orange peel is tossed onto the stream surface and timed for a given distance of travel (Appendix A). From the stage and velocity readings at STB, in combination with a surveyed cross section, SEC staff estimated stream discharge at the time of sampling. The equation used to estimate discharge was:

$$Q = V*A$$

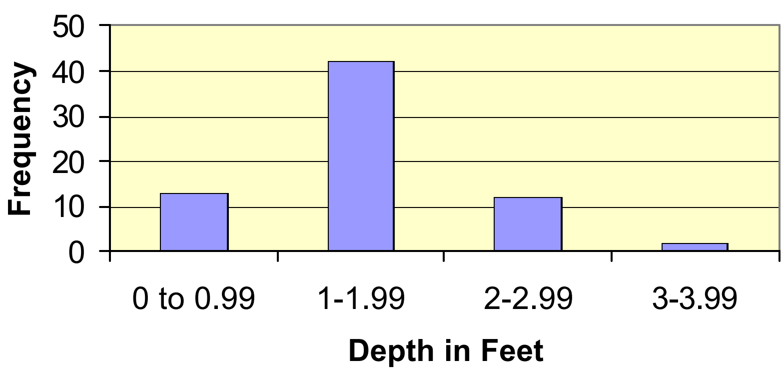
where
Q = discharge in feet^3/second
V = velocity in feet/second
A = cross section of stream in feet^2, evaluated in a biannual survey by SEC staff.

For more information on the variables in this equation, see the QAPP (Appendix A).

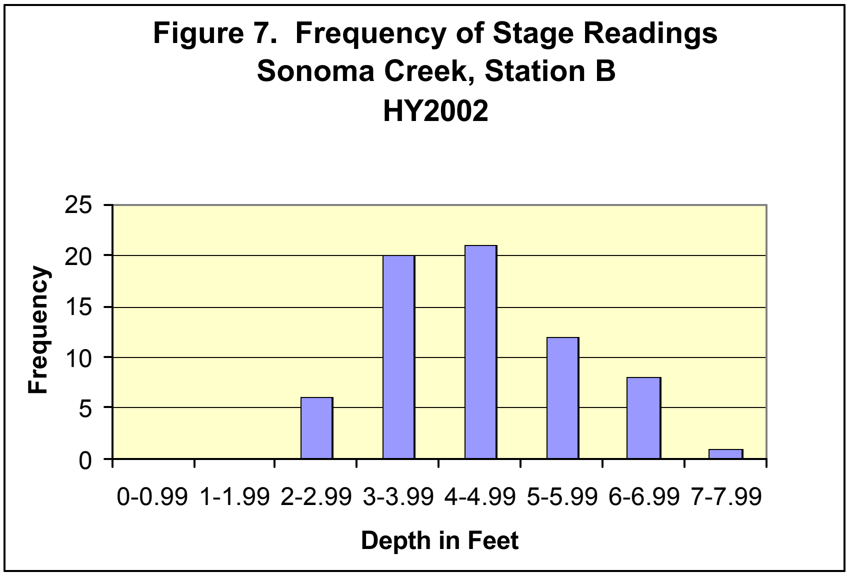
3.4.1.2 Results of Stage Monitoring

Samplers took 69 stage readings at the staff gauge at STA. Values ranged from 0.18 to 3.35 feet (not including one reading that was over the maximum gauge measurement of 3.35 feet). The mean stage value for STA was 1.59 feet ($\pm$ 0.73 feet), with a median of 1.50 feet and standard error of 0.09 feet. The frequency of occurrence of the 69 stage readings at STA is in Figure 6.

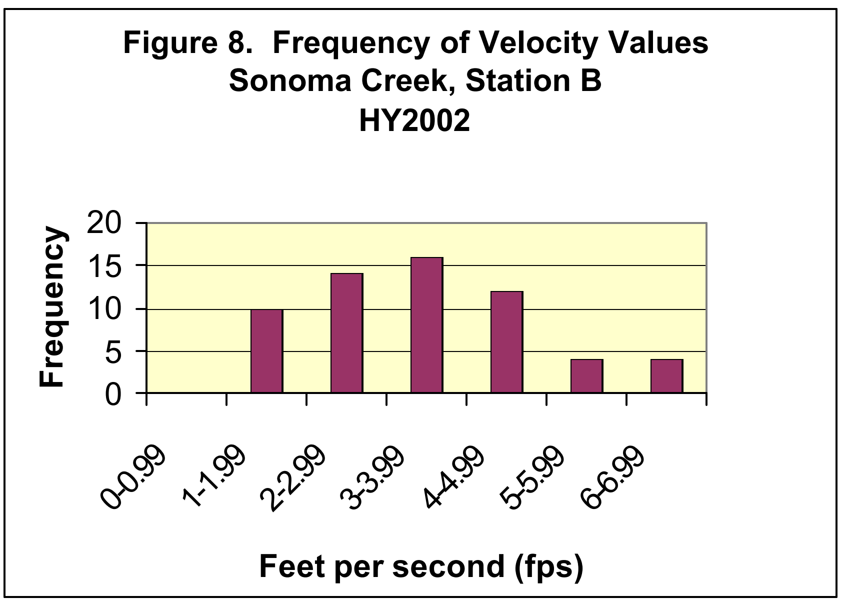
Figure 6. Frequency of Stage Readings Sonoma Creek, Station A HY2002



Samplers took 68 stage readings using the wire-weight gauge method at STB. Values ranged from 2.82 to 7.70 feet in depth, with a mean of 4.52 feet ($\pm$ 1.17 feet), median of 4.43 feet, and standard error of 0.14 feet. A histogram of the 68 stage readings taken at STB in HY02 is in Figure 7.

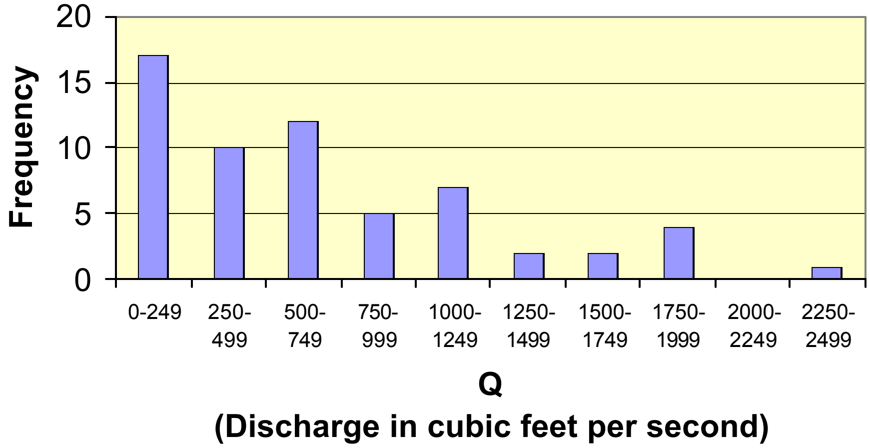


Of the 60 velocity readings samplers completed at STB, 1.52 feet per second (ft/sec) was the minimum and 6.70 ft/sec was the maximum. Mean was 3.48 ft/sec ($\pm$ 1.41 ft/sec), median was 3.48 ft/sec, and standard error was 0.18 ft/sec. A histogram of 60 velocity values is in Figure 8.



From the 60 velocity readings, 60 estimates of discharge were calculated for STB. The minimum discharge reading was 114.65 cubic feet per second (ft^3/sec), and the maximum was 2,324.00 ft^3/sec. Mean was 701.91 ft^3/sec ($\pm$555.14 ft^3/sec), median was 558.09 ft^3/sec, and standard error was 71.67 ft^3/sec. A histogram of the 60 discharge estimates from STB is in Figure 9.

Figure 9. Frequency of Discharge Estimates Sonoma Creek, Station B HY2002



Results of stage monitoring at STA and STB are summarized in the tables below.

Table 4. Summary of Stage Monitoring at STA, Sonoma Creek Watershed, HY02

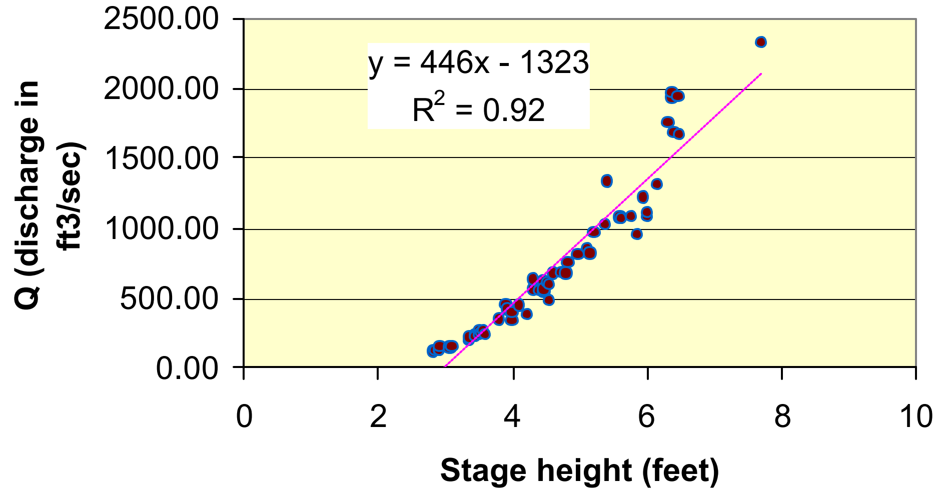
STA	Minimum (feet)	Maximum (feet)	Mean (feet)	3.4.1.3 Median (feet)	Standard Deviation (feet)	Standard Error (feet)
Staff Gauge	0.18	3.35	1.59	1.50	0.73	0.09

Table 5. Summary of Stage, Velocity, and Discharge Monitoring at STB, Sonoma Creek Watershed, HY02

STB	Minimum	Maximum	Mean	3.4.1.4 Median	Standard Deviation	Standard Error
Wire-Weight Gauge	2.82 feet	7.70 feet	4.52 feet	4.43 feet	1.17 feet	0.14 feet
Velocity	1.52 ft/sec	6.70 ft/sec	3.48 ft/sec	3.48 ft/sec	1.41 ft/sec	0.18 ft/sec
Discharge	114.65 ft^3/sec	2,324.00 ft^3/sec	701.91 ft^3/sec	558.09 ft^3/sec	555.14 ft^3/sec	71.67 ft^3/sec

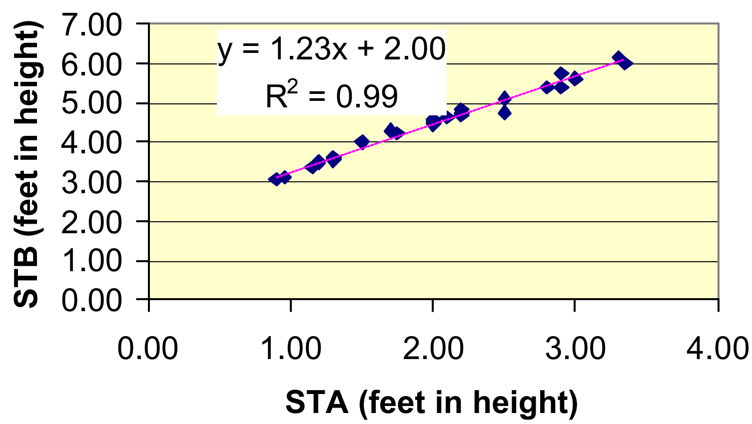
A graph of the relationship between stage height and estimated discharge for STB is in Figure 10.

Figure 10. Comparison of Stage Height and Estimated Discharge Sonoma Creek, Station B HY2002



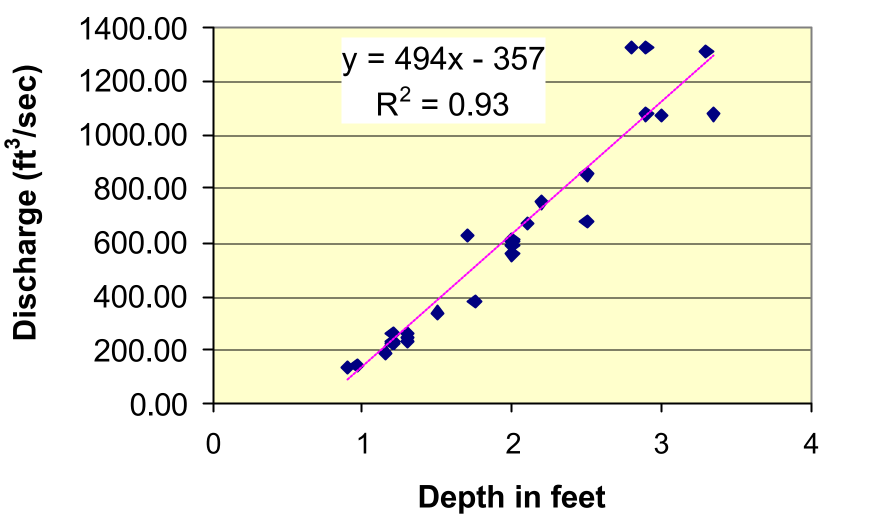
On 38 occasions samplers measured stage at STA within 15 minutes of measuring stage at STB. A graph of the relationship between the 38 STA staff gauge readings and STB wire-weight gauge readings is in Figure 11.

Figure 11. Comparison of Stage Readings Sonoma Creek, STA vs. STB HY2002



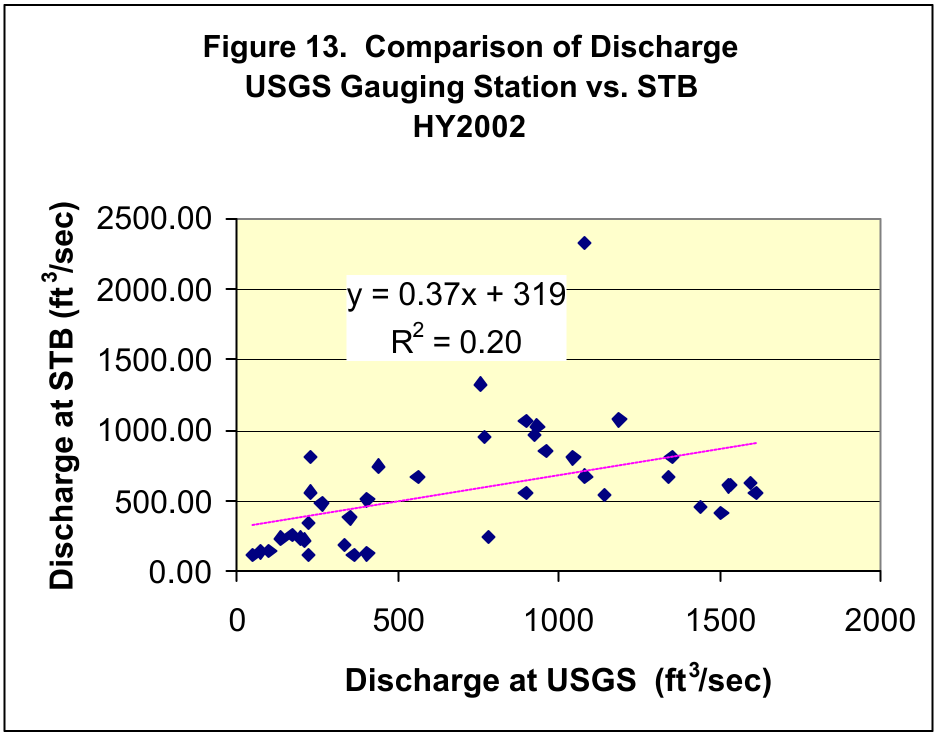
On 35 of the 38 occasions where samplers measured stage at STA within 15 minutes of measuring stage at STB, they also measured stream velocity. Figure 12 is a graph of the relationship between STA staff gauge measurements (35 readings) and estimated discharge at STB.

Figure 12. Comparison of Stage Height at STA with Estimated Discharge at STB Sonoma Creek, HY2002



Finally, we graphed our estimates of discharge at STB against estimated discharge at the U.S. Geological Survey (USGS) gauge at Agua Caliente. The USGS gauge recorded daily mean values of streamflow beginning October 21, 2001, at 00:15 (Webster, 2002). (The USGS gauge is now recording realtime information for Sonoma Creek and presenting it at: http://waterdata.usgs.gov/ca/nwis/current?type=flow&group_key=huc_cd&search_site_no_station_nm=11458500.)

SEC staff and volunteers made 40 discharge measurements at STB that were within 5 minutes of readings taken at the USGS gauging station. Figure 13 compares the 40 measurements from each dataset.



3.4.1.3 Discussion of Stage Monitoring

Stage readings at STA, taken most often during and directly following storms, were most frequently >1 foot and <2 feet. Concurrent readings at STB, a deeper channel area confined in part by concrete piers and walls, were most frequently >3 and <5 feet. Stream velocities at STB, also taken most often during and directly following storms, were most frequently <5 fps. Stream discharge estimates calculated from the STB storm velocities were most frequently <250 ft^3/sec.

From the regression derived from comparing stage height and estimated discharge at STB, we can generally predict discharge at STB from the STA staff gauge as follows:

$$y = 446x - 1,323$$

where
x = depth at STB (feet)
y = discharge at STB (ft^3/sec).

The regulating equation only applies when $x \geq 3.0$.

Predicted discharge at STB for major depth values is summarized in Table 6.

Table 6. Predicted Discharge from Depth, STB, HY2002

Depth (feet)	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0
Predicted Discharge (ft^3/sec)	15	461	907	1,353	1,799	2,245	2,691	3,137

From the regression derived from comparing stage height at STA and STB, STB readings are predicted to be more than 2 feet higher than STA readings taken concurrently:

$$y = 1.23x + 2.00$$

where
x = depth at STA staff gauge (feet)
y = depth at STB (feet).

Predicted depth at STB from example depth readings at STA is summarized in Table 7.

Table 7. Predicted Depth, STB, HY2002

Depth at STA (feet)	0.25	0.5	0.75	1.0	2.0	3.0	3.35
Predicted Depth at STB (feet)	2.31	2.62	2.92	3.23	4.46	5.69	6.12

From the regression derived from comparing stage height at STA with estimated discharge at STB, discharge at STB is predicted as follows:

$$y = 494x - 357$$

where
x = depth at STA staff gauge (feet)
y = discharge at STB (ft^3/sec).

The regulating equation only applies when the STA staff gauge reads $\geq$0.73 foot.

Predicted discharge at STB for example depth readings at STA is summarized with observed mean discharge in Table 8. The number of observed values for each depth reading is small (n=1 to 5).

Table 8. Predicted and Observed Mean Discharge, STB, HY02

Depth at STA Staff Gauge (feet)	Predicted Discharge at STB (ft^3/sec)	Observed Mean Discharge at STB (ft^3/sec)
0.75	14	NA
1.0	137	148
1.5	384	340
2.0	632	596
2.5	879	853
3.0	1,126	1,071
3.35	1,299	1,077

From the regression derived from comparing estimated discharge at STB with readings from the USGS gauge at Agua Caliente, discharge at STB from the USGS gauge is predicted as follows:

$$y = 0.37x + 319$$

where
x = discharge at USGS gauge (ft^3/sec)
y = discharge at STB (ft^3/sec).

Predicted and estimated values of discharge for STB for major discharge values from the USGS gauge are summarized with observed mean discharge in Table 9.

Table 9. Predicted Discharge, STB, HY02

Discharge at USGS Gauge (ft^3/sec)	Predicted Discharge at STB (ft^3/sec)	Observed Mean Discharge at STB (ft^3/sec)
50	338	115
100	356	146
250	411	118
500	504	1,077
750	597	NA
1,000	689	853
1,500	874	682
2,000	1,059	NA

The equation predicts higher flows at STB than at the USGS gauge when the discharge estimate for the USGS site $\leq$506 ft^3/sec. Above 506 ft^3/sec at the USGS gauge, flows at STB are predicted to be lower. We do expect flows at the USGS gauge in Agua Caliente to be higher than at STB during storms, when flow is augmented in a downstream direction; however, we don't have physical evidence to support the prediction that Sonoma Creek loses water between STB and downstream Agua Caliente at the lower flows. Again, the number of observed values for each depth reading is small (n=1 to 3). The two datasets appear to be too poorly correlated to make good predictions.

3.4.1.4 Summary of Stage Monitoring

- SEC staff monitored stage (creek level) at STA and STB on Sonoma Creek in Eldridge, California. At STA, monitors read a staff gauge. At STB, monitors used a wire-weight gauge to measure stage from Bucky's Bridge.
- Stage readings at STA, taken most often during and directly following storms, were most frequently >1 foot and <2 feet.
- Concurrent readings at STB, a deeper channel area confined in part by concrete piers and walls, were most frequently >3 feet and <5 feet.
- Stream velocities at STB, also taken most often during and directly following storms, were most frequently <5 fps.
- Stream discharge estimates calculated from the STB storm velocities were most frequently <250 ft^3/sec.
- Estimates of discharge predicted from depth readings at STB range from 15 ft^3/sec at 3 feet to 3,137 ft^3/sec at 10 feet (although the observed maximum for HY02 was 2,324 ft^3/sec at 7.7 feet).
- Stage height at STB is generally more than 2 feet higher than stage height read concurrently at STA.
- Discharge at STB predicted from depth at the STA staff gauge ranges from 137 ft^3/sec at 1 foot of depth to 1,299 ft^3/sec at 3.35 feet of depth.
- From the data we have to date, discharge at STB is difficult to predict from discharge at the USGS gauge in Agua Caliente.

3.4.2 Grab Sampling

To monitor turbidity and suspended sediment concentration (SSC), SEC collected grab samples of stream water from Sonoma Creek and tributaries. Because we were interested in turbidity related to higher flows, we collected samples during and directly following wet storms.

3.4.2.1 Methods of Grab Sampling

SEC staff established two ongoing turbidity and SSC sampling stations in the Sonoma Creek watershed during HY 2002, as listed in Table 3 (Section 3.4.1.1) and shown on Plate 11. Station selection criteria are discussed in the QAPP (Appendix A).

In addition to grab sampling at STA, SEC collected 21 grab samples at 13 occasional sampling sites ("Other sites"), as listed in Table 10, below. All but four Other samples were taken during storm conditions: the remaining four were taken in response to a landowner complaint about the clarity of the water in Nathanson Creek near Second Street at a time of base flow (i.e., a white discharge had been observed in that reach). Storm samples were grabbed throughout the watershed, in reaches of diverse stream order. (Stream order is a classification of the relative position of a stream with respect to its tributary network. Streams with no tributaries are first-order streams; two first-order stream segments flowing together make a second-order stream and so on downstream. See Plate 12 for a map of stream order within Sonoma Valley, as plotted using the Strahler method of stream network classification [Strahler 1957] on a modified USGS base map of intermittent and perennial streams.) Five of the Other sites are on first-order streams; four are on second-order; three are on third-order; and one is on fourth-order (see Plate 12). Examples of site photographs are in Figure 14.

Table 10. Other Sites in Sonoma Creek Watershed, HY 2002

Site Code	Site Name	Stream Order	Number of Grab Samples	Site Description
CCA	Carriger Creek at Arnold Drive	2	1	Right bank* above bridge
CCG	Calabazas Creek in Glen Ellen	1	1	Left bank downstream of O'Donnell bridge
CCL	Carriger Creek at Leveroni Road	3	1	Right bank above bridge
FCL	Frey Canyon Creek (Annella) at Lawndale Bridge	1	2	Mid upstream side of Lawndale Bridge
NC2	Nathanson Creek at Second Street East	2	2	Mid downstream side of bridge
NCP	Nathanson Creek at Nature Preserve	2	2	Left bank
NCT	Nathanson Creek at Patten Street	3	2	Mid downstream side of bridge
SCD	Sonoma Creek at Larson Dam	3	2	Right bank above dam at Larson Park
SCH	Sonoma Creek at Highway 12 in Kenwood	2	2	Left bank above Highway 12 bridge
SCS	Sonoma Creek at Sugarloaf	1	2	Left bank above Goodspeed bridge
SCW	Sonoma Creek at 986 Warm Springs Road	1	2	Left bank, from boulder bar
SCZ	Sonoma Creek at Highway 121 bridge	4	2	Under bridge

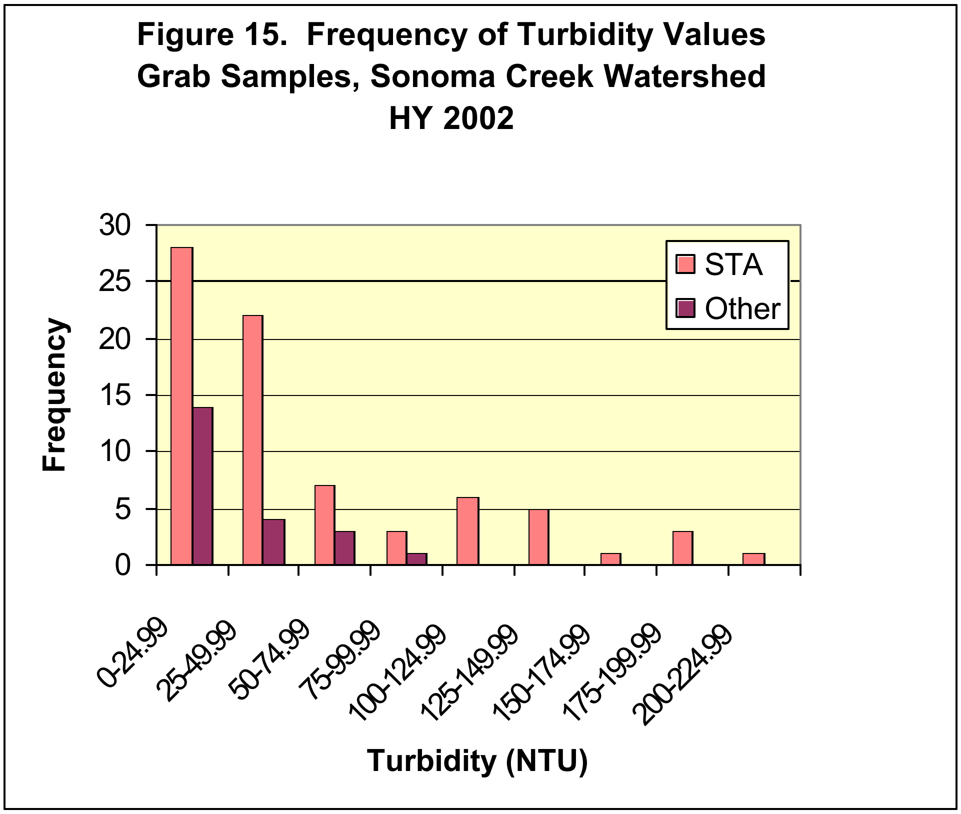
*Bank sides identified looking downstream.

Grab sampling consisted of the simultaneous filling of one HACH cell (i.e., sample bottle later inserted in the 2100P HACH turbidimeter for turbidity analysis) and one SSC bottle. We used a device that allowed us to stand on shore and sample the stream just below the water surface. See the QAPP, Appendix A, for details about sampling protocols.

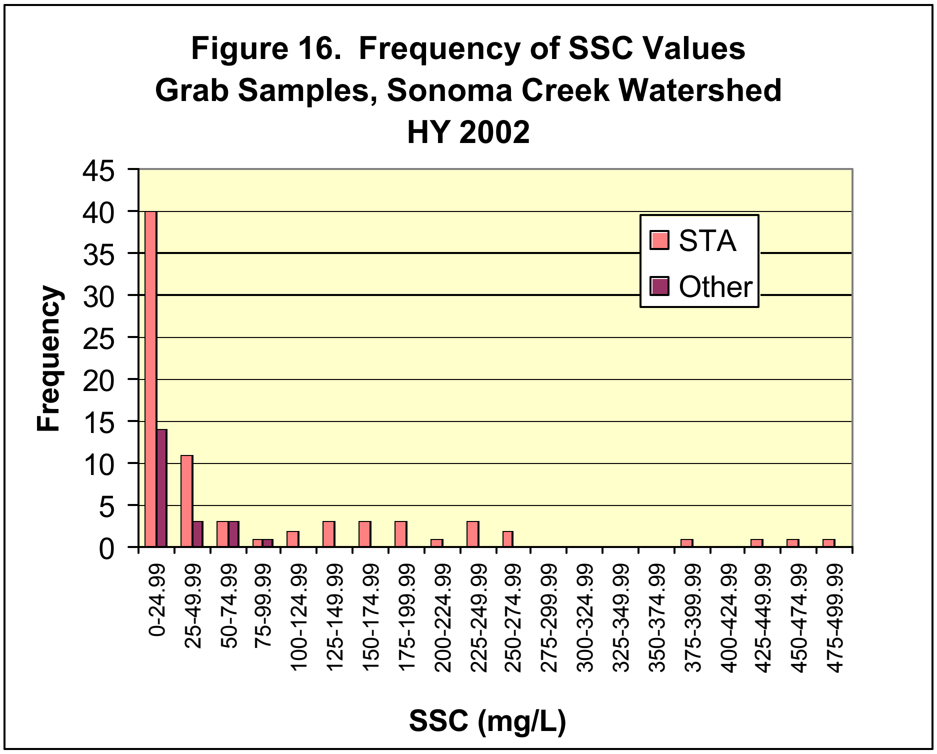
SEC staff analyzed grab samples for turbidity in the field using the turbidimeter. Samples were then delivered to the M.U.D. Laboratory at the Sonoma Valley Watershed Station, Eldridge, California, for SSC analysis. Methods used in laboratory analysis are discussed in detail in the QAPP, Appendix A. Quality assurance/quality control (QA/QC) of laboratory data is discussed in the project QA/QC report, Appendix B.

3.4.2.2 Results of Grab Sampling

Grab samples made up 99 of the 108 samples collected and analyzed in HY 2002 (78 from STA and 21 from other sites). Observed turbidity in the grab samples from throughout the watershed ranged from 1.18 to 318.00 NTUs. The mean turbidity value for the year was 56.58 NTUs (±57.79 NTU), with a median of 34.30 NTUs and standard error of 6.54 NTUs. A histogram of turbidity values (which does not show the single high value of 318.00 NTUs) in the 99 grab samples from all sites during all weather conditions in HY02 is in Figure 15.



Observed SSC values in the 99 analyzed grab samples ranged from 0 to 625.97 mg/L. The mean SSC value for the year was 85.42 mg/L (±119.43 mg/L), with a median of 23.73 mg/L and standard error of 13.61 mg/L. A histogram of the SSC values (which does not show the single high value of 625.97 mg/L) from all sites in all weather conditions is in Figure 16, below.



Tables 11 and 12 summarize turbidity and SSC values for grab sampling in Sonoma Creek watershed in HY 2002.

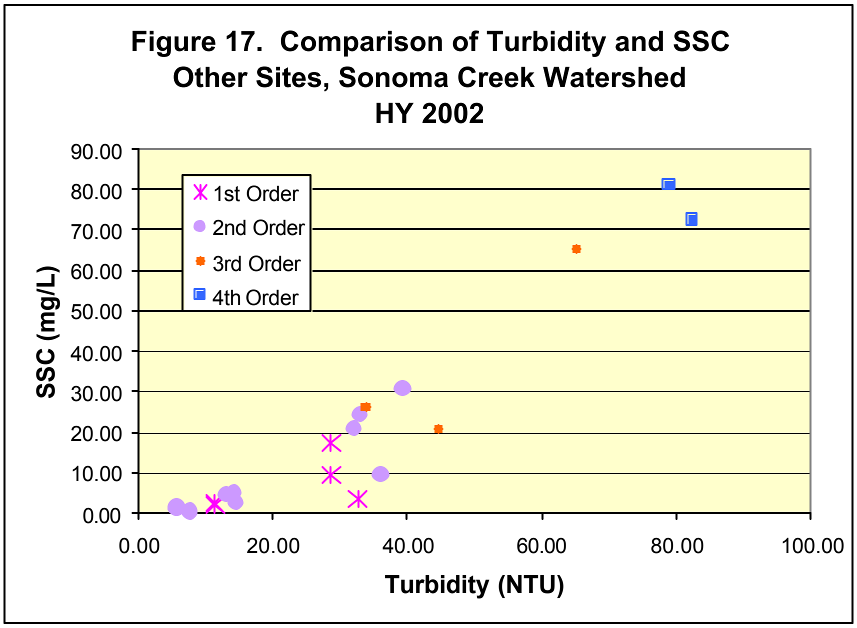
Table 11. Summary of Turbidity Values (NTU), Grab Samples, Sonoma Creek Watershed, HY02

Sample Site	Minimum	Maximum	Mean	3.4.2.3 Median	Standard Deviation	Standard Error
STA	1.18	318.00	56.68	34.30	57.79	6.54
Other	5.78	82.30	31.20	28.60	24.58	5.36

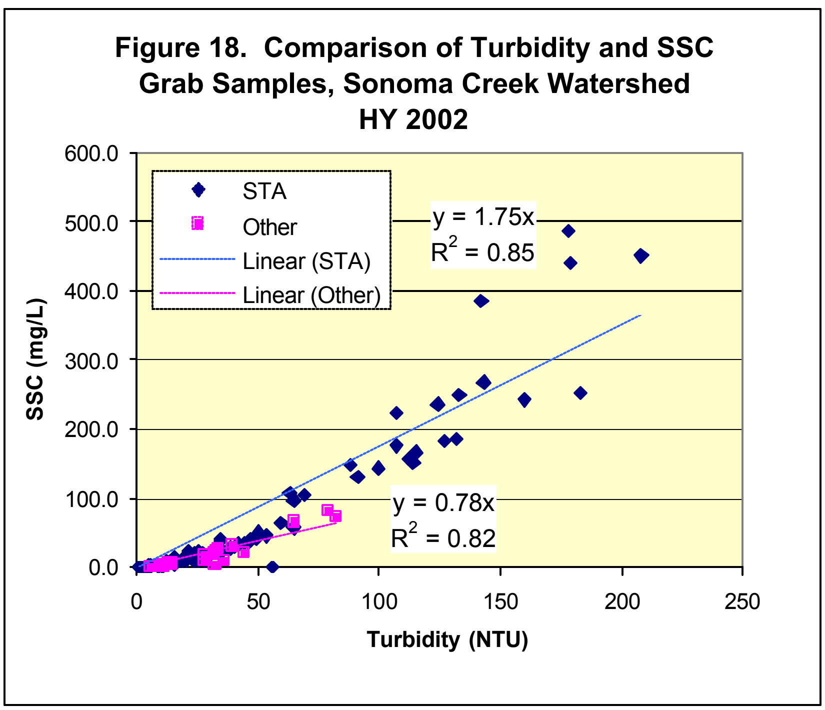
Table 12. Summary of SSC Values (mg/L), Grab Samples, Sonoma Creek Watershed, HY02

Sample Site	Minimum	Maximum	Mean	3.4.2.4 Median	Standard Deviation	Standard Error
STA	0	625.97	85.42	23.73	119.43	13.61
Other	0	81.25	23.66	17.43	25.22	5.50

Figure 17 shows the relationship of turbidity to SSC at Other sites, with samples broken out by stream order.



The relationship of turbidity to SSC at Other sites is graphed with that at STA in Figure 18.



From the comparison of turbidity and SSC in grab samples collected simultaneously throughout the watershed, we derived the following regressions:

For STA grab samples:

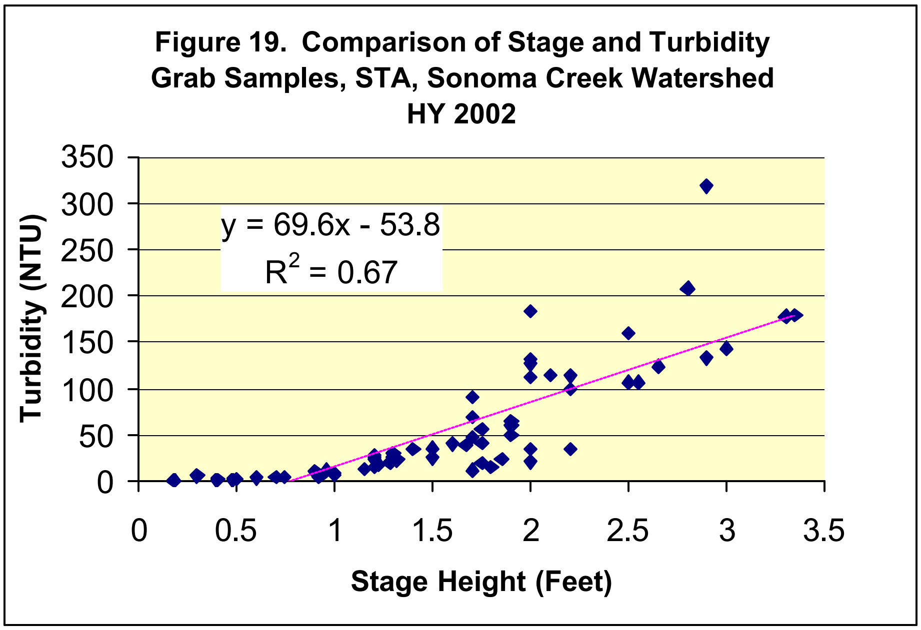
$$y = 1.75x$$

and for Other grab samples:

$y = 0.78x$

where
y = SSC in mg/L
x = turbidity in NTU.

To understand how turbidity relates to higher flows, we compared turbidity and stage height for the STA grab samples (Figure 19).



The relationship between stage height and turbidity at Station A is as follows:

$y = 69.6x - 53.8$

where
y = turbidity in NTU
x = stage height in feet.

3.4.2.3 Discussion of Grab Sampling

Grab samples from the Sonoma Creek watershed in HY 2002, collected primarily during and directly after storms but also during dry spells, indicate a wide range of turbidity and SSC values (more than 300 NTU for turbidity and 600 mg/L for SSC). The Other samples, in a smaller data set, were collected only during and immediately following storms (they do not represent baseline conditions) and show a smaller range of values (around 80 NTU and 80 mg/L). Mean values of both turbidity and SSC are lower in the Other samples than in the STA samples, probably because some Other samples were collected in lower-order stream reaches than STA (some samples were collected in first- and second-order stream reaches; STA is in a third-order stream reach). Because water turbidity is expected to increase in a downstream direction as the creek moves into less pristine areas, sampling lower-order stream reaches should yield lower turbidity values, as supported by our results (Figure 17, Comparison of Turbidity and SSC, Other Sites).

STA grab samples yielded greater SSC values relative to turbidity (SSC [mg/L] = 1.75 times Turbidity [NTU]) than did the Other samples (where SSC [mg/L] = 0.78 times Turbidity [NTU]), indicating greater amounts of sediment-related turbidity in the STA samples than the watershed-wide samples. Because two of the Other samples were taken from Sonoma Creek in tidally influenced zones, turbidity also could be related to dissolved solids rather than SSC. However, the dataset for Other samples was small; more data are needed for better comparison to STA.

Increasing flows related to increasing turbidity in grab samples. The highest values recorded for turbidity and SSC, 318.00 NTU and 625.97 mg/L, respectively, are higher by far than the other recorded values for both parameters. Both high values were recorded at high stage readings: 2.9 feet on the STA staff gauge (near the gauge top) and 5.76 feet on the volunteer monitor's wire weight gauge at STB (13:55, December 20, 2001). SEC volunteers at STB estimated flow at 13:40 on December 20, 2001, to be 1,076 cubic feet per second (ft^3/sec); flow recorded for that time at the U.S. Geological Survey (USGS) stream gauge downstream on Sonoma Creek at Agua Caliente Road was 843 ft^3/sec (Webster 2002).

At STA, grab samples taken at stage height $\geq$1.0 foot are predicted by the equation (Turbidity [mg/L] = 69.6 times Stage [ft] – 53.8) to have 15.8 NTU or greater. Field observations at STA showed that, at stage heights $\geq$1.2 feet, turbidities are 15.7 NTU or greater, increasing with stage. The equation also predicts that NTU will be <0 when stage is $\leq$0.77 foot; therefore, our equation relating turbidity to stage at STA applies only when stage >0.77 foot.

3.4.2.4 Summary of Grab Sampling

- SEC staff established two ongoing turbidity and SSC sampling stations and 13 occasional sampling sites in the Sonoma Creek watershed during HY 2002.
- Grab sampling consisted of the simultaneous filling of one HACH cell and one SSC bottle. Sampling was primarily done during and directly following wet storms.
- SEC staff analyzed grab samples for turbidity in the field using a HACH 2100P turbidimeter and then delivered samples to the M.U.D. Laboratory at the Sonoma Valley Watershed Station, Eldridge, California, for SSC analysis.
- Observed turbidity in 99 grab samples ranged from 1.18 to 318 NTU. Observed SSC values ranged from 0 to 625.97 mg/L. Mean values of each parameter respectively were 34.40 NTU and 23.73 mg/L at STA and 28.60 NTU and 17.43 mg/L at the Other sites.
- Higher stream order related to greater observed values of turbidity; however, the dataset was small. More samples are needed throughout the watershed for a better understanding of how stream order relates to turbidity.
- STA grab samples yielded greater SSC values relative to turbidity (SSC [mg/L] = 1.75 times Turbidity [NTU]) than did the Other samples (where SSC [mg/L] = 0.78

times Turbidity [NTU]), indicating greater amounts of sediment-related turbidity in the STA samples than the watershed-wide samples.

- Increasing flows related to increasing turbidity in grab samples by the equation Turbidity [NTU] = 69.6 times Stage [ft] – 53.8 when stage >0.77 foot at STA.

3.4.3 Depth-Integrated Sampling

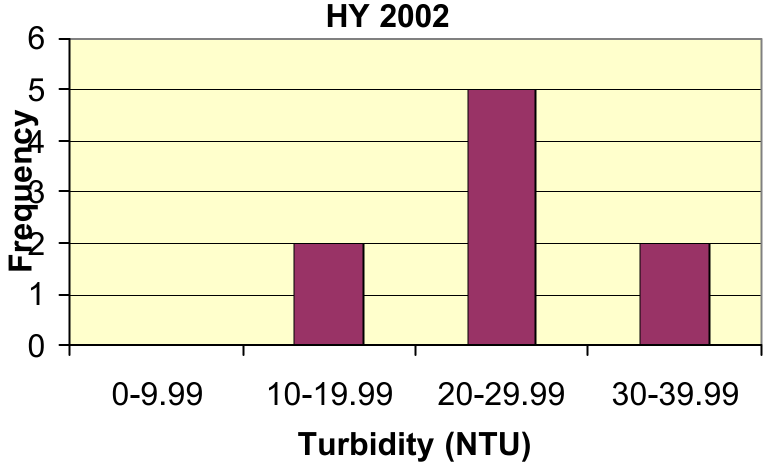
3.4.3.1 Methods of Depth-Integrated Sampling

Depth-integrated (DI) sampling was done using a sampler lowered through the water column to the stream bottom to collect sample at all stream depths. Samples were collected only during and directly following wet storms. Because the DI equipment was purchased and ready for use toward the end of the wet season, we collected only a few, late-season samples. See the QAPP, Appendix A, for details about sampling protocols.

3.4.3.2 Results of Depth-Integrated Sampling

Nine DI samples were collected at STB and analyzed for both turbidity and SSC. Observed turbidity in these samples ranged from 10.60 to 32.20 NTUs. The mean turbidity value for STB was 24.17 NTUs (± 7.59 NTUs), with a median of 26.90 NTUs and standard error of 2.53 NTUs. A histogram of the nine turbidity samples from STB in HY02 is shown in Figure 20.

Figure 20. Frequency of Turbidity Values
DI Samples, STB, Sonoma Creek
HY 2002



Observed SSC in samples from STB ranged from 1.17 to 24.75 mg/L. The mean SSC value for STB samples was 10.91 mg/L (± 7.08 mg/L), with a median of 10.83 mg/L and standard error of 2.36 mg/L. A histogram of nine SSC values for STB is shown in Figure 21.

Figure 21. Frequency of SSC Values DI Samples, STB, Sonoma Creek HY 2002

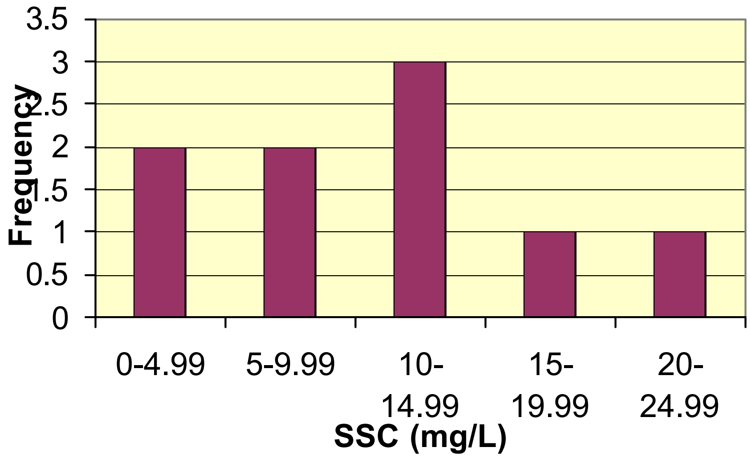
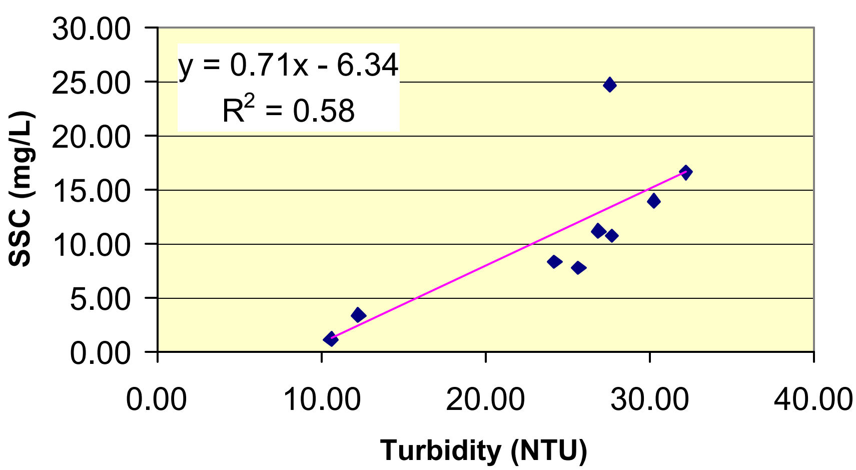


Table 13. Summary of NTU and SSC Values, STB, HY 2002

Parameter	Minimum	Maximum	Mean	3.4.3.3 Median	Standard Deviation	Standard Error
Turbidity (NTU)	10.60	32.20	24.17	3.4.3.4 26.90	7.59	2.53
SSC (mg/L)	1.17	24.75	10.91	3.4.3.5 10.83	7.08	2.36

Figure 22 shows the relationship of turbidity to SSC at STB in HY 2002.

Figure 22. Comparison of Turbidity and SSC STB, Sonoma Creek HY 2002



The relationship between turbidity and SSC at STB is as follows:

$$y = 0.71x - 6.34$$

where
y = SSC in mg/L
x = turbidity in NTU.

The regulating equation only applies when turbidity $\geq$ 8.94 NTU.

3.4.3.3 Discussion of Depth-Integrated Sampling at STB

Mean values of turbidity (24.17 NTUs) and SSC (10.91 mg/L) in DI samples from STB were lower than turbidity and SSC in grab samples from STA (56.68 NTU and 85.42 mg/L, respectively) and Other sites (31.20 NTU and 23.66 mg/L, respectively). Also, the relationship of SSC to turbidity at STB (SSC = 0.71 times Turbidity – 6.34) indicates less SSC relative to turbidity than at STA and the Other sites (where SSC = 1.75 times Turbidity and SSC = 0.78 times Turbidity). Because the DI sampler collects sample from throughout the water column (even near the stream bottom, where we expect to find more sediment on the move), we expected the DI samples to be "dirtier" than the grab samples. Our results showed the opposite. However, the dataset for STB samples was small; more data are needed for better comparison of DI and grab sampling.

3.4.3.4 Summary of Depth-Integrated Sampling

- Nine DI samples were collected at STB only during and directly following wet storms. These samples were analyzed for both turbidity and SSC.
- Observed turbidity in the DI samples ranged from 10.60 to 32.20 NTUs; observed SSC ranged from 1.17 to 24.75 mg/L.
- The relationship between SSC and turbidity at STB (SSC [mg/L] = 0.71 times Turbidity [NTU] – 6.34) indicates lower SSC relative to turbidity than in the grab samples from STA (where SSC [mg/L] = 1.75 times Turbidity [NTU]) and Other sites (where SSC [mg/L] = 0.78 times Turbidity [NTU]).
- The DI dataset is small; more samples are needed for valid comparison with grab samples.

3.4.4 Automated Data Collection

In stream sampling for turbidity, automated data collection is important for establishing a continuous record to compare with grab samples. Where the grab samples take a snapshot of conditions at any moment, the continuous record portrays the duration of storm-related turbidity, rate of clearing after turbid events, and lag time between peak rainfall and peak turbidity.

3.4.4.1 Methods of Automated Data Collection

SEC installed an automated monitoring station at STA to record air temperature, stream water temperature, turbidity, stream water depth, and inches of rainfall. The station consists of a water depth probe in a PVC housing attached to the concrete wall remaining from the old SDC dam, Eldridge, California (STA), and a turbidity probe in a small PVC housing at the foot of the same wall. Photographs of STA are in Figure 3. More information about the automated station is in the QAPP, Appendix A.

On July 30, 2001, at 16:00 Daylight Savings Time (DST), the automated monitoring station at STA began by recording air temperature, stream water temperature, stream water depth, and inches of rainfall every 15 minutes. On September 18, 2001, at 10:45, the station began recording these four parameters every 10 minutes. On October 30, 2001, at 13:25 Pacific Standard Time (PST), when the stream water level was deep enough, we installed a turbidity probe at STA. Thereafter the STA datalogger read all the above parameters plus a fifth, turbidity, every 10 minutes. Readings of all parameters continued until December 1, 2001, when the depth probe began to malfunction, presumably because the stream water level had gotten too deep for the pressure transducer's capabilities (Allen, 2002). The depth gauge was taken offline altogether during the January 1, 2002, storm, when the depth probe housing blew out from the wall to which it had been fastened. During replacement, the probe housing had to be relocated; therefore the depth probe did not provide consistent readings throughout the season. However, to augment information from the automated data collection system's depth gauge, SEC staff and volunteers recorded depth information from readings on the staff plate at STA and took depth readings at nearby STB.

Automated data collection of all parameters besides depth continued until 13:10 DST on April 25, 2002 (when in-stream probes were removed because of low flow in the creek). During the low-flow season, the automated station at STA takes readings every 10 minutes of air temperature and rainfall only.

3.4.4.2 Results of Automated Data Collection

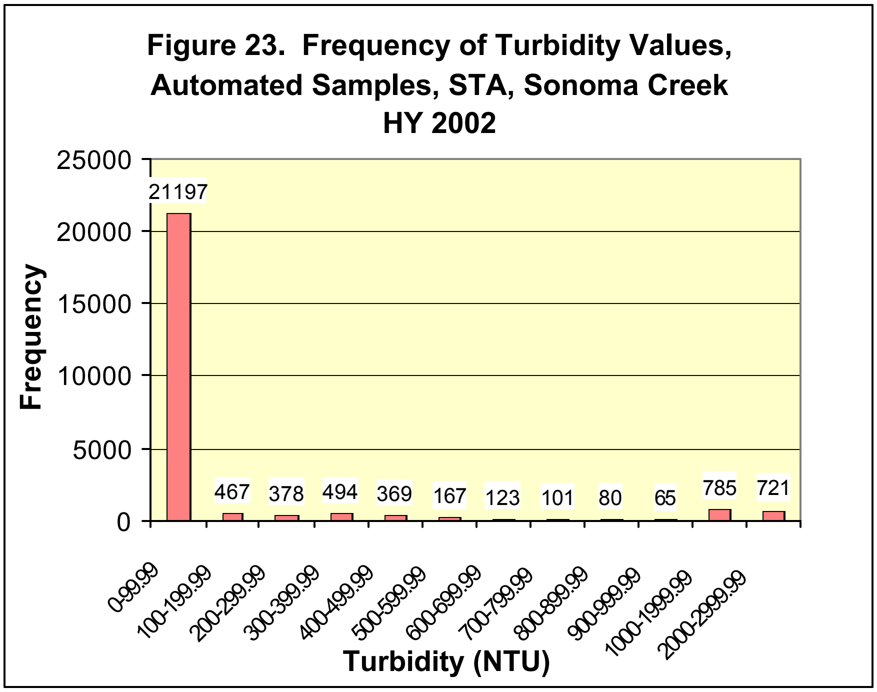
The automated data collection system at Station A took 24,947 measurements each of air temperature, stream water temperature, stream water depth, turbidity, and rainfall between October 30, 2001, at 13:25 PST and April 25, 2002, at 13:10 DST. The data set most relevant to this study, turbidity, is summarized below. (Note: had the depth probe not blown out during the January 1, 2002, storm, water depth also would be summarized here.) Rainfall measurements are discussed further with storm turbidity data.

Table 14. Summary of Turbidity Data, Automated STA, Sonoma Creek, HY02

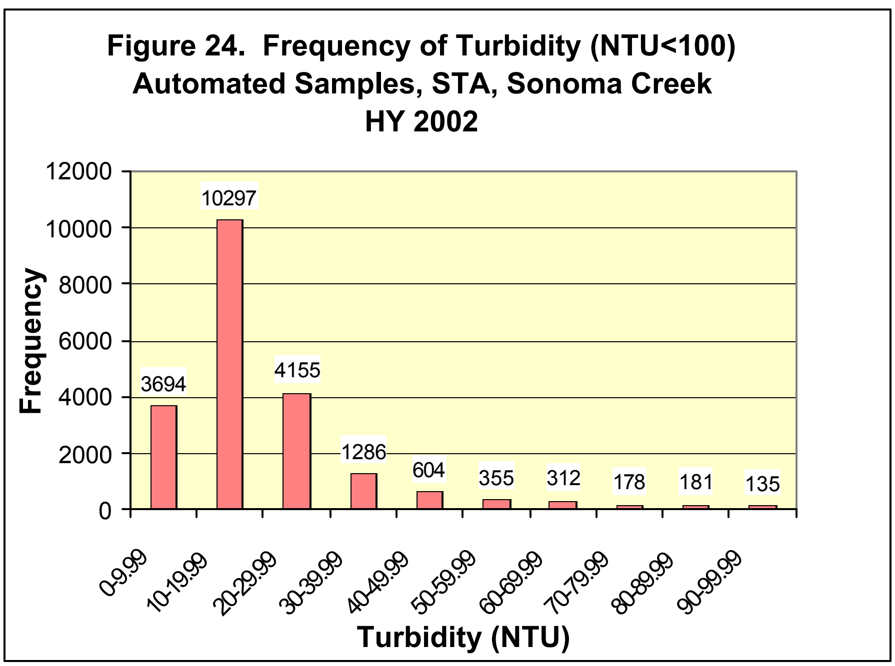
Month and Year	Number of Readings	Minimum (NTU)	Maximum (NTU)	Mean (NTU)	3.4.4.3 Median (NTU)	Standard Deviation (NTU)	Standard Error (NTU)
October 2001 (from 10-30 13:25)	200	6.0	10.0	7.9	8.0	0.9	0.07
November 2001	4,316	3.2	2047.2*	47.8	9.2	225.7	3.44
December 2001	4,460	7.2	2047.2*	376.9	26.8	688.3	10.31
January 2002	4,185	0.0	2047.2*	409.9	18.0	608.5	9.41
February 2002	3,824	2.4	206.0	24.5	20.0	16.2	0.26
March 2002	4,442	12.4	181.2	22.1	17.2	15.5	0.23
April 2002 (until 4/25, 13:10)	3,520	12.4	1844.8	46.6	24.4	98.1	1.65
All	24,947	0.0	2047.2*	158.7	18.4	431.6	2.73

*Turbidity probe's default maximum reading. See Section 3.4.4.3, Discussion of Automated Data Collection.

Figure 23 presents all turbidity values read between October 30, 2001, at 13:25 PST and April 25, 2002, at 13:10 DST at the automated station at STA. The values associated with each histogram bar equal the number of 10-minute periods during which turbidity was read in the range shown.



The greatest frequency of values for the sampling period fell in the NTU <100 bin (i.e., turbidity was <100 NTU for 21,197 10-minute intervals, or 3,533 hours). Figure 24 graphs the 21,197 values where NTU <100.



The greatest number of values fell in the 10 to 19.99 NTU bin (10,297 readings, or 1,716 hours, in that range).

To correlate automated results with grab results, we graphed the relationship of turbidity values collected by the automated system (NTU-A) with those collected during grab sampling (NTU-G). As the automated system took readings every ten minutes, it captured 77 turbidity values within five minutes of the 78 grab sampling events conducted at STA. Figure 25 presents the comparison of NTU-A and NTU-G at STA.

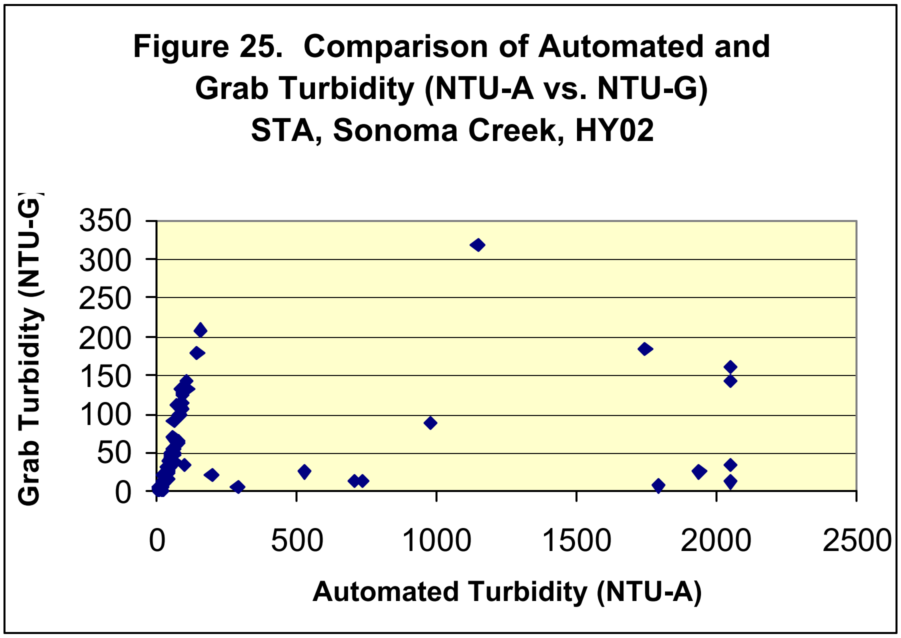


Figure 25. Comparison of Automated and Grab Turbidity (NTU-A vs. NTU-G) STA, Sonoma Creek, HY02

The best-correlated portion of the dataset is the lower end, where NTU-A <100. Figure 26 compares NTU-A and NTU-G when NTU-A <100.

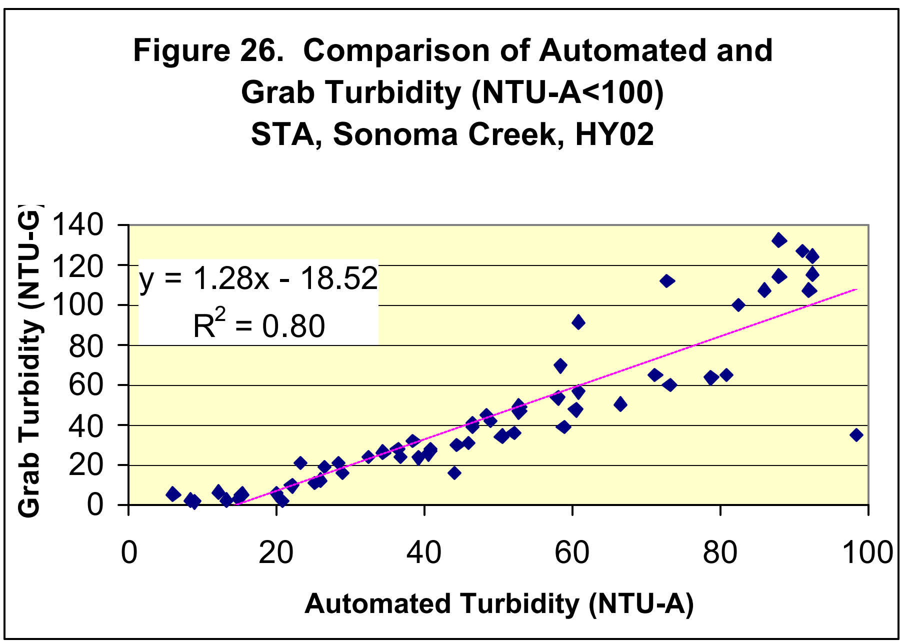


Figure 26. Comparison of Automated and Grab Turbidity (NTU-A<100) STA, Sonoma Creek, HY02

The relationship between NTU-A and NTU-G at STA is as follows:

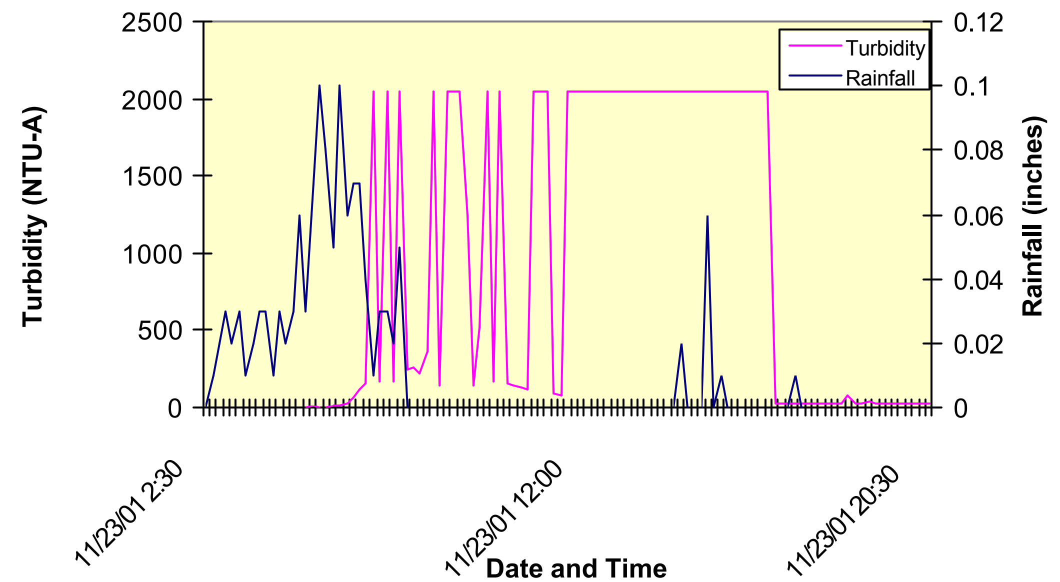
$$y = 1.28x - 18.52$$

where
y = grab turbidity in NTU (NTU-G)
x = automated turbidity in NTU (NTU-A).

The regulating equation only applies when NTU-A $\geq$14.45 and appears strongly correlated to the dataset only when NTU-A <100.

Data from the automated collection system at STA was used to estimate times of elevated turbidity during five storms in HY02. We defined the beginning of a storm as the time at which STA began recording rainfall. We defined the end of a storm as the time at which turbidity in Sonoma Creek cleared to its pre-storm level or to a non-turbid level, whichever came first. (Non-turbid is defined herein as $\leq$26 NTU-A, a value predicted to be equal to 15 NTU-G or 27 mg/L SSC, the minimum concentration defining turbid water [Anderson, 1975]). A value of 26 NTU-A is much smaller than the overall mean NTU-A at STA [158.7 NTU-A]). Graphs of each storm and associated rainfall are in Figures 27 through 31.

Figure 27. Turbidity Exposure
November 23 (18.17 hours)
STA, Sonoma Creek, HY 2002
Total Rainfall = 1.26 in/Maximum Intensity = 0.46 in/hr



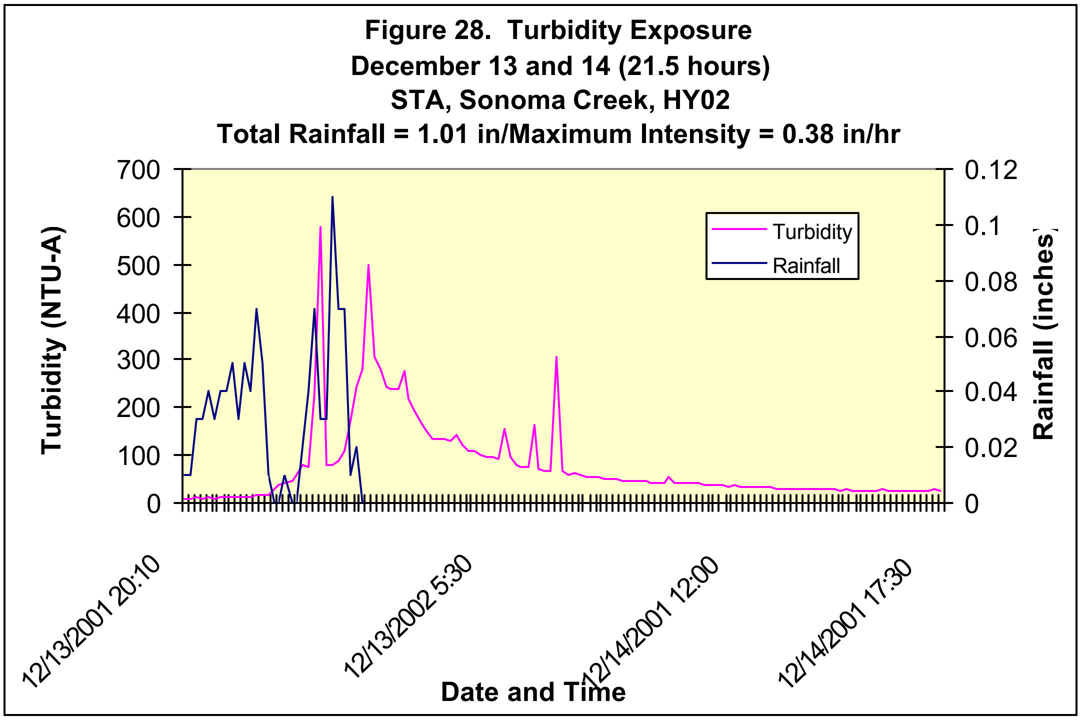


Figure 28. Turbidity Exposure
December 13 and 14 (21.5 hours)
STA, Sonoma Creek, HY02
Total Rainfall = 1.01 in/Maximum Intensity = 0.38 in/hr
Turbidity (NTU-A)
Rainfall (inches)
Turbidity
Rainfall
12/13/2001 20:10
12/13/2002 5:30
12/14/2001 12:00
12/14/2001 17:30
Date and Time

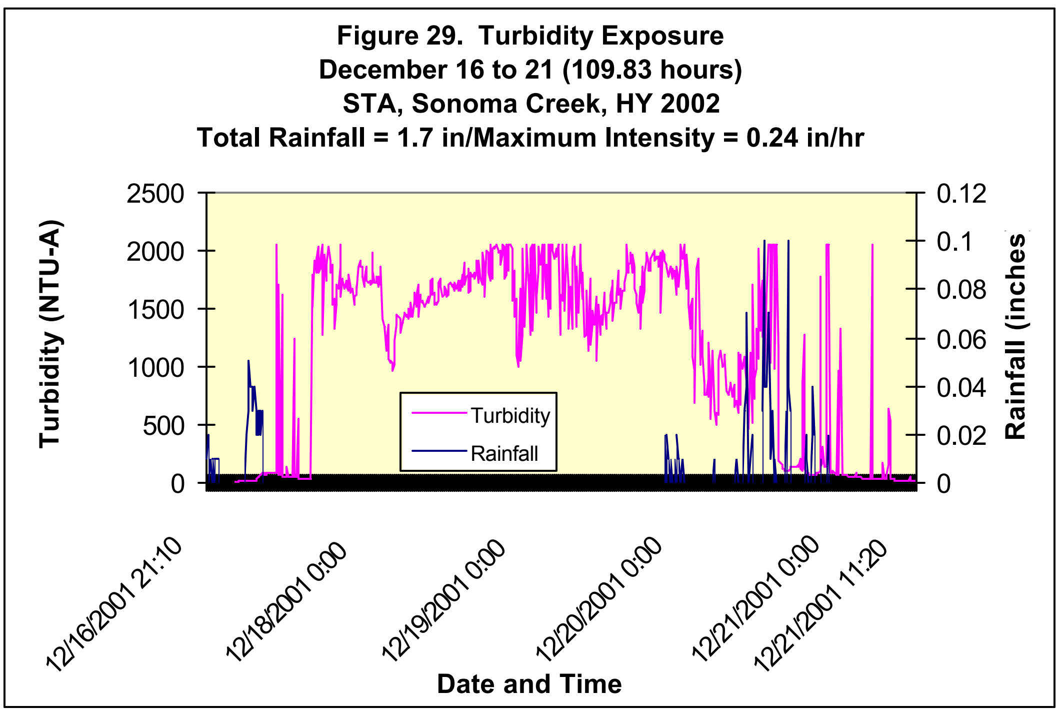


Figure 29. Turbidity Exposure
December 16 to 21 (109.83 hours)
STA, Sonoma Creek, HY 2002
Total Rainfall = 1.7 in/Maximum Intensity = 0.24 in/hr
Turbidity (NTU-A)
Rainfall (inches
Turbidity
Rainfall
12/16/2001 21:10
12/18/2001 0:00
12/19/2001 0:00
12/20/2001 0:00
12/21/2001 0:00
12/21/2001 11:20
Date and Time

Figure 30. Turbidity Exposure
February 19 to 21 (51.17 hours)
STA, Sonoma Creek, HY 2002
Total Rainfall = 0.34 in/Maximum Intensity = 0.11 in/hr

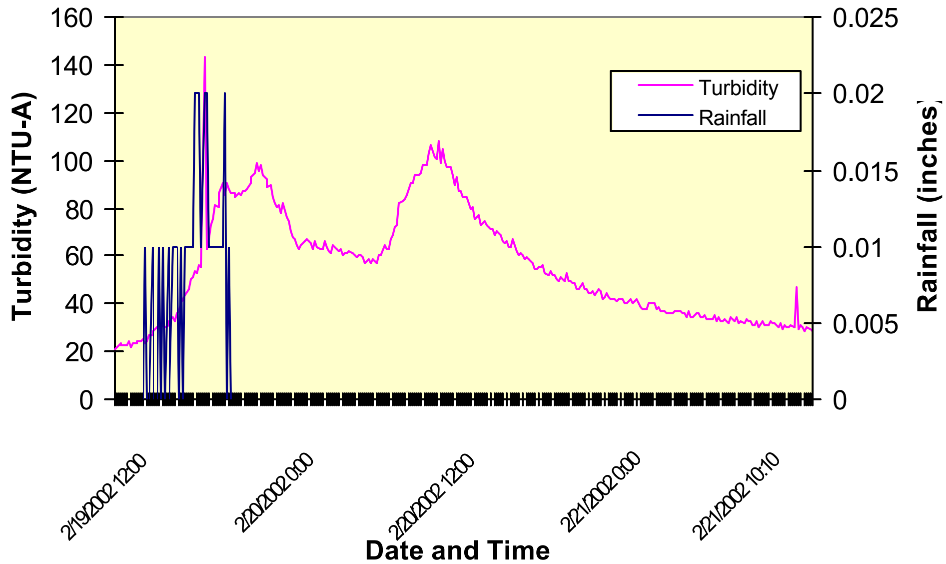
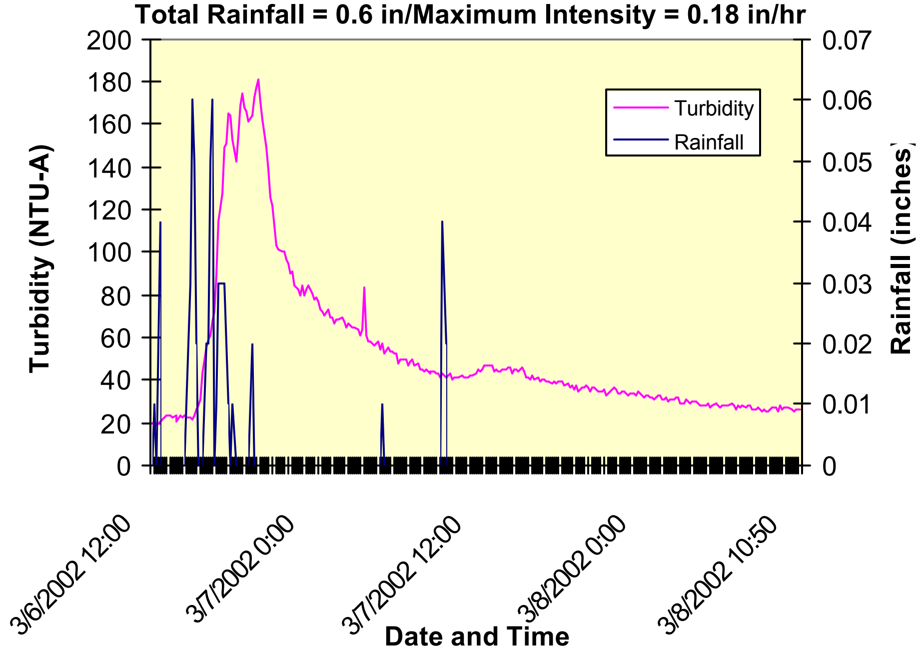


Figure 31. Turbidity Exposure
March 6 to 8 (47 hours)
STA, Sonoma Creek, HY 2002
Total Rainfall = 0.6 in/Maximum Intensity = 0.18 in/hr



Lag times between peak rainfall and peak turbidity ranged from 1.25 hours for November 23, 2001, and 4.5 hours for December 16 to 21, 2001. Maximum rainfall intensity (inches of rainfall per hour) ranged from 0.11 to 0.46 inches per hour, the 1.26-inch-total November storm being the most intense.

Table 15. Storm Intensity and Lag Times, Five Storms, HY 2002

Storm	November 23, 2001 (18.17 hr storm; 1.26 in rainfall) (Max NTU-A = 266)	December 13 to 16, 2001 (21.5 hr storm; 1.01 in rainfall) (Max NTU-A = 304.4)	December 16 to 21, 2001 (109.83 hr storm; 1.7 in rainfall) (Max NTU-A = 208.4)	February 19 to 21, 2002 (51.17 hr storm; 0.34 in rainfall) (Max NTU-A = 108.4)	March 6 to 9, 2002 (47 hr storm; 0.6 in rainfall) (Max NTU-A = 181.2)
Lag Time (hr)	1.25	2.0	4.5	4.2	3.3
Intensity (in/hr)	0.46	0.38	0.24	0.11	0.18

The time required for turbidity to clear from its maximum NTU-A value for each of the five storms is expressed in Table 16. Again, we defined the beginning of a storm as the time at which STA began recording rainfall. We defined the end of a storm as the time at which turbidity in Sonoma Creek cleared to its pre-storm level or to a non-turbid level, whichever came first. (Again, non-turbid is defined herein as $\leq$26 NTU-A, a value predicted to be equal to 15 NTU-G or 27 mg/L SSC, the minimum SSC defining turbid water [Anderson, 1975]).

For this analysis, we eliminated spiked values (which we defined as those NTU-A values that changed in a positive direction more than 50% in a 10-minute period) and the saturated value (2047.2 NTU-A) and followed the underlying record of climbing or declining readings. For some storms, the elimination of spiked readings resulted in extremely conservative estimates of maximum NTU-A values (i.e., values in the hundreds instead of thousands).

Table 16. Clearing Rates, Five Storms, STA, HY02

Turbidity	Clearing Times (time after maximum NTU-A value in hours)				
Percentage of Maximum NTU-A Value Recorded for Storm	**November 23, 2001 (Max NTU-A = 266)**	**December 13 to 16, 2001 (Max NTU-A = 304.4)**	**December 16 to 21, 2001 (Max NTU-A = 208.4)**	**February 19 to 21, 2002 (Max NTU-A = 108.4)**	**March 6 to 9, 2002 (Max NTU-A = 181.2)**
90	0.25	0.25	0.25	0.75	0.25
75	0.75	1.0	0.5	2.5	1.0
50	2.75	1.5	1.5	8.0	2.25
25	9.0	4.25	4.25	27.5	11.5
10	9.5	11.25	NA	NA	NA
0*	9.75	13.25	23.75	27.5	35.5

* 26 NTU-A or pre-storm NTU-A value
NA Not applicable. Value would be smaller than 26 NTU-A or pre-storm NTU-A

Estimated turbidity exposure times for the five storms are listed below in Table 17. The exposure time for each storm was equal to the number of hours that NTU-A was recorded at or above a given value.

Table 17. Turbidity Exposures, Five Storms, STA, Sonoma Creek, HY 2002

Turbidity (NTU-A)	Duration of Exposure (Hours)				
Automated Value	**November 23, 2001 (18.17 hr storm; 1.26 in rainfall)**	**December 13 to 16, 2001 (21.5 hr storm; 1.01 in rainfall)**	**December 16 to 21, 2001 (109.83 hr storm; 1.7 in rainfall)**	**February 19 to 21, 2002 (51.17 hr storm; 0.34 in rainfall)**	**March 6 to 9, 2002 (47 hr storm; 0.6 in rainfall)**
≥0	18.17	21.5	109.83	51.17	47
≥10	15	19.83	109	51.17	47
≥15	14.84	19.33	103.66	51.17	47
≥25	12.5	16.67	102.33	48.84	43.5
≥50	10.67	8.83	91.16	27	14
≥100	10	4.67	80.66	1.17	4.67

For each turbidity exposure for the five storms, we calculated dose indices using the equation Dose Index = natural log [SSC x hours exposed]. Newcombe and Jensen (1996) developed dose indices as measures of fish response to SSC in the Russian River watershed. (See Appendix C for the dose indices calculated for each storm.) From the dose indices, we calculated severity indices, measures of potentially deleterious effects on salmonids in the affected water bodies (Table 18). We do not present values of <15 for NTU-A because the regulating equation comparing NTU-A with NTU-G at STA (and consequently, affecting the derived values for SSC) does not apply when NTU-A $\leq$14.45.

Table 18. Severity Indices, Five Storms, STA, Sonoma Creek, HY 2002

Turbidity Threshold/ Predicted SSC	Severity Index (Severity Index Ranking= 0.7491 [SSC dose index + 0.7625])				
NTU-A/mg/L	November 23, 2001 (18.17 hr storm; 1.26 in rainfall)	December 13 to 16, 2001 (21.5 hr storm; 1.01 in rainfall)	December 16 to 21, 2001 (109.83 hr storm; 1.7 in rainfall)	February 19 to 21, 2002 (51.17 hr storm; 0.34 in rainfall)	March 6 to 9, 2002 (47 hr storm; 0.6 in rainfall)
15/1.19	2.72	2.92	4.18	3.65	3.59
25/23.59	4.83	5.04	6.41	5.85	5.77
50/79.59	5.62	5.48	7.23	6.32	5.83
100/191.58	6.23	5.66	7.8	4.63	5.66

The significance of the severity indices is discussed below.

3.4.4.4 Discussion of Automated Data Collection

The automated data collection system at STA performed well in collecting all datasets but depth readings, which were unusable because of depth probe blowout and reinstallation mid season. Thus we have a continuous record of air temperature, stream water temperature, stream water depth, turbidity, and rainfall between October 30, 2001, at 13:25 PST and April 25, 2002, at 13:10 DST.

Of the 77 automatic turbidity readings taken within 5 minutes of 78 grab sampling events, four readings were 2,047.2 NTU. The value was repeated throughout the season and is apparently a maximum reading delivered by the probe at times when it does not see its light signal properly (Allen, 2002). The four 2,047.2 NTU readings corresponded to grab samples with turbidity values of 12.7, 34.4, 142, and 160 NTU. Although results from four samples may not determine a trend, their range supports the hypothesis that 2047.2 NTU is not an accurate reflection of actual turbidity but is due to a limitation in the probe. The maximum reading showed up only during turbid conditions, however, suggesting that although it may not be numerically accurate it does indicate elevated turbidity.

The majority of NTU-A readings for the season were <40. Mean turbidity values increased from November 2001 to January 2002 and decreased in February and March 2002. Mean values increased again in April, after major winter storms had passed, although the increase (approximately doubling, from a mean of 24.5 and 22.1 NTU in February and March to 46.6 NTU in April) was not as large as the increase from November 2001 to January 2002 (approximately increasing by a factor of eight, from 47.8 NTU in November to 376.9 and 409.9 NTU in December 2001 and January 2002).

The increase of turbidity in April may have been due to increasingly warm days and lower water levels, optimal conditions for algal growth.

The comparison of NTU-A with NTU-G at STA indicates that the two datasets are well correlated only when NTU-A $\geq$14.45 and $\leq$100. For that range, NTU-A values are greater than NTU-G values by a minimum of 28 percent.

Lag times between peak rainfall and peak turbidity for the five storms monitored from November to March ranged from 1.25 to 4.5 hours, with shorter lag times earlier in the season. Maximum rainfall intensity ranged from 0.11 to 0.46 inches per hour, the November storm being the most intense. Lag times were shorter for the more intense storms: the number of hours was smaller between peak rainfall and peak turbidity when rain fell harder (see Table 15). Maximum NTU-A was also highest for the two most intense storms (266 and 304.4 NTU-A for November 23 and December 13 to 16, respectively).

Clearing after storms occurred such that 90 percent of maximum NTU-A values were generally reached within 0.25 hours (15 minutes), 50 percent in less than 3 hours, and 0 percent (total clearing) in less than 36 hours. The amount of time required to achieve total clearing increased from 9.75 hours in November 2001 to 35.5 hours in March 2002. This increase in clearing time may have been due to baseline turbidity increasing with the season, as rainfall introduced more and more pulses of sediment. Therefore chronic turbidity levels may be sustained longer later in the wet season, as is also suggested by our results for duration of exposure (Table 17). Wet storms with less than 1 inch of rain in February and March 2002 sustained turbidity levels $\geq$25 NTU-A three to four times longer than did storms in November and December 2001.

Severity indices calculated for the five storms indicate values ranging from 2.72 in all storms to 7.8 in the December 16 to 21, 2001, event. At turbidity/SSC values above 25 NTU-A/23.59 mg/L, severity indices were always above 4 (a severity index of 4 corresponds to short-term reduction in feeding rates). Severity indices were more often above 5, associated with minor physiological stress, increased coughing rates, and increased respiration rates. Severity indices for the longer or more intense events rose above 6, associated with moderate physiological stress, and 7, associated with moderate habitat degradation and/or impaired homing.

Developing dose and severity indices for Sonoma Creek using our methods assumes that the hours of elevated turbidity due to SSC are contiguous during storms rather than separated by times of low turbidity/SSC. Because stream clearing generally occurs uniformly, without much spiking to higher levels once turbidity values begin dropping, this assumption may be true. Our storm graphs (Figures 27 through 31) show contiguous values of elevated turbidity and uniform clearing in cases where the saturated reading of 2047.2 NTU is not common.

3.4.4.5 Summary of Automated Data Collection

- The automated data collection system at Station A (STA) took 24,947 measurements each of air temperature, stream water temperature, stream water depth, turbidity, and rainfall between October 30, 2001, at 13:25 PST and April 25, 2002, at 13:10 DST.
- Minimum NTU-A was 0.0, maximum was 2,047.2 ($\pm$431.6), mean was 158.7, median was 18.4, and standard error was 73.
- The relationship between NTU-A and NTU-G at STA is as follows:

$$y = 1.28x - 18.52$$

where
y = grab turbidity in NTU (NTU-G)
x = automated turbidity in NTU (NTU-A).

The regulating equation only applies when NTU-A $\geq$14.45 and appears strongly correlated to the dataset only when NTU-A <100.

- Data from the automated collection system at STA was used to estimate times of elevated turbidity during five storms in HY02.
- Lag times between peak rainfall and peak turbidity ranged from 1.25 hours for November 23, 2001, and 4.5 hours for December 16 to 21, 2001. Maximum rainfall intensity (inches of rainfall per hour) ranged from 0.11 to 0.46 inches per hour, the 1.26-inch-total November storm being the most intense.
- Estimated turbidity exposure times for the five storms, the number of hours that NTU-A was recorded at or above a given value, ranged from 18.17 to 109.83 hours at $\geq$0 NTU to 10 to 80.66 hours at $\geq$100 NTU.
- Extended times of elevated turbidity exposure resulted in severity indices (measures of deleterious effects on salmonids) ranging from 2.72 to 7.8. At turbidity/SSC values above 25 NTU-A/23.59 mg/L, severity indices were always above 4 (a severity index of 4 corresponds to short-term reduction in feeding rates). Severity indices were more often above 5, associated with minor physiological stress, increased coughing rates, and increased respiration rates. Severity indices for the longer or more intense events rose above 6, associated with moderate physiological stress, and 7, associated with moderate habitat degradation and/or impaired homing.

4.0 Recommendations

Trail monitoring for future road remediation projects should continue to focus on stream-intensive sediment sources, as indicated by fieldwork conducted during the wet season. Our findings indicate that focusing on poorly designed roads is a sound approach to reducing soil loss in upland areas: we estimated low yields of sediment eroding from remediated trails and continued high yields eroding from unremediated roads. Road prescriptions must focus, however, on the hydrological connection between the sediment source and receiving waters.

Although the RUSLE model serves well in a qualitative or relative evaluation of background erosion potential, it may only be a coarse tool for actually quantifying background soil loss with a high degree of accuracy. In subsequent work, we will evaluate this model's precision in quantifying annual soil loss. We will attempt to compare measured soil loss values to the model's predicted values on a subwatershed scale. Furthermore, we will conduct a sensitivity analysis of the model's factors to determine potential sources of error and develop a confidence interval for the predicted values.

Future water-quality sampling should focus on fine-tuning our project design to better understand human impacts on sediment delivery to waterways, now that equipment has been acquired, protocols have been established, and preliminary results are in hand. Datasets identified in this report as being too small for valid comparison (i.e., depth-integrated [DI] samples, watershed-wide samples) should be supplemented in future monitoring. Questions worth answering include what are turbidity:SSC relationships at Other sites? How do DI samples relate to NTU-A and NTU-G samples? What are the most important factors causing elevated stream turbidity: rainfall intensity, storm duration, watershed land uses, and channel erosion? How do flows at the USGS gauging station relate to other locations in the Sonoma Creek watershed?

To answer these questions, we specifically recommend that future turbidity and SSC monitoring includes the following:

- Increased sample collection at Other sites (grab sampling in four to five storms in major tributaries directly upstream of their confluences with Sonoma Creek)
- Collection of at least twenty DI samples at STB (better: DI sampling on at least falling limb of four to five storms across STB cross section) to correlate to grab and automated samples at STA
- Continued use of the automated station to monitor all previously measured parameters at STA
- Complete land-use map coverage for Sonoma Valley for the SEC GIS database
- Correlation of sample results to RUSLE-style model of sediment production potential for Sonoma Valley
- Measured or estimated flows at times of sample collection at Other sites (along with continued measurement of flows at STA and STB and correlation to discharge measurements at USGS gauge).

5.0 Task Products

Copies of 319(h) quarterly progress reports, listing task products submitted for this project, are included in Appendix D.

6.0 Disclosure Statement

Funding for this project has been provided in part by the USEPA pursuant to Assistance Agreement No. C9-989697-00-0 and any amendments thereto which has been awarded to the State Water Resources Control Board (SWRCB) for the implementation of California's Nonpoint Source Pollution Control Program. The contents of this document do not necessarily reflect the views and policies of the USEPA or the SWRCB, nor does

mention of trade names or commercial products constitute endorsement or recommendation for use.

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9.0 Glossary

Gully	Linear erosional feature cut deeper and wider than rills
Hydrologic year (HY)	A water year, extending from October 1 to September 30 a year later. Hydrologic year 2002 (HY02) extends from October 1, 2001, to September 30, 2002.
Inboard ditches	Ditches running along the inside (uphill side) of trails.
Mass wasting	Large-scale soil movement in and on hillslopes through processes such as landslides and soil creep.
Rill	Groove that parallels the direction of runoff and that is up

	to 1 square foot in cross section.
Sheet erosion	Erosion removes an approximately even layer of soil from the ground surface. The layer can be microscopically thin.
Sidecast	Cast to the side, as off the side of a road.
Stage	Height of the water surface in a stream above a predetermined point that may be on or near the channel bottom. Also: gauge height.
Stream order	Classification of the relative position of a stream with respect to its tributary network. Headwater stream reaches are lower in stream order than downstream reaches.
Subwatershed	The land area discharging to a major perennial, intermittent, or ephemeral drainage.


Plate 1. Locator Map
Annadel State Park
Santa Rosa, California
Annadel SP
LEGEND
Sonoma Creek Watershed
Park Boundary
1000 0 1000 2000 3000 Feet
Sonoma Ecology Center
GIS/GPS Project
October 2002

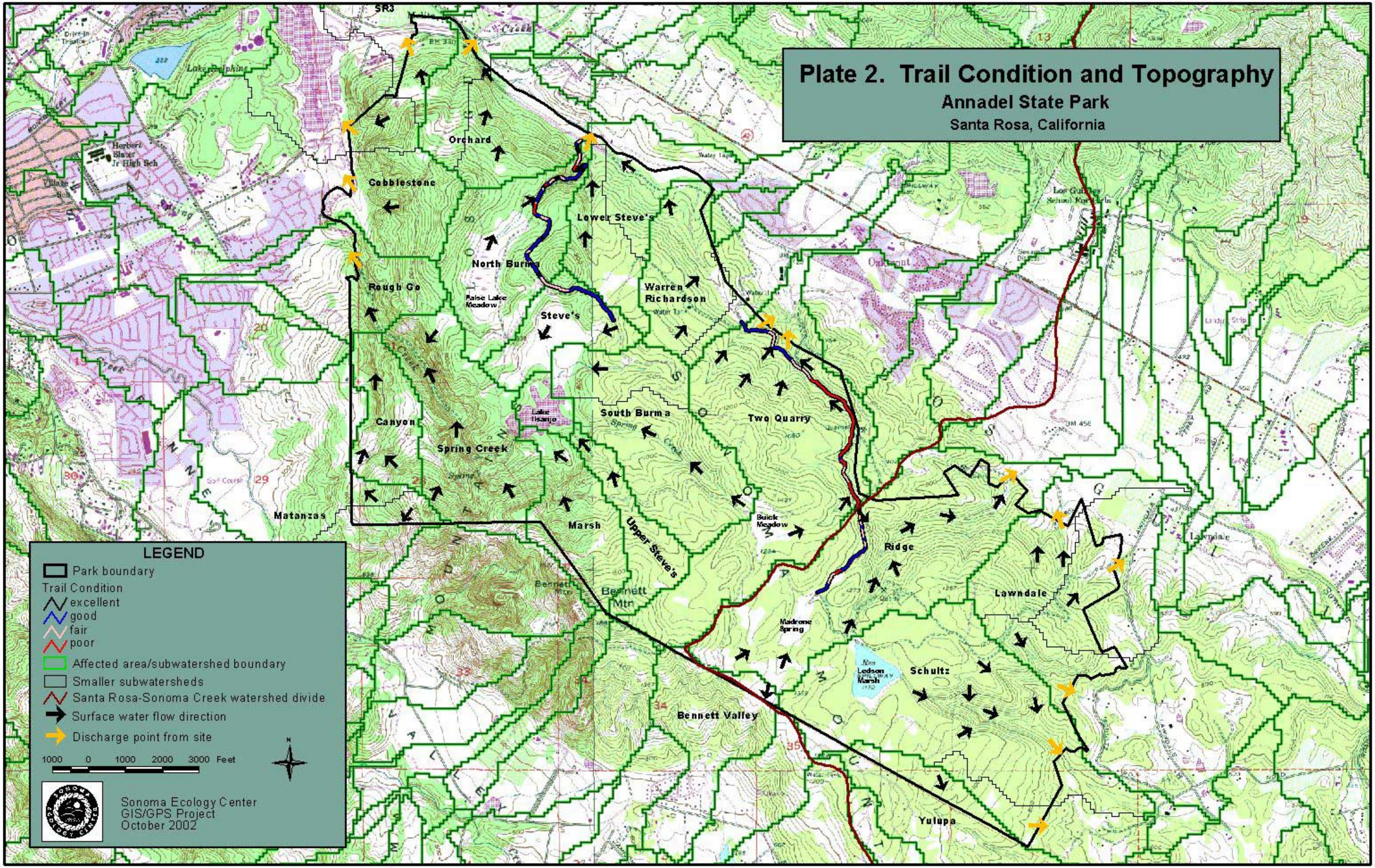
Plate 2. Trail Condition and Topography
Annadel State Park
Santa Rosa, California
LEGEND
Park boundary
Trail Condition
excellent
good
fair
poor
Affected area/subwatershed boundary
Smaller subwatersheds
Santa Rosa-Sonoma Creek watershed divide
Surface water flow direction
Discharge point from site
1000 0 1000 2000 3000 Feet
N
Sonoma Ecology Center
GIS/GPS Project
October 2002
Orchard
Cobblestone
Lower Steve's
North Burma
Rough Go
False Lake Meadow
Steve's
Warren Richardson
Two Quarry
South Burma
Lake Ilsanjo
Canyon
Spring Creek
Matanzas
Marsh
Upper Steve's
Buick Meadow
Ridge
Lawndale
Madrone Spring
Ledson Marsh
Schultz
Bennett Mtn
Bennett Valley
Yulupa
SR3
Lake Ralphine
Herbert Slater Jr High Sch
Los Guilicos School
Oakmont

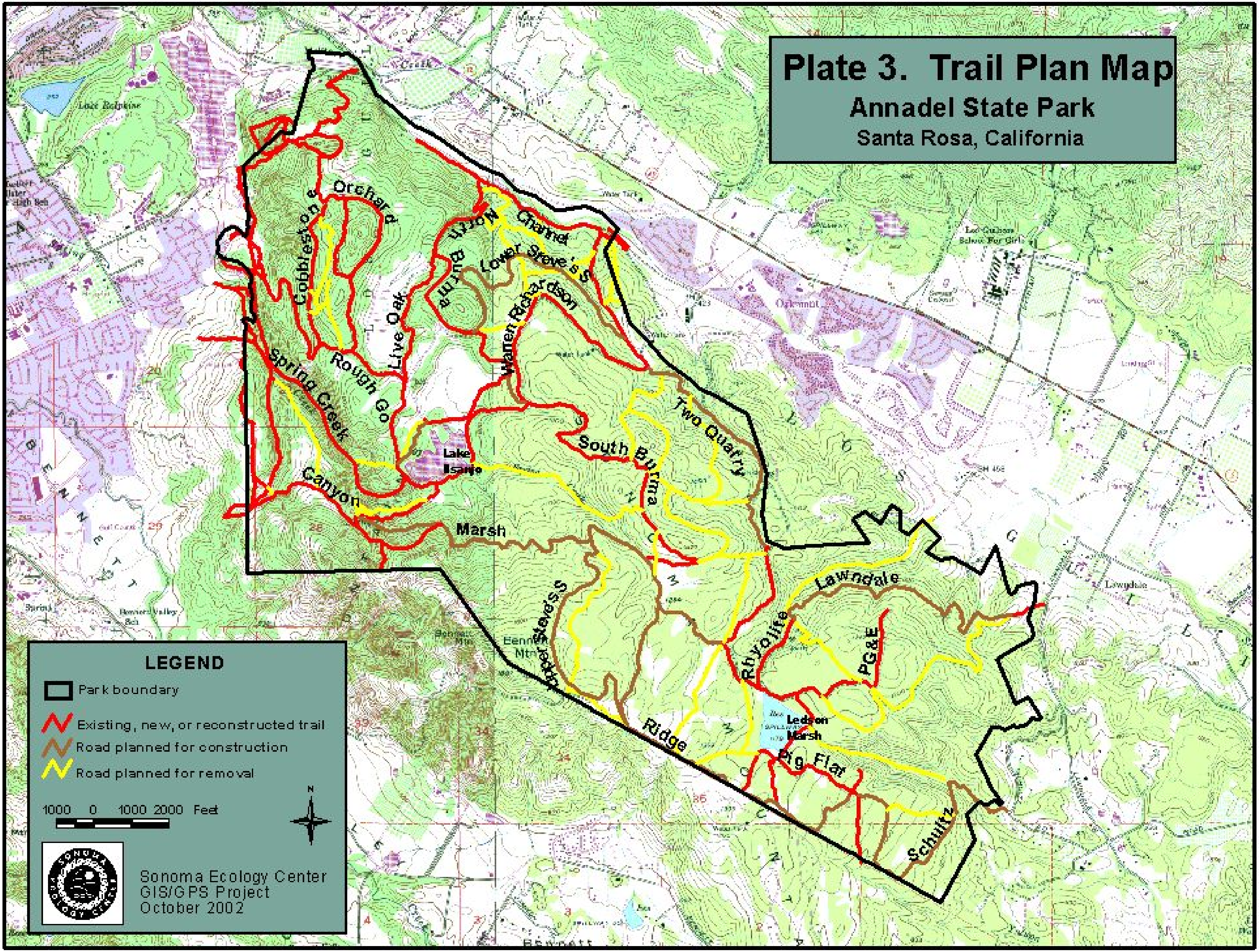

Plate 3. Trail Plan Map
Annadel State Park
Santa Rosa, California
Orchard
Cobblestone
North Burma
Channel
Lower Steve's S
Richardson
Live Oak
Rough Go
Spring Creek
Warren Richardson
Two Quarry
South Burma
Lake Ilsanjo
Canyon
Marsh
Steve's S
Lawndale
Rhyolite
PG&E
Ledson Marsh
Ridge
Pig Flat
Schultz
LEGEND
Park boundary
Existing, new, or reconstructed trail
Road planned for construction
Road planned for removal
1000 0 1000 2000 Feet
N
Sonoma Ecology Center
GIS/GPS Project
October 2002

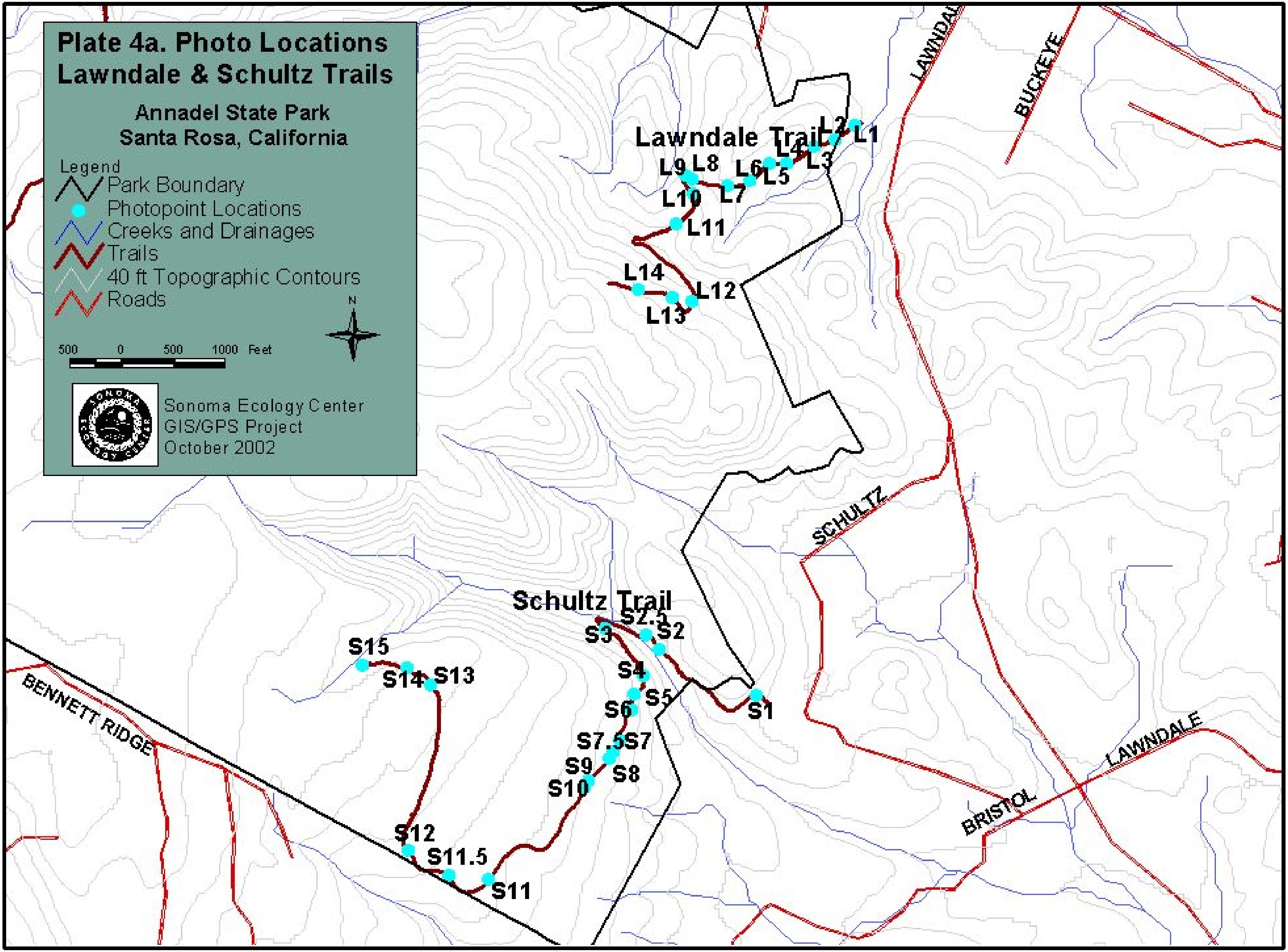

Plate 4a. Photo Locations
Lawndale & Schultz Trails
Annadel State Park
Santa Rosa, California
Legend
Park Boundary
Photopoint Locations
Creeks and Drainages
Trails
40 ft Topographic Contours
Roads
N
500 0 500 1000 Feet
Sonoma Ecology Center
GIS/GPS Project
October 2002
Lawndale Trail
L1
L2
L3
L4
L5
L6
L7
L8
L9
L10
L11
L12
L13
L14
LAWNDALE
BUCKEYE
SCHULTZ
Schultz Trail
S1
S2
S2.5
S3
S4
S5
S6
S7
S7.5
S8
S9
S10
S11
S11.5
S12
S13
S14
S15
BENNETT RIDGE
BRISTOL
LAWNDALE

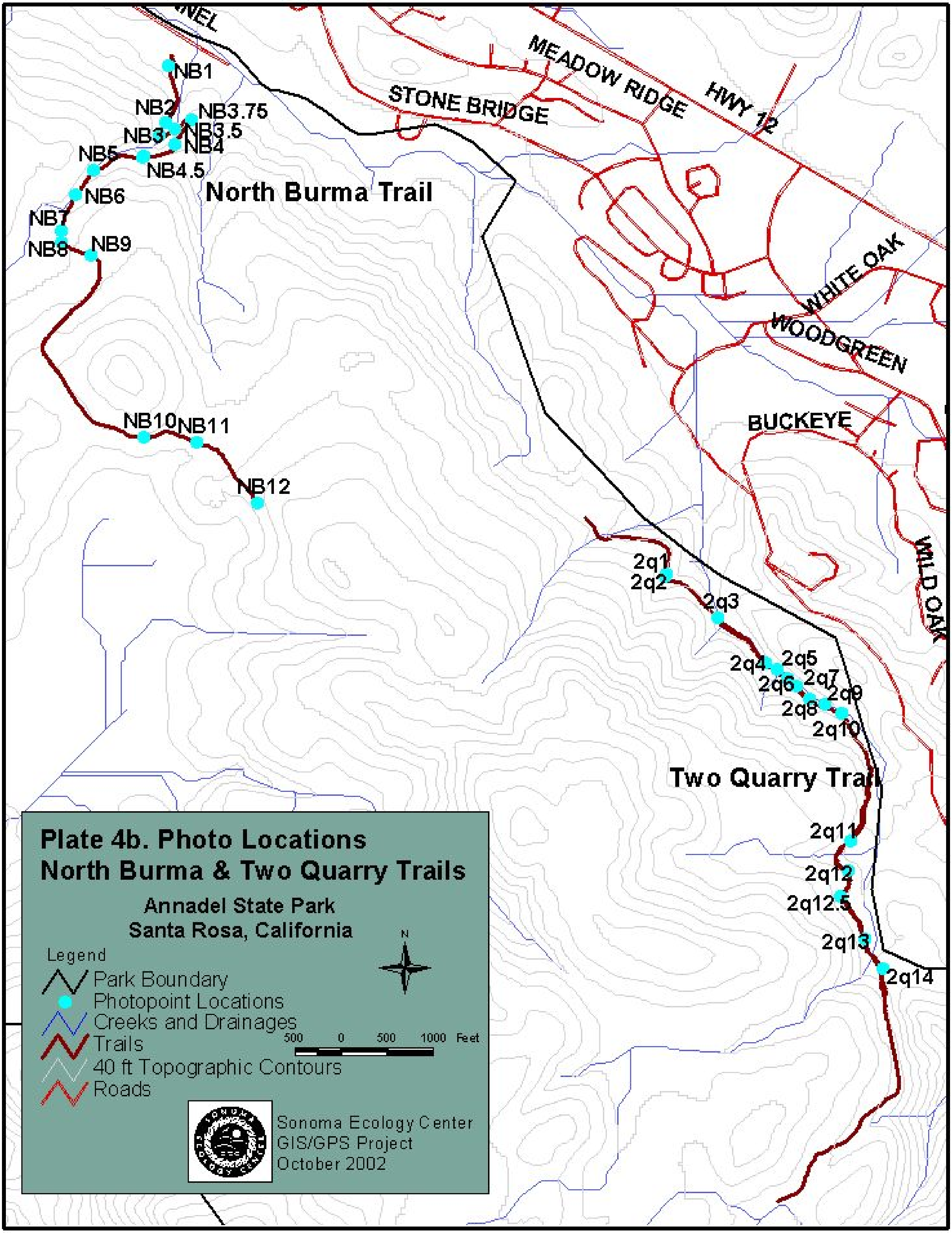

Plate 4b. Photo Locations
North Burma & Two Quarry Trails

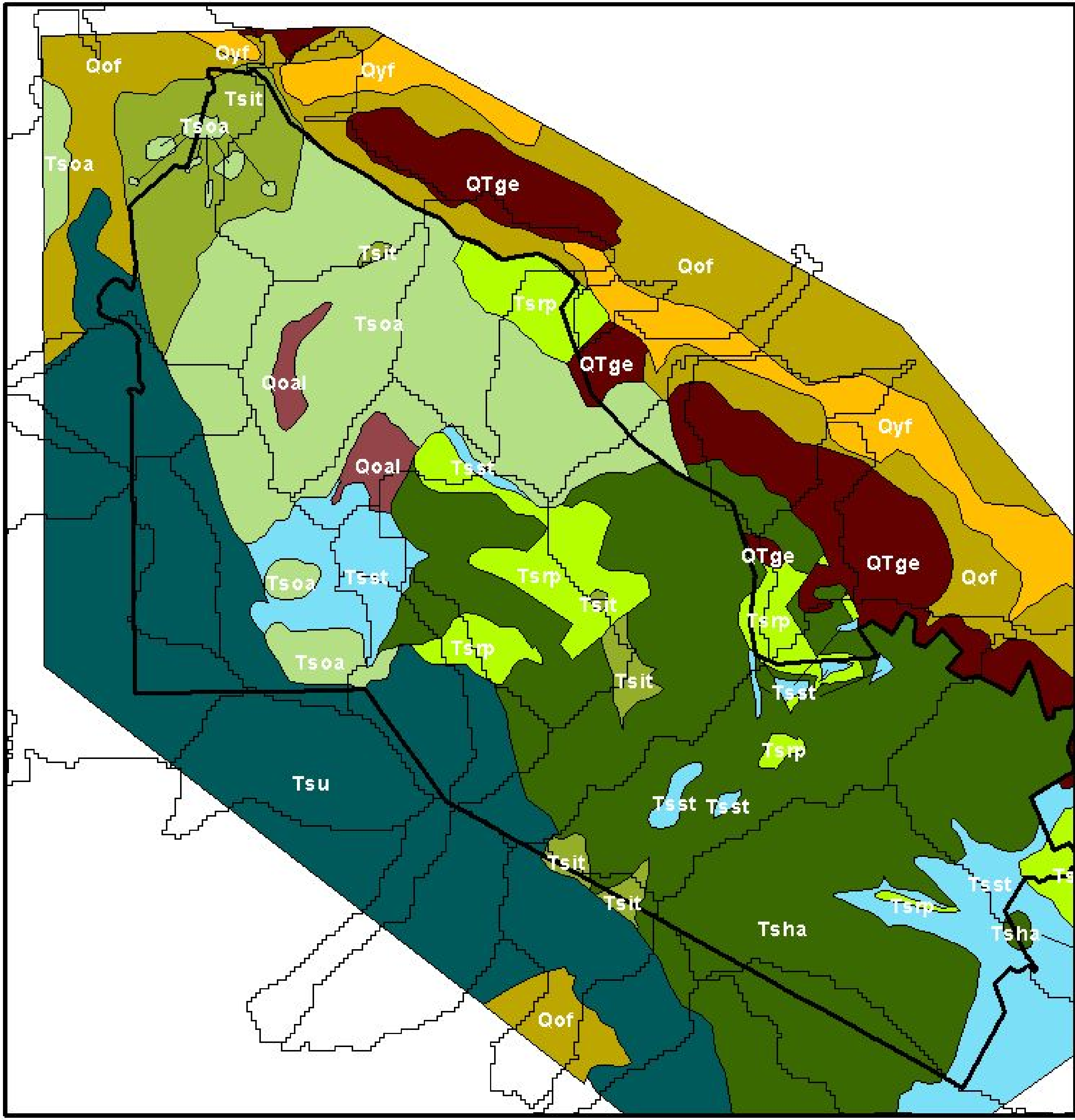

Plate 5.
Geology Map
Annadel State Park
Santa Rosa, California

Subwatersheds

Park Boundary

Quaternary Rock Units

- Qyf — Younger Alluvial Fan Deposits - Sand, silt and gravel deposited on eroded portions of Qof
- Qof — Older Alluvial Fan Deposits - Sand and gravel derived from erosion of surrounding highlands
- Qoal — Older Alluvium - Sand and gravel deposited in upland valleys
- QTge — Glen Ellen Formation - Sand, silt, gravel and lesser amounts of tuff

Tertiary Sonoma Volcanics Units

- Tsha — Massive flows and flow breccias of andesite
- Tsit — Ash-fall and ash-flow tuff of intermediate composition
- Tsoa — Massive flows and flow breccias of basaltic andesite
- Tsrp — Massive flows and flow breccias of rhyolite and perlite
- Tsst — Ash-fall and ash-flow of silicic composition
- Tsu — Undifferentiated mafic to silicic lava and pyroclastic rocks

500 0 500 1000 Meters

N

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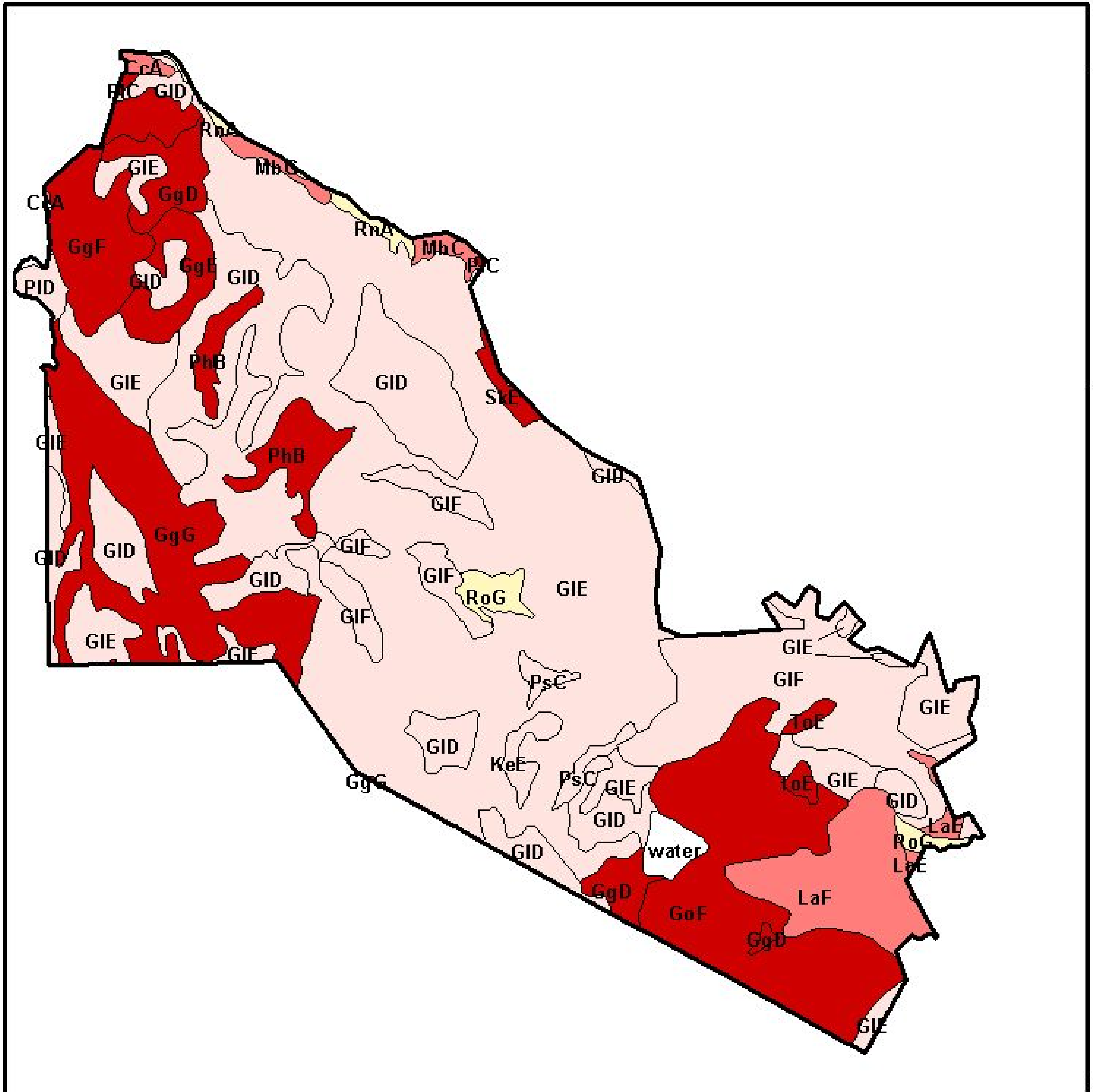

Plate 6a. K Factor
Annadel State Park
Santa Rosa, California

Park Boundary

Soil Erodibility (K-factor)

- 0
- 0 - 0.05
- 0.05 - 0.2
- 0.2 - 0.28
- 0.28 - 0.37

Soil Types

CcA	Clear Lake clay loam 0-2% slope
GlD	Goulding cobbly clay loam 5-15% slope
GlE	Goulding cobbly clay loam 15-30% slope
GlF	Goulding cobbly clay loam 30-50% slope
GgD	Goulding clay loam 5-15% slope
GgE	Goulding clay loam 15-30% slope
GgF	Goulding clay loam 30-50% slope
GgG	Goulding clay loam 50-75% slope
GoF	Goulding-Toomes clay loam 9-15% slope
HbC	Haire gravelly loam 0-9% slope
KeE	Kidd - stony loam 2-30% slope
LaE	Laniger loam 15-30% slope
LaF	Laniger loam 30-50% slope
MbC	Manzanita gravelly silt loam 0-9% slope
PlC	Pleasanton-Haire Complex gravelly and clay loam 0-9% slope
PlD	Pleasanton-Haire Complex gravelly and clay loam 9-15% slope
PhB	Pleasanton clay loam 2-5% slope
PkC	Pleasanton gravelly clay loam 2-9% slope
PsC	Positas gravelly loam 0-9% slope
RnA	Riverwash
RoG	Rock Land
SkE	Spreckels loam 15-30% slope
ToE	Toomes rocky loam 2-30% slope

500 0 500 1000 Meters

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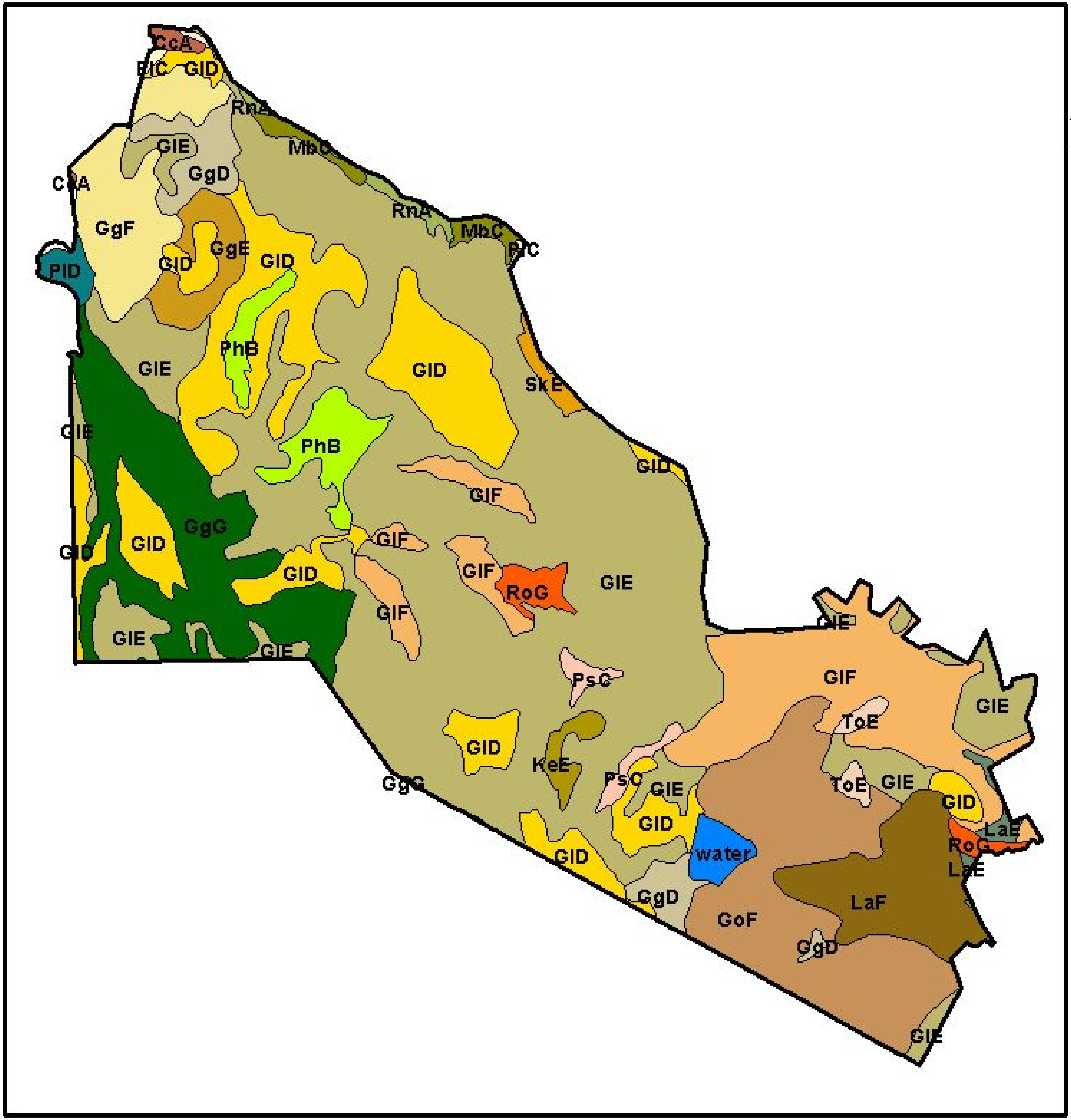

Plate 6b. Soil Types
Annadel State Park
Santa Rosa, California

Park Boundary

Soil Types

- CcA Clear Lake clay loam 0-2% slope
- GID Goulding cobbly clay loam 5-15% slope
- GIE Goulding cobbly clay loam 15-30% slope
- GIF Goulding cobbly clay loam 15-30% slope
- GgD Goulding clay loam 5-15% slope
- GgE Goulding clay loam 15-30% slope
- GgF Goulding clay loam 30-50% slope
- GgG Goulding clay loam 50-75% slope
- GoF Goulding-Toomes clay loam 9-15% slope
- KeE Kidd stony loam 2-30% slope
- LaE Laniger oam 15-30% slope
- LaF Laniger loam 30-50% slope
- MbC Manzanita gravelly silt loam 0-9% slope
- PIC Pleasanton-Haire Complex gravelly clay loam 0-9% slope
- PID Pleasanton-Haire Complex
- PhB Pleasanton clay loam 2-5% slope
- PsC Positas - gravelly loam 0-9% slope
- RnA Riverwash
- RoG Rock Land
- SkE Spreckels loam 15-30% slope
- ToE Toomes rocky loam 2-30% slope
- Water

N

500 0 500 1000 Meters

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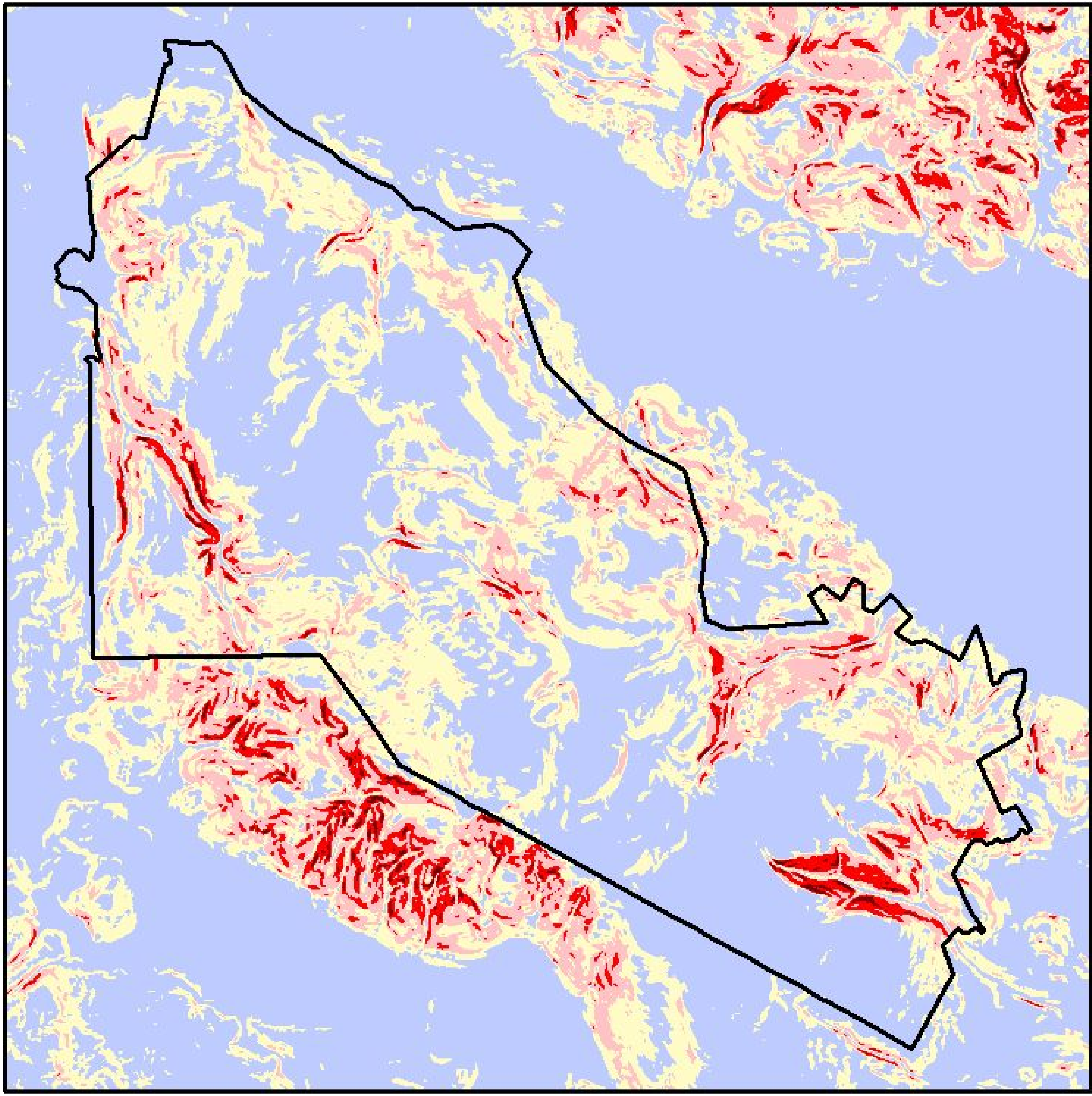
Plate 7a. Slope
Annadel State Park
Santa Rosa, California



Park Boundary

Percent Slope

- 0 - 20%
- 20 - 40%
- 40 - 60%
- 60 - 80%
- 80 - 100%
- 100 - 150%
- No Data

N

500 0 500 1000 Meters

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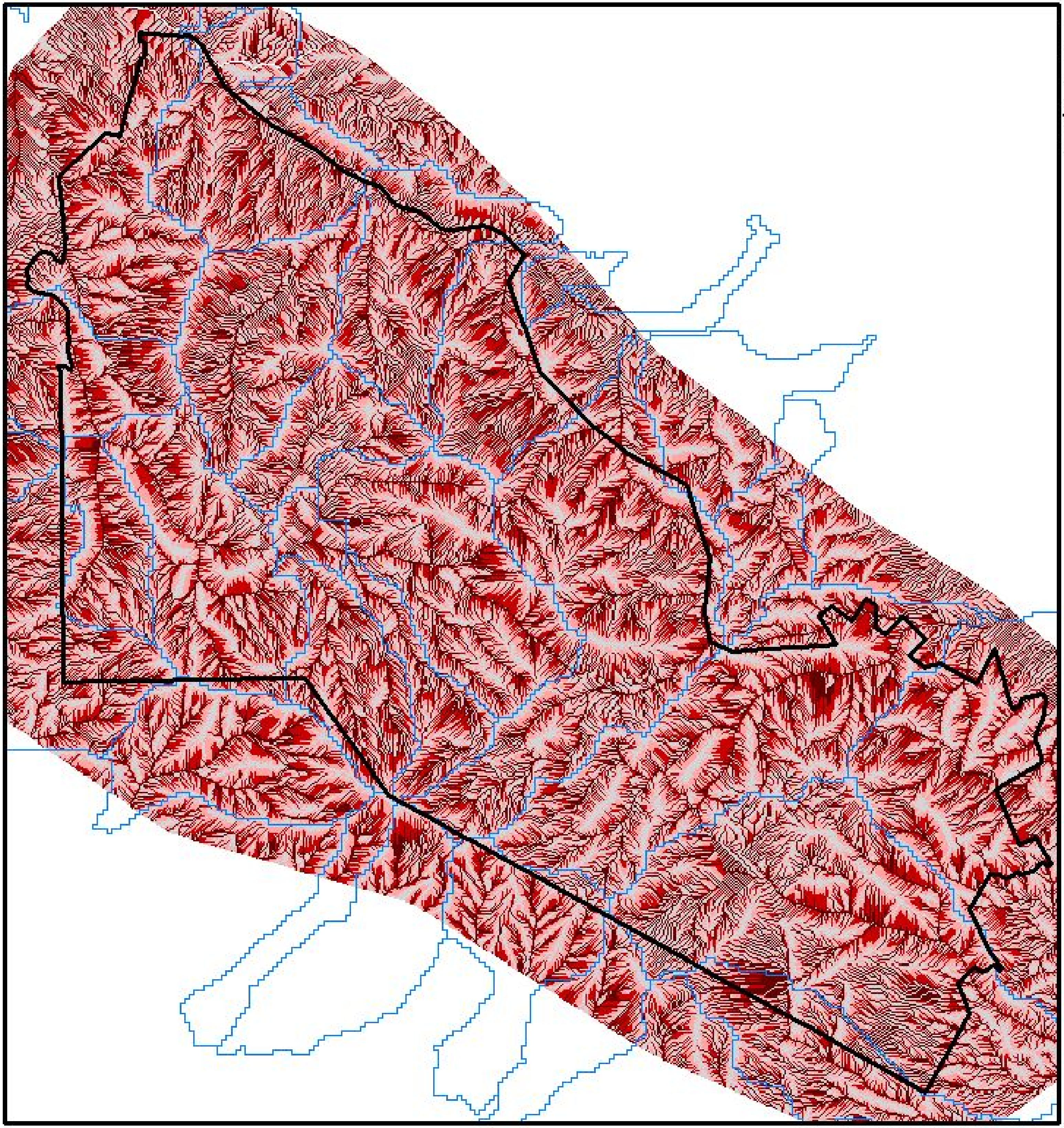

Plate 7b.
Upslope Catchment Area
Annadel State Park
Santa Rosa, California

Park Boundary
Subwatersheds
Upslope Catchment Area (# 10m cells)
1 - 2
3 - 6
7 - 17
18 - 213449
No Data

N

500 0 500 1000 Meters

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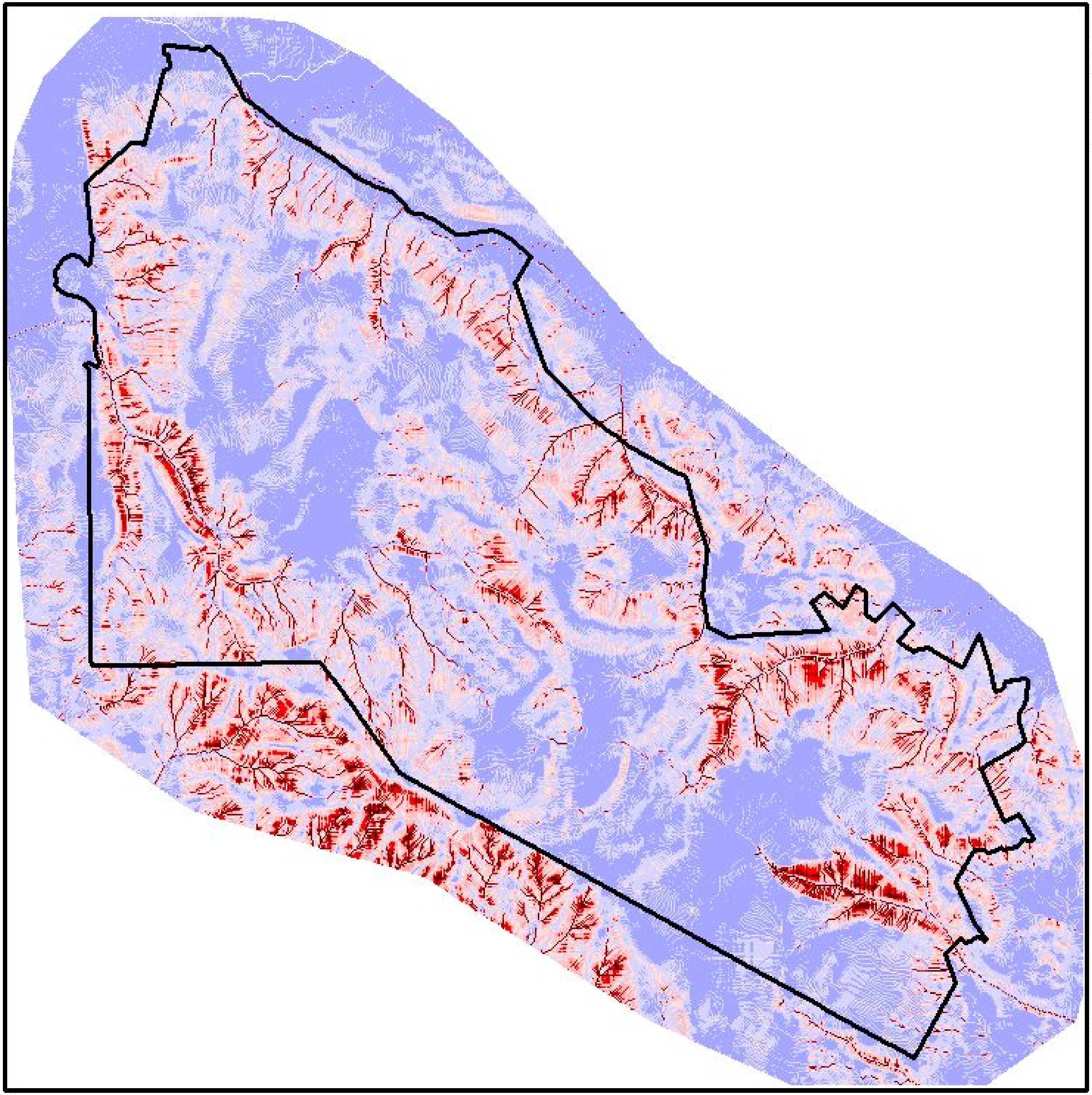

Plate 8. LS Factor
Slope & Catchment Area
Annadel State Park
Santa Rosa, California

Park Boundary

LS Factor
- 0 - 0.116
- 0.116 - 0.414
- 0.414 - 0.712
- 0.712 - 1.011
- 1.011 - 1.309
- 1.309 - 1.607
- 1.607 - 1.906
- 1.906 - 2.204
- 2.204 - 38.298
- No Data

N

500 0 500 1000 Meters

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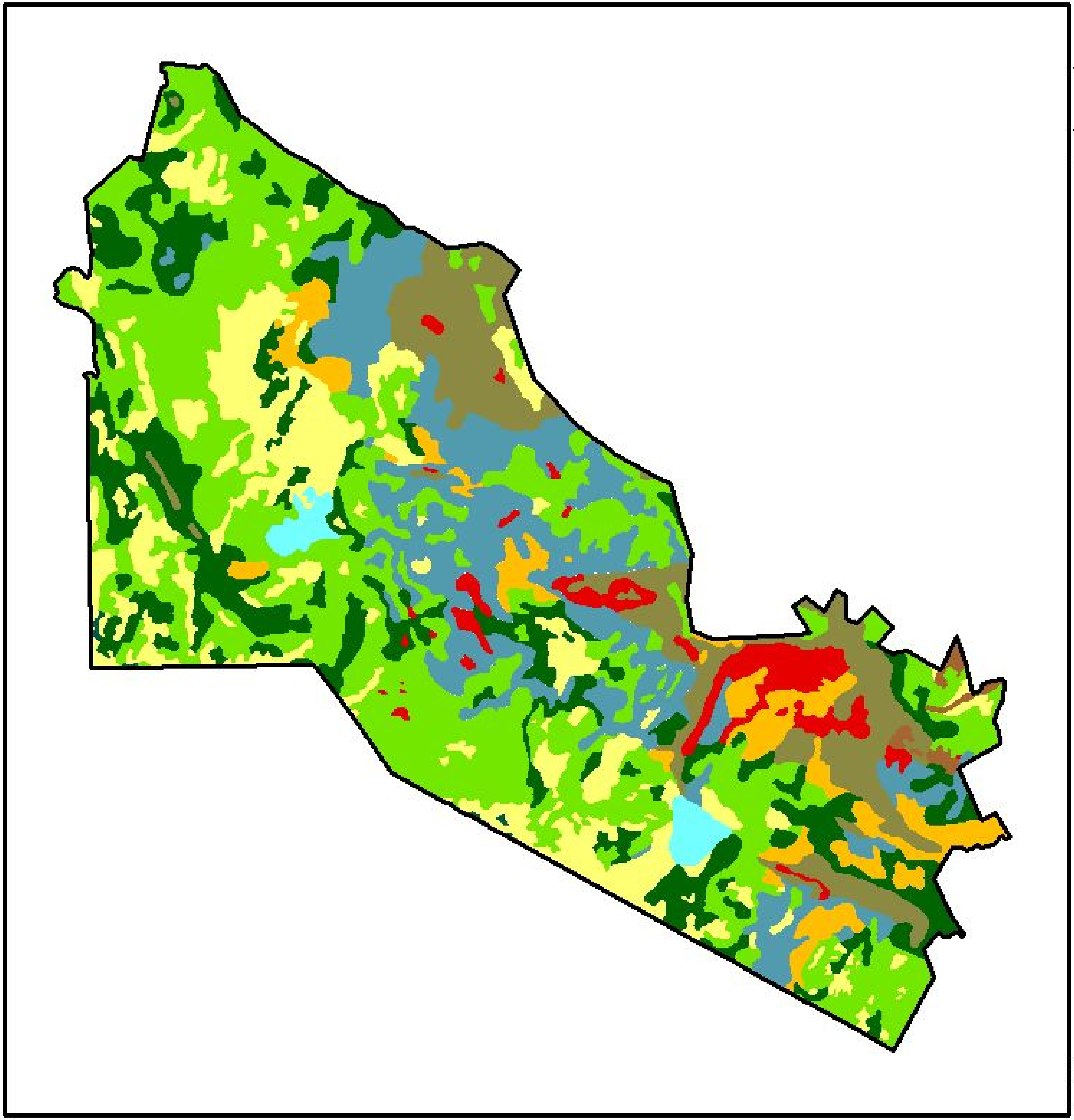

Plate 9a.
Vegetation Types
Annadel State Park
Santa Rosa, California

Park Boundary
Vegetation communities
White Oak Woodland
White Oak Savanna
Mixed Hardwood Forest
Redwoods
Douglas Fir Forest
Douglas Fir Transition
Live Oak Forest
Eucalyptus
Chaparral
Grassland
Water

N

500 0 500 1000 Meters

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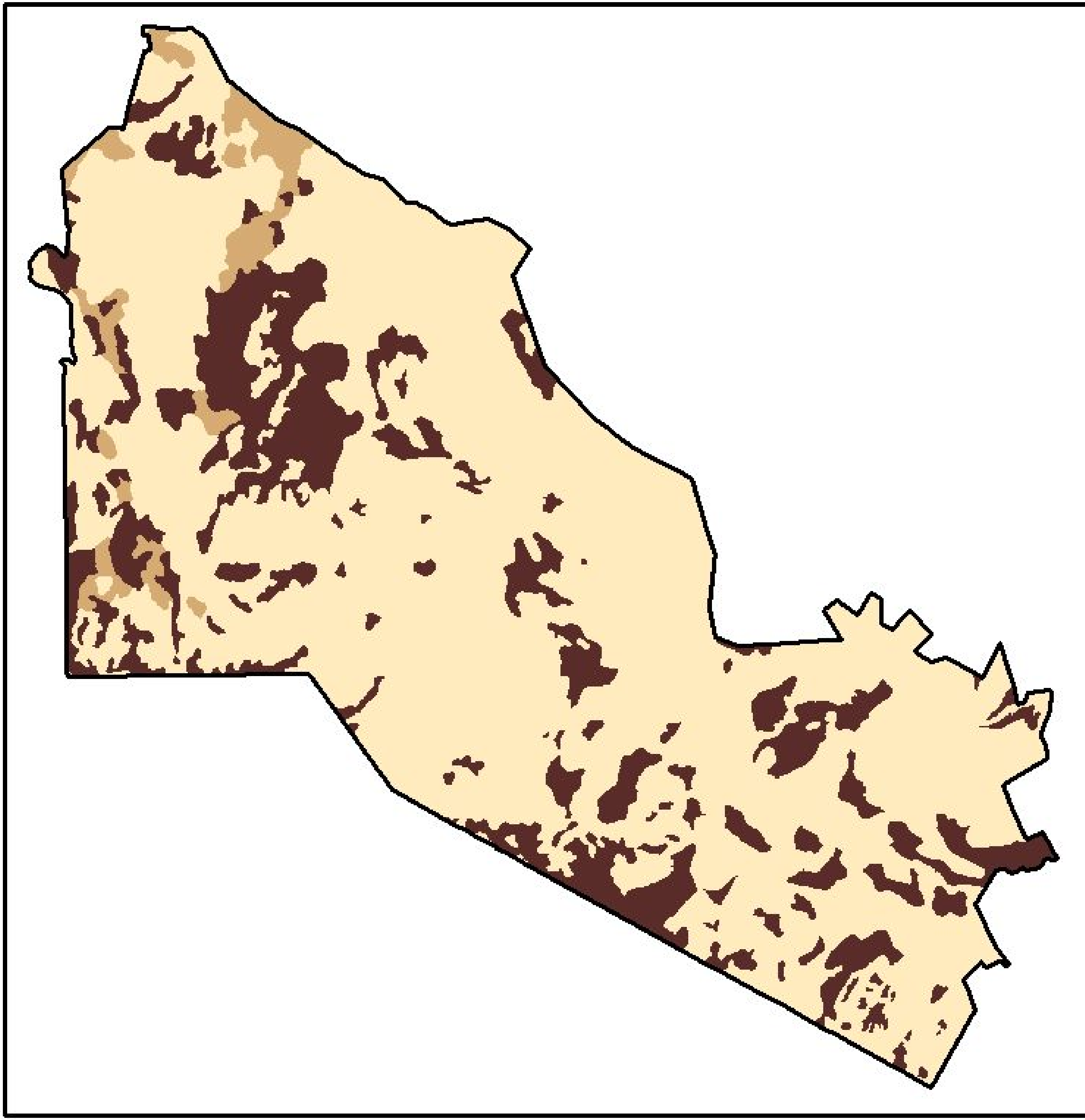

Plate 9b.
C Factor
Annadel State Park
Santa Rosa, California

Park Boundary
C Factor
0 - 0.015
0.015 - 0.03
0.03 - 0.045
0.045 - 0.06
No Data

N

500 0 500 1000 Meters

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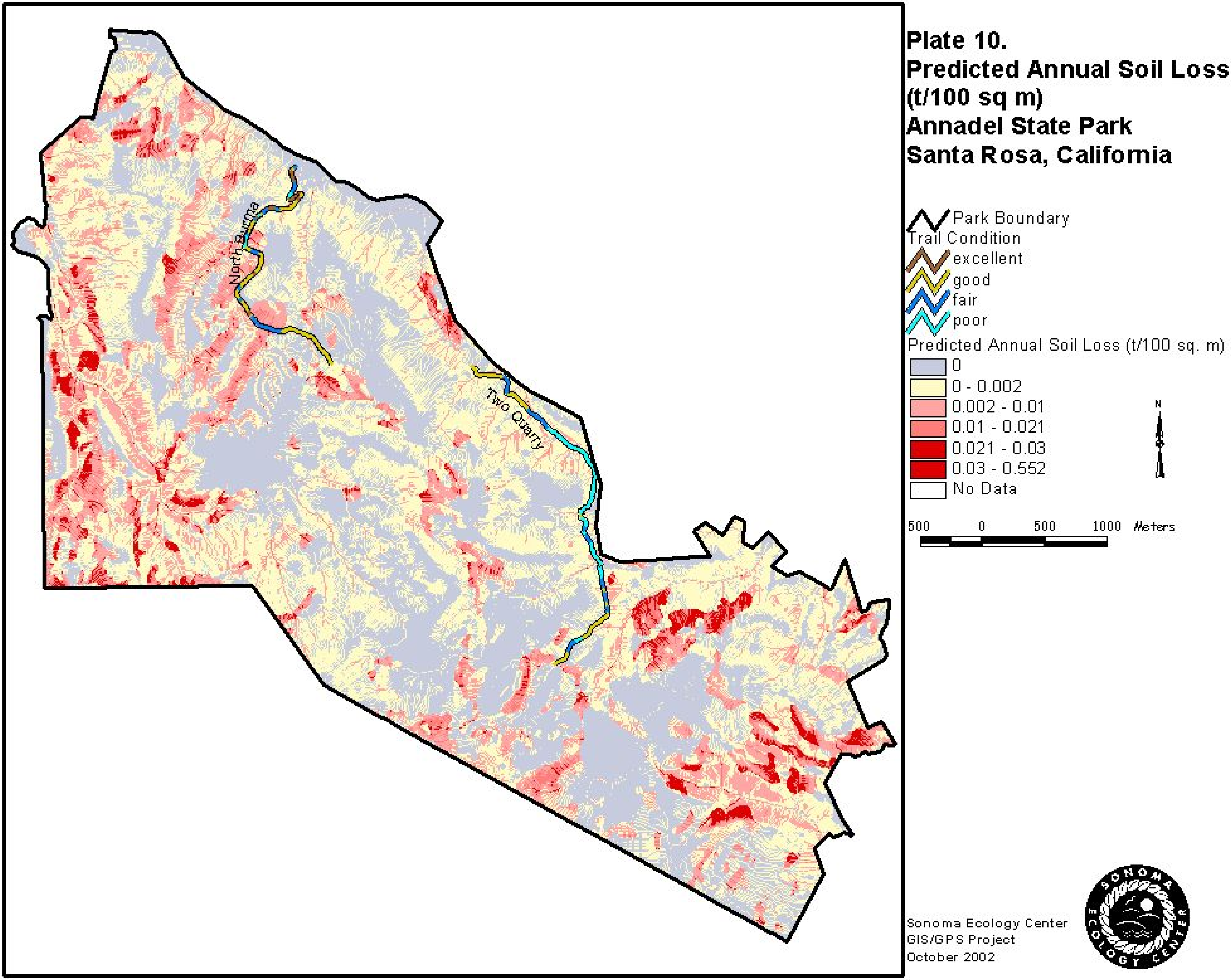
**Plate 10.
Predicted Annual Soil Loss
(t/100 sq m)
Annadel State Park
Santa Rosa, California**



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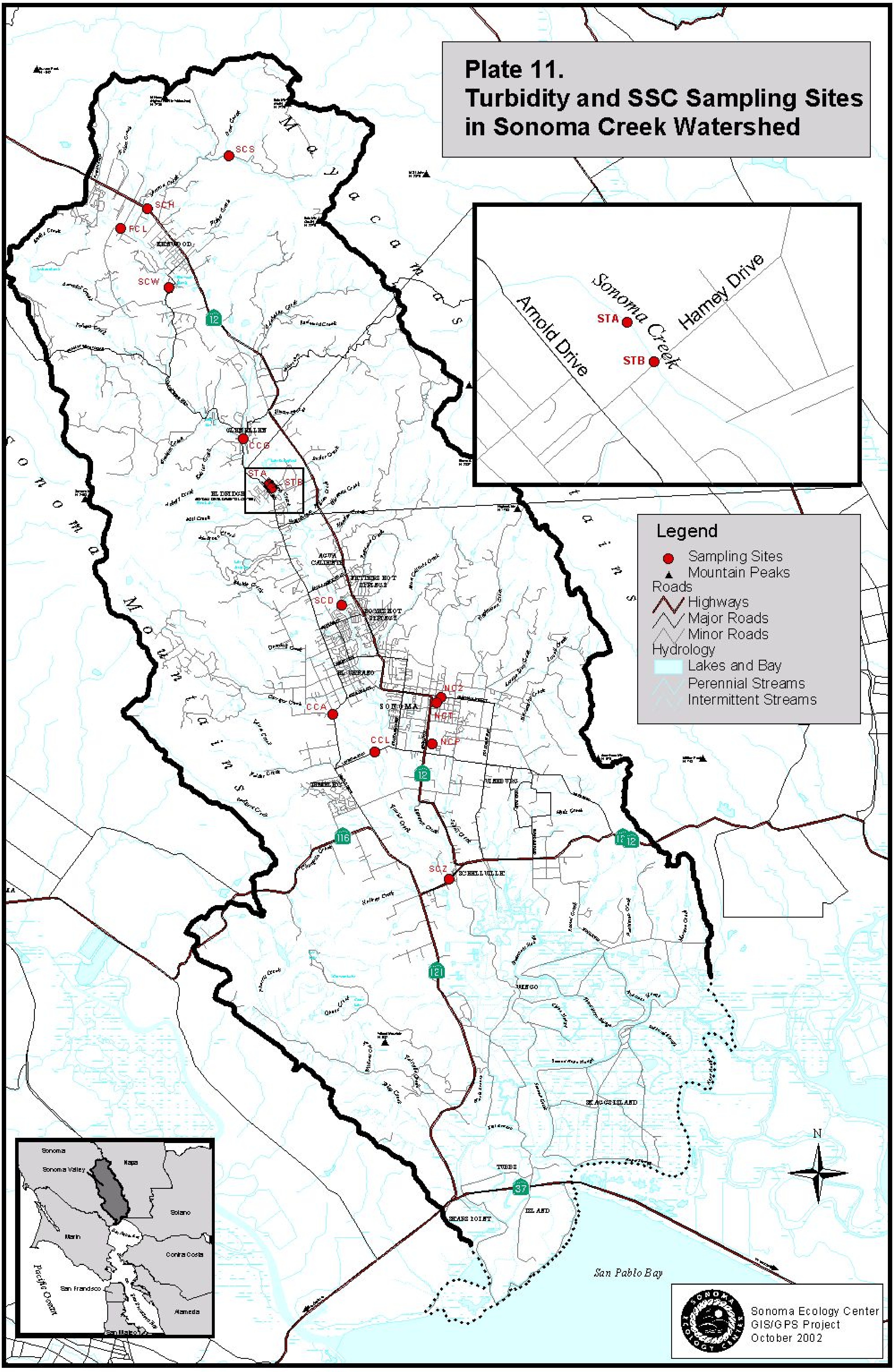

Plate 11.
Turbidity and SSC Sampling Sites in Sonoma Creek Watershed

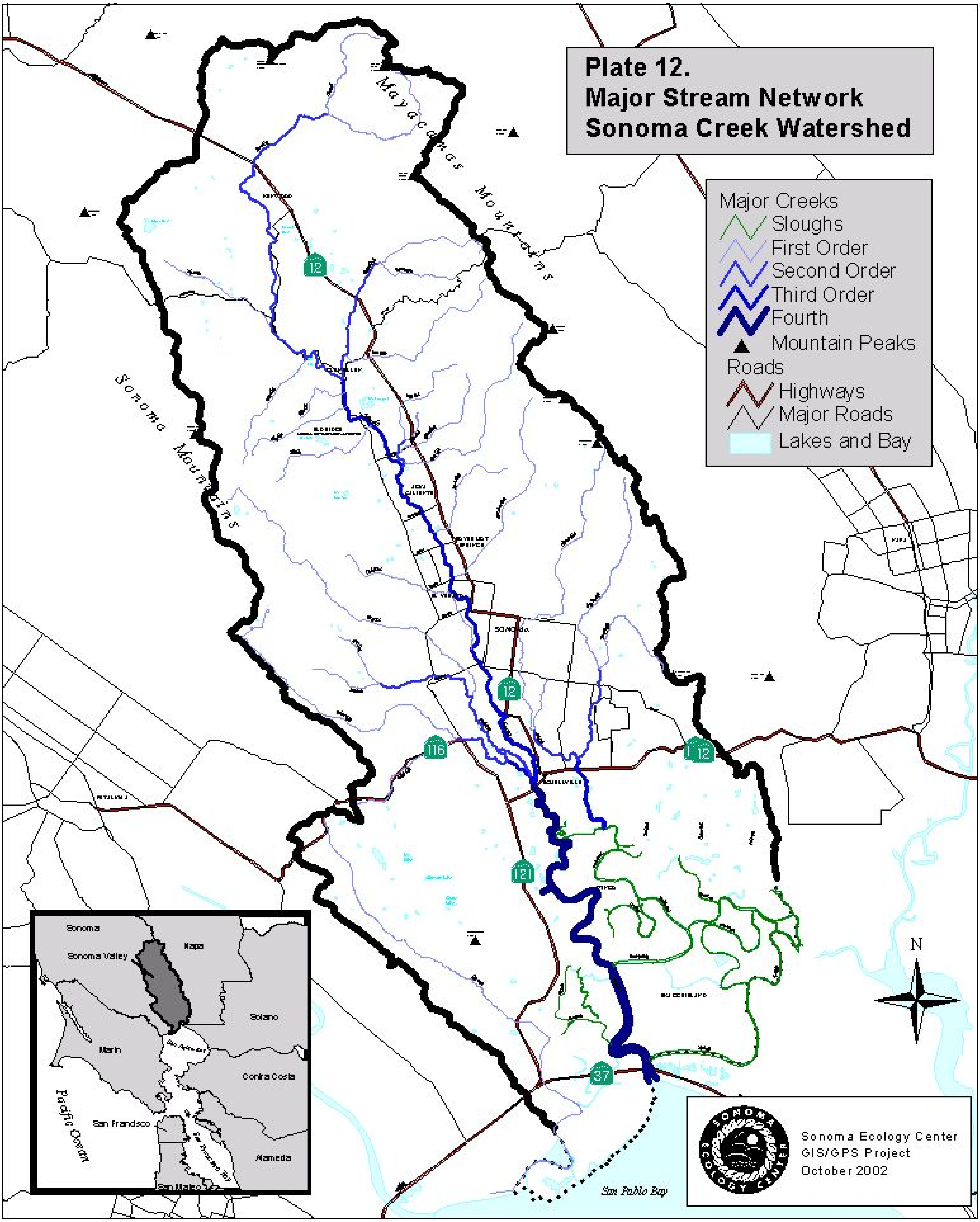

Plate 12.
Major Stream Network
Sonoma Creek Watershed
Major Creeks
Sloughs
First Order
Second Order
Third Order
Fourth
Mountain Peaks
Roads
Highways
Major Roads
Lakes and Bay
Mayacamas Mountains
Sonoma Mountains
12
116
121
37
N
San Pablo Bay
Sonoma
Sonoma Valley
Napa
Solano
Marin
Contra Costa
Pacific Ocean
San Francisco
Alameda
San Mateo
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