RODEO VALLEY/ TENNESSEE VALLEY/ REDWOOD CREEK WATER QUALITY MONITORING REPORT

OCTOBER 1996-MARCH 1997

INSTITUTE OF CHEMICAL BIOLOGY

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ABSTRACT

The watersheds of Rodeo Creek, Tennessee Valley Creek, and Redwood Creek in Marin County, California were monitored for a five month period from October of 1996 to March of 1997. Physical and chemical indicators of water quality were measured. The first sampling was conducted in October at the end of the dry season. Subsequent sampling events were performed within twenty-four hours of a major storm, in November, January, and March. Levels of Coliform bacteria were measured in October and November. Measurements were also taken from Mountain Lake in San Francisco, California in October and November. Additional chemical parameters were tested on one occasion after a large storm event in January to serve as supplemental data for the stations which were believed to be the most affected by stable runoff. The gathered data indicates that the five bodies of water are fairly stable and clean, with the exception of high coliform levels resulting from horse stable runoff.

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INTRODUCTION

The Golden Gate National Recreation Area (GGNRA) contains much of the undeveloped land located in the southern reaches of Marin County. The National Park Service (NPS) manages GGNRA and determines how the natural resources of these lands may be best utilized by the public, while maintaining the most natural state possible. NPS programs include habitat restoration, establishment of parks and recreation facilities, community education efforts, and maintenance of current facilities. Preserving the natural state of those lands requires that the resources of the area under consideration be properly studied and the potential and real impacts of their use be known in order to make balanced decisions (NPS 1993).

In an effort to assist the National Park Service in determining the impact of land use practices on the water quality of three creeks, one lagoon, and one lake during storm runoff events, the Institute of Chemical Biology (ICB) conducted an aquatic monitoring program during the 1996-1997 rainy season. The project served to gather baseline data for the following water bodies.

Mountain Lake is located in the Presidio of San Francisco and is one of the few remaining natural lakes in San Francisco. Mountain Lake is fed by two subterranean springs and serves as habitat for a variety of aquatic organisms and a recreational area for the residents and tourists of San Francisco. Prior to the construction of Park Presidio Boulevard in 1937, the lake was known to vary in depth from 20 to 30 feet. Presently, however, the lake reaches a maximum depth of approximately 10 feet.

Rodeo Creek extends approximately six miles westward from the upper reaches of Rodeo Valley near Sausalito, to Rodeo Lagoon near Fort Cronkhite. NPS maintains a set of horse stables near the creek approximately two miles from Rodeo Lagoon. Rodeo Lagoon intermittently connects to the Pacific Ocean during the winter when the sand dunes along the shore are breached. Rodeo Valley and Rodeo Beach are highly utilized for recreation, being easily accessible from San Francisco and U.S. Route 101. The water quality of Rodeo Lagoon is of particular concern because it serves as a feeding ground for migrating seabirds such as brown pelicans and resident shorebirds such as great egrets. It also provides valuable habitat for the tidewater goby, an endangered fish species limited to brackish waters along California's coast (NPS 1992). The water quality of Rodeo Creek influences that of the lagoon, especially during times of heavy runoff.

Tennessee Valley Creek consists of two forks, both of which originate in the center of Tennessee Valley. One tributary flows northward for approximately two miles where it is joined by Oakwood Creek, and then continues on for another two miles to Richardson Bay. The other fork flows southward approximately eight miles to Tennessee Cove where it enters the Pacific Ocean. The north fork flows through a fairly dense urban area before emptying into Richardson Bay. The west fork passes two stables (Miwok and NPS) before reaching the Pacific Ocean. The west fork is also accompanied by a network of popular hiking trails (NPS 1995).

Redwood Creek originates from a number of natural springs near the summit of Mt. Tamalpais in southern Marin County. Redwood Creek flows southwest through the Muir Woods National Monument to Muir Beach, where it joins the Pacific Ocean. The Tinker stables are situated in a small valley near Muir Beach. Runoff from the stables occasionally enters Redwood Creek approximately 1/4 mile upstream of Muir Beach. The only developed area along the watershed is a small rural community near Muir Beach; this is also the location of a public beach. The mouth of Redwood Creek historically emptied into a lagoon, known as Big Lagoon, which was subsequently filled in to construct a parking area for the public beach. One of the proposed NPS project plans is to restore Big Lagoon (NPS 1993).

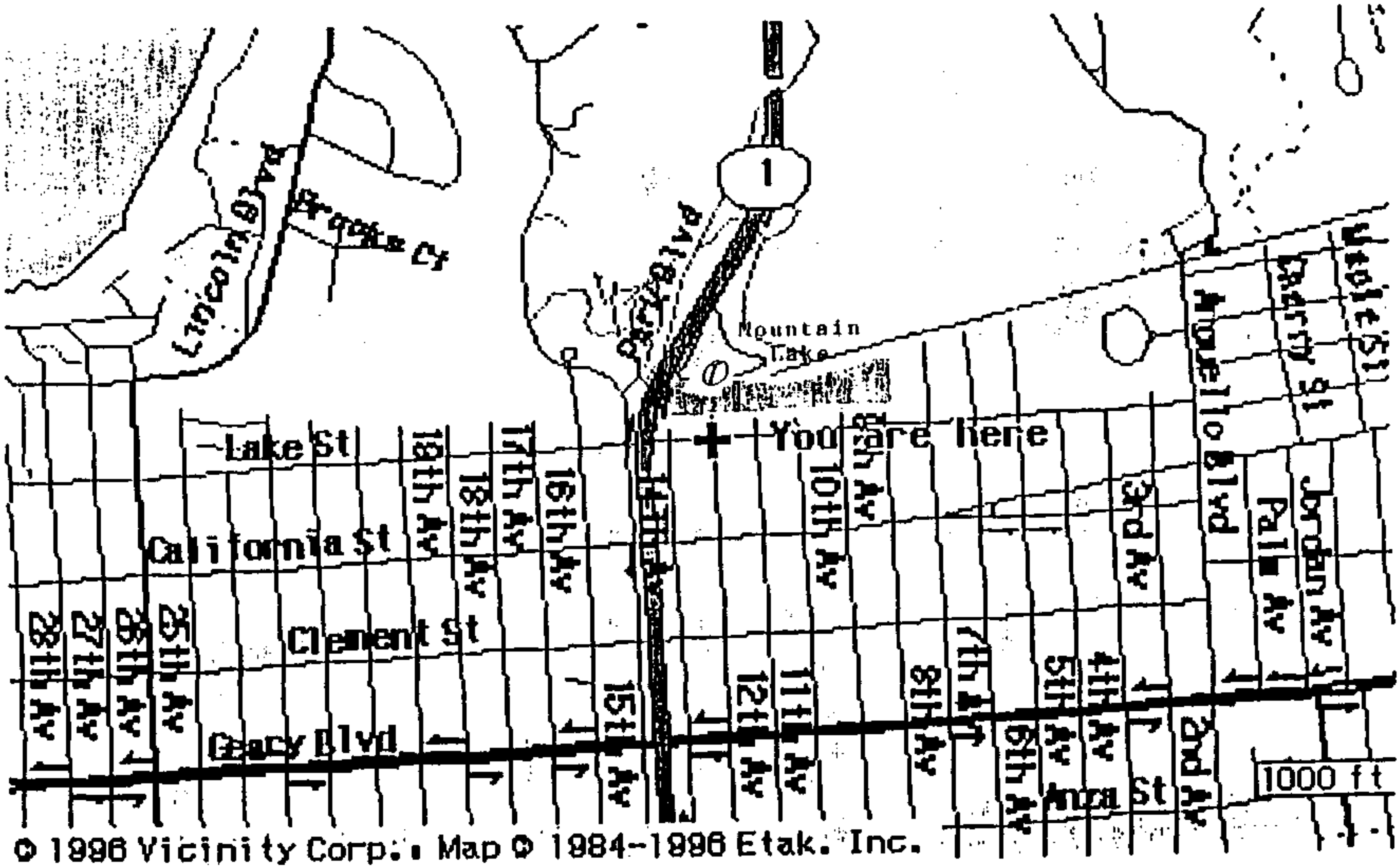
1. MATERIALS AND METHODS

Rodeo Creek and Lagoon, Tennessee Valley Creek, and Redwood Creek were monitored at the end of the dry season (October 1996) and after three major winter storm events (November 1996, January 1997, and March 1997). Due to the existence of previously collected data on Mountain Lake (Codemo *et al.* 1995), this site was only sampled twice (October 1996 and November 1996). The presented data include results of stream flows, water quality analyses, and Coliform bacteria analyses. For previous data on Rodeo Creek and Lagoon, the reader is referred to Codemo *et al.* (1996) and Podlech *et al.* (1993); further Redwood Creek data are available in Podlech *et al.* (1995, 1994).

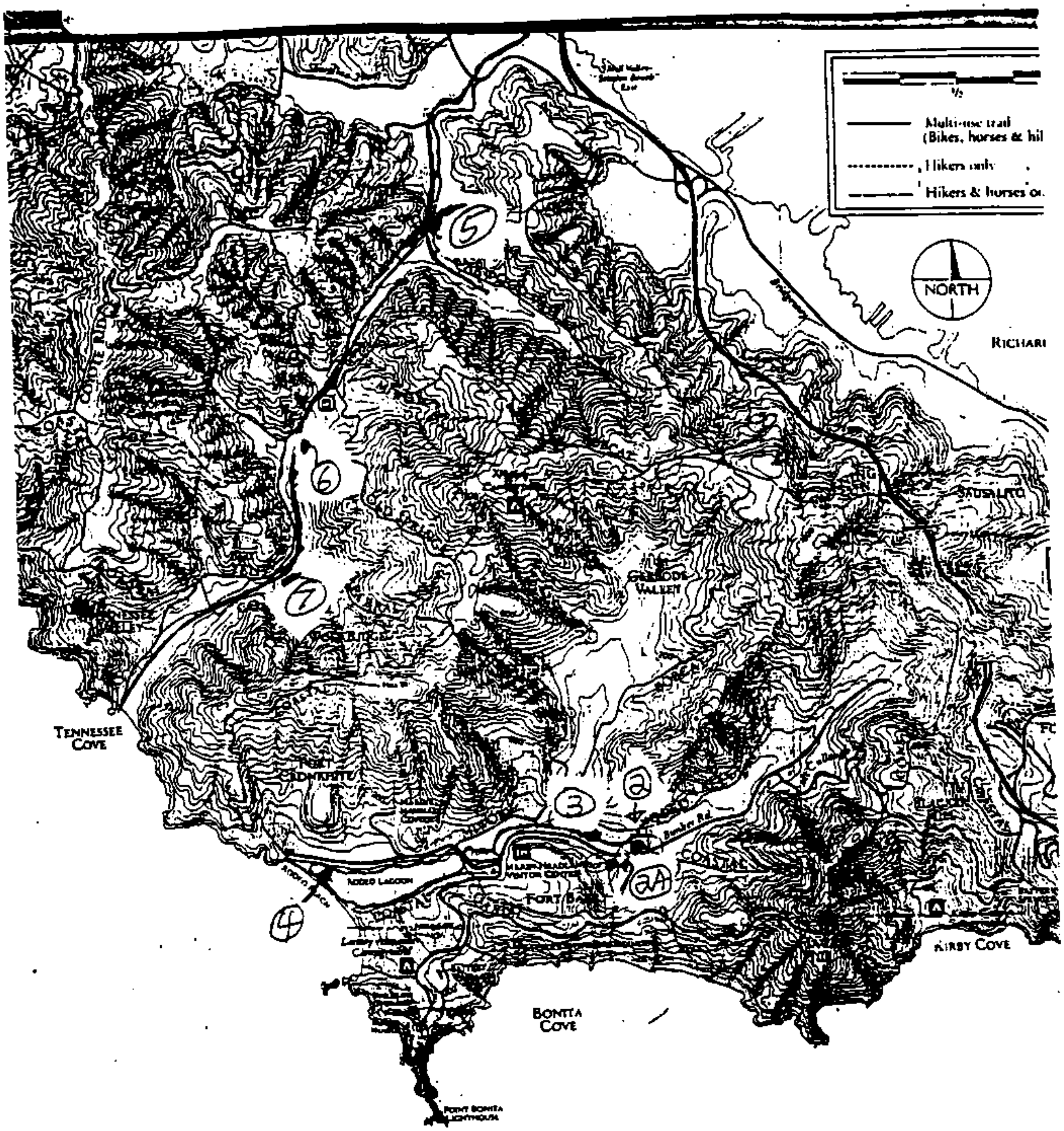
Ten stations were selected by the National Park Service for water quality sampling. Locations of the stations are provided in Table 1 and on Maps 1, 2, and 3. Stations were selected to collect baseline data on each watershed and for their locations above or below potential sources of runoff.

Table 1: 1996-1997 sampling locations on Mountain Lake, Rodeo Creek and Lagoon, Tennessee Valley Creek, and Redwood Creek. An asterix (*) denotes stations from which only coliform samples were collected.

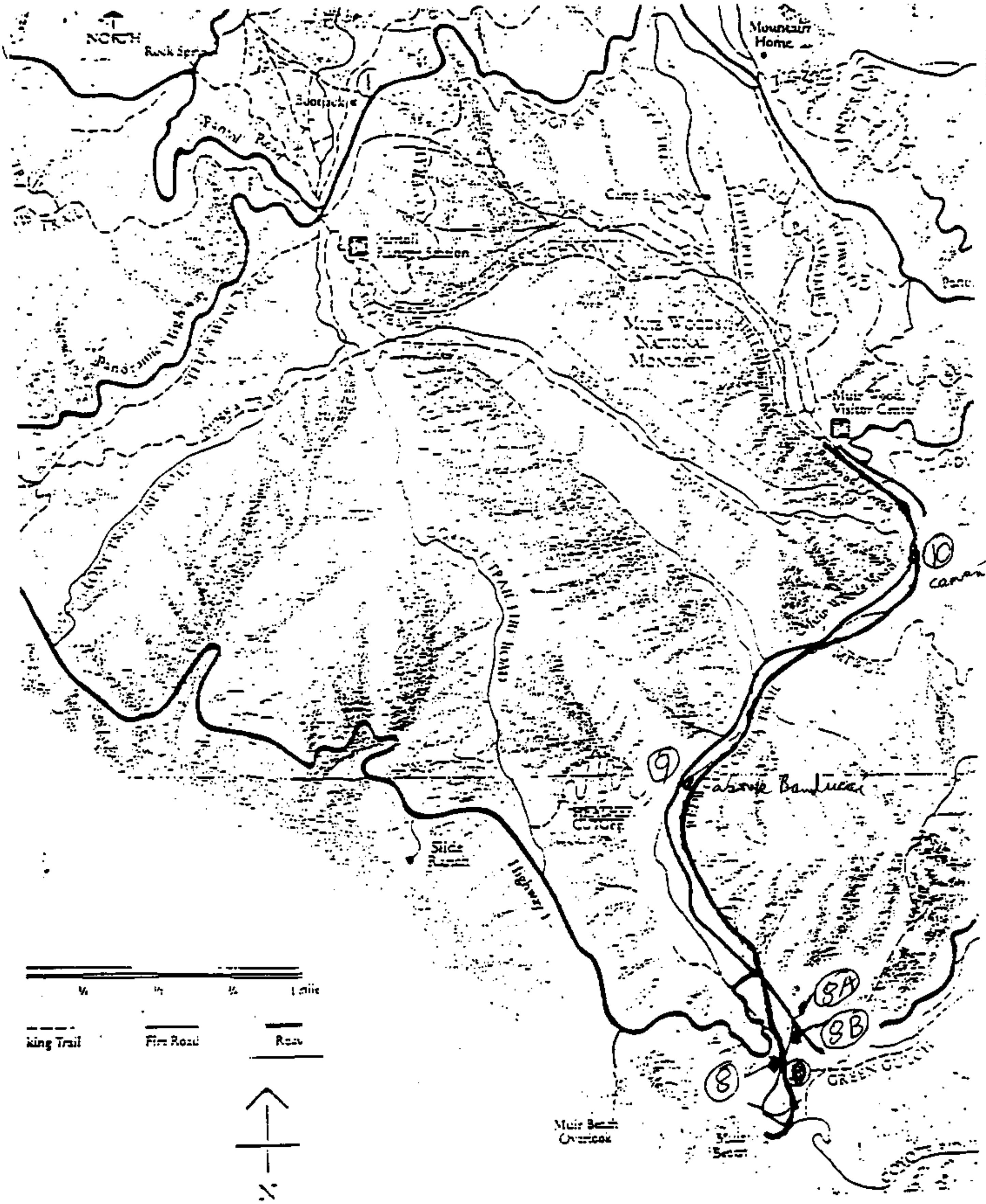
Station	Location
1	Mountain Lake, south shore
2	Rodeo Creek: upstream of stables
2A*	Rodeo stable direct runoff
3	Rodeo Creek: downstream of stables
4	Rodeo Lagoon, at foot bridge
5	~~Tennessee Valley~~ [Nyhan] Creek: Oakwood Creek
6	Tennessee Valley Creek: below Miwok Stables
7	Tennessee Valley Creek: below NPS stables
8	Redwood Creek: Pacific Way bridge
8A*	Tinker stable direct runoff
8B*	Tinker stable culvert runoff
9	Redwood Creek: Banducchi bridge
10	Redwood Creek: Muir Woods bridge [concrete]



MAP 1; Station *1*, Mountain Lake, San Francisco, California.



Map 2: Stations on Rodeo Creek and Tennessee Valley Creek, Marin County, CA.



Map 3: Stations on Redwood Creek, Marin County, CA

1.1 Physical Characteristics

Stream Flow

Flow was determined from the velocity, depth, and width of cross-sectional areas of the streams at each station. Water velocity was measured using a Swoffer pygmy current meter. Flows are reported to the nearest 0.1 cubic foot per second(cfs). Flow measurements were taken during the dry season (October 24, 1996) and after three major storm events (November 19, 1996; January 25, 1997; March 2, 1997). Previously installed staff gauges were read at stations 4, 8, 9, and 10 to provide information on the relative height of the water column.

1.2 Water Quality

Measurements of air and water temperature (°C), dissolved oxygen (mg/L), dissolved oxygen saturation (%), turbidity (nephlometric turbidity units, NTU), conductivity (µmhos/cm), and hydrogen ion concentration (pH) were collected during the dry season (October 24, 1996) and after three major storm events (November 19, 1996, January 25, 1997, and March 2, 1997). A list of field instruments used may be found in Appendix A. On the same sampling days, water samples from all stations were collected in 500 mL plastic bottles and analyzed for total suspended solids (TSS) at the ICB laboratory. Values are reported in mg/L.

On the same sampling days, water samples from all stations were collected in 125 mL plastic bottles, stored on ice, and analyzed for ammonia (NH_3) at the ICB laboratory within 24 hours. The method for ammonia analysis may be found in APHA (1995).

1.3 Additional Chemical Tests

Upon special request from the National Park Service, additional chemical parameters were tested after the January 25 storm event for the stations which were believed to be most affected by stable runoff. One station was chosen from each watershed. Additional water samples from stations 2A, 7, and 8B (see Maps 2 and 3) were collected in 500 mL plastic bottles, stored on ice, and analyzed for orthophosphate (mg/L), nitrate (mg/L), and ammonia (mg/L) at the ICB laboratory within 24 hours. Samples to be tested for orthophosphate and nitrate were filtered through 0.45 µm filters prior to analysis. The method for orthophosphate analysis may be found in APHA (1995), and the method for nitrate analysis may be found in HACH (1989).

1.4 Coliform Bacteria

Analyses of water samples for coliform bacteria including total coliform (most probable number/100 mL, MPN), *Escherichia coli* (MPN), and fecal coliform (presence/absence) were performed by the Marin County Health Laboratory in San Rafael, California. Samples were collected in 125 mL plastic bottles, stored on ice, and delivered to the lab for analysis within five hours of collection. Coliform samples were collected on October 24, 1996 and November 19, 1996. Laboratory business hours prohibited sample collection on other sampling dates *(i.e.,* weekends). Samples were analyzed using multiple tube fermentation techniques.

Three additional stations (2A, 8A, 8B) were sampled only for Coliform analysis. These stations were chosen to obtain direct runoff samples from horse stables before entering any of the creeks being studied. Locations of the stations are provided in Table 1 and on Maps 2 and 3.

2. RESULTS AND DISCUSSION

All physical and chemical data collected from stations 1 through 10 during the monitoring period are listed in Tables 2 through 5. Special request data for nitrates, orthophosphates, and ammonia are listed in Table 6. Data for coliform bacteria are listed in Table 7.

2.1 Physical Characteristics

Stream Flow

Stream flow in Rodeo Creek and Tennessee Valley Creek is supplied primarily by surface runoff from rainfall. Therefore these streams may cease to flow during drier months of the year. Redwood Creek, in addition to runoff, is also charged by groundwater which accumulates in its watershed. Consequently this stream flows throughout the year. Heavy runoff from large storm events flushes sediments and debris from the stream bed and stream channel as well as from surrounding land areas. Excessively high flows may shift stream substrates and dislocating benthic macroinvertebrates and fish eggs (Brown *et al.* 1993). Low flows occurring during the dry season may only minimally sustain aquatic life due to low levels of dissolved oxygen and increased water temperature. Low flows also lessen the extent of dilution of any nutrients or pollutants introduced into the stream (Brown *et al.* 1993).

Rodeo Creek flows ranged from a low of 0.1 cfs on October 24 at Station 2 to a high of 86.2 cfs at Station 2 on January 25. Tennessee Valley Creek was intermittently dry at Station 5 and completely dry at stations 6 and 7 on October 24. Flows were as high as 63.4 cfs on January 25 at Station 7. Redwood Creek flows ranged from a low of 1.2 cfs on October 24 at Station 8 to levels on January 25 that were high enough that measurements could not be taken safely.

The flow data for these watersheds show the lowest flow to be on October 24 during the dry season, and rank the size of the storm events in the following ascending order: November 19, March 2, and January 25. Precipitation data for Marin County during the monitoring period is presented in Appendix B.

Stream flow data provide a gauge of the volume of water traveling through streambed channels and may be of use in explaining the amount of erosion and the turbidity of the water. Turbidity typically rises during and after a rainstorm due to erosion (Sugerman 1994).

The greater length of Redwood Creek (~20 miles) and its course through steep, mountainous terrain provide a much greater opportunity for runoff to collect than the relatively short runs (~5-8 miles) of Rodeo Creek and Tennessee Valley Creek through low coastal hills. Redwood Creek is also fed year-round by several springs and by subsurface waters. Tennessee Valley Creek contained little or no flowing water on October 24, suggesting it to be very dependent upon runoff. Rodeo Creek and Redwood Creek had minimal flows on October 24.

2.2 Water Quality

Water and Air Temperature

Water and air temperatures fluctuate seasonally and diurnally based on weather conditions. Changes in temperatures may have effects on the metabolism and reproduction of aquatic organisms. The molting of some aquatic insects is triggered by temperature. Water temperature also determines the extent to which oxygen will dissolve and saturate the water, with less oxygen dissolving in waters of higher temperature. The rates of many chemical reactions involving the concentrations and form of organic compounds may vary greatly with temperature changes (IHD-WHO 1978).

Water temperatures ranged from a low of 9.7°C on March 2 at Station 3 to a high of 13.9°C on November 19 at Station 3. Temperatures remained relatively constant within each stream system, and all stations exhibited a general decrease in temperature corresponding with cooler winter weather and the lesser amount of daylight hours. The colder temperatures observed on March 2 occurred because measurements were taken early in the morning, as opposed to midday on the other dates. The water temperature of Mountain Lake was moderate, around 15-16°C. Because of the large surface area of Rodeo Lagoon, the water temperature, measured within 1 foot of the surface, varied according to climate.

Conductivity

The conductivity of a natural body of water refers to its capacity to conduct an electric current. The unit of electrical conductivity used is the inverse of the resistance occurring between two electrodes separated by a distance of one centimeter. The value of conductivity in µmhos/cm roughly correlates to the total amount of dissolved substances (including colloidal particles) in the water, dissociated into cations and ions, or strong and weak electrolytes (IHD-WHO 1978). All dissolved substances increase the osmotic pressure exerted on aquatic organisms and their internal organs (Brown *et al.* 1993).

The high conductivity values of 600-800 µmhos/cm at Mountain Lake represent the large amount of solids dissolved in the lake.

Conductivity values for the three streams ranged from a low of 65 µmhos/cm at Station 10 on November 19 to a high of 270 µmhos/cm at stations 5 and 6 on November 19. Streams with mixed fish populations usually have a conductivity ranging from 150-500 µmhos/cm (Brown *et al.* 1993). An inverse correlation between the flow and conductivity (Tables 2 through 5) suggests that as flow decreases, dissolved solids become more concentrated thus increasing conductivity.

The conductivity values for Rodeo Lagoon are extremely high when compared to that of the freshwater streams and lake. On October 24, conductivity was measured at 12,000 µmhos/cm indicating large amounts of dissolved substances, mainly sodium chloride. The salinity of the lagoon is expected to be higher during the summer when more water evaporates and only limited amounts of freshwater from Rodeo Creek are added. By March 2, the conductivity decreased to 4,500 µmhos/cm, almost one third its original value. During the winter months, the breaching of the sand bar, along with increased amounts of freshwater derived from Rodeo Creek, diluted and decreased the salt concentration of Rodeo Lagoon.

Dissolved Oxygen

Most aquatic organisms are dependant on dissolved oxygen for survival and many species of algae and fish require a semi-specific concentration. Dissolved oxygen concentrations vary with depth and temperature, time of day, flow rate, and other physical parameters (Eckblad 1978). Oxygen is consumed rapidly during the breakdown of organic matter. In a process known as eutrophication, an aquatic system is loaded with nutrients due to the input of wastewater or runoff, causing algal blooms, which quickly deplete the oxygen during die-off. Most organisms can grow successfully with dissolved oxygen levels exceeding 5 mg/L. If levels drop to 3-5 mg/L, organisms become stressed. At levels under 3 mg/L, hypoxia occurs and many species may die. At levels under 0.5 mg/L, anoxia occurs and any organism requiring oxygen dies (Sugerman 1993).

The dissolved oxygen levels in Mountain Lake were constant around 2.8 mg/L. Aquatic organisms with lower oxygen requirements would be expected to survive in Mountain Lake.

Dissolved oxygen levels in Rodeo Creek ranged from a low of 7.0 mg/L at Station 3 on January 25 to a high of 10.8 mg/L at Station 2 on March 2. Dissolved oxygen levels in Tennessee Valley Creek ranged from a low of 7.2 mg/L at Station 5 on October 24 to a high of 11.0 mg/L at Station 5 on March 2. Dissolved oxygen levels in Redwood Creek varied from a low of 7.7 mg/L at Station 8 on October 24 to a high of 11.2 at Station 8 on March 2.

For Rodeo Lagoon, the dissolved oxygen level was highest on October 24. A green algal bloom was observed in the lagoon on October 24. The associated high photosynthetic activity could account for the high dissolved oxygen concentration and saturation values of 10.1 mg/L and 104%, respectively. The lowest oxygen level recorded at Rodeo Lagoon was 7.5 mg/L on January 25.

From these data, it can be concluded that all locations except Mountain Lake contained adequate supplies of dissolved oxygen to support a wide variety of aquatic life.

Ammonia

Ammonia levels are affected by the amount of organic decomposition occurring. The presence of ammonia is a result of the biochemical degradation of protein substances. High levels of ammonia may therefore indicate the addition of organic substances, such as fecal matter. Changes in ammonia concentrations may indicate the degree of pollution by organic, nitrogen-containing compounds common in animal waste (IHD-WHO 1978).

The USEPA (1986) limit for ammonia in natural waters for the protection of wildlife is 0.02 mg/L. Ammonia values for Mountain Lake were 0.23 mg/L on October 24 and 0.18 mg/L on November 19. Ammonia values for all three streams were less than 0.02 mg/L on each sampling date. Values for Rodeo Lagoon reached a high of 0.22 mg/L on November 19.

Hydrogen ion concentration (pH)

The reciprocal of the hydrogen ion concentration is called pH. A change of one unit on the pH scale represents a tenfold change in the hydrogen ion concentration. The most important determinant of pH is the carbon dioxide-bicarbonate-carbonate equilibrium. The amounts of these ions present are determined by the amount of photosynthesis occurring and the biochemical oxidation of organics, the chemical conversions of some mineral substances, and the amounts of various acids *(e.g.,* from decomposing plant matter) present (IHD-WHO 1978).

The USEPA (1986) recommended pH range for the protection of aquatic wildlife is 6.5 to 8.5. In Mountain Lake, the pH was constant around 7.5. The pH would be expected to remain constant in a lentic body of water with limited in- and out-flow.

Stream pH values ranged from a low of 6.5 at Station 2 on January 25 and March 2 to a high of 8.1 at Station 10 on October 24. The stream pH values were fairly constant during the monitoring period, falling mostly between 7.0 and 7.9.

For Rodeo Lagoon, the pH level of 9.2 on October 24 can be correlated with a high rate of photosynthesis (IHD-WHO 1978). The dissolved oxygen levels decreased during the winter months. February was unusually dry and sunny and algae were beginning to proliferate by March 2. Measurements on that date show an increase in turbidity and dissolved oxygen levels. However, the pH level continued to decrease. This suggests that other contributors to the hydrogen ion concentration varied during the winter months.

Turbidity

Turbidity is a measure of the optical clarity of water (Sugerman 1993). Contributors to turbidity are suspended materials such as silt or fine soil particles, plankton, and minuscule pieces of dead organisms (IHD-WHO 1978). The primary cause of turbidity is erosion of land by storm runoff and erosion of the stream channel by water turbulence. Runoff from agricultural lands also contributes to high turbidity (Sugerman 1993).

Turbidity levels over 400 NTU may be harmful to the early life stages of some fish (McKee and Wolf 1963). For Mountain Lake, turbidity was constant around 5.5-5.9 NTU. This turbidity level can be detected as a slight murkiness in the water. Stream turbidity levels ranged from 1.3 NTU at Station 8 on October 24 to a high of 569 NTU at Station 5 on January 25. For Rodeo Lagoon, turbidity was highest on October 24 at 37.0 NTU and the decreased throughout the monitoring period.

Total Suspended Solids (TSS)

Total suspended solids are a measure of the amount of particles suspended in the water column. The main source of these particles is erosion. Heavy loads of suspended solids can reduce primary productivity by blocking light penetration, and may smother fish eggs or fry (Brown *et al.* 1993).

The levels of total suspended solids after storm events ranged from 8.3 mg/L at Station 5 on November 19 to 250.9 mg/L at Station 5 on January 25. During the heavy runoff of January 25, the lowest total suspended solids value was 23.7 mg/L at Station 10. For Rodeo Lagoon, a decrease of total suspended solids values during the monitoring period, from 17.4 mg/L to 9.7 mg/L, may also be noted (filtered algae are included in total suspended solids values), with the exception of the heavy runoff on January 25 which raised the total suspended solids value to 20.7 mg/L.

Table 2: GGNRA Water Quality, October 1996. Stations 6 and 7 had no surface water flow; Station 5 had intermittent surface flow

Station	1	2	3	4	5	6	7	8	9	10
Date	10/24	10/24	10/24	10/24	10/24	10/24	10/24	10/24	10/29	10/29
Time	1030	1100	1130	1200	1220	1230	1235	1300	830	855
Weather	drizzle	drizzle	drizzle	drizzle	drizzle	drizzle	drizzle	drizzle	overcast	overcast
Water Temp (C)	15.8	11.7	11.8	14.2	12.8	---	---	12.9	11.7	11.7
Conduct (µmhos/cm)	800	185	185	12000	425	---	---	230	180	170
DO (mg/l)	2.7	8.5	8.6	10.1	7.2	---	---	7.7	8.7	10.3
DO Sat (%)	27	84	79	104	68	---	---	75	80	94
Flow (cfs)	---	0.1	0.1	--	---	---	---	1.2	9.2	9.3
Staff Gauge (in)	---	---	---	dry	---	---	---	2.04	dry	2.64
TSS (mg/l)	1.7	5.3	6.6	17.4	1.0	---	---	1.7	13.2	41.6
Turbidity (NTU)	5.8	13.2	8.5	37.0	4.0	---	---	1.3	18.1	15.2
pH (pH units)	7.5	7.5	7.4	9.2	7.8	---	---	7.5	7.9	8.1
Ammonia (mg/l)	0.23	<0.02	<0.02	NA	<0.02	---	---	<0.02	0.02	<0.02

Table 3: GGNRA Water Quality, November 1996.

Station	1	2	3	4	5	6	7	8	9	10
Date	11/18	11/18	11/18	11/18	11/18	11/18	11/18	11/18	11/18	11/18
Time	1030	1315	1330	1400	1425	1505	1450	1535	1550	1615
Weather	rain	rain	rain	rain	rain	rain	rain	rain	overcast	overcast
Water Temp (C)	14.8	12.9	13.3	14.9	13.9	13.3	13.3	12.8	12.8	12.7
Conduct (µmhos/cm)	670	180	180	8000	270	270	230	180	180	65
DO (mg/l)	2.9	10.00	9.4	7.9	9.2	7.7	9.7	9.2	9.5	10.1
DO Sat (%)	28	95	90	88	88	74	92	87	89	95
Flow (cfs)	---	2.0	0.7	---	0.2	0.1	0.7	9.0	9.4	14.2
Staff Gauge (in)	---	---	---	dry	---	---	---	2.44	dry	2.84
TSS (mg/l)	21.4	13.6	14.8	11.3	8.3	13.8	17.2	3.6	5.3	0.8
Turbidity (NTU)	5.9	32.0	82.9	19.6	23.8	59.6	21.6	6.6	14.1	7.8
pH (pH units)	7.6	7.3	7.3	7.9	7.6	7.1	7.1	7.5	7.6	7.6
Ammonia (mg/l)	0.18	<0.02	<0.02	0.22	<0.02	<0.02	<0.02	<0.02	0.02	<0.02

Table 4: GGNRA Water Quality, January 1997.

Station	1	2	3	4	5	6	7	8	9	10
Date	---	1/25	1/25	1/25	1/25	1/25	1/25	1/25	1/25	1/25
Time	---	1045	1115	1130	1230	1315	1250	1400	1440	1500
Weather	---	rcnt. rain	rcnt. rain	rcnt. rain	rcnt. rain	rcnt. rain	rcnt. rain	rcnt. rain	rcnt. rain	rcnt. rain
Water Temp (C)	---	11.8	12.2	12.7	11.9	12.9	12.9	12.3	12.2	12.3
Conduct (µmhos/cm)	---	90	88	5000	78	85	88	92	90	80
DO (mg/l)	---	7.2	7.0	7.5	7.3	10.4	10.6	10.7	10.8	10.7
DO Sat (%)	---	66	65	72	68	97	99	100	100	100
Flow (cfs)	---	---	79.9	---	40.60	55.0	63.4	NA	NA	NA
Staff Gauge (in)	---	104.1	---	submerged	---	—	—	submerged	4.10	3.50
TSS (mg/l)	---	209.0	94.9	20.7	250.9	77.9	48.1	70.3	68.3	12.2
Turbidity (NTU)	---	6.5	141.0	3.4	569.0	90.0	102.0	87.9	62.3	23.7
pH (pH units)	---	6.5	6.6	7.5	7.2	7.3	7.5	7.4	7.3	7.4
Ammonia (mg/l)	---	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02

Table 5: GGNRA Water Quality, March 1997.

Station	1	2	3	4	5	6	7	8	9	10
Date	---	3/2	3/2	3/2	3/2	3/2	3/2	3/2	3/2	3/2
Time	---	0750	0805	0825	0900	0925	0945	1030	1100	1120
Weather	---	rcnt, rain	rcnt, rain	rcnt, rain	rcnt, rain	rcnt, rain	rcnt, rain	rcnt, rain	rcnt, rain	rcnt, rain
Water Temp (C)	---	9.8	9.7	11.7	10.0	10.0	10.3	10.7	10.3	10.9
Conduct (µmhos/cm)	---	135	120	4500	185	145	120	140	140	130
DO (mg/l)	---	10.8	10.6	9.4	11.0	10.7	10.7	11.2	11.0	10.7
DO Sat (%)	---	95	93	89	96	94	95	100	99	95
Flow (cfs)	---	3.8	2.5	---	0.6	0.1	2.9	10.9	8.7	14.3
Staff Gauge (in)	---	---	---	1.80	---	---	---	2.38	dry	2.32
TSS (mg/l)	---	25.8	44.2	4.8	6.4	29.9	9.4	5.1	2.3	2.4
Turbidity (NTU)	---	46.9	21.4	9.7	20.0	27.5	54.9	3.2	1.8	1.6
pH (pH units)	---	6.5	7.3	6.9	7.8	7.6	7.4	7.7	7.7	7.5
Ammonia (mg/l)	---	<0.02	<0.02	0.10	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02

2.3 Additional Chemical Tests

Additional chemical test results for stations in direct contact with stable runoff are listed in Table 6. These tests were performed on only one occasion (January 25) and therefore are only single data points being compared to established standards. The cited USEPA criteria are for freshwater, not direct stable runoff (such as samples from stations 2A and 8B) and are therefore only included for comparison.

Orthophosphate

Orthophosphate, a limiting nutrient for aquatic plants, is a universal indicator of water quality. Orthophosphates used in fertilizers may be carried as runoff into streams and lead to eutrophication and algal blooms. USEPA (1986) recommends that orthophosphate concentrations not exceed 0.05 mg/L to protect aquatic life. The results show levels of orthophosphate above the USEPA limits for freshwater for stations 2A and 8B, the direct stable runoff samples, but not for Station 7.

Nitrate

Nitrates are a common by-product of the decomposition of organisms and other organic materials. Nitrate is commonly used as the principal constituent in many fertilizers. The upper limit for nitrate for domestic water use is 10.0 mg/L (USEPA 1986). Nitrate levels were well below the USEPA limit for freshwater.

Ammonia

See section 2.2 for a discussion of ammonia.

The USEPA (1986) limit for ammonia in natural waters for the protection of wildlife is 0.02 mg/L. The results show levels of ammonia above USEPA limits for freshwater for stations 2A and 8B, the direct stable runoff samples, but not for Station 7.

Table 6: Chemical analysis for selected stations on January 25, 1997.

Station:	**2A**	**7**	**8B**
Orthophosphate (mg/L):	0.344	0.056	0.095
Nitrate (mg/L):	0.84	0.56	0.84
Ammonia (mg/L):	0.11	<0.02	0.11

2.4 Coliform Bacteria

Coliform bacteria encompass all of the aerobic and facultative anaerobic, gram-negative, non-endospore forming, and rod-shaped bacteria which ferment lactose with gas formation within 48 hours at 35°C (APHA 1995). Coliform bacteria inhabit the lower intestines of mammals and may constitute up to fifty percent of some feces. The presence of these bacteria in natural bodies of water indicates contamination by sewage or animal waste (Sugerman 1993). Some coliform bacteria in untreated water samples are to be expected (Brown *et al.* 1993). Coliform bacteria results are listed in Table 7.

Fecal coliform bacteria were present in all samples collected. Total coliform was present at high levels at all stations. The lowest total coliform count for October 24 was 330 MPN at Rodeo Lagoon. Most stations contained 1600 MPN or more. Total Coliform levels at all stations increased considerably during runoff on November 19, with a lowest recorded value of 920 MPN at Rodeo Lagoon.

E. Coli levels on October 24 ranged from a low of 49 MPN at Station 2 to >2400 MPN at several stations. During the November 18 storm, *E. coli* values increased noticeably at all stations, especially stations 2, 2A, 8A, and 8B. The level at Station 5 actually decreased, suggesting that the sample collected from the intermittently dry stream on October 24 may not have been representative of the normal conditions at that stream. Standing waters may have higher bacteria levels because the water is not being diluted by the flow of the stream.

Table 7: Total coliform and E. coli values for all 13 sampling stations. Some samples were collected by NPS. Values are reported in Most Probable Number (MPN) per 100 ml. No collectible flows are indicated by --- .

Station	Location	Date	Coliform (MPN)	E. coli (MPN)
1	Mountain Lake	10/24/96	>2400	>2400
		11/18/96	>2400	>2400
2	Rodeo Creek, upstream of stables	10/24/96	540	49
		11/18/96	>2400	>2400
2A	Rodeo stable runoff	10/24/96	---	---
		11/18/96	>2400	>2400
3	Rodeo Creek, downstream of stable	10/24/96	1600	540
		10/29/96	>2400	>2400
		11/18/96	>2400	1600
4	Rodeo Lagoon	10/24/96	330	23
		11/18/96	920	350
5	Tennessee Valley, Oakwood Creek	10/24/96	>2400	>2400
		11/18/96	>2400	1600
6	Tennessee Valley, Miwok stables	10/24/96	---	---
		11/18/96	1600	920
7	Tennessee Valley, NPS stables	10/24/96	---	---
		11/18/96	>2400	540
8	Redwood Creek, Pacific Way bridge	10/24/96	1600	170
		10/29/96	>2400	>2400
		11//18/96	>2400	540
8A	Tinker stables, direct runoff	10/24/96	---	---
		11/21/96	>2400	>2400
8B	Tinker stables, culvert runoff	10/24/96	---	---
		10/29/96	>2400	>2400
		11/21/96	>2400	>2400
9	Redwood Creek, Banducchi bridge	10/24/96	1600	920
		11/18/96	1600	240
10	Redwood Creek, Muir Woods bridge	10/24/96	240	240
		11/18/96	1600	920

3. CONCLUSION

The gathered data suggest that Redwood Creek is the most stable of the three watersheds in terms of stream flow and consistency of physical and chemical properties conducive to aquatic life. Runoff from the Tinker stables are high in orthophosphate and coliform bacteria. These stables are within approximately 1/4 mile of Redwood Creek. Stations downstream from these stables did show a marked increase in Coliform bacteria levels during runoff events.

Tennessee Valley Creek is a much smaller stream than Redwood Creek and is very dependent upon rainfall to sustain flows. The data and observations for Tennessee Valley Creek suggest that it would be dry for most of the late summer and fall months. However, Tennessee Valley Creek does not exhibit any severe effects in terms of water quality due to either of the two stables situated in close proximity. This would suggest that the stables are either lightly used, or well maintained and cleaned.

Rodeo Creek had consistently high Coliform bacteria levels, suggesting that sources of wastewater or animal waste exist above the stables on the valley floor. This is consistent with data presented in Podlech *et al.* (1993) when the highest coliform levels in Rodeo Creek were observed upstream from the stables. Runoff from the Rodeo stables are high in orthophosphate and Coliform bacteria. These stables are within less than 1/4 mile of Rodeo Creek. Stations downstream from these stables did show a marked increase in Coliform bacteria levels during runoff events.

Based on the data presented in Table 7, the three watersheds studied all have some level of contamination with coliform bacteria, with a noticeable increase during the first runoff of the year.

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APPENDIX A

Field Equipment

Air and Water Temperature, and Dissolved Oxygen:	YSI model 55 dissolved oxygen meter
Conductivity:	YSI model 33 C-S-T meter with platinized nickel electrode
Turbidity:	Hach 2100P turbidimeter
pH:	Hanna pH pen
Flow:	Swoffer pygmy current meter

APPENDIX B

Precipitation (in.) in Marin County during the 1996-1997 monitoring period

Department of Water Resources
CALIFORNIA COOPERATIVE SNOW SURVEYS
1997 WY Monthly Precipitation

River Basin/Station	Oct	Nov	Dec	Jan	Feb	Mar	Oct-Feb
COAST-MARIN							
Lagunitas Lake							
Avg.	3.05	5.51	8.97	10.96	8.67	6.64	37.16
% Avg.	57%	119%	264%	142%	7%	N/A	97%