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U. S. DEPARTMENT OF THE INTERIOR
FISH AND WILDLIFE SERVICE
REGION 1, PORTLAND, OREGON

Impacts to Humboldt Bay NWR From Forestry and Dairy Activities in the Salmon Creek Watershed

Final Report, Investigation ID #: 1261-1N52

By

John Henderson

Sacramento, California
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ABSTRACT. The freshwater creeks, brackish water sloughs, saltwater marshes and mud flats found on the Humboldt Bay National Wildlife Refuge provide habitats for at least 110 species of birds, 110 species of fish, 30 species of mammals, and many unique floral species found in and around the bay. The Salmon Creek Unit of the refuge drains a 23.5 square mile watershed managed primarily for timber production and livestock grazing and is recognized as critical habitat for coho salmon, a federally listed species. In 2000 water quality parameters (dissolved oxygen, pH, temperature, suspended sediment, turbidity, ammonia, other nutrients, etc.) were evaluated in Salmon Creek during high (winter) and low (summer) flow conditions and during periods when sensitive life stages of salmon are utilizing the creek. Dissolved oxygen in the upper watershed generally remained above 60 percent of saturation at the Alicia Pass Site and above 90 percent at the Salmon Pass Site. The dissolved oxygen at the lower watershed Refuge site was around 80 percent of saturation, in June, steadily declined to below 50 percent of saturation after August 13, and remained at or below 30 percent of saturation from September 2 through October 21. Dissolved oxygen was consistently below 3 mg/L from September 14 through October 21 at the Refuge site. After the first major rainstorm (> 2 inches) at the end of October, flows in Salmon Creek increased due to precipitation runoff and dissolved oxygen concentrations returned to levels above 70 percent of saturation. At the Refuge site, the dissolved oxygen concentrations did not meet the numerical criteria for dissolved oxygen objectives as stated in the Water Quality Control Plan for the North Coast Region of California. Total suspended solids increased dramatically in the October 30 water samples after a heavy 2-day rainstorm. The highest levels of both BOD_5 and TSS were in water samples collected from Little Salmon Creek.

Background

The Humboldt Bay National Wildlife Refuge occupies portions of estuarine bottomlands around Humboldt Bay in Humboldt County on the north coast of California. The freshwater creeks, brackish water sloughs, saltwater marshes and mud flats found on the Refuge provide habitats for at least 110 species of birds, 110 species of fish, 30 species of mammals, and many unique floral species found in and around the bay (Barnhart et al., 1992). The Salmon Creek Unit (Refuge), located on South Humboldt Bay, is named for Salmon Creek, which drains a 23.5 square mile watershed managed primarily for timber production and livestock grazing. Located within the upper watershed of Salmon Creek, 11 miles east of Humboldt Bay, is the Headwaters Forest Preserve (Headwaters), an old-growth redwood forest preserved through the efforts of many governmental and non-governmental organizations, including the U.S. Fish and Wildlife Service (Service). Approximately 1 mile of Salmon Creek courses through the Salmon Creek Unit before meeting Hookton Slough, a tidal arm of South Humboldt Bay. Much of Salmon Creek is channelized through the refuge, and the current mouth of Salmon Creek is south of where the natural mouth was located. Tidal action in Salmon Creek is muted due to the placement of a tidal gate at the mouth of Salmon Creek.

Fish monitoring conducted by the Service between 1989 and 1991 documented coho (*Oncorhynchus kisutch*) and chinook (*Oncorhynchus tshawytscha*) Salmon and steelhead (*Salmo gairdneri*) trout in Salmon Creek. Because out migrating salmon have been documented leaving Salmon Creek, this creek is recognized as critical habitat for coho salmon, a federally listed species. In 1997, the California Department of Fish and Game (CDFG) directed a stream inventory of Salmon Creek from Hookton Slough to approximately 10 miles upstream. Twenty-five sites were electrofished on 4 days in September 1997 by the CDFG and no coho salmon were observed (California Department of Fish and Game, 1997). The CDFG inventory concentrated on channel form and habitat type and, except for water temperature, did not report water quality parameters. Cooperative regional coho surveys organized by the Forest Science Project at Humboldt State University did not find coho juveniles in the Salmon Creek reaches surveyed in 2001 (Dana McCanne, Forest Science Project, personal communication). Surveys of Salmon Creek by the Cooperative Regional Coho Surveys scheduled for 2003 will include coho and steelhead counts.

Agricultural activities (primarily forestry, dairies, and cattle ranches) within the Salmon Creek watershed are possible contributors of contaminants to Salmon Creek. The levels of contaminants in Salmon Creek have been high enough to make the creek highly turbid and foul-smelling at Hookton Road during summer low flow periods (Karen Kovacs, California Department of Fish and Game, personal communication). It is suspected that poor water quality in Salmon Creek has resulted in the deaths of juvenile salmonids found in the creek during the summer months (U.S. Fish and Wildlife Service, 1998).

Water quality in Salmon Creek is related to land uses in the upper and lower watershed. Timber production and harvesting activities in the upper watershed are the suspected primary source of suspended sediment and elevated turbidity in Salmon Creek and secondary sources of nutrients and pesticides. Erosion of logging roads, clear cuts and channel disturbances would be the primary sources of suspended sediment, elevated turbidity, and nutrients mobilized from disturbed soil.

Agricultural activities in the lower watershed are the suspected primary source of nutrients, bacteria, pesticides, and pharmaceuticals. Loss of streambank vegetation due to unrestricted grazing and channelization in the lower watershed may be a secondary source of suspended sediment and turbidity which may adversely affect the habitat quality of Salmon Creek. The contaminants introduced to Salmon Creek in the lower watershed are suspected of having a high biochemical oxygen demand (BOD) leading to episodes of depressed dissolved oxygen. At least one dairy operation, which closed sometime before June of 2000 was situated close enough to Salmon Creek that solid and liquid wastes from the milking parlor and surface runoff from holding pens could directly enter the creek.

Study Objectives

The main objective of this study was to evaluate water quality parameters (D.O., pH, temperature, suspended sediment, turbidity, ammonia, other nutrients, etc.) in Salmon Creek during high (winter) and low (summer) flow conditions and during periods when sensitive life stages of salmon are utilizing the creek.

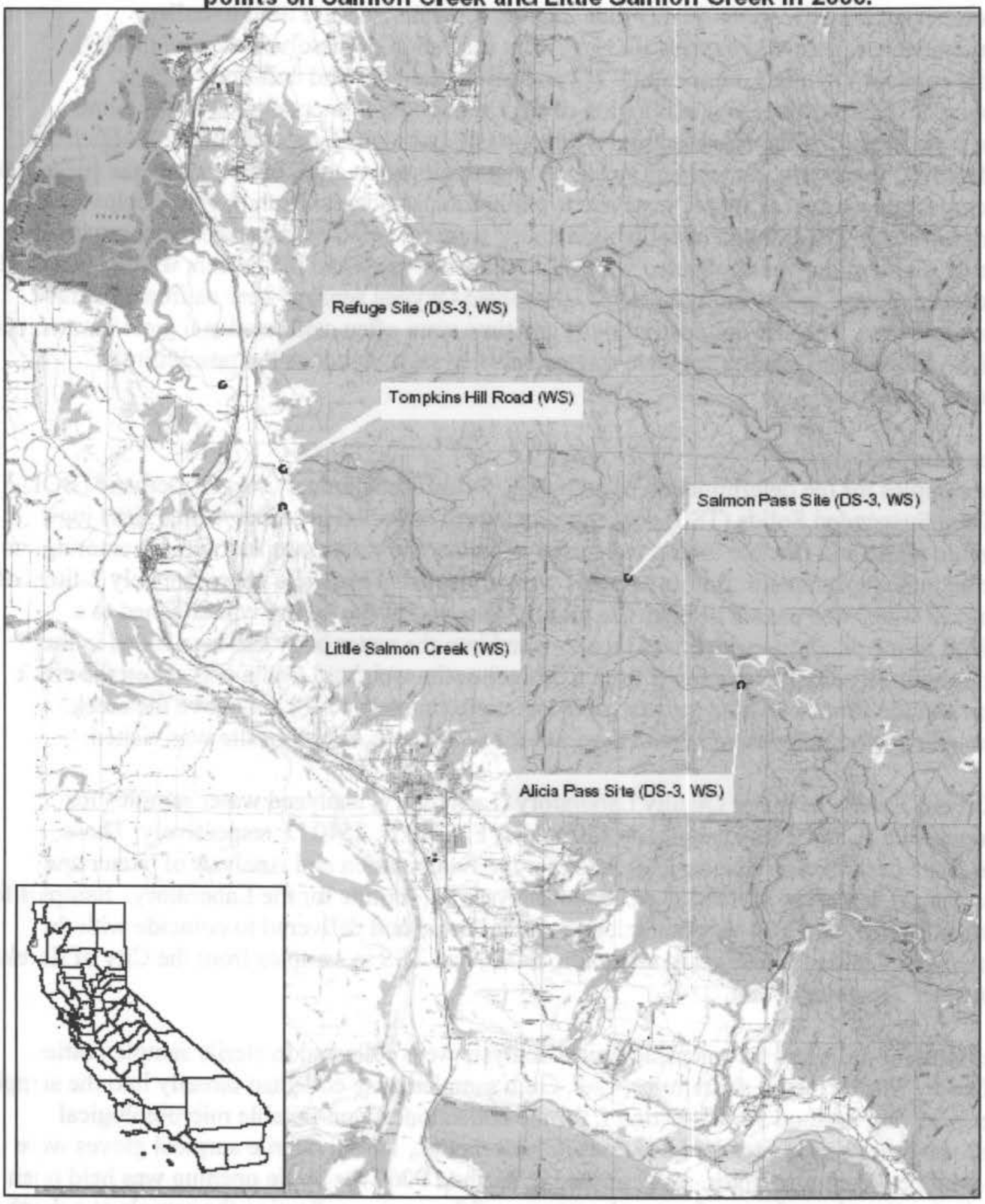
Methods

Site Selection

The watershed was initially divided into three sections with the forested area defined as the upper watershed, the pasture lands between the forested area and the Refuge as the middle watershed, and the bottomlands on the Refuge as the lower watershed. Sampling sites (Map 1) were situated at points which are close to the transition between the watershed sections. A sampling point at the lower end of Little Salmon Creek was included to document the contributions from this sub-unit of the Salmon Creek watershed. DataSondes were deployed at locations that were secure, representative and, when possible, convenient to access. The Alicia Pass Site was initially chosen as a water quality monitoring site for the upper watershed because a branch of Salmon Creek could be accessed by vehicle through Alicia Pass. The flow rate in this branch later became too low for monitoring to continue. The upper watershed water quality monitoring site was moved to the Salmon Pass Site, which was accessed on foot by hiking from Salmon Pass approximately 30 minutes in and 45 minutes out. A water quality monitoring site in the lower watershed was located at the Salmon Creek control structure on the Refuge (Refuge Site). DataSondes were suspended from the fyke trap support at the control structure. A secure location to deploy a DataSonde at the transition between the upper and middle sections of the watershed was not found.

Sites where water samples were collected included the DataSonde deployment sites and the Thompkins Hill Road and Little Salmon Creek sites (Map 1). Thompkins Hill Road crosses

Map 1. Map of Datasond-3 (DS-3 deployment sites and water sampling (WS) points on Salmon Creek and Little Salmon Creek in 2000.



Salmon Creek just downstream of where the creek emerges from the forested area and Thompkins Hill Road also crosses Little Salmon Creek near the confluence with Salmon Creek. The bridges across both creeks were used as sampling platforms.

Datasonde Measurements

Hydrolab DataSonde 3, water quality data logging instruments were used to collect measurements of dissolved oxygen (DO), percent saturation of dissolved oxygen (%DO), specific conductivity (SC), temperature (T) and pH on the hour and half-hour during deployment. Maintenance and calibration of the DataSondes was conducted prior to unit deployment following the manufacturer's directions (Hydrolab Corporation, 1994). Each unit was deployed for approximately one week. A post-deployment calibration check was conducted to document deviations of sensor response to calibration standards. Both the pre-deployment calibration and post-deployment calibration check were recorded on datasheets along with any remarks. Calibration was conducted with calibration standards and pH buffers which bracketed the values expected in the natural waters. Dissolved Oxygen sensors were calibrated at the deployment sites. Specific conductivity, pH and time were often calibrated at a more convenient location. Individual DataSondes were rotated between sites to reduce the possibility of systematic errors.

Water Samples

Water samples for the determination of ammonia, 5-day Biochemical Oxygen Demand (BOD_5) and Total Suspended Solids (TSS) concentrations were collected in amber 4-liter glass jugs. A peristaltic pump and flexible tubing were used to collect the water samples without entering the water body being sampled. Before samples were collected at each site approximately 2-liters of de-ionized water was passed through the tubing. One end of the tubing was attached to a weighted frame on a rope which was then lowered into the water body and suspended in the water column (if sampling occurred from a bridge) or the weighted frame was set on the creek bottom and the frame elevated the tube opening approximately 17-18 cm above the creek bottom. Collected samples were stored on wet ice while each sampling site was visited.

The City of Eureka's, Water Quality Laboratory (Laboratory) analyzed water samples for ammonia, BOD_5, and TSS by methods 4500- NH_3 F, 5210 B, 2540 D, respectively. These methods are described in Standard Methods for the Examination and Analysis of Water and Wastewater (Clesceri et al. 1998). All three analyses are routine for the Laboratory. Samples for ammonia, BOD5, and TSS determinations were collected and delivered to coincide with the Laboratory schedule for analyzing ammonia, BOD_5 and TSS in samples from the City of Eureka Wastewater Treatment Plant.

Water samples collected for microbiological analysis were collected in sterile sample bottles supplied by North Coast Laboratories, Ltd. Grab samples were collected directly into the sample bottle following Method 9060, Section f, for the collection of non-potable microbiological samples as described in Standard Methods (Clesceri et al., 1998). Sterile surgical gloves were worn while collecting samples. As described in Method 9060 the bottle opening was held open towards the direction of water flow and upstream of the person collecting the sample at a depth of approximately 15 centimeters.

Water samples collected for bacteriological analysis were examined at North Coast Laboratories, Ltd., in Arcata, California. This facility is used extensively by communities in the Humboldt Bay region for bacteriological examination of municipal water supplies. Standard Methods 9221 A, B, C and E, were used for the Total Coliform and Fecal Coliform counts and Method 9230 B was used for the Fecal Streptococcus counts (Clesceri et al., 1998). Method 9221 is the Multiple-tube Fermentation Technique for bacteria of the coliform group and for these samples a 3 x 5 dilution series matrix was used. All samples were held on wet ice during the collection period and delivered to the laboratory within the six hour holding time specified in the method.

Results

Graphical representations of the water quality parameters measured and recorded by the DataSondes at the Refuge Site and the Headwaters sites are located in Appendix A. The horizontal-axis on the Refuge Site graphs shows time beginning on June 15, 2000, at 7:30 p.m. and ending November 11, 2000, at 12:00 p.m. The Headwaters data begins on July 22, 2000, at 7:30 p.m. at the Alicia Pass Site and the last data point graphed is for November 7, 2000 at 12:00 p.m. at the Salmon Pass Site. Water quality monitoring at the Alicia Pass was discontinued on September 21 due to low water levels in that branch of Salmon Creek. Water quality monitoring began again at the Salmon Pass site on October 4. The vertical-axis on each graph shows the water quality parameter in the appropriate units for that parameter. At the Refuge Site approximately 48,000 data points were recorded and at the Headwaters sites approximately 27,000 data points were recorded. Gaps in the data are due to technical or scheduling problems and no data was collected for those periods.

Water samples were collected from the Salmon Creek watershed during two dry season sampling events and one wet season event and at three to four sites each event. Water samples from the Salmon Creek watershed were collected from three to four sites each event. Table 1 shows the results for the chemical analysis of samples from the three water sampling events which occurred on September 20- 21, October 4, and October 30, 2000. Water-quality parameters (Temperature, DO, SC and pH) entered in Table 1 for the Refuge, Alicia Pass and Salmon Pass Sites are from the automated DataSonde measurements and the values entered are those which were recorded closest to the time water samples were collected. The water quality data for Thompkins Hill Road and Little Salmon Creek in Table 1 are spot measurements taken at the time the water samples were collected. Table 2 shows the bacteriological examination results from the three water sampling events.

Table 1. Analytical Results for Water Samples collected in Salmon Creek and Little Salmon Creek.

Pre-precipitation Sampling Events

Site[a]	Date	Time	Temperature (°C)	Conductivity (μS/cm)	pH (Units)	DO (mg/L)	BOD5 (mg/L)	Ammonia (mg/L)	TSS (mg/L)
Refuge Site	9/20/00	1320	14.5	426	7.22	2.31	< 5.0	< 0.5	1.0
Thompkins Hill Road	9/20/00	1350	18.0	514	7.03	6.49	< 5.0	< 0.5	< 1.0
Alicia Pass Site	9/20/00	1210	11.5	346	6.75	6.84	< 5.0	< 0.5	< 1.0
Refuge Site	10/4/00	1230	11.6	462	7.09	2.59	< 2.0	< 0.5	6.0
Thompkins Hill Road	10/4/00	1155	11.7	528	7.01	7.74	< 2.0	< 0.5	1.0
Salmon Pass Site	10/4/00	1010	11.0	273	7.33	9.80	< 2.0	< 0.5	< 1.0

Post-precipitation Sampling Event

Site[a]	Date	Time	Temperature (°C)	Conductivity (μS/cm)	pH (Units)	DO (mg/L)	BOD5 (mg/L)	Ammonia (mg/L)	TSS (mg/L)
Refuge Site	10/30/00	0810	11.0	394	7.42	9.33	3.1	<0.5	97
Thompkins Hill Road	10/30/00	0634	10.9	391	8.03	10.17	2.4	<0.5	190
Little Salmon Creek	10/30/00	0710	11.1	199	7.83	10.46	4.7	<0.5	320
Salmon Pass Site	10/30/00	1005	9.6	218	7.35	10.55	<2.0	<0.5	15

[a]Refuge Site= Salmon Creek at Salmon Creek Unit control structure; Thompkins Hill Road=Salmon Creek at Tompkins Hill Road; Little Salmon Creek= Little Salmon Creek at Thompkins Hill Road; Alicia Pass Site=Tributary of Salmon Creek at Headwaters via Alicia Pass; Salmon Pass = Salmon Creek at Headwaters via Salmon Pass

Table 2. Bacteriological Examination Results (most probable number/100mL) for Water Samples collected in Salmon Creek and Little Salmon Creek.

Pre-precipitation Sampling Events

Site[a]	Date	Time	Total Coliform	Fecal Coliform	Fecal Strep
Refuge Site	9/20/00	1320	30	17	2
Thompkins Hill Road	9/20/00	1350	≥1600	300	90
Alicia Pass Site	9/20/00	1210	30	<2	4
Refuge Site	10/4/00	1230	300	NT	NT
Thompkins Hill Road	10/4/00	1155	220	NT	NT
Salmon Pass Site	10/4/00	1010	22	NT	NT

Post-precipitation Sampling Event

Site[a]	Date	Time	Total Coliform	Fecal Coliform	Fecal Strep
Refuge Site	10/30/00	0810	≥1600	NT	NT
Thompkins Hill Road	10/30/00	0634	≥1600	NT	NT
Little Salmon Creek	10/30/00	0710	≥1600	NT	NT
Salmon Pass Site	10/30/00	1005	≥1600	NT	NT

[a] Refuge Site= Salmon Creek at Salmon Creek Unit control structure; Thompkins Hill Road=Salmon Creek at Tompkins Hill Road; Little Salmon Creek= Little Salmon Creek at Thompkins Hill Road; Alicia Pass Site=Tributary of Salmon Creek at Headwaters via Alicia Pass; Salmon Pass = Salmon Creek at Headwaters via Salmon Pass; NT= not taken

Water Quality

a) Upper watershed

The DS-3 data shows that DO in the Headwaters generally remained above 60 percent of saturation at the Alicia Pass Site and above 90 percent at the Salmon Pass Site. The magnitude of the DO probe drift error for DS-3s deployed in the Headwaters was approximately 25 percent at the Alicia Pass site and DO probe drift was approximately 5 percent at the Salmon Pass site. The effect of a film that developed over the surface of the DO probe membrane at the Alicia Pass Site can be clearly seen in the DO graph for the Headwaters Sites as the measurements trend downward and then abruptly rises after maintenance and calibration at the beginning of the next deployment period. The film on the DO membrane appeared to be mineral in nature similar to a flocculent which also accumulated on stream substrate at the Alicia Pass Site. Manually removing the film during the post-deployment calibration check also restored the sensor response to a value much closer to the calibration value. Measurements of DO at the Salmon Pass Site were more consistent because the film which appeared on the DO membrane at the Alicia Pass Site did not appear on the DO membrane at the Salmon Pass Site and post-deployment calibration checks at Salmon Pass Site showed less sensor drift.

Temperature at the Headwaters sites remained below 14° C at both monitoring sites for the entire record. The group of readings between October and November taken in the main stem of Salmon Creek at the Salmon Pass Site are in the 11° C range and drop below 10° C after the first rainstorm of the fall.

Measurements of pH at the Headwaters sites were prone to some drift or fouling during the deployment period; however, measurements only varied over the range of 6.6 to 7.8 pH units during the monitoring period.

Specific Conductivity at the Alicia Pass Site started at between 280 and 300 μS/cm but quickly rose to over 320 μS/cm during August. Creek flow rates at Alicia Pass Site dropped sharply during the same period. Specific Conductivity at the Salmon Pass Site was approximately 100 μS/cm lower that the conductivity at the Alicia Pass Site.

b) Middle and lower watershed

The DO at the Refuge Site was around 80 percent of saturation, in June steadily declined to below 50 percent of saturation after August 13, and remained at or below 30 percent of saturation from September 2 through October 21. Dissolved Oxygen was consistently below 3 mg/L from September 14 through October 21 at the Refuge Site. After the first major rainstorm (> 2 inches) at the end of October, flows in Salmon Creek increased due to precipitation runoff and DO concentrations returned to levels above 70 percent of saturation (around 7 to 8 mg/L). The DO concentrations fell again to 60 percent of saturation when Salmon Creek flow rates again dropped. The lowest measured DO of 0.95 mg/L was recorded on October 20, 2000 at 1:30

a.m.

At the Refuge Site the average water temperature from the beginning of the record on June 15 to September 16 was 14.5° C. The average temperature from September 17 to November 11 was 12.1° C. The highest recorded temperature of 16.3° C was measured on July 29, 2000 at 5:00 p.m. and the lowest of 9.76° C on October 23 at 10:30 a.m.

Some upward drift or fouling of the pH sensor occurred at the Refuge Site. This effect is probably responsible for the pattern of pH measurements at the beginning of the deployment period being less than the pH measurements recorded at the end of the previous deployment period; however, the drift was minor and all pH readings were within 0.7 pH units of neutral the entire record.

Specific Conductivity at the Refuge Site showed some variation between deployment periods; however, SC overall rose steadily from June to the first part of November. This increase in SC may have been due to evapo-concentration in Salmon Creek at the Control Structure. The highest SC at the Refuge Site was 100 μS/cm higher that the highest SC measured at the Alicia Pass Site and 200 μS/cm higher than the Salmon Pass Site.

Discussion and Recommendations

The dairy operation adjacent to and upstream of the Refuge ceased operations at some point during the winter of 1999-2000. Dairy operations are regulated and inspected by the State of California, Regional Water Quality Control Boards (RWQCB). After an inspection by the North Coast RWQCB staff it became evident that the necessary improvements to the dairy facilities, which would bring the operation into compliance with State regulations, would not be economically feasible (Bill Winchester, North Coast RWQCB, personal communication). All data collected for this study were collected after the dairy was no longer operating.

The DataSonde measurements and the data in Tables 1 and 2 generally show that water quality in Salmon Creek decreases from the Headwaters to the middle and lower sections of the watershed. Ammonia was not detected in any water sample collected from Salmon Creek. The lower detection limit of 0.5 mg/L for ammonia was too high for this type of study but this is the lowest detection limit the laboratory could attain. Total suspended solids increased dramatically in the October 30 water samples after a heavy 2-day rainstorm. The highest levels of both BOD_5 and TSS were in water samples collected from Little Salmon Creek.

At the Refuge Site, the DO concentrations did not meet the numerical criteria for dissolved oxygen objectives as stated in the Water Quality Control Plan for the North Coast Region of California (hereafter called the Basin Plan) (RWQCB, 1993). The beneficial uses of Salmon Creek have been identified as cold water habitat capable of supporting the spawning and migration of listed salmonid species and other wildlife (RWQCB, 2002). As such, the DO concentration in Salmon Creek should never fall below 7.0 mg/L and during critical spawning and egg incubation periods the DO concentration should never be reduced below 9.0 mg/L and in general the DO in cold water fish habitat should not fall below 6.0 mg/L (RWQCB, 1993).

The literature reviewed supports the DO objectives in the Basin Plan. Salmonids are particularly sensitive to depressed levels of dissolved oxygen (Heath, 1987). Any level of dissolved oxygen below the threshold level for any particular species will require the expenditure of excess energy to maintain homeostasis, leading to stress. For developing coho salmon, the dissolved oxygen threshold for normal development over 6 to 8 weeks in laboratory conditions was 4.0 to 4.5 mg/L (Brett and Blackburn 1981). Delayed hatching of salmonid eggs may occur if the dissolved oxygen falls below air saturation (Doudoroff and Shumway, 1970). Larval salmonids are more sensitive to low dissolved oxygen levels than adult salmonids, making them especially intolerant of anaerobic stream conditions (Heath, 1987). Dissolved oxygen concentrations ranging from 4 to 9 mg/L are required for food conversion in coho salmon and saturation levels are required for juveniles to attain top swimming speeds (U.S. Fish and Wildlife Service, 1986a). Chinook salmon require greater than 5.0 mg/L DO for adult upstream migration and juvenile chinook salmon avoid waters where DO concentrations are less than 3.0 mg/L at the temperatures seen at the Refuge Site (U.S. Fish and Wildlife Service, 1986b).

Aquatic invertebrates are also affected by abnormal dissolved oxygen levels. Chronic low dissolved oxygen, as well as other abnormal water quality parameters important to insect health, can lead to changes in invertebrate community composition (Unsinger, 1956).

The optimal or preferred water temperatures for salmonids vary between species and between life stages of a species. For coho the preferred range of temperatures for adult migration upstream is 7.2 to 15.6° C, while the preferred spawning and egg incubation ranges are 4.4 to 9.4° C and 4.4 to 13.3° C respectively (U.S. Fish and Wildlife Service, 1986b). A summer steelhead stream should be 10 to 15° C (U.S. Fish and Wildlife Service, 1986a). Chinook salmon can tolerate higher water temperatures than other Pacific salmonids (U.S. Fish and Wildlife Service, 1986c). The lethal temperature limits for coho, chinook and steelhead are all above 20° C. Temperatures recorded in Salmon Creek may have been at times slightly outside of the preferred ranges for salmonids but did not approach lethal limits for coho, chinook or steelhead.

The Basin Plan does not give specific objectives for conductivity in Salmon Creek. Conductivities measured in Salmon Creek may have exceeded the numerical objectives for other coastal streams in the region such as the Mad River, Eel River and the Van Duzen River. The numerical criteria for SC in the Basin Plan is given in 90 and 50 percentile values over a calendar year and the conductivity at the Refuge Site after August exceeds the 90th percentile objectives in all three referenced water bodies. Further water quality monitoring in Salmon Creek would show how the conductivity compares to the objectives on calendar year basis.

At the Refuge Site, the conductivity record does not indicate any tidal influence at that point in Salmon Creek. The tide gate at the mouth of Salmon Creek on the Refuge mutes the tidal action in Salmon Creek and apparently allows water to accumulate behind the tide gate to a point just upstream of the control structure (at least in water year 2000 this was the case) and the flow was stagnant at the Refuge site. Additional work should be conducted to determine if Salmon Creek from the Refuge Site to the mouth of Salmon Creek is adequately oxygenated over the entire reach through the entire year.

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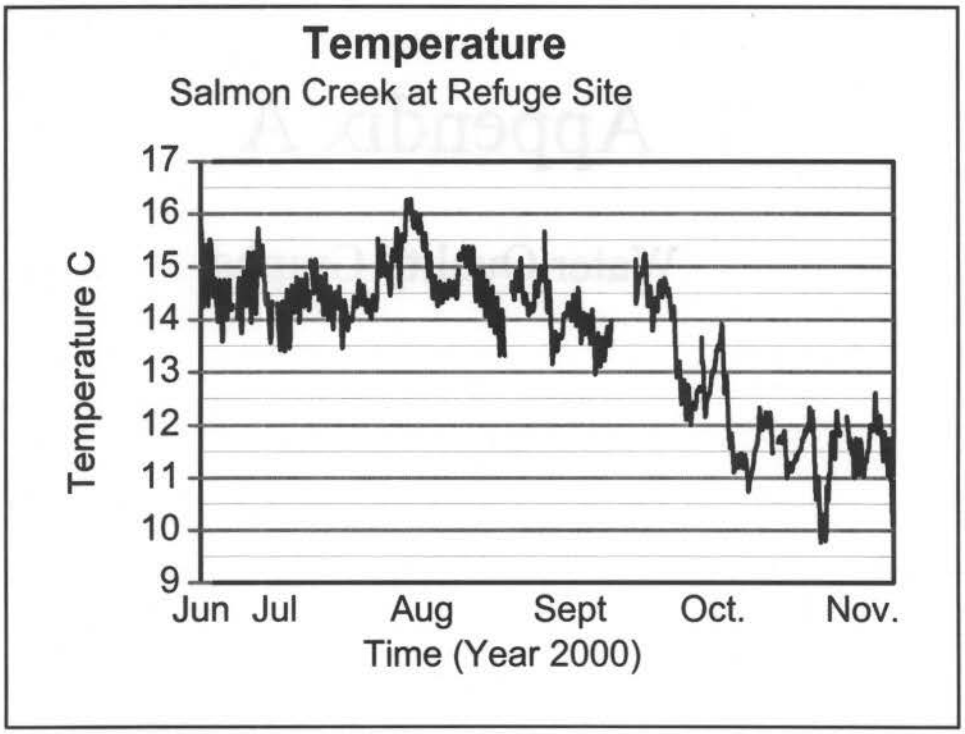
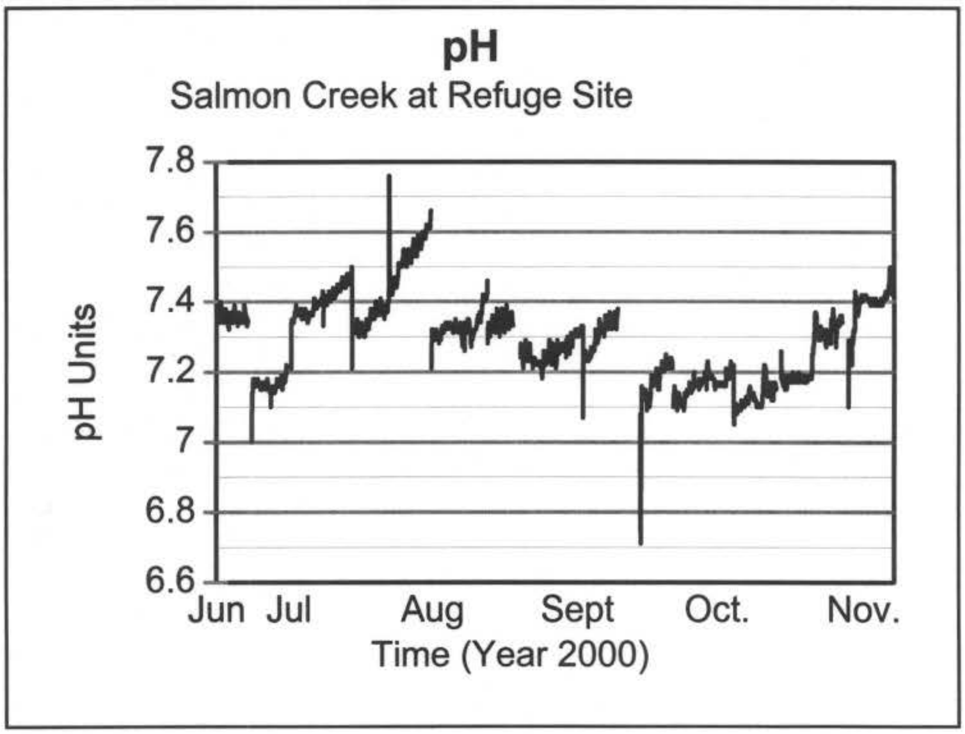
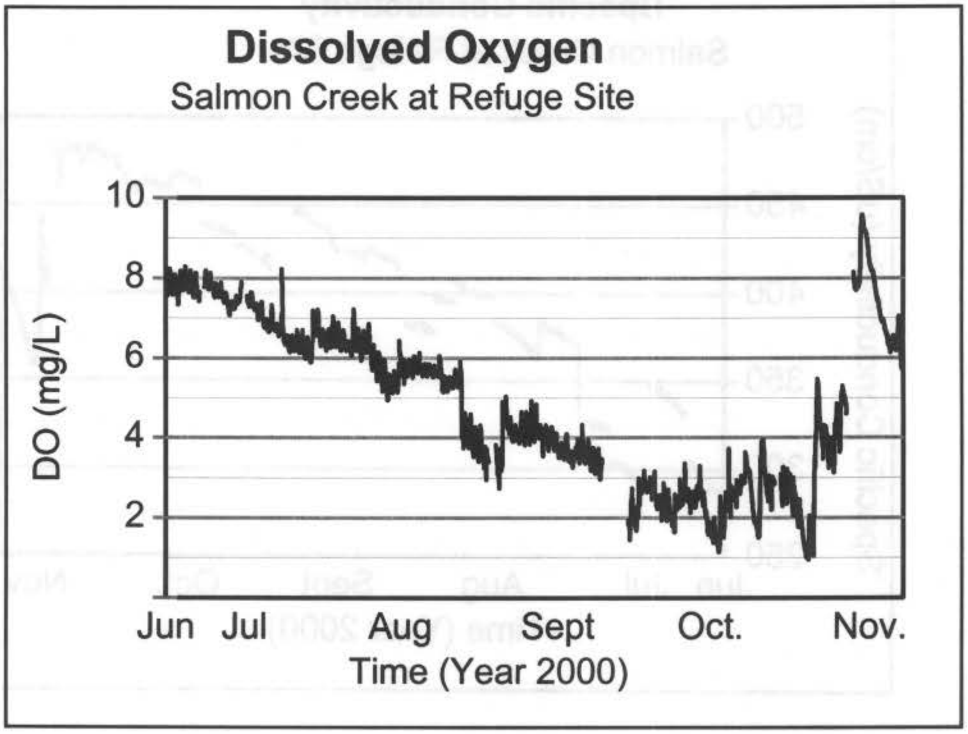
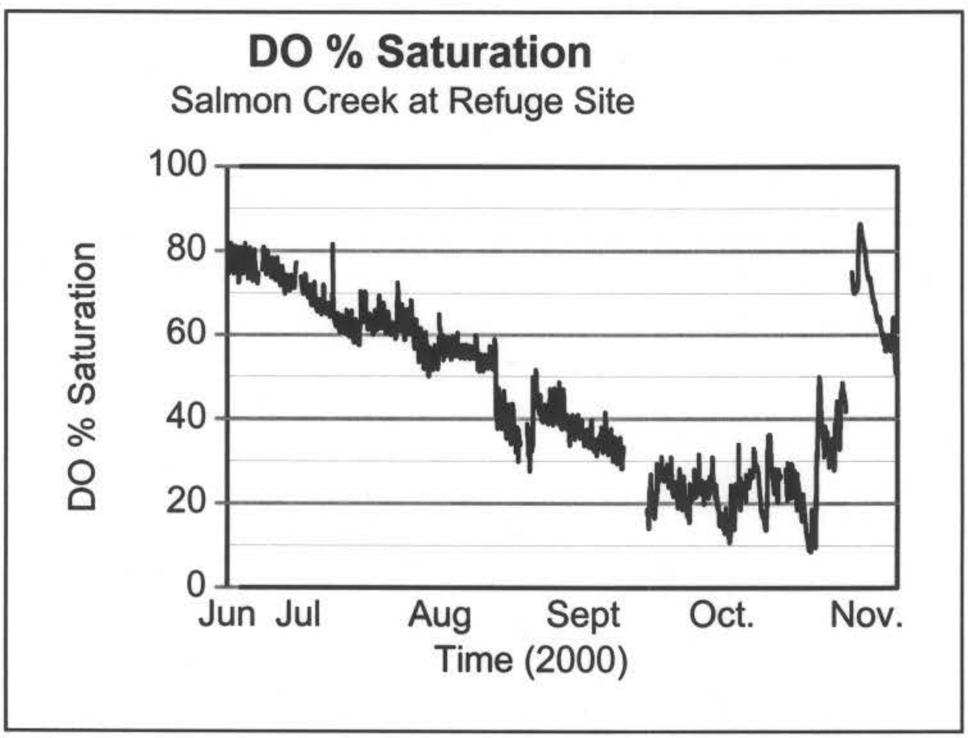
Appendix A

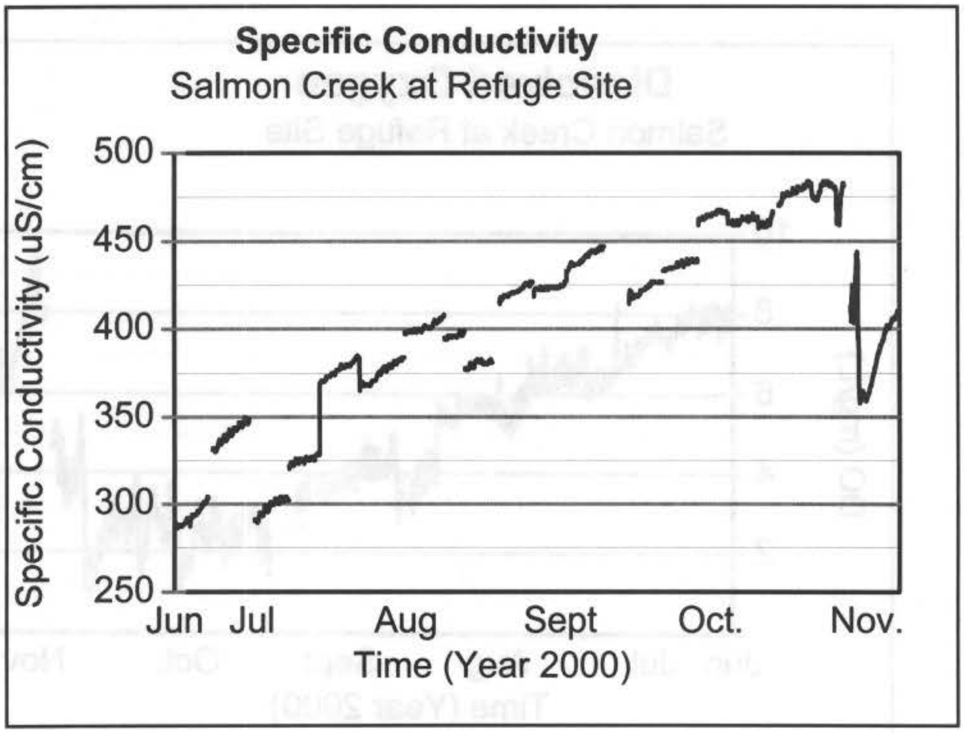
Water Quality Graphs

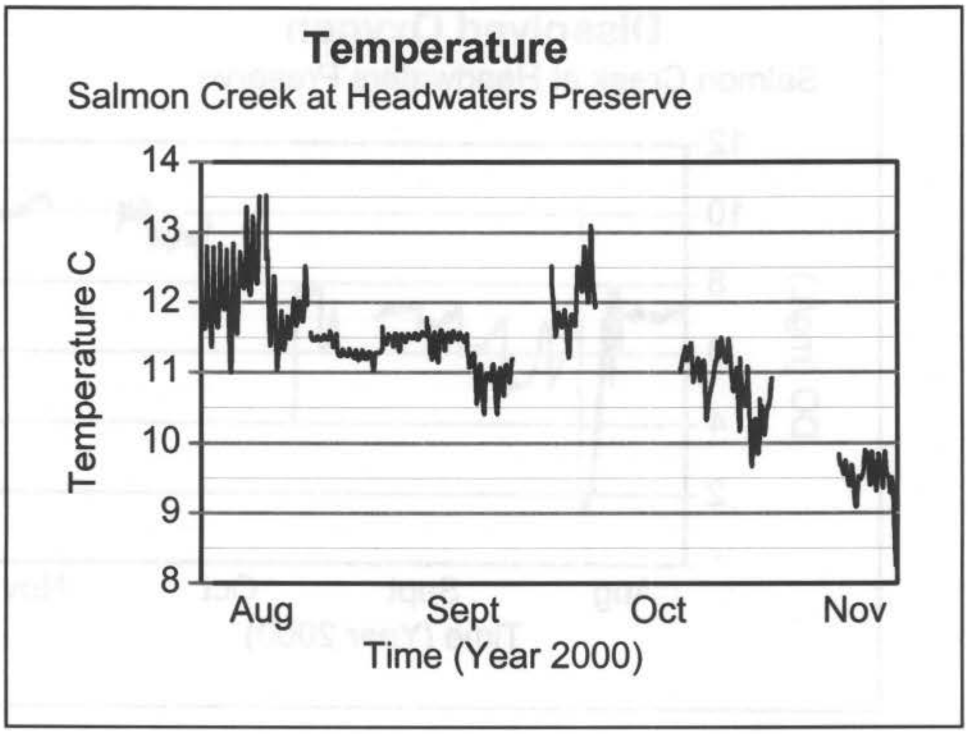

Temperature
Salmon Creek at Refuge Site
17
16
15
14
13
12
11
10
9
Temperature C
Jun Jul Aug Sept Oct. Nov.
Time (Year 2000)

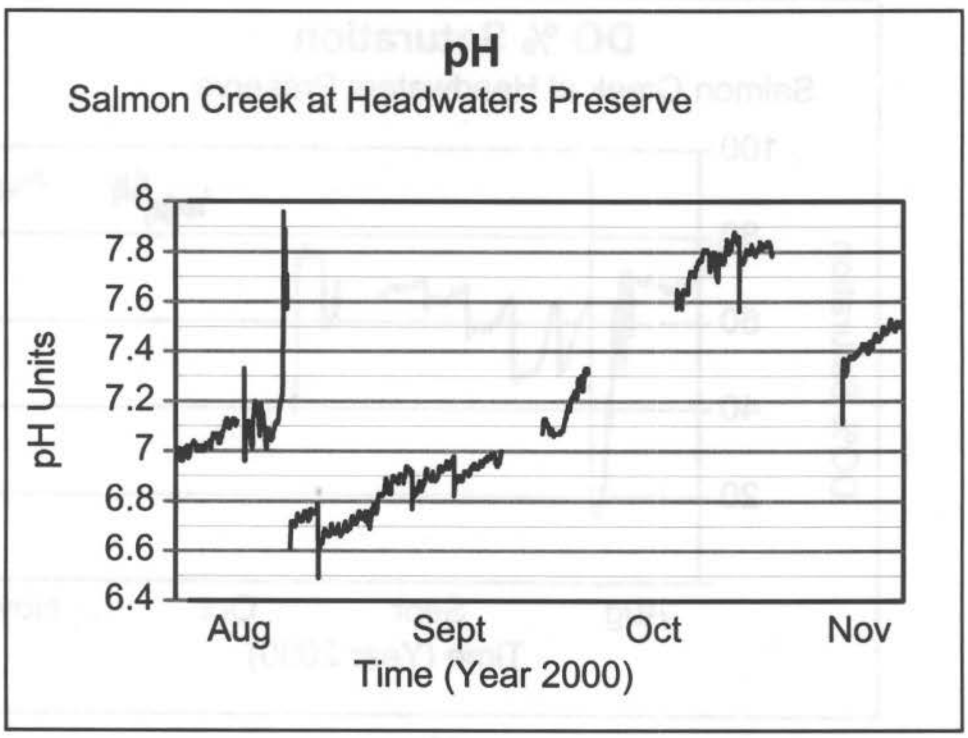

pH
Salmon Creek at Refuge Site
7.8
7.6
7.4
7.2
7
6.8
6.6
pH Units
Jun Jul Aug Sept Oct. Nov.
Time (Year 2000)

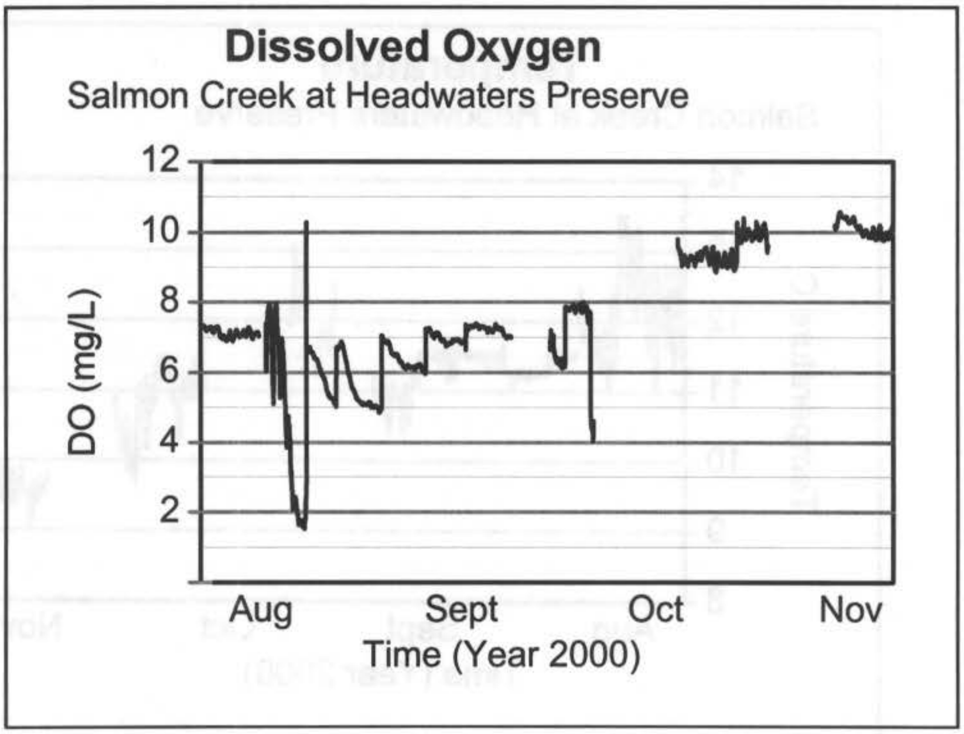

Dissolved Oxygen
Salmon Creek at Refuge Site
10
8
6
4
2
DO (mg/L)
Jun
Jul
Aug
Sept
Oct.
Nov.
Time (Year 2000)

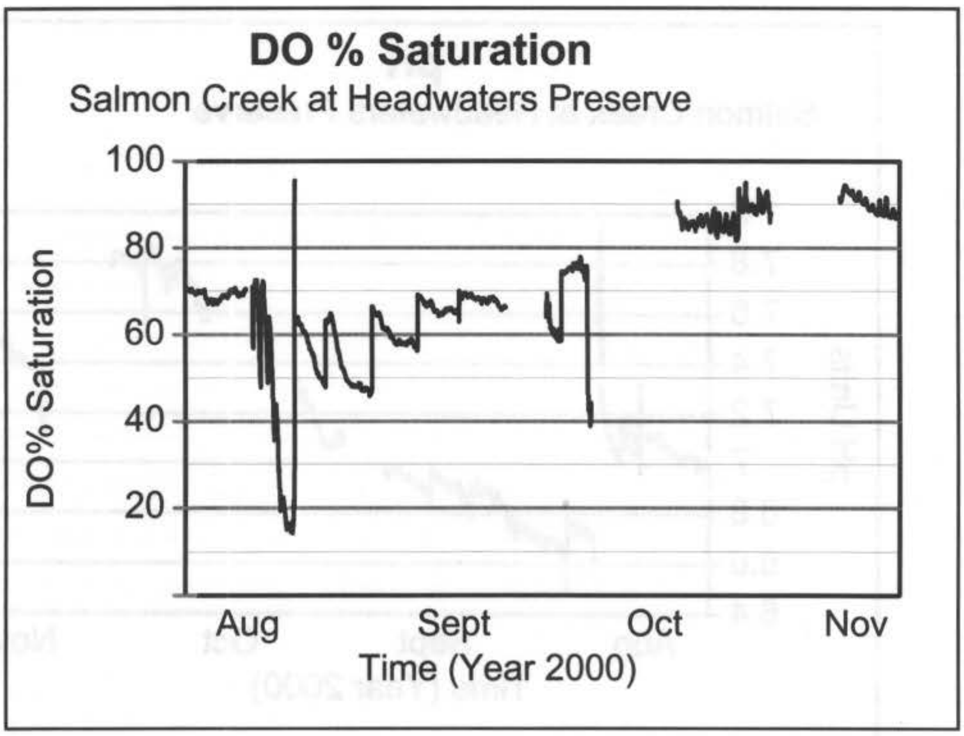

DO % Saturation
Salmon Creek at Refuge Site
100
80
60
40
20
0
DO % Saturation
Jun
Jul
Aug
Sept
Oct.
Nov.
Time (2000)

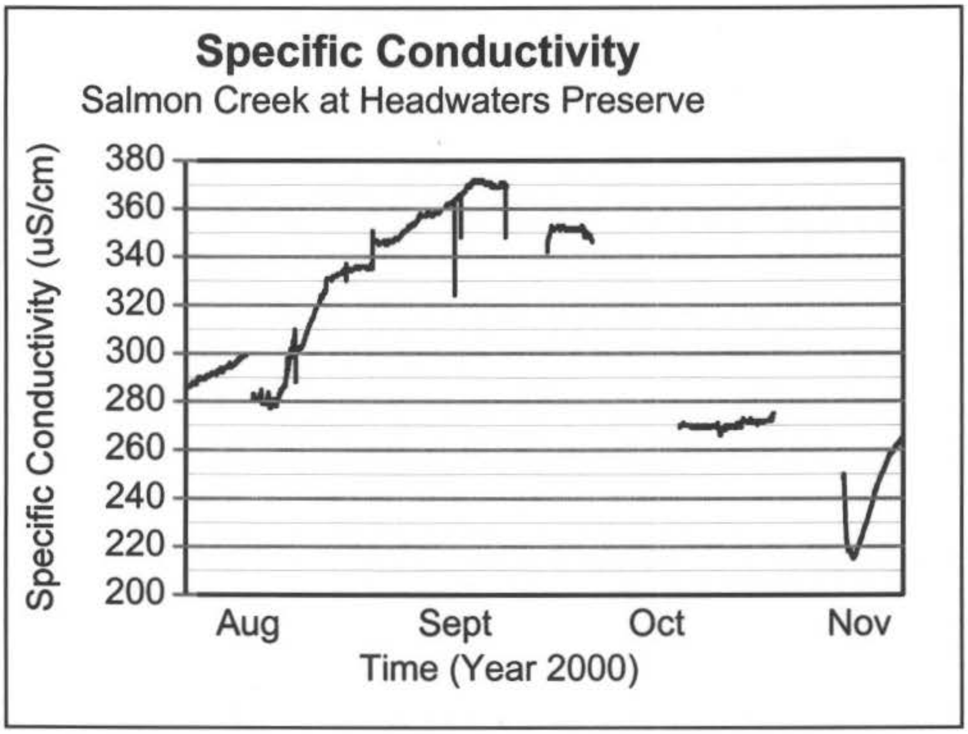

Specific Conductivity
Salmon Creek at Refuge Site
Specific Conductivity (uS/cm)
500
450
400
350
300
250
Jun
Jul
Aug
Sept
Oct.
Nov.
Time (Year 2000)


Temperature
Salmon Creek at Headwaters Preserve
Temperature C
14
13
12
11
10
9
8
Aug
Sept
Oct
Nov
Time (Year 2000)


pH
Salmon Creek at Headwaters Preserve
pH Units
8
7.8
7.6
7.4
7.2
7
6.8
6.6
6.4
Aug
Sept
Oct
Nov
Time (Year 2000)


Dissolved Oxygen
Salmon Creek at Headwaters Preserve
12
10
8
6
4
2
DO (mg/L)
Aug
Sept
Oct
Nov
Time (Year 2000)


DO % Saturation
Salmon Creek at Headwaters Preserve
100
80
60
40
20
DO% Saturation
Aug
Sept
Oct
Nov
Time (Year 2000)


Specific Conductivity
Salmon Creek at Headwaters Preserve
Specific Conductivity (uS/cm)
380
360
340
320
300
280
260
240
220
200
Aug
Sept
Oct
Nov
Time (Year 2000)