87-e24

Segment No. 10-22-10

WA-22-4045

Effects of McCleary Wastewater Treatment Plant Effluent on Water Quality and Macroinvertebrate Community Structure in Wildcat Creek, Washington

by

Will Kendra

Water Quality Investigations Section
Washington State Department of Ecology
Olympia, Washington 98504

April 1987

ABSTRACT

A water quality survey of Wildcat Creek was conducted in August 1986 to assess the effects of McCleary Wastewater Treatment Plant effluent on the receiving environment. Prior to upgrade in 1980-81, wastewater discharge caused violations of state water quality standards for dissolved oxygen, un-ionized ammonia, fecal coliform bacteria, total residual chlorine, and aesthetic values. None of these impacts were found at present, despite a 50 percent reduction in receiving water flows. Further, macroinvertebrate community structure improved relative to pre-upgrade conditions. Violations of state temperature standards in 1986 were likely the result of illegal discharges by Simpson Timber Company. At 7Q10 streamflows and plant design capacity, receiving-water-to-effluent dilution ratios would drop from 4:1 to 2.5:1. In the absence of plant upsets, only the temperature standard is expected to be violated under these conditions.

INTRODUCTION

Wildcat Creek is located in eastern Grays Harbor County and is tributary to the Chehalis River via Cloquallum Creek. Wildcat Creek is 9.2 miles long and drains an area of about 21 square miles (Figure 1). The stream consists of three forks: East, Middle, and West. Wildcat Creek technically becomes East Fork Wildcat Creek above the West Fork confluence, but the "East Fork" designation will be disregarded for the remainder of this report.

The Wildcat Creek watershed is relatively undeveloped. Characteristic land uses include logging and limited animal pasturing. The city of McCleary (population 1,300) is located at about river mile (r.m.) 5. Simpson Timber Company is the major commercial enterprise in town.

McCleary Wastewater Treatment Plant (WTP) serves the entire community, including process and sanitary wastewaters generated at Simpson. Treatment was originally by trickling filter, but upgrade to advanced secondary in 1980-81 was accomplished through installation of a biological tower (for nitrification), additional clarification, and dechlorination. Effluent is discharged to Wildcat Creek (Class A) immediately below the mouth of Sam's Canal (r.m. 4.75). There are no other permitted discharges to the drainage in the vicinity of McCleary.

Historical water quality problems in Wildcat Creek were largely attributed to WTP impacts (Devitt, 1973; Musgrove, 1977). The receiving environment was found to be periodically toxic to salmonids and mussels, and significant changes in the macroinvertebrate community were observed below the discharge. Concern over water quality degradation and possible effects on salmon and steelhead runs led to WTP upgrade in the winter of 1980-81.

The Southwest Regional Office (SWRO) of Ecology requested the Water Quality Investigations Section (WQIS) conduct a post-upgrade receiving water survey of Wildcat Creek. Objectives of the survey were:

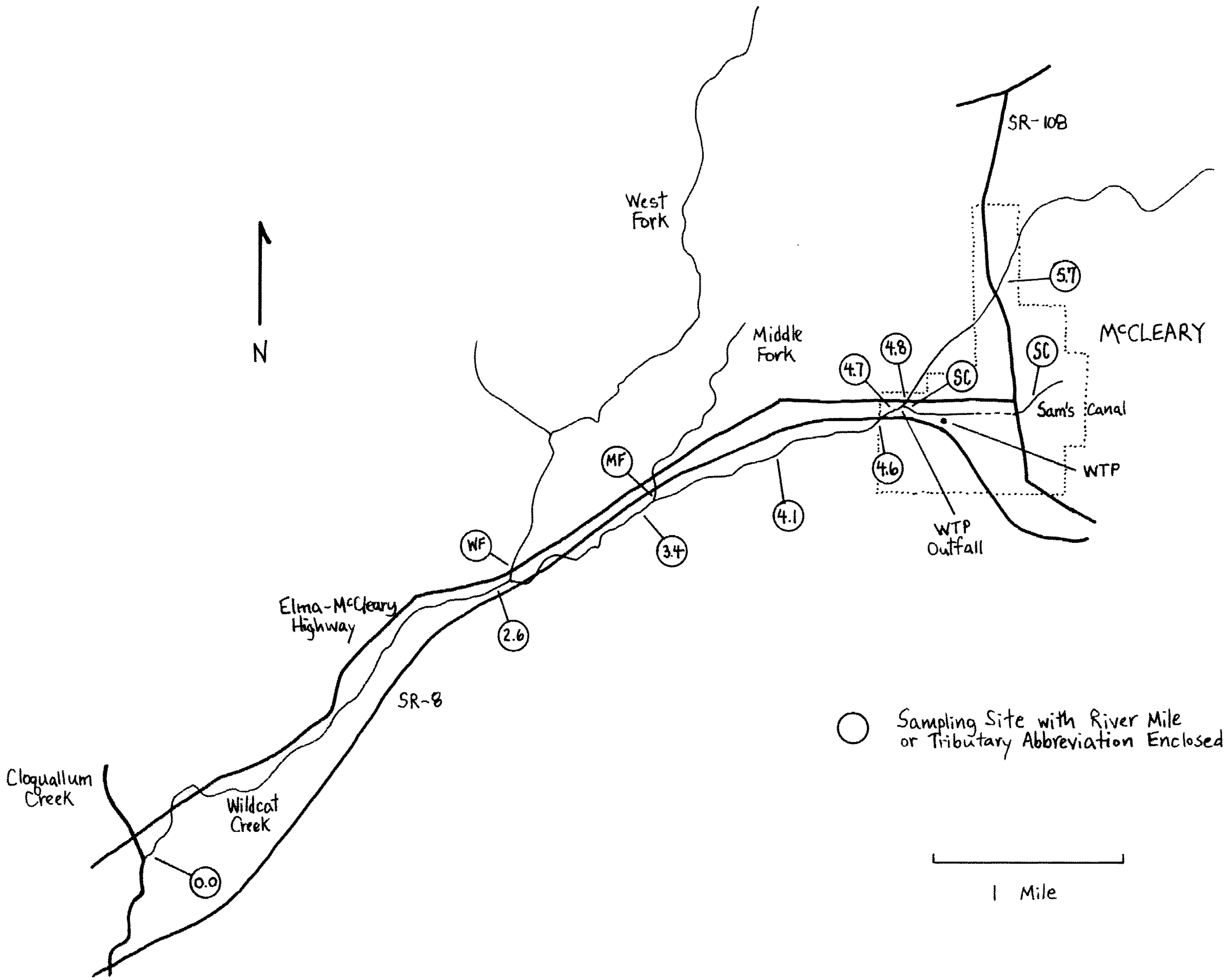


Figure 1. Map of Wildcat Creek showing location of sampling sites during an August 1986 water quality survey.

- Characterize the effects of WTP effluent on water quality and the macroinvertebrate community in Wildcat Creek.
- Evaluate changes in water quality and biota of Wildcat Creek attributable to the WTP upgrade.
- Calculate total maximum daily loads of waste constituents to Wildcat Creek.

Field assistance was provided by Norm Glenn of WQIS. A concomitant Class II inspection of the WTP was performed by Don Reif of WQIS. Class II findings will be reported under separate cover (Reif, in prep.).

METHODS

Water quality sampling was conducted August 26-27, 1986. Weather was warm and sunny, with no rain having fallen in the preceding several weeks. Twelve sites were selected, eight on the mainstem and four on tributaries (Figure 1). Site 4.7 was located downstream of the WTP effluent mixing zone.

Sampling was performed working upstream from the creek mouth both days. Field measurements included discharge (Marsh-McBirney flow meter), temperature (mercury thermometer), pH (Orion meter), specific conductance (Beckman meter), dissolved oxygen (azide-modified Winkler titration), and total residual chlorine (LaMotte-Palin colorimetric kit). Turbidity, nutrient (nitrate-nitrite, ammonia, and total phosphorus), biochemical oxygen demand (BOD_5), and fecal coliform samples were iced and shipped to Ecology's Manchester Laboratory for analysis as per EPA (1979) and APHA, et al. (1985).

Results at eight sites were compared to the findings of Musgrove (1977). Data were from mid-August 1977 and represent 48-hour means, except for residual chlorine (24-hour mean) and fecal coliforms (single grabs). To facilitate comparisons, dissolved oxygen data from 1977 were used only when sampling times were within three hours of 1986 sampling times.

Macroinvertebrates were sampled using the methods and sites of Musgrove (1977). Briefly, triplicate Hester-Dendy (1962) multiple-plate artificial substrate samplers were placed instream at each of eight locations on July 14, 1986. Each sampler exposed slightly more than one square foot of surface for the attachment of organisms. Samplers were retrieved after six weeks, washed through a 0.6 mm screen, and preserved in 70 percent ethanol. A single sampler at site 4.7 was lost. Collection and processing techniques are discussed in detail by Slack, et al. (1973) and Weber (1973).

Macroinvertebrates were identified to order using the keys of Merritt and Cummins (1978) and Pennak (1978). Organisms were further discriminated by morphological features to the finest taxonomic level possible, hereafter referred to as "species." Species richness was calculated by the rarefaction method of Heck, et al. (1975). Equitability and diversity were calculated as per Weber (1973).

RESULTS AND DISCUSSION

Water Quality

Prior to upgrade, McCleary WTP discharged effluent directly to Sam's Canal. The present outfall is an 18-inch concrete pipe that extends across the width of Wildcat Creek (Figure 2). Five diffuser ports are spaced about three feet apart and three feet from either bank. Each port consists of a four-inch diameter pipe projecting horizontally outward one to two feet from the main outfall line. The ports discharge effluent in a downstream direction above the surface of the receiving water. All ports were flowing during the survey, the fifth (distal) more slowly. The WTP operator noted that children play in the vicinity of the outfall and sometimes partially block one or more of the ports with aluminum cans.

Results of water quality sampling are shown in Table 1. WTP effluent was in compliance with NPDES permit limitations (Reif, in prep.). Effects of WTP discharge on Wildcat Creek were most dramatic for conductivity, nitrate-nitrite, and total phosphorus. Increases in temperature, turbidity, and fecal coliforms were attributed to Sam's Canal. Dissolved oxygen concentrations declined somewhat below the outfall, but percent saturation values were fairly constant. The slight drop in oxygen concentrations was likely a function of low dissolved oxygen and increased water temperature in Sam's Canal (i.e., high temperatures reduced the oxygen-carrying capacity of the receiving water).

The receiving-water-to-effluent dilution ratio was 4:1. Tributary contributions and other inflows resulted in a final dilution ratio at the mouth of Wildcat Creek of 19:1, still well below the recommended mix of 100:1 (Ecology, 1985). The five-port diffuser provided excellent initial dilution, likely moderating the immediate adverse impacts expected with such a low dilution ratio.

Wildcat Creek flows declined 46 percent (0.6 cfs) between r.m. 5.7 and 4.8 (i.e., upstream of the WTP outfall and Sam's Canal). This loss effectively reduced the receiving-water-to-effluent dilution ratio by 33 percent (6:1 to 4:1). Property along the reach is owned largely by Simpson Timber Company. An eight-foot dam at r.m. 5.1 provides storage in the event of fire. There are no existing water rights for this portion of the stream (W. Bergstrom, Ecology, personal communication). The water loss could be the result of ground water infiltration, particularly if the pumping of nearby wells produces a hydraulic gradient away from the creek. However, the loss may also be due to illegal withdrawal.

Water quality in tributaries to Wildcat Creek was good, except for Sam's Canal (Table 1). Flow and temperature increased 0.4 cfs and 6.2°C, respectively, as Sam's Canal passed through McCleary. These

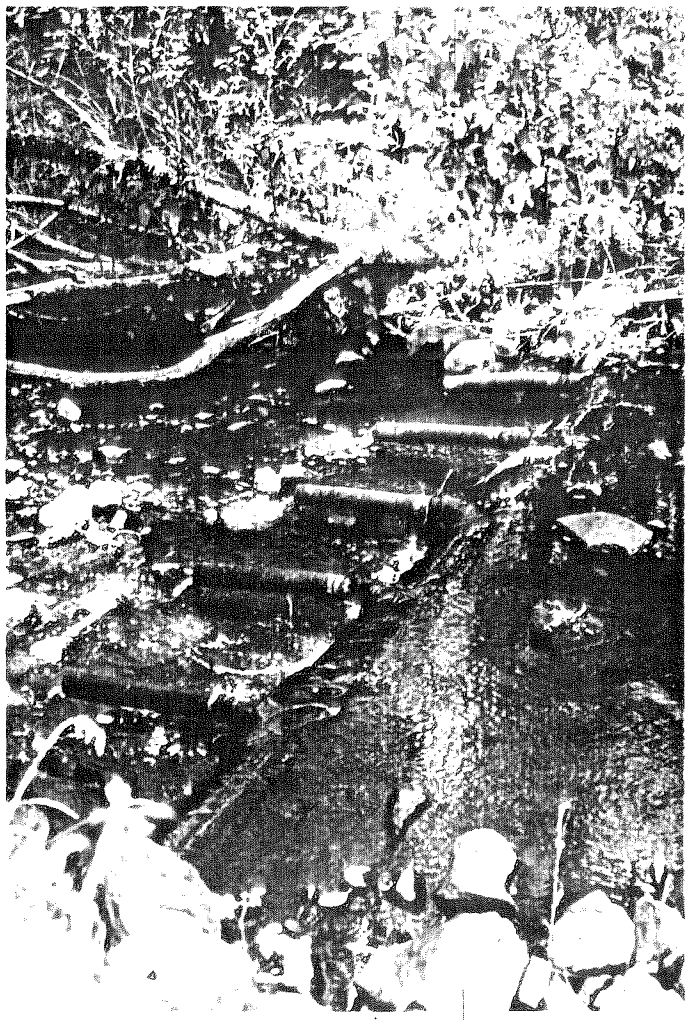


Figure 2. Photograph of McCleary WTP outfall diffuser, located at r.m. 4.75 of Wildcat Creek.

Table 1. Water quality data collected in Wildcat Creek and tributaries on August 26-27, 1986.

Sampling Site	River Mile	Date	Time	Flow (cfs)	Temp. (°C)	pH (S.U.)	Cond. (umhos/cm)	D.O. (mg/L)	D.O. (% sat.)	Turb. (NTU)	NO_3-N + NO_2-N (mg/L)	NH_3-N (mg/L)	Total P (mg/L)	BOD-5 (mg/L)	Fecal Coliforms (#/100 mL)	Chl. Resid. (mg/L)
Wildcat Creek																
Abv. SR-108	5.7	8/26	1753	1.3	16.6	7.4	90	8.80	90	<1	0.23	0.01	0.01	--	39	--
		8/27	1607	1.3	16.8	7.3	90	9.00	93	2	0.25	<0.01	0.01	--	19	--
Abv. WTP Outfall	4.8	8/26	1550	0.7	16.6	7.3	97	8.80	90	<1	0.29	<0.01	0.01	--	13	--
		8/27	1408	0.7	17.7	7.3	95	8.40	88	<1	0.23	0.01	0.01	<4	13	--
Blw. WTP Outfall	4.7	8/26	1545	1.8	19.4	7.5	153	8.00	87	2	2.3	0.03	1.2	--	32[a]	<0.1
		8/27	1348	1.5	20.1	7.4	151	8.00	88	2	2.2	0.02	1.1	<4	55[a]	<0.1
Blw SR-8	4.6	8/26	1500	1.6	18.9	7.5	150	8.30	89	2	2.2	0.03	1.3	--	31[a]	<0.1
		8/27	1321	1.7	19.2	7.5	153	8.30	90	3	2.1	0.03	1.1	--	45[a]	<0.1
0.5 mi blw. SR-8	4.1	8/26	1423	1.5	17.6	7.6	149	8.55	90	2	2.0	0.02	1.2	--	20[a]	--
		8/27	1158	1.5	17.5	7.5	140	8.30	87	2	1.5	0.01	0.66	--	28	--
Blw. Middle Fork	3.4	8/26	1128	2.6	15.3	7.5	130	8.90	89	1	1.4	<0.01	0.51	--	15	--
		8/27	1052	2.3	16.2	7.5	133	8.80	89	1	1.3	0.01	0.45	--	10	--
Blw. West Fork	2.6	8/26	1004	4.7	14.2	7.5	112	9.30	91	<1	0.77	0.01	0.14	--	12	--
		8/27	0938	4.4	15.1	7.4	110	9.15	91	2	0.77	0.01	0.15	--	13	--
Mouth	0.0	8/26	0916	6.3	14.5	7.2	102	8.80	86	<1	0.53	<0.01	0.05	--	37	--
		8/27	0848	5.9	15.5	7.4	100	8.75	87	<1	0.53	0.01	0.04	--	61	--
Tributaries																
West Fork	2.6	8/26	1008	1.4	14.0	7.4	85	9.10	88	1	0.38	0.01	0.02	--	23	--
		8/27	1001	1.5	14.9	7.2	85	8.80	87	1	0.38	0.01	0.02	--	18	--
Middle Fork	3.4	8/26	1137	0.6	14.7	7.5	98	8.95	88	<1	0.27	<0.01	0.02	--	1	--
		8/27	1109	0.6	15.5	7.3	103	9.45	95	1	0.27	<0.01	0.02	--	3	--
Sam's Canal at Mouth	4.75	8/26	1557	0.5	25.5	7.3	110	6.80	83	3	0.06	0.02	0.03	--	80[a]	--
		8/27	1404	0.5	25.1	7.4	109	7.30	88	4	0.07	0.02	0.03	<4	64[a]	--
Sam's Canal at Park	--	8/26	1723	0.1	19.2	6.7	85	6.45	70	3	0.22	0.02	0.02	--	12	--
		8/27	1540	<0.1	19.0	6.7	82	6.55	71	4	0.19	0.02	0.02	--	25	--
McCleary WTP[b]	4.75	8/26	0950	--	19.4	7.6	440	--	--	5	12	0.15	4.6	--	--	--
		8/26	1510	--	21.4	7.4	440	8.2	93	4	15	0.13	4.7	--	4	<0.1
		8/27	1025	--	20.4	7.7	420	--	--	5	12	--	5.3	--	8[c]	--
		8/27	0900[d]	0.3[e]	--	7.5	--	--	--	4	14	--	5.5	10	--	--

[a]Many background organisms. [b]Data from Reif (in prep.). [c]Mean of 2 samples. [d]24-hour composite sample. [e]24-hour mean flow.

changes apparently occurred in the segment of the canal which is underground. Several municipal storm sewer outfalls are located in this reach. Heat balance calculations show the storm sewer discharge(s) likely had an average temperature of 26.8 ^{o}C (Appendix A). Consequent temperature increases in both Sam's Canal and Wildcat Creek violated state water quality standards.

Simpson Timber Company formerly had an NPDES permit to discharge noncontact cooling water to Sam's Canal via a municipal storm sewer. At present, the only permitted discharger in McCleary is the WTP. However, SWRO inquiries revealed that Simpson did in fact have two existing illegal discharges to the storm sewer and, ultimately Sam's Canal (G. Cloud, Ecology, personal communication). The quality of these discharges may explain the increase in canal pH (6.7 to 7.4) as well as the abundance of background microorganisms found in fecal coliform samples collected at the canal mouth.

Comparison of conditions in Wildcat Creek before and after the WTP upgrade shows marked water quality improvements (Figure 3). The receiving-water-to-effluent dilution ratio in 1977 was better (5:1), but impacts were considerably worse. The dissolved oxygen curve for 1977 reveals a downstream sag of 1.9 mg/L. Effluent BOD_5 was 26 mg/L in 1977 compared to 10 mg/L in 1986. Review of inorganic nitrogen graphs shows that instream nitrification (i.e., bacterial conversion of ammonia to nitrate) also exerted an oxygen demand in 1977. Upgrade of the WTP has all but eliminated ammonia from the receiving environment during the summer low-flow period; however, nitrate-nitrite and total phosphorus levels remain high. Mean fecal coliform densities between the outfall and Middle Fork confluence were 458/100 mL in 1977 compared to 26/100 mL in 1986.

In 1977, McCleary WTP discharge caused violations of state water quality standards for dissolved oxygen, un-ionized ammonia, fecal coliform bacteria, and total residual chlorine. In addition, aesthetic values were impaired. Musgrove (1977) reported the presence of sewage odors and "slime growths" as far downstream as the SR-8 overpass (r.m. 4.6). None of these conditions were found in 1986 despite a 50 percent decrease in receiving water flows (2.4 cfs to 1.2 cfs). A blue-gray hue imparted by WTP effluent persisted to r.m. 4.1, but the visual effect was too subtle to constitute an impairment of aesthetic values. The only violation of water quality standards in 1986 occurred with temperature, but the illegal discharges were likely the causative agent.

Macroinvertebrates

Results of macroinvertebrate sampling in Wildcat Creek are summarized in Table 2 and detailed in Appendix B. The dominant organism by far was the Ephemeropteran *Paraleptophlebia*; it accounted for 74 percent of mayflies collected and was present at all sites except Sam's Canal. The amphipod *Anisogammarus* was dominant at the mouth of Wildcat Creek; it represented 71 percent of all organisms collected there. Interestingly, Holsinger (1972) reported that "*Anisogammarus* is found in

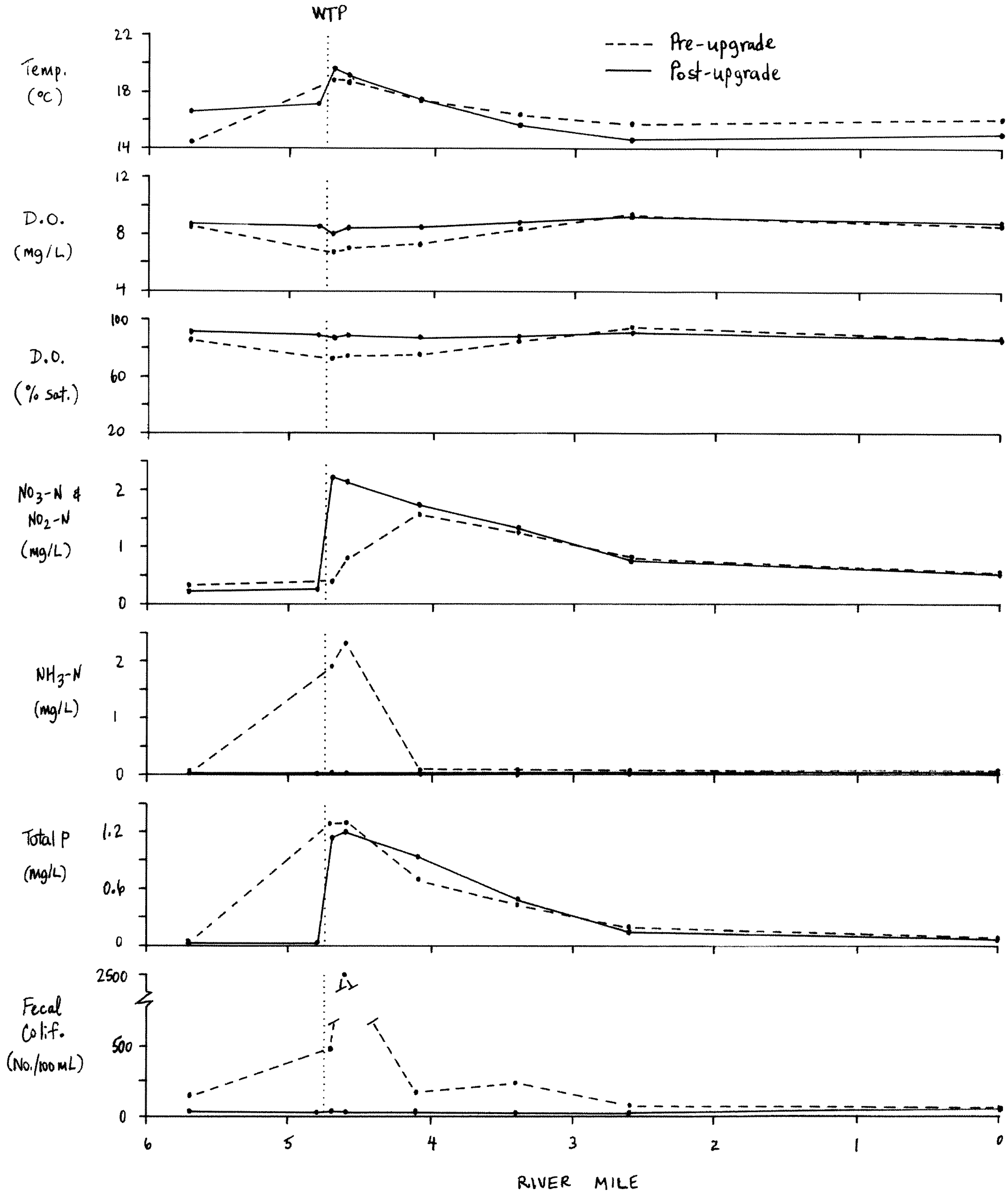


Figure 3. Comparison of water quality in Wildcat Creek before and after upgrade of McCleary WTP. Pre-upgrade data from Musgrove (1977).

Table 2. Abundance and composition of macroinvertebrate communities in Wildcat Creek, August 1986.

Sampling Site	River Mile	Sample Number	Depth (ft.)	Velocity (fps)	Number of Individuals Per Taxon* O	A	D	E	P	T	G	M	Total Number
Wildcat Creek													
Above SR-108	5.7	1	1.3	0.4	2	--	8	35	3	1	7	1	57
		2	1.7	0.3	--	--	7	42	2	2	26	1	80
		3	1.7	0.2	1	--	1	45	1	2	15	1	66
Below WTP Outfall	4.7	1	1.6	0.2	4	--	32	24	1	--	29	3	93
		2	1.4	0.2	4	--	19	20	1	2	18	3	67
Below SR-8	4.6	1	1.9	0.3	3	--	51	21	--	1	12	11	99
		2	2.0	0.3	1	--	34	19	4	--	21	10	89
		3	1.8	0.1	2	--	12	38	2	3	32	12	101
0.5 mi below SR-8	4.1	1	1.0	0.3	3	--	6	18	6	1	1	1	36
		2	1.1	0.2	--	--	1	32	4	--	13	--	50
		3	1.4	0.1	--	--	6	57	1	2	19	1	86
Below Middle Fork	3.4	1	1.6	0.2	--	--	6	22	11	5	--	--	44
		2	1.3	0.2	--	--	10	63	12	3	3	1	92
		3	0.8	0.3	--	--	8	40	9	11	1	1	70
Below West Fork	2.6	1	0.7	0.3	--	5	8	21	9	2	--	--	45
		2	0.5	0.5	--	2	15	23	7	1	3	--	51
		3	0.8	0.4	--	38	4	32	6	4	1	2	87
Mouth	0.0	1	1.8	0.5	--	48	3	8	1	--	--	--	60
		2	1.6	0.4	--	41	5	13	4	3	--	--	66
		3	1.5	0.5	1	71	8	11	2	3	--	3	99
Sam's Canal at Mouth	4.75	1	0.4	0.4	14	--	3	--	--	--	--	3	20
		2	0.4	0.4	17	--	1	--	--	--	2	2	22
		3	0.3	0.7	30	--	4	1	1	--	1	1	38

*O = Oligochaeta
A = Amphipoda
D = Diptera
E = Ephemeroptera
P = Plecoptera
T = Trichoptera
G = Gastropoda
M = Miscellaneous

freshwater only on a marginal basis (three species along the Pacific coast) and is primarily a brackish and marine group." Wildcat Creek is located more than 25 miles upstream of the Grays Harbor Estuary.

Monitoring of macroinvertebrates is useful in receiving water studies because wastewater effluents can eliminate sensitive species and enhance tolerant forms. Six indices were calculated to assess macroinvertebrate community structure in Wildcat Creek: abundance, species richness, equitability, diversity, percent EPT (Ephemeroptera-Plecoptera-Trichoptera), and percent Diptera. Diversity has two components: species richness and equitability. Richness is a measure of the expected number of species per sample after all samples are scaled down ("rarified") to the same number of organisms. Equitability reflects the distribution of individuals among the species. Percent EPT (the mayfly-stonefly-caddisfly complex) provides an index of sensitive invertebrates, while percent Diptera provides a measure of more tolerant forms.

Macroinvertebrate community structure in Wildcat Creek is shown in Table 3. Abundance appeared to increase slightly below the outfall, but variability was high. ANOVA on log-transformed data demonstrated a significant ($p<0.01$) difference in abundance among sites. However, multiple comparisons (Duncan's procedure in Ott, 1977) revealed the only difference in abundance was between Sam's Canal and the remaining sites. That is, the WTP did not significantly affect macroinvertebrate abundance in mainstem Wildcat Creek.

Unexpectedly, species richness, equitability, and overall diversity also appeared to increase below the WTP outfall. But Weber (1973) warns that the equitability and diversity of samples containing less than 100 organisms should be evaluated with caution, if at all. The percentage of sensitive macroinvertebrates (EPT) declined below the outfall while the proportion of tolerant forms (Diptera) increased. However, shifts in species composition may not be entirely due to WTP effluent. Percent EPT was also depressed in Sam's Canal, which is tributary to Wildcat Creek immediately upstream of the outfall. The apparent decline in species richness, equitability, diversity, and percent EPT at the mouth of Wildcat Creek can be attributed to the dominance of the amphipod *Anisogammarus*.

Comparison of 1977 and 1986 macroinvertebrate data demonstrates marked improvements in community structure (Figure 4). Prior to WTP upgrade, organism abundance in Sam's Canal (former outfall) and at site 4.7 was very high, but the communities were mostly comprised of pollutant-tolerant invertebrates (Dipterans). In 1986, abundance was unchanged along mainstem Wildcat Creek. Diversity declined below the outfall in 1977 and recovered by r.m. 2.6. Post-upgrade diversities were highly variable but no distinct trends were evident. Percent composition of sensitive and tolerant species followed similar patterns in 1977 and 1986, but the upgrade served to smooth extreme lows and highs in the vicinity of the outfall.

Table 3. Six measures of macroinvertebrate community structure in Wildcat Creek, August 1986. Each measure represents the mean of three Hester-Dendy samples (except r.m. 4.7 which had only two samples).

Sampling Site	River Mile	Abundance ± Std. Error	Species Richness	Equitability	Shannon-Weaver Diversity	Percent EPT[a]	Percent Diptera
Wildcat Creek							
Above SR-108	5.7	68 ± 7	6	0.69	2.46	66	8
Below WTP outfall	4.7	80 ± 13	7	0.75	3.05	30	31
Below SR-8	4.6	96 ± 4	9	0.75	3.43	30	34
0.5 mi. below SR-8	4.1	57 ± 15	6	0.68	2.13	70	9
Below Middle Fork	3.4	69 ± 14	8	0.71	2.95	86	12
Below West Fork	2.6	61 ± 13	9	0.82	3.26	60	17
Mouth	0.0	75 ± 12	5	0.41	1.73	20	7
Sam's Canal at Mouth	4.75	27 ± 6	5	0.55	1.38	2	10

[a]Ephemeroptera-Plecoptera-Trichoptera complex.

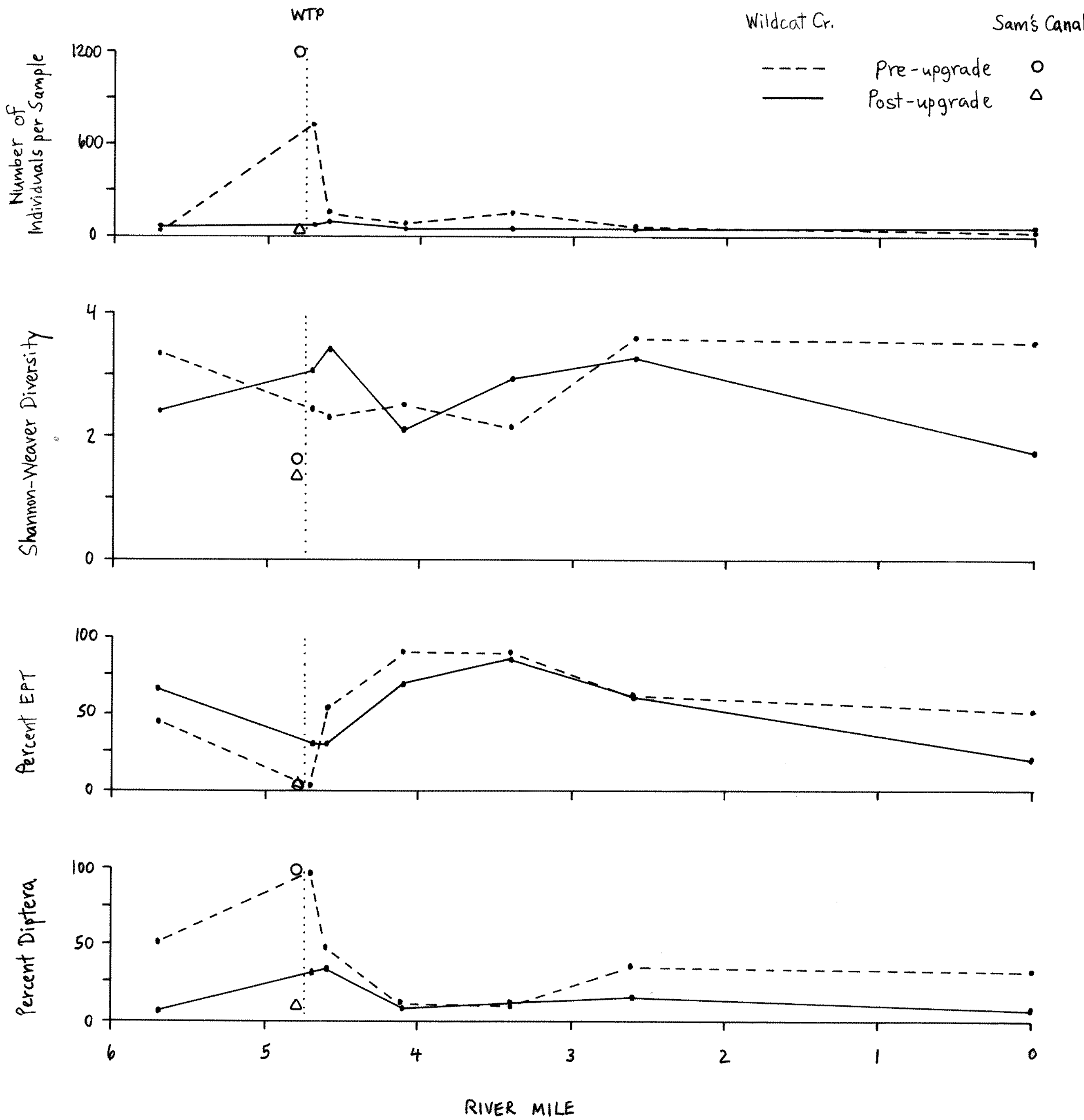


Figure 4. Comparison of macroinvertebrate community structure in Wildcat Creek before and after upgrade of McCleary WTP. Pre-upgrade data from Musgrove (1977).

Total Maximum Daily Loads (TMDLs)

TMDL analyses were performed to assess the waste assimilative capacity of Wildcat Creek under "7Q10" critical-flow conditions (7Q10 is the low mean discharge expected to occur during seven consecutive days on an average of once in 10 years). Of particular interest was the response of the receiving environment to WTP discharges at design capacity. Parameters of concern include temperature, fecal coliforms, dissolved oxygen, un-ionized ammonia, and nutrients.

The 7Q10 flow and corresponding temperature of Wildcat Creek immediately above the WTP outfall were estimated to be 1.0 cfs and 21.2^{o}C (Appendix C). At design capacity, the receiving-water-to-WTP-effluent dilution ratio would be 2.5:1 (1.0:0.4 cfs). Elimination of the illegal discharges to Sam's Canal could considerably reduce temperature impacts, but the trade-off may be loss of 0.4 cfs of receiving water and concomitant reduction of the WTP dilution ratio to 1.5:1. If the 0.4 cfs was lost, the expected 7Q10 temperature (T) of Wildcat Creek immediately above the WTP outfall would be 17.5^{o}C, predicted as follows:

$$(0.5 \text{ cfs})(17.2^{o}\text{C}) + (0.1 \text{ cfs})(19.1^{o}\text{C}) = (0.6 \text{ cfs})(T).$$

At design capacity, WTP effluent would likely raise the 7Q10 temperature (T) of Wildcat Creek to 18.7^{o}C, predicted by:

$$(0.6 \text{ cfs})(17.5^{o}\text{C}) + (0.4 \text{ cfs})(20.4^{o}\text{C}) = (1.0 \text{ cfs})(T).$$

In this event, WTP discharge would violate the Class A water quality criterion (Chapter 173-201 WAC): "temperature shall not exceed 18.0^{o}C . . . due to human activities."

Mass balance equations were similarly used to evaluate bacterial contamination at 7Q10 flows and WTP design capacity. If fecal coliforms were discharged at the existing permit limit of 200 organisms per 100 mL, receiving water densities (FC) at 2.5:1 dilution would be 88 per 100 mL, predicted as follows:

$$(0.5)(13) + (0.5)(72) + (0.4)(200) = (1.4)(FC).$$

If the 0.4 cfs associated with the illegal discharges was lost, the dilution ratio would drop to 1.5:1 and fecal coliform densities (FC) would increase to 94 per 100 mL, predicted by:

$$(0.5)(13) + (0.1)(72) + (0.4)(200) = (1.0)(FC).$$

The Class A water quality criterion specifies a geometric mean of 100 fecal coliforms per 100 mL, thus the existing permit limit would marginally protect beneficial uses under critical low-flow conditions. The above temperature and bacterial analyses accentuate the significance of the unexplained 0.6 cfs decline in flow between r.m. 5.7 and 4.8.

Instream changes in dissolved oxygen were computer-simulated under various BOD, nitrification, and flow regimes using a modification of the Hammer-MacKichan (1981) oxygen sag model (Figure 5; Appendix D). Curve 1 is a plot of field data from the present survey. Model calibration results are shown by Curve 2; predictions acceptably match field data. Curve 3 models the effect of elimination of illegal discharges to Sam's Canal under present conditions (i.e., assumes 0.4 cfs is entirely removed). The expected elevation of dissolved oxygen levels is a function of increased receiving water dissolved oxygen as well as the increased solubility of oxygen in water at lower temperatures.

Curves 4 through 6 model 7Q10 low-flow conditions at WTP design capacity. Curve 4 shows predicted dissolved oxygen levels in the absence of instream nitrification. A violation of the water quality standard would occur at r.m. 4.7, but high temperatures and relatively low dissolved oxygen in Sam's Canal would likely be the causative agent. Curve 5 illustrates the predicted effect including instream nitrification (where effluent ammonia equals the NPDES permit limit of 2 mg/L). A slight oxygen sag may occur at r.m. 4.6, and the oxygen standard could be violated for about 0.5 mile. Removal of the illegal discharges to Sam's Canal would prevent instream dissolved oxygen violations, though the slight sag would persist (Curve 6).

Mass balance relationships were used to predict the toxicity of un-ionized ammonia under 7Q10 conditions. If effluent ammonia at design capacity was equal to the permit limit of 2 mg/L, the NH_3-N level after mixing would be 0.6 mg/L, predicted as follows:

$$(1.0 \text{ cfs})(0.01 \text{ mg/L}) + (0.4 \text{ cfs})(2.0 \text{ mg/L}) = (1.4 \text{ cfs})(NH_3\text{-N}).$$

A similar balance for temperature calculates to 21.0°C and a pH of 7.4 units is assumed. Under these conditions, the chronic toxicity threshold for un-ionized ammonia would occur at a total ammonia (NH_3-N) concentration of 1.2 mg/L (EPA, 1986). As a result, effluent ammonia would not cause instream toxicity to aquatic life. A similar 7Q10 analysis was performed to predict un-ionized ammonia toxicity in the event of elimination of the illegal discharges. Total ammonia calculates to 0.8 mg/L, as follows:

$$(0.6 \text{ cfs})(0.01 \text{ mg/L}) + (0.4 \text{ cfs})(2.0 \text{ mg/L}) = (1.0 \text{ cfs})(NH_3\text{-N}).$$

Temperature recalculates to 18.7°C, which at a pH of 7.4 units yields a chronic toxicity threshold of 1.4 mg/L NH_3-N (EPA, 1986). Again, effluent ammonia would be non-toxic following dilution with receiving water.

Nitrogen and phosphorus loads in Wildcat Creek were largely a product of effluent from McCleary WTP (Figure 6). Nitrogen loads remained elevated throughout the stream course, but phosphorus loads declined steadily. Further investigation of nutrient sources and sinks in the watershed would be required to interpret these trends. One possibility is that phosphorus is a limiting nutrient in the system, thus uptake by primary producers may account for its downstream depletion. There were no visible signs of excessive periphyton growth in Wildcat Creek,

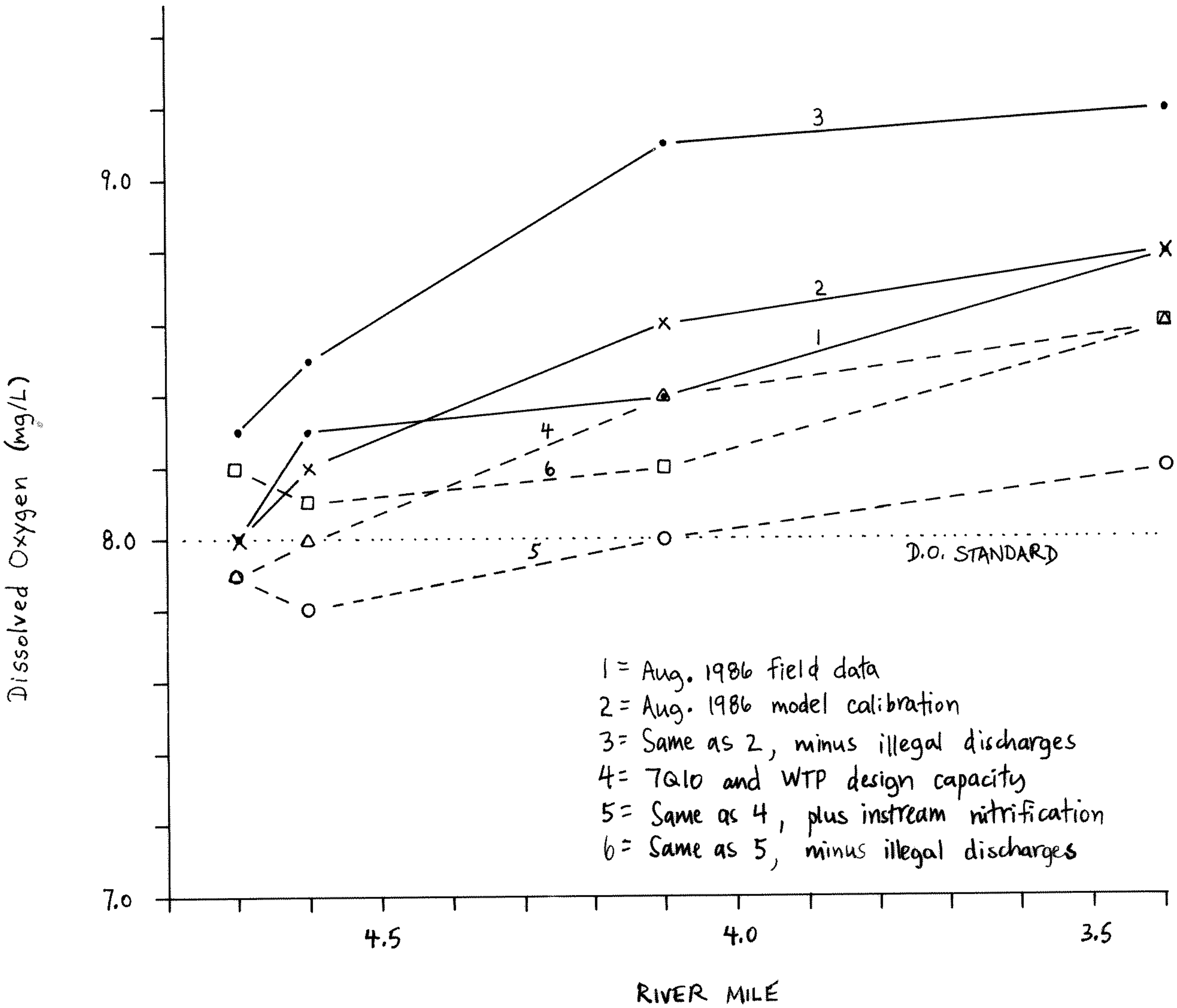


Figure 5. Actual and predicted dissolved oxygen concentrations in Wildcat Creek under various BOD, nitrification, and flow regimes. Model parameters are given in Appendix D.

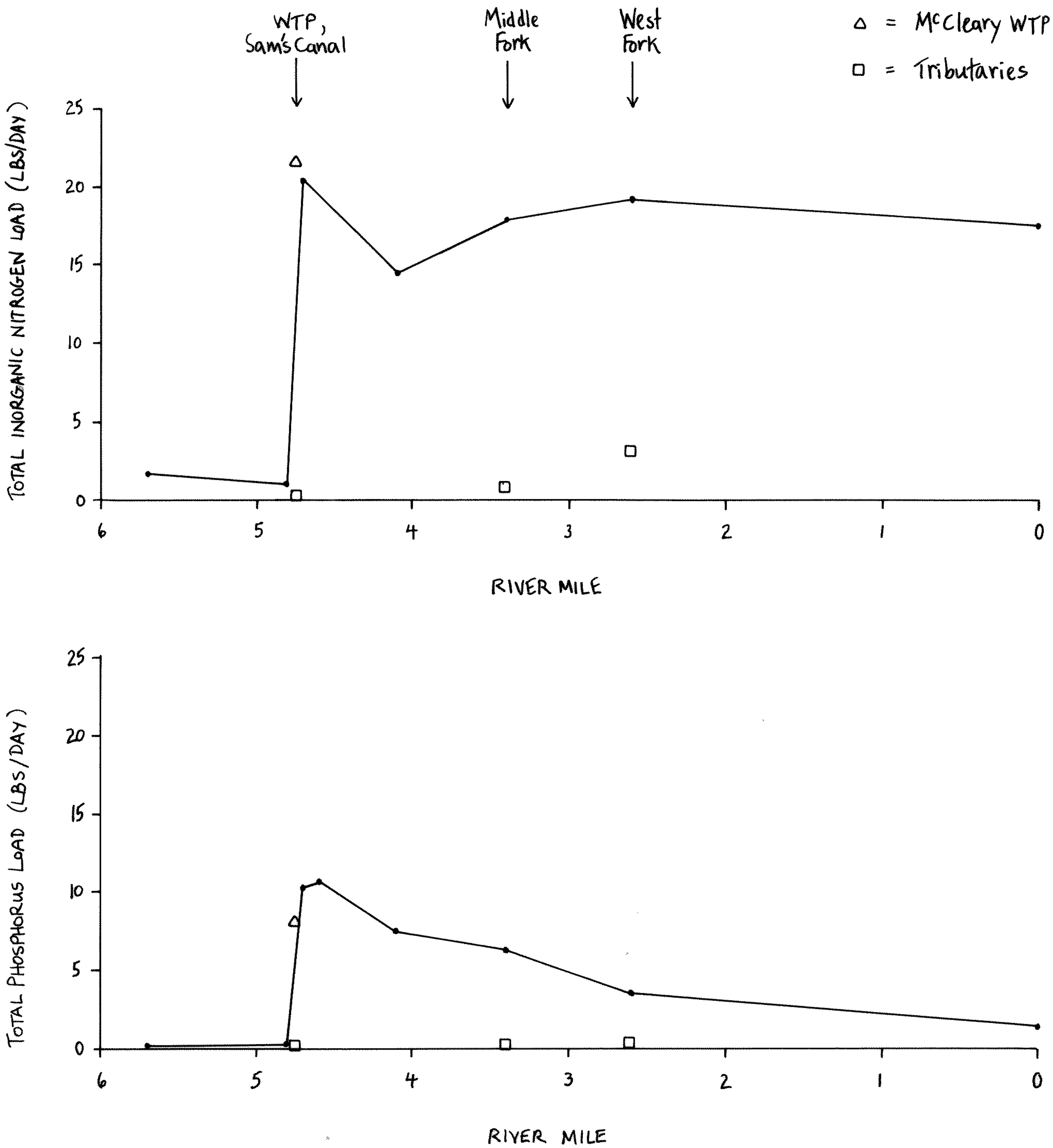


Figure 6. Nitrogen and phosphorus loads in Wildcat Creek, August 1986.

but stream banks and islands were heavily vegetated with sedges, rushes, and grasses.

No state or federal water quality criteria directly address nutrient enrichment of receiving waters. Mills, et al. (1985) suggest that potential eutrophication problems are likely to occur where total nitrogen exceeds 0.92 mg-N/L and total phosphorus exceeds 0.13 mg-P/L. These conditions exist in Wildcat Creek from r.m. 4.7 to about r.m. 2.6, hence this reach of the stream may be considered water quality-limited (i.e., nutrient inputs exceed the assimilative capacity of the creek). At 7Q10 flows and WTP design capacity, instream concentrations and loads of nutrients are expected to be higher yet. Substantial reductions in effluent nutrient loads would be required to lower instream concentrations below the eutrophication threshold cited above.

CONCLUSIONS AND RECOMMENDATIONS

- The receiving-water-to-WTP-effluent dilution ratio in Wildcat Creek was 4:1, well below the recommended mix of 100:1. The outfall diffuser provided excellent initial dilution, but the ports should be submersed to discourage both damage and direct wastewater contact by children at play.

- Upgrade of McCleary WTP considerably improved water quality in Wildcat Creek. A previous survey in 1977 demonstrated violations of state water quality standards for dissolved oxygen, un-ionized ammonia, fecal coliform bacteria, total residual chlorine, and aesthetic values. None of these conditions were found in 1986 despite a 50 percent decline in receiving water flows. While not studied in the present work, the persistence of instream salmon and mussel toxicity is regarded as highly unlikely.

- Comparison of pre- and post-upgrade macroinvertebrate communities also showed improvements. Prior to upgrade, abundance of pollution-tolerant invertebrates increased downstream of the outfall. In 1986, WTP effluent did not affect organism abundance. Percent composition of sensitive and tolerant forms followed similar patterns in 1977 and 1986, but the upgrade dampened extreme lows and highs previously associated with wastewater discharge.

- Wildcat Creek flows inexplicably declined by nearly half upstream of the WTP outfall, effectively reducing receiving-water-to-effluent dilution ratios by a third. Nearby, flows and temperatures in Sam's Canal increased substantially, possible due to illegal storm sewer discharges by Simpson Timber Company. Temperature increases in Sam's Canal and subsequently Wildcat Creek were in violation of state water quality standards. The illegal discharges should be eliminated or, if permitted, conditioned to meet state temperature standards. Further investigation is warranted to determine if there is a relationship between the flow loss in Wildcat Creek and the flow and temperature increases in Sam's Canal.

- At 7Q10 stream flows and WTP design capacity, the receiving-water-to-effluent dilution ratio is predicted to be 2.5:1. Under these conditions, WTP effluent is expected to cause temperature standard violations (assuming elimination of the present temperature problem). Dissolved oxygen sags and un-ionized ammonia toxicity should be negligible, but fecal coliform levels may approach the standard for Class A waters. In the event WTP operations become upset, major water quality problems may result from low dilution. Land application of effluent is advised if plant upsets occur during the summer low-flow period.

- Effluent nutrient loads to Wildcat Creek were largely unaffected by the upgrade and are expected to increase in the future. The two-mile reach of the stream below the outfall may be considered water quality-limited due to excessive inputs of nitrogen and phosphorus. Potential eutrophication impacts may be mitigated through nutrient removal at the WTP, but knowledge of existing eutrophication problems is too limited at present to justify further upgrade. However, the eutrophication issue should be addressed in depth prior to future WTP expansion.

REFERENCES

APHA, et al. (American Public Health Association, American Water Works Association, and Water Pollution Control Federation), 1985. Standard Methods for the Examination of Water and Wastewater. 16th ed. Washington D.C. 1268 pp.

Devitt, R., 1973. Wildcat Creek, drainage ditch, STP effluent. Wash. Dept. of Ecology memorandum to M. Price. Olympia, WA. 4+ pp.

Ecology (Washington State Department of), 1985. Criteria for Sewage Works Design. Ecology report 78-5, Olympia, WA. 276 pp.

EPA (U.S. Environmental Protection Agency), 1979. Methods for Chemical Analysis of Water and Wastes. EPA 600/4-79-020. Cincinnati, OH. 460 pp.

EPA, 1986. Quality Criteria for Water, 1986. U.S. Environmental Protection Agency report EPA 440/5-86-001. U.S. Gov't. Printing Office, Washington, D.C.

Hammer, M.J., and K.A. MacKichan, 1981. Hydrology and Quality of Water Resources. John Wiley and Sons, New York, NY. 486 pp.

Heck, K.L., Jr., G. Van Belle, and D. Simberloff, 1975. Explicit calculation of the rarefaction diversity measurement and the determination of sufficient sample size. Ecology 56:1459-1461.

Hester, F.E., and J.S. Dendy, 1962. A multiple-plate sampler for aquatic macroinvertebrates. Trans. Am. Fish. Soc. 91(4): 420-421.

Holsinger, J.R., 1972. The Freshwater Amphipod Crustaceans (Gammaridae) of North America. Biota of Freshwater Ecosystems Identification Manual No. 5. U.S. Environmental Protection Agency, Washington, D.C. 89 pp.

Merritt, R.W., and K.W. Cummins (eds.), 1978. An Introduction to the Aquatic Insects of North America. Kendall/Hunt Publishing Co., Dubuque, IA. 441 pp.

Mills, W.B., D.B. Porcella, M.J. Ungs, S.A. Gherini, K.V. Summers, L. Mok, G.L. Rupp, G.L. Bowie, and D.A. Haith, 1985. Water Quality Assessment: A Screening Procedure for Toxic and Conventional Pollutants in Surface and Ground Water, Part 1. U.S. Environmental Protection Agency report EPA/600/6-85/002a. Athens, GA. 609 pp.

Musgrove, N., 1977. Water Quality Studies of Wildcat Creek near McCleary, Washington, Summer 1977. Wash. Dept. of Ecology report. Olympia, WA. 25+ pp.

Ott, L., 1977. An Introduction to Statistical Methods and Data Analysis. Duxbury Press, North Scituate, MA. 730 pp.

Pennak, R.W., 1978. Fresh-water Invertebrates of the United States. 2nd Ed. John Wiley and Sons, New York, NY. 803 pp.

Reif, D., in preparation. McCleary WTP Class II Inspection. Wash. Dept. of Ecology, Olympia, WA.

Slack, K.V., R.C. Averett, P.E. Greeson, and R.G. Lipscomb, 1973. Methods for Collection and Analysis of Aquatic Biological and Microbiological Samples. Techniques of Water-Resources Investigations of the United States Geological Survey, Chapter A4. U.S. Gov't. Printing Office, Washington, D.C. 165 pp.

USGS (United States Geological Survey), 1972. Water Resources Data for Washington, 1971: Part 1. Surface Water Records. Tacoma, WA. 427 pp.

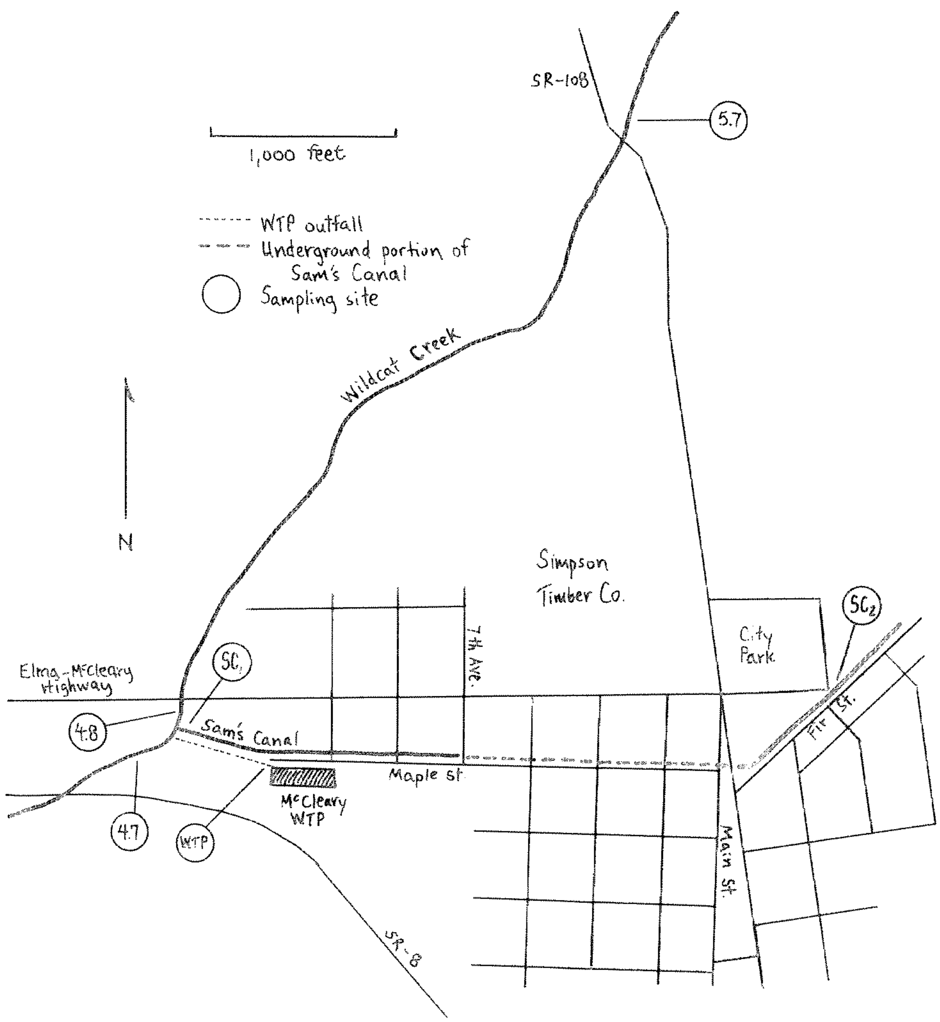
Weber, C.I. (ed.), 1973. Biological Field and Laboratory Methods for Measuring the Quality of Surface Waters and Effluents. U.S. Environmental Protection Agency report EPA-670/4-73-001. Cincinatti, OH. 175+ pp.

Williams, J.R., and H.E. Pearson, 1985. Streamflow Statistics and Drainage-Basin Characteristics for the Southwestern and Eastern Regions, Washington: Volume I. Southwestern Washington. USGS Open-file Report 84-145-A. Tacoma, WA. 424 pp.

Appendix A. Changes in flow and temperature observed in Wildcat Creek and Sam's Canal in the vicinity of McCleary on August 26-27, 1986.

The map below shows Wildcat Creek and Sam's Canal as they flow through McCleary in a west-southwest direction. Two-day means for flow and temperature at the various sampling sites are as follows:

Sampling Site	Flow (cfs)	Temp. (°C)
5.7	1.3	16.7
4.8	0.7	17.2
4.7	1.6	19.8
SC_1	0.5	25.3
SC_2	0.1	19.1
WTP	0.3	20.4



There was a loss of 0.6 cfs of stream flow in Wildcat Creek as it passed through property largely owned by Simpson Timber Company. However, there was 0.4 cfs increase in flow and a 6.2°C increase in temperature in Sam's Canal as it passed through town. The increase in flow between SC_1 and SC_2 apparently occurs in the portion of the canal which is underground. Several municipal storm sewer outfalls are located in this reach. In order to cause a temperature increase of 6.2°C between SC_1 and SC_2, the storm sewer discharge(s) would need to have a temperature (T) of:

$$(0.1)(19.1) + (0.4)(T) = (0.5)(25.3) \qquad T = 26.8^{\circ}C$$

However, the canal is slow-moving and fully exposed to sunlight between 7th Avenue and its confluence with Wildcat Creek. Thus it is possible that solar warming accounts for all or part of the observed temperature increase in the canal. To test this hypothesis, we can turn to data generated by Musgrove (1977). She measured flow and temperature in Sam's Canal near 7th Avenue and the mouth in August 1977:

Sampling Site	Flow (cfs)	Temp. (°C)
Near 7th Avenue	0.5	22.7
Canal Mouth	0.9	21.0
WTP	0.5	19.4

Data from McCleary WTP are included because it formerly discharged to Sam's Canal between 7th Avenue and the mouth. The expected temperature (T) at the mouth of the canal in 1977 should be:

$$(0.5)(22.7) + (0.5)(19.4) = (0.9)(T) \qquad T = 23.4^{\circ}C$$

Since the actual temperature measured in 1977 was 21.0°C, it would seem that cooling (evaporative) processes exerted a greater effect than solar warming. One might argue that the above equation is inappropriate because 0.5 cfs plus 0.5 cfs does not equal 0.9 cfs. If we assume the 0.9 cfs was an artifact of rounding and that the actual flow at the mouth was 1.0 cfs, the expected temperature (T) can be recalculated as:

$$(0.5)(22.7) + (0.5)(19.4) = (1.0)(T) \qquad T = 21.0^{\circ}C$$

In this instance, the actual and expected temperatures equate. Still, both scenarios point to the same conclusion; namely, that Sam's Canal is not appreciably warmed by solar radiation in its exposed lower reach. Thus the calculated 26.8°C temperature of the storm sewer discharge(s) in 1986 is likely a close approximation.

State water quality standards (Chapter 173-201 WAC) for Class A waters specify that "temperature shall not exceed 18.0°C . . . due to human activities." Further, "when natural conditions exceed 18.0°C . . . no temperature increase will be allowed which will raise the receiving water temperature by greater than 0.3°C." The observed temperature increase of 6.2°C in Sam's Canal violates the latter criterion. In addition, heat-balance calculations show the expected temperature (T) of Wildcat Creek below the canal mouth but above the WTP outfall to be:

$$(0.7)(17.2) + (0.5)(25.3) = (1.2)(T) \qquad T = 20.6^{\circ}C$$

Thus Sam's Canal raises the temperature of Wildcat Creek by 3.4°C. In the absence of storm sewer discharge(s), the canal would raise the temperature (T) of Wildcat Creek to:

$$(0.7)(17.2) + (0.1)(19.1) = (0.8)(T) \qquad T = 17.4^{\circ}C$$

Clearly, the storm sewer discharge(s) cause(s) the temperature of Wildcat Creek to exceed the water quality criterion of 18.0°C. The actual temperature below the WTP outfall mixing zone was 19.8°C, which is 0.8°C cooler than above the outfall (20.6°C). The temperature drop may be attributed to evaporative cooling in the long, shaded pool below the outfall.

Appendix B. Abundance of individual macroinvertebrate species collected in Wildcat Creek, August 1986 (semicolons separate individual species within each larger taxonomic group). Where both larvae and pupae of Trichoptera or Diptera were present in a sample, the developmental stage with the greater number of species was used to calculate species richness, equitability, and diversity (Table 3).

			Number of Individuals Per Taxon																
								Insecta											
					Crustacea				Diptera							Trichoptera		Mollusca	
Sampling Site	River Mile	Sample Number	Oligochaeta	Hydracarina	Amphipoda	Cladocera	Copepoda	Coleoptera	Larvae	Pupae	Ephemeroptera	Hemiptera	Megaloptera	Odonata	Plecoptera	Larvae	Pupae	Gastropoda	Pelecypoda
Wildcat Creek																			
Above SR-108	5.7	1	2	1	--	--	--	--	6;1	1	14;11;10	--	--	--	1;1;1	1	--	6;1	--
		2	--	--	--	--	--	1	4;3	--	31;7;2;1;1	--	--	--	2	2	--	26	--
		3	1	--	--	--	--	1	--	1	37;7;1	--	--	--	1	2	--	15	--
Below WTP Outfall	4.7	1	4	--	--	--	1	--	6;4;2;1;1;1	8;8;1	21;2;1	--	--	2	1	--	--	29	--
		2	4	--	--	--	3	--	3;1;1	8;3;2;1	20	--	--	--	1	2	--	17;1	--
Below SR-8	4.6	1	3	1	--	--	7	3	16;8;1;1	10;7;3;2;1;1;1	20;1	--	--	--	--	1	--	8;3;1	--
		2	1	3;1	--	--	4	--	9;4;1;1	12;3;2;1;1	19	--	2	--	4	--	--	19;2	--
		3	2	3;1;1	--	--	3	2;1	6;1	1;1;1;1;1	37;1	--	1	--	1;1	1;1	1	25;4;3	--
0.5 mi. below SR-8	4.1	1	3	--	--	--	--	--	2;1;1	1;1	9;9	--	--	--	4;2	1	--	1	1
		2	--	--	--	--	--	--	--	1	32	--	--	--	4	--	--	9;2;2	--
		3	--	--	--	--	--	--	5	1	57	--	1	--	1	2	--	16;2;1	--
Below Middle Fork	3.4	1	--	--	--	--	--	--	3;1	1;1	13;6;2;1	--	--	--	6;5	3;1;1	--	--	--
		2	--	--	--	--	--	1	4;2;1;1	1;1	47;7;6;3	--	--	--	10;2	2;1	--	3	--
		3	--	--	--	--	--	1	3;3;1	1	32;4;3;1	--	--	--	7;2	4;2;2;2	1	1	--
Below West Fork	2.6	1	--	--	5	--	--	--	2;2;1	1;1;1	11;7;1;1;1	--	--	--	6;1;1;1	1;1	--	--	--
		2	--	--	2	--	--	--	5;3;3;1;1;1	1	12;7;2;2	--	--	--	4;2;1	1	--	2;1	--
		3	--	1	38	--	--	--	1;1;1;1	--	22;8;1;1	1	--	--	5;1	2;1;1	--	1	--
Mouth	0.0	1	--	--	48	--	--	--	2;1	--	6;1;1	--	--	--	1	--	--	--	--
		2	--	--	41	--	--	--	1;1;1;1	1	5;4;3;1	--	--	--	4	2;1	--	--	--
		3	1	1;1;1	71	--	--	--	4;1;1;1	1	6;3;2	--	--	--	2	3	--	--	--
Sam's Canal at Mouth	4.75	1	14	--	--	1	1	--	1;1;1	--	--	--	--	1	--	--	--	--	--
		2	17	--	--	--	2	--	1	--	--	--	--	--	--	--	--	2	--
		3	30	--	--	--	1	--	1;1;1	1	1	--	--	--	1	--	--	1	--

Appendix C. Estimation of 7Q10 flow and corresponding temperature of Wildcat Creek immediately upstream of McCleary WTP outfall.

Lack of continuous gage measurements on Wildcat Creek required estimation of the 7Q10 receiving water flow using data from a temporary (1971) Ecology ambient monitoring site at r.m. 3.0 (22J070), as well as long-term (1946-1972) USGS records from gage 12032500 on Cloquallum Creek (USGS, 1972; Williams and Pearson, 1985). A linear relationship between the two sites was calculated as follows:

	Discharge (cfs)	
Date	Cloquallum Creek	Wildcat Creek r.m. 3.0
7/06/71	59	9
7/19/71	41	6
8/02/71	34	5
8/16/71	29	5
9/06/71	35	6
9/20/71	28	3

Wildcat Cr. flow = (0.16) (Cloquallum Cr. flow) - 0.4 $r^2 = 0.88$

The 7Q10 flow for Cloquallum Creek is 17.1 cfs. Substituting into the regression equation yields an estimated 7Q10 of 2.3 cfs at Wildcat Creek r.m. 3.0. However, r.m. 3.0 is downstream of the WTP by 1.7 miles. Further calculations are necessary to estimate the 7Q10 flow for a point immediately upstream of the outfall (i.e., the "dilution water" low flow).

In August 1986, flows at r.m. 3.4, r.m. 2.6, and the West Fork were 2.4, 4.6, and 1.4 cfs, respectively. Subtracting the West Fork flow from r.m. 2.6 yields a discharge of 3.2 cfs immediately upstream of the West Fork. Therefore, the flow at r.m. 3.0 was between 2.4 cfs and 3.2 cfs in August 1986. To complete this analysis, an average flow of 2.8 cfs will be used.

The dilution water low flow (i.e., the 7Q10 flow above the outfall) can be estimated as follows:

$$\frac{\text{7Q10 flow at r.m. 3.0}}{\text{1986 flow at r.m. 3.0}} = \frac{\text{7Q10 flow of dilution water}}{\text{1986 flow of dilution water}}$$

$$\frac{2.3}{2.8} = \frac{7Q10}{1.2}$$

$$7Q10 = 1.0 \text{ cfs}$$

Assuming discharge of Sam's Canal remains constant, the 7Q10 flow of Wildcat Creek at r.m. 4.8 would be 0.5 cfs (1.0 - 0.5). Further, if temperatures remain unchanged, the temperature (T) of the dilution water at low flow would be:

$$(0.5)(17.2) + (0.5)(25.3) = 1.0(T) \qquad T = 21.2^{\circ}C$$

Thus, flow and temperature of 7Q10 dilution water would be 0.2 cfs lower (1.2 - 1.0) and 0.6°C higher (21.2 - 20.6; Appendix A) than conditions observed in 1986.

Appendix D. Model parameters used in a TMDL analysis of oxygen depletion in Wildcat Creek.

Model Parameter	Curves*				
	2	3	4	5	6
WTP					
Flow (cfs)	0.3	0.3	0.4	0.4	0.4
Temperature (^{o}C)	20.4	20.4	20.4	20.4	20.4
Dissolved oxygen (mg/L)	8.2	8.2	8.0	8.0	8.0
NH_3-N (mg/L)	0.14	0.14	0.14	2.0	2.0
Ultimate BOD (mg/L)	14	14	21	21	21
Receiving Water					
Flow (cfs)	1.2	0.8	1.0	1.0	0.6
Temperature (^{o}C)	20.6	17.4	21.2	21.2	17.5
Dissolved oxygen (mg/L)	7.95	8.3	7.8	7.8	8.25
NH_3-N (mg/L)	0.01	0.01	0.01	0.01	0.01
Ultimate BOD (mg/L)	4	4	4	4	4
Width (ft)	10	10	10	10	10
Depth (ft)	0.3	0.3	0.3	0.3	0.3
Velocity (fps)	0.5	0.5	0.5	0.5	0.5
Rate Constants (per day)					
Deoxygenation rate for BOD (carbonaceous)	1	1	1	1	1
Deoxygenation rate for NOD	0	0	0	6	6
Reaeration rate	20	20	20	20	20

*See Figure 5 for description of curves 2-6.