Physicochemical and Biological Characteristics of Hills Creek Reservoir

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HILLS CREEK RESERVOIR

A SUMMARY REPORT

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and

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ABSTRACT

Physicochemical and biological variations in Hills Creek Reservoir, Oakridge, Oregon and physicochemical characteristics of influent tributaries and effluent water were investigated weekly from mid-May 1975 to mid-February 1976. Lotic and limnetic parameters measured were ammonia, nitrite, nitrate, soluble orthophosphate, suspended solids, turbidity, conductivity, pH, and water temperature. Insolation, tributary flows, reservoir algal populations, and **r**eservoir dissolved oxygen were also measured.

In late spring and summer a strong, shallow metalimnion develops in the reservoir between 12 m to 20 m water depth. Biological debris or potential "recyclable" nutrients in the epilimnion are wind-rafted and mixed with downwelling Willamette River water. The result is that biological activity is restricted to a shallow, nutrient poor epilimnion.

The disappearance of the metalimnion in late fall results in a uniformly turbid reservoir and uniform soluble orthophosphate concentrations at all depths. However, nitrogenous nutrient concentrations vary in an unpredictable manner due to different degrees of decay and oxidation. Also during this time clear, cold Willamette River water enters the main pool at all depths. The exception is during a major storm when the Willamette River increases its suspended load and becomes very turbid. These waters enter the reservoir as turbidity currents. The reservoir temperatures remain uniform at all depths, but a pycnocline develops which isolates the turbid mid- and lower waters from the surface waters.

Mass-balance calculations indicate that the reservoir retained 35.2 kg/sec total suspended solids and 12.2 g/sec soluble orthophosphate and released 24.1 g/sec nitrogenous nutrients during the major storm interval between 5 November 1975 and 17 January 1976. A spring-summer model and a fall-winter model are proposed to explain some observed physicochemical and biological behaviors of Hills Creek Reservoir.

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INTRODUCTION

Previous Studies

As a result of the large December 1964 flood, a particularly apparent turbidity problem developed at Hills Creek Reservoir, in the Upper Willamette Basin. Causes and sources of the turbidity problem were uncertain and conflicting opinions were expressed. When the pool and pool release waters in 1965 failed to eliminate the existing turbidity, the Portland District, U. S. Army Corps of Engineers and other Federal Agencies began limited sampling programs in the reservoir and of effluent waters.

The Corps of Engineers reviewed turbidity problems with Oregon State University personnel in 1970 and an investigation of Hills Creek Reservoir turbidity problem was initiated in May and terminated in September 1971. The purpose of the study was to (1) determine the causes and sources of turbidity at Hills Creek Reservoir, (2) compare turbidity at Hills Creek Reservoir with that at other reservoirs in the Willamette River Basin, (3) examine, on the basis of information obtained for Willamette Basin Reservoirs, the potential for turbidity problems at Lost Creek Reservoir, upper Rogue River, Oregon (then under construction), and (4) consider preventative and/or corrective measures which might be taken to minimize the turbidity problem at Hills Creek Reservoir (Youngberg, Klingeman, et al., 1971). The results of this investigation were reported by Youngberg, Klingeman, et al. (1971).

Current Research

Sporadic investigation of the turbidity problem, by the Oregon Department of Environmental Quality and certain Federal Agencies, was continued between 1971 and 1974. In November 1974, Oregon State University was contracted by the Portland District, Corps of Engineers to re-evaluate certain biological aspects and to determine physicochemical lotic and limnetic characteristics of Hills Creek Reservoir. The specific objectives of this study were to (1) initiate an uninterrupted sequence of data, concerning reservoir turbidity, reservoir algae and release water quality, (2) determine the allochthonous and autochthonous sources of algal nutrients, (3) determine factors which may influence the vertical and horizontal distribution of algae in the reservoir, (4) locate point sources of material that enter the reservoir and alter nutrient concentrations and turbidity, (5) obtain information about Hills Creek Reservoir during the period December through March when the pool is at a minimum, and (6) operate a laboratory facility at Hills Creek Reservoir on a permanent basis for an entire year.

A field laboratory was established in the former Project Engineer's office at Hills Creek Reservoir and became functional in May 1975. Reservoir sampling began at this time; tributary sampling began in June and nutrient analyses of reservoir and tributary waters began in July 1975. This summary report discusses the water quality research at Hills Creek Reservoir between May 1975 and mid-February 1976, at which time the sampling ceased.

SAMPLING AND ANALYTICAL PROCEDURES

Collection of Samples

Three sampling stations were established in the reservoir. Station 1 was located in the Hills Creek Arm; station 2 was located in the widest reach of the main pool and station 3 was at the log boom located in the main pool. These stations are shown in Figure 1. The reservoir stations were sampled



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weekly. Stations 1 and 2 were sampled from surface to near bottom with 62 Van Doren bottles. Three 1-2 samples were taken from each selected sampling depth for algal enumeration, nutrient analyses, pH, turbidity, conductivity, and suspended solids. Light penetration was measured at these stations with a Kahl, Model 268WA310, submarine photometer. The readings were converted to percent surface radiation available with depth. Dissolved oxygen was determined with a portable Yellow Springs Instruments, Model 54, oxygen meter, immediately, on the samples taken for nutrient analyses. Station 3 was sampled from surface to 12 m for algal enumeration, dissolved oxygen, pH, conductivity and turbidity. The 1-2 sample bottles were amber Nalgene plastic. After samples were obtained, the bottles were stored in an insulated cooler. It was felt that using dark bottles and keeping the samples cool would minimize chemical and biological changes between collection time and analysis.

Surface to bottom temperature profile datawere obtained with a Montedoro-Whitney, Model TC-5A, portable thermistor probe, at stations 1 and 2, and from surface to 12 m at station 3.

All flowing tributaries entering Hills Creek Reservoir and effluent water from the reservoir were sampled weekly. Sampling sites were located out of the reach of the reservoir and in flowing waters. These sites are shown in Figure 1. Temperatures were obtained with a cladded mercury thermometer. The depth and width of each tributary (except Hills Creek, Sand Prairie and Middle Fork) were measured and the water velocity determined with General Oceanics, Model 2030, Digital Flowmeter. Flow data on Hills Creek, Sand Prairie, and Middle Fork, Willamette River were obtained from the Geological Survey. A 1-& sample was taken from all flowing influent waters and from effluent water for nutrient

analyses, pH, turbidity, conductivity and suspended solids.

Analyses of Water Samples

All physical and chemical analyses were performed as described in Standard Methods for the Examination of Water and Wastewater (1971) and/or in Methods for Chemical Analysis of Water and Wastes (1974). Because of personnel constraints and the large number of samples, single nutrient analyses were performed. All samples were analyzed within 24 hours from collection.

Dissolved oxygen

As mentioned, a Yellow Springs Instruments, Model 54, oxygen meter was used to determine dissolved oxygen in reservoir water samples. No dissolved oxygens were determined on tributaries or release water. Prior to each sampling trip the oxygen meter was air calibrated and appropriate barometric and temperature corrections made. The probe was slowly agitated in a freshly drawn water sample until the system equilibrated. The water temperature and dissolved oxygen was then read from the meter. The dissolved oxygen values are reported in ppm (mg/ ℓ).

pH

Immediately upon return to the laboratory, the water pH was determined with an Orion 407A electrometer, interfaced with a Corning ruggedized Ag/AgCl-glass reference combination electrode. The system was calibrated with a pH 7 standard. Since natural waters are unbuffered, it was necessary to immerse the combined electrode, without stirring, in the water for 5 minutes. This insured an adequate response time for the system.

Nutrient analyses

A Bausch and Lomb Spectronic 700, U.V.-visible spectrophotometer, was used

to determine nutrient concentrations. The spectrophotometer was calibrated for ammonia, nitrite, nitrate, and soluble orthophosphate. Calibration curves were calculated over the range of 0-100 μ g/ ℓ for each nutrient (Imbrie, 1955). Each sample series for nutrient analyses was accompanied by reagent blanks and two standards. The blanks and standards were treated in the same manner as the unknowns. Since replicas were not analyzed, there is some uncertainty in precision. Based upon instrumental calibration curves, Table 1 gives tabulated 95% confidence levels for a single nutrient determination (Larsen and Wagner, 1975).

Matched 5 cm quartz cells were used in the nitrite, nitrate, and soluble orthophosphate determinations, while matched 1 cm quartz cells were used in the ammonia determination.

Highly turbid samples were filtered through Millipore, binder free, borosilicate prefilters, backed with Millipore BD, polyvinyl chloride filters (0.6μ) . The filtrates were analyzed for nutrients and reagent blank corrections made on the gross data. Nutrients in lightly turbid samples (<4 NTU) were determined without filtering and reagent blank and turbidity corrections applied to the gross data. All nutrient data are reported as $\mu g/\ell$ of the element.

Ammonia/ammonium was always the first nutrient analyzed. This insured minimal loss of ammonia gas. It was determined by the phenate method. Nitrite was determined by the diazotization method, soluble orthophosphate by the combined reagent technique (ascorbic acid reduction) and nitrate by Cu-Cd reduction, followed by diazotization, and by the ultraviolet method.

Suspended solids

Total, fixed and volatile suspended solids were determined by filtering

Determined	95% Co	onfidence Level,	Single Determina	ation
Concentration (µg/l)	NH ₃ -N (µg/l)	NO ₂ -N (µg/l)	NO ₃ -N (μg/ደ)	P0 ₄ -P (μg/l)
0	<u>+</u> 20.81	<u>+</u> 0.31	<u>+</u> 20.51	<u>+</u> 6.18
10	<u>+</u> 20.34	<u>+</u> 0.27	<u>+</u> 20.11	<u>+</u> 6.14
20	<u>+</u> 19.93	<u>+</u> 0.25	<u>+</u> 20.09	<u>+</u> 6.13
30	<u>+</u> 19.58	<u>+</u> 0.28	<u>+</u> 20.31	<u>+</u> 6.12
40	<u>+</u> 19.28	<u>+</u> 0.33	<u>+</u> 20.78	<u>+</u> 6.11
50	<u>+</u> 19.05	<u>+</u> 0.40	<u>+</u> 21.51	<u>+</u> 6.12
60	<u>+</u> 18,89	<u>+</u> 0.47	<u>+</u> 22.46	<u>+</u> 6.14
70	<u>+</u> 18.78	<u>+</u> 0.56	<u>+</u> 23.612	<u>+</u> 6.16
80	<u>+</u> 18.76	<u>+</u> 0.64	<u>+</u> 24.94	<u>+</u> 6.20
90	<u>+</u> 18.79	<u>+</u> 0.73	<u>+</u> 26.41	<u>+</u> 6.24
100	<u>+</u> 19.39	<u>+</u> 0.83	<u>+</u> 27.99	<u>+</u> 6.29

Table 1. 95% Confidence Level for Single Ammonia, Nitrite, Nitrate, and Orthophosphate Determinations.

the water through prewashed, fired and preweighed Millipore AP-40, binderfree, borosilicate filters. One liter samples for reservoir analyses and 500 mm aliquotes from the tributary and release waters were filtered. The filters were dried for one hour at $103-105^{\circ}$ C, cooled and weighed. The net weight was taken as total suspended solids. The filters were then fired at 550° for 15 minutes, cooled and again weighed. This net weight was taken as fixed suspended solids. The difference between the net total suspended solids and net fixed suspended solids was considered suspended volatile solids (and some waters of hydration). Suspended solids are reported in mg/m and the standard deviation in the determinations was found to be +0.1 mg/m.

Turbidity

Turbidity was determined with a Hach, Model 2100A, Turbidity Meter, calibrated against secondary standards. These standards were originally calibrated against primary formazin standards. The turbidity is reported in Nephilometric Turbidity Units (NTU) and is assumed to be equivalent to Jackson Turbidity Units (JTU) and Formazin Turbidity Units (FTU).

Conductivity

Conductivity was measured using a Hach, Model 2511, Conductivity Meter. The conductivity meter was temperature compensated to 25° C and was calibrated against a NaCl standard. The conductivities are reported as μ mhos/cm.

Algal enumeration

A 1-2 water sample from the surface, 4 m, 8 m and 12 m from each reservoir station was returned to the laboratory. Two 75 m2 subsamples from each sample were drawn off and preserved with Lugol's solution. An appropriate portion of the subsample was then filtered on a 25 mm Millipore RA filter (1.8μ) ,

cleared with immersion oil and mounted on microscope slides for counting (Millipore Bulletin AB310). From one to four passes across the filter were counted and all counts converted to cells or colonies/%.

Summaries of data

Weekly summaries of influent and effluent water temperature, pH, conductivity, suspended solids, nutrients and flows have been tabulated in Appendix I. Similarly, temperature profile data, pH, conductivity, dissolved oxygen, turbidity, suspended solids and nutrients for reservoir stations 1 and 2 are tabulated in Appendix II. Limited data on station 3 are also in this appendix.

The percentage transmittance of surface light at stations 1 and 2 are tabulated in Appendix III.

The algal species enumeration for stations 1, 2, and 3, at the surface, 4 m, 8 m, and 12 m, are given in Appendix IV.

Insolation

A solar radiation pyrheliograph recorder, Belfort Instrument Company, Catalog Number 5-38504, was mounted on the laboratory roof. The instrument recorded total daily incident solar radiation for the duration of the study. A Dietzgen polar planimeter was used to measure the area under each day's inked record; the chart readings were thereby converted to Langleys/day (gram calories/cm²/day). The insolation records are tabulated and reported as Langleys/day in Appendix V.

RESULTS AND DISCUSSION

Results and discussion of allochthonous sources and variations are restricted to the two major tributaries entering Hills Creek Reservoir. These tributaries are Hills Creek and Middle Fork Willamette River (referred to in the text as Sand Prairie). Reduced data on all tributaries entering Hills Creek Reservoir are found in Appendix I.

Discussion of autochthonous variations are confined to reservoir station 2, located in the center of the main pool (Figure 1). Reduced data on reservoir stations 1, 2, and 3 are found in Appendix II.

Allochthonous Sources and Variations

Time-series physicochemical variations in Hills Creek are shown in Figure 2 and variations in Middle Fork Willamette River, at Sand Prairie, are shown in Figure 3.

Temperatures increased in both tributaries through the summer months. Maximum temperatures occurred in mid-August. The temperatures then gradually decreased and finally reached a relative constant 5°C. Sand Prairie, at maximum temperature, was slightly higher than Hills Creek. This may have been due to surface water temperatures at Timpanogas Lake, the headwaters of the Middle Fork.

The pH remained relatively constant in both streams during the summer months. The pH began to decrease in mid-October; this was due to high rainfall. Sand Prairie had a higher pH than Hills Creek: In August the pH reached 8.

As streamflows decreased and groundwater sources dominated, the conductivities increased. Conductivity in Hills Creek gradually increased and reached



Figure 2. Time-series of Physicochemical Characteristics of Hills Creek.





a maximum of 72 μ mhos/cm in mid-September; whereas, Sand Prairie rapidly increased in conductivity, and remained between 60-64 μ mhos/cm from mid-August to late September. When the rains began in October and stream discharge increased, conductivities decreased. This was obviously due to dilution of the harder groundwaters.

Turbidities in both tributaries increased as stream flows increased. Hills Creek became very turbid, compared to Sand Prairie, during the storm in October. Undoubtedly, there was a local slumping of slope material within the Hills Creek drainage. Both tributaries recovered rapidly from turbid conditions. Turbidity appears to be related to total suspended solid concentrations in the tributaries; however, no correlation could be formed between total suspended solid concentrations and turbidities. This is understandable since turbidities depend not only upon suspensoid concentrations, but also upon particle sizes and nature of the suspensoids (organic and/or inorganic). Sand Prairie is more competent for sediment transport than Hills Creek. This is particularly evident in December.

Nutrient concentrations were somewhat related to stream flows. Increased flows were accompanied by increased nutrient concentrations. The concentrations, of course, would depend upon (1) what degree of litter had decayed in the watershed and was carried by runoff, (2) what amounts of nutrients have percolated downward through soil horizons to reappear through "pulsed" groundwaters and (3) the amounts of nutrients "recycled" through rainfall. Ammonia-nitrogen concentrations slowly increased from September to mid-February. This increase is more evident in Hills Creek than in Sand Prairie. The average ammonianitrogen concentration in Hills Creek was calculated as $34.1 \pm 13.4 \mu g/2$, while the average concentration in Sand Prairie water was $32.4 \pm 13.9 \mu g/2$.

Nitrate-nitrogen concentrations showed a more cyclic trend (time-series data averaged). Maximum concentrations in the cycle occurred in late October, early November and early January in Hills Creek. Maximum concentrations in the cycle for Sand Prairie occurred in early October, late October and early December. Average nitrate-nitrogen concentrations were calculated to be $27.7 \pm 24.1 \ \mu g/\ell$ for Hills Creek and $12.9 \pm 13.3 \ \mu g/\ell$ for Sand Prairie water. Soluble orthophosphate-phosphorous concentrations were associated with high stream flows, turbid conditions and high total suspended solid concentrations. Calculated average soluble orthophosphate-phosphorous concentrations were $26.6 \pm 7.7 \ \mu g/\ell$ in Hills Creek and $34.5 \pm 9.9 \ \mu g/\ell$ in Sand Prairie water.

Autochthonous Variations

Pool elevation and depth-time variations in temperature are shown in Figure 4. As pool elevation decreased, the thermocline was eventually drawn off by the regulating outlet and penstock.

Depth-time series of pH are given in Figure 5. The pH in the upper layers (0 - 12m), during development of the thermocline in May and early June, reflected control by snowmelt. The pH then reached maximum pH during maximum biological activity from mid-June to late July. The pH then decreased gradually at all depths and pH values were similar from surface to bottom depth. This was probably due to vertical mixing as the thermocline was destroyed. During the summer months the deeper water layers were not as basic as the upper layers. This was probably due to organic debris being moved from the surface layers by wind, mixed with water from Sand Prairie and carried below the thermocline, where decay occurred.



Figure 4. Pool Elevation and Depth-Time Temperature Isopleths, Station 2, Hills Creek Reservoir.



Figure 5. Depth-Time Series of pH at Station 2, Hills Creek Reservoir.

Variations in dissolved oxygen, with time and depth, are shown in Figure 6. The general trend was for dissolved oxygen to decrease as biological activity and water temperature increased. As the thermocline developed, lower water layers were isolated from surface aeration. Wind rafted, surface and nearsurface, organic debris was mixed with downwelling Sand Prairie water. The decay of this debris and oxidation of ammonia to nitrate would also explain the low dissolved oxygen below the thermocline. Lowest dissolved oxygens were observed at 12 m and 20 m where some decaying detritus came to rest on the thermocline.

Time-depth variations in turbidity are given in Figure 7, and in total suspended solid concentrations in Figure 8. During the bloom, in early June, the surface water increased in turbidity and total suspended solid concentration. However, turbidity and total suspended solid concentrations remained low above the thermocline during the remainder of the summer and fall months. As expected, turbidity increased with depth during these months, but total suspended solid concentrations did not increase. This can be explained by the insensitivity of the analytical methods to determine small concentrations (<0.1 mg/ ℓ) of suspended clay minerals. Beginning in November, turbidities increased in the surface layers (0 - 20 m) and the reservoir became uniformly turbid (Appendix III). Not until heavy storms occurred in December and January did depths below 20 m increase in turbidity and total suspended solid concentrations. This increase was due to allochthonous sources (see Figure 3). The storm in January will be considered in further detail. On 7 January 1976, reservoir and Sand Prairie waters had similar temperatures. Reservoir turbidity was near uniform as shown in Figure 9. Sand Prairie water increased its total suspended solid concentration and turbidity. This water did not enter the reservoir uniformly throughout



Figure 6. Depth-Time Series of Dissolved Oxygen, Station 2, Hills Creek Reservoir.

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Figure 7. Depth-Time Series of Turbidity Station Hills Creek Reservoir.

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Figure 8. Depth-Time Series of Total Suspended Solids, Station 2, Hills Creek Reservoir.

all depths, but entered as a density current (turbidity current), due to additional suspended load. This effect can be seen in Figures 7, 8, and 9. After this initial pulse of material into the reservoir, between 30 m and 60 m, the reservoir waters decreased in total suspended solid concentrations and in turbidity. The sequence of this event is seen in the vertical turbidity profiles shown in Figure 9. The decrease in turbidity can be explained by (1) deposition of suspensoids, (2) dilution by less turbid waters proceeding the turbid pulse, and/or (3) displacement of the turbid water by clearer water. Particle size analysis of suspended solids from 20 m, 40 m, 50 m, and 60 m, taken on 14 January 1975, showed little variation in either mean or median particle size diameters. Median and mean diameters were around 5.0 μ and 4.4 μ , respectively. Further data reduction revealed that the particles were fairly uniformly sorted, tended toward finer particle size diameters, and near normally distributed at 40 m and less normally distributed (tails of distribution have less spread than normal distribution) at 30 m, 50 m, and 60 m. Detailed analyses are given in Table 2.

Time-depth variations in total nitrogen concentrations (Σ NH₃-N, NO₂-N, NO₃-N) are shown in Figure 10. During August, September, and October, total nitrogen concentrations were lower in surface, 4 m, 8 m, 12 m than at 20 m and below. Some organic material rested on the thermocline (ca. 12 - 20 m) and was decaying. Wind action had rafted organic material toward Sand Prairie water. This material mixed with and downwelled with Sand Prairie water. The eventually released nutrients were no longer available for biological activity above the biocompensation zone. When the thermocline was destroyed, the water column became nearly uniform in its total nitrogen concentration. In December, a rapid decrease in nitrogen concentration occurred. Much of this nitrogen was removed during reservoir drawdown (Figure 14).



Figure 9. Vertical Profiles of Turbidity from 7 January to 11 January 1976, Station 2. Hills Creek Reservoir.

Table	2.	Particle	Size	Analyses	of	Samples	from	30 r	n, 4	0 m,	50	m,	and	60	m,
Hills	Cree	ek Reservo	pir,	14 January	y 19	976.									

			1.00	Inman 1	Indices, Ph	i-Units ^a	
Depth	Turbidity	Total Suspended	Md b	M _∲ C	σ _φ d	ح ^e	β _φ f
(m)	(NTU)	(mg/1)	(median)	(mean)	(sorting)	(skew- ness)	(peaked- ness)
30	32	18.6	7.45Φ (5.72μ)	.7.73¢ (4.71µ)	1.050	0.27	0.45
40	41	19.4	7.60φ (5.15μ)	7.75φ (4.65μ)	1.03¢	0.15	0.60
50	54	41.4	7.80φ (4.49μ)	7.90φ (4.19μ)	0.95 ∳	0.12	0.56
60	76	87.4	7.70φ (4.81μ)	7.90φ (4.19μ)	1.10φ	0.18	0.52
^a _φ = 1	log 2 lôg d _(mm)	$(d_{(mm)} = 2^{-\phi}).$					
^b M _φ = 1	^{ź(φ} 16 ^{+ φ} 64 ⁾						
^c Md _¢ =	^{• ¢} 50 [•]	`					
$d_{\sigma_{\phi}} = \frac{1}{2}$	^{ź(¢} 84 ^{- ¢} 16)	. Standard devia	tion in te	erm of We	ntworth Sca	le.	
e _d =	$\frac{M_{\phi} - Md_{\phi}}{\sigma_{\phi}}$.	<pre>d = o, particle s bution tends t d > o, distribu phi-units).</pre>	ize distri cowards coa ition tends	bution is rser parts towards	s symmetric ticles (sma smaller pa	al;d< o ller phi orticles	, distri- -units); (larger
$f_{\beta\phi} = \frac{1}{2}$	^{2(φ} 95 - φ ₅) σ _φ	$-\sigma_{\phi} \cdot \beta_{\phi} = 0.65$ norma have	5, particle 1 distribu more sprea	e size dis ition; β _φ ad than no	stribution > 0.65, ta ormal distr	is norma ils of d ibution.	l; β _φ < 0.65, listribution



Figure 10. Depth-Time Series of Total Nitrogen, Station 2, Hills Creek Reservoir.





Variations in soluble orthophosphate concentrations with time and depth are given in Figure 11. Much that has been mentioned about total nitrogen concentrations in surface waters holds for soluble orthophosphate concentrations. However, there is a complication associated with phosphates. They are predominately adsorbed by inorganic hydrous oxides and clay minerals. Assuming a constant equilibrium coefficient between soluble and sorbed phosphates, the more clayey suspended solids found in the water, the more soluble orthophosphate would be expected. This phenomenon was observed from the surface to 20 m depths from mid-September to mid-February. Below 20 m the soluble orthophosphate concentrations gradually increased with depth. When the thermocline disappeared, surface to bottom soluble orthophosphate concentrations become near uniform. During the January storm, soluble orthophosphate concentrations increased at 4 m, 8 m, 20 m, and 50 m. The increased concentrations in upper waters was probably due to an increase in suspended material, "recycled" soluble orthophosphate-phosphorous in rainfall and soluble orthophosphate-phosphorous carried by surface runoff waters into the reservoir. The increase at 50m can be attributed to Sand Prairie water and its subsequent occurrence as a density current within the reservoir.

Light penetration measurements were made from 28 August until the end of the study. The reduced data are in Appendix IV. The lower limit of the photic zone (compensation depth) (Parsons, 1973) was about 12 m during September and came up to a minimum of 4 m in December, January and February. The photic zone remained above the thermocline all summer. The viable algae were effectively limited to the area above the thermocline and were isolated from the lower waters which were relatively rich in nutrients.

50	1	10 1	1AT	25	-	10	15 2	02	- -	81	JU 0 13	20	15	5	AU 10 1	GUS 5 20	7	31	SEP 5 10	15	8CR	5	51	013	120	R 2.5		101	5 20	-15	5	BECI 10 1	5 20	25		JA1	152	0 2 5		FE0	-	NY 25
40	PH		H			-		14										-				+	-		-	-		t		-		1			-	+			+			-
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Figure 11. Depth-Time Series of Soluble Orthophosphate, Station 2, Hills Creek Reservoir. Algal samples were collected from 15 May 1975 to 11 February, 1976. Samples were taken at three stations (shown as Stations one, two, three, Figure 1). Samples from four depths at each station were taken (surface, 4 m, 8 m, and 12 m). A taxa list of the algal species observed during the study is given in Table 3. Weekly counts of the algae in cells per liter are given in Appendix V. The dynamics of the populations can be characterized very generally by looking at the growth patterns of the five major taxa observed (Figure 12). This figure shows the population counts for the five taxa plotted weekly for the surface sample at station 2. The counts were transformed to Log_{10} since the magnitude of the differences were so great.

By 22 May the water temperature had warmed considerably (12.85⁰C) and the reservoir was receiving an average of 511 Langleys/day (gram calories/cm²). Larson reported a Spring Asterionella formosa Hassall growth in Hills Creek Reservoir during the summer of 1971 (Youngberg, Klingeman, et al., 1971). If such a Spring pulse occurred in 1975, it was prior to the beginning of the sampling period. The initial phytoplankton populations sampled were dominated by Anabena circinalis Rabenhorst. Hutchinson suggests that an Anabena circinalis Rabenhorst population would lead one to suspect that "the water has a pH greater than seven, that nitrogen is being fixed, that there may well be an obvious water bloom and that the ratio of plant to animal plankton may be quite large" (Hutchinson, 1967). All the conditions mentioned, except nitrogen fixation, were observed. Anabena circinalis Rabenhorst dominated the phytoplankton until about the first of July, growing almost unialgally throughout early June. It was during this time that the algae were most noticeable marcoscopically. The Anabena colored the water a brighter green and gave it an opaque appearance. Larson reported mats of decaying algae during the summer of 1971 (Youngberg,

Table 3. Taxa List for Hills Creek Reservoir, 15 May 1975 to 15 February 1976.

Chlorophyta

Ankistrodesmus falcatus (Corda) Ralfs

Botryococcus Braunii Kützing

Eudorina elegans Ehrenberg

Pandorina morum (Mueller) Bory

Staurastrum paradoxum Meyen

Tetraedron quadratum (Reinsch) Hansgirg

Volvox aureus Ehrenberg

Chrysophyta

Mallamonas sp.

Bascillariophyta

Asterionella formosa Hassall

Fragilaria capucina Desmazières

Fragilaria crotonensis Kitton

Melosira granulata (Ehrenberg) Ralfs

Melosira italica (Ehrenberg) Kützing

Stephanodiscus astrea var. minutula (Kützing) Grunow

Pyrrophyta

<u>Ceratium</u> <u>hirundinella</u> (Mueller) Dujardin

Cyanophyta

Anabena circinalis Rabenhorst

Anabena sp.

Cryptophyta

Cryptomonas obovoidea Pascher

Cryptomonas ovata Ehrenberg



Figure 12. Time-Series of Five Most Abundant Species at the Surface, Station 2, Hills Creek Reservoir.

Klingeman, et al., 1971). Floating mats of algae were not found in 1975. Cryptomonas ovata Ehrenberg appeared in the initial sample of 15 May and was found in most samples throughout the summer. Cryptomonas ovata Ehrenberg is a flaggelated unicellular species with a gullet. It may be that Cryptomonas ovata Ehrenberg is more heterotrophic than the other algal species found and can maintain a viable population all year since it responds less critically to the same environmental changes that most algae do. On 9 July, Fragilaria crotonensis Kitton, Asterionella formosa Hassall, and Melosira granulata (Ehrenberg) Ralfs all appeared for the first time. These three algae are all members of the Bascillariophyta. Anabena circinalis Rabenhorst was virtually gone from the samples on this date. Melosira granulata (Ehrenberg) Ralfs quickly disappeared and did not reappear at station 2 until the second of October. Fragilaria crotonensis Kitton and, to a lesser extent, Asterionella formosa Hassall bloomed throughout July and into August. There was a short reappearance of Anabena circinalis Rabenhorst in September. As previously mentioned, Melosira granulata (Ehrenberg) Ralfs reappeared on 2 October and bloomed throughout October and into November. Light levels (Figure 13 and Appendix VI) dropped dramatically at the beginning of October. Temperature began to drop in October and through November. These two factors undoubtedly led to the overall decline in cell numbers in November and December. The great influx of water during storms and subsequent flushing during post-storm drawdown caused the winter populations to be so diluted, that on 18 December 1975, no viable cells were found at station 3. From 21 January until 11 February 1976, when the study ended, very few cells were found at any of the stations.

Hutchinson lists the dominant genera found in Hills Creek Reservoir as indicators of eutrophic waters, i.e., <u>Anabena</u>, <u>Asterionella</u>, <u>Fragilaria</u>, <u>Melosira</u> and <u>Stepanaodiscus</u>. (Hutchinson, 1967)

Incident Solar Radiation

Daily radiation values in Langleys/day are listed in Appendix V. The daily radiation values were averaged for the period from one sampling data to the next (approximately one week) and plotted in Figure 13. There was a dramatic decrease in radiation during the first week in October. Hutchinson presents mean monthly estimates of daily direct radiation for an altitude of five hundred meters and a latitude of 47° (Hutchinson, 1957). The values given are in close agreement with those found for Hills Creek Reservoir (ca. 470 m elevation and 44° N).

Effluent Water Variations

Variations in water leaving Hills Creek Reservoir are shown in Figure 14. Temperature maximum was not reached until early October, when the upper, warmer waters were being removed.

There was a gradual decrease in pH, with a minimum occurring in late December. This trend was also seen at all depths in the reservoir (Figure 4).

Conductivity did not show trends observed in Hills Creek and Sand Prairie waters. Biological activity, physicochemical reactions and, to some extent, mixing above and below the thermocline in the reservoir may have mediated trends in conductivity of the effluent water.

Turbidity and total suspended solid concentrations were very low during summer months and into mid-November. From November until the end of the study, turbidity occurred as pulses, but total suspended solid concentrations increased only slightly.







Figure 14. Time-Series of Physicochemical Characteristics of Effluent Water from Hills Creek Reservoir (Middle Fork, Willamette River).

Ammonia-nitrogen and nitrate-nitrogen concentrations showed inverse relations in the effluent water. This relation might be due to inhibited <u>Nitrosomonas</u> and <u>Nitrobacter</u> activities. The general trend was for ammonianitrogen concentrations to increase and nitrate-nitrogen concentrations to decrease. Average ammonia-nitrogen was $52.5 \pm 29.9 \ \mu g/\ell$ and the average nitrate-nitrogen was $40.3 \pm 18.0 \ \mu g/\ell$. Total nitrogen concentrations showed spureous variations, but the general trend was a gradual increase from August to November, and then a rapid increase to maximum concentrations between December and January, followed by a rapid decrease through January and February.

Soluble orthophosphate-phosphorous concentration gradually decreased from August through September. The concentration then increased and remained constant during October. It sharply increased through November and into early December. Beyond December the concentration remained constant at 30 μ g/ ℓ . The average concentration was found to be 20.9 ± 9.0 μ g/ ℓ .

CONCLUSIONS

Uninterrupted data sequence on tributaries entering Hills Creek Reservoir and on Hills Creek Reservoir, from 15 May 1975 to 11 February 1976, has given insight into the dynamics of a mid-water withdrawal reservoir and the influence inflowing tributary waters exert upon turbidity and nutrient characteristics within the reservoir.

Tributaries may be classified by their competence to transport suspended sediments and dissolved nutrients into the reservoir. Primary sources are Hills Creek and Middle Fork, Willamette River (Sand Prairie). Secondary sources are Packard Creek, Coffee Pot Creek and, during storms, Larison Creek. All other tributaries may be considered tertiary and/or guaternary in importance.

The two primary tributaries are free flowing into the reservoir. All other tributaries flow into backwater emboyments, connected to the reservoir by culverts. This physical manipulation of inflowing water premixes tributary and reservoir waters. These embayments also act as stilling basins in which suspended sediments transported by tributaries, are deposited.

Hills Creek and Sand Prairie waters could not be identified in the reservoir by conductivity, pH, or nutrient concentrations. Biological and physicochemical processes, such as absorption and desorption of CO₂, precipitation and particulate sorption, and wind mixing in the epilimnion and current mixing in the hypolimnion, alter the individual features of each water mass in the reservoir.

Turbidity within the reservoir can be associated with water conditions in Hills Creek and Sand Prairie. Tributary turbidities occur as pulses, with rapid recovery times, and are due to local and temporal unstable soil conditions in each watershed drained.

Turbid tributary waters enter the reservoir as turbidity currents (density currents) which increase the reservoir turbidity from mid-depth to the bottom.

No statistical correlation could be established between turbidity and suspended solids, either in the main tributaries or in the reservoir. This is to be expected since turbidity is wavelength dependent and shape and particle size dependent. Also certain particles are anisotropic in their nephliometric characteristics.

Time variations in soluble ammonia/ammonium, nitrite and nitrate concentrations were observed in all tributaries. Ammonia tended to increase in concentration from mid-August, whereas nitrate concentrations were variable and associated with tributary flows. These variations are due to the stages of leaf-litter

decay in the watersheds, oxidation (nitrification) and/or reduction (denitrification) by soil bacteria. Similar variations occur within the reservoir and are due to oxidation/reduction and bacterial action in the sediment. To some extent, volatile suspended solids represent particulate organic debris and potential nitrogenous and phosphate nutrient sources. After each major storm, reservoir verticle profiles show systematic increases in volatile suspended solids, from mid-water to bottom water, and pronounced, but random, increases in total nitrogen.

Soluble orthophosphate concentrations in all tributaries increase as major storms move through the area and as tributary flows increase. However, the long-term trend was for soluble orthophosphate concentrations to remain near constant. The increase in concentrations are associated, but not correlated, with tributary turbidities and total suspended solids. Equilibrium exists between water soluble orthophosphate and clay sorbed phosphate. An increase in suspended solids can contribute to an increase in soluble orthophosphate concentrations in the tributaries and within the reservoir.

Mass balances of total nitrogen, soluble orthophosphate and total suspended solids were calcuated for the major storm interval between 5 November 1975 to 17 January 1976. Total suspended solids entering the reservoir were 3.85 x 10^7 mg/sec and solids leaving the reservoir were 3.29 x 10^6 mg/sec. Total nitrogen was 4.79 x 10^7 µg/sec entering and 7.20 x 10^7 µg/sec leaving the reservoir. Soluble orthophosphate was 3.07 x 10^7 µg/sec entering and 1.79 x 10^7 µg/sec leaving the reservoir. During this interval, the reservoir retained 35.2 kg/sec total suspended solids and 12.2 g/sec soluble orthophosphate and released 24.1 g/sec total nitrogen.

Phytoplankton activity is restricted to a very shallow, nutrient poor

epilimnion during the spring and summer months. Once the metalimnion disappears and the reservoir overturns in late fall and winter, the insolation and water temperatures are so low that no appreciable algal blooms can occur. Nutrient concentrations available for the spring algal blooms are probably $60 \mu g/l$ total nitrogen and $30 \mu g/l$ soluble orthophosphate.

Descriptive Model

From the preceding results and discussion and conclusions, a proposed descriptive model for Hills Creek Reservoir has been developed for spring-summer behavior and fall-winter behavior.

Spring-summer model

The metalimnion (thermocline) is well established between 10 m to 20 m in late spring and early summer. This isolates the epilimnion from the hypolimnion and prevents replenishment of nutrients in the epilimnion. Cooler, nutrient-rich tributary waters enter the reservoir as interflow or underflow in the hyperlimnion. The development of the shallow epilimnion and the 12 m biocompensation depth throughout the summer, restrict algae to a shallow nutrient pool. Some detrital material from each successive bloom settles upon the metalimnion, where it decays and some of the solubilized nutrients become available for the next bloom. Upward mixing of these "recycled" nutrients is by wind-generated wave action. The summer winds are also responsible for the nutrient-poor epilimnion. Under wind stress, algae and algal debris are rafted from the main pool epilimnion and mixed with colder, downplunging Sand Prairie water. Some nutrients are returned to the epilimnion by upwelling near the dam. However, most of the upwelling nutrients are withdrawn from the reservoir by the penstock. This spring-summer model is diagrammatically presented

in Figure 15 (a).

Fall-winter model

The metalimnion is rapidly destroyed in late fall by drawoff through the regulating outlet and penstock, and by epilimnion cooling due to low insolation. This results in an isothermal reservoir, with uniform turbidity and soluble orthophosphate concentrations. Tributary water temperatures are near that of the reservoir and tributary waters inflow at all depths.

During major storms, turbid tributary waters enter the isothermal reservoir as turbidity currents (density currents). These turbidity currents result when tributary suspended loads increase, which increase the water bulk density. They downplunge into the reservoir and develop very turbid conditions from midto bottom water depths. The turbidity currents induce surface currents which converge with the turbidity currents. These surface waters downwell and override the turbidity currents. The reservoir remains isothermal but a pycnocline develops, which isolates the turbid waters from clearer surface waters. As these turbidity currents slowly move through the reservoir, their particle size distributions change and their suspended loads decrease and, of course, turbidities decrease. The results are a decrease in bulk density, disappearance of the pycnocline, and eventual mixing with upper waters. The proposed fall-winter model is shown in Figure 15 (b). Various mechanisms contributing to the decrease in suspended solids and turbities are Stokes settling, flocculation, dilution by overriding water, and displacement by clearer inflowing waters.







(b) FALL-WINTER CONDITIONS



Figure 15 (a): Proposed Spring-Summer Reservoir Model; (b): Proposed Fall-Winter Reservoir Model.

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