Water quality: temperature to toxics

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The mill demonstrated that its new diffuser outfall complied with state-imposed water-quality standards by conducting field tests when river flow was low and water temperatures were high.

Boise Cascade Corp. operates a 1280-metric-ton/day bleached and unbleached kraft pulp and paper mill at Wallula, Wash. Secondary treated effluent is discharged to the Columbia River through a submerged diffuser outfall. The new outfall was completed in June 1989 to maintain compliance with Washington State's water-quality standards for temperature and dissolved oxygen (DO) beyond the authorized dilution zone.

A field study was conducted during late summer 1989 to demonstrate compliance with these criteria during the river's annual period of lowest ambient water quality. A supplemental evaluation of projected compliance with new state criteria for toxic substances was also conducted based on estimated effluent dilution factors. This report reviews the design basis for the diffuser outfall and presents the approach and results of compliance evaluations.

Background

Study area

The new outfall discharges to the Lake Wallula reach of the Columbia River at mile 316 (km 509), about 39 km upstream from McNary Dam and 13 km downstream from the confluence of the Columbia and Snake rivers. **Figure 1** is a map of the study area. The outfall, which discharges at a depth of about 17 m, is located within the deep channel along the western shore. This is the river's original channel, which existed before construction of McNary Dam.

River flow varies from a regulatory minimum flow during summer months of about 1400 m^3/s (50,000 ft^3/s) to the 100-year flood condition of about 19,000 m^3/s (660,000 ft^3/s) during spring snowmelt in the tributary basin. Typical low flows in the study reach during late summer-early fall are approximately 3000 m^3/s (100,000 ft^3/s), with about 25% contributed by the Snake River.

McNary Dam is a river-run hydroelectric project. Consequently, river velocities in the main channel of the study reach are continuously downstream and vary roughly in proportion to river discharge. Field measurements in 1987 showed that average current velocities at the diffuser site were about 18 cm/s (0.6 ft/s) for a 2500-m^3/s (90,000 ft^3/s) river flow (*1*). Currents in the wide shallow area between the new diffuser and the mill site are reduced and are occasionally subject to stagnation and reversal near shore—by the effects of strong winds blowing predominantly upstream.

Ambient water quality

The river water in the study reach is a mixture of the Columbia and Snake rivers. There is some variability in ambient water quality because of incomplete mixing in the short distance below the confluence. Based on quarterly sampling in each river above the confluence (*2*), the dissolved-oxygen range is typically 8-14 mg/L for the Columbia and 6-14 mg/L for the Snake (1981-84). Similarly, the temperature range is 2-21°C for the Columbia and 3-23°C in the Snake.

Lowest natural ambient water quality, in terms of highest temperature and lowest DO, occurs during the warm, low-flow period of late summer to early fall. Local field surveys conducted during such periods in recent years for Boise Cascade and by the Washington Department of Ecology (WDE) show that ambient DO in the study area remains marginally to well above 8 mg/L. Maximum temperatures are in the range of 20°C water-column average, with temperatures up to 24°C in the stratified surface layer caused by solar heating.

Water-quality standards

The WDE has adopted water-quality standards for the Columbia River (*3*). The established criteria for temperature and DO are:

- **Temperature** shall not exceed 20.0°C as the result of human activities. When natural conditions exceed 20°C, the maximum allowable temperature impact is 0.3°C.
- **Dissolved oxygen** shall exceed 8 mg/L. When natural conditions are less than 8 mg/L, the natural conditions become the criteria and no measurable degradation is allowed. During such periods, maximum allowable DO impact is 0.2 mg/L (*1*).

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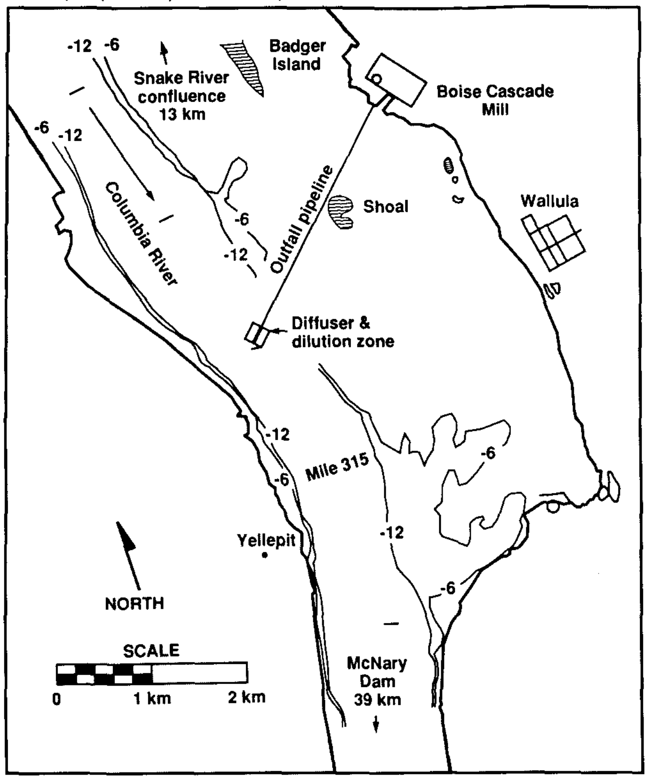
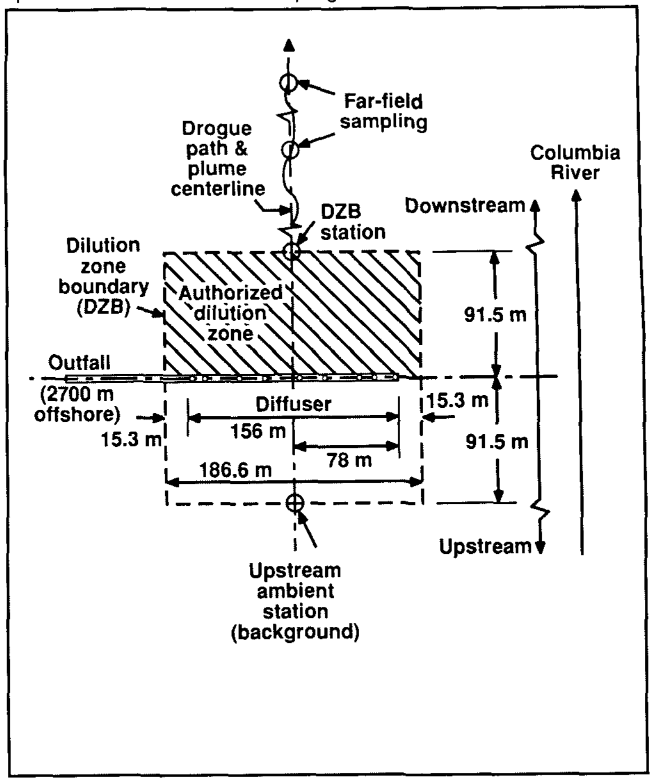
1. Study area on the Columbia River. The individual numbers represent the depth (meters) below low pool.



2. Outfall and associated dilution-zone boundary. Location of upstream and downstream sampling stations are also illustrated.



I. Projected impact of outfall discharges under worst-case conditions and during typical summer low flow

Design condition	River flow, m^3/s	Initial dilution (S_a)*	Projected impact on water quality: Temp., °C	DO, mg/L
Worst case	1400	160	+0.2	-0.2
Typical summer low flow	3000	240	+0.1	-0.1

Source: Ref. (1).

*S_a = initial dilution at the DZB and represents the ratio of parts of receiving water to one part effluent. S_a is a function of the diffuser design.

II. Sodium content as measured upstream, in the DZB, and in the mill effluent

Sample location	Sodium, mg/L: Range	Average
Upstream (ambient background)	4.0-6.1	5.0
DZB (plume downstream)	3.9-7.3	5.6
Effluent composite (two samples)	326-368	347

These criteria apply beyond the authorized dilution-zone boundary (DZB) surrounding the wastewater discharge as described in the NPDES (National Pollution Discharge Elimination System) permit. The DZB for the new outfall at Wallula extends 91.5 m (300 ft) upstream and downstream from the diffuser section and 15.3 m (50 ft) beyond each end of the diffuser. The diffuser and its authorized DZB are illustrated in **Fig. 2**.

Outfall and diffuser parameters

The mill discharges approximately 114,000 m^3/day (30 Mgal/day) of combined secondary treated effluent and condenser cooling water. In the summer, the discharge's typical BOD_5 load is 2700-4500 kg/day, with temperatures of 36-40°C.

Outfall design was based on worst-case conditions of lowest flow and lowest ambient water quality (1). Given these constraints, allowable impacts on ambient water quality beyond the DZB were limited to 0.3°C and 0.2 mg/L DO.

The new outfall discharges at a depth of 17 m about 2700 m offshore from the mill (Fig. 1). The diffuser section is 156 m long and is equipped with 48 10.2-cm-diam. ports that discharge horizontally along the diffuser at equally spaced intervals. The schematic in Fig. 2 shows the diffuser and the authorized DZB. **Table I** shows the projected impact of effluent from the new outfall under worst-case conditions and during typical periods of low flow in the summer.

Compliance evaluation

Field survey

To determine the actual impact on temperature and DO, a field survey of water quality was conducted on Sept. 6 and 7, 1989, in accordance with the sampling plan approved by WDE. Based on historic records, this late-summer, low-flow, warm-water period was selected to demonstrate compliance with temperature and DO criteria during the annual period of expected lowest natural water quality.

The diffuser is a continuous source of effluent. Compliance was evaluated based on measurements taken at the intersection of the plume centerline and the edge of the downstream DZB. The study focused on temperature and DO in the expected zone of maximum effluent concentration—at the plume centerline—and did not address distribution and variability over the full plume width.

Background temperature and DO for the water column were measured at depths of 1 m, 8 m, and 15 m at a station upstream from the outfall diffuser. Subsequent measurements were taken at the center of the downstream DZB and at progressive locations along the plume centerline in the far-field area downstream. Each sampling run was guided using current drogues suspended beneath a marker float. The drogues, released at the upstream station and tracked downstream, allowed us to monitor impacts within an approximate water parcel moving downstream through the center of the diffuser discharge to the DZB and beyond. Figure 2 shows the location of the sampling stations. Divers marked the center of the diffuser and put the upstream and DZB stations into position. These locations were marked for the duration of the field survey by anchored taut-line buoys.

Temperature and DO were measured using a Hydrolab Surveyor II field instrument with a submersible sonde unit. The sonde was equipped with: (a) a membrane-covered polarographic cell and water-circulator assembly for DO; (b) a linear-resistance thermistor for temperature; and (c) a bonded strain gauge for depth. The sampling boat had a digital display unit for parameter readout. Calibration accuracy to 0.1°C for temperature and 0.1 mg/L for DO was validated using factory calibration procedures. These were supplemented by coincident water sampling by certified thermometer and by laboratory analysis for Winkler DO. Readout sensitivity and stability were high. Temperature and DO were recorded to a precision of 0.01 and rounded to the nearest 0.1 after applying calibration factors.

A total of 19 pairs of data were collected from all three depths (1 m, 8 m, and 15 m), first at the upstream background station and then at the downstream DZB station as the drogue passed. This represents the water quality along the flow path of the plume centerline. Also, two complete sampling runs were extended through the potential oxygen-sag region in the far-field plume by sampling at progressive drogue locations at 15–20-min intervals as the drogue was transported more than 2.5 km downstream by river currents over a 4-h period.

In addition, water samples were collected at the upstream and DZB stations and analyzed for color and sodium (Na) as a basis for estimating dilution characteristics of the effluent plume. Effluent characteristics were determined by composite sampler and laboratory analysis for BOD, color, and Na, and by continuous flow and temperature recorders. Effluent discharge during the sampling periods averaged about 114,000 m^3/day (30 Mgal/day). Effluent temperatures were 36–38°C. River flow was 3000–3500 m^3/s.

Results

Field data were evaluated for compliance with the water-quality criteria established for temperature and DO (*4*). Compliance was determined by:

1. Direct comparison of temperature and DO measurements in the downstream effluent plume (DZB and far-field oxygen-sag region) with the applicable water-quality criteria.
2. Comparison of plume measurements with upstream background measurements to estimate compliance with allowable degradation increments when natural water quality falls below the threshold criteria.

Analysis of the data revealed that:

- Natural DO during the field survey was higher than the defined criterion. The ambient DO range was 9.0–10.2 mg/L, while the minimum water-quality criterion was set at 8 mg/L (*3*).
- DO measurements in the effluent plume at the DZB and downstream through the potential oxygen-sag region ranged from 8.8 mg/L to 10.2 mg/L, and therefore were in compliance with the 8.0-mg/L water-quality criterion.
- Natural temperature ranged from 19.4°C to 20.4°C. The only value exceeding the 20.0°C water-quality criterion occurred in the late afternoon within 1–2 m of the surface. The high temperature was caused by solar warming.
- Except for the naturally elevated ambient surface temperature, all temperature measurements at the downstream DZB were in compliance with the 20.0°C criterion.
- For the natural temperature condition exceeding the criterion, an apparent impact of 0.1°C was measured at the surface, which is well within the allowable increment of 0.3°C.

These results demonstrate that the new outfall is in compliance with applicable water-quality criteria for temperature and DO.

During the field survey we noted that, for minutes at a time, the quality of the ambient water varied by magnitudes approximating the allowable degradation criteria (0.3°C and 0.2 mg DO/L) during conditions of low water quality. Presumably, this reflects incomplete mixing of the ambient water mass below the confluence of the Columbia and Snake rivers. Under these conditions, it is difficult to reliably measure small impacts or to attribute them to cause and effect, since there is no constant upstream basis with which to compare downstream water quality. Our approach, wherein we sample an approximate parcel of water along the path of a drogue, tends to minimize the potential effect of these natural variations. However, it cannot eliminate them.

Comparison of the depth and the arithmetic means of all 19 measurements for each station showed that the average values of temperature and DO at the upstream background and DZB stations were essentially the same for both the 1-m and 8-m depths. At the 15-m depth,

III. Water-quality evaluation for toxic substances

Water-quality parameter	Toxicity criteria,[a] µg/L Acute	Toxicity criteria,[a] µg/L Chronic	Effluent concentrations, µg/L: Secondary (mill analysis)[b]	Effluent concentrations, µg/L: After cooling-water dilution (1.5:1)[b]	Effluent concentrations, µg/L: At DZB (S_a = 160)[b]	Compliance at DZB (chronic)	Estimated min S_a to meet acute criteria[c]
Aldin/dieldrin (sum)	2.5	0.0019	ND < 15	< 10.0	< 0.06	Unknown	< 4:1
Ammonia (total)	5590	764	8200	5467	34	Yes	1:1
Ammonia (nonionized)	181	26	N/A	N/A	N/A		
Cadmium	1.8	0.66	ND < 5	< 3.3	< 0.02	Yes	< 1.9:1
Chlordane	2.4	0.0043	ND < 0.5	< 0.3	< 0.002	Yes	< 0.1:1
Chlorine	19	11	ND < 100	< 66.7	< 0.42	Yes	< 3.5:1
Chloropyrifos	0.083	0.041	N/A	N/A	N/A		
Chromium (hexa)	16	11	N/A	N/A	2.92[d]	Yes[d]	
Chromium (tri)	984	117	N/A	N/A	2.92[d]	Yes[d]	
Chromium (total)	None	None	700	466.7	2.92		
Copper	9.2	6.5	60	40.0	0.25	Yes	4.3:1
Cyanide	22	5.2	ND < 10	< 6.7	< 0.04	Yes	< 0.3:1
DDT & metabolites	1.1	0.001	ND < 0.1	< 0.07	< 0.0004	Yes	< 0.1:1
Endosulfan	0.22	0.056	ND < 0.1	< 0.07	< 0.0004	Yes	< 0.3:1
Endrin	0.18	0.0023	ND < 0.1	< 0.07	< 0.0004	Yes	< 0.4:1
Heptachlor	0.52	0.0038	ND < 0.05	< 0.03	< 0.0002	Yes	< 0.1:1
Hexachlorocyclo hexane (lindane)	2	0.08	ND < 0.05	< 0.03	< 0.0002	Yes	< 0.02:1
Lead	34	1.3	110	73.3	0.46	Yes	2.2:1
Mercury	2.4	0.012	ND < 0.2	< 0.13	< 0.001	Yes	< 0.1:1
Nickel	789	88	30	20.0	0.13	Yes	0.03:1
Parathion	0.65	0.013	N/A	N/A	N/A		
PCB	2	0.014	ND < 0.5	< 0.33	< 0.002	Yes	< 0.2:1
Pentachlorophenol	15.0	9.5	ND < 100	< 66.7	< 0.42	Yes	< 4.4:1
Selenium	260	35	ND < 5	< 3.3	< 0.02	Yes	< 0.01:1
Silver	1.2	None	ND < 20	< 13.3	< 0.08	No criterion	< 10.8:1
Toxaphene	0.73	0.0002	ND < 1	< 0.67	< 0.004	Unknown	< 0.9:1
Zinc	65	59	160	106.7	0.67	Yes	1.6:1

[a]Based on WAC-173-201-047 (3) and EPA Federal Criteria for Water (6).
[b]N/A = not measured in NPDES analysis; ND = not detectable in effluent at detection level shown.
[c]S_a = effluent dilution in receiving water.
[d]Assuming total chromium is either all hexavalent or trivalent.

comparison of averages showed a temperature increase of 0.1°C and a DO decrease of 0.1 mg/L at the DZB. While it is not clear that these small apparent impacts at the 15-m depth are entirely the result of effluent discharge, both are well within the respective allowable impact criteria. This indicates that the outfall would also comply with the allowable degradation criteria during periods of low natural water quality.

Dilution

Another approach to evaluating potential impact on water quality is to estimate effluent dilution in the receiving water. During the field survey, four sets of water samples were collected at the 1-m, 8-m, and 15-m depths at both the upstream and DZB stations. The samples were analyzed for color and sodium and then compared with effluent values. Results for sodium are presented in **Table II**.

An estimate of the apparent dilution factor for nondecaying substances can be obtained using Eq. 1. (5):

$$S_a = (C_e - C_a)/(C_f - C_a) \tag{1}$$

where

S_a = dilution factor

C_e = effluent concentration

C_a = ambient background concentration

C_f = concentration in effluent plume

Based on this limited sampling, the resulting calculated effluent-plume dilution factors range from about S_a = 200 to more than 700 (one part effluent to 200-700+ parts receiving water), essentially indicating plume conditions ranging from partially mixed to well mixed. Extrapolating this to water quality at the measured ambient levels, impacts of 0.1°C and 0.1 mg/L DO could result from dilution factors of about S_a = 200. (Impacts would be less for higher values of S_a.) This tends to support the field-survey monitoring results, which showed that apparent impacts based on comparison of mean values at the 15-m depth are limited by dilution to the range of 0.1°C temperature and 0.1 mg/L DO.

Toxic substances

Background

The WDE adopted new water-quality criteria for 25 toxic substances, including selected metals, pesticides, and ammonia (*3*), consistent with federal quality criteria for water (*6*). Both acute and chronic criteria are specified for each substance. Based on recent WDE guidance, chronic criteria must be met at the DZB. However, NPDES permits proposed for reissuance beginning in 1990 will include a new provision for compliance with acute criteria based on a 5:1 effluent dilution (*7*).

Criteria for 9 of the 25 listed substances are dependent upon temperature, hardness, pH, and/or presence or absence of salmonids. Thus the criteria for these nine substances are not expressed as specific numeric values. Rather, they are expressed by formulae involving these parameters, and it is necessary to assign ambient water-quality conditions for these parameters in order to derive the appropriate criterion.

Boise Cascade conducted a comprehensive effluent analysis for the Wallula pulp and paper mill in February 1989. Included were effluent concentrations for 20 of the 25 toxic substances listed in state criteria. (There were no measurements for nonionized ammonia, chloropyrifos, parathion, or hexavalent and trivalent chromium, although total chromium and total ammonia were reported.)

The measured values apply to the approximately 76,000 m^3/day (20 Mgal/day) of secondary treated effluent. This effluent is subsequently diluted by a factor of about 1.5:1 through addition of close to 38,000 m^3/day (10 Mgal/day) of cooling water prior to discharge of the combined flow through the outfall. Based on diffuser design studies(*1*), the estimated initial dilution of effluent at the DZB under worst-case conditions (lowest flow) was in the range of $S_a = 160$. Therefore, the combined initial dilution at the DZB of the analyzed secondary treatment effluent is estimated at 240:1 (i.e., $1.5 \times 160 = 240$).

Compliance evaluation

Approach. Characteristics of the diluted effluent were compared with water-quality criteria for each of the 20 measured toxic substances. Historic water-quality data for the Columbia and Snake rivers were reviewed to select representative worst-case conditions. These, in turn, were used to establish criteria for the nine toxic substances expressed as functions of temperature, hardness, pH, and presence of salmonids. Typical worst-case values selected were:

Temperature	=	20°C for nonionized and total ammonia.
Hardness	=	50 mg/L ($CaCO_3$) for all hardness-dependent criteria. Toxicity decreases as hardness increases; 50 mg/L is a typical low value.
pH	=	7.5 for nonionized ammonia and pentachlorophenol. Toxicity decreases as pH increases.
	=	8.0 for total ammonia. Toxicity decreases as pH decreases. Typical pH range is 7.5–8.0.
Salmonids	=	Present.

We then listed the acute and chronic criteria for the given (16 substances) and calculated (nine substances) values. Compliance was estimated by comparing the diluted effluent concentrations at the DZB with the chronic criteria for the toxic substances. For reference, we estimated the minimum dilution resulting in compliance with acute criteria.

Results. Evaluation results are presented in **Table III.** Review of these results demonstrates projected compliance with chronic criteria for the toxic substances.

Of the 20 measured constituents, 18 are in compliance with respective chronic toxicity criteria at the DZB. The other two substances, aldrin/dieldrin and toxaphene, were not measurable at the detection limits used in the effluent analysis. However, the chronic criteria for these parameters are so low (0.0019 µg/L for aldrin/dieldrin and 0.0002 µg/L for toxaphene) that compliance determination may not be accurate based solely on a detection limit. These substances are pesticides and are not used in mill operations. Therefore, no impact from mill effluent would be expected, and the effluent can be judged in compliance.

Five of the toxic substances for which criteria are set were not specifically included in the effluent analysis. However, we believe that the following considerations support our contention that these substances are essentially in compliance with chronic criteria.

- EPA has established a criterion for total ammonia (*6*). Total ammonia was measured in the effluent analysis, and estimated concentrations at the DZB were in compliance with the chronic criterion.
- Chloropyrifos and parathion are pesticides and are not used in mill operations. There is no reason to believe that mill effluent would contain these substances.
- Total chromium was measured. Even under the conservative assumption that the total chromium value was either all hexavalent or all trivalent chromium, the resulting concentrations at the DZB would still meet the chronic criterion for each substance.

In addition, a 5:1 effluent dilution ($S_a = 5$) would appear to meet acute criteria for the toxic substances measured in the effluent analysis, with the exception of silver. Determination for silver is limited by the analytical detection limit.

Conclusion

The effluent plume from the new outfall is within the water-quality criteria established by the state for temperature and dissolved oxygen. Compliance was established by conducting field studies during low-flow conditions on the river during the late summer.

Field tests indicate that the outfall satisfies chronic criteria for 25 toxic substances. The mill expects to demonstrate compliance with these criteria when NPDES permits are reissued in 1990.☐

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The authors wish to acknowledge the regulatory guidance and cooperation provided by the Washington Department of Ecology.

Received for review Jan. 16, 1990.

Accepted April 25, 1990.

Presented at the TAPPI 1990 Environmental Conference.