PAST AND PRESENT WATER-QUALITY CONDITIONS IN THE HANFORD REACH OF THE COLUMBIA RIVER

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Abstract

Twelve water quality variables from upstream and downstream locations in the Hanford Reach of the mainstem Columbia River, southcentral Washington, were compared for the time intervals 1951 to 1953 and 1986 to 1988. During the 1951 to 1953 interval, beta radioactivity and, most likely, water temperatures in the Hanford Reach were higher downstream than upstream, while dissolved oxygen and sulfate were significantly lower. The increases of beta radioactivity and temperature downstream were due to the cooling water discharges of five single-purpose reactors on the Hanford Site. The last single-purpose reactor closed in January 1971. By 1986 to 1988, beta radioactivity and water temperatures were similar upstream and downstream, but nitrate had become significantly higher downstream. Comparison of 1951 to 1953 with 1986 to 1988 showed, as expected, that beta radioactivity was much lower today. Phosphate in the Hanford Reach has decreased significantly over 35 years, while biochemical oxygen demand, dissolved oxygen, and nitrate have increased. The detected changes were relatively small, and the quality of water in the Hanford Reach remains well within Washington State standards for Class A waters. Occasional lower pH values originating upriver violate these standards.

1. INTRODUCTION

We examined water-quality variables from the Hanford Reach, Columbia River during two time intervals, 1951 to 1953, and 1986 to 1988. These intervals are separated by 35 years, over which major changes have occurred in Hanford Site activities and in the Columbia River Basin of eastern Washington. We present the results, as far as available data permit, of quantitative comparisons, Washington. We present the results, as far as available data permit, of quantitative comparisons, first between upstream and downstream stations relative to the Hanford Reach within each period, and second, between the two periods.

The Hanford Site covers 1,450 km^2 in the desert-steppe region of southeastern Washington. The site was selected during World War II (1943) as an isolated area to produce a new radioactive element, plutonium. Since that time, Hanford has served as a national center for the production of defense material, and for energy research and development. Recent work has emphasized radioactive waste disposal and mitigation, as well as environmental characterization. Hanford operations, for the most part, have complied over the years with applicable rules and regulations on protection of environmental quality.

Some Hanford activities require large amounts of water from the Columbia River. From 1944 to January 1971, river water was used to cool as many as eight single-purpose plutonium-production reactors and chemically recover isotopes from irradiated fuel. During these years, the production reactors released radioactivity, heat, and lesser amounts of chemicals directly to the Columbia River in their cooling water effluent (Foster et al., 1961). No environmental regulations existed at the time that applied to these releases. But they were, nevertheless, closely monitored and controlled to avoid adverse affects to aquatic biota and people living downstream.

In recent years, river water was used to cool a dual-purpose reactor (N Reactor) that produced both plutonium and steam, an adjacent facility that converts the steam to electricity (Hanford Generating Project), and a commercial, nuclear-fueled power plant [Washington Public Power Supply System Nuclear Project-2 (WNP-2)]. The new facilities, designed to comply with applicable federal and state regulations to protect the environment, release very little radioactivity, heat, or chemicals to the Hanford Reach. Lesser amounts of river water are used for other onsite purposes. All source effluent streams are now controlled by National Pollution Discharge Elimination System (NPDES) permits. Small amounts of radioactivity from low-level radioactive liquid wastes that were released in past years to the ground near the interior of the Hanford Site now enter the Columbia River via groundwater seepage (McCormack and Carlile, 1984).

The objective of our analysis was to identify any significant changes in water quality that might be related to activities on the Hanford Site, or that might have occurred in the Hanford Reach as a result of changes in the Columbia River Basin over a 35-year interval.

2. THE HANFORD REACH

The Hanford Reach extends from the city of Richland at river kilometer (RKm) 545 to Priest Rapids Dam at RKm 654. In this reach, the Columbia River flows through the northern part of the Hanford Site and along its eastern boundary. Historically, annual flows in the mainstem Columbia River peaked with the spring spate in May through June, and temperatures peaked in August and early September (Whelan and Newbill, 1983). Today, extremes of river flow and river temperature in the Hanford Reach are moderated by storage and controlled releases at upstream dams.

Many environmental changes have occurred over the past 35 years. Generally, the mainstem Columbia River upstream and downstream from Hanford has been transformed into a series of impoundments by hydroelectric and water storage dams. Upstream, the largest of these, Grand Coulee Dam, was completed in 1941, while another, Rock Island Dam, was built in 1933. Both were operational during 1951-1953. Since then, Chief Joseph (1955), Priest Rapids (1959), Rocky Reach (1961), Wanapum (1963), and Wells (1967) dams were installed between Grand Coulee and the Hanford Site. Furthermore, use of river water upstream from Hanford has increased for agriculture (Stober et al., 1979) and, at some urban locations, for industrial processes (U.S. Bureau of Reclamation, 1976) over the past 35 years.

From 1951 to 1953, five single-purpose reactors at Hanford were discharging cooling water containing radioactivity, heat, and some process chemicals (i.e., sodium dichromate) to the Hanford Reach. A sixth reactor started operation in 1953. Because of large discharge volumes, some features of these effluents would be expected to have a significant effect on water quality below the release points.

From 1986 to 1988, in contrast, discharges from N Reactor, HGP, WNP-2, and other releases on the Hanford Site were regulated and monitored under NPDES permits. Thus, they would be expected to lack significant effects and be environmentally benign.

3. METHODS

We selected water-quality data from three sources. The 1951 to 1953 data were from tables in the first comprehensive survey of water-quality conditions in the mainstem Columbia River (Robeck et al. 1954). The 1986 to 1988 data were from computerized records of samples collected by Pacific Northwest Laboratory (PNL) and the U.S. Geological Survey (USGS). Sampling locations are shown in Figure 1. Some of the recent data have been summarized and published in annual reports for the Hanford Site (PNL, 1987; Jaquish and Mitchell, 1988) and the state of Washington (McGavock et al., 1988).

Water-quality variables were analyzed from both intervals according to instructions in available "standard methods" (i.e., American Public Health Association et al., 1975), which have been periodically updated. Analytical procedures are identified in the sources cited. We compiled data for all water-quality variables obtained in both the 1951 to 1953 and 1986 to 1988 time periods that could be used for comparison. We assumed that analytical methods used 35 years apart provided comparable data, except when they obviously did not.

During 1951 to 1953, upstream sample locations were at Priest Rapids (Priest Rapids Dam was not completed until 1959), below Priest Rapids, and above the "Hanford Works" (early name for the Hanford Site); downstream locations were at the former Hanford ferry crossing (RKm 581) and Richland. The ferry crossing, several kilometers below the single-purpose reactors, was far enough downstream so that the cooling water effluent was well mixed with river water (Jaske and Synoground, 1970). To negate the possibility of limited inshore mixing, we used only samples taken 60 meters or more offshore during 1951 to 1953. Downstream, Richland was the last sampling point upstream from the influence of discharges from the Yakima River. During 1986 to 1988, the only upstream station was at Vernita Bridge (several kilometers below Priest Rapids Dam), and the only downstream station was the city of Richland pumphouse. These stations are used consistently today by PNL and the USGS for monitoring water quality upstream and downstream from the Hanford Reach.

Descriptive statistics (mean, range, standard deviation) were obtained with a computerized statistical program. Upstream (US) versus downstream (DS) data for each period, and for past (1951 to 1953) and present (1986 to 1988) periods, were compared with the Student's t-test for unpaired sample means of unequal size. There was one exception. For pH, where comparison of means was inappropriate, we used the nonparametric Kolmogorov-Smirnov test to compare data distributions and the nonparametric Mann-Whitney U test to compare data ranks. Because beta radioactivity data downstream from the reactors in 1951 to 1953 had an abnormal distribution, we used log (natural) transformations before applying the t-test. The key statistic for detecting a difference was the 5% level, where values less than 0.05 called for rejection of the null hypothesis that population means were equal.

4. RESULTS

Values associated with water-quality characteristics upstream and downstream in the Hanford Reach during 1951 to 1953 and 1986 to 1988 are summarized in Table 1. Results of statistical comparisons within and between periods are summarized in Table 2.

4.1 Alkalinity

Alkalinity in the Hanford Reach ranged from 51 to 86 mg/L. Alkalinity of upstream water samples did not differ significantly from those downstream during either 1951 to 1953 or 1986 to 1988. Alkalinity could not be compared between 1951 to 1953 and 1986 to 1988 because methods used in sample analysis differed.

4.2 Ammonia Nitrogen (NH_3)

The ammonia nitrogen content of upstream water samples did not differ significantly from those downstream during either 1951 to 1953 or 1986 to 1988. Further, the amount of ammonia nitrogen in river water did not differ significantly between 1951 to 1953 (average 0.025 mg/L) and 1986 to 1988 (average 0.024 mg/L).

4.3 Beta Radioactivity

Beta radioactivity in upstream water samples during 1951 to 1953 was low, mostly <10 pCi/L. Because beta activity could not be measured at <10 pCi/L at that time, the computed mean for upstream stations (12.2 pCi/L) was erroneously high. Beta radioactivity at downstream stations in 1951 to 1953 was much higher, averaging 4166 pCi/L, a result of discharges from the five single-purpose reactors operating at Hanford at that time.

Beta radioactivity in upstream water samples during 1986 to 1988 was also low, averaging 1.27 pCi/L. Improved analytical techniques now allowed lower detection levels. Beta radioactivity in downstream water samples averaged 1.18 pCi/L in 1986 to 1988. The difference between upstream and downstream samples was not statistically significant.

Data on background radiation in upstream water samples in 1951 to 1953 and 1986 to 1988, could not be compared because analytical precision differed. Beta radioactivity in downstream water samples was much lower, on the average, in 1986 to 1988 (1.18 pCi/L) than in 1951 to 1953 (4166 pCi/L). The decline reflected termination of cooling water discharges from all of Hanford's single-purpose reactors.

Beta radioactivity from downstream stations in 1951 to 1953 and 1986 to 1988 was analyzed by seasonal periods. During 1951 to 1953, the single-purpose reactors at Hanford operated at relatively consistent power levels. However, the amounts of measurable beta radioactivity in Hanford Reach water varied with season, probably reflecting changes in river flow. Peak annual flows from April through June provided greater dilution capacity. During 1986 to 1988, with beta radioactivity near background levels, there was no apparent effect from river flow.

	Mean (pCi/L)	
Period	1951-1953	1986-1988
January-March	6086	1.02
April-June	2410	1.23
July-September	3170	0.98
October-December	4916	.40

4.4 Biological Oxygen Demand (BOD)

The BOD of upstream water samples did not differ significantly from those downstream during either 1951 to 1953 or 1986 to 1988. However, the average BOD in all samples was significantly higher in 1986 to 1988 (average 2.36 mg/L) than in 1951 to 1953 (average 0.45 mg/L).

4.5 Dissolved Oxygen (DO)

The DO content of downstream water samples was significantly lower than those from upstream during 1951 to 1953, but not during 1986 to 1988. However, the difference was relatively slight. River water averaged 11.1 mg/L DO upstream in 1951 to 1953 compared to 10.1 mg/L DO downstream. Furthermore, the DO of river water from all 1951 to 1953 samples (average 10.5 mg/L) differed significantly from that of all 1986 to 1988 samples (average 11.7 mg/L). The amount of DO in river water entering and leaving the Hanford Reach appears to have increased over the 35-year interval.

4.6 Nitrogen (NO_3)

The nitrate content of upstream water samples did not differ significantly from those downstream during 1951 to 1953, while a slight but significant difference occurred during 1986 to 1988. Downstream samples in 1986 to 1988 contained more NO_3 (average 0.28 mg/L) than upstream samples (average 0.13 mg/L). The amount of nitrate in river water from all 1986 to 1988 samples (average 0.21 mg/L) was significantly greater than in all 1951 to 1953 samples (average 0.06 mg/L).

4.7 pH

In the Hanford Reach, pH values are generally greater than 7.0. The pH of upstream water samples did not differ significantly from those downstream during either 1951 to 1953 or 1986 to 1988. However, pH differed significantly between 1951 to 1953 (range 7.5-8.4) and 1986 to 1988 (range 6.0-8.8).

In 1986 to 1988, some samples contained abnormally low values, indicating acidic conditions (<7.0). The occasional acidic readings appeared in both upstream and downstream. Seasonally (Figure 2), the acidic readings appeared during June (when water levels in the Hanford Reach are high), and during August and September (when water levels are usually low). When these values (as "outliers") were removed, pH data from 1951 to 1953 and 1986 to 1988 were similar.

4.8 Phosphorus (PO_4)

Amounts of phosphorus in the Hanford Reach ranged from 0.00 to 0.12 mg/L. Phosphorus in upstream samples did not differ significantly from those downstream during either 1951 to 1953 or 1986 to 1988. However, the amount of phosphorus in all 1986 to 1988 samples (average 0.024 mg/L) was significantly lower than those in 1951 to 1953 (average 0.038 mg/L).

4.9 Sulfate (SO_4)

Amounts of sulfate in the Hanford Reach ranged from 0.0 to 33.0 mg/L. Sulfate in downstream water samples was significantly lower than in those upstream during 1951 to 1953. No down-stream samples were obtained during 1986-1988. However, sulfate levels in river water upstream during 1951 to 1953 (average 13.2 mg/L) did not differ significantly from those upstream during 1986 to 1988 (average 11.7 mg/L).

4.10 Temperature

Water temperatures were not measured daily during 1951 to 1953, nor were they taken on comparable dates upstream and downstream. Because temperatures in the Hanford Reach change daily with climatic conditions, the 1951 to 1953 records could not be used for statistical comparison either upstream or downstream or with 1986 to 1988 data. In contrast, water temperatures were measured continuously both upstream and downstream during 1986 to 1986. (We used the average daily temperature every fifth day to simplify statistical compilation.)

Upstream and downstream temperatures during 1951 to 1953 undoubtedly differed because of heat released to the Hanford Reach in cooling water discharges of the five single-purpose reactors. However, insufficient data were available to examine this relationship.

Upstream water temperatures during 1986 to 1988 (average 11.4°C) did not differ significantly from those downstream (average 11.6°C). Insolation at some seasons often causes a slight warming downstream in the Hanford Reach, but this effect was not apparent.

4.11 Total Coliform Bacteria

Total coliform bacteria in upstream water samples did not differ significantly from those downstream in either 1951 to 1953 or 1986 to 1988. Furthermore, there was no significant difference between total coliforms in all 1951 to 1953 samples (average 455/100 mL) and all 1986 to 1988 samples (average 309/100 mL). Numbers of coliforms appearing in water samples varied greatly.

4.12 Turbidity

Turbidity in upstream water samples did not differ significantly from those downstream in either 1951 to 1953 or 1986 to 1988. Comparisons could not be made between intervals because analytical methods differed.

5. DISCUSSION

The nature of activities at Hanford has drawn attention to the possibility that effluent generated onsite might affect water quality in the Columbia River downstream. To explore this possibility, we compared water-quality data from above (upstream) and below (downstream) effluent release points on the Hanford Site during both 1951 to 1953 and 1986 to 1988. We also compared two time intervals, one before (1951 to 1953) and the other after (1986 to 1988) effluent discharges at Hanford became subject to federal and state environmental statutes. Over the past 35 years, numerous changes have taken place in the Columbia River ecosystem and its drainage basin, which increase the complexity of identifying cause-and-effect relationships.

The data available allowed comparison of 12 water-quality variables in relation to the Hanford Reach.

5.1 Upstream Versus Downstream 1951-1953

In the 1951 to 1953 period, the discharge of cooling water from five single-purpose production reactors significantly increased levels of beta radioactivity downstream (Table 2). The discharges contained a complex mix of beta and gamma radionuclides (Watson and Templeton, 1973), primarily short-lived activation products created by bombardment of constituents in river water by neutrons in the reactor core (Foster, 1972). Intensive field and laboratory investigations performed while the reactors were operating indicated no harm to aquatic organisms nor, more importantly, to humans using river water downstream (Parker et al., 1965).

Although data did not allow comparison of upstream and downstream temperatures, there is little doubt that significant amounts of heat were added to the Hanford Reach by cooling water discharges from 1951 to 1953 (i.e., Jaske and Synoground, 1970).

Dissolved oxygen and sulfate were also significantly lower downstream in the 1951 to 1953 period. We do not know if the lower values reflect an effect from the former reactor discharges at Hanford. As a general rule, warm water retains less oxygen than cold water. However, thermal increments below the Hanford single-purpose reactors were generally in the range of 1 to 2°C, and they were unlikely to measurably affect the DO content of river water.

5.2 Upstream Versus Downstream 1986-1988

In the 1986 to 1988 period, beta radioactivity and water temperature did not differ significantly above and below the Hanford Reach (Table 2). All single-purpose plutonium-production reactors had been closed for 15 years. Background beta radioactivity in river water averaged about 2.0 pCi/L.

Amounts of nitrate in river water during 1986 to 1988 were significantly higher downstream than upstream, indicating one or more sources of nitrate contamination along the Hanford Reach. One possibility is seepage of ground water from the Hanford Site along the west side of the Columbia River. The unconfined aquifer contains low levels of nitrate from sources related to (1) past practices of releasing liquid wastes to the ground, (2) past or present agricultural activities, and (3) leachate from manure of research animals (Cline et al., 1985; Evans et al., 1988). Possible offsite sources of nitrate included irrigation return water and seepage associated with extensive irrigation north and east of the Columbia River.

5.3 1951-1953 Versus 1986-1988

Beta radioactivity in river water below Hanford fell from an average of 4166 pCi/L in 1951 to 1953 to 1.18 pCi/L in 1986 to 1988. This decrease was highly significant, reflecting cessation of cooling water discharges after closure of the last single-purpose plutonium-production reactor at Hanford in January 1971. Concentrations of fission-produced radionuclides in biota downstream from Hanford decreased to extremely low or unmeasurable levels within 18 to 24 months after the reactor discharges stopped (Cushing et al., 1981).

Limited temperature data during 1951 to 1953 prevented comparison with temperatures in 1986 to 1988, but average values downstream from Hanford would be expected to decline slightly after cessation of discharges from the single-purpose reactors. Releases of stored water from Lake Roosevelt, behind Grand Coulee Dam, were sufficiently great to influence water temperatures downstream after 1941 (Jaske and Goebel, 1967). All other reservoirs built between Grand Coulee Dam and Priest Rapids Dam during the past 35 years are "river run" and thus have limited water retention times (Ebel et al., 1989). They are unlikely to measurably affect water temperatures in the Hanford Reach.

BOD, DO, and nitrate in water from the Hanford Reach were significantly higher in 1986 to 1988 than in 1951 to 1953. These water-quality features are often interrelated. Higher DO might result from mixing of air with river water in the plunge basin and tailgates at Priest Rapids Dam, completed in 1959. Increased primary production of phytoplankton in upstream reservoirs might also increase amounts of DO but, in this case, the increased DO might also result in higher respiratory demand of decomposing organic matter. The significant increases in BOD and nitrate could reflect the continued expansion of agricultural activities (livestock, fertilizers, and irrigation) over the past 35 years in areas upstream of and adjacent to the Hanford Site. Ground-water seepage from Hanford probably contributes small amounts of nitrates (PNL, 1987; Jaquish and Mitchell, 1988). Total nitrate in the nation's surface water, including the Pacific Northwest, is undergoing an increasing trend, a phenomena attributed to both agricultural activity and deposition (Smith et al., 1987).

Significantly lower levels of phosphorus in the Hanford Reach could reflect increased photosynthetic activity of phytoplankton in impounded waters of upriver reservoirs built since 1953. In fact, some of the increase in BOD and DO in 1986-1988 might also reflect primary production of phytoplankton in upriver reservoirs. But levels of NO_3 also increased. In most situations, both NO_3 and PO_4 would be expected to decrease from photosynthetic activity, depending on the presence or absence of limiting concentrations.

Significantly lower pH values occasionally appear in the Hanford Reach. Values that once ranged from pH 7.5 to 8.4 now extend from pH 6.0 to 8.8. The lower, acidic readings were usually evident as "outliers." If outliers were removed, average pH values between 1951 to 1953 and 1986 to 1988 did not differ significantly.

Acidic pH values appeared upstream as well as downstream and, thus, did not result from activities on the Hanford Site. A lowering of normal pH values could be caused by an influx of acidic industrial waste (American Public Health Association et al., 1975). If so, the evidence points to an unknown source above the Hanford Reach. An occasional low pH value does not indicate significant deterioration of water quality. Future sampling should verify low pH occurrances and, if detected, identify source or sources.

5.4 Compliance with State Regulations

Water quality in the Hanford Reach of the Columbia River is subject to standards established by the State of Washington (WDOE 1982). However, regulatory limits exist only for a few water-quality variables. Generally, applicable standards for water designated as Class A (Excellent) are met today in the Hanford Reach at both upstream and downstream sampling locations. There is little indication of significant deterioration in water quality from sources on the Hanford Site, upstream of the Hanford Site, or north and east of the Columbia River adjacent to the Hanford Site.

State standards require fecal coliforms to be less than or equal to 100 organisms/100 mL of water, but 10% or less of the samples may exceed 200 organisms/mL. We compared counts of total coliform bacteria, which generally provide higher numbers than counts of fecal coliforms. For total coliforms, water in the Hanford Reach showed no significant change over 35 years. Examination of related PNL data for the years 1986, 1987, and 1988 indicate that median concentrations of fecal coliforms at upstream and downstream stations in the Hanford Reach were generally below Class A requirements (Dirkes, 1987; 1988).

State standards require more than 8 mg/L of DO in Class A waters. Samples from the Hanford Reach were consistently above these standards. In fact, DO levels have increased from an average of 10.5 mg/L in 1951 to 1953 to an average of 11.7 mg/L over the past 35 years.

State standards require a pH range of 6.5 to 8.5, with less than a 0.5-unit induced variation. Water in the Hanford Reach was usually within these standards, with some exceptions occurring both upstream and downstream in 1986 to 1988. These exceptions apparently originate upstream above Priest Rapids Dam.

State standards require turbidity to be less than or equal to background levels. Assuming "background" to be represented by river water below Priest Rapids Dam, turbidity below Hanford does not violate state standards.

Gross beta radioactivity in the Hanford Reach now corresponds closely with background levels, including the increment from atmospheric fallout in the upper Columbia River watershed. Beta radioactivity in the Hanford Reach averaged 1.3 pCi/L upstream and 1.2 pCi/L downstream during 1986 to 1988. These measurements are well below applicable drinking water standards of 50 pCi/L (Washington State and U.S. Environmental Protection Agency).

Gross beta radioactivity is only an indication of general radiological quality. The extensive monitoring program conducted each year at PNL provides a comprehensive picture of radiological contamination in the Hanford Reach. In 1988, for example, concentrations of all radionuclides were extremely low, being essentially undetectable without use of special sampling techniques and analytical procedures. Gross alpha radioactivity in the Hanford Reach was well below the applicable drinking water standard of 15 pCi/mL.

These data indicate that past and present operations at Hanford have not significantly affected Columbia River water quality.

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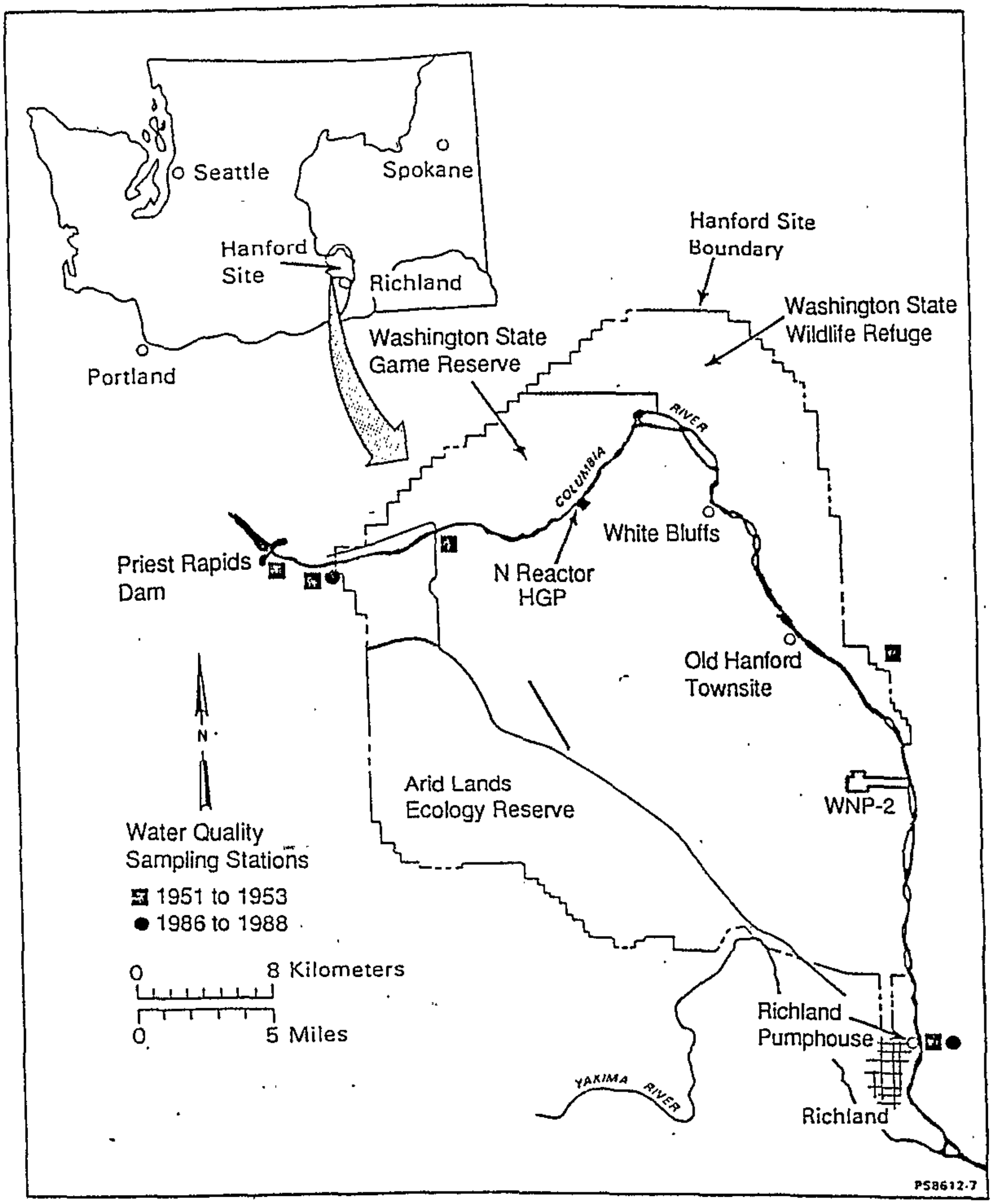
Figures

Figure 1. Locations of upstream and downstream sites for determining water quality of the Hanford Reach during 1951 to 1953 and 1986 to 1988.

Figure 2. Distribution of pH values during 1986 to 1988 in the Hanford Reach by month. Values below pH 7.0 are atypical and may represent the disposal of acidic liquids at one or more upstream locations.


Seattle
Spokane
Hanford Site
Richland
Portland
Hanford Site Boundary
Washington State Wildlife Refuge
Washington State Game Reserve
RIVER
COLUMBIA
White Bluffs
Priest Rapids Dam
N Reactor HGP
Old Hanford Townsite
N
Arid Lands Ecology Reserve
WNP-2
Water Quality Sampling Stations
1951 to 1953
1986 to 1988
0 8 Kilometers
0 5 Miles
Richland Pumphouse
YAKIMA RIVER
Richland
PS8612-7

9212560166

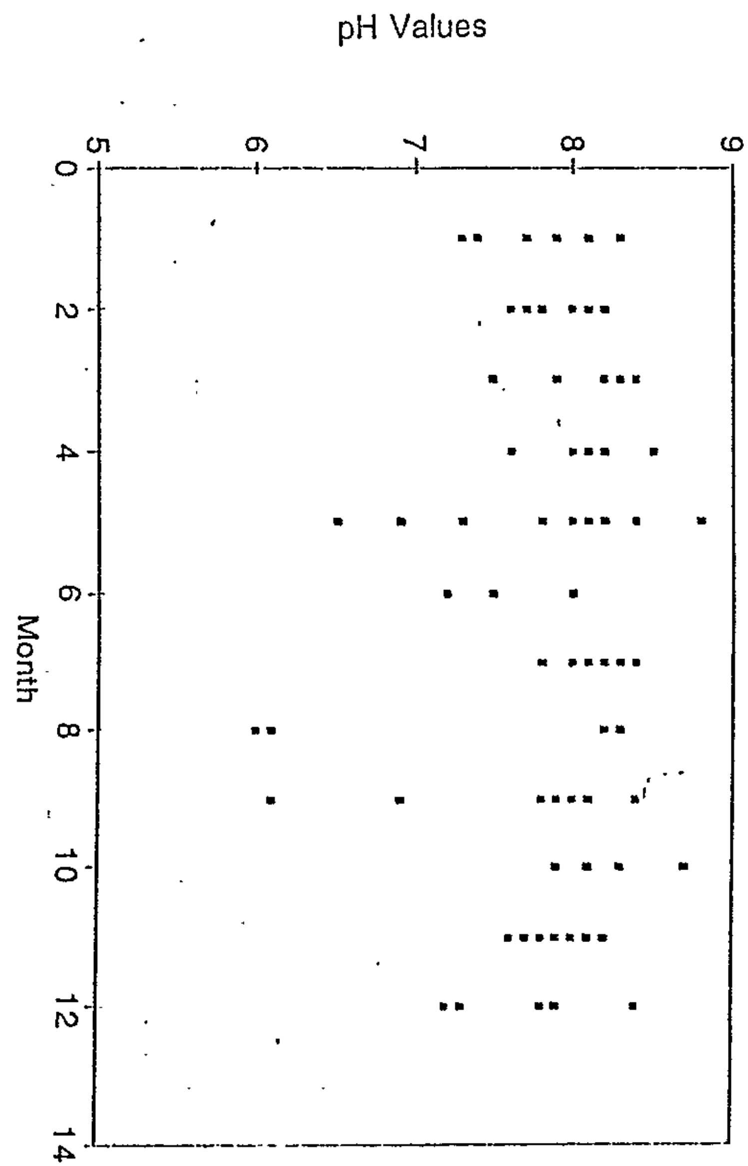

pH Values
5
6
7
8
9
0
2
4
6
8
10
12
14
Month

Table 1. Values Associated With Water-Quality Variables in the Hanford Reach of the Columbia River, Past and Present.

		Upstream				Downstream			
WQ Variable	Unit	No. of Samples	Mean	Min/Max	SD	No. of Samples	Mean	Min/Max	SD
1951 to 1953 (Reactor Operation)									
alkalinity[(a)]	mg/L	63	66.7	55.0-86.0	7.22	197	68.2	51.0-85.0	6.50
ammonia (NH_3) nitrogen	mg/L	43	0.02	0.00-0.18	0.03	171	0.03	0.00-0.08	0.02
beta[(b)] radioactivity	pCi/L	58	12.2	10.0-30.0	5.09	452	4,166	270-19,000	3,121.40
biochemical oxygen demand	mg/L	4	0.18	0.00-0.60	0.28	19	0.51	0.10-1.30	0.35
dissolved oxygen	mg/L	27	11.1	8.8-14.8	1.94	44	10.1	8.4-13.8	1.35
nitrogen (NO_3)	mg/L	13	0.07	0.00-0.20	0.05	18	0.05	0.00-0.10	0.03
pH	pH units	60	NA[(c)]	7.8-8.4	NA	192	NA	7.5-8.4	NA
phosphorus (PO_4)	mg/L	43	0.04	0.00-0.12	0.03	176	0.04	0.00-0.12	0.03
sulfate (SO_4)	mg/L	45	13.2	3.0-33.0	6.27	181	10.8	0.0-30.0	4.62
temperature	°C					data not usable			
total coliform[(d)]	#/100 mL	21	504	36-2400	525.7	42	431	43-2400	506.8
turbidity[(e)]	JTU	49	6.8	1.0-18.0	4.04	189	6.6	1.0-88.0	7.31

Table 1. (contd)

WQ Variable	Unit	Upstream No. of Samples	Upstream Mean	Upstream Min/Max	Upstream SD	Downstream No. of Samples	Downstream Mean	Downstream Min/Max	Downstream SD
1986 to 1988 (Post Reactor Operation)									
alkalinity[(a)]	mg/L	18	61.1	50.0-75.0	7.62	12	60.0	48.0-72.0	6.82
ammonia (NH_3) nitrogen	mg/L	18	0.02	0.01-0.07	0.02	11	0.03	0.01-0.04	0.02
beta radioactivity	pCi/L	36	1.27	0.07-2.84	0.81	36	1.18	0.02-2.83	0.67
biological oxygen demand	mg/L	36	2.55	0.40-8.30	1.83	36	2.16	0.50-5.90	1.07
dissolved oxygen	mg/L	18	11.6	8.8-13.8	1.68	12	11.7	9.50-13.60	1.54
nitrogen (NO_3)	mg/L	36	0.13	0.02-0.53	0.10	36	0.28	0.05-2.10	0.39
pH	pH units	51	NA	6.0-8.8	NA	45	NA	6.1-8.7	NA
phosphate (PO_4)	mg/L	18	0.02	0.01-0.06	0.01	11	0.02	0.01-0.04	0.01
sulfate (SO_4)	mg/L	18	11.7	9.9-13.0	1.20			no downstream data	
temperature[(f)]	°C	219	11.4	1.5-20.3	5.74	219	11.6	1.2-21.1	5.84

Table 1. (contd)

WQ Variable	Unit	Upstream No. of Samples	Upstream Mean	Upstream Min/Max	Upstream SD	Downstream No. of Samples	Downstream Mean	Downstream Min/Max	Downstream SD
total coliform[d]	#/100 mL	36	364	2.0-2400	624.7	36	254	2.0-1600	403.3
turbidity[e]	NTU	18	1.27	0.10-4.00	0.95	11	1.47	0.10-3.20	1.09

(a) Alkalinity as mg/L $CaCO_3$ was determined by the methyl orange method in 1951 to 1953, and by potentiometric titration in 1986 to 1988. Data obtained by the two methods are not comparable.
(b) Beta radioactivity could not be measured below 10.0 pCi/L in 1951 to 1953. For statistical description, the "less than" (<) sign was removed, which set the minimum at 10.0 for upstream values and inflated the mean. Downstream values were much greater because of reactor discharges at Hanford.
(c) NA = not available. applicable
(d) The maximum number of coliform bacteria counted was 2400.
(e) Turbidity was measured in Jackson Turbidity Units in 1951 to 1953, and in Nephelometric Turbidity Units in 1986 to 1988.
(f) Calculated on basis of daily averages.

Table 2. Statistical Comparisons of Water-Quality Variables in the Hanford Reach of the Columbia River, Past and Present. Interpretations were based on the standard 5% significance level (Snedecor and Corchran, 1980).

WQ Feature	Comparison[a]	Statistic[b]	Significance	Interpretation
alkalinity	US vs DS 51-53	-1.565	0.115	no significant difference
	US vs DS 86-88	0.387	0.703	no significant difference
	51-53 vs 86-88	----	----	data not comparable
ammonia (NH_3) nitrogen	US vs DS 51-53	-1.100	0.272	no significant difference
	US vs DS 86-88	-0.538	0.601	no significant difference
	51-53 vs 86-88	0.201	0.835	no significant difference
beta[c] radioactivity	US vs DS 51-53	-10.126	0.000	significantly higher DS
	US vs DS 86-88	0.514	0.615	no significant difference
	US 51-53 VS US 86-88	----	----	data not comparable
	DS 51-53 vs DS 86-88	60.249	0.000	significantly lower 86-88
biochemical oxygen demand	US vs DS 51-53	-1.751	0.091	no significant difference
	US vs DS 86-88	1.116	0.267	no significant difference
	51-53 vs 86-88	-5.998	0.000	significantly higher 86-88
dissolved oxygen	US vs DS 51-53	2.529	0.013	significantly lower DS
	US vs DS 86-88	-0.092	0.925	no significant difference
	51-53 vs 86-88	-3.226	0.002	significantly higher 86-88
nitrogen (NO_3)	US vs DS 51-53	1.195	0.240	no significant difference
	US vs DS 86-88	-2.165	0.032	significantly higher DS
	51-53 vs 86-88	-2.880	0.005	significantly higher 86-88
pH	US vs DS 51-53	KS: 0.065	0.331	no significant difference
		MW: 5480	0.243	no significant difference
	US vs DS 86-88	KS: 0.145	0.239	no significant difference
		MW: 1015	0.161	no significant difference
	51-53 vs 86-88	KS: 0.229	0.028	significantly lower 86-88
		MW: 10624	0.021	significantly lower 86-88
phosphorus (PO_4)	US vs DS 51-53	0.178	0.853	no significant difference
	US vs DS 86-88	0.204	0.834	no significant difference
	51-53 vs 86-88	2.267	0.023	significantly lower 86-88
sulfate (SO_4)	US vs DS 51-53	2.828	0.005	significantly lower DS
	US vs DS 86-88	----	----	no downstream data
	US 51-53 vs US 86-88	0.999	0.678	no significant difference
temperature	US vs DS 51-53	-----	-----	data not comparable
	US vs DS 86-88	-0.409	0.686	no significant difference
	DS 51-53 vs DS 86-88	-----	-----	data not comparable

Table 2. (contd)

WQ Feature	Comparison[a]	Statistic[b]	Significance	Interpretation
total coliform bacteria	US vs DS 51-53	0.534	0.602	no significant difference
	US vs DS 86-88	0.885	0.617	no significant difference
	51-53 vs 86-88	1.635	0.100	no significant difference
turbidity	US vs DS 51-53	0.167	0.862	no significant difference
	US vs DS 86-88	-0.542	0.599	no significant difference
	51-53 vs 86-88	----	----	data not comparable

(a) US = upstream, DS = downstream.
(b) Means were compared by the Student's test for all water quality variables. Therefore, the "statistic" represents the "t-statistic," with one exception. For pH, where both the Komogorov-Smirnov (KS) and Mann-Whitney U (MW) tests were used, "statistic" represents the respective computed values.
(c) The lower limit for detection of beta radioactivity during 1951 to 1953 was 10 pCi/L. Much lower limits could be measured by 1986 to 1988. Thus, background levels of beta radioactivity (i.e., upstream data) between the two periods could not be compared.