ALASKA POWER AUTHORITY

SUSITNA HYDROELECTRIC PROJECT

POSITION PAPER

FISHERIES ISSUE F-2.3

EXECUTIVE SUMMARY

Issue

Significance of potential changes in heavy metal concentrations on salmon and resident fish habitats and populations downstream of the dam.

Position

It is the Alaska Power Authority's Position that the Susitna Hydroelectric Project will not substantially increase the concentrations of most heavy metals in fish of the Susitna River system. Some increases in tissue levels of mercury are expected to occur in reservoir and riverine fishes, but low levels of biological activity in the reservoirs are expected to minimize such increases. No mitigation measures are proposed by the Power Authority other than monitoring selected fish species for unsafe tissue levels of total and/or methylmercury.

Present Knowledge

As reported in the License Application (2)[1/], a number of metals in the Susitna River exceed criteria for the protection of freshwater organisms under natural conditions. The most biologically significant of these metals are mercury, copper, cadmium, and zinc. Of these, only mercury is both present in high concentrations in the existing system and known to bioaccumulate to unsafe levels in aquatic organisms.

1/ Numbers in parenthesis identify references listed at the end of the paper.

Various authors have reported elevated concentrations of some inorganic constituents in newly impounded reservoirs (3, 6, 7). These increased concentrations are due to:

1. Dissolution of inundated soils and rocks.

2. Increased rates of mineral dissolution due to the chelation of metal cations by humic substances. Chelation is the formation of a molecule involving a metal ion and two or more organic ions.

3. Biologically-mediated action involving metals in flooded topsoil horizons.

Post-impoundment water quality studies in reservoirs have shown only one metal, mercury (Hg), to systematically bioaccumulate to ecologically unsafe concentrations as a direct result of impoundment (1, 6, 22). Mercury normally is biologically active only when combined with a methyl (CH_3) ion, a process that is usually mediated by certain microbes. After impoundment, microbial methylation of mercury associated with organic matter in soils and newly inundated detritus of Watana and Devil Canyon Reservoirs is likely to result in mercury levels in reservoir fish higher than current natural concentrations. Certain environmental conditions in the reservoirs will tend to minimize mercury biomethylation and subsequent bioaccumulation, notably:

1. Low year-round water temperature,

2. Low benthic microbiological activity,

3. Blanketing of inundated organic matter with a layer of inorganic sediments,

4. Relatively limited fish populations.

The impact of the Project on mercury concentrations in downstream fishes will likely be a function of several unknown and unpredictable factors: the amount and chemical composition of mercury exported from the reservoirs, the amount and chemical composition of mercury existing in riverine habitats downstream and in situ methylation and uptake of mercury in downstream habitats. The flux of total mercury through aquatic habitats downstream of the proposed reservoirs will be substantially less than under current natural conditions, but it is not presently possible to accurately predict the levels of methylmercury that will be discharged from the reservoirs. Mercury accumulation in fish downstream may be largely due to in situ methylation and uptake, and it will probably be influenced by project-induced changes in stream biological productivity at all trophic levels.

Cadmium, in contrast to mercury, is not present in high concentrations in the Susitna River. Thus, it is not likely that appreciable concentrations will be leached from the soils inundated by the impoundment. Therefore, although cadmium is known to bioaccumulate, the element is not likely to have any substantial effect on fish resources in the Susitna River.

Zinc and copper can be toxic but are not known to bioaccumulate (23). Leaching of these metals is neither predictable nor quantifiable at this time. Leaching can be exacerbated by the presence of humic substances, which are abundant in the watershed, but the toxicity of metals bound to humics is much lower than that of free metal ions (18, 23).

Resident species in both the impoundment zone and downstream habitats are expected to be more subject to potential impacts of heavy metals than anadromous species of fish. Anadromous salmon in riverine habitats downstream of the project will accumulate only a small portion of their total tissue concentration of mercury while in fresh water. Most of the accumulation of mercury in salmon tissue will take place in the marine environment and will not be detectably affected by the Project.

Mitigation Measures Endorsed by the Alaska Power Authority

The Alaska Power Authority proposes to include the monitoring of mercury bioaccumulation in selected sport fishes of the Susitna watershed in the Long Term Monitoring Program now in preparation. If the monitoring program indicates significant heavy metal bioaccumulation, plans will be prepared, in consultation with appropriate state and Federal agencies, to mitigate potential environmental hazards.

ALASKA POWER AUTHORITY

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INTRODUCTION

Issue

Significance of potential changes in heavy metal concentrations on salmon and resident fish habitats and populations downstream of the dams.

Position

It is the Alaska Power Authority's position that the Susitna Hydroelectric Project will not substantially increase the concentrations of most heavy metals in fish of the Susitna River system. Some increases in tissue levels of mercury are expected to occur in reservoir and riverine fishes, but low levels of biological activity in the reservoirs are expected to minimize such increases. Mitigation measures which are proposed by the Power Authority include monitoring of selected fish species for unsafe tissue levels of total and/or methylmercury.

DISCUSSION

Current Knowledge

Impoundment of flowing waters can affect the dissolved element content of the water, including toxic trace metals. The leaching of inundated soils can initially elevate the concentrations of some inorganic and organic constituents in newly impounded reservoirs. These concentrations gradually fall back as the reservoirs age (3, 6, 7).[1/] The elevated concentrations are due to:

[1/] Numbers in parenthese refer to literature listed in the bibliography at the end of the paper.

1. Dissolution of newly inundated soils and rocks,

2. Higher rates of mineral dissolution due to the chelation of metals by natural organic solutes (i.e., humic substances),[2]

3. Microbial action upon metals in flooded top soil horizons.

All minerals are soluble to some extent. The inorganic content of surface and groundwater reflects this solubility. Complexing agents, however, can cause a mineral to appear more soluble than would be predicted by its thermodynamic solubility product (32). Natural organic acids are ligands[3] capable of binding metals. Humic substances[4] are especially noted for this and much effort has been spent characterizing their binding of metals (8, 11, 18, 30). Humic substances are leaching agents. They have the ability to mobilize a wide variety of metal ions in rock weathering processes. Their metal leaching ability is due to their role as ligands in natural solutions. Metal complexing capacities of humic substances vary with the sources of humus as well as with the metals (18). Humic substances are common throughout the tundra bogs of the Susitna River drainage basin.

Review of data for total and dissolved metals concentrations in the Susitna River provides insights into the natural mineral deposits in the watershed as well as the propensity for metal-related biological effects after impoundment. Metal monitoring in the Susitna River has included the major cations calcium (Ca), magnesium (Mg), sodium (Na), and potassium (K), as

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2/ Chelation is the formation of a molecule (usually in ring form) involving a metal ion and two or more organic ions.

3/ In coordination chemistry, the metal cation is called the central atom. The ligands are anions or molecules which donate both electrons to form the coordinate bond (32).

4/ Humic substances encompass a heterogenous polymer system composed of complex organic molecules, usually with molecular weights of 300-200,000, some of which are insoluble (humins), base soluble (humics), or acid soluble (fulvics), and all of which are derived from the decomposition of vegetable or animal materials.

well as aluminum (Al), cadmium (Cd), copper (Cu), iron (Fe), lead (Pb), manganese (Mn), bismuth (Bi), mercury (Hg), nickel (Ni), selenium (Se), and zinc (Zn). Dissolved lead, nickel and selenium concentrations are very low (if not below instrument detection limits) and are considered insignificant. Aluminum, iron, manganese, nickel, and bismuth (as dissolved, total, or both) are reported in the License Application to exceed criteria for the protection of freshwater organisms under the present, natural conditions (2). However, in comparison to mercury, cadmium, copper, and zinc, these metals are less important in a biological sense because they are not particularly toxic. Mercury, cadmium, copper and zinc seem to be found in high enough concentrations in the Susitna River to warrant additional discussion in this position paper (2,26).

Many post-impoundment water quality studies in reservoirs have shown that, of the four more toxic metals mentioned above, only mercury systematically bioaccumulates as a direct result of impoundment (1, 6, 22). Therefore, mercury is given special attention in this position paper.

Mercury

Concentrations in the Susitna River. The U.S. Geological Survey (USGS) has monitored dissolved and total recoverable mercury at various points in the Susitna River. These data were inappropriately presented in the License Application as Figures E.2.115 and E.2.116. The detailed mercury data, taken directly from the annual USGS Water Resource Data reports, are shown in Table 1. Total Hg ranged from zero to 0.8 ug/L; dissolved Hg varied between 0 and <0.5 ug/L. The levels of dissolved Hg shown in Table 1 are on the high end of the range of Hg typically found in unpolluted North American surface waters (23). The concentrations probably reflect natural deposits in southcentral Alaska (20, cited *in* 23).

Twenty-five to fifty percent of the total mercury in the Susitna River occurs as the dissolved species.[5] Published investigations have generally found less than ten percent of the total mercury in aquatic environments to be dissolved Hg. Mercury in natural waters is strongly associated with suspended particles (18, 21, 23, 29). While dissolved organic ligands could be responsible for the high percentage of Hg that is dissolved, comparison of the dissolved Hg and dissolved organic carbon in Susitna River water (Table 1) does not indicate a simple relationship. Moreover, examination of the data does not indicate an obvious on simple relationship between total or dissolved Hg concentrations and the levels of dissolved organic carbon, suspended solids, or discharge in the Susitna River. This may indicate a need for further data and/or different techniques for sampling and analysis of mercury concentrations and mercury species composition.

<u>Potential Impacts on the Reservoir and Downstream Fisheries</u>. It has been demonstrated that mercury levels in aquatic biota can increase following impoundment (1, 6, 9). The source of the mercury is the inundated soils. Bodaly et al. (6) implicated organic topsoil horizons as the major source of accumulated mercury. Rudd et al. (29), studying industrially produced mercury pollution in a northwest Ontario river system, reported that most mercury in the system was buried below surficial sediments (in organic-poor sediments), and probably did not contribute substantially to mercury bioaccumulation. Soils in the Susitna Project impoundment zones are fairly typical of those formed in cold, wet climates on glacial till or outwash. They include acidic, saturated, peaty soils of wetlands, acidic, relatively infertile soils of the forests, and raw gravels and sands along the river.

Mercury is generally bioaccumulated in the methylated form (12). Methylation occurs by microbial action on the Hg (II) ion in both aerobic and anaerobic environments. Conditions enhancing the metabolism of soil and aquatic microorganisms will enhance mercury biomethylation. Rudd and Turner (28) demonstrated increased mercury bioaccumulation in fish with increased primary productivity. Wright and Hamilton (34) showed that an increase in

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[5] Dissolved constituents are operationally defined as those that pass through 0.45-micron pore filters (26).

microbial nutrients in sediments resulted in higher rates of mercury methylation and bioaccumulation. They also showed even higher rates of mercury methylation upon the addition of microbial nutrients to the water column, indicating that methylation occurs primarily at the sediment-water interface.

In contrast to methylmercury's tendancy to bioaccumulate, inorganic mercury is strongly associated with inorganic particulates (10, 16, 21, 23). In fact, application of organic-poor sediments to in situ enclosures in a mercury contaminated system in Ontario resulted in decreased rates of bio-accumulation (27). Laboratory tests by Jernelov and Lann (19) showed that mercury biomethylation rate was reduced to less than 0.1 percent of that in untreated controls after treatment with freshly ground silica; the sediments apparently bound the mercury, making it less available for biomethylation and/or bioaccumulation. In their mercury amelioration study, Rudd et al. (29) concluded that elevated concentrations of suspended sediments substantially reduced methylmercury accumulation in fish, while stimulation of primary productivity increased methylmercury bioaccumulation.

Bioaccumulation is a function of an organism's rate of uptake versus elimination. The bioaccumulation factor for mercury is high because its uptake is relatively fast, but its elimination relatively slow. High temperature accelerates the uptake of mercury compounds by accelerating the metabolic and respiratory rates of the organisms and increasing the need for food (12, 34).

Mercury levels in organisms seem to vary directly with trophic position. Piscivorous fish and other predators generally have the highest concentrations (24, 25). Work by Fimreite et al. (14) in Canada showed the magnification of mercury bioaccumulation from fish to fish-eating birds.

Table 1

SUSITNA HYDROELECTRIC PROJECT
AVAILABLE USGS DATA — METAL ANALYSES[1]

Date d-m-y	Discharge (cfs)	Suspended Solids (mg/L)	Dissolved Organic C (mg/L)	Cadmium Total	Cadmium Dis-solved	Copper Total	Copper Dis-solved	Iron Total	Iron Dis-solved	Mercury Total	Mercury Dis-solved	Total	Dis-solved
Station: Susitna River at Gold Creek (15292000)													
140677	52,000	915	-	<10	-	50	-	20,000	100	0.2	-	80	-
100877	20,000	656	-	<10	-	50	-	18,000	-	0.3	-	80	-
041077	8,500	22	-	<10	-	<10	-	850	40	0.2	-	30	-
230681	17,500	327	2.8	0	<1	31	4	15,000	90	0.4	0	60	6
210781	42,600	680	18.0	5	1	190	5	19,000	120	0.3	0.2	120	10
300382	1,520	8	1.6	<1	<3	2	1	40	15	<0.1	<0.1	10	<12
010782	24,500	303	2.0	1	1	23	3	12,000	140	<0.2	<0.1	50	14
160982	34,600	812	-	1	<1	56	7	14,000	120	<0.2	<0.1	90	5
Station: Susitna River at Sunshine (15292780)													
250381	3,800	2	2.6	0	<1	5	4	160	40	0.1	0.1	20	30
250681	55,000	735	-	0	<1	52	4	26,000	190	0.6	0	200	6
230781	86,300	713	4.7	1	0	42	3	23,000	250	0.3	0.1	90	20
020782	58,700	659	4.7	<1	<1	30	5	20,000	220	0.2	<0.1	80	9
150982	70,100	1,620	-	<1	<1	75	12	29,000	200	0.2	0.1	130	17
Station: Susitna River at Susitna Station (15294350)													
031085	47,500	159	-	10	0	20	5	3,800	120	0.2	0.2	10	10
170376	5,380	2	-	10	0	10	2	240	60	0	0.1	30	0
280576	67,900	257	-	2	1	40	10	3,300	140	<0.5	<0.5	20	0
260776	99,100	785	-	<10	0	50	0	26,000	30	0.3	0	100	0
061076	30,600	191	-	<10	0	<10	1	5,400	40	0.3	0.4	30	10
090377	6,790	-	-	<10	0	<10	2	560	90	0	0	20	10
230577	86,800	378	-	<10	0	20	1	10,000	150	0	0	50	20
190877	148,000	1,490	0.1	10	1	90	1	42,000	70	0.2	0	180	4
131277	7,020	10	0.7	0	0	7	4	360	60	0	0	20	10
050478	6,420	2	-	1	1	3	1	230	60	0	0	10	10
240578	55,300	-	1.8	0	1	24	4	5,600	110	0.1	0	30	10
170778	120,000	773	2.3	2	1	45	1	24,000	20	0.2	0.1	90	10
150179	9,890	3	9.3	0	1	3	2	490	90	0.1	0	10	3
140579	86,800	683[2]	6.8	1	0	25	4	14,000	170	0.2	0	50	10
190679	95,200	416	0.9	1	1	29	1	12,000	0	0.1	0	60	10
170979	87,700	901	0.6	0	<1	37	1	26,000	40	0.1	0	80	<3
120380	9,360	3	-	0	0	5	2	450	150	0.1	0	20	<3
160680	144,000	458	5.9	0	-	26	2	16,000	20	0.1	0	50	<3
300780	207,000	1,490	3.7	0	0	75	3	38,000	140	0.1	0	140	7
090481	7,780	4	2.1	0	<1	3	0	390	160	0.1	0	60	<3
120681	88,600	326	3.4	2	<1	28	7	15,000	90	0.3	0	50	20
150781	173,000	920	2.9	0	<1	90	5	28,000	50	0.8	0.2	160	6
090482	4,000	9	-	<1	<3	2	1	320	65	<0.1	<0.1	10	<12
190582	54,800	526	-	<1	<3	28	5	9,900	190	0.1	<0.1	60	<12
140782	103,000	797	-	1	<1	32	3	7,900	69	0.2	0.2	110	5

1/ All concentrations are in micrograms per liter unless otherwise indicated
2/ Estimated

410758
850215

Bioaccumulation of mercury occurs rapidly, within one to three years of impoundment (1, 6). Abernathy and Cumbie (1) demonstrated that mercury accumlation by fish in new South Carolina impoundments decreases with reservoir age, beginning as early as five years after impoundment. In northern Manitoba, Bodaly et al. (6) found no significant declines in fish mercury levels within five to eight years after impoundment, with the possible exception of whitefish (Coregonus clupeaformis). Reservoirs age more quickly in the warm climate of South Carolina than in the subarctic conditions in northern Manitoba. The mercury methylation and bioaccumulation rates in the Susitna Project reservoirs, which may vary directly with the aging process, will probably decrease due to the following combination of factors: relatively cold temperature, low levels of reservoir primary productivity, death and replacement of the initial fish populations, and a continually deepening layer of predominately inorganic sediment, which acts as a blanket to isolate the inundated soils and vegetation from the overlying water column.

Review of the relevant literature supports the following conclusions regarding the potential for bioaccumulation of mercury in fishes in the Susitna Reservoirs. After inundation, microbiological methylation of mercury from the organic soil horizons of Watana and Devil Canyon Reservoirs may result in mercury levels in the reservoir fish somewhat higher than current concentrations. Environmental conditions at the sediment-water interface in Watana and Devil Canyon Reservoirs will tend to minimize biomethylation and subsequent bioaccumulation of mercury in the reservoirs. Methylmercury release from sediments at 4°C has been found to be 50 to 70 percent of that at 20°C, in laboratory studies (34). Biomethylation may be directly related to microbiological activity in sediments (5, 34). This implies that biomethylation will be low in the cold Susitna reservoirs. Additionally, the high inputs of inorganic suspended sediments (glacial flour) may scavenge mercury from the water column. The suspended solids that settle to the floor of the reservoir will blanket the inundated soils and vegetation, and tend to isolate the organic matter reported to be the major source of mercury for methylation and bioaccumulation. Thus, even though there may be some detectable increases of mercury in reservoir fishes in both impoundments, natural conditions should tend to keep these increases low. Moreover, fish populations in the reservoirs are not expected to be high, nor are they expected to be significantly harvested by man (2, 13).

We have found no studies of mercury accumulation in fish downstream of newly impounded reservoirs. The impact of the Project on mercury accumulation in fish downstream will likely be a function of the mercury species and quantities exported from the reservoirs and in situ effects involving mercury in downstream habitats. Since mercury is transported primarily in suspension (inorganic Hg), a net reduction in the flux of mercury downstream will result from impoundment construction. Quantitative estimates of methylmercury export from the reservoirs cannot be reliably predicted at this time. Mercury accumulation in fish downstream from the dams may be largely a process of in situ methylation and uptake, which will be influenced by project-related changes in river productivity at all levels of the aquatic ecosystem. Instream mercury methylation (and accumulation) may change with alterations in microbial activity resulting from changes in turbidity, productivity, and supply of organic material to methylating bacteria.

Copper

Concentration in the Susitna River. The USGS has monitored total and dissolved copper concentrations in the Susitna River and has published this information in their annual Water Resource Data reports. Total and dissolved copper concentrations are tabulated (Table 1). Total copper ranged from less than 10 ug/L to 190 ug/L; dissolved copper ranged from zero to 12 ug/L. While total copper concentrations in Susitna River water are typical of most rivers, dissolved copper concentrations are on the high end of published concentration ranges (15, 23, 33). Thus, a relatively high percentage of copper in the Susitna River is transported as the soluble form. Total copper appears to be linearly correlated with suspended solids, but not to dissolved copper. Dissolved copper apparently is not related to dissolved organic carbon.

Potential Impacts on Reservoir and Downstream Fisheries. Many studies have shown that copper does not bioaccumulate, even in polluted waters. Copper is, however, toxic to aquatic plants, invertebrates and fishes (23). Acute toxicity to freshwater fishes depends upon copper speciation, which is largely a function of water hardness and concentrations of suspended solids and organic ligands.

Copper is likely to be leached from inundated soils following the impoundment of the Susitna River. We have found no studies of this phenomenon in the published literature. However, increased concentrations of humic solutes, from soils and decomposing vegetation, can bind metals in the rocks and soils, and increase their concentration in the water column. Schnitzer and Kahn (30) noted copper's particular affinity for humic ligands. However, organocopper complexes are significantly less toxic than free Cu or hydroxocopper, so increased levels of dissolved copper do not necessarily indicate a more biologically toxic condition in the aquatic habitat (23).

Cadmium

Concentrations in the Susitna River. Total and dissolved cadmium concentrations in the Susitna River are shown in Table 1. Total cadmium ranged from zero to ten ug/L; dissolved cadmium was always determined to be less than 3 ug/L. Cadmium levels in the Susitna River do not seem to be related to river discharge, suspended solids concentrations, or levels of dissolved organic carbon. In fact, the concentrations of total and dissolved cadmium are generally low, compared to those reported elsewhere (23).

Potential Impacts on Reservoir and Downstream Fisheries. No published studies on cadmium leaching from inundated soils in new impoundments have been found, but it may occur. A quantitative estimate of cadmiam leaching from the project reservoir(s) is not possible to make at this time. Assuming that soil cadmium levels are not high (a potentially valid assumption, given the low levels in river water), cadmium leaching by humic substances will be less than copper leaching, because cadmium has a much lower affinity for organic ligands than copper (32).

Zinc

Concentrations in the Susitna River. Zinc levels in the Susitna River, as reported by the USGS, are shown in Table 1. Total zinc varies from 10 to 200 ug/L; dissolved zinc ranges from zero to 30 ug/L. Zinc exists primarily in the particulate form in the Susitna River, contrary to a study by Tessier et al. (33) on two rivers in Quebec, where zinc was found to exist primarily as the dissolved form. In fact, many studies have shown zinc in natural waters to be predominantly in the soluble fraction (4, 31). Total zinc in the Susitna River appears to be linearly related to suspended solid concentrations, and seasonally fluctuates in a manner similar to that of suspended solid concentrations (and river discharge). Dissolved zinc does not appear to be related to suspended solids, dissolved organic carbon, or total zinc. Dissolved zinc exhibits much less seasonal variation than total zinc, possibly indicating that groundwater is a major source of dissolved zinc in the Susitna River.

Potential Impacts on Reservoir and Downstream Fisheries. We have found no reports of elevated zinc concentrations in newly impounded reservoirs. It is possible that inundation of rock and soil will leach zinc into the water column, but it is impossible to quantify this at present.

There is little evidence that zinc bioaccumulates in exposed plants or animals. The presence of organic chelates (i.e., humic solutes) may significantly reduce sorption of zinc by fish (23).

MITIGATION

Mitigation Measures Endorsed by the Alaska Power Authority

The Alaska Power Authority has proposes to include the monitoring of mercury bioaccumulation in selected sport fishes of the Susitna watershed in the Long Term Monitoring Program now in preparation. If the monitoring program indicates unsafe concentrations of mercury in selected sport fish tissues, plans will be prepared, in consultation with appropriate state and Federal agencies, to mitigate for potential heavy metal-related environmental hazards.

References Cited

1. Abernathy, A.R., and P.M. Cumbie. 1977. Mercury accumulation by largemouth bass (Micropterus salmoides) in recently impounded reservoirs. Bull. Environ. Contam. Toxicol. 17(5): 595-602.

2. Alaska Power Authority. 1983. Susitna Hydroelectric Project. FERC License Application Project No. 7114-000. Volume 5A Exhibit E, Chapters 1 and 2. Prepared by Acres American.

3. Baxter, R.M. and P. Glaude. 1980. Environmental effects of dams and impoundments in Canada: experience and prospects. Can Bull. Fish Aquatic Sci. 205: 34 p.

4. Benes, P., and E. Steinnes. 1974. In situ dialysis for the determination of the state of trace elements in natural waters. Water Research 8: 947-953.

5. Bisogni, J.J. Jr., and A.W. Lawrence. 1975. Kinetics of mercury methylation in aerobic and anaerobic aquatic environments. J. Water. Poll. Cont. Fed. 74(1): 135-152.

6. Bodaly, R.A., R.E. Hecky, and R.J.P. Fudge. In press. Increases in fish mercury levels in lakes flooded by the Churchill River diversion, northern Manitoba. Can. J. Fish. Aquat. Sci.

7. Campbell, P.G., B. Bobee, A. Caille, M.J. Demalsy, P. Damalsy, J.L. Sasseville and S.A. Visser. 1975. Pre-impoundment site preparation: a study of the effects of topsoil stripping on reservoir water quality. Verh. Internat. Verein. Limnol. 19: 1768-1777.

8. Christman, R.F. and E.T. Gjessing, Eds. 1983. Aquatic and terrestrial humic materials. Ann Arbor Science Publishers, Ann Arbor MI. 538 pp.

9. Cox, J.A., J. Carnahan, J. DiNunzio, J. McCoy, and J. Meister. 1979. Source of mercury in fish in new impoundments. Bull. Environ. Contam. Toxicol. 23: 779-783.

10. Cranston, R.E., and D.E. Buckley. 1972. Mercury pathways in a river and estuary. Environ. Sci. Technol. 6: 274-278.

11. Davis, J.A. 1984. Complexation of trace metals by absorbed natural organic matter. Geochim. Cosmochim. Acta 48: 679-691.

12. EPA (Environmental Protection Agency). 1980. Ambient water quality for mercury. EPA 440-5-80-058, 136 pp.

13. FERC (Federal Energy Regulatory Commission). 1984. Draft Environmental Impact Statement for Susitna Hydroelectric Project, FERC No. 7114-Alaska. FERC/DEIS-0038.

14. Fimreite, N., W.N. Holsworth, J.A. Keith, P.A. Pearce, and I.M. Gruchy. 1971. Mercury in fish and fish-eating birds near sites of industrial contamination in Canada. Can. Field. Nat. 85: 211-220.

15. Gibbs, R.J. 1977. Transport phases of transition metals in the Amazon and Yukon Rivers. Geol. Soc. Amer. Bull. 88: 829-843.

16. Hannan, P.J. and N.P. Thompson. 1977. Uptake and release of Hg-203 by selected soil and sediment samples. J. Water Poll. Control. Fed. 49: 842-847.

17. Harza-Ebasco Susitna Joint Venture. 1984. Aquatic Plan of Study Fiscal Year 1985. Susitna Hydroelectric Project Document No. 591. Alaska Power Authority, Anchorage, AK.

18. Jackson, K.S., I.R. Jonasson, and G.B. Skippen. 1978. The nature of metals-sediment-water interaction in freshwater bodies, with emphasis on the role of organic matter. Earth-Sci. Rev. 14: 97-146.

19. Jernelov, A. and H. Lann. 1973. Studies in Sweden on feasibility of some methods for restoration of mercury-contaminated bodies of water. Environ. Sci. Technol. 7(8): 712-718.

20. Jonasson, I.R., and R.W. Boyle. 1972. Geochemistry of mercury and origins of natural contamination of the environment. Canad. Mining & Metallurg. Bull. January, 1972. pp. 1-8.

21. Lockwood, R.A. and K.Y. Chen. 1973. Absorption of Hg (II) by hydrous manganese oxides. Environ. Sci. Technol. 7(11): 1028-1034.

22. Meister, J.F., J. DiNunzio and J.A. Cox. 1979. Source and level of mercury in a new impoundment. J. Amer. Wat. Wrks. Assoc. 1979: 574-576.

23. Moore, J.W., and S. Ramamoorthy, 1984. Heavy metals in natural waters: Applied Monitoring and Impact Assessment. Springer-Verlag, New York.

24. Phillips. G.R., T.E. Lenhart and R.W. Gregory. 1980. Relation between trophic position and mercury accumulation among fishes from the Tongue River Reservoir, Montana. Environ. Res. 22: 73-80.

25. Potter, L., D. Kidd, and D. Strandiford. 1975. Mercury levels in Lake Powell. Bioamplification of mercury in man-made desert reservoir. Environ. Sci. Tech. 9(1): 41-46.

26. R&M Consultants, Inc. 1982. Water Quality Annual Report, 1982. Alaska Power Authority, Anchorage, AK. Prepared for Acres American, Inc.

27. Rudd, J.W.M., and M.A. Turner. 1983a. The English-Wabigoon River system: II. Suppression of mercury and selenium bioaccumulation by suspended and bottom sediments. Can. J. Fish. Aquat. Sci. 40: 2218-2227.

28. Rudd, J.W.M., and M.A. Turner, 1983b. The English-Wabigoon River system: V. Mercury and selenium bioaccumulation as a function of aquatic primary productivity. Can J. Fish. Aquat. Sci. 40-2251-2259.

29. Rudd, J.W.M., M.A. Turner, A. Furutani, A.L. Swick, and B.E. Townsend, 1983b. The English-Wabigoon River system: I. A synthesis of recent research with a view towards mercury amelioration. Can J. Fish. Aquat. Sci. 40: 2206-2217.

30. Schnitzer, M. and S.U. Khan. 1972. Humic Substances in the Environment. Mercel Dekker, New York. 344 pp.

31. Steinberg, C. 1980. Species of dissolved metals derived from oligotrophic hard water. Water research 14: 1239-1250.

32. Stumm, W., and J.J. Morgan. 1981. Aquatic Chemistry, 2nd Edition. John Wiley and Sons, New York, 780 pp.

33. Tessier, A., P.G.C. Campbell and M. Bisson. 1980. Trace metal speciation in the Yamaska and St. Francois Rivers (Quebec). Can. J. Earth Sci. 17: 90-105.

34. Wright, D.R. and R.D. Hamilton. 1982. Release of methylmercury from sediments: effects of mercury concentration, low temperature and nutrient addition. Can. J. Fish. Aquat. Sci. 39: 1459-1466.