INTERIM REPORT ON PROPOSED KRAFT PULP MILLS ON THE FRASER RIVER NEAR PRINCE GEORGE WITH RECOMMENDATIONS FOR THE TREATMENT AND DISPOSAL OF WASTES

THIS REPORT HAS BEEN PREPARED BY THE TECHNICAL STAFFS OF THE DEPARTMENT OF FISHERIES OF CANADA AND THE INTERNATIONAL PACIFIC SALMON FISHERIES COMMISSION IN COLLABORATION WITH THE FISH AND GAME BRANCH, BRITISH COLUMBIA DEPARTMENT OF RECREATION AND CONSERVATION.

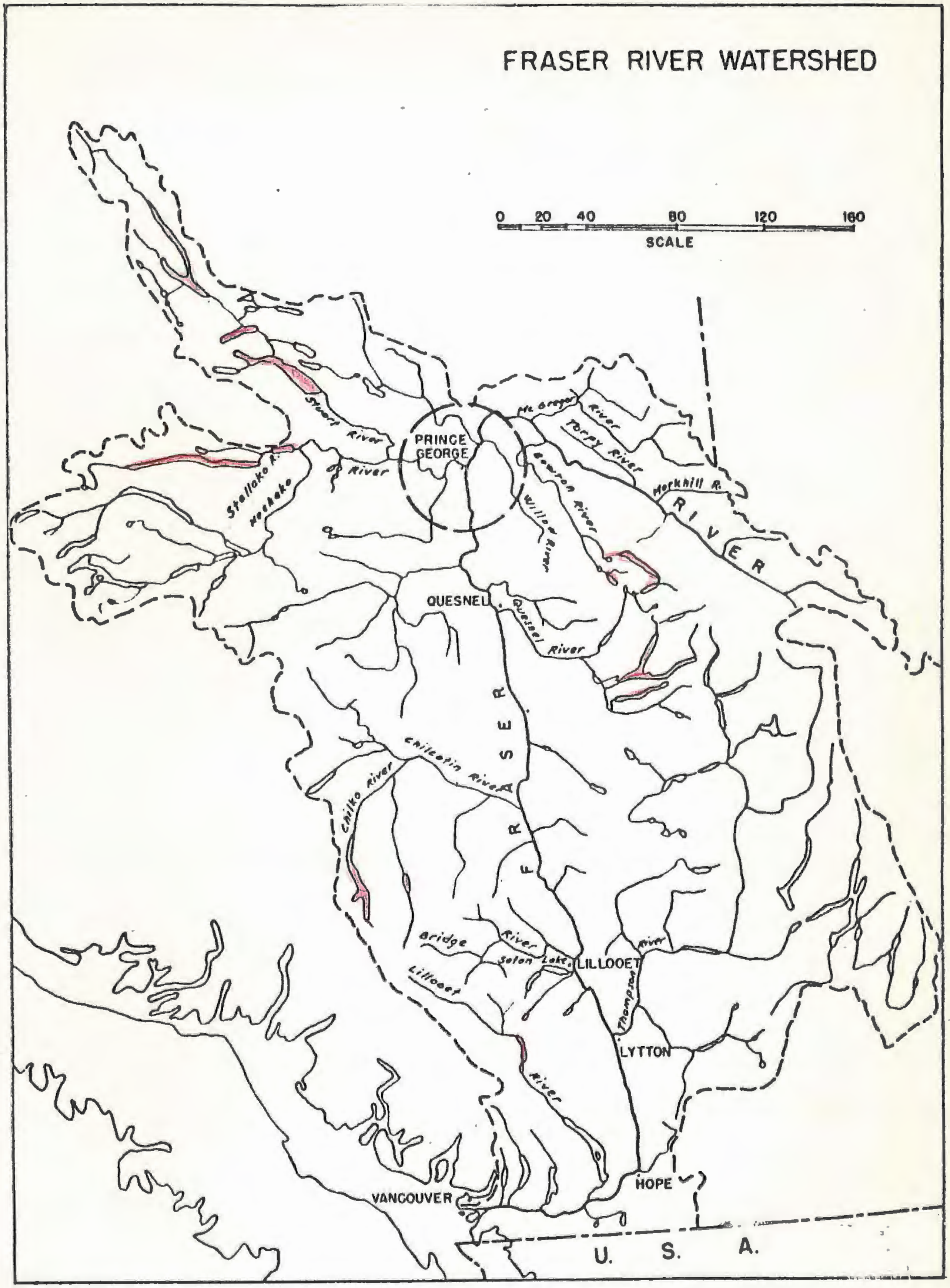
Vancouver, B. C.

September, 1961.

INTERIM REPORT ON PROPOSED KRAFT PULP MILLS ON THE FRASER RIVER NEAR PRINCE GEORGE WITH RECOMMENDATIONS FOR THE TREATMENT AND DISPOSAL OF WASTES

THIS REPORT HAS BEEN PREPARED BY THE TECHNICAL STAFFS OF THE DEPARTMENT OF FISHERIES OF CANADA AND THE INTERNATIONAL PACIFIC SALMON FISHERIES COMMISSION IN COLLABORATION WITH THE FISH AND GAME BRANCH, BRITISH COLUMBIA DEPARTMENT OF RECREATION AND CONSERVATION.

Vancouver, B. C.
September, 1961.


FRASER RIVER WATERSHED
0 20 40 80 120 160
SCALE
PRINCE GEORGE
QUESNEL
LILLOOET
LYTTON
HOPE
VANCOUVER
U. S. A.
Stuart River
Stellako R.
Nechako River
Mc Gregor River
Torpy River
Bowron River
Willow River
Morkill R.
RIVER
Quesnel River
FRASER
Chilcotin River
Chilko River
Bridge River
Seton Lake
Lillooet River
Thompson River

Interim Report on Proposed Kraft Pulp Mills on the Fraser River near Prince George with Recommendations for the Treatment and Disposal of Wastes

Basis of Report

During recent months several enquiries have been received by the Department of Fisheries of Canada with respect to the waste disposal aspects of pulp mills under consideration in the vicinity of Prince George on the Fraser River. Preliminary information indicates that the proposed pulp mills would produce kraft pulp or bleached kraft pulp, with initial production capacities of 300 to 400 tons per day and possible future expansion of production to 500 tons per day per mill. At the time of preparing this report, it is known that one mill proposes to produce bleached kraft pulp, and so far as can be determined the others would produce unbleached kraft. In view of the importance of the Fraser River system in the production of commercially valuable stocks of salmon and steelhead trout as well as sport fish, it has been recognized that careful consideration must be given to the possible effects of waste disposal from such mills on these stocks.

This report presents an evaluation of the fishery that could be affected, together with assessment of the effects of pulp mill waste disposal and of practical means of waste reduction or treatment. The conclusions and recommendations set forth the guiding principles for requirements necessary for the protection of the fishery. As will be evident from the text of the report, additional research is required to fully evaluate the effect of pulp mill wastes on salmon and sport fish, and also on methods of eliminating sources of harmful wastes from pulp mill effluent. It is not the purpose of this report to review all aspects of these two phases of the problem, but use will be made of any data available which is pertinent to the problems being examined.

The Salmon and Steelhead Trout Fishery of the Fraser River System

The Fraser River system is one of the world's largest producers of salmon. Five species of Pacific salmon are indigenous to the system as well as steelhead trout and all these are utilized commercially. The International Pacific Salmon Fisheries Commission is responsible under Treaty between Canada and the United States for the protection, preservation, and extension of the sockeye and pink salmon stocks of the Fraser River system. During the period 1957-60 the commercial pack of Fraser River sockeye had an average annual value of $20,330,000 on the basis of the wholesale prices for each year. Approximately forty per cent of this pack was derived from sockeye runs which migrate up the river past Lillooet to spawning grounds on the Chilko, Quesnel, Bowron, Stuart and Stellako River systems. The total pack of sockeye obtained during the period 1957-60 was almost 58 per cent of the total pack obtained during 1910-13 which is considered to represent the historical potential of the river. The potential level of production represented by the period 1910-13 would have an average annual value of $44,116,000 on the basis of 1960 wholesale prices, of which 60 per cent would be derived from the runs migrating upstream past Lillooet. It is expected that this potential can be achieved in relatively few cycles.

Pink salmon catches in recent cycles are not indicative of the production possible. The 1959 pack had a value of $7,780,000, whereas the 1947 pack would have a value of $19,200,000 and there is evidence that this run was only about one-third of the potential size of catch when the runs are fully restored. Since pink salmon runs occur only in odd numbered years on the Fraser River, the average annual value would be one-half the above values. Pink salmon do not migrate up the Fraser River past Lillooet in any significant numbers. In 1957 there were over 1 1/4 million spawners in the Fraser River below Hope and this area together with the Thompson River system represents the main potential for expansion to the originally established production. While no pink salmon would be in the immediate vicinity of the mills at Prince George, possible effects of mill wastes on these lower Fraser River populations must be considered.

The present wholesale value of the Fraser River chinook (spring) salmon pack is approximately $3,000,000 annually, of which about 50 per cent is derived from stocks which spawn upstream from Lillooet principally in the Chilko, Quesnel, Stuart, and Nechako River systems and in the Fraser River above Prince George and many of its tributaries in this area, such as the McGregor, Torpy, Morkill and Bowron Rivers.

Coho salmon migrate up the Fraser River as far as Seton Creek at Lillooet, but the major spawning grounds above Hope are in the Thompson River system. The catch of this species has an average annual value of at least $1,375,000. Chum salmon spawn in tributaries downstream from Hope with a large population spawning in the main stem of the Fraser River. Neither of these species would be in the vicinity of the pulp mills near Prince George, but as with pink salmon, consideration must be given to possible effects of the pulp mill wastes on these populations. Steelhead trout migrate up the Fraser River into the Chilko River system. Ling, rainbow trout, sturgeon and whitefish contribute to the sport fishery in the Fraser River near Prince George. The value of these species as sport fish is difficult to assess but as population increases, the value of these fish for sport fishing is bound to increase. The salmon migrating up the Fraser River are also a substantial source of food for approximately 10,000 native Indians, who fish for the salmon at many locations along the entire length of the Fraser River, up to Prince George, as well as on many of its tributaries.

Each of the species of salmon and trout have different freshwater life histories. These have been described in detail in other reports and will not be repeated here. Table 1 presents a summary of the periods during which the species are present in the river system during various phases of their life cycles, both at Prince George and at Hope.

TABLE 1: Period of Occurrence of Salmon and Trout in the Fraser River.

(a) At Prince George

	As Fry	Yearling Migration	Adult Migration
Sockeye	Not present	April 15 - June 20	July 5 - October 7
Chinook	All months	April 1 - July 20	July 1 - August 26

(b) At Hope

	As Fry	Yearling Migration	Adult Migration
Sockeye	Not present	April 15 - June 20	June 20 - October 26
Pink	Mar.1-May 31	Not present	Aug. 20 - October 6
Chinook	All months	April 1 - July 25	All months
Steelhead	All months	April 15 - July 15	January to December
Coho	All months	April 15 - June 30	August 15 - January 15
Chum	Mar.1-June 30	Not present	October 1 - January 15

<u>Wastes From Kraft Pulping Process</u>

Since the details of the kraft pulping process are adequately described in the literature, full description of the process will not be attempted in this report. The kraft process is now the principal alkaline pulping process. It produces pulp by treating wood chips with a solution of sodium sulphide and caustic soda to separate the cellulose fibres from lignin in the wood. The cellulose fibres are then separated from the cooking liquor which contains the dissolved lignin together with the cooking chemicals as well as a number of other materials. As much as possible of the cooking liquor is retained within the mill for recovery of process chemicals. This procedure is followed as a matter of economy, but it also results in minimizing the pollution load in the waste waters discharged from the mill. The separated cellulose fibres are washed and may then be formed into unbleached kraft products, or kraft pulp bales for shipment or may be further processed by bleaching for use in making bright kraft pulp or paper products.

(a) Water Requirements

Since the amount of water used by a pulp mill is one of the factors which influence the characteristics of the wastes discharged from the mill, it is of value to consider the amounts of water required and means of reducing the water requirement.

Early texts on unbleached kraft pulp making indicate a maximum water requirement of 115,000 U.S. gallons per ton of air dry pulp produced (1). However in the interests of economy water use has been reduced considerably in modern kraft mills. White water from machines, showers and condensers is recirculated, weak black liquor is used for volume make up in the digesters and dilution in the blow tank, and washings from the liquor room are used for smelt dissolving. These practices were reported in the literature to reduce the freshwater requirements to 30,000 to 60,000 gallons per ton, with an average of 35,000 gallons per ton of pulp (2, 3, 4, 5, 6, 7). More recently (8) it has been reported that the average water requirement for kraft pulping is 20,000 gallons per ton. At one kraft pulp mill where management takes every possible precaution to minimize the pollution load in the mill effluent, water requirements have been reduced to about 17,000 gallons per ton including the hydraulic log barker.

Where bleached kraft pulp is to be produced, additional fresh water is required, the amount being determined by the brightness of the product desired and practice followed in re-use of waters. In multistage bleaching employed on kraft pulps about 10,000 gallons are required per ton of pulp for each stage. Hard bleaching kraft pulps may require as many as 6 or 7 stages, which would require 60,000 to 70,000 gallons per ton. However, again in the interest of water economy, as much as possible of this water is re-used in modern mills (9), and the freshwater requirement is reduced to 20,000 to 40,000 gallons per ton, (8) depending on the degree of bleaching required.

(b) <u>Waste Sources and Characteristics</u>

1. <u>Water Treatment Wastes</u>

Fresh water taken into the mill system may require treatment for removal of suspended materials. The most common treatment is flocculation with alum and settling, sometimes followed by filtration. The accumulated sludge and aluminum hydroxide precipitate must be removed periodically from the treatment basin. The precipitates formed are injurious to fish through clogging and corrosive action on the gill tissues (10) and the disposal of the sludge to the Fraser River could create a hazard to salmon migrating in the river. It is essential therefore that this sludge be disposed of on plant property where it cannot be washed into the river.

2. <u>Hydraulic Log Barker Wastes</u>

Hydraulic log barkers are commonly used for the removal of bark from pulp logs, although mechanical barkers are also used where suitable. Mechanical barkers are preferable in respect to reducing water requirement and reducing waste disposal problems. Hydraulic barkers require up to 1800 gpm of water depending on type and size. The waste waters contain dirt and disintegrated bark particles of various sizes, and dissolved wood solubles. It is common practice to recover a large portion of the bark particles by coarse and fine screening, but even the effluent from such screening may contain up to 0.2% solids by weight, depending on the type of screening used. Continuous operation of a hydraulic barker at 1800 gpm at 0.2% suspended solids content would represent a waste discharge of 216 tons of suspended solids per day. The waste waters would also have a 5 day BOD of at least 100 ppm.

The disposal of these wastes to the Fraser River would present an additional physical hazard to salmon due to clogging action of the solids on the gills. Accumulations of the waste on the river bed would also result in release of decomposition products such as hydrogen sulphide which are toxic to fish.

In an effort to conserve water, some mills have installed very fine mesh final screening of barker effluent and recirculate the clarified water to the barker. In one instance the fine screening is followed by settling in a lagoon, from which the water is discharged to an adjacent stream.

In the interest of water economy and waste disposal reduction, it is suggested that at any hydraulic barker installation, consideration should be given to the recirculation of clarified barker effluent. A suggested method of screening would consist of coarse screening on a vibrating 3/4 inch mesh screen, followed by a 150 mesh Sweco type screen.

The minimum requirement would consist of screening followed by settling to produce an effluent containing not more than 0.3 pounds of settleable solids per 1000 gallons. If mechanical log barkers are used the wastes should be burned or otherwise disposed of on land.

3. Pulping and Bleaching Wastes

In a modern kraft pulp mill the loss of pulping chemicals can be kept to 5% of the amount used in the digesters (9) or about 108 pounds expressed as sodium sulphate per ton of pulp produced. In one mill this loss has been reduced to 80 pounds through in-plant practices which will be described later. Table 2 gives the breakdown of the source of losses, expressed in pounds of sodium sulphate per ton of pulp produced (9).

TABLE 2: Sources of Chemical Loss From Kraft Pulp Mills

Recovery Furnace Stack	50% or 54 lbs
Pulp Washing	35% or 38 lbs
Fibre	7% or 7 lbs
Other (Condensates)	8% or 9 lbs

The final pulp wash and the contaminated condensates are normally discarded, and are the principal sources of pollution from the pulping operation. The characteristics of the three sources of these wastes are approximately as follows:

Evaporator Condensate	3200 gpt	600 - 800 ppm BOD
Evaporator Hot Well	1800 gpt	100 ppm BOD
Final Pulp Wash	5000 gpt	400 - 600 ppm BOD

If unbleached kraft pulp is produced, there will be an additional effluent of surplus white water from the Fourdrinier machine. In order to save water and fibre, it is common practice to recover fibre from the machine waters in a save-all and to recirculate as much white water as possible. The effluent from this stage is between 3500 and 5000 gpt with a BOD of 100 ppm. Efficient save-alls can reduce the fibre loss to 0.3 pounds or less per 1000 gallons.

The final combined effluent from a kraft pulp mill will have a pH between 7.5 and 11.5. Data for three mills (7, 11, 12) indicates a normal range between 8.5 and 10.0. The BOD of effluents from modern mills may be 30 pounds of oxygen per ton of pulp (8), although BOD's as high as 60 pounds and as low as 15 pounds have been reported depending on in-plant practice to reduce the loss of strong wastes. Suspended solids are reported to be generally less than 20 pounds per ton and total solids 200 to 300 pounds per ton (8).

Bleaching of kraft pulps is done by multistage treatments with chlorine, caustic soda and hypochlorite with intermediate and final washes to remove the solubilized impurities and a final treatment with dilute sulphurous acid. Depending on the character of the pulp and the degree of bleaching desired the chlorination and caustic treatments may be done twice, followed by one or more stages of hypochlorite treatment. Normally the only flow to sewer is from the chlorinated pulp washer and from the first caustic extraction, as these waters contain from 60% to 70% of the impurities. It is general practice to make as much re-use of water as possible within the process, and in addition white water may be used in the final hypochlorite stage (9). The effluent from the bleach plant operation will have a BOD of 10-34 pounds of oxygen per ton of pulp (8, 9). The pH of the effluent may vary between 2.7 and 8.0 depending on the resulting mixture of the acid and alkaline wastes from the batch process (8, 13). The total solids content ranges between 0.1% and 0.2% (8), which at 40,000 gpt water amounts to 330 to 660 pounds per ton of pulp, and suspended solids amount to 15 to 25 pounds per ton (8). The dissolved solids consist of chloride, sulfate, hydroxide and carbonate salts of sodium and calcium, as well as soluble forms of lignin.

Combining the alkaline pulping waste with the bleach plant wastes produces an effluent which would have a pH from 4.5 to 6.0 although a pH as low as 2.7 has been observed (13). Where the combined mixture has a pH less than 6.0 sulphides and mercaptans will be absent and the effluent will have high clarity and stability (13). The BOD of the combined effluent is reported to be in the range from 40 to 55 pounds per ton of pulp produced (8).

According to Sutermeister (14) kraft mill effluents may contain the following compounds: sodium carbonate, sodium hydroxide, sodium sulphide, sodium sulphite, sodium sulphate, sodium chloride, hydrogen sulphide, methyl mercaptan, and sodium combined with resin and fatty acids (soaps). Van Horn, Anderson and Katz (11) list the following additional components of kraft mill effluent: sodium thiosulphate, formaldehyde, crude sulphate soap, sodium oleate, phytosterol, and sodium abietate. Table 3 lists reported measurements of some of the characteristic components of the waste (7, 11, 12).

Effect of Wastes on Salmon and Trout

The effects on salmon and trout of kraft pulp mill effluent must be considered with respect to the dissolved oxygen demand, toxicity of chemical compounds, pH, suspended solids content and temperature of the waste.

(a) Dissolved Oxygen

It is generally recognized that the dissolved oxygen concentration of rivers and streams must be above a certain minimum level to maintain fish and other aquatic life and that the minimum level varies with different forms of life and habitat. A number of experiments have been conducted to determine the minimum requirements of salmon, but these are limiting values and are not considered representative of the requirements of salmon migrating hundreds of miles up or down a river. Great physical exertion and physiological changes in maturing adult salmon will undoubtedly require more than minimum dissolved oxygen content for survival. Ellis (15) concluded that 5 ppm dissolved oxygen seems to be the lowest value which may reasonably be expected to maintain a varied fish fauna when the

TABLE 3: Chemical Analyses of Main Sewer Effluent, Kraft Pulp Mills

Substance	Mill	Concentration in PPM Min.	Max.	Average
Sulphides	1	0	88.4	4.46
	2	0	4.5	1.61
	3	0	0.2	0.04
	4	0	0.5	0.07
Mercaptans	1	0.6	15.8	2.74
	2	3.4	5.5	4.45
	3	1.2	8.6	3.46
	4	3.4	5.8	4.29
NaOH	1	0	391.0 pH ≈ 12	28.97
	2	0	22.8	6.41
	3	4.0	85.3	32.1
NaOH + Na_2S	4	0	36.0	16.51
Resin Acid Soaps	1	2.0	18.0	5.37
	2	3.0	5.0	3.67
	3	0	2.0	1.2
	4	1.6	18.0	4.66
pH	1	7.6	10.6	8.7
	2	7.2	9.7	8.55
	3	8.75	11.3	10.0
	4	7.6	9.95	9.16

water temperature is 20°C or higher, and that cold water fishes may require even higher dissolved oxygen levels. Alderdice (34) has found that at oxygen levels below saturation value, the resistance times of young coho salmon to oxidized kraft black liquor are strongly depressed. These and other considerations lead to the conclusion that the dissolved oxygen content of streams supporting the higher forms of cold water fish should not be greatly reduced below natural levels, but it is not possible on the basis of available knowledge to specify a generalized limit.

The dissolved oxygen content of the Fraser River at Prince George varied between 9.3 and 12.9 ppm during one year of record (16). During this period the oxygen content varied between 91% and 101.6% of saturation, indicating that there was an existing oxygen demand in this portion of the Fraser River. Actual measurements in April, 1954 determined the 5 day BOD to be 3.07 ppm at 20°C (17). Table 4 presents estimates of the dissolved oxygen content of the Fraser River at Shelley (above Prince George) based on available data.

The period of lowest oxygen concentration is during September, and the period of lowest total oxygen content in the river is during April. A detailed analysis of the Fraser River between Prince George and Pavilion using available data on natural BOD and re-aeration rate (17) indicates that with pulp mills discharging in the vicinity of Prince George, the maximum oxygen deficit will occur between 1 and 1.4 days travel time downstream, which is in the vicinity of Quesnel. Table 5 summarizes the basic conditions for the calculations.

A series of calculations showed that a BOD loading of 13.5 ppm in excess of the natural loading could be applied at Prince George without causing serious depletion of dissolved oxygen in the river. This loading corresponds to 795,000 pounds per day of 5 day BOD, which at the average figure of 55 pounds BOD per ton of bleached pulp produced, would correspond to a production of 14,500 tons

TABLE 4

Minimum Monthly Flows and Dissolved Oxygen

Fraser River at Shelley

Period 1950-59

	Discharge cfs	Temp. °F. Max.	Min.	Oxygen Saturation %	Dissolved Oxygen ppm at 950 millibars	Totals Oxygen Flow lbs per day
Jan.	4120	33	33	94	12.7	282,000
Feb.	4000	33	33	95	12.8	273,000
Mar.	3850	33	33	95	12.8	263,000
Apr.	3950	48	33	95	10.4 - 12.8	218,000 - 270,000
May	9000	51	40	100	10.5 - 12.2	508,000 - 593,000
June	37600	54	45	100	10.1 - 11.4	2,060,000 - 2,310,000
July	25500	64	50	101.6	9.1 - 10.7	1,235,000 - 1,455,000
Aug.	15100	64	49	100	9.0 - 10.7	730,000 - 876,000
Sept.	7570	58	42	91	8.7 - 10.6	350,000 - 427,000
Oct.	6070	48	41	92	10.0 - 11.0	324,000 - 356,000
Nov.	3840	38	33	92	11.5 - 12.4	236,000 - 254,000
Dec.	3480	33	33	93	12.5	232,000

TABLE 5: Conditions for the Calculation of Oxygen Depletion

	Date Sept. 30, 1951	April 15, 1957
Flow Prince George to Quesnel, CFS	11,050	7,870
Temp. °F	51	33
Initial Oxygen deficit, ppm	0.95	0.65
K_1 (deoxygenation constant)	0.097	0.0625
K_2 (reaeration constant)	0.85	0.55
Initial dissolved oxygen, ppm	9.5	12.7

per day. This production is nearly ten times the capacity of the mills being proposed, and it is not considered that the proposed pulp mills alone would cause any serious depletion of dissolved oxygen in the Fraser River.

It is possible that disposal of the pulp mill wastes without diffusion into the main stream of the Fraser River could cause local depletions of oxygen. Pulp mill effluents can be completely devoid of oxygen (7), and the discharge of about 32 cfs from a 350 ton bleached kraft mill without diffusion could create a band of low oxygen concentration in the river for considerable distance downstream from the mill. Such a band of low oxygen concentration could be fatal to fish. Even diffusion into the entire cross-section of the river could lower the dissolved oxygen as much as 0.2 ppm. Therefore, diffusion of the effluent into the river is a necessary requirement.

(b) Toxicity

The effluents from kraft pulp mills and from bleaching plants contain materials which are known to be toxic to fish. Bioassay tests on the toxicity of many of the individual materials have been reported in the literature (11, 12). Hydrogen sulphide, methyl mercaptan, sodium thiosulphate, crude sulphate soap, fatty and resin acid soaps, sodium oleate, sodium abietate, phytosterol and sodium sulphydrate are among the more toxic materials, with minimum lethal concentrations in 120 hour tests of 5 ppm or less. These tests do not necessarily represent the toxicity of the total kraft effluent, but they do serve to indicate some of the materials that should be removed from the effluent if possible, in order to reduce toxicity. Inplant practices to remove these materials from the effluent can be of significant value in reducing the toxicity of the effluent.

Bioassay tests have also been conducted using whole pulp mill effluent. Many of these tests have been conducted in sea water and are not strictly applicable to fresh water media. These tests also have the common deficiency of using mortality in a selected time period as the measure of toxicity. However, the data are widely referred to as guides for establishing toxic concentrations of pulp mill effluents and it is felt that brief discussion of them is warranted.

Dimick and Haydu (12) conducted tests with coho salmon in running fresh water over a period of 5 weeks and found no mortalities at a dilution of kraft mill effluent of 1:20. They did observe that some fish were distressed at times but later apparently recovered. From this observation it may be concluded that a 1:20 dilution was close to the critical concentration and that dilutions of this magnitude would be far from adequate for salmon which have to migrate hundreds of miles up and down a river.

Alderdice and Brett (18) conducted tests with sockeye using full bleached kraft effluent in sea water in enclosed aquaria. The experimental results showed a 77% mortality in the test period of 17 days at a dilution of 1:20 and no mortality at a 1:50 dilution. Here again it must be concluded that dilution greater than 1:20 would be required to protect salmon migrating long distances in a river, and the only safe conclusion from the data would be that a 1:50 dilution is required. Brett (19) has stated that even a 1:40 dilution of bleached kraft effluent may be inadequate for the location he was considering.

The Washington State Department of Fisheries (13) has reported on an extensive series of tests of both kraft and bleached kraft pulp effluents in running sea water and fresh water using juvenile coho and chinook salmon. Most of the tests were conducted in sea water and extended over a period of 30 days. From the published data on these tests it is concluded that a dilution of 1:50 of bleached kraft effluent and 1:100 of unbleached kraft pulp effluent and 1:40 of bleach plant wastes alone would be necessary just to ensure that no immediate mortalities would occur in a 30 day exposure. These tests were conducted with kraft mill effluent that was stored up to 3 to 4 days during the course of the tests.

Fujiya (20) has reported on a histo-pathological study of kraft mill effluents on Sparus macrocephalus, and found that concentrations of 10 ppm COD (Chemical Oxygen Demand) of kraft mill effluent in sea water were histo-pathologically harmful, with only a 12 to 24 hour exposure. This concentration of pulp mill effluent corresponded to a dilution of 1:30 to 1:80 for the mill studied. It is possible that if the exposure time was increased to two or three weeks, the same results may have occurred at much lower concentrations of mill effluent.

All of the bioassays reported on Pacific salmon have used juvenile salmon as the test fish. It is generally believed that the young salmon are more sensitive to toxic materials than mature salmon. However no tests have been made on salmon eggs or on alevin or fry. As previously mentioned, there are large pink salmon spawning grounds in the Fraser River below Hope. The eggs and alevin and fry in these spawning grounds would be exposed to water carrying the pulp mill wastes for a period of up to six months. While the concentration of the wastes in the Fraser River at this point may be about one-quarter of the concentration at Prince George at minimum flows, and the wastes may have lost some of their toxicity while travelling down the river, the possibility exists that the wastes may still be harmful to these early life stages of the salmon. At present there is no basis for evaluation of this aspect of toxicity of the wastes, and specific recommendations cannot be made until evidence is available.

As previously noted, the results of bioassays conducted in salt water are not strictly applicable to fresh water. Investigations by Alderdice (32) have shown that, at temperatures and dissolved oxygen levels having minimal influence on resistance, the median resistance time of coho smolts to weak oxidized kraft black liquor was optimal at a salinity of 11.3 °/oo (parts per thousand). When salinity was increased to 22.5 °/oo the resistance time was reduced to 40% of the optimal value, and when fresh water was used (zero salinity) the resistance time was reduced to 6 to 7% of the optimal value. At present there is not sufficient data available to interpret the results of various bioassays in salt water in terms of toxicities in fresh water, but it is indicated that toxicities in fresh water could be several times those in salt water. Alderdice (34) has also found that water temperature and dissolved oxygen level have a very significant effect on toxicity of kraft black liquor, and that the resistance of coho salmon was greatly reduced when oxygen levels were less than saturation.

It must be concluded from these tests that there is insufficient information concerning the relationship between prolonged exposure, temperature, oxygen concentration and salinity and the toxicity of kraft mill effluent. It is certain that the undiluted wastes are extremely toxic to juvenile salmon. There is no information available concerning the effect of kraft mill effluent on adult salmon which would have to migrate hundreds of miles in the diluted effluent during a period of relatively high water temperatures, or concerning its effect on salmon eggs and alevin which would be exposed for long periods during low flow when the diluted waste would be at its maximum concentration. On the basis of the available evidence, it is indicated that dilution ratios of 1:100 of kraft mill effluent and 1:50 of bleached kraft mill effluent in the Fraser River at Prince George may be inadequate to protect the fishery and that dilution ratios of several times these amounts may be necessary.

In considering disposal of toxic wastes to the Fraser River system, it must be born in mind that ultimately there may be many sources of wastes, including pulp mills, and that the combined wastes may be more toxic to fish than the individual wastes. It has been the policy therefore to require that the concentration of individual waste effluents be lowered to non-toxic levels prior to dilution and disposal in the river, and treatment to achieve this requirement has been generally possible and practicable. The large volume of effluent from pulp mills and the complexity and low concentration of the dissolved materials make it more difficult to achieve this requirement. However, much can be done to reduce the quantities of toxic materials reaching the effluent, and such measures have been found to be both practical and economical. Following is a summary of in-plant practices that should be followed to reduce the amount of toxic materials in the effluent. These practices will also reduce the quantity of fresh water required in the mill.

(1) Blow and relief condensates are reported to be the richest in BOD and odor of any portion of kraft pulp effluent, with from 15 to 20 pounds of BOD per ton of pulp. It has been found (21) that these condensates can be used for make-up in the causticizing system, replacing all fresh water previously used in this system, and such practice should be adopted.

(2) Turpentine should be recovered from the top relief and blow condensates. This may be sold if suitable, or may be burned in the recovery furnace to obtain its heat value. The water effluent should be passed through a Bergstrom tower for removal of volatile sulphides and mercaptans.

(3) All spills in the digester, blow and wash rooms should be collected and returned to the black liquor system so that the chemicals may be recovered.

(4) Demister entrainment pads should be installed in the multiple effect evaporators to reduce the carry-over of chemicals to the condensate. This practice also reduces the BOD of the condensate (21).

(5) Evaporator condensates, as well as having a high BOD, contain hydrogen sulphide and methyl mercaptan. Reports from one mill indicate a range in concentration of 26.6 to 51.8 ppm of sulphides and 11.6 to 20.5 ppm of mercaptans (7). Bergstrom towers have been successfully employed to remove a large percentage of these materials and should be provided. It has also been found that the remaining gases in the effluent from the Bergstrom tower and the effluent from the condenser hot well have caused odor problems in the receiving water. Study of this has shown that chlorination of these effluents sufficient to oxidize the remaining sulphur compounds has reduced this problem and it is recommended that this practice be adopted. In this regard, the amount of chlorine added should be controlled so that chlorine will not be substituted into the hydrocarbons (21).

(6) Resin soaps should be separated from the black liquor during the multiple effect evaporation and be disposed of by burning in the recovery furnace.

(7) Countercurrent washing should be employed in the pulp washers, and the water from the first washer should be used for dilution of stock in the blow tank and be recirculated until it contains sufficient concentration of chemicals to be discharged to black liquor storage for evaporation. The final weak wash should be recirculated for stock dilution and if possible be used instead of fresh water in the preceeding countercurrent washes. Screenings rejected before and after the countercurrent washers should be disposed of on land or be burned.

(8) Weak wash waters from the lime mud washer in the causticizing plant should be used for smelt dissolving.

(9) All dumps and spills in the evaporator, boiler and liquor make-up areas should be collected in a sump from which the liquid may be lost by evaporation or percolation into the ground. The sump should be constructed so that collected sludge can be readily removed for disposal on land.

Even with the adoption of the foregoing practices, the effluent still contains lethal concentrations of materials known to be toxic. The concentration of some of these materials in the final effluent from kraft pulping may be from 2 to 20 ppm of resin acids, 3 to 6 ppm of mercaptans and 0 to 0.5 ppm of sulphides. At one mill where these in-plant practices are carefully conducted, the river which receives the mill wastes has a noticeable odor of sulphur compounds and the bed of the river downstream from the mill outfall is covered with a thin layer of slimes. These two problems of slimes and odors are reported to have been greatly reduced by the foregoing in-plant practices (21) but they have not been completely eliminated.

It is not known to what extent the foregoing in-plant practices are followed at the various mills from which effluent samples have been obtained for the bioassays previously referred to. At present there is no rational basis for relating these practices to effluent toxicity. The available evidence indicates that where these procedures are followed a dilution ratio of about 1:200 of unbleached kraft effluent may be adequate for survival of juvenile salmon, trout and aquatic invertebrates, although this is by no means conclusive. Assuming that a dilution of 1:200 would be satisfactory for a mill at Prince George, then on the basis of a minimum flow of 3480 cfs above Prince George and 5330 cfs below Prince George, it is estimated that the effluent from a production of 560 tpd of kraft pulp above Prince George and an additional 300 tpd below Prince George could be allowed without exceeding this dilution ratio. In the event that combinations of bleached and unbleached kraft pulp mills are established, then on the basis of the indicated relative toxicities of the effluents and the average effluent volumes from the two types of mills, one ton per day of bleached kraft pulp will be considered to be the equivalent of 1½ tons per day of unbleached kraft pulp. Thus the total production of 860 tpd of kraft pulp calculated above would be the equivalent of about 570 tpd of bleached kraft pulp. This amount of production is only slightly more than the one bleached kraft mill being considered. Since it is possible that two or more mills of this same approximate size may be located in the area, it is evident that the in-plant practices previously detailed would not be adequate to protect the fishery and that further reduction in toxicity would be necessary.

One method being tested for further elimination of BOD and toxic materials is spray irrigation of evaporator condensates on land (21). If suitable land is available this procedure could be adopted at Prince George at least from May to September. Since these wastes normally have a temperature in excess of 100°F it is possible that spraying or flood irrigation might be continued through the winter period, if the ground could be kept from freezing. This could only be determined by actual test.

It has been reported (28) that removal of 67 to 76 per cent of the BOD from bleached kraft and neutral sulphite semi-chemical pulp mill effluent, has resulted in substantial recovery of sensitive bottom organisms in the receiving water. While in this instance the recovery of these organisms may have been primarily associated with the return of adequate dissolved oxygen levels, nevertheless, since these organisms have been found to have the same approximate sensitivity as fish to the toxic components of kraft mill effluent, it is also possible that some reduction in toxicity of the waste occurred as a result of the treatment. Data on the relationship between BOD removal and the toxicity of kraft mill effluent to salmon is not available. From the nature of biological treatment it is to be expected that some reduction in toxicity would accompany BOD reduction. However, not all the dissolved materials in pulp mill effluent are readily oxidized by short period biological treatment. This is shown by reported results of activated sludge treatment (33) where BOD reductions of 78 to 90% were obtained but COD reductions were only 38 to 64%. It has not yet been established which components of black liquor are the principal causes of toxicity nor is it possible to differentiate between BOD and COD as possible indicators of relative toxicity of pulp mill effluent. Reductions in BOD necessarily result in reductions in COD, although the reductions need not be proportional.

It has already been determined that oxygen depletion in the Fraser River would not present a problem for the magnitude of pulp production under consideration, but this does not necessarily preclude treatment for BOD or COD reduction if it can be done economically and at the same time achieve reduction in toxicity. The more elaborate forms of treatment for BOD reduction such as biofiltration and activated sludge are expensive and difficult to operate on pulp mill wastes. The cost of such facilities to treat only the strong BOD wastes might be as much as $500,000 for a 400 tpd mill and would add about 2 per cent to the capital cost of the mill. Considerable experience has been obtained in the Southern United States with the operation of retention lagoons for suspended solids and BOD removal. Retention in shallow ponds for 20 days achieved up to 85% reduction in BOD (29). Aeration has also been found to reduce considerably the retention time required for removal of BOD in storage lagoons (30). BOD removals of 64 to 93 per cent have been observed in a period of 4 days retention at temperature of 20 to 40°C. Experience with sewage lagoons under ice cover up to 26 inches thick (31) has shown that BOD removals of 70 to 96 per cent can be achieved under these conditions, although the lagoons become anaerobic. Anaerobic conditions result in the formation of sulphides which could possibly nullify previous treatment for removal of sulphides. Aeration of the lagoon would prevent anaerobic conditions under ice cover, and there appears to be no reason why such lagoons could not be successfully operated under ice and snow cover. Aerated lagoons represent a form of treatment intermediate between activated sludge and lagoons. They require more space than activated sludge plants, but may be less expensive to construct depending on availability of land and suitability of topography.

It has been observed during the conduct of bioassays (13) that storage of pulp mill effluent samples for a period of 5 to 8 days resulted in very substantial loss of hydrogen sulphide and methyl mercaptan from the samples. As will be discussed later, it has also been observed that retention of unbleached kraft pulp mill effluent resulted in a decrease of pH which ranged from 0.05 to 0.2 pH points per day of storage. It is considered therefore that a lagoon which will retain the whole mill effluent, other than those components which it has been specified can be discharged without further treatment, for a period of at least 5 days would be an essential part of the pulp mill waste treatment facilities. In addition to allowing stabilization of the effluent, the lagoon would serve to even out fluctuations in effluent quantity and characteristics, and could also be operated as an aerated lagoon for reduction of BOD and COD. On the basis of available evidence regarding toxicity and the probability of several pulp mills being established in the vicinity of Prince George, it is considered that such treatment to remove at least 70% of BOD and 50% or more of COD should be provided. It is also considered essential that the effluent to be discharged to the Fraser River should be diffused into the entire cross section of the river in order to avoid possible localized toxic conditions in the river.

(c) Suspended Solids

The detrimental effects of disposal of suspended wood and fibre solids to the Fraser River have already been discussed. Most pulp mills practice conservation of wood fibre through the use of save-alls and recirculation of white water. Normally white water from the Fourdrinier wire is passed through a Sveen-Pederson save-all or equivalent for the recovery of fibre. The fibre is returned to stock make-up and as much as possible of the water is recirculated. All dumps and spills in the machine and stock rooms should either be returned to stock or passed through the save-all. An efficient save-all should reduce the fibre content of white water to 0.3 pounds per 1000 gallons. Under these conditions surplus white water may be discarded to the mill outfall without further treatment.

The remaining sources of suspended solids, other than from the causticising plant, are the final pulp washer and the bleach plant. As previously noted the amount of suspended solids will normally range from 25 to 45 pounds per ton of pulp. At 400 tpd production this amounts to 10,000 to 18,000 pounds of solids per day. Up to 90% or more of these suspended solids can be removed in a lagoon providing 20 hours retention or in clarifiers with shorter detention (22). Such a lagoon or clarifier should be provided for removal of suspended solids in the effluent prior to treatment in the retention lagoon. The pulping and bleaching wastes should be combined prior to entering the settling lagoon and if necessary the pH should also be adjusted at this point to permit settling or retention of any precipitates that are formed.

(d) pH

It is considered that to avoid harm to fish, waste effluents should have a pH averaging between 7.0 and 8.0 and in extremes not more than 8.5 or less than 6.7 prior to discharge to the Fraser River. This is a standard requirement applied by the Department to all industrial wastes, arrived at on the basis of available evidence (23). Discharge of acid or alkaline wastes could ultimately alter the pH of the river significantly, particularly alkaline wastes which would not be buffered by the river water. It is considered that such a situation must be avoided, and therefore all waste discharges must meet the foregoing requirement.

As previously noted, the pH of kraft pulping effluent may range from 7.5 to 11.5 and combined bleached kraft pulp effluent from 4.5 to 6.0. In the case of bleached kraft effluents, because of the stability of the materials producing the acidity, it may be necessary to control the pH of the effluent by the addition of lime or caustic soda or other suitable chemical.

In the case of a mill producing unbleached kraft pulp, it is possible that some reduction in pH could be obtained by lagooning the waste. Measurements made by the Washington State Department of Fisheries while conducting bioassays with kraft effluent showed reductions of pH of stored samples ranging from 0.05 to 0.2 pH points per day of storage (24). This is another factor in favor of a retention lagoon. While the reduction actually obtained may not be sufficient to lower the effluent pH to the acceptable limit, it may nevertheless allow considerable saving in chemical cost.

(e) Effluent Temperature

The temperature of the combined wastes from pulp mills is reported to be between 65 and 80°F, although the temperature of some of the components of the waste may be as high as 150°F. If the effluent is adequately diffused into the river, the temperature rise of the river during critical warm water periods would be negligible. At minimum flows the temperature rise from the total production proposed might be as much as 1.4°F but this is not considered to be of great significance during the winter months as there are no salmon spawning grounds on the Fraser River in the immediate vicinity of Prince George and this increase in temperature will be rapidly dissipated to the atmosphere.

(f) Sphaerotilus

The introduction of pulp mill effluents into rivers has been observed to cause the growth of Sphaerotilus on the river bed. These "slimes" may accumulate to considerable depth on the river bed, thereby smothering salmon spawning beds. Large mats of it may become detached from the river bed and float downstream. In some locations this has created a problem for commercial net fishermen (25, 26).

The growth of Sphaerotilus is considered to be associated with the disposal of wastes which provide a supply of the necessary nutrients. Growth rate cannot necessarily be correlated to the BOD of the wastes (27). It has been found experimentally that Sphaerotilus will grow in kraft pulp mill effluent containing 2 ppm or more of kraft black liquor, and that growth is not inhibited by the presence of bleach plant wastes (25).

It is believed that the black liquor concentration in the Fraser River at Prince George will be less that 2 ppm at minimum river flow if the mill effluent is diluted in the river at a ratio of 1:100 or more. Observations on the Columbia River indicate that Sphaerotilus does not grow in the river adjacent to kraft pulp mills which operate chemical recovery systems. However, it has also been observed (26) that growth of Sphaerotilus occurs even at 1:500 dilution of bleached kraft mill waste. Observations reported in the literature (25, 26) indicate that the growth of Sphaerotilus is limited to a distance of 4 to 15 miles downstream from the mill source. During periods of high water temperature the extent of infestation has been observed to be greatly reduced (26). Growth ceases at temperatures lower than 40 to 45°F. The greatest extent of infestation occurred between temperatures above this to about 62°F and declined rapidly above this temperature.

There are no important salmon spawning grounds in the Fraser River immediately downstream from Prince George in the area that would be most affected by growth of Sphaerotilus. The principal salmon spawning grounds in the main Fraser River downstream from Prince George are located below Hope. It is considered to be unlikely that the effluent from the proposed mills will promote growth of Sphaerotilus in the Fraser River below Hope, although this can only be determined by actual observation after the mills are in operation. At the present time there are no known successful means of preventing the growth permanently, although it has been delayed by intermittent discharge of the wastes (26).

(g) Water Intake Screens

Fresh water intakes in the Fraser or Nechako Rivers should be suitably screened to prevent salmon fry and smolts from being drawn into the water system. Standard specifications for the necessary screening are given in Appendix A.

Conclusions and Recommendations

The major hazard to the Fraser River fishery that would be created by kraft pulp mills in the vicinity of Prince George is the toxicity of the effluent to salmon. On the basis of available data on toxicity it is concluded that the untreated effluent from even one kraft pulp mill of the size being considered could result in concentrations of toxic materials in the Fraser River at Prince George which would approach the tolerance limit of salmon. It must be stressed that the toxicity data on which this conclusion is based are not considered to be completely adequate, and it is possible that even these concentrations may be harmful. Until additional data are available on the toxicity of the effluents to salmon throughout their freshwater life cycle, the conclusions reached in this report regarding toxicity must necessarily be considered as being only tentative and subject to change.

It is concluded that in order to safeguard the salmon fishery of the Fraser River, the disposal of wastes from pulp mills in the vicinity of Prince George, or at any other location on the river system must be very cautiously considered. It is known that the quantity of toxic materials discharged from a kraft pulp mill can be very considerably reduced by the in-plant procedures outlined in this report.

Spray or flood irrigation offers prospect as a means of further reducing the quantity of toxic materials discharged. Treatment of mill effluent for BOD and COD reduction may also be used as a means of reducing effluent toxicity. The total production of kraft pulp that could be undertaken without hazard to the fishery would depend largely on the success of measures employed to reduce effluent toxicity. It is therefore recommended that any pulp mill to be located on the Fraser River near Prince George should undertake to investigate the feasibility of means of reducing the toxicity of the effluent in addition to those specified in this report, and should implement such additional measures as are found to be practical.

On the basis of the evidence presented in this report, it is recommended that the following provisions be made at any kraft pulp mill on the Fraser River near Prince George, in order to protect the fishery. All facilities required by these recommendations shall be subject to approval by the Department of Fisheries of Canada before the facilities are built.

1. Water intakes in the Fraser or Nechako Rivers should be screened to exclude salmon fry and migrants in accordance with the standard specification detailed in Appendix A.
2. Sludge from the raw water treatment should be disposed of on land where it cannot be washed into the Fraser River.
3. The effluent from hydraulic log barkers should be clarified and recirculated, or otherwise should be clarified by suitable means to produce an effluent containing not more than 0.3 pounds of settleable solids per 1000 gallons. Clarified effluent may be discharged without further treatment.
4. The following in-plant practices should be followed to reduce the amount of toxic materials in the effluent:
   (a) Blow and relief condensates should be used for make-up in the causticizing system.

(b) Turpentine should be recovered from the top relief and blow condensates for disposal, and the water effluent from the turpentine decanter should be passed through a Bergstrom tower for removal of volatile sulphides and mercaptans.

(c) All spills in the digester, blow and wash rooms should be collected and returned to the black liquor system for recovery of chemicals.

(d) Demister entrainment pads should be installed in the multiple effect black liquor evaporators to reduce carry-over of chemicals to the condensate.

(e) Evaporator condensates should be treated in a Bergstrom tower for removal of sulphides and mercaptans and the effluent from the Bergstrom tower and from the evaporator hot well should be chlorinated sufficiently to oxidize the remaining sulphur compounds.

(f) Resin soaps should be separated from the black liquor during the multiple effect evaporation and be disposed of by burning in the recovery furnace.

(g) Countercurrent washing should be employed in the pulp washers, and the water from the first washer should be used for dilution of stock in the blow tank and be recirculated until it contains sufficient concentration of chemicals to be discharged to black liquor storage for evaporation. The final weak wash should be recirculated for stock dilution and if possible be used instead of fresh water in the proceeding countercurrent washes. Screenings rejected before and after the countercurrent washers should be disposed of on land or be burned.

(h) Weak wash waters from the lime mud washer in the causticizing plant should be used for smelt dissolving.

(i) All dumps and spills in the evaporator, boiler and liquor make-up areas should be collected in a sump from which the liquid may be lost by evaporation or percolation into the ground. The sump should be constructed so that collected sludge can be readily removed for disposal on land.

5. White water from the Fourdrinier machine should be passed through a save-all for recovery of fibre and the clarified white water should be recirculated as much as possible. Surplus white water should contain not more than 0.3 pounds of settleable solids per 1000 gallons and, under these conditions, may be disposed of without further treatment. All dumps and spills in the machine and stock rooms should either be returned to stock or passed through the save-all.

6. Emergency discharges of digesters should be retained within the mill system for recovery of chemicals and removal of wood chips or fibre. Under no circumstances should such discharge be made directly to the mill effluent sewer.

7. Sewers carrying high BOD wastes should be constructed so that these wastes can be diverted for separate treatment or disposal if feasible methods are developed.

8. A settling lagoon should be provided to receive the mill wastes and retain them for at least 20 hours for removal of suspended solids. The sewers from the kraft pulping operation and from bleaching operation should be kept separate up to the effluent settling lagoon, where they should be mixed prior to discharge to the lagoon. If necessary, the pH of the waste discharge should be adjusted at this point to produce an effluent with a pH averaging between 7.0 and 8.0 and in extremes not more than 8.5 or less than 6.7.

9. The effluent from this lagoon should then flow to a second larger retention lagoon. This second lagoon shall provide at least five days retention. It should be baffled to prevent short circuiting of flow and should be constructed so that accumulations of scum on the surface, and accumulations of sludge on the bottom can be readily removed for disposal on land. This lagoon should be provided with suitable aeration devices to prevent anaerobic conditions under ice cover. Reduction of BOD and COD may also be accomplished in this lagoon, or other additional facilities. Suitable aeration devices should be provided to supply sufficient oxygen and mixing of contents of the lagoon, or other facility, to achieve the maximum practicable reduction of BOD and COD. If required, the necessary nutrients should be added to promote reduction of BOD and COD. It is recommended that this treatment should achieve at least 70 per cent reduction of BOD and 50 per cent or greater reduction in COD. The 5 day retention lagoon is considered to be the minimum necessary for this treatment and would be subject to revision based on actual operating experience in reduction of toxicity of the effluent.

10. The effluent from the retention lagoon should be discharged to the receiving water through a submerged diffuser which will rapidly dilute the effluent into the river. It will be necessary that such diffusers be constructed in a manner which will intercept the flow of the river across its entire cross section.

11. A system of monitoring for chemical loss and measurement of pH and flow should be incorporated in the mill design. The following instrumentation is suggested as a minimum requirement consistent with determination of flows of the various sources of effluent and determination of sources of chemical loss so that corrective action can be taken.

    (a) pH of effluent from final lagoon

(b) Flow of bleached and unbleached sewers prior to discharge to settling lagoon

(c) Flow of final pulp wash overflow, overflow from save-all and contaminated condensate

(d) Conductivity meters should be placed in suitable locations to measure the conductivity of the following wastes; evaporator condensates, Bergstrom tower effluent, blow condensate, relief condensate, final pulp wash overflow, the chlorinated pulp wash water and first bleach alkali extraction effluent.

Detailed chemical analyses should be carried out in the effluent for a period of two to three months after start-up of the plant and on the basis of this data a system of regular sampling should be instituted to check the effluent for concentrations of materials designated by the Department. A regular sampling program should also be instituted from the start to check the efficiency of BOD and COD removal. The results should be made available to the Department of Fisheries at regular intervals.

Finally, it is emphasized that this report has been prepared to consider specifically the fishery problems associated with the construction of kraft pulp mills in the immediate vicinity of Prince George, discharging their effluent into the Fraser River, and that the conclusions and recommendations would not necessarily apply for mills in other locations in the Fraser River system. The report has not considered the additional effects of pulp mill effluent from other areas in the Fraser River system, nor the synergistic or additive effects of other sources of pollution that may now exist or may exist in the future. These effects could become significant and it is possible, therefore, that the conclusions reached in this report may have to be modified in the future to require additional treatment of the effluent from the pulp mills considered in this report.

APPENDIX A

Suggestions for a stationary type screen at water intakes to prevent losses to juvenile salmon and trout

1. Acceptable screening shall consist of two screens at least two inches apart.

2. The outer screen shall have not less than two meshes per inch. (Suggested sizes - 3 mesh, .072 diameter wire)
   or - 2 mesh, .105 " ")

3. The inner screen shall have not less than eight meshes per inch. (Suggested size - 8 mesh, .028 diameter wire)

4. The openings in the inner screen shall be not more than 0.10 inches square.

5. The open areas of the outer screen shall be not less than the open area of the inner screen.

6. An area of 10 square feet of screen shall be provided for each cubic foot per second (375 Imperial gallons per minute) of water diverted.

7. Screen panels or frames shall be suitably mounted with openings around the panels not larger than 0.10 inches.

8. The screen shall be easily accessible for cleaning and shall be cleared of debris at regular intervals.

Screens with the above specifications are applicable to relatively small diversions including pump intakes. Large diversions usually present difficult cleaning problems and will generally require special consideration, perhaps involving a self-cleaning type screen.

REFERENCES

1. Joint Textbook. Committee of the Paper Industry of the United States and Canada. The Manufacture of Pulp and Paper, McGraw-Hill, 1938, Volume IV, Section 7, page 26.

2. Nordell, Eskill. Water Treatment for Industrial and Other Uses, Reinhold Publishing Company, 1951, page 153.

3. Anonymous. Fraser Companies Newcastle Kraft Mill and Edmundston Bleach Plant, Paper Industry 32:1, April 1950, page 34.

4. McGinn, E.P. H.R. McMillan Export Company, Pulp Division, Paper Trade Journal 131:10, Sept. 7, 1950, page 109.

5. Anonymous. Fibreboard Products Incorporated, Paper Trade Journal 131:10 Sept. 7, 1950, page 91.

6. Anonymous. Riegel Caroline Corporation, Most Modern Kraft Pulp Mill, Paper Trade Journal 135:12, Sept. 19, 1952, page 84.

7. Allen, D.E. Bergstrom Tower Removal of Effluent Toxic Compounds, Pulp and Paper 25:9, February, 1951, page 56.

8. State of California, State Water Pollution Control Board, Publication No. 17, Waste Treatment and Disposal Aspects to Development of California's Pulp and Paper Resources, 1957.

9. Casey, J.P. Pulp and Paper Chemistry and Chemical Technology, Interscience Publishers, New York, 1952, Vol. 1.

10. Doudoroff, P. and M. Katz, Critical Review of Literature on the Toxicity of Industrial Wastes and Their Components to Fish, II The metals as Salts, Sewage and Industrial Wastes, Vol. 25, No. 7, July, 1953.

11. Van Horn, W.M., J.B. Anderson and M. Katz. The Effect of Kraft Pulp Mill Wastes on Some Aquatic Organisms, Transactions of the American Fisheries Society, 75, page 55, 1949.

12. Dimick, R.E. and E. Haydu. The Effect of Kraft Pulp Mill Waste Liquors and Some of Their Components on Certain Salmonoid Fishes of the Pacific Northwest, National Council for Stream Improvement, Technical Bulletin Number 51, May, 1952.

13. State of Washington, Department of Fisheries, Research Bulletin No. 5, Sept., 1960, Toxic Effects of Organic and Inorganic Pollutants on Young Salmon and Trout.

14. Sutermeister, E., Chemistry of Pulp and Paper Making, John Wiley and Sons, New York, 1941, page 113.

15. Ellis, M.M. Water Purity Standards for Freshwater Fishes, Fish and Wildlife Service, Special Scientific Report No. 2, 1944, page 6.

16. British Columbia Research Council, Water Quality in the Fraser-Thompson River System in British Columbia, A Report Prepared for the Dominion-Provincial Board, Fraser River Basin, April, 1952.

17. Unpublished data, on file in the offices of the International Pacific Salmon Fisheries Commission, New Westminster, B.C.

18. Alderdice, D.F. and J.R. Brett. Some Effects of Kraft Mill Effluent on Young Pacific Salmon, Journal of the Fisheries Research Board of Canada, Vol. 14, No. 5, September 1957, page 703.

19. Brett, J.R. Implications and Assessments of Environmental Stress, University of British Columbia, H.R. MacMillan Lectures on Fisheries, The Investigation of Fish-Power Problems, 1958, page 69.

20. Fujiya, Masaru. Effects of Kraft Pulp Mill Wastes on Fish, Journal of the Water Pollution Control Federation, Vol. 33, September, 1961, page 968.

21. Morgan, Oliver P. A Summary of the Air and Water Pollution Abatement Efforts at Weyerhaeuser Kraft Mill at Springfield, Oregon, Presented at Northwest Industrial Waste Conference, Pullman, Washington, May 25, 1961.

22. Berger, Herbert F. Solids Removal Practices in Southern Kraft and Newsprint Mills, Paper Trade Journal, Sept. 21, 1959.

23. A Report on the Wastes from Oil Refineries and Recommendation for Their Disposal, Department of Fisheries of Canada, Fisheries Research Board of Canada and the International Pacific Salmon Fisheries Commission, June, 1953.

24. Letter from G.A. Holland, Washington State Department of Fisheries, Sept., 1961.

25. Lilcoln, J.H. and R.F. Foster, Report on Investigation of Pollution in the Lower Columbia River, for the Washington State Pollution Commission and Oregon State Sanitary Authority, 1943.

26. Cawley, W.A. An Effect of Biological Imbalance in Streams, Sewage and Industrial Wastes, Vol. 30, No. 9, September, 1958, page 1174.

27. Harrison, M.E. and H. Heukelekian. Slime Infestation - Literature Review, Sewage and Industrial Wastes, Vol. 30, No. 10, October, 1958, page 1278.

28. Pearman, Ben V. and Oliver B. Burns. Activated Sludge Treatment of Kraft and Neutral Sulfite Mill Wastes, Sewage and Industrial Wastes, Vol. 29, No. 10, October, 1957, page 1145.

29. Bishop, F.W. and J.W. Wilson. Southland Paper Mills Waste Treatment and Disposal, Sewage and Industrial Wastes, Vol. 26, No. 12, December, 1954, page 1485.

30. Blosser, R.O. Oxidation Lagoons, Tappi, Vol. 43, No. 5, May, 1960, page 454.

31. Towne, W.W., A.F. Bartsch and W.H. Davies, Raw Sewage Stabilization Ponds in the Dakotas, Sewage and Industrial Wastes, Vol. 29, No. 4, April, 1957, page 377.

32. Alderdice, D.F. Personal Communication, October 12, 1961.

33. Laws, Robert L. and Oliver B. Burns, Jr. Recent Developments in the Application of the Activated Sludge Process for the Treatment of Pulp and Paper Mill Wastes, Pulp and Paper Magazine of Canada, Technical Section, November, 1960.

34. Alderdice, D.F. Annual Report of the Biological Station, Nanaimo, B.C., for 1960-61, Fisheries Research Board of Canada.

ROGER DUHAMEL, F.R.S.C.
Queen's Printer and Controller of Stationery
Ottawa, 1966
(72)