OCCASION

This publication has been made available to the public on the occasion of the 50th anniversary of the United Nations Industrial Development Organisation.

DISCLAIMER

This document has been produced without formal United Nations editing. The designations employed and the presentation of the material in this document do not imply the expression of any opinion whatsoever on the part of the Secretariat of the United Nations Industrial Development Organization (UNIDO) concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries, or its economic system or degree of development. Designations such as "developed", "industrialized" and "developing" are intended for statistical convenience and do not necessarily express a judgment about the stage reached by a particular country or area in the development process. Mention of firm names or commercial products does not constitute an endorsement by UNIDO.

FAIR USE POLICY

Any part of this publication may be quoted and referenced for educational and research purposes without additional permission from UNIDO. However, those who make use of quoting and referencing this publication are requested to follow the Fair Use Policy of giving due credit to UNIDO.

CONTACT

Please contact publications@unido.org for further information concerning UNIDO publications.

For more information about UNIDO, please visit us at www.unido.org

UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION
Vienna International Centre, P.O. Box 300, 1400 Vienna, Austria
Tel: (+43-1) 26026-0 · www.unido.org · unido@unido.org

33 p.
tables

RESTRICTED

21400

DP/ID/SER.A/1749
29 January 1996
ORIGINAL: ENGLISH

HIGH LEVEL ADVISORY SERVICES FOR THE BAIKALSK PULP AND PAPER MILL

SI/RUS/94/801/11-51

RUSSIAN FEDERATION

Technical report: Environmental assessment of mill operations at BPPM*

Prepared for the Government of the Russian Federation
by the United Nations Industrial Development Organization,
acting as executing agency for the United Nations Development Programme

Based on the work of Engineer N. McCubbin,

Backstopping officer: R. M. Viegas Assumpcao
Chemical Industries Branch

United Nations Industrial Development Organization
Vienna

---

* This document has not been edited.

V.96 80481

Summary Table of Contents

Detailed Table of Contents

List of tables

1. Summary

1.1 Overview

This report discusses the environmental status of the Baikalsk Pulp and Paper dissolving kraft pulp mill located in Baikalsk, in the Siberian region of Russia.

The mill is located on Lake Baikal, which is a unique body of water, being pristine, and containing one fifth of the world's fresh water. The mill has been in operation since the late 1960s, and was equipped since original startup with a waste treatment system that is still one of the best five in the world's pulp and paper industry.

The special status of Lake Baikal has led to pressures to close the mill, on the basis of improving the natural beauty of the area, to improve the possibility of the region being designated a World Heritage Site, and to avoid any risk of presently unforseeable environmental damage becoming evident in the future.

1.2 Conclusions

The following conclusions are based on information available at the conclusion of the author's first mission to Baikalsk. They may be slightly modified when conclusions of the other experts in the team become available. Such changes will be the subject of the report to be submitted after the pulp, effluent treatment and wood processing consultants have completed their investigation and presented their comments.

1.2.1 Comparison of Baikalsk mill with world standards

The mill effluent discharges, even as long ago as 1970, were as good as any pulp mill in the world prior to about 1989. Since then, approximately five mills in the world have environmentally comparable effluent quality.

The atmospheric emissions from the mill are moderate by world standards, and there are no known negative effects beyond local odour and the unsightly voluminous steam emission.

1.2.2 Solid wastes

Sludge from waste treatment has been incinerated in an environmentally sound manner for some years. However, a combination of primary, biological and lignin sludge was stored in basins at very low consistency for the first several years of the mills operations, This storage, still quite liquid, is currently well contained, but the possibility of deterioration, or natural disaster, releasing the sludge to the Lake exists, whether the mill continues to operate or not. If the mill does shut down, then contingency plans to deal with the sludge will be necessary.

Mill garbage is stored in sealed landfills, and the leachate is monitored. There is no apparent environmental risk.

Mill ash is stored in sealed basins. Two old, unused basins are closer to the lake that would be considered acceptable today. The ash is stable, and has been revegetated. It is best to leave them untouched. If consideration is given to removing the ash, then the possibility that the removal works would be more environmentally harmful than allowing the ash to remain should be the subject of a special study.

1.2.3 Effects of mill operations on Lake Baikal

The lake is large, exceptionally deep, and contains many endemic species, including the freshwater seal.

There is no scientifically measurable damage to the lake's ecosystem due to the Baikalsk mill, and there are only quite minor measurable effects on the ecosystem.

The conditions in and around the lake have been studied extensively since before construction of the mill, with the most intensive studies having taken place in the past 15 years. A number of international researchers have studied the lake conditions, as well as a variety of Russian researchers and regulatory personnel.

We were unable to find any indication of accumulation in fish or seals of the organochlorines normally associated with the discharges from bleached pulp manufacturing, such as the chloroguiacols, 2,3,7,8 TCDD or 2,3,7,8 TCDF, although such substances are frequently found in fish in receiving waters below conventional bleached chemical pulp mills. We believe that this is due to the advanced, and unconventional, effluent treatment system at the mill, which is discussed elsewhere in this report

There is some accumulation of the classic bleached pulp mill organochlorines in sediments within the range of a few hundred metres of the Baikalsk mill's effluent discharge point (Passivirta 1993) Changes in the chemistry of bottom sediments and benthos are measurable in this area. However, there is still a healthy benthic population.

The pollutants identified in water, fish and seals include various forms of PCB, HCH and DDT, but none of the organochlorines normally associated with pulp bleaching operations.

There is some forest damage at the 100 to 1150 metre elevations in mountainous close to the mill. This was recorded in the 1980s, when sulphur dioxide emissions were approximately double today's values.

Otherwise, there are no detectable damage from the mills atmospheric emissions, either due to direct fallout, or to runoff from surrounding land.

1.2.4 Mill developments

Since the early 1970s the mill has installed various improvements to the environmental protection systems, including sludge incineration, then improved high temperature incineration, optimization of polymer use in physical chemical treatment, reduction of effluent flows, and optimization of the biological treatment systems. This has led to a modest improvement in effluent characteristics.

The mill has studied some technologies which would reduce the formation of pollutants, including extended cooking and oxygen delignification. Since the late 1980s cleaner technology for manufacturing bleached papergrade and dissolving pulps has been developed. This will make it possible to eliminate the formation and discharge of chlorinated organic substances, and to reduce the discharges of unchlorinated substances to a small fraction of current values. It will be possible to eliminate effluent discharges completely within a few years. These are mentioned below, and will be the subject of more detailed reports by other UNIDO consultants.

1.3 Recommendations

The following recommendations are offered as suggestions to the other team members, and are intended to promote effective discussion of alternatives and the development of final conclusions by the team as a whole.

1.3.1 Pulping and bleaching processes

In view of the regulatory climate, and the current status of bleaching technology worldwide, the author considers that only possibility of the continued operation of the mill being approved by the Ministry for Environmental Protection is for it to be converted to Totally Chlorine Free (TCF)[1], **with maximum recycle of bleach plant filtrates to the mill's recovery boilers**.

Such a mod tion would eliminate the effects of the effluent on the lake.

Conversion to TCF operations will, in principle, allow the complete elimination of mill effluent discharge, but analysis of mill mass and energy balances will be required to determine whether it is better to reduce the effluent discharge to very low values, or to eliminate it.

---

[1] TCF is defined as bleaching pulp without any use of chlorine compounds In the case of the Baikalsk mill, this would require replacement of chlorine, sodium hypochlorite and chlorine dioxide with oxygen, ozone and hydrogen peroxide, or other chlorine free chemicals

1.3.2 Waste treatment

The present waste treatments system performs better than virtually all waste treatment systems in pulp and paper mills in the world. It is unlikely that any upgrading is justified for environmental reasons, but there are some opportunities to reduce operating costs, primarily by reducing the raw waste load, as discussed above. **However, this comment is made prior to receiving the opinion of Dr. Huber.**

Dr. Huber is requested to define the changes in chemical consumption and effluent quality that can be expected when the untreated mill effluent characteristics are improved by modernization of the pulping and bleaching technologies.

1.3.3 Atmospheric emissions

Analyse the sources of the TRS, and consider action to reduce the total to well below 1 kg/ton pulp. This is feasible, but costs will, of course, be a consideration.

Estimate the change in use of coal that will result from the proposed process modifications, so that the change in emissions of sulphur dioxide can be predicted. A more energy efficient mill, using as much waste wood and pulping liquor as possible, as fuel, will reduce sulphur dioxide emissions.

1.3.4 Mill products

In view of the TCF technology being considered, and the conservative nature of the waste treatment system, there will be no significant difference in environmental impact of various grades of kraft pulp, whether unbleached, paper grade bleached kraft or dissolving grades.

Likewise, there will be no significant difference in the environment effect of the mill's operations between operations on hardwood or softwood, provided that the production system installed does not cause overload of the mill's recovery boilers and their gas cleaning systems. There is no real possibility of overloading the effluent treatment system.

1.3.5 On site storage

It is recommended that the technical and economic feasibility of recovering the sludge stored since the early 1970s and incinerating it in the existing sludge incinerators be established.

1.3.6 Effluent discharge regulations

It is recommended that the Ministry of Environmental Protection convert the mill discharge regulations to limit the mass flow of each substance of interest, instead of the current practice of defining regulations as concentrations of pollutant.

1.3.7 Final report

The final report of the group must first allow the Russian Ministry of Environmental Protection reach a decision on whether a reprofiled mill can continue to operate at Baikalsk.

The conclusions of the expert group should also include a clear definition of the changes recommended to the mill in terms that will:

Define the technical criteria sufficiently well for engineering of the changes

Provide means of verifying that the mill upgrade meets the intent of the recommendations

Define the attainable characteristics of the effluent and atmospheric emission streams.

2. Introduction

2.1 Background

UNIDO retained the author, as well as five other specialists from outside Russia, and one Russian specialist, with expertise in forest industry technology and economics, to assess the environmental impact of the mill operations on the ecosystems of Lake Baikal.

The author visited Baikalsk from the 14th until the 22nd of February 1995. Mr. Jalkanen, pulping and bleaching specialist, and Mr. Salama, financial consultant, also visited the mill from the 14th of February, but both remained for longer periods to gather information. There were on-going discussions amongst these three experts at Baikalsk, but neither Mr. Salama nor Mr. Jalkanen had formed any conclusions at the time this report was written.

The author has had no opportunity to discuss the project with the experts in waste treatment, wood processing or socio economic issues prior to writing this report. We have had extensive discussions with Dr. Grachev, but had not seen his analysis of Russian language literature relevant to the environmental aspects of the Baikalsk mill.

This report is the first from the team, and is therefore subject to revision as other information becomes available, and the other experts form their conclusions.

2.2 Lake Baikal

Lake Baikal is recognized by ecologists worldwide as a unique body of water. One of the basic assumptions of this report is that it is deserving of a high degree of protection from damage due to human activities. Many species in the lake are endemic, including the Baikal seal. Since the seal is at the top of the lake's food chain, it is a good indicator of the degree of bioaccumulation of chemicals introduced by man.

There is an extensive body of literature on environmental studies on Lake Baikal, with a considerable proportion of investigations having been implemented by non-Russian organizations, including scientists from Finland, Japan, USA, the Netherlands and several other countries. Only a few references are presented herein. They have been selected to include a wide variety of researchers from Russia, Scandinavia and North America, so that worldwide scientific opinion is considered.

There is relatively little industrial activity in the Baikal basin, and several investigations have concluded that the principal source of man-made pollutants is long distance airborne transport of organochlorines (e.g. Kucklick, 1994).

We discussed the extensive investigations of the Lake with Dr. Beim, director of the Institute of Ecotoxicology in Baikalsk and Dr. Grachev on the Soviet Academy of Science, Siberian Branch, Limnological Institute in Irkutsk. They have been closely associate with environmental issues in the lake for many years, and are agreed that there is no scientifically measurable effect of the Baikalsk mill's discharges on the lake.

Dr. Gratchev, and presumably others, have serious concerns about the aesthetic impact of the mill, due to odor and the physical appearance of the plant.

Environmental studies of the lake have focused on organochlorines, as has been common practice throughout the world. There has been no attention directed toward unchlorinated organics from the pulp mill. Several recent Canadian and Scandinavian investigations (e.g. Folke, 1995, Carey, 1994) have shown that, if organochlorine discharges are low (AOX under about 2 kg/ton), that unchlorinated organics are more environmentally significant[2]. Questions about fish reproduction, age of sexual maturity and others have been raised, and it appears that the residual liquors from the unbleached part of kraft mills are a more significant factor than the organochlorines. The suggested changes in mill process take this into account, and will result in recovery and incineration of at least 80%, and probably over 95% of the unchlorinated substances.

2.3 Baikalsk mill

The mill was built in the late 1960s, and used the pulping and bleaching technology that was normal at that time. Several grades of dissolving pulp are produced using the standard prehydrolysed kraft process, with conventional chlorine based bleaching The mill is described in detail elsewhere, and the process is discussed herein only where necessary to clarify discussions of environmental effects.

2.4 Local regulations

The Russian Ministry of Environmental Protection (MEP), through a regional Committee of Environmental Protection, defines discharge rates. The environmental laws are based on needs of Lake Baikal, and consider the effects of all discharges.

The regulations are expressed as the maximum allowable daily average concentration of various substances in the effluent (Refer also to the discussion on page 9).

BOD_{50} is considered to be the ultimate BOD.

The mill currently operates under "Temporary" effluent discharge limits, which are negotiated each year. The published "Absolute" limits for effluent discharges are an appropriate target for evaluation of technical alternatives for production of pulp on the mill site. However, our analysis indicates that the numbers are unattainable with even the best technology available in the world today. The only practical way of achieving such low discharges is probably to use the TCF technology discussed elsewhere in this report, and then recycle most of the effluent to the mill. In this case, it will be possible to comply with the absolute limits in terms of mass flow per hour discharged, but probably not in term of concentration, until mill effluent flow is completely eliminated.

---

[2] *At Baikalsk. AOX discharges are currently under 1 kg/ton pulp, and normally about 0 5 kg/ton*

The norm for mercury concentrations in the discharge is defined as being equal to the background level in the lake, and is 0.00048 mg/l

The regulations are expressed as maximum allowable concentrations of a number of substances, as shown in Table 1. Note that the regulations are expressed in terms of concentration in mg/l. The table includes the author's calculations of the equivalent in mass flow (g/hour) and production based discharges (g/ton).

Table 1 Effluent discharge regulations for the Baikalsk mill

Parameter	Temporary	Absolute regulations		
	mg/l	mg/l	g/hour	g/ton
Suspended solids	4.00	0.8	6,975	289
BOD_5 (Unfiltered)	2.60			0
BOD_{50} (Unfiltered)	12.00	1.33	11,597	480
COD	50.00	4.9	42,724	1,769
Lignin	10.00	2.	17,438	722
Furfural	0.60	0.01	87	4
Volatile phenols	0.01	0.	0	0
Chloroform	0.15	0.1	872	36
Soap	3.00	0.1	872	36
Mercury	0.00048	0.00048	4	0
Dimethyl sulphide	0.03	0.03	262	11
Dimethyl disulphide	0.04	0.02	174	7
Ammonia nitrogen	1.00	0.04	349	14
Nitrate	2.00	5.	43,596	1,805
Chloride	120.	30.	261,576	10,829
Sulphate	207.	10.	87,192	3,610
Methanol	0.10	0.1	872	36
Turpentine	0.124	0.11	959	40
Extractable oil	0.08	0.02	174	7
Al_3^{++}	0.08	0.04	349	14
Hydrogen sulphide	0.001	0.009	78	3
Total pnosphorus	0.19		0	0
Phosphates		0.04	349	14
Surfactants	0.10	none		
AOX	1.13		0	
Formaldehyde	0.10		0	
Nitrite	0.001	absent		
pH	6.0 - 8.0	6.0-8.0		
Floating substances	absent	absent		
2,3,7,8 TCDD	non detect (at	1ppt)		

It is perhaps interesting to compare the regulatory limits for the Baikalsk mill with those currently proposed by the US Environmental Protection Agency for a similar mill. The EPA guidelines are expressed in kg/ton pulp, and it is not uncommon for local regulations to be as low as 20% of these numbers, but there are no US regulations as stringent as those applicable to Baikalsk. EPA proposes the following:

Table 2 US EPA proposed guidelines for bleached kraft mills

TSS	17,000 g/ton
BOD5	8200 g/ton
AOX	0,267
Chloroform	5 g/ton
COD	25000 g/ton (for papergrade kraft)
2,3,7,8 TCDD	Non detect at 10 ppq

The EPA is therefore more demanding than the Baikalsk regulations for chloroform, and, effectively, for 2,3,7,8 TCDD since their detection limit is lower. The EPA requirements for the major group parameters, BOD, TSS and COD are much less stringent than those for Baikalsk.

2.5 Concentration basis of regulations

The local regulations that apply to the mill effluent discharge, discussed above, are based on the concentration of various substances in the mill effluent, whereas the best accepted practice is to define maximum allowable discharges based on the mass of each substance.

In the past, the use of concentration based standards at Baikalsk has been essentially equivalent to a mass discharge limitation, since the Baikalsk mill effluent flow has not varied substantially over the years. However, in view of the probability of major process changes to reduce the mill's discharges, it is recommended that the regulations be based on mass flows.

The lake has no interest in the concentration of any pollutant in the discharge pipe (except for very local dilution, discussed below). The principal concern for a receiving water like Lake Baikal is the accumulation of persistent substances which may damage the ecosystem, perhaps in ways not yet understood. To minimize this risk, effluent limiting regulations should aim at minimizing absolute discharges, by being based on mass flows. A practical starting point would be to simply convert today's standards to mass flows by simple multiplication of the current flow by the specified concentrations.

If the concentration basis for effluent criteria is retained, it is conceivable that an engineering analysis of a particular process modification could lead to selection of a process that would lead to the mill maintaining the currently high effluent flows, instead of a much lower flow with perhaps somewhat higher concentration of pollutants.

The present effluent quality is such that local effects within a hundred meters of the discharge pipe are trivial. While it is theoretically conceivable that a substantial reduction in the mill effluent flow would raise the concentration of pollutants very close to the effluent pipe, we do not believe that this is a serious consideration, since the reductions in flow will, in practice, be accompanied by reductions in mass flows of pollutants discharged.

2.6 Discharge taxes

The mill is subject to taxes on pollutants discharged, including parameters where the mill complies with discharge limiting regulations. The taxes are based on the discharge rates of individual substances. The legal rates lead to taxes that would exceed the mill's total income, so in practice a tax is negotiated that is approximately 10% of the mill's profit. If discharges exceed the temporary regulations, then the tax actually charged is liable to be assessed at 20% of profits.

The tax is heavily weighted against discharges of organochlorines, so that any measures taken to reduce or eliminate such substances have a significant effect on tax liabilities. In 1995, virtually all of the calculated tax liability is due to AOX. If a TCF process is installed, then the associated elimination of the AOX tax alone would lower the calculated tax to below 10% of the mill's profit, so there would be a real financial incentive to further reduce discharges of the taxed parameters.

Payment of the discharge taxes is a substantial but not crippling cost to the mill. However, the fact that the amount paid is subject to negotiation is a potential liability. Reduction of discharges so that the tax liability is small would clearly be in the mil's interest, and is considered in the economic analysis.

3. Effluent Discharges

The mill has had an advanced effluent treatment system since production commenced in the late 1960s. The treatment system will be analyzed in detail by Dr. Huber and the following comments are intended to assist in this analysis, as well as in developing a recommended plan for upgrading the mill to reduce effluent discharges.

3.1 System description

Sewers are collected in two mixing/stabilization tanks prior to biological treatment. There is no primary clarifier, or other removal of suspended solids prior to biological treatment.

3.1.1 Biological treatment

There are two conventional activated sludge treatment (AST) systems in operation.

One AST treats the "black" wastes, consisting of the discharges from cooking, brownstock washing, woodroom and causticizing plant. The nominal feed flow is 60,000 m^3/day and retention time is 20 hours. It has 2 secondary clarifiers, each 24 m diameter.

The other AST system treats the other mill wastes (defined as the "white" stream in mill reports), including all roof drains and surface water runoff from the mill, and sanitary sewage. It's nominal feed flow is 200,000 m^3/day, and retention time is 3 hours. It has 5 secondary clarifiers, each 40 m diameter.

The treated effluent flows from both systems are combined with the underflow from the sludge thickening operations for further treatment.

3.1.2 Physical chemical treatment

The combined effluent is further processed by precipitation assisted by alum and polyacrylide polymer. This process is not conventionally used in the worldwide pulp and paper industry, because of relatively high costs. However, a few mills have comparable systems and the process is well proven.

pH is controlled by sulphuric acid, and the alum and polymer are added before a set of 6 flocculating clarifiers, each 54 metres diameter.

3.1.3 Sand filters

Sand filters were installed at the time of mill construction, but are no currently used, since they did not further purify the effluent from the above mentioned physical chemical system,

3.1.4 Polishing

There are three polishing basins with 24 hours retention to allow any residual settleable solids to precipitate. The last basin is aerated to raise dissolved oxygen in the effluent to about 7 mg/l.

3.1.5 Discharge

The effluent is discharged through two submerged diffusers approximately 150 metres offshore, at a depth of 40 metres. There was no visible effluent at the time of the visit, and others have confirmed that the effluent discharge is never visible.

3.1.6 Spill protection

In event of spills from the mill which would effect the biological treatment system, the effluent can be stored for up to 24 hours, and then discharged slowly to the treatment system. The supervisors report that this has rarely been required, and that the spill basin has never been completely filled.

3.1.7 Sludge disposal

All sludge from biological treatment and physical chemical treatment are thickened by floatation, centrifuge, and hot gas drying, and then incinerated in a pair of fluidized bed incinerators. Underflow from the dewatering stages is returned to the effluent treatment system.

The sludge disposal system has a design capacity of 120 ton/day, but there are only approximately 40 ton/day sludge to process, so some of the equipment is on stand-by.

3.2 Effluent characteristics and impacts

Average 1994 discharges are summarized in Table 3.

Table 3 Characteristics of Baikalsk mill effluent in 1994

Effluent flow m^3 per day	156,775	156,775		
Effluent flow m^3 per ton	450	450	0	
	mg/l	**kg/day**	**g/ton**	**g/hour**
Suspended solids	2.3	439	1,259	18,290
BOD5 (Unfiltered)	1.9	298	855	12,411
BOD50 (Unfiltered)	10.3	1,615	4,633	67,283
COD	45.	7,055	20,240	293,954
Lignin	4.2	658	1,889	27,436
Furfural	0.04	6.3	17.99	261
Volatile phenols	0.017	2.7	7.65	111
Chloroform	0.135	21.2	61	882
Soap	1.68	263	756	10,974
Mercury	0.00037	0.058	0.17	2
Dimethyl sulphide	0.026	4.1	11.69	170
Dimethyl disulphide	0.062	9.7	27.89	405
Ammonia nitrogen	0.3	47.	134.93	1,960
Nitrate	0.56	87.8	251.88	3,658
Chloride	107.5	16,853	48,351	702,223
Sulphate	165.7	25,978	74,529	1,082,403
Methanol	0.001	0.2	0.45	7
Turpentine	0.07	11.	31.48	457
Extractable oil	0.052	8.2	23.39	340
Al3++	0.06	9.4	26.99	392
Hydrogen sulphide	trace		0.	0
Total phosphorus	0.007	1.1	3.15	46
Phosphates				
Surfactants	0.05	7.8	22.49	327
AOX	1.23	193	553	8,035
Formaldehyde	0.042	6.6	18.89	274
Nitrite	trace		0.	0

3.2.1 Traditional pollutants

The discharges of traditional pollutants are extremely low, primarily due to the conservative design and the effective operation of the effluent treatment system.

3.2.2 Organochlorines

The discharges of chloroform are well above the values attained by many modern mills, but correspond with the current production technology where sodium hypochlorite bleach is used.

The AOX discharge is approximately 0.5 kg/ton pulp, which is well below the value normally associated with the bleaching technology used at Baikalsk. It is widely accepted any value of AOX discharge below about 2 kg/ton pulp provides no indication of the toxicity of a mill effluent.

Dioxins are not measured frequently, so that there is no value shown in Table 3. Measurements in recent years have shown that discharges are non detectable to the level of 1 ppt. This is a less sensitive level of detection than is normal in Scandinavia and North America. It is impossible to estimate the actual discharges of 2,3,7,8 TCDD without analysis. Consideration of the mill process operations suggests formation of the quantities of 2,3,7,8 TCDD that were common in most bleached kraft mills in the mid 1980s. However, dioxins travel with suspended solids, so it is quite likely that they are being removed and incinerated in the Baikalsk mill's unusually efficient effluent treatment system.

3.2.3 Nutrients

The concentration of nutrients in Lake Baikal water is very low, and it is desirable to maintain this characteristic. The input of phosphorus to the lake from the mill is only 1.1 kg/day, which is trivial relative to natural contributions, so the mill can be considered as having no effect on the phosphorus balance of the lake. In most parts of the world, phosphorus discharge concentrations of up to about 1 mg/l are considered acceptable for sensitive waters. The Baikalsk mill discharge is only 0.007 mg/l phosphorus.

The input of 47 kg/day of ammonia nitrogen is likewise trivial relative to the nutrient budget of the lake.

3.2.4 Mercury

There is some mercury in the wood entering the mill, but the principal source of mercury is contamination of the sodium hydroxide (caustic) purchased by the mill. Mill staff report that they purchase caustic from the lowest-mercury source available. The absolute discharge of 0.00037 mg/l is below the reported background concentration in Lake Baikal. If the mill installs more modern pulping and bleaching systems, then the quantity of caustic purchased will drop substantially, so the mercury discharge will also.

Meuleman *et al* (1993) studied mercury level in the water column and fish in Lake Baikal. They concluded that mercury concentrations are low. The samples taken near the Baikalsk mill showed that concentrations of total Hg, labile Hg and inorganic labile Hg in samples at two locations and four depths close to the Baikalsk mill were indistinguishable from the other eighteen sample points in the lake.

Beim and Grosheva (1993) point out that no increased Hg accumulation by aquatic organisms and bottom sediments in the area of the Baikalsk mill effluent discharge was found. Aquatic organisms grown during one month in the effluents medium did not accumulate Hg in comparison with the control animals. They attributed the absence of effects of Hg to the efficiency of the mill's unconventional physical chemical treatment system.

3.2.5 COD

The current COD discharge of 20 kg/ ton pulp is low by world standards, and is indicative of low discharges of pulping residuals (black liquor). The latter have been recently associated with sub-lethal toxic effects on fish in Scandinavia, Canada and the USA. It is doubtful whether any effects would be seen in Lake Baikal, due to the low discharge value and high dilution in the lake.

3.2.6 Effects of effluent on lake

There have been many investigations of the conditions in Lake Baikal. Some focused on the mill, to determine whether it was effecting the lake, while others looked at the lake as a whole, and only considered the mill incidentally. The general conclusion is that there are some effects, but no damage, to the lake that can be attributed to the mill operations.

Falkner (1991) investigated the geochemistry of Lake Baikal and concluded that the lake is well mixed. They found no indication that the Baikalsk mill has caused any accumulation of any sodium, calcium, potassium, chloride or sulphate (all of which are present in relatively high concentrations in the mill effluent).

Hayashi (1993a) concluded that despite human developments at the north and south ends of the lake, and anthropogenic activities on the largest tributary (Selenga River), it is not possible to discern any water pollution by analysis of the main hydro-chemical parameters. They also concluded that variations in benthic sediments were explainable only by natural geochemical variability. They recommended on-going monitoring to detect any deterioration in the lake due anthropologic or natural causes.

Hayashi (1993b) investigated the bottom sediments in the Lake Baikal, primarily to determine that changes over the period 1961 to 1993. They concluded that the expected accumulation of sediments in the canyons of the lake bottom did not exist, except for a minor amount in a spot 0.3 km immediately surrounding the outfall. The mill commenced discharges in 1966, discharging approximately 10 mg/l suspended solids. This has been decreased progressively to the current level of approximately 3 mg/l.

Hayashi concluded that there was no difference between heavy metals content of bottom sediments around the mill effluent discharge from sediments elsewhere in Lake Baikal. They also showed that there has been no increase in the fraction of organic carbon in bottom sediments since the mill commenced discharging effluent.

They determined the concentrations of ligno-humic acids (LHA) in bottom sediments and concluded that for samples taken around the mill effluent outfall, this was somewhat lower or equal to values elsewhere in the lake. They noted that the N content of the LHA (2.5% to 4%) was typical of natural lignin, and differed from the N content of the lignin in the pulp mill effluent.

Hayashi noted that background concentrations of total organic chlorine (TOCl) in Lake Baikal sediments vary from 0.02% to 0.05%, whereas in an area of 20 km^2 around the mill effluent outfall they found TOCl concentrations from 0.05% to 0.17%. This does not give any indication of the toxicity, if any, of these organochlorines.

This is a clear indication that the mill effluent has some effect on the sediment but few, if any scientists would consider it the TOCl measured to be damaging. They will probably all be mineralized if TOCl discharge is eliminated.

Passavirta (1993) showed lower organochlorine concentrations in bottom sediments at the Baikalsk mill effluent discharge than at the outfalls of all three Finnish mills studied. They did not discuss organochlorine emissions rates, but it is well known that prior to 1988, the discharges from Finnish bleached kraft mills were typically 4 to 8 kg/ton pulp and that large quantities of settleable solids were discharges prior to the installation of treatment works in the 1980s. In contrast, Baikalsk effluent has always been treated to the unusually pure condition indicated in Table 3 on page 13. Baikalsk organochlorines have probably been relatively low molecular weight and relatively readily biodegradable.

Organochlorine accumulation in sediments in Lake Baikal was determined by Maatela (1990). They found concentrations of organochlorines ranging from 440 micro g/l within a few metres of the outfall to 25 micro g/l at 300 metres east to background (<20 micro g/l) at 300 metres west and 3.5 km east.

3.3 Risks of environmental accidents

3.3.1 Chemical leaks

The risk of chemical leaks in pulp mills must always be evaluated. The principal hazards are black liquor, sulphate soap and fuel oil.

In all cases, the distance from the lake is such that a direct spill to the lake is not a real risk, but discharge via the mill sewer system must be considered. All rainwater and other surface waters are collected and routed to the mill effluent treatment system, avoiding one of the common causes of contamination of receiving waters in many other mills.

The effluent treatment system is protected from spills in two ways:

> Firstly, departments containing black liquor and soap have recovery systems so that any large spills can be recovered.
>
> Secondly, there is a storage basing with capacity for 24 hours capacity to which the mill effluent can be diverted in the event of an uncontrollable spill of black liquor or other substance. This allows the problem to be corrected, or the mill shut down if rapid correction is not possible. Mill staff report that the spill basin has been used on several occasions, but that it has never been filled to capacity.

Spilled liquor cannot be recovered, but is discharged to the treatment system at a rate appropriate to the capacity of the biological and physical chemical treatment system to process it.

As mentioned elsewhere, the treatment system is generously dimensioned, which provides both resilience and the capacity to process unusually large loads.

3.3.2 Oil storage

The oil storage tanks are dyked, and presuming adequate annual inspections are carried out, and the system is maintained, there is no risk of spills.

The quantity of oil stored on site should always be the minimum necessary for safe and reliable operation of the mill.

3.3.3 Tall oil and turpentine

Tall oil and turpentine are recovered from the pulping process. The tanks are protected, and presuming adequate annual inspections are carried out, and the system is maintained, there is no risk of spills.

The quantity of these products stored on site should always be the minimum necessary.

3.3.4 Earthquakes

Lake Baikal is in an earthquake zone, and the mill buildings are designed accordingly. However, as recent events in Kobe in Japan have demonstrated it is impossible to be certain that there will be no ruptures of tanks, pipes etc. during an earthquake, so the environmental consequences must be considered.

The following issues are important:

Sludge storage (discussed on page 23)
Turpentine and tall oil storage
Black liquor
Fuel oil
Ash storage (discussed on page 24).

The quantities of turpentine, tall oil and fuel stored are relatively small, so that we do not believe that a single incident which would lead to contamination of the groundwater, and ultimately some leakage to the lake would be significant relative to the total effect of a major earthquake on Lake Baikal. However, there is no rational way of evaluating this risk. It would perhaps be relevant to compare the quantities of oil stored in the total Baikal basin relative to the quantity stored in the mill. Obviously the latter would be only a small proportion.

3.3.5 Effluent system failure

Complete failure of the effluent system will occur if electrical power is lost. In this case, the effluent would be diverted to the spill basin and the mill shut down. Some partially treated effluent could flow by gravity to the final treatment basins, but would not be discharged to the lake.

Presuming reasonable care and attention, we do no consider this to be a significant risk.

3.3.6 Personnel

The attitude and training of the personnel, and the level of support and attention paid to environmental protection by mill staff are as important as the physical equipment and technology installed, in controlling effluent characteristics. The personnel are particularly important with respect to avoidance of environmental accidents.

The author has had occasion to inspect or actively work in over a hundred pulp and paper mills in all continents except Australia. The evidence of management commitment and staff support for the environmental protection measures in the Baikalsk mill is equal to the best few mills known to the author. This was evident in discussions with staff, the extensive testing of effluents, and the ongoing improvements in the environmental protection systems that have been undertaken over the 30 years of mill operation.

4. Atmospheric Emissions

The atmospheric emissions from the mill have been measured for many years. Recent annual summary data are presented in Table 4, and are discussed below.

Table 4 Annual atmospheric emissions

	1990	1991	1992	1993	1994
Particulate (90% from coal)	7857	8361	5497	4005	3661
Sulphur dioxide	2301	2306	2305	3623	2960
Carbon dioxide	1109	937	665	695	812
Nitrogen oxides	2062	1356	3556	3220	2551
Hydrogen sulphide	592	360	200	158	110
Methyl mercaptan	141	121	70	67	67
Dimethyl sulphide	40	38	134	139	161
Dimethyl disulphide	37	39	15	106	128
Chlorine	3.10	3.10	3.10	3.10	3.10
Chlorine dioxide	6.30	5.70	10.00	5.80	4.20
Turpentine vapour	37.10	104.60	46.40	46.40	46.40
Total emissions, tons/year	14184	13630	12502	12067	10503

All data expressed in tons per year.

The data from Table 4 are also presented in terms of discharges per unit production in Table 5.

Table 5 Production based atmospheric discharges

	1990	1991	1992	1993	1994
Mill production	147,453	138,073	148,383	122,804	120,253
Particulate(90% by coal)	53,285	60,551	37,046	32,613	30,442
Sulphur dioxide	15,603	16,698	15,532	29,502	24,617
Carbon dioxide	7,521	6,787	4,480	5,657	6,748
Nitrogen oxides	13,981	9,820	23,968	26,221	21,214
Hydrogen sulphide	4,016	2,604	1,347	1,283	916
Methyl mercaptan	956	876	472	542	556
Dimethyl sulphide	269	277	902	1,135	1,336
Dimethyl disulphide	249	282	104	861	1,066
Total reduced sulphur	**5,490**	**4,038**	**2,825**	**3,821**	**3,875**
Chlorine	21	22	21	25	26
Chlorine dioxide	43	41	67	47	35
Turpentine vapour	252	758	313	378	386

Data are expressed in g/ton pulp, except for mill production which is in tons/year.

The foregoing data were supplied by the mill staff, and correspond quite closely with independent measurements by the Russian Service of Hydrology and Meteorology.

The discharge rates are quite low relative to normal practice when the mill was built, and reflect the installation of 1960/1970 state of the art emission control. In all cases, technology exists to reduce discharges to a small fraction of their current rates, although in most cases the costs of retrofitting modern technology would be significant. The environmental significance of each discharge is discussed below.

4.1 Significance

In contrast to the situation with effluent discharges, there has been relatively little information published on the effects of the atmospheric emissions, presumably because they are not of widespread concern. Pavlov *et al* conducted an evaluation of the influence on mill emissions on the area. The document is undated, but the rates of atmospheric discharge quoted in correspond with those shown in Table 4 for the 1985 to 1987 period. Mill discharges have been reduced substantially since then as shown in Table 4.

4.1.1 Particulate emissions

Particulate deposits from the mill are detected over an areas of approximately 50 sq. km around the mill (equivalent to a radius of approximately 4 km) according to Pavlov. He noted no effects of such deposits, and we would expect none.

A report by the Russian Service of Hydrology and Meteorology shows that the level of suspended particulate in Baikalsk averaged 0.2 mg/m^3 in 1985/86, and it has presumably dropped since. This is rather lower than in the other 12 locations tested, but is above the levels generally considered as desirable in Canada, where 0.070 mg/m^3 is the air quality objective.

It would appear *a priori* that the ambient particulate concentration is excessive in the Baikalsk region, but this is not consistent with the geographical location, or our observation during our site visit. There may be differences between sampling or analytical procedures. There was not sufficient time in the project to investigate this issue.

Our conclusion is that there is some measurable effect of the mill on local particulate and dustfall levels, but no indication that they are damaging, or above the levels normal in inhabited areas.

4.1.2 Sulphur dioxide

The mill discharges shown in Table 4 and Table 5 are typical for a modern pulp mill.

The annual average ambient sulphur dioxide concentrations in Baikalsk is reported to be 0.05 mg/m3, which is below the level considered as maximum acceptable by most standards. It is also somewhat below the values reported for other parts of the Lake Baikal region by the Russian Service of Hydrology and Meteorology. One can conclude that the sulphur dioxide discharged by the mill is insignificant.

4.1.3 Odour

The characteristic odour of kraft pulp mills is due to emissions of a mixture of reduce sulphur gases, of which the principal ones are hydrogen sulphide, methyl mercaptan, dimethyl sulphide and dimethyl disulphide. These are generally known collectively as Total Reduced Sulphur (TRS). These are formed in the pulping process, and are emitted from various points in the process. They are unrelated to bleaching.

The mill odour control system is quite comprehensive, but does not include all of the best technology available. On a subjective level, the author, and Messrs. Jalkanen and Sakala (all of whom have visited many pulp mills) felt that the mill odour in the Baikalsk area was very low during their visit.

The mill emission data shown in Table 5 demonstrates that almost 4 kg TRS are emitted per ton kraft pulp produced. This is well above the normal discharge from a modern kraft mill, and the relatively low odour impact of the mill is probably due to the use of high stacks for all discharges. These gases have quite a short half-life, so that there is no environmental reason not to disperse them.

The most recent review of the issue of potential health effects of TRS emissions from pulp mills was by Tatum (1995). She conducted an extensive review of available literature, including 30 epidemiological studies of populations exposed to low concentrations of reduced sulphur gases, including several populations living around pulp mills. She concluded that there is no evidence of relationship between exposure to TRS gases and disease, but that there are reports of people complaining about subjective annoyance due to these gases.

The odour is scientifically insignificant, but unpleasant in the immediate vicinity of the mill. Any judgment of it is one of aesthetic values.

4.1.4 Health

There are no known adverse health effects attributable to the mill atmospheric emissions.

4.1.5 Aesthetics

It has been suggested the mill be closed due to the physical appearance of the stack emissions. There is no doubt that they are not beautiful, but there is no practical way of reducing their visibility.

Many North American mills take measures to explain to the public that the visible discharges are essentially all water vapor, which assists somewhat in reducing complaints by the public and the press.

The visibility is scientifically insignificant, and any judgment of it is one of aesthetic values.

4.2 Risks of environmental accidents

Atmospheric pollution accidents in pulp mills are rare, because they contain few substances or equipment liable to cause such events.

4.2.1 Chlorine gas

The greatest risk is probably failure of a liquid chlorine storage tank or rail car. Liquid chlorine is delivered in tank cars, which are immediately unloaded to a 150 ton capacity storage tank.

Except for some very recent installations which include building enclosures and high dispersion stacks, the precautions against leaks are preventative in nature in virtually all mills worldwide. The Baikalsk mill appears to be using acceptable standards, on the basis of our visit.

Historically, the Baikalsk mill, in common with the pulp industry worldwide, has a good track record in this respect. Whatever reprofiling is undertaken will probably result in the complete elimination of chlorine use in the mill.

The elimination of the risk of chlorine leaks is one reason (in addition to reduction to organochlorine formation and reduction in operating costs) for the mill to consider elimination of chlorine bleaching.

4.2.2 Other gases

Failure of a chlorine dioxide tank will cause some gas discharge, but this is more of an issue of safety in the workplace than environmental protection or public health, because the quantity of gas released is relatively small.

5. Solid wastes and groundwater

5.1 Mill garbage

Solid waste is stored in landfills, and covered with vegetation when full. Prior to 1984, the solid waste disposal basins were lined with clay. Since then, basins are lined with a plastic film with 500mm clay on each side. Groundwater seepage is checked by well points, and no leakage has been found.

We do not consider that this is an environmental problem.

5.2 Effluent treatment sludge

For the first several years of mill operation, effluent treatment sludge were stored at approximately 0.5% consistency in basins, with a total capacity of approximately 5,000,000 m^3.

This sludge is still in the basins, at distances ranging from 4 km to 8 km from the lake shore. Rainwater accumulation is pumped to the mill effluent treatment system during summer months. There are no indications of leaching from the sludge basins, and any effects can be expected to be very local. Experience around the world has shown that leakage from such basins is limited to the first few years of their life, because the natural filtering action of the soil combined with anaerobic activity leads to development of an impermeable layer.

For several years following the mill commissioning in 1966, sludge was stored in 10 clay lined basins. There is no measurable leakage, and the basins are considered stable. Any runoff flows to a natural creek that passes through the mill's effluent treatment installation, without being connected to it hydraulically. The quality of water in the creek is monitored, and equipment is installed to pulp the water to the waste treatment process in the event of it being contaminated. The runoff does not contain any measurable quantities of lignin or other organics (Private communication, Dr. A Beim, Institute of Ecotoxicology, Baikalsk).

Beim (199x) showed that the lignin sludge was not mutagenic, and was unable to detect chlorodioxins and chlorofurans (detection limit was 100 ppq). More sensitive methods would probably detect some dioxins and furans since it can be expected that the mill generated similar quantities of these substances to the many other bleached kraft mills around the world using similar technology. Dioxins tend to travel with the suspended solids in mill effluents. In view of the extremely effective removal of suspended solids from the mill effluent, it seems probable that the dioxin and furans that were produced, during the early years of the mill's operation, are mostly in the sludge. Decomposition is extremely slow in the dark conditions in a sludge storage basin or pile. The only way of eliminating the dioxins is to incinerate the sludge.

The dioxins remain attached to the suspended solids, and the basins are very watertight, so the risk of dioxins being found in leakage is slight.

The only significant environmental risk is of a failure of one or more of the sludge basins, combined with such a heavy flow that the effluent treatment system could not process the discharge. This must be considered remote in view of the length of time the basins have existed. Continuing monitoring of the condition of the basins, including an annual inspection would be prudent.

The only way of eliminating the risk of a natural disaster, such as an earthquake, causing the discharge of the contents of these basins is to incinerate the sludge. It is probably feasible to return the liquid fraction of the basin contents to the mill sludge incineration system over a period of several years, but the costs must be weighed against the benefits. If the mill is closed down, then the sludge incineration system could, in principle, be kept open to destroy these materials. Some of the sludge is probably sufficiently stabilized that it is best left in the basins, after the liquid ands semiliquid material has been removed. It is recommended that the costs and technical feasibility of doing so be evaluated

5.3 Ash

Boiler ash has been stored in lined basins on site since the mill commenced operations. Two basins are close to the lake shore. These have not been used for several years, and are now revegetated. The ash is relatively dry, similar to soil in consistency, and there is no leachate. While these basins are close to the lake, it would probably cause more environmental damage to attempt to remove the ash than to leave it in place. There is little or no environmental benefit in moving it.

The retaining dykes should be maintained, and inspected annually.

5.4 Groundwater

Precautions have been taken to protect the lake from groundwater seepage from the industrial area, which includes mill-site and some surrounding small enterprises. The land all slopes gently toward lake. Some groundwater contamination is collected in wells downhill of mill, and pumped back to the mill effluent treatment system. The main contaminant is black liquor. Approximately 100 m^3/h of groundwater is recovered year round at a concentration similar to that of treated effluent.

This is a much more conservative approach to groundwater than is normally taken in a pulp mill.

6. Mill Development

The following suggestions are offered for consideration by the pulp processing and economical experts.

Any process changes to be recommended should be on a logical path towards complete elimination of process effluent in the future, as the technology for complete mill process closure is developed. This approach is being taken by several of the more technically advanced pulp and paper companies, and essentially consists of cooking to low kappa numbers, improving brownstock washing, eliminating chlorine, while always increasing the proportion of total material removed from the wood that is recovered and burned, usually in the mill's chemical recovery boiler.

6.1 Organochlorine discharges

While there is no scientific rationale for completely eliminating organochlorines, there are reasons to reduce discharges substantially. The economic incentive of avoiding taxes on organochlorines may justify conversion to Totally Chlorine Free (TCF) operation. Complete elimination of the use of chlorine compounds is desired by most of the environmental pressure groups, whether in Russia or elsewhere. Some customers of pulp, particularly in Germany. demand TCF pulp.

There are risks associated with converting the mill to a TCF process to the extent that there are not yet any TCF dissolving kraft pulp mills in operation in the world. However, there is one dissolving sulphite operation at Lenzing, and a TCF dissolving kraft mill is under construction by Klabin in South America. If it is decided to convert the Baikal mill to TCF operation, then some laboratory investigations would be required to confirm feasibility and define the process parameters.

The process changes that are effective in reducing organochlorine discharges can also reduce the discharges of unchlorinated organics substantially, and these subjects should be considered in tandem.

6.2 COD

COD is not itself a direct indicator if mill effluent toxicity, but is a useful indicator of the degree of mill process closure.

As shown by Folke (1995) it is desirable to reduce mill effluent COD if the sub-lethal toxic effects are to be minimized. This requires the maximum recycle of pulping residues from washing, and bleaching, and from spills of black liquor.

6.3 Effluent flow

The mill effluent flow, by itself, has no environmental significance. Local regulations currently encourage high effluent flow, since they are based on concentrations of various substances in the effluent.

However, reducing the effluent flow will generally reduce discharges of pollutants, since the treatment system tends to operate at a limiting concentration. Reducing effluent flows will have little effect on the costs of operating the biological treatment systems, since the latter depend on BOD load, but will reduce the cost of operating the physical chemical treatment system substantially.

If a TCF process is installed, it will be possible to replace much, but not all, of the water used in the mill with treated effluent, so that the net flow discharged could be reduced by at least 75%, without further new technology being required. Engineering analysis may demonstrate the feasibility of reducing effluent flow to a small fraction of today's value, or of eliminating effluent discharges completely.

6.4 Recommended process changes

It is recommended that the following process changes be evaluated by the other experts involved in this study. All processes reduce the cost of operating the mill, by reducing chemical consumption, and replacing relatively expensive chemicals (hypo and chlorine dioxide) with relatively inexpensive oxygen and ozone. However, the capital costs are significant and must, of course, be evaluated.

Much of the caustic currently purchased would be replaced by oxidized white liquor, thus reducing costs and reducing the import of mercury to the mill along with the caustic.

6.4.1 Extended cooking

Extended delignification to kappa numbers about half the traditional values has become a well established technology over the past five years. It would allow recovery of almost half the black liquor organics that are currently discharged. The low kappa numbers attained are a prerequisite for successful implementation of ozone delignification.

6.4.2 Brownstock washing and screening

It is essential that the brownstock knotting, washing and screening system operate without any effluent discharge if the benefits of the other process improvements are to be realized. It is also well known that the pulp must be adequately washed (to a COD carryover of under 10 kg/ton) if the subsequent oxygen delignification stage is to produce high quality pulp.

The use of an open washing stage to minimize organochlorine formation is not recommended, since it causes discharge of toxic, unchlorinated organics.

6.4.3 Oxygen delignification

Oxygen delignification is widelv practiced, and is a key element of any effective action to improve the mill effluent characteristics.

6.4.4 Ozone delignification

The pulp should be further delignified by ozone prior to caustic extraction. This removes metals effectively, and allows recovery of the subsequent extraction stage effluent.

Presently proven technology allows recovery of most of the filtrates, but a purge flow for metals is currently required. This discharge will contain the same metals from the wood as are presently discharged from the Baikalsk mill.

The best ozone delignification system, with respect to the environment, that is currently operating is provided by Sunds, and has been operating at Franklin, Virginia, USA for two years. The sequence is OAZ Eop D, using high[3] consistency oxygen and ozone stages. The key environmental factor at this mill is that the filtrates from the O, Z and Eop stages are recycled to the mill's recovery system.. Three further high consistency ozone systems have been ordered, (In Scandinavia, USA and South Africa) and are under construction at the time of writing. All have been ordered by technically sophisticated companies after careful examination of the Franklin system, demonstrating that the process can now be considered as proven technology.

There are about 10 other ozone delignification systems operating in kraft mills, all using medium consistency ozone stages. None recover the filtrates effectively, although they have plans to do so. Difficulties with the heat and hydraulic balance make recovery of the filtrates more problematic than in high consistency systems, and it remains to be seen whether it can be accomplished economically. At present, medium consistency ozone systems are less expensive than high consistency systems, but it may be more expensive if additional equipment is required so that the filtrates are to be recycled.

6.4.5 Elimination of effluent

When chlorine has been eliminated, and the bleach filtrate recycled to the recovery system, as discussed above, the quantities of chlorides, sulphates and sodium in the effluent will be very low, corresponding approximately the quantities arriving with the wood, and some minor losses of pulping liquors. It will be possible to recycle most of the treated effluent to the mill, to replace fresh water.

In principle, it will be possible to eliminate all effluent, but detailed mass and energy balances will be required to establish this. Some fresh water will be required, but this can possible be balanced by natural evaporation from the process, which may well include a cooling tower. If effluent cannot be avoided, then the volume will be sufficiently low to consider spray irrigation, with some storage during the winter months.

---

[3] *In this context "high" implies a consistency over 30%, while "medium" refers to operating consistencies around 15%*

7. References

Beim, Albert M and Elena I Grosheva, 1993. Ecological Chemistry of Mercury Contained in Bleached Kraft Pulp Mill Effluents. Journal Water, Air and Soil Pollution,.

Beim, Albert, and Elena I. Grosheva, 199x. New Kind of Complex Wastes Lignin Sludge Ecologo-Chemical Characteristics. Institute of Ecological Toxicology, USSR State Committee on Environment Protection 665914 Baikalsk, Irkutsk Reg. P.O. Box 48

Beljavtseva, G. and E. Grosheva, 1993. Balance of Chlororganic Compounds in Bleached Pulp Production. Institute of Ecological Toxicology, Baikalsk, Russia. Published in Journal Cellulose Paper and Board (Russia).

Carey, J. A Chung, H Cook and D. Halliburton, 1994 Overview of Current Canadian Federal Regulatory Regime for the Bleached Pulp and Paper Industry . Proc. 2nd International Conference on Environmental Fate and Effects of Bleached Pulp Mill Effluents, Vancouver, 1994 (Environment Canada).

Falkner, Kelly, K. Chris Measures, Sarah Herbelin, John Edmond and Ray Weiss, 1991 The Major and Minor Elements Geochemistry of Lake Baikal. Limnology and Oceanography, Vol. 36, No. 3, May 1991

Folke, Jens, 1995 Does COD provide a Useful Indication of the Sub-lethal Toxicity of ECF and TCF Effluents? Proc Non Chlorine-Bleaching Conf., Amelia Island, Florida., 1995 (Miller Freeman Publications, San Francisco).

Hayashi, S., A. Beim, and E. Grosheva, 1993a. Study on Bottom Sediments Pollution by Waste Water Suspended Solids in Lake Baikal. Institute for Ecological Toxicology, P.O. Box 48, Baikalsk, Irkutsk Region Russia 665914.

Hayashi, S., A.. Beim, and E Grosheva, 1993b. Lake Baikal, Modern Geochemistry and Pollution.. Institute for Ecological Toxicology, P.O Box 48, Baikalsk, Irkutsk Region Russia 665914

Kucklick, John R., Terry F. Bidleman, Laura McConnel, Michael D. Walla, Gennadi P. Ivanov, 1994 Organochlorines in the Water and Biota of Lake Baikal. Environmental Science and Technology, 28 1 1994 pp 31-35

Maatela, Paula, Jaakko Paasiverta, Michail Grachev, and Evgeny Karabanov., 1990 Organic Chlorine Compounds in Lake Sediments V. Bottom of Baikal Near a Pulp Mill. Limnological Institute of the Siberian Branch of the Academy of Sciences, USSA 3 Ulan-Batorskaya St., 66403 Irkutsk, U.S.S.R. Chemosphere, Vol 21, No 12 pg 1381-1384, 1990.

Meuleman, C., M Leermakers, V. Grachev, and W. Baeyens, 1993. Mercury Speciation in Lake Baikal. Analytical Chemistry Department, Free University of Brussels, Pleinlaan 2, B-1050 Brussels, Belgium.

Passivirta, J. P., Maatela, 1993 Organochlorine Compounds in Lake Sediments Role of the Forest Industry. Journal of Wood Chemistry, N 1-3 pg 3-25 1993.

Pavlov, B. K., A M. Beim, V. G Khotilovitch, (undated) Evaluation of the Effects of Atmospheric Industrial Ejections on Forest Ecosystems on Lake Baikal, South Coast (Library of institute of Ecotoxicology, Baikalsk)

Tatum, Vickie I., 1995 Heath Effects of TRS compounds. Proc TAPPI Environmental Conference, Atlanta, GA, USA, 1995

------------------ end of report ------------------