Current Technology for Control of Phosphorus and BOD Discharges in Effluents from Three Kraft Pulp Mills on the Androscoggin River

prepared for

State of Maine
Department of Environmental Protection

by

N. McCubbin Consultants Inc.

Neil McCubbin, P. Eng
Marten Krogerus
140 Fisher's Point
Foster
Québec J0E 1R0
CANADA
Tel : 450 242 3333
Email: N@McCubbin.ca

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Version 2 issued to correct typographical errors in Table 8. These affected phosphorus discharges from the Jay mills, for Scenarios 1, 2 and 3, as well as the associated totals in the table. The value of 0.07 lb/ton for phosphorus discharge from the Jay mill for scenario 2 in Table 1 was previously 0.06.

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1. Executive summary

This report reviews proven technology for reduction of discharges of phosphorus and BOD from three pulp and paper mills on the Androscoggin River, upstream of Gulf Island Pond.

It is concluded that reductions of up to 80% in total BOD and 65% in total phosphorus are attainable, which would represent discharges very substantially below paper industry averages, but not as low as the best in the US or overseas.

There is a very wide variety of combinations of technology available for reducing effluent discharge. Three potential scenarios were developed for each mill, to illustrate a range of possible levels of effluent improvement and estimated costs. They are summarized in Table 1 below, along with data on discharges from benchmark mills in the US and overseas.

Table 1 Recent and attainable effluent discharge characteristics of various mills

	BOD lb/t	Phosphorus lb/t	TSS lb/t
Current discharges			
Fraser Nexfor, Berlin, NH	10.9	0.21	6.3
MeadWestvaco, Rumford, ME	1.3	0.10	2.7
International Paper, Jay, ME	1.8	0.11	7.6
Glatfelter, Spring Grove, PA	0.9	0.01	1.4
International Paper, Ticonderoga, NY	1.6	0.05	4.0
Kuusakoski, Finland	0.4	0.02	1.6
Kaukas, Finland	1.1	0.02	2.9
Veitsiluoto, Finland	4.0	0.03	2.3
Scenario 1 upgrade to mill			
Fraser Nexfor, Berlin, NH	8.5	0.06	5.7
MeadWestvaco, Rumford, ME	0.8	0.06	2.6
International Paper, Jay, ME	1.0	0.09	7.2
Scenario 2 upgrade to mill			
Fraser Nexfor, Berlin, NH	1.9	0.05	5.7
MeadWestvaco, Rumford, ME	0.7	0.05	2.3
International Paper, Jay, ME	1.0	0.07	5.5
Scenario 3 upgrade to mill			
Fraser Nexfor, Berlin, NH	1.5	0.04	4.9
MeadWestvaco, Rumford, ME	0.6	0.05	1.9
International Paper, Jay, ME	0.9	0.06	4.5

All data presented in lb/ton finished product to facilitate comparison between mills.
Data on Androscoggin River and Finnish mills was provided by mill staff. NY and PA by State regulators.
The benchmark mills in PA, NY and Finland are all bleached kraft mills, with integrated paper manufacturing, and produce a range of products comparable to the Androscoggin River mills. They are described in the body of the report.
These values illustrate discharge levels attainable with application of certain specific technology, based on available data. Further engineering study of each situation would be required to define appropriate discharge permit limits, and consider variability factors.

The estimated costs for implementing the alternative scenarios are presented in Table 2 below.

Notice, that in most cases the annual direct operating and maintenance costs for the mills would be reduced. However, when recovery of the capital costs is also considered, the net impact on the manufacturing cost of the product may increase or decrease.

Table 2 Capital and operating costs for alternative measures for discharge reduction

	Capital Cost $000	O & M Cost / Saving $000/yr	Equivalent Annual Cost $/t product
Scenario 1			
Fraser Nexfor, Berlin, NH	220	415	$1.33
MeadWestvaco, Rumford, ME	19,100	-3,225	-$1.37
International Paper, Jay, ME	14,850	-1,835	-$0.08
Total	**34,170**	**-4,645**	
Scenario 2			
Fraser Nexfor, Berlin, NH	7,500	1,115	$6.06
MeadWestvaco, Rumford, ME	23,100	-3,315	-$0.80
International Paper, Jay, ME	16,850	-1,813	$0.31
Total	**47,450**	**-4,013**	
Scenario 3			
Fraser Nexfor, Berlin, NH	32,100	1,960	$17.48
MeadWestvaco, Rumford, ME	27,100	-3,955	-$1.03
International Paper, Jay, ME	25,850	-2,213	$1.34
Total	**85,050**	**-4,208**	

"O & M" refers to cost for raw materials, energy and direct labor.

The manufacturing costs in each mill are unknown, and are confidential to the companies, so it is not feasible to relate the above costs to manufacturing costs. However, typical sales prices for pulp and paper, as sold in large quantities by the mills, are well known. The highest cost shown above corresponds to approximately 1.5% of such prices.

More modest discharge reductions can be attained at much lower costs, as shown in the table..

2. Summary of report

2.1 Overview

This report reviews the technology available to reduce discharge of phosphorus and BOD from three pulp mills discharging to the Androscoggin River in Maine and New Hampshire. Estimated costs of implementing various alternative measures to reduce discharges of phosphorus and BOD by 15% to 90% from the present levels are presented.

The objective of the study was to present factual information based on worldwide experience in the pulp and paper industry that will assist the Gulf Island Pond Working Group in arriving at a consensus.

It is universally accepted in the paper industry that cost-effective control of effluent discharges can best be achieved by judicious integration of:-

- Selection of raw materials;
- Pollution prevention technology within the manufacturing process and
- Efficient treatment of the waste waters before discharge

It is feasible to reduce average[1] phosphorus discharges in the Androscoggin mills to below 0.06 lb/ton finished product[2] by upgrading the conventional activated sludge treatment systems presently installed in the three Androscoggin kraft mills, combined with internal mill upgrades to reduce raw waste formation, using technologies already proven in widespread mill use. The Glatfelter mill in Spring Grove, PA reports a phosphorus discharge of only 0.01 lb/ton, so it is tempting to conclude that such exemplary performance would be reproducible in the Androscoggin River mills. However, Glatfelter mill has been focusing on effluent control for 40 years, and has developed very sophisticated skills in this area. It takes a considerable amount of time to do this.

It is feasible to reduce BOD discharges to well below 2 lb/ton paper, which is below the US average, and is comparable to best few kraft mills in the world.

Mills with tertiary treatment systems can operate with phosphorus discharges as low as 0.01 lb/ton but at relatively high cost. The authors are aware of half a dozen tertiary treatment systems in the 350 or so bleached kraft mills in the world, including one in the US (International Paper at Ticonderoga, NY), which are still in operation. The lowest known discharge is at Baikalsk Pulp and Paper in Siberia, which uses activated sludge treatment followed by chemical coagulation.

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[1] Unless otherwise specified, "average" in this report refers to discharges or operating conditions, averaged over a recent year, or at least a few months when a full year's data is not available. Any permit limitations must also consider normal variability and an appropriate margin of safety in the operations.

[2] When comparing performance of mills it of different sizes, it is necessary to relate discharges to production rates. Air Dry US tons of bleached market pulp and Finished US tons are used as the reference here unless otherwise stated. Any references to kg/ton or g/ton refer to the metric ton.

There are two US mills known to the authors, which are comparable to the Androscoggin River mills in age, range of products manufactured and complexity, and which operate with very low phosphorus and BOD discharges. These are Glatfelter at Spring Grove, PA and International Paper at Ticonderoga, NY. Discharges of phosphorus from these mills average 0.01 lb/ton paper and 0.35 lb/ton paper produced respectively. It is noticeable that the Glatfelter mill, which has only conventional secondary treatment, operates with a lower discharge than the Ticonderoga mill which has secondary and tertiary treatment.

The technical content of this report draws heavily on design and mill operating experience in Finland. It is the major pulp and paper producing country in the world with climatic conditions and terrain similar to Maine, which also has a history of successful control of phosphorus discharges from pulp and paper mills.

Extensive data on the effluent treatment systems in the three mills under discussion was provided by mill staff, but only limited information was provided on the pulp and paper manufacturing equipment and operations. The Department recognizes the concerns of the industry with regard to the release of manufacturing or operating information that is business confidential information. The authors visited each of the three mills in November 2003 to inspect the waste water treatment systems and exchange ideas and data with mill staff. The content of this report is based on these visits, a review of the documents on the Gulf Island Pond working group at http://www.maine.gov/dep/blwq/topic/gip/submit1.htm and the two authors' experience totaling 60 years working with waste water discharge control in the paper industry worldwide.

Only proven technology, already established in the pulp and paper industry is used as the basis of this analysis.

2.2 Current situation

2.2.1 Mills and discharges

The three integrated bleached kraft pulp and paper mills on the Androscoggin River, which are the principal sources of effluents carrying phosphorus and BOD are listed in Table 3. All three mills manufacture a wide range of coated and uncoated papers from local wood. They were equipped with waste water treatment plants over 20 years ago, which dramatically reduced the impact of the effluents on the river.

Table 3 Pulp and paper mills on the Androscoggin River

		Pulp production t/day		Finished products t/d	
Town	**Company**	**Bleached kraft**	**Groundwood**	**Market pulp**	**Paper**
Berlin, NH (Pulp mill)	Nexfor Fraser Papers Inc.	725	0	450	0
Berlin, NH (Paper mill)	Nexfor Fraser Papers Inc.	0	0	0	600
Rumford, ME	Mead Westvaco	1,450	200	300	1,650
Jay, ME	International Paper Inc.	1,637	324	300	1,820

Pulp and paper rates expressed in finished US tons/day. Data on Jay mill refer to licensed production.
Data for the Jay mill include Wausau-Mosinee Paper (Otis), since the Jay WWTP processes Otis effluent and the combined discharge is under a single NPDES permit.

Current effluent discharges all comply with effluent discharge permits, at virtually all times. Average discharges for the past year (several months in the case of Berlin) are summarized in Table 4. They are typical of the range seen in US mills, although a few mills operate with much lower values.

Table 4 Current effluent discharges from pulp and paper mills on the Androscoggin River

Mill	Effluent flow MGD	BOD lbs/day	Phosphorus lbs/day	TSS lbs/day
Berlin, NH (Pulp mill)	15.2	3,400	200	4,500
Berlin, NH (Paper mill)	11.1	7,000	Low, but unknown	1,500
Rumford, ME	30.4	2,630	200	5,300
Jay, ME	40.9	3,450	200	14,500

Data shown for discharges is the most recent available to the authors. It is indicative of current discharges.

2.2.2 Androscoggin River and Gulf Island Pond

The Androscoggin River flows through Berlin, NH, then approximately 50 miles to the Rumford mill, and 20 miles further to the Jay mill. Each mill discharges all effluents to the river. Some areas downstream of the Jay mill are reported to have dissolved oxygen levels below state water quality standards when the river flow is low. The principal area of current concern is the impoundment of Gulf Island Pond, where the combination of oxygen demand and nutrients is sufficiently high to create algae blooms and depressed dissolved oxygen levels which cause a portion of the pond to fail to meet water quality standards.

Modeling by Maine DEP indicates that it may be desirable to reduce BOD and/or phosphorus discharges by in the order of one third to two thirds. The technologies evaluated in this report are aimed at covering this range, to assist the stakeholder group in arriving at a consensus on what action to take, if any

The three mills mentioned above are the dominant anthropogenic source of pollutants in the river.

The effect of a pound of BOD discharged from the Berlin mill on Gulf Island Pond will be much less than a pound from Jay, due to natural oxidation in the longer run of river. Analysis or discussion of this and related issues of reactions of pollutants in the river is beyond the scope of this report, but is addressed in the DEP model of the river.

2.3 Opportunities for reducing mill effluent

2.3.1 Integrating manufacturing process with effluent treatment

All pulp and paper mills that operate cost-effectively and with very low effluent discharges rely on a holistic approach where manufacturing and waste water treatment plants (WWTPs) are optimized as an overall system, and all personnel operating or maintaining mill equipment are trained in minimizing effluent discharges.

Early installations of waste water treatment in US mills, over 30 years ago, such as at MeadWestvaco at Covington, VA and Spring Grove, PA , all had serious operating difficulties until mill management developed techniques for integrating manufacturing with effluent treatment. Detailed reference is made in this report to the Glatfelter mill at Spring Grove because it is a very old mill, manufactures a wide range of coated and uncoated papers like the Androscoggin River mills, and it operates profitably while being the lowest effluent discharger in the US, and one of the lowest in the world.

2.3.2 Proven and economic technology

There are many technologies and operating practice that have been in use for some time in profitable, operating mills which can potentially be used to reduce the discharges of pollutants that affect the Androscoggin River. These include personnel training[3], improved process control for phosphorus addition, correction of weaknesses in existing waste treatment systems, recovery of unplanned mill process losses, oxygen delignification and replacement of aeration tanks in the mills' waste water treatment plants.

[3] *"Personnel training" is used in the broad sense, and included visiting exemplary mills across the US and overseas, and attendance at off-site specialized courses and conferences. Such training is applicable to staff from several mill manufacturing and maintenance departments, as well and waster water treatment plant operators.*

The measures suggested as applicable in this report include some that may improve the mills' profitability. Others range in cost from trivial amounts up to about 1.5% of the total sales[4] of the mills concerned[5].

Mills such as Glatfelter in Spring Grove, PA, and several mills in Finland, that consistently exceed the industry average return in capital invested make extensive use of most of the technologies suggested herein as being useful for reducing phosphorus and BOD discharges, demonstrating that they are not unrealistic economically. These mills rely on a combination of appropriate manufacturing processes and effluent treatment to achieve low discharges cost effectively.

The authors have focused on technology that is technically feasible, where the risk of failure could very low if installed in the three Androscoggin River mills. Tertiary treatment technology is discussed only briefly, since it does not have a proven track record, and does not offer any outstanding potential advantages over more traditional technology.

2.3.3 Water conservation and effluent flows

The waste water volume has a significant impact on the phosphorus load discharge in a number of ways.

- Reducing volume improves removal of the suspended solids that carry much of the phosphorus in treated effluent
- Less nutrient chemicals are required to maintain adequate concentration for the efficient BOD removal.
- Reducing effluent flow tends to force phosphorus to leave the mill process as solid waste, combined with relatively inert landfill, rather than in the effluent.
- Water conservation programs generally reduce mill manufacturing costs by recovering energy and fiber.

The Berlin, Rumford and Jay mills all discharge relatively high specific waste water volume figures of, 27,700, 17,500 and 20,250 gallons per ton product, respectively. Many older mills operate at less than half these values, showing that substantial reduction of effluent flow is technically feasible.

In the case of mills like Rumford and Jay where the efficiency of the WWTP is quite high, reducing effluent flow is a logical step towards cost effective reduction of the impact of the mill on the river.

The authors have not presented any specific water flow reduction measures herein, since the mills did not provide sufficient data for analysis.

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[4] *Assumptions in this report are based on published prices for paper products, sold in bulk from the mills.*

[5] *Wherever possible, capital costs are combined with operating costs by application for a capital cost factor, to reduce the combination to one value, that can be used to calculate the real, long term cost per lb of each pollutant removed.*

2.3.4 Phosphorus balance

There was very little information available on the entry of phosphorus to each mill, the internal phosphorus flows, and the exit points. It is suggested that each company develop a phosphorus balance for its own mill operations, to a level of detail similar to the example in Figure 14 on page 59. Calculation of such a balance should be part of any on-going program to reduce phosphorus, since an improved understanding is essential for selecting the most cost-effective measures.

The means of disposal of lost or rejected lime and contaminants from the recausticizing cycle can have a major impact on phosphorus discharges, so this area of the mill should be included in the phosphorus balance. In most mills, the process should be arranged so that the phosphorus losses are landfilled securely, and not discharged to the WWTP. However, a detailed study of the in-mill phosphorus balance is required to determine the optimal process configuration.

2.3.5 Zero capital cost measures

All three mills can benefit from programs to extend the effluent control know-how of operators, maintenance personnel and supervisors in the WWTP and major manufacturing departments. In addition to the normal in-mill training, these should include visits to exemplary mills across the US and overseas, as well as attendance at courses and industry conferences specialized in in-plant control and treatment of effluent in pulp mills. In visiting the mills, we noted that the staff who are directly involved in operating, supervising and maintaining the systems have less time and resources available for such professional development activities than we have seen in some of the mills that are outstandingly successful in minimizing effluent discharges.

In addition to the technical knowledge gained by visiting the mills with exemplary performance, there is considerable value in mill operating personnel seeing first hand what can be achieved. People who believe in a technology or operating procedure are the most likely to implement it well and inspire others.

Control of phosphorus addition to the WWTP based on the mass balance of phosphorus in the system, and the concentration of phosphorus in the biomass in the aeration tanks can be implemented to reduce discharges while also reducing operating costs by up to $100,000 per year in each mill. The associated technology is discussed later in this report.

2.3.6 Low capital cost measures

All three mills have most of the elements of modern spill recovery systems, but discharge data shows that there are opportunities to use techniques from the most efficient mills to make spill prevention and recovery much more efficient, thus recovering chemicals and reducing BOD discharge by 15% or more.

Some low-capital cost upgrades to the WWTP at Berlin and Jay are feasible, and perhaps at Rumford

2.3.7 Major mill and WWTP upgrades

The two mills pulping softwoods, Rumford and Jay, can reduce operating costs, and improve effluent discharges significantly by installing modern two-stage oxygen delignification systems. This process is very widely used in the industry, and is found in all low-effluent mills.

All three of the pulp mills, the WWTPs can be upgraded to state-of-the-art performance by replacing the aeration tanks, and associated equipment, in conjunction with the above mentioned measures to upgrade operating know-how. In the case of the Berlin paper mill, a new activated sludge treatment system would be required to reach state-of-the-art performance

2.4 Alternative scenarios in each mill

The body of this report discusses some technologies available for reducing effluent discharges at the three Androscoggin River mills. This should not be taken to suggest that other approaches should be excluded. In particular, the effluent flow from all three mills is high relative to the best mills in the world. Reduction of about 50% is technically feasible, using the same techniques as other mills that operate with low effluent flow. Such major improvements to mil water systems require several years to implement, since water cycles in mills are complex, and already involve extensive recycling. However, significant reduction is attainable in the short and medium term. This avenue is not explored herein, since the mills did not provide information on the existing water systems.

Three alternative scenarios have been developed for each mill, which are broadly similar, but differ according to site specific circumstances. The elements of each scenario are interrelated to some extent, but not completely tied together. It could be realistic to consider some elements independently. There is a large variety of alternative combinations that could be employed.

Management of a mill could adopt ONLY the WWTP aspects of a scenario, or ONLY the in-plant pollution prevention measures. **However, this would not be likely to lead to optimal results, either environmentally or economically.**

Scenarios 2 and 3 incorporate the elements of scenario 1, so Scenarios 1 & 2 or Scenarios 1 & 3 could logically be implemented sequentially. It would not be realistic for a mill to implement Scenario 2, and then Scenario 3 shortly afterwards.

2.4.1 Features of mill upgrade scenarios common to all mills

All mills could use improved control of the phosphorus balance in the WWTP, upgraded spill control and extended staff training to improve operations.

2.4.2 Fraser Nexfor at Berlin

This mill was recently recomissioned by new owners, with new managers, after an extended shutdown preceded by management that has been widely criticized. Operations are not yet stabilized, and some modifications are in progress that will reduce effluent discharges below those current at the time of writing.

The mill effluent BOD is relatively high, and can be reduced by about 80% by the installation of state-of-the-art activated sludge treatment for the paper mill and upgrading the pulp mill system. Phosphorus discharges can concurrently be reduced by around 75%. If combined with internal measures, the cost of such treatment will be minimized, and operation with low phosphorus discharge would be possible.

If oxygen delignification is installed and the pulp mill WWTP upgraded to state-of-the-art design, then only a modest further improvement is attainable.

About 20% BOD reduction can be achieved with low cost measures at the pulp mill by better utilization of existing equipment and capacity, and by better spill control. The potential for phosphorus reduction is up to 70% reduction compared with current discharge.

A considerably higher BOD reduction can be achieved with additional biological treatment of the paper mill effluent which currently represents about 70% of the total BOD load from Berlin mills.

For all discharge parameters the attainable levels stated include the assumption that in-mill measures will contribute to the reduction as well. In the case of phosphorus the predictions involve a relatively high degree of uncertainty due to lack of data on the mill.

Detailed data on the technical aspects and estimated costs of the alternative scenarios is presented on the following page

Table 5 Impact on effluent quality and costs of alternative upgrades for Berlin mill

	BOD lb/d	P lb/d	TSS lb/d	Capital Cost $000	O & M Cost $000/yr	Equivalent Annual cost $000/year	Equivalent Annual cost $/t product	BOD removal $/ton BOD	P removal $/ton P
Current discharge =	10,400	200	6,000						
Effluent control measure	**Reduction in Discharge**								
Spill control	1,500	25	0	100	0	12	$0.04	$0.05	------
Extend effluent control know-how	------	------	------	0	25	25	$0.08	------	------
Additional WWTP operator	------	------	------	0	250	250	$0.75	------	------
Improved Phosphorus Control	0	90	0	0	-120	-120	-$0.36	------	-$7.62
Utilization of North Aeration Basin	2,000	5	600	100	260	272	$0.82	$0.78	$310.86
Improve Flow Arrangements	200	5	0	20	0	2	$0.01	$0.07	$2.74
Totals for Berlin Scenario 1	**2,300**	**140**	**600**	**220**	**415**	**441**	**$1.33**	**$1.10**	**$18**
Percentage reduction in discharge	22%	70%	10%						
Discharge if Scenario 1 is implemented	**8,100**	**60**	**5,400**						
Spill control	1,500	25	0	100	0	12	$0.04	$0.05	------
Extend effluent control know-how	------	------	------	0	25	25	$0.08	------	------
Additional WWTP operator	------	------	------	0	250	250	$0.75	------	------
Phosphorus Control	0	95	0	0	-120	-120	-$0.36	------	-$7.22
Utilization of North Aeration Basin	2,000	5	600	100	260	272	$0.82	$0.78	$310.86
Install aerobic selector	400	10	1,200	300	0	36	$0.11	$0.51	$20.57
State-of-the-art - AST in paper mill	6,200	???	100	7,000	700	1,540	$4.63	$1.42	
Totals for Berlin Scenario 2	**8,600**	**150**	**600**	**7,500**	**1,115**	**2,015**	**$6.06**	**$1.34**	**$77**
Percentage reduction in discharge	83%	75%	10%						
Discharge if Scenario 2 is implemented	**1,800**	**50**	**5,400**						
Spill control	1,500	0	0	100	0	12	$0.04	$0.05	------
Extend effluent control know-how	------	------	------	0	25	25	$0.08	------	------
Additional WWTP operator	------	------	------	0	250	250	$0.75	------	------
Phosphorus Control	0	132	0	0	-115	-115	-$0.35	------	-$4.98
Oxygen delignification	1,000	0	0	20,000	1,200	3,600	$10.83	$20.57	------
State-of-the-art - AST in pulp mill	2,500	130	1,200	5,000	-100	500	$1.50	$1.14	$21.98
State-of-the-art - AST in paper mill	6,200	???	100	7,000	700	1,540	$4.63	$1.42	**???**
Totals for Berlin Scenario 3	**9,000**	**160**	**1,300**	**32,100**	**1,960**	**5,812**	**$17.48**	**$3.69**	**$208**
Percentage reduction in discharge	87%	80%	22%						
Discharge if Scenario 3 is implemented	**1,400**	**40**	**4,700**						

Impacts of individual process upgrades on effluent discharge characteristics are not simply additive, since there are interactions between individual process changes.
The Equivalent Annual Cost includes the cost of the capital investment, converted to an equivalent annual cost.
The costs shown in the last four columns are each calculated from the columns to the left. They cannot be added directly.
Costs shown as dollars per ton include annual costs and the cost of capital. They are calculated from the equivalent annual cost, divided by the relevant quantity.

2.4.3 Mead Westvaco at Rumford

There is a potential to improve phosphorus and BOD discharges up to about 40% by improving black liquor spill recovery and phosphorus control at the WWTP.

Further improvement (about 10 percentage points) can be achieved by installing oxygen delignification , reducing coating losses and improving WWTP design.

Additional improvement by some 10 percentage points or so would be attainable by installing a state-of-art WWTP, which would simultaneously reduce operating costs, albeit at considerable capital cost.

Since the mill has a reasonably large softwood line, installation of oxygen delignification would offer a better return on investment than the average return on capital invested for the paper industry, while reducing discharges of BOD and phosphorus.

For all discharge parameters the attainable levels stated include the assumption that in-mill measures will contribute to the reduction as well. The predictions involve a degree of uncertainty due to lack of data on the mill.

Detailed data on the technical aspects and costs of the alternative scenarios is presented on the following page

Table 6 Impact on effluent quality and costs of alternative upgrades for Rumford mill

	BOD lb/d	P lb/d	TSS lb/d	Capital Cost $000	O & M Cost $000/yr	Equivalent Annual cost $000/year	Equivalent Annual cost $/t product	BOD removal $/ton BOD	P removal $/ton P
Current discharge =	2,630	200	5,300						
Effluent control measure	Reduction in Discharge								
Spill control	700	0	0	100	0	12	$0.02	$0.10	——
Oxygen delignification	1,100	6	250	19,000	-3,200	-920	-$1.35	-$4.78	——
Extend effluent control know-how	——	——	——	0	25	25	$0.04	——	——
Phosphorus Control	0	30	0	0	-50	-50	-$0.07	——	-$9.52
Totals for Rumford Scenario 1	**1,100**	**80**	**250**	**19,100**	**-3,225**	**-933**	**-$1.37**	**-$4.85**	**-$67**
Percentage reduction in discharge	42%	40%	5%						
Discharge if Scenario 1 is implemented	**1,530**	**120**	**5,050**						
Spill control	700	0	0	100	0	12	$0.02	$0.10	——
Oxygen delignification	1,100	6	250	19,000	-3,200	-920	-$1.35	-$4.78	-$876
Extend effluent control know-how	——	——	——	0	25	25	$0.04	——	——
Phosphorus Control	0	50	0	0	-80	-80	-$0.12	——	-$9.14
Increase operating level of aeration tanks	400	6	500	2,000	-60	180	$0.26	$2.57	$171
Reduce coating loss	200	6	500	2,000	saving	——	——	——	——
Totals for Rumford Scenario 2	**1,250**	**100**	**750**	**23,100**	**-3,315**	**-543**	**-$0.80**	**-$2.48**	**-$31**
Percentage reduction in discharge	48%	50%	14%						
Discharge if Scenario 2 is implemented	**1,380**	**100**	**4,550**						
Spill control	700	0	0	100	0	12	$0.02	$0.10	——
Oxygen delignification	1,100	6	250	19,000	-3,200	-920	-$1.35	-$4.78	——
Extend effluent control know-how	——	——	——	0	25	25	$0.04	——	——
Phosphorus Control	0	80	0	0	-80	-80	-$0.12	——	-$5.71
State-of-the-art activated sludge process	1,500	80	1,000	8,000	-700	260	$0.38	$0.99	$18.57
Totals for Rumford Scenario 3a	**1,500**	**110**	**1,500**	**27,100**	**-3,955**	**-703**	**-$1.03**	**-$2.68**	**-$37**
Percentage reduction in discharge	57%	55%	28%						
Discharge if Scenario 3a is implemented	**1,130**	**90**	**3,800**						
Spill control	700	0	0	100	0	12	$0.02	$0.10	——
Oxygen delignification	1,100	6	250	19,000	-3,200	-920	-$1.38	-$4.78	——
Extend effluent control know-how	——	——	——	0	25	25	$0.04	——	——
Phosphorus Control	0	84	0	0	-70	-70	-$0.11	——	-$4.76
Install biological suspended carrier process	1,500	80	1,000	7,500	200	1,100	$1.65	$4.19	$79
Totals for Rumford Scenario 3b	**1,500**	**85**	**1,500**	**26,600**	**-3,045**	**147**	**$0.22**	**$0.56**	**$9.88**
Percentage reduction in discharge	57%	43%	28%						
Discharge if Scenario 3b is implemented	**1,130**	**115**	**3,800**						

Impacts of individual process upgrades on effluent discharge characteristics are not simply additive, since there are interactions between individual process changes.
The Equivalent Annual Cost includes the cost of the capital investment, converted to an equivalent annual cost.
The costs shown in the last four columns are each calculated from the columns to the left. They cannot be added directly.
Costs shown as dollars per ton include annual costs and the cost of capital. They are calculated from the equivalent annual cost, divided by the relevant quantity.

2.4.4 International Paper at Jay

Effluent TSS concentration is high, and this could be reduced substantially by internal measures or treatment. The existing aeration tank is too large, too shallow and not well shaped for efficient operation. The system was originally constructed as an aerated stabilization basin, according to common practice at the time.

Phosphorus discharges can be reduced by up to about 50% by improving spill control, installing upgraded oxygen delignification, better phosphorus control at WWTP and by improving the WWTP design and operation. The TSS discharge is anticipated to drop considerably as a result of upgrading WWTP design.

Since the mill has reasonably large softwood line, installation of a modern two-stage oxygen delignification would offer a better return on investment than the average return on capital invested for the paper industry, while reducing discharges of BOD and phosphorus.

Current flow is almost 40,000 gallons/ton product, which is well over double that of the lowest flow comparable mills. Thus it is realistic to assume that the flow can be reduced by 50% by proven technology. The mill did not provide sufficient data to allow assessment of costs.

For all discharge parameters the attainable levels stated include the assumption that in-mill measures will contribute to the reduction of discharges. In the case of phosphorus the predictions involve a degree of uncertainty due to lack of data on the mill, and the company's somewhat unusual use of phosphorus in papermaking.

Detailed data on the technical aspects and costs of the alternative scenarios is presented on the following page

Table 7 Impact on effluent quality and costs of alternative upgrades for Jay mills

	BOD lb/d	P lb/d	TSS lb/d	Capital Cost $000	O & M Cost $000/yr	Equivalent Annual cost $000/year	Equivalent Annual cost $/t product	BOD removal $/ton BOD	P removal $/ton P
Current discharge =	3,450	200	14,500						
Effluent control measure	**Reduction in Discharge**								
Spill control	1,000	N/A	0	50	0	**6**	**$0.01**	**$0.03**	**------**
Oxygen delignification upgrade	1,000	N/A	800	14,800	-2,100	**-324**	**-$0.49**	**-$1.85**	**------**
Extend effluent control know-how	-----	-----	-----	0	25	**25**	**$0.04**	**------**	**------**
Additional WWTP operator	-----	-----	-----	0	250	**250**	**$0.38**	**------**	**------**
Phosphorus Control	0	20	0	0	-10	**-10**	**-$0.02**	**------**	**-$2.86**
Totals for Jay Scenario 1	**1,500**	**20**	**800**	**14,850**	**-1,835**	**-53**	**-$0.08**	**-$0.20**	**-$15.14**
Percentage reduction in discharge	43%	10%	6%						
Discharge if Scenario 1 is implemented	**1,950**	**180**	**13,700**						
Spill control	1,000	N/A	0	50	0	**6**	**$0.01**	**$0.03**	**------**
Oxygen delignification upgrade	1,000	N/A	800	14,800	-2,100	**-324**	**-$0.49**	**-$1.85**	**------**
Extend effluent control know-how	-----	-----	-----	0	25	**25**	**$0.04**	**------**	**------**
Additional WWTP operator	-----	-----	-----	0	250	**250**	**$0.38**	**------**	**------**
Phosphorus Control	0	30	0	0	12	**12**	**$0.02**	**------**	**$2.29**
Upgrading of aeration basin	1,000	40	4,000	2,000	0	**240**	**$0.36**	**$1.37**	**$34.29**
Totals for Jay Scenario 2	**1,600**	**60**	**4,000**	**16,850**	**-1,813**	**209**	**$0.31**	**$0.75**	**$20**
Percentage reduction in discharge	46%	30%	28%						
Discharge if Scenario 2 is implemented	**1,850**	**140**	**10,500**						
Spill control	1,000	N/A	0	50	0	**6**	**$0.01**	**$0.03**	**------**
Oxygen delignification upgrade	1,000	N/A	800	14,800	-2,100	**-324**	**-$0.49**	**-$1.85**	**------**
Extend effluent control know-how	-----	-----	-----	0	25	**25**	**$0.04**	**------**	**------**
Additional WWTP operator	-----	-----	-----	0	250	**250**	**$0.38**	**------**	**------**
Phosphorus Control	0	35	0	0	12	**12**	**$0.02**	**------**	**$1.96**
State-of-the-art activated sludge process	1,500	65	6,000	11,000	-400	**920**	**$1.38**	**$3.50**	**$81**
Totals for Jay Scenario 3	**1,800**	**90**	**6,000**	**25,850**	**-2,213**	**889**	**$1.34**	**$2.82**	**$56**
Percentage reduction in discharge	52%	45%	41%						
Discharge if Scenario 3 is implemented	**1,650**	**110**	**8,500**						

Impacts of individual process upgrades on effluent discharge characteristics are not simply additive, since there are interactions between individual process changes.
The Equivalent Annual Cost includes the cost of the capital investment, converted to an equivalent annual cost.
The costs shown in the last four columns are each calculated from the columns to the left. They cannot be added directly.
Costs shown as dollars per ton include annual costs and the cost of capital. They are calculated from the equivalent annual cost, divided by the relevant quantity.

2.5 Attainable effluent quality in Androscoggin River mills

Discharges corresponding to the more detailed tables above are summarized in Table 8 below. and also in the executive summary. In all cases, data represent long term averages. The normal variability factors should be applied if any of these numbers are to be used for developing effluent discharge permits.

These values are comparable to the best mills in the US, but are not as low as the best in the world, because mill effluent flows are high by world standards, and the authors did not have sufficient information on the mills to assess potential measures of reducing the flows.

Table 8 Attainable effluent discharges from mills on the Androscoggin River, lb/day

	BOD	Phosphorus	TSS
Current discharges			
Fraser Nexfor, Berlin, NH	10,400	200	6,000
MeadWestvaco, Rumford, ME	2,630	200	5,300
International Paper, Jay, ME	3,450	200	14,500
Total for current situation	**16,480**	**600**	**25,800**
Scenario 1			
Fraser Nexfor, Berlin, NH	8,100	60	5,400
MeadWestvaco, Rumford, ME	1,530	120	5,050
International Paper, Jay, ME	1,950	180	13,700
Total for Scenario 1	**11,580**	**360**	**24,150**
Scenario 2			
Fraser Nexfor, Berlin, NH	1,800	50	5,400
MeadWestvaco, Rumford, ME	1,380	100	4,550
International Paper, Jay, ME	1,850	140	10,500
Total for Scenario 2	**5,030**	**290**	**20,450**
Scenario 3			
Fraser Nexfor, Berlin, NH	1,400	40	4,700
MeadWestvaco, Rumford, ME	1,130	90	3,800
International Paper, Jay, ME	1,650	110	8,500
Total for Scenario 3	**4,180**	**240**	**17,000**
Reduction for Scenario 3 over current	75%	60%	34%

Refer to detailed tables on each mill in preceding pages for breakdown of data and also for cost information

2.6 Caveats

2.6.1 Engineering and scientific issues

The recommendations and conclusions regarding improvement opportunities in the Androscoggin River mills discussed in this report are based largely on information provided by the mills reviewed, and rely in part on the accuracy thereof. For the wastewater treatment processes extensive data were made available on most aspects of interest, but some mills provided little data on phosphorus. Due to the concerns with the release of business confidential information, the mills provided little data on the manufacturing systems.

Since the final discharges to recipient are dependent on the environmental performance of both in-mill and waste water treatment systems, the authors have made a number of assumptions based on public documents, typical performance levels at other similar installations, past experience and best engineering judgment. Readers should consider that there may be technical and economical reasons, unknown to the authors at this point, why the proposed measures or removals may not be applicable to a specific mill. We acknowledge that this is a weakness of this study and emphasize the need for confirmation of our assumptions. We recommend additional analysis of effluents and in-plant streams, particularly phosphorous in order to engineer cost-effective and efficient improvement measures.

2.6.2 Costs

Estimates of the capital and operating costs herein are based on the best information available to the authors, and their extensive experience in the industry. Where the sources are public, they are cited, but most of the data is from the authors' files on other projects, so the sources be identified.

Most of the underlying cost information is from retrofitting upgrades in US mills, so it refers to comparable working conditions, normally in restricted space. However, each site has its own specific problems, which can only be identified by developing detailed flowsheets, site plans, equipment layouts and investigating local sub-surface conditions. These aspects can affect capital costs, but rarely by more than plus or minus 30%.

3. Introduction

3.1 Terms of reference

N. McCubbin Consultants Inc. (McCubbin) was engaged by the Maine Department of Environmental Protection (MDEP) on 15th September 2003 to assess the current technology available for reduction of phosphorus discharges from the pulp and paper mills in Berlin, NH, Rumford, ME and Jay, ME

The specifications of the work to be performed, defined in McCubbin's contract with Maine DEP, and can be summarized as follows:

- Review all materials supplied by the DEP and the mills,
- Visit each mill to inspect existing waste water treatment systems,
- Become familiar with mill operations and site constraints,
- Identify the status of phosphorus control in the three mills
- Identify potential improvements for reducing discharges of BOD, and Total Phosphorus to meet the goals specified in DEP's treatment options matrix.
- Review projected costs and give expert opinion regarding process controls, treatment, other technologies and expected costs of all options presented.

3.2 Background

Mitnik (2003) indicates that a significant reduction of the current discharge of BOD and phosphorus by point sources is necessary to acheive compliance with water quality criteria in the Androscoggin River.

McCubbin was retained by the Maine DEP in March 2003 to briefly review technical options for reducing phosphorus discharges by the three kraft pulp mills on the river. The budget available did not allow for visits to each mill, or extensive analysis of data. The report was submitted to DEP in June 2003, and is available to the public.

McCubbin was retained in September 2003 to analyze the mills' operations and the technology available for reducing discharges of BOD, TSS and phosphorus. The mandate includes estimating the capital and operating costs of applying upgrades.

Data on current mill operations, and comments on effluent control technology, in this report are based on more complete information than the above mentioned report presented in spring 2003, so should be considered to supercede it.

3.3 Pulp and paper mills discussed in this report

The technology discussed herein is limited to measures potentially applicable to the three mills of interest, which are listed in Table 3.

All three mills produce bleached chemical pulp by the traditional kraft process with modern spent cooking liquor ("black liquor") recovery, using Elemental Chlorine Free (ECF) bleaching. Two of the mills also manufacture some groundwood pulp, which is not bleached. Most of the pulp produced is used to manufacture paper on site. In the case of Berlin, the pulp and paper mills have separate effluent treatment plants, and largely separate water systems. At Rumford and Jay, the pulp and paper mills are integrated. The Jay mill treats the effluent from a nearby paper mill owned by a third party, Wausau Papers Otis Mill Inc. (Otis). The IP and Otis mills at Jay are considered as one mill for the purpose of this report.

The following pages describe the aspects of the November 2003 status of each mill that are relevant to the current mandate. Values shown are used as the basis for calculations of potential effluent improvements and costs discussed later in this report.

The data presented is extracted from responses to a questionnaire sent to the mills by McCubbin, public data, and information collected during a one-day site visit to each mill between 11th and 13th November 2003 by both authors of the present report. Department staff were present at each of these three visits.

3.3.1 Berlin mills

There are two mills in Berlin, the pulp mill (formerly known as the "Burgess" mill), and the paper mill three miles downriver (formerly known as the "Cascade" mill). The mills are owned and operated by Nexfor Fraser Papers Inc. Each has separate effluent treatment systems and outfall, but operate under one combined effluent discharge permit. A summary of current mill design and operating data that are relevant to the issues under discussion in this report is presented in Table 9 on page 21.

The Berlin mills were closed and largely abandoned by their former owners for approximately two years. Fraser purchased the mills recently, corrected a number of equipment deficiencies, and recommenced paper production in 2001, and pulp production in early 2003. At the time of writing, some mill system upgrades which will reduce effluent discharges were in progress, and the mills were not yet operating at full production rates, so data on effluent discharges and mill characteristics are somewhat tentative.

The pulp mill produces approximately 700 t/day kraft pulp, most of which is bleached by an ECF process. Approximately 300 t/day is dried on site in a single dryer and sold as market pulp and the remainder is delivered by pipeline to the paper mill. The mill formerly produced both hardwood and softwood pulp in separate fiber lines, but Fraser chose to upgrade the hardwood line and permanently close down the softwood line.

Pulping is conventional, without extended cooking, oxygen or ozone delignification. Bleaching is by a typical ECF process.

Mill staff advises that most areas handling black liquor are protected by spill recovery sumps, which automatically route spills to the black liquor system. There are no data available to assess the effectiveness of this system.

The paper mill produces approximately 600 t/day of a wide variety of papers. There are five paper machines, but at the time of writing not all were in operation, due to conditions in the paper market.

The mill produces a wide variety of paper grades, including some deep colors and food packaging specialties. This requires very frequent grade changes, and separation of some paper machine white water systems to respect FDA regulations, which is turn, limits the potential for water conservation and internal BOD reduction measures.

An unusual situation exists, that should allow the mill to cut effluent flow substantially once an upgrade program currently under construction is completed in 2004. Bleached pulp is produced at approximately 10% consistency, and is diluted to 1.5% with fresh water for transport by gravity pipeline to the paper mill, approximately 3 miles away. At the paper mill, the pulp is thickened to roughly 10% and the "transport" water discarded to the mill sewer. This contributes in the order of 50 m^3/ton of pulp (approximately 2.6 MGD) to the paper mill effluent flow, which is about one quarter of the total current flow. Such water always carries some suspended solids, representing a loss of marketable fiber.

A system to return much of this discarded water to the pulp mill for reuse for pulp transport is under construction at the time of writing, and is expected to be operational early in 2004. This will increase operating temperatures in the paper mill, and recover fiber. It will also reduce the effluent flow from the paper mill substantially. Since the company did not provide internal mill process data, the authors can not estimate the magnitude of the savings attainable.

Table 9 Summary of current mill operations

		Berlin	Rumford	Jay
Effluent before treatment				
Effluent flow	MGD	26.3	34.1	38.5
Effluent flow	gallons/ ton	27,700	17,500	20,250
BOD after primary treatment	lbs/day	28,800 *	61,850	79,266
TSS after primary treatment	lbs/day	12,500 *	24,526	48,691
Phosphorus after primary treatment	lbs/day	unknown	346	607
WWTP				
Primary clarifiers		190 *	220	2 x 290
Up flow rate in primary clarifier	USG/sq ft/day	536 *	900	720
Primary clarifiers – Berlin paper mill	ft diameter	130	---	---
Up flow rate in primary clarifier	USG/sq ft/day	837	---	---
Aeration tank volume	million gallons	3.6 *	8.9	32
Aeration power installed	HP	1075 *	4440	4125
Aeration power installed	kW hr/lb BOD removed	0.76 *	1.35	0.98
Sludge age		4 *	6	9
Secondary Clarifiers	No. and diameter	1 x240 *	3 rectang.	2 x 255
Up flow rate in secondary clarifiers		342 *	564	420
Permit limits				
Permitted BOD discharge (summer)	lb/day max month	13,400	12,000	10,900
Permitted TSS discharge (summer)	lb/day max month	28,000	32,900	12,000
Permitted BOD discharge (winter)	lb/day max month	14,000	12,000	17,700
Permitted TSS discharge (winter)	lb/day max month	28,000	32,900	25,000

Data approximate the normal values for the current mill configuration. Actual values will vary day to day with market conditions and paper grades being manufactured, as well as random variations in operations
Data were not available for the Berlin paper mill, so some totals for this mill are absent in this table.
Asterisked items for Berlin refer to the pulp mill only.

Pulp mill WWTP

The pulp mill waste water treatment plant (WWTP) consists of a primary clarifier which treats all of the effluent, followed by an activated sludge system, with a single secondary clarifier, as shown in Figure 1.

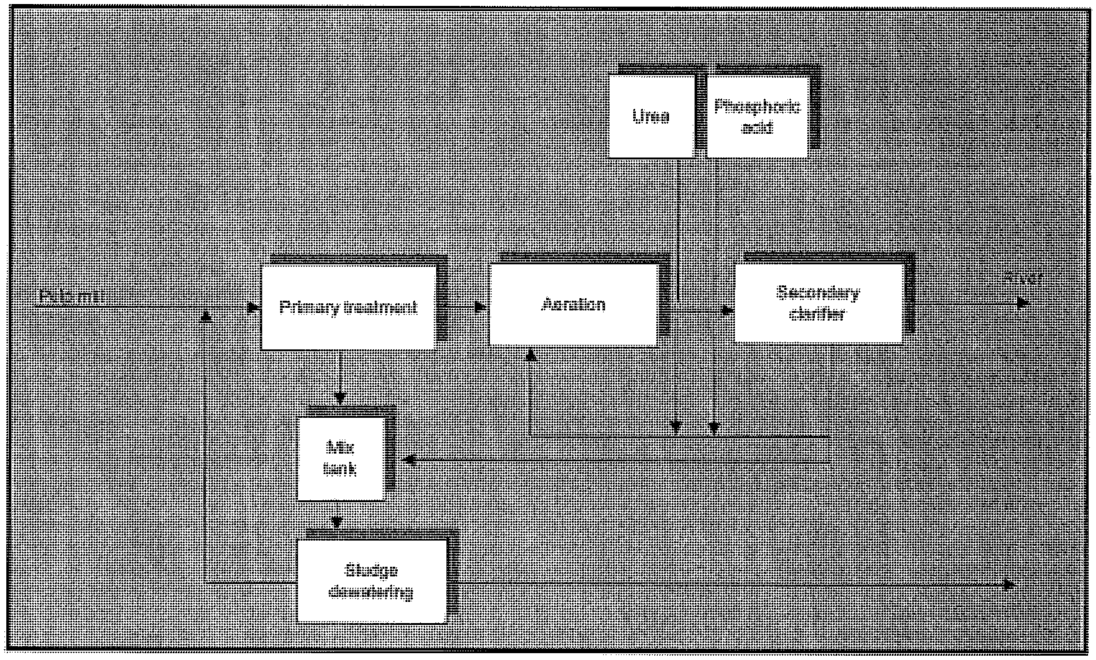

Figure 1 Block diagram of waste water treatment plant at Berlin pulp mill

There are two aeration basins in series, (North and South) with a total retention time of approximately 11 hours at average flow. Since restarting the pulp mill in 2003, mill staff have decided to bypass the North basin, stating that settlement of solids in the secondary clarifier is better in this mode of operation.

Phosphorus is added to the system to maintain 0.5 to 1 mg/L residual in the aeration tank. Staff advise that normally, 300 to 450 lbs/day phosphorus is added to maintain this nutrient concentration. However, there has been very little data on the monitoring of control of phosphorus available for review at the time of the authors' site visit.

During the last period September to November 2003, the concentration of Mixed Liquor Suspended Solids (MLSS) in aeration tank has generally been in the range of 2,000 to 3,000 mg/L.

Dissolved oxygen levels are reported to vary from 1 mg/L at the inlet to 0.5 mg/L at the outlet. Sludge volume index (SVI) is reported to normally be around 100.

There is one operator on duty, 24 hours/day, with technical support from the company's central technical services and a senior environmental engineer locally.

The sludge dewatering system includes gravity tables, a screw press and a belt press, and runs 24 hours/day. Operation was described by staff as being "difficult", which is not unusual. Many mills take time to optimize such systems. The ratio of primary to secondary sludge is approximately 25:75, by volume.

Paper mill WWTP

The paper mill WWTP consists of a primary clarifier, which treats all of the effluent, followed by an aerated stabilization basin (ASB). Mill staff report that there is no noticeable biological activity, and hence no BOD reduction, in the ASB, although there is a significant reduction in effluent BOD across the primary clarifier. There is no addition of phosphorus to the system, but there is some naturally present in the waste waters. The company does not measure phosphorus discharge.

There is a polishing pond following the aeration basin, with a total retention time of approximately 2 days at average flow.

3.3.2 Rumford mill

The Rumford mill is owned by MeadWestvaco, and produces both softwood and hardwood kraft pulp; all of which is bleached by an ECF process. The softwood/hardwood ratio varies, with softwood normally representing one third to one half of the total production. There is also a groundwood mill on site. Most of the pulp is used in the paper mill on-site, to produce a variety of coated communication grade paper, while the balance is sold as market pulp.

A summary of current mill design and operating data that are relevant to the issues under discussion in this report is presented in Table 9 on page 21.

There are two pulping lines. The "A" line produces softwood pulp in a continuous digester, followed by a pressure diffuser, pressure knotting, 3 stage vacuum washing, pressure screening, and a decker. Softwood is bleached in a D Eop, D sequence.

The "B" line produces hardwood, using 10 Batch digesters (digesters No. 1 to 4 can swing to produce softwood) followed by pressure knotting, a CB washer, 3 stage DD washer, unbleached HD storage, pressure screening, decker, and bleaching by the D Eop D sequence.

Chlorine dioxide is produced by an R-8 chlorine dioxide generator.

The mill has a conventional kraft recovery system, with modern NDCE boiler, and steam plant which burns mill waste, tire waste, and fossil fuel, to generate steam and power for the mill.

There are four paper machines, with on-machine coaters, and one pulp dryer.

A new brown stock washer was added to the hardwood line in late 2002. Mill staff reported that this achieved a considerable reduction in effluent color, to the present level of approximately 75 lb/ton pulp.

Color is not directly relevant to the issue of phosphorus and BOD that impact Gulf Island Pond, but it is a useful indication of the effectiveness of the control of black liquor organic losses within the mill. The lowest color discharge known to the authors in a US mill without any specific treatment system for color reduction is at Appleton, Roaring Spring, PA, where the discharge is 54 lb/ton pulp. The Roaring Spring mill produces only hardwood pulp, so could be expected to discharge somewhat less color than Rumford mill. The Glatfelter mill at Spring Grove, PA produces a 50/50 mixture of hardwood and softwood pulp and discharges 55 lb color per ton pulp produced. Most mills in the US discharge considerably more color, generally in the range 100 to 200 lb/ton.

The foregoing suggests that control of black liquor organics losses at the Rumford is tighter than in most US mills, but that losses are approximately double that of the best two US mills. Thus, it appears that it should be possible to reduce untreated BOD load to the WWTP, using technology already used in mills operating in the US. This will assist in reducing final discharge BOD and phosphorus as discussed later in this report.

It is not possible to compare color discharges from the Rumford mill with overseas mills, due to lack of data.

<u>Rumford WWTP</u>

The waste water is treated in a primary clarifier, followed by an activated sludge treatment plant, as shown in Figure 2. The aeration tank consists of two similar, triangular basins in parallel, approximately 12 feet deep. The site is very congested, so expansion of the aeration tank would be relatively expensive.

The secondary clarifiers are rectangular, which is rather unusual in paper industry treatment systems.

Sludge is dewatered and incinerated on site.

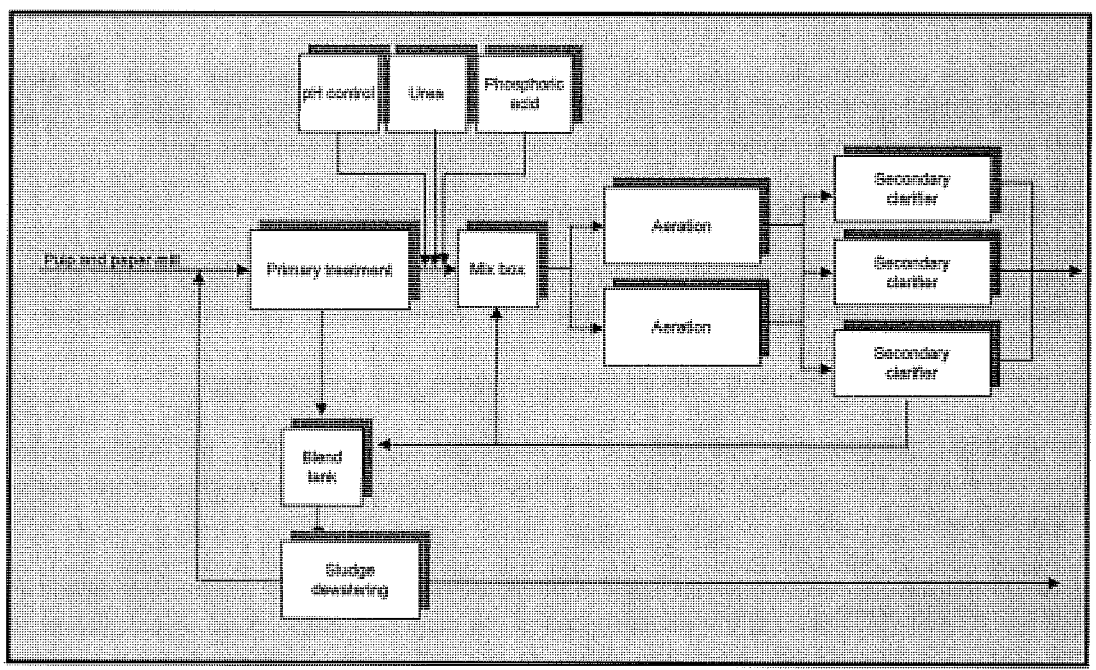

Figure 2 Block diagram of waste water treatment plant at Rumford mill

3.3.3 Jay mill

There are two mills in Jay, International Paper Inc (commonly referred to as "IP") and Wausau-Mosinee Paper Inc. (commonly known as "Otis") Ownership and management of the two mills is entirely separate, but IP mixes all effluent from the Otis mill with its own, and treats the combined stream in the WWTP. The discharge is controlled as a single discharge by the following a group of permits:

Issued by	**Number**
U.S.EPA	ME0001937
ME.DEP	W-000623-44-C-R
Jay	No.5

While the mills are legally separate, the WWTP and effluent discharge are one system from the standpoint of engineering analysis and development to of effluent discharge permits, and are referred to as the "Jay" mill herein, except where it is necessary to distinguish between the two.

The **IP mill at Jay** produces both hardwood and softwood pulp, all of which is bleached by an ECF process. Most of the pulp is used in the paper mill on-site, to produce approximately a variety of coated and uncoated communication grade paper.

A summary of current mill design and operating data that are relevant to the issues under discussion in this report is presented in Table 9 on page 21.

Pulp is produced on separate lines for hardwood and softwood, with a combined recovery system. Bleaching is ECF, in two separate lines, with an oxygen delignification system in the softwood line.

The mill has a conventional kraft recovery system for black liquor and cooking liquor preparation.

There are five paper machines, of which four are equipped with on-machine coaters. Mill staff commented that any water conservation measures they could institute would have to maintain separation of water systems between machines, to preserve product quality. This separation is common practice. Although combining water systems can reduce capital costs, it is often avoided for the reasons stated by the Jay mill staff.

The **Otis mill at Jay** produces coated and uncoated paper, but does not manufacture any kraft pulp. This mill contributes approximately 2.9 MGD and 8,000 lbs/day to the total waste water stream, which is roughly 10% of the total. There are no data available on the phosphorus content of the Otis mill effluent, but it is probably small, since papermaking activities do not normally discharge significant quantities of phosphorus.

Effluent flow from the Otis mill is equivalent to 14,250 USG/ton (60 m^3/t) which suggests that there are significant opportunities for reducing the flow in a cost effective manner.

Jay WWTP

The WWTP has a conventional primary clarifier, followed by an activated sludge system with two secondary clarifiers, with 4 m (12 ft) sidewall.

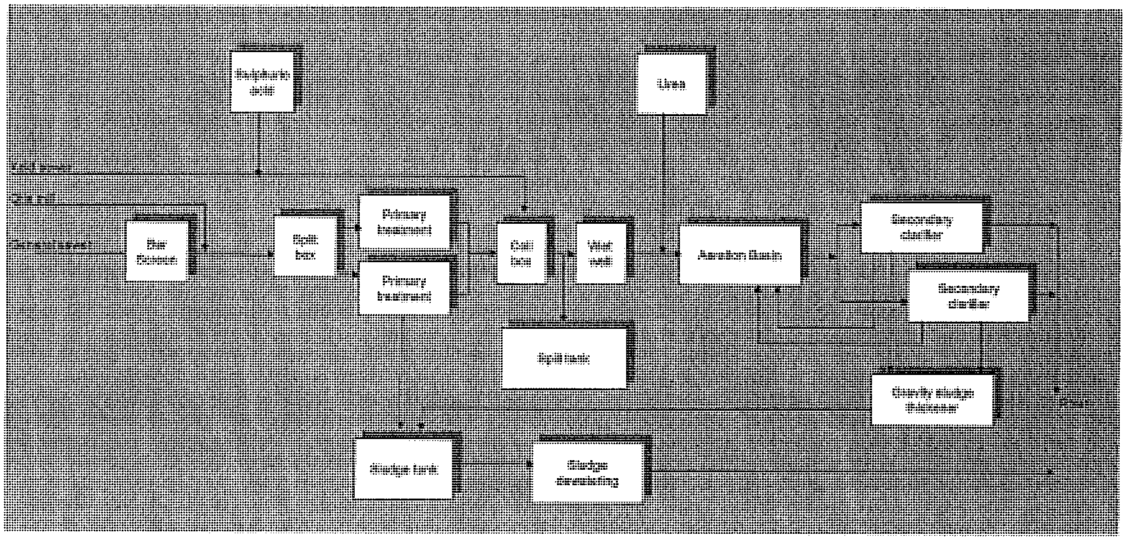

Figure 3 Block diagram of waste water treatment plant at Jay mill

The aeration tank is a single earthen basin of roughly circular form, equipped with surface aerators. The aeration basin functions as a fully mixed reactor, in principle, but mill staff noted that some areas are not well mixed. IP has recently installed additional mixing devices. There is a considerable accumulation of sludge in the system.

A problem with the design of the system at Jay is that there is insufficient mixing in the large, relatively shallow aeration basin. In an activated sludge treatment (AST) the suspended solids concentration may be 10-fold that of the aerated stabilization basin (ASB) process that this basin was originally designed for. In the AST process, the biosolds solids rapidly begin flocculation which enhances settling, which leads to sludge build up on the floor of the basin. This is the case in the system at Jay. IP is aware of this issue, and have advised that further corrective measures are being investigated.

An essential condition for good performance in an activated sludge system is than no sludge is allowed to settle in the aeration tank. Any settled sludge will, due to the high oxygen uptake rate, and lack of oxygen availability, rapidly turn anoxic and in time become anaerobic. Experience from several installations have shown that settled sludge usually causes instability, poor sludge characteristics, periodical release of nutrients and organic matter and toxicity by generation of reduced sulfur compounds. Confounding conventional wisdom on WWTP operation, the data on the Jay system shows quite low phosphorus discharge concentrations, but a relatively high TSS discharge.

IP has used polymers to assist settling in the secondary clarifiers for some years, to ensure that the mill discharge complies with the effluent discharge permit. The company has not stated the cost of these chemicals, but indicated that they are very expensive. The need, or perceived need, for such chemical addition to maintain a desired TSS discharge that is well above the norm for activated sludge systems is indicative of problems with the microbiology of the WWTP. Many systems in the pulp and paper industry operate with significantly lower discharge of suspended solids without the use of polymers in the clarifiers. The sludge returned to the aeration tanks contains some of the polymers and probably contributes to the accumulation of solids on the bottom of the tank, which has caused the mill operators difficulties for some years.

Phosphorus was added in the form of a urea-ammonium polyphosphate blend with a P content of around 2.6%. Mill staff report that they have operated without any phosphorus addition on a trial basis in the past, in anticipation of proposed rules to limit phosphorus discharges. In these cases, the effluent P remained unchanged, but the ortho-P at the aeration basin discharge dropped to levels considered dangerously low by the operators.

More recently, they have found that the phosphorus discharged by the mill to the WWTP has risen high enough to operate without phosphorus addition at the WWTP.

3.4 Basis for estimating cost of technology upgrades

3.4.1 Perspective on costs

To put the costs discussed in this report in perspective, it is useful to note that a new kraft mill, producing 1,500 tons per day, would probably cost about a billion dollars. The current book value of Maine mills is much lower, since they are not new, and are mostly smaller. In recent years, new fiberlines built overseas have 1500 to 2500 t/day capacity. It is generally considered that any new bleached kraft mill must produce at least 1,500 t/day to be economically viable. This is because of the economies of scale inherent in modern, low-pollution, pulp manufacturing equipment. These new mills discharge much lower quantities of all pollutants than Maine mills, including phosphorus, BOD and TSS, but only some of their technical features can realistically be retrofitted in older mills.

Because mill replacement costs in Maine would be in the order of a billion dollars each, it is probable that any such dramatic modernization would involve some consolidation of pulp production from a number of smaller sites. The authors assume that such a radical modernization and restructuring of the Maine pulp and paper industry will not take place in the foreseeable future.

Bleached softwood and hardwood kraft pulps sell today on the open market for $550/ton, which is 5% to 10% higher than a few months ago (FOEX 2003).

Commodity grades of communications papers such as lightweight coated, copy paper etc sell at about $1000/ton (FOEX 2003). Coated papers sell for somewhat higher prices.

Prices historically vary over a year by up to $100/ton in response to the normal market pressures of supply and demand. Pulp prices have been as high as $800/ton, and as low as $400/ton in the past ten years. Paper prices are less volatile. The impact of a change in operating costs on the viability of a mill can be considered in this context. Future selling prices are unpredictable.

The estimated costs of mill and WWTP upgrades discussed herein are expressed in costs per ton product in most cases, so the reader may evaluate them in this context.

3.4.2 Capital costs

This report includes estimates of probable capital costs for various potential process upgrades to reduce phosphorus discharges. They are based on the authors' experience in comparable projects, and published data.

3.4.3 Operating costs

Similar remarks to those above concerning capital costs apply to operating cost estimates. The authors assumed that costs shown in Table 2 prevail for raw materials, labor and energy for the purposes of calculating costs herein. Notice that the assumed labor cost has no impact on capital cost estimates, since these are calculated from known project costs elsewhere, without detailed analysis of the labor component.

Table 10 Unit costs assumed for raw materials, energy and labor

	Units	Cost
Marginal electric power (purchased from utility)	$/kWh	$0.05
Steam (marginal cost)	$/US 000 lbs	$3.93
Liquid oxygen delivered by truck	$/ US ton	$82
Oxygen generated on site	$/ US ton	$36
Ozone (excl oxygen feed, but incl. power)	$/ US ton	$1,182
Hydrogen peroxide	$/ US ton	$527
Sodium chlorate	$/ US ton	$464
Sodium hydroxide	$/ US ton	$300
Sodium sulphate	$/ US ton	$127
Sulfuric Acid	$/ US ton	$64
Anthraquinone	$/ US ton	$5,200
Methanol	$/ US ton	$282
Chlorine dioxide	$/ US ton	$791
Softwood chips at entry to digester	$/ US ton	$89
Hardwood chips at entry to digester	$/ US ton	$75
Chelant	$/ US ton	$1,818
Phosphorus cost (nutrient as P)	$/ US ton	$2,218
Nitrogen cost (nutrient as N)	$/ US ton	$318
Polymer cost	$/ US ton	$7,000
Sludge disposal	$/ US ton	$91
Operating labor (to fill 24 hour shift position)	$/ man year	$250,000
Technician, working 5 dayshift week, including lab facility cost	$/ man year	$100,000

Cost shown are based on mill data known to the authors, but are NOT based on knowledge of site specific prices in the Androscoggin mills. They are believed to be sufficiently representative of local costs to provide realistic estimates of costs. Mills were asked to comment on these values in November 2003 and did not disagree with them.

3.4.4 Integration of capital and operating costs

Comparison of costs for various alternative scenarios of upgrading mill and/or WWTP systems is complicated by the fact that most involve both a capital cost, and an on-going operating cost or saving. To simplify such analysis, the authors have converted capital costs into an equivalent operating cost, by assuming that the effect on a company's bottom line of a capital cost of one dollar is equivalent to accepting a long-term annual operating cost of twelve cents. Thus a "Capital Conversion Factor" (CCF) of 0.12 is used to covert capital costs to equivalent operating costs.

The precise value of the CCF depends on the excess of interest rates over inflation, corporate tax rates, and the number of years assumed for the project life. The spread between interest rates and inflation is relatively constants, as are corporate tax rates. Differences of several percent in these values has only a small impact on the CCF. Detailed analysis of the calculations of CCF show that assumption of project life has little impact on the value, provided that it is over 15 years. Corporate tax rates depend on many factors in large companies with multiple installations, but tend to be relatively constant, since most corporations arrange their fiscal affairs to minimize such tax.

The authors have been involved in a number of projects where the CCF was calculated by site specific analysis of all factors. In these projects, the value ranged from 0.09 to 0.13, so the value of 0.12 was selected for this project.

3.4.5 Caveat concerning cost estimates

Cost discussed herein are based on those known to have been incurred by other mills, and are presented to indicate probable costs in the Maine mills. They do not take account of all the site-specific construction problems, and any product specific issues that may exist. However, since they are based on actual costs for retrofitting equipment in older mills, with a range of site-specific problems, producing mainstream products, and the Maine mills are not atypical, the costs are considered to be realistic.

The author recognizes that there are disadvantages in presenting cost estimates without analysis of each mills site-specific situation and historical performance data, but considers that this is much better than ignoring costs in a report of this nature. The capital and operating costs associated with the techniques discussed herein vary from very small to substantial amounts of money, relative to the financial scale of the pulp industry.

Should the Department of Environmental Protection or the three paper companies involved wish to define costs more rigorously this can be accomplished after inspecting each mill, and considering data on the manufacturing operations.

3.4.6 Perspective on "tons"

To compare performance of different pulp and paper mills, it is standard practice in the industry and regulatory agencies all over the world to relate values such as costs and effluent discharges to a ton of pulp, as is done in this report.

It appears at first sight to be very simple to define the production rate of a mill. However, one can run into endless debates on the moisture content of the product, whether off-grade paper is included, whether quantity sold or quantity manufactured is used etc, to say nothing about the differences between US tons, long tons and metric tons.

One can also debate whether to average last week's, last month's or last year's production to characterize a mill.

All data herein has been converted to US tons, (except for any data quoted in kg/ton or grams/ton, when the metric ton is used). Once that is done, the difference between each way of measuring production rates is under 10%. For the purposed of this report, this is a trivial amount. We are interested in whether discharge from a mill is 5 lbs/ton or 1 lb/ton, not in small differences.

It is important that effluent discharges be related to actual mill production rates at the time the data were collected (averaged over a reasonable period). Values such as theoretical capacities can be misleading, since it is common for mills to operate well above their nominal capacity, due to modifications or operator skill. It is also common for mills to operate well below nominal capacity with market conditions are poor. Likewise, production rates quoted in environmental permits as maximum permissible, or "rated" can be quite different from practical reality.

As far as possible, "tons" refers to finished tons of product.

3.5 Units and terms used herein

3.5.1 Units of measurement

Refer also to the US – SI conversion table appended.

The Maine mills follow common paper industry practice and use a mixture of US units (gallons, lbs and US tons) along with metric units such as mg/L. Some US regulatory data is expressed in metric units and some in US units.

Virtually all data on mills outside the US that can be used to assess the potential for application of upgraded technology, or discussed in the literature, is expressed in metric units (more precisely, the International System, known universally by it French language abbreviation, "SI").

The authors have attempted to use the units most appropriate to the situation in this discussion. In all cases, any values expressed in lb/ton refer to the US ton, while those in kg or grams/ton refer to the metric ton, (=1000 kg = 2205 lbs). Notice that 1 kg/t = 2 lb/t, when considered this way.

An **Air Dry** ton of market pulp refers to pulp that is 90% dry. The term "Air Dry" is often used incorrectly to refer to paper, and may refer to 90% dry, or may mean paper as it is produced on the paper machine, typically 92% to 94% dry. The correct term is "**Finished ton**" for machine dry paper. The quantitative difference is too small to b significant in the context of this report.

The **BOD** data measured and published by mills and regulatory agencies in Finland and Sweden is expressed as a 7-day BOD. To be comparable with the US standard of measuring 5 day BOD (BOD_5) the Scandinavian data have been recalculated using a factor of 0.85, which is widely accepted as appropriate. Scandinavian data reported herein are therefore directly comparable to US data.

The term "**BOD**" herein refers to five day BOD, unless otherwise stated.

3.5.2 Terminology

It is assumed that the reader is familiar with the normal technical terms in the areas of the report of interest to him/her. Some key terms that are subject to differing interpretations are defined below, in the context of this report.

The expression "**Sludge age**" used in the report refers to the calculated value;
(Total Mass of Suspended Solids in Aeration tank) divided by the
(Mass of Suspended Solids removed as surplus sludge) + (Mass of Suspended Solids leaving with treated effluent.), calculated on the basis of one day's flow.

Secondary treatment refers to biological treatment, including any clarifiers ("secondary clarifiers") used to return biomass (sludge) to the aeration tank.

Tertiary treatment refers to installations to treat waste waters after they leave the secondary clarifier of an activated sludge plant. This may consist of coagulation to form pollutants into solid flocs, followed by flotation or sedimentation to remove the solids, and the associate sludge dewatering and disposal. The use of coagulants in the secondary clarifier, with return of sludge to the aeration tank is not considered to be tertiary treatment. It is simply a variation of secondary treatment.

Sludge is the term most widely used in the industry to refer to the mass of biologically active solids formed in biological treatment systems. "Biomass" is synonymous with "sludge" in this context. The quantity of total suspended solids (TSS) in the aeration tank is frequently expressed as Mixed Liquor Suspended Solids (MLSS), and the term "MLSS" is often used to refer to the sludge or biomass in the aeration tank.

4. Discharge control in pulp and paper manufacture

4.1 Phosphorus

4.1.1 Sources

Phosphorus is not used in the pulp and paper manufacturing process, but enters the mill with the wood supply, raw water and other purchased raw materials, principally with the lime or lime-rock (calcium carbonate). Phosphorus may also enter the system as wood waste fuel used in power boilers. The phosphorus remains in the ash that may be sluiced into sewer or sewered as scrubber liquid.

Some of the phosphorus entering the production processes is discharged with the effluent to the mill's waste water treatment plant (WWTP). A few percent leave with the product, and the remainder landfilled with ash from wood waste boilers or with lime rejects and/or losses from the causticizing system. Refer to Figure 4, and to the discussion of phosphorus balances on page 57.

Phosphorus is often added to the biological treatment to ensure optimal biological performance. Control of this addition is critical to minimizing discharges of phosphorus discharges to receiving waters. **As discussed in this report, current practices in the three Androscoggin River mills can be improved at very low cost, with anticipated reductions in operating costs.**

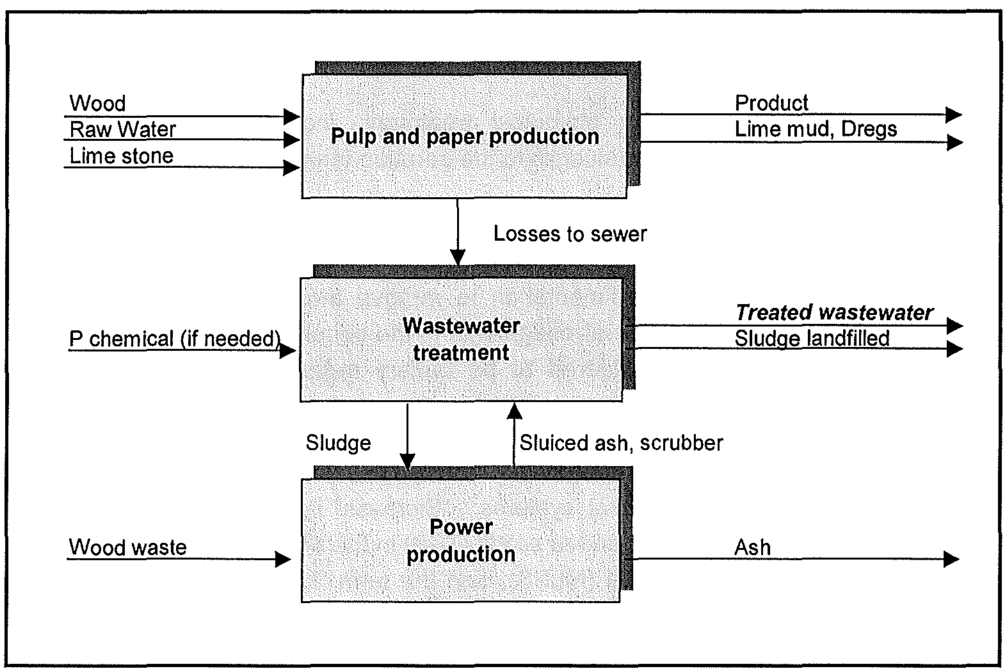

Figure 4 Principal flows of phosphorus in a pulp and paper mill

4.1.2 Waste water treatment

Phosphorus cannot be destroyed in a treatment plant, since it is an element. It can be removed by addition of coagulating chemicals, and subsequent precipitation, or else by designing and operating an activated sludge system to maximize the fraction of phosphorus that is retained in the waste sludge. **The best performing pulp and paper mills in the world, with respect to phosphorus discharges rely on this latter approach, combined with reduction of effluent flows to relatively low values, and minimizing the addition of phosphorus to the WWTP**.

Biological treatment requires phosphorus for the microbial degradation process that is the essential feature of the process for reducing BOD and Chemical Oxygen Demand (COD). In principle, the more BOD that enters the process, the more phosphorus is required. In pulp mill waste waters, the natural content of phosphorus in influent is usually considered inadequate for optimal treatment, so phosphorus is often added. In an ideal process, virtually all of the naturally incoming and added phosphorus will be removed from the waste water with the excess sludge, and disposed of or used in an environmentally sound manner.

Whatever sludge is produced, must be stored in secure landfill, used beneficially for land improvement or incinerated. In the latter case, the phosphorus in the ash must be controlled to avoid discharge to watercourses.

4.1.3 Factors impacting on the discharge of phosphorus

The discharge of phosphorus from a pulp and paper mill is dependent primarily on

- Phosphorus load in untreated waste water (discharge from production processes to treatment);
- Waste water volume (per ton of product);
- BOD variability (good spill control); and
- Operation and design of waste water treatment process.

A prerequisite for low phosphorus discharge is that untreated waste water does not contain abnormally high amounts of phosphorus. A high phosphorus content in untreated waste water may be due to elevated phosphorus amounts in raw materials used (wood, raw water, lime, fuel) or increased losses of materials (fiber, black liquor, lime mud) in the production processes. A third reason for high phosphorus content in untreated waste water may be the use of phosphorus containing chemicals in the production process.

An in-mill phosphorus mass balance will reveal sources and losses, and in case of high untreated phosphorus, will give valuable information about opportunities to correct the situation.

Waste water volume has a direct impact on the phosphorus discharged in dissolved form since a small concentration residual is usually considered necessary and maintained at a uniform level. The impact of effluent volume on dissolved phosphorus discharge is shown in Figure 5.

An important secondary impact of effluent flow on phosphorus discharge is that much of the phosphorus discharged from a WWTP is carried by the suspended solids. The lower the effluent flow, the greater the efficiency of the secondary clarifier(s) in reducing this discharge of solids. Refer to Figure 6 on page 35.

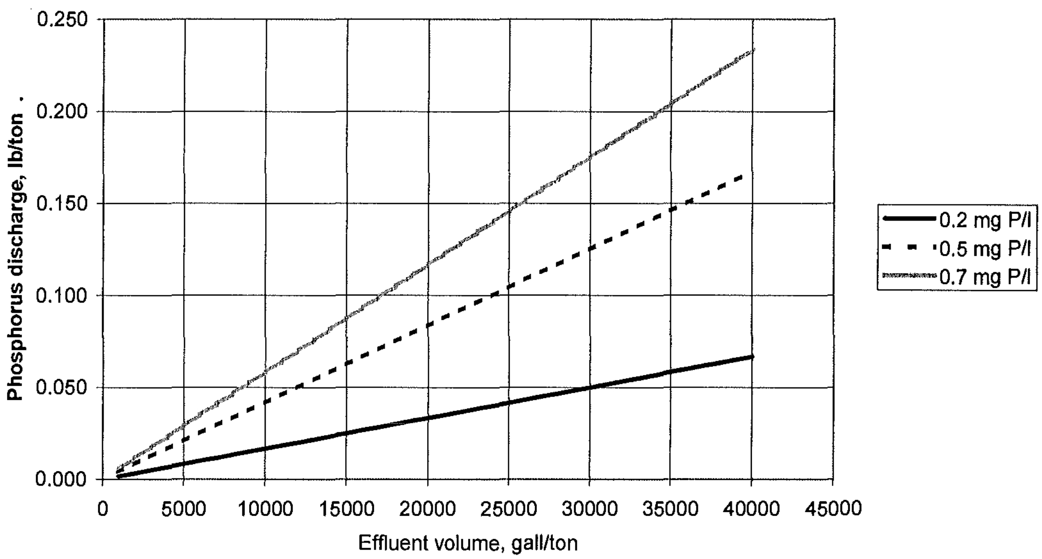

Figure 5 Impact of effluent volume on dissolved phosphorus discharge

Variability of influent BOD is an important factor especially when the treatment system is not optimized. High variability in influent BOD is typically caused by spills and losses in the production. Thus, high variability also results in overall higher BOD loads on the effluent treatment system.

High variability in mill losses of BOD often causes operational problems in treatment plants, including making it very difficult for operators to optimize the addition of nutrients. As a result, phosphorus and nitrogen are overdosed to ensure that the plant is never deficient in nutrients. Any phosphorus not assimilated will be discharge with the treated effluent.

In poorly designed treatment systems, high variability in BOD and flow normally cause periodic discharges of increased concentrations of TSS. Since TSS incorporates both phosphorus and BOD, these parameters will also increase in the effluent discharged.

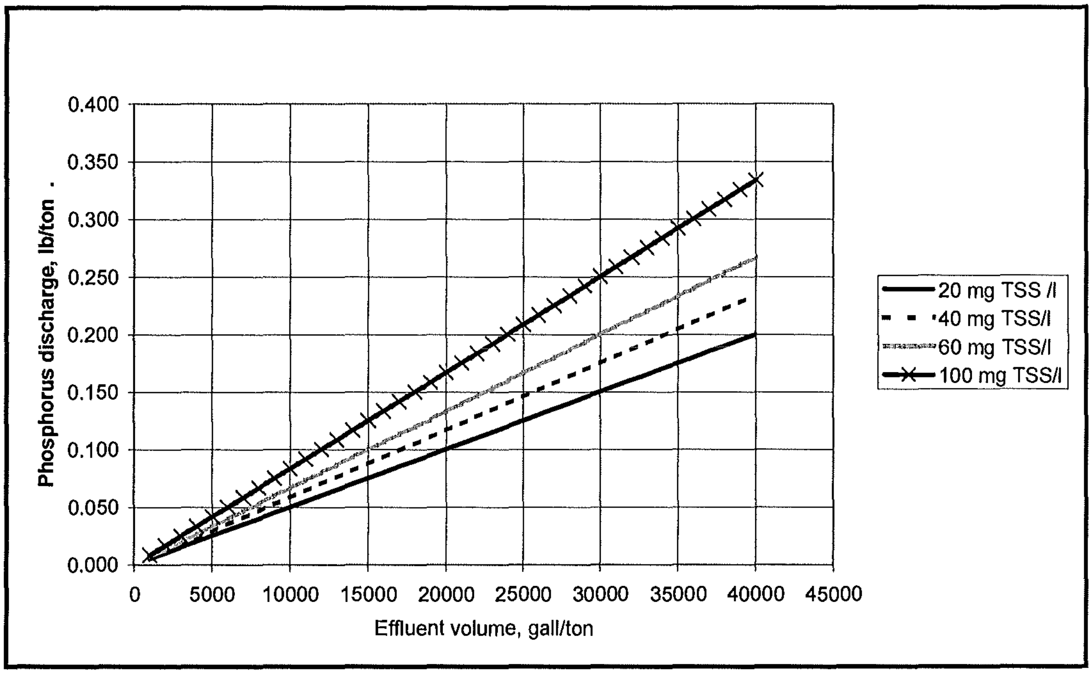

Figure 6 Impact of TSS on total phosphorus discharge
(Assumptions: 0.7% P in TSS and 0.5 mg dissolved P/l)

It is important to understand the different forms in which phosphorus may appear. In biologically treated waste water, phosphorus normally exists in the soluble phase as ortho or polyphosphates, and also in a "solid" phase incorporated with the biomass. The efficiency of control methods is often dependent on the composition of the phosphorus in the waste water. Some of the influent phosphorus may be biologically inert and cannot be efficiently used by the microbes.

The natural variations in the microbiological culture also have an impact on phosphorus discharge, particularly those which involve occasional phosphorus uptake and release. Analysis of sludge in aeration tanks indicates that the phosphorus content may vary between 0.3% and 0.8% depending on treatment conditions. A small change in phosphorus content of the sludge may result in considerable discharges of dissolved phosphorus.

Generally, operators should adjust the addition rate of phosphorus to take account of changes in the phosphorus content of the biomass in the aeration tank. The objective is to keep the phosphorus content of the biomass stable and as low as possible while preserving sludge characteristics. The person responsible for the technical operation of each WWTP must develop knowledge of the optimal level of his/her system.

4.2 BOD

4.2.1 Sources

The principal source of BOD in pulp mills is the fraction, approximately 60%, of the raw wood that is separated from the fibers, so that the latter can be used for papermaking. Prior to bleaching the pulp, most of the organics[6] are recovered from the pulp in "brown stock washers". The efficiency of brown stock washers in the industry is currently much better than in the past, and may vary from 97% to over 99%.

The total BOD generation in pulping is roughly 600 lb/ton pulp, with the exact value depending on wood species and pulping conditions. With the best washing, 99.5% of this will be recovered, and only about 3 lb/ton pulp is lost. The worst brown stock washing system in the US known to the authors (it is not in Maine or New Hampshire) loses about 20 lb BOD per ton pulp. The mills did not provide information on current washing systems to the authors, so it is impossible to comment on where they stand in the above range of BOD losses.

Where the mill operates with a closed water cycle in the screening system downstream of the brown stock washers, this BOD will exit from the first stage of the bleach plant, so will show as being zero in many mill reports.

The recovered organics, known universally as "black liquor" are concentrated and burned in the mill's recovery boiler(s) to recover heat and oxidize them to carbon dioxide and water vapor, while recovering chemicals for reuse in the mill's pulping system. Modern recovery boilers are very efficient in destroying organics, and discharge only very small quantities of pollutants. Sulfur dioxide and particulate discharge is close to zero. Disposal of waste organics in the recovery boiler is environmentally superior to any form of external waste water treatment in a pulp mill.

After washing, the pulp is bleached, where organics are removed and discarded to the WWTP in the bleach plant filtrates. The quantity will typically represent 40 lb BOD/ton pulp in an older softwood fiber line, or 20 lb/ton in a hardwood line.

The principal sources of BOD from paper mills are loss of fiber, and loss of coating materials. Fiber losses generally have relatively little impact on the treated effluent or the biological treatment plant, since they are mostly removed in the mill's primary clarifier. Coating losses represent a significant discharge of BOD, and are important both because of the organic content and because they contain fine inorganic material that interferes with the biomass in the aeration tanks.

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[6] *Strictly speaking, wood fibers are organic. However, it is common practice in the industry to consider the fibers to be inorganic, since they are insoluble in water, and to consider the remaining, soluble fraction of the wood to be "organic" This terminology is used herein.*

4.2.2 Benefits of reducing BOD of untreated waste waters

In the biological treatment process, organic matter (BOD) is degraded by microbes to carbon dioxide and water. Some of the BOD is used to grow more microbes. Phosphorus has an essential role in the metabolism taking place. Generally you can say that the larger incoming organic load will require more phosphorus for the biochemical reactions and more phosphorus will then leave the plant as well.

Further, any reduction in the BOD of the untreated waste water effectively increases the retention time in the activated sludge system, which helps the operators develop sludge that settles well, thus minimizing the TSS discharges, with its associated phosphorus and BOD.

Therefore, an important part of phosphorus control is to implement in-mill measures to reduce organic load (BOD) from production. The most important ones are listed in EU BAT Reference document, summarized in Table 14 on page 47.

4.3 Suspended solids

Suspended solids (TSS) are discharged form pulp and paper mills due to losses of fiber, coating solids, lime and dirt removed from the main fiber process streams. Most of these, except the fine material from coating systems, settle well in the primary clarifier, so have little impact on the final effluent. Coating losses can have a significant impact on the effluent treatment system, and are also expensive.

The principal source of suspended solids in the treated effluent is the biomass formed in the secondary treatment system. Control of TSS discharges is therefore primarily a function of the secondary treatment system.

4.4 Benchmarking other kraft pulp and paper mills

The phosphorus discharges from the three mills under discussion are typical of the North American industry. However, a number of mills in the US and overseas are required by regulation to limit discharges to much lower values. The performance of some is discussed below. These data demonstrate that operation at lower discharge levels than are current in Maine is technically feasible. The mills concerned are profitable, sustainable businesses, demonstrating that their performance is economically feasible.

Similar comments apply to BOD and TSS discharges.

4.4.1 North American mills

Phosphorus discharges by pulp mills have not generally been a major issue in the US, so there is a paucity of readily available data on discharges. Where phosphorus discharges are regulated to low values, it is normally by the State rather than the EPA, so that accessing all the discharge data requires more personnel time that is available for the present report, although the data are legally public. The following is based on information readily available to the authors.

The **Glatfelter mill at Spring Grove, PA** is of particular interest to the current report for many reasons. It is similar to the Androscoggin mills in that it produces a range of papers from both hardwood and softwood kraft pulp manufactured on site. The mill is over 100 years old, and operates in a physically constrained location. The mill equipment has been frequently upgraded, but there have been no complete fiberline rebuilds in the past 40 years or more. The Spring Grove mill has long been known in the pulp and paper industry as a low discharge installation, presumably because it is located on very small receiving water, and has been under strong regulatory and public pressure for many years. The mill and company have won many awards for good management of their business, and the company has consistently reported high profits and return on investment. These values cannot be related directly to the Spring Grove mill, but since it is the major producing unit of the Glatfelter company, it suggests strongly that the engineering, equipment selection and operational decisions taken by this company are good.

The mill operates with very tight spill control in-plant, and has a conventional activated sludge WWTP. Phosphorus discharges are consistently under 0.1 mg/L, according to the discharge data published by the Pennsylvania DEP.

The average BOD and TSS discharges are 0.9 and 1.4 lb/ton respectively demonstrating the low phosphorus discharges are compatible with low discharges of BOD and TSS. Variability of BOD discharges is also low, as shown in Figure 7.

At the time of writing, the mill is reported to be installing an oxygen delignification system for their hardwood line, as well and an ozone bleaching stage to reduce effluent color. This will probably result in a modest reduction in BOD and TSS discharges.

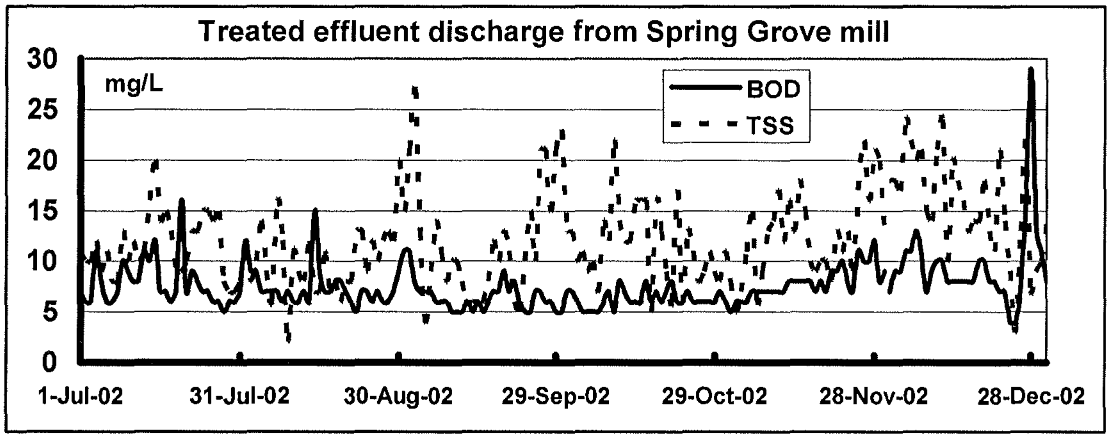

Figure 7 Effluent discharge BOD and TSS from P. H. Glatfelter mill, Spring Grove, PA

The treatment system at Spring Grove mill has the following key features;

- 3 primary clarifiers in parallel
- aerated equalization basin, retention time 24 hours
- 3 aeration basins in series. One is a stabilizer for aeration of return sludge, while the other two are contact basins in series for aeration of the mixed liquor. (Contact stabilization). Total aeration volume is estimated at 5 MG. Using the assumption of 3000 mg/L MLSS and 30 lb BOD/ton in influent, the sludge age would be about 15 days
- 4 secondary clarifiers, (2x 95 ft and 2 x 98 ft diameter), with up flow rate of 383 g/sq ft/day.

Woodard and Curran (2003, page 12) described the WWTP at Spring Grove mill as "oversized" and the secondary clarifiers as "large" but the values above correspond closely to the recommended rate for such equipment.

The **International Paper mill at Ticonderoga, NY** is of interest, because they operate under the most stringent phosphorus discharge permit known to the authors in the US. This is a middle-aged mill, built in the 1960s, almost simultaneously with the Jay mill, and produces both hardwood and softwood kraft pulp, and communications grade fine papers.

The effluent discharge permit limits phosphorus discharges to 88 lbs/day maximum daily average, and 0.5mg/L (NY 1997) which is equivalent to approximately 0.1 lb/t as total P, at the mill's average effluent flow of 16.5 MGD. To comply with such a value, the mill will have to operate with an average phosphorus discharge of below about 50 lbs/day. As shown in Table 2, the mill has been operating with an average discharge of 30 lbs/day, which is equivalent to approximately 0.035 lb/ton product.

Actual discharges for a recent 16 month period are shown in Table 2, which shows monthly averages, as well as the highest daily value for each month for phosphorus. This table shows that the mill system is capable of restricting the highest discharge of phosphorus in any one day to 0.13 lbs/t product, and also maintaining an average phosphorus discharge of 0.05 lbs/ton product, measured as total P.

Table 11 Effluent discharges from International Paper Co mill, Ticonderoga, NY

	BOD mg/L Avg day	TSS mg/L Avg day	P (total, as P) Max lbs/day	P (total, as P) Avg lbs / day	P (total, as P) Max day lb/t	P (total, as P) Avg day lb/t
Jul-03	9	21	60	36	0.07	0.04
Jun-03	8	26	57	35	0.07	0.04
May-03	10	19	30	18	0.04	0.02
Apr-03	14	23	41	23	0.05	0.03
Mar-03	12	28	46	24	0.05	0.03
Feb-03	16	30	42	30	0.05	0.04
Jan-03	15	33	107	44	**0.13**	**0.05**
Dec-02	13	36	38	30	0.04	0.04
Nov-02	11	22	46	29	0.05	0.03
Oct-02	10	27	51	39	0.06	**0.05**
Sep-02	7	25	53	37	0.06	0.04
Aug-02	4	20	57	37	0.07	0.04
Jul-02	6	19	57	41	0.07	**0.05**
Jun-02	7	14	26	18	0.03	0.02
May-02	9	34	31	20	0.04	0.02
Apr-02	11	23	40	21	0.05	0.02
Mar-02	11	27	34	23	0.04	0.03
Averages	**10**	**25**	**48**	**30**	**0.06**	**0.03**
Maxima	**16**	**36**	**107**	**44**	**0.13**	**0.05**

Data extracted from EPA's PCS database, which is based on mill's monthly reports to environmental regulators.
"lbs/t" refers to pounds per ton finished product.
Refer to PCS, permit number NY0004413 for source and further information.

The above data are presented below in terms of pounds per ton finished product, to facilitate comparison with other mills discussed herein.

Table 12 Production specific effluent discharge from International Paper, Ticonderoga, NY

	BOD	Phosphorus	TSS
Average lbs/ton product	1.6	0.03	4
Maximum day in 16 months	2.4	0.05	5.6

Data are calculated from averages from Table 11 and a production rate of 850 finished tons per day.

It would be useful to Maine DEP to compare the effluent discharged from the secondary clarifiers at Ticonderoga to other mills. These data were not available to the authors at the time of writing, but could perhaps be made available to the Department. The secondary clarifiers at Ticonderoga are heavily loaded, with an up flow rate around 800 g/sq ft/day.

The effluent treatment system originally consisted of primary clarification, followed by activated sludge treatment. A tertiary system using coagulation and sedimentation was added some years later.

The aeration tank was built originally to be an aerated stabilization basin (ASB), so is unusually large. Its surface area is 775,000 sq ft, and it is 14 feet deep, so the approximate capacity is 75 million gallons, representing about 4 days retention time, neglecting sludge build-up. Some years ago, it was partially filled with settled biomass, but the current condition and actual volume are not known.

This is very similar to the Jay system, which was built with 4.6 day retention. Both mills have a history of using chemicals to assist settling of solids in the secondary clarifiers, and thus accumulating sludge in the aeration tanks.

The secondary clarifier up flow rate at Ticonderoga is 730 gal/sq ft/day, which is well above the loading of 420 gal/sq ft/day normally considered desirable. Despite this, the performance of the plant is excellent.

There are two tertiary clarifiers, each 182 feet diameter, which is equivalent to an up flow rate of 380 gal/sq ft/day.

4.4.2 Finland

Many the kraft mills in Finland are located on lakes or rivers whose ecology is phosphorus limited, so much emphasize has been put on reducing phosphorus discharges over the past 10 to 20 years. The climate in Finland is similar to that in Maine (or perhaps somewhat colder), so the operating constraints on the treatment plants are similar.

There are no common discharge regulations for the pulp and paper mills. There are some general guidelines and overall government decisions but the real control is by an individual discharge permit for each mill. The permit typically includes waste water discharge limits for TSS, COD, BOD, Absorbable Organic Halogen (AOX) and phosphorus. The current permits are based on earlier permit levels, current emission levels, recipient status and possible pertinent guidelines.

The discharge limits in current permits are expressed as ton or kilograms per day. There are no concentration based phosphorus limits in the permits. The averaging period may be a single day, one month or one year. For phosphorus, the limit is typically for a monthly averaging period. The permit limits have been converted to equivalent lb/ton in Table 2 below.

The table below presents the phosphorus discharge limits for selected ECF-bleached kraft pulp and paper mills. As seen in the table, the actual discharges are often substantially below the permitted level.

Table 13 Phosphorus discharge limits for Finnish ECF-bleached kraft pulp and paper mills

Mill	Phosphorus discharge limit lb P/day	lb P/ton	Actual phosphorus discharge lb P/day	lb P/ton
UPM-Kymmene, Kaukas	77 (annual) 154 (monthly)	0.023 (annual) 0.046 (monthly)	69	0.021
UPM-Kymmene, Kuusankoski	110	0.034	51	0.016
Stora Enso, Veistiluoto	132	0.055	67	0.028
Botnia and UPM-Kymmene, Rauma	154	0.050	71	0.023

Discharge data are for 2002. Permit data is from 2001.
Values expressed in lb/ton (finished US tons) are not in mill permits, but are shown here to facilitate comparison with other mills.

The UPM-Kymmene, **Kaukas** mill, produces daily 2,180 tons ECF-bleached kraft pulp, 550 ton groundwood pulp and 1650 tons Low and Medium Weight Coated printing paper. The pulp mill has a 1000 ADMt/d HW line and a 1200 ADMt/d SW line. Both lines have batch digesters (Superbatch), four stage washers and two-stage oxygen delignification. Bleaching is accomplished with chlorine dioxide, oxygen and peroxide. Paper is produced on two paper machines and three coating machines. All waste water from wood handling, pulp mill and paper mill is directed to the waste water treatment plant. The treatment involves the following treatment steps; 2 circular primary clarifiers (dia 184 ft), equalization basin (12 h retention), 38 ft deep aeration tank with 3 cells in series (24 hour retention) and 3 circular secondary clarifiers (dia 217 ft). The primary and secondary sludge is dewatered in thickeners and then with screw presses. Dewatered sludge is mixed bark and incinerated in power boiler.

The UPM-Kymmene, **Kuusankoski** mills produces daily 1,320 tons ECF-bleached kraft pulp, 630 tons groundwood pulp and 3,200 tons of coated printing paper. The pulp mill has a 800 ADMt/d HW line and a 650 ADMt/d SW line. The SW line has oxygen delignification and D-Eop-D-D bleaching sequence. The hardwood line does not have oxygen delignification, and uses D-Eo-D-Ep-D bleaching. Paper is produced on 2 machines. Part of the paper production is carried out at Voikkaa mill located a few miles from the pulp mill. All waste water from wood handling, pulp mill and paper mill including Voikkaa mill is directed to the waste water treatment plant. The treatment involves primary clarifiers, 30 ft deep aeration tank (22 hour retention) with four cells in series and rectangular secondary clarifiers with a surface area of 100,000 sq ft, giving an upflow rate of 300 g/sq ft/day..

The StoraEnso, **Veitsiluoto** mill produces daily 1,080 tons ECF-bleached kraft pulp, 330 tons groundwood pulp and 2,390 tons coated journal paper and newsprint. The pulp mill has a 600 ADMt/d HW line and a 500 ADMt/d SW line. Both lines have single oxygen delignification stages and (OPO)-D-(Ep)-D bleaching sequence. Paper is produced on two machines. All waste water from wood handling, pulp mill and paper mill is processes in the waste water treatment plant. The low waste water volume is notable, 4000 g/ton (about 16 m^3/t). The treatment involves primary clarifiers, conventional aeration tank of 17 hour retention, and circular secondary clarifiers. The effluent passes a polishing pond prior to discharge.

The Botnia and UPM-Kymmene, **Rauma** mill produces daily 1590 tons TCF-bleached kraft SW pulp, 1450 ton groundwood pulp and 3100 tons newsprint and printing paper on two sites a short distance apart, but closely integrated, and with a single WWTP. The pulp mill has batch digesters (Superbatch), two stage oxygen delignification and Z/Q-P-Z/Q-PP bleaching sequence. All waste water from wood handling, pulp mill and paper mills is directed to the WWTP. This consists of a 200 ft diameter primary clarifier, equalization basin (4 h retention), 27 ft deep aeration tank with 2 cells in series (48 hour retention) and two 200 ft circular secondary clarifiers.

All mills but Rauma were started up at least 40 years ago. However, they have been continuously upgraded and most of the machinery is modern. Rauma mill was new in 1996, but the paper mill is much older. It is notable that while the Rauma pulping line was built to operate with very low effluent discharge, the older Veitsiluoto mill discussed above discharges less effluent.

In 2000, the environmental legislation was modified in line with the EU IPPC-directive (Integrated Pollution Prevention Control). This legislation introduces the concept of "Best Available Techniques[7] and Associated Emission Limits". Also, the law involves a new integrated approach to permitting, with the intent that a single mill permit will cover all emissions and environmental issues related to the operations at the site.

By the end of 2004, all pulp and paper mills must apply for a new permit according to the new legislation. The permit application process has started for most mills but no new permits have been granted for a pulp mill at the time of writing. However, it is expected that there will be no major changes compared to current permit conditions.

In Finland, the first biological waste water treatment plants in the pulp and paper industry were started–up in the early 1980s. During the following 10 to 15 years practically all pulp and paper mills installed secondary treatment systems. Presently, all but two of the 15 bleached kraft pulp mills have activated sludge treatment systems. The other two mills operate aerated stabilization basins.

Performance of many of the treatment plants built in the 1980s was poor relative to today's levels. Since many of the waste water recipients in Finland are small lakes, the environmental impact was not reduced as much as had been hoped. Initially the discharge of nutrients (N, P) from the pulp and paper industry increased as a result of implementation of secondary treatment. In an attempt to improve the situation, many programs were initiated to find methods for optimization of the activated sludge processes and decrease the discharge of nutrients.

The research revealed that the main reasons for poor performance were weaknesses in the design of some plants, the lack of effective control of the processes, and deficiencies in the handling of sludge. The earliest studies carried out at the activated sludge plants revealed poor design especially in the aeration systems and secondary clarifiers. Most of them were upgraded over the next few years.

[7] *Although often referred to as "BAT", the EU concept, and the resulting discharge limitations, recommendations etc. are quite different from "BAT" as the term is defined by US EPA and used routinely in the US.*

The situation regarding the nutrient discharge has improved significantly during the last 10 years, as shown in Figure 8. The improvements over the years are due to a combination of capital investment and improving operating skills.

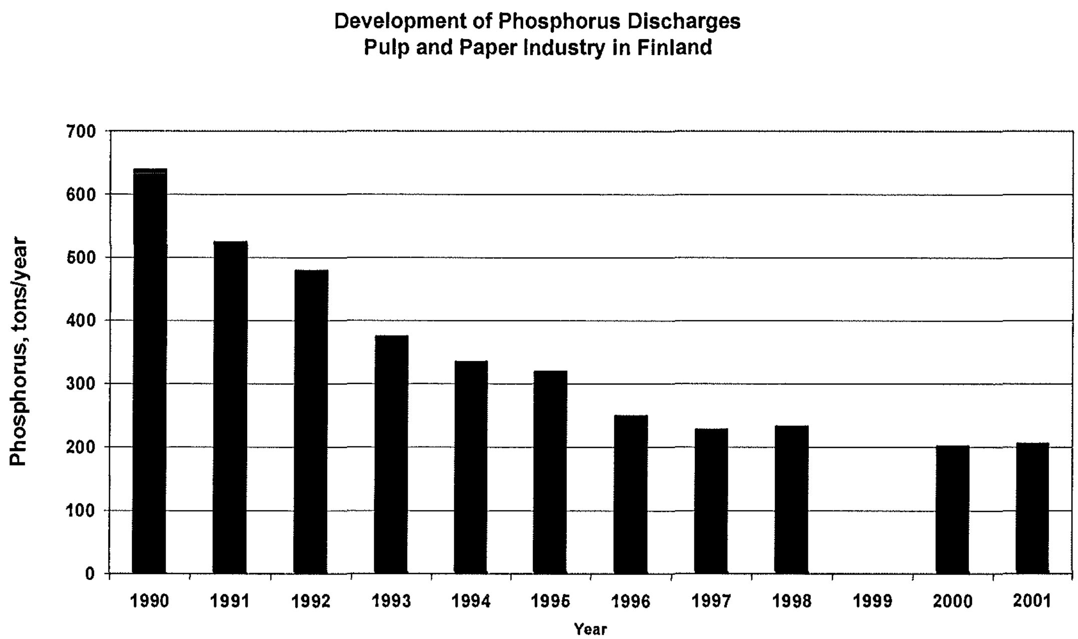

Figure 8 Discharge of phosphorus from pulp and paper Industry in Finland 1990-2001
(Data for 1999 not available)

In the 1990s, the focus shifted to the control and operation of the plants. By careful control of nutrient dosage and by operating with high sludge age, a stable discharge of low phosphorus concentration has been achieved at many plants. The dissolved portion of phosphorus is then typically at 0.08 to 0.2 mg/L.

According to environmental performance statistics from 1998 the total phosphorus discharges from bleached pulp mills were between 0.08 and 1.1 mg P/L., as shown in Figure 9 and Figure 10.

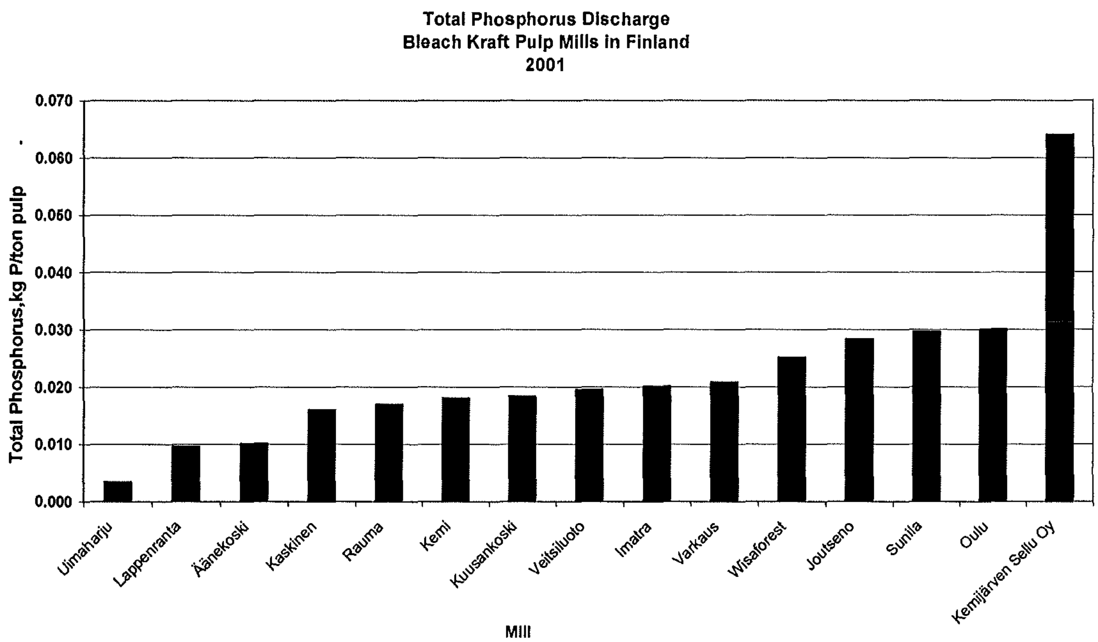

Figure 9 Phosphorus discharge concentrations for bleach kraft pulp mills in Finland

The production facilities of the five best mills can be described briefly as follows:

- Stora Enso, Uimaharju, (Enocell) Bleached hard and softwood pulp 1600 ton/d;
- UPM-Kymmene, Lappeenranta. Integrated bleached soft and hardwood 1900 t/d, 470 t/d mechanical pulp and 1350 ton/d paper;
- Stora Enso, Imatra Integrated bleached hard and softwood 1600 t/d, 650 t/d unbleached and CTMP pulp and 2700 ton/d paper and board;
- Metsä-Botnia, Kaskinen Bleached hard and softwood pulp 1000 ton/d; and
- Sunila, Kotka Bleached softwood pulp 850 ton/d.

The two best performing mills (Enocell at Uimaharju and Lappeenranta) operate without adding any phosphorus to the treatment plants under normal conditions. The residual dissolved phosphorus in the activated sludge system discharge is allowed to drop down to 0.05 to 0.1 mg/L. Mill staff have advised that no operational problems have been observed due to the low phosphorus levels in the processes. It is noticeable that the COD removal in these treatment plants is amongst the best in Finland.

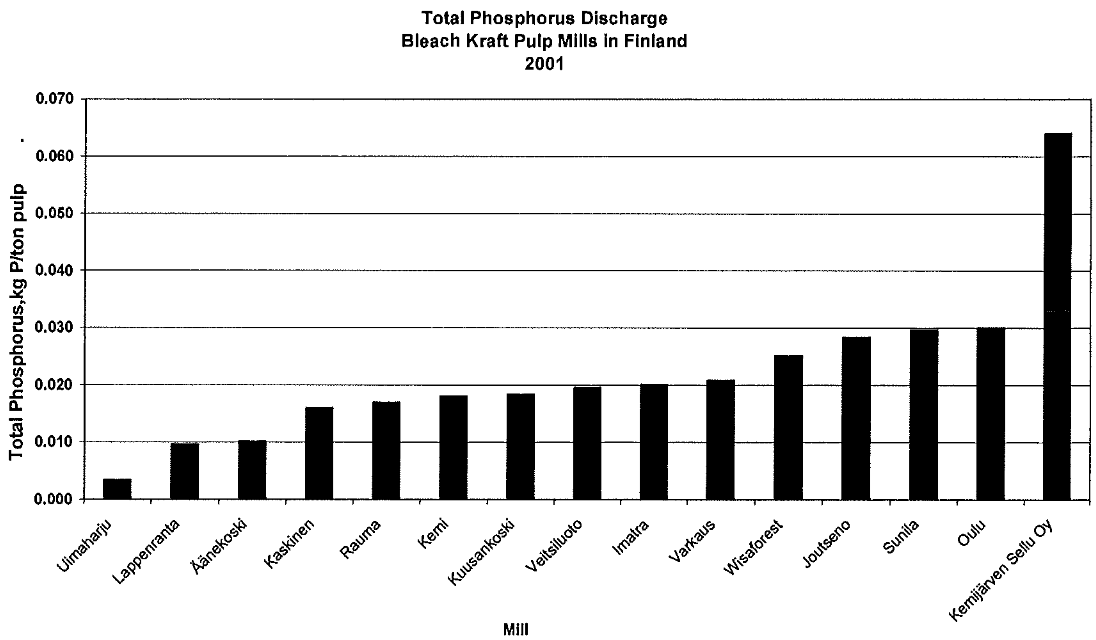

Figure 10 Phosphorus discharges from bleach kraft pulp mills in Finland 2001

Figure 10 shows recent discharge rates in kg/ton pulp. If expressed in lb/ton, the values would be double those shown. If converted to lb/ton paper, the values would drop very roughly one third, depending on the paper production rates. Data necessary for the conversion calculation were not readily available to the authors at the time of writing.

The key feature of Figure 10 is that it demonstrates that 14 of the 15 bleached kraft mills in Finland discharge under 0.06 lb phosphorus per ton pulp. Except for the Enocell mill at Uimaharju and the Sunila mill, these are all integrated pulp and paper mills.

4.4.3 European Union

According to the EU directive 96/61/EC, all EU member states must develop their environmental legislation, regulations and permitting procedures in line with a common standard. The directive outlines the concept of Best Available Techniques (BAT)[8], a level of environmental performance that must be used as a reference level in establishing national regulations, guidelines and individual permits. Each EU member country will incorporate local requirements and conditions into the regulations.

[8] *The term "BAT" as used in Europe is quite different in concept from "BAT" as used by the US EPA and many industries in the US.*

The IPPC-directive stipulates that a Reference Document on Best Available Techniques shall be prepared for each identified branch. Consequently a BAT Reference Document on BAT for the Pulp and Paper Industry has been developed (European Commission 2001).

Chapter 2 of the BAT Reference Document describes the kraft pulping process and specifically the technologies and techniques that are considered BAT, as shown in Table 14.

Table 14 BAT for kraft pulp mills (European concept)

General measures

- Training, education and motivation of staff and operators
- Process control optimization
- Sufficient maintenance of the technical units and the associated abatement techniques
- Environmental management systems which optimizes management, increases awareness, and include goals and measures, process and job instructions etc.

Measures for reducing emission to water

- Dry debarking of wood
- Modified cooking either in batch or continuous system
- Highly efficient brown stock washing and closed cycle brown stock screening
- Oxygen delignification
- ECF bleaching with low AOX or TCF bleaching and recycling of some, mainly alkaline process water from the bleach plant
- Stripping and reuse of the condensates from evaporation plant
- Effective spill monitoring, containment and recovery system
- Sufficient capacity of the black liquor evaporation plant and the recovery boiler to cope with the additional liquor and dry solids load
- Collection and reuse of clean cooling waters
- For prevention of unnecessary loading and occasional upsets in the external effluent treatment process due to cooking and recovery liquors and dirty condensates, sufficiently large buffer tanks for storage are considered necessary
- Primary waste water treatment
- External biological waste water treatment

Source European Commission (2001).
Although often referred to as "BAT", the EU concept, and the resulting discharge limitations, recommendations etc. are quite different from "BAT" as the term is defined by US EPA and used routinely in the US.

The discharge or consumption levels that are associated with BAT are shown in Table 15 for effluents after primary treatment (i.e. entry to secondary treatment). The corresponding values for effluents after secondary treatment are presented in Table 16. Notice that the phosphorus discharge is reduced across secondary treatment.

Table 15 Emission levels after primary treatment in mills applying BAT

Parameter	Unit	Bleach kraft production
Process water amount	gallons/ ADt	7,200 – 12,000
COD	lb/t	60 – 90
BOD	lb/t	25 – 40
TSS	lb/t	4 – 8
AOX	lb/t	0 – 0.8
Total P	**lb/t**	**0.08 – 0.12**
Total N	lb/t	0.6 – 0.8

Source European Commission (2001).
These values refer to pulp production. Almost all mills are integrated, and produce paper also.
The values would be 10% to 25% lower if referenced to paper production.

The phosphorus concentration corresponding to BAT Reference Requirements in the tables above is 0.3 to 0.6 mg/L. Notice that the effluent flows and pollutant discharges are low, relative to the Androscoggin River mills, **except that BOD discharges from Rumford and Jay are close to the mid-point of the BAT range.**

Table 16 Emission levels downstream of biological treatment in mills applying BAT

Parameter	Unit	Bleach kraft production
Process water amount	gallons/ ADt	7,200 – 12,000
COD	lb/t	16 - 46
BOD	lb/t	0.6 - 3
TSS	lb/t	1.2 - 3
AOX	lb/t	0 – 0.5
Total P	**lb/t**	**0.020 – 0.060**
Total N	lb/t	0.2 – 0.5

Source European Commission (2001).
These values refer to pulp production. Almost all mills are integrated, and produce paper also
The values would be 10% to 25% lower if referenced to paper production.

4.4.4 Competing overseas mills

Scandinavian mills are mentioned extensively in this report, partly because the authors know them well, and most of the bleached kraft mills in Europe are in Scandinavia.

The integrated kraft mills in Western Europe, outside Finland, generally operate with low effluent discharges, similar to the Finnish data discussed herein.

There are a considerable number of mills in the newly developing pulp and paper exporting countries in South America and Indonesia that compete with US mills. Those in South America are generally much larger than those in Maine, are relatively new and were built from scratch to comply with effluent discharge regulations that are more stringent than those normal in the US. The most recent mills in Chile are being built with primary, secondary and tertiary treatment.

The authors are familiar with many of these mills, and feel that although their effluent discharges are consistently lower than the better US mills, they do not serve as a useful reference, since they are very recently constructed, are built on sites well suited to large mills, and had a high degree of effluent control integrated with the initial design.

The large new mills built in Indonesia over the past ten years are designed to environmental standards that are as high as those in South America or the most demanding European levels. However, the authors do not have first hand knowledge of the level of compliance by regulations in the Indonesian mills

5. Measures for reduction of discharges from Maine mills

This chapter discusses generic measures for reduction of phosphorus and BOD discharges by pulp and paper mills, which are applicable to the three Androscoggin River mills. Refer to subsequent sections for discussion of specific mills.

Various process upgrades that can be used to reduce phosphorus and discharges to the WWTP are described below. All measures discussed are in widespread commercial use in integrated kraft mills. Some of the upgrades have already been implemented in one or more Maine mills.

As in the case of any process upgrade, site-specific engineering analysis is required to define costs and feasibility sufficiently well for a decision to be reached on implementation.

5.1 Internal process measures to reduce load on WWTP

A wide variety of process modifications have been introduced in the paper industry over the past 40 years to reduce formation and discharge of pollutants, upstream of effluent treatment. These are variously known as "**in-plant measures**", "**pollution prevention**", or "**cleaner technology**". These measures may involve novel equipment, but most are simple good engineering and operational practices. Some generate a highly positive return on investment, while others add to the cost of manufacturing. In some cases this cost is partially or totally offset by reductions in effluent treatment costs.

Despite the popular theory that industry will always do what is profitable, a number of profitable opportunities for pollution prevention remain in most mills in the world.

A vast range of pollution prevention technology has been discussed in the open literature, including the IPPC report (European Commission 2001) and a series of conferences run by TAPPI and other organizations, particularly since 1990. There are at least 100,000 references in the scientific literature, specific to pollution prevention in the pulp and paper industry.

Measures of particular relevance to the three Androscoggin River mills are discussed below.

5.1.1 Development of in-house operating know-how

There is large body of knowledge on operation of in-plant pollution prevention measures and operation of biological treatment plants in kraft pulp and paper mills. While it is useful for mill management, staff and operators to learn from advice from corporate or external experts, as well as from the scientific literature, **there is no substitute for the on-site mill personnel visiting exemplary operations, and attending specialized training courses**. In addition to collecting information, the personal contact with others facing similar effluent control problems is invaluable, and facilitates on-going contact and exchange of solutions to the myriad daily problems of operating a mill cost-effectively in an environmentally sound manner. **For a mill to operate cost effectively with low effluent discharges, many people need to have appropriate knowledge, not only the WWTP operators.**

State certification programs for WWTP operators are a good foundation for mill personnel involved in treatment plant operation, but do not adequately address the special difficulties of treating pulp and paper mill waste waters, since the technology and practices involved are oriented to municipal waste waters. Such programs do not address paper mill pollution prevention technology at all.

It was learned during the mill visits that operating, maintenance and technical staff travel relatively rarely to other installations, particularly if they are beyond a day's drive from the mill.

The authors consider that it is appropriate and cost-effective for the three mills under discussion to each have an annual budget to allow the following

- Visits by a team of three mill personnel to at least three exemplary mills.
- Attendance by four personnel at separate courses specialized in pulp and paper mill effluent control or treatment, or at pulp and paper industry environmental conferences.

These activities should be both **across the US and overseas**, and a variety of personnel should be involved, including operations, engineering and maintenance. The total cost would be in the order of $25,000 per year for each mill, which is trivial relative to the potential savings in mill operating costs that can be realized.

Several exemplary mills are discussed in this report. There are some others in the US, but few, if any, in Canada that are comparable with the situation in the three Androscoggin mills. There are many overseas mills which discharge much less effluent than the three Androscoggin mills, but those outside Europe are mostly quite new, and/or operate in more favorable climates. A number of European mills are comparable in age, type, wood species and operate in cold climates, similar to that in Maine.

5.1.2 Control of unplanned discharges to the WWTP

From about 60% to 95% of the pollutant discharges from pulp and paper mills are deliberate, and are often known as "**planned discharges**". They may be necessary to remove contaminants from the process, or they may be caused by limitations in the installed equipment. Some of these limitations can be corrected by the investment of capital, or by improved maintenance, while others are inherently unavoidable, at least with today's technology.

From 5% to 40% of discharges are unplanned, and are caused by equipment failures, operator error, or poor operating practices. They are often known as "**spills**" or "**unplanned discharges**" They may be as simple as tanks overflowing due to failure of a level control, an operator not caring about his work, or a maintenance worker dumping the contents of a tank to repair an adjacent pump. Spills can also be due to subtle weakness in process control systems, or instability of the manufacturing process, that require a considerable amount of time by an expert engineer to diagnose.

The spills of particular interest to this report are from the black liquor system, which is spread over half the kraft mill's area, and from coating preparation areas.

The mills did not provide any data allowing assessment of coating spills, although it was noted that the content of inorganic material, probably coating solids, in the biomass is high in the Rumford mill. Based on the ash content in the aeration tank the coating spills at Rumford have been estimated to 15,000-18,000 lb/day.

5.1.3 Reduction of spills of black liquor organics

It is impractical to measure spills of black liquor in a kraft mill, due to the multiplicity of possible sources. The total amount of spills can be determined by conducting a detailed mass balance to quantify formation of black liquor, quantities of make-up chemical purchased and the planned discharges to sewer. The quantities of unknown losses that will be found serve to quantify total spills.

Development of complete mass balances will typically cost up to $200,000 in a mill of the complexity under discussion. There are many benefits to such an undertaking beyond identifying spills, since opportunities for reducing energy and chemical consumption and reducing losses to the sewers are always uncovered.

An alternative approach to assessing the opportunities for spill reduction is to compare the variability of untreated effluent discharges with those from mills with excellent spill control. This was discussed by McCubbin (2001). A copy of the article is appended to this report.

The organic discharges to the WWTP can be assessed by measurement of color, BOD, COD or other relevant parameters, Much of the data currently available was gathered as part of compliance with EPA guidelines for "Best management Practices" under the Cluster Rule.

Figure 11 presents a graph of daily color measurements in a complex integrated kraft paper mill in the US, which has both softwood and hardwood fiber lines and several paper machines.

The mill was built before 1940, and all spill control facilities were installed many years after mill construction. All areas in the mill handling black liquor are equipped with adequate instrumentation to control the process and avoid overflows, as well as spill recovery sumps in floor drains from where any spills are automatically pumped back to the black liquor system for incineration in the mill's recovery boiler.

The daily measurements of the mass flow of color are normalized for production by dividing by the average pulp production for the 180 days concerned.

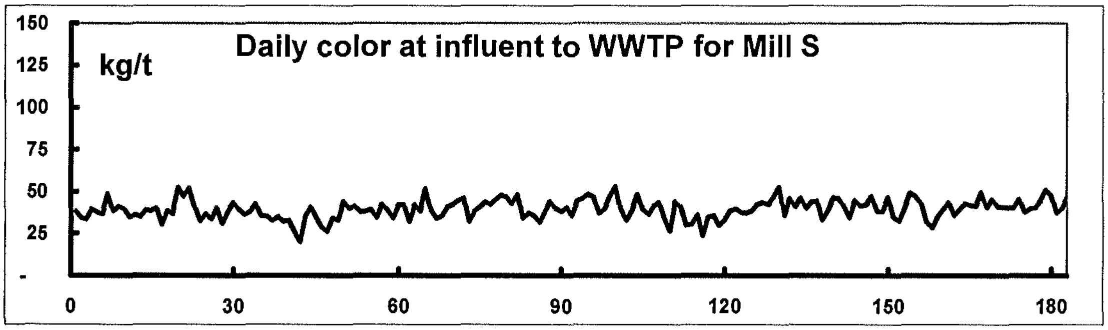

Figure 11 Organic discharge from mill S, with excellent spill control

Figure 12 shows comparable data from mill "T", also in the US. It is somewhat simpler than Mill S, but is very old, and has to comply with extremely stringent color and BOD discharge limits.

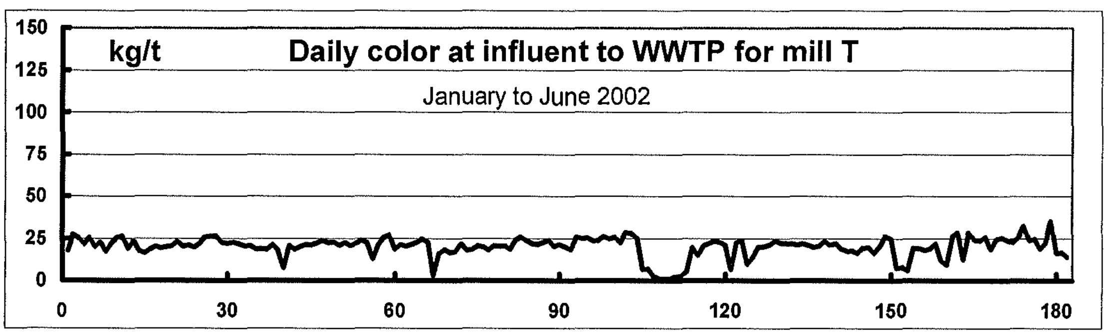

Figure 12 Organic discharge from Mill T, demonstrating excellent spill control

Personnel at mills "S" and "T" are well trained and highly motivated to operate with minimal spills. Management commitment and operator motivation is the most important factor in the success of these systems.

The daily untreated color discharges from another mill, quite similar to mill S, are shown in Figure 13. Despite having essentially the same equipment, the discharges are spectacularly higher. The only discernable differences between Mill X and the Mills T & S are management commitment and operator skill.

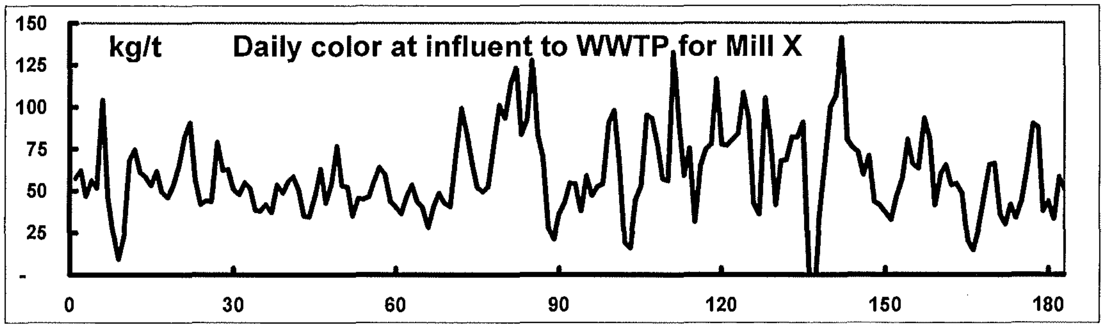

Figure 13 Color discharge at a mill with poorly operated spill control procedures

The spill control techniques are quite well known, and have been discussed by many authors, including McCubbin (2001).

Data on unplanned discharges, and comments specific to each mill on the Androscoggin River, are discussed later in this document.

5.1.4 Benefits of reducing BOD of untreated waste waters

In the biological treatment process, organic matter (BOD) is degraded by microbes to carbon dioxide and water. Some of the BOD is used to grow more microbes. Phosphorus has an essential role in the metabolism taking place. Generally you can say that the larger incoming organic load will require more phosphorus for the biochemical reactions and more phosphorus will then leave the plant as well.

Further, any reduction in the BOD of the untreated waste water effectively increases the sludge age in the activated sludge system, which helps the operators develop sludge that settles well, thus minimizing the TSS discharges, with its associated phosphorus and BOD.

Therefore, an important part of phosphorus control is to implement in-mill measures to reduce organic load (BOD) from production. The most important ones are listed in EU BAT Reference document, summarized in Table 14 on page 47.

5.1.5 Brown stock washing and screening

Efficient brown stock washing and screening, with complete recovery of screening system filtrates, is one of the cornerstones of cost effective effluent discharge control. The systems in the Androscoggin River mills appear to be at least reasonably good, but mills did not provide data for any evaluation by the authors. Potential upgrades to this area of the mill are not discussed herein.

5.1.6 Oxygen delignification

Most overseas mills and about half the pulp production in North America use an oxygen delignification stage to remove 30% to 60% of the organics associated with the washed brown stock before it is routed to bleaching. These organics are recovered with the black liquor, and burned in the recovery boiler, as discussed above. Most new fiber lines built anywhere in the world since 1980, and virtually all since 1990, have incorporated oxygen delignification.

Retrofitting oxygen delignification is an effective way of improving the environmental performance of any kraft mill, and is discussed for each mill later in this report.

There has been much controversy over oxygen delignification since the first commercial applications in 1970. From the commercial standpoint, retrofitting an oxygen delignification system to a typical kraft production line requires a capital investment from fifteen to about forty million dollars, and replaces chemical consumption ranging from about from half a million to ten million dollars per year[9]. It is not surprising that the chemical supply companies and the equipment builders publish contradictory data and opinions on the desirability of the oxygen delignification process.

There is a considerable economy of scale in the equipment, so that capital costs are relatively lower for large fiberlines. The existing fiberlines in Maine are smaller than normally found in modern mills, which tends to lower the economic potential for retrofitting oxygen delignification.

The capital cost of retrofitting oxygen delignification is largely independent of wood species, but the chemical cost savings are much larger for softwood lines than for hardwood, so the economics are much more attractive for softwood.

Management in some mills are reluctant to retrofit oxygen delignification because of an oft repeated myth that it will cause overload of the mill's chemical recovery system, and hence limit pulp production capacity. There is virtually no solid data to support this, and much to contradict the myth. If the mass and energy balance of any proposed system is calculated carefully, the change in load on the recovery boiler can be calculated. Unfortunately, this is often not done, or is not done properly, when assessing the feasibility of retrofitting oxygen delignification. Particularly in the case of modern two stage oxygen delignification systems, it is common

[9] *Overall economic analysis must consider other issues also, including energy consumption and maintenance of the additional equipment.*

practice to increase the target kappa number at the exit from the digester, and gain up to 1.5% in pulp yield, with a corresponding drop in recovery boiler load.

There is no controversy over the fact that oxygen delignification is a technically effective way of reducing mill effluent BOD, COD, and color as well as the discharge of the range of undesirable substances in black liquor.

Recent oxygen delignification installations use two pressurized stages, and can reduce the kappa number (a measure of the lignin content, and hence BOD generation in the downstream bleaching process) by up to 60%. In softwood mills, oxygen delignification can also improve process yield and hence increase mill production capacity slightly, while reducing the load on the recovery system.

Site specific costs and potential environmental benefits are discussed below for each of the three mills under discussion.

5.1.7 Water conservation

The waste water volume has a significant impact on the phosphorus load discharge in a number of ways.

- Most of the phosphorus and much of the BOD in treated mill effluent is carried by the suspended solids. Reducing the effluent flow through the secondary clarifier in any existing system will reduce the suspended solids discharge, due to improved settling.
- The addition of nutrients for treatment is often controlled by the residual phosphorus concentration in the treatment plant outlet; so higher waste water volume will normally result in higher phosphorus load discharge.
- In mills with low effluent flows, an increased proportion of the phosphorus that enters with the wood will leave the mill system with the slaker grits and green liquor dregs, instead of with the effluent.

Water conservation will impact not only on phosphorus discharges but will normally reduce the quantities of pollutants discharged from the production systems to treatment, losses of fiber and perhaps most importantly mill energy consumption. Treatment plant performance in general will improve with reduced flows.

The Berlin, Rumford and Jay mills all discharge relatively high specific waste water volume figures of, 27,700, 15,600 and 21,500 gallons per ton product, respectively. For comparison Finnish integrated mills discharge between 4,000 and 10,000 gallons per ton product. The lowest effluent flow in a North American mill is from the Domtar, Windsor, QC integrated fine paper mill, which discharges slightly under 10,000 gal/ton product, while the Spring Grove mill discharges 13,600 g/ton. The data suggests that the Androscoggin mills have considerable potential to reduce effluent flows.

Generally, it is technically straightforward to reduce effluent flow to about 14,000 gal/ton product. The design and operating practices to reduce mill effluent to this level are fairly well known, and are well proven. Capital costs are normally in the hundreds of thousands of dollars, and there is normally some reduction in operating costs, due to reduction in water treatment costs, as well as energy and fiber savings.

Implementing major water conservation programs requires some time, because it involves engineering study, and operator education, and is best accomplished step-by-step. All three mills under discussion are complex, and already practice extensive recycle of water. Significant reductions in water use can be attained in the short term, but several years would be required to reach the optimal level.

Further reduction of effluent flow usually requires significant investments, and may incur operating costs also.

Some mill staff have commented that a cooling tower would be required for the effluent if flows were reduced. This may be so, but there is usually a potential reduce heat losses in the mill, thus reducing effluent temperature, and avoiding the cost of the tower, while reducing energy costs.

The mills did not provide sufficient data for the authors to investigate effluent flow reduction for each or to develop site specific costs.

There is a considerable body of literature on water conservation in the pulp and paper industry. "Water Management in Paper Mills" (Peel 2001) focuses on papermaking, while "Water Use Reduction in the Pulp and Paper Industry" (PAPTAC 2001) covers the whole industry with a tendency to focus on pulping.

5.1.8 Phosphorus balance

There is very little information available on the entry of phosphorus to each mill, the internal flows, and exit points. None of the three mills under discussion have a detailed phosphorus balance. It is suggested that each company develop a phosphorus balance for its own mill operations, to a level of detail similar to the example in Figure 14 on page 59. Calculation of such a balance should be part of any on-going program to reduce phosphorus, since an improved understanding is essential for selecting the most cost-effective measures.

Phosphorus enters the pulping process primarily as in the wood raw material but also to some extent in lime rock, hog fuel and raw water. The amount of phosphorus entering the pulping process will thus be dependent on the concentration on phosphorus in these materials and their consumption rates.

Phosphorus in raw wood has been reported by various authors to vary from about 0.2 to 0.5 lb/ton pulp. No systematic difference between Scandinavian and US woods has been noted.

The mill's wood supply is normally the dominant source of phosphorus.

In the pulping process a part of the phosphorus is dissolved from the wood into the black liquor. In washing stages the black liquor washed out from the remaining pulp. Normally, all liquor and wash water is recovered. Only small amounts remaining in the pulp and occasional liquor losses flow to sewer. These losses contain phosphorus dissolved in black liquor in addition to other components. Any reduction in black liquor losses recovery will thus reduce phosphorus losses.

Almost all of the black liquor is recovered, incinerated in the recovery boiler and recausticized. The phosphorus in the black liquor concentrates in the green liquor and likely ends up in the lime cycle as Ca-phosphate which has a low solubility

The portion of phosphorus that remained with pulp after washing will be dissolved into filtrates in the bleaching process. These filtrates are ultimately sewered and directed to wastewater treatment plant. This amount of phosphorus sewered via bleach plant is relatively large but constant.

As shown in Table 17, the quantity of phosphorus discharged by the three Androscoggin River mills is roughly triple that found in the three comparable Finnish mills listed. None of the Finnish mills involved has taken any measures to control phosphorus at this point in the process, as far as is known. Differences in the wood supply are unlikely to account entirely for the difference in phosphorus flows. The differences between phosphors discharges shown are believed to result from the differing degrees of process closure in the mills.

If spill control upgrades and oxygen delignification were installed in the three Androscoggin River mills, and any measures indicated by calculating the phosphorus balance, then the phosphorus content of the untreated effluent would drop to levels similar to those in the European benchmark mills mentioned.

Table 17 Quantities of phosphorus in mill effluents after primary treatment

Mill	Current	Estimated after upgrades	Control measures
Berlin	90	58	Spill control, OD
Rumford	80	51	Spill control, OD
Jay	145	56	Spill control, OD
Kaukas	33	-	Spill control, OD low effluent flow etc
Rauma	22	-	Spill control, OD low effluent flow etc
Kuusankoski	41	-	Spill control, OD low effluent flow etc
EU BAT	40 - 60	-	Refer to EU BAT report

Data refer to total phosphorus, grams/ton measured after primary treatment, upstream of any addition for the WWTP

Figure 14 shows the principal flow of phosphorus in a kraft pulping process. Optimally phosphorus should be discharged to sewer only from bleach plant. All phosphorus that was dissolved in black liquor should be taken out dry as lime mud.

Generally, the phosphorus content of the waste waters entering the biological treatment system appears to depend on how tightly the mill pulping and liquor cycles are closed. There is little literature on this issue, which is all the more reason for determining the actual phosphorus balance in the Androscoggin River mills.

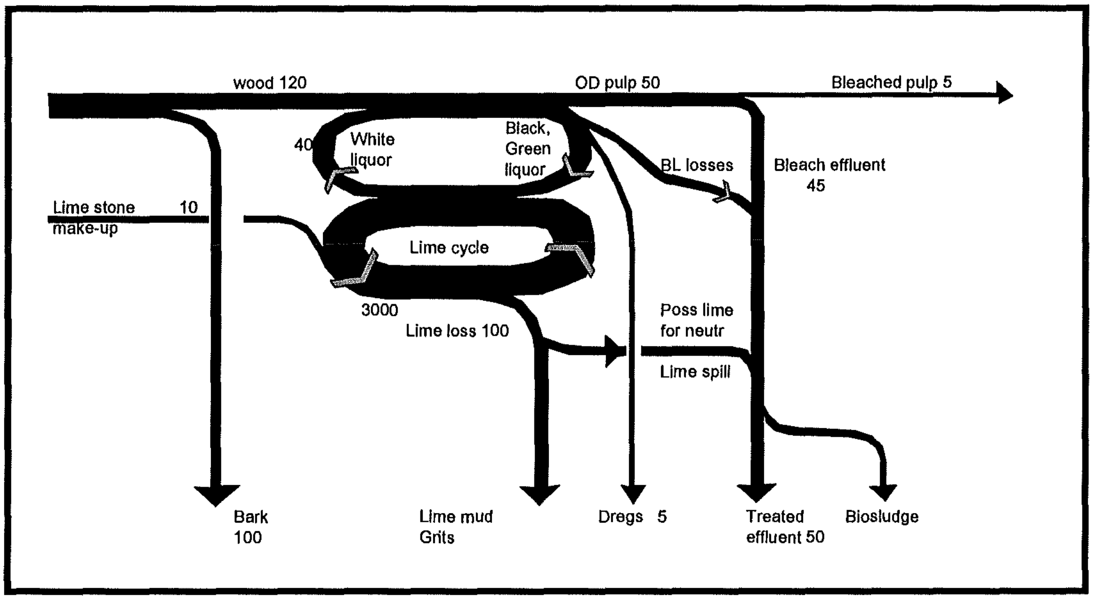

Figure 14 Phosphorus balance in a Canadian bleached kraft mill

Ulmgren (1995) shows that phosphorus tends to accumulate in the green liquor/lime cycle as the kraft liquor cycle is progressively closed. He also shows that the phosphorus can be effectively purged from the system by discarding lime mud, suggesting that up to 5% may need to be discarded in highly closed mills (He is writing in the context of mills discharging under 2500 gallons per ton pulp).

In Eastern North America, lime mud can generally be used beneficially as a soils conditioner, and helps counteract the effects of acid rain

In the kraft process, the lime mud flow, as CaCO3, is typically about 800 lb/ton pulp, and losses with slaker grits and green liquor dregs are about 3% to 10% of this flow. Thus, normal losses of lime mud will generally suffice to purge phosphorus from the liquor cycle when it is recovered by improved brown stock washing, oxygen delignification, or spill recovery.

In the different scenarios presented in sections 6 to 8 for reduced discharges of BOD and P the assumption is that the three mills will through internal measures reduce their phosphorus discharge to treatment plant down to a typical level for bleached kraft mills. Today all three mills have discharges that exceed normal standard levels. Since no in-mill data has been available the reason for this cannot be assessed at this point.

5.1.9 Lime losses

All kraft mills use several hundred tons per day of lime as part of the chemical recovery process. Virtually all of this is recycled in a closed loop within the mill, but a small fraction is lost to mill sewers, and some may be deliberately discharged to by-pass equipment deficiencies, or to purge contaminants that interfere with the pulping process. A Sankey diagram of the phosphorus balance prepared by one of the authors for a Canadian softwood kraft mill is presented in Figure 14. Distribution of phosphorus flows in the Androscoggin River mills will be broadly similar. Notice that the principal phosphorus input is with the raw wood, and than almost half of this is in the bark. These values are likely to vary fairly widely according to wood species and region.

Lime mud may be a significant source of phosphorus in the waste water at some mills. Since it is not clear how well the phosphorus present (as $CaPO_4$) can be utilized, excess lime mud should not be sewered but should be recovered dry and landfilled or used for soil improvement. Also, discharge of fly ash into sewers by wet ash and flyash handling systems may increase phosphorus discharge to the WWTP. Provided that the mill's WWTP really requires this phosphorus, it does not contribute to the final discharge.

Since no information has been available regarding mill status or lime discharges from the three reviewed pulp mills, no specific measures can be proposed at this point.

However, it seems likely that there is an opportunity to reduce phosphorus discharges by study of the lime system in each mill.

5.2 Measures in WWTP to reduce discharges

5.2.1 Optimal operation of the biological treatment system

Optimization of phosphorus dosage is of major importance in trying to achieve low phosphorus discharge levels. In biological treatment phosphorus is an essential element that must be available for the microbes to assure good treatment performance.

None of the activated sludge treatment plants in the three Androscoggin River mills have the features required to achieve very low phosphorus levels in the treated effluent but there are **some opportunities for improvement from current levels without significant capital expenditure**. Since the treatment plants operate with a relatively high organic load, optimization will include careful monitoring of both phosphorus balance and suspended solids characteristics.

Presently, mills control phosphorus addition by attempting to maintain a selected target concentration in the treated effluent. As a general "rule of thumb", the limiting concentration for total phosphorus is often stated to be 0.5 mg/L. However, many mills, including the Glatfelter mill at Spring Grove, PA operates routinely with phosphorus discharge below 0.1 mg/L, while maintaining low BOD and TSS discharges, as discussed on page 38.

The results of the best Finnish mills (Enocell and Lappeenranta) demonstrate that a stable process can be operated with very low residuals (0.05 to 0.1 mg P/L) and with practically zero addition of phosphorus. Experience from several years of operation reveals no operational problem that can be related to the low phosphorus level. At these mills, phosphorus is added only during shutdown periods. Refer to report section 4.4.2 commencing on page 41.

There is a serious weakness in the classic approach of controlling phosphorus addition by feedback from the phosphorus discharge concentration, although it is widely used. The problem is that there is roughly a ton of phosphorus in the circulating biomass (also known as the "sludge" or "MLSS") in each plant, and this sludge remains in the plant for several days. The normal addition rates of phosphorus are in the order of 200 lbs/day. Thus an operator making an adjustment in flow to control the residual P discharge, would probably make a change of under 50 lb/day. Due to the large inventory of phosphorus, and the long retention time of sludge, it will take weeks for such an adjustment in phosphorus feed to show any stable effect. This is too long a lag time to permit stable control. In effect, control of phosphorus addition is a very difficult problem for normal process control technology.

One solution adopted in a number of successful activated sludge plants is to calculate the phosphorus balance, including concentration of phosphorus in the MLSS, and use this as a guide for adjusting phosphorus addition. This allows reduction of the dosage to minimal values, without jeopardizing BOD removal efficiency.

Application of this approach would include regular monitoring of the phosphorus balance of the biological system. The objective is to develop an understanding of the relationship between the phosphorus content in incoming waste water, MLSS and effluent waste water. Once good information about the phosphorus balance has been obtained, the phosphoric acid dosage can be reduced progressively towards zero. In addition to phosphorus monitoring, the characteristics of MLSS need to be carefully determined during the period of reducing phosphorus discharge.

In the optimized system, any dosage of phosphorus should be based on MLSS phosphorus content in the system as well as the residual dissolved phosphorus in treated effluent. It is common, but not universal, practice for kraft pulp mills in Finland to use this approach and to operate without any addition of phosphorus to the effluent treatment system, while maintaining excellent effluent quality.

As preliminary figures we propose to set the targets at follows:

- Gradually reduce dosage of phosphoric acid towards zero
- Control the P concentration of MLSS to minimum 0.5% (tentative target)
- Control the dissolved P (filtered P) in final effluent to minimum 0.2 mg P/l

Subsequently, it will be possible to develop operating techniques to further reduce phosphorus discharges, if the treatment systems are upgraded. Application of these advanced phosphorus control techniques requires the attention of a knowledgeable person resident at the mill, and would be assisted by participation in the program for studying other mills and staff education discussed on page 51.

Monitoring and control

To achieve good results, a biological treatment process requires adequate monitoring and control. The operators and personnel need to be trained and educated to understand the implications of data collection and consequences of the various control measures that may be implemented.

Process monitoring requires measurements and frequent sampling of the key process streams within the WWTP that indicate the status of the treatment process. If phosphorus concentrations are not measured regularly in the various streams, optimal nutrient addition cannot be attained. It is common, but poor, practice to simply fix the phosphorus addition rate, normally in excess of what is required to ensure that it will be sufficient for all conditions.

Management of suspended solids is very important in the discharge of phosphorus, and is largely under the operator's control, presuming that the plant is well designed. The deficiencies in the design of the systems under discussion prevent operators from attaining the very low discharge concentrations found in some mills, although there are possibilities for some improvements, as discussed elsewhere in this report. Any elevated concentrations of suspended solids will correspondingly increase the concentration of phosphorus in the treated waste water.

Personnel

Dedicated, knowledgeable and motivated personnel are essential for optimal operation of the process. We have seen many cases where expensive, well designed plants have been operated by inadequately trained personal, with highly unsatisfactory results. Further, there must be sufficient personnel time allocated for the individuals to perform their assigned work well. The common practice of expecting an individual to operate other major mill systems, such as boilers rarely, if ever, results in optimal WWTP performance or minimal costs. Operating and maintenance costs in poorly operated plants are usually high.

Most, if not all, biological treatment systems in the pulp and paper industry that operate to a high level of performance have at least one full-time professional supervisor who is educated in microbiology, and **has sufficient time and resources to continuously investigate the process**, and study successful operation in other plants.

In most pulp and paper mills where effluent quality is excellent there are two operators per shift in the WWTP. Their duties include continuous analysis of the process, undertaking all laboratory testing, (except for any specialized tests or quality control samples sent to outside laboratories) monitoring untreated effluent quality and taking action to encourage specific mill departments to correct operating problems that cause difficulties in the WWTP.

One of the reasons for having two operators is that one can spend time in the mill and communicating with mill operators to resolve issues that cause excessive effluent discharge.

5.2.2 Optimal design of biological treatment system

The optimal design of a biological treatment system is crucial for a good treatment result. The most important objective is to design a system that can absorb and handle normal variations in incoming flow and organic loads and has the capacity to manage occasional spills without causing major disturbances.

It is important that biological systems be designed to maintain stable conditions for the microbiological activity so that the best performing microbes will be selected and dominate in the system.

Treatment process stability is one of the most desired features and requirements to achieve very low discharges. A plant that does not possess the necessary stability features may have their normally very good results spoiled due to occasional poor performance.

Most of the integrated kraft/paper mills in the world that operate with excellent effluent characteristics have state-of-the-art air activated sludge treatment systems. There is no clear advantage over this process exhibited by other processes such as oxygen activated sludge treatment, tertiary treatment or other process, although a few are used in specific mills.

The main principles used in the design to achieve stability include:

- Good solids separation in primary clarifiers (max up flow rate of 900 gal/ft^{2}d)
- Equalization of influent waste water flows in equalization basin (retention 6-12 hours);
- Spill pond to divert possible occasional unrecoverable spills;
- Sufficient aeration volume to achieve a high sludge age (minimum 15 days) [10];
- Optimal aeration tank/basin design and aeration type to ensure good quality of micro-organisms
    - deep aeration tanks to improve energy efficiency (24 – 36 ft)
    - optimal flow pattern through plug flow, cells in series, and/or selector
- Sufficient sludge storage volumes in secondary clarifiers and low up flow rate. (max 420 gal/ft^{2}d)

In Finland, it can be observed that pulp mills fulfilling these requirements generally have a very high performance level with respect to BOD removal and phosphorus discharge control.

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[10] The ability of a plant to maintain a high sludge age does not by itself reduce phosphorus discharge. However, high sludge age is normally necessary to allow operators to attain stability and optimal discharge conditions.

Most of the highly efficient Activated sludge treatment systems designed since about 1990 in the pulp and paper industry employ a "**selector**", or similar arrangement at the input to the aeration tank to improve biomass quality. This is simply a tank where the return sludge and the incoming effluent are mixed intimately, and held in a condition with lower dissolved oxygen for about half an hour. This develops a microbial population that is more appropriate to the objectives of the treatment plant than if no selector is used. In particular, selectors generally reduce the formation of poorly settling filamentous bacteria, thus avoiding the need to treat the sludge with chlorine, as is often necessary in one of the Androscoggin river mills.

To further reduce pollutants after conventional biological treatment, a polishing unit may be used. In Finland there is one pulp mill (Stora Enso, Enocell) operating a large polishing pond or so-called "Ecological Lagoon". It is effective in reducing BOD and COD in the discharge, and in averaging out variations in effluent characteristics. In the long term, its impact on phosphorus discharges is not significant, although the reduction in short term variations is noticeable. It seems unlikely that such an installation would have a significant effect on the receiving water's response to phosphorus discharges.

The proper design and operation of sludge handling facilities is very important as well. In many cases a recirculation load of phosphorus between treatment and sludge handling has been discovered and found to be a cause of high discharges. This aspect of operations was not studied for this report, since there were not sufficient data available on the internal phosphorus balance of the mills and WWTP systems. One benefit of calculating and maintaining phosphorus balances is that opportunities for improvement usually become evident.

5.3 Tertiary treatment

Phosphorus in the biologically treated waste water can be removed by chemical precipitation and separation in a tertiary treatment step. In this treatment process, typically an alum or ferric salt is used to coagulate and precipitate any dissolved phosphorus to a solid phase that can be separated. Separation of solids may be either by sedimentation or by flotation. Sometimes further removal is accomplished by sand filtration. Handling and disposal of sludge from such systems is usually problematic.

Woodard & Curran (2003) discussed tertiary treatment for Androscoggin River mills, and showed that it can be used to reduce phosphorus discharges.

However, it is also desired to reduce discharges of BOD to the Androscoggin River, and tertiary treatment is quite inefficient in this respect, when applied to biologically treated pulp industry waste waters.

While it would be technically feasible to apply tertiary treatment in all three of the Androscoggin River mills, it has not been investigated in detail in this report, since the operating costs are so high that implementation is improbable.

The following discussion summarizes the information that led the authors to conclude that tertiary treatment is not likely to be an effective way of reducing phosphorus and BOD discharges from the three mills under discussion.

5.3.1 Current applications of tertiary treatment in North America

The Tembec mill at Skookumchuk, BC uses tertiary treatment for color removal, but ther are no data available on its impact on phosphorus discharges. It is used for only a few months per year, during low river flow periods, due to high chemical costs.

The International Paper mill at Ticonderoga, NY has used tertiary treatment for some years, and operates with quite low phosphorus discharge, as discussed on page 40. However, the P and BOD discharges still exceed those of the Glatfelter mill at Spring Grove, PA, which uses only conventional activated sludge.

5.3.2 Current applications of tertiary treatment in Scandinavia

In the Nordic countries, tertiary treatment (chemical coagulation) can be found at a number of newsprint mills but only at two kraft pulp mills, one in Finland and one in Sweden. The Finnish mill, StoraEnso Varkaus mill, is an integrated mill producing 500 ton/d softwood and hardwood bleached pulp, 660 ton/d mechanical pulp and 1400 ton/d paper. The waste water treatment system includes biological treatment in an aerated lagoon and clarification followed by chemical precipitation and flotation as a tertiary step. The start-up on the tertiary treatment was in late 2001 and optimized operation was not reached until late year 2002. The current discharge data summarized in Table 18 below demonstrate that a very low level of phosphorus discharge was achieved. Since the system did not achieve significant reduction in TSS, any reduction in BOD was probably modest.

Table 18 Performance data of the Varkaus integrated pulp mill with tertiary treatment

Parameter	Unit	Total influent	After biological treatment	After tertiary treatment
Flow	MGD	15.8	15.8	15.8
TSS	lb/d	90,000	4,840	4,620
Total P	lb/d	110	66	20-35
Total P	mg/L	0.8	0.5	0.2 to 0.3

The capital cost of tertiary treatment at the Varkhaus mill was between two and three million dollars.

In Sweden, the Stora Enso, Skoghall mill operates a treatment system that includes an aerated stabilization basin followed by chemical precipitation. The Skoghall mill is an integrated board mill producing kraft pulp, CTMP and liquid packaging board. The phosphorus concentration in the treated waste water at Skoghall mill is about 0.5 mg /L, which is no better than the best activated sludge systems.

5.3.3 Tertiary treatment is South American kraft mills

The Riocell mill near Porto Allegre has operated with an oxygen activated sludge secondary treatment system and a tertiary treatment system since 1982. Effluent flow is 38 m^3/t (11,000 g/ton) pulp, which would be lower if calculated on the basis of the paper production in the adjacent paper mill which shares the WWTP. Phosphorus discharge is reported to be 0.046 lb/ton pulp.

Kraft mills presently under construction in Chile are equipped with primary, secondary and tertiary treatment systems. The objective of tertiary treatment is primarily to remove effluent color. There are no data further available to the present authors on performance or design criteria.

5.3.4 Costs of tertiary treatment

The EU BAT reference document presents a cost estimate of about $US 2.6 million for the capital cost of a 700 ton/d pulp mill and $US 3.8 million for a 1400 ton/d kraft pulp mill (European Commission 2001). Woodard and Curran (2003) estimated considerably higher capital .

The EU BAT document suggests that the annual operating cost would be in the order of $60,000. The present authors consider that this underestimates the likely cost in Maine. Maintenance of such a system alone would cost approximately this amount. The principal operating cost in tertiary treatment systems is the supply of chemicals. The Woodard report (discussed on page 64) suggests an annual operating cost of several million dollars, but this is based on an unrealistic target for final phosphorus concentration, and on very limited laboratory testing.

The Baikalsk bleached kraft mill in Russia has operated an extremely efficient tertiary treatment system for over 25 years, with phosphorus discharge of 3 g/ton pulp (0.007 lb/ton). The chemicals cost approximately a million dollars per year, based on US chemical prices.

The annual cost of operating a tertiary treatment system in each of the mills discussed herein would probably be in the order of a million dollars. Tests on each mill effluent would be required to determine the quantities required.

The authors do not see tertiary treatment as likely to be economically feasible in the Androscoggin River mills, so have not included it in the three alternate upgrade scenarios. However, there is no doubt that it is technically feasible, and it is possible that one or more mills may develop a cost effective variation.

5.4 Simultaneous precipitation of solids in secondary clarifier

It is not unknown for mills to add coagulants to the secondary clarifier in activated sludge plants, to reduce suspended solids discharges.

The Jay mill uses this approach to limit suspended solids discharges at certain periods of the year. There are indications that this practice leads to accumulation of biomass on the bottom of aeration tanks (as at the Jay mill). It is well known that biomass accumulations have a negative effect on the operation of activated sludge systems

The International Paper mill at Ticonderoga, NY has described such practices in the open literature, but has discontinued use of polymers and other coagulant aids in their secondary clarifiers.

The authors understand that the operating costs were high, but have no quantitative information.

None of the kraft pulp mills in Finland or in Sweden operates their activated sludge process with addition of coagulation chemicals into the biological process (so-called simultaneous precipitation). However, there are at least a few newsprint mills that do so. In many cases the objective is to enhance COD removal rather than to reduce phosphorus discharges. Dosages are rather small.

One of the newsprint mills (1800 ton/d) that operates simultaneous precipitation in a two-stage biological treatment process (submerged biofilter + activated sludge) discharges 0.2 mg P/L as an annual average.

The use of simultaneous precipitation is not considered conventional or according to BAT (European Commission 2001). It is not known to what degree the phosphorus precipitated will be available for the micro-organisms. There is a risk the added phosphorus and coagulant will interact resulting in extra chemical and sludge handling costs.

The authors have no data to suggest that this is a valid, sustainable treatment option for the mills under review, so have not included simultaneous precipitation in the alternate upgrade scenarios. However, one or more mills may develop it to satisfactory, cost effective operation.

6. Opportunities for discharge control at Berlin mill

The BOD of the effluent after primary treatment is about average for the US at 40 lb/ton pulp.

This demonstrates that there are opportunities for reduction such discharges, by implementing technologies already common in the industry. The company declined to provide the authors with data on the mill manufacturing operations, so the following is based on information available from submissions to the Gulf Island Pond Stakeholder Process, and from the open literature on the pulp and paper industry.

The untreated suspended solids loss from the paper mill is quite high at 80 lb/ton, but is reduced to around 3 lb/ton by the treatment system. The phosphorus and BOD content of these solids will be very low, so there are no obvious opportunities for improving treated effluent by fiber recovery. Since taking over the mill, Fraser-Nexfor staff have reduced the fiber loss significantly and have on-going plans for further reduction.

6.1 Berlin Scenario 1

Scenario 1 for the Berlin mill involves spill control, operator education, and low-capital costs for upgrades to the WWTP.

6.1.1 Spill control and effluent stabilization in pulp mill

Daily measurements of COD entering the aeration tank at the WWTP in the Berlin pulp mill are shown in Figure 15. Data are available only for the period shown, since the mill recommenced operation only in early 2003, after an extended shutdown and change in ownership. The graph is drawn with a six-month scale for the X-axis to facilitate comparison with other graphs in this report.

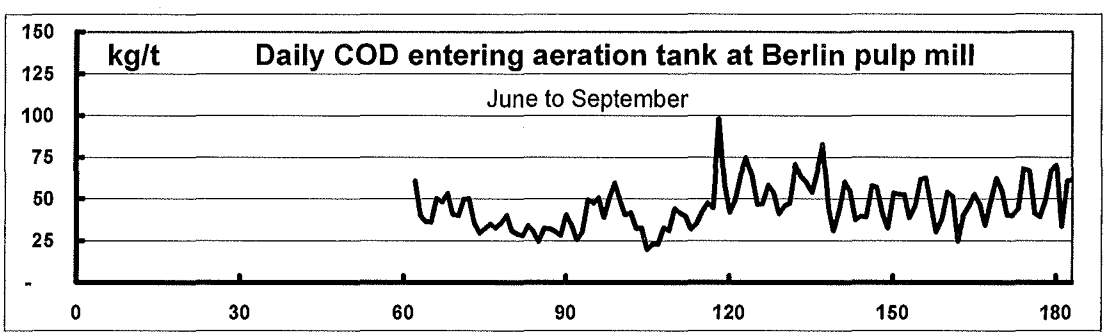

Figure 15 Organic discharge to WWTP in Berlin pulp mill

Comparison with Figure 11 and with Figure 12 on page 53 demonstrate that the variation in organic discharge is relatively large from one day to the next. The difference in absolute values in not significant, since organic discharge from the Berlin mill is measured in COD rather than as color.

Mill staff advise that there are spill recovery sumps in all areas handling black liquor, so the Berlin mill appears to have similar spill recovery sumps to Mills S and T discussed earlier. It is assumed for the purposes of this report that some upgrading would be required, so an allowance of $100,000 is included in cost estimates. The net operating and maintenance cost for such a system is assumed to be zero, because there is a significant energy, chemical and fiber value in material recovered in a properly designed system.

It is impossible to determine the extent to which the variation in Berlin effluent COD is due to recent startup, but it is clear that improvement is attainable by improvement of operator skill, and perhaps some correction of any weaknesses in the spill recovery facilities.

The average of the data in the graphs is 45 kg/t pulp (90 lb/t). The graph shows that the mill frequently operated with a discharge below 30 kg/t pulp (60 lb/t), suggesting that the base value with minimal spills is at this level. It may be lower, since even the good days probably include minor spills.

This suggests that untreated COD can be reduced by 30 lb/t pulp, which corresponds to approximately 10 lb BOD/t pulp, or 7,250 lbs/day. This represents approximately 25% of the mills current untreated BOD load on the WWTP.

In the current treatment plant the reduction in BOD would enable operation at about 1-2 days higher sludge age. BOD reduction percentage will likely improve by 2-4 %-units. This corresponds to 1500 lb BOD/d reduction. Less variations can be expected in TSS (and phosphorus) discharges as well. These improvement are relatively small would be noticable.

6.1.2 Operations of the WWTP

This scenario involves operator training, improvement of phosphorus control, re-commissioning of the North aeration basin and improvement of the method of introducing the recycled activated sludge to the aeration basin.

Operating crew

To minimize discharges of phosphorus, BOD and TSS, a second operator could be added to the current one-man crew (refer to discussion on page 62). If an additional group of operators have to be hired to cover all shifts, rather than transferring other staff, then the annual cost would be approximately $250,000.

To upgrade performance of the WWTP, whether in its existing form, or after implementation of equipment upgrades discussed below, or other upgrades, a program for extending effluent control know-how as discussed on page 51 is considered part of Scenario 1.

Optimization of phosphorus control

Apply the phosphorus control approach described on page 33.

The potential for phosphorus reduction through phosphorus control is estimated in Table 19, for the optimal situation. The full benefits would not be realized at Scenario 1. Refer to Table 5 on page 11 for the intermediate situation for Scenarios 1 and 2.

Table 19 P balance in Berlin pulp mill WWTP, after Scenario 3 is implemented

Stream	Unit	Value	Comments
Influent	lb P/d	158	Assumed 0.55% P of BOD in influent (1)
Nutrient Addition	lb P/d	0	
Sludge withdrawn	lb P/d	-89	Assumed 0.5%P in MLSS (2)
Treated effluent	lb P/d	69	
	mg Tot P/l	0.45	
	mg Susp P/l	0.15	Assumed 30 mg TSS/l avg
	mg Diss P/l	0.30	
Reduction	lb P/d	132	From current situation

(1) No actual data available. Estimated based on data from other mills (0.3 – 0.6%)
(2) Optimum level will depend on sludge age and ash content.

This measure will not impact effluent BOD.

Assuming an additional 5 hours per week of technician/engineer time would be devoted to monitoring phosphorus addition, the cost would be $12,000/year. The dosage of phosphorus can potentially be reduced to zero, saving in the order of $125,000/year. If some phosphorus dosage is still required, then the saving would be less, but still a substantial fraction of this value.

Utilization of the North aeration basin

Currently, only one (South) of two aeration basins is in use. The South aeration tank has a volume of 3.6 MG. With the current MLSS content of approximately 3000 mg/L, the sludge age will be not more than approximately 4 days. The treatment plant must therefore be considered as a highly-loaded activated sludge process. This assessment is also supported by the relatively low BOD removal percentage (88%).

Utilization of the North aeration basin (3.9 MG) in series with the South aeration basin would increase the total volume to 7.5 MG.

Operation would be adjusted to increase MLSS levels, to around 3,500 mg/L. Thereby, the sludge age will be increased from approx. 4 days to 13 days which will improve BOD removal and make the process much more stable.

The measure will reduce average BOD discharge from the pulp mill by approximately 2000 lb/d or 2.7 lb BOD/t. The measure will indirectly impact on phosphorus discharge by making the process more stable and thus assist in attaining a lower (or zero) phosphorus addition. Assuming a drop in TSS concentration of 5 mg/L, the reduction in phosphorus discharge would be 5 lb/d.

The capital cost of this measure is estimated at up to $100,000, including possible dredging of the lagoon (2500 cy yds sludge) and maintenance of exiting aerators, etc.

Use of more aeration capacity (energy) will increase operating cost by approx $260,000/year.

Improve flow arrangements for influent and return sludge in aeration tank

In an optimized aeration tank system, the influent and the return sludge should be introduced as close as possible to each other. The preferred option is to mix the streams in a "selector" tank prior to aeration basin, where the mixture will reside for about half an hour in a somewhat oxygen deficient state. This has been shown to develop a healthier biomass than immediate introduction of the recycled sludge to the aeration tank. The use of a selector will reduce the risk for filamentous bacteria growth, as mentioned previously.

At the Berlin pulp mill treatment plant, the influent and the return sludge streams are discharged into the aeration basin relatively far from each other. In order to improve the flow pattern of the system both return sludge and influent should be introduced at the same point or alternatively, a separate mix tank or selector prior to aeration should be constructed.

This option covers the rearrangement of piping so that sludge and the effluent from the primary clarifier enter the aeration tank at the same point.

The measure will not result in any immediate measurable impacts on the BOD of the treated effluent but will make the process more stable and improve solids characteristics. Also, indirectly the measure will reduce phosphorus discharge by making the process more stable and thus assist in attaining a lower (or zero) phosphorus addition.

The cost of this measure is estimated at approximately $20,000.

Refer to Table 5 on page 11 for a summary of changes in effluent characteristics that may result from application of the technology discussed here, and the associated costs.

6.2 Berlin Scenario 2

6.2.1 Internal process measures

The measures discussed under scenario 1 for spill control are considered to be part of scenario 2 also.

6.2.2 Upgrade pulp mill WWTP

The measures discussed under scenario 1 for upgrading operations in the WWTP are considered to be part of scenario 2.

In addition this scenario involves construction of an activated sludge treatment system for the paper mill, and installation of a selector in the pulp mill WWTP.

Install a selector to mix influent and return sludge prior to aeration tank

Install an aerobic selector, as discussed on page 63. ahead of the aeration basin. Tentatively, the appropriate size would be 600,000 gallons. This measure will make the process more stable and improve solids settling characteristics. Also, indirectly the measure will impact positively on phosphorus discharge by making the process more stable and thus assist in attaining a lower (or zero) phosphorus addition.

The measure will not result in any immediate impacts on the BOD of the treated effluent but will make the process more stable and improve solids characteristics. Also, indirectly the measure will reduce phosphorus discharge by making the process more stable and thus assist in attaining a lower (or zero) phosphorus addition. Assuming a drop in TSS of 10 mg/L the impact on phosphorus would be 10 lb/d and on BOD 400 lb/d.

The cost of this measure is estimated at approximately $300,000.

6.2.3 Berlin paper mill WWTP

Presently, this operates essentially as a primary treatment system. Mill staff showed that the small Aerated Stabilization Basin (ASB) is not operating effectively, although the effluent runs through it, and the discharge complies with the discharge permit.

This system discharges almost 7,000 lb/day of BOD, which is about two thirds of the total from the Berlin mill.

Retention time is very short, and would have to be increased to approximately 5 days, and about 400 HP of aeration power added to make the system effective as an ASB. It appears unlikely that space is available for conversion to an ASB. The system is presently deficient in nutrients, so a nutrients system would be required.

Berlin mill staff indicated that their objective is to reduce the flow from the present value of 11 MGD to a volume that could be pumped to the pulp mill WWTP through an unused pipeline that was formerly used to transfer softwood pulp from the pulp mill to the paper mill.

This is perhaps the best solution, but will require a major upgrade in the paper mill's water systems, and cannot be evaluated by the present authors with the information available at the time of writing.

There is sufficient space on site for an activated sludge system. A state of the art system would be the logical choice, except that perhaps there would be no need for an equalization basin since the effluent source is a paper mill that cannot spill black liquor.

The existing primary clarifier is somewhat undersized, but seems to be performing well. When the mill completes the projects currently under way for return of pulp transport water to the pulp mill, the load will be reduced.

The capital cost of a new activated sludge system, including secondary clarifier and sludge dewatering would be approximately $7 million, and the annual operating cost $700,000/year.

The current discharge of BOD could be reduced to 1000 lb/day, TSS to 1,400 lb/day and the phosphorus discharge would be approximately 20 lb/day

Refer to Table 5 on page 11 for a summary of changes in effluent characteristics that may result from application of the technology discussed here, and the associated costs.

6.3 Berlin Scenario 3

6.3.1 Internal process measures

The measures discussed under scenario 1 for spill control, upgrading operations in the WWTP, and installing oxygen delignification are considered to be part of scenario 3 also.

6.3.2 Upgrade pulp mill WWTP to state-of-the-art design

<u>State-of-art activated sludge treatment plant</u>

At Berlin pulp mill, upgrading of existing treatment plant to state-of-art level would imply the building of a new aeration tank with new aeration system. The existing aeration tank could possibly be used as an equalization tank. The existing primary and secondary clarifiers are up to the standard of a state-of-the-art activated sludge system.

A new 7.5 MG plug-flow aeration tank with selector would have to be constructed. The aeration tank should be 33 ft deep with a diffuser system for aeration.

The measure alone will reduce average BOD discharge from the pulp mill by approximately 2500 lb/d or 3.4 lb BOD/t.

The measure will indirectly impact on phosphorus discharge by making the process more stable and thus enable a lower (or zero) phosphorus addition. The estimated phosphorus discharge is below 69 lb/day. The reduction in phosphorus will thus be at least 130 lb P/d, when considering the benefit of all changes. The average TSS concentration will be below 25 mg/L.

The cost of this measure is estimated to be $5,000,000 and includes new aeration tank, aeration system, piping arrangements and other related costs.

A more efficient aeration system will create savings in energy use estimated at $100,000/year.

6.3.3 Oxygen delignification

As discussed on page 55, retrofitting an oxygen delignification system would be an effective way of reducing BOD discharge from the mill. Capital costs are estimated to be $20 million, with an operating cost saving of about $5/ton pulp. The net effect would be to increase the mill operating costs by approximately $5/ton pulp, and reduce BOD load on the treatment plant by 4,700 lb/day.

In the current treatment plant, the reduction in BOD would enable operation at about 1 day higher sludge age. BOD reduction percentage will likely improve by 1-2 %-units, which corresponds to a 1000 lb/day BOD reduction. Less variations can be expected in TSS (and phosphorus) discharges as well. These improvements though relatively small, would be noticeable.

Installation of oxygen delignification should result in about 26 lb/d lower discharge of phosphorus to the treatment plant. The phosphorus content of the influent wastewater will then be 0.12 lb/ton which is a typical level for pulp and paper mill that is operating well. This amount of phosphorus removed from the sewer will exit the mill with waste sludge, lime mud, dregs and ash.

6.3.4 Coating loss control

There were no data on coating losses made available during the authors' visit to the mill in November 2003. If these are significant, then the coating loss control measures discussed below for the Rumford mill may be useful, and could be profitable.

6.3.5 Berlin paper mill WWTP

Install state-of-the-art activated sludge treatment system as discussed on page 72.

Refer to Table 5 on page 11 for a summary of changes in effluent characteristics that may result from application of the technology discussed here, and the associated costs.

7. Opportunities for discharge control at Rumford mill

The BOD and phosphorus of the effluent after primary treatment is relatively low at 28 lb/ton finished product, considering that the mill does not have oxygen delignification in either pulp line

This demonstrates that there are relatively few opportunities for reduction of organic discharges, by implementing technologies already common in the industry.

Current effluent flow is 15,600 gallons/ton product, which is about double that of the lowest flow comparable mills. One strategy would be for the mill to reduce the flow by up to 50%. As discussed on page 56, this would be a long term project, although significant progress can be made in the short term.

The mill did not provide sufficient data to allow any assessment of costs, but did note that their studies had shown that a cooling tower for effluent would probably be necessary. These are commonly installed in the Southern US, and the lowest effluent flow kraft mill in Canada (Domtar at Windsor, Quebec) has one. Alternatively, it may be possible to recover sufficient energy in the manufacturing process to avoid the effluent temperature being too high for the WWTP. Various approaches are used, including heat exchange of incoming water with discharges and reduction of water use in hot processes, thus reducing energy input and heat to the sewers. If a detailed mass and energy balance is calculated, and perhaps pinch technology applied, then opportunities for energy and water conservation always become apparent.

The company declined to provide the authors with data on the mill manufacturing operations, so the following is based on information available from submissions to the Gulf Island Pond Stakeholder Process, and from the open literature on the pulp and paper industry. It was not possible to analyze water conservation potential in sufficient detail to develop costs. If the flow were reduced, then the costs of effluent treatment upgrades discussed below in the three scenarios would also be reduced.

Specific opportunities for effluent reduction within the Rumford mill are discussed below.

7.1 Rumford Scenario 1

Scenario 1 consists of improving spill control, upgrading operating know-how as discussed on page 51, and improving the WWTP operations without capital investment.

7.1.1 Spill control and effluent stabilization

Daily measurements of COD entering the aeration tank at the WWTP in the Rumford mill are shown in Figure 16. The data are based on kg/ ton pulp

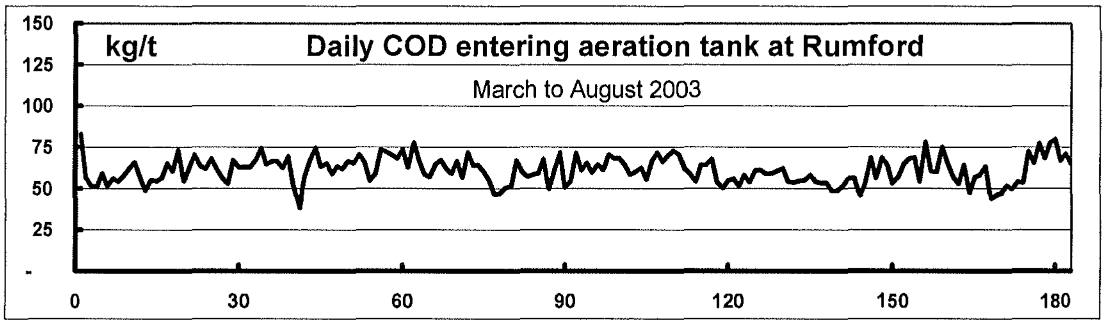

Figure 16 Organic discharge to WWTP in Rumford mill

Comparison with Figure 11 and with Figure 12 on page 53 demonstrates that the day-to-day variation in organic discharge is somewhat larger at Rumford than it could be. The difference in absolute values between the above graph and the others is not significant, since organic discharge from the Rumford mill is measured in COD rather than as color.

Mill staff advise that there are spill recovery sumps in all areas handling black liquor, so the Rumford mill appears to have similar spill recovery sumps to Mills S and T discussed earlier. It is assumed for the purposes of this report that some upgrading would be required, so an allowance of $100,000 is included in cost estimates. The net operating and maintenance cost for such a system is assumed to be zero, because there is a significant energy, chemical and fiber value in material recovered in a properly designed system.

It is not possible for the authors to determine specific causes for the variation in Rumford mill untreated effluent COD, but it is clear that improvement is attainable by improvement of operator skill, and perhaps some correction of any weaknesses in the spill recovery facilities.

The average of the data in the graphs is 61 kg/t pulp (122 lb/t). The graph shows that the mill operated 20% of days with a discharge below 54 kg/t pulp (108 lb/t), suggesting that the base value with minimal spills is at or below this level. It may be lower, since even the good days probably include minor spills.

This suggests that untreated COD can be reduced by 14 lb/t pulp, which corresponds to approximately 5 lb/t of BOD, or 7,000 lbs/day. This represents approximately 10% of the mill's current untreated BOD load on the WWTP.

In the current treatment plant, the reduction in BOD would enable operation at about 3 days longer sludge age. BOD reduction percentage will likely improve by about one percentage point. This corresponds to 700 lb BOD/d reduction. Less variation can be expected in TSS and phosphorus discharges. These improvements are relatively small but measurable.

7.1.2 Oxygen delignification in softwood and/or hardwood lines

As discussed on page 55, retrofitting an oxygen delignification system would be an effective way of reducing BOD discharge from the mill to the treatment plant.

Capital costs are estimated to be $19 million for the softwood line, with a direct operating cost saving of about $15/ton pulp. After allowing for maintenance and repayment of capital, the net effect would be to reduce the mill operating costs by approximately $5/ton softwood pulp, and reduce BOD load on the treatment plant by 16,000 lb/day.

For the hardwood line, capital costs would be about $21 million, with savings in chemical costs of about $4.50/ton hardwood pulp. The net effect would be an increase of approximately $4/ton hardwood pulp in manufacturing costs. The BOD load to the activated sludge treatment system would be reduced by approximately 5,500 lb/day.

It appears that it would be profitable to implement a modern two-stage oxygen delignification system in the softwood line, but not in the hardwood line. This is compatible with the actions of the owners of many profitable mills over the past 20 years. If the implementation of oxygen delignification avoids capital expenditure in the WWTP (which is heavily loaded at present) then the economics of OD could be very attractive in this mill.

Assuming oxygen delignification on the softwood line only, the BOD load to treatment would drop by approximately 16,000 lb/d. In the current treatment plant the reduction in BOD would enable operation at about 5 days higher sludge age (new about 11 days). BOD reduction percentage will likely improve by about 0.5 to 1 percentage points. This corresponds to 1100 lb BOD/d reduction. Considerably variation can be expected in TSS and phosphorus discharges as well.

The combined impact of all in-mill measures should result in about 128 lb/d lower discharge of phosphorus to the treatment plant. The phosphorus content of the influent wastewater would then 0.1 lb/ton which is a typical level for pulp and paper mill that is operating well. The phosphorus removed from the sewer will leave the process with the waste sludge, lime mud, dregs and ash.

7.1.3 Operations of the WWTP

To upgrade performance of the WWTP, whether in its existing form or after implementation of equipment upgrades discussed below, or other upgrades, a program for extending effluent control know-how as discussed on page 51 is considered part of option 1.

<u>**Optimization of phosphorus control**</u>

Apply the phosphorus control approach described on page 33.

Estimated impact on effluent discharge

The potential for phosphorus reduction through phosphorus control is estimated in Table 2 for optimal conditions. In the case of scenarios 1 and 2, only a partial saving would be realized, as shown in Table 6 on page 13.

Table 20 P balance in Rumford mill WWTP after implementing Scenario 3 measures

Stream	Unit	Value	Comments
Influent	lb P/d	218	Assumed 0.55% P of BOD in influent (1)
Nutrient Addition	lb P/d	66	
Excess sludge	lb P/d	-171	Assumed 0.5%P in MLSS (2)
Treated effluent	lb P/d	113	
	mg Tot P/l	0.40	
	mg Susp P/l	0.10	Assumed 20 mg TSS/l avg
	mg Diss P/l	0.30	
Reduction	lb P/d	84	From current situation

1) No actual data available. Estimated based on P balance and data from other mills (0.3 – 0.6%

(2) Optimum level will depend on sludge age and ash content

This measure will not impact effluent BOD.

Assuming an additional 5 hours per week of technician/engineer time would be devoted to monitoring phosphorus addition, the cost would be $12,000/year related to this measure. Assuming that the dosage of phosphorus can be reduced to zero the saving would be approximately $80,000/year. If some phosphorus dosage is still required, then the saving would be less, but still a substantial fraction of this value.

Refer to Table 6 on page 13 for a summary of changes in effluent characteristics that may result from application of the technology discussed here, and the associated costs.

7.2 Rumford Scenario 2

The measures discussed under scenario 1 for spill control, oxygen delignification and upgrading operations in the WWTP are considered to be part of scenario 2 also.

In addition, scenario 2 includes increasing the volume of the aeration tanks in the WWTP by raising the operating level, and internal measures to reduce coating material loss.

7.2.1 Increase operating level of aeration tanks and convert to series operation

At Rumford mill there are two aeration basins operated in parallel. Each basin has a volume of 4.42 MG. With the current MLSS content of approximately 4700 mg/L, the sludge age will be approximately 6 days. The treatment plant must therefore be considered as a highly loaded activated sludge process. Despite the high load, the operators achieve 96% BOD removal, which is very good.

It appears that the level of aeration basin No. 1 could be increased by up to 3 ft, and the flow rearranged so that the aeration basins are operated in series. This would increase the volume of basin No. 1 by nearly 1.0 MG. As a result the, sludge age of the system can be increased by about 1 day. If both aeration basin levels would be increased by 3 ft the average sludge age would be increased by 2 days. Detailed engineering analysis will be required to determine the maximum practical increase in basin depth. Any increase at all will be helpful to the process.

Even if the increase in sludge age seems marginal, the impact on process stability may be considerable, especially in combination with other measures described under Rumford 1 and 2.

Also, the increase of aeration depth will slightly improve the energy efficiency of aerators.

The objective of this measure is to make the process more stable and reduce the solids load on the secondary clarifiers.

The measure will not result in any direct impacts on the BOD of the treated effluent but will likely make the process more stable and improve solids characteristics. The solids load variation on secondary clarifiers will stabilize. Assuming a drop of 0 to 5 mg/L of TSS the impact on phosphorus would be 0 to 6 lb/d

Also, indirectly the measure will impact positively on phosphorus discharge by making the process more stable and thus assist in attaining a lower (or zero) phosphorus addition.

Cost estimate

This is an unconventional measure, to take advantage of a potential opportunity. It is not possible to estimate the capital cost of this measure without detailed engineering analysis. It seems likely that the cost would not exceed a million dollars. A comparable increase in aeration tank volume could be achieved by building an additional aeration tank for around $2 million.

The increased depth will improve aeration energy efficiency by approximately 15% which corresponds to an operating cost saving of $60,000/year.

Reduce incoming ash content to reduce ash in MLSS

At Rumford mill, the ash content of MLSS varies between 35% and 55%. A normal ash content for a relatively young sludge as at Rumford (sludge age 6 days) would typically be less than 10%.

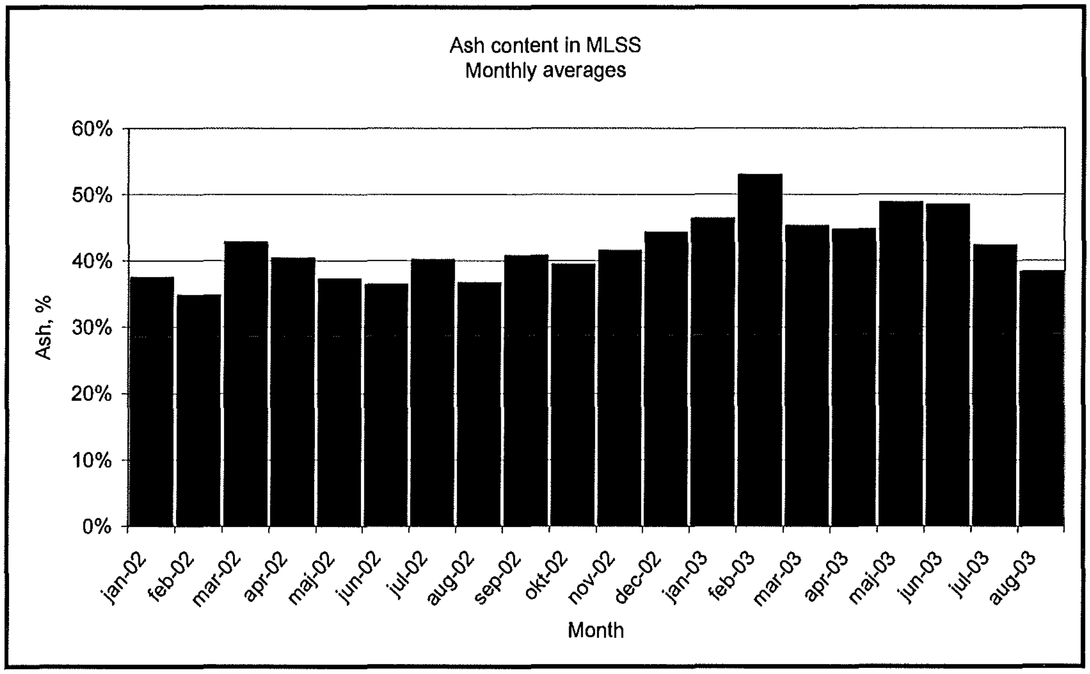

Figure 17 Inorganic content of biomass in Rumford aeration tank

It is clear that there is large amount of dead load circulating in the system occupying valuable volume and creating an unnecessary high solids load on the secondary clarifiers.

The volume occupied by excess ash is estimated to 2.7 MG. If this volume could be used by biomass the actual sludge age could be increased from 6 to 10 days.

It is likely that the ash in the MLSS originates from coating operations at the paper machines. Coating solids are discharged to the sewer at a rate of approximately 10,000 lb/d. This material formulation may be separated from the effluent in a small dedicated treatment system.

Coating formulation or liquid discharges normally include both undiluted coating color from coating kitchen and coater station as well as diluted coating components from washing of machinery. When a system is installed for coating losses, all effluents containing sufficient amounts of coating components are normally collected and treated. There are two basic treatment alternatives; recovery or simply removal of coating components.

In case where coating is recovered, the coating effluent is treated with ultrafiltration, and the permeate is discharged to sewer while the concentrate is recycled to the coating station and added to the coating formulation. There are a few successful reference installatoins in Europe of coating formulation treatment with ultrafiltration. One is at the M-Real mill in Kirkniemi which uses Metso CR filters.

Where the coating effluent is treated without recovery, the material is treated with coagulation, flocculation and sedimentation (typically in a lamella clarifier). The treated effluent is directed to biological treatment plant and settled sludge is dewatered and disposed of by landfill. The UPM-Kymmene, Kaukas in Finland uses this treatment option.

While it is obviously desirable to recover the coating losses for re-use, instead of simple treating them, recovery is not always feasible. Mills did not provide information on the coating process, or the sources of the losses, so the authors cannot suggest the best approach. Recovery of coating losses is a relatively new technique, which appears useful, but requires site-specific study.

In some mills with high coating losses, significant improvement can be attained with improved maintenance and operating techniques. Since the authors did not see the systems in the Androscoggin mills, they cannot assess the degree of improvement attainable.

Estimated impact on effluent discharge

The increased sludge age will reduce BOD of the discharged effluent by approximately 200 lb/d, which is approximately 10% of the current total.

More stable operation will reduce average TSS in effluent by approximately 0 to 5 mg/L which corresponds to a reduction of 0 to 6 lb/d total phosphorus.

Cost of control of coating losses

The cost of a coating treatment system is very much dependent on technology, scope and local circumstances. The EU BAT document presents an estimate of $1.4 to $1.6 million US for a separation system using coagulation, flocculation and sedimentation (without recovery) for 1000 t/d production. The operation cost is given as $75,000 to $150,000/year excluding landfill costs.

A system employing recovery of coating components using ultrafiltration separation costs $0.5 to $1.5 million to treat 50,000 to 100,000 g/day coating formulation. The operating cost will be dependent on to what degree the concentrate can be reused in the coating. In some cases a pay-back time of 1-2 years has been reported.

Refer to Table 6 on page 13 for a summary of changes in effluent characteristics that may result from application of the technology discussed here, and the associated costs.

7.3 Rumford Scenario 3

The measures discussed under scenario 1 for spill control, oxygen delignification and upgrading operations in the WWTP are considered to be part of scenario 3 also.

In addition, scenario 3 includes upgrading the WWTP to state of the art design by installing a new aeration tank, or a suspended biofilm pre-treatment system.

7.3.1 Upgrade WWTP to state-of-the-art design

As in the other two Androscoggin River mills, upgrading the existing WWTP to a state-of-the-art activated sludge system would improve effluent characteristics substantially. In view of the limited space available on the Rumford site, both a conventional approach and a suspended biofilm system are discussed below.

Option A: State-of-art activated sludge treatment plant

At Rumford upgrading of existing treatment plant to state-of-art level as described on page 63 would imply the building of a new aeration tank with new aeration system. The existing aeration tank could possibly be used as an equalization tank. The existing primary clarifiers are up to the standard of a state-of-the-art activated sludge system. The secondary clarifiers are not ideal, but could be used, with improved feed arrangement.

A new 15 MG plug-flow aeration tank and 0.5 MG selector would have to be constructed. The aeration tank should be 33 ft deep with a diffuser system for aeration.

A study by mill staff and Woodard & Curran indicated that space for such a system is available in the location of an unused thermo-mechanical pulp mill near the existing WWTP.

Estimated impact on effluent discharge

The measure will reduce average BOD discharge from the pulp mill by approximately 1000 to 1500 lb/d or 0.5 to 0.75 lb BOD/ton product.

The measure will indirectly impact on phosphorus discharge by making the process more stable and thus enable a lower (or zero) phosphorus addition. The estimated phosphorus discharge is would be below 114 lb P/day, which is about 60% of the current discharge. TSS discharge would be reduced by approximately 5 mg/L

Cost estimate for state-of-the-art AST system

The capital cost of this measure is estimated to be $7 million and includes new aeration tank blasted in rock and lined with "shotcrete" lining, aeration system, piping arrangements, demolition of TMP building, a pump station and other related costs.

A more efficient aeration system together with the reduced BOD load will create estimated savings in energy use of $700,000/year.

Option B: Install biological suspended carrier process as pre-treatment prior to activated sludge treatment

Due to the limited aeration volume available the existing activated sludge process is highly loaded having only about 6 days of sludge age. In order to achieve stable conditions and less BOD and phosphorus discharge, more than 15 days of sludge would be required.

Since limited space is available to increase aeration basin volume, a biological pre-treatment process could be a preferable option. For example, a suspended carrier biofilm process has a potential of reducing up to 60% of influent BOD. The BOD load to the existing activated sludge process would thus be reduced correspondingly and enable operation at about 15 days of sludge age.

A notable benefit of the suspended biofilm process is reduced sludge production (lb biosludge/lb BOD removed). A supplier of such systems claims the sludge production is almost half of conventional activated sludge systems. This process is relatively new to the pulp and paper industry, but reports on its operation known to the authors are favorable. Further investigation would of course be required before selecting this process.

The measure will reduce average BOD discharge to the river by approximately 1000-1500 lb/d or 0.5-0.75 lb BOD/t.

This measure will indirectly impact on phosphorus discharge by making the process more stable and thus enable a lower phosphorus addition. The estimated phosphorus discharge is under 114 lb/day (82 lb/d reduction compared with current) and the average TSS reduction approximately 5 mg/L.

The capital cost of a suspended carrier biofilm process is estimated at about $7.5 million including two reactor tanks (total 2.1 MG), carriers, blowers, piping, etc. The operating cost is estimated at $200,000/year.

Refer to Table 6 on page 13 for a summary of changes in effluent characteristics that may result from application of the technology discussed here, and the associated costs.

8. Opportunities for discharge control at Jay mill

The BOD of the effluent after primary treatment is about average, at 34 lb/ton product, measured at the entrance to the Activated sludge treatment system

This demonstrates that there are opportunities for reducing such discharges, by implementing technologies already common in the industry. .The following is based on information available from the Project XL web site which is maintained by IP, the open literature, and IP submissions to the Gulf Island Pond Stakeholder Process,.

Specific opportunities for effluent reduction within the Jay mill are discussed below.

8.1 Jay Scenario 1

Scenario 1 consists of improving spill control, upgrading operating know-how as discussed on page 51, retrofitting oxygen delignification for the softwood line, and improving the WWTP operations to the extent possible without capital investment.

8.1.1 Spill control and effluent stabilization

Daily measurements of BOD entering the aeration tank at the WWTP in the Jay mill are shown in Figure 18 below.

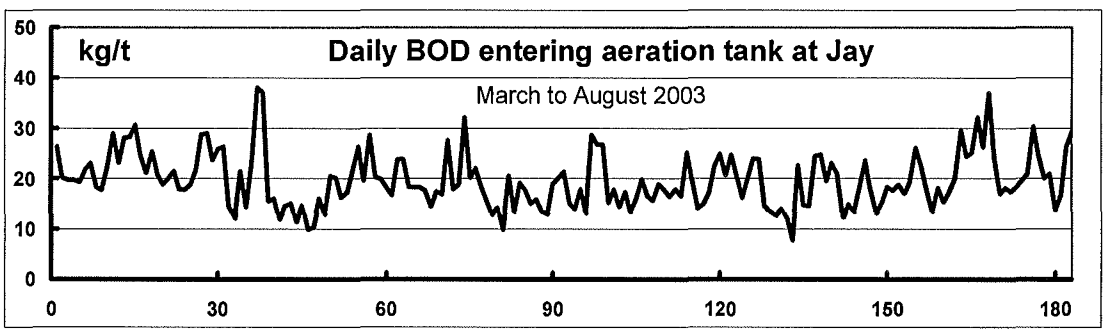

Figure 18 Organic discharge to WWTP in Jay mill

Comparison with Figure 11 and with Figure 12 on page 53 demonstrates that the day-to-day variation in organic discharge is larger at Jay than it could be. The difference in absolute values in not significant, since the organic discharge from the Jay mill is measured in BOD rather than as color.

Mill staff advise that there are spill recovery sumps in all areas handling black liquor, so the Jay mill appears to have similar spill recovery sumps to Mills S and T discussed earlier. As part of project XL, IP have upgraded the spill recovery system, but It is assumed for the purposes of this report that some further upgrading would be required, so an allowance of $50,000 is included in cost estimates. The net operating and maintenance cost for such a system is assumed to be zero, because there is a significant energy, chemical and fiber value in material recovered in a properly designed system.

It is impossible for the authors to determine specific causes for the variation in Jay effluent COD, but it is clear that improvement is attainable by improvement of operator skill, and perhaps some correction of any weaknesses in the spill recovery facilities.

The average of the data in Figure 18 is 20 kg/t pulp (40 lb/t). The graph shows that the mill operated 20% of days with a discharge of BOD below 15 kg/t pulp (30 lb/t), suggesting that the base value with minimal spills is at or below this level. It may be lower, since even the good days probably include minor spills.

This suggests that untreated BOD can be reduced by 10 lb/t pulp, which corresponds to approximately 16,000 lbs/day. This represents approximately 10% of the mill's current untreated BOD load on the WWTP.

In the current treatment plant the reduction in BOD would enable operation at about 2 days higher sludge age. BOD reduction percentage will likely improve by 1-2 percentage points. This corresponds to up to 1,000 lb BOD/d reduction. In addition, reduced variation can be expected in TSS and phosphorus discharges. These improvements are relatively small but noticeable.

8.1.2 Oxygen delignification in softwood line

There is already a partial oxygen delignification system in operation in the softwood line. This could be converted to a modern two stage system for around 70% of the cost of a new system, or approximately $15 million. This would reduce direct operating costs by approximately $7/ton softwood pulp, and, after deducting maintenance and capital costs, would have the net effect of reducing manufacturing costs by approximately $1/ton of softwood pulp, or about 50 cents/ton of total mill product. BOD discharge to the WWTP would be reduced by 8,000 lbs/day.

In the hardwood line, oxygen delignification would have a capital cost of approximately $21 million, and would increase net manufacturing costs by $4/ton hardwood. BOD discharge to the WWTP would be reduced by approximately 4,000 lbs/day.

Assuming OD on the softwood line only the BOD load to treatment would drop by approximately 8,000 lb/d. In the current treatment plant the reduction in BOD would enable operation at about 12 days sludge age instead of the current level of 9 days. BOD reduction percentage will likely improve by about 1-2 %-units. This corresponds to 1,000 lb BOD/d reduction. Considerably less variation can be expected in TSS and phosphorus discharges as well, and the need for polymers in the secondary clarifiers would be reduced or eliminated. The current cost of these chemicals is not known, so there was no attempt made to estimate the potential savings.

The combined impact of all in-mill measures should result in about 375 lb/d less discharge of phosphorus to the treatment plant. This phosphorus removed from the sewer will leave the process with waste sludge, lime mud, dregs and ash. The phosphorus content of the influent wastewater would then be 0.11lb/ton which is a typical level for a pulp and paper mill.

8.1.3 Operations of the WWTP

This scenario involves operator training, improvement of phosphorus control, recovery for phosphorus from the waste fuel incinerator and improvement of the method of introducing the recycled activated sludge to the aeration basin.

Operating crew

To minimize discharges of phosphorus, BOD and TSS, a second operator should be added to the current one-man crew (refer to discussion on page 62).

To upgrade performance of the WWTP, whether in its existing form, or after implementation of equipment upgrades discussed below, or other upgrades, a program for extending effluent control know-how as discussed on page 51 is considered part of option 1.

Optimization of phosphorus control

Apply the phosphorus control approach described on page 33.

Estimated impact on effluent discharge

The potential for phosphorus reduction through phosphorus control is estimated in Table 21 below, for optimal conditions. In the case of Scenarios 1 and 2, part of the benefits of improved control would be realized, as shown on Table 7 on page 15.

Table 21 Future P balance in Jay mill WWTP, after implementing Scenario 1

Stream	Unit	Value	Comments
Influent	lb P/d	233	Assumed 0.55% P of BOD in influent (1)
Nutrient Addition	lb P/d	108	
Excess sludge	lb P/d	-171	Assumed 0.5%P in MLSS (2)
Treated effluent	lb P/d	171	
	mg Tot P/l	0.50	
	mg Susp P/l	0.20	Assumed 40 mg TSS/l avg
	mg Diss P/l	0.30	
Reduction	lb P/d	35	From current situation

(1) No actual data available. Estimated based on data from other mills (0.3 – 0.6%
(2) Optimum level will depend on sludge age and ash content

This measure will not impact effluent BOD.

Cost estimate

Assuming an additional 5 hours per week of technician/engineer time would be devoted to monitoring phosphorus addition, the cost would be $12,000/year.

At present, the mill WWTP operator does not add phosphorus to the WWTP, because of the use of phosphorus chemicals in one of the paper machine coating systems. This is a rather unusual practice, and can presumably be avoided by chemical substitution. There is no cost assigned to the modification, since many other mills find that it is cost effective to operate with other chemicals, and IP did not provide any data to support the use of such a substance that increases phosphorus discharge.

Once the paper coating issue is resolved, any dosage of phosphorus can potentially be avoided. Saving cannot be predicted at the time of writing.

Refer to Table 7 on page 15 for a summary of changes in effluent characteristics that may result from application of the technology discussed here, and the associated costs.

8.2 Jay Scenario 2

The measures discussed under scenario 1 for spill control, oxygen delignification and upgrading operations in the WWTP are considered to be part of scenario 2 also.

In addition, scenario 2 includes upgrading the aeration tank of the WWTP to reduce its volume, remove at least some of the biological sediment, remove abandoned equipment and convert it to plug flow.

8.2.1 Upgrade WWTP

Upgrading of aeration basin to improve aeration and flow pattern

The existing aeration basin has a volume of about 200 MG of which approximately 75% is filled with sediments. The volume available to the biological process is thus about 32 MG. The basin, originally built as an aerated stabilization basin, is a more or less a completely mixed system with regard to flow patterns. The risk for short circuiting is obvious. Aeration is carried out with floating aerators. A few mixers have been installed to improve mixing conditions. **The settled sludge (about 170 MG) is most probably causing periodic release of phosphorus, and makes it virtually impossible to attain stable, efficient operation.**

In order to improve efficiency of the existing basin the following measures are recommended:

- Build flow diversion berms out of "ashcrete[11]" to make the flow pattern close to plug-flow and to optimize aeration volume
- Remove any sediments of biological sludge by dredging the active volume
- Remove all of the non-operable aerators from the basin
- Rearrange the working aerators to ensure sufficient aeration and mixing in all parts of the basin
- Restrict use of polymers at secondary clarifier to emergency situations only
- Study operations in other companies to develop operating techniques to avoid use of polymers in the secondary clarifiers.

To achieve stable process conditions at least 15 days of sludge age is recommended. Assuming a MLSS of 3000 mg/L, the necessary volume with current influent loads would be about 35 MG.

Estimated impact on effluent discharge

As a result of aeration tank upgrading the following performance figures would be expected:

- BOD removal of 97% which represents a reduction of 1000 lb/d, or 0.6 lb/t
- About 30 mg/L TSS or less in final effluent
- A reduction of total phosphorus in final effluent by approximately 90 lb/d
- Reduction or elimination of the use of polymers in the secondary clarifiers.

Cost estimate

The capital cost is estimated at $2 million including dredging of aeration basin to remove the biosoldis, "ashcrete" filling and aerator rearrangements.

[11] The Jay mill presently has a program, to use "ashcrete" the by product for solid waste incineration and an off-site cement kilns, to reduce the volume of the aeration tank. This material appears suitable for building dividing finger berms to channel the effluent flow, while the basin is in operation.

There would be a considerable reduction in operating cost, since the use of polymers in the secondary clarifiers would be reduced or probably eliminated.

8.3 Jay Scenario 3

The measures discussed under scenario 1 for spill control, oxygen delignification and upgrading operations in the WWTP are considered to be part of scenario 2 also. In addition, scenario 2 would involve upgrading the WWTP to state-of-the-art design.

8.3.1 Upgrade WWTP to state-of-the-art design

As in the other two Androscoggin River mills, upgrading the existing WWTP to a state-of-the-art activated sludge system would improve effluent characteristics substantially.

At the Jay pulp and paper mill the upgrading of existing treatment plant to state-of-art level would imply the building of a new aeration tank with a new aeration system. A part of the existing aeration tank could possibly be used as an equalization basin.

The 45 MG aeration tank would be constructed as a 33 ft deep tank with selector and plug flow mode. The tank would be equipped with a diffuser aeration system.

The existing primary and secondary clarifiers are adequately sized, even for the current relatively high flows.

Estimated impact on effluent discharge

This measure alone will reduce average BOD discharge by approximately 1500 lb/d

The measure alone will indirectly impact on phosphorus discharge by making the process more stable and thus enable lower phosphorus addition. The estimated phosphorus discharge reduction is about 65 lb/day.

Cost estimate

The capital cost of this measure is estimated to be. $11 million and includes new aeration tank, aeration system, piping arrangements and other related costs.

A more efficient aeration system and lower influent BOD load will create savings in energy use estimated at $400,000/year, and the cost of polymers in the secondary clarifiers would be eliminated.

8.3.2 Elimination of use of phosphoric acid in paper making

At the time of writing, one paper machine was using phosphorus containing chemicals for paper manufacture, which causes a relatively large phosphorus discharge. This is unusual in the industry. Since competitive companies operate without this material in the paper mill, and there was no information presented to support its use, it is assumed that the phosphorus can be replaced by more conventional chemicals.

8.3.3 Internal treatment of coating losses

The coating losses in the Jay mill are unknown. Data presented on MLSS in the WWTP at the time of the authors' visit to the mill in November 2003 were not credible, since they included many values where the inorganic fraction exceeds 100%. Mill staff have not offered any explanation at the time of writing.

If the losses are high, as seems likely from review of project XL data, then coating loss control measures similar to those discussed above for the Rumford mil may be useful, and perhaps even profitable.

8.3.4 Removal of phosphorus from Waste Fuel Incinerator scrubber effluent

The Waste Fuel incinerator at the mill is equipped with a wet scrubber, which discharges to the WWTP. Approximately 20% of the phosphorus in the untreated waste is from this source. If the mill is successful in eliminating addition of phosphorus to the WWTP, but the quantity of phosphorus discharges still exceeds that considered acceptable, it may be necessary to replace the scrubber with an electrostatic precipitator, or treat this waste stream with lime to precipitate the phosphorus. Since this is only a possibility for the future, no cost allowances are included.

Refer to Table 7 on page 15 for a summary of changes in effluent characteristics that may result from application of the technology discussed here, and the associated costs.

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Spill Recovery

The articles on the following pages discuss spill control technology, as it could be used in the Androscoggin River mills

PRACTICAL SOLUTIONS

Water Treatment

Neil McCubbin, N. McCubbin Consultants Inc.; neil@mccubbin.ca

Spill control: Assessing your situation

Good spill control can help curb costs and calm public perceptions. Specific conductivity is the most successful parameter for monitoring black liquor spills.

Editor's Note: This is the first part of a two-part article. The second part will appear in a future issue of Solutions!

In most mills, improved control of spills of black liquor, white liquor, green liquor and paper coatings is the most cost-effective approach to reducing effluent discharges and lowering wastewater treatment system (WWTS) operating costs. Capital costs are generally low (from trivial up to a few hundred thousand dollars). Spill control operating costs are normally modest.

All mills discharge certain liquid effluents to remove substances that cannot be tolerated in the product, or in the recovery boiler in the case of kraft mills. These include cooling water, boiler blow down, bleach plant filtrates and many more. Other planned discharges, such as filtrates from brown stock screening, wet debarker effluent, and acid wastes from chlorine dioxide generation, can be eliminated by use of suitable equipment.

Planned discharges are generally predictable, and can be established quite accurately by a mass balance, particularly if modern process simulation tools are used. Some unplanned discharges are inevitable, however, and are usually contained by mill safety systems. These "spills" include leaks, off-spec product dumps, tank overflows, and equipment drainage prior to shutdown.

Unplanned discharges typically have a greater impact on WWTS costs and on public opinion than do planned discharges. In a modern mill with closed screening, oxygen delignification, ECF bleaching, condensate stripping, and a good WWTS, spills can cause up to half the color in the final discharge, and up to one-third of the operating costs of the treatment plant. Reducing spills will often allow a mill expansion without also expanding the WWTS, or having to apply for a modification to the effluent discharge permit.

Neil McCubbin is president, N. McCubbin Consultants Inc., Foster, Quebec, Canada. Reach him at neil@mccubbin.ca

U.S. RULES

The Cluster Rule promulgated by the U.S. Environmental Protection Agency (EPA) in 1998 includes requirements for mills to implement "best management practices" plans (BMP). These, in effect, are spill control systems for black liquor. The essence of the rule is that mills must record variability of effluent before treatment and take corrective action to reduce peaks. The rule leaves decisions on control criteria to mill management. It is worded in such a way that imaginative statisticians could derive BMP plans that comply with the law without improving effluent characteristics. Such plans become merely a paperwork burden on mill staff, with no benefits.

Most U.S. mills are actively working on compliance with the spirit as well as the letter of BMP rules. While such projects almost always improve spill control, compliance with EPA guidelines alone does not guarantee optimal spill control.

WHAT TO MEASURE?

The prime target for most spill control programs is black liquor. Other substances, such as soap and turpentine, are a concern because they can cause catastrophic spills that drastically reduce the performance of the biological section of the WWTS. That is normally avoided by total closure in the same way as bunker C oil spills are prevented from reaching the receiving waters.

Specific conductivity is the most successful parameter in current use for continuous monitoring for black liquor spills is. It will also detect spills of white and green liquor, and usually soap (because some black liquor normally travels with soap). Conductivity measurements will not detect paper coatings or turpentine.

Most other parameters that may appear to be of interest suffer from cost or maintenance complexity of the sensors (for example total organic carbon, immediate BOD, color, and sodium).

Spills have to be monitored instantaneously by conductivity or other continuous

This is one of a series of columns prepared by the Bleaching Committee of TAPPI's Pulp Manufacturing Division. For more information on TAPPI's next Process Closure Course, contact Tony Johnson by email at ajohnson@beca.co.nz or Neil McCubbin at Neil@McCubbin.ca sensor, at multiple points, to initiate appropriate corrective responses. A longer-term assessment is also useful, particularly to benchmark your mill against other mills. COD and color are useful for such assessments.

Most mills consider that an effluent stream should be pumped back to the black liquor system when the conductivity exceeds 5000 micromhos/cm (µmhos). This corresponds to a black liquor concentration of about 0.5%. Some mills have set points for recovery as low as 2500 µmhos. You should determine and correct the causes of the high conductivity whenever possible.

PRACTICAL EXAMPLE

The three graphs at right (**Figure 1**) represent six months of daily color flows for three mills, expressed as kilograms of color per average ton of pulp production at the influent to the WWTS. The mills are similar. The principal difference is the execution of the spill control programs. All mills have two fiber lines. The mills have paper machines built before 1940 and are located on severely restricted sites with far from optimal layout of the equipment and sewer systems. All three mills have complete coverage with spill recovery sumps, and a number of conductivity monitors with data display and alarms on the operator's control panels. Management at all three mills believe they have excellent control of spills. In the author's view, the performance of the systems shown ranges from average to excellent.

Clearly the staff at mill S are the most effective at controlling spills. The data in **Table 1** show that their color discharge is also lowest. (In all cases the color in the treated effluent is about 30% lower.)

Table 1 also shows that the data underlying the "better looking" graphs exhibit lower coefficients of variance (CoV), but the reader is cautioned against making a simple assumption that this value is a good measure of spill control. One major spill in a year would raise the CoV for mill S to well above the others, but it would still be a mill with excellent performance. Spectacular spills are normally due to known events that mills learn not to repeat.

	Mill S	Mill C	Mill L
Mean color discharge, kg/ton*	39	52	59
Standard deviation	6	19	25
Coefficient of variance	15%	36%	42%

*"kg/ton" refers to kilograms of color measured each day divided by the mill's average production rate, both measured over a six month period in 2000.

Table 1: Statistical summary of color discharges at entry to WWTS

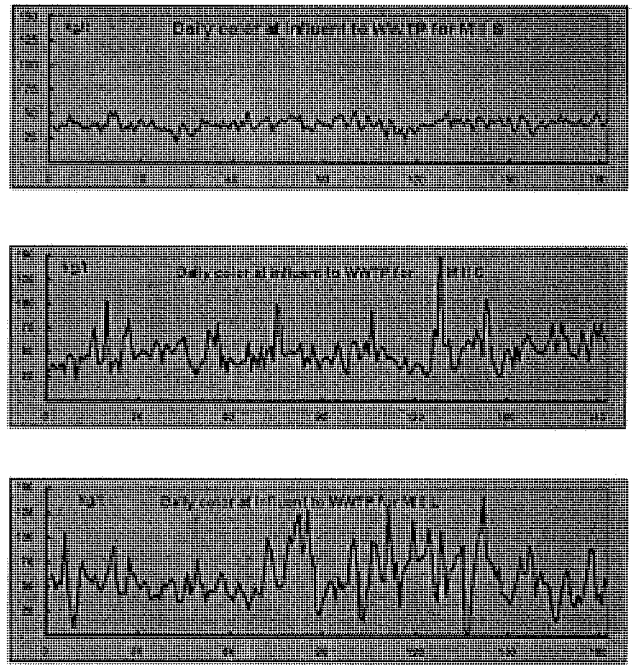

Figure 1: Daily color flow for three different mills

The CoV is also misleading in a mill with high constant losses due to poor brown stock washing or other reasons, since a very poor spill control system is masked.

WHAT IS "GOOD" SPILL CONTROL?

At first sight, it seems obvious that a statistically based measure could be used to assess effluent data from departments or entering the mill's WWTS and provide a barometer of the effectiveness of spill control. However, nobody has yet developed a practical tool for this. *NCASI bulletin 805*, published in May 2000, provides an indication of the complexity of the issue, but is oriented towards assessing compliance with EPA regulations, rather than to optimal reduction of spills.

Low discharge of color or COD is generally indicative of good spill control, partly because mills with aggressive spill control systems usually also have tight control of planned discharges. For mills with oxygen delignification, discharges, before treatment, below about 40 kg color/ton or 30 kg COD/ton, suggest good control. If the mill does not have oxygen delignification, then both values would be about 10 kg/ton higher. These are only rough rules-of-thumb, since COD and color discharges depend on several aspects of mill operation. **S!**

PRACTICAL SOLUTIONS

Water Treatment

Neil McCubbin, N. McCubbin Consultants Inc.; neil@mccubbin.ca

Spill control, Part II: Reducing spills

When it comes to spill control, prevention is better than cure. A well-trained operating staff offers the best defense against spill problems.

Editor's Note: This is the second part of a two-part article; the first appeared in November's issue.

The previous article in this series discussed the background to spill control, and provided some guidelines on assessing you own mill's performance. This month we will look at ways of reducing spills.

First and foremost, prevention is always better than cure. Appropriate instrumentation is important, but the key is the knowledge and motivation of the mill staff, particularly at the level of operators and maintenance tradesmen. The principal difference between the three mills in **Figure 1 and Table 1** is operator skill and attitude.

Since prevention is never completely effective, spill recovery sumps with automatic activation are required in critical areas. Simple, single line mills typically require 3 to 6 sumps, though some mils require a dozen or so. Actual requirements are very site specific, and usually involve some compromise between the ideal configuration and the costs of retrofitting.

TRAINING

Most mill personnel, particularly at the level of operator/maintenance trade level, have only a hazy idea of what is important in spill prevention and control. Once made aware of the type and size of spills that are significant, many are extremely resourceful in developing improved operating techniques to reduce the frequency and magnitude of the spills.

Training programs should be tailored to the mill's specific systems, and to the level of knowledge of the personnel. Training should explain the key parameters, and how the department worked in affects the effluent discharge. Each piece of equipment or operating procedure that can generate spills should be identified and explained, and corrective action defined. In all cases, training should encourage feedback from operators and maintenance people, since they know many local details well.

A good spill control systems provides operators with continuous, rapidly updated, data on key factors of plant operation. Operators must understand these data, be able to diagnose causes, and take corrective action. Initial training requires several hours of class time for each student, with a couple of hours refresher each year for most operators and maintenance personnel.

Continuous feedback helps workers learn from mistakes. Mills where spills are controlled successfully normally have a report of all major incidents at daily production meetings, and advise all operators in relevant departments about what happened and how to avoid repeat incidents.

INSTRUMENTATION

Much of the data required is the same as is needed to run an efficient plant; but additional information-including levels of all major tanks and equipment, overflow alarms and conductivity in individual floor drains-is also required.

Mills should continuously measure conductivity in each operating area of interest. Locations should be selected so that they will serve to locate spills in a reasonably small area (such as an evaporator set or the digester department) all under the control of one operator. Sensors should not be located where false positives will occur, such as when an ion-exchange water treatment system is regenerated with caustic. If this is unavoidable, operators must be trained to interpret the data.

Where tank overflows are a problem, an overflow detector is useful. Some mills monitor temperature in the overflow pipe, since this will detect foam overflows that fail to show on the tank level monitor.

Neil McCubbin is president, N. McCubbin Consultants Inc., Foster, Quebec, Canada. Reach him at: neil@mccubbin.ca

LEARN MORE!

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Data must be immediately available to the operators who control the system. In mills with modern distributed control systems, it is best to make the values available on the mill's data bus so that environmental staff, supervisors, and management can also review the data on their desktop computers. In a simple, single line mill, half a dozen conductivity monitors are normally appropriate; a very complex mill may require up to about 30.

RECOVERY SUMPS

To recover spills while corrective action is being taken, the normal approach is to install sumps in the mill's floor drains equipped with pumps that start automatically on high conductivity, and pump the contents of the floor drain to either the weak black liquor storage tank or to the blow tank, depending on whether there is likely to be fiber present in the recovered liquor or not.

There are no rational design criteria for sizing these sumps and pumps, which leads to some rather bizarre designs. Mills build sumps of varying sizes, and some are as large as 20-ft by 20-ft, with a depth of 6 feet or more, and two continuous duty vertical pumps. This is not necessary. Successful spill recovery systems often have sumps as small as 4-ft square, a couple of feet deeper than the floor drain they are installed in, and one submersible or light-duty vertical pump.

AVOIDING CONTAMINATION

Water is a major enemy of spill control systems, and is actually a contaminant, since it dilutes the spill, perhaps preventing cost effective recovery. Many mills make the mistake of arranging systems to recover every drip in the areas of concern. Unfortunately, this leads to dilution of the spills so that the many small events pass unnoticed; the dilution of larger spills causes unnecessary loads on evaporators, and perhaps even failure of the system.

Continuous clean water discharges must be kept separate from the floor drains in the areas protected by spill recovery. Some mills run a stainless or plastic pipe as a clean sewer down existing floor drains, so that they can maintain gravity flow. **S!**

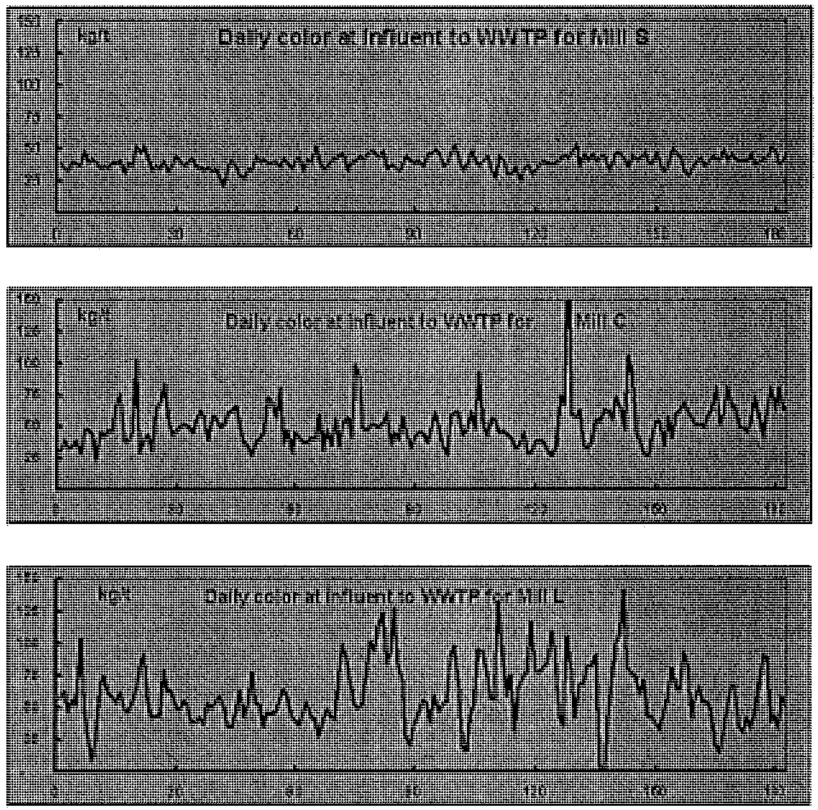

Figure 1 (above): Daily color flow for three different mills. Clearly, the staff at Mill S is the most effective at controlling spills. Effective training and a proactive operator attitude are responsible for much of the improvement.

Table 1 (below): Statistical summary of color discharges at entry to waste water system, showing that Mill S also has the lowest color discharge. The data underlying the "better looking" results in Figure 1 exhibit lower coefficients of variance, but the reader is cautioned against making a simple assumption that this value is a good measure of spill control.

	Mill S	Mill C	Mill L
Mean color discharge, kg/ton	39	52	59
Standard deviation	6	19	25
Coefficient of variance	15%	33%	42%

"kg/ton" refers to kilograms of color measured each day divided by the mill's average production rate, both measured over a six month period in 2000.

Unit conversion factors

Most units in this report are stated in the traditional US system, but some data are presented in the Système International (SI).

Conversion factors between traditional and SI units are shown on the following page.

CONVERSION FACTORS

1 kg (kilogram)	= 2.205 pounds (lb.)	[lb x 0.4536 = kg]
1 t (ton)	= 1.102 short (US) tons	[s. tons x 0.9072 = tons]
1 ADt	= 0.9 oven dry tons pulp	
1 m (metre)	= 3.281 feet	[feet x 0.3048 = m]
1 km (kilometre)	= 0.6214 miles	[miles x 1.609 = km]
1 hectare	= 2.471 acres	[acres x 0.4047 = hectares]
1 km^2	= 100 hectares	
1 km^2	= 0.3861 square miles	[sq. mi. x 2.590 = km^2]
1 L (liter) of water	= approx. 1 kg	
1 m^3 of water	= 1000 L	= approx. 1 ton
	= 35.31 cubic feet	[cubic feet x 0.02832 = m^3]
	= 220.0 Imp. gal.	[Imp. gal. x 0.004546 = m^{3}]
	= 264.2 US gal.	[US gal. x 0.003785 = m^3]
1 m^3/t	= 239.7 US gal./short ton	[1000 gal/ton x 4.171 = m^3/t]
1 kg/ton	= 2 lb/short ton	[lb/ton x 0.5000 = kg/t]

Fractional Units

1 ton	(metric ton)	= 10^6 g	= 1000 kg
1 kg	(kilogram)	= 10^3 g	= 1000 g
1 g	(gram)	= 1 g	= 1000 mg
1 mg	(milligram)	= 10^{-3} g	= 1000 µg
1 µg	(microgram)	= 10^{-6} g	= 1000 ng
1 ng	(nanogram)	= 10^{-9} g	= 1000 pg
1 pg	(picogram)	= 10^{-12} g	= 1000 fg
1 fg	(femtogram)	= 10^{-15} g	= 1000 ag
1 ag	(attogram)	= 10^{-18} g	

Approximate Equivalents

1 g/L	= 1 g/kg	= 10^{-3} g/g	= "1 part per thousand"	
1 mg/L	= 1 mg/kg	= 10^{-6} g/g	= "1 part per million"	ppm
1 µg/L	= 1 µg/kg	= 10^{-9} g/g	= "1 part per billion"	ppb
1 ng/L	= 1 ng/kg	= 10^{-12} g/g	= "1 part per trillion"	ppt
1 pg/L	= 1 pg/kg	= 10^{-15} g/g	= "1 part per quadrillion"	ppq