CONTROLLING LOG DEBRIS IN THE FRASER RIVER

by

JAMES RICHARD HUGHES

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Department of Community & Regional Planning

The University of British Columbia
2075 Wesbrook Place
Vancouver, Canada
V6T 1W5

Date April 28/77
ABSTRACT

Every year about 9 million m$^3$ of logs are transported for processing, to the Lower Fraser River in British Columbia. During the transportation and handling about 3% of these logs escape from their booms, from the sorting grounds or from the mill ponds. These escaped logs represent over 75% of the debris coming from the river, and account for about 8.8 million dollars of clean-up, salvage, log loss and boat and property damage costs. There are also other social and environmental costs that are not easy to calculate, but which may be high. The purpose of this research is to determine a pricing and regulation policy which would control log loss to the extent that total social costs would be minimized.

Hemlock logs are a particular problem because they have a high density and escape relatively easily from log rafts. It is found that the most cost effective means of reducing the total social costs of escaped logs would be to handle all hemlock logs, and a portion of the other logs, in a manner such that single logs cannot escape. These logs should be sorted and bundled on land at the logging operation, transported in bundle booms to the mill and bundles should then be opened only on mill decks. The costs of dryland bundling and of mill up-grading to accept bundles is determined. These costs together with the costs mentioned above, are calculated as a function of the
volume of timber bundled. A social least-cost point is calculated and a socially optimal level of implementation for the control scheme is derived. Finally, the pricing and regulation policy options that could be applied to achieve the desired level of hemlock bundling are considered. It is concluded that to institute a pricing policy which allows individual mills to choose which means of log transport and handling they will use, but obliges them to meet the social costs of escaped logs due to their decision, is feasible and in the interests of the forest products industry and of society as a whole.
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A note of thanks should also be given to all those who took the time to provide the information which was needed in order to complete the necessary research. It would not be possible to list all those who helped in some way, but two persons, Wally Bowden of the Council of Forest Industries and Ken Boyd of MacMillan Bloedel deserve recognition for their most valuable assistance.
I INTRODUCTION

Wood debris has always been a natural component of the Fraser River system in British Columbia, but in recent times man's activities, including logging, have created additional sources of wood debris. For example, large volumes of debris are being generated by the use of the Fraser River for the transportation, storage and processing of timber. The volume of wood debris from these unnatural sources is now ten times as great as the volume of natural debris. The presence of this debris in the waters of the Fraser and ultimately in the Strait of Georgia interferes with shipping and pleasure boating by causing considerable damage to boats. Also significant clean-up and control costs are sustained by various users and jurisdictional bodies on the river, and various environmental 'costs', such as decreased oxygen levels in the river, may be caused by the debris.

Every year about 9 million m$^3$ of timber is brought to the Fraser for processing. At present around 60% of this wood is bundled, yet 3% of the total volume is escaping from the mill ponds, from the sorting grounds around Vancouver and from the flat rafted booms. These escaped logs result in costs of no less than 8.8 million dollars. The forest industry spends 4.4 million dollars for log recovery and loses at least 3 million dollars worth of logs annually. Also society bears costs of
around $300,000 for beach clean-up and for sweeping log debris from harbours and bays, and 1.1 million dollars in boat and property damage. There are believed to be other unquantified social and environmental costs which are not included in the above cost estimate. It is therefore evident that log debris results in substantial costs; these costs are unnecessary and are reduceable.

Hemlock accounts for half of the timber processed on the Fraser, yet escaped hemlock is responsible for just over 7 million dollars or 71% of the total cost to the forest industry and to society. Hemlock logs are a particular problem because of their high density which enables them to escape relatively easily from flat rafts. Also hemlock logs on the bottom of log bundles absorb a lot of water and will often escape from the mill ponds into the river. These logs are usually low floating and are particularly hazardous to boats in the river and Strait of Georgia because they float at the interface between the salt water and the lower density fresh water, and are very difficult to see.

In this report it is suggested that control measures should be implemented to control log escape. With the primary measure being the bundling of all hemlock. It is also suggested that logs should be controlled further by dryland sorting and by providing bundle lifting equipment at the mills so that bundles
would only be broken open on the mill deck. These measures would ensure that no individual logs would be able to float free in the water at any time during transportation and handling. To undertake the control of all logs would cost over 12 million dollars, but to control all hemlock would cost under 7 million dollars. Preventing the escape of all logs would not be socially optimal. But it would be near optimal, to control the escape of hemlock, since the costs of the proposed control program would be less than the benefits which would be obtained if no hemlock logs were escaping.

In chapter V these various costs are used to derive a social total-cost curve. From this curve is calculated a social least-cost point which indicates that 72% of all timber should be controlled in some manner, and that all hemlock and 44% of the other species should be controlled. If the environmental costs and the unquantified social costs not including boat damage, are less than about 1.1 million dollars the cheapest effective control measure would be dryland sorting/bundling. However if these costs are above 1.1 million dollars, it becomes socially cost-effective to include bundle lifting equipment at the mills.

At present the forest industry is finding that by undertaking a dryland sorting/bundling program they will be able to reduce operating expenses. It appears that the industry will
be reaching the optimal level of bundling in the near future. However this program will be only partially successful in reducing log escape. If environmental and unquantified social costs are high it would be necessary for the forest industry to undertake mill up-grading in order to reduce log escape from the mill ponds. But there is not an economic incentive for them to implement such a control measure. It would therefore be necessary for an administrative body to intercede and encourage the forest industry to control log escape and to internalize the costs which they are inflicting upon society.

This study is concluded with a comparison of three administrative measures; self-regulation, legal enforcement and a charge system. And it is shown that a charge system would be relatively easy to implement for controlling log escape on the Fraser. Log recovery presently is handled by a cooperative association consisting of salvagers and the forest companies. A charge based on the volume of recovered logs belonging to each company would likely be an effective means for inducing companies to reduce log escape. It is found that a charge of approximately 20% of the present recovery cost would induce the firms on the Fraser to adopt methods of log handling and transportation which would minimize the external costs to society, escaped logs.
Debris: Types

In the Fraser there are different types of debris causing different kinds of problems. But as well as the various problems associated with each debris type, there are different means available for dealing with each type of debris in order to either prevent its generation or to remove it. Thus it is useful and often necessary to know the source and nature of the debris in order to understand the range of the problems which will arise, and also to implement a means of control.

Although it is not very often possible, it is useful to know certain things about a particular debris accumulation that is under consideration, in order to determine the problems which are associated with that debris. The useful information includes the average size, shape and condition and also the source, volume and species mix of the debris accumulation.\(^1\) Since most of this specific information is lacking attempts at defining simple classification systems, of the various types of debris, have been made.\(^2\) One simple system for debris classification, which will be used for the remainder of this report, has the following categories:

1) natural debris;

2) floating logs, low-floaters, dead-heads;
3) logging waste (eg. slash, bark, and small trees);
4) sawmill waste (eg. ends, bark and splintered wood);
5) construction waste (eg. beams, planks and pier timbers);
6) dunnage (waste from shipping, eg. crates);
7) miscellaneous (eg. floats freed by floods).

Some types of debris cause more problems and result in greater damage and costs than do other types. Low-floaters, for example, though at times less prevalent than some kinds of natural debris may cause greater damage to boats due to their low visibility. Generally the first four types of debris in the above list are the most common, causing the most problems and resulting in the greatest costs. But in certain areas and at certain times the last three may cause greater problems, resulting in serious damage and various costs.

A. Natural Debris

About 150 kms east of Vancouver is the Stein River, (see Figure 1). The watershed of this river is an unlogged preserve in the natural state for over 130 kms. Yet even in this pristine environment the amount of debris which has accumulated is reported to be quite high. The Skwawka River watershed area, above Queens Reach, is a similar area in the natural state. In this area also there are reported to be large
accumulations of debris. It seems evident that since man's activities play an insignificant role in the generation of present debris volumes in these watershed areas, there are important natural forces which cause the generation of the large amounts of debris which is to be found along the banks and sandbars or floating in the water of a river.

Two large contributors to the volume of natural debris are erosion and landslides. But other natural factors such as age, wind, flood, fire (caused by lightning), snow, ice, insects and fungi all contribute to the death of trees and bushes. Some of this dead material is inevitably washed into rivers during periods of high run-off.

B. Logs

Logs which escape due to poor handling at the log sorting and storage grounds and at the mills, during transport, or because of boom break-up due to bad weather or accidents also add a significant amount of debris to the total amount generated in the Fraser River or in nearby water bodies. Although most of these logs are of commercial value and are quickly recovered they are free in the water often for many hours or even days, and during that time are part of the total volume of debris. Of concern also are those logs which escape but due to their low commercial value are rejected by log salvagers and remain in the
water until they are either collected by patrol vessels, sink or are washed ashore or out into Georgia Strait, where they remain a problem.

Some of the reasons for logs escaping from flat rafts in the Fraser River, as elsewhere, are: 1) when booms are brought into the fresher water of the Fraser from the salt water of the Strait, the more dense logs often float lower than more buoyant boomsticks, or high floating logs escape over low floating boomsticks; 2) storms, strong currents and wash from passing boats can shake logs free from booms both while in transit and while they are tied-up; 3) high towing speeds, quick starts and stops and fast turns can also cause logs to escape; 4) poor tie-up, especially in tidal areas where booms can be partially grounded and careless boom construction can subject booms to wash and to tidal and current pressures and can result in logs escaping or in a break-up of the entire boom, logs can also escape through gaps between the boomsticks in poorly constructed booms; 5) when logs remain in the water for long periods they absorb water and become less buoyant, this is particularly the case with logs which are on the bottom of bundles or are on the bottom of a barge-dumped piles, which remain in a tangled heap. When the bundles or piles are broken apart in the water, the heavier logs will often escape under the mill pond retaining boomsticks.
Figure 2: MAJOR LOG HOLDING GROUNDS
Hemlock logs have generally a greater chance, than other kinds of logs, of escaping from booms for any reason. This propensity to escape is due primarily to two factors: 1) hemlock logs are often splintered, rotten and hollow in the core or punky; and 2) small and second-growth hemlock logs have a density which is very near the density of water. Many of the hemlock logs which escape become low-floaters or dead-heads.

C. Other Debris

In addition to the escape of commercially valuable logs, small, rotten and badly weathered logs; bark, slash sawn ends and splintered wood are produced by the log milling operations. Little of this mill debris is generated in open waters. On the other hand significant accumulations of mill debris occur in rivers, bays and inlets, from generation at log dumping and sorting grounds and at mill log-ponds.

Debris: Volumes

In an earlier paragraph the natural river areas of the Stein and Skwawka were mentioned. The debris on these rivers is almost entirely the result of natural forces. Whereas in contrast, it has been found that in B.C. watersheds, where man carries on his activities, the percentage of natural debris drops from near 100% for the virgin areas to an average of
Debris studies undertaken at the Mission Bridge on the Fraser river, a river intensely used by man, have shown that the debris which is the result of natural causes dropped to a low of 32% during 1972. The average yearly percentage of natural debris passing into the lower portions of the Fraser, over the past five years, has been around 40%.

The relative percentages of both natural and manmade debris vary considerably from year to year. With respect to natural debris, there exists a definite correlation between the water level, resulting from increased or decreased runoff, and the volume of natural debris which is flowing in the river. A large portion of the natural debris, probably over half, comes from the Fraser freshet which usually occurs during the months of May and June. The amount of manmade debris is also affected by the prevailing weather conditions since a large portion of the slash and other debris will often be left on the land or be beached, and will not be washed off until there is a very high tide, a flood, or increased run-off. Other factors including the level of activity at the mills will affect the total volume and relative percentages of debris on the river. Debris generation will obviously vary greatly on a day to day, month to month and year to year basis. Equally the respective sizes, shapes and types of material are going to fluctuate in accord with the various conditions affecting debris generation and flow rates. Therefore it must be understood that the average rates
of debris flow used in this study do not describe the volume of debris that can be expected on any particular day.

Studies of debris on the Fraser River from 1971 through 1974, have estimated that the average yearly flow of debris which passes under the Mission Bridge, from upstream sources, is around 57 thousand m$^3$. Of this total, 23 thousand m$^3$ (40%) is believed to be natural and 34 thousand m$^3$ (60%) manmade. Of the debris passing under the Mission Bridge 17 thousand m$^3$ (30% of the total debris) was determined to be logging and mill waste, 16 thousand m$^3$ (28%) was found to be saw and pulp logs and another 1 thousand m$^3$ (2%) was lumber and industrial waste. In comparison, a similar study of debris in most of the major lakes and streams in British Columbia has determined that 43% of the debris was man made, and of the total debris 20% was the result of logging activities and consisted of logging and mill wastes. Another 20% was found to consist primarily of sawn logs which escaped from storage or dumping grounds and from rafts, and a final 3% was generated by other human activity.

The results from the Fraser River studies are comparable with the findings of the broader B.C. study. The relative percentages of each type of manmade debris are in approximately the same proportion in both studies. The proportions are somewhat higher in the Fraser River as would be expected. On the Fraser there is probably more of man's activities including
log handling and mill operations, which would generate debris, than on any other B.C. river or lake.

The volume of debris which flows down the river is large, but the volume which is added in the lower Fraser, in the vicinity of Vancouver is much greater. In addition to the debris which arrives from up river there are two other major sources of debris. One of these is the debris generated by the mills which line the banks of the river and the other is the escaped logs which originate from the log transportation and storage operations in the estuary and the lower reaches of the Fraser, which include large volumes of logs brought into the river from points outside the Fraser watershed.

To consider these other sources of debris it is useful to note that 9 million $m^3$ of timber per year is being transported through the mouth of the river, to mills on the lower Fraser. This is an average, considering that the volume of logs arriving in the river depends to a great extent on the state of the timber market. The amount of timber going to the North Arm and into the Main Channel is about the same, with each receiving approximately half of the total. Of the total amount of timber arriving, one half or 4.5 million $m^3$ is hemlock, approximately one quarter is fir and pine and the remaining quarter consists of other species such as cedar, cyprus, spruce and balsam. The number of logs which escape and become uncontrolled and the
amount of debris which is generated by the mills, appears to be related to the total volume of logs being processed.27

There is approximately .5 m³ of mill debris produced per 100 m³ of timber processed;28 therefore in the lower Fraser it is expected that during a year approximately 45 thousand m³ of debris will be produced by the forest industry. This is in agreement with the figures obtained from the N.F.H.C. (North Fraser Harbour Commision). They state that they presently deal with, on average, 23 thousand m³ per year.29 This debris is contained in bag-booms30 and is burned. It is believed that since the mills on the Main Arm handle a similar amount of raw timber they also generate a similar amount of debris, but this debris is set free in the river and is not contained.31

Various studies indicate that the mean of the rate of log escape for all species is around 3%, although the rate has been determined, from estimates cited in the literature, to range anywhere from .2% to 12%, depending on the the species and on a number of factors such as: 1) the means of transportation: barge, flat raft or bundle boom; 2) towing methods; 3) the method of sorting: dry land or water; 4) the type of storage: dry land or water; 5) the length of time logs remain in the water; 6) prevailing weather conditions; and 7) the method and point of scaling/counting.32
The rate of escape is probably higher than 3% for hemlock due to the propensity of this species to become low floating and to deadhead. Whereas, the rate of escape for other species is probably below 3%. The data given in the previously mentioned studies indicate that more than 5% of the hemlock logs and around 1% of the logs of other species, being brought to the mills on the Fraser River, escape from their booms in the vicinity of Vancouver. Using these figures it can be calculated that of the 4.5 million $m^3$ of hemlock brought to the mills annually, approximately 225 thousand $m^3$ escapes, and for the same volume of the other species, 45 thousand $m^3$ escapes.

Only a portion of this volume of freed logs will actually escape on the river in the vicinity of the mills. A large number of logs will escape in the storage and sorting grounds in Howe Sound and around Point Grey where the logs stay in the water for, often, considerable periods of time and have an opportunity to absorb a lot of water. Also a portion will become free during towing to the mills and in the lower reaches of the Fraser where the logs encounter the lower density fresh water. Escape rates given in the literature have been calculated by comparing log volumes at the sorting area and at the mills, thus it is not possible to derive a figure for the actual escape rate on the river. Nevertheless, since logs processed on the Fraser account for more than 80% of the timber brought to the Vancouver area, the number of escaped logs
around Vancouver is probably directly related to the volume of logs being towed to the mills on the Fraser. Therefore the volume of escaped logs (270 thousand m³) has been included in the tabulation of the volume of debris coming from the Fraser River.

To complete the estimate of the amount of debris which is in the water (not necessarily free or uncontained) at the lower end of the Fraser, it is necessary to include two other minor debris sources. There is at most 6 thousand m³ of natural debris added to the Fraser's debris volume below the Mission Bridge. Some of this probably comes from the Pitt and Alouette Lake areas. As well as the natural debris there is another 3 thousand m³ of debris, generated by other industry, which is not directly attributable to the activities of the forest industry.

**TABLE 1: DEBRIS FROM THE FRASER RIVER (in thousands of m³)**

<table>
<thead>
<tr>
<th>Source</th>
<th>From Up River</th>
<th>% of T</th>
<th>% of T</th>
<th>From Below Mission</th>
<th>% of T</th>
<th>% of T</th>
<th>Total</th>
<th>% of T</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural</td>
<td>23 (40)</td>
<td>(6)</td>
<td>6 (2)</td>
<td>29 (8)</td>
<td></td>
<td></td>
<td>57 (100)</td>
<td>(15)</td>
</tr>
<tr>
<td>Logging/Mill</td>
<td>17 (30)</td>
<td>(5)</td>
<td>45 (13)</td>
<td>62 (16)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SAW LOGS</td>
<td>16 (28)</td>
<td>(4)</td>
<td>270 (84)</td>
<td>286 (75)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td>1 (2)</td>
<td>(0)</td>
<td>3 (1)</td>
<td>4 (1)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MANMADE</td>
<td>34 (60)</td>
<td>(9)</td>
<td>318 (98)</td>
<td>352 (92)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TOTAL</td>
<td>57 (100)</td>
<td>(15)</td>
<td>324 (100)</td>
<td>381 (100)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(*please see text above)
In the coastal waters of B.C. it is reckoned that 40% of all logs which escape are recovered, 35% (chiefly hemlock) sink to the bottom and 25% are lost in the Strait or to sea.\textsuperscript{37} Data obtained from Gulf Log Salvage Co-operative Association indicate that in the Fraser the recovery rate for logs in general is higher than in the coastal waters, around 45% as compared with the coastal average of 40%.\textsuperscript{38} This is probably due to the contained nature and smaller area of the river and nearby bays and because of the larger number of salvagers.\textsuperscript{39} Thus it can be calculated that of the 270 thousand m\textsuperscript{3} of escaped logs (from booms towed to the mouth of the Fraser through the Strait) 120 thousand m\textsuperscript{3} are recovered. Without evidence to the contrary it must be assumed that the percentage of sunken Fraser River logs is the same as the percentage for the B.C. coast. Therefore about 95 thousand m\textsuperscript{3} sinks. The remainder of about 20% or 55 thousand m\textsuperscript{3}, is the volume of logs which is estimated to be lost from the Fraser River.

Although balsam logs and possibly logs of other species do at times become dead-heads or sink, this problem is confined almost entirely to hemlock.\textsuperscript{40} From information supplied by those handling logs on the river and from data on log sinkage rates, it is estimated that close to 95% of the logs which sink are hemlock.\textsuperscript{41} Therefore it is calculated that about 90 thousand m\textsuperscript{3} of hemlock logs, which escape from log booms being transported to the mills in the lower Fraser for processing, are
lost through sinking. And since hemlock represents 225 thousand m$^3$ (83%) of the total escaped volume (270 thousand m$^3$), it is not unreasonable to assume that it accounts for a similar proportion of the timber which is lost to the Strait or to sea. Thus it can be calculated that about 45 thousand m$^3$ of hemlock is lost. This leaves a volume which is probably being recovered, of about 90 thousand m$^3$ of hemlock. This recovered volume results in a recovery rate of 40% which happens to be the coastal water average.

The N.F.H.C. maintains accurate records on the number of dead-heads which they remove from the water every year; this is on average 2500 logs representing an estimated 4-6 thousand m$^3$. The majority of these logs are taken to Canada Forest Products' Eburn mill and the remainder are taken to the Iona burning site. It seems, from available information that the F.R.H.C. (Fraser River Harbour Commission) also removes about the same volume per year, from the river. There are also a small number of dead-heads which are retrieved by salvagers. Therefore it can be computed that around 10 thousand m$^3$ of escaped dead-heads are removed from the Fraser on a yearly basis. A similar amount, attributable to the Fraser River timber, is removed from Howe Sound and the other Vancouver waters by a salvager, Archie Heleta.
### TABLE 2: LOSS AND RECOVERY OF ESCAPED LOGS (in thousands of m³)

<table>
<thead>
<tr>
<th>HEMLOCK</th>
<th>SINKS</th>
<th>90</th>
<th>%</th>
<th>% OF T</th>
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<tbody>
<tr>
<td></td>
<td>RECOVERED</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>FLOAT</td>
<td>70</td>
<td>(31)</td>
<td>(26)</td>
</tr>
<tr>
<td></td>
<td>D.H.</td>
<td>20</td>
<td>(9)</td>
<td>(7)</td>
</tr>
<tr>
<td></td>
<td>TOTAL</td>
<td>90</td>
<td>(40)</td>
<td>(33)</td>
</tr>
<tr>
<td></td>
<td>LOST LOGS</td>
<td>45</td>
<td>(20)</td>
<td>(17)</td>
</tr>
<tr>
<td></td>
<td>TOTAL</td>
<td>225</td>
<td>(100)</td>
<td>(83)</td>
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<table>
<thead>
<tr>
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<th>SINKS</th>
<th>95</th>
<th>(35)</th>
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<tbody>
<tr>
<td>RECOVERED</td>
<td>120</td>
<td>(45)</td>
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<tr>
<td>LOST LOGS</td>
<td>55</td>
<td>(20)</td>
<td></td>
</tr>
<tr>
<td>TOTAL</td>
<td>270</td>
<td>(100)</td>
<td></td>
</tr>
</tbody>
</table>

**Debris: Problems**

From the indications of the amount of debris which is being generated in other forest industry sites near Vancouver, specifically in Howe Sound, Burrard Inlet and False Creek, and in the rivers such as the Squamish, it appears that the Fraser River contributes the largest amount of debris to the waters around Vancouver. From a number of studies and from an estimate made by the co-ordinator of the debris control program of the Council of Forest Industries, it can be concluded that at least 80% of the debris which is found in the water or on the beaches of the lower Strait near Vancouver has originated on the Fraser, or from log booms being towed to the mills on the river.
The nature of the prevailing winds and the currents in the Strait of Georgia tend to cause drift material coming down the Fraser to disperse in an arc from Lulu Island to Howe Sound; this is primarily the case with southwesterly to southeasterly winds. Under certain conditions and with winds from the opposite direction, drift may end up on the east shores of the Gulf Islands. In whichever direction the winds occur, the debris is swept back and forth with the winds and tides, often for months, until it finally sinks, is carried out to sea or is deposited on the coastal beaches around Vancouver or on the Gulf Islands. But the erosion and the turnover of debris on the beaches appears to be quite rapid and a relatively stable amount of debris is maintained. Also historical information given by the authors of three different debris-study reports, regarding the amount of debris on the beaches and in the water of the Strait, indicates that the debris accumulations are not getting worse. On the contrary, salvaging and clean-up activities, appear to have reduced the accumulated amount of debris.

Both in the waters of the Fraser and in the Strait of Georgia and on the beaches around Vancouver the remaining debris is creating a number of problems which result in considerable costs. Logs and other forms of large debris, in the shipping channels, are a major hazard to moving boats, and significant damage occurs every year as a result of boats encountering floating debris. The problems are particularly acute with the
more dangerous low floating logs which are partially or entirely submerged and with the dead-heads which can have a very small portion of their volume above water.

Mill debris containment, removal and disposal and clean-up of both the water and the beaches to remove logs and other debris involves expenditures on the part of many jurisdictional bodies. The Harbour Commisions, the Department of Public Works, the Park boards in the G.V.R.D., the Council of Forest Industries and the B.C. Forest Service all are involved in clean-up programs. The forest industry's companies also suffer direct costs in the form of mill debris bagging and disposal and log recovery costs and indirect costs through the clean up and control operations of the Council of Forest Industries.

There are also environmental problems such as pollution of the fish spawning areas, bark and debris accumulation in feeding grounds, oxygen depletion in the water due to decaying debris and log accumulations in recreational areas. These problems result in costs, to the fishing industry and to society at large, which may or may not be substantial.

Thus, the four categories of damage costs associated with the debris generated primarily by the forest industry can be identified as:
COSTS ASSOCIATED WITH FOREST INDUSTRY DEBRIS

1) Debris clean-up costs;
2) the costs of log recovery and log loss;
3) costs resulting from damage to boats and to other property; and
4) environmental costs.
III THE COSTS OF LOG DEBRIS

In this section, the costs of log debris as indicated on the previous page, will be considered. Since the margin-of-error in the data used for calculating these costs is not known in many cases, care has been taken to provide reasonably accurate but conservative estimates of the costs. Therefore it is possible that the actual costs to society are higher than indicated in this section. Consequently the benefits arising from a reduction in these costs, may be greater than indicated.

Clean-up Costs

Debris in the Fraser and in the Strait results in significant clean-up costs. But only a small portion of the clean-up expenditures are effective, as the clean-up is expensive and clean-up work is quickly invalidated by the accumulation of new deposits. An effective program to reduce the volume of debris must include control of the generation of debris and utilization of the collected or controlled debris in order to recoup some of the expenses. But no program will be entirely effective in removing all debris immediately. Accretion of natural debris, logging waste disposal, log spills, log losses, and industrial disposal in the river will result in a continual flow of debris into the river and Strait.
In the Vancouver area there are primarily four groups responsible for the clean-up of floating debris. These are, the North Fraser Harbour Commission (N.F.H.C.), the Fraser River Harbour Commission (F.R.H.C.), the Department of Public Works (D.P.W.) and the Council of Forest Industries (C.O.F.I.).

The N.F.H.C. spends around $160,000 per year on their patrol vessel. They estimate that $50,000 of the cost of operating the boat is directly attributable to the cost of debris clean-up, primarily removal of dead-heads from the channels.\(^3\) The F.R.H.C. estimates that in the operation of their boat they incur a similar expense of $50,000 through the removal of debris trapped on bridge and causeway supports and through the removal of dead-heads from the channels.\(^4\) The D.P.W. also operates a boat. Its operation cost is estimated to be around $250,000 per year. It is used for some Ministry of Transport work but at least $100,000 of the cost is directly attributable to debris clean-up.\(^5\) The C.O.F.I. operates two boats, one in Howe Sound and the other on the Fraser. These boats are not used for debris clean-up, except in emergencies, but are used for boom patrol, in order to reduce log theft and to police boom construction.

The costs of boat operation, which can be directly attributed to debris, total approximately $300,000. But there are indirect costs which could also be included in the cost
estimate. These boats, during their general patrol operations are used for policing log and debris booms. The operators report log spills and poorly constructed and broken booms and thus are responsible for reducing the amount of debris which escapes into the Strait. It is very difficult to estimate the percentage of the operating costs which is attributable to the prevention of debris escape, although it is believed that it represents a substantial portion of the cost.  

Some of the other costs which result from debris clean-up are: 1) beach clean-up by the Parks Board, estimated to be $100,000; 2) sweeping programs operated by the National Harbours Board and by C.O.F.I. using hired tugs, $50,000; 3) the Iona burning site, operated by the N.P.H.C., $50,000; 4) disposal or burning of debris by the C.O.F.I. or by the B.C. Forest Service, $50,000; 5) administrative costs sustained by the C.O.F.I.; 6) increased dredging costs due to the problems of removing submerged debris; and 7) prevention, collection and disposal by the individual companies. No estimate is currently available on the various company programs. Adding these costs to the cost of operating the boats a conservative estimate, of $500,000, can be derived for the cost of clean-up.  

It is also interesting to note a project undertaken in 1975 by the C.O.F.I. During the months of May and June a pair of booms were constructed across a portion of the Fraser, adjacent
to Vasasus Island, west of Hope. A total volume of debris of 10 thousand m³ was contained. This represents about 37% of the total amount of debris which would have been flowing down the river during the time the boom was in operation. The cost of this operation was over $100,000. The C.O.F.I. is planning a similar, continuing, operation for the Fraser, and it is estimated that this program will cost as much as $300,000 to construct and $50,000 per year to operate. As well as this boom the C.O.F.I. would like to operate debris burning sites for the Main Arm of the Fraser and the Vancouver Harbour. These burning programs could cost $200,000 per year.¹³

From Table 2 (page 20) it can be seen that 45 thousand m³ of hemlock logs and 10 thousand m³ of logs of other species is lost. As well as the logs there is an estimated 56 thousand m³ of debris from natural sources, from mills or from other human activity, which is escaping with the logs into open water.¹⁴ These two types of debris, about 111 thousand m³ in total, account for the greatest portion of the direct clean-up costs. In addition to this amount there is the debris, including a portion of the debris generated at the mills and some natural and man-made debris, which is bagged at or near the source of generation. The amount of debris which is bagged in this manner is estimated to be about 55 thousand m³, or about 33% of the total of 166 thousand m³ which would need to be removed from the water and beaches by clean-up operations.¹⁵ Most of this
bagged debris is towed directly to the Iona burning site and accounts for only a small portion of the total clean-up costs.

In Table 3 is shown the estimated cost of clean-up attributable to the different kinds of debris. As was mentioned in a previous section, it was concluded that 80% of the debris in the lower Strait originates from the Fraser or from booms being towed to mills on the Fraser. Thus it can be calculated that the cost for clean-up of Fraser River debris is around $400,000 (second column, Table 3). A portion (33%) of this debris, that which is bagged and towed to the burning sites, results only in burning and administrative costs. Therefore it is necessary to deduct 33%, which is probably too high, from these costs, in order to obtain the cost attributable to escaped debris (third column). Logs account for almost the entire cost of boat operation and beach clean-up, but probably, only their proportionate amount (49% of the 111 thousand m$^3$ of escaped debris) of the other costs. Hemlock probably accounts for 82% of the cost of boat operation and beach clean-up and a proportionate amount (40%) of the other costs. Therefore the cost of clean-up of logs has been calculated to be $299,000, and specifically of hemlock logs, $246,000 (fourth and fifth columns respectively).
The Costs of Log Salvage and Log Loss

The institution responsible for the salvage of logs is the Gulf Log Salvage Co-operative Association. "It was established by legislation under the Forest Act of B.C. as a non-profit organization consisting of members from the forest industry, log insurance agencies, brokers, and towing interests. Gulf Log Salvage is primarily a marketing organization designed to return lost profits to the forest industry through the recovery and sale of salvaged logs."¹⁶ G.L.S. acts as an intermediary in most transactions between holders of valid log salvage permits and the firms owning or buying the logs. When G.L.S. has logs belonging to a particular mill, that mill has first option to buy back the logs at a price set by G.L.S., or determined through agreement with the mill. If the mill does not wish to purchase the logs they are sold to the highest bidder."¹⁷
From data supplied by G.L.S. it can be calculated that for the past three years (1974-1976) the average cost, to the mills, of the recovery of one cubic meter of logs was $39.18. And from Table 2 it can be estimated that the yearly volume of recovered logs is about 110 thousand m$^3$. This does not include the 10 thousand m$^3$ of dead-heads recovered in debris clean-up operations. Thus the total cost of recovering the logs based on the non-profit status or G.L.S., is around 4.3 million dollars.

Gulf log salvage does not keep, easily obtained, figures on its volume by species, so it is not possible to determine whether the cost of recovering hemlock is different from the average cost given above. But since the volume of hemlock tends to consist of the smaller logs, the cost per cubic meter could be higher because the cost of handling the smaller more numerous logs is probably greater. Without supporting data, only a conservative estimate of 3.1 million dollars can be calculated, for the cost of recovery of the 80 thousand m$^3$ of escaped hemlock, not including 10 thousand m$^3$ of dead-heads.

As well as the cost of the recovery of merchantable logs there is the cost of the logs which are lost or sink. If it is assumed that the bid-price paid for salvaged logs equals the cost of recovery by salvagers making 'marginal profits', then it can be concluded that the logs which are not recovered have at best the same value. However, it is probable that the
unrecovered logs are not as valuable, and for this reason they are not retrieved. It is believed by those involved with debris clean-up, that no less than half of the wood in the logs which escape has any value for lumber or for wood chips for paper production. The situation is probably the same for the wood of logs which sink. Therefore with an estimated volume of 150 thousand m$^3$ of timber which is being lost or is sinking it can be calculated that at minimum 3 million dollars worth is potentially usable. Hemlock represents about 90% or 135 thousand m$^3$ of this lost timber and therefore at least 2.6 million dollars worth of the potentially useable wood.

**Boat and Property Damage**

The data on boat damage is sparse; therefore to determine the amount of boat damage attributable to debris is very difficult. Prior to this present study the most recent cost estimate of damage to pleasure craft was made in 1967, and to fishing vessels in 1970. In order to obtain a total cost figure which would at least approximate the actual level of damage occurring today, it was necessary to obtain a more up-to-date and more accurate estimate of debris damage. Through discussions with a number of marine underwriters about the matter, it was found that there is no attempt made to keep statistics for the entire insurance industry; in fact few insurance companies maintain any statistics for their own
company, which would have made it possible calculate the needed estimates. In an attempt to rectify this, a sample questionnaire was presented to the Hull Damage Committee of the Marine Underwriters for Vancouver. This committee represents about 10 companies with around 90% of the present insurance policies. After a hopeful initial response, these companies proved unwilling to provide any information. There is apparently a very competitive environment in which these companies operate and they fear that if any data, even of a very general nature, were given out it might adversely affect their competitive position. It was therefore necessary to arrive at an estimate through a different method.

In B.C., most of the appraisals of boat damage and repair costs are done by firms which are separate from the insurance companies. The appraisers are most often experienced in boat design or repair and operation, and some have engineering degrees. Data was obtained from very helpful personnel in three of the largest companies, representing about 70% of the total claim-appraisals. In this section will be presented the estimates of damage costs, based upon the information obtained from these appraisers.

For small craft, under 10 m, the major type of reported damage seems to be damage to propellers and to the engine and steering mechanism. On inboard/outboard engines the leg which
holds the propeller is apparently very easily damaged, even though the leg is designed so that it will flip up if debris is hit. But at speeds of around 30 km/hr a pleasure boat begins to plane; its bow lifts out of the water and its weight is displaced to the stern, thus a considerable force is required to lift the leg over the debris. The pressure often causes damage, or complete breakage, even if the leg has been lifted. Similar kinds of damage occur to the leg of outboard engines. Damage to the propeller, leg, and steering mechanism on inboard/outboards and outboards is the most commonly reported form of damage to pleasure craft, in the Vancouver area.

It is not as common for tugs, fishing boats or other commercial vessels to be damaged. Most of these boats are well built, with steel or aluminum hulls and with propeller guards. Also the operators of these boats are usually professionals and they are well aware of the dangers of debris. But damage does occur even to these boats. At night, in fog, or in poor weather conditions these boats can encounter unseen debris; a log can cause damage if it is driven 'up the spout' leading to the propellers or if it strikes the propeller, propeller guard or shaft or the rudder with sufficient force.

Though there are not a great number of commercial vessels damaged, the total cost of damage can be quite high. Damage to a propeller of a large vessel, 25 m and longer, may be very
expensive to repair as a considerable cost must be incurred in order to dry-dock the boat and repair or replace the damaged portion. When damage does occur, the larger the boat usually the more expensive will be the repair costs.\textsuperscript{23}

Estimates made from the average reported number of boats which sustained damages caused by hitting debris in the waters around Vancouver, are given in the following Table.\textsuperscript{24} These estimates are rough, but the total calculated figure for damage is believed to be lower than the actual cost of damage. In the paragraphs following the Table consideration shall be given to a few of the costs which are not included in the table because of the difficulty of obtaining data.

<table>
<thead>
<tr>
<th>TABLE 4: BOAT DAMAGE CAUSED BY DEBRIS (in the Vancouver area)</th>
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<tbody>
<tr>
<td>% OF TOTAL DAMAGE</td>
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<tr>
<td>PLEASURE CRAFT</td>
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<td>POWER</td>
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<td>SAIL</td>
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<td>FISHING</td>
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<td>DEEP SEA</td>
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<td>TOTAL</td>
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</table>

In 1967 it was estimated that over 30% of all boats in B.C.
where not insured. The appraisers who provided the information, did not believe that the number of uninsured boats is as high as 30% but estimated that the figure was closer to 10%, for 1976. The uninsured boats in B.C. are probably of low relative value, such as car-tops, inflatables, row-boats and canoes. Most larger pleasure craft and commercial vessels are insured. However, some damage resulting from debris, undoubtedly occurs to the uninsured boats. The damage costs for uninsured boats is believed to be relatively low since the total value of the boats and their equipment is probably not high, and these boats are generally slower moving when in the water. Although the total damage may not be very high, the damage to uninsured boats should be included in the damage calculations.

As well as considering the damage sustained by uninsured boats, it should be noted that there is unreported damage which occurs to insured boats. The deductible amount for most marine insurance policies is somewhere between 1 and 10 percent of the value of the boat, or about $200 and up. But since the cost of just hauling a boat and having a propeller balanced can be over $120 it is believed that most owners report their damage, as often prop-guards, shafts and struts and rudders and hulls are also damaged. Probably most, if not all, damage of any consequence or over $200 is reported, but significant small amounts of unreported damage may still be occurring. This damage may be repaired at the owners expense or it may be that the
damage is ignored, although it may affect the re-sale value of the boat, or result in compounded costs when other damage occurs. The absolute amount of unreported damage is probably low, nevertheless this damage should be included in the calculations.

A further boat damage cost which is not included in the above is damage to boats which are not insured in the Vancouver area. It is believed that over 10 thousand non-resident pleasure craft entered the B.C. waters, by sea, in 1976. A large proportion of these boats probably traversed the waters adjacent to the Fraser estuary. There are also a great number of commercial vessels which enter the Vancouver area every year. As with non-insured boat damage and damage of under $200, it is very difficult to obtain empirical data on the damage to these non-resident boats, but it is still necessary to consider this damage in the cost calculations.

Another cost which is not included in the above Table is the cost or value of lost lives. Drowning statistics from the B.C.-Yukon Red Cross indicate that 12 deaths occurred in their jurisdiction in 1975, which were caused by overturned boats. The B.C. Safety Council stated, in 1967, that there were two deaths during the previous year, which could be attributed to boats hitting debris. It is unlikely that every year two deaths, in the Vancouver area, can be attributed to debris since
the primary reasons for boats capsizing are high speed turns, large wakes, rough water and mishandling of light boats such as canoes. But even if only one death per year, or every two years, can be attributed to debris, which originated on the Fraser River, this should be noted while appraising the more easily calculated costs.

There are two other factors which should be considered when estimating boat damage costs. One factor of concern is that while their boats are under repair, fishermen, tug operators and other commercial boat operators, often incur costs resulting from the value of lost work time. The second factor is that insurance estimates are not always commensurate with the level of actual repair costs, thus it is often necessary for the boat owner to pay an additional amount, above the appraisal. There is probably a degree of over payment by the insurance companies, but on the whole the estimates of damage tend to be on the low side. The resulting value of either of these costs have not been included in the above calculations.

It is also worth noting that damage to boats is not the only damage cost which is attributable to debris. Fishermen claim that a significant, though low, level of damage to nets, lines and other equipment is caused by debris. Also at times sea planes, bridge and pier supports and other equipment and structures are damaged by floating debris. It is believed that
from the evidence given in the various reports it can be concluded that these costs, and the costs discussed in the above paragraphs, total at least $500,000. Also, as was stated previously, the estimated figure for total boat damage to insured boats is believed to be lower than the actual figure, therefore a rounded figure of 2 million dollars per year would be a reasonable conservative estimate of the total amount of damage which can be attributed to debris.

In Table 2 it can be seen that about 175 thousand m$^3$ of lower Fraser logs float free and are uncontained for at least a short period of time, in the waters of the Fraser or adjacent to the Fraser. It can also be seen that of this amount, 55 thousand m$^3$ is lost in the waters of the Strait. Furthermore, of the remaining 206 (381-175=206) thousand m$^3$ of Fraser debris (Table 1), 95 thousand m$^3$ sinks (Table 2) and at least 55 thousand m$^3$ is contained in bag booms and taken to the Iona burning site. This leaves 56 thousand m$^3$ of debris which escapes with the logs. Thus, the total volume of debris which escapes from the Fraser is 231 (175+56) thousand m$^3$, and the total volume which goes unrecovered is 111 (55+56) thousand m$^3$. Since it is believed that Fraser River debris accounts for about 80% of the debris in the waters around Vancouver, it can be calculated that the total volume of debris is somewhere between 288 (231×0.8) and 138 (111×0.8) thousand m$^3$, with lower Fraser logs accounting for between 60% (175×288) and 40% (55×138).
respectively. Similarly hemlock logs account for between 47% (135\*288) and 33% (45\*138).

If uncontained or escaped debris from the Fraser caused damage to boats in proportion to its relative abundance it would be expected that between 33% and 47% of the damage, caused by debris, would be attributable to hemlock. But much of the debris in the lower Fraser and in the lower Strait is not a major hazard to boats since it is too small or it is quite visible, floating high on the surface of the water. The major menace to boats is probably the low floating logs and to an extent the dead-heads, which are difficult to see even in the best of weather. These low floating logs are not only a hazard in the Fraser where there is fresh water with a lower density than sea water, but they are a hazard even in the Strait near the mouth of the Fraser, where salt water predominates.

"Upon attaining the Strait, the waters of the Fraser tend to form a layer overriding and mixing with the saline waters. During the freshet, water with low salinity extends from the Fraser Delta across the Strait to Valdes and Galiano Islands..." Logs and debris which just sink in fresh water, therefore, may only sink to the more dense saline water, then drift out below the surface into the Strait and re-appear there at the drift line between fresh water and sea water."

It is difficult to determine a specific figure for the
percentage of the damage attributable to any particular kind of debris, but since most of the low floating and dead headed logs are hemlock, it probably accounts for a greater proportion of damage than would be immediately attributed on a strictly proportional basis of relative abundance. It seems reasonable to infer that Fraser River hemlock causes at least 50% of the total volume of damage to boats on the Fraser River and in the lower Strait. Since it has been estimated that there is a total damage cost of 2 million dollars caused by Fraser debris, it can be concluded that escaped hemlock logs, transported for processing in the lower Fraser, cause at least 1 million dollars worth of damage.

The logs of other species which float higher, are more visible, and are less abundant than hemlock probably cause relatively less damage. A possible minimum estimate is that they account for only 5% of the total damage to boats, or around $100,000. Thus it is estimated that logs, in general, account for around 1.1 million dollars worth of boat damage, leaving a high estimate of $900,000 caused by natural and other man-made debris.
Environmental Costs

As with most river systems, there is in the Fraser River system, considerable uncertainty associated with the extent of the environmental impacts of log pollution. And although some of the environmental effects associated with wood transportation operations are highly visible, the constraints of data availability and the complexity of the pollution problem do not allow exact, or even general analysis. However, to entirely ignore the costs of environmental damage, both as lost profits to someone else and as the 'cost' to the environment would be misleading. Therefore identified below are a few of the possible environmental damages which may result from log transportation and which will be reducable through changed methods of transporting the logs.

The quality of the Fraser River environment may be deteriorating, due to log transportation, in the following ways:

1) Bark, debris and logs sink to the bottom, these materials can blanket the entire bed. The sunken material can smother existing benthic (bottom living) life forms and prevent repopulation. Also these accumulations may persist for long periods of time, placing high demands on dissolved oxygen (B.O.D.), covering feeding grounds, and generating toxic organic compounds and anerobic decay products. As a consequence the water quality level may drop below that "necessary for the
maintenance of a productive biological community".\textsuperscript{42}

2) Logs, and especially bark, while in the water continue to leach dissolved organic compounds which, when concentrated, are toxic to fish.\textsuperscript{43} Also these leachates place a demand on oxygen for biochemical decay, and can cause discoloration of surrounding waters.\textsuperscript{44}

3) Log rafts anchored in the river can cover areas which could otherwise be used for fishing or boating.\textsuperscript{45} Also the booms, which are usually anchored near the shore for a major portion of the year, shade the bottom of the river and cause disruptions in the production of aquatic life.\textsuperscript{46}

4) "It is generally accepted that vigorous streamside vegetation maintains streambank stability, and that rivers with relatively stable banks are more productive for fish and wildlife."\textsuperscript{47} The denuding of river banks, caused by water flow alterations, wakes from towed booms, beached booms and escaped logs which are washed ashore, therefore, affects streambank stability and releases a steady flow of silt and sediment into the water. This can result in feeding grounds being covered and in the smothering of fish eggs on spawning grounds and of invertebrate bottom fauna in nursery areas.\textsuperscript{48}

5) Large numbers of beached logs affect the use of beaches and river banks and may be considered unaesthetic by some people.

No attempt, that is known by the author, has been made to
put quantifiable values on any of these environmental 'costs'. It is also clear that for the purposes of this study it would be very difficult to determine what percentage of these 'costs' could be attributed to escaped logs and to the respective methods of transporting logs. However, it is evident that escaped logs are causing problems which undoubtedly result in real costs both to society and to the environment. Therefore as the costs of controlling logs are calculated and compared with the costs of the uncontrolled logs, it is hoped that the reader will continue to realize that the environmental 'cost' could be large and therefore the total costs of the uncontrolled logs may be substantially greater than indicated.
IV THE COSTS OF PREVENTING LOG ESCAPE

In this section, the costs of preventing log escape will be considered. These consist primarily of the costs of constructing dryland sorting/bundling operations, bundling timber on land and up-grading the mills so that bundles can be removed from the water before they are split open. Where accurate data needed to determine these costs was not available, high estimates have been used. Therefore it is probable that the actual cost of an industry control program would not be as high as is indicated in the following section.

Many of the people involved with log handling on the B.C. coast believe that the major step that must be taken in order to reduce log loss substantially is to eliminate water based, loose log sorting, storage and towing of all logs or at least of hemlock logs. The most feasible method of eliminating the problem of loose logs is to ensure that the logs are contained in bundles during the entire time that they are in the water. A bundle is a quantity of logs of around 30 m³ which is bound with two or three cables.

There are only two other means for preventing log escape, which could be considered as even remotely developable for the B.C. coast: barging or trucking logs to the mills. But barging is not an alternative as the capital expense of both the barge
and the cranes needed for loading and unloading, is too high as compared with rafting methods.\textsuperscript{2} Trucking logs to the mills on the Fraser is not an alternative either, since the mills are designed to receive logs from the water, not from the land.\textsuperscript{3} Also both barging and trucking would require changes in the method of timber storage, presumably involving areas on land. However the problems of acquiring sufficient land behind the mills,\textsuperscript{4} problems with the timber drying out and with insect infestation,\textsuperscript{5} the need for spraying with water and insecticides and the unsightly nature of large piles of timber would seem to preclude these alternatives for log transportation to mills on the Fraser River.\textsuperscript{6}

Figure 3 on the page 46, illustrates schematically the coastal flow pattern for logs. The methods of log sorting, storage and towing which prevent logs from being loose in the water are designated by the hashed (- - - -) lines. With these procedures all small diameter hemlock logs (less than sixteen inches across the butt) and, if cost effective, all large hemlock logs plus logs of other species would be sorted into bundles on land. Logs which arrived by truck at a sorting area would be removed from the truck, sorted and bundled and then moved to the dumping apparatus. For operations utilizing central sorting grounds, the truck bundles would be dumped into the water, towed to the sorting area and removed from the water for sorting. In both cases, when the sorted bundles were
Figure 3: COASTAL LOG FLOW (Approximate percent distribution, excl. west coast of Vancouver Island)

Suggested control routes

(Log flow)

(For at least all hemlock)
complete, they would be lifted by a crane-like apparatus and lowered gently into the water. The bundles would then be combined into sturdy bundle-booms which would be towed either to the mills or to the storage grounds, depending on the log demands at the mill.

From a survey of 30 of the largest forest industry companies operating on the B.C. coast and transporting over 90% of the total volume of timber processed, it was possible to determine that in 1976 around 60% of the total log production was bundled at the logging operation dump or at a central sorting ground. Of this about half or 30% of the total production, was bundled and sorted on land. Also from this survey it was determined that it is primarily the largest companies which are undertaking bundling of timber in a serious manner. They also have a tendency to bundle more of their timber destined for mills in the Vancouver area. For instance MacMillan Bloedel bundles 70% of its timber in the Vancouver District but only 63% in the Alberni District. And Rayonier bundles close to 95% in its Mainland division yet only 19% in its Quitsano division. From this it might be concluded that a greater proportion of the Fraser timber is bundled, than for the entire coast, but without the facts to substantiate this it was assumed that relatively similar percentages could be applied to both the coastal and Fraser River timber. Since specific data pertaining to Fraser timber is not available it was necessary to
make this assumption so that the respective levels of land bundling, water bundling and flat rafting of Fraser timber could be determined. It must be emphasized that this probably results in an underestimate of the amount of Fraser timber which is land bundled as the evidence given above indicates, and consequently results in an overestimate of the costs. Therefore of the 9 million m$^3$ of timber transported to the Fraser mills, a minimum of about 5.4 million m$^3$ is bundled and 3.6 million m$^3$ is flat rafted, and of the bundled timber 2.7 million m$^3$ is bundled on land and 2.7 million m$^3$ on water.

Although most of the smaller operations bundle only a portion of their hemlock, some of the large companies, such as MacMillan Bloedel and B.C. Forest Products, processing in total more than half of the coastal production, bundle at least 95% of their hemlock. Therefore it is reasonable to infer that of the coastal production more than 60% and perhaps 75% of hemlock is bundled. Thus it is safe to conclude that about 3.4 million m$^3$ of the Fraser River hemlock is being bundled, with about 1.7 million m$^3$ bundled on land and 1.7 million m$^3$ bundled on the water, and that around 1.1 million m$^3$ is flat rafted.

**Dryland Sorting Costs**

The most efficient dryland sorting area is apparently a small area of land located beside a river or bay. The small
area allows for effective sorting of logs into 10 to 15 different log-type bundles, but with a minimal amount of log movement. And when bundles are completed they can be moved easily into the water. As a further consideration, dryland storage is very expensive, and is not necessary when completed bundles can be put into the water easily. Therefore large areas of land are not needed for the scaling/sorting, bundling and dumping operations. The ideal size for a sorting area is less than 2 ha and probably around 1 ha.11

At present there are 65 dryland sort areas on the B.C. coast, these are handling about one third of the total coastal production.12 Most of these sorting areas can process more timber than they are presently handling, but there is a maximum distance for transporting logs by truck, beyond which it is cheaper to install a new dryland sorting area. It is not known how many sorting areas would be needed in order to process all the coastal production. Although, it is believed that if 65 not fully utilized sorting grounds are presently handling one third of the timber then probably less than 200 well located sorting grounds should be able to process the entire annual production of coastal timber.13

Only a portion of the 200 dryland sorting areas would prepare timber for the Fraser River mills. The Fraser receives about one third of the coastal production of timber, so it is
expected that at least one third of the sorting areas would be needed to supply the Fraser Mills. But it is not possible to build only half a sorting area. And since some sorting grounds send their timber to more than one milling area, a larger proportion of the sorting grounds would be needed if only Fraser timber were to be bundled. As an upper limit, half (100) of the total number of proposed sorting areas would be the approximate number that would be needed to process the timber going to Fraser mills.

Since one third of the proposed total number of sorting grounds, for coastal timber, have been built it might also be assumed that about a third of the sorting areas for Fraser timber have been built. But to be conservative, it will be assumed that only one quarter are in operation and that 75 would have to be constructed in order to bundle and sort all Fraser timber. Finally, hemlock represents about one half of the total volume of timber being transported to the Fraser, therefore at least half of the dryland sorting areas would be needed for hemlock. This is the case only if all the sorting areas are near the average size and handle primarily one species, but since neither of these suppositions would be easy to prove it will be assumed that possibly 70 sorting areas would be used for bundling hemlock destined for the Fraser, and that it would be necessary to build 45 of these.
Dryland sorting areas must be relatively level with easy access for logging trucks. And since these areas are very intensely used it is advisable to pave the areas with asphalt or with soil-cement or to spread a heavy layer of gravel. The costs of levelling and paving can vary greatly. Some areas need extensive blasting whereas others have very gravelly soil and need no preparation except for clearing. On the whole the average cost for an entire sorting area of around 1 ha with log moving, bundling and dumping equipment and adequate paving, would be around $500,000.

The total cost of constructing 75 sorting grounds to handle all Fraser timber would be at most 37.5 million dollars. Most of these sorting grounds could be used indefinitely to process timber from relatively large areas of managed forest. Therefore if the affected firms were to distribute this cost over a twenty year period at 10% interest per annum, the annual cost to the forest industry would be 4.3 million dollars. A similar calculation of the cost of the 45 mills estimated above to be needed to process and bundle Fraser hemlock gives a total cost of around 22.5 million dollars. If this amount were amortized over 20 years, the annual cost would be 2.6 million per year.

During the sorting and bundling process a considerable amount of debris from bark, tree branches and splintered wood, accumulates on the sorting pavement. The amount of debris which
accumulates depends on the species being worked, and ranges from .6 m$^3$ to 11 m$^3$ with an average of 3.2 m$^3$ of debris generated for every 100 m$^3$ of timber handled. The average cost of removing the debris is around $.25 for the removal of 3.2 m$^3$ of debris. Thus with the sorting and bundling of all timber on land there would be a cost of $15,000 for the clean-up of 186 thousand m$^3$ of debris generated by the processing of an additional 5.8 million m$^3$ of timber. For the 2.8 million m$^3$ of hemlock, producing 90 thousand m$^3$ of debris the additional cost would be $7,000.

Bundling and Sorting Costs

The additional cost above the cost for flat rafting, of bundling and sorting on land and booming the bundles into well constructed booms, is less than $1.00 per cubic meter. And the additional cost of bundling and sorting on land is probably no more than $.10 per cubic meter above the cost of water sorting and bundling. It may actually be cheaper to sort and bundle on land since the cost of water operations has been escalating quite rapidly, and also because of the new 'pressed sleeve' method of securing bundling cables which was developed recently by the Forest Engineering Research Institute of Canada, and which enables land bundling to be undertaken efficiently and cheaply with a minimum of capital expenditure. Therefore as shown in Table 5, the total additional cost of bundling Fraser
River timber can be calculated to be at most 3.9 million dollars and the cost of bundling hemlock can be calculated to be 1.3 million dollars.

<table>
<thead>
<tr>
<th></th>
<th>VOLUME (millions)</th>
<th>COST (per m³)</th>
<th>TOTAL COST</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALL TIMBER</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LAND SORTED/BUNDLED</td>
<td>2.7</td>
<td>0.00</td>
<td>270,000</td>
</tr>
<tr>
<td>WATER SORTED/BUNDLED</td>
<td>2.7</td>
<td>0.10</td>
<td></td>
</tr>
<tr>
<td>FLAT RAFTED</td>
<td>3.6</td>
<td>1.00</td>
<td>3,600,000</td>
</tr>
<tr>
<td>TOTAL</td>
<td>9.0</td>
<td>100%</td>
<td>$3,870,000</td>
</tr>
<tr>
<td>ALL HEMLOCK</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LAND SORTED/BUNDLED</td>
<td>1.7</td>
<td>0.00</td>
<td>170,000</td>
</tr>
<tr>
<td>WATER SORTED/BUNDLED</td>
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<td>0.10</td>
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</tr>
<tr>
<td>FLAT RAFTED</td>
<td>1.1</td>
<td>1.00</td>
<td>1,100,000</td>
</tr>
<tr>
<td>TOTAL</td>
<td>4.5</td>
<td>50%</td>
<td>$1,270,000</td>
</tr>
</tbody>
</table>

Mill Up-grading Costs

Most mills on the Fraser River are presently equipped with jack ladders designed to lift single logs from a mill-pond onto the mill-deck. In order to utilize this type of conveyor feed, log bundles arriving at the mill must be opened in the water and the logs loaded singly onto the jack ladder.\(^{22}\) The major problem with this system is that when the bundles are broken in the water the low floaters that have accumulated moisture during transportation sink or escape. If the unopened bundles were lifted onto a deck and then opened, there would be no chance for
Figure 4: MAJOR FOREST PRODUCT MILLS

- Pulp mills
- Sawmills
- Plywood plants and veneer mills
- Shake and shingle mills
the logs to become loose in the water. But only a few of the mills on the lower Fraser are equipped to remove bundles from the water intact. Also there is not always room available at the mills, without additional deck construction, for bundle lifts. And with the varying size of bundles (15-60 m³) some of the existing bundle lifts would not be able to handle the larger bundles. Either the bundle size must be standardized, which would be very difficult because of the large variety of log lengths and diameters, or facilities must be built to handle large and small bundles.

In order for mills to accommodate bundled logs it would be necessary for them to upgrade their log handling facilities. Some of the suggested methods for hoisting bundles onto the mill-deck are: 1) cranes; 2) steel-mesh platforms with hydraulic lifts, the bundle would be floated onto the platform and lifted up to the deck level; 3) jack ladders and conveyer systems with a capacity for large bundles; and 4) hydraulic arms, the bundle would be floated onto the arms, the arms would raise the bundle and at deck level roll it onto the deck. The cost of installing one of these facilities including necessary decking, ranges from .5 million dollars to 3.5 million dollars depending on the size of the mill and the volume of timber being handled.

On the Fraser there are about 60 mills ranging from the extremely small ones to 1 or 2 which can handle a volume as
large as 900 thousand m$^3$ per year. But it is difficult to
determine the volume handled by the various mills on the Fraser
without enquiring at almost every individual mill. Also the
nature of the forest industry is such that the continuing
operation of many of the mills is precarious. When enquiries
were made about the number of mills which would need to be
upgraded, specific information was obtained from only a few of
the largest companies. It was suggested by the few who provided
any information that maps supplied by Rivtow-Straits and the
B.C. Forest Service, should be used to determine the number of
mills on the Fraser.\textsuperscript{28} Using these maps and the data on the
volumes of the thirty largest companies, provided in the survey
of log transportation on the B.C. coast, mentioned on page 47,
rough, but representative, figures were derived for the number
and size of the mills which would need conversion to be able to
handle bundled logs.

Over 20 of the very small mills handle cedar and produce
shakes, fence posts and other similar products. These mills buy
1 or 2 large cedar logs at a time and are not really of concern
in this study. There are actually less than 30 mills on the
Fraser which could be considered to be important,\textsuperscript{29} and since
they include the mills of companies such as MacMillan Bloedel,
Canada Forest Products, Rayonier and Crown Zellerbach, they
probably handle more than 90% of the timber on the Fraser.
From the maps and from the coastal log transportation data it was determined that of the 30 mills, 10 are relatively small and it would cost .5 million dollars to upgrade each one so that it could handle bundles. Similarly the next 10 largest mills would cost on average 1 million each, the next 6 about 2 million each, and the largest four, 3 million each, thus the total cost to the forest industry might be 39 million or around 4.5 million dollars per year, at an amortization rate of 10% per annum over 20 years.

As a comparison, it might be considered that ten mills each handling 900 thousand $m^3$ of timber per year could process the entire Fraser volume. If these mills were each to install a 3 million dollar system the total cost to the forest industry would be 30 million dollars. If this cost were distributed over a twenty year period, at 10% interest per annum, the yearly cost to the forest industry would be around 3.4 million dollars. But since there are not 10 mills this size, but about 30 of various sizes, it would be expected that the total cost, as derived in the previous paragraph, for the conversion of the 30 mills would be higher. The cost difference for the conversion of 30 mills has been estimated to be greater by a total of 9 million dollars, or 1.1 million dollars per year.

Since hemlock represents about half of the total volume of timber, probably at least half of the mills would have to be
converted to handle the bundles, if only hemlock were bundled. Companies with more than one mill on the Fraser, such as MacMillan Bloedel could reassign a portion of their timber. But since most mills handle more than one species and are the only mill on the Fraser of each particular company, it would be necessary to convert more than half of all the mills. On the basis of the mills on the Fraser which presently handle hemlock it can be assumed that no more than two thirds of the 30 mills would be upgraded, and that 7 small mills, 7 medium sized mills, 4 of the large mills and 2 of the largest would be outfitted with bundle handling equipment. Thus the total cost would be 24.5 million with a yearly cost of nearly 2.8 million dollars.

As with the dryland sorting sites there will be a considerable amount of debris generated at the mills. At present about half of the total volume of this debris is contained in bag booms and is towed to burning sites, the rest is set free in the river or disposed of in some other way, (see page 15). If logs were bundled and opened on the decks the amount of debris produced would probably be greater than at present since more bark would have remained on the logs than if they had been flat rafted. If it is assumed that the amount of debris would increase by at most 50%, to about .75 m$^3$ per 100 m$^3$ then the amount of debris produced if all the wood were bundled, would be 68 thousand m$^3$. Similarly the amount of hemlock debris would be 34 thousand m$^3$. The present cost of
removing all the mill debris in a manner which minimizes the escape rate, is estimated to be around $30,000.\textsuperscript{32} This increase in debris would result in a maximum increase of 50% in the disposal costs, and the total cost of removing all the debris would be at most $43,000, with $22,000 of this being for hemlock.

**Bundle Booming: Savings**

The forest industry would not be confronted with just costs, when following a bundle booming policy. There are some savings. For instance, although bundle booms result in longer towing times due to increased drag, at least three times as much timber can be transported in a bundle boom as in a flat boom of the same surface area. Therefore fewer trips are necessary and total towing charges will be lower.

The amount which can be saved is on average at least $.11 per cubic meter of timber transported.\textsuperscript{33} Therefore, if the additional 3.6 million m\textsuperscript{3} of timber were bundled there would be a savings of $396,000. Similarly, if the 1.1 million m\textsuperscript{3} of hemlock were bundled the savings would be $121,000. There would also be a similar but smaller savings when the booms were towed from the storage grounds to the mills.\textsuperscript{34}

Bundle booms of the same volume as flat booms require about
half as much area for water storage. Thus, there would probably be some savings in the water surface and upland lease fees. But these would be minimal since the bundle booms could only be stored in the outer portion of the storage grounds due to their deeper draft. If excess storage capacity did become available in the river or in the Pitt area it is expected that more booms would be brought in from Howe Sound and other storage areas since the Fraser and Pitt being fresh water, are the largest areas where logs can be stored without being infested with wood boring animals. Any savings from reduced fees or reduced log damage would probably be consumed by the necessity of constructing concrete or stronger wooden pilings for anchoring bundle booms.

Carrying through the policy of bundling on land and opening the bundles on the mill deck would dramatically reduce the number of lost logs. Bundle booms, especially those containing bundles secured using the 'pressed sleeve' method loose very few logs. The possible savings from reducing log loss has been covered in the previous chapter, but there is a further saving possible. Since there is a reduced chance of log loss from bundle booms due to theft or major loss resulting from a boom break-up, insurance rates on the booms would be reduced by around 25%.

There is at least one other advantage of log bundling.
This is that bundling allows for a greatly improved inventory of the logs being processed. Bundles can be marked and a complete history of the logs can be maintained. This allows for more efficient utilization of timber since the contents of each boom can be easily determined. Their inventory statistics can be used for planning purposes both by the log supply divisions of the individual companies and by other organizations including the B.C.F.S. and the C.O.F.I.
V DETERMINING THE OPTIMAL SOCIAL COST

To institute a program which would eliminate practically all log loss due to handling and processing would cost the forest industry about 13 million dollars per year. But if the industry were to undertake this program there would be significant reductions in the costs which are presently being borne both by the industry itself and by other users of the river. It is believed that there is an optimal level of control for the discharge of logs. A possible means for controlling this discharge has been suggested, and it is now necessary to determine whether there is in fact an optimal method and level of implementation, where the total social cost will be minimized. In seeking this minimum social cost it will be assumed that the forest industry will continue to operate on the Fraser and that the social minimum cost is not an absolute minimum, but a minimum within a sub-system of the entire socio-economic environment.

Total Cost Curves

In figure 5 on page 63, are cost curves which show how the various costs would change as the proportion of bundled logs was changed, and what would be the total social cost at each level of bundling. On the graph the various points (derived from Table 5) representing the bundling of hemlock and other species,
Figure 5: TOTAL COST CURVES

1. Log recovery
2. Log loss
3. Boat damage
4. Towing
5. Summed t.c.c. (land bundling & mill up-grading)
6. Summed t.c.c. (land bundling)
7. Summed t.c.c. (water bundling of flat rafted timber)
8. Mill up-grading
9. Dryland sorting areas
10. Bundling

$ (MILLIONS)

0 1 2 3 4 5 6 7 8 9 10

0 10 20 30 40 50 60 70 80 90 100

HEMLOCK | OTHER
LAND BUNDLED | WATER BUNDLED
HEM. | OTHER
FLAT RAFTED

% BUNDLED
are designated by the vertical lines below the horizontal scale. Since escaped hemlock logs cause relatively more damage and result in relatively larger costs to the industry and to society in general, the hemlock would be dealt with first in each of the steps of improved control in any program undertaken by the industry. As each firm attempts to minimize its costs it will invest where the marginal return would be greatest, and this would be in dealing with hemlock first.

Curve 1 on the graph represents the cost of log recovery. At present the total cost of recovery is around 4.4 million dollars. But if the industry installed bundle lifting equipment and broke open the presently bundled timber only on the mill deck, there would be a decrease in the number of logs escaping from the mill pond, and therefore a reduction in the cost of recovery. Similarly if the industry moved a larger number of its bundling/sorting operations onto land, and continued the mill up-grading, there would be an even more rapid decrease in log escape. Finally, if the number of flat-rafted logs was decreased to zero, log escape resulting from normal handling would be eliminated. This of course does not include loss due to severe accidents.

It is evident from the literature and from conversations with people in the forest industry that for different log handling procedures there are different escape rates. The
information indicates that around 2% (30 thousand m³) of the hemlock logs which are presently being bundled on land are escaping from the mill pond. Also 5% (85 thousand m³) of the water bundled hemlock and 10% (110 thousand m³) of the flat rafted hemlock is believed to be escaping. For the other species escape rates of .5% (6 thousand m³), .75% (32 thousand m³), and 1.3% (7 thousand m³) respectively, are apparent.

Using the percentages of Table 2 (page 20), each of the escape volumes calculated above, was disaggregated into the proportion which sinks, is recovered and is lost. For example the first 19% of all hemlock timber is bundled on land and accounts for an escape rate of 30 thousand m³ annually from the mill ponds. Of this, 12 thousand m³ (40%) sinks, 12 thousand m³ is recovered and 6 thousand m³ (20%) is lost. The volume of dead-heads which is not being recovered by salvagers but by the harbour boards was then deducted from the recovered volume. For the above case it was calculated that 11 thousand m³ is the volume of escaped hemlock from the first 19% of the timber, which would need recovery. This represents about 10% of the total 122 thousand m³ recovered. It can be assumed that it represents 10% of ($440,000) of the cost of recovery, since there are almost 2000 salvagers around Vancouver, who generally do not have a large capital investment. Many undertake salvage operations only as a part-time venture depending on the number of logs available and on the price. Entry into the activity and
departure from it is easy and since there are no significant economies of scale it is possible to assume that a linear decline in recovery costs would occur in each portion of the recovery program, as an increasing amount of hemlock was bundled. Thus, this section of the curve was drawn as a linear function. Then the proportion of the cost was calculated for each of the other segments on the curve, and drawn accordingly.

Using a series of similar calculations the points were derived, which were needed in order to construct the curve (2) representing log loss and sinkage. In this case the percentage of the cost was calculated using the same escape rates as for the log recovery curve. But the calculation was based on the 150 thousand m$^3$ of lost and sunk timber (see Table 2). For the boat damage (3) and the debris clean-up (not illustrated) curves, the same rates of escape were used but the hemlock was separated from the other species for calculating the percentage of the cost since it would not have been representative to use the percentage of the cost based on the proportion of debris. Hemlock for instance, accounts for 1 million dollars worth of damage to boats and other property, whereas the other species account for only $100,000.

The amount of damage caused by hemlock probably is proportional to the volume of that species which floats free. Thus, to derive the the cost of damage caused by hemlock, the
percentage of escaped logs was calculated in each of the three segments of the curve which apply to hemlock, and then the same proportion of the 1 million dollars of damage was calculated.

With regard to the clean-up cost curve (not illustrated, but included in the calculations) it is the case that even if the amount of log debris were reduced, much if not all of the clean-up cost would still have to be borne by the various institutions because natural debris and debris from accidents and from other human activities would still be generated. Also there would not be a reduction in the costs of the patrol boats. However, the forest industry's responsibility for debris would be reduced and also there would be benefits available to the other users of the river through the changes in the nature of the patrol and clean-up operations. So even though society might continue to spend the same amount for clean-up operations, the proportion of that expenditure attributable to log debris would be diminished. Thus a declining cost curve has been used for the calculations.

The curves representing the cost of up-grading the mills (8) and of constructing the dryland sorting areas (9) are 'step' functions. The first has an average step of $150,000 and 300 thousand m³. The second has an average step of $57,000 and 120 thousand m³. On the graph these steps would be too detailed to illustrate, and for calculation purposes a linear function
represents a reasonable approximation of the actual cost curve. The two curves cross the horizontal axis at different points since they apply to different volumes of timber. As no mills on the Fraser are equipped to handle bundle booms in the prescribed manner, it would be necessary to convert some of the mills to handle the timber which is presently being bundled. However, since 30% of Fraser timber is bundled on land it would be necessary to construct dryland sorting areas for only the remaining 70%.

Curve 10 represents the cost of moving the bundling operation for water bundled timber onto land and secondly the cost of bundling on land the timber which is presently flat-rafted. The cost of sort and mill debris clean-up have also been included in the calculations, these have not been illustrated. It has been assumed that these costs increase relative to the volume of timber bundled, or handled at the mills.

On the graph is also shown the sum (5) of all the total cost curves (1-4 & 8-10). For comparison, curve 6 represents the sum of the total cost curves when the cost of mill up-grading (8) is not included. For calculation of this curve the total cost curves (1-3 & 4) have been adjusted to include the cost of the log debris which would still be generated at each level of bundling, even if other control measures were
undertaken. If there were no mill up-grading, log bundles would be opened in the mill ponds and some logs would be lost. Curve 7 represents the sum of the total cost curves when the costs of both mill up-grading and the dryland sorting areas (8 & 9), are not included. In this case as well the total cost curves must be adjusted since there would be even less debris eliminated. To derive these curves it was assumed that for each unit of timber bundled the same proportion of logs would escape from the mill pond as is now escaping from the bundled 30%.

As can be seen the point at which the total social cost would be lowest is where the entire volume of Fraser hemlock is bundled and controlled in some manner (curve 6). Also 44% of the other timber would have been bundled at this point. All three of the control methods which are considered, result in total social costs being lower with 72% of the timber bundled, than they are now with 30% bundled. But it must be noted that not all timber should be bundled!

The option of bundling on water (curve 7) the remaining flat-rafted hemlock does reduce total social costs but not as effectively as either of the methods which include land operations. By bundling on land, the timber which is presently bundled on the water and also all flat-rafted hemlock, a savings to society of just under 1.1 million dollars would be realized. To include equipment to remove bundles from the water at the
mills, would result in a smaller savings, of about $665,000. Therefore, assuming that all relevant social costs are included in the summed total cost curves and assuming that the forest industry is to continue operating, it can be concluded that bundling on land is the most effective means for minimizing the total social cost.

As was pointed out beginning on page 40, there may be substantial environmental and social costs resulting from log debris on the Fraser. Although it is difficult to put a dollar value on such factors as degradation of the benthic environment, reductions in salmon populations, visual blight and interference with recreation, the derived cost curves can be used to show what effect additional social and environmental costs would have on the optimal level of bundling and control. For instance, if it is assumed that hemlock causes $500,000 worth of environmental damage and results in other presently unaccounted costs and if these costs decline as hemlock is controlled, then the curves can be adjusted by adding the appropriate cost to each point along the summed total cost curve. This figure was chosen since it is a moderate estimate of environmental damage. For ease in calculation it has been assumed that the other species account for an additional 10% of the damage. Thus the total damage would be $550,000. With an additional social cost of $550,000 it is found that the option of bundling on land (curve 6) would reach its optimum at 72% bundling, at a total
social cost of over 8.3 million. Whereas the option which includes mill up-grading would have a total cost of about 8.6 million. If 1.1 million dollars is taken to be the unaccounted social cost it is found that the optimal costs of both options differ by $46,000. As the estimated additional social cost increases above 1.1 million the option which includes mill up-grading is the cheapest, by an increasing margin. Thus it can be seen that the value place upon reduced environmental degradation and on improved recreational value will determine which means of control is desirable in order to achieve a socially optimal level of log discharge.

Policy Mechanisms for Inducing the Control of Log Debris

The discharge of logs by the forest industry can be likened to the discharge of any industrial effluent. The portion of the effluent considered valuable is recovered and the rest is allowed to escape. And as with industrial pollution, escaped logs are primarily a problem because of their effects on others outside of the polluting firm. The external effects and costs of log debris are not included in the cost considerations of the forest industry and therefore will be borne by the affected people until it becomes uneconomical for the forest companies to allow logs to escape. Thus the problem of debris is primarily an economic problem.
In this paper management and technological methods have been suggested for dealing with the problem of log debris. But these methods are only proximate means for reducing log escape, for there is still the matter of inducing the individual companies to apply these measures. There are primarily three means for inducing compliance with a suggested measure. These are ethical persuasion or self-regulation, legal enforcement, and monetary imposition or subsidization.

A. Self Regulation

Activities of the individual forest companies are monitored and reasonably well controlled through voluntary compliance by the C.O.F.I. Recommendations made by this institution are usually followed, although the C.O.F.I. has no legal powers to require compliance, and have been somewhat successful in encouraging improved bundling and log-debris control operations. But so far, measures taken by the individual companies have not been entirely altruistic. As the price of log handling has increased the value of delivered timber has also increased and the escape and loss of large numbers of logs has been felt by the companies and has encouraged them to reduce log escape. Control measures suggested by the C.O.F.I. or the B.C.F.S. will be rejected by the individual companies if they involve internalization of presently external costs, unless there is immediately some private net economic benefit. It would be
especially difficult for the small firms to undertake control measures such as mill up-grading, even if the long run benefits to them, the industry and society could be substantial. Furthermore the costs of a control measure such as mill up-grading which may be rather insignificant, as additional cost per cubic meter of logs processed, for a large company may be prohibitive for a smaller firm.\(^5\) Thus the conclusion reached, is that self-regulation by the forest industry is not going to be an effective means for controlling log escape, since log companies are not required to comply with suggested control measures, and will not comply if there are no immediate net economic benefits from doing so.

B. Legal Enforcement

there are a number of existing pieces of legislation such as the Harbour Commissions Act, the Fisheries Act, the Provincial Health Act, the Environment and Land Use Act and the Canada Water Act, all of which contain provisions that appear to have sufficient legislative powers to control log escape.\(^6\) But there are numerous difficulties with proving liability in the case of damage to boats or to the environment, on the part of log owners. Also credible techniques for measuring damage to the environment or to aesthetic quality have not been adequately developed to the point where they are widely accepted by the courts.\(^7\) Thus even with adequate legislation it has not been
possible to control log escape.

A second reason for the failure of legal restraint is that laws controlling log handling methods would be difficult to enforce and would have to be equally applicable to all companies. For instance, it would be necessary to use broad guidelines which would apply to every firm in order to make the regulation easily enforceable. Yet it is conceivable that some of the smaller firms which produce only a few of the escaped logs, might be eligible for exemption since the costs of log control could be considerably higher than the level of damage caused by their escaped logs. Under a general law a small firm would be required to comply even if the economics of the situation both for the firm and for society would indicate that non-compliance would be more cost-effective. But with a law applying only to specific firms, all kinds of policing and administrative problems would arise. Therefore it can be concluded that legislated control will probably continue to be an ineffective means for controlling log escape. We are left with one alternative, to use a monetary mechanism to encourage the log companies to carry the full cost of their operation.

C. 'Enforcement' Through Pricing

Measures which subsidize polluters with public money to enable them to implement control operations, or which charge for
the 'right' to pollute and compensate those affected by the pollution, are possible means which can be suggested for ameliorating the problems of uncontrolled effluents. But these measures are often as difficult to implement and to control as are other means involving legislation. There are also problems with subsidy or charge determination and with questions of equity. However, as will be shown in the following paragraphs, there may be reasons for preferring a pricing system as compared with self-regulation or legal enforcement, also the implementation of a charge system may be quite feasible, given the present institutional structures involved in log handling and control on the Fraser River.

There are primarily three reasons for preferring an economic means and particularly an effluent charge, for achieving improved water quality. First, a charge which allows a firm to continue polluting or discharging logs, if they find that paying a charge is cheaper than implementing a control measure, tends to induce the least costly combination of measures for waste reduction by each polluter, and the least-cost distribution of waste reduction among polluters, thereby minimizing the real resources cost of attaining the water quality desired. This is important on the Fraser since there are differences in economies of scale for the affected forest industry firms and there would be different responses to the charge. For example, individual companies when faced with the charge would possibly decide to
alter their log handling procedures, increase the amount of timber bundled, cut back production, switch to other species less likely to escape or sink, pay the charge or implement a combination of these or other measures. Thus the individual firm would be enabled to make its decision on economic grounds, without any compulsion from others.

It is this lack of compulsion which is the second reason for preferring an economic means of control. For with a charge system the desired results can be achieved without the difficulties inherent in a legislated system of control which requires that all comply. Also the charge system makes economical, control measures which otherwise would not be considered, and especially not under a self-regulated system.

Thirdly, the polluting firms in comparing their marginal costs and marginal charges would decide whether it would pay to reduce their discharge levels and to what degree. Consequently the individual users of the public water course would be competing for its use and establishing a rental value, and the rental value would be accruing to the public.

Further advantages are available with the use of a charge system. The individual firm in comparing the marginal cost of control with the marginal cost of the charge has an incentive to reduce the cost effect of the charge by undertaking innovative
research into more efficient control techniques. A situation such as this is not likely to arise if firms are only encouraged to reduce their losses to a specified level, as they would be under a voluntary or legislated program. Secondly the charge system would generate revenue which could be used to compensate other users of the Fraser who suffer damages from the remaining uncontrolled logs. Thus, the implementation of a charge program for managing uncontrolled logs would not only help to minimize total social costs but would also deal to a certain extent with the problems of equity.

There are probably a number of different aspects of the log transportation and handling process which could have a charge placed on them in order to control log escape or discharge, on the Fraser. For instance, flat rafted hemlock booms brought into the river could be charged on a volume basis. Since there are harbour patrol vessels on the Fraser, and since log companies are presently required to pay channel fees and storage fees, the implementation of the additional charge for flat rafted hemlock would be fairly simple. However, this method of charging would likely not result in a reduction of log escape to the level desired. For even if all hemlock entering the river were bundled there would still be log escape from the mill ponds and from the water based sorting grounds around Vancouver. And as was pointed out previously this strategy of bundling (Figure 5, curve 7) the remaining flat rafted hemlock does not result in
the lowest social cost.

To charge a tax on mills which do not have bundle lifting equipment or to tax companies which sort logs on the water would result in similar problems. It would not be necessary for the forest companies to change the other aspects of their log handling and transportation process, if only one portion were taxed. Therefore direct charges on the offending methods of handling and transporting logs would not necessarily result in the reduction of log escape. Thus it can be concluded that in order to achieve the desired ends it is probably necessary to use an indirect charge.

An indirect charge to change the methods of log handling and transportation, is ideally suited to the particular situation of log pollution on the Fraser. At present most logs which are recovered by salvagers are transferred to the owners or to buyers through Gulf Log Salvage. Furthermore, since most recovered logs have a 'timber-mark' stamped on them, log ownership can be readily ascertained. Therefore, it would be quite feasible to charge log owners an additional amount which would encourage them to reduce log discharge. This charge could be assessed on the volume of recovered logs belonging to each company and could be collected with the other transactions. On logs which had lost their 'timber-mark' from a long period of time in the water or on the beaches, the charge could be
assessed in proportion to the number of marked logs belonging to each firm, which were processed by G.L.S. Finally, to encourage the salvagers to return recovered logs to G.L.S. and to prevent a secondary market from being formed, where salvagers would sell large volumes of logs directly to the mills, a portion of the assessed charge could be paid to the salvagers. This would also have another effect; log salvage could probably be undertaken more intensely if there were a larger monetary return available. Thus log clean-up, through recovery, would be improved.

From the above, it can be seen that to implement a charge system on the Fraser to control the discharge of logs, would be relatively easy. The institutional system already exists for measuring the level of discharge or log escape, by each individual polluter and also for collecting the charge. It is also likely that companies faced with this charge would be induced to change their methods of log handling and transportation in order to reduce the number of logs which are escaping from booms being towed to or processed in the Fraser River.

Setting a Charge

In order to determine the charge which would be appropriate for reducing log escape, it is necessary to consider the costs at each level of log bundling, which would be borne by the firms
Figure 6: **SETTING A CHARGE** (On recovered hemlock)

11 Charge: $10 per m³
12 Charge: $7.50 per m³
13 Summed t.c.c.: Forest industry cost curve similar to curve 5 (not including boat damage, curve 5).
14 Summed t.c.c.: 6-3.
15 Summed t.c.c.: 7-3.
which operate on the Fraser. In Figure 6 is illustrated these total costs. Curve 13 represents the sum of the costs of log recovery (Figure 5, curve 1), log loss (2), towing (4), debris clean-up (not illustrated), mill up-grading (8), dryland sort construction (9) and bundling (10). These are the costs the industry would incur under a program which would eliminate all water-based log sorting, and would have logs transported only in bundles with the logs lifted onto the mill deck before the bundles were opened. As can be seen, it is not likely that the industry would implement any part of this system voluntarily since its costs at any level of bundling would be substantially higher than the costs would be if no timber were bundled.

The total cost curves have also been derived for the industry if they undertook dryland sorting (14) but no mill up-grading, and only water bundling (15) of the remaining flat rafted timber. These curves are similar to the total social cost curves (6 & 7) in Figure 5. In these two cases it can be seen that for the forest industry the least-cost point would be at 72% bundling, including the bundling of all hemlock. This is the same point which was also determined to be the least-cost point for the sum of the social costs.

It should be noted that the conservative estimates of the benefits (costs of log debris) result in this point being less accentuated than if the benefits are higher. If the benefits
are higher the portion of the curve to the left of the 72% point will be steeper and the 72% point will be shifted upwards slightly. The costs (of preventing log escape) have been consistently over-estimated. If the costs are lower the right side of the curve (to the left of the 72% point) will be shallower and the 72% point will be shifted down. However it is unlikely that the costs are low enough to shift the right side of the curve below the cost level at the 72% bundling and control point. Therefore it can be concluded with some assurance that the 72% point is the least cost point.

A comparison between curves 14 and 15 indicates that the option which includes dryland sort construction (14) will result in the lowest cost for the forest industry, with a savings of around $244,000. Therefore if there are no other major costs, the forest industry would be expected to be heading towards this point with their log handling programs.

In the late 1960's it was recommended by the C.O.F.I. that the forest companies begin to seriously consider bundling. And one of the men most involved with the bundling program of B.C.F.P. has stated recently in a speech that "it is in the log handling portion of our business that we can still find the greatest opportunity for improvements in productivity and cost effectiveness." Many others involved with log handling on the B.C. coast also realize that there are good reasons for
persuing a bundling program. And many are beginning to find that dryland sorting and bundling results in cost reductions. At the present time around 60% of all logs are being bundled. This is up from about 25% in 1970. And it is believed that by 1980, 75% of all logs will be bundled. If the figures in this paper are correct it might be concluded that this predicted level of 75% will not be achieved, rather the industry will probably find that beyond about 72% costs of bundling rise too dramatically. However it must be noted that this predicted level is for the entire B.C. coast whereas the calculations in this paper are for the Fraser alone. With rough weather in some areas requiring special control measures, the cost situation in other log processing areas may be different.

A similar prediction has been made by the individual firms in the forest industry, which indicates that by 1980 the amount of timber bundled on land at the logging operation will rise from about 30% to over 40% of all timber. Thus it can be concluded that bundling and bundling/sorting on land, are considered to be cost effective, and that the industry is heading toward the derived least-cost point.

If there were no other costs to be considered this paper could be completed by stating that the industry will be reaching their least-cost point shortly and will thereby be minimizing the total social costs. However, as was pointed out on page 41
and following, it is necessary to include the unaccounted environmental and social costs in any consideration of log debris. These unaccounted costs are probably high, and if they are reducable by bundling and other control operations, then the control operation which includes mill up-grading becomes an important option in controlling log discharge.

In order to encourage companies to up-grade their mill equipment so that they could remove entire bundles from the water, it would be necessary to impose a charge to shift their least-cost point to the social minimum-cost point of 72% bundling. Using the figures from Table 2 it can be seen that 90 thousand m$^3$ of hemlock is recovered. Furthermore, from the figures mentioned on page 65, it can be calculated that 12 thousand m$^3$ would escape from the land bundled hemlock, 34 thousand m$^3$ from the water bundled and 44 thousand m$^3$ from the flat rafted hemlock. Thus if a charge were set at $7.50 per m$^3$ of recovered hemlock the total charge on the industry would be $675,000. And if the first 12 thousand m$^3$ was not allowed to escape the charge would drop by $90,000 to $585,000. The containment of the next 34 thousand m$^3$ would result in a reduction of $255,000. Finally the containment of the last 44 thousand m$^3$ of hemlock would drop the charge to zero. This effect has been illustrated by adding it to the summed cost curve (13). This results in curve 13 being shifted upwards so that it has the shape of curve 12. As can be seen the charge of
$7.50 per cubic meter was chosen deliberately to result in a curve where the three low points on the curve are about at the same cost level. Curve 11 represents the effect of a $10 charge. Thus it can be concluded that a charge of just over $7.50 would change the forest industry's cost curve so that it would be induced to shift its bundling and control operations to the social minimum-cost point.

At present the recovery cost for one cubic meter of logs is around $39, so a charge of just over $7.50 would be an increase of about 20% in the recovery cost. It is therefore quite obvious that this level of charge could not be imposed in one increment. It would be necessary to gradually increase the charge over a number of years, from a low starting point. This would give the forest industry time to adjust and to make the needed capital changes. It is also possible that the cost curves derived in this paper are not completely accurate. It would therefore be important to consider this as a reason for approaching the proposed charge level slowly, since the actual charge needed could be below that suggested. Should a charge of just over $7.50 be too low, the charge could be raised until the desired effect was achieved. The purpose of this exercise is not to determine an exact charge but to give an approximate estimate of the charge based upon the available data, and upon assumptions about the shape of the cost curves.
The derived charge is a minimum tax for inducing the forest industry to move towards the socially optimal point with its control operations. At any point of control below the 72% level, the costs to those outside the forest industry may be higher than the amount collected from the charge. If this is the case, total compensation for damages would not be possible using only the collected money. Also at the social optimum some logs from the remaining 28% of the uncontrolled timber would still be escaping and causing damage, but those persons damaged by the escaped logs would not be compensated. However, it is not clear whether the charge should be raised so that rather than just change the industry cost curves to make control possible, the amount collected should provide total compensation. Nor is it evident that the industry should be required to pay compensation for damages when it is controlling log escape at the social optimum. And it would seem that the charge should not be imposed at a level which would lead to excessive investment in log handling equipment. These issues indicate that the minimum tax for inducing changes in log control would not necessarily solve all the problems of log debris on the Fraser River, and that there are matters of political concern and for further study.
VI SUMMARY AND CONCLUSIONS

1) There are two major sources of debris on the Fraser River. Natural debris accounts for 8% of the debris and man-made debris contributes 92%. Escaped logs represent 75% of the total Fraser debris.

2) For the 9 million m$^3$ of timber brought to the Fraser, half is hemlock. For all species, 270 thousand m$^3$ (3%) escapes. Of this 35% sinks, 45% is recovered and 20% is lost. For hemlock 225 thousand m$^3$ (5%) escapes; 40% of this amount sinks, 40% is recovered and 20% is lost.

3) Logs escape because of:
   a) high or low bouyancy;
   b) storms, currents, boat wakes;
   c) improper boom towing methods;
   d) poor boom tie-up and construction; and
   e) being submerged in bundles or under barge-dumped piles.

4) Costs associated with forest industry log debris are:
   a) debris clean-up, $299,000;
   b) log recovery, 4.3 million dollars;
   c) log loss, 3 million dollars;
   d) boat/property damage, 1.1 million dollars; and
e) environmental damage and other social costs. Hemlock accounts for at least 80% of the cost of log debris.

5) In order to eliminate the escape of all logs it would be necessary to bundle and sort timber on land and remove unopened bundles from the water at the mill. The costs of preventing all log escape are:

a) dryland sort construction, 4.3 million dollars;
b) debris clean-up at sort, $15,000;
c) bundling, 3.9 million dollars;
d) mill up-grading 4.5 million dollars; and
e) debris clean-up at mill, $43,000.

Thus the total annual cost would be about 12.8 million dollars. To handle the hemlock which is not bundled on land, in this comprehensive manner would cost 6.7 million dollars. Together with the reduced costs (point 4, above) there are two other reasons for implementing this control measure; 1) reduced towing expenses and 2) improved inventory control. The inventory statistics would be useful for industry planning purposes, and there might be better utilization of timber flows. Other less comprehensive methods were also considered. One would consist of water bundling the remaining flat rafted timber, the other of land bundling all timber.

6) The point at which the total social cost would be lowest is where the entire volume of Fraser hemlock is bundled and
controlled in some manner. Also 44% of the other timber would have been bundled at this point. All three of the control methods which are considered, result in total social costs being lower with 72% of the timber bundled, than they are now with 30% bundled. But it should be noted that not all timber should be bundled!

The control method which includes the bundling of timber on land would be better than present timber processing methods since it would save society 1.1 million dollars. The method which includes mill up-grading would save society $665,000. And if unquantified social and environmental costs are above 1.1 million dollars then the control measure which includes mill up-grading would be the best for minimizing total social costs.

7) The industry is expected to be at the optimal level of dryland sorting and bundling around 1980. In reaching this point, total social costs and industry costs will be minimized. However the program which the industry is pursuing does not include mill up-grading. If unquantified environmental and social costs are high then it would be necessary to encourage the industry to internalize the costs which they are inflicting upon society. In this study it has been determined that a pricing mechanism, a charge on recovered logs, is better than self-regulation or legislated enforcement for achieving a reduced level of log discharge. The charge system is advocated
because:

a) It is feasible to implement since the institutional arrangement already exists. Gulf Log Salvage is responsible for managing the return or sale of recovered logs. A charge could be easily assessed on these logs.

B) A company's least-cost combination of measures for the pollution and the least-cost distribution among polluters will be induced, minimizing the real cost of achieving a reduced level of discharge.

C) Innovative cost-effective methods of log handling and transportation will be encouraged.

D) Companies will be competing for the 'right' to pollute and thus the use of the river, establishing a rental value on a common property resource.

E) Revenue from the charge can be used for among other things, compensation of injured members of society.

A charge of just over $7.50 per cubic meter of recovered timber would theoretically be the charge necessary to induce mill up-grading in order to reduce log escape to the socially optimal level. This charge would be a 20% increase on the present recovery cost. It would therefore be necessary to impose the charge slowly, increasing the amount incrementally, so that the industry would have time to make capital adjustments.
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II COMPOSITION OF WOOD DEBRIS IN THE LOWER FRASER

1 13.7
2 2; 6.2; 8.5; 11.7
3 39
4 Stan Nichols of B.C.F.P.
5 3.8; 4.1
6 2
7 4.4-9; 7; 11.9; 23
8 2; 4.10; 23; 29
9 4.11; 6.4; 23; 39
10 2; 20
11 4.4-9; 7; 11; 30
12 28; 30; A dead-head is a log which has more than three quarters of its length submerged, and/or one end diameter entirely above the surface of the water.
13 Slash consists of branches, tree-tops, bushes, small trees and other logging waste.
14 3.8; 4.13-17; 8.68
15 8.68
16 3.1
17 2; 8.5
18 8.4
19 2; 8.5
20 8.17
21 The spring run-off period, around May to June.
22 2
23 2; 8.5
24 3.1
25 1; 4.3,4; 8.10; 27
26 1; 4.3
27 8.11
28 8.11,68
29 8.11,35
30 A series of logs connected with chains; generally not of a fixed shape.
31 8.16; 35
32 1; 2; 3; 4.8,10; 8.8,10; 23; 28; 36
33 8.8
34 see 45
35 8.16
III THE COSTS OF LOG DEBRIS

1 13
2 13
3 35
4 30
5 30
6 29; 36
7 6.15
8 8.70; 36
9 35
10 36
11 36
12 36
13 2; 36
14 8.11-17
15 8.11-17; 35
16 11.5
17 28
18 8.65,66; 12
19 28
20 4.34,35
21 33; 34
22 33; 34; 37
23 32; 34; 37
24 4.34-37; 11.12,13; 24; 32; 34; 37
25 B.C. Safety Council
26 34; 37
27 37
28 37
29 32; 37
30 16
31 19
32 11.1
33 8.11-17; 35
34 4.44; 27; 28; 29; 30; 36
IV THE COSTS OF PREVENTING LOG ESCAPE

1.3,14,15; 4.23,27,38; 27; 28; 39
2.1.17; 27; 39
3 27; 39
4 27; 39
5 1.15; 4.38
6 27; 39
7 4.37; 8.16; 28
8 28; 36
9 28
10 27; 39
11 27; 28; 38; 39
12 28; 38
13 At 3 million m$^3$ of timber with 200 sorting grounds, each ground would handle 150 thousand m$^3$ per year. With only 200 operating days per year 750 m$^3$ of timber would be processed daily. With average bundles at 30 m$^3$ each, sorting grounds would produce 25 bundles per day or 3 per hour.
14 1.14,15
15 39
16 28; 39
17 28; 39
18 28
19 27; 39
20 27; 39
21 21; 39
22 27
23 2; 20
24 1.20
25 1.20
26 29
27 27
28 2; 20; 27 ; 28
29 2
30 27
31 26
5 DETERMINING THE OPTIMAL SOCIAL COST

1 1; 2; 3; 4.8,10; 8.8,10; 23; 28; 36
2 10.98,99
3 11.22
4 9.3,135; 11.26
5 11.27
6 10.60-69
7 10.72
8 9.169
9 11.33
10 9.169
11 11.33
12 11.29,33
13 11.27,33
14 1; 23
15 39
16 28; 36
17 27
18 4.6,7; 28; 36; 39
19 28; 36; 39
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