Environmental Considerations in the Pulp and Paper Industry

World Bank/December 1980
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in the
Pulp and Paper Industry

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Foreword

This document is intended as an environmental manual for the pulp and paper sector. Its main purpose is to provide general guidance to those planning, assessing or instituting projects involving the production of pulp and/or paper.

While the material has been prepared primarily for use by the staff of The World Bank, its use by other institutions and agencies is both welcomed and encouraged. It is hoped that the document will be particularly helpful to administrators, planners, environmentalists and others—both public and private—concerned with forest products industrial development.

Experience in many countries has shown that if inadequate consideration is given to the environmental consequences of man's activities, serious damage can occur and correction is both slow and extremely costly. This fact is particularly relevant to the global pulp and paper industry because of the industry's vast size and its interaction with varied environmental components, from the forest resources to the culture of the Earth's inhabitants. It is encouraging that in many forest products development projects, it has been possible to strike a balance between industrial activities and environmental quality, at marginally extra costs. However, if this experience is to become commonplace, environmental factors must be given appropriate consideration during the project's evolution.

The guidelines presented in this manual are not rigid. No two situations are identical and modifications may be required for the application of these guidelines to specific circumstances. It is intended that this document be read in conjunction with the more general World Bank publication, "Environmental Considerations for the Industrial Development Sector." The general manual contains, for instance, a Glossary of Terms, which is also applicable to the contents of this manual.

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Chapter 1
Overview of the Industry

Its structure and Relationship with the Environment

1.1 The Importance of the Pulp and Paper Industry

More than 99.5% percent of pulp and paper products are produced from the pulp of natural fibrous stems. In countries with minimal forest resources, up to half of the pulp is produced from recycled paper but on a world basis, only about 25 percent of pulp is manufactured from recycled material. Consequently, the manufacture of virgin pulp is a large-scale international business, with about 70 nations producing approximately 120 million tons each year. The leading pulp producers are the U.S.A., with about 35 percent of the world’s production, and Canada with about 10 percent. They are followed by the U.S.S.R., Japan, Sweden, Finland, China and Brazil. Approximately 20 percent of the world’s virgin pulp is produced in Asia, South America and Africa, and this proportion is increasing.

While wood is used to produce about 94 percent of virgin pulp, non-wood sources are also important, particularly in developing countries. Bagasse, straw and bamboo are the main non-wood sources of pulp; minor sources include reed, hemp, jute, flax, cotton and rags.

The dominating consumption of pulp fibers is for paper and paperboard, this outlet accounting for approximately 95 percent of all pulp produced. The remaining 5 percent is high-grade material, referred to as dissolving pulp, which is mainly used to produce rayon. On a world basis, about two-thirds of paper pulps are used to produce various papers, including newsprint, while the other third is used for various kinds of paperboard.

1.2 Conventional Pulping Processes

Fibers are the basic raw material for papermaking. These fibers are mainly composed of cellulose, which constitutes 40 to 50 percent of the dry weight of wood and non-wood fiber sources. The other major chemical components of fibrous materials are the hemicelluloses and lignin; these substances cement the fibers together. Minor components include
mineral matter and various substances extractable with solvents. Long fiber length is an important characteristic in imparting strength to paper. Usually, softwoods such as pine have longer fibers than hardwoods. In general, the non-wood plants used to produce pulp and paper have short fibers. Consequently, when a choice is available, softwoods are the preferred fiber resource. Some developing countries, particularly in the temperate region, are establishing softwood plantations by replacing indigenous species.

The purpose of pulping is to liberate the fiber from the wood. There are basically two methods of accomplishing this: mechanical pulping and chemical pulping. On a world basis, the split in production between the two methods is roughly $\frac{1}{3}$ and $\frac{2}{3}$, respectively.

Mechanical pulping involves grinding the wood. The fibers are damaged but the yield is high, typically 95 to 97 percent of the dry weight of the wood. Since fiber strength is degraded, it is most common to grind the long-fibered softwood species so the residual strength is still reasonably good. However, in some areas of the world where softwoods are not available, hardwoods are being used to produce mechanical pulp, often after a mild chemical treatment of the wood to soften the bonding lignin and to minimize the degradation of the fibers in the grinding process. Because of their lower strength, mechanical pulps are used mostly in paper grades where strength is not a critical specification or where the strength deficiency can be remedied to some extent by the addition of a proportion of stronger chemical pulp.

Chemical pulping involves chemical treatment of wood to remove lignin and carbohydrates that cement fibers together. This makes fiberizing possible without mechanical treatment. The fibers are relatively undamaged and they are considerably longer than groundwood fibers. As a result, chemical pulps have higher strength than mechanical pulps and are in greater demand for end uses where strength is an important consideration.

In chemical pulping processes, such as kraft (also called sulphate), about half of the raw material is solubilized in the cooking liquor. This spent material, lignins, hemicelluloses and carbohydrates, is concentrated and then burned in a boiler to produce steam, which is sometimes converted to electrical energy. This so-called “recovery” operation also reconstitutes chemicals that are required in the pulping process. If a mill has integrated power generation facilities, the steam and electrical energy produced by the recovery operation, when supplemented by a furnace burning woodwaste, are sufficient to make a modern kraft mill nearly energy self-sufficient.

Mechanical pulping processes require a large amount of electrical energy to grind the wood. Since these processes do not generate liquors
containing dissolved wood material which can be burned for energy-recovery, this electricity must either be supplied from the national grid or generated on-site through burning of auxiliary fuels, such as oil, coal or fuelwood.

The development of mechanical pulping illustrates the evolution of trends in technology, wood resource abundance, energy, product quality and labor requirements. Mechanical pulp was first produced in North America by the stone-groundwood process in the mid 1800s; this process involved pressing wet logs against a rotating grindstone. The process was, and still is, relatively labor intensive and it produces a pulp from softwoods at a comparatively low cost. These mills were often located near a source of hydro-power which was used to turn the grindstones. In the 1950s, when labor became scarcer and more costly, suitable pulping logs were less available and energy was still cheap, the refiner mechanical pulping process was developed. This technique involves grinding wood particles such as wood chips and residual sawmill wastes between revolving plates. The pulp is generally of better quality than that from a stone-groundwood mill and is more suited to modern high-speed paper machines. This type of pulping usually requires less labor than a stone groundwood mill but electrical energy requirements are about 40 percent higher. The logical extension of the refiner-groundwood process was thermo-mechanical pulping, first used commercially in the early 1970s. Thermo-mechanical pulping involves pre-treating the wood chips with steam to soften the wood before refining. Although more expensive, the pulp produced from the thermo-mechanical process is of significantly better quality than refiner-groundwood pulp. Newsprint has been manufactured solely with thermo-mechanical pulp but some chemical pulp furnish is normally required for strength purposes. Pre-treatment of the chips in the thermo-mechanical process releases more wood extractives; thus the water pollution load is somewhat more severe than with stone or refiner groundwood pulping. More recently still, has been the advent of the chemi-thermo-mechanical process in which the chips are chemically treated in the steaming vessel. Pulp quality is further improved, energy requirements somewhat reduced and water pollution load is increased. With this process, and with thermo-mechanical pulping, there is a potential for minor air pollution problems from releases of volatile wood compounds.

A chemical pulp mill is a more complex facility than a groundwood mill and the capital investment for a chemical pulp mill is accordingly higher. Chemical pulping is more expensive due to the cost of chemicals and a pulp yield which is normally only about half that of mechanical pulping. Also, there is more potential for environmental pollution with chemical pulping. However, the higher strength and greater versatility
of chemical pulps allow them to command a selling price about twice that of groundwood pulps. Because of their lower cost and special physical characteristics, groundwood pulps are used principally in large-volume and uniform grades of paper such as newsprint, where price is more of a concern than quality.

A small portion of the world's pulp, about 10 percent, is produced by processes that involve a combination of pulping methods. These processes typically involve a limited chemical treatment of the wood, followed by the application of mechanical methods to liberate the fibers. The yield with these processes typically lies between those for mechanical pulping and for conventional chemical pulping processes such as kraft. Two of the most important of these types of processes are the neutral sulphite semi-chemical process and the high-yield kraft process.

There are, therefore, a wide range of pulping processes to suit the particular end product. In general, the manufacturing cost and pollution-potential increase in proportion with the quality and strength of the pulp. These comparisons are shown in Table 1-1.

Where pulp is to be used for the manufacture of high-quality papers, the pulp is usually bleached, using various chemicals. For groundwood pulps, the discoloring material is whitened and since most of the material remains with the pulp, there is little attendant yield loss. With chemical pulps, the discoloring material is removed from the pulp by dissolution, with yield losses of up to 10 percent.

The two main chemical pulping methods used today are the sulphite process and the kraft process. The sulphite process was the dominant pulping process until approximately 1935 because sulphite pulp was considerably cheaper and easier to produce than kraft pulp. After 1935, technical advances and improved plant design brought kraft pulp costs in line with those of sulphite pulp; the most important factor in this was the development of a kraft recovery cycle which generates most of the steam required by the mill and recovers the cooking chemicals with a high efficiency. The situation of comparative costs continues today, with product quality favoring the kraft process. The kraft process has been found adaptable to practically all wood and non-wood sources of fiber and can be applied in many situations where sulphite pulping is unsuitable. Kraft pulps produce stronger paper than sulphite pulps. The main disadvantage of the kraft process is that kraft pulps require more bleaching. However, development of bleaching technology, particularly the introduction of chlorine dioxide bleaching, has facilitated bleaching kraft pulps at acceptable cost.

In the pulp and paper industry as we know it today, the kraft process is the dominant chemical pulping process. Although the kraft process may undergo some modifications, it will continue to be important, in
**TABLE 1-1: Comparison of Softwood Pulping Processes**

<table>
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<tr>
<th></th>
<th>Mechanical Pulping</th>
<th>Chemical Pulping</th>
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<tbody>
<tr>
<td></td>
<td>Stone Groundwood</td>
<td>Refiner Groundwood</td>
</tr>
<tr>
<td>Yield on Dry Wood</td>
<td>96–97%</td>
<td>94–95%</td>
</tr>
<tr>
<td>Energy Requirements</td>
<td>energy intensive</td>
<td></td>
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<tr>
<td>Pulp Strength</td>
<td>lowest</td>
<td>increasing to</td>
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<tr>
<td>Technological Complexity</td>
<td>lowest</td>
<td>increasing to</td>
</tr>
<tr>
<td>Capital Cost</td>
<td>lowest</td>
<td>increasing to</td>
</tr>
<tr>
<td>Labor Requirements</td>
<td>high</td>
<td>low</td>
</tr>
<tr>
<td>Water Pollution Potential</td>
<td>low</td>
<td>low</td>
</tr>
<tr>
<td>Air Pollution Potential</td>
<td>nil</td>
<td>nil</td>
</tr>
</tbody>
</table>

its basic form, for some time, particularly in developing countries. About 80 percent of all world chemical pulp mills are kraft.

While some end uses favor the sulphite process, it is expected that the use of the sulphite process will decline in the future and that few new installations will involve this process; however, unforeseen breakthroughs in sulphite pulping technology, which is more conducive to manufacture of by-products from the waste liquor, may change this trend.

1.3 Magnitude of Typical Projects

In industrialized countries, chemical pulp mills seldom have a capacity of less than 500 tons of pulp per day. However, in developing countries, pulp mill capacities as low as 50 tons per day can be justified due to different economic and social circumstances. For example, non-wood fiber sources, which tend to be common to developing countries, favor smaller mills because of transportation economics.

Paper mills can be either separate or integrated with pulp mills. Where the product is various grades of printing, writing and specialty papers, paper machine capacities are generally comparatively low, and seldom exceed 100 tons per day. This is the case particularly in developing countries where the few paper machines in a typical country are required to produce many and varied grades of paper that the internal market demands. Where machines produce a single grade and where quality is of lesser importance, such as with newsprint and wrapping paper, machines usually have greater capacities and are almost always integrated with pulp mills.

From the environmental standpoint, pulp mills and integrated pulp and paper mills have broadly similar problems, and while mitigating measures may differ, these types of mills can be considered equal during project planning stages. Non-integrated paper mills usually have a relatively minor pollution potential and it is not uncommon for new paper mills to be located in urban areas. It should not be implied from this that lesser importance should be given to pollution control at non-integrated paper mills. Rather, the problems and solutions are more straightforward, providing the issues are identified and addressed early in the planning process.

For a pulp or integrated pulp and paper mill with a production capacity of 150 tons per day, the land area required for the mill site would typically be about 200 hectares. The site must be close to the fiber resource, transportation, power networks, an adequate work force and a good supply of fresh water.

A modern 150 ton/day chemical pulp mill typically uses up to 200 m$^3$ of fresh water per ton of pulp. Thus, a mill must normally be located
close to adequate receiving waters for wastewater discharges; these receiving waters may be the ocean, a large lake, or a river with a minimum flow adequate to assimilate the appropriately treated effluent. Mills with smaller production rates and less noxious effluents, such as non-integrated paper mills, may be able to use the effluent for irrigation purposes or have common treatment with municipal sewerage systems.

The land area required to supply the fiber resource depends on the type of material harvested and the climate. For pulpwood, rotations of 12 to 15 years for coniferous species and of 5 to 10 years for broad-leaved species are common in the tropics and subtropics, and between 20 to 30 years for conifers and 8 to 15 years for broad-leaved species in the temperate zones. In Chile, a newsprint mill with a capacity of about 200 tons per day has about 16,000 hectares of *Pinus radiata* under plantation to supply the pulp furnish. In Burma, approximately 200 hectares of bamboo would be required for each ton per day of pulp mill capacity.

In an industrialized country, a pulp mill with a daily capacity of 750 tons would employ about 300 people in the mill and a similar number to harvest the wood. However, these operations are generally sophisticated and highly mechanized. In developing countries, conditions usually favor more people-intensive operations and as a result, the number of people employed could be up to ten times higher than in industrialized nations. A pulp mill and the associated harvesting operations also generate indirect employment in the form of shopkeepers, school teachers, private contractors and the like. Such indirect employment is usually several times greater than the direct employment created.

Energy requirements vary with the type of process used. Chemical pulping processes are potentially almost energy self-sufficient in instances where wastewood co-generation is practiced, while mechanical pulping processes require energy input. Electrical energy requirements for mechanical pulping processes range between 1200 and 2500 kwh per ton of pulp, depending on the wood species, pulping process and product; this is equivalent to approximately 0.1 to 0.2 tons of oil per ton of pulp. For all pulping processes, the required input of external energy can be minimized by generating energy from the available waste wood materials, or, as is becoming increasingly popular, by establishing fuel-wood plantations near the mill site.

### 1.4 Possible Impacts

Pulp and paper mills built prior to about 1970 were planned in an economic and social climate quite different from that of today. In those days, generally, wood was relatively cheap and plentiful, and energy and chemicals abundant and fairly inexpensive. With a few exceptions,
notably in Central Europe where the wood resources are scarce and where trans-frontier pollution was recognized sooner than in other countries, the political climate in most industrialized nations encouraged rapid growth with minimal regard for conservation practices. As a result, pulp and paper mills focused on making as much product as possible, while giving little attention to how this was achieved, other than considering the total production cost.

This historical analysis emphasizes the rapid change during the 1970's. Wood resources are now no longer considered to be unlimited, and new pulp mill developments generally must take place in “frontier” areas; mill construction costs, energy and chemical prices have escalated; and the emergence of environmental awareness has penetrated national and corporate policy planning. These events have radically affected the design and operating philosophies of pulp and paper mills. Consequently, this industrial sector on a worldwide basis, is one of the most advanced in understanding the effects of its activities and in developing methods to control its effects on the social, terrestrial, aquatic and atmospheric environments.

Of all the forms of pollution, air pollution is usually the most noticeable and objectionable to the general public. The main potential emissions from pulp mills are particulates and odor. However, particulates can be removed and odor can be restricted to an almost “odor-free” level, except during process upsets and extremely adverse meteorological conditions. Compared to other industries such as metal smelting, the modern pulp and paper industry does not have serious air pollution problems. However, the pulp and paper industry, in general, has serious water pollution problems. Nonetheless, these problems can be avoided by proper mill design and operation coupled with adequate treatment and disposal of effluent. It is possible to operate a pulp mill with virtually no objectionable air or water emissions, at minimal extra costs.

It is important, however, to emphasize that there may be subtle effects of air and water emissions that are presently not understood. In particular, scientists are concerned that there may be a relationship between health effects and long-term exposure to low water-borne and air-borne concentrations of pulp mill contaminants. While such a relationship may or may not exist, it is prudent to consider that it might.

The harvesting of fiber resources usually represents the most significant potential environmental impact in pulp and paper projects. Poor harvesting practices can lead to soil erosion with attendant reduction in water quality in streams and rivers. Sensitive tropical soils can be modified by extensive exposure to the sun. Also, harvesting drastically alters the habit for terrestrial wildlife. There could be a reduction in the potential use of the forest by local people for gathering fuel wood, hunting,
fishing, picking fruits and vegetables and collecting building materials. Increased access to the forest by men and equipment may lead to a higher frequency of forest fires. It is emphasized however, that with good forestry practices there are excellent opportunities for environmental benefits, through improved wildlife management, and better access for recreational enjoyment.

Agriculture can be affected by a pulp and paper project in a number of ways. Since pulp mills are usually located in rural areas, some people who have traditionally been farmers, work at the mill and in the forest; this leaves fewer people to produce the same quantity of food, and to do this, they must become more efficient. This problem can be compounded in cases where fiber resource plantations displace valuable agricultural land. In some cases, treated mill wastewater can be used for irrigation, thereby complementing agriculture; however, where the pulping process involves bleaching, high salt concentrations may make the waste water unsuitable for agricultural uses.

The effects of a pulp mill development on local inhabitants can be both positive and negative. For example, urbanization can increase the potential for increased communication of disease but better medical attention is available. Urbanization increases communications, transportation and the general level of social services but the number of workers attracted to an area by a new industry may exceed this increase in available services.

Overall, judicious employment of modern technology allows mill designers to minimize negative impacts on the environment and maximize positive impacts such that development of a pulp and paper enterprise can be of net benefit socially, economically and in some cases environmentally.
Chapter 2

Environmental Input into Project Planning

It is World Bank policy to review and evaluate every investment project from the standpoint of its potential effects on the environment. In practice, this review process has one of three outcomes: no apparent problem; no apparent problem, providing appropriate remedial measures are instituted; and potential problem requiring further elaboration. It is probably accurate to state that virtually all proposed pulp or integrated pulp and paper projects initially fall into the last category, but move into the middle category as the project planning progresses. This fact alone should be sufficient justification for suitable environmental input into project planning.

It is also the World Bank's experience that no project has been deemed not viable solely because of the cost of pollution control. As a rule of thumb, depending on the definition of pollution control the probable cost of applying modern environmental controls to a new pulp mill is less than three percent of the initial investment. However, this cost escalates if precautionary measures are not included until the eleventh hour. Also, while pollution control incorporated into the mill process generally carries a return on the investment, this incremental return is usually fairly low, which causes a dilemma when capital funds are limited.

It must be emphasized that the high cost of pollution control systems in many industrialized countries are mainly caused by retroactively correcting past mistakes. The prospect in, and the wish of, almost all developing countries is to prevent these costs by not permitting environmental degradation from occurring in the first place.

Until recently, environmental concerns have been generally ignored or inadequately considered in most development plans, both in developed and developing countries. Today, it is recognized that man cannot continue to disregard the natural environment and environmental concerns must be incorporated into the planning and decision making processes, just as other factors are taken into account. It should be possible,
with the proper approach, without great disruption or cost, to decide to abandon or change proposals at an early stage or to seek alternatives to projects which have an unacceptable effect on the environment, in much the same way that technical or financial reasons may alter the concept of a project.

A common sequence of events in the development of any project is illustrated in Table 2–1. Initially, the opportunity or need for a development must be identified, based on the availability of a resource. Then, informal investigations are conducted to determine, in a general manner, whether the identified resource offers some prospect of successful utilization and that there are no obvious major obstacles to the project.

**TABLE 2–1: Sequence of Events in Project Development**

<table>
<thead>
<tr>
<th>Identify Opportunity</th>
<th>— Based on the resources.</th>
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<tr>
<td>Preliminary Investigations</td>
<td>— Informal studies to determine if a viable project seems to exist.</td>
</tr>
<tr>
<td>Preliminary Feasibility Study*</td>
<td>— Formal evaluation of opportunity and establishment of project parameters.</td>
</tr>
<tr>
<td>Feasibility Study—Stage 1*</td>
<td>— Definition of project, resource studies, market evaluations, selection of site alternatives and alternatives for production process and capacity.</td>
</tr>
<tr>
<td>Feasibility Study—Stage 2*</td>
<td>— Site identification and detailed estimates of cost and financial evaluations.</td>
</tr>
<tr>
<td>Financing</td>
<td>— Commitment of capital.</td>
</tr>
<tr>
<td>Design Development</td>
<td>— Establish final design parameters of mill and order major process equipment. Preparatory site work.</td>
</tr>
<tr>
<td>Engineering and Construction</td>
<td>— Detailed design of mill components and purchase of equipment. Erection of buildings and equipment installation.</td>
</tr>
<tr>
<td>Start-up and Operation</td>
<td>— Operation of individual equipment and integration of operation to achieve rated capacity.</td>
</tr>
</tbody>
</table>

*There is some scope for simplification and combination of the three stages of feasibility study, depending on the project.*
The next step is normally a preliminary feasibility study to get a more specific definition of the most likely viable project and possible alternatives and to undertake some technical, economic and environmental studies to determine whether a full feasibility study would be justified. Environmentally, these studies consider potential areas for industrial sites and identify sensitive aspects of the project which require more detailed study.

Having confirmed that a viable project probably exists in the preliminary feasibility study, a full-scale feasibility study is undertaken to confirm the preliminary findings and to develop more detailed estimates upon which a final assessment of the proposed project can be made. In major projects, the feasibility study is often divided into two stages. In the first stage detailed evaluations of the resource are made; possible alternatives are assessed and the preferred manufacturing processes and size of plant are selected; and possible industrial sites are identified and evaluated. In the second stage of the feasibility study, the best site is selected and detailed capital and manufacturing cost estimates are prepared and financial evaluation and risk analyses are made.

It is during the first stage of the feasibility study that the main environmental assessment should be undertaken. Environmental data, along with technical and economic information, are used to compare the various alternatives, to make decisions on their acceptability and to determine the optimum project configuration.

Integration of environmental concerns into planning and decision-making involves a sequence of steps. The first step is the preparation of a description of the existing environment, before it is altered by the development. This environmental inventory provides a baseline against which predictions of change due to the proposed development action can be measured.

In developing countries, some environmental inventory data are generally available from government agencies. This basic information includes meteorological data from regional monitoring stations; long-term flows and water quality data for local surface waters, particularly the projected source of process water; existing land use and planned developments in the region; present uses of surface waters in the forest and development site areas; data concerning natural plant and animal life and rare or endangered species in the region, particularly in the forest areas; description of archaeologically or historically significant sites in the region; existing or proposed industrial activities in the area and their environmental consequences, and regional population and infrastructure statistics. The collection of this information usually requires visits to local, regional and national government agencies. In many cases, information available will be incomplete and field studies
by experienced environmental experts are necessary to provide proper inventory data.

Based on the inventory and proposed development plans, interactions between the development actions and the existing environment can be predicted and a measure of the order of importance of these interactions made. Prediction of potential interactions must relate many development actions and environmental factors and place value judgments on impacts that are difficult to quantify. Some systematic methods developed to evaluate and compare these intangible environmental aspects are described in Chapter 3.

Once the major potential environmental impacts are identified, remedial measures to minimize adverse effects or to enhance the existing environment can be incorporated into the development plans. Remedial measures can include air pollution control systems, wastewater treatment and disposal facilities, process changes, and modified forestry activities. These measures are incorporated into the cost and financial studies in stage two of the feasibility study.

Upon completion of the feasibility study, the technical, commercial and environmental viability of the proposed development project has been established and the requirements to minimize adverse affects on the environment to acceptable levels have been determined. During the design development phase of the project, parameters are studied and components designed to meet the established environmental constraints. At this stage, special studies are initiated to develop technical information for design of process and treatment systems. These studies may include atmospheric modelling to evaluate dispersion of air emissions, biological and assimilative capacity studies to determine best means of effluent treatment and discharge into the receiving water, water quality monitoring to provide data for design of process water supply facilities and reforestation studies to optimize future production from forested areas.

During the engineering and construction phases, the mill design is established, the process equipment is purchased, the site is prepared and buildings are erected and services and equipment installed. Environmental input during these phases is important. The layout of the process, the type of equipment selected and the methods of construction can all have a major effect on the operating efficiency and reliability of pollution control systems. Operating reliability of treatment systems is a significant consideration. In most mills, production is the prime objective and pollution control receives much less attention from operating and maintenance personnel. Thus, equipment and systems must be designed to minimize operational and maintenance problems to achieve emission objectives.
Environmental Monitoring

In most instances, forestry developments are sited in rural areas where detailed knowledge of local ecosystems is not extensive. Therefore, environmental baseline studies are normally desirable to provide detailed scientific data on the physical, chemical and biological characteristics of an area, before any significant changes are caused by development activities. The data provide a documented reference against which future perturbations can be monitored. They also provide detailed local information on the capacity of the ecosystems to assimilate various wastes from the proposed development, identify sensitive components of the local environment that may require special attention and provide guidance for the design of process and waste treatment facilities so that environmental damages can be averted or minimized.

Post-operational environmental monitoring is desirable to provide continuous feedback to the operator of a development on the effects of the operation on the environment. It enables definition and quantification of environmental changes due to the operation and identifies those areas where modifications to the process or operating procedures are necessary to reduce adverse effects. Just as continuous sampling and testing are used to control the quality of manufactured products, environmental monitoring provides quality control for the surrounding environment which is used to assimilate the by-products of the manufacturing process.

Management and Operator Attitudes

A successful pulp and paper enterprise is one in which all personnel are motivated to meet the objectives of the enterprise. Almost all pulp and paper operations have corporate policies pertaining to protection of the environment. The more difficult task is to put these policies into practice.

Mills which have most successfully implemented their environmental policies are usually those which place equal importance on sustaining production and on ensuring satisfactory operation of pollution control systems. They view waste treatment processes as part of the overall mill operations. Consequently, all levels of personnel, and not just waste treatment plant operators, contribute to the pollution control efforts.

There are many means of ensuring that pollution control is considered integral with mill operations: daily production reports list the pollution statistics of the previous day; operators of production departments are given a brief pollution control course during their basic training; a system is developed for reporting and appraising every spill; each department is given a targeted effluent loss; maintenance needs for pollution control equipment are given a reasonably high priority. Above all, a clean and
tidy mill goes a long way towards creating employee pride in the workplace which is partly manifested in a good environmental effort. If this basic philosophy of viewing environmental protection as being an integral part of the overall project is followed through the planning, development and operation of the project, a major step will be made towards creating an harmonious balance between industry and the environment.
Chapter 3
Environmental Assessment
Methodology

3.1 Introduction
An environmental impact assessment involves the prediction of environmental changes that may result from proposed development actions. The main function of the assessment is to identify contentious environmental issues, such that mitigating measures can be considered. If done properly, the impact assessment incorporates environmental factors into the overall appraisal of a proposed development during the project conception and the planning stages, before irrevocable decisions concerning the project are made. With any proposed development, it is common economic and engineering practice to analyse the need for the development and its commercial viability. It is almost impossible to realistically express environmental factors in monetary terms such that they can be included in this traditional cost-benefit analysis. Thus other methods are used to ensure that unquantified environmental factors receive proper consideration, along with the engineering and economic factors, in the evaluation of proposed development actions.

3.2 Components of an Environmental Impact Assessment
An environmental impact assessment consists of five basic components:

(a) A complete analysis of the need for the proposed development action. The justification should include the full range of values to be derived, not just the cost-benefit analysis. It should also include a discussion of the overall development objectives and, if possible, technological alternatives to achieve them.

(b) A description of the physical, chemical, biological and social environments that may be affected, including careful delineation of the boundaries of the project. There should be special emphasis on rare or unique aspects of the environment, both good and bad, that
might not be common to other similar geographical areas. There should be sufficient information to permit an objective evaluation of the environmental factors which could be affected by the proposed actions. Biologically, the description should include all factors which make up the ecosystem of the area. A brief list of the major topics usually included in the description of the existing natural and man-made environments for a major pulp mill development project is shown in Table 3-1. Actual topics for any one project would depend on the circumstances at that project.

(c) A description and discussion of pertinent details of the proposed development action. This should include discussion of possible alternative engineering methods or approaches to accomplish the proposed objectives. The analysis should be done in sufficient detail that all actions which may have an impact on the environment are checked. The description of the proposed action should also include details of the project’s infrastructure.

The details of the proposed action should outline the basic production processes, giving physical dimensions, capacities, and raw materials, along with a simple process flow diagram. Air emissions and wastewater discharges should be shown on the flow diagram and internal and external treatment systems should be described. Estimated characteristics of final discharges should be given.

Alternative site locations for the proposed development, the environmental and other factors considered, and the reasons for selecting the favored site should be presented. The main process alternatives considered should also be presented, reasons given for the process selected, and general effects of the process on key environmental areas should be discussed. Pollution control system alternatives should be presented and selected control methods stated, giving the reasons for their selection.

(d) Evaluation of the probable impact of the variety of specific aspects of the proposed action upon the variety of existing environmental parameters. The discussion of these items should especially include the following:

(i) Any probable adverse affects which cannot be avoided.

(ii) The relationship between local short-term uses of man’s environment and the maintenance and enhancement of long-term productivity.

(iii) Any irreversible and irretreivable commitments of resources which would occur if the proposed action were implemented.
### TABLE 3-1: Possible Topics Included in Description of the Environment

<table>
<thead>
<tr>
<th>Natural Environment</th>
<th>Manmade Environment</th>
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<tbody>
<tr>
<td><strong>Atmosphere</strong></td>
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<tr>
<td>Climate, Air Quality</td>
<td>Demography</td>
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<tr>
<td><strong>Land</strong></td>
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<tr>
<td>Topography, Geology</td>
<td>Economic and Social Conditions</td>
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<td>Soil Characteristics</td>
<td>Government Structures and Services</td>
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<tr>
<td>Groundwater Characteristics</td>
<td>Land Use</td>
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<tr>
<td>Flora and Fauna</td>
<td>Existing and Planned Archeological and Historical Sites</td>
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<tr>
<td>Rare or Endangered Species</td>
<td>Tourism and Recreation</td>
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<td>Sensitive Areas</td>
<td>Sensitive Areas</td>
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<tr>
<td><strong>Water</strong></td>
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<tr>
<td>Volumes and Flowrates</td>
<td>Communications</td>
</tr>
<tr>
<td>Water Quality—Physical, Chemical, Biological Physical Characteristics of—Water Body—Flora and Fauna—Rare or Endangered Species—Sensitive Areas</td>
<td>Transportation</td>
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<td>Resource and Energy Use</td>
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<tr>
<td>Forest Fuels and Electricity Minerals and Chemicals Fisheries</td>
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<tr>
<td>Water Use Programs Hydroelectric Water Supply Systems Irrigation Wastewater Systems</td>
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<tr>
<td>Proposes Development Projects</td>
<td></td>
</tr>
<tr>
<td>Aesthetics Noise, Odor, Scenic</td>
<td></td>
</tr>
</tbody>
</table>
(iv) Where appropriate, a discussion of problems and objections raised by government agencies and by private organizations and individuals and the means by which these issues can be resolved.

(e) A discussion of the relative merits of various proposed actions and alternative engineering plans and an explanation of the rationale behind the final choice of action and the plan for achieving the stated objectives.

3.3 Procedures for Assessment of Environmental Impact

It is extremely important that an environmental assessment of a proposed project be directed at that particular project and that it be no more detailed than necessary. If the assessment contains excessive superfluous detail, then its usefulness to the decision makers is reduced. For example, there might be no need for an environmental impact assessment for a small paper mill project if it is decided that no deleterious changes will occur, provided suitable provisions are made for effluent treatment. However, the other extreme might be a large, integrated forest products development proposed for an ecologically sensitive area. In this latter example, intense environmental studies might be necessary to ensure that conflicts are resolved.

Effective prediction of the environmental impact of a proposed development must relate large numbers of actions and environmental factors and place value judgements on impacts which are difficult to quantify. There is no rigid formal method for making evaluations; a good deal of flexibility is needed because projects differ greatly. However, particularly for large scale projects, some form of structured methodology is desirable to keep things in focus and in the proper perspective. Several methods, which provide guidelines for evaluating both tangible and intangible aspects of environmental quality are widely used. Two of the most popular general methodologies for impact prediction are the Leopold Matrix and the procedure developed at the Battelle Columbus Laboratories in the United States. Of these two methods, the Leopold Matrix is the most widely used.

The Leopold Matrix

The Leopold Matrix is a large two-dimensional matrix. It lists on one axis, the development actions which could cause environmental impact, and on the other, existing environmental conditions that may be affected. The items on the axes are general enough to be used as a reference checklist of the full range of actions and impacts that may relate to the proposed development. The axis listing environmental factors
that may be affected is also useful as a reference and checklist in describing the existing environment.

Each matrix intersection requires the consideration of the impact of an action on an environmental condition. Both the magnitude and the importance of the impact are considered. The term magnitude is used in the sense of degree, extensiveness or scale of the action. Importance is an indication of the significance of the effect of the particular action on the environmental factor under analysis. Magnitude and importance are generally assigned numbers from 0 to 10 for each intersection. Unlike magnitude of impact, which can be more readily evaluated on the basis of facts, evaluation of the importance of impact generally will be based on the judgement of the evaluator.

To illustrate the difference between magnitude and importance consider the effect of the discharge of hot cooling water on the receiving water temperature. The magnitude of the effect would be proportional to the increase in receiving water temperature above normal temperatures. The volume of receiving water affected would also be reflected in the value assigned to magnitude. The importance of the effect would depend on the extent of undesirable ecological reactions. For example, a one-degree rise in receiving water temperature would have greater ecological consequences in the path of fish migration in a river than it would in a small area of the ocean. This example also illustrates that the importance of each specific impact must include consideration of the consequences of changing the particular condition (e.g. temperature) on other factors in the environment (e.g. fish).

The most efficient way to use the matrix is to check each action which is likely to be involved in the proposed project. Each of the actions thus checked is evaluated in terms of magnitude of effect on environmental characteristics. Where a potential interaction is considered to be likely, and significant, a slash is placed diagonally in each block. In marking the matrix, it is important to remember that actions such as construction, may have major short-term impacts which are healed in a few years and thus of minor or negligible importance in a long-term reference. Conversely, other actions with lesser initial impact may produce more significant and persistent secondary effects and therefore have major impact in a long-term time frame (e.g. forest harvesting). In the associated text discussing the matrix, one should indicate whether short-term or long-term impact has been considered.

After all boxes which represent possible impact have been marked with a diagonal line, the most important ones are evaluated individually. A number from 1 to 10 in the upper left-hand corner indicates the relative magnitude of impact; the number in the lower right-hand corner indicates the relative importance of the impact.
After the numbers are placed in the slashed boxes, they are evaluated. Special note is taken of exceptionally high individual numbers. Beneficial impacts can be identified with +, because alternative plans may have different degrees of both beneficial and detrimental impacts. However, there is a trend not to differentiate between positive and negative aspects because subsequent procedures are intended to enhance positive impacts and minimize negative ones. It must be emphasized that no two boxes on any one matrix are precisely equitable; however, if alternatives are under consideration, identical boxes in the various matrices can be compared directly.

The text describing the assessment should be a discussion of individual boxes marked with the larger numerical values for magnitude and/or importance. Those columns which cause a large number of actions to be marked, regardless of their numerical values, should also be discussed in detail. Likewise, those elements of the environment which have relatively large numbers of boxes marked should be addressed.

The matrix serves as an abstract of the text, to enable reviewers to determine quickly the activities which would have significant impacts and their relative importance, as evaluated by the originators of the report.

The use of the rating scheme discourages purely subjective opinion and requires those preparing an impact statement to attempt to quantify their judgement of probable impacts. The rating also allows reviewers to follow the originator’s line of reasoning and aids in identifying points of agreement and disagreement.

At first appearance, the general matrix developed by Leopold is intimidating, as it contains 8,800 possible interaction cells. However, this is not a serious drawback because on first analysis, many of the cells drop out because they are not important or relevant. Even the large general matrix may not contain all elements necessary to make a full analysis of every project encountered. In these cases, the matrix can be expanded as needed to accommodate all necessary considerations. The number of applicable interactions for a typical forest products project usually is between 25 and 50.

Figure 3–1 is an example of the application of the Leopold Matrix to a forest products project in a developing country.

The procedure does not limit the detailed consideration of any specific aspect of the environment; a separate expanded matrix for any environmental aspect can easily be developed. However, the Leopold method has some limitations. It does not address the problem of selecting the relative weight to be given to the importance of each cellular relationship in the overall analysis. By leaving the evaluator on his own in this respect, there is considerable room for bias. This bias can be
## Figure 3-1
Example Environmental Impact Matrix (Leopold Method)

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<td>9</td>
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<td>Land (hunting, camping)</td>
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</tbody>
</table>

**Magnitude of Interaction**

- Impact of Interaction
- Importance of Interaction

In this case:

- Magnitude of Interaction: 0
- Importance of Interaction: 0
partly overcome by obtaining opinions from a number of persons representing different environmental disciplines.

*The Battelle Method*

Although the Battelle method was developed to evaluate the environmental effects of water resource developments, the procedure is suitable for many types of development projects. The method, which evaluates environmental impacts in units having a common measure, is systematic in nature and alerts the user to environmentally sensitive areas. Consequently, there is an enhanced probability of the results being replicable by different analysts.

The method is hierarchical in structure to account for different levels of information used in the impact analysis. The four levels of information used are shown in Figure 3–2. The primary categories are Ecology, Environmental Pollution, Aesthetic and Human Interest. Secondary areas are also identified; for example, Environmental Pollution includes Water Pollution, Air Pollution, Land Pollution and Noise Pollution. Each of these categories is further divided into selected environmental parameters such as pH and BOD that are worthy of separate consideration. The most specific level of information involves data that are used to evaluate the effects on the selected parameters.

Developments may create both beneficial and adverse impacts on the environment. Since properties of the environment are not commonly measured in units with a common base, it is difficult to evaluate net environmental effects of a project and to make trade-offs in selecting among alternatives. To solve this problem, a technique is used to attempt to transform all parameters into commensurate units. There are three steps in this process.

*Step 1: Transforming parameters estimates into environmental quality.* Environmental quality is defined as a number between 0 and 1, where 0 denotes very bad quality and 1 denotes very good quality. When environmental quality is defined in this way, it is possible to account for any changes that improve quality and are thus beneficial impacts. It is also possible to account for marginal deterioration of the environment without waiting until a standard is reached or exceeded.

*Step 2: Weighting of Parameters.* When viewing the parameters as part of the total environmental system, it must be recognized that some parameters are more important than others. To reflect this, a total of 1,000 points or parameter importance units (PIU) are distributed among the parameters. Assignment of the relative weights (PIU) in Figure 3–2 was made by quantifying the Battelle research team's subjective value judgements.
Step 3: Obtain commensurate units. The expected future condition of environmental quality is evaluated "with" the project and "without" the project. A difference in environmental impact units (EIU) between these two conditions constitutes either an adverse (loss in EIU) or beneficial (gain in EIU) impact.

\[
EIU = \sum_{i=1}^{m} (V_i)_1 w_i - (V_i)_2 w_i
\]

Where:

- \((V_i)_1\) environmental quality value for parameter i, with a project (value between 0 and 1)
- \((V_i)_2\) same without a project
- \(w_i\) relative weight (importance) of parameter i (ie. the PIU)
- \(m\) Total number of parameters

It is important to know if any "fragile" elements of the environment would be disturbed by a development. The approach used to identify potential problem areas is to flag parameters that would change significantly in the adverse direction. After items have been flagged, the development agency must investigate the potential problem area in detail to determine whether or not a problem exists.

Since it lists fewer interrelationships, the Battelle system is somewhat less complex than the Leopold Matrix, but it has other limitations. The method assigns weights, but the principles for the weighting are not clear. Biased weighting can shift the outcome of the evaluation or minimize apparent environmental impacts. Also, the methods by which parameter estimates such as temperature, are transformed to a number representing environmental quality may grossly oversimplify the extremely complex and interrelated nature of the environment. The method does not adopt the Leopold approach of keeping factual data separate from the subjective data in the final analysis. The great usefulness of the Battelle system is when a comparative environmental analysis is required, for instance, when comparing alternative manufacturing processes or sites.

3.4 Format for Conducting Environmental Impact Assessments for International Pulp and Paper Developments

An environmental impact assessment in a developing country is considerably different from that in industrialized countries. One of the major
differences is that in an industrialized nation, the justification of the need for the project is often one of the most contentious issues. In developing countries, the need for the basic project is usually established by national priorities and the scope of the impact assessment is restricted to the minimization of the impact of the project and the consideration of alternatives. Another major difference is that in developing countries, basic environmental data and other necessary relevant information are not always available in adequate quantity or quality. In industrialized nations, there is usually an over-abundance of relevant information. Consequently, the approach to environmental impact assessment in a developing country is necessarily less rigorous and less structured than in industrialized nations.

The first major step in predicting the environmental impact of a proposed pulp and paper project in a developing country is to visit the project area. This visit, which typically may last about two weeks, should be made by one or more trained persons with experience in environmental impact assessment in developing countries. The purpose of the visit is to view the project area and to gather information. Typical information needs for a fairly large project are listed in Table 3-2. Prior to this visit, the study team should become acquainted with general background information on the proposed project and review available information from previous studies conducted in the area.

When visiting the project area, particular attention should be given to proposed sites for the proposed pulp and paper mill. These sites should usually be located close to acceptable receiving waters and should be a large area of reasonably level, accessible land, above flood level with good soils for structural foundations. The potential sites should also be considered with respect to their proximity to the fiber resource and to required services such as electrical power and transportation. The terrain around the proposed sites should be appraised as to its possible effect on the dispersion of air emissions.

Required data, such as listed in Table 3-2, are often difficult to obtain. Consequently, it is important to seek the knowledge of as many people in the area as possible; this includes local and regional officials, leaders of local existing industries and officials of government agencies, both at the regional and central government level. Data collected should be as long-term as possible. A definite attempt should be made to assess the reliability of the data.

Relevant pollution control standards should be determined; these may include regional, national and international standards. Also, any other environmental constraints imposed by governments, lending agencies or the developer should be identified.

After the visit to the project area, the study team should evaluate the
TABLE 3-2: Typical Data Needs

<table>
<thead>
<tr>
<th>Receiving Waters</th>
<th>Existing Land Uses in Forest Area and at Potential Mill Sites</th>
</tr>
</thead>
<tbody>
<tr>
<td>—Quantity (e.g. river flows throughout the year)</td>
<td>—Agricultural uses and crop productivity</td>
</tr>
<tr>
<td>—Water quality</td>
<td>—Wildlife</td>
</tr>
<tr>
<td>—Present uses (e.g. agriculture, domestic supply, etc.)</td>
<td>—Archeological or historic sites</td>
</tr>
<tr>
<td>—Value of any fisheries</td>
<td></td>
</tr>
<tr>
<td>Metereological</td>
<td>Existing Infrastructure</td>
</tr>
<tr>
<td>—Wind speed and direction</td>
<td>—Roads, power lines, railroads, sea ports</td>
</tr>
<tr>
<td>—Rainfall</td>
<td>—Housing</td>
</tr>
<tr>
<td>—Temperature</td>
<td>—Medical facilities</td>
</tr>
<tr>
<td>—Air Quality</td>
<td>—Recreation areas</td>
</tr>
<tr>
<td>Topography and Geology</td>
<td>Existing Social Structure</td>
</tr>
<tr>
<td>—Maps with elevation markings</td>
<td>—Population in area</td>
</tr>
<tr>
<td>—Soils data</td>
<td>—Level of labor skills</td>
</tr>
<tr>
<td>—Groundwater availability</td>
<td>—Types of employment</td>
</tr>
</tbody>
</table>

Information obtained and identify any information gaps. Studies required to obtain needed information should be recommended and initiated. Based on the information available, a preliminary environmental impact assessment would then be prepared. This assessment is integrated with other pertinent project information on the resource, economics and potential markets, to form a basis for the decision-making process.

Environmental impact assessment at later stages of project development may require further site visits and more detailed studies. The depth of subsequent studies would depend on the outcome of the initial assessment.

There are two significant generalizations which should be kept in mind when conducting environmental impact assessments. Firstly, environmental considerations usually play a minor role in determining the suitability of development alternatives. Secondly, potential air pollution is usually of lesser significance than potential water pollution in determining the suitability of a pulp mill site, because air pollution is easier to control. Large chemical pulp mills require a large quantity of process water and large receiving waters. As a result, the availability and suitability of receiving waters often is the governing environmental criteria in determining the pulp mill site and the type of manufacturing process used.
Chapter 4
Water Pollution Control

4.1 Introduction
In many countries where pulp and paper is a leading industry, it also has the questionable distinction of being one of the main dischargers of man-made pollutants. Consequently, potential problems due to water pollution are a serious concern.

The effluent from most mills is discharged to a receiving water, where pollutants are intended to be assimilated by dilution and degradation. The tolerance of the receiving water to wastewater discharge is determined by its ability to accept pollutants, while maintaining certain biological, physical and chemical standards. These water quality standards vary with intended water use, but most are established on the basis of the requirements for the healthy life of aquatic organisms, especially fish. It is important to recognize that various types of receiving waters have vastly different assimilative capacities; the tolerance of an ocean to effluents is quite different to that of a small river.

It might be argued that, because oceans and streams are all part of the same total environment, there should be no distinction between the permitted effluent quality discharged to either waterbody. The weakness of this argument is that there is a significant cost and associated disbenefits (e.g. energy use) of applying pollution controls beyond those required to maintain certain water quality standards. The goal is to establish the appropriate standards and to design and operate the manufacturing facility to ensure compliance with those standards.

4.2 Effects of Contaminants on The Environment
Pollutants discharged by a pulp and paper mill can be characterized by the following environmental parameters and effects: biochemical oxygen demand, suspended solids, pH, toxicity, taste, odor, fish-flesh-tainting, color, dissolved solids, eutrophication, foam and scum, slime growths, thermal effects and persistent organic compounds.
Biochemical Oxygen Demand (BOD)

Fish and other aerobic aquatic organisms need dissolved oxygen for life. Requirements vary with the organism and its temporal behavior. Salmonids, one of the more sensitive species of fish, can survive for a short time at a dissolved oxygen concentration of 2 mg/l, but a concentration of 7 to 8 mg/l is required for them to carry out normal activities, without stress, on a long-term basis. The concentration of dissolved oxygen in receiving waters is lowered by the oxygen demanding degradation of biodegradable materials. This BOD is exerted in two stages. The first stage, involving the oxidation of readily decomposable materials such as sugars, resin and fatty acids, terpenes and alcohols, is complete after a few weeks. The second stage, which continues for much longer, involves the slow decomposition of the biodegradable portion of the lignin.

There is some evidence that slime, which occasionally appears in rivers downstream of effluent outfalls, is related to high BOD discharges by pulp and paper mills.

If the quantity of receiving water available for effluent dilution and the receiving water’s natural reaeration potential are not adequate, the discharged BOD can significantly decrease the dissolved oxygen concentration, possibly to the point where organisms are adversely affected. At worst, the dissolved oxygen could be totally depleted, causing an anaerobic environment which could result in the release of obnoxious odors and toxic sulphides, and the death of most aerobic organisms, including fish.

Control of the discharge of BOD is an important concern for all types of pulp and paper mills.

Suspended Solids

Suspended solids, more accurately termed nonfiltrable residue, include settleable and nonsettleable matter. These solids are mainly bark and wood fibers originating from debarking operations and pulp and paper processing. The main component of the fibers is cellulose, which can normally be biodegraded within approximately 30 days. To a lesser extent, there are also inorganic solids from the chemical recovery, paper making, and power departments. These inorganic solids are mainly grits and lime solids, fly-ash, paper fillers and coating materials.

Suspended solids are a threat to many aquatic organisms. For example, the plugging of fish gills by particulate matter can cause mortality. Solids suspended in the water increase water turbidity, reducing light penetration and therefore restricting phytoplankton production. Under quiescent conditions, most of the fibers will settle to the bottom, where they destroy fish spawning grounds and smother benthic organisms,
which are the basic food for many fish. While on the bottom, the fibers decompose, thereby exerting benthic oxygen demand on the water. If the rate of deposition exceeds the rate of decomposition, a blanket of fiber is established on the bottom. This blanket eliminates or alters the composition of bottom-dwelling organisms. Furthermore, conditions under the surface of the blanket are anaerobic. Accordingly, products of anaerobic decomposition are released to the water above, thereby adding to receiving water BOD. Anaerobic activity can produce hydrogen sulphide and if the sediments are disturbed, pockets of hydrogen sulphide trapped in the sediment will be released abruptly and fish kills may result.

Control of the discharge of suspended solids is a fundamental consideration for all types of pulp and paper mills.

Toxicity

Pulp and paper mill effluents are complex and variable mixtures of a large number of known and unknown compounds, many of which can cause adverse effects on fish and other important aquatic organisms. If present in the receiving waters at sufficiently high concentration, these compounds can result in lethal toxicity. At reduced concentrations, there may be sublethal effects which impair the productivity and well being of the aquatic organisms.

Unfortunately, the established basis for making decisions related to the disposal of toxic effluents is somewhat tenuous and arbitrary. This is due both to the variable nature of effluents and to the fact that toxicity is difficult to assess, as the result of a number of complicating factors. One of these complicating factors is that the sensitivity of organisms to toxicity is variable and a given species may be extremely sensitive to one component but very tolerant to other components. Furthermore, some organisms show different sensitivity to toxicity at different stages in their life cycle. Although bioassays are usually conducted on species which are considered to be sensitive to toxicity, often salmonid fishes, it is difficult to be certain that test results properly reflect the toxicity levels for other organisms that may be present in the receiving water. Another complicating factor is that the sensitivity of an organism to toxic compounds is greatly affected by environmental conditions such as temperature, pH, dissolved oxygen, alkalinity and salinity. When there is some form of environmental stress, an organism is generally more sensitive to toxic compounds. For example, a reduction in the dissolved oxygen concentration from 6.5 to 4.0mg/l can triple the toxicity of kraft mill effluent to salmonids. Therefore, results of tests under ideal conditions in aquaria do not necessarily reflect the toxicity levels appropriate to the receiving water.
Various parameters such as growth and behavior patterns have been used to evaluate sublethal effects on fish. The threshold for most responses tested appears to be 0.05 to 0.20 of the 96-hour LC₅₀ value for lethal toxicity (the LC₅₀ value is the concentration which is lethal to 50 percent of the test organisms). Prolonged exposure does not appear to lower the threshold for sublethal response significantly, even though exposures up to 200 days have been tested. Consequently, the recommended maximum allowable concentration of effluent in the receiving water is approximately 0.05 of the 96-hour LC₅₀ value for a representative and sensitive species of aquatic fauna.

Effluent pH has been identified as a significant factor in toxicity. For example, when the pH of a bleached kraft mill effluent was adjusted from 2.6 to 7.0, the LC₅₀ value changed from 10 to 50 percent by volume. Unfortunately, most of the study of effluent toxicity has been done in the context of the temperate climates and is heavily concentrated on salmonid fishes. Thus, it is difficult to relate available information to the tropics and their associated aquatic organisms.

**Taste, Odor and Fish-Flesh Tainting**

Phenols, sulphur compounds and terpenes found in kraft mill effluents can cause problems with water taste, water odor and fish-flesh tainting. These problems are not usually serious but they can potentially be a nuisance. With mechanical pulping processes, these factors are of a reduced concern.

**Color**

Effluent color is objectionable mainly from an aesthetic viewpoint. However, color reduces phytoplankton production by restricting the transmission of light into the water. Reduction in phytoplankton production not only reduces the production of zooplankton and fish, but can also lower the concentration of dissolved oxygen. Color problems are mainly a concern with chemical pulp mills, particularly those with bleach plants and are of lesser significance at mechanical pulp mills. Minimal color problems are experienced at paper mills except in the few instances where colored grades of paper are produced.

**Thermal Effects**

Thermal effects on aquatic organisms have been studied mainly in the context of the temperate climate. Nonetheless, it is clear that significant increases in receiving water temperature above normal ambient levels could be lethal to, or otherwise adversely affect, tropical aquatic or-
organisms. In general, however, thermal pollution is only of significant potential concern where the receiving water is small and confined, or in special circumstances where fish may be attracted to the warmer water and affected by other compounds in the effluent.

**Persistent Organics**

Persistent organics refer to compounds such as DDT and polychlorinated biphenyls (PCBs) which degrade extremely slowly in the environment and often can be concentrated to high levels in biological tissues via a food chain. Water fleas can accumulate PCBs to a concentration approximately 10,000 times higher than the concentration in water, during an exposure of four days. Since persistent organics are a serious health concern, any known hazardous substance such as DDT and PCBs should be avoided in pulp and paper projects. Specifically, persistent organic pesticides should not be applied to forests and PCBs should not be used in electrical equipment at the mill.

Information related to inherent production of persistent organics by pulping processes is very limited but the information that is presently available indicates that there is not a significant problem. For example, in one set of tests, a food chain consisting of bacteria, water fleas, molluscs and guppies was exposed to bleach plant effluent; the resulting maximum concentration of chlorinated compounds in the fish and molluscs was only 20 times higher than the concentration in the test solution. These results indicate that at concentrations of bleach plant effluent in receiving waters, accumulation of toxicants is minimal. Moreover, when these organisms were removed from the test solution and placed in clean water, they completely eliminated the accumulated substances in ten days.

Much research work has been undertaken in recent years on the potential for formation of persistent chlorinated organic compounds in the bleaching process. This work stems from the concern that the compounds may have mutagenic and carcinogenic properties. Available evidence indicates a relatively small generation of mutagenic compounds which are fairly readily biodegradable. The problem, therefore, appears minor, but further sophisticated research work is required before definitive conclusions can be reached concerning health risk and remedial measures.

**Miscellaneous Potential Problems**

The concentration of dissolved solids in pulp mill effluents usually is not high enough to cause an environmental problem. The only potential
concern is that at low dilution of bleaching effluents in the receiving waters, the water may have excessive concentrations of dissolved salts to be suitable for irrigation and other agricultural uses.

Cultural eutrophication generally is not a problem because pulp mill effluents usually have low concentrations of nitrogen and phosphorous.

Foam and scum can be an aesthetic problem where the effluent is not properly dispersed in the receiving water and the effluent treatment system is not adequate.

4.3 Effluent Characterization

Some of the important characteristics of effluents from various pulp and paper processes are listed in Table 4-1. Data on effluent toxicity are not given because published values are extremely variable and difficult to interpret due to complexities associated with the test. Nonetheless, it can be stated that most untreated pulp mill effluents are lethally toxic to sensitive aquatic species and that dilutions varying from 1:1 to 10:1 are required to avoid lethal toxicity. Paper mill effluents are much less toxic than pulp mill effluents.

Biologically treated effluents are usually, but not always, non-toxic to fish in a bioassay test at full concentration.

Detailed effluent characterization data for the kraft process are given in Table 4-2. These data illustrate what can be accomplished by applying conventional in-plant techniques and demonstrate that in a modern kraft mill, the bleach plant effluent is the most significant contributor to the mill pollution load. As well as being responsible for about half the effluent volume and half of the $\text{BOD}_5$, the bleach plant discharges about 85 percent of the colored materials found in bleached kraft mill effluent; it is also the most significant source of toxicity.

4.4 Control Technology

(a) General

There are two basic locations for controlling water pollution from an industry: in-plant and out-plant. Both means are applied to arrive at the desired effluent quality. In-plant control is defined as special processes, equipment and operating practices to reduce the amount of deleterious substances at, or close to, the source. Out-plant controls are those which treat the effluent generated by the mill.

It is fundamental to recognize that internal controls are preferred over external treatment. In-plant controls inherently carry a return on investment due to fiber, chemical and energy recovery. External controls seldom provide such return.
<table>
<thead>
<tr>
<th>Process</th>
<th>Suspended Solids</th>
<th>BOD₅</th>
<th>Waste Water</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Range kg/ton</td>
<td>Mean kg/ton</td>
<td>Range m³/ton</td>
</tr>
<tr>
<td>Older Technology</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wood preparation</td>
<td>0–50</td>
<td>20</td>
<td>0–20</td>
</tr>
<tr>
<td>Unbleached kraft</td>
<td>10–60</td>
<td>30</td>
<td>10–90</td>
</tr>
<tr>
<td>Bleached kraft</td>
<td>20–120</td>
<td>60</td>
<td>30–80</td>
</tr>
<tr>
<td>Mechanical pulping</td>
<td>10–40</td>
<td>20</td>
<td>10–40</td>
</tr>
<tr>
<td>Paper making</td>
<td>10–100</td>
<td>30</td>
<td>2–20</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Newer Technology</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wood preparation</td>
<td>0–5</td>
<td>1</td>
<td>0–2</td>
</tr>
<tr>
<td>Unbleached kraft</td>
<td>5–20</td>
<td>10</td>
<td>10–20</td>
</tr>
<tr>
<td>Bleached kraft</td>
<td>5–20</td>
<td>10</td>
<td>20–40</td>
</tr>
<tr>
<td>Mechanical pulping</td>
<td>5–30</td>
<td>15</td>
<td>15–25</td>
</tr>
<tr>
<td>Paper making</td>
<td>1–20</td>
<td>10</td>
<td>1–10</td>
</tr>
</tbody>
</table>
### TABLE 4-2: Wastewater Characteristics from an Older and Modern Bleached Kraft Pulp Mill (excluding wood preparation)

<table>
<thead>
<tr>
<th></th>
<th>With Minimal In-Plant Pollution Abatement</th>
<th>With In-Plant Pollution Abatement</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Volume $m^3$/ton</td>
<td>$BOD_5$ kg/ton</td>
</tr>
<tr>
<td>Foul Condensates</td>
<td>10</td>
<td>12</td>
</tr>
<tr>
<td>(Digester and Evaporators)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Washing and Screening</td>
<td>50</td>
<td>10</td>
</tr>
<tr>
<td>(Including Spills)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Recausticizing</td>
<td>10</td>
<td>1</td>
</tr>
<tr>
<td>Liquor Spills</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Bleach Plant</td>
<td>100</td>
<td>25</td>
</tr>
<tr>
<td>Pulp Driers</td>
<td>10</td>
<td>2</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>15</td>
<td>5</td>
</tr>
<tr>
<td>Total</td>
<td>200</td>
<td>60</td>
</tr>
</tbody>
</table>
The guidelines that should be followed in the conceptual and planning phases of a project, to control water pollution, are as follows:

1. Ensure that the receiving water is able to accept a suitably treated effluent.
2. When possible, select an environmentally compatible manufacturing process and site.
3. Identify principal water pollution potential/environmental resource interactions.
4. Identify the relevant laws and regulations that must be complied with.
5. Develop, and continually update, the basic process design, both in-plant and out-plant.
6. Ensure the design is compatible with mill energy, water and chemical balances and that it takes into account process upsets and back-up systems.

In most mills, only a few effluent parameters are considered in detail. These parameters are biochemical oxygen demand, suspended solids and pH. Regulatory agencies seldom have requirements for other parameters, on the basis that if the fundamental parameters are acceptable, the others are concurrently acceptable. Of course, there are exceptions; for instance, color may require attention when discharge is to a small, clear river in an area designated for tourism.

(b) IN-PLANT CONTROLS

All pulp mills employing chemicals to separate cellulose from the raw material use the same basic techniques. The wood chips are “cooked” under high pressure and temperature with the pulping chemicals; the fiber is separated from the liquor and washed; in some instances the pulp is bleached; the pulp is cleaned; and the pulp is then dried and formed into the end-product. The liquor is usually thickened, and burned to provide energy and the residual chemicals are converted back to pulping chemicals.

Groundwood mills, as the name implies, grind the raw material. The pulp is then washed, sometimes brightened, and cleaned; it is then formed into the final product, usually in combination with stronger chemical pulps.

The following describes typical in-plant control measures for a kraft mill; techniques for other types of mills are similar.

Wood Debarking

In some countries, wood is debarked by hand in the forests, for several
reasons: it is labor intensive; it reduces wood damage by insects, which usually are found between the bark and wood; it reduces transportation costs and it returns some organic material to the forest floor. However, most forest products enterprises deliver undebarked wood to the mill where the bark can be removed more efficiently by mechanical means and where the bark can be used as fuel.

There are basically four types of debarking processes:

- **Hydraulic.** A high-pressure water jet peels the bark off the wood. It is used with irregularly shaped logs, very large diameter logs and where the bark is difficult to remove by other means.
- **Mechanical.** The log travels through the debarker where the bark is scraped off by knives, chains or similar devices.
- **Wet Drum.** The logs tumble in a long revolving cylinder partially filled with water, which softens the bark. The bark is knocked off by the tumbling action of logs.
- **Dry Drum.** This is similar to wet drum debarking except that water is not used in the drum.

In general, there is less damage to the wood and slightly less loss of wood with the removed bark when wet types of debarking are employed. These methods predominated many years ago, especially in areas where the logs were frozen in winter. However, improvements to the dry debarking process, the higher fuel value of dry bark and the cost and difficulty of treating wet debarker effluents make dry debarking preferable. Many mills have a mechanical debarking line to handle straight and uniform logs and a dry drum debarking line to handle crooked logs. Most dry debarking is preceded by, and followed by, log washing to remove dirt, sand and stones. The volume of effluent from this operation is low; after removal of sand, this effluent can be recycled to the log washer.

The other traditional source of water pollution from the wood preparation area is debris. This debris used to be flushed into large sewers and thence to the receiving water. Where feasible, debris on the floor should be collected by hand, thereby providing unskilled employment and reducing effluent discharge.

With appropriate design and careful operation, the effluent load from the woodroom operation can be reduced to almost zero.

**Digester Area**

The chips are cooked in a large vessel under high temperature and pressure. In some mills, batch digesters are employed which, as the name implies, is a batch operation, taking up to four hours to fill the
The digester with chips, cooking chemicals and steam, then to bring it to the right temperature and pressure and to hold it there, then to blow the contents to the blow tank where the softened chips shatter and the fibers are separated. Such arrangements have several batch digesters.

The alternative means of cooking is by the continuous digester which is a system where chips, cooking chemicals and steam are fed at a continuous rate as the chips are cooked as they move down the vessel.

In any new pulp mill, a careful technical and economic analysis is done to determine whether continuous or batch cooking is best. Economics aside, continuous digesters are more sophisticated and require a high calibre of operator control. Batch digesters are normally preferred in smaller mills, with varied products and where less skilled operators are available. A concern with the continuous digester is that if it breaks down, the whole mill shuts down, but if one batch digester fails, production can still be sustained with the others.

There is little difference in the water pollution load between continuous and batch digester plants. With smooth operation, continuous digesters are marginally preferable since they produce slightly lower quantities of effluents and odorous gases which can be handled more easily, since the flows are continuous. In general, from the environmental standpoint, smooth operation favors continuous digesters, but if mill operation is erratic, batch digesters are preferred because of their greater flexibility.

The only "normal" effluent from the digester plant is the condensate formed after cooking. This condensate has a low volume but is extremely foul, and with softwood pulping, can contain fairly large quantities of turpentine—up to 15 liters per ton of pulp. In modern mills, the turpentine is separated, decanted and either sold as a by-product or burned for energy recovery. The underflow from the turpentine decanting system is combined with other foul condensates from the mill for selective treatment, usually by stripping. After stripping, these condensates are recycled to the process. In older mills, the digester foul condensate was sewer, contributing up to 25 percent of the mill's water pollution load, as measured by BOD.

Modern mills, therefore, have the potential to have almost no process effluent from the digester plant during normal operation.

Pulp Washing

The pulp and liquor are separated in the washing plant usually on rotary drum washers where the pulp and wash water flow countercurrently. Some modern mills employ "diffusion washers" where the liquor is strained from the pulp in a closed vessel. The relative merits of diffusion and drum washing are broadly comparable to those between continuous
and batch digesters discussed earlier; a careful analysis is required at each installation.

Traditionally, poor pulp washing has been the greatest source of controllable water pollution from a kraft mill. Inadequate washing greatly increases losses of chemicals, wood extractives, BOD, color and toxic materials, and also causes increased consumption of bleaching chemicals.

Losses of black liquor to sewer escalate when the mill production rises above its design level. There is a five or ten-fold difference in the water pollution load from the washing plant of a mill with poor, as opposed to good, pulp washing. Some of the more advanced modern mills have been operated with a completely closed washing plant, with almost no process effluent being sewered. The value of recovered chemicals and energy, plus the desire to decrease the water pollution load, have provided the incentive for modern mills to increase the number of washing stages.

It would be prudent for the owner and designer of a new mill to ensure that the initial design incorporates adequate pulp washing, taking into account capital and operating costs, effluent load and the impact on external treatment facilities. This evaluation should be extended to the cooking process and bleach plant where there is some flexibility in the degree of delignification, or pulping yield. Parameters to be balanced are the energy gained by liquor recovery, bleaching chemical usage and pulp quality.

With appropriate design, it is possible to have almost zero discharge of process effluents from the washing plant.

Screening and Cleaning

All pulp and paper mills employ methods to remove undesirable solid material from the pulp. This undesirable material includes uncooked wood (knots), slivers of wood (shives) and sand and grit (dirt). Knots and shives are removed by screening and the dirt by centrifuges. In older mills, the waste streams from these separation devices were usually sewered, frequently at a high rate, necessitated by inadequate equipment and the need to purge a considerable quantity of rejects to keep the pulp quality acceptable. Modern mills use a variety of means to recover wood rejects. These methods of recycle generally involve either re-cooking or refining. Dirt rejects can be concentrated in a low volume waste stream by using additional cleaning stages. Another fundamental method of reducing cleaning and screening losses is by ensuring proper preparation of the raw material (chips) fed to the digesters.

All mills require a waste stream to purge undesirable solid material from the pulp. An older and inefficient mill wasted up to five or six
percent of the pulp production via this purge. A newer mill with good quality chips, an appropriate screening and cleaning process, adequately sized equipment, and diligent maintenance and operation, is capable of maintaining reject losses at less than \( \frac{1}{2} \) percent of production. The benefit of good initial design is clear when one recognizes that loss of 1 ton of clean fiber to sewer each day represents an annual revenue loss of about $200,000, at 1980 prices.

**Bleaching**

The bleach plant in a modern bleached kraft pulp mill contributes up to 70 percent of the mill's effluent flow, 85 to 90 percent of the effluent color, about 50 percent of the effluent BOD, and the bulk of the toxic compounds. The bleach plant effluent is usually highly acidic.

The first consideration in the design of a bleach plant is to ensure that, before bleaching, the pulp is well washed to remove black liquor. Black liquor carry-over unnecessarily increases bleaching chemical consumption.

The second consideration is to ensure that the desired final brightness is compatible with the product market. Bleached kraft pulp sold on the highly competitive international market would be of a different quality than pulp destined for a captive market within a country where decorative aspects, such as degree of whiteness, are of less concern.

The third consideration is to select a bleaching sequence compatible with chemical supply, product quality, environmental concerns and operating skills. Environmentally, it is preferable to minimize chlorine usage because of the threat of generation of toxic chlorinated organics; however, chlorine is, and will continue for some time to be, the most fundamental bleaching agent. Substitution of chlorine dioxide for some of the chlorine produces a milder effluent with less color and toxicity, but with slightly greater BOD.

The fourth consideration having a bearing on the bleach plant design is the degree of filtrate recycle achieved by implementing countercurrent washing techniques. Filtrate recycle reduces energy and chemical use, as well as the quantity of effluent, and effluent quality is somewhat improved. However, excessive recycle requires extreme operational control and carries an increased risk of upsets. The ideal bleach plant is designed for a fairly open mode of initial operation, with closing of the system as skills develop.

**Pulp Drying and Paper Making**

It is difficult to generalize about pulp drying and paper making processes due to many variations of raw materials, grades, additives and products.
At one extreme is a mill which dries a single grade of pulp without additives. A well designed pulp drying machine can be integrated with the preceding departments, all excess water and effluents being cascaded back to those departments. At the other extreme, is a paper machine producing various grades of cultural papers; even if this paper machine is integrated with a pulp mill, its effluents cannot be cascaded back due to potential contamination by additives such as fillers, binders, and dyes.

In general, the effluents from a pulp dryer or paper machine are fairly innocuous, consisting usually of fiber and filler material. They are seldom toxic and have a low BOD. The exception is when operating and process problems cause spills. During normal operation, the pulp dryer or paper machine area should have no process effluent sewered.

**Evaporators and Liquor Recovery**

The evaporator department receives the black liquor, at about 85 percent water content, and concentrates it to about 30 percent water content, at which point the liquor is incinerated in the recovery furnace. Evaporation takes place in several stages, usually about six. The evaporated water is condensed and segregated into clean and foul condensates. The so-called clean condensates are directly re-used elsewhere in the mill as hot water. The foul condensates, high in pollutant concentrations, were sewered in older mills. Modern mills combine the evaporator foul condensates with digester foul condensates and strip out the obnoxious components. Stripping with air will remove odorous sulphur-type compounds but little BOD is removed. By stripping with steam, BOD-causing compounds such as methanol can also be removed; the stripped volatiles are contained in a small waste-gas stream which is usually incinerated in the lime kiln.

Justification of a condensate stripping system is difficult when based strictly on economics. A system for typical 500 ton/day kraft mill might cost $500,000 to $1 million (1980 costs), the former being integrated with the mill, the latter being retrofitted. Justifications include reduced out-plant treatment requirements; reduced effluent BOD toxicity, odor and tainting potential; and heat recovery.

Virtually all new kraft mills in industrialized countries install condensate stripping systems, as do most new mills in developing nations.

**Recausticizing and Lime Reburning**

In a kraft mill, the recausticizing department prepares the basic chemicals required for the cooking process. The chemical smelt from the
recovery furnace is dissolved to form green liquor which contains various impurities, mainly carbon and sulphides of iron. These impurities (dregs) are separated from the green liquor by sedimentation, filtered and washed to recover active chemicals, and then disposed of. Most older mills send the dregs to the sewer; modern mills collect them for land disposal. The clarified green liquor is reacted with burned lime in a slaker to form calcium hydroxide. The grits from the slaker are removed and normally directed to land-disposal. The lime slaker overflows to the causticizers, where the cooking chemicals, sodium hydroxide and sodium sulphide are formed, along with a precipitate, calcium carbonate. The calcium carbonate (lime mud) is separated from the cooking chemicals (white liquor) in a white liquor clarifier. The lime mud is washed, de-watered and then fed to the lime kiln, for conversion into burned lime.

The chemical cycle in a kraft mill is, therefore, such that were it not for losses to the effluent and atmosphere, no chemical make-up would be required. However, losses do occur; the basic make-up chemicals are sodium sulphate (salt cake) and calcium carbonate (limestone). The most modern mills are able to almost eliminate sulphur losses and make-up with a non-sulphur chemical such as sodium carbonate.

The recausticizing department, while simple in concept is prone to heavy effluent losses. Erratic operation of other mill departments can cause inventory imbalances in the recausticizing plant and the density of the lime mud, together with its abrasive nature, causes occasional equipment failures. Often a tank of lime mud must be emptied to allow repairs; therefore, it is important that spare tanks and clarifiers be available.

A poor recausticizing department of a large pulp mill might sewer 30 to 40 ton/day of lime mud, continuously. By contrast, a conservatively sized recausticizing department in a well-operated modern mill is capable of keeping its lime mud losses to zero. In addition to economic consequences, heavy losses of lime mud are undesirable since they easily plug underground sewers and often cause breakdowns of out-plant equipment such as clarifiers.

**Power Boiler**

Almost all pulp mills have a power boiler to generate additional steam and electrical energy. The most common fuel is bark, which is supplemented by gas, oil, coal or fuelwood. Because of the high cost of imported oil, many mills in tropical and sub-tropical countries establish plantations of fast-growing fuelwood for use in power boilers. There is no question that if properly managed, this practice is environmentally suitable, on both a global and local scale. The effluents from the power
boiler area contain mainly ash. Older mills used to flush the ash down the sewer. Modern mills employ various methods of ash collection, usually for land disposal. Bark ash is excellent for soil amendment.

**Mill Services**

The most significant effluent from the mill services departments is the blowdown sludge from the raw water treatment plant. In most instances, regulatory agencies permit this stream to be returned to the river, since except for the fairly innocuous treatment plant chemicals such as aluminum hydroxide, the solids originated from the river. The greatest quantities of blowdown sludge always occur during periods of high river flow, when the dilution of the effluent is the greatest.

**Sanitary Sewage**

It is advisable that any new pulp or paper mill segregate sanitary sewage, from the mill buildings and local townsite, from the process effluents. The primary reason is that there is some concern that the warm process effluents may be an ideal environment for some fecal bacteria and viruses to proliferate. Where sanitary effluents must be combined with process effluents, it is recommended that the sanitary sewage be appropriately treated and disinfected.

**Spill Control**

It has been estimated that in the average pulp mill, one third of the losses of BOD and fiber are caused by spills. The reasons for this include undersized equipment, equipment breakdown, poor operation and deliberate management decisions to use the sewer system as a means of balancing and sustaining mill operation.

The subject of causes of spills and their control is one of the most difficult to analyze in the context of in-plant pollution abatement, because spills usually occur without warning. When there are spills, operating priorities are usually such that by the time the spillage is halted, the spilled material has entered the out-plant treatment system or the receiving water. It is obvious that the best spill containment system is one which prevents spills from occurring in the first place. There are methods of planning spill containment, control and recovery, which culminate in the following criteria:

1. Ensure equipment is adequately sized, not only for both average and maximum production, but also for the reprocessing of collected spills.
2. Provide back-up equipment for critical mill components.
3. Provide large storage capacities, especially between the various processing departments.
4. Place level recording and alarm instrumentation on all pulp and liquor tanks.
5. Provide means of recovering liquor and stock from major pipes and tank and vat overflows and drains.
6. Provide monitoring and alarm instrumentation in significant departmental sewers.
7. When a large tank has to be emptied for maintenance purposes and its contents cannot be removed, forewarn the out-plant treatment plant operators so they can respond accordingly.
8. Establish an operator training program at all management and operator levels, to stress the importance of preventing spills.
9. Document the causes and magnitude of all significant spills to allow future rectification.

Several of the above criteria require no cost to implement. Those which require expenditures are clearly best done in the initial mill design; however, this does require analysis and justification. Partial justification is apparent when one recognizes that a complete spill control system for a medium sized kraft mill can be paid for based on several 50 ton stock spills or one or two days of mill downtime caused by insufficient storage.

(c) Out-Plant Controls

All new pulp or paper mills have some form of external effluent treatment which normally fall into the categories of neutralization, primary treatment to remove settleable suspended solids and, where needed, biological treatment to reduce the raw effluent BOD. In general, wastewater treatment plants provide the necessary degree of effluent stabilization to allow treated effluent quality targets to be met continually.

As a guideline, the ideal site for an effluent treatment plant is one which does not require effluent pumping, where lengths of pipelines are minimized, where the mill departmental sewers are arranged to allow flexibility in out-plant design and operation, and where the land area and topography are adequate to exclude restrictions on the system design.

All mills not discharging effluents to seawater should usually have a near-neutral effluent pH; coastal mills need not always neutralize effluents due to the large buffering capacity of seawater. All new mills should have some form of primary treatment to prevent settleable material from entering the receiving water and almost all mills discharging to freshwater systems should employ biological treatment to stabilize the effluent.

With respect to receiving water quality, there should be no measurable change in the receiving water pH after discharge; the effluent dilution should be at least 10 to 20 times the effluent concentration acutely
lethal to indigenous fish, this being the generally recommended safety factor to preclude sub-lethal toxic effects; and the receiving water $\text{BOD}_5$ should not be increased, after effluent dilution, by more than 1 to 2 mg/l, this being the concentration that research studies have shown no measurable change in fish behavior or growth. It should be emphasized that these criteria represent consensus based largely on studies on cold water fish such as salmon. Effects of pulp mill effluent on warm water fish have received much less study, but it is thought that warm water fish are more tolerant of environmental stress than are salmonid species.

The following sections describe common features in an out-plant treatment system.

**Screening**

However carefully a mill is operated, large pieces of assorted material find their way into sewers. The corrective measure employed is to provide grating or removable slabs sewers within the mill and screens on combined sewers before the outplant treatment system. These screens can either be cleaned automatically by mechanical means or, if desired, by manual methods. This is an example of a choice where a capital cost savings of perhaps $50,000 is possible, but it does require a guarantee of immediate attention by personnel when, say, a spill of knots enters the sewer. Some mills include rock traps before the screens to collect heavy material.

**Neutralization**

Bleached kraft pulp mill effluents are highly acidic and effluents from mechanical pulp mills and most paper mills are mildly acidic. Neutralization is usually required to prevent sewer pipe deterioration, equipment corrosion and to protect treatment systems. Also, many fresh water bodies have inadequate buffering capacity.

Mills which have to raise or lower the pH only slightly, normally do so with liquid alkalis such as caustic soda or acids such as hydrochloric. Bleached kraft pulp mills require fairly substantial neutralization and usually feed some form of lime from the recausticizing department to the acidic wastes from the bleach plant. A 500 ton/day bleached kraft pulp mill might require 5 to 10 tons of lime per day for neutralization purposes.

When the pH of an effluent must be decreased to achieve neutralization, as is sometimes the case with unbleached kraft mills, acid is used. Extreme care must be exercised when this is done because of the potential for toxic hydrogen sulphide gas evolution caused by the reaction of residual black liquor and acids.
The high cost of effluent neutralization is often unrecognized in the planning stages of a mill. As in many aspects of pulp mill pollution control, these costs are largely a function of the mill operation; for instance, poor pulp washing in a kraft mill requires increased bleaching chemical consumption, which creates a more acidic bleach plant effluent.

Primary Treatment

The purpose of primary treatment is to remove settleable suspended solids from an effluent. It is normally accomplished in a clarifier, which is a circular tank where the particles are allowed to settle by gravity. The sludge collected at the bottom of the tank is scraped to the center and withdrawn.

The size of clarifier is contingent on the type of mill, but the surface area should be such as to give an upward rise rate of about 1 m/hr. Chemical pulp mill suspended solids settle better than those from mechanical pulp mills, and those from paper mills usually better than those from pulp mills. High temperatures and variations in the raw effluent quality inhibit settling. The clarifiers at some mills incorporate slow stirring in the center section to encourage agglomeration of particles; these operations sometimes add conditioning chemicals to enhance flocculation.

The sludge withdrawn from the clarifier can be handled by a variety of methods, the appropriate method being dependent on land availability, climate, sludge quality and nature, the ultimate disposition of a dewatered sludge and the labor-intensity required. Mills in arid areas with large areas of suitable land might be able to pump sludge to ponds, where it dewatered naturally. Mills which elect to landfill the sludge cake might be able to dewater to a truckable consistency (about 20 percent) by mechanical means such as vacuum filters. Mills which choose to burn the sludge would dewater to the maximum consistency reasonably attainable (about 35 percent) by filters and/or presses.

Some mills use settling basins, either following the clarifier or to replace the clarifier. The settling basins are usually constructed in tandem and are operated one at a time, each having a detention time of about eight hours. Settling basins perform well providing they are cleaned of sludge at regular intervals. If this is not done, the settled solids will turn septic and generate foul smelling odors and solids may float to the surface and overflow with the effluent. Since the cost of desludging settling ponds is high, some mills line the ponds with a firm base to allow access by mechanical equipment such as tractors. In general, studies have shown that it is more economic to remove suspended solids in a clarifier and mills which incorporate settling basins usually do so as a second stage of primary treatment which can also serve as
a back-up in cases of clarifier breakdown. Newer mills segregate low-solids bearing sewers and pipe them directly to the settling basins, thereby by-passing the clarifiers; potentially high-solids bearing sewers pass through the clarifier and then the settling basins.

The out-plant sewer and treatment arrangement for a typical modern bleached kraft mill is shown in Figure 4-1.

**Biological Treatment**

Biological treatment of effluent is required by governmental laws and regulations for virtually all new mills in the major pulp-producing countries, and many older mills in these countries have installed such facilities. New mills located in environmentally sensitive areas in developing countries also use biological treatment.

Biological treatment, sometimes called secondary treatment, is an accelerated biological purification process. Colonies of micro-organisms consume biodegradable matter in an environment adjusted to suit their growth and living requirements. Some bacteria and micro-organisms thrive in the absence of oxygen. These organisms, called anaerobic bacteria, can only tolerate oxygen-free conditions. However, anaerobic treatment process for pulp and paper mill effluents are seldom applied, firstly because the waste characteristics are not particularly conducive to anaerobic degradation and secondly and more importantly, because foul odors are generated due to the sulphur compounds contained in most mill effluents.

Aerobic biological treatment requires oxygen to be added to the system at a rate equal to the oxygen demand of the micro-organisms. This oxygen is transferred from the air to the treatment plant by a variety of mechanical devices or bubblers. Pulp and paper effluents are deficient in basic nutrients, nitrogen and phosphorous, so these elements must usually be added to the treatment plant in the form of commercial fertilizers. Biological treatment is most effective at near neutral pH values and at temperatures in the range of 25 to 45°C.

Biological treatment accomplishes several objectives: it reduces the BOD$_5$, usually by 70 to 95 percent; it reduces the acute toxicity of the effluent, usually to render it non-toxic to fish at 100 percent treated effluent concentration (there are some bleached kraft mills in Canada with well designed and operated systems which have never experienced a lethal toxicity test failure at 100 percent effluent concentration); it reduces less defineable parameters such as taste, foaming potential, odor and fish-flesh-tainting potential; and it creates a consistent and stable effluent. The creation of a stable and consistent effluent, is especially significant with pulp mill effluents, since the untreated wastewater characteristics are usually erratic. A consistent effluent allows the designer
FIGURE 4-1: Typical Basic Flow Diagram for a Modern Bleached Kraft Pulp Mill
to assess the impact on the receiving water based on near-average, rather than peak conditions.

Biological treatment does have several disadvantages: capital and operating costs are relatively high; electrical energy requirements for aerators, typically two to four percent of the mill electricity requirements, are high; color is not significantly reduced and land area requirements are high. Despite these constraints, biological treatment is almost always the most cost-effective means of protecting receiving water quality.

In the initial planning stages of a pulp and paper project, all mills regardless of location should ensure that the site arrangement is compatible with the installation of biological treatment. As the feasibility studies progress, it may be identified in some situations that there is no need for such treatment. However, in general, all mills with pulping facilities discharging to fresh water systems or ecologically sensitive marine areas, such as river estuaries, would elect, or be required, to install biological effluent treatment.

The types of aerobic biological treatment plants are described in the General Manual for the Industrial Development Sector. For pulp and paper effluents, the strongly recommended scheme is the aerated lagoon system. This involves one or several lagoons, with a hydraulic detention of several days where oxygen is added by aeration devices. As a rule of thumb, one cubic meter of lagoon volume is required for every 30 grams of $\text{BOD}_5$ fed to the lagoon daily. One kilowatt of aeration power is required to treat 20 kilograms of $\text{BOD}_5$ fed to the lagoon.

A typical modern 500 ton/day bleached kraft pulp mill, with a water use of 100 $m^3$/ton and a raw effluent $\text{BOD}_5$ load of 30 kg/ton would result in the following basic design parameters for an aerated lagoon:

- **Raw $\text{BOD}_5$ load** = $500 \times 30 = 15,000$ kg/day
- **Effluent flow** = $500 \times 100 = 50,000$ $m^3$/day
- **Lagoon volume** = $15,000 \div 0.03 = 500,000$ $m^3$
- **Lagoon detention** = $500,000 \div 50,000 = 10$ days
- **Aerator power** = $15,000 \div 20 = 750$ kw

The lagoon volume of 500,000 $m^3$, in this example translates to about 10 hectares of land for a lagoon 5 meters deep. The $\text{BOD}_5$ reduction with a detention of 10 days would normally be about 90 percent, reducing the effluent $\text{BOD}_5$ concentration from 300 to 30 mg/l. Assuming reasonable mill and lagoon operation, the treated effluent would likely always be non-toxic to fish in an acute bioassay test at full effluent concentration. It would be unlikely, with this relatively long detention, that artificial nutrients would be required to sustain biological activity, except perhaps in light doses during the first year or so of operations.
Taking this example one step further using the guideline receiving water criteria outlined earlier, the minimum dilution in the receiving water can be calculated. Based on toxicity, a 20 to 1 dilution is required to ensure that sub-lethal biological effects do not occur. Based on the increase in receiving water BOD₅, if it is decided that a 1 mg/l increase can be tolerated, the minimum dilution is 30:1, assuming a treated effluent BOD₅ concentration of 30 mg/l. The minimum dilution of 30:1 governs, and the minimum river flow, therefore, should be greater than 18 cubic meters a second.

The above example is fairly simplistic but it gives an appreciation for some of the considerations in the planning process. More detailed analysis of the receiving water quality, uses, needs and importance, will refine the permitted change caused by effluent discharge and flexibility is possible in the design of the aeration lagoon to allow for an improved or reduced effluent quality.

Where possible, aeration lagoons should have as long a detention time as economically reasonable since longer detentions reduce or eliminate the need for artificial nutrients to be added. Long detention lagoons also buffer spills and upsets better and create a more stable and consistent effluent.

Other variations of biological effluent treatment, such as the activated sludge process, should only be considered in extreme cases where adequate land is not available for aerated lagoons. The activated sludge process, and its variations, requires capital and operating expenditures at least double those of an aerated lagoon (where suitable land is available for the lagoon). Moreover, activated sludge systems require a high degree of operator attention and skills and they are very susceptible to upsets caused by changes in raw effluent quality.

### Outfalls

Modern mills discharge the treated effluent into the receiving water in a manner intended to maximize the immediate dilution, to eliminate foam, to minimize the zone over which aquatic organisms might be affected and to reduce unsightly conditions. To accomplish this, the effluent is discharged below the low water level and air is prevented from being entrained in the effluent. Discharge in sensitive receiving waters is normally done through multiple-port diffusers.

### 4.5 Dispersion of Pollutants

To properly address the required degree of effluent dilution and dispersion, the receiving water must be studied. There is a vast difference in the behavior of effluent plumes between discharges to sluggish rivers, swift rivers, lakes, and seas and oceans. Also, the intended use of the
receiving water must be evaluated, taking into account such factors as recreation, potability, fishing potential, other industries, future considerations, regulatory guidelines and the like.

Various mathematical models are available to predict dispersion and dilution in receiving water. These physical models are not particularly reliable and in certain situations must be reinforced with actual field testing, for instance by tracer studies in rivers and oceanographic measurements in marine areas.

Various methods are also available to predict the fate of effluents in receiving waters. There are established procedures, for instance, to determine the dissolved oxygen profile in a river downstream of a BOD discharge. This methodology, usually known as assimilative capacity evaluation raises the question about the basis on which man's activities should be permitted to alter water quality. Should it be such that it allows no measurable change in fish or biological behavior? Should it be such that it does not overly stress fish or other biological organisms? Or, should some degradation be tolerated? There is no simple answer to these questions and the dilemma encompasses national and international policy. It is rapidly becoming the policy in most countries that the most stringent criterion be established when new industries are created; that is, that no detrimental change to the water quality or to the uses of the water be permitted. While such a policy seems horrendous to a developer, there are many examples to demonstrate that, with appropriate foresight and planning, this goal can be achieved at minimal cost. It is The World Bank's experience that no proposed Bank-funded pulp and paper project has been deemed uneconomic due to the cost of implementing appropriate environmental controls.

4.6 Costs

It is difficult to generalize about the costs of water pollution control for modern pulp and paper mills, due to three fundamental reasons:

1. It is becoming increasingly difficult to define pollution control.
2. Some systems to reduce the quantity and improve the quality of effluents carry an inherent return on the investment.
3. Costs are situation-specific.

It is often stated that the capital cost of water pollution control systems for a modern mill ranges between one and five percent of the initial investment for the entire development. The cost to retrofit pollution abatement facilities to a mill is always considerably higher. Operating costs for a primary and secondary treatment system are typically one to three dollars per ton of production.
The greatest single capital cost items for an effluent treatment system are pipelines and the civil and structural works associated with biological treatment. The costs of these items can be reduced with proper site selection. The highest operating costs are associated with solid wastes handling and disposal, energy to power aeration equipment and nutrient chemicals to enhance the biological treatment process. Mill design and operation influence all of these operating costs.
Chapter 5
Air Pollution Control

5.1 Introduction

Many older (built 10 to 20 years ago) kraft mills cause severe air pollution. Causes might be the equipment used, the condition of the mill, production output well in excess of the original design, geographical location, or stack discharge parameters. With some of these older mills, the odor occasionally can be detected 50 to 100 kilometers away. This is the case because the human nose can detect some of the odorous kraft compounds at concentrations as low as one part per billion in air. Properly designed modern kraft mills typically are capable of achieving emissions of odorous compounds just two or three percent of those of older and overloaded mills.

The most extreme cases of air pollution are normally experienced in countries with temperate climates, which usually have poor conditions for atmospheric dispersion. Tropical and sub-tropical climates are such that there are seldom extended periods of stable atmospheric conditions and as a result, dispersion of air pollutants is better than in temperate climates.

5.2 Effects of Air Pollution

(a) Odor

Although odor is principally an aesthetic concern, it is usually regarded as one of the most important and most difficult environmental problems of a kraft pulping operation. The problem stems from the fact that some of the contaminants released have extremely low odor thresholds and have obnoxious odors. For example, the odor threshold of hydrogen sulphide \((\text{H}_2\text{S})\) and the organic sulphides is about 1 to 10 parts per billion, in air.

With mechanical pulping, odor is not a particular problem. However, compounds such as terpenes and phenols which are released in small quantities from most pulping operations have slight odors which may be of minor concern.
(b) **Occupational and Public Health**

If a mill is properly designed and operated, concentrations of vapors and particulate in the working environment will not normally cause a significant threat to worker health. However, during process upsets and equipment malfunction, or because of human error, hazardous quantities of toxic gases can be released in localized areas; for example, there have been many instances of fatalities in kraft mills due to incidents where high concentrations of hydrogen sulphide or chlorine have been generated. This type of accident, though less common, can also occur in mechanical pulping operations. By maximizing the quality of the air in the work place, not only is worker health and safety enhanced, but production efficiency is also improved.

Quantities of hydrogen sulphide, organic sulphides, chlorine and chlorine dioxide emitted from kraft mills are generally well below levels that could result in ambient air-borne concentrations that are considered toxic to man, animals or plants. The air pollutant that is the main health concern in ambient air is sulphur dioxide. Concentrations of about 5 mg/m$^3$ (gas) cause increased airway resistance in healthy individuals and long-term exposure to concentrations as low as 0.03 mg/m$^3$ (gas) has been related to health problems.

(c) **Economic Damage**

Many adverse consequences of air pollution may be directly or indirectly measured in terms of monetary loss. High levels of smoke, soot and other particulates increases the rate of soiling of clothes, house furnishings, displayed merchandise, and interior surfaces. This would be of concern in the immediate vicinity of pulp mills. Sulphur dioxide emissions can cause damage to plants, animals, metals and fabrics at points many kilometers from a pulp mill.

Plants are the most sensitive receptors of air pollution. The type and severity of damage depends on a number of factors including species sensitivity, concentration of the pollutant, time of exposure and other environmental and horticultural factors. Extensive damage to plants has been reported for long-term exposures to SO$_2$ concentrations as low as 0.03 mg/m$^3$ (gas). For a summary of the effects of sulphur dioxide and the damage that it may cause, the reader is referred to the companion World Bank manual “Environmental Considerations for the Industrial Development Sector”.

(d) **Atmospheric Clarity and Transportation Safety**

Discharge of particulate and water vapor by both kraft and groundwood mills can result in reduced atmospheric clarity in the vicinity of the mill.
Condensation of water vapor, the most important factor, is dependent on atmospheric conditions and the amount of particulate discharged by the mill. Atmospheric conditions provide the driving force for condensation, while particulate provide the required nucleation sites. As ambient humidity increases or ambient temperature decreases, condensation increases. High emissions of sodium chloride, at mills where wood is transported in salt water, increases water vapor condensation. The decrease in visibility due to condensed water vapor can represent a localized problem for air and road traffic.

The condensation of water vapor emissions is often viewed by the layman as pollution. Unfortunately, well designed mills tend to have a greater tendency for such condensation because of reduced emission temperatures which result from better heat recovery and a greater number of exhaust scrubbers. Cooling towers, which are sometimes installed to minimize water usage, increase water vapor emissions.

5.3 Emission Characterization

(a) Kraft Process

The major gaseous emissions from the kraft process are malodorous reduced sulphur compounds, which include hydrogen sulphide (H$_2$S), methyl mercaptan (CH$_3$SH), dimethyl sulphide (CH$_3$SCH$_3$), and dimethyl disulphide (CH$_3$SSCH$_3$); oxides of sulphur (SO$_2$); and oxides of nitrogen. Organic compounds, other than those containing sulphur, can also be emitted; these include terpenes, hydrocarbons, alcohols and phenols. Water vapor is discharged in substantial quantities.

The major potential sources of reduced-sulphur gaseous emissions from the kraft process include digester blow and relief gases, vacuum washer hood and seal tank vents, multiple-effect evaporation hotwell vents, recovery furnace flue-gases, smelt dissolving tanks, slaker vents, black liquor oxidation tank vents, lime kiln flue-gases, and wastewater treatment operations. Table 5–1 shows typical emission rates of total reduced sulphur compounds from an older kraft mill in poor condition and from a modern kraft mill equipped with the latest air pollution control systems. These values should be viewed only as approximations which are intended to give some appreciation for the general magnitude of various emissions. The most important fact is the dramatically lower odorous emissions attainable in a new mill. In particular, the potential reduction of 99 percent in TRS emissions from the recovery boiler should be noted. In the past, “high level” recovery boiler emissions were the dominant cause of odor from a kraft mill; more recently, “low level” emissions, such as those from tank vents and building exhausts are becoming the more dominant causes of mill odor.
TABLE 5–1: Typical Total Reduced Sulphur (TRS) Emissions From Older and Modern Mills

<table>
<thead>
<tr>
<th>Source</th>
<th>Discharge Rate</th>
<th>TRS Emissions</th>
<th>Older Mill</th>
<th>Modern Mill</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Normal m³/ADT</td>
<td>kg/ton</td>
<td>kg/ton</td>
<td></td>
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<tr>
<td>Digester area</td>
<td>—</td>
<td>0.80</td>
<td>0</td>
<td></td>
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<tr>
<td>Washing and Screening</td>
<td>2,500</td>
<td>0.30</td>
<td>0.10</td>
<td></td>
</tr>
<tr>
<td>Evaporators</td>
<td>10</td>
<td>2.00</td>
<td>0.05</td>
<td></td>
</tr>
<tr>
<td>Recovery Boiler</td>
<td>10,000</td>
<td>5.00</td>
<td>0.05</td>
<td></td>
</tr>
<tr>
<td>Dissolving Tank</td>
<td>600</td>
<td>0.20</td>
<td>0.02</td>
<td></td>
</tr>
<tr>
<td>Lime Kiln</td>
<td>1,100</td>
<td>0.20</td>
<td>0.07</td>
<td></td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>—</td>
<td>0.80</td>
<td>0.06</td>
<td></td>
</tr>
<tr>
<td>TOTAL</td>
<td></td>
<td>9.3</td>
<td>0.35</td>
<td></td>
</tr>
</tbody>
</table>

The major source of sulphur dioxide emissions is the kraft recovery furnace. These emissions result from the combustion of sulphur-containing black liquor. Sulphur trioxide is also released, but at lower concentrations, particularly when sulphur containing fuel oil is added as an auxiliary fuel. Sulphur dioxide can also be released from the lime kiln, smelt dissolving tank and waste-wood fueled power boilers. Burning fuel oil or coal in power boilers may increase the SO₂ emissions, particularly where the fuel contains high concentrations of sulphur.

The SO₂ content of recovery furnace flue-gases is related to the types of furnace and its operation. For older conventional recovery furnaces, SO₂ concentrations in the flue-gas are usually less than 150 mg/m³ (gas) due to the absorption of SO₂ in the liquor in the direct contact evaporator. With newer, “low-odor” furnaces, where there is no direct contact of black liquor and flue-gases, SO₂ concentrations in the flue-gas typically range up to about 1000 mg/m³ (gas). With both types of furnaces, improper operation can increase flue-gas SO₂ concentrations to as much as 3000 mg/m³. If oil is burned as an auxiliary fuel, SO₂ concentrations increase, particularly for fuel with a high sulphur content.

Problematic emissions of sulphur dioxide are not usually related to mill or furnace design, but rather to maintaining correct operating conditions in the furnace. The exception occurs when the ratio of sulphur to sodium in the process becomes too high; here, concentrations of SO₂ in the flue-gas can be as high as 3000 mg/m³.

Oxides of nitrogen can be formed in any fuel combustion process by
TABLE 5-2: Typical Emission Rates For SO₂ and NOₓ From Kraft Pulp Mill Combustion Sources (Before Control Devices)

<table>
<thead>
<tr>
<th>Emission Source</th>
<th>SO₂</th>
<th>SO₃</th>
<th>NOₓ(as NO₂)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recovery Furnace:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No Auxiliary Fuel</td>
<td>0–40</td>
<td>0–4</td>
<td>07–5</td>
</tr>
<tr>
<td>Auxiliary Fuel Added</td>
<td>0–50</td>
<td>0–6</td>
<td>1–10</td>
</tr>
<tr>
<td>Lime Kiln Exhaust</td>
<td>0–2</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Smelt Dissolving Tank</td>
<td>0–0.2</td>
<td>—</td>
<td>10–30</td>
</tr>
<tr>
<td>Power Boiler*</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2% Sulphur Fuel Oil</td>
<td>6–20</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2% Sulphur Coal</td>
<td>7–30</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Where all electrical power is produced on site, the emissions would be higher.

the reaction of oxygen and nitrogen at elevated temperatures. The major constituent formed is nitric oxide, a small portion of which can be oxidized to nitrogen dioxide. Nitrogen oxide emissions from recovery furnace and lime kiln are lower than for most other fuel combustion processes due to the flame temperature reduction by the large concentrations of water vapor present. A summary of typical emission rates for oxides of sulphur and oxides of nitrogen is presented in Table 5-2. Small quantities of chlorine and chlorine dioxide, released during pulp bleaching and during the preparation of bleaching chemicals, are a potential concern from the point of view of occupational health within the mill area and local aesthetic problems outside the mill.

As with other emissions, particulate discharges are highly dependent on the actual mill system. In particular, the power and recovery furnace emissions are related closely to fuel type, boiler design, fuel quality, ash removal techniques, boiler configuration, operating conditions and boiler size. A summary of typical emission rates for particulate is presented in Table 5-3.

(b) MECHANICAL PULPING

The only potential air pollutants of concern with mechanical pulping processes are particulate and SO₂ discharged by power boilers. Emissions of these pollutants would depend on the type of fuel and the quantity of power produced on site.

Small quantities of organics such as alcohols, terpenes and phenols could be discharged, especially with the more recent mechanical pulping
TABLE 5-3: Typical Emissions of Particulate Matter From Older and Modern Mills

<table>
<thead>
<tr>
<th>Source</th>
<th>Modern Mill</th>
<th>Older Mills</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Normal m³/ton</td>
<td>kg/ton</td>
</tr>
<tr>
<td>Recovery Boiler</td>
<td>10,000</td>
<td>1.0</td>
</tr>
<tr>
<td>Lime Kiln</td>
<td>1,100</td>
<td>0.2</td>
</tr>
<tr>
<td>Slaker Vent</td>
<td>200</td>
<td>0.1</td>
</tr>
<tr>
<td>Dissolving Tank</td>
<td>600</td>
<td>0.2</td>
</tr>
<tr>
<td>Power Boiler</td>
<td>10,000</td>
<td>1.0</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>0.5</td>
<td></td>
</tr>
<tr>
<td>TOTAL</td>
<td>3.0</td>
<td>32.0</td>
</tr>
</tbody>
</table>

systems such as thermo-mechanical and chemi-thermo-mechanical pulping, but these are seldom of sufficient quantity to be of concern. Operational results describing the emissions from new mills employing these emerging processes have yet to be published.

5.4 Abatement Techniques

(a) General

In a few instances where an option is available for producing the required product, environmental factors can have a significant influence on the selection of the pulping process to be used. Appropriate weighing of environmental concerns in the site selection phases of a project is also strongly desirable; if a kraft mill is to be located beside a major tourist development, the decision-makers should be aware of the potential long-term consequences of such a location and perhaps seek an alternative.

The general guidelines that should be followed in the conceptual and initial planning phases of a project to minimize air pollution are as follows:

1. If a choice is available, select an environmentally compatible manufacturing process.
2. Ensure environmental factors are adequately weighted in the site identification process.
3. Identify principal air pollution potential/environmental interactions.
4. Develop design emission criteria and ensure these are compatible with modern design and pollution control laws and regulations.
5. Develop and continually review the process and equipment design, taking into account design and potential maximum production, process upsets and back-up systems.

6. Ensure the air pollution abatement design is compatible with mill energy, water and chemical balances.

7. Ensure fuels (especially hog fuel) are properly prepared prior to combustion.

Usually only three emission parameters are considered in air pollution control designs for pulp mills: total reduced sulphur, sulphur dioxide and particulate matter. Other parameters such as water vapor or oxides of nitrogen, are usually restricted to special cases.

(b) Kraft Mills

Except in extreme cases of poor topography, adverse climatological conditions and sensitive land use, sulphur dioxide is not a problem for kraft mills and adequate control is possible by proper operation, especially that of the liquor recovery furnace, and appropriate selection of auxiliary fuels. In extreme cases, fuel desulphurization, flue gas SO₂ removal or process modification may be necessary.

The technical literature covers air pollution abatement techniques and mill design consultants and equipment suppliers continually keep abreast of developments. The following summary of modern air pollution abatement methods for a kraft mill highlights the major features that are usually incorporated in a good modern mill:

- **Non-condensable Gases** are collected and incinerated. These gases, once the predominant low-elevation emission of odors, are rich in hydrogen sulphides and organic compounds such as methyl mercaptan, dimethyl sulphide and dimethyl disulphide. Collectively, non-condensable gases contain up to 2.5 kg of total reduced sulphur (measured as H₂S per ton of pulp), which if not eliminated would increase the TRS emissions from a modern mill eight-fold (see Table 5–1). The non-condensable gases originate in various parts of the mill, especially from the digester and evaporator departments and four condensate stripping.

  Non-condensable gases are collected in a header, sometimes scrubbed with an alkaline solution (such as white liquor or weak wash) to recover a portion of the sulphur, and then burned. The preferred incineration point is the lime kiln, where the TRS is converted to sulphur dioxide, which is largely recovered by absorption on the lime dust and in the liquid in the lime kiln exhaust scrubber. Non-condensable gases can also be incinerated in a recovery boiler or power boiler but there is a greater risk of explosion, particularly
operators are not highly skilled. In extremely sensitive areas, a dedicated incinerator is often installed as a back-up unit.

The capital cost of a non-condensable gas destruction system is about $0.5 to 1.0 million (1980) for a 500 ton/day mill. Operating costs are fairly low; in fact, there may be a benefit by virtue of sulphur recovery and reduced fuel use in the lime kiln. Extreme care is mandatory in both the design and the operation of non-condensable gas handling systems, due to the explosion potential.

- **Recovery Furnace.** The odorous emissions from the recovery furnace were once the greatest cause of concern in the kraft industry. Nowadays they can be restricted to about 10 percent of the total mill TRS emissions. The key to good control is adequate boiler capacity and appropriate furnace design features.

  Older designs, especially in North America, used the recovery furnace flue gases to aid in black liquor evaporation by using a so-called "direct contact evaporator", which, especially in overloaded mills, created substantial hydrogen sulphide emissions. Today, such installations are seldom used in new mills and there is no direct contact between black liquor and the recovery furnace flue-gases.

  The particulates in the recovery furnace exhaust are almost always collected in electrostatic precipitators. Older designs, when make-up chemical costs and environmental considerations were minimal, were based on a collection efficiency of about 95 percent. Almost all recent electrostatic precipitators are designed for a collection efficiency in excess of 99 percent and some have efficiencies of 99.5 percent. In this range, the law of diminishing returns predominates and in specifying electrostatic precipitators, the designer must carefully balance costs, environmental requirements and energy consumption.

- **Power Boilers.** All new kraft mills (and usually mills using other processes) have a steam-generating power boiler to provide process steam and electrical energy. These boilers are normally base-fuelled with woodwaste and fuelwood, which are supplemented with oil, natural gas or coal. Sulphur dioxide emissions are a function of the sulphur content of the fuel.

  As with recovery boilers, the power boiler sizing and design are fundamental to reducing emissions. Also, proper fuel preparation and ash removal techniques are important. There is increasing interest in removing some of the moisture from wood fuels before incineration to increase energy generated.

  The techniques used to reduce fly-ash from power boiler exhausts are usually based on mechanical methods, such as cyclone separators or baffled chambers, which can be about 90 percent efficient. In cases where greater removal efficiencies are required, a few mills use elec-
tostatic precipitators. Scrubbers are seldom used, but are sometimes justified on the basis of recovered hot water.

- **Lime Kiln.** Lime kiln exhausts are usually scrubbed in a venturi scrubber to remove particulates. Removal efficiency is related to the pressure drop across the scrubber and is usually in the range of 95 to 99 percent when modern venturi scrubbers are employed.

  The scrubber plume can be a problem because it does not rise much as it is relatively cool. Consequently, odorous emissions are not well dispersed and can be of local concern. These odorous emissions are best controlled within the recausticizing process by ensuring lime mud is well washed with clean hot water or treated condensates.

- **Dissolving Tank and Water and Slaker Vent Exhausts.** Modern mills usually scrub these exhausts with alkaline solutions, to control TRS and particulate emissions and to recover chemicals and heat.

- **Bleach Plant Washer Hood Exhaust.** Sometimes these exhausts are scrubbed to control chlorine and chlorine dioxide emissions. Older mills did not treat these emissions.

- **Brownstock Washer Hood Exhausts and Tank Vents.** Odorous emissions from these sources are fairly low. Some of the most advanced mills collect these exhausts and direct them to a boiler, such as the power boiler, for use as make-up air.

- **Wastewater Treatment Area.** Odor from effluent treatment systems is an emerging concern in the industry. These odors are caused either by the ponds becoming septic, resulting in hydrogen sulphide generation and release, or by stripping of volatile compounds contained in the effluent. Control is best accomplished by good mill process design especially minimizing black liquor losses, and by ensuring that there is sufficient aeration that the effluent ponds do not become anaerobic.

(c) **OTHER MILLS**

Air pollution from mechanical pulp mills and paper mills is minimal. Abatement techniques are usually required only for the power boiler. Occasionally, steam emission control is necessary.

### 5.5 Dispersion of Pollutants

It is frequently argued that it is acceptable to use the environment to dilute potential contaminants to acceptable levels. In the context of air pollution, this involves modifying discharge conditions, such as the heights of stacks, to enhance dispersion. A more valid argument would be that appropriate controls should be installed in the production proc-
ess, and that discharge parameters, such as stack height, should be optimized to suit the individual site circumstances.

Dispersion is strongly dependent on local topography and atmospheric conditions such as wind speed, wind direction, atmospheric stability and solar radiation. Since most pulp mills are located beside large bodies of water, atmospheric conditions at the site are frequently quite different than at a nearby town. In ideal circumstances, weather records can be obtained from the nearest meteorological station during mill feasibility studies. However, it is usually desirable to establish a nominal automatic weather station on site as soon as a decision is made to proceed with a project. The measurements from an on-site station can be used both for environmental planning, as well as for mill design, such as arranging the best layout for lumber and chip storage.

There are many mathematical models available to predict dispersion of pollutants in the atmosphere. The sophistication of these models varies widely, from rough "nomograph" methods to complex grid cell models which take topography and multiple emissions into account. Almost all dispersion modelling is done by computer. Since the models often do not accurately reflect reality, the reliability of predictions is usually fairly poor. Nevertheless, dispersion modelling is a good means of defining the best means of reducing the effects of air pollution.

In a recent dispersion modelling study undertaken by the authors, a modern mill, with projected odorous emission characteristics similar to those in Table 5-1, was studied to determine the optimum height of the combined recovery/power boiler stack. In that study, which was directed at a mill on the Mediterranean Sea coast, it was determined, on a theoretical basis, that during normal mill operation, the odor from the mill would seldom be detected at groundlevel during the summer; however, the odor would be noticed fairly frequently during winter, and especially during upset mill operation, when predicted groundlevel TRS concentrations would increase about fivefold near the mill. The TRS emissions from the recovery boiler accounted for only about 10 percent of the groundlevel TRS concentration and it was concluded that to minimize the mill odor, primary design emphasis should be given to curtailing miscellaneous emissions from tank vents, washer hoods and the like. A particularly interesting conclusion was that there was virtually no benefit, in that instance, to increasing the height of the major stack beyond the base height of 1½ times the maximum building height (to minimize turbulence effects). In another study for a mill in a sub-tropical climate, it was determined that a major benefit would result from combining major emissions into a single, tall stack.

The value of dispersion modelling, therefore, in determining design criteria to minimize the effects of emissions, cannot be understood. But
to be valid, the basic mill process design should be established and the detailed local meteorological data fairly well known early in the design stages. Also, the modelling should be done prior to irrevocable decisions on stack design.

5.6 Costs

It is impossible to state costs of air pollution abatement control with any degree of accuracy. This is the case for the following reasons: first, it is becoming increasingly difficult to define a pollution control feature; second, most abatement systems are integrated in the mill process; third, most modern abatement processes offer some direct benefits (recovery of heat, chemicals etc.); fourth, the environmental and social gains (physical and mental health, enjoyment, etc.) caused by cleaner air are hard to express in monetary terms.

In general, a rough estimate of the capital cost of applying modern air pollution control features is one percent of the mill capital requirements. This definition implies that the mill could be built and operated with one percent less capital requirement; however, such a mill would likely not be tolerated by regulatory bodies, the local residents, and probably the organizations loaning capital for the project. Retrofitting air pollution control systems in a pulp mill is much more expensive and much less efficient than systems integrating into the mill as it is built. Furthermore, retrofitting equipment is often physically difficult because of space limitations.
Chapter 6
Land Pollution Control

6.1 Introduction

Of the three primary receptacles of pollution (water, air, and land), land has historically been given the least attention in the pulp and paper industry. In contrast to air and water pollution, there are aspects of land pollution which are largely irreversible. For example land is alienated; groundwater and surface water can be polluted by leachates, the effects of which may not be manifested immediately. Once groundwater becomes polluted, it is extremely difficult to rectify the problem; even if the source of pollution is eliminated, a long time is required for the concentrations of contaminants to decrease to acceptable levels. Throughout the world, past indiscriminate management of landfills is now being recognized as causing serious delayed-action pollution and health problems.

One example will demonstrate the potential for “mistakes” in disposing of wastes from the forest products industry. Polychlorinated biphenyls (PCB), persistent and highly toxic chemicals used principally in electrical equipment, occasionally requires disposal because of contamination. In the past, the fluid material was typically sealed in a container and dumped at a landfill site. Years later, the container leaks and the PCB slowly diffuses into the environment, via groundwater and streams. Identification of such problems is extremely complex and costly, even in highly industrialized nations; it is virtually impossible in developing countries, many of which do not have the equipment and analytical capabilities to detect such environmental poisons. The solution, as in all components in environmental management, is to anticipate problems, and plan accordingly. In this instance, no known highly toxic chemicals such as PCB’s, should be disposed of with general industrial refuse. They should be stored and processed separately. Even better, in the instance of new mills, would be to ensure in the design that PCB’s are not used in any electrical, or other equipment.

In industrialized countries, regulatory attention to solid wastes disposal systems has proceeded at a slower pace than that to air and water pollution control. Presently, there appear to be no countries with na-
tional regulations governing solid wastes disposal, but guidelines and regulations have been established at regional levels in some countries. These guidelines and regulations usually center on, first, identification of the nature of the waste, and, second, disposal procedures based on the particular waste characteristics. It is reasonable to expect greater regulatory emphasis on solid wastes disposal in the future. This is logical and reasonable since of all the pollution—potential segments of the pulp and paper industry, the greatest prospect for waste reduction and improved management practices is in the solid waste disposal field.

Many solid wastes can be reused for domestic or industrial purposes or disposed of by means other than by landfilling. In the planning stages of a project, emphasis should be given first to minimizing quantities of solid wastes generated, second to segregating the wastes in a manner which will allow flexible disposal options, and third, to developing disposal methods suitable to the particular situation.

6.2 Effect of Solid Wastes

Without proper planning, landfilling of solid wastes can create the following major types of problems:

a. Subsurface leaching with subsequent contamination of groundwater and surface waters.

b. Destruction of ecologically sensitive areas, such as marshes.

c. Odors.

d. Proliferation of rodents, scavengers and insects.

e. Alienation of land which could be put to alternative and more beneficial uses.

f. Fires.

g. Health hazards.

h. Unsightly conditions.

Studies have shown that leachates from typical pulp mill solid waste disposal sites exhibit a high toxicity and color, and have a relatively low pH. The leachate quality from landfills containing bark and fiber is closely related to the structure of the deposited material, as discussed below:

- Softwoods with high pitch content release more toxic materials than hardwoods.

- Leachates from hardwoods are more highly colored than leachates from softwoods.

- Leachates from deposited sludges from chemical pulp mills are more contaminated than leachates from paper mill sludges.

- Where active biological matter (e.g. excess biological treatment plant
sludges) is deposited with biodegradable matter such as bark and fiber, noxious gases (e.g. hydrogen sulphide) can be generated, and the leachate can have a very high oxygen demand.

- Leachates from bark and fiber generally contain high levels of dissolved metals, with leachates from clarifier sludges sometimes exhibiting unacceptably high concentrations of undesirable metals originating from the manufacturing complex, for instance, copper and chromium.

- Some types of pulp and paper operations, notably waste paper deinking mills, may have high levels of persistent organics (e.g. PCB's) and heavy metals in the leachates from solid wastes disposal sites.

### 6.3 Solid Waste Characterization

The characteristics of solid wastes from pulp and paper operations vary enormously between mills. On a proportional basis, the approximate production of solid wastes for the industry as a whole in North America is as follows:

<table>
<thead>
<tr>
<th>Waste Type</th>
<th>Percentage of Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wastewater sludges</td>
<td>45%</td>
</tr>
<tr>
<td>Ash</td>
<td>25%</td>
</tr>
<tr>
<td>Bark, wood waste</td>
<td>15%</td>
</tr>
<tr>
<td>Paper, trash</td>
<td>10%</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>5%</td>
</tr>
</tbody>
</table>

About three quarters of the solid wastes generated by the industry are organic.

Table 6-1 gives typical quantities and compositions of solid wastes generated by three types of mill:

- a 200 ton/day modern kraft pulp mill with integrated woodyard and debarking facilities, and a bark-burning power boiler. This mill incorporates a sawmill with a sawed-wood production equal in weight to chip production. All bark, with no excess, is incinerated in the power boiler.

- a 150 ton/day newsprint mill, using a furnish of groundwood pulp (125 ton/day) from forest debarked pulp logs, and the remainder, purchased pulp. Steam is generated using oil as a fuel in the power boiler.

- a 100 ton/day paper mill processing purchased pulp.

In all instances, it is assumed that primary effluent treatment is employed at the mill.

Using typical moisture contents and bulk densities, the volume of solid wastes requiring disposal for the 200 ton/day kraft mill is about 9,500 m³/year, enough to cover one hectare, one meter deep, each year.
### TABLE 6-1: Solid Wastes Characterization

<table>
<thead>
<tr>
<th>Source</th>
<th>Main Constituents</th>
<th>% Organic Content</th>
<th>200 ton/day kraft mill</th>
<th>150 ton/day newsprint</th>
<th>100 ton/day paper mill</th>
</tr>
</thead>
<tbody>
<tr>
<td>Log pond, woodroom</td>
<td>stones, mud, bark sand</td>
<td>50–100</td>
<td>0–3000</td>
<td>500</td>
<td>100–500</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>300</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Boiler ash</td>
<td>ash, sand</td>
<td>50–100</td>
<td>700–1800</td>
<td>1200</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Knots, screen rejects</td>
<td>wood slivers, fiber fines</td>
<td>90–100</td>
<td>0–1000</td>
<td>300</td>
<td>0–500</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>100</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Recausticizing rejects</td>
<td>lime, mud, grit, dregs</td>
<td>0–5</td>
<td>500–2000</td>
<td>1300</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wastewater sludges</td>
<td>fiber, sand, clays</td>
<td>85–95</td>
<td>300–3000</td>
<td>1400</td>
<td>500–2500</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>170–1700</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1200</td>
</tr>
<tr>
<td>Paper, trash</td>
<td>various</td>
<td>80–90</td>
<td>50–300</td>
<td>100</td>
<td>30–200</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>150</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>20–150</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>50</td>
</tr>
<tr>
<td>TOTAL</td>
<td></td>
<td></td>
<td>4800</td>
<td>1605</td>
<td>20–150</td>
</tr>
</tbody>
</table>

*Note: The lower end of the "range" reflects a carefully designed and well managed mill; the upper end of the "range" reflects a loosely designed and poorly operated mill. The "typical" figures represent solid wastes generation rates for fairly modern mills.
Chemical pulping operations, especially those with integrated wood-rooms and bark, wood or coal burning boilers, have the potential for highest rates of solid wastes generation. In general, of the chemical pulping alternatives, kraft mills generate the greatest quantities of solid wastes; the quality of kraft mill solid wastes is also potentially the most noxious.

The volume and nature of the solid wastes generated by the pulp and paper industry is dependent on the circumstances at individual mills. For instance, a kraft mill which is able to dewater sludges from the effluent treatment system, and burn them, will halve the volume of solid wastes requiring disposal. Therefore, ranges are given in Table 6–1 to illustrate tight and loose mill design and operation.

Waste characterization in Table 6–1 excludes substances such as waste oil, toxic chemicals, such as laboratory chemicals, electrical equipment insulating fluids, paint, and domestic garbage. These should be segregated from industrial refuse and processed separately.

The generation rate of solid wastes from pulp mills is presently greater in the major pulp-producing countries than in developing countries. This is principally due to the lower proportion of mills in developing countries which generate sludges from effluent treatment plants. It is also attributable to partial debarking in the forests and to the fewer integrated sawmill/pulpmill complexes in developing countries (i.e. the tendency to process whole logs in contrast to sawmill residue) as well as to the economic and social pressure for maximum wood utilization. However, the present trend in developing countries is for a fairly rapid growth of solid wastes generation, caused by increased effluent treatment, greater mechanization of wood handling facilities and reduced debarking in the forest.

6.4 Control Technology

There are five distinct considerations necessary to minimize solid wastes disposal costs and to mitigate adverse environmental effects:

a. Reduction at source.
b. Segregation at source.
c. By-product utilization.
d. Appropriate planning of disposal sites.
e. Appropriate management of disposal operations.

These considerations are discussed below.

a. REDUCTION AT SOURCE

Sludges from the wastewater treatment process constitute by far the
greatest volume of solid wastes created by the pulp and paper industry. Practically all new mills are required to install systems to minimize settleable fiber reaching water-courses, and most existing mills recognize the probability that they will eventually be required to do likewise.

For a chemical pulp mill, fiber losses range from $\frac{1}{2}$ to 4 percent of the production, depending on particular conditions, such as the equipment and tankage in the mill, the steadiness of operation and the attention given by all levels of operating personnel and management to prevention of unnecessary losses. Often, dumping fiber to the sewer is a convenient means of overcoming operating problems. There have been many instances when installation of a clarifier was justified solely on the basis that management could actually see the amount of good fiber being lost. In these instances, measures to reduce losses can be easily justified; at a product price of $450/ton, one ton a day of sewered clean fiber represents an annual revenue loss of $150,000.

The technology of pulp mills is such that, with careful design and diligent operation, fiber losses can be kept within $\frac{1}{2}$ percent of production. Similar savings can be accomplished with paper mills. The techniques to accomplish such reductions are not sophisticated. Most can be done with suitable sizing of equipment, tankage and, above all, the motivation of all levels of operating personnel and management. Guidelines for mill design and operation to accomplish minimal generation of solid wastes are as follows:

- Strive to make the raw materials such as wood chips, hog fuel, and chemicals as clean and uniform as is economically reasonable.
- Develop realistic and firmly controlled operating consumption standards for all raw materials.
- Identify parts of the mill which are prone to losing solid material and assess design and operating changes to improve the operation.
- Establish a monitoring system to measure losses of fiber and other process solid wastes and to identify sources of loss of good fiber.
- Develop a criteria for determination of the viability of additional control or recovery measures. For instance, “if 1 ton/day fiber can be recovered, the capital cost should be less than $200,000”, etc.

There are many opportunities to minimize solid wastes generated from pulp and paper operations. The difference between a “loose” and “tight” mill’s wastes quantities could vary by a factor of ten.

b. Segregation at Source

It is important to consider solid wastes segregation at the source because beneficial use can be made of several wastes. Generally, attempts should
be made early in the project planning stages to keep the following types of waste segregated:

- Fibrous sludges
- Inorganic chemical sludges (lime, grits, dregs etc.)
- Bark, wood wastes
- Ash
- Oil
- Hazardous chemicals, including contaminated oil
- Scrap metal
- Domestic and putrescible matter
- Biological sludges

Particularly important is the need to have a plan to keep wastes which may contain hazardous chemicals separate from other bulky wastes. Such hazardous wastes might include, but not necessarily be restricted to, the following:

- Insulating oils from electrical equipment.
- Sludges from chemical plants integrated with the mill, especially sludges from mercury-cell chlor-alkali plants.
- Contaminated dyes and sludges from cleaning tanks which contain noxious chemicals.
- Laboratory chemicals and mercury from instrumentation.
- Herbicides and fungicides.
- Flammable and corrosive liquids.

c. By-product Utilization

Most of the solid wastes from pulp and paper mills are organic. They can be used as a fuel, for agricultural or other purposes. Once placed on a landfill, there is no means of recovering by-products because of cross-contamination.

In most developing countries, there is a high latent demand for building materials. Fibrous sludges and/or bark are suitable materials for manufacturing wallboard-building papers (roofing paper) products. While such manufacturing options are not directly related to the mainstream function of the pulp or paper mill, they can aid in better utilization of resources. To resolve a solids waste disposal problem by turning the waste into a useable product is a significant resource-use accomplishment.

Similarly, fibrous sludges can be used for agricultural purposes. Studies have shown that crop yields can markedly improve when sludges are applied as a soil amendment or mulch. In some instances, heavy clay soils can be put to agricultural use by applying a high dose of fibrous
sludge (about 1000 tons/hectare), preferably with a nitrogen based fertilizer, tilling the land, and permitting it to lie fallow for a year or two. Fibrous sludges are also conducive to composting and in rural regions with suitable accelerating culture, such as fish processing plant wastes or manure, a useful activity for unskilled local people could be established.

Ash from bark burning boilers is rich in plant nutrients, particularly potash. It could be used as a soil amendment, especially in acid soils. Many pulp and saw mills in developing countries have programs in which employees are allowed to take scrap wood home as a fuel.

It is recognized that several of the ways in which solid wastes from mills can be reused are not only the direct responsibility of the mill, but may include local and regional government authorities. Many by-products require the cooperation of different government departments, other industrial enterprises and local people. It is not essential that programs to make maximum utilization of solid wastes be established from the outset, but it is important that the potential planning be done with the possibility that alternative uses might become viable.

d. Disposal Site Planning

The land required for operation of a solid wastes disposal site is highly dependent on the type of mill and the methods used to minimize quantities of wastes. The typical 200 ton/day kraft mill characterized in Table 6-1 might require about $\frac{1}{2}$ hectare per year.

Seldom does one encounter an ideal site, and judgements are necessary in site selection. Identification of a disposal site should be based on the following criteria:

- It should be within an economical distance of the mill and be readily accessible to trucks and firefighting equipment.
- It should not be on land that has alternative use potential, such as agricultural land, or land reserved for future mill use or effluent lagoons.
- It should have few residences in the vicinity.
- It should not be swampy ground and should not be close to important water courses or wells.
- It should preferably be well above the groundwater table.
- It should be on firm ground, preferably with a low permeability.
- It should have a nearby source of cover material.

Under certain, but increasingly rare circumstances, it is possible to dispose of sludges by lagooning. This practice, however, is usually restricted to arid areas where large amounts of land are available, where ground-
water contamination is not a potential problem and where a certain amount of obnoxious odor can be tolerated.

Second to finding other uses for waste sludges, the preferred means of sludge disposal is incineration, typically in a wood, bark or coal fueled furnace. To accomplish this, however, requires substantial sludge de-watering and careful blending with the prime fuels. Disposing of sludge in this manner seldom permits useful heat recovery because of the sludge’s fairly high moisture content; it can detrimentally affect furnace operation and adds a disproportionate inorganic load to the system. Therefore, while burning in a furnace is a preferred means of sludge disposal, it should be approached cautiously and a second option, land disposal, always should be contemplated.

c. DISPOSAL OPERATIONS

Once a mill is operating, the following basic recommendations are made for operation of the disposal system:

- Keep an approximate inventory of materials and quantities of solid wastes disposed.
- Continually keep the operation tidy and safe (follow guidelines for covering with fill material, dump in a pre-planned manner, ensure a firefighting contingency plan is available, install fencing, etc.).
- Keep an inventory of options available, and priorities to minimize generation of wastes.
- Seek means of putting solid wastes to secondary uses (by-product manufacture, agriculture, fuel, scrap metal etc.).
- Establish a simple groundwater monitoring program to measure long-term trends (perhaps measure basic chemical parameters in four wells or pits around the site at monthly intervals).
- Keep in mind the eventual use and reclamation opportunities of the disposal site.
- Ensure hazardous materials are processed separately.

The costs of solid wastes disposal are significant and an unfortunate habit in the past has been to regard this aspect of environmental management as a “dump”. It is difficult to reverse this lowly image, but it can be done if one recognizes that a tidy and clean mill operation gives rise to greater productivity because of improved working conditions.

6.5 Costs

The collection, transportation and disposal of solid wastes costs in the order of $10 to $20 for each cubic meter of material. Disposal costs for
the "typical" 200 ton/day kraft mill, with primary clarification and land disposal of sludges, would therefore be about $140,000 annually, or about $2 per ton production. Add to this indirect costs such as land alienation and intangible costs such as the deliterious effect of leachates, and it is readily apparent that improper solid wastes disposal practices are not only environmentally unsound, but also costly. The high costs are likely to escalate further with increasing regulatory emphasis on environmental controls.
Chapter 7
Environmental Laws and Regulations

7.1 Introduction
There are presently few developing countries with national environmental regulations applicable to the pulp and paper industry. In some countries, legislation has been passed which stipulates in a general way that projects should be built in a manner that pollution does not occur and that national resources, such as fish, are to be protected. In some instances, the environmental consultant for a proposed forest products industry has been requested to draft pollution control regulations applicable to the specific project.

The purpose of environmental laws and regulations differs between industrialized and developing countries. Pollution control legislation in the more advanced industrialized nations is directed principally at reversing environmental degradation caused by past actions. On the other hand, legislation in developing countries should, ideally, be structured to prevent unacceptable pollution from occurring as industrial development is initiated.

7.2 Structure of Legislation in Major Pulp-Producing Countries
Pollution control legislation in the major pulp and paper producing countries takes many forms, as described below:

- In Japan, regional bodies administer national water and air pollution Acts. Minimum standards, which become more stringent in stages, apply to all pulp and paper mill liquid effluents. Air emission standards are based on designated area priorities.

- In Canada, federal liquid effluent regulations, which stipulate minimum standards, apply to all mills. Most provinces administer the federal regulations, usually in conjunction with provincial regulations. Some provinces apply uniform standards whereas in others, a permit system based on governmental and environmental priorities is ap-
plied. Source air emission and solid waste disposal regulations are administered by the provinces. Generally, dialogue is encouraged between regulatory agencies, industry and the public.

- In the United States, national water pollution control regulations are in effect. These call for all mills to achieve discharge levels based on “best practicable control technology currently available” by 1977 and “best available technology economically achievable” by 1983. Air emissions are usually regulated by individual states; however, there are proposed federal air quality regulations for all new or expanded operations. The formulation and administration of pollution control regulations in the United States relies heavily on the “adversary” approach and many disputes are brought before the courts for resolution.

- In France, an agreement was signed in 1972 between the industry and government which provided for a phased water pollution abatement program for every mill. The programs were based on the type of production at each mill and the priorities in the watershed where the mill is located.

- In Sweden and Finland, allowable discharges are set by permit after application has been made to the applicable legal and administrative agencies. While neither country has specific discharge requirements, guidelines have been established taking into account available technology, environmental quality, etc. In practice, existing mills negotiate an upgrading schedule and new mills are designed to water discharge and air emission requirements that are comparable to those in countries where specific regulations have been established, for instance Canada and the United States.

In some industrialized countries in Europe, a fee is levied on wastewater discharges. This fee, which is usually based on a complicated formula involving certain effluent parameters, financially penalizes firms with poor discharge quality. Sometimes the formula incorporates an increase in the fee as time progresses.

While there are many means of applying and enforcing environmental legislation, there is always one common goal: use legislation pursuing industry to reduce its wastewater discharges and air emissions to more acceptable levels. While the definition of acceptable levels varies between countries, the target discharge levels are relatively comparable. Currently, the discrepancy in allowable discharge values between countries relates more to the time frame during which the ultimate goals are to be achieved.

Environmental legislation therefore, takes one or a combination of the following approaches:
- A discharge fee based on the amount of specified pollutants.
- A case-by-case analysis based on the particular situation and receiving environment at each mill.
- Uniform minimum standards.

Probably the most successful approach, and that which is usually encouraged, is to establish discharge guidelines based on best practicable technology (proven abatement technology at reasonable cost). These guidelines are then used, together with an assessment of the particular mill situation, in developing a legally binding permit. Permit values would likely be comparable to the guideline values but some parameters would be relaxed or tightened depending on specific priorities. A good permit requires routine measuring and reporting procedures. Ideally, it should also include environmental monitoring requirements so that a periodic assessment can be made of the actual effects of the mill on the surrounding environment.

This chapter only discusses regulatory approaches at the national or regional level. In some instances, local by-laws regarding pollution control are enacted. However, such local regulations are seldom worthwhile since local governments do not have the technical expertise to develop appropriate values or the capabilities to monitor compliance. Also, local governments frequently display bias in setting allowable discharges. These biases may range from high values to attract industry to “pollution havens” to unachievably low values based on political motives. In an ideal sense, industry should be willing to apply pollution controls suitable to the particular case and legislation is merely a means of formalizing the appropriate standards.

It is also emphasized that while all major pulp-producing countries have pollution control legislation directed at the pulp and paper industry, there are many mills in every country not in compliance with stated requirements. In almost all instances, regulations are directed at new mills, with the goal that existing mills upgrade operations to new mill standards. For instance, a new recovery boiler for a large kraft mill may cost $50 million or more. That mill would usually not be required to meet the best emission standards (i.e. install a new recovery boiler) until the original boiler’s condition or capacity becomes such that it needs replacement.

Finally, it should be remembered that the pulp and paper industry is a high-technology industry, and environmental regulations in many major countries assume high-technology abatement systems will be applied. However, such technology is sometimes undesirable. In certain instances it may be preferable to relax standards to control air and water pollution in a less sophisticated, but more reliable manner.
7.3 Water Pollution Control

All major pulp and paper producing countries have various forms of legislation covering water pollution control, but not all regulations are in a form whereby fixed discharge values can be assigned to industrial sectors. In many countries with few major industries, waste-water regulations are frequently based on sewage characteristics, which are not necessarily applicable to industrial effluents.

While numbers differ, there are many similarities between water pollution control regulations for new mills in major nations:

- Guidelines or objectives are set for certain types of production.
- In certain countries, maximum permissible changes to the receiving water quality are set. Sometimes, the uses of the receiving water are designated.
- An effluent discharge permit is issued, usually before mill start-up, and ideally in the early stages of mill design. Permit values are similar to the “guideline” or “objective” values but may vary depending on the expected effect of effluent on the receiving waters.
- Permitted values are based, where possible, on quantity of pollutant rather than concentration. This approach encourages conservation of water in the mill.
- Sanitary sewage from mill buildings and townsites is usually required to be treated separately from mill process effluents.
- The effluent discharge permit stipulates effluent monitoring requirements and in some instances, receiving water monitoring.
- Only a few major effluent parameters are listed in permits.

The following discusses the significant parameters normally considered in the regulatory process:

a. Flow—This is almost never stipulated except in instances where it is required to calculate mass discharge (e.g. 20,000 m$^3$/day at 200 mg/l = 4000 kg/day).

b. pH—In practically all instances, effluents discharge to fresh water systems are required to have a near-neutral pH, usually between pH 6 and 9. In some situations with high receiving water buffering capacity, for instances in sea water, a permitted change in receiving water pH is stated; for example “the receiving water pH may not deviate from background level by more than 0.2 units beyond 50 meters from the outfall.”

c. Suspended Solids—Sometimes also called non-filtrable residue, suspended solids is the most widely applied parameter in effluent regulations. Unfortunately, the value for any particular sample is very dependent on the actual test procedure, particularly the volume of
### TABLE 7-1: Typical Guideline Values of Allowable Suspended Solids Losses From New Pulp and Paper Mills

All values shown in kg per air dry ton of product

<table>
<thead>
<tr>
<th>Jurisdiction</th>
<th>Type of Mill</th>
<th>Un-bleached Kraft</th>
<th>Bleached Kraft</th>
<th>TMP</th>
<th>Fine Paper</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>United States:</td>
<td>Average over 30</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Best Practicable Technology</td>
<td></td>
<td>6.0</td>
<td>16.4</td>
<td>8.4</td>
<td>5.9</td>
<td></td>
</tr>
<tr>
<td>Canada, Federal</td>
<td></td>
<td>4.0</td>
<td>5.0</td>
<td>9.0</td>
<td>10.0</td>
<td>—</td>
</tr>
<tr>
<td>Canada, British Columbia</td>
<td></td>
<td>10.0</td>
<td>10.0</td>
<td>10.0</td>
<td>10.0</td>
<td>—</td>
</tr>
<tr>
<td>European Economics Community</td>
<td></td>
<td>10.0</td>
<td>20.0</td>
<td>5.0</td>
<td>—</td>
<td>Proposed</td>
</tr>
<tr>
<td>France</td>
<td></td>
<td>10.0</td>
<td>20.0</td>
<td></td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Finland, Norway</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>No precise standards</td>
</tr>
<tr>
<td>Sweden</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

sample used and the type of filter paper. It is therefore essential that regulations specify the test procedure to be used.

Table 7-1 shows typical guideline values of allowable suspended solids losses from four different types of new mills. These values reflect what is considered reasonably attainable with conventional treatment, usually primary clarification by sedimentation followed by biological treatment; the figures for Canada (federal) are to be achieved before entering a biological treatment plant.

d. **Biochemical Oxygen Demand (BOD)**—This parameter is an internationally recognized measure of biodegradable matter. The test is arbitrary but BOD is fundamental to designing biological treatment systems. Since it affects the oxygen balance in receiving waters, BOD is used by scientists studying the impact of waste water discharge. Most countries use a 5 day test (BOD$_5$), but some European countries measure BOD over 7 days (BOD$_7$), the latter giving a 10 to 15 percent higher value.

There are some alternatives to the BOD test: Chemical Oxygen Demand (COD), Total Organic Carbon (TOC) and Permanganate
TABLE 7-2: Typical Values of Allowable BOD$_5$ Discharges from New Pulp and Paper Mills

All values shown in kg per air dry ton of product

<table>
<thead>
<tr>
<th>Jurisdiction</th>
<th>Un-bleached Kraft</th>
<th>Bleached Kraft</th>
<th>TMP:</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>United States:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Best Practicable Technology</td>
<td>2.8</td>
<td>8.1</td>
<td>5.6</td>
<td>Average over 30 days</td>
</tr>
<tr>
<td>Canada, Federal</td>
<td></td>
<td></td>
<td></td>
<td>Toxicity control limits</td>
</tr>
<tr>
<td>Canada, British Columbia</td>
<td>7.5</td>
<td>7.5</td>
<td>7.5</td>
<td>Proposed</td>
</tr>
<tr>
<td>European Economic Community</td>
<td>5.0</td>
<td>9.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>France</td>
<td>5.0</td>
<td>9.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Finland, Norway, Sweden</td>
<td></td>
<td></td>
<td></td>
<td>No precise standards</td>
</tr>
</tbody>
</table>

Number, all of which are much quicker tests. Some of these alternatives are applied in pulp and paper effluent regulations in various countries, but usually only where regulations have been derived from those applying to municipal sewage treatment. These alternatives are sometimes used by the more advanced mills as rough, but rapid indicators of effluent quality; however, their relationship to BOD is only approximate and specific to the particular effluent. It is likely that BOD will continue to be the most widely used measure of biodegradable organics in pulp and paper mill effluents.

BOD values stated in regulations are fairly comparable, as shown in Table 7-2. In general, regulatory bodies set allowable discharge BOD values at 20 to 25 percent of the raw BOD losses attainable from a modern mill in good condition. The basis for this percentage is that a BOD reduction of 75 to 80 percent is achievable with reasonably designed biological treatment system; a concurrent reduction of other deleterious substances (toxicity, tainting potential etc.) also occurs.

e. Toxicity—Toxicity as applied to effluents, is defined as lethal or acute toxicity. Lethal toxicity is usually reported as the percentage
of effluent in clean water at which 50 percent of test organisms (usually small fish) will die in 4 days (96 hours). The actual test is expensive and requires special knowledge and care. It is therefore not widely used. Canada is the only country which presently has effluent toxicity regulations. The Canadian regulations, which all new mills are required to comply with, state that the effluent after treatment, at a 65 percent effluent concentration, must kill no more than 20 percent of the test fish after 96 hours, in a bioassay where the effluent is being continuously replaced. In essence, this means that all fish should survive at 100 percent effluent concentration in a static bioassay test where the effluent is not continuously replenished.

f. Color—There is no country with national regulations to limit the color of the effluent. There are a number of mills, particularly in Sweden, Finland, Japan and the United States which, for individual reasons, have color removal systems, but it is generally acknowledged that treatment for color removal is both costly and technically difficult. The most effective method of restricting effluent color is to install suitable production processes. In general, a new mill should not be located where the impact of effluent color is deemed unacceptable.

Color is mainly a psychological parameter, and its effect is related to the nature of the receiving water and the attitude of the viewer. Color discharge to a sluggish muddy river in an industrialized area is much less noticeable or objectionable than color discharge to a clear and shallow stream in a pristine area.

g. Temperature—Thermal discharges from pulp and paper mills are relatively low and except in a few special instances, are not of concern. Where the receiving water is a small river with important fish resources, some consideration might be given to establishing a permissible change in receiving water temperature based temperature tolerances of the fish or other aquatic organisms.

7.4 Air Pollution Control

The structure of air pollution control legislation is more consistent between major pulp-producing countries than is that for water pollution control. Without exception, regulatory bodies require new mills to achieve emission characteristics attainable through the application of modern technology. Modern mills in developing countries, whether or not emission regulations exist, are also generally specified to meet these same criteria. The incremental cost of designing control systems to meet these criteria is minimal, whereas the cost of applying retrofitted systems is substantially higher.
Measuring techniques and units of measurement vary between countries and when emission values are stipulated, it is important that techniques be specified. It is becoming customary to use units of measurement based on Normal conditions—dry gas, one atmosphere pressure and a specified temperature, usually 20°C.

The following parameters are usually considered in the regulatory process.

a) **Sulphur Dioxide**—As noted in Chapter 5, sulphur dioxide emissions are seldom of concern in the pulp and paper industry. Exceptions might be with sulphite pulp mills and mills using large quantities of high sulphur-content fossil fuels. While it is unlikely that new sulphite mills will be built in the near future, if any are, it is essential that exhaustive expert studies be done to ensure that damage will not occur.

Some regulatory agencies set a permissible limit on sulphur dioxide emission from kraft mill recovery furnaces. Typically, this value if 200 ppm as SO₂ (about 500 mg/m³).

Often ambient air quality objectives are specified for sulphur dioxide. In this case, predictions of ambient air quality are made during the design to ensure that remedial measures are adequate. Typical values are:

<table>
<thead>
<tr>
<th>Time Period</th>
<th>Permissible Average SO₂ Concentration in Ambient Air</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 hour</td>
<td>450 µg/m³</td>
</tr>
<tr>
<td>1 day</td>
<td>150 µg/m³</td>
</tr>
<tr>
<td>1 year</td>
<td>25 µg/m³</td>
</tr>
</tbody>
</table>

b) **Particulate Matter**—Most regulatory agencies place limits on particulate matter in the various stack exhausts. In some instances, weights are stipulated, based on production, whereas in others, a concentration is stipulated. Typical values are as follows:

<table>
<thead>
<tr>
<th>Stack</th>
<th>Particulate Matter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recovery Furnace</td>
<td>150–250 mg/Nm³</td>
</tr>
<tr>
<td></td>
<td>1.5–2.5 kg/ton</td>
</tr>
<tr>
<td>Lime Kiln</td>
<td>200–300 mg/Nm³</td>
</tr>
<tr>
<td></td>
<td>0.4–0.6 kg/ton</td>
</tr>
<tr>
<td>Bark Burning Power Boiler</td>
<td>150–250 mg/Nm³</td>
</tr>
<tr>
<td>Dissolving Tank</td>
<td>0.2–0.3 kg/ton</td>
</tr>
</tbody>
</table>
Some jurisdictions place limits on acceptable ambient air suspended particulate concentrations. The following values, which refer to typical desirable concentrations in residential areas, may be used by the designer of the mill, and by the owner of the mill, during pre and post-operational environmental monitoring:

<table>
<thead>
<tr>
<th>Time Period</th>
<th>Total Suspended Particulate Matter</th>
</tr>
</thead>
<tbody>
<tr>
<td>24 hours</td>
<td>150 ( \mu g/m^3 )</td>
</tr>
<tr>
<td>1 year (geometric mean)</td>
<td>60 ( \mu g/m^3 )</td>
</tr>
</tbody>
</table>

c) **Total Reduced Sulphur**—The odorous compounds emitted by kraft mills are collectively referred to as total reduced sulphur (TRS) compounds. They are expressed as TRS, reported either as hydrogen sulphide \((H_2S)\) or as sulphur \((S)\). As in particulate matter, some jurisdictions place limits on total weight emitted, whereas in others, concentration is specified.

Typical values for new mills are as follows:

<table>
<thead>
<tr>
<th>Stack</th>
<th>Total Reduced Stack Sulphur Reported as (H_2S)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recovery Furnace</td>
<td>5–10 mg/Nm(^3) 0.05–0.10 kg/ton</td>
</tr>
<tr>
<td>Lime Kiln</td>
<td>20–40 mg/Nm(^3) 0.03–0.07 kg/ton</td>
</tr>
<tr>
<td>All other sources</td>
<td>0.15 kg/ton</td>
</tr>
</tbody>
</table>

In a few instances, the designer is given ambient air guidelines to apply to design. Typically, TRS values \((H_2S)\) are 7 \( \mu g/m^3 \), the approximate odor threshold value, over one hour of measurement, and 3 \( \mu g/m^3 \), when measured over 24 hours.

### 7.5 Land Pollution Control

Solid wastes disposal is less easy to regulate than air or water pollution. The more advanced regulatory agencies will usually accept a solid wastes disposal scheme if the criteria outlined in Chapter 6 are followed.

In some instances, domestic garbage is not allowed to be mixed with industrial refuse. In other instances, landfill management practices, such as covering procedures and monitoring techniques, are specified.
Chapter 8
Nonwood Plant Fiber Based Industry

8.1 Introduction
On a world-wide basis, about 5 percent of the virgin pulp that is used to make pulp and paper products comes from nonwood fibrous materials. Although nonwood plants are used to a limited extent in North America and Europe, they represent a major source of fibrous raw materials in many developing countries. Their importance is increasing in developing countries because rising energy costs have strained foreign currency reserves and created a shortage of foreign funds to purchase imported pulp and paper products. Furthermore, the relatively small size of nonwood-based mills is amenable to simple and labor-intensive technology. Virtually all products from nonwood fiber mills are destined for domestic markets.

Nonwood materials used to make pulp, paper and paper board products include agricultural residues such as bagasse, cereal straw and rice straw; natural plants such as bamboo, papyrus, esparto and other grasses; and cultivated fiber crops such as jute, hemp, kenaf, crotalaria, flax, abaca, sisal, henequen, banana, pineapple fiber, cotton fiber and cotton linters. The most widely used nonwood fibrous materials are cereal straw, rice straw, bamboo and bagasse. The chemical composition of some of these nonwood materials are compared to wood in Table 8-1.

The processes used to make paper and paper board from nonwood materials are generally similar to those employed in the wood-based sector of the industry. However, nonwood fibrous materials have some characteristics which make them somewhat difficult to handle with equipment and processes developed specifically to handle wood. For some nonwood materials, such as straw and bagasse, technology has been developed to improve manufacturing capabilities but for other materials, specific process technology has yet to be developed.
TABLE 8-1: Concentrations of Important Chemical Constituents in Various Fiber Sources

<table>
<thead>
<tr>
<th></th>
<th>Cellulose</th>
<th>Pentosan</th>
<th>Lignin</th>
<th>Ash</th>
<th>Silica</th>
</tr>
</thead>
<tbody>
<tr>
<td>Softwoods</td>
<td>40–45%</td>
<td>7–14%</td>
<td>20–35%</td>
<td>0.3%</td>
<td>0.006%</td>
</tr>
<tr>
<td>Hardwoods</td>
<td>40–45</td>
<td>19–26</td>
<td>20–25</td>
<td>0.4–0.8</td>
<td></td>
</tr>
<tr>
<td>Cotton Linters</td>
<td>80–85</td>
<td>3</td>
<td>1.0–1.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flax</td>
<td>70–80</td>
<td></td>
<td>0.7–1.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hemp</td>
<td>65–75</td>
<td></td>
<td>1.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Jute</td>
<td>60–65</td>
<td></td>
<td>0.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rice Straw</td>
<td>25–35</td>
<td>25</td>
<td>12</td>
<td>14–18</td>
<td>6–8</td>
</tr>
<tr>
<td>Cereal Straw</td>
<td>35–50</td>
<td>25–30</td>
<td>15–20</td>
<td>6–8</td>
<td>2.5</td>
</tr>
<tr>
<td>Bamboo</td>
<td>35–55</td>
<td>16–30</td>
<td>22–30</td>
<td>1–5</td>
<td></td>
</tr>
<tr>
<td>Esparto</td>
<td>50</td>
<td>27–32</td>
<td>17–19</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Bagasse</td>
<td>30–40</td>
<td>25–32</td>
<td>18–20</td>
<td>2</td>
<td>1.5–2</td>
</tr>
</tbody>
</table>

8.2 Raw Material Preparation

The treatment of the bulky nonwood raw materials during fiber preparation is necessarily somewhat different from methods used to handle wood. Straws and grasses are usually cut to provide uniform and efficient feeding to pulping equipment. Extensive cleaning and screening is required to separate fibrous material from undesired materials such as grain, nodes, dirt, soil, chaffs and leaves. Material losses are significant, averaging about 3 percent. In modern mills, cleaning can be done in a dry system using air. Dry cleaning has become a standard practice in many larger cereal straw mills, taking precedence over wet cleaning methods. Atmospheric emissions thus require careful control. Normally, dry cyclone-type cleaners are used and the collected dust and dirt is incinerated and heat recovered. For other nonwood raw materials such as bamboo, kenaf and rice straw, wet cleaning has many advantages including reduction of fines losses, removal of dirt, removal of silica and increase in moisture content to provide a more uniform material for chipping or pulping. Wastewater discharges from raw material preparation are a considerably greater problem than in a wood-based mill; however, technology has been developed to adequately treat these wastewaters. Mildly contaminated wastewater streams from the pulp and paper operations can often be used as the source of water for the materials preparation area.
8.3 Pulping and Washing Processes

Several processes are used to pulp nonwood plant materials; however, two processes, soda and sulphate, predominate. These two processes permit economical recovery of chemicals from the cooking and pulp washing liquors. The choice between the soda and sulphate processes is usually governed by the cost of make-up chemicals, since pulp yield and pulp properties are generally similar. In many countries, technical and economic considerations favor the soda process for pulping non-wood plant materials.

In older mills and in instances where labor-intensive operations are desired, pulping may be done in batch digesters. Continuous pulping systems have been adopted in most newer and larger installations. Continuous digestion produces a more uniform product and the chemical, steam and manpower requirements are somewhat lower than with the batch system. Since recovery of pulping chemicals is easier with a continuous pulping process, chemical losses to the sewer are generally lower.

Most nonwood plant materials produce a pulp that is considerably more difficult to wash than wood pulps. Nonwood pulps are slow draining due to low porosity of the pulp mat caused by swelling of the fibers due to high hemicellulose content and the short fiber length. Therefore, pulp washers must be 25 to 30 percent larger in area than those for softwood pulps. Even with larger washers, chemical losses are generally higher than in wood pulp mills and solids content of wash liquors is usually lower. Soda losses from the brownstock washing operations of 5 to 10 percent are normal even in well-run nonwood mills, compared to 1 to 2 percent in a modern wood-based operation. BOD losses are also considerably greater in nonwood mills.

8.4 Chemical Recovery

When pulping most nonwood plant materials, the recovery of chemicals is much more difficult than recovery in wood pulp mills. In the past, chemical recovery was not practiced at most nonwood mills but today, recovery is often necessary to reduce the large quantities of pollutants that would otherwise be released to the environment.

The main factor which affects the operation and efficiency of the chemical recovery system is the high hemicellulose and high silica content of most nonwood materials which end up in the black liquor system. This results in high silica and hemicellulose concentrations in black liquor which increases its viscosity and makes evaporation and firing into a furnace extremely difficult. The high silica levels also contribute to rapid scale formation in the evaporators, reducing efficiency and increasing downtime for tube cleaning and maintenance. Several meth-
ods are used to minimize the adverse effects of the silica in the black liquor. These significantly improve the operation but operation efficiency remains lower than that achieved in comparable wood pulp mills. Other problems which affect the operation of nonwood recovery systems include weaker black liquor due to more difficult washing and lower calorific value as a result of higher ash and hemicellulose content and lower lignin content of most nonwood materials.

More frequent downtime for cleanout and maintenance causes greater sewer losses as liquor is dumped, tanks and evaporators are acid washed and liquor lines are flushed. The provision of large dump tanks in the recovery area can, if operated effectively, reduce the quantity of chemicals sewered. Segregation, storage and controlled release of recovery area sewers is desirable, if biological treatment is practiced, to minimize the impact of abnormal liquor losses on the treatment efficiency.

8.5 Out-Plant Pollution Control

The contaminants discharged from nonwood-based pulp and paper mills are very similar to those discharged by wood-based mills. Aqueous effluents contain fibers, organic chemicals extracted from the raw materials and pulping chemicals; atmospheric emissions contain particulate matter and odorous gases. The processes employed to treat the discharges are also similar.

External wastewater treatment facilities normally include settling or clarification to remove settleable solids and biological oxidation to reduce the oxygen demand and toxicity of the effluents. Efficient clarification often requires the addition of settling aids or long detention times, as the small nonwood fibers settle very slowly. Dewatering of the collected sludge is difficult due to the slow drainage characteristics of most nonwood sludges and sludge handling facilities must be designed accordingly. Suspended solids losses from modern nonwood pulp and paper mills typically range from 30 to 60 kg per ton of product.

The quality of the effluent from a nonwood mill is generally more variable than that from a comparable wood-based mill, due to the greater difficulties in the operation of pulp washing and chemical recovery facilities. Thus, for successful biological treatment, outplant surge and equalization capacity is needed, in addition to the inplant spill recovery systems. Aerated lagoons are the most common form of biological treatment; due to their large volume, they are much less susceptible to upsets from flow surges and chemical spills than smaller high-rate treatment systems. Discharges of BOD₃ from nonwood mills with chemical recovery typically range from 30 to 80 kg/ton, before treatment.

Methods of disposal of treated mill effluents are the same as for wood
mills and the same criteria must be considered to maintain environmental quality. One means of disposal often available to nonwood mills is land irrigation. The source of nonwood fiber is usually close to the mill and the crops often require irrigation during the dry season. Where straw washing is practiced, this effluent is especially amenable to irrigation. The dry season is also usually the time when surface water flows are low and minimum dilution water is available for the disposal of mill effluent. Thus, land disposal can be practiced during the dry season and at other times, disposal can be to surface waters. Such a system can reduce overall effluent treatment costs, where suitable land is available.

Atmospheric emissions from mills using nonwood fibers have received very little study. However, different fiber sources have little noticeable effect on air emissions. The kraft chemical recovery process in a nonwood mill produces about the same quantities of particulates and odorous gases as wood-based mills during normal operation. However, the liquor characteristics make nonwood recovery systems difficult to operate continuously and emissions increase during upsets, startups and shutdowns. Control technology for particulate and gaseous emissions is the same as in wood-based mills.

The soda pulping process is often used for nonwood fiber materials. The absence of large quantities of sulphur in process streams greatly reduces the level of odorous emissions compared to the kraft process. Thus, in soda mills, odor control systems are not usually required.

In summary, the nonwood fiber based industry has greater environmental problems than the wood-based industry and the relative costs for comparable pollution control are greater. The equipment and basic technology used in nonwood mills was originally developed for wood based materials. The total system, even with the many minor modifications made today, is less efficient and thus losses to the environment in a nonwood mill are greater than those from a wood-based mill.
Chapter 9
Environmental Planning
Check-List

9.1 Introduction
The following check-list is presented to aid project-planners in selecting the appropriate level of effort during the various stages of a development. These guidelines are not rigid and are intended only to portray the typical sequence of events during a large forest products development project. Actual environmental inputs are always specific to the particular circumstances. The assumed stages of a project are those shown in Figure 2–1 (Chapter 2).

It is emphasized that the scope of this manual is restricted to the environmental activities of pulp and paper processing. In a typical forest products development, there are two other basic environmental impacts which are often of a greater magnitude than the activities of the production facility: the impact of forestry operations and the social and cultural impact of introducing a technologically modern industry into an undeveloped region. Studies addressing these issues should parallel those related to the manufacturing operation.

9.2 Opportunity Identification
No environmental input required.

9.3 Preliminary Investigations
The objective of this phase is to determine whether the identified resource offers some prospect of successful utilization and that there are no obvious major obstacles to the project.
- No formal environmental input.
- Are there any obvious factors which would preclude the project on environmental grounds?
- Have previous proposals for development in the project area looked at environmental issues?
• What is the government policy regarding introduction of industry to the project area?
• Do there appear to be possible mill sites in the project area, taking into account basic needs (resource, water, transportation, power, etc.)?

9.4 Preliminary Feasibility Study

The objective of this phase is to obtain a more specific definition of the most likely viable project and to undertake technical, economic and environmental overview studies to determine whether a full feasibility study would be warranted.

General
• What are the most probable production processes?
• Where are the markets for the end-product?
• Define existing transportation, communication and power systems and identify deficiencies.
• Assemble governmental environmental laws and regulations, especially those relating to pre-investment requirements (e.g. environmental assessments).
• Identify potential financial backers to the project and determine if they have environmental guidelines or requirements.
• Make preliminary contact with the environmental officials of the various interested governments.
• Assemble the readily available environmental data on the project area.

Water
• What are the flows of the rivers in the area?
• What are the physical and chemical characteristics of lake and/or river waters?
• What uses are made of local lakes and rivers?
• What appears to be the present condition of the possible receiving waters?
• Does disposal of suitably treated effluent appear to pose a problem?

Air
• What are the basic meteorological characteristics and topography of the area?

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• Are there other uses of the area (e.g., tourism) which may conflict with a pulp and paper mill?
• Do emissions, with suitable control devices, appear to pose a potential problem?

**Land**

• No environmental input required.

**Summary**

• Are there any irreconcilable environmental problems associated with the proposed project? If so, are alternatives (e.g., different manufacturing process) available?
• What appear to be the major environmental interactions on which later studies should concentrate?
• Are there serious deficiencies in the environmental knowledge of the area? If so, initiate work to obtain required information.
• If the proposed project appears viable, outline a scope of work for subsequent detailed environmental impact studies.

### 9.5 Feasibility Study—Stage 1

The first stage of the feasibility study selects the preferred manufacturing process and size of plants and assembles all information required to determine the viability of the project.

• Visit the project area to identify potential site areas.
• Discuss the proposed project with government officials and solicit their assistance in obtaining relevant data.
• Obtain governmental laws and regulations relating to air, water and land pollution control. If none are applicable to the pulp and paper industry, initiate discussions as to whether specific criteria might be established if the proposed project proceeds.
• Develop basic flow sheets of the proposed manufacturing facility.
• Determine the environmental design philosophy of the mill—e.g., should it be labor intensive? Should control emphasis be placed inside the plant or outside the plant?
• Ensure that adequate information of the environmental characteristics of the project area is available for use in the environmental assessment analysis.
9.6 Feasibility Study—Stage 2

The second stage of the feasibility study culminates in a decision regarding the project’s commercial, technical and economic viability.

- Select the preferred site and ensure that it meets the approval of relevant government agencies. Environmentally, a good site is one which satisfies the following criteria:
  
  (a) Is located on sufficient land area to provide a logical and unrestricted placement of facilities with respect to processing.
  
  (b) Does not require displacement of homes.
  
  (c) Is on land not conducive to intensive agriculture or other uses.
  
  (d) Is close to the receiving water for effluent release and of sufficient elevation to allow gravity flow of process wastewater.
  
  (e) Is usually downwind of major population centers and where stable atmospheric conditions seldom occur.
  
  (f) Permits emissions without injury to animals, plants, soil or water.
  
  (g) Allows effluent discharge without significant harm to the biophysical aquatic environment.
  
  (h) Is accessible to social amenities, a reasonable skilled labor base, support industries, services and the like.
  
  (i) Is in an area designated for industry and where the local people desire industrialization.
  
  (j) Is remote from areas of prime tourism and recreational potential.
  
  (k) Does not interfere with endangered, rare or important species of wildlife.
  
  (l) Does not conflict with aspects of historical significance.
  
  (m) Is close to good transportation networks.
  
  (n) Is in close proximity to an environmentally suitable energy supply.
  
  (o) Incorporates a secure supply of raw materials, energy, water and other services.

- Undertake an environmental assessment generally following guidelines presented in Chapter 3.

- Identify deficiencies in data that might be required for design purposes.

9.7 Basic Design and Design Development

This stage follows acceptance of, and commitment of capital to the project. The mill design criteria are established and major items of equipment are purchased.
General

- Initiate monitoring necessary for mill design (e.g. establish a weather station).
- Establish, and continually update, the environmental design criteria for the mill.

Water

- Select the targetted treated effluent quality, taking into account government requirements, appropriate technology, receiving water quality and approximate costs.
- Seek the regulatory authorities agreement to the design effluent quality before equipment is purchased and construction commences.
- Establish the effluent treatment scheme.
- Determine the effluent treatment plant layout and the location of the outfall.
- Ensure the layout is compatible with possible mill expansion or additional treatment facilities.
- Determine the treatment scheme for sanitary sewage from the townsite, construction camps, and mill buildings.
- Identify parameters that should be measured before mill start-up to monitor the effects of mill effluent.

Air

- Select the targetted emission quality.
- Seek the regulatory authorities agreements to design emission quality before equipment is purchased.
- Specify emission quality in the relevant invitations to bid for equipment.
- Establish the appropriate stack heights.
- Identify air quality parameters to be measured before mill start-up, to evaluate the effects of emissions after start-up.

Land

- Establish the relevant solid wastes disposal regulations.
- Project the quantity and nature of expected solid wastes.
- Ensure that solid wastes generation is minimized and that, where possible, wastes are segregated at source.
* Ensure that hazardous wastes will not be disposed of with general industrial refuse.
* Determine whether, for the region under study, there are prospects for secondary uses of solid wastes.
* Select the preferred means of disposing of organic solid wastes. For instance, if they are to be incinerated with bark, this might affect the furnace design and the type of equipment preferred for sludge de-watering.
* Select a solid wastes disposal site in accordance with guidelines shown in Chapter 6.
* Establish the relevant solid wastes disposal regulations.

### 9.8 Detailed Engineering and Construction

* Continually update the environmental design criteria.
* Ensure mill design is in accordance with the project’s environmental design philosophy.
* Institute operator training programs and ensure all mill operators are given a basic course on environmental protection.
* Institute pre-operational environmental monitoring programs.

### 9.9 Start-Up and Operation

* Regularly monitor waste water streams and gaseous emissions for selected parameters. Where a particular discharge consistently has abnormally high values, corrective action should be taken; this may involve process and/or equipment modifications.
* Periodically monitor the quality of the receiving water (biological chemical and physical parameters) and the local atmosphere.
* Monitor the effect of solid waste disposal practices on the environment. This may involve test holes to measure groundwater quality in the vicinity of the site.
* Maintain programs to keep environmental awareness of all employees at a high level.
* Keep abreast of developing technology with the view of improving environmental control measures in priority areas.
* Be vigilant and maintain an open attitude on the possible effects of the operation on the environment.
Bibliography


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