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The Influence of Log Handling on Water Quality

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THE INFLUENCE OF LOG HANDLING ON WATER QUALITY

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ABSTRACT

The water storage of logs is widely practiced in the Pacific Northwest. An investigation has been made to determine the effect of this practice on water quality.

Soluble organic matter and some inorganics leach from logs floating in water and from logs held in sprinkled land decks. The character and quantity of leachate from Douglas fir, ponderosa pine and hemlock logs have been examined. Measurements including BOD, COD, PBI, solids and toxicity have shown that in most situations the contribution of soluble leachates to holding water is not a significant water pollution problem.

The most significant problem associated with water storage appears to be the loss of bark from logs during dumping, raft transport and raft storage. Dislodged bark can float until it becomes water logged and sinks forming benthic deposits. Floating bark is aesthetically displeasing and could interfere with other beneficial uses of a lake, stream or estuary. Benthic deposits exert a small, but measurable oxygen demand and may influence the biology of the benthic zone. Implementation of corrective measures by the timber industry to reduce bark losses could make the water storage of logs a practice which is compatible with a high quality environment.

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CONCLUSIONS

The following conclusions are based upon the results of a three year research investigation outlined in this report.

1. Water storage of logs is widely practiced in Oregon, Washington and Alaska.

2. Leachates from logs held in water storage contribute organic substances which exert a BOD and COD. In most situations the quantity of these substances which enter the holding water do not represent a significant water quality problem.

3. Log leachates exert some acute toxicity to fish.

4. Color-producing substances measured by the PBI are found in log leachates, and are derived primarily from bark.

5. Bark is dislodged from logs in significant quantities during dumping and raft transport activities. Considerably more bark is dislodged from Douglas fir logs than from ponderosa pine logs.

6. Log dumping methods significantly influence the amount of bark which is dislodged from logs.

7. Dislodged bark sinks at a rate dependent upon particle size and species of tree.

8. Bark deposits exert a small, but measurable, demand for oxygen from overlying waters.

9. Should the loss of bark to holding water be minimized by improved handling practices by the timber industry, the water storage of logs would not constitute a major water quality problem.

RECOMMENDATIONS

1. Further study should be undertaken to determine the effect of bark deposits on the biology of the benthic zone and to evaluate the effect on water quality created by the dredging of bark deposits.

2. The timber industry should strive to improve methods of depositing logs into water storage areas. Methods for consideration might include: (a) debarking logs on land before dumping, (b) installation of a sling hoist or fork lift to convey logs from trucks to holding water or (c) utilization of a man-made dumping channel or pond adjacent to storage areas which would retain floating and sunken bark.

3. The water storage of logs, with provisions for minimizing bark losses, should not be discouraged unless a suitable alternate storage method is available which results in less input to the environment.

INTRODUCTION

Purpose

This research was intended to evaluate the water pollution potential of log storage practices in the Pacific Northwest. Specific aims of the research were the determination of:

- the quantity, character and pollution potential of substances "leached" from logs while floating in water,
- the degree to which leached substances are toxic to biological life as measured by bioassays,
- the extent and rate at which leached substances are degraded biologically,
- the distribution of debris under and in the vicinity of log rafting and storage areas,
- the rate and extent of aerobic biodegradation of benthic bark deposits, and
- the extent of log raft storage in the Pacific Northwest.

Scope

This research included both laboratory and field studies dealing with pollution problems from soluble leachates and bark debris from several species of timber in the Pacific Northwest. The three year project was conducted in a region extending from California to Alaska, however, the major study area was central and western Oregon.

Background

Timber is a bountiful resource in the Pacific Northwest and is an important factor in the economic stability of the region. The timber industry, which includes the production of pulp and paper, lumber, plywood, and a multitude of other forest products, ranks as the region's leading industry (19).

The numerous sawmills and pulp and paper mills which dot the Pacific Northwest find it necessary to retain large inventories of logs to provide a continuous timber supply throughout the year. Logs which are simply piled upon the land, soon dry out at the ends and deep cracks develop longitudinally. This phenomenon, referred to as "end checking", greatly enhances product wastage. End checking can be minimized by sprinkling land-decked logs or, more commonly, by floating the logs in water. Rafted logs are commonly found in lakes, rivers, estuaries, sloughs and man-made ponds. Oregon alone has over 12,000 acres of log ponds and 2,000 acres of sloughs and canals used for log storage (18).

Prior to this research investigation little effort had been put forth to determine the magnitude of the pollution problem associated with log handling practices. McHugh, Miller and Olsen (18) surveyed over 80 log ponds in Oregon in an attempt to find a chemical means to measure the degree of pollution of a pond. Generally, they found the log pond waters to be high in chemical oxygen demand (200 ppm to 700 ppm) and total solids (200 ppm to 800 ppm). Average concentrations of 0.48 ppm for phosphates, 0.56 ppm for nitrates, and 5 ppm for soluble carbohydrates were reported. Very low concentrations of nitrites, sulfates, and dissolved oxygen were found for most of the ponds. The researchers concluded that ponds containing logs without bark (peelers) were just as polluted as those containing an equivalent volume of bark-covered logs per unit volume of water.

Ellwood and Ecklund (8) reported the following values for a log pond storing ponderosa pine: suspended solids, 38 ppm; dissolved oxygen, 0 ppm; and pH 6.8. The authors attributed the strong, sour smell of log ponds to the production of organic acids as a result of carbohydrate breakdown by microorganisms present in the ponds.

Henriksen and Samdal (11) agitated bark with distilled water and measured the chemical oxygen demand (COD) at different intervals. After 65 hours they found that a total of 43,200 mg COD/kg bark had been extracted.

Wood bark pollutants from both softwood and hardwood trees were evaluated by Sproul and Sharpe (24). They measured the quantity of COD, color, lignin-like extracts and other "pollution parameters" which enter natural water from benthic bark deposits and from drainage from bark piled on land.

Wood is customarily differentiated into major cell wall components and extraneous components. The major cell wall components consist of cellulose, hemicelluloses and lignin. Cellulose makes up 40 to 50% of wood by weight. Hemicelluloses are polysaccharides which are closely related chemically to cellulose. Lignin forms the boundary between adjacent cells and acts as a cementing material which bonds the cells together (6). With the exception of a small part of the lignin these components are insoluble in organic solvents and in water (27).

The extraneous components are soluble in many solvents, including water, and are frequently termed extractives for that reason. The character of the extractives depends upon the species of wood but generally include tannins, resins, essential oils, fats, terpenes, flavanoids, quinones, carbohydrates, glycosides, and alkaloids (27).

Douglas fir and ponderosa pine are the two predominant timber species in the Pacific Northwest; therefore, their extractives are of particular interest. Considerable research has been conducted on the extractives from the bark of the above two species. Since the vast majority of ponded logs still have their bark intact, the bark extractives could well be the major components of the pond water.

Kurth and Hubbard (16) have reported that the principal water soluble extractive of Douglas fir and ponerosa pine bark is tannin. They found the tannin content of Douglas fir bark to vary from 7.5 to 18% (based on oven-dry bark weight) and that of ponderosa pine bark from 5.6 to 11.4%. Although the above percentages are based on hot-water extractions, Kurth (14) has found that the tannin content of bark taken from ponded logs is considerably lower, indicating that tannin is also soluble in cold-water.

In addition, Kurth, Hubbard and Humphrey (17) have found ponderosa pine bark to have a water soluble reducing sugar content of 3 to 6% (based on oven-dry weight of bark) whereas Douglas fir bark contained only one-tenth of this amount.

Organization of Research

Initial phases of this research involved the development and application of techniques and methodology for evaluating the rate of leaching of soluble organics from logs immersed in water; the quantity of bark dislodged from logs during unloading and transport operations; the rate of bark deposition; the distribution of bark debris in benthic deposits; and the rate of oxygen uptake by benthic deposits containing bark debris. Results of these determinations provided a basis for predicting the magnitude of pollution from the water storage of logs. These studies were conducted both in controlled laboratory experiments and in field situations.

Extensive field investigations at three different locations in Oregon were undertaken after the developmental work in an attempt to determine the impact of log handling activities on water quality. Results of direct water quality measurements in selected log storage areas were compared with predicted values.

An unproductive attempt was made to ascertain the magnitude of pollution problem in the Northwest resulting from the log handling activities. Limited quantitative data was obtained.

EXPERIMENTAL APPARATUS AND PROCEDURES

Introduction

A search of the technical literature revealed that very little research activity had been undertaken regarding pollution problems associated with log handling and storage. Furthermore, very few standard methods or procedures have been reported for studying problems of this type. As a consequence a considerable portion of this research effort was devoted to the development of apparatus and procedures which could provide meaningful information on this somewhat unique problem. The following sections of this phase of the report describes in considerable detail the apparatus and procedures developed to study leachate and bark problems associated with the water storage of logs.

Leachate Studies

General. Floating logs present two different types of surface for contact with the water, the cross-cut end sections and the cylindrical surface. Since logs in floating rafts are generally 20-40 feet in length, the cylindrical surface area contributes the majority of the surface area exposed. Laboratory facilities at Oregon State University were not adequate to handle full-length logs, consequently sections 14-20 inches long were used. These sections had a much higher ratio of end area to cylindrical area. Since the leaching mechanism was not clear at the beginning of the research, the relative effect of the end area versus cylindrical area had to first be determined. This was accomplished by application of a masking material to the cross-cut ends. A discussion of the procedure developed for masking log ends is presented in Appendix A.

Static tests. The three species of timber selected for this study were Douglas fir, ponderosa pine and hemlock. These are the most prevalent species in Oregon and the Pacific Northwest. Log sections were cut from freshly felled trees in central and western Oregon. Some of the sections were debarked by hand and others were left with bark intact to determine the effect of bark on the leaching rate of soluble substances from logs. The cross-cut ends of selected log sections were sealed with paraffin whereas others were left unsealed.

The prepared log sections were immersed in six custom-built,150-liter plexiglas tanks. All tanks were fabricated from one quarter-inch clear plexiglas sheet stock to allow visual observation of the logs during the leaching period. Figure 1 shows the construction details of the holding tanks. Water-tight joints were developed by cementing the sections together with dichloromethane solvent. The tank dimensions were chosen to maximize the size of samples within the storage space available. Two shelves were constructed in a temperature-controlled room to support the test tanks. There was no outflow from the test tanks in the static leaching tests. However, some mixing was provided in each tank to reduce the development of concentration gradients near the log surfaces. Teflon

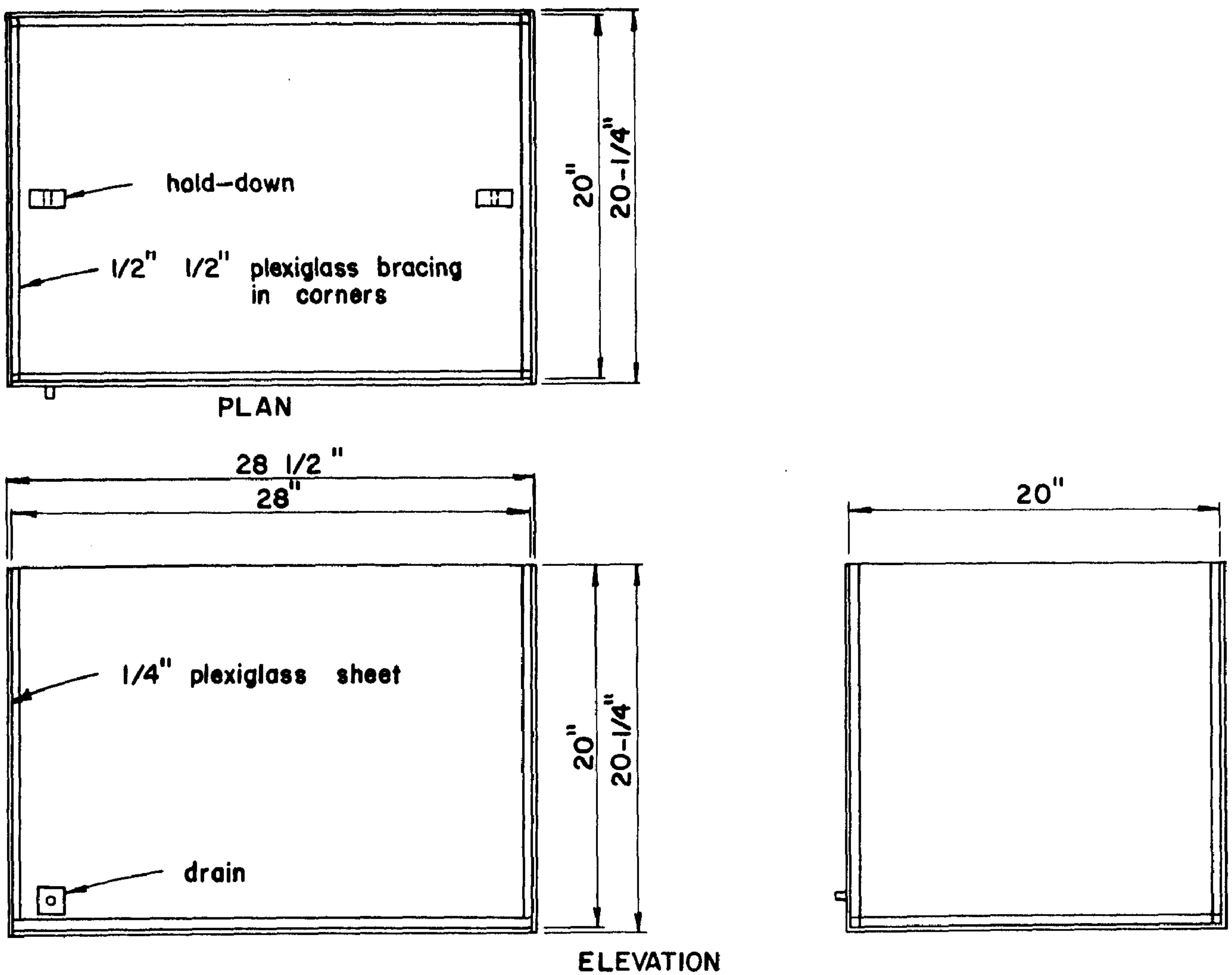


FIGURE 1. Log Storage Tanks for Leaching Studies.

coated stirring bars were placed in each tank and were rotated by magnetic stirrers mounted flush with the shelf surface as shown in Figure 2.

Log samples were held at 20°C ± 0.5 throughout the test period to provide a consistent basis for comparison of the experimental data. This temperature was selected because it approximated the mean summer water temperatures surrounding existing log rafts in the inland and coastal waters of Oregon.

Mercuric chloride was added to each tank to provide a mercuric ion (Hg++) concentration of 2 to 25 mg/l. This metabolic poison was added to retard biological degradation of the organic material leached from the logs. Other methods of inhibiting biological growth were considered including pH extremes, heat sterilization and organic biocides. These were rejected due to the uncertainty of an effect on leaching rate and measured indices of pollution. For instance organic biocides would add COD, total organic carbon and volatile solids to the storage water.

Samples of leachate were withdrawn from the six test tanks at specified intervals during 7 to 40 day log storage periods and analyzed for the following indices of pollution: chemical oxygen demand (COD), Pearl-Benson Index (PBI), total solids, total volatile solids, total organic carbon, wood sugar, biochemical oxygen demand (BOD) and acute toxicity. BOD and toxicity determination were performed on samples which were pretreated by selective chelation to remove the mercuric ion added as a preservative. A discussion of the mercury removal technique is given in Appendix B. A more detailed description of the apparatus and procedures used in the leaching studies is given by Graham (10) and Atkinson (3).

Dynamic leaching tests. The second type of log leaching study involved a flow-through system. The plexiglas holding tanks used for the static leaching study were adapted for flow-through experiments. An overflow port was positioned at the end opposite the inflow to minimize short circuiting. Tap water was metered at different flow rates into different test tanks holding Douglas fir and ponderosa pine logs. Evaporation losses were controlled by covering the tanks with plastic sheets. Mercuric chloride was added to the inflow water to maintain a concentration of about 50 mg/l (as Hg++). The poison was to retard biological breakdown of leached organic substances. Since constant flow was exceedingly difficult to maintain at the required low rates, overflow was collected in a carboy and measured every 2 to 3 days with a graduated cylinder. Overflow samples were collected for COD analysis only.

Bark Studies

The following experimental methods were developed to study the quantity of bark dislodged from logs, the rate of bark deposition, the distribution of bark in the benthic zone and the oxygen demand resulting from bark deposits.

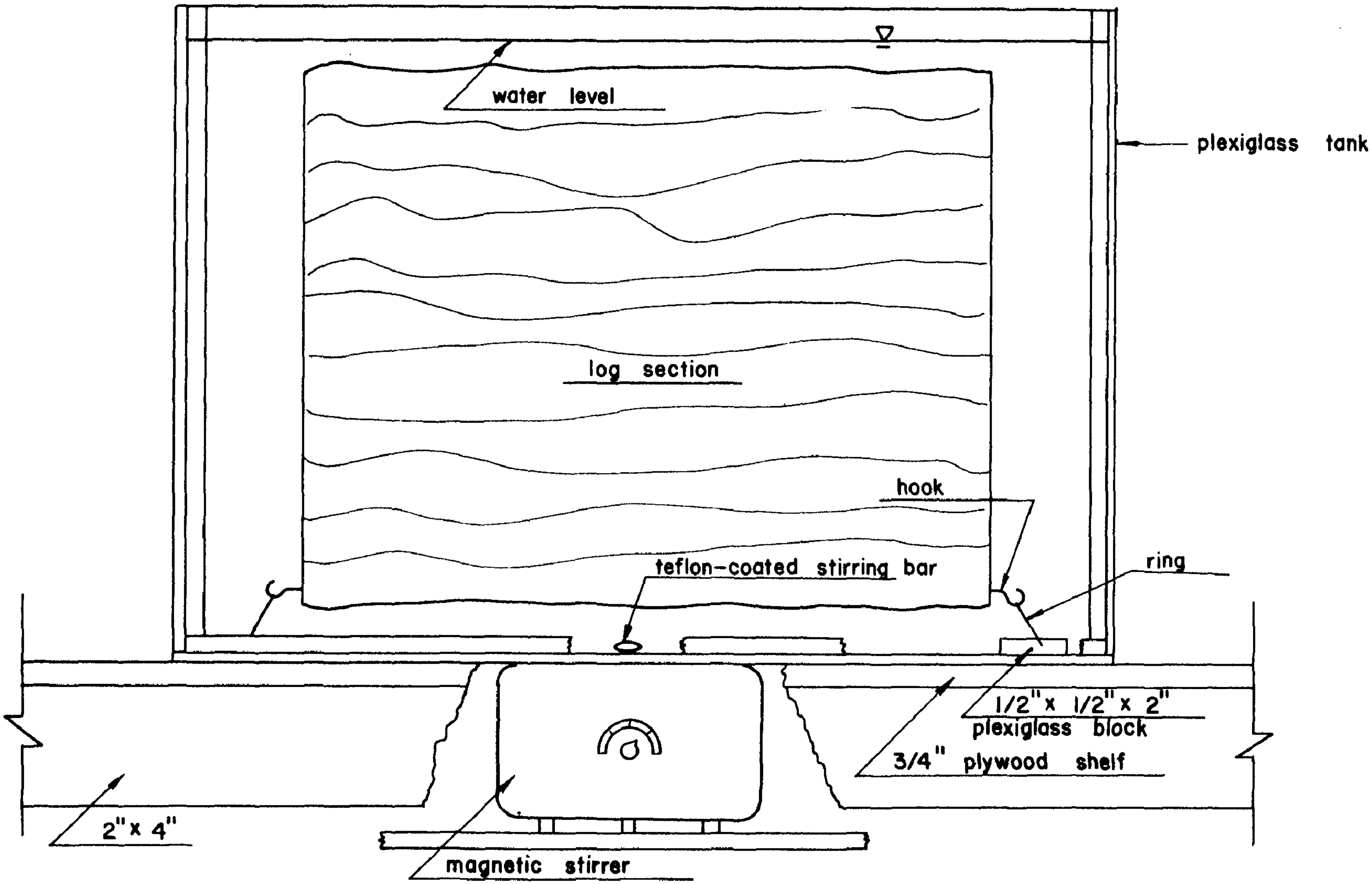


FIGURE 2. Schematic of Leaching Apparatus.

Dislodged bark. In order to accurately determine the percentage of bark missing from logs in rafts, a photographic measurement technique was developed. A slide camera was mounted on a custom-made 20-foot tripod as shown in Figures 3 and 4. The legs were made from 2-inch aluminum tubing in two ten-foot sections and one 8-foot section. The tripod could be readily assembled and disassembled on the log rafts. The camera was a Hasselblad model 1000F. Ektachrome-X 120 film was used at a shutter speed of 1/250th of a second. The camera shutter was controlled by a long shutter release cable held by the operator on a log raft or boat adjacent to the log raft being photographed. Photographic slides were also taken of loaded log trucks to provide information on bark losses during the unloading operation. The camera was held by hand at a distanc of approximately 20 feet. Tabulated photographic measurements are given in Appendix C.

The photographic slides of log rafts were projected upon a reverse-image slide viewer. The viewer consisted of a mirror set at an angle to project an image on a horizontal viewing surface. The viewing surface was a 2-foot square frosted plexiglas sheet. Figure 5 is a schematic representation of the slide viewer. Planar areas of logs with and without bark were measured with a polar planimeter from the image projected on the plexiglas sheet.

Bark sinking studies. The rate at which dislodged bark sinks in water was evaluated with grab samples and graded samples of Douglas fir and ponderosa pine bark.

In the first experiment, grab samples of bark were deposited in 55-gallon drums which were filled with water. The drums were kept uncovered out-of-doors. At specified intervals during the experimental run the bark remaining on the surface was removed by a screening device. Sunken bark was retrieved by passing the water in the drum through a fine sieve. Floating bark was returned to the drum and the drum was refilled. The sunken bark, which was collected on the sieve, was dried and analyzed for total and volatile solids. A schematic representation of this test procedure is shown in Figure 6.

In a parallel experiment, randomly collected samples of Douglas fir and ponderosa pine bark were screened through custom-fabricated sieves which had square openings of 1/2, 1, 2, 3 and 4 inches on a side. The graded bark pieces were then placed in open 55-gallon drums filled with tap water. Duplicate tanks were set up for all samples. Sunken bark was collected, dried and analyzed by the procedures described above.

Benthic deposits. A core sampling procedure was developed to study the distribution of bark debris in benthic deposits. Sample tubes were made from 2-inch diameter, thin-walled aluminum tubing, 18 to 36 inches long. One end of the tubing was reinforced and threaded for connection with the benthic sampler.

The benthic sampler, shown in Figures 7 and 8, consisted of three separate sections. The top section was made of four pieces of 1/2-inch galvanized

FIGURE 3. Custom Made Tripod on Floating Log Raft.

steel pipe each four feet long. These pipes were threaded on both ends and one end had a 1/2-inch coupling permanently attached to it. The pieces of pipe could be added or removed to allow for the variable depth of water encountered while sampling.

The middle section consisted of a 1/2-inch check valve and connecting pipe fittings. The check valve held the sample in the sample tube by maintaining a vacuum seal in the sample tube as the tube was withdrawn from the benthic deposits. The water displaced from the sample tube during sampling discharged externally through the check valve.

The bottom section was made of a 2-inch pipe coupling welded to a 1/4-inch by 3 1/2-inch square steel plate. The plate had a 1/2-inch diameter hole drilled through its center point to allow for the discharge of the water from the sample tube. The sample tubes were easily screwed into and out of the 2-inch coupling.

Samples withdrawn from the deposits were immediately frozen inside the sample tube to preserve the vertical distribution of solids. The sample freezing unit, shown in Figure 9, was a 6-inch diameter insulated aluminum tube. The tube acted as the freezing chamber when dry ice and acetone were added. A center well inside the tube was made of window screen and held in position with four evenly spaced vertical wood slats. The sample tubes were inserted into the center well and the dry ice chips were added between the center well and the aluminum tubing. The aluminum tube was wrapped in 1 1/2-inch thick fiberglas insulation and enclosed in a 1/2-inch plywood carrying case.

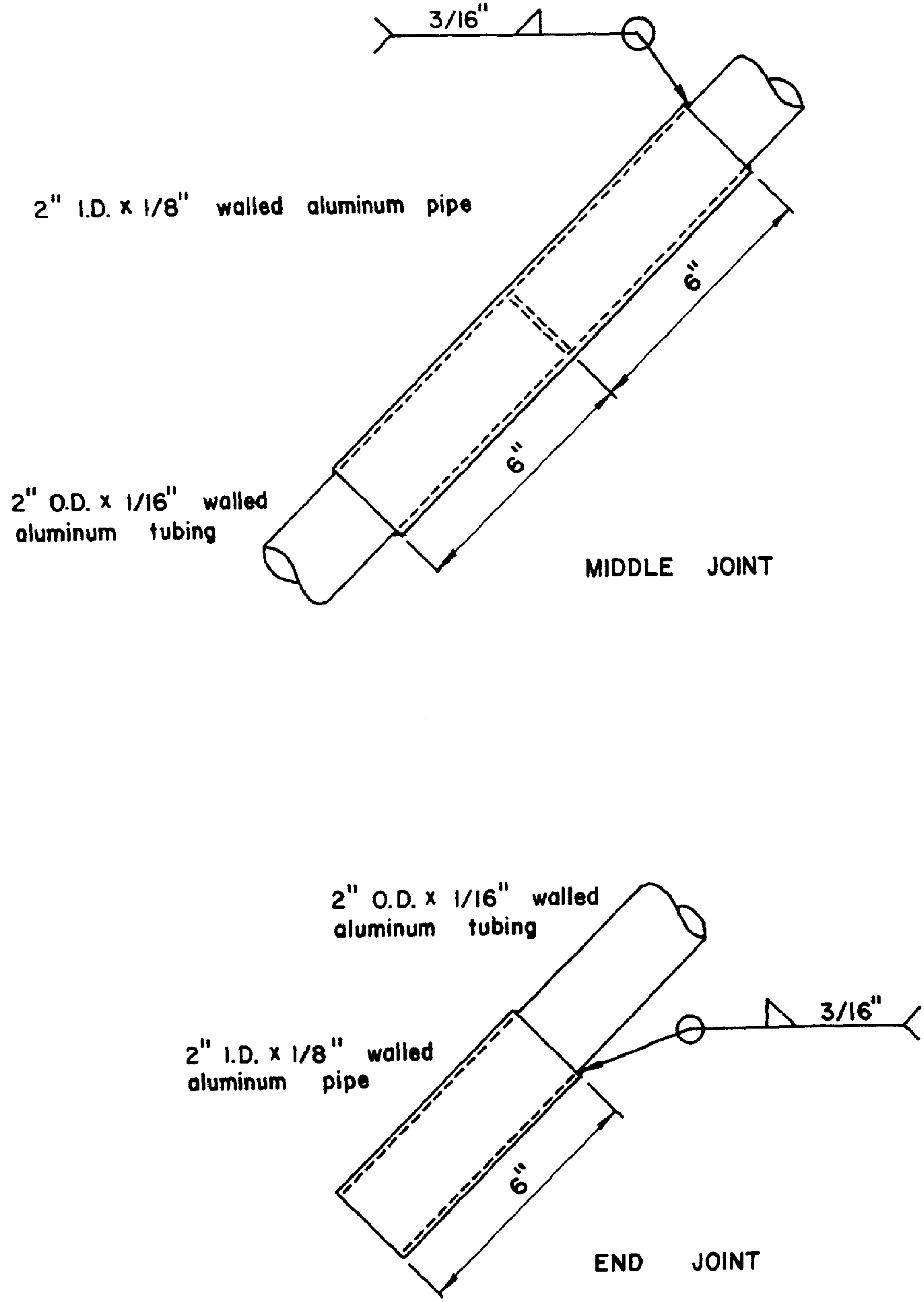


FIGURE 4. Details of Tripod Leg Joints.

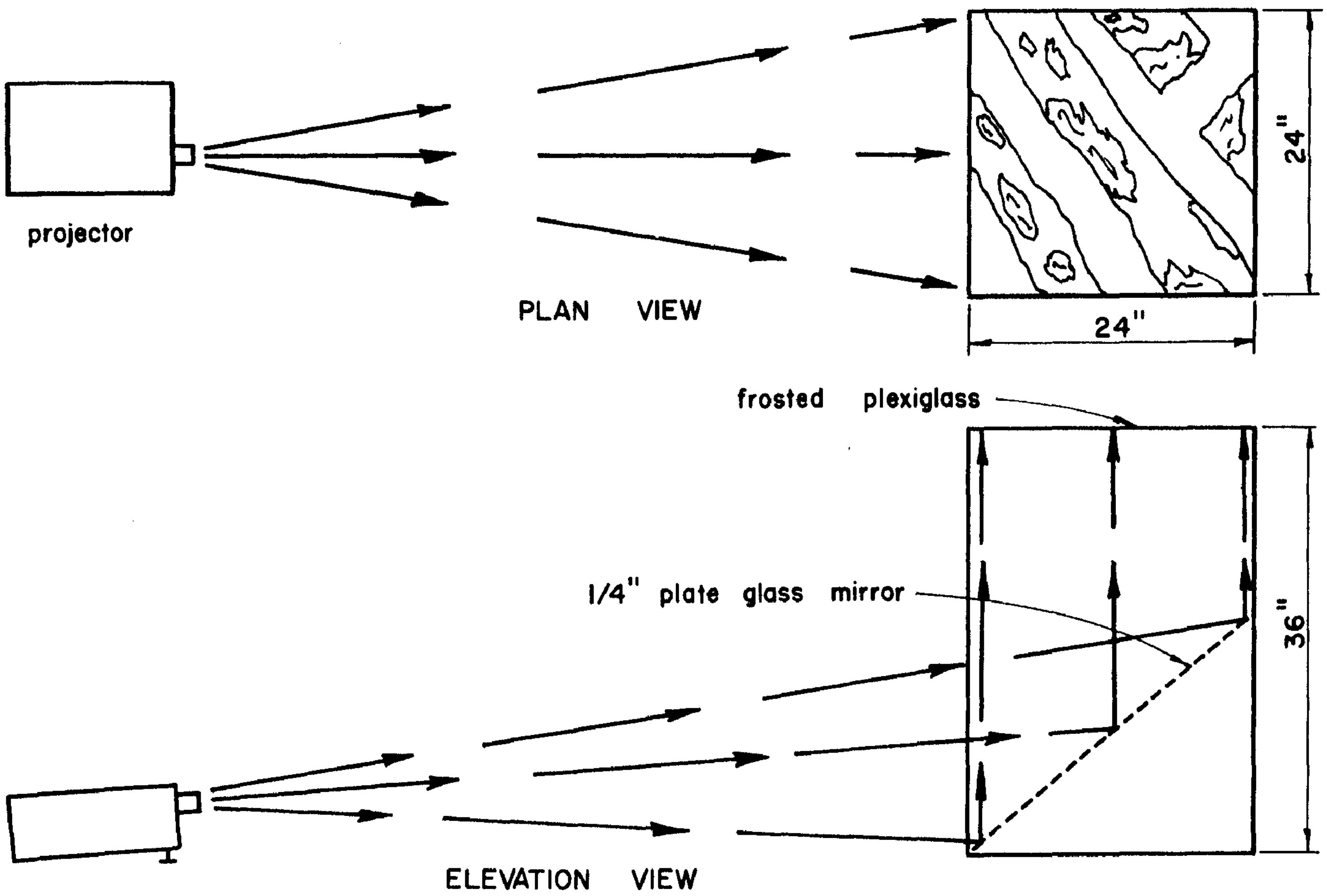


FIGURE 5. Reverse Image Slide Viewer with Slide Projector.

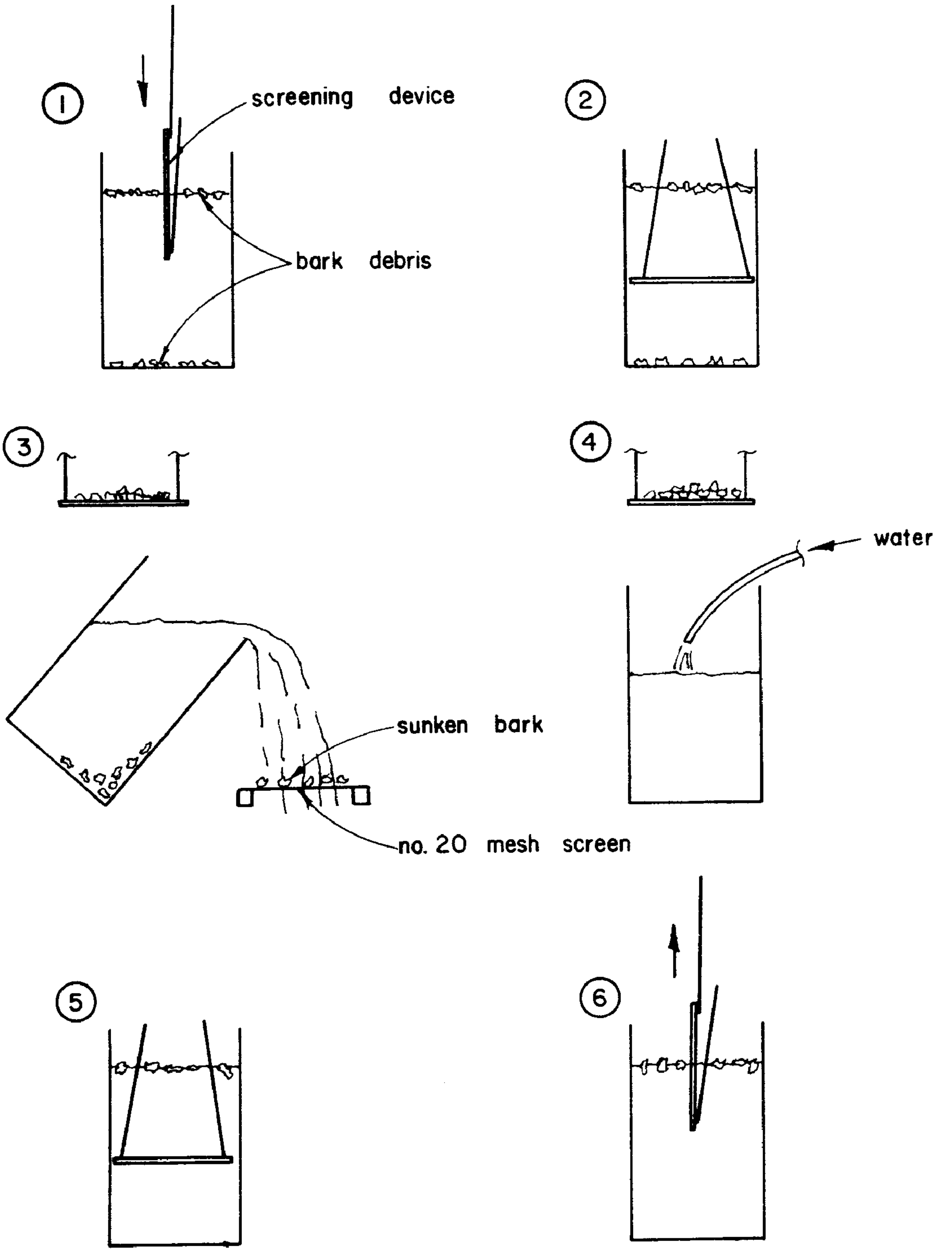


FIGURE 6. Schematic Representation of Sunken Bark Removal from Laboratory Test Barrels.

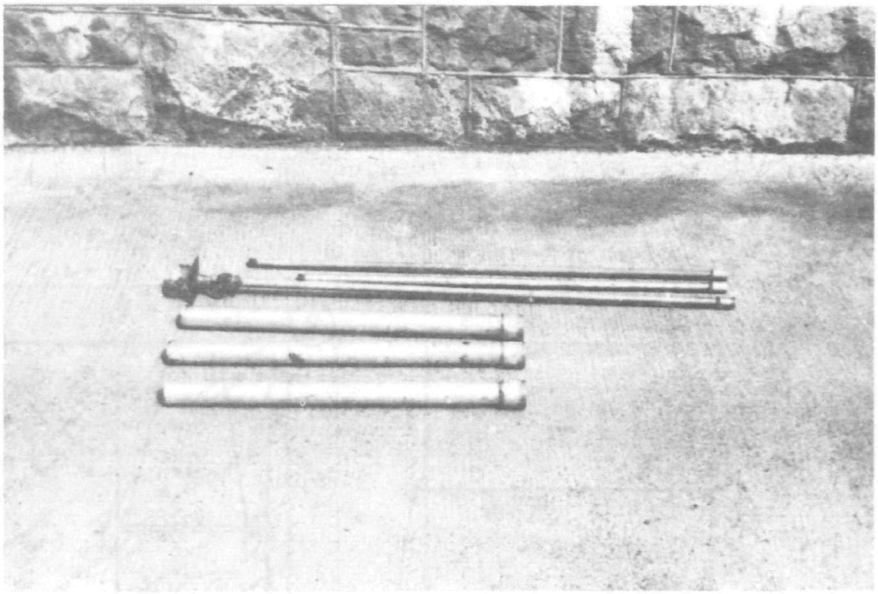


FIGURE 7. Benthic Sampling Apparatus.

Sampling was done from boats or, when possible, from the log rafts. A minimum of two persons were required for sampling, one to physically obtain the samples and the second to freeze and store the samples and to record the location of the samples. Maps were drawn to record the specific location of each sample taken.

Samples were taken in the sampling tubes mounted on the benthic sampler. The sampling tube was gently forced into the benthic deposit until a solid bottom was reached, and was then removed. In some cases a solid bottom was not reached because of a very deep, soft deposit. In this case the sample tube would fill until the frictional skin resistance of the sample in the tube exceeded the frictional resistance of the entire sampler moving through the bottom deposit. This condition was not frequently encountered in the sites selected for this study. The check valve kept the semi-fluid sample from dislodging from the sample tube while the sample was brought to the water surface. At the water surface a rubber stopper was placed in the open end of the sample tube to prevent dislodgment and loss of the sample during the freezing process. The sample and sample tube were then taken to the boat while still connected to the benthic sampler.

The sample tube, containing the sample, was removed from the benthic sampler and immersed into the dry ice-acetone mixture with the rubber

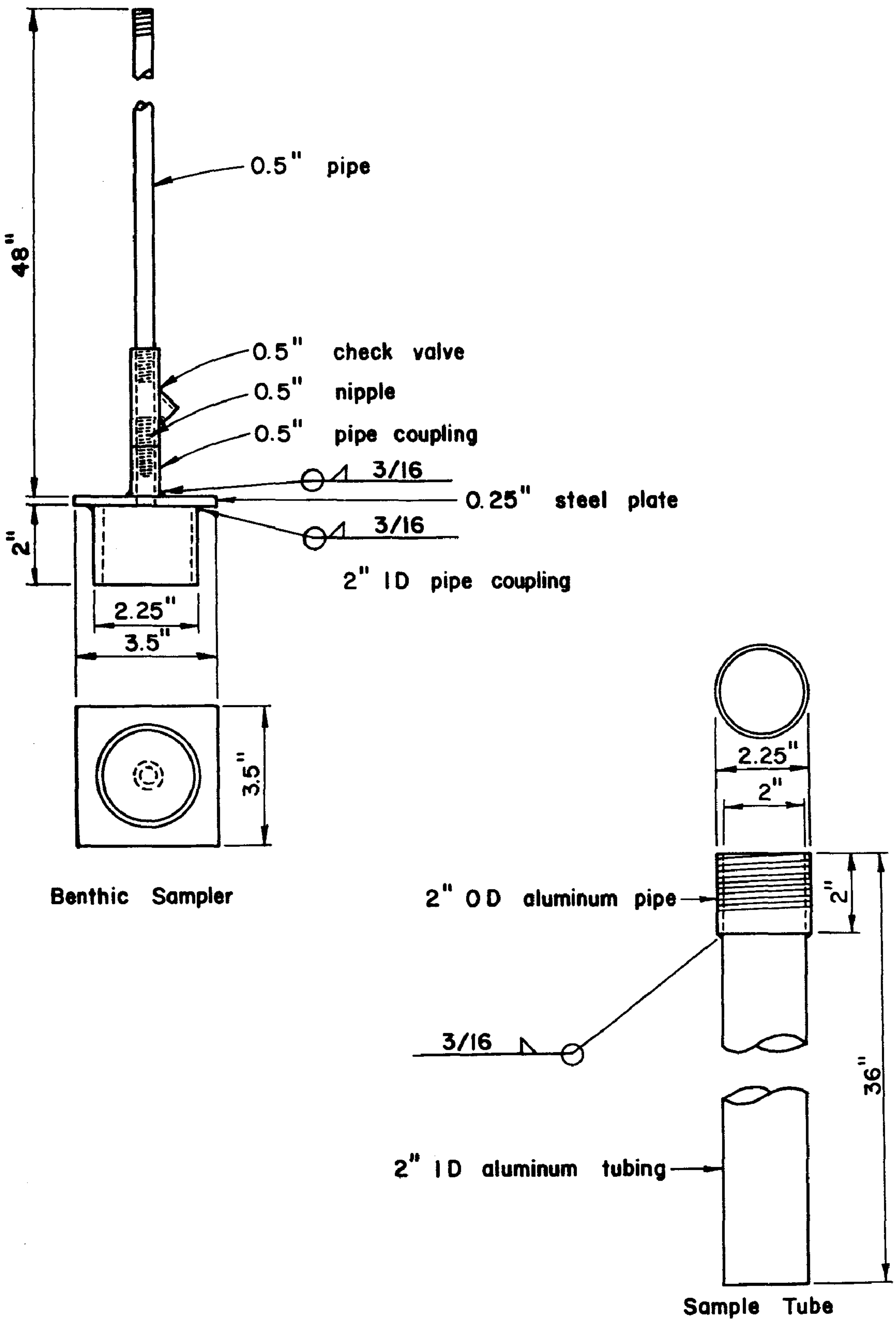


FIGURE 8. Details of Benthic Sampling Apparatus.

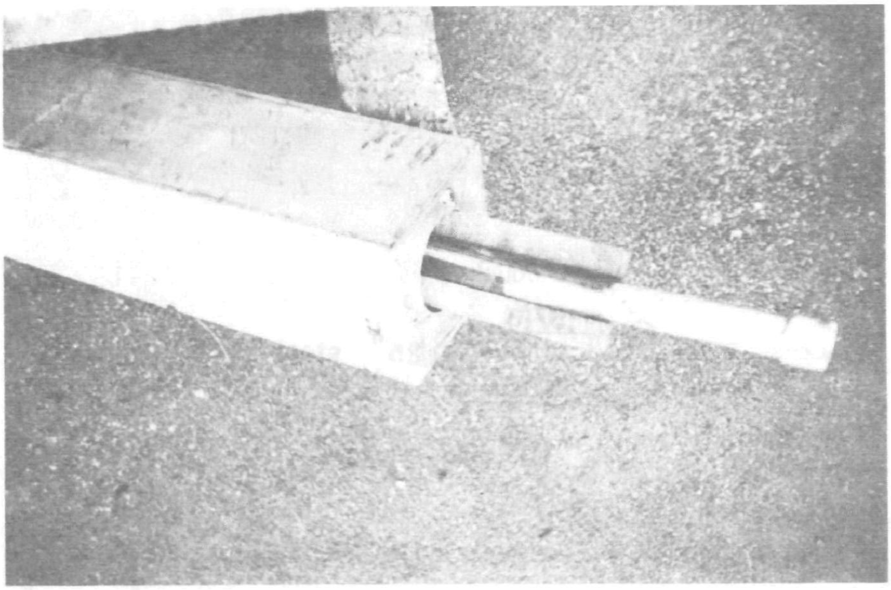


FIGURE 9. Freezing Chamber for Benthic Core Samples.

stoppered end down. The sample tube remained in the freezing unit until the sample was completely frozen. About three to five minutes were needed to freeze a 24-inch long sample. Frozen samples from the freezing unit were tied to the boat by a cord and placed in the river or bay. The warm water in the river or bay melted a thin layer of the sample next to the sample tube. This procedure required about three minutes. The sample tube was then removed from the water and shaken vertically to release the frozen sample from the tube, completely intact. Figure 10 shows a frozen sample as removed from the sample tube. The samples were then wrapped in plastic paper, held in place with a strip of masking tape at the top of the sample. Packaged samples were labeled to correspond with the map location from where the samples were taken. The samples were placed in a portable ice chest and covered with chipped dry ice to keep them frozen during transport to the laboratory. At the laboratory the samples were removed from the portable ice chests and placed in a chest type freezer until removed for analysis.

A portable power circular saw fitted with a 7 1/4-inch abrasive blade was used to cut the frozen cores into 2-inch thick wafers starting from the water-soil interface. In order to decrease the ignition time of samples, the wafers were then cut exactly in half. These pieces were then dried in a drying oven at 103°C for 24 hours.

FIGURE 10. Frozen Sample from Benthic Deposit.

The dried samples were placed in a tarred evaporating dishes which had been previously fired at 600°C for 15 minutes and cooled in a dessicator. The samples were ground with a mortar and pestle before placing in the evaporating dish if a large amount of cohesion existed in the samples. Loose samples were finely ground in the evaporating dish with a small scoop. The dish plus sample was then weighed on a Mettler 46 analytical balance.

Samples were preignited with a bunsen burner for 60 minutes to burn the large pieces of bark debris. Next,the samples were placed in the muffle furnace at 600°C for another 60 minutes to ignite all of the volatile material. After this final ignition, the dish and sample were allowed to cool in the open air for a few minutes and then were placed in a dessicator until they had reached room temperature. The sample and dish were then weighed on the Mettler balance and the percentage of volatile solids calculated.

A more detailed description of the apparatus and technique used in the bark study is provided by Williamson (26).

Benthic respirometer. A special respirometer was designed and fabricated to provide in situ oxygen uptake measurements on benthic deposits. The apparatus shown in Figure 11 was made from a plexiglas half-cylinder housing, 79 cm long with an inside radius of 24 cm. This chamber, when enclosed at both ends and bottom, contained a volume of 65 liters and covered a planar area of 0.24 square meters. A 4.5 inch galvanized metal skirt was attached to the bottom of the chamber to penetrate the deposits and restrict the zone of measurement.

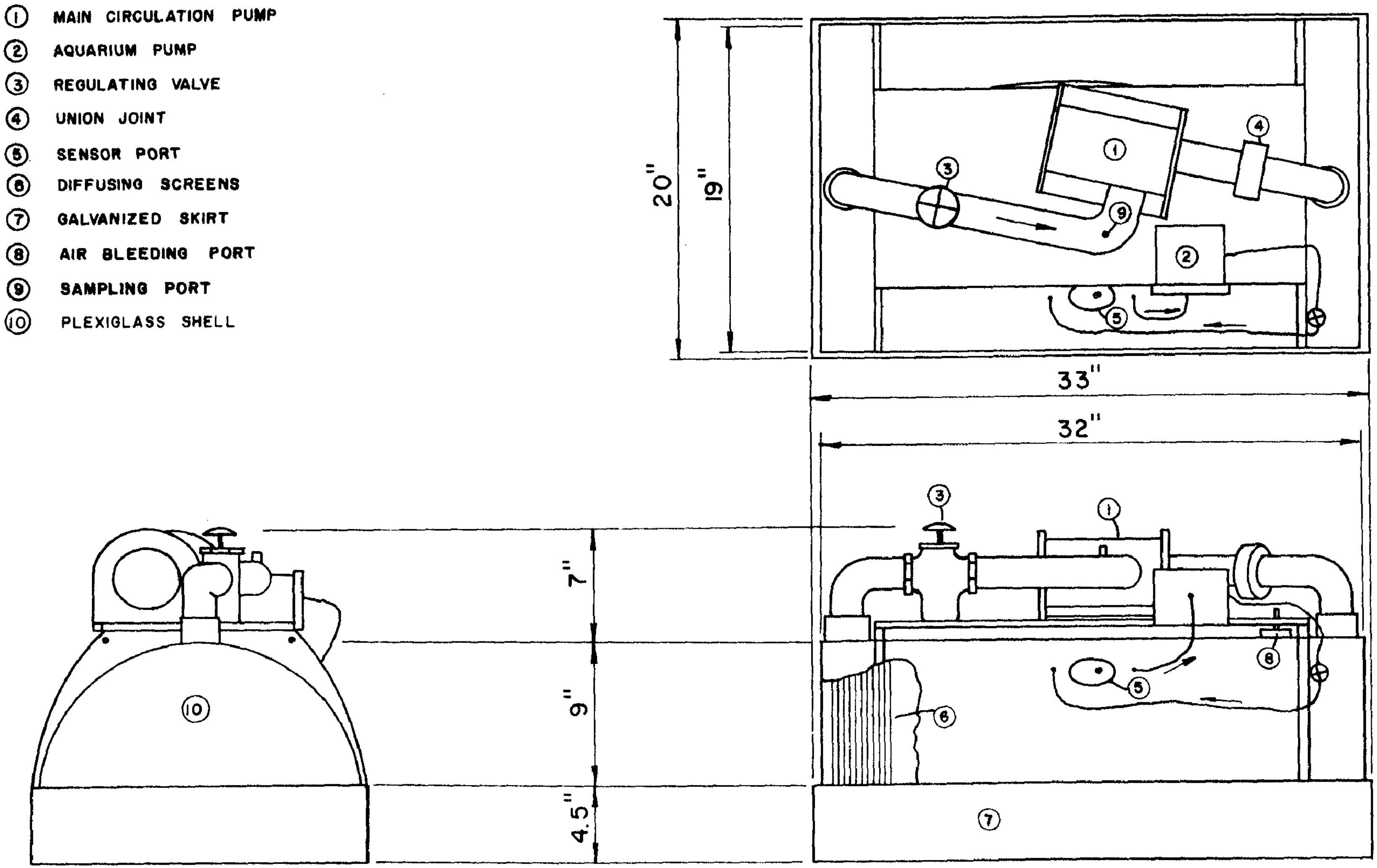


FIGURE 11. <u>IN SITU</u> Benthic Respirometer.

A 40 gpm (at 10 ft head) centrifugal submersible pump and connecting piping were mounted on the housing for circulation of water through the chamber. The recycled water passed through a series of nylon window screens positioned at the inlet and outlet ends of the chamber. The screens served as baffles to provide a nearly uniform vertical flow profile.

Once designed and fabricated, the respirometer was tested in a large laboratory tank which had side wall windows. A brightly colored dye was injected into the intake end of the respirometer and was followed visually and photographically as it passed through the chamber. The inlet and outlet baffles were found to be effective in minimizing short circuiting. The frontal edge of the dye tracer moved relatively uniformly through the chamber. Valve settings on the recirculation pump were calibrated with the dye tracer test results.

A YSI (Yellow Springs Instrument Company) dissolved oxygen sensor was mounted in the chamber as shown in Figure 11. The sensor lead was connected above the water surface to a YSI oxygen meter. A small aquarium-type pump and connecting tubing were mounted on the housing and recycled liquid in the chamber past the oxygen sensor at a rate sufficient to prevent stagnation. A 1.0 mv potentiometric recorder was connected to the oxygen meter to obtain a continuous readout of dissolved oxygen.

Electrical power was supplied to the oxygen meter, submersible pumps and recorder by a 1500-watt gasoline-powered generator.

A trained scuba diver placed the respirometer in the appropriate location for benthic oxygen uptake measurements. The following procedure was followed by the diver and assisting personnel:

1. Open union joint, air bleeding valve and sample port.

2. Remove inlet hose from the aquarium pump.

3. Submerge the respirometer in the water. Start the pump, then rotate and shake to remove entrained air bubbles in the pump and piping. Turn off pump.

4. Force the respirometer into the deposit. A knife or trenching tool may be needed in hard deposits.

5. Start pump to flush the respirometer.

6. Calibrate oxygen meter and sensor and insert sensor into the port on the respirometer.

7. Close union joint, air bleeding valve and sample port.

8. Attach aquarium pump inlet hose.

9. Take grab samples from sample port for dissolved oxygen analysis by a chemical method and for other desired analyses.

10. Check seal around skirt and check for proper valve settings.

11. Start recorder and take oxygen uptake readings.

12. Operate system until a uniform uptake rate is established, usually 2 to 4 hours.

13. Take grab samples from the sample port for subsequent analyses.

14. Turn off the power, remove the sensor and remove the respirometer.

15. Take core samples at the respirometer site, to determine total and volatile solids.

Analytical Methods

Pearl-Benson Index (PBI). The concentration of tannin, lignin and other phenolic compounds leached from log segments while in water storage was determined by the standardized Pearl-Benson, or Nitroso method (7). PBI is a colorimetric determination of the quantity of lignin and other phenolic compounds present in a sample. The PBI test is used to evaluate spent sulfite liquor (SSL) concentration in waste streams from pulp mills. A DU spectrophotometer was used to measure the color developed in the test. A standard SSL in a range of known concentrations was used to standardize test results. The standard was calcium SSL, (Orzan+), made from a ten percent concentration of SSL.

Chemical oxygen demand (COD). COD analyses were made using the Jeris "rapid" COD technique (13). The standard COD method (1) was applied to one series of samples to obtain a correlation between the rapid and standard procedures. Results with the Jeris method were within 4 percent of those obtained by the standard method.

Biochemical oxygen demand (BOD). Five day BOD analyses were made using 300 milliliter BOD bottles and applying the dilution technique described in Standard Methods (1). Seed for the BOD tests was obtained from a bench scale activated sludge unit containing microorganisms acclimated to effluent from a fibreboard plant. The unit was batch fed daily to accomplish the acclimation of seed.

BOD reaction rate (k-rate). Oxygen uptake data used in k-rate determination was obtained using the Hach manometric BOD apparatus. Interval oxygen uptake readings correspond to the BOD exerted. The determination of k-rate was accomplished by matching curves obtained from experimental data to standard curves obtained using a mechanical plotter in connection with the Oregon State University computer. To obtain a standard curve for matching with an experimental curve, 5-day BOD values from experimental data and an assumed series of k-rates were supplied as input to the computer program. A series of mechanically plotted curves was obtained. The closest fit between standard and experimental plots determined k-rate.

Reducing sugar content. Reducing sugar content was determined using techniques described by Somogyi (23) and the procedure presented by Hodge and Hofreiter (12). The titrimetric method applying the 1945 alkaline copper reducing agent was used.

Bioassay for toxicity determination. Bioassays were conducted at the Oregon State University Oak Creek Laboratory by a standardized procedure (1). The test tanks were located in a constant temperature room held at 14°C. Test fish were acclimated to Oak Creek water.

Each bioassay test unit consisted of a 2-gallon circular cardboard container fitted with a plastic liner. Six liters of water were placed in the container and a stream of air was bubbled slowly through the water for 24 hours before the test fish were introduced. A total of 10 fish were used in every unit and the number of dead fish counted visually at 24 hour intervals for a period of 96 hours. The water was not mechanically stirred and the fish were not fed during the 96 hour test period. No fish was used more than once and surviving fish were kept separated from the remaining unexposed test fish. Oak Creek water was also used for log storage to eliminate differences in quality between bioassay and storage water.

Two types of fish were acquired for use as test organisms in toxicity determination. Chinook salmon, *Oncorhynchus tshawytscha* (Walbaum), approximately three months of age, were used until the supply was exhausted. The salmon were obtained in May, 1969 from the Department of Fisheries and Wildlife Hatchery, Netarts, Oregon. Kamloops rainbow trout, *Salmo gairdneri* (Richardson), also three months of age, were purchased from Trout Lodge Springs Hatchery, Soap Lake, Washington. The trout were obtained in June, 1969 and were used during the remainder of the study.

EXPERIMENTAL FINDINGS

Part I: Leachates

Introduction

Soluble organic matter and color-producing, lignin-like substances which are extracted from logs floating in water can lead to a gradual deterioration of holding water quality. The organics, measured in this study as BOD, COD, TOC and volatile solids, can create a dissolved oxygen demand on the holding water during biodegradation and could lead to foaming problems. Color-producing substances measured by the PBI test affect the aesthetic quality of water and, thereby reduce its value for recreational use and as a water supply source. Furthermore, some of the water soluble extractives may be deleterious to fish and other forms of aquatic life.

The quantity and character of substances leached from logs in water storage were determined by both static and dynamic leaching tests conducted under carefully controlled laboratory conditions. A description of the apparatus and procedures used in these tests is presented in an earlier section of this report.

Static Leaching Tests

Set-up. In initial experiments, Douglas fir and ponderosa pine log sections were submerged in tap water and in saline water poisoned with mercuric chloride. Some of the sections had ends sealed with paraffin; others had all bark removed and ends sealed; whereas others remained unaltered, i.e., bark intact and ends open. Chemical analyses were performed on samples of water withdrawn at specified intervals during 30-40 day holding periods to measure the rate of leaching of soluble,color-producing substances and organic matter. Several duplicate runs were made to determine the reproducibility of experimental findings. Close agreement was consistently observed for the duplicate samples.

Color-producing substances. Soluble tannins and lignin-like substances impart a yellow to brown color to natural waters. The addition of these substances to log holding water was measured by the PBI test with results expressed as grams of equivalent spent sulfite liquor (10% solids basis) per square foot of cylindrical log surface area submerged.

The experimental results plotted in Figure 12 clearly illustrate that nearly all of the color, as represented by PBI, is contributed by the log bark. This was not unexpected since bark is known to contain a considerable quantity of water extractable tannins and lignins. The peeled logs (w/o bark) of both species yielded very low PBI values after 40 days of soaking. Furthermore, the rate of PBI loss to the holding water was found to be significantly higher for the unaltered log with

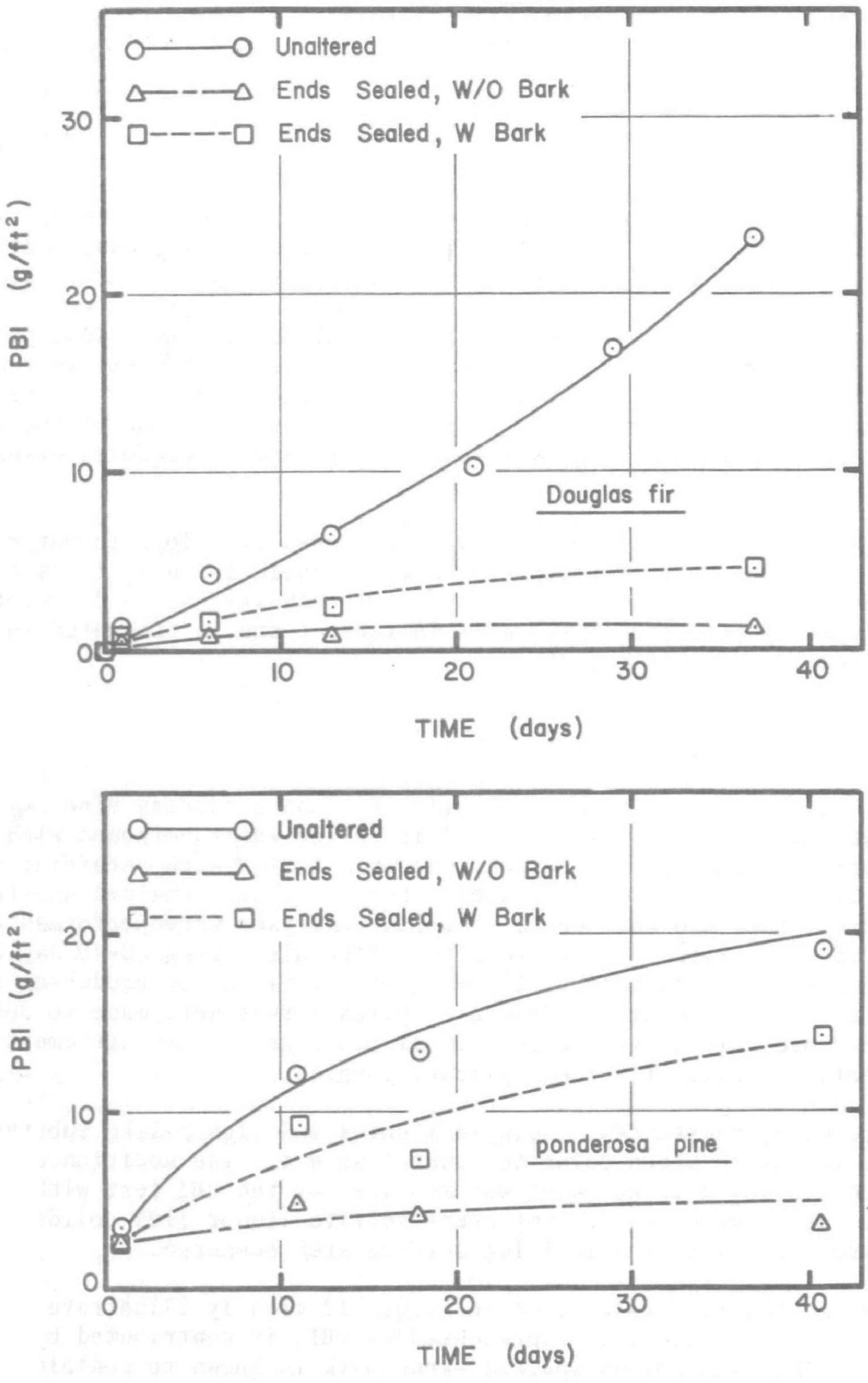


FIGURE 12. PBI Results for Douglas Fir and Ponderosa Pine Logs in Fresh Water.

unsealed ends. This demonstrates that the ratio of end area to cylindrical surface area is significant and must be considered in field application of laboratory results.

Soluble organics. The loss of soluble organic matter from floating logs was measured initially by COD, TOC, total solids and total volatile solids tests. BOD determinations were made in a later study. Experimental results obtained during a 37-40 day test are graphically presented in Figures 13, 14, 15 and 16. Each graph shows that ponderosa pine logs yielded significantly greater quantities of organic matter per square foot submerged than Douglas fir logs. This observation is consistent with the findings of Kurth, et.al. (17). They found that the extractable tannins from pine bark contain nearly 10 times more soluble sugar than do the tannin extracts from the bark of Douglas fir.

The rate of leaching of soluble organics during the first 3 to 4 days of soaking was apparently influenced by the presence of intact bark. This is illustrated in Figures 13 and 14. The logs with ends sealed and bark removed, lost COD and TOC at a higher initial rate; however, the rate decreased as the soaking period lengthened.

The open ends of floating logs are responsible for a substantial portion of the soluble organics lost to the holding water. This is readily apparent in Figures 13 and 14 when comparing the COD and TOC contributed by unaltered logs with that from logs having sealed ends but bark in place. This observation is not surprising since the physiological flow pattern of water and nutrients proceed longitudinally through a living tree. By using the calculation method outlined in Appendix D it can be estimated that 12 percent of the COD lost from a 30-foot long Douglas fir log 2 feet in diameter is derived from the end section.

A high percentage of the total solids leached from the experimental logs were found to be volatile. Figures 15 and 16 show that over 80 percent of the solids leached from the Douglas fir log in 40 days were volatile, and nearly 62 percent of the solids from the pine logs were volatile.

Saline water. A vast quantity of Douglas fir logs are rafted and held in storage for extended periods of time in the saline estuaries and bays along the Pacific coast. A laboratory experiment was undertaken to determine whether the leaching rate of substances from logs held in saline water is measurably different from the rate for logs held in fresh water. A saline water solution was artifically prepared by mixing equal quantities (by volume) of fresh tap water and synthetic sea water. Nearly identical unaltered Douglas fir logs were submerged in both the saline preparation and in an equivalent quantity of fresh tap water. Figure 17(a) shows COD exerting substances were extracted from the logs at nearly the same rate regardless of the character of the holding water. There was less than 10 percent difference in total loss of COD after 38 days of soaking.

The PBI results shown in Figure 17(b) indicate that considerably more lignin-like material was present in the fresh water after 38 to 40 days of soaking than in the saline water. The apparent lower PBI yield in

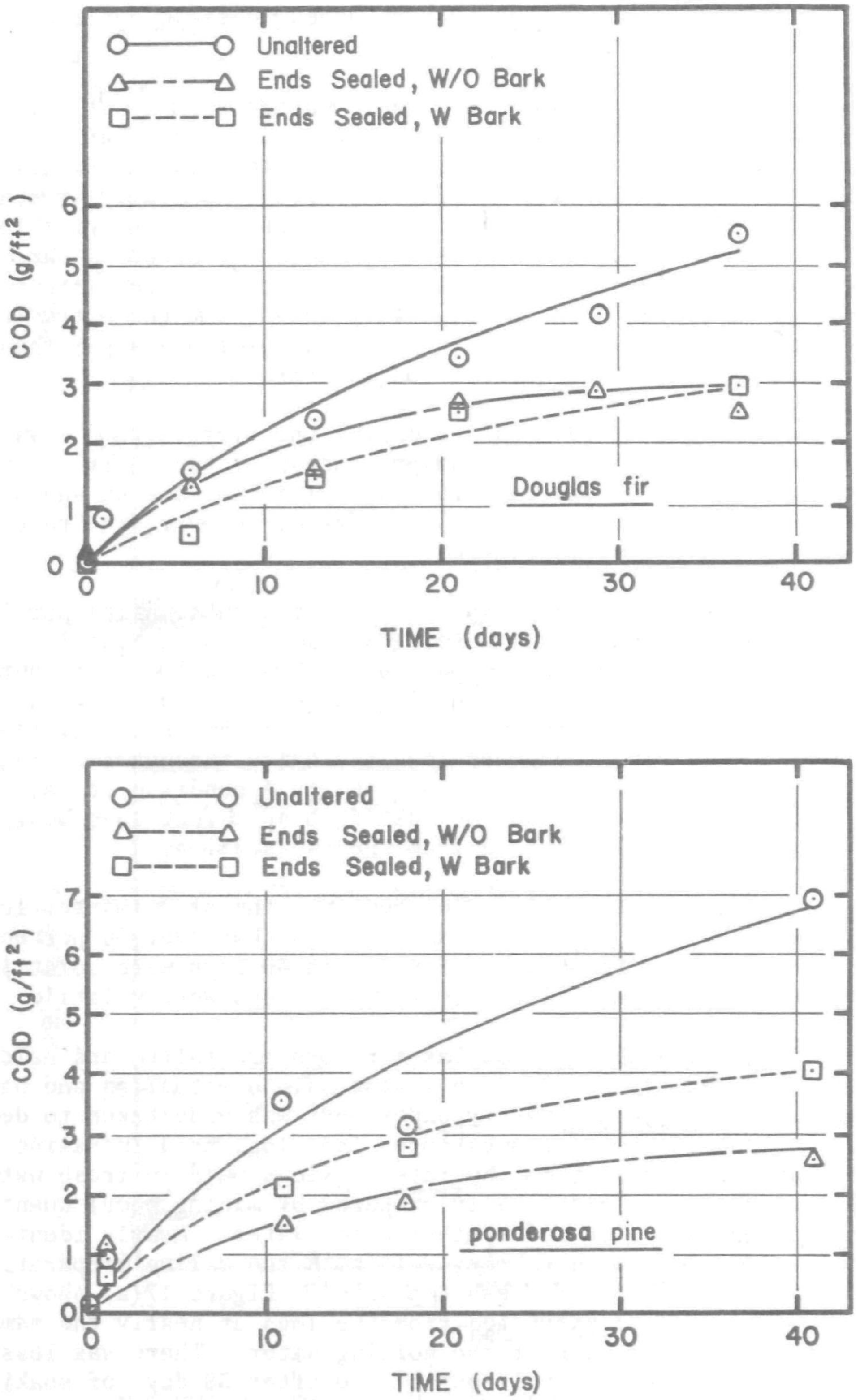


FIGURE 13. COD Results for Douglas Fir and Ponderosa Pine Logs in Fresh Water.

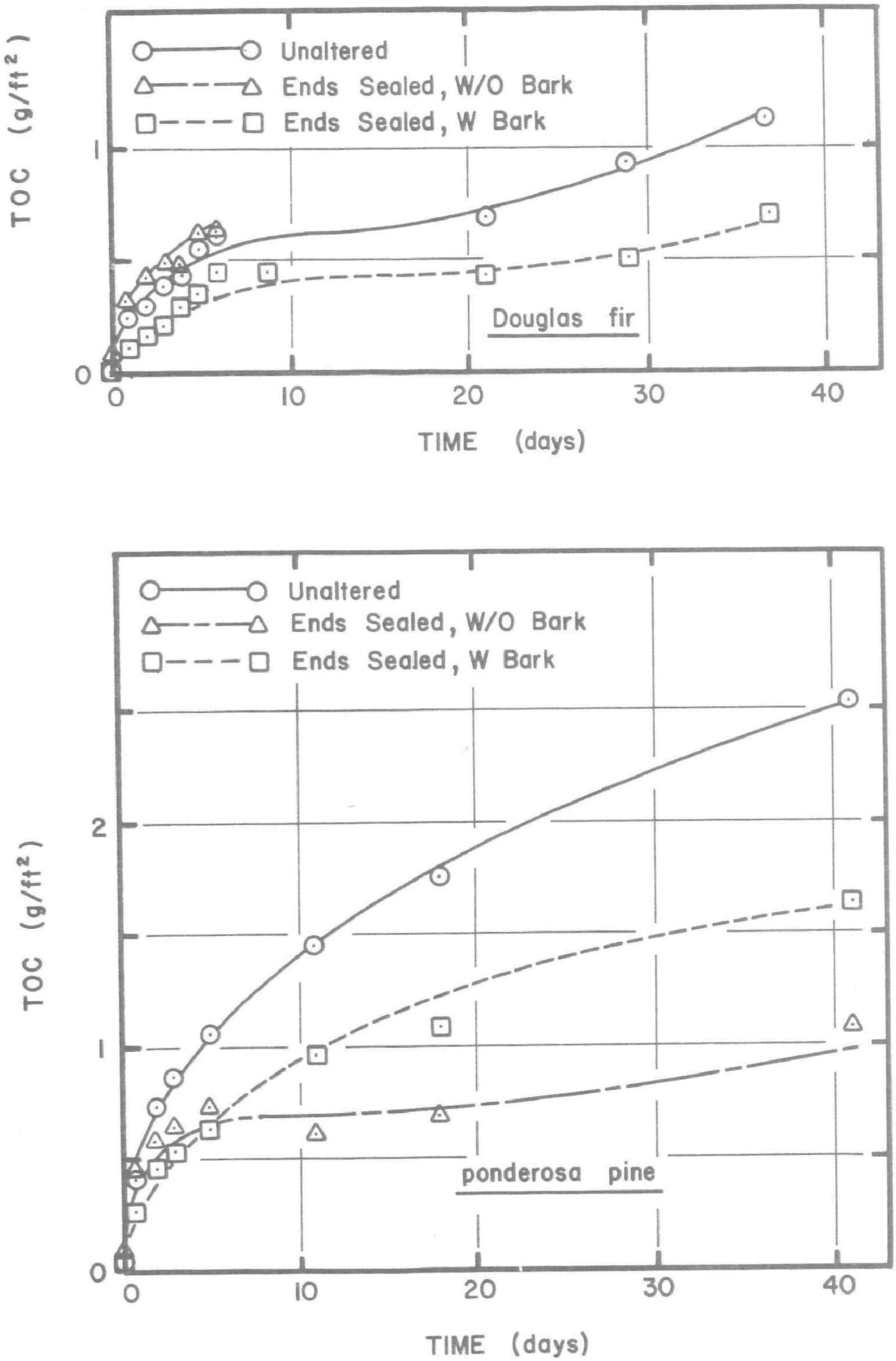
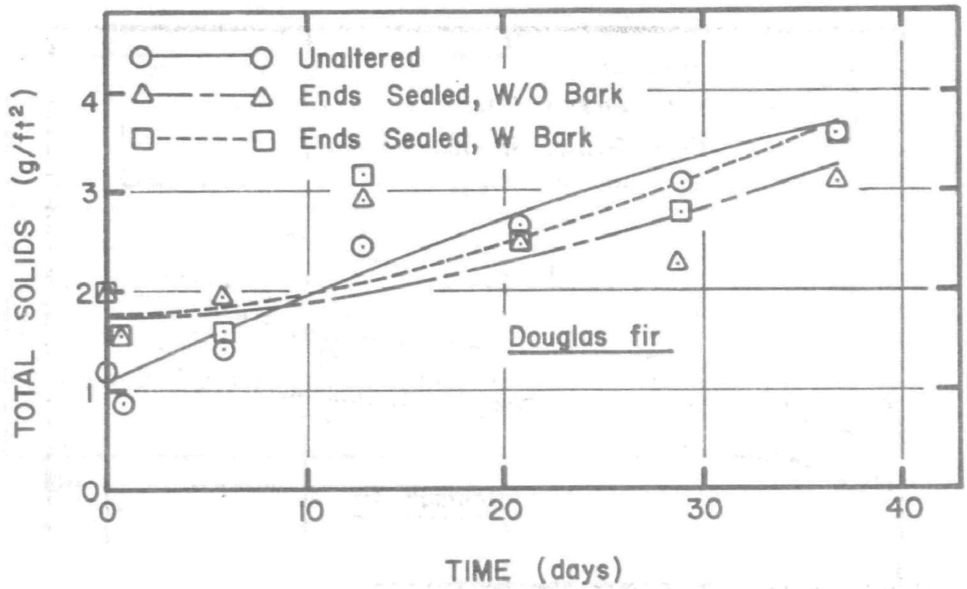


FIGURE 14. Total Organic Carbon (TOC) Results for Douglas Fir and Ponderosa Pine Logs in Fresh Water.



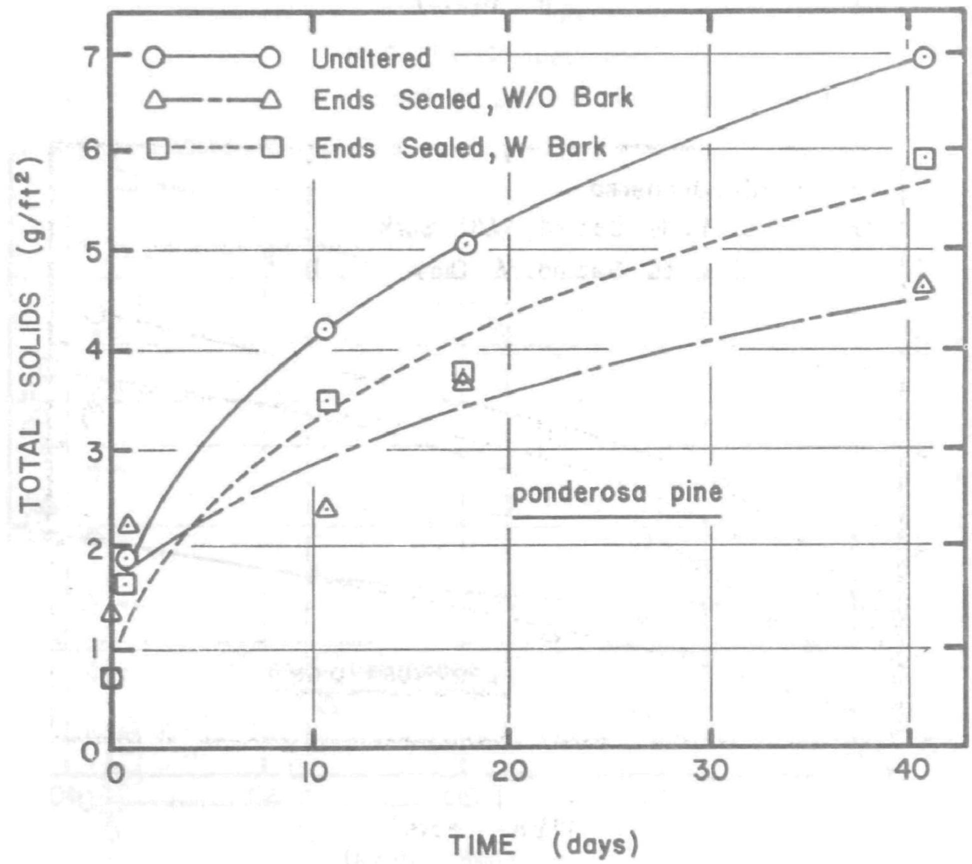


FIGURE 15. Total Solids Results for Douglas Fir and Ponderosa Pine Logs in Fresh Water.

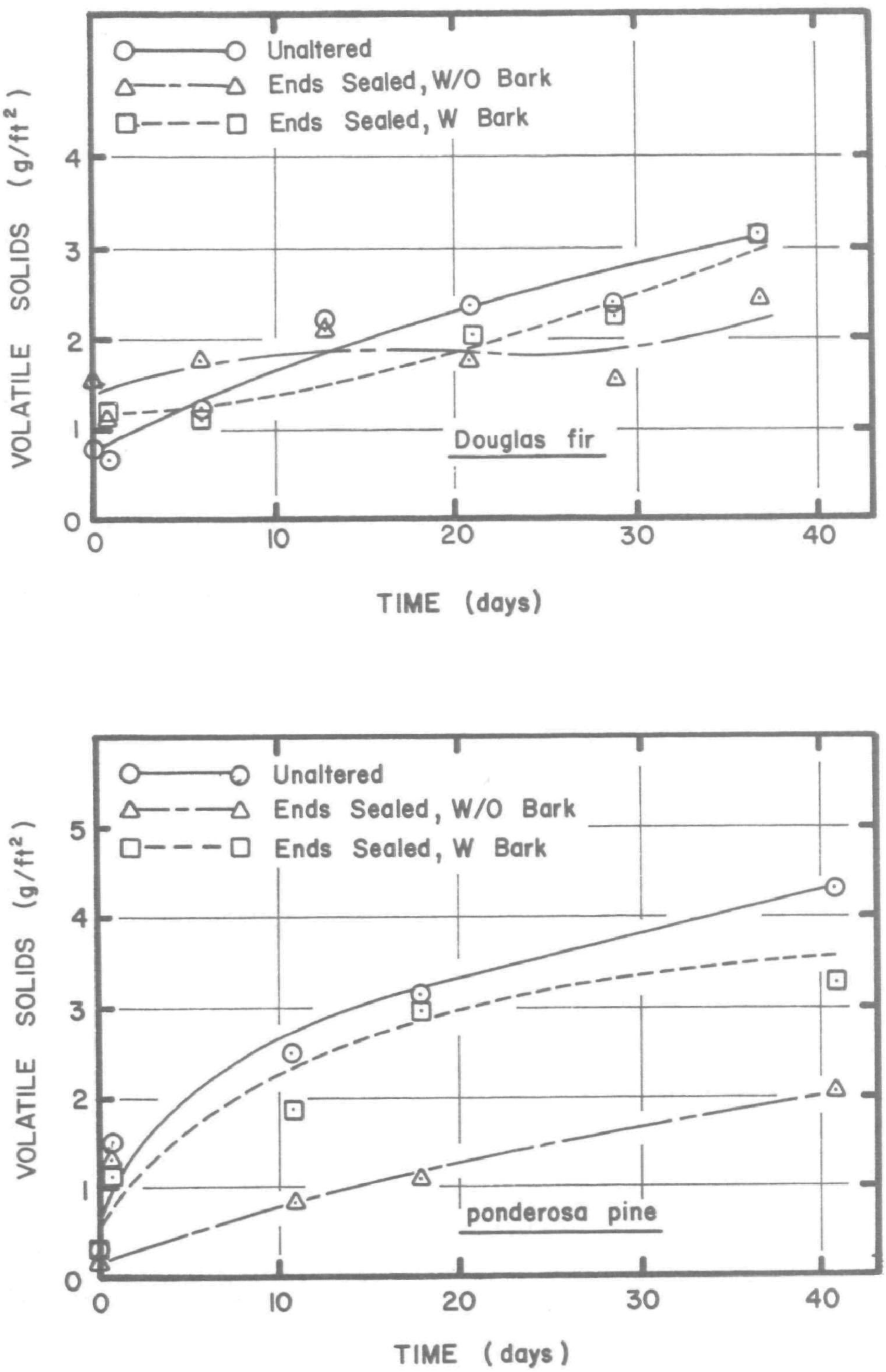
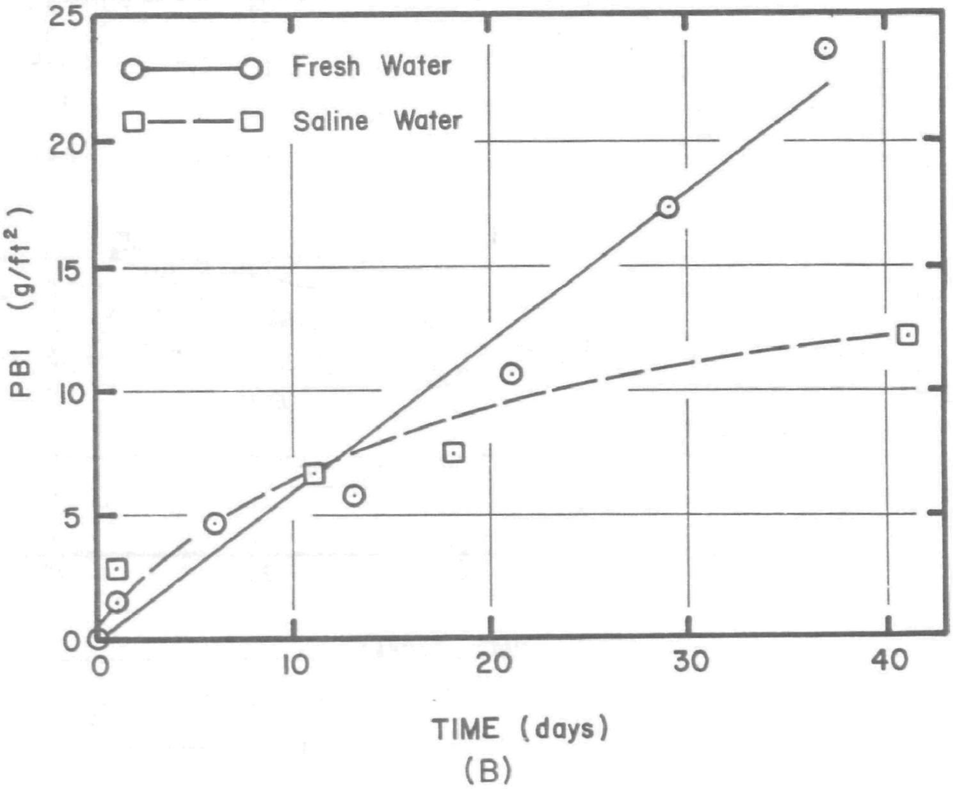


FIGURE 16. Total Volatile Solids Results for Douglas Fir and Ponderosa Pine Logs in Fresh Water.



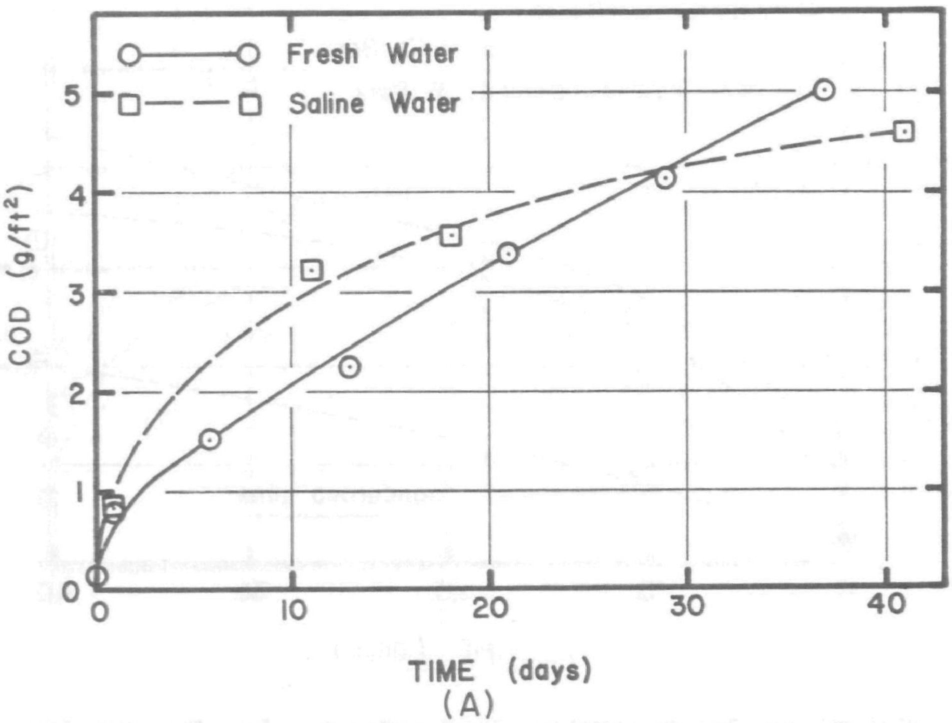


FIGURE 17. COD and PBI Results for Unaltered Douglas Fir Logs in Fresh and Saline Water. (note: (A) COD and (B) PBI.)

salt water may be due to the precipitation of lignin-like substances by divalent cations present in high concentrations in the water. This precipitation phenomen was observed by Andrews (2) in a study of kraft pulp mill discharges into saline waters.

Effect of holding water quality. Two different conditions occur in actual log rafting and storage operations which were not represented by the laboratory experiments outlined above.

First, log rafts in flowing natural waters such as rivers and estuaries are subjected to a continual interchange of water over the log surfaces. Consequently there is little tendency for the formation of a concentration gradient of leached substances which might retard the rate of diffusion. This condition was approximated in the laboratory by placing a presoaked Douglas fir log, which had been submerged for 40 days into a tank of fresh water and measuring the release of COD and PBI. The results of this experiment plotted in Figures 18 and 19 show that the amount of COD leached from the log in each 40-day period was very nearly the same, indicating that a continuous rate of leaching is likely if a concentration gradient is not allowed to develop. This observation is significant since logs are frequently held in water storage for 80 days or longer. Further information regarding the rate of leachate over extended storage periods is presented in the section of this report entitled "Dynamic Leaching Experiments."

The second field condition worthy of consideration occurs when freshly cut logs are deposited into relatively stagnant log ponds or some lakes. In these situations where only minimal water interchange is possible, a concentration gradient does develop which could alter the rate of diffusion. A laboratory experiment was set up to determine whether the leaching rate from a freshly cut log is retarded by polluted water.

A freshly cut, unaltered Douglas fir log was placed into a tank of water which had previously held a similar log for 38 days. The rate of leaching of COD was followed for 42 days and the results plotted in Figure 18. The plot shows that nearly 5 grams of COD/ft^2 were lost in fresh water whereas a similar freshly cut log lost only 1.7 grams of COD/ft^2 in the polluted water. This implies that a concentration limit is approached in stagnant log pond waters independent of the quantity of logs stored or the length of storage period.

BOD, toxicity, and sugars. A parallel, static leaching study was conducted to determine the BOD, toxicity and wood sugar content of log leachates.

Douglas fir, ponderosa pine and hemlock logs, 15 inches in diameter, were cut into sections 20 inches long and suspended in storage tanks as described earlier in this report. Bark was completely removed from some of the log segments. Water from a creek near Oregon State University's Oak Creek Laboratory was used in all experiments since this water was also used to rear test fish for bioassays.

The log segments were held submerged for seven days in the creek water poisoned with 2 mg/l Hg^{++} in the form of $HgCl_2$. Following the storage period at 20° $\pm$ 2°C, aliquots removed from each holding tanks were depoisoned by chelation (see Appendix B) then analyzed for BOD_5, BOD decay constant, wood sugars and acute toxicity. COD determinations were also made to correlate test results with those reported above. Results of all analyses except toxicity were expressed as grams leached per square foot of cylindrical log surface area submerged (g/ft^2).

Experimental results summarized in Table 1 include experiments with one hemlock log, one ponderosa pine log and two Douglas fir logs which differed considerably in age. In addition, two adjacent segments from the same Douglas fir log were tested to determine the reproducibility and reliability of results.

Results show that leachates from ponerosa pine, hemlock and older Douglas fir logs, with and without bark, are not acutely toxic to salmon and trout fry in 96 hour exposure. The leachate from the younger Douglas fir log did result in mortality to some test fish. Log sections without bark were more toxic than comparable sections with bark intact. TLm_{96} values ranged from 20 to 93% (v/v) for leachate from the young Douglas fir logs. This slight, but measurable, toxicity for the young fir log might be attributed to the much greater release of soluble substances to the holding water.

This study also revealed that a considerable portion of the substances which leach from logs is biodegradable and represents a significant oxygen demand on holding waters. Table 1 shows BOD_5 values as high as 1.3 g/ft^2. BOD:COD values are commonly used as an indicator of the biodegradability of a waste. BOD_5 represents the oxygen required to biologically degrade a given sample of organic matter, whereas COD represents the amount of oxygen required to chemically decompose organic matter. BOD_5:COD values for the log leachate were found to range between 0.1 - 0.45. This compares with a BOD_5:COD of about 0.7 for glucose and 0.5 for raw domestic sewage.

A considerable portion of the BOD-exerting compounds in the log leachate were wood sugars. Table 1 shows that 0.18 to 0.41 grams of sugar leached per square foot of submerged log in 7 days. The high BOD decay constants, 0.17 - 0.40, determined for log leachate can be attributed to the presence of this large fraction of readily degradable wood sugars. As expected, ponderosa pine logs which released the highest amount of sugar also had the highest decay rate. The BOD decay constant is a measure of the rate at which oxygen is consumed by bacteria during the biodegradation of organic matter. A high rate constant (0.15 - 0.3) indicates the presence of a readily degradable substance.

Even though a measurable quantity of biodegradable and toxic substances leach from floating logs the severity of pollution problem associated with this storage depends upon the quantity of logs stored, the age and species of logs and the flow rate of the holding water. Each field situation should be evaluated separately.

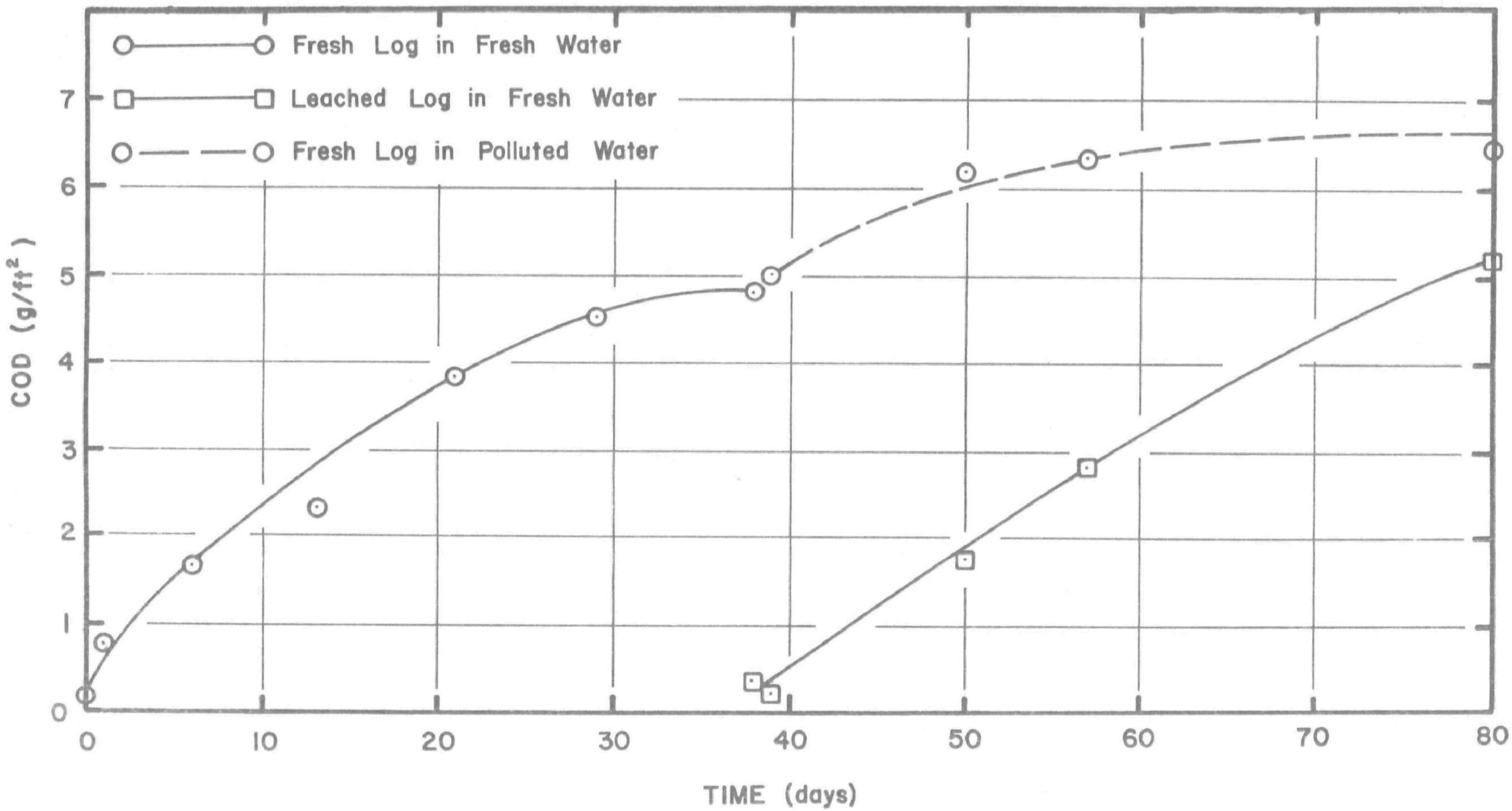


FIGURE 18. COD Results for Unaltered Douglas Fir Logs in Fresh Water and Water Which Was Polluted by a Submerged Log.

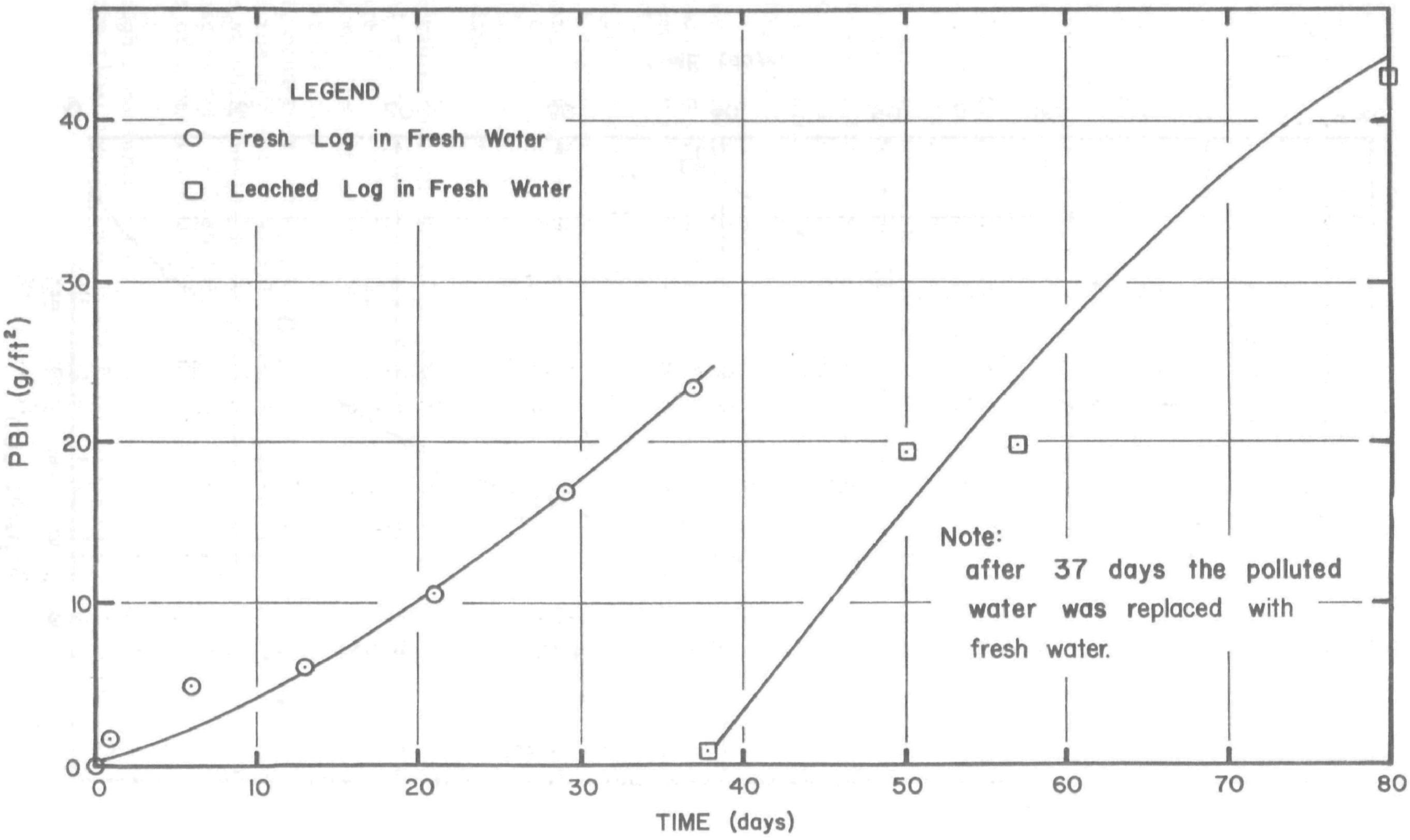


FIGURE 19. PBI Results for Unaltered Douglas Fir Log in Fresh Water.

Table 1. BOD, COD, PBI and Toxicity Associated with Leachate from Logs Held in Static Water Storage for Seven Days

Log Description			BOD	BOD decay rate	COD	BOD:COD	Reducing sugars	PBI as 10% SSL	Toxicity	
Species	Age	Bark	g/ft²[1](mg/l)[2]	$days^{-1}$	g/ft²(mg/l)		g/ft²(mg/l)	g/ft²(mg/l)	TLm_{48}	TLm_{96}
Douglas fir	50 yr	with	0.90 (84)	0.25	3.25 (193)	0.28	0.41 (24)	7.11 (426)		
Douglas fir	50	with	1.20 (84)	0.32	3.91 (272)	0.31	0.66	12.5 (46)		20% v/v
Douglas fir	50 yr	w/o	0.93 (44)	0.19	3.18 (287)	0.29	0.41 (37)	4.45 (402)		
Douglas fir	50	w/o	1.30 (120)	0.26	3.38 (313)	0.38	0.50 (46)	10.8 (1005)		24% v/v
Douglas fir	120 yr	with	0.11 (6)	0.17	1.0 (53)	0.11	0.31 (16)	0.66 (35)	10% kill in 60% soln. after 72 hrs	
Douglas fir	120	w/o	0.56 (42)	0.30	1.89 (189)	0.30	0.41 (31)	2.98 (233)	93 % v/v	
Hemlock	50 yr	with	0.27 (15)	0.13	1.82 (101)	0.15	0.23 (13)	2.06 (114)	no kill in 96 hrs	
Hemlock	50	w/o	0.93 (79)	0.28	2.04 (174)	0.45	0.18 (15)	1.91 (163)		
Ponderosa pine	70 yr	with	0.80 (42)	0.31	4.25 (221)	0.19	0.84 (44)	7.48 (416)	no kill in 96 hrs	
Ponderosa pine	70	w/o	1.36 (92)	0.40	2.63 (177)	0.52	0.16 (11)	0.79 (53)		

[1] g/ft² of submerged surface area

[2] mg/l in test tank

Log leaching equation. Based upon results obtained from the static log leaching tests the following equation was derived for application in field situations:

$$T = [(1-x)(D)(A_c)] + [(x)(C)(A_c)] + [(f_1)(B-D)(A_E)]$$

where

T = total pollutant contribution from logs (grams)

$B = \dfrac{\text{grams leached from test log (ends unaltered, w/bark)}}{\text{ft}^2 \text{ cylindrical area}}$

$C = \dfrac{\text{grams leached from test log (ends sealed, w/o bark)}}{\text{ft}^2 \text{ cylindrical area}}$

$D = \dfrac{\text{grams leached from test log (ends sealed, w/bark)}}{\text{ft}^2 \text{ cylindrical area}}$

A_E = total submerged end area of logs (ft^2)

A_c = total submerged cylindrical area of logs (ft^2)

x = fraction of bark missing from logs

$f_1 = \dfrac{\text{cylindrical area of log}}{\text{end area of log}}$

The term $[(1-x)(D)(A_c)]$ represents the contribution from the cylindrical log area with bark intact. Correspondingly, the $[(x)(C)(A_c)]$ term is the contribution from the cylindrical area without bark and the $[(f_1)(B-D)(A_E)]$ term is the contribution from the end areas.

This equation is in slightly different form than the one proposed by Graham (9) in an earlier study. Example calculations applying this equation are given in Appendix D.

The above equation can be used to compare the quantity of organic matter in log leachate for different storage conditions, species of logs and surface conditions of logs. Table 2 summarizes the estimated contribution of COD, TOC, TS and TVS from Douglas fir and ponderosa pine logs, two feet in diameter and thirty feet long. Calculated values are shown for logs with all bark intact and only 50 percent of the bark intact. These values show that pine logs add nearly 22 percent more COD and 99 percent more TOC than fir logs of comparable size and degree of submergence.

Table 2. Estimation of Pollutants Contributed by Douglas Fir and Ponderosa Pine Logs Two Feet in Diameter and Thirty Feet Long Floating One-half Submerged.

Log species	Water exposure period (days)	COD (g)		PBI (g)		TVS (g)		TOC (g)	
		100% Bark	50% Bark	100% Bark	50% Bark	100% Bark	50% Bark	100% Bark	50% Bark
Douglas	10	144	163	265	204	164	174	48	-
fir	35	331	332	683	522	278	249	71	-
Ponderosa	10	210	183	710	555	211	154	98	-
pine	35	403	344	1375	915	349	268	161	-

Dynamic Leaching

General. In rivers, estuaries, and flow-through log ponds, water continuously flows past rafted logs. This dynamic situation would discourage the build-up of a concentration gradient of leached substances at the water-log interface. A laboratory experiment was set-up to evaluate the influence of hydraulic flow rate on the rate of leaching. The apparatus and procedures developed for this experiment are presented in an earlier section of this report.

Poisoned log holding water was passed through test tanks at rates low enough that some measurable accumulation of pollutants could be obtained, yet fast enough to prevent the development of a concentration gradient. Flow velocities below 0.01 ft/min were needed to obtain sufficient leachate concentration for analysis, even though low velocities in excess of 50 to 100 feet per minute are not uncommon in natural flowing streams and estuaries. Both Douglas fir and ponderosa pine log segments (unaltered) were studied. Samples of overflow were periodically collected and analyzed for COD and nitrate and Kjeldahl nitrogen.

COD. The plot of cumulative COD in Figure 20 shows that the rate of leaching of organic substances is nearly the same for static and low flow rates. However, at the higher flow rates, the rate of leaching was rapid initially then leveled out after 30 days of immersion. This indicates that in swift waters soluble organics will leach at a more rapid rate than in more stagnant waters such as overflowing ponds, lakes and sloughs. Furthermore, leaching from the ponderosa pine logs will be essentially complete within 30 to 35 days. Previous static leaching tests had indicated that the rate of leaching might remain constant for 80 days or more.

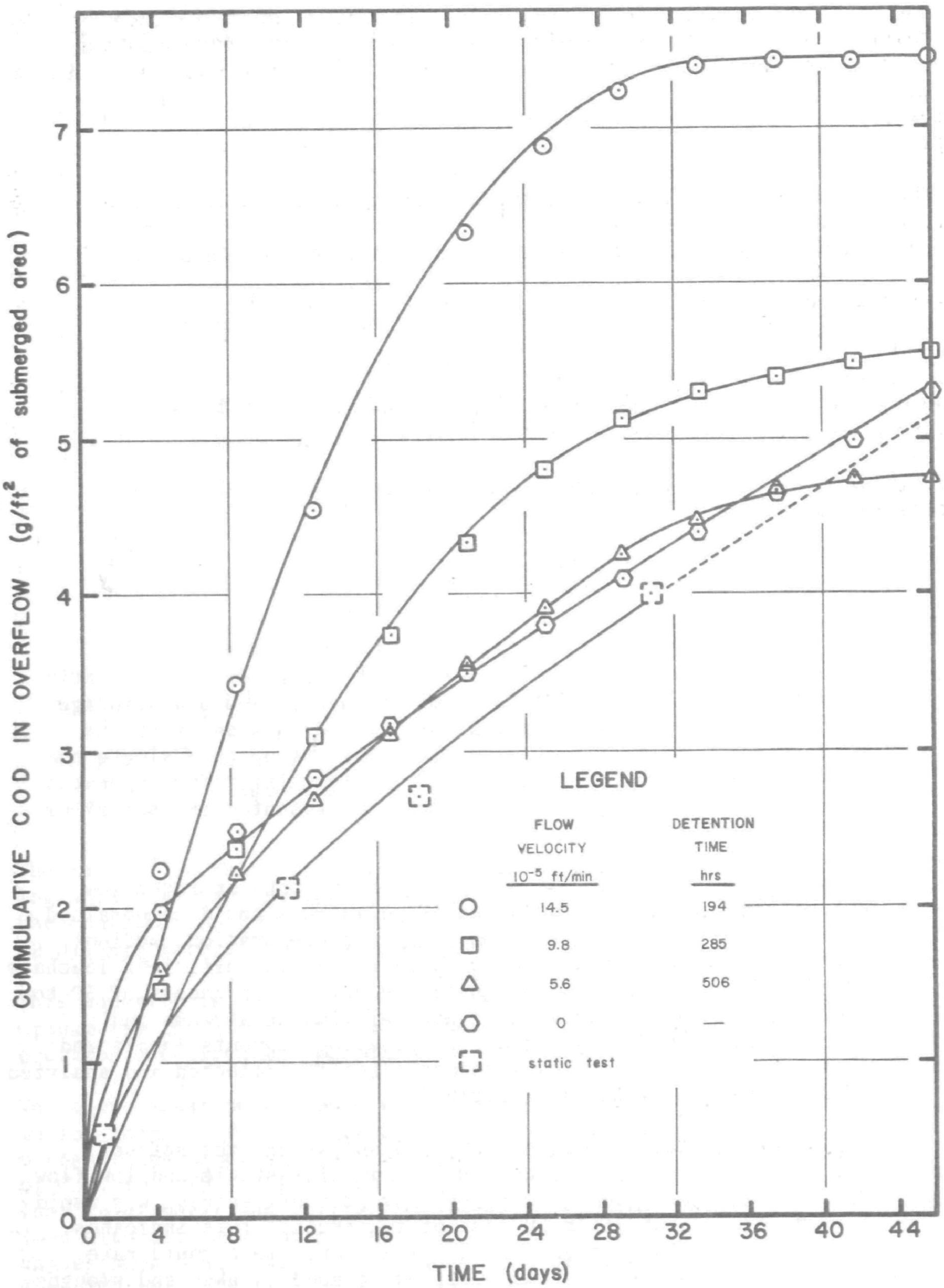


FIGURE 20. Leachate COD from Dynamic Storage Tests with Ponderosa Pine Logs.

Cumulative COD results from Douglas fir logs plotted in Figure 21 also reveal that logs held in dynamic water systems will contribute leachates to the water at higher rates than in stagnant situations. The rate of leaching does not appear to be directly related to flow rate, however, since similar quantities of soluble organics were leached from the tanks at all three flow velocities. Even though the rate of leaching declined after 25 to 30 days considerable material was still removed from the logs.

At the high flow rates found in natural streams, the initial leaching rate would likely be very high. No high rate studies were run during this research investigation because of the difficulty in collecting sufficient leachate for reliable quantitative measurement. A closed recycle system might have been applicable in the dynamic leaching studies.

Nitrogen. Total Kjeldahl nitrogen and nitrate nitrogen determinations were made during the dynamic leaching experiment on samples of leachate from Douglas fir logs. Results in Table 3 show that a close relationship exists between COD and Kjeldahl nitrogen in the log leachate. Values ranges from 0.055 to 0.073 grams of nitrogen per gram of COD with an average of about 0.061. Nitrate nitrogen appeared in negligible quantities in the leachate samples tested.

Table 3. Total Kjeldahl Nitrogen and COD in Leachates from Douglas fir Logs During Dynamic Leaching Studies

Storage time hours	COD g/ft²*	N g/ft²	N/COD
100	1.28	0.093	0.073
200	2.39	0.156	0.065
300	3.65	0.214	0.059
400	4.77	0.269	0.057
500	5.79	0.322	0.056
600	6.69	0.369	0.055
			Avg 0.061

*grams per ft² of submerged surface area

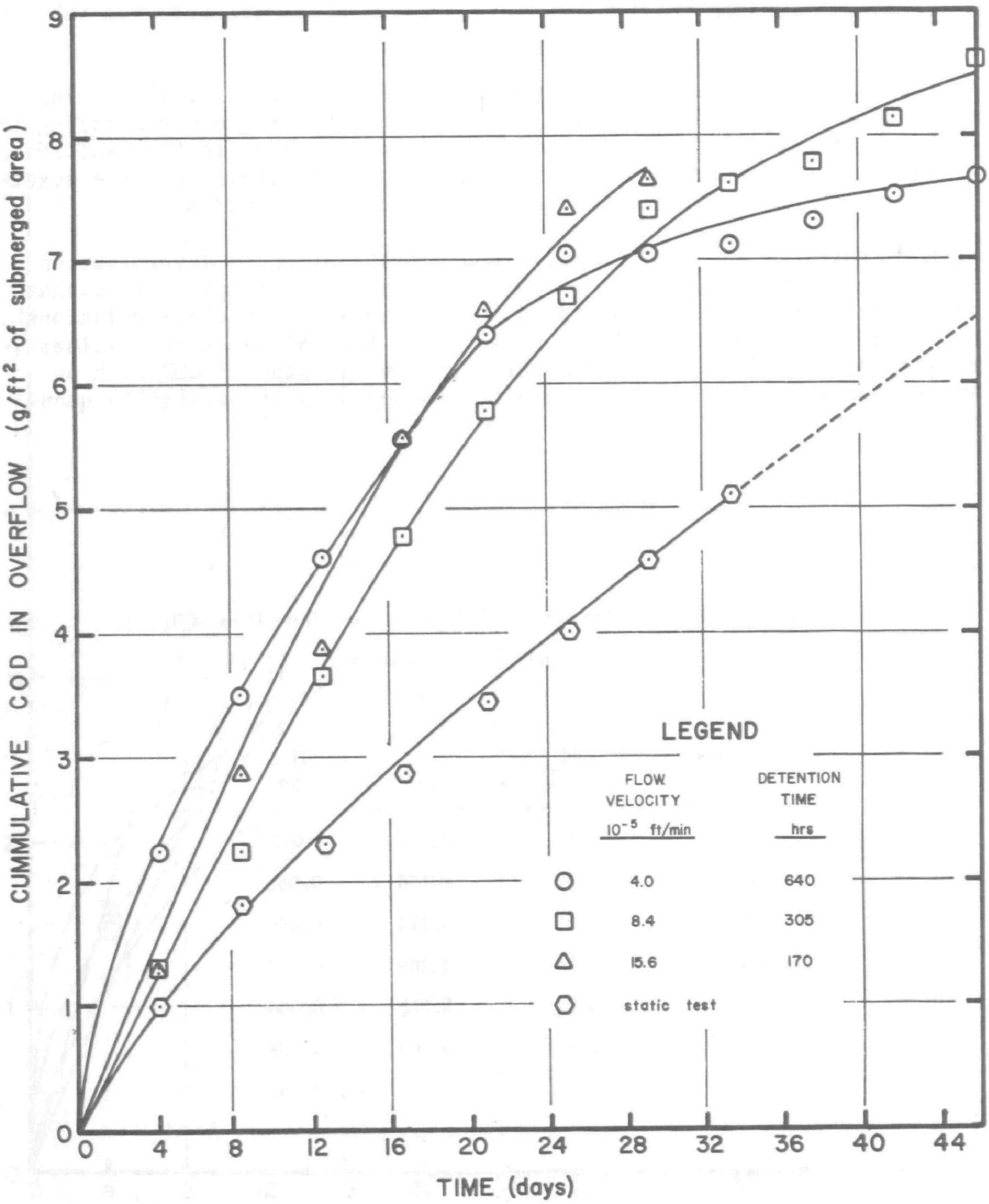


FIGURE 21. Leachate COD from Dynamic Storage Tests with Douglas Fir Logs.

Phosphorus. Total phosphate phosphorus determinations were made on leachate samples. Results showed only trace quantities collected throughout the entire dynamic leaching experiment.

Log Ponds

The pollution potential of logs rafted in lakes and rivers is readily apparent. Not so apparent, but very much a pollution threat, are the numerous log ponds which dot the Pacific Northwest. A great number of these ponds are operated on an overflow basis with the overflow being discharged to the nearest water course. The fact that there are approximately 12,000 acres of log ponds in Oregon alone, stresses the extent of the problem.

Four log ponds situated at different locations in Oregon were selected for evaluation. These ponds exhibited different physical characteristics as indicated in Table 4. Several points were sampled within each pond to determine if the pond water was homogeneous with respect to chemical characteristics.

The BOD_{20} (20-day BOD) values for each pond were much lower than corresponding COD values. For example Pond B had a COD of 504 mg/l and a BOD_{20} of only 167 mg/l. This difference can be readily explained by recognizing what each test measures. The COD test measures all organic compounds which can be oxidized to carbon dioxide and water by strong chemical oxidizing agents, whereas the BOD determination measures the oxygen required to biologically oxidize an organic material. Since many wastes contain organic compounds that cannot be stabilized totally through biological action, the COD values are generally higher than the BOD_{20} values. BOD_{20} was used to estimate the ultimate BOD of the pond water. Furthermore, the biodegradable substances which do leach from logs are attacked immediately by microorganisms in pond water. This results in a reduction of BOD and also BOD:COD ratios.

Another important parameter of any waste is the BOD reaction rate constant denoted as k. Values for k can be found by solving the general BOD equation (20) when the BOD_5 and BOD_{20} values are known. High k values indicate rapid exertion of BOD. Very simple substrates such as sugars are degraded rapidly thus the k rates are high (0.20 to 0.30 day^{-1}). The k rates for the four ponds ranged from 0.03 to 0.08 day^{-1}) which indicates that the organic compounds present in the water were somewhat complex and difficult to biodegrade.

All of the ponds contained sufficient amounts of nitrogen and phosphorus to support biological growth. The concentration of these elements increased as the degree of pollution (in terms of COD and BOD) increased. This suggests that some of the nitrogen and phosphorus must come from the logs, although neither pine nor fir contain much of these elements. An important source of the nitrogen and phosphorus is from the benthic deposits in the ponds. All the ponds tested were fairly old and had extensive deposits which consisted of bark, wood, dead algae and aquatic

Table 4. Physical Characteristics of Selected Log Ponds in Oregon

Pond	Surface area, acres	Average depth, ft	Age of pond, years	Type of logs stored	Length of storage	Water source	Remarks
A	26	8	11	Douglas fir	1-3 yrs	stream	non-overflowing except during high runoff periods; sanitary wastes dumped into pond.
B	20	6-8	14	Douglas fir	80% of logs about one week	wells	non-overflowing except during high runoff periods; sanitary and glue wastes from plywood dumped into pond
C	2-1/2	12	19	85% ponderosa pine 15% Douglas fir	two weeks	stream	overflowing at about 400 gallons per minute
D	3	4-5	39	over 90% ponderosa pine	one week	springs: irrigation ditch	overflowing at about 16 gallons per minute

vegetation. As these materials undergo decomposition, nitrogen and phosphorus are released for reuse by the microorganisms feeding on soluble leachates. Other nutrient sources would include surface runoff, the source water and some sanitary wastes which are dumped into the ponds.

The indices used to define the character of log pond waters included chemical oxygen demand (COD), biochemical oxygen demand (BOD), dissolved oxygen (D.O), phosphates, nitrates, total Kjeldahl nitrogen, total solids, settleable solids, alkalinity, oxygen transfer coefficient, K_La, and Pearl Benson Index (PBI). The methods of measurement are described under the section of this report entitled EXPERIMENTAL APPARATUS AND PROCEDURES.

Table 5 summarizes the results of analyses performed on water samples from each of the four ponds. Generally, the ponds proved to be quite homogeneous with respect to the various parameters measured. Therefore, data from only one sampling point for each pond is listed in Table 5.

The length of storage time and hydraulic overflow rate seem to significantly influence the chemical nature of the log pond water. Ponds B and D, which had short log storage times and low overflow rates, exhibited much higher values for most all the characteristics studied than ponds A and C.

As logs are added to a pond, leaching of the water soluble materials begins immediately. As time goes on these materials are depleted until finally no further leaching can take place. Therefore, the shorter the log storage period, the greater the amount of substances available to be leached. A pond with a mean log storage time of one week will build up greater concentrations of tannins, wood sugars, etc., than a pond which stores the same logs for a year.

The high overflow rate shown for Pond C resulted from the addition of large quantities of fresh water to the pond. Therefore, the concentrations of leached substances did not build up in Pond C as they did in ponds with low discharge rates.

As shown in Ponds B and D, the chemical oxygen demand (COD) of a log pond can be quite high (504 and 353 mg/1, respectively), indicating that much of the material leached from the logs was organic.

The Pearl Benson Index (PBI) is a measure of the lignin-like substances dissolved in water. In all cases the PBI values were closely related with the COD values. COD values for the four ponds ranged from 24 to 504 mg/1 and the corresponding PBI values ranged from 35 to 545 mg/1. This could be expected since the same compounds detected by the PBI test would also contribute to the COD.

The dissolved oxygen (D.O) level in all ponds was quite low (0.0 to 1.5 mg/1), even close to the surface. This indicates that extensive biological activity was taking place within the ponds. The quiescent condition of the ponds also contributed to the low D.O. values since oxygen transfer is much less effective under these conditions.

Table 5. Chemical Characteristics of Log Ponds Studied

Pond	TS,[a] mg/l	% VS[b]	SS[c], mg/l	DO, mg/l	Temp., °C	pH	COD, mg/l	BOD_{20}, mg/l	BOD_5, mg/l	$\frac{BOD_5}{COD}$	k, day^{-1}	N[d], mg/l	NO_3-N[e] mg/l	PO_4, mg/l	PBI, mg/l
A	254	59	43	0.1	22	6.9	116	48	29	0.25	0.08	2.4	0.6	0.5	175
B	747	55	180	0.3	21.5	7.1	504	167	54	0.11	0.03	10.4	1.5	1.2	545
C	356	31	4	1.5	23	7.5	23	10	6	0.25	0.08	1.0	0.1	0.1	35
D	606	46	122	0.7	21.5	7.4	353	116	68	0.19	0.08	4.9	0.7	2.0	338

[a] TS = total solids

[b] VS = volatile solids

[c] SS = suspended solids

[d] N = total Kjeldahl nitrogen (ammonia plus organic nitrogen)

[e] NO_3-N = nitrate nitrogen

Cold Decks

General. There are several locations in Oregon and the Pacific Northwest where the water storage of logs is not permitted or is not practical. In such instances the industry must store their inventory of logs on land in cold decks. In order to minimize losses of timber through splitting of log ends, the decked logs are frequently sprinkled with water. Water which pases over the logs picks up water soluble organics and inorganics from the wood. Consequently, underflow from sprinkled cold decks contain similar pollutants to those extracted during submerged water storage. Cold deck underflow is sometimes recycled although more commonly it is discharged to a receiving body of water.

A field study was undertaken to obtain cold deck leaching data for comparison with laboratory findings. The number and surface area of logs together with hydraulic flow rate and measured BOD of the cold deck runoff are given in Table 6. Based upon a BOD to COD ratio of 0.46 (estimated from static leaching experiments), the resultant daily COD contribution in the under flow would be 147 lbs/day. Using these data, a value of 0.085 g COD/ft^2 can be calculated per 100 hours of sprinkling. This value corresponds closely to the slope of the COD vs time curve in Figure 18 for ponderosa pine logs with bark intact for an extended storage period. Thus, it may be reasoned that the data obtained in the laboratory leaching tests can provide a good prediction for cold deck operation in the field.

Table 6. Ponderosa Pine Cold Deck Data

parameter	sampled value
Mean log diameter	19.2 inches
Mean log length	32.5 ft
Number of logs/25 lin. ft	350
Lineal feet of cold deck	1740 ft
Estimated number of logs	24,400
Estimated surface area	4.0×10^6 ft^2
Mean BOD of runoff	19 mg/1
Flow	0.426 mgd
BOD/day	67.5 lbs/day

Part II: Bark Debris

Introduction

Trees felled in the forest are generally sawed into logs which vary in length from 20 to 40 feet. Logs are transported to temporary land or water storage sites by truck or rail car. Water storage sites include lakes, rivers, estuaries and man-made ponds.

Logs are deposited into a water storage area by several methods including direct vertical dump, sloped slide and cable hoist. The logs are then aligned into rafts for subsequent transport and storage. This repeated handling results in the loss of considerable amounts of bark from the logs. Bark dislodged in water will sink either immediately or after a short soaking period. Bark which settles to the bottom of water courses forms benthic deposits which may have deleterious effects on aquatic organisms inhabiting the benthic zone. Additionally, benthic deposits can exert a demand for dissolved oxygen from overlying waters. The methods used in the developmental phases of the bark study are described in the section of this report entitled EXPERIMENTAL APPARATUS AND PROCEDURES.

Dislodged Bark

The application of two-dimensional photography for estimating losses of bark from logs required pre-evaluation of several potential sources of error since logs are three-dimensional and photographs are planar.

First, optical dispersion in the camera field was determined by photographing one-foot square pieces of paper placed randomly on the ground beneath the tripod-mounted camera. The squares were compared in the resulting photographs. The degree of dispersion was found to be negligible.

Actual photographic scale was found to be insignificant since the percentage of bark missing was computed. The projection of the curved surfaces of the logs upon the planar surfaces of the photographic slides did not represent the true surface area of the logs. However, on a statistical basis, the percentage of bark missing in any differential area would be distorted equally. This rationalization was verified by physically measuring the total surface area of several logs and the area of missing bark, then comparing with photographic results for the same logs. Several logs were also rotated in the water and examined for missing bark on all surfaces to insure that the percentage of bark missing from the air-exposed surface was representative of the entire log.

Results of numerous photographic measurements of loaded log trucks, and rafted logs, before and after raft transport, are given in Appendix C for Douglas fir stored in Yaquina Estuary and for ponderosa pine stored in the Klamath River. Results summarized in Table 7 reveal that nearly 22 percent of the original bark was lost from Douglas fir logs during unloading and raft transport compared to only 6 percent for ponderosa pine logs. This large difference can be explained by two factors, the species of logs studied and the abrasiveness of unloading operations.

Unloading operations examined on the Yaquina Estuary were more abrasive than the operations on Klamath River due to the greater height the logs had to fall to the water surface during direct dumping. At Yaquina Estuary the elevation difference between the unloading deck and the water surface varied with tidal fluctuation from 8 to 15 feet. A fall of only 6 to 8 feet was observed on the inland Klamath River. This difference in distance gave the logs a greater impact velocity which increased the amount of bark dislodged.

Probably the major factor responsible for the wide difference in bark loss is the difference in character of the two species of logs studied. As shown in Table 7, 18 percent of the Douglas fir bark was lost during felling operations compared to only 6 percent for the pine logs. During earlier leaching experiments, sections of both the fir and pine logs were debarked by hand. Douglas fir bark peeled easily and in large chunks whereas a chisel had to be used to peel the ponderosa pine logs.

A study was undertaken to compare bark losses caused by different unloading techniques. Fortunately for research purposes, the vertical dump apparatus used at the Yaquina Estuary site up to 1968 was replaced in 1969 by a cable sling system. Therefore, similar log types were studied during the same month in both years. Data from 190 photographic observations were analyzed statistically as shown in Table 8 to ascertain the relative bark losses from the two methods. The vertical dump method was found to be the most abrasive, as expected, with bark losses of 17.1% compared to only 8.2% for the cable hoist system. Therefore, the method of dumping selected by the timber industry can substantially affect the quantity of bark debris released to a water course.

Bark Sinking Rate

Bark sinking rate is dependent upon the moisture content of the bark particles, the size of bark particles and the rate at which water diffuses into the bark pores. Most pieces of bark will float for a short period of time before they soak up moisture which increases their density and causes them to sink.

The first sinking rate study involved a direct comparison of grab samples of Douglas fir and ponderosa pine bark randomly collected at log dumping sites. The ponderosa pine bark debris consisted mostly of small, thin chips approximately 1/16-inch thick with a 1/2-inch mean diameter, plus a few large bark pieces approximately 3/8-inch thick with a 1 to 3-inch mean diameter. The Douglas fir bark debris consisted mostly of large

Table 7. Incremental Percentages of Bark Dislodged During Logging, Unloading, and Raft Transport

Area studied (species of logs)	Percentage of Bark Dislodged: During logging	During unloading	During raft transport	During unloading and transport
Yaquina Estuary (Douglas fir)	18.2	16.8	4.9	21.7
Klamath River (ponderosa pine)	5.7	---	---	6.2

Table 8. Bark Losses from Douglas Fir Logs During Unloading by Two Different Methods

Sample statistic	Vertical Hoisting	Direct Dumping
Bark removed before unloading		
No. of observations	59	38
Mean ($\bar{X}_1$)	24.8%	18.0%
Standard deviation (s)	12.1%	11.5%
Bark removed after unloading		
No. of observations	73	20
Mean ($\bar{X}_2$)	33.0%	35.1%
Standard deviation (s)	13.4%	6.9%
Bark dislodged during unloading		
Mean ($\bar{X}_2 - \bar{X}_1$)	8.2%	17.1%
Pooled deviation (s)	12.7%	11.6%
Sampled standard error ($s_{\bar{X}_2 - \bar{X}_1}$)	2.5%	3.2%

1) Percent dislodged represents $\frac{\text{debarked area}}{\text{total surface area}}$ X 100.

pieces approximately 3/8-inch thick, 1 to 3 inches wide and 1 to 6 inches long, although, there were some small bark chips.

The cumulative amount of bark which had sunk was measured several times during the 60-day study. Results plotted in Figure 22 show that about 10% of the bark of both species sank the first day. These were mainly the very small bark chips. After 30 days of storage, nearly 70% of the pine bark had sunk whereas only 47% of the fir bark had sunk. This could be accounted for by the higher quantity of small pine bark particles. At the end of 60 days, the quantity of bark of both species which had sunk leveled out to approximately 75%. This data indicates that at least 10% of the bark dislodged during unloading operations will sink within the first day and probably in the vicinity of the dump site. Furthermore, approximately 65% of the bark dislodged during dumping and raft transport will deposit in the raft transport and storage areas, if the logs remain rafted for 60 days. Logs are frequently held in rafts for 60 days or longer. The remaining bark which does not sink within 60 days, will either float with the prevailing currents or become trapped in the log rafts. Bark trapped in log rafts is frequently removed from the water at the log processing site by a skimming mechanism.

Other experiments were undertaken to ascertain the effect of bark particle size on sinking rate. Cumulative amounts of sunken bark are plotted in Figures 23 and 24 for Douglas fir and ponderosa pine bark respectively. These results clearly indicate that sinking rate is dependent upon particles size. All of the 0-1/2" size bark of both species sank within 20 days of immersion whereas only 3% of the 4" or greater particles of ponderosa pine sank during this same period. The large Douglas fir bark sank more rapidly than the pine, i.e., 27% sank within 20 days.

Table 9 shows the relative particle size distribution, on a dry weight basis, for samples collected around log dumping sites in a random manner. Approximately 30% of the pine bark was 0 to 1/2-inch in size whereas only 22% was 4 inches or larger

Benthic Distribution

Bark debris arising from log storage activities, eventually sinks and becomes incorporated in the benthic deposits if not physically removed from the water. The aim of this part of the study was to determine the amount of bark in the benthic deposits as a function of depth from the water-soil interface.

Many techniques were considered for obtaining representative benthic samples. The method selected involved freezing an intact core sample followed by analysis of the sample for volatile solids as a function of depth. COD determinations were considered as an indicator of bark in the benthic zone, however, due to the high and variable concentrations of chlorides in the overlying water this pollutant index was rejected. Chlorides interfere with COD determinations and require special consideration during analysis. The volatile solids test was finally selected

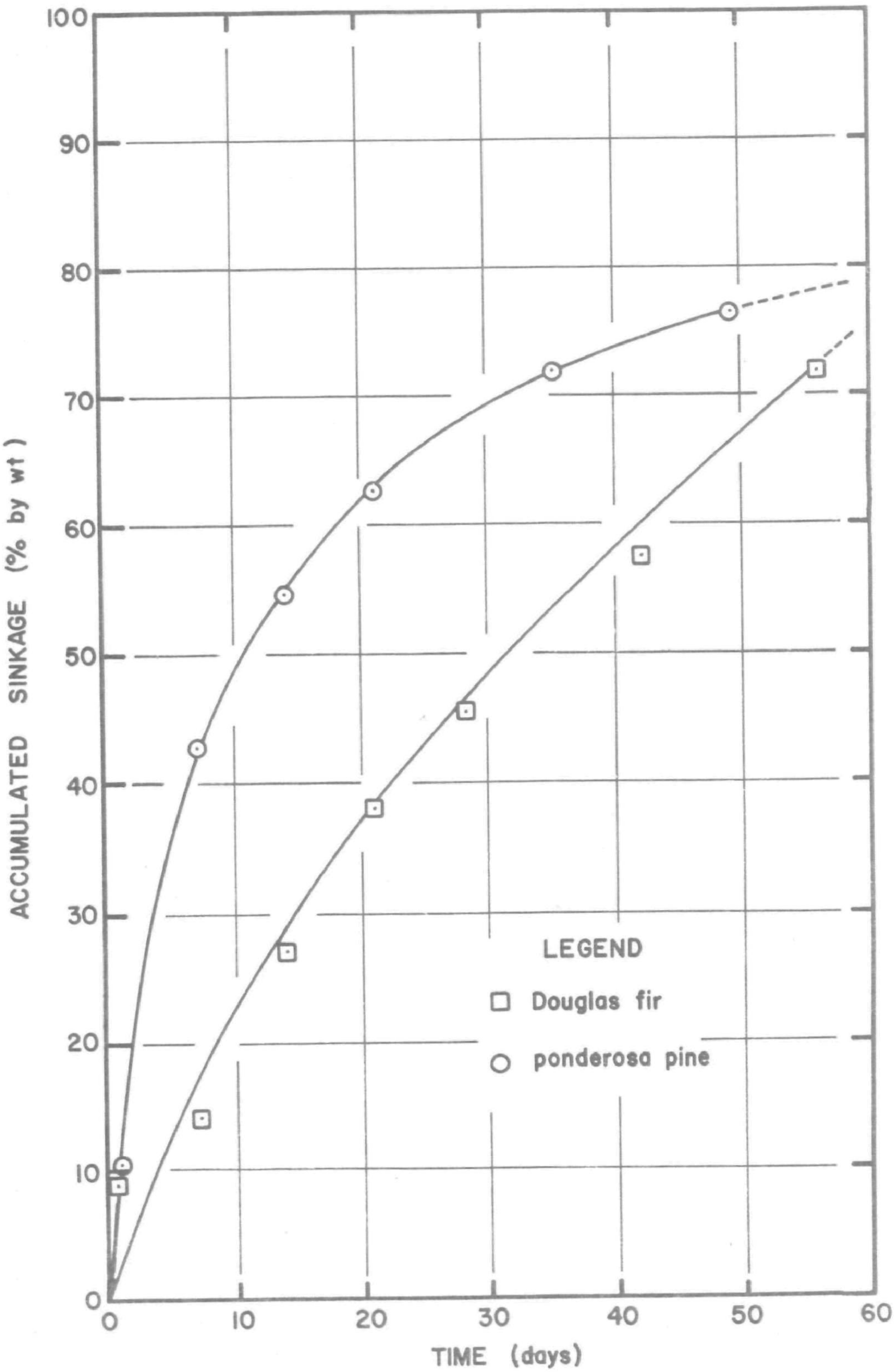


FIGURE 22. Sinkage for Composite Grab Samples of Bark.

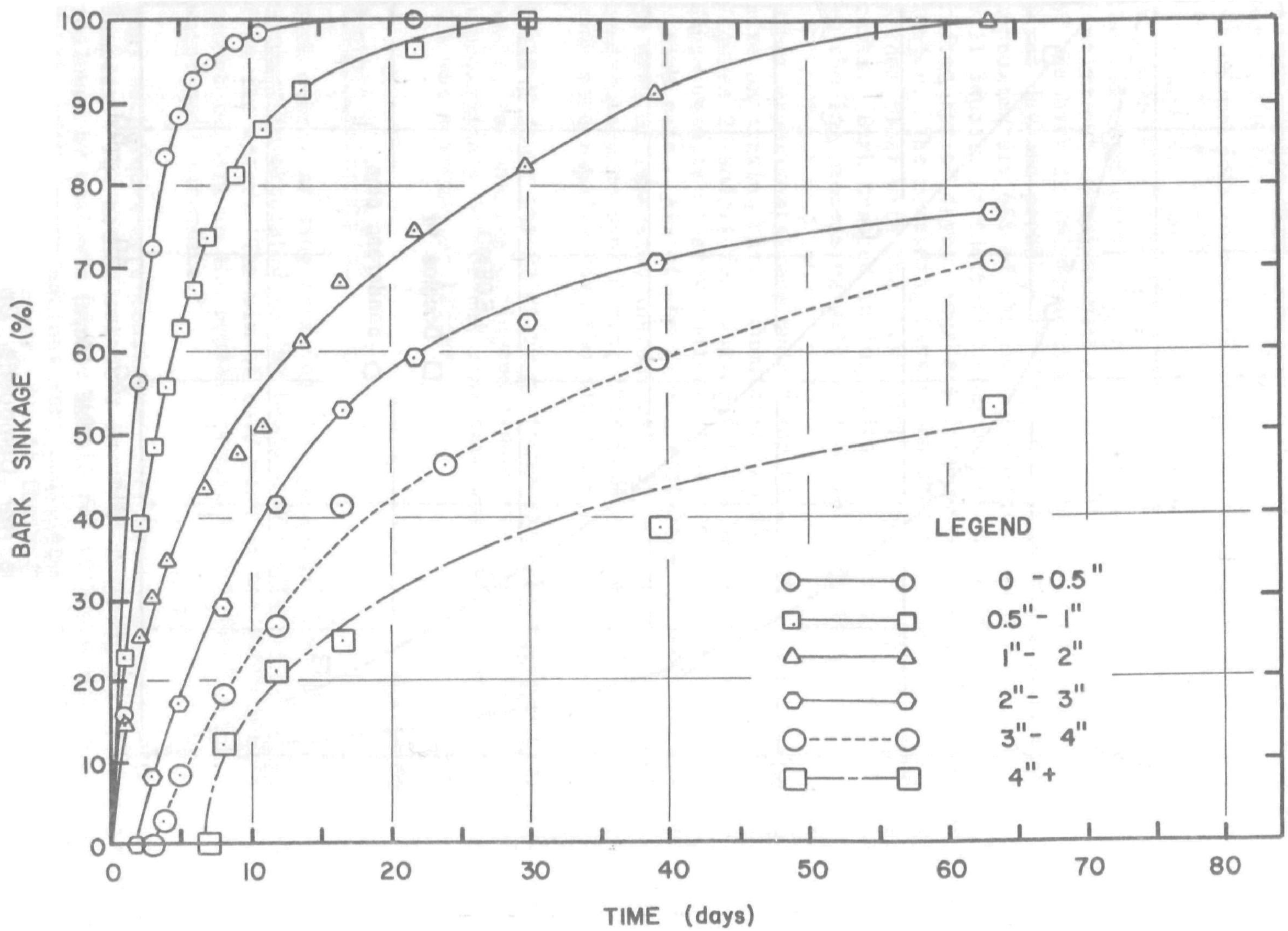


FIGURE 23. Percent of Bark Sunk for a Graded Sample of Douglas Fir Bark.

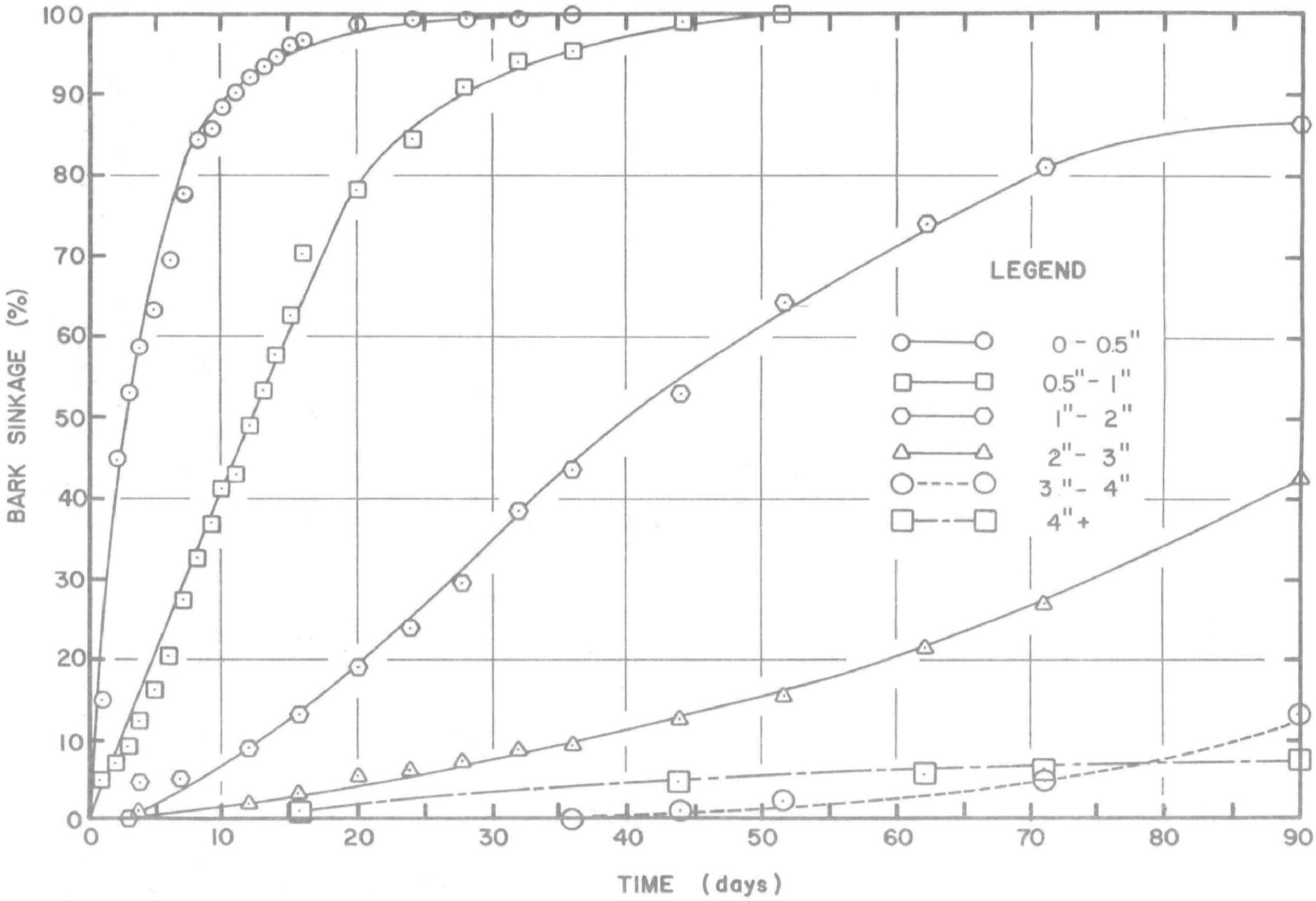


FIGURE 24. Percent of Bark Sunk for a Graded Sample of Ponderosa Pine Bark.

Table 9. Size Distribution of Samples of Bark Collected Randomly from Log Dumping Areas

Particle size range inches	Ponderosa pine % by weight	Douglas fir % by weight
0 - 1/2	18.3	10.2
1/2 - 1	12.2	12.0
1 - 2	13.3	8.5
2 - 3	14.4	17.2
3 - 4	17.0	25.2
4 +	24.8	27.0

as the index of bark present in the deposits since this measurement is a indicator of organic substances and is not influenced by chlorides. Organic substances other than bark which are measured by the volatile solids test could include micro- and macro-organisms, debris from overland run-off, industrial waste sludges and others. The presence of significant quantities of these substances in the deposits could have resulted in a measurement error, however, much of the error was eliminated by correcting all readings with volatile solids values taken from control areas without bark deposits.

The assumption was made in this study that the difference in volatile solids in soil samples taken from log dumping and storage areas and corresponding values for samples from control areas without bark storage represents the volatile solids added by bark debris. The volatile solids content of bark varied considerably with the species of wood and the extent of biodegradation or decay of bark in deposits. Therefore volatile solids values can be correlated to the amount of bark in a benthic deposit but cannot be used as a direct measure of actual bark. Experimental results are reported as grams volatile solids per cubic foot for the soil depth sampled.

Benthic deposits were studied at log dumping and storage sites in the Yaquina Estuary and the Klamath River. The sites studied on the Yaquina Estuary are shown in Figure 25 and the Klamath River sites are shown in Figure 26. Volatile solids data obtained at log storage site D in Yaquina Estuary are presented in Table 10 and are plotted in Figure 27. Descriptive maps for the other study sites in Yaquina Estuary and Klamath River are presented in a M.S. thesis by Williamson (26).

Some general trends were noted using the core sampling data. Bark debris did not accumulate in the channel of Yaquina Estuary, probably due to the high flow velocity. Most of the bark was localized in dumping and storage areas and quiescent regions. Bark debris was found uniformly distributed across the slow moving upper reaches of the Klamath River, with the largest accumulations in the dumping regions. Furthermore, logs are stored on a high percentage of the river surface area.

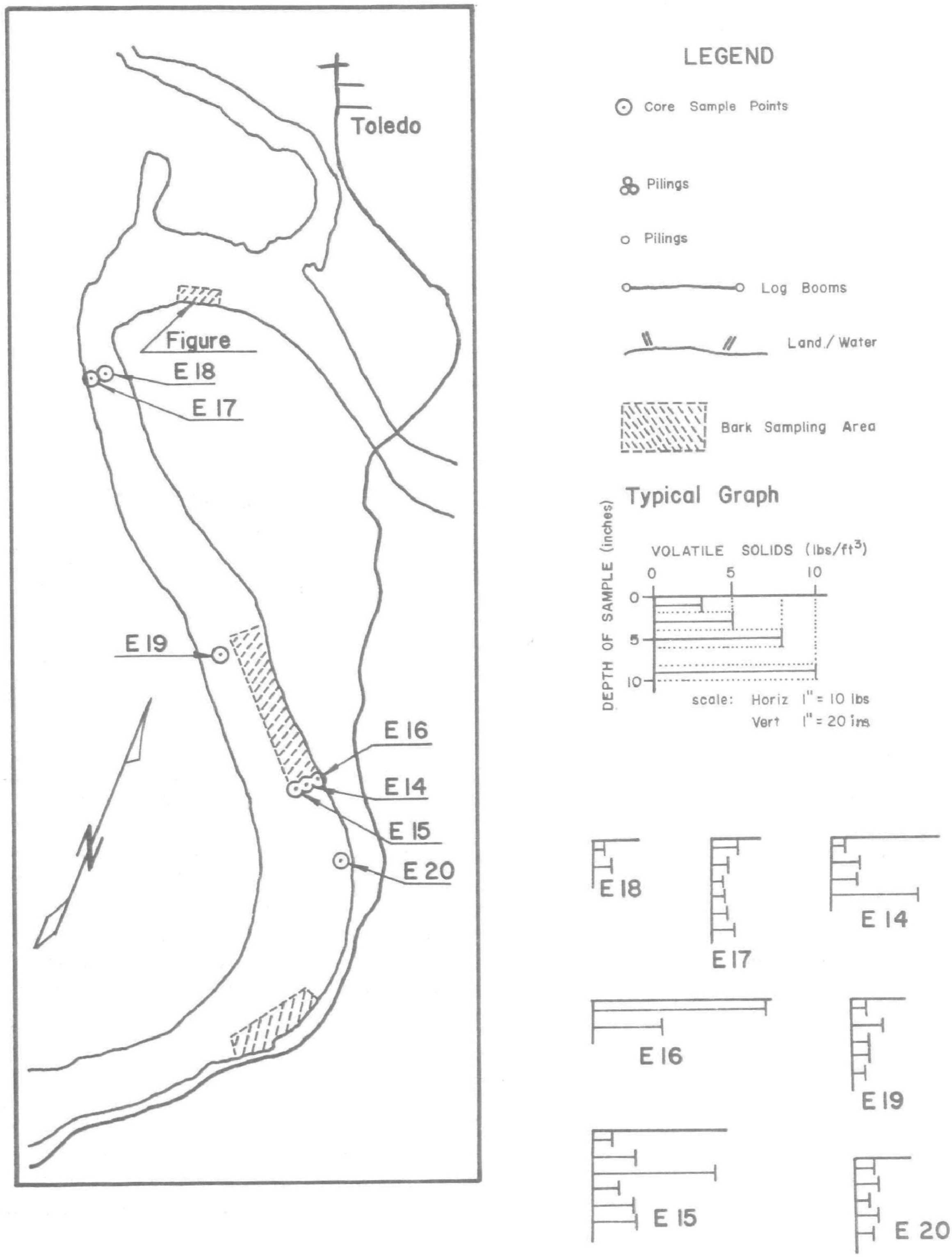


FIGURE 25 .Sampling Areas for Bark Distribution Study at Yaquina Estuary.

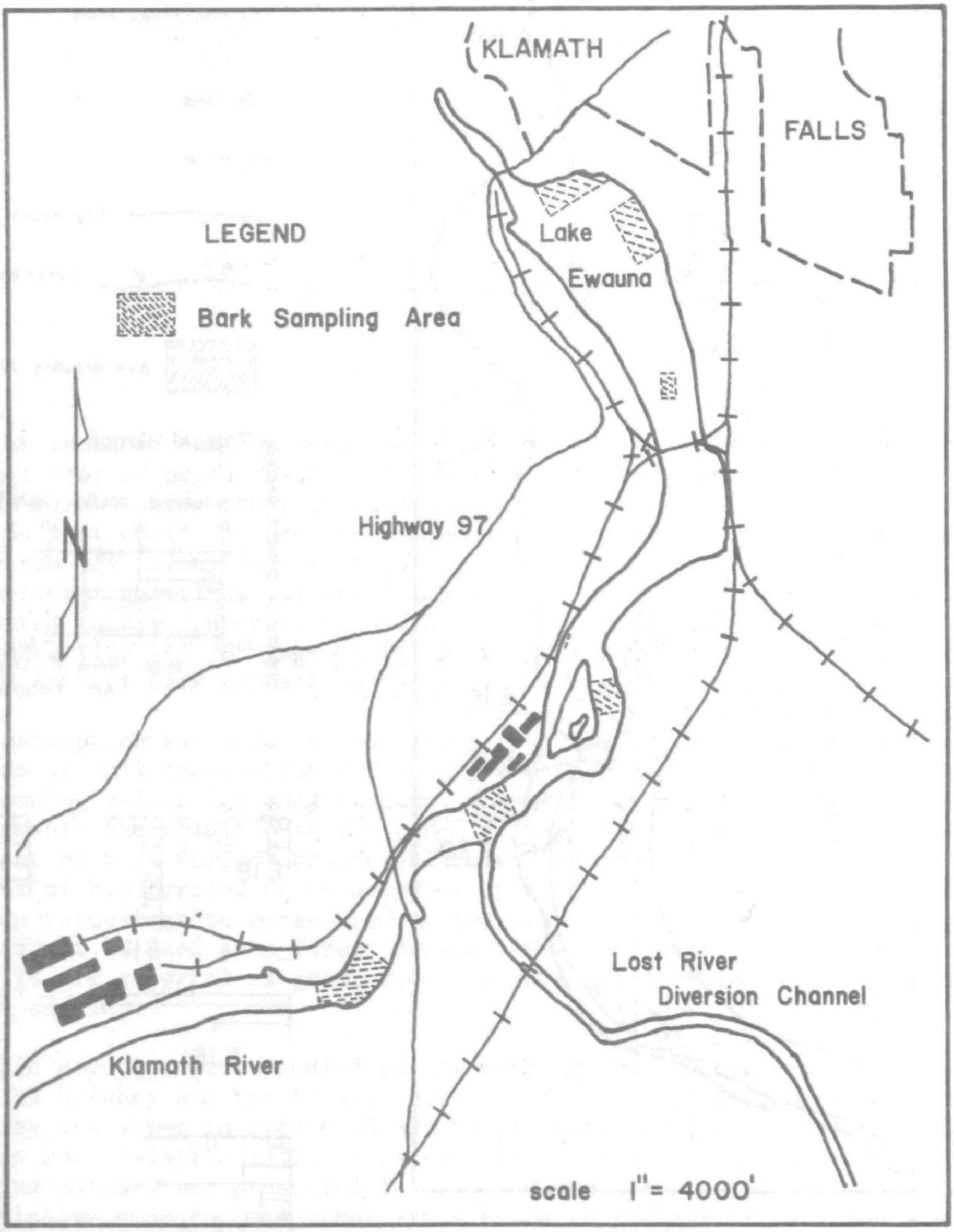


FIGURE 26. Sampling Areas for Bark Distribution Study at Klamath Falls.

Table 10. Average Unit Weights, Percentage of Volatile Solids and Volatile Solids per Cubic Foot for Core Samples from Area D (Figure 25)

Depth (Inches)	Number of samples Extending through Stated Depth	Unit Weight Mean (lbs/ft^3)	Unit Weight Ave. Deviation	% Volatile Solids Mean	% Volatile Solids Ave. Deviation	Volatile Solids lbs/ft^3
0 - 2	11	34.78	6.75	9.22	3.28	3.21
2 - 4	12	50.81	11.37	8.90	4.59	4.52
4 - 6	12	49.39	6.43	9.53	5.42	4.70
6 - 8	12	51.98	8.34	9.93	4.49	5.16
8 - 10	11	54.27	19.00	12.20	7.51	6.62
10 - 12	11	50.13	14.59	9.85	5.12	4.94
12 - 14	8	48.00	10.29	7.61	3.26	3.65
14 - 16	8	57.00	11.97	7.14	3.92	4.07
16 - 18	3	60.88	6.10	7.86	3.03	4.79
18 - 20	2	59.35	6.92	12.70	2.70	7.54
20 - 22	1	43.46		11.72		5.09

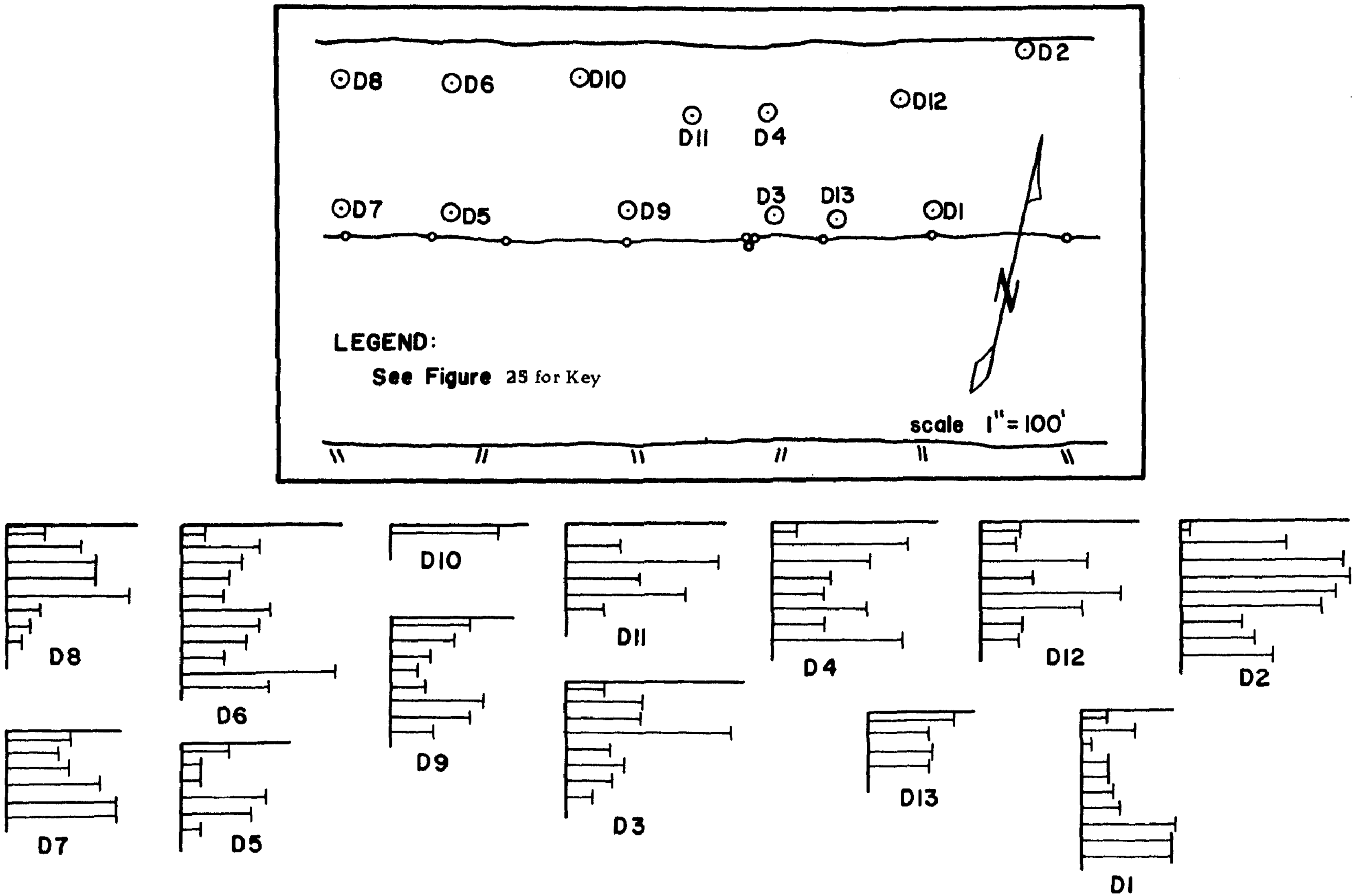


FIGURE 27. Bark Distribution at a Typical Log Storage Area in Yaquina Estuary.

Table 11. Total and Volatile Solids for Benthic Core Samples as a Function of Depth Below the Water-Soil Interface

Depth (inches)	% volatile solids	Total solids (grams)	%volatile solids	Total solids (grams)	% volatile solids	Total solids (grams)	% volatile solids	Total solids (grams)
				Sample No.				
	Control - 5		Control - 6		A - 1		A - 2	
0 - 2	9.52	12.48	4.69	22.43	31.90	10.92	22.65	13.13
2 - 4	7.48	15.57	4.91	19.40	20.77	18.91	24.42	16.18
4 - 6	7.72	18.61	3.82	22.38	13.75	22.89	20.34	15.66
6 - 8	4.48	25.54	5.12	24.13	25.07	18.12	14.94	23.42
8 - 10	6.98	18.30	8.79	31.25			19.10	19.87
10 - 12	7.34	14.77						
				Sample No.				
	A - 3		A - 4		A - 5		A - 6	
0 - 2	40.73	8.68	43.57	6.07	19.27	8.03	16.35	14.51
2 - 4	36.54	9.37	29.98	12.14	25.91	16.55	24.46	18.68
4 - 6	33.56	15.14	35.37	14.20	24.14	19.16	26.32	13.94
6 - 8	25.25	25.12					22.37	15.90
8 - 10							22.63	14.22
10 - 12							24.65	18.28
12 - 14							17.12	19.21

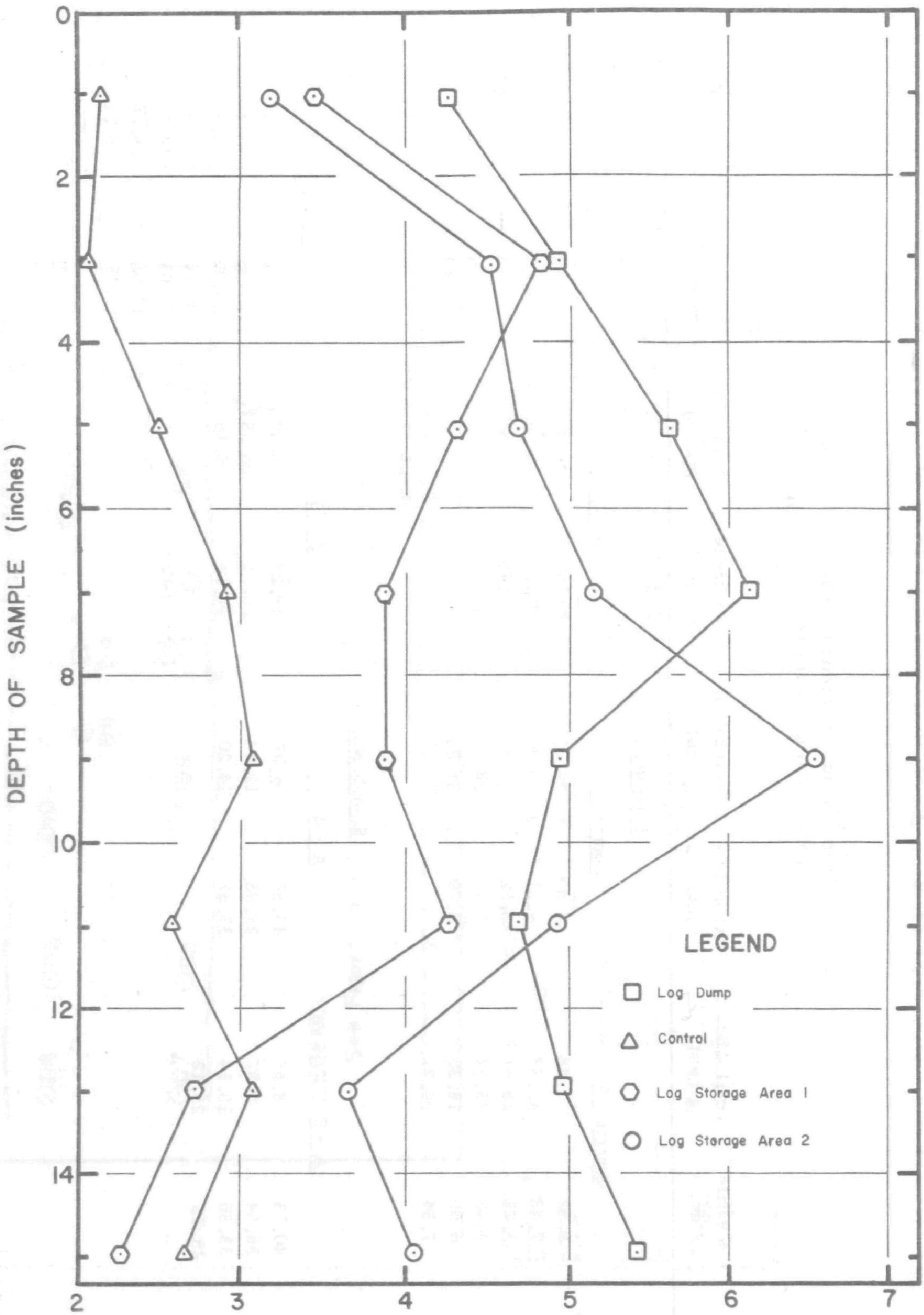


FIGURE 28. Volatile Solids of Benthic Deposits at Selected Sites in Yaquina Estuary.

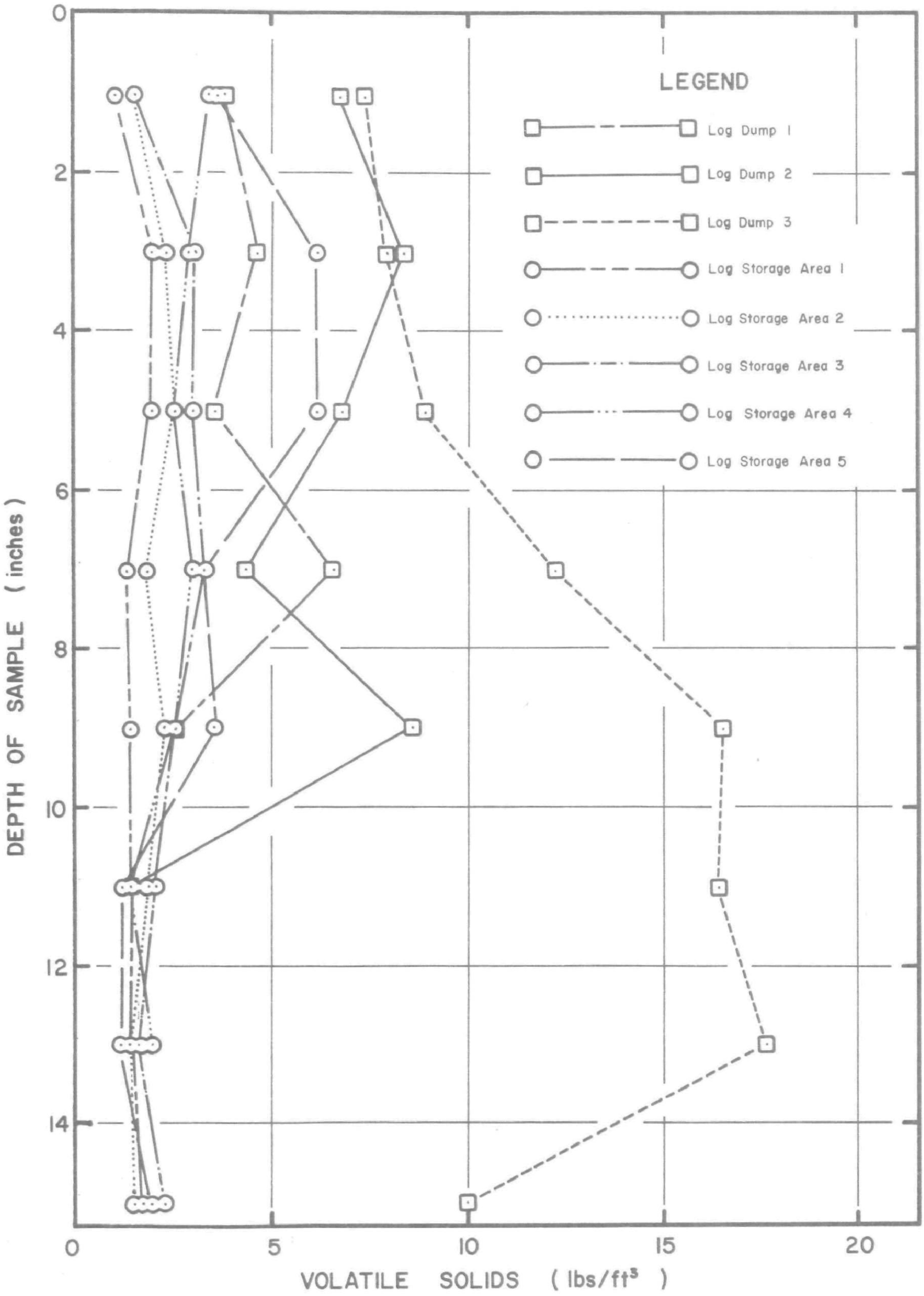


FIGURE 29. Volatile Solids of Benthic Deposits at Selected Sites in the Klamath River.

To characterize a given segment of the benthic zone, the average volatile solids were computed. For each small area sampled the average percentage of volatile solids and the average dry weight were computed for successive 2-inch wafers cut from core samples beginning at the soil-water interface. From these data the average pounds of volatile solids per cubic foot of soil was computed. A complete report of all core test results is given by Williamson (26). Typical results are presented in Table 11. A plot of volatile solids as a function of depth is shown in Figures 28 and 29. The control samples noted in Figure 28 had volatile solids values ranging from 2 to 3 pounds per cubic foot. These volatile solids were probably contributed by biological growth in benthic deposits and volatile portions (humus) of the soil.

Figure 28 shows an average increase of 0.1 to 2.8 pounds of volatile solids per cubic foot for samples from the log storage area over samples from the control area. The average of the increases is approximately equal to two pounds of volatile solids per cubic foot. In the log dumping area, increases from 1.9 to 3.8 pounds of volatile solids per cubic foot over the control samples are shown with an average increase of approximately 2.5 lb VSS/cu ft.

Figure 29 shows an average volatile solids content in the log storage areas of approximately two pounds per cubic foot at the Klamath River site. No control samples were taken because no area could be found which was not affected by log rafting. Since the soil is of volcanic origin, the background volatile solids content from soil humus would probably be small. A large algae bloom does occur, however, in the upper Klamath River, which could add some organic matter to the benthic zone.

The volatile solids in the log dumping areas at Klamath River sites averaged about six pounds per cubic foot for the first six inches of depth. This is an increase of approximately four pounds of volatile solids per cubic foot over the log storage areas. At Yaquina Estuary an increase in volatile solids of only 0.5 lb/ft^3 was found for the log dumping areas over adjacent log storage areas.

The large difference in bark distribution between the two study areas is probably due to swifter moving water at Yaquina Estuary as compared to the Klamath River. In the Klamath River the debris would tend to stay in the log dumping and storage areas after sinking, whereas at the Yaquina Estuary the tides would tend to redistribute the sunken debris over a wide area.

The curve in Figure 29 corresponding to the log dumping area on the Klamath River, shows a volatile solids content of approximately 15 lbs/cu ft for samples taken from a depth of 6 to 16 inches. Visual observation revealed that this sample was nearly 100 percent bark. The volatile solids content of bark alone would vary, however, depending upon stage of decomposition.

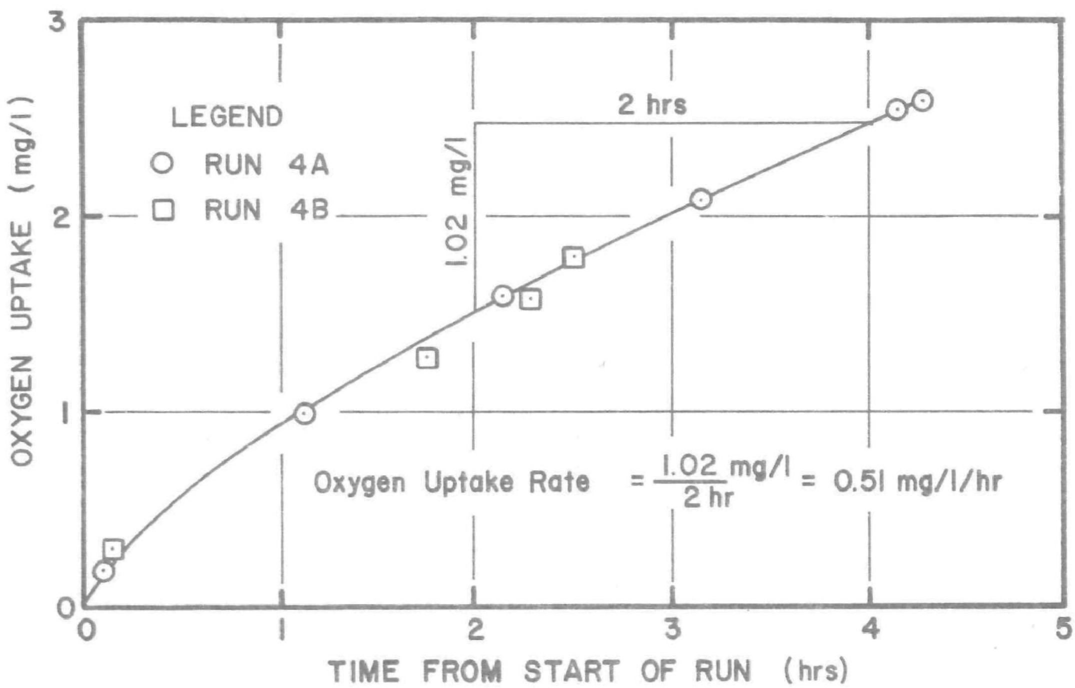


FIGURE 30. Insitu Benthic Oxygen Demand Results for Two Respirometer Runs at the Same Test Site on the Little Deschutes River near Gilchrist, Oregon.

Benthic Oxygen Uptake

The rate of oxygen consumption by benthic bark deposits was evaluated at four locations in central and western Oregon. Ponderosa pine logs were stored at the two interior locations and Douglas fir was the predominant species stored at the coastal sites.

Oxygen uptake readings as mg/l O_2 were recorded continuously during each test run and test results were plotted as shown in Figure 30. Using these plots together with the volume enclosed by the respirometer and the planar surface area covered by the respirometer, values with units mg O_2/m^2/day were calculated. Following each experimental run (2 to 8 hours duration), the respirometer was removed and core samples were taken at the exact location of the respirometer emplacement. The top two inches of the cores were tested for volatile solids content. Experimental runs were conducted in areas containing different amount of bark in the benthic deposits. Control areas, with little or no bark in benthic deposits were also tested.

Volatile solids values and oxygen uptake readings were modified by subtracting comparable values from control samples. The results summarized in Table 12 represent the averages of several runs at each different location. The volatile solids and oxygen uptake values for the control areas indicate the presence of biodegradable organic matter from sources other than log storage activities. These sources could include dead and living organisms, debris washed from the watershed, man-made wastes and others.

Figure 31 is a plot of oxygen uptake versus volatile solids content of benthic deposits, corrected for the contribution from control samples. The curve shows that as the concentration of volatile solids increases, oxygen uptake increases up to approximately 2 to 2.5 g O_2/m^2/day. These values can be compared with the results obtained by Steiñ, et.al. (25) for cellulose deposits in the vicinity of pulp mills. They found uptake values of 3.6 g O_2/m^2/day, however, they did not relate their uptake readings to the volatile solids content of the benthic samples. They also discovered that benthic oxygen demand is related only to the surface area of the deposit and not to the depth. Therefore, very deep undisturbed deposits are no more of a problem from an oxygen depletion standpoint than are shallow deposits.

Table 12. *In Situ* Benthic Oxygen Uptake as a Function of Volatile Solids Content in the Top Two Inch Layer of Bark Deposits

Run No.	Location	Species of logs	Volatile solids (g/cm^3)		Oxygen uptake (g/m^2 -day)	
			Average of top 2"	Increase above control values	Average	Increase above control values
Control	Bend	Ponderosa pine	0.009	----	0.25	----
1	"	"	0.026	0.017	0.79	0.54
2	"	"	0.048	0.039	1.0	0.7
3	"	"	0.084	0.075	1.7	1.5
Control	Gilchrist	Ponderosa pine	0.009	----	0.40	----
4	"	"	0.089	0.080	1.7	1.3
5	"	"	0.083	0.074	1.8	1.4
6	"	"	0.136	0.127	3.2	2.8
7	"	"	0.150	0.141	2.6	2.2
Control*	N. Fork Coos River	Douglas fir	0.013	----	1.9	----
8	" "	"	0.046	0.023	3.0	1.1
9	" "	"	0.079	0.056	4.4	2.5
Control	S. Fork Coos River	Douglas fir	0.018	----	1.7	----
10	" "	"	0.032	0.014	2.6	0.9
11	" "	"	0.030	0.012	3.8	2.1
12	" "	"	0.032	0.014	2.3	0.6
13	" "	"	0.031	0.013	2.3	0.6

*Average of five runs

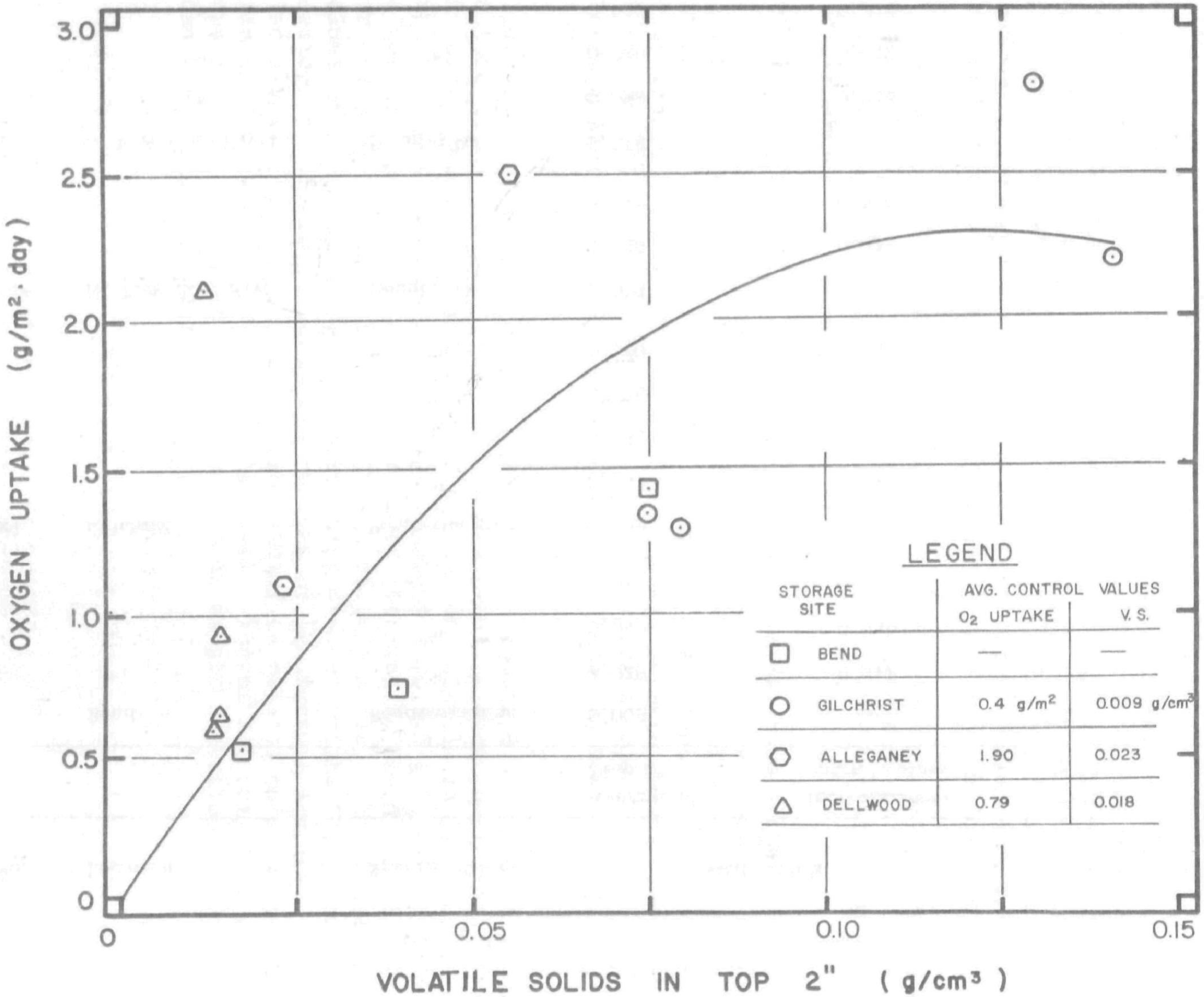


FIGURE 31. Benthic Oxygen Demand as a Function of Volatile Solids. (all values corrected for corresponding control area values)

Part III: Comprehensive Field Studies

Introduction

During the initial phases of this research investigation, apparatus and procedures were developed for the prediction of pollution from log storage activities based upon the quantity of logs in water storage, length of storage period, and the hydraulic characteristics of the body of holding water. All experimental results were reported with units which could be directly extrapolated for field application. In order to determine the reliability and validity of the predictive information, field studies were conducted at four log storage sites: one in central Oregon near Bend, on the Deschutes River; another south of Bend on the Little Deschutes River; and the third and fourth on the north and south forks of the Coos River in western Oregon. Ponderosa pine logs were stored at the interior sites whereas Douglas fir and hemlock logs were stored on the Coos River. The quantity of logs in storage and approximate length of storage period were determined through cooperation with the appropriate mill personnel at the various sites and by direct measurement. Hydraulic flow data were determined at each site with current meters and flow cross-section measurements; water quality measurements were made on samples taken upstream and downstream of the log storage sites.

Log Volume-Area Relationship

All leachate data (with the exception of toxicity) taken during the developmental phases of this study are reported in the units, grams of pollutant leached per square foot of log area submerged. Therefore, for extrapolation of this information to field application, the degree of log submergence had to be determined. This was accomplished by taking numerous field measurements of logs at different stages of storage. Depth of submergence was measured with a steel ruler and expressed as percentage of diameter submerged. Results of measurements on Douglas fir and ponderosa pine logs are presented in Table 13. Freshly dumped fir logs were found to be submerged up to 66% of their diameter, whereas similar logs stored for more than 30 days were only 70% submerged. Ponderosa pine logs, held in water over 30 days, were found to be approximately 69% submerged.

Since the timber industry generally uses board feet as an expression of log volume held in storage, a relationship had to be developed between board feet stored and square feet of raft area. This was done using log scaling notes from the timber industry and the Scribner log rule (5).

Then by combining the log submergence data with the log surface area-volume information, a reasonable estimate could be made of log area submerged per 1,000 board feet stored. A summary of these calculations is given in Table 14.

Table 13. Percentage of Log Submergence in Water (Based on Diameter)

Parameter	Douglas fir (freshly dumped)	Douglas fir (stored for an extended period)	Ponderosa pine (stored for an extended period)
Number of logs measured	118	323	278
Mean ($\bar{X}$)	66.0%	70.5%	69.0%
Standard deviation	46.8	70.4	117.2
95% confidence limit	64.8 - 67.2	69.6 - 71.4	67.7 - 70.3

Table 14. Statistical Data for Raft Volume-area Parameters

Species	Board ft/sq ft of raft area	End area submerged/1000 bd ft (ft^2)	Cylindrical area submerged /1000 bd ft (ft^2)
Douglas fir			
mean ($\bar{X}$)	4.8	7.2	249.0
no. of observations	5	5	5
standard deviation	0.61	0.42	10.8
95% confidence interval	4.1 - 5.6	6.6 - 7.7	235.6 - 262.4
Ponderosa pine			
mean ($\bar{X}$)	7.2	6.5	157.1
no. of observations	4	4	4
standard deviation	0.85	0.48	67.10
95% confidence interval	5.9 - 8.6	5.7 - 7.3	50.2 - 264.0

Gilchrist Lake

The first comprehensive field study was undertaken on the Little Deschutes River near Gilchrist in central Oregon. Ponderosa pine logs were stored in a small reservoir created by a dam on the river. Logs have been stored for many years at this site which has resulted in a benthic accumulation of bark debris in various stages of degradation. However, since 1969, all logs stored at this site have been completely debarked prior to dumping, consequently, very little bark now enters the reservoir from log handling activities. No attempts have been made to remove existing bark deposits. The volume of the reservoir was determined by depth measurements to be about 8.7 million cubic feet.

Flow in the Little Deschutes River during the study period (June 19 to 29, 1970) was measured with a Pygmy current meter at a control section in the stream. Average flow during the sampling period was 46.5 cfs (30 mgd) which corresponded to a theoretical hydraulic detention time of 52 hours. A plot of measured flow during the test period is shown in Figure 32. A Rhodamine dye tracer was added at the inlet end of the pond to determine the actual detention time. Results of the dye dump plotted in Figure 33 show a peak dye concentration in the reservoir outlet of 23 hours after injection at the inlet. This is 0.6 of the theoretical detention time. Even though some short circuiting of flow was noted, it was not judged to be critical for subsequent water quality measurements.

Grab samples were taken daily at six intermediate stations within the reservoir. In addition, samples were collected every four to six hours at the inlet and outlet ends of the reservoir. Samples were analyzed for BOD, COD, PBI, and total organic carbon. Results of tests on samples taken within the reservoir indicated that the reservoir was nearly completely mixed. The inlet and outlet sample data were used to measure the contribution of pollutants from the stored logs. Analytical results are shown in Tables 15 and 16.

The predicted quantity of pollutants based upon the equation developed during the laboratory leaching studies (see Appendix D) is also included in Table 16. An estimated 70,000 board feet of peeled ponderosa pine logs were held in storage for a mean storage period of 30 days. Based upon this input information, the following values were calculated: COD, 18 lbs/day; BOD_5, 4 lbs/day; PBI, 40 lbs/day; and TOC, 8 lbs/day. Assuming a mean flow rate through the storage area of 46.5 cfs, the concentration of pollutants leached could be calculated to be BOD, 0.01 mg/1, COD, 0.06 mg/1; PBI, 0.16 mg/1; and TOC, 0.03 mg/1.

It is readily apparent from Table 16 that a considerably higher quantity of pollutants were measured in the system than were predicted from laboratory studies. This can be accounted for by the extreme difficulty in measuring BOD, COD, PBI and TOC at low concentrations, and in obtaining consistent values at each sampling point during the sampling period. First, BOD values below 1.0 mg/1 have questionable significance. Furthermore, the average influent BOD value was 0.25 with a standard deviation

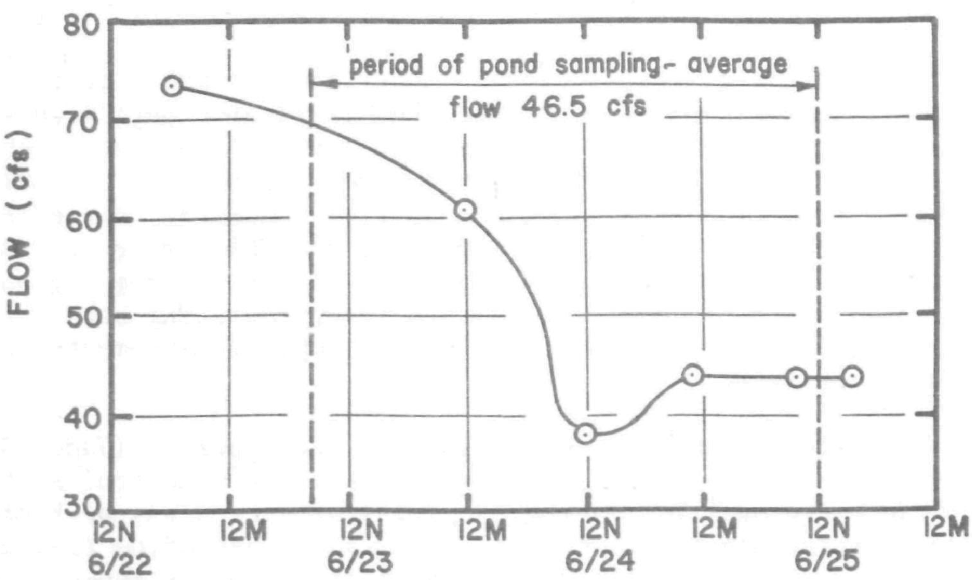


FIGURE 32. Little Deschutes River Flow Curve Upstream from Gilchrist Pond.

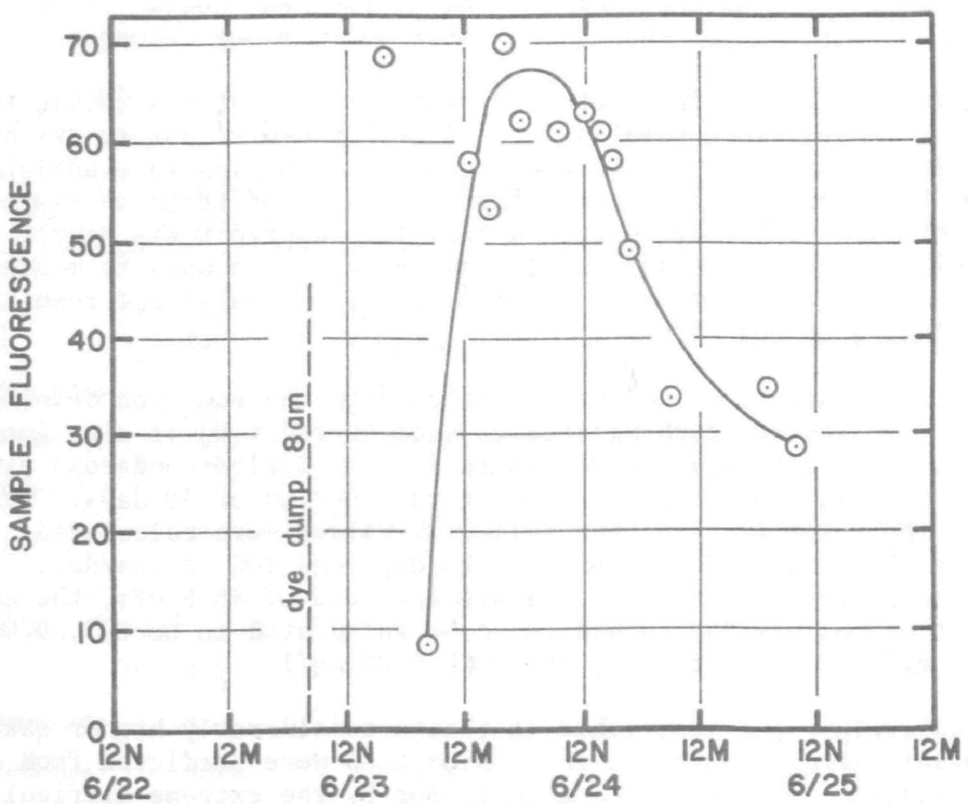


FIGURE 33. Results of Dye Tracer Study at Gilchrist Pond.

Table 15. Measured Concentration of COD, BOD, PBI and TOC at the Inlet and Outlet of the Gilchrist Log Storage Site

	COD, mg/1		BOD, mg/1		PBI, ppm SSL (10% solids)		TOC, mg/1	
Date	inlet[1]	outlet[2]	inlet	outlet	inlet	outlet	inlet	outlet
6/23/70	5.4	8.5	0.4	1.9	0.18	---	3	9
6/24/70	14.2	----	0.1	0.8	----	1.45	14	--
	4.8	14.7			1.00	2.09	4	16
	12.1	7.6	0.2	1.5	2.30	1.21	3.5	12.3
	5.2	----	0.3	0.8	6.76	25.3	5	25
		----			2.30	---	4	16
6/25/70	8.7	----					2	4
	8.3	----			1.87	11.23	5	25
	13.5	14.0			2.00	2.37	3.5	12
	5.7	5.4					3.5	12
Mean	8.7	10.0	0.25	1.25	1.61	1.78	3.7	4.7
Std. dev.	3.7	4.1	0.13	0.55	0.83	0.54	0.95	1.87

[1] Inlet samples taken at 4 hour intervals

[2] Outlet samples taken 30 minutes after inlet samples

Table 16. BOD, COD, PBI and TOC in Inflow and Outflow from Gilchrist Log Storage Reservoir

Pollution index	Inflow mean concentration mg/1	Outflow mean concentration mg/1	Measured increase		Predicted increase	
			mg/1	lb/day[2]	mg/1	lb/day
BOD	0.25± 0.13	1.25± 0.55	1.0	250	0.02	4
COD	8.7± 3.7	10.0± 4.1	1.3	325	0.07	18
PBI[1]	1.6± 0.83	1.8± 0.54	0.2	50	0.16	40
TOC	3.7± 0.95	3.9± 1.87	0.2	50	0.03	8

[1] PBI is expressed as ppm SSL (10% by weight)

[2] lb/day based on a flow of 46.5 cfs (30 mdg)

of 0.13 mg/l and the mean effluent concentration was only 1.25 mg/l with a standard deviation of 0.55 mg/l. Therefore, with this spread of data, the 1.0 mg/l difference in BOD must be considered insignificant. However, when 1.0 mg/l is multiplied by the flow of 46.5 cfs, a large daily BOD contribution (540 lbs) is calculated; yet only four pounds of BOD were expected in the leachate per day. Similar reasoning can be applied to explain the variation in PBI, COD, and TOC results.

Perhaps a closer comparison in results could have been obtained if more logs would have been held in storage or the flow rate would have been reduced substantially. Regardless of which values are used, it is important to note that the storage of peeled ponderosa pine logs in this particular situation did not have a significant effect on the quality of the holding water, even though a slight increase in pollutant level was detected.

Deschutes River Storage

The second log storage area studied was on the Deschutes River near Bend, Oregon. Approximately 2.5 million board feet of ponderosa pine logs were stored in the river in the area under study. Most of the bark remained intact on the logs. River flow was measured to be 1,360 cfs during the study period.

Water samples were collected immediately upstream and downstream from the storage area at six to eight hour intervals for three days. Samples were analyzed for BOD, COD, PBI and TOC. Average results from eight samples at each site are shown in Table 17. The predicted contribution of pollutants is also given in Table 17. Refer to Appendix D for computation of predicted leachate values.

These results clearly show that the quantity of pollutants picked up by log storage was not detectable within the limits of test accuracy and sample variability. The average BOD values for influent and effluent samples were exactly the same. Again, when trace concentrations are multiplied by very large flows, a considerable number of pounds are calculated. Therefore, it appears more reasonable to determine the quantity and species of logs in water storage, then predict the effect on the holding water, rather than rely upon direct water quality measurements.

Coos Bay Study

The final log storage sites selected were on the north and south forks of the Coos River in western Oregon. Douglas fir and hemlock logs with bark intact (except for that lost during dumping and raft transport) were held in rafts for one or more days. The rafts were then taken by tug to the lower bay for processing. The log storage areas were in the upper tidal water, very near to the free flowing streams. Therefore, the log

Table 17. BOD, COD, PBI and TOC in Inflow and Outflow from the Log Storage Area on the Deschutes River

Pollution index	Inflow concentration mg/l	Outflow concentration mg/l	Measured increase		Predicted increase	
			mg/l	lb/day[2]	mg/l	lb/day
BOD	1.9± 0.5	1.9± 0.5	0	0	<0.01	50
COD	6.0± 1.6	6.5± 1.6	0.5	70	<0.01	110
PBI[1]	2.2± 2.17	3.9± 0.99	1.7	220	<0.01	40
TOC	0.1± 0.15	1.1± 1.4	1.0	130	<0.02	360

[1]PBI is expressed as ppm SSL (10% by weight)

[2]lb/day is based on a flow of 1360 cfs (880 mdg)

holding water moved both up- and downstream during each tidal cycle, with some net movement downstream due to stream inflow. This tidal fluctuation, combined with the large volume of fresh water inflow, greatly complicated the direct measurement of differences in water quality upstream and downstream from the rafted logs.

Predicted values for the logs stored in the North Fork area are given in Table 18 and those for the South Fork are given in Table 19. Supporting calculations are included in Appendix D.

Results shown in these tables reveal that less than 1.0 mg/l of all pollution indices measured were added to the log handling water. Since this quantity is too small to verify by field measurement, especially in a situation in which the stream and tidal hydraulics are complicated, only limited effort was made to determine the "actual" impairment to water quality from the log rafts. The direct measurements that were made proved to be widely variable, and in some instances showed a decrease in pollutant level during water passage through the log storage area.

Benthic oxygen demand determinations were made at several points in and around the log storage areas. Values of 1.7 to 3.8 g O_2/m^2/day were determined for the south fork storage area, whereas values ranged from 1.9 to 4.4 g O_2/m^2/day for the north fork storage site. A summary of oxygen uptake values is given in Table 12. Assuming an average demand of 3.0 g O_2/m^2/day and a log storage area of 200 meters by 20 meters (4,000 m^2), the total demand for oxygen would be 12,000 grams or 26.5 lbs per day. With a stream flow of 20 mgd, the resulting depletion of dissolved oxygen from the overlying water would be only 0.16 mg/l. This deficit could not be determined by conventional analytical methods used in the field.

Table 18. Predicted Increases in BOD, COD, PBI and TOC from the Log Storage Area on the North Fork Coos River

Pollution index	mg/1[2]	lb/day
BOD	0.20	33
COD	0.69	112
PBI[1]	0.54	86
TOC	0.27	43

[1]PBI is expressed as ppm SSL (10% by weight)

[2]Concentration is based on a flow of 30 cfs (19.4 mgd)

Table 19. Predicted Increases in BOD, COD, PBI and TOC from the Log Storage Area on the South Fork Coos River

Pollution index	mg/1[2]	lb/day
BOD	0.09	12
COD	0.30	40
PBI[1]	0.62	83
TOC	0.12	16

[1]PBI expressed as ppm SSL (10% by weight)

[2]Concentration is based on a flow of 40.3 cfs (26.0 mgd)

Part IV: Magnitude of the Problem

One of the specific aims of this research program was to survey the magnitude of the pollution problem in the Pacific Northwest resulting from log handling and storage. Such a survey requires the active participation of saw mills, pulp mills, and other industries which utilize raw timber. Several attempts were made to organize this survey through various timber industry associations, without success. The industry was found to be reluctant to divulge information regarding log inventories, length of storage and conditions for storage. Perhaps as state and federal pollution control authorities press for tighter control of all pollution discharges, information of this type will become more readily obtainable. Some semi-quantitive information was obtained, however, during visits to the states in the Northwest region which have log storage problems.

Oregon

Several species of timber including Douglas fir, ponderosa pine, white pine, hemlock and cedar are harvested in Oregon. Nearly one-half of the 5000 manufacturing firms in the state depend upon this timber resource (19). Furthermore, the 400 billion board feet of raw timber produced in Oregon ranks as the largest single state output in the nation.

Large inventories of logs are held in lakes, rivers, estuaries, and man-made ponds. Oregon has over 12,000 acres of log ponds and 2,000 acres of sloughs and canals used for log storage (18). In some areas of the state the Department of Environmental Quality has required that all logs be peeled before storage in a water course. Land storage of logs, with and without sprinkling, is also widely practiced.

Washington

Vast quantities of logs are stored in rivers, lakes, estuaries, and man-made log ponds in the state of Washington. Land storage of logs is also widely practiced. No estimate was obtainable regarding the quantity and species of logs stored.

California

California officials in Sacramento indicate that little, if any, water storage is permitted in the northern California timber regions. Most all logs are held in cold decks on land.

Alaska

There are only two major log storage sites in Alaska at the present time. These are located near Sitka and Ketchikan. Logs are primarily held in saline water bays and estuaries. The logs are strapped into bundles, then the bundles are rafted for transport and storage. No attempt was made in this investigation to study the effect of bundling on the loss of bark, however, this procedure should reduce bark losses. Furthermore, it is likely the rate of leaching and benthic oxygen uptake rate would be reduced in the very cold Alaskan waters.

DISCUSSION

Storage of vast quantities of logs is extremely important to the timber industry in the Pacific Northwest due to the prevailing regional weather pattern. Timber cutting and overland hauling activities are essentially limited to the dry summer and fall months. Heavy winter and spring rains and snows restrict field activities. Yet, production at saw mills, pulp mills, and other forest products industries must continue throughout the entire year.

Logs can be stored on land or floated in rafts in rivers, lakes, or man-made ponds. Logs which are not kept moist soon dry out at the ends and cracks develop. This phenomenom referred to as "checking" enhances insect attack and results in extensive wastage of the resource. Logs stored upon dry land can be sprinkled to retard checking.

The presence of logs in water can cause several problems. Log rafts frequently cover large areas of streams, lakes and estuaries which have other benefical uses such as boating, fishing, crabbing, etc. Some logs become water soaked, escape from the raft and float partially submerged in the water course creating a hazard to boaters. Other logs sink and accumulate on the bottom of the water course. There is also some objection to the presence of rafted logs for aesthetic reasons. Two other problems are associated with log storage which perhaps are not so obvious but are of concern i.e., the quantity and effect of substances which leach (or dissolve) out of the logs and the bark which is dislodged from the logs. These latter two problems were dealt with in detail in this research investigation.

Leachates from logs in water storage contained mostly organic substances which exert both a chemical and biochemical oxygen demand (COD and BOD). This organic chemical composition was also shown by the fact that 60 to 80 percent of the solids leached were volatile. The tannins and lignin-like substances added a brownish color to the leachates and were quantitated by the Pearl Benson Index (PBI). Even though these substances are not known to be injurious to aquatic organisms or humans, the added color is often aesthetically undesirable.

Laboratory results with 20-inch long log sections of ponderosa pine and Douglas fir logs showed that when logs are held in stagnant, non-flowing systems, leachates emerge at a relatively constant rate for up to 80 days. However, when water is passed by the logs in a flow-through system the initial leaching rate is substantially higher but declines after 20 to 30 days. No studies were attempted at the high flow rates experienced in some natural streams and estuaries. Apparently, a concentration gradient builds up around the logs in a static system which retards the rate of leaching. This gradient would not likely exist in free flowing systems.

The leaching rates determined in this study are absolute rates, and as such would tend to be conservative. In actual field situations where microbial biodegradation of leached substances would take place, the measured amount of BOD, COD, solids, etc., would generally be less than predicted. This was found to be the case with log pond waters. Log pond waters tested generally had much lower BOD to COD ratios than would have been predicted from the leachate studies in which biological activity was arrested with chemical poison. This low ratio resulted since only biodegradable substances are measured by the BOD test whereas both biodegradable and non-biodegradable organic substances are measured in the COD test.

The technique developed during this investigation for poisoning samples then depoisoning at a later time for biological analyses such as BOD and acute toxicity could be applied to many other types of experiments and for routine sample preservation (21).

Experimental data shows that more color-producing and soluble organic substances were leached from ponderosa pine logs than from comparable Douglas fir logs. This observation is consistent with the findings reported by Kurth, et.al. (17). They found that the leachates extracted from pine bark contain nearly ten times more soluble sugar than the extracts from Douglas fir.

As expected, log sections with bark intact imparted much more color to the water than pine with the bark removed. Bark is known to contain many water soluble extraneous components, including tannins and lignin-like substances which can produce color. The exposed cut ends of the logs tend to expedite the release of color and soluble organics. A comparison of data shown in Figure 12 for unaltered test logs with those for logs with ends sealed clearly illustrate this fact. This observation was not unexpected since the physiological flow pattern of water and nutrients is longitudinally through a living tree.

Leaching rate does not appear to be affected by saline water as shown by COD results in Figure 17a. A significantly smaller value for PBI did result in saline water, however. This may be explained by the precipitation of lignin-like substances which have a net positive surface charge, through the formation of a complex with chloride ions present in high concentrations in the saline water. Andrews (2) observed this phenomenom during his study of the fate of color in kraft waste when discharged into sea water.

Log leachates were found to be relatively non-toxic to salmon and trout fry during exposure periods of up to four days. Similar observations have been reported by Servizi (22) for leachate from bark using adult sockeye salmon as the test fish.

Only trace amounts of nitrogen and phosphous were found in the log leachates. This is understandable since ponderosa pine and Douglas fir contain very small amounts of these nutrients.

Results from brief laboratory and field studies on runoff from sprinkled cold decks showed that this water leaches soluble organics from the logs as it trickles across the log surfaces. Consequently, cold deck runoff will probably require some form of treatment prior to discharge into a receiving body of water. An alternate solution would be to form a closed recycle loop and avoid discharging the polluted water.

Loss of bark from logs during storage is related to the species of timber and the method of log handling. Ponderosa pine bark tends to adhere more tightly to the wood surface than does Douglas fir bark. Consequently, fir logs would be expected to lose more bark than pine under similar handling conditions. This hypothesis was verified by direct field measurement. Approximately 22% of the bark was lost from Douglas fir logs during unloading and transport compared to only 6% for ponderosa pine. Similarly, Douglas fir logs lost 18% of their bark during felling operations and truck loading compared to less than 6% for ponderosa pine.

The rate at which barks sinks when placed in water is a function of bark density, water absorption rate and particle sizes. Laboratory studies on ponderosa pine bark revealed that all particles less than 1/2-inch in mean diameter sank within 20 days whereas only 3% (by weight) of the bark pieces 4 inches or larger sank during this period. Generally, a large fraction of dislodged pine bark is in the small size classification which would result in a high overall rate of sinking. Sinking studies on bark samples collected at random near log dumps verified that overall, on a dry weight basis, pine bark tends to sink at a faster rate than Douglas fir bark.

Sunken bark accumulates on the bottom of holding water systems to form benthic deposits. Bark deposits were found to range in thickness from several feet at log dumping sites to less than an inch in adjacent log storage sites. Since some bark floats for a period of time, it can be carried considerable distances with prevailing currents before sinking. Consequently, bark can be found in benthic deposits at locations far removed from the dumping and storage areas. Volatile solids measurements on core samples revealed an average increase of 2 to 2.5 pounds of volatile solids per cubic foot in log storage areas compared to samples from control areas (without log handling).

The presence of bark in the benthic deposits could result in several problems. Bark is a form of biodegradable organic matter which when undergoing biodegradation results in the consumption of dissolved oxygen from overlying waters. Fortunately, the rate of bark decomposition is very slow due to its complex chemical composition and to the low water temperatures at many storage sites. This low rate was shown by *in situ* benthic respirometric measurements in log storage and control areas. The maximum oxygen uptake values found ranged from 2 to 2.5 g $O_2/m^2/day$ greater than control values and the rate appeared to be independent of depth of deposit. It is apparent from these results that benthic oxygen demand will only become a significant problem in situations where an extensive area of a water body is covered with bark and/or the hydraulic flow is very small. Such conditions could be found in lakes, sloughs, and man-made ponds. Davison and Hanes (4) have also found that oxygen uptake rate is independent of depth for compacted sludge deposits.

Since the quantity of substances leaching from logs in water storage is, in general, minute when diluted with the large hydraulic flows found in many water courses used for storage, it is virtually impossible to detect an increase in pollutant level due to the logs. The recommended procedure for evaluating the impact of log storage on water quality is to apply the predictive equations developed in this study. Several unsuccessful attempts were made in the field to directly measure an increase in pollutatnt load resulting from water storage of logs. This is not to infer that log storage does not add pollutants to the holding water, but only that the input from leaching is generally small. Dislodged bark is another matter. Methods for controlling bark losses must be developed and implemented, such as improved methods of depositing logs into the holding water. Debarking of logs prior to water storage has been successfully used at several locations in Oregon and could possibly be applied in other situations. Banding logs in bundles may be another effective method for reducing bark losses.

Based upon the information generated in this three-year investigation, it appears that the widely practiced water storage of logs does not have a severe impact on water quality in the Pacific Northwest. Improved methods of handling logs during dumping, rafting and transport could significantly reduce bark losses and thereby prevent the build up of benthic deposits. Research is currently being conducted by this investigator to evaluate the effects of bark deposits on aquatic organisms.

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The principal project investigator was Frank D. Schaumburg, Associate Professor of Civil Engineering, Oregon State University, Corvallis, Oregon 97331.

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APPENDIX A

DEVELOPMENT OF MASKING PROCEDURES

Soluble leachates from logs immersed in water emerge from both the cross-cut ends and the cylindrical surface of the logs. Evaluation of the relative contribution from each of these types of surface was accomplished by masking the cross-cut ends of some of the log section to prevent leaching through the ends. The procedures followed in the selection of an appropriate masking substance and subsequent application of the substance are described below. Four commercially available products were tested as sealants or masking agents. These included: (1) Teflon spray supplied by Connecticut Hard Rubber Co., New Haven, Connecticut; (2) Epoxy sealer supplied by Travaco Laboratories Inc., Chelsea, Mass.; (3) Paraffin wax supplied by Union Oil Co. of California; and (4) silicone lubricant supplied by Dow Corning Corp., Midland, Michigan. The effectiveness of each product was evaluated by total carbon determinations of log holding water. Other important factors considered were: ease of application, durability, sealing quality and product cost. The first experiment involved a determination of the contribution of carbonaceous substances to the holding water by each sealant. Plexiglas blocks, 1/8" thick and 0.4 ft^2 were used as the base material for the sealants, since no measurable quantities of organics leach from plexiglas. Each sealant was applied to individual pieces of plexiglas and allowed to harden. Two blocks of epoxy sealer were prepared, one air-dried, the other oven-dried for 3 hours at 103°C. All blocks were then immersed in 1000 ml beakers containing 850 ml of distilled water.

Two mg/l of mercury (as Hg^{++}) was added to the water in the form of a solution of mercuric chloride ($HgCl_2$), to prevent any interference from biological growth. The water temperature was held at 20°C $\pm$ 0.5 throughout the experiment. Samples were taken from each beaker and tested for total carbon content.

The total carbon data given in Table 20 for the plexiglas blocks showed that the silicone grease contributed the least carbonaceous material. The other sealants, listed in order of increasing total carbon contribution, were paraffin, Teflon spray, oven-dried epoxy sealer and air-dried epoxy sealer.

The second experiment was designed to determine the sealing quality of each product. Several uniform cubical blocks were cut from the same Douglas fir log. The total surface area of each block was approximately 0.73 square feet. Each of the four sealants was applied to a separate block so that the surface was completely covered. Each block was completely immersed in 1500 ml of water poisoned with 2 mg/l Hg^{++} and held submerged by a clamp. An unsealed control block was also prepared and handled in the same manner. The temperature was held at 20°C $\pm$ 0.5 throughout the experiment. Samples taken from each beaker were analyzed for total carbon content.

Table 20. Total Organic Carbon (TOC) in Leachate from Plexiglas Blocks and Wood Blocks Coated with Different Masking Substances.

Plexiglas Blocks

Time (hours)	Mg TOC/ft² of surface area submerged					
	A	B	C	D	E	F
0	0					
24	30.3	70.5	25.4	39.2	25.4	23.5
96	6.9	109.		7.9	38.2	36.2
154	5.9	95.0	27.4	8.8	18.6	45.0

Wood Blocks

Time (hours)	Mg TOC/ft² of surface area submerged			
	A	B	C	D
0	0			
31	171	34.3	16.4	37.3
72	243	38.0	16.2	61.5
120	280	29.8	15.1	62.8

A - Uncoated control

B - Epoxy sealer - air dried

C - Paraffin

D - Silicone grease

E - Teflon

F - Epoxy sealer - air dried

Total carbon data for the wood blocks showed that the greatest total carbon contribution was from the block sealed with silicone grease, and the least contribution was from the paraffin-coated block. The total carbon value of the epoxy sealed (air-dried) block after five days immersion was approximately 30 mg/ft^2 or about twice that of the paraffin covered block for which the TOC value was about 15 mg/ft^2.

Teflon spray was eliminated from practical, full scale application because it was non-viscous and failed to seal the cracks in the wood block.

The total carbon contribution of the epoxy sealer compared favorably with the other products only after pre-drying in an oven. Since this method of drying was not practical for the large log sections and because of the possible detrimental effect it could have on the leaching characteristics of the logs, the epoxy sealer was eliminated from consideration.

The total carbon data for the wood block indicated that the silicone grease did not seal effectively. A possible explanation for this is that the silicone grease remained in a highly viscous state and therefore was easily displaced when the sample was handled. This problem could probably have been reduced by covering the sealed area with a plexiglas sheet, but this was not a practical solution considering the time and materials involved.

Paraffin was chosen as the most desirable sealer because it satisfactorily met the requirements of low carbon contribution to the surrounding water, excellent sealing quality, ease of application and relatively low cost. Paraffin sealant was applied by dipping the end of each log in liquid paraffin and allowing it to solidify onto the appropriate wood surface. A double boiler arrangement was used to melt the paraffin and to keep it at a constant temperature of 60°C during application. While the paraffin was cooling on the log, any bubble present was rubbed away by hand. This process was repeated until a coating of paraffin approximately 1/4-inch thick was secured on the log end.

APPENDIX B

LEACHATE PRESERVATION WITH THE MERCURIC ION

Many substances which leach from logs during water storage are biodegradable. Since non-sterile systems were used in these studies, bacteria and other microorganisms were very likely present in the holding water, in the test tanks and on the log sections. Consequently, organic substances which leached into the log holding water were subject to biodegradation before qualitative and quantitative measurements could be made. The rate of leaching measured would have been the net result of addition of leachate minus losses due to biodegradation.

Several methods were considered for the preservation of organic substances during leaching tests which lasted from 4 to 40 days, including alteration of pH, heat sterilization, organic toxicants, and heavy metal toxicants. Only the heavy metal toxicants appeared feasible since the other methods would have affected rate of leaching or the character of leached substances.

Since biological tests such as BOD and toxicity by bioassay, were to be performed on the leachate some procedure was required for complete removal of the toxic agent added during the log storage period. For other chemical tests such as COD, solids, PBI, etc., removal of the toxic agent was not required since there was no interference with the analytical procedures.

Schaumburg (21) describes a sample preservation technique in which the mercuric ion can be added to water samples as a chemical preservative then removed by chelation prior to biological analyses such as BOD or acute bioassay. This sample preservation method was used in this study to prevent biodegradation of organic substances which leached from logs floating in water. The mercuric ion was added to test tanks filled with tap water and holding submerged log sections. Following a storage period of seven days, samples of the holding water were withdrawn and the mercuric ion was removed by selective chelation. Samples were then analyzed for BOD and acute toxicity.

In order to verify the effectiveness of the chelating agent in removing mercury from aqueous solution a bioassay experiment was performed using chinook salmon fry as test fish. Twenty liters of the Oak Creek water used for rearing test fish was allowed to stand quiescent for seven days after which time, the mercury was removed by chelation. Three grams per liter of chelex 100 (50 mesh) size was mixed with the poisoned water for 30 minutes. The resin was then allowed to settle out during a 60 minute holding period. Supernatant water was tested for acute toxicity by the standard bioassay procedure (1). Results showed that all ten test fish died in a control sample containing 2 mg/l Hg^{++} and <u>not chelated</u>. One fish died in an unpoisoned Oak Creek water control and <u>none</u> of the test fish died during a 96-hour exposure period in the poisoned sample which had been treated with a chelating agent.

This preservative technique was applied in all subsequent experiments in which log leachate was preserved during a seven day holding period then tested for acute toxicity following chelation.

A detailed account of the developmental work leading to the application of this poisoning-depoisoning procedure for bioassay is given by Atkinson (3).

APPENDIX C

QUANTITY OF BARK DISLODGED DURING LOG HANDLING

Douglas Fir Logs on Trucks (Yaquina Estuary)

Slide no.	Total area	Area of bark dislodged		Percent dislodged
1	180.29	31.00		17.19
2	121.99	29.37		24.08
3	152.71	10.19		6.67
4	194.79	13.82		7.09
5	287.40	43.32		15.07
6	215.57	21.13		9.80
7	234.12	30.39		12.98
8	108.35	57.68		43.23
9	218.70	39.63		18.12
10	201.13	21.57		10.72
11	189.78	17.57		9.26
12	259.13	29.91		11.54
13	259.76	20.42		7.86
14	213.69	15.73		7.36
15	206.19	29.88		14.49
16	178.71	6.76		3.78
17	274.43	41.25		15.03
18	249.05	41.28		16.57
19	221.17	69.99		31.65
20	258.27	37.75		14.62
21	264.56	74.90		28.31
22	218.19	41.00		18.79
23	227.58	26.48		11.64
24	255.42	47.71		18.68
25	207.72	47.55		22.89
26	176.26	36.85		20.91
27	188.14	4.04		2.16
28	194.82	13.73		7.05
29	199.06	24.30		12.21
30	173.70	63.52		36.57
31	204.23	94.74		46.39
32	124.40	34.39		67.84
33	209.02	9.35		4.47
34	207.27	8.83		4.26
35	185.44	33.83		18.24
36	166.48	26.04		15.64
37	112.23	23.05		20.54
38	124.17	37.10		29.88
TOTAL	7663.92	1306.05		18.25
			Average Deviation	9.60

Douglas Fir Logs After Dumping (Yaquina Estuary)

Slide no.	Total area	Area of bark dislodged	Percentage dislodged
1	282.65	118.59	41.96
2	248.55	74.29	29.89
3	250.36	65.42	26.13
4	237.46	95.19	40.09
5	205.53	53.18	25.87
6	265.18	113.61	42.84
7	269.27	77.75	28.87
8	272.05	93.66	34.43
9	278.20	111.33	40.02
10	215.30	67.02	31.13
11	223.68	54.56	24.39
12	254.83	117.45	46.09
13	266.64	73.70	27.64
14	292.42	133.04	45.50
15	257.57	77.16	29.96
16	257.72	86.03	33.38
17	213.25	86.52	40.57
18	217.42	84.56	38.89
19	198.07	70.68	35.68
20	214.68	81.33	37.88
TOTAL	4920.83	1735.07	35.06
		Average Deviation	5.89

Douglas Fir Logs After Raft Transport (Yaquina Estuary)

Slide no.	Total area	Area of bark dislodged	Percentage dislodged
1	307.34	121.78	39.74
2	276.44	76.55	27.69
3	252.26	56.47	22.39
4	225.87	95.11	42.11
5	228.21	54.21	23.75
6	200.41	79.57	39.70
7	161.73	115.81	71.61
8	241.92	115.64	47.80
9	243.60	111.52	45.78
10	240.70	108.40	45.06
11	176.31	59.72	33.87
TOTAL	2554.79	994.78	39.95
		Average Deviation	9.57

Ponderosa Pine Logs on Trucks and Trains (Klamath River)

Slide no.	Total area	Area of bark dislodged		Percent dislodged
1	150.54	2.73		1.81
2	124.55	2.86		2.30
3	118.71	3.82		3.22
4	138.30	4.76		3.44
5	143.78	5.12		3.56
6	172.82	12.22		7.07
7	172.62	6.85		3.97
8	144.90	8.19		5.65
9	134.84	8.59		6.37
10	170.78	26.22		15.65
11	170.36	39.60		20.59
12	160.11	8.50		5.31
13	145.50	5.61		3.85
14	145.92	5.24		3.59
15	130.14	5.09		3.91
16	119.58	4.97		4.16
17	160.86	4.92		3.06
18	171.75	9.72		5.66
19	163.30	6.02		3.87
20	128.85	8.77		6.81
21	167.03	4.77		2.86
22	139.44	7.13		5.11
23	128.54	6.30		4.90
24	179.27	7.97		4.45
25	181.32	3.75		2.07
26	107.84	14.77		13.70
27	138.10	4.00		2.90
28	126.60	5.24		4.14
29	148.21	6.75		4.55
30	149.57	6.60		4.41
31	176.42	7.70		4.36
32	137.16	12.34		9.00
33	140.31	8.86		6.32
34	128.32	6.00		4.68
35	140.47	9.55		6.80
36	155.31	14.99		9.65
TOTAL	5334.02	306.52		5.66
			Average Deviation	3.49

Ponderosa Pine Logs After Unloading and Raft Transport (Klamath River)

Slide no.	Total area	Area of bark dislodged	Percent dislodged
1	270.08	15.01	5.56
2	247.61	74.82	30.22
3	282.44	22.19	7.86
4	318.53	47.04	14,77
5	271.49	39.17	14.43
6	266.25	26.52	9.96
7	244.49	22.61	9.25
8	142.08	11.01	7.75
9	252.77	57.64	22.80
10	284.37	36.53	12.85
11	301.59	7.94	2.63
12	223.34	21.90	9.81
13	250.71	43.90	17.51
14	277.70	17.79	6.41
15	243.82	18.16	7.45
16	290.28	33.11	11.41
TOTAL	4167.80	495.34	11.92
		Average Deviation	5.14

APPENDIX D

METHOD FOR EXTRAPOLATION OF LABORATORY TEST DATA FOR FIELD APPLICATION WITH EXAMPLE CALCULATION

Several types of surface conditions are found for logs in water storage which tend to influence the rate at which soluble substances leach from the logs. Some of the original bark is dislodged and lost from logs during dumping and transport activities. The percentage of bark missing depends upon the species of log and the abrasiveness of handling. The presence or absence of bark affects the character and quantity of leachate. There is also a difference in leaching rate between the exposed ends and cylindrical surface of the logs.

All of these conditions were examined in controlled laboratory experiments reported in the EXPERIMENTAL FINDINGS section of this report. The following equation was generated from observed laboratory data for application in field situations:

$$T = [(1-x)(D)(A_c)] + [(x)(C)A_c)] + [(f_1)(B-D)(A_E)]$$

T = total pollutant contribution from field logs (grams)

B = $\dfrac{\text{grams leached from test log (ends unaltered, w/bark)}}{\text{ft}^2 \text{ of cylindrical area}}$ (from Figures 13-16)

C = $\dfrac{\text{grams leached from test log (ends sealed, w/o bark)}}{\text{ft}^2 \text{ of cylindrical area}}$ (from Figures 13-16)

D = $\dfrac{\text{grams leached from test log (ends sealed, w/bark)}}{\text{ft}^2 \text{ of cylindrical area}}$ (from Figures 13-16)

A_E = total submerged end area of field logs (ft^2)

A_c = total submerged cylindrical area of field logs (ft^2)

x = fraction of bark missing from field logs

f_1 = $\dfrac{\text{cylindrical area of test log}}{\text{end area of test log}}$

= 2.66 for Douglas fir test logs

= 2.71 for ponderosa pine test logs

The following calculations demonstrate the application of the leachate equation at four log storage sites in Oregon.

Gilchrist Reservoir Site

Storage Conditions --

1. area of log rafts - 70,000 ft^2 (based on actual field measurement)
2. species - ponderosa pine
3. all logs peeled before storage
4. average length of storage - 30 days

Calculations --

1. board feet = $(70{,}000\ ft^2)\left(\frac{7.2\ \text{board ft}}{\text{square ft}}\right) = 5.04 \times 10^5$ board ft

   See Table 14 for conversion factor

2. A_E - $(504\ \text{M bd ft})\left(\frac{6.5\ ft^2}{\text{M bd ft}}\right) = 3.28 \times 10^3\ ft^2$ of end area submerged

   See Table 14 for conversion factor

3. A_C = $(504\ \text{m bd ft})\left(\frac{160\ ft^2}{\text{M bd ft}}\right) = 8.06 \times 10^4\ ft^2$ of cylindrical area submerged

   See Table 14 for conversion factor

4. Constants B,C, and D from Figures 13, 14 and 15.

Constant	Time Basis	COD g/ft^2	TOC g/ft^2	PBI g/ft^2
B	1/30 d	6.0	2.2	17.0
	1/day	0.20	0.073	0.57
C	1/30 d	2.35	0.8	4.0
	1/day	0.077	0.027	0.13
D	1/30 d	3.55	1.4	12.0
	1/day	0.12	0.046	0.40

5. "f_1" factor - 2.71
6. "x" factor - 1.0 (all logs completely peeled)
7. Solving the leachate equation:

$$T_{COD} = [(1-1)(0.12)(8.06 \times 10^6)] + [(1.0)(0.077)(3.06 \times 10^4)]$$
$$+ [(2.71)(0.08)(3.28 \times 10^3)]$$
$$= 0 + 6.2 \times 10^3 + 0.71 \times 10^3$$
$$= 6.91 \times 10^3 \text{ grams COD leached per day}$$
$$= \underline{\underline{15.2 \text{ lbs COD leached per day}}}$$

$$T_{PBI} = [(1-1)(0.40)(8.06 \times 10^4)] + [(1.0)(0.13)(8.06 \times 10^4)]$$
$$+ [(2.71)(0.17)(3.28 \times 10^3)]$$
$$= 0 + 10.5 \times 10^3 + 1.5 \times 10^3$$
$$= 12 \times 10^3 \text{ grams PBI leached per day}$$
$$= \underline{\underline{26.4 \text{ lbs PBI leached per day (equivalent SSL - 10\% by weight)}}}$$

$$T_{TOC} = [(1-1)(0.046)(8.06 \times 10^4)] + [(2.71)(0.027)(3.28 \times 10^3)]$$
$$+ [(2.71)(0.027)(3.28 \times 10^3)]$$
$$= 0 + 2.18 \times 10^3 + 0.24 \times 10^3$$
$$= 2.42 \times 10^3 \text{ grams TOC leached per day}$$
$$= \underline{\underline{5.3 \text{ lbs TOC leached per day}}}$$

8. BOD Apply a BOD/COD factor of 0.19 for ponderosa pine logs without bark (refer to Table 1) to estimate BOD added:

$$0.19 \times 15.2 \text{ lbs COD/day} = \underline{\underline{2.9 \text{ lbs BOD leached per day}}}$$

Deschutes River Site

Storage Conditions --

1. quantity of logs in storage - 2.5×10^6 board feet (mill estimate)
2. species and condition - ponderosa pine, unpeeled (assume 12% bark missing)
3. average length of storage - 30 days

Following the calculation procedure outlined above for the Gilchrist site, the following values are obtained:

Pollution Index	Quantity Leached lbs/day
COD	109
BOD	50
PBI	356
TOC	43

Coos River North Fork Site

Storage Conditions --

1. quantity of logs in storage - 69,000 ft^2 (based on field measurements)

2. species and condition - Douglas fir, 12 percent bark missing

3. average length of storage period - 1 day

Following the calculation procedure outlined above for the Gilchrist site, the following values are obtained:

Pollution Index	Quantity Leached lbs/day
COD	112
BOD	33
PBI	86
TOC	48

Coos River South Fork Site

Storage Conditions --

1. quantity of logs stored - 23,000 ft^2 (based on field measurements)

2. species and condition - Douglas fir, 12 percent bark missing

3. average length of storage period - 1 day

Following the calculation procedure outlined above for the Gilchrist site, the following values are obtained:

Pollution Index	Quantity Leached lbs/day
COD	40
BOD	12
PBI	83
TOC	17

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16. Abstract The water storage of logs is widely practiced in the Pacific Northwest. An investigation has been made to determine the effect of this practice on water quality.

Soluble organic matter and some inorganics leach from logs floating in water and from logs held in sprinkled land decks. The character and quantity of leachate from Doublas fir, ponderosa pine and hemlock logs have been examined. Measurements including BOD, COD (1.0-4.2gm/ft^2 per week), PBI, solids and toxicity (no kill to 20% TLm 96) have shown that in most situations the contribution of soluble leachates to holding water is not a significant water pollution problem.

The most significant problem associated with water storage appears to be the loss of bark from logs during dumping, raft transport and raft storage. Bark losses from 6.2% to 21.7% were measured during logging and raft transport. Dislodged bark can float until it becomes water logged and sinks, forming benthic deposits. Floating bark is aesthetically displeasing and could interfere with other beneficial uses of a lake, stream or estuary. Benthic deposits exert a small, but measurable oxygen demand and may influence the biology of the benthic zone. Implementation of corrective measures by the timber industry to reduce bark losses could make the water storage of logs a practice which is compatible with a high quality environment.

17a. Descriptors

bark, leachate, bark sinkage, toxicity, water pollution, oxygen demand, log storage, bark deposits, benthic deposits

17b. Identifiers

bark, BOD, forest industry pollution, logging wastes, Pacific NW logging, leachate characteristics.

17c. COWRR Field & Group

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