Research Report

WATER QUALITY IMPACTS ASSOCIATED WITH LEACHATES FROM HIGHWAY WOODWASTES EMBANKMENTS

INTERIM REPORT
September 1980

Public Transportation and Planning Division

Washington State
Department of Transportation

WA–RD–39.1

In cooperation with
U.S. Department of Transportation
Federal Highway Administration

Report No. 4

WATER QUALITY IMPACTS ASSOCIATED WITH LEACHATES FROM HIGHWAY WOODWASTES EMBANKMENTS

A report prepared for the
Washington State Department of
Transportation Highway Runoff Water
Quality Research Project

by

Kurt H. Vause
John F. Ferguson
Brian W. Mar

Department of Civil Engineering
Water and Air Resources Division
University of Washington
Seattle, Washington 98195

September, 1980

TABLE OF CONTENTS

INTRODUCTION

Woodwaste was first used in sections subject to subsidence or sliding in order to reduce the load bearing on poor foundation materials during construction of the Trans-Canada Highway in 1959-63 (Smith and Coulter, 1978). The installation of woodwaste fills, according to current design in Washington, involves excavation of native material and old roadway, usually to below the groundwater table. A drain system of small diameter pipes is laid before the woodwaste is placed. The drains function to reduce the groundwater level within the fill, but also remove water that has infiltrated through the fill. To protect against deterioration, embankment backslopes are usually sealed with an emulsified asphalt-woodwaste mix. The emulsified asphalt mix serves as a "crust" that inhibits air and water from entering the fill (Nelson and Allen, 1974). The remaining portion of the fill is capped with typical highway sub-base aggregate followed by the actual road surface. Material properties and stability characteristics of woodwaste fills under various hydrogeologic conditions have been described (Lea and Brawner, 1963; Nelson and Allen, 1974; Nelson and Allen, 1976; Econotech Services, Ltd., 1977; Smith and Coulter, 1978).

Important considerations in the design are long-term stability and potential environmental impacts associated with woodwaste instead of native material. Design periods of 15 years have been used in Washington and seem to be conservative. There is no question but the fills reduce maintenance and are a cost-effective solution in certain conditions. The deterioration of the woodwaste results directly in release of water pollutants. The rate and extent may depend upon many factors, including the species, type and size of the woodwaste, the amount of water contact, the presence of oxygen and microorganisms, and the temperature. There is an extensive literature on leaching from and degradation of wood that is relevant to degradation of woodwaste fills and the resultant production of organic water pollutant. However, the literature does not answer the critical questions about the amounts of various pollutants that are emitted or their rates, the environmental effects from the emissions, or the mitigation measures that might be used. A research program was undertaken at the University of Washington to address these questions to provide guidance in design and assessment of environmental impacts.

LITERATURE REVIEW

The initial reactions of woodwaste in fills are probably simple leaching of soluble compounds from the wood. The nature of leachate resulting from extraction of woodwaste with water has been studied by Hrutfiord and Dawson (1974), and Schermer and Phipps (1976). Hrutfiord and Dawson summarize classes of compounds found in hot-water extraction of Western Red Cedar (*Thuja plicata*), Western Hemlock (*Tsuga heterophylla*), and Douglas Fir (*Pseudotsuga mengiesii*) wood and bark. Total extractive content of wood varies from about 6 to 10 percent (weight basis), with readily degradable wood sugars constituting a maximum of about 1 percent by weight. Extractive composition differs widely between species and between wood and bark of the same species. The majority of wood extractives are composed of phenolic compounds which in their polymeric forms (tannins) contribute acidity and color to the leachate. Bark extracts are mostly flavinoids or simple phenolic compounds. In the case of cedar wood leachate, measurable levels of tropolones are present which are toxic at low concentrations.

Over longer times, microbiological attack also takes place. Studies have found a variety of fungi, yeast and bacteria active in decay of wood stored as roundwood or in chip piles (Lawson and Still, 1957; Rothrock, 1961; Saucier and Miller, 1961; Lindgren and Eslyn, 1961; Bjorkman and Haeger, 1963; Hajney, 1966; Panshin and DeZeeuw, 1970; Eslyn and Laundrie, 1973; Alexander, 1977).

Rates of degradation in pulpwood and pulp chips stored outside have been measured (Ference and Gilles, 1956; Klemm, 1957; Lingreen and Eslyn, 1961; Rothrock, et al., 1961; Saucier and Miller, 1961; Somsen, 1962; Bjorkman and Haeger, 1963; Hajny, 1966; Feist, Springer and Hajny, 1971; Feist, Springer and Hajny, 1972; Eslyn and Laundrie, 1973), although unfortunately very little of the data pertains to losses in wood species indigenous to the Northwest. In general, the data indicate weight losses on the order of between 1 to 2 percent per month during the first six months of storage. Trends in some of the data suggest that the rate of degradation increases with time, probably due to increasing numbers of microorganisms being established within the wood over time.

Life expectancy of submerged woodwaste is much longer than that of woodwaste above the groundwater table, since studies have shown that wood stored under submerged conditions is much more resistant to decay (Chesley, et al., 1956; Klemm, 1957; McKee and Daniel, 1966; Eslyn and Laundrie, 1973; Evans, 1973).

Characteristics of Leachates

The organic nature of woodwaste leachate is usually expressed in terms of Chemical Oxygen Demand (COD), Biochemical Oxygen Demand (BOD) and Total Organic Carbon (TOC). These parameters serve as gross measures of organic pollutant concentrations in water and wastewater samples. Benedict (1971). Schaumberg (1973), Phipps and Schermer (1974), Shermer and Phipps (1976), Econotech Services, Ltd. (1977) and Cameron (1978) have used these parameters to characterize leachate quality. Typically, pollutant concentrations have been found to rapidly increase to some peak value, then decline in an almost exponential fashion with time to low residual concentrations. Peak values of COD, BOD_5, and TOC reported range from 290 to 12,500 mg/l COD, 36 to 6640 mg/l BOD_5 and 850 to 8500 mg/l TOC. Residual concentrations exhibit a wide range of values as well, with reported values ranging from 30 to 5000 mg/l COD, 10 to 2200 mg/l BOD_5 and 70 to 1800 mg/l TOC. Residual COD concentrations of 500-1000 mg/l have been observed (Schermer and Phipps, 1976) in leachates from woodwaste fills surrounding the Grays Harbor, Washington area which are several years old.

Typically woodwaste leachates are highly colored, the intense color being attributed to tannins and tannins combined with dissolved iron (Hrutfiord and Dawson, 1974; Evans, 1973). Mass quantities of color leached from woodwaste, which is measured by equivalent concentrations of potassium chlorplatinate needed to cause the same intensity of color as in the actual leachate, have been estimated by Benedict (1971). Fresh woodwaste was found to leach more color than aged materials.

Leachate acidity results from high concentrations of dissolved carbon dioxide and from soluble organic acids. (The high concentration of carbon dioxide in the gas phase results from microbial degradation of wood). pH values have been reported as low as 3.0 for fresh Western Red Cedar woodwaste leachate, while typical values lie in the range of 4.0 - 6.0 (Econotech Services, Ltd., 1977; Schermer and Phipps, 1976; Cameron, 1978).

High concentrations of various metals and anions are typically found in woodwaste leachate streams (Sweet and Fetrow, 1975; Econotech Services, Ltd., 1977; Cameron, 1978). The organic fraction of a woodwaste material does not contain these inorganic elements in appreciable quantities, therefore the source of these ions is probably dirt, rock, etc., mixed with wood or from reactions of leachate with native material surrounding the woodwaste.

Though several studies of mass emission of pollutants have been made, the direct extrapolation of these data to highway woodwaste embankments in the Pacific Northwest to predict ultimate pollutant emissions is not possible. First, the hydraulic loadings usually model rainwater rather than groundwater infiltration. Second, most data pertains to tree species which are not indigenous to the Pacific Northwest. Since extractive content and composition varies greatly among different species, the data may not represent leachates from embankments in Washington State. Third, the size distribution of particles is unspecified or not representative of woodwate used in embankments. For all these reasons it was judged necessary to measure leachate production both at a woodwate fill and in laboratory studies designed to simulate groundwater and rainwater using woodwaste typical of that used in Washington.

Water Quality Impacts of Leachate

Potential environmental effects associated with woodwaste leachates include: 1) Contamination of groundwater or surface water with dissolved organics and inorganics such as iron and manganese; 2) Depletion of dissolved oxygen in surface receiving waters resulting from biological oxidation or organics in leachate; 3) Depression of receiving water pH with the introduction of acidic leachate; 4) Toxicity to aquatic fauna resulting from a lowering of pH or presence of toxic constituents; 5) Aesthetic effects, such as undesirable odors, colors, slime growths or staining.

The aesthetic impacts from woodwaste leachates include odors, biological growths and stains. Odors are usually reported as hydrogen sulfide (H_2S), although few quantitative data have been presented to substantiate these findings. Other compounds mentioned as being odor causing include thiols and other unidentified sulfur compounds (Phipps and Schermer, 1974; Econotech Services, Ltd., 1977).

Biological growths in areas affected by leachate flow have been reported (Evans, 1973; Phipps and Schermer, 1974; Econotech Services, Ltd., 1977). Typically reported are long, grey slime growths referred to as *Sphaerotilus*, a common filamentous organisms. Staining of areas adjacent to woodwaste fills commonly occurs. Often observed are oily, irridescent films on the surfaces of leachate pools, the film being formed upon exposure of leachate to light and air. The films have been attributed to precipitation of metal sulfides and to separation of terpene compounds under stagnant conditions, although no quantitative data are provided to substantiate those conclusions. Bacterial films have also been found to exist in stagnant water as surface sheens growing and oxidizing reduced sulfides, iron and organics.

Measures to Mitigate Impacts

Measures designed to reduce potential water quality impacts associated with leachates consist of three basic approches (Conroy, 1979):

1. Flow reduction
2. Leachate treatment
3. Material control

Flow Reduction

Flow reduction has been debated as being a short-term solution to potential long-term pollution problems. If a fixed mass of pollutants will be leached out over time, reduction in flow rate may reduce mass emissions to a level which can readily be assimilated by a receiving water, but may in the process increase pollutant concentrations and lengthen the duration of the emissions.

Flow reduction can be accomplished by: 1) Installation of buried drains to intercept and drain away groundwater flow from the fill; 2) Construction of highly permeable gravel blankets underneath fills to reduce the amount of groundwater flow infiltrating into woodwaste; and 3) Various capping techniques which reduce the amount of surface runoff infiltrating through the fill material. Drains have been utilized by the Washington Department of Transportation in construction of several highway embankments, and various capping techniques are described in the literature (Nelson and Allen, 1974; Phipps and Schermer, 1974).

Leachate Treatment

Leachate treatment methods which have been proposed include overland flow, land treatment via filtration through soils or gravel, leachate recycling back through the fill, and biological stabilization in oxidationponds or aerated lagoons. Studies evaluating treatment efficiency of filtration through fresh soil or gravel (Schermer and Phipps, 1976; Econotech Services, Ltd., 1977) indicate that toxicity is greatly reduced or eliminated by filtration. Soils are more effective in removing BOD, COD and tannins than gravel.

Material Control

Material control is a means by which undesirable leachate characteristics may be avoided through selection of woodwaste of a given species. Practical difficulties in obtaining a homogeneous woodwaste material limits the feasibility of this approach. However, pre-treatment of the material, involving washing prior to placement in a fill is also suggested as a means to prevent significant leachate generation in the field.

Prevention of Degradation within Embankments

Current design practices of the Washington State Department of Transportation to seal embankment sections include extension of paved surfaces to roadside culverts and drainage channels, and construction of emulsified asphalt-woodwaste mixtures on the outer layers of fill side slopes. Alternative techniques have been utilized in British Columbia. Six-mil thick polyethylene sheeting has been used successfully in two B.C. highway embankment sections to seal the fill contents from air (Smith and Coulter, 1978). Anaerobic conditions within these fills were quickly established, as indicated by the presence of methane in the gas phase.

Chemical treatment of wood to prevent deterioration has been studied (Springer, *et al.*, 1973). Addition of specific organic compounds inhibits microbial growth for a limited period, after which some biological activity occurs. Chemical treatment is less desirable than physical measures, however, since chemical costs can be excessive and the possibility exists for adverse environmental impacts.

RESEARCH NEEDS

A research program was initiated at the University of Washington, Department of Civil Engineering, in which laboratory and field studies were conducted to:

1. Quantify organic pollutant mass emissions from woodwaste and identify factors affecting pollutant emissions. Of the previous literature published, few conclusions are directly applicable to highway embankments in the Pacific Northwest.

2. Document the nature and cause of any aesthetic impacts resulting from leachates from highway embankments.

The laboratory studies were developed based on the expectation that mass emissions of pollutants would be dependent upon rates of water application and that significant differences between submerged, continuous flow and intermittent, infiltrating flow would be realized. High concentrations of pollutants were expected to occur during most of the study period with residual concentrations to be observed only at the end of the period. A similar pattern was expected to occur in the field, with the result being that the laboratory tests would confirm and supplement observations made of a highway fill using similar waste material. Also, anaerobic biological activity was presumed to be present in embankments of this type, with the result being that measurable quantities of carbon dioxide and methane from within the interior portions of the fill would be found. Aesthetic impacts similar to those seen at other similar sites such as biological growths and odors were expected as well.

EXPERIMENTAL APPARATUS, DESIGN AND FIELD SITE MONITORING

Objectives

The objectives of field investigations were three-fold, to:

1. Develop estimates of the cumulative mass of pollutants which may be leached from woodwaste in highway embankments in Washington State in terms of the parameters, BOD, COD, and TOC;

2. Evaluate leachate characteristics and trends with time, including COD, BOD, and TOC, as well as pH, color and specific conductance;

3. Assess whether significant microbial activity is present within a highway fill constructed according to WDOT standards.

The purpose of the laboratory studies were to assess the relationship between hydraulic loading rate and total mass of pollutants leached, and to verify the findings of the field investigations.

Selection of Field Sites

To develop estimates of cumulative mass of pollutants leached, it was necessary to obtain data from a highway fill from the onset of construction. In conjunction with Washington State Department of Transportation officials, selection of a field site was made. Included in one State Highway project (Job No. 78W119-SR 302 reconstruction from Victor Cutoff Rd. to Purdy) was a woodwaste fill section approximately 137 m (450 ft.) long and containing approximately 3790 m^3 (4950 yd^3) of compacted woodwaste. Located near the town of Victor, Washington (Figure 1) on SR 302, the fill is situated immediately adjacent to a rocky beach on Case Inlet of Puget Sound.

The fill was installed to replace native material subject to periodic slides due to high groundwater and poor soil characteristics. Figure 2 illustrates the hydrology and soil characteristics and a cross-section of the fill. In some sections, portions of asphalt overlays were found during excavation to exceed 3.0 m (10 ft.) in thickness. Construction of the site was initiated in December, 1978, and took approximately one month to complete. An underdrain system of small, perforated pipes enchased in polyurethane foam bags filled with vermiculite is installed at the base of the fill. The perforated pipe is then connected to a 7.6 cm (3 inch) carrier pipe, which ultimately discharges collected leachate through an outfall onto the rocky

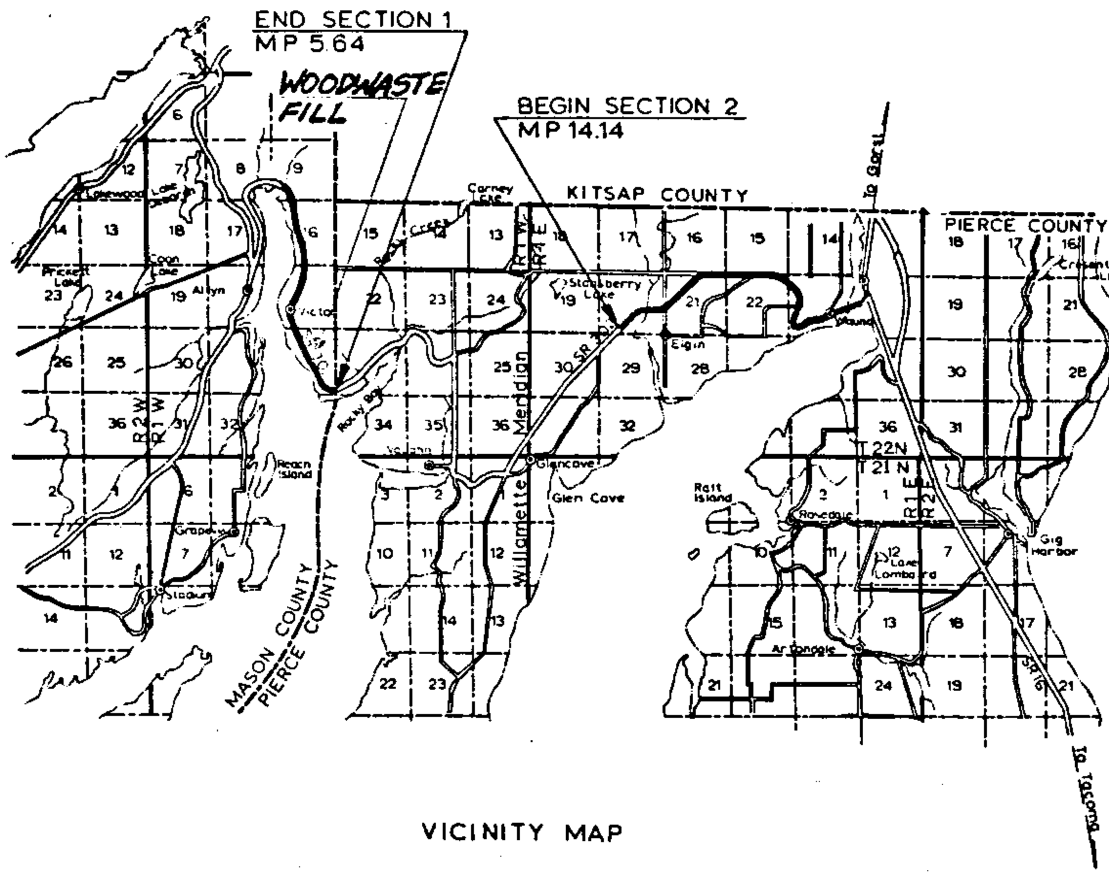

Figure 1. Location of Map-Sr 302 Woodwaste Fill Site.

beach adjacent to the fill. Samples of leachate from the underdrain system are obtained by collecting them from the end of the outfall located on the adjacent beach face. A 15.2 cm (6 inch) diameter slotted PVC pipe located on the east side of the fill collected some leachate as well. Surface water runoff from a paved ditch was mixed with the leachate and discharged through a 0.76 m (2.5 ft.) corrugated metal pipe out onto the beach face just above the 7.6 cm outfall.

Groundwater levels in the immediate vicinity of the fill were monitored using monitoring wells made of PVC pipe driven vertically to depths below the base of the fill.

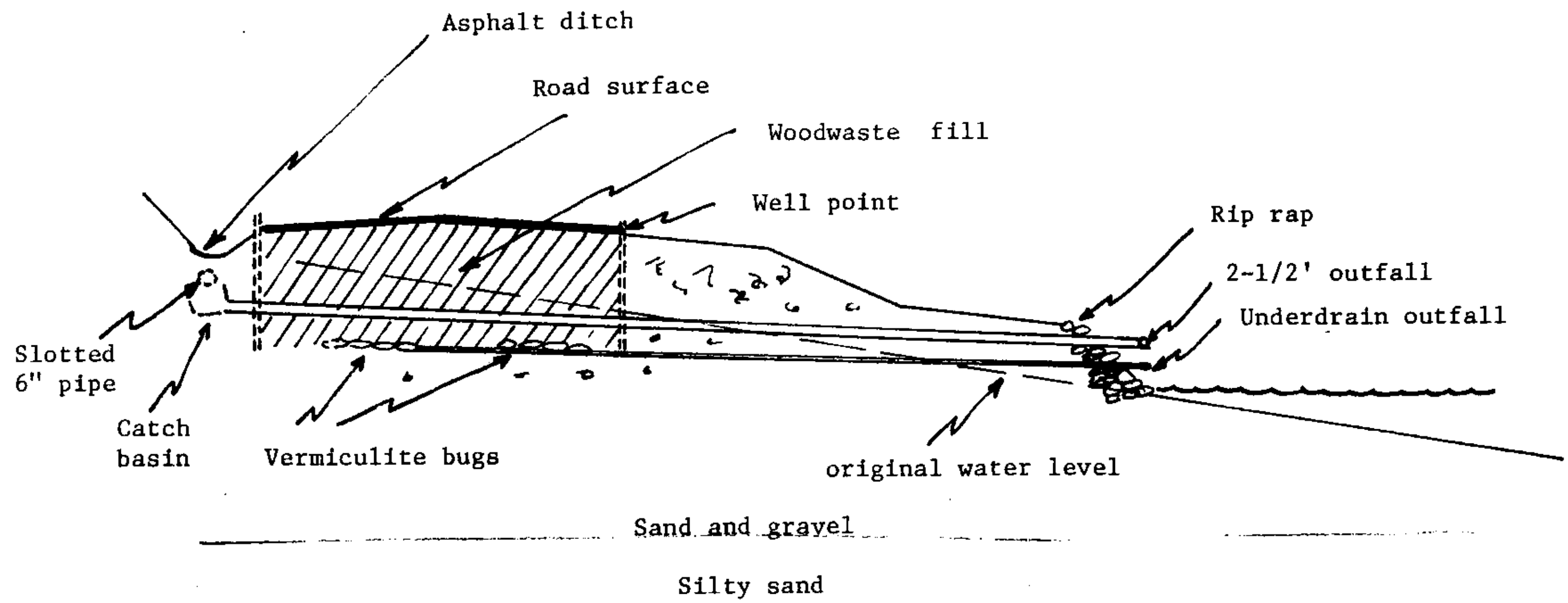

Figure 2. Schematic of woodwaste embankment site.

During the final stages of construction at the site, a gas-sampling device was installed in the side slope to monitor gases within the fill. The device consists of a 2.22 cm. (7/8 inch) I.D. x 1.8 m. (6 ft.) long iron pipe perforated with holes. A beveled steel point was attached to the casing to serve as a cutting edge when inserted in the fill. A silver solder seal was fused between 0.95 cm. (3/8 inch) copper tubing and the other end of the pipe. The copper tubing was attached to a gas-tight brass valve.

Laboratory Apparatus and Design

Six laboratory columns were constructed. Four columns were continuously leached using tap water at different flow rates estimated to be representative of a range of groundwater flow conditions. A replicate column (Column D) was run for one of the four columns (Column C) in order to provide a check on the reproductability of the experimental data. The sixth column (Column F) simulated conditions of infiltrating precipitation.

Laboratory columns were cylindrical acrylic, 1.52 m. (5 ft.) tall and 15.2 cm. (6 in.) in diameter (Figure 3). Influent and effluent ports were installed on the top and base of the columns, respectively. Attached to the effluent part was 0.95 cm. (3/8 in.) diameter Tygon tubing. The ends of the tubing were elevated to maintain complete subjergence of the column. Inside the columns, three dispersion rings were placed in each column at approximately equal spacing to prevent short-circuiting of flow.

Continuous feed of tap water to five columns was accomplished using peristaltic pumps. Two, 37.81 (10 gal.) tanks served as reservoirs from which tap water was pumped to the columns. Due to mechanical failures with some of the pumps, several pumps were utilized during the study.

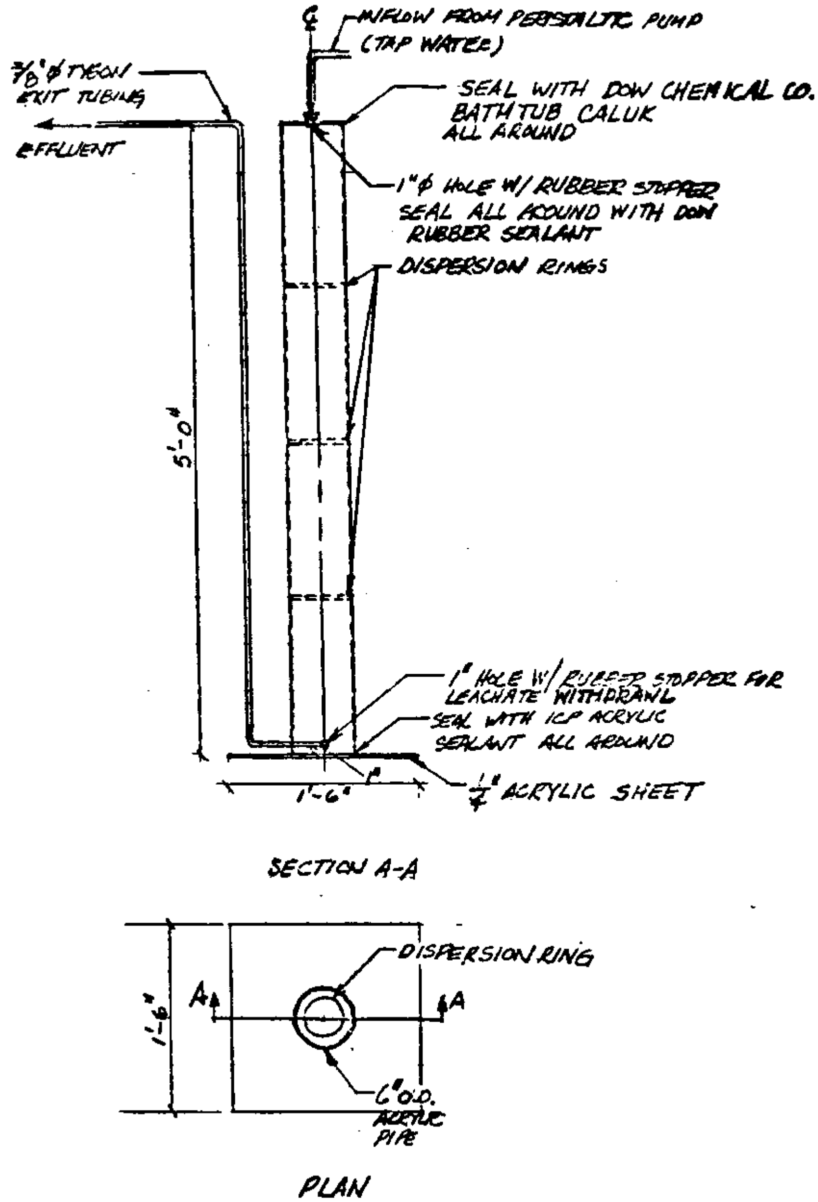

Figure 3. Schematic of Laboratory column.

Woodwaste used in laboratory studies was obtained from the SR 302 site during December, 1978, as the material was being placed in the highway fill. Approximately 150 kg, (330 lbs.) of woodwaste was selected from different locations within the fill and composited into a heterogeneous mix. About 11.4 kg. (25 lbs.) of native soil materials stockpiled at the site were also obtained and added to the mix to provide a microbial seed. The material was stored in sealed polyethylene bags until used one month later.

Samples of the woodwaste mix were analyzed for moisture content, volatile solids and species composition. Due to the small particle size of the material no exact determination was made of the relative percentages of wood and bark present or of species composition.

Packing of the columns was done by hand using a hand-held "tamper" to simulate compaction in the field by construction equipment. After packing, each column was sealed and the contents submerged. Column F, which simulated partially submerged conditions, was allowed to drain and the volume of leachate collected. The remaining five columns were allowed to sit for a period of less than 24 hours, after which water application was initiated on January 23, 1979.

Laboratory Program

The five submerged columns were leached continuously using a range of flow rates estimated to be representative of groundwater flow conditions. Using best available data on hydrogeologic conditions and soil types present at the SR 302 site and assuming that groundwater flow would not significantly differ at the site after construction, it was estimated that groundwater flow into the fill would be 0.015 $l/day/cm^2$ of area normal to flow (5.6×10^{-6} $cfs/ft.^2$) Assuming that this inflow would be representative of average inflow conditions, flow rates were set for laboratory columns to encompass a range of flow rates about this average value.

Table 1: Laboratory Flow Rates

Column	Hydraulic Loading Rate$(1/d/cm)^2$	Flow Rate(ml/hr)
A	2.57×10^{-2}	180
B	1.43×10^{-1}	1000
C	7.14×10^{-2}	500
D	7.14×10^{-2}	500
E	7.14×10^{-3}	50
F	6.95×10^{-4}	2.54m/yr*

* equivalent to 100 in. precipitation per year

Analyses for COD, TOC, pH, color and specific conductance were conducted, usually within 24 hours after collection of the sample and always within 96 hours after collection.

Flow rates for each column were monitored approximately every two days.

Field Site Sampling Program and Procedures

It was originally scheduled that the underdrain system outfall be sampled periodically for pollutant concentration and flow rate. However, the underdrain system could not remove sufficient groundwater to prevent a rise in groundwater table in the fill. Contamined water was also discharged from the 15.2 cm (6 inch) drain located on the east side of the fill (Figure 3). Seepage from the toe of the side slope of the fill began to appear after approximately 60 days also. Seepage within the inter-tidal zone of the adjacent rocky beach face was detected as well. Associated with these seeps or flows being discharged directly onto the the beach face were stains of three varieties: 1) a blackening of beach substrate in the immediate vicinity of the 7.6 cm. diameter outfall; 2) a brownish-orange staining of beach substrate along the length of the fill; and 3) patches of beach face which were stained with an irridescent oily surface film. As a result, a more extensive sampling program was undertaken to evaluate the characteristics of these seeps or flows.

During the first 20 weeks of leaching (from 2 January through 25 May, 1979), samples were taken twice per week; sampling frequency was reduced to once per week through October, 1979. Samples were also taken in September, 1980 to to monitor the longer term leaching and effects at the site.

Gas samples were periodically withdrawn to monitor gas composition from the non-submerged portion of the fill. Samples were withdrawn into 250 ml. gas sampling tubes using a hand-operated vacuum pump. Due to delays in equipment set-up, samples could not be analyzed for periods up to four months after collection.

Groundwater levels in monitoring wells (Figure 4) were determined by sight using calibrated rods or measuring tapes.

EXPERIMENTAL RESULTS

Laboratory simulation of woodwaste leaching shows good agreement with other data for leachate generated under conditions simulating both groundwater submergence and precipitation infiltration. Furthermore, the characteristics of leachate obtained at the SR 302 site are similar to those of laboratory generated leachates using identical woodwaste. A complete summary of results of leachate routinely collected and analyzed for COD, TOC, BOD, pH, color, and conductivity are reported by Vause (1980).

Leachate pH in laboratory columns A through D slowly increase over time but in a fluctuating, irregular manner from values slightly below 5 to values near 6.

The pH curve of SR 302 underdrain outfall effluent is significantly different than the laboratory data in that three distinct periods exist, the first being a period of approximately 70 days duration in which pH averages about 3.5, the second in which there is a sharp increase in pH to about 5.0 over 30 days, and the third being a period in which pH slowly increases with time to about 5.3-5.5 in 250 days. The pH value had increased to 5.9 after 650 days, which was still depressed below that of uncontaminated groundwater which had a pH of 6.76. Comparison with monitoring well data collected over the entire period shows that the sharp increase in pH corresponds to a time at which steady-state equilibrium in groundwater elevation within the fill was reached.

Specific conductance rapidly reaches a peak value, indicating a flushing of dissolved inorganics initially, then decays relatively rapidly to some low equilibrium value. The values depend inversely on the hydraulic loading. The trend in measured conductance of the SR 302 outfall effluent resembles that of the columns. Apparent color measurements follow the same trend as specific conductance in laboratory leachates; in general, peak color concentrations occur early during leaching, then decline to low levels. Leachate pH, color and specific conductance characteristics of seepage samples were collected at two locations at the SR 302 site. The character of field seeps does not appear to correlated well to any one particular laboratory column, most likely as a result of reactions with surrounding soil.

Various samples of leachate from the SR 302 site and the laboratory were analyzed for suspended and dissolved matter. Measured suspended solids emissions were very low, less than 15 mg/l, for both outfall leachate and laboratory samples. Concentrations were slightly higher in leachate seeps with values ranging from 18 to 39 mg/l TSS; but the higher concentrations can be attributed in part to contamination during sample collection. Organic pollutant emissions were measured over time using the parameters COD, BOD_5, and TOC. Figures 4 and 5 illustrate COD concentrations vs. time for laboratory column and SR 302 outfall effluents. The organic strength of the outfall effluent had decreased by an additional 75% by September, 1980 to values of 38 μg/l COD and 13 μg/l TOC.

The data show a rapid leaching of COD in columns leached at high hydraulic loadings, while lower hydraulic loadings result in extended periods during which COD concentrations are high. Peak COD concentrations vary from a low of 1340 mg/l for SR 302 outfall effluent to a high of 2970 mg/l for Column F dosed intermittently to simulate rainfall infiltration.

Periodic BOD_5 tests were run on selected samples of laboratory and field leachate samples. Results are presented in Figure 6.

Seepage samples from the SR 302 site were analyzed for COD, TOC and BOD as well (Table 2).

Dissolved oxygen (D.O.) and sulfide meaurements were conducted on selected samples of leachate from the SR 302 site. The data show leachate from the outfall to be anoxic, i.e., with virtually no dissolved oxygen.

Aesthetic problems at the SR 302 site developed within a few months after leachate began to flow. Among them were odors, discoloration of beach substrate adjacent to the site, and slime growths at various places along the length of beach adjacent to the fill. Discoloration of beach substrate consisted of: a) a persistent blackening of beach substrate in the immediate vicinity of the underdrain outfall; and b) a brownish orange staining of beach substrate along the length of the fill with isolated patches of blue-black staining upon which an irridescent surface film existed. Observations suggest that dense growth of fungi, algae and bacteria are the major cause of the discoloration in the area surrounding the underdrain system outfall, while chemical precipitation of metal sulfides is not as significant a factor. The

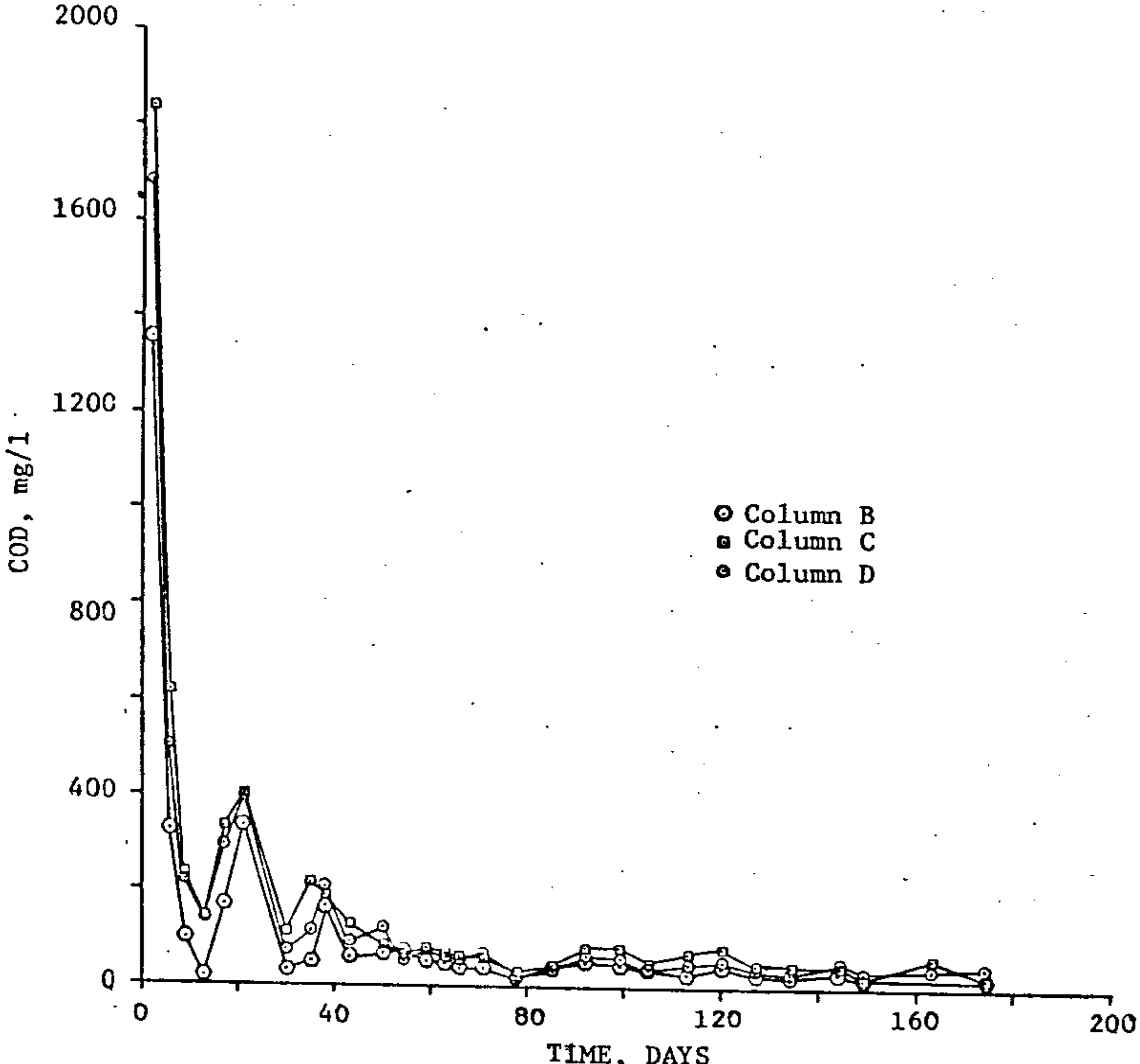

Figure 5. COD concentration vs. time- Columns B,C and D

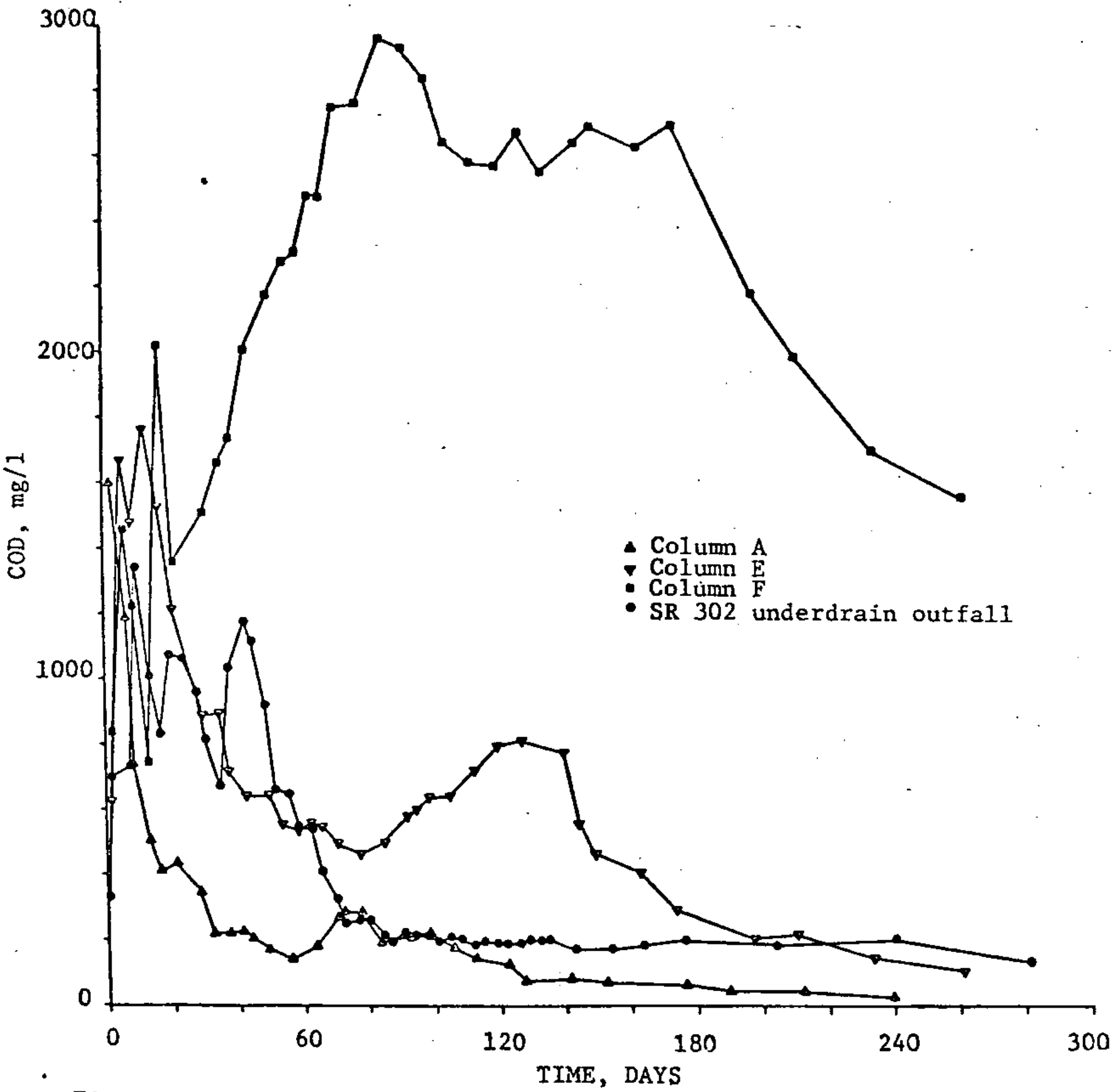

Figure 6. COD concentration vs. time- Columns A,E,F and SR 302 underdrain outfall

irridescent surface films may be terpenes or related compounds separating from stagnant leachate much as gasoline separates from water. The brownish-orange discoloration along the beach face is most likely iron and manganese oxides. Undersides of orange stained rocks had black discoloration. When treated with a strong acid, this black precipitate evolves characteristic sulfide odors, leaving a rust colored slurry.

Given the peak and residual concentrations of pollutants and their mass emission rates, water quality degradation of Case Inlet has been insignificant. The emissions are low compared to the volume of tidal water present. However, it is not known if biological effects, including toxicity of leachate to intertidal marine organisms occurred at the SR 302 site. No studies have been performed on the leachate to try to identify specific compounds known to be toxic from previous studies nor have toxicity studies using beach organisms been done at this time. Also, significant aesthetic impacts occurred along the beach face adjacent to the embankment including staining and odors. The effects have persisted to September, 1980, but the severity is much reduced compared to the first months of leachate generation.

DISCUSSION OF RESULTS

Leachate Characteristics

Field and laboratory leachate pH observed in this study are in the same range as data from other leachate studies, although color measurements reported here are significantly less than those values found in the literature. pH values of SR 302 outfall leachate during the first 70 days range between 3.1-3.5 and are approximately the same as those reported by Schermer and

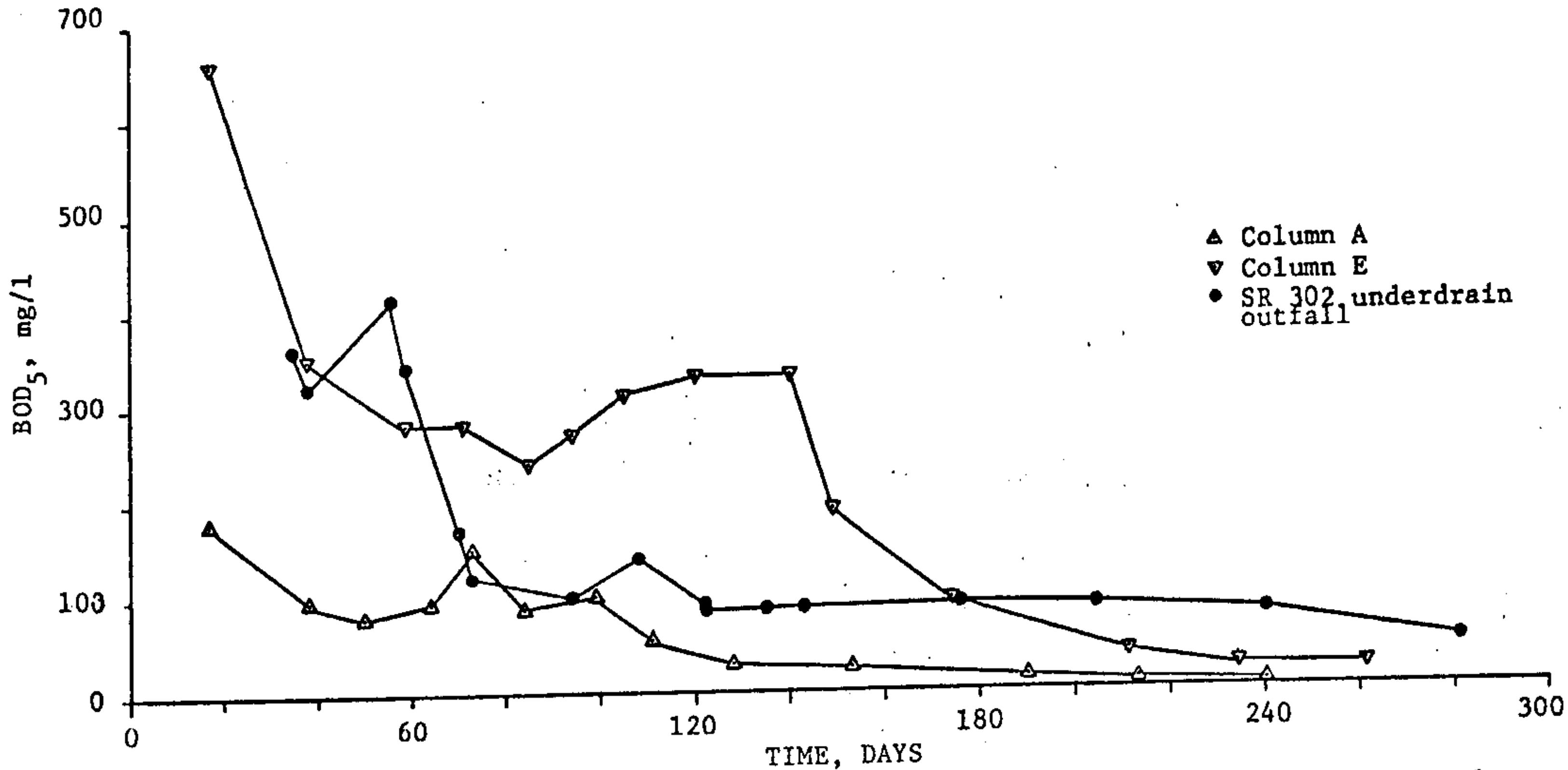

Figure 6. BOD_5 concentration vs. time- Columns A,E and SR 302 underdrain outfall samples

Table 2. Summary of Leachate COD, BOD and TOC of Seepage Samples at SR 302 Woodwaste Fill

Date	Days since leaching begins	Location of Sample	COD, mg/l	BOD, mg/l	TOC, mgC/l
3/9/79	66	Seep from toe of side slope (approx. Sta. M.P. 5.40)	4180	-	500
3/16	73	"	3600	-	300
3/23	80	"	4220	-	300
3/30	87	"	3570	1590	300
4/6	94	"	2660	990	420
"	"	Seep from toe of side slope (approx. Sta. M.P. 5.43)	3630	1130	-
"	"	Seep from toe of side slope (approx. Sta. M.P. 5.41)	3090	1050	-
4/13	101	Seep at toe of side slope (approx. Sta. M.P. 5.40)	2050	-	430
8/29	240	Seep at toe of side slope (approx. Sta. M.P. 5.43)	-		
10/9	281	"	4080	-	180
5/12	129	Seep at beach from rock rip-rap (approx. Sta. M.P. 5.43)			
5/17	135	"	470	-	140
5/25	143	"	400	-	100
6/05	154	"	430	-	190
6/15	164	"	390	-	150
6/27	176	"	390	180	120
7/24	204	"	250	120	130
8/29	240	"	200	94	43
10/9	281	"	90	29	29

Phipps (1976) for Red Cedar leachate from static leaching tests. Also, the gradual increase in pH with time, at a rate of about 1 pH unit per 8 months during the later period of the study (100-280 days) is approximately the same as the trend reported by others.

Organic pollutant strength of leachates measured in terms of COD, TOC and BOD_5 in this study generally compare favorably with results presented by others with some exceptions due to differences in hydraulic loading rates, storage age, and species type present. Peak COD values of laboratory leachates from Column A through E and SR 302 outfall leachate in the range of between 1350 to 1850 mg/l compare well with values reported by Benedict (1971) of between 1980 and 2600 mg/l for fresh woodwaste continuously leached at roughly equivalent hydraulic loadings. TOC values for Douglas Fir and Western Red Cedar bark leachates from laboratory studies (Econotech Services, Ltd., 1977) simulating rainfall infiltration and leaching at 100"/yr (2.54 m/yr) agree with TOC values measured of Column F leachate. In each study, TOC values on the order of between 140 to over 600 mg C/l have been found.

Experimental data from laboratory and field studies suggest that cumulative COD and TOC mass emissions reach some limiting or "ultimate" value after a long period of leaching with total mass emissions increasing as hydraulic loading is increased. A simple model was used:

$$M = M_{max} \ (1 - 10^{-kt})$$

where M = cumulative mass of pollutant leached over time, t,

M_{max} = ultimate mass of pollutant leached

K = rate constant

t = duration of leaching

The equation can be used to evaluate the significance of observed differences in calculated ultimate mass emissions between columns and field resulting from hydraulic loading variations. The data from this study suggest pollutant emission loads to be in the range of $40 \pm 10 \times 10^{-3}$ lb COD/lb solid (80 ± 20 lb/ton), $10 \pm 2.5 \times 10^{-3}$ lb TOC/lb solid (20 ± 5 lb/ton), and $15 \pm 3.8 \times 10^{-3}$ lb BOD_5/lb solid (30 ± 7.5 lb/ton). Many values in the literature (e.g., Benedict, 1971) are outside this range because of differences in the type of wood leached and storage ages of materials. Ranges of values are given here because there is approximately 25% error in the reported calculations, and given this amount of variability in the results, the data do not show a significant effect of hydraulic loading on ultimate pollutant emissions. This is an important conclusion. The total mass of pollutants apparently is nearly constant. The rate of emission and concentration varies depending on hydraulic loading.

The first-order models used to estimate ultimate or total pollutant emissions can also be used to evaluate the period during which pollutants are released from woodwaste. The term $(1-10^{-kt})$ in the models is set equal to 0.99, and the value of t for a given rate constant, k, is found. Rate constants vary from a low of 0.0010 day^{-1} for Column F to 0.013 day^{-1} for Columns B and C, which when converted results in a range of effective leaching periods of between 154 and 2000 days. There was a general trend of lowered rates at lowered hydraulic loading. Estimated leaching period for the SR 302 site is slightly more than one year (417 days), and falls within the time frame estimated by Columns A and E hydraulically loaded at rates which bracket that calculated to be occurring at the SR 302 site.

Based on data collected from the WR 302 woodwaste fill site, two distinctly different leaching processes appear to have occurred. First, relatively rapid leaching of woodwaste submerged within groundwater took place since data indicate that the groundwater table rose within a few months after construction of the site to within a few feet of the ground surface and was associated with a peak in organic pollutant concentrations in the leachate. Then, upon equilibrium of the groundwater table at around 70 days, leachate strength rapidly declined; that is, organic pollutant emissions from the outfall fell to lower but stable levels (less than 30 lb/day COD, 10 lb/day TOC, and 15 lb/day BOD). After a period of several months, pollutant emissions declined even further. At the end of the monitoring period at 281 days, the first order model estimate was that 65% of ultimate pollutants had been leached. After 60 days outfall emission was 4.5 lb/day COD and 1.5 lb/day TOC.

The second type of leaching at the SR 302 site consists of precipitation infiltration and subsequent removal by gravity drainage. The character of this leachate was seen to fluctuate substantially with time in an irregular manner, and the presence of measurable quantities of volatile or organic acids suggests that at least a portion of this leachate was derived from microbial metabolic activity of complete saturation by the action of a passing moisture front.

CONCLUSIONS

Based on the results of this investigation, the following conclusions can be made concerning the use of woodwaste in highway embankments:

1. Generation of pollutants from woodwaste highway embankments consists primarily of physical leaching of wood extractives. Limited gas sampling and analysis for organic acids indicated that microbial fermentations were of secondary importance.

2. The mass emission of pollutants from woodwaste can be adequately described using a first order model; that is, the mass of pollutants leached follows an equation of the form:

$$M = M_{max}(1-10^{kt})$$

where

M_{max} = ultimate pollutant load

M = cumulative mass of pollutant leached over t

k = rate constant

t = time, days

This implies that a fixed amount of pollutants can be leached from a given mass of woodwaste. No significant difference in cumulative mass of pollutants leached is apparent when the hydraulic loading is varied.

3. The following ultimate pollutant mass emissions have been estimated from laboratory and field studies:

lb COD/lb dry solid leached = $(40\pm10)\times10^{-3}$ (80±20 lb/ton solid)

lb TOC lb dry solid leached = $(10\pm2.5)\times10^{-3}$ (20±5 lb/ton solid)

lb BOD/lb dry solid leached = $(1.5\pm3.8)\times10^{-3}$ (30±7.5 lb/ton solid)

These amounts represent a significant potential for water pollution, considering the mass of woodwaste used in typical fills.

4. Given peak and residual concentrations of pollutants and leachate volumes, water quality degradation of Case Inlet due to woodwaste leachate from the SR 302 site has been minor.

5. The composition of gases in the non-submerged portion of the SR 302 embankment indicates a sustained growth of microorganisms on the periphery of the fill.

6. Metal ion accumulation in leachate results from passage of low pH leachate through surrounding soils. However, concentrations found (Vause, 1980) are not high enough to cause toxicity problems.

7. Beach discoloration at the SR 302 site is in large part of a biological nature in the area immediately surrounding the 7.6 cm underdrain outfall; along the beach face adjacent to the length of the fill discolorations are of a chemical nature, presumably iron and manganese oxides and sulfides.

8. The pollutant emissions potentially can cause serious contamination of groundwater - an effect that was not significant at the SR 302 site, but might be at others.

RECOMMENDATIONS

With a hydrogeologic study of proposed fill sites, the results of this study can be used to estimate the mass and duration of pollutant emissions.

Potential adverse effects may include groundwater or surface water contamination, depletion of dissolved oxygen, toxicity, and slime growths and precipitates. If any of these are found to be unacceptably significant, mitigation measures should be used. Based on the study, the following measures may be considered.

1. Improved underdrain design may be used to divert groundwater from the fill. If water contact in the fill is reduced the rate of pollutant emission will be correspondingly reduced. The underdrain system at SR 302 was not adequate to prevent a high groundwater table in the fill and a high rate of emissions.

2. Increased underdrain capacity can also eliminate seepage at the toe of the fill with the undesirable aethetic effects of slime growth and discoloration.

3. Measurement of gases in the non-submerged portion of the embankment shows that the emulsified-asphalt woodwaste mix along the side slope is ineffective in sealing off the fill contents from exposure to air and from infiltration of rainwater. An improved impervious layer on the upper surface of the woodwaste could reduce leachate generation.

4. If site design is such that ground or surface water intrusion cannot be avoided, several strategies are possible.

a. A buffer zone between the fill and the nearest surface water may be available to allow seepage or groundwater flow to be treated by the processes of self-purification. The unavoidable aesthetic impacts in the zone may be acceptable compared to water pollution in the receiving water.

b. At locations with large potential dilution, e.g., Case Inlet, an underdrain outfall designed for dispersion may avoid beach impacts of the leachate.

c. Leachate may be collected and drained to a municipal wastewater system. Leachate may also be treated by land application or aerobic biological treatment processes developed for sanitary landfill leachates or industrial wastes. Treatment has very high initial and operating costs and would be used only as a last resort.

5. Material control is a technique which theoretically can be used to limit potential water quality impacts. However, it is extremely difficult to obtain homogenous woodwaste in the quantities required for a highway embankment.

6. Woodwaste might be pretreated (Conroy, 1979) by soaking woodwaste materials with water applied via sprinklers, fire hoses, etc., in a confined, impervious area. The leachate generated can be collected and treated as necessary in existing wastewater treatment facilities.

ACKNOWLEDGEMENTS

This work was supported by the Washington State Department of Transportation Contract No. V-1804. Any opinions, findings, conclusions or recommendations expressed in this report are those of the authors and do not necessarily reflect the views of the Washington State Department of Transportation or the University of Washington.

REFERENCES

Alexander, M. Introduction to Soil Microbiology, 2nd edition, John Wiley & Sons, New York (1977).

Benedict, A.H. "An Investigation of the Effects of Bark Leaching and Benthal Decomposition on Receiving Water Quality," National Council of the Paper Industry for Air and Stream Improvements, Tech. Bull., No. 247 (1971).

Bjorkman, E., and Haeger, G.E. "Outdoor Storage of Chips and Damage by Micro-organisms," Tappi, 46(12):757 (1963).

Cameron, R.D., personal communication (1978).

Chesley, K.G., Hair, J.C., and Swartz, J.N. "Underwater Storage of Southern Pine Pulpwood," Tappi, 38(9):609 (1956).

Conroy, F., personal communication (1979).

Econotech Services, Ltd. "Consequences of Leaching from Pulp and Paper Mill Landfill Operations," CPAR Project Report 363-2, Fisheries and Environmental Canada, Environmental Protection Service (September 1977).

Eslyn, W.E., and Laundrie, J.F. "How Anaerobic Storage Affects Quality of Douglas-Fir Pulpwood Chips," Tappi, 56(7):129 (1973).

Evans, R.S. "Hogged Wood and Bark in British Columbia Landfills: Report of a Round Table Conference," Information Report VP-X-118, Dept. of the Env., Can. For. Serv., WFPL (1973).

Feist, W.C., Springer, E.L., and Hajny, G.J. "Encasing Wood Chip Piles in Plastic Membranes to Control Chip Determination," Tappi 54(7):1140 (1971).

Feist, W.C., Springer, E.L., and Hajny, G.J. "Determining Loss of Wood Substance in Outside Chip Storage: A Comparison of Two Methods," U.S.F.S. Research Note FPL-189 (1972).

Ference, G.M., and Gilles, T.L. "The Determination of Straw-Piled Pulpwood," Tappi 39(6):406 (1956).

Hajny, G.L. "Outside Storage of Pulpwood Chips," Tappi, 49(10):97A (1966).

Hrutfiord, B.F., and Dawson, H. "The Nature of Organic Leachate from Wood Waste: Literature Review," unpublished paper (1974).

Klemm, K.H. "Pulpwood Transportation to the Mill and Methods of Storage," Pap. Trade J., 141(33):46 (1957).

Lawson, L.R., Jr., and Still, C.N. "The Biological Decomposition of Lignin-Literature Survey," Tappi, 40(9):56A (1957).

Lea, N.D., and Brawner, C.D. "Highway Deisgn and Construction over Peat Deposits in the Lower Mainland Region of British Columbia," Highway Research Board (1963).

Lindgren, R.M. and Eslyn, W.E. "Biological Deterioration of Pulpwood and Pulp Chips During Storage," Tappi, 44(6):419 (1961).

McKee, J.C. and Daniel, J.W. "Long Term Storage of Pulpwood in Sealed Enclosures," Tappi, 49(5):47A (1966).

Nelson, D.S. and Allen, W.L., Jr. "Sawdust as Lightweight Fill Material," Federal Highway Administration, Offices of Research and Development, Report No. FHWA-RD-74-502 (1974).

Panshin, A.J. and DeZeeuw, C. Textbook of Wood Technology, 3rd edition, Vol. I, McGraw-Hill Book Co., Inc., New York (1970).

Phipps, J.B. and Schermer, E. "Proceedings, Woodwaste Leachate Symposium," Grays Harbor College (December, 1974).

Rothrock, C.W., Jr., Smith, W.R. and Lindgren, R.M. "The Effects of Outside Storage on Slash Pine Chips in the South," Tappi, 44(1):65 (1961).

Saucier, J.R. and Miller, R.L. "Deterioration of Southern Pine Chips During Summer and Winter Storage," For. Prod. J., 11(8):371 (1961).

Schaumberg, F.D. "The Influence of Log Handling on Water Quality," Office of Res. Monitoring, EPA R2-73-985 (1973).

Schermer, E.D. and Phipps, J.B. "A Study of Woodwaste Leachate," Choker Research, Grays Harbor College (1976).

Smith, R.S. and Coulter, T.S. "Use of Lightweight Sawmill Residue in Highway Embankments," Canada Dept. of the Env., Forestry Directorate, WFPL (1978).

Somsen, R.A. "Outside Storage of Southern Pine Chips," Tappi, 45(8):623 (1962).

Springer, E.L., et al. "Evaluation of Chemicals for Preserving Wood Chips Using Pile Simulators," Tappi, 56(6):125 (1973).

Sweet, H.R. and Fetrow, R.H. "Ground-Water Pollution by Woodwaste Disposal," Ground-Water, 13(2):227 (1975).

Vause, K.H. "Water Quality Impacts Associated with Leachates from Highway Woodwaste Embankments," University of Washington, Department of Civil Engineering, Master's thesis, 1980.