Effect of Hardwood Leaf Litter on Water Quality and Treatment in a Western Oregon Municipal Watershed

by

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> Water Resources Research Institute Oregon State University Corvallis, Oregon

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ABSTRACT

Streamside red alder (<u>Alnus rubra</u> Bong.) stands are common in many municipal watersheds in the Oregon Coast Range; autumn leaf fall from such stands has been suspected of causing periodic domestic water quality problems. Field and laboratory studies were conducted to (1) evaluate water quality problems caused by leaf litter on a representative municipal watershed in the region, (2) clarify relationships between water quality and variables such as leaf quantity and water flow, and (3) examine the influence of alder leaf extracts on conventional water treatment processes and products.

Studies conducted on the Seaside municipal watershed in northwest Oregon showed the potential for water quality effects (particularly increased color) by alder leaves, but stream sampling during 1981-82 revealed no chronic problems. The few observed short-term increases in stream water color occurred near the onset of storm flows and thus were probably due to the flushing of storage sites containing organic material. Only with an extended period of unusually low flows and maximum leaf fall are significant water quality problems likely to occur in this particular stream system.

Laboratory leaching of alder leaves with filtered stream water showed a fairly constant release of colored organic material over time; running water was more efficient than still water in leaching this material. In still water, a linear increase in water color occurred with increases in leaf mass added; for a given leaf mass there appeared to be a limit to the amount of colored material that could be removed in the first 48 hours of leaching. Laboratory tests also showed that ultraviolet absorbance (254 nm) may provide a reasonable estimate of dissolved organic carbon concentrations in systems dominated by alder leaf inputs.

Laboratory studies of the influence of alder leaf extracts (ALE) on water treatment processes showed potentially significant effects. Chlorine demand of ALE, based on total organic carbon (TOC), averaged 1.7 mg Cl₂/mg TOC. Trihalomethane (THM) formation increased with increasing pH and Cl₂/TOC ratio with maximum formation under the conditions tested (pH=8.5, Cl₂/TOC ratio=4.3/1) being 60 mg CHCl₃/mg TOC. Natural organic matter in stream water from the Seaside watershed exerted less chlorine demand and produced lower THM concentrations per mg TOC than did ALE. Phenolic compounds listed as EPA priority pollutants were not produced at detectable levels by chlorination of ALE. Coagulation with a cationic polyelectrolyte (quaternary ammonium salt structure) was partially successful in removing ALE (expressed as TOC), but a complete sequence of coagulant addition, flocculation, sedimentation, and filtration was not investigated.

In terms of bacterial disinfection efficiency, leaf leachate organics could reduce available chlorine by exerting chlorine demand, thus removing residual protection in the municipal water distribution system. In addition, dramatic regrowth of bacteria was promoted, as measured by total coliforms and standard plate count bacteria. This could lead to deteriorated water quality and to noncompliance with Safe Drinking Water Act regulations.

FOREWORD

The Water Resources Research Institute, located on the Oregon State University campus, serves the State of Oregon. The Institute fosters, encourages and facilitates water resources research and education involving all aspects of the quality and quantity of water available for beneficial use. The Institute administers and coordinates statewide and regional programs of multidisciplinary research in water and related land resources. The Institute provides a necessary communications and coordination link between the agencies of local, state and federal government, as well as the private sector, and the broad research community at universities in the state on matters of water-related research. The Institute also coordinates the inter-disciplinary program of graduate education in water resources at Oregon State University.

It is Institute policy to make available the results of significant water-related research conducted in Oregon's universities and colleges. The Institute neither endorses nor rejects the findings of the authors of such research. It does recommend careful consideration of the accumulated facts by those concerned with the solution of water-related problems.

A more detailed account of portions of this study are included in the M.S. thesis of R. Lynn Taylor entitled "The Effects of Red Alder Leaf Fall on the Water Color and Other Water Quality Characteristics of a Small Watershed in Northwest Oregon" and dated March 14, 1983. His M.S. degree was awarded by Oregon State University in June 1983.

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INTRODUCTION

The input of leaves and other fine organic debris to forest streams contributes to the dynamic environment of these streams. Aquatic organisms receive much of their energy and nutrient requirements from this source, and many such organisms have developed life cycles that are intertwined with the regular input and processing of organic material (Cummins, 1974; Cummins, et al., 1980; Fisher and Likens, 1972; Hynes, 1975; Merrit and Lawson, 1978; Vannote, et al., 1980).

Aquatic systems can, however, become temporarily overloaded with natural inputs of organic matter that reduce water quality, especially with respect to domestic use. For example, undesirable color, taste and odor characteristics have been linked to leaf litter inputs to streams and reservoirs (Allen, 1960; Corbett and Heilman, 1975; Slack, 1964). Such water quality changes are particularly evident during periods of low flow, but even short term reductions in water quality can present problems for potential users and aquatic life (Nykvist, 1962; Ponce, 1974; Slack and Feltz, 1968).

Organic material in domestic water supplies can also result in problems with respect to water treatment and subsequent use. Chlorination of organic-rich water, for example, may exacerbate undesirable taste and odor problems. These changes in taste and odor may be caused by halogenated organics, especially trihalomethanes, which can be produced by chlorinating water containing dissolved organic matter (Bellar, et al., 1974; Rook, 1976; Stevens, et al., 1976; Symons, et al., 1975). It has also been recently suggested that trihalomethanes are potentially carcinogenic, although a link between the ingestion of these compounds and cancer in humans has not yet been clearly established (Carlo and Mettlin, 1980; Maugh, 1981; National Academy of Science, 1980; Tuthill and Moore, 1980; Wilkins, et al., 1979).

Past logging in Oregon has resulted in the replacement of old-growth conifer stands with red alder stands along many forest streams, particularly those located in the Coast Range. Problems of color, taste, and odor in local water supplies have been observed where such conditions exist (State Water Resources Board, 1973). Federal, state, and local officials also recently met to review and discuss similar problems found on the Seaside municipal watershed.¹ Beyond these general observations, however, no detailed studies have been made in Oregon of domestic water quality problems caused by hardwood leaf litter. This research was therefore designed to document and evaluate this problem in a preliminary manner for the Seaside municipal watershed.

¹Meeting at Seaside Town Hall, January 29, 1981.

Field work was conducted to describe and quantify leaf litter inputs and accompanying water quality levels before, during, and after peak autumn leaf fall. Laboratory studies were designed to clarify the relationships between water quality and such variables as leaf quantity, contact time, and water flow. Water quality evaluations focused on water color, which was expected to provide a relatively simple but useful index of overall water quality and organic matter content. With respect to water treatment, the influence of the alder leaf extract (ALE) on the performance of conventional water treatment processes was investigated, including effects of chlorination on trihalomethane compound (THM) formation and disinfection efficiency, and removal potential by coagulation with polyelectrolytes.

METHODS

Field Studies

Leaf litter and stream water sampling were conducted on the Seaside municipal watershed (Figure 1), located approximately 10 km southeast of Seaside, Oregon on the South Fork of the Necanicum River (Lat. 45° 53' 35", Long. 123° 49' 55", T.5N., R. 9W., Clatsop County, Oregon). The city's diversion dam is found a few kilometers upstream of the confluence of the South Fork and the main Necanicum near state highway 26. A stream gauge located about 50 m above the diversion provides flow records (Water Resources Department, 1981).

Total watershed area is 20.2 km^2 , with three major sub-basins representing 54, 30, and 16 percent of the total area, respectively. Mid-autumn flows at the diversion in 1981 were about 1.0 m³/s, while flows at the lower portions of the three tributaries were about 0.4, 0.3, and 0.08 m³/s, respectively. Mean stream width and depth for the watershed at about this flow level (weighted by lengths of channels) were 2.6 m and 6.1 cm, respectively.

The streams on the watershed generally follow a pool-riffle-pool sequence, with pools, riffles, runs, cascades, and backwaters representing about 35, 35, 20, 7, and 3 percent of the total stream length, respectively. Channel gradients range from about 0.25 percent at the diversion, to about 2.5 percent at the lower tributaries, to about 10 percent in the upper reaches. Channel side slopes generally range from 10-25 percent, with a few over 40 percent.

The stream bottom material is quite coarse throughout the watershed, primarily comprised of cobbles and gravels. Very little large organic debris is found in the channels. Upper stream banks are generally uniform, and appear quite stable. Major soils on the Seaside watershed are deep (>lm), well-drained silt loams formed in colluvium, with organic matter contents of less than 12 percent.²

Relatively uniform red alder (<u>Alnus rubra</u>, Bong.) stands dominate the riparian zone throughout the watershed. These stands developed following harvesting of the previously-existing conifer forest, and range from 20-27 years of age. Average stem density in the streamside alder stand is about 740 trees/ha, average diameter at breast height (dbh) about 23 cm, and average tree height from 18-24 m. Tree canopy cover is quite uniform and high throughout the riparian zone, averaging about 94 percent. The heavy shading results in fairly limited and low-lying understory vegetation.

²From soil maps on file at the USDA Soil Conservation Service Office, Seaside.



Figure 1. Seaside Municipal Watershed, South Fork Necanicum River, with approximate locations of water and leaf sample points and approximate Seaside ownership, Clatsop Co., Oregon.

A network of 23 litter traps (0.25 m^2) was established at 16 stations on the watershed (Figure 1) to quantify stream leaf inputs during autumn 1981. These traps were normally emptied once a week, and the samples returned to the laboratory where non-alder material was removed (usually negligable) and the remaining samples dried at 50° C for 48 hours and weighed.

Water quality sampling generally took place in close proximity to the leaf collection sites (Figure 1). The general objectives of the water sampling were to follow through time the quality of the water: 1) just above the city diversion, 2) in upstream areas with potential influence upon downstream water quality, and 3) in in-channel and off-channel pools where leaf accumulation and slow-moving or still water occurred together.

Stream water samples were collected at the same time of leaf sampling, with two grab samples taken at each station, a general water quality sample and a dissolved oxygen (DO) sample. The DO samples were fixed in the field according to the azide modification of the Winkler method, using Hach dry chemical powder pillows (Hach Co., 1978). These and the other samples were then stored on ice and transferred to a cold room upon returning to the laboratory. DO titrations were normally conducted with 8 hours of sample collection, while the other analyses (true color, conductivity, pH, and nitrate-nitrogen) were completed within 48 hours.

The Hach DR-EL/2 field laboratory was used according to the manual (Hach Co., 1978) for the analyses of true color and nitrate-nitrogen. Electrical conductivity was measured with a portable Hach meter, model 16300. These instruments were used because they were readily available, simple to operate, and of sufficient reliability for general water quality surveys (Boyd, 1977). A calibrated Corning 130 pH meter was used to measure pH of the samples.

Stream temperatures were taken with a field thermometer at the time water samples were taken. In addition to the autumn 1981 sampling period, water sampling and analyses were conducted on a monthly basis at six stations from January through March 1982.

Laboratory Studies: Leaf Leaching

Leaching experiments were conducted under controlled laboratory conditions with dried alder leaves placed in stream water. Leaves were obtained in early November 1981 by pruning branches from standing alder trees on Oregon State University's McDonald Forest near Corvallis. The leaves were then dried at 50⁰ C for 48 hours, placed in polyethylene bags, and refrigerated until used. Water for the leachings was collected in March and April 1982 from the South Fork Necanicum. The water was kept refrigerated and then filtered with Whatman GF/F filters (effective pore size 0.7 um) prior to use. All leachings were conducted in the dark at 10° C, which was near the middle of the temperature range (6.7-13.8°C) observed on the South Fork Necanicum in autumn 1981. The leaching of soluble substances has been generally shown to be independent of temperature within this range (Petersen and Cummins, 1974; Barnes, et al., 1978).

Leaching over time in still water was evaluated using a constant leaf mass (1.0 g) and water volume (450 ml) for 9 time periods: 2, 6, 12, 24, 48, 72, 96, 336, and 648 hours. The first 7 leaching times were expected to show effects primarily due to physical leaching, while the latter 2 times were likely to include some microbial effects. Five replicate leaching jars per time period were prepared and each jar was swirled at least once a day to evenly mix the sample and to help maintain aerobic conditions.

Leaching with time in moving water was studied using three replicate recirculating chambers and the leaves and water prepared as described earlier. The leaf mass to water volume ratio was also 1g/450 ml, although proportionally larger amounts of each were used in the chambers (22.2 g/101). After the addition of the leaves, 50 ml samples were removed for analysis (and replaced with equal volumes of fresh stream water) at 2, 6, 12, 24, and 48 hours.

The effects of leaf loading on the quality of still stream water was examined with the following mass/volume ratios after 48 hours of leaching: 0.25 g/l, 0.50g/l, 1.00 g/l, 2.22 g/l, and 5.6 g/l. These loadings were considered representative of the general range encountered in nature, and the 48-hour leaching was again expected to primarily show the effects of physical leaching.

Water samples obtained from all of the leaching treatments were filtered with Whatman GF/F filters and analyzed using the procedures and equipment described previously. In addition, leaf material remaining after the leachings was dried at 50°C and reweighed to determine weight losses due to leaching.

Since the analysis of water color is solely an index of water quality, another laboratory experiment was conducted to define a relationship between dissolved organic carbon (DOC) and light absorbance in the visible (color) and ultraviolet (UV) wavelength ranges. Concentrated red alder leachate was prepared using a 6.66 g/l loading for 48 hours at 10° C. A dilution series was then prepared from filtered (Whatman GF/F) leachate and analyzed for DOC using wet oxidation and sealed ampules with an Oceanographic International Corp. (OIC) carbon analyzer (Model 0524AA). A spectral absorbance analysis was made on the dilution series samples using a double beam spectrophotometer (Hitachi model 100-60) to determine peak absorbance. No distinct peak was found so absorbance measurements were made at 455 nm (platinum-cobalt color) and 245 nm, which is used for UV analysis of a wide range of substances and is near the maximum bulb intensity of the spectrophotometer.

Laboratory Studies: Water Treatment

Laboratory studies of ALE effects on water treatment processes were conducted under controlled conditions using three leaf extract solutions or dilutions thereof. Dried, crushed alder leaves were mixed wih stream water at concentrations of 5000 ppm, 500 ppm and 50 ppm. After brief initial rigorous mixing, the mixtures were gently agitated at $10-12^{\circ}$ C for 48 hours. Small samples were removed for total organic carbon (TOC) determination at 0.3, 1, 3, 7, 23, and 40 hours. After 48 hours the extracts were filtered through a sintered glass filter and stored at 4° C for use in experiments.

Chlorine demand of alder leaf extract was determined by treating a diluted ALE solution (30 ppm TOC) with varing amounts of calcium hypochlorite. After about 20 hours at 12°C, residual chlorine was determined by amperometric titration (American Public Health Association, 1980) and chlorine demand was calculated. Several measurements were also made with 2 hour contact time to qualitatively assess the rate of leaching.

Total phenolic compounds in ALE (64 ppm TOC solution) were determined by a colormetric procedure (Singleton and Rossi, 1965). Most phenol derivatives and some non-phenolic compounds, are determined by this procedure.

Chlorination of diluted alder leaf extract was conducted in 300ml BOD bottles. Chloroform (CHCl3) formation was measured at two pH levels (7.1 and 8.5) and two chlorine levels (17 ppm and 69 ppm). TOC of the diluted extract was 16 ppm and the temperature was 12°C. Reaction times were 17, 39 and 113 hours. After reaction the chloroform was extracted into trimethylpentane and determined by gas chromatography (GC) analysis.

To assess THM formation potential of natural stream organics, stream water was obtained from the Seaside watershed on October 26, 1982 and November 12, 1982 at sample locations 1 and 7. Sample location 7 was a pool on the east tributary stream of the south fork of the Necanicum River. Sample location 1 was just upstream from the dam at the Seaside water intake. Seaside city tap water was also sampled. Stream water and hypochlorite were mixed in BOD bottles and incubated at 12°C for 48 hours. Then 10 ml solution was placed in a 15 ml vial containing excess sodium thiosulfate to reduce residual chlorine. The mixture was extracted with 2 ml trimethylpentane, and the extract analyzed for trilhalomethanes by GC.

Three of the reaction mixtures from the study of chloroform formation from ALE were combined and processed for determination of chlorinated phenolic compounds that may have formed. The principal steps in the analysis were: (1) removal of residual chlorine; (2) acidification, then extraction with dichloromethane (DCM); (3) extraction with NaOH; (4) reacidification and re-extraction with DCM; (5) concentration of DCM solution and displacment of DCM with 2-propanol; and (6) GC analysis with flame ionization detector. This procedure can detect the following phenols listed as EPA priority pollutants (Federal Register, 1979) among others: 2-chlorophenol, phenol, 2,4-dimethylphenol, 2,4-dichlorophenol, 2,4,6-trichlorophenol, 4-chloro-3-methylphenol and pentachlorophenol.

Coagulation studies were performed in a jar test apparatus with 11 beakers and variable speed paddle stirrers. The mixtures were rapidly stirred for 15 seconds after the coagulant was added. Then slow stirring was employed for 10-to-30 minutes followed by settling. ALE test solution was prepared by filtration to remove particulates, and dilution with stream water to 30 ppm TOC. The initial measured turbidity of this solution was 0.7 NTU. The flocculants tested were all from American Cyanamide Co. and included cationic (573C and 515C), nonionic (990N), and anionic (873A) flocculants.

The leaching in still water procedure was used to establish the impact of leaf leachates on the microbiological and related chlorine demand properties of the water that serves as a source of municipal drinking water. In these experiments stream water was inoculated with 0, 5, 50, or 500 ppm of dry leaf matter and analyzed at 0 to 48 hours for total coliforms (TC) and for standard plate count (SPC) bacteria using membrane filtration procedures (American Public Health Association, 1980). Samples were incubated at 10° C. After 48 hours of storage, samples were dosed wth 1.5 ppm initial free chlorine residual using a concentrated stock solution of calcium hypochlorite. The stock chlorine solution was prepared the day of use and standardized by amperometric titration. The amount of free residual chlorine remaining after 1 hour of incubation at 10° C was quantitatively determined by amperometric titration (American Public Health Association, 1980).

RESULTS

Field Studies

Alder leaf fall rates in riparian zones on the Seaside watershed ranged from about 2 $g/m^2/day$ in September to a peak of about 12 $g/m^2/day$ in late October (Figure 2). Total cumulative leaf fall between September and December was about 322 g/m^2 , which is consistent with leaf fall data that have been reported for other red alder stands in western Oregon (Zavitkovski and Newton, 1971). Leaf fall appeared fairly similar among the various trap locations, as might be expected from the relatively uniform riparian stand conditions throughout the watershed.

Water color near the city diversion during autumn 1981 ranged from about 10 to 30 platinum-cobalt units, with an average level of about 20 (Figure 2). This is slightly higher than the color observed during winter 1982 (Appendix 1). All color values are based on weekly or monthly sampling, however, and it is possible that color levels extended beyond the observed levels for short periods. An observed color level of 45 units for tap water collected in Seaside on October 27 (a day when stream sampling was not conducted) supports this possibility.

Stream water color showed a slight trend of higher levels with increasing leaf fall, but a strong relationship that may have otherwise been evident was complicated by the large fluctuations in streamflow during autumn 1981 (Figure 2). With respect to flow, relatively high and low color levels showed some tendency for occurrence on the rising and falling limbs of the hydrograph, respectively. Isolated pools within the stream channel showed some high color levels (Figure 3), while pools in partial or direct contact with flowing stream closely resembled the flowing water (Appendix 2 and 3). The tendency toward higher color levels on the rising limbs of the hydrograph may thus partially reflect the accessing of isolated pools that are highly colored.

Stream water sampling revealed no specific source area for the observed color. The east tributary (Figure 1) tended to be the most colored, especially during low flows (Appendix 2), but it also contributes the least to the flow of the South Fork Necanicum.

Stream dissolved oxygen near the city diversion remained near saturation during autumn 1981, and the accompanying water temperatures were relatively cool (Figure 4). Isolated pools



Stream flow and water color for the South Fork Necanicum River near Seaside diversion (Station 1S), and riparian zone leaf fall during autumn 1981, Seaside municipal watershed, Clatsop Co., Oregon. (NOTE: Streamflow measurements were obtained daily, while leaf fall and water color were normally measured once a week.) Figure 2.

(5/_EW) MOJJ WH3HIS

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Water color and dissolved oxygen in an isolated pool (Station 14Pb) on the east tributary during autumn 1981, Seaside Municipal Watershed, Clatsop Co., Oregon. Figure 3.

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showed some very low DO levels, although over time these DO levels fluctuated considerably (Figure 3). Water color in these pools appeared to be inversely related to the DO level, as might be expected from the presence or absence of oxygen-demanding colored organic matter.

Stream pH at the city diversion remained near neutral during autumn 1981 (Figure 5). Stream acidity appeared to slightly increase as flows and leaf fall initially became greater. Lowest pH levels on the watershed were observed in the isolated pools, but even these were only slightly acidic (pH 6.1; Appendix 2). Stream conductivity throughout the watershed was generally less than 50 mhos/cm. The highest conductivity levels occurred during the early autumn low flows and in isolated pools (Appendices 2 and 3).

Stream nitrate-nitrogen concentrations were generally highest during the early autumn low flows (0.25-0.50 mg/l), some samples 1.00 mg/l). However, the nitrate levels dropped and remained consistently low as soon as the flows increased ($\leq 0.25 \text{ mg/l}$, the effective detection limit of the technique that was used). Only selected stations were thus sampled after mid-October and these remained low in nitrate-nitrogen through the remaining sampling periods.

Laboratory Studies: Leaf Leaching

In the laboratory, alder leaf leaching in still water showed a strong relationship between color development and duration of leaching (Figure 6). After the first few hours of leaching, the rate of color generation appeared fairly constant at about 2 units per hour. This suggests a generally uniform and physical leaching process, although some cloudiness that developed between 72 and 96 hours indicated some microbial activity.

Leaf weight changes, conductivity, and pH also showed some distinct patterns with duration of leaching (Appendix 4). Most of the total leaf weight loss observed after 4 weeks of leaching (-30.7%) occurred within the first 48 hours (-22.0%), with the most rapid weight loss taking place in the first 6 hours (-10.3%). Conductivity increased rapidly also during the first 6 hours of leaching (+25 umhos/cm), after which changes were relatively small. Values for pH clearly decreased during the first few days of leaching (from 6.8 to 5.8), but after this pH moved back toward the original level, possibly due to microbial activity.

Running water was more efficient than still water in generating color from alder leaves, but this difference was only apparent for leaching times greater than 2 hours (Figure 7;







Figure 6. Relationship between water color and leaching time of red alder leaves in still water. The leaf mass to water volume ratio was 2.2 g/l.



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Appendix 5). Color development between the two treatments seemed to diverge the most between 2 and 6 hours of leaching, after which the rates of color change were similar.

Changes in the conductivity and pH of running water showed little difference from the still water leaching (Appendix 5). Changes in conductivity and pH are apparently not greatly affected by whether or not the water is moving, at least for leaching up to 48 hours.

Results of the 48-hour mass loading series leaching show a strong and positive relationship between the quantity of leaves leached and the degree of color development (Figure 8). Similarly strong relationships were also found with conductivity and pH (Appendices 6 and 7), although pH decreases with increases in leaf loading.

The percent decrease in leaf weight after 48 hours was essentially the same regardless of the initial quantity of leaves leached (Appendix 8). This indicates that there is a given, relatively uniform amount of material that is readily available for leaching per unit of leaf mass over 48 hours. Again, this points to a largely physical leaching process within this time frame.

Red alder leaf leachate showed a strong relationship between dissolved organic carbon and visible light absorbance at 455 nm (Pt-Co color) and also between DOC and ultraviolet light absorbance at 254 nm (Figures 9 and 10). Thus, a relatively simple and inexpensive measurement such as absorbance may provide a reasonable prediction of the amount of DOC present in stream water. Since these results were from laboratory conditions with alder leaves as the sole source of organic matter, however, this would have to be verified using samples collected in the field.

The color/carbon ratios for samples evaluated in this procedure were generally uniform for color levels down to about 30 units, but became variable below this (Appendix 9). In contrast, the ratios of UV absorbance to DOC were relatively constant throughout the range of measurement. The relationship developed for UV absorbance (Figure 10) may therefore be a more reliable estimator of DOC, particularly where color and the accompanying DOC levels are relatively low.

Laboratory Studies: Water Treatment

TOC values of the ALE solutions prepared for the laboratory studies are summarized in Table 1. Only the 48 hour solutions were used in treatment studies. Leaf matter recovered after 48



Figure 8. Relationship between water color and mass loading of red alder leaves in still water for 48 hours.



Figure 9. Relationship between dissolved organic carbon (DOC) in mg/l and water color (absorbance at 455 nm) in red alder leaf leachates.



UV Absorbance (254 nm)

Figure 10. Relationship between dissolved organic carbon (DOC) in mg/l and ultra violet absorbance (254 nm) in red alder leaf leachates.

hours and dried at 103°C showed a 37% weight loss, presumably as soluble (filterable through Whatman GF/C paper) organic matter.

The chlorine demand of ALE was measured after 2 and 20 hours at varying chlorine dosages (Table 2). The chlorine demand appears to be exerted in the first 2 hours of reaction time. Based on average results, chlorine demand is approximately 1.7 mg Cl₂/mg TOC, although some dependence on concentration of chlorine was exhibited.

The measurement of phenolic compounds in ALE (64 ppm solution) found 24 ppm phenolics expressed as gallic acid. Since gallic acid is 49% carbon by weight, phenolic compounds account for about 20% (12 ppm) of the TOC in the ALE solution.

Results of the effect of chlorination on chloroform formation from ALE are depicted in Figure 11. Chloroform formation was increased both at high pH (8.5 vs. 7.2) values and at elevated chlorine/TOC ratios (4.3 vs. 1.1 by weight). Chloroform formation was completed by the first measurement period (17 hours) for all but the highest pH and Cl/TOC ratio sample, which showed increasing chloroform concentration over the 113 hour total reaction time. Under these optimum conditions tested, the ratio of CHCl₃ formed/TOC is about 60 ppb CHCl₃/ppm TOC.

Table 3 summarizes stream TOC values and chloroform formed by chlorination of stream water. Chloroform greatly exceeded other THM compounds formed, two of which were tentatively identified as CHBrCl₂and CHBr₂Cl. Chloroform formation is again clearly seen to depend on Cl₂/TOC ratio, which ranged from about 0.4/1 to 2.7/1. Chlorine demand averaged about 1.2 mg Cl₂/mg TOC for the stream water, while chloroform formation at the higher chlorine dosage (8 ppm) averaged about 15 ppb CHCl₃mg TOC.

Results of the measurements for chlorinated phenolic compounds formed during chlorination of ALE proved negative. None of the compounds listed as EPA priority pollutants were detectable (lower limit of detection approximately 0.02 ppb).

Coagulation study results are summarized in Table 4. Successful coagulation, as determined by observable floc formation, was only achieved for the cationic polyelectrolyte of quaternary ammonium salt structure. Optimum dosage of the coagulant (Magnifloc 573C) was at a coagulant/TOC weight ratios of about 0.5 Interpretation of results in terms of turbidity is not meaningful, as the initial ALE solution, although highly colored, is not turbid in the sense of light reflection (NTU) measurement.

Dut no sti en tino	Leaf/W	ater Rat	io	
(hr.)	5000	500	50	
0.3	> 250	25		
1	antie dans state	37	10	
3	-	50	10	
7		50	10	
23	-	50	10	
48	630	66	10	

Table 1. Total organic carbon contents (ppm) of alder leaf extracts used in water treatment experiments.

Table 2. Chlorine demand of alder leaf extract (30 ppm total organic carbon concentration).

Run	Chlorine Dose (ppm)	Residual Chlorine (ppm)	Chlorine Demand (ppm)
20 hr. (Contact		
1	9.2	0	
2	18.4	0	
3	27.6	0	
4	36.8	0.1	37
5	46.0	7	39
6	55.0	5	50
7	64.0	10	54
8	74.0	18	56
9	92.0	31	61
2 hr. (Contact		
12	36.0	5	31
13	46.0	0	
14	55.0	4	51





				the second s			
Run	Sample Site	Sample Date	TOC (ppm)	Added Cl (ppm)	Resid. Cl (ppm)	рН	CHC13 (ppb)
l	Pool	Oct. 26	5.4	2.4	0	7.0	18
2	Pool	Oct. 26	4.0	8.0	2.3	7.2	69
3	Dam	Oct. 26	3.5	2.4	0	7.2	22
4	Dam	Oct. 26	3.0	8.0	3.1	7.3	51
5	Pool	Nov. 12	5.0	2.4	0	6.7	1
6	Pool	Nov. 12	3.5	8.0	5.5	7.3	8
7	Dam	Nov. 12	3.5	2.4	0.3	7.5	22
8	Dam	Nov. 12		8.0	5.5	7.5	36
	Dam	Oct. 26		Untreated			**BD
	Dam	Nov. 12		Untreated			**BD
14a	City Tap l	Oct. 26	3.0	*		7.5	55
14	City Tap l	Nov. 12	3.0	*		7.4	65
15	City Tap 2	Nov. 12	2.5	*		7.5	67

Table 3. Chloroform formation in South Fork Necanicum River water.

*Chlorine added by city during normal treatment. **BD = below detectability

Magnifloc Coagulant*			Result	ts		
573C:						
Dosage, mg/1	0.3	1		13	30	100
Floc Formation	no	no		yes	no	no
Turbidity, NTU						0.5
515C:						
Dosage, mg/1	0.3	1	3	10	30	100
Floc Formation	no	no	no	no	no	
990N:						
Dosage, mg/l	0.3	1	3	10	30	100
Floc Formation	no	no	no	no	no	
873A:						
Dosage, mg/1	0.3	1	3	10	30	100
Floc Formation	no	no	no	no	no	no
573C:						
Dosage, mg/1	2	4	8	16	32	64
Floc Formation	no	no	some	yes	no	no
Turbidity, NTU	0.8	1.2	2.7	1.0	1.8	0.7

Table 4. Coagulation of Alder Leaf Extract

*Structure of magnifloc coagulant (American Cyanamid Co.):

573C: quaternary ammonium

515C: resin amine

990N: polyacrylamide 873A: polyacrylamide

Table 5 summarizes the results of leaf litter leachates on the microbiological and chlorine demand characteristics of the stream water. The verified total coliform (TC) count at zero time in control water was 5/100ml while the standard plate count (SPC) for bacteria was $1.7 \times 10^4/100$ ml. Both counts are indicative of a very high quality source water. After 48 hours incubation control water controls remained essentially unchanged. These results contrast with those seen in the leaf-supplemented samples. Verified coliform counts increased by 3, 4, and 5 orders of magnitude respectively, with 5, 50 and 500 ppm of added dry leaf litter. SPC bacteria increased similarly but levels were about 100-fold higher than the TC population.

Chlorination of the control water was effective in eliminating coliforms. However, chlorination of the amended samples only reduced coliform counts about 10- to 100-fold. The chlorine demand was significant in all samples except in the control.

Sample	Prechlo TC	rination SPC	Postchlo TC	rination SPC
Control (0-time)	5	1.7x10 ⁴	N.D.	N.D.
Control (48-hr)	13	1.4x10 ⁴	0 (0.04FRC)	1.6x10 ³
5 ppm Leaves (48-hr)	1.1x10 ³	4.3x10 ⁴	1.8x10 ² (No FRC)	1.9x10 ⁴
50 ppm Leaves (48-hr)	2.4x10 ⁴	8.8x10 ⁵	4.0x10 ² (No FRC)	8.2x10 ⁴
500 ppm Leaves (48-hr)	1.1x10 ⁵	2.3x10 ⁷	1.9x10 ⁴ (No FRC)	1.3x10 ⁷

Table 5. Influences of Alder Leaf Leachates on Microbial Regrowth and Chlorine Demand of Necanicum River Water

TC, SPC: Total coliforms, standard plate count bacteria
N.D.: Not determined
FRC: Free residual chlorine (ppm)

Samples were chlorinated after 48-hr of circulation at 10°C. The chlorine dose was initially 1.5 ppm FRC.

DISCUSSION AND CONCLUSIONS

The field study showed that stream water color at the city of Seaside diversion was slightly higher during the September 1982 low flow period than during winter 1982. This early autumn color level (about 20 units) is also slightly higher than the maximum standard of 15 units set for drinking water by the U.S. Public Health Service (U.S. Public Health Service, 1961). This is a relatively low color level, however, and probably would not generate many complaints or aesthetic concerns.

Other water quality parameters that were measured on the Seaside watershed in 1981 were consistent with the observation that autumn leaf fall did not have a substantial chronic impact on low flow water color in 1981. For example, DO concentrations remained near saturation at all of the flowing stream sample stations. Conductivity did not show much difference between fall and winter values. The stream pH was somewhat higher during the low flow period than at other times, but remained near neutral.

On several occasions in autumn 1981 significant color levels were observed in the stream or in Seaside tap water on or near the rising limb of storm flows. This suggests that as flows rise, storage sites for leaf material and dissolved organics (e.g. isolated pools, dry portions of the stream channel, streamside areas, soil, and roadside drainages) are accessed and enough material is quickly added to increase water color. This condition would be expected to occur only a few times each autumn during the first few storms, when there is an opportunity for organic matter to accumulate between storms.

Of the several possible sites of organic matter that could have contributed to the observed color increases during increasing flows on the Seaside watershed, no single source stands out. Isolated pools were present but were not abundant or large. Soils on the watershed are not high in organic matter, which otherwise can contribute significantly to water color (Christman and Ghassemi, 1966). Thus, a variety of sources may be important in the observed patterns of varying water color.

The laboratory results demonstrate the potential for alder leaves to cause rapid and substantial changes in stream water color. Appreciable increases in water color occurred after just 2 hours contact time and color continued to increase for up to 4 weeks of leaching. A relatively constant rate of color generation was observed over this period, which suggests that physical leaching is the primary mechanism for the removal of colored compounds. Running water is generally more efficient than still water in removing colored compounds from alder leaves, very likely because material is quickly carried away from the leaf surfaces. Rapid removal of material is probably less of a factor shortly after the initial addition of leaves to water, however, as shown by the lack of differences in color development between still and running water after only 2 hours of leaching.

Water color after 48 hours of leaching appears to be directly related to the mass of alder leaf material added per unit volume of water. In addition, the percent weight loss of the original dry weight of leaves seems constant regardless of the mass loading level, indicating that there is a limit to the amount of material that can be physically leached from a given leaf mass over a short period. Where alder leaves are the dominant source of organic matter, therefore, a primary factor that would determine water color is the ratio of leaf mass to water volume. Where leaf inputs are uniform, the controlling factors would be flow and contact time. Watershed characteristics such as area and morphology would obviously be important in influencing stream flow and velocity and the subsequent dilution and contact time of water with leaf material.

A rough calculation of expected water color at the Seaside diversion under very low flow and high leaf inputs produced an estimated color level of 108 units (Appendix 10). This calculation was based on several assumptions derived largely from the field and laboratory observations. These included the use of the lowest monthly flow occurring in the last 5 years (0.1 m³/s, August 1979) and the peak leaf fall rate during autumn 1981 (11.7 $g/m^2/day$). A similar calculation for moderate flow conditions produced an estimated color level of 15 units. Actual water color during peak 1981 leaf fall and similar flows was about 20 units, which lends support to the estimated value for the low flow situation.

Other variables can affect water color besides those considered in the above estimate, however, including the input of colored compounds from sources other than direct leaf fall and the removal of colored matter by microbial activity. The calculation is therefore not intended to be a precise prediction of water color level but rather a demonstration of the potential for alder leaves to cause significant color development on the Seaside watershed.

Based on the field and laboratory observations and the above estimation, a stream the size of the South Fork Necanicum appears to normally be too large to show chronic water quality problems due to autumn leaf inputs. Water color in this stream system can certainly reach noticeable levels, but such conditions should normally be sporadic and short-lived. Chronic color and other water quality problems from leaf litter could, however, occur on other Northwest watersheds. Stream systems with lower flows and similar leaf inputs, streams with many pools or slow velocity, and small reservoirs with significant leaf inputs are some situations that could produce such problems. It is essential that each watershed and water supply system be carefully examined to accurately evaluate existing and potential water quality problems that may be attributable to hardwood leaf litter inputs.

With respect to water treatment processes, extracts from leaf litter significantly affect chemical and microbiological aspects of the chlorination process. At least partial removal by coagulation with cationic polyelectrolytes appears feasible, although an investigation of the effects of a complete conventional treatment process sequence (coagulatant addition, flocculation, sedimentation, and granular media filtration) was not undertaken.

Dissolved organic carbon (measured as TOC) was shown to leach rapidly from alder leaves, producing an alder leaf extract (ALE) or "tea". Approximately 20% of the ALE organics were attributable to phenolic compounds. The remainder of the extracted organics are expected to be predominately cellulosic or nitrogen-based compounds.

Upon chlorination, chlorine demand exerted by ALE was in the range of 1.7 mg Cl2/mg TOC, while for stream water the demand was about 1.2 mg Cl2/mg TOC. The somewhat lower demand of the stream water organics can be attributed to several factors, including their heterogeneous nature and their likely higher oxidation state due to previous microbial degradation. Chlorine demand of this magnitude can significantly influence disinfection efficiency and maintenance of a free chlorine residual in the Seaside water distribution system. It was not determined whether elevated TOC concentrations in the water supply exist for sufficient durations to justify direct removal of TOC by additional treatment processes.

Chlorination of organic compounds in water supplies is known to generate numerous chlorinated organic compounds, predominantly in the trihalomethane (THM) family (e.g., Symons et al., 1975). Many of the compounds formed, including THM's, are thought to be carcinogenic (National Academy of Science, 1980). In this study, optimum conditions tested (pH 8.5, Cl2/TOC ratio = 4.3/1) produced 60 ug CHCl3/mg TOC for ALE. Thus, a concentration of only 2 ppm ALE in a water source could produce THM's upon chlorination that exceed the 100 ppb recommended drinking water standard (Federal Register, 1982). Chlorination of organic matter in the stream water produced about one-fourth the CHCl₃ per mg TOC as was produced by ALE, although the uncertainty in this number is rather large because of the low TOC value. The maximum chloroform concentration produced was 69 ppb, which is close to the maximum measured in Seaside tap water on two sample days (67 ppb) and well within the drinking water standard.

Chlorinated phenolic compounds and other phenols listed as EPA priority pollutants were not formed in detectable concentrations by chlorination of ALE. Despite the relatively high concentration of phenolic compounds in ALE (20% of the TOC), they apparently are unreactive with chlorine under the conditions of the experiment.

Coagulation with cationic polyelectrolytes may prove at least partially successful in removing organic compounds from ALE. Floc formation was achieved with a quarternary ammonium structured material (percent active compound not listed) at a coagulant/TOC weight ratio of 0.5/1, although dosages would be expected to vary considerably in the stream water as the concentration and consistency of suspended solids changed. The fraction of TOC removable by a complete sequence of coagulant addtion, floculation, sedimentation, and granular media filtration was not investigated. Thus, the overall effect of coaguation on THM formation can not be assessed.

The impact of leaf litter leachates on the regrowth of TC and SPC bacteria were quite dramatic. The total coliform indicator population increased 10 thousand to 100 thousand-fold in just 2 days of incubation at 10° C. Since the river supplies the water for the community of Seaside, the regrowth of the indicator population could cause sporadic occurrences of coliform-positive water samples in the distribution system. The presence of such coliforms resulting from regrowth on leaf leachates would not present a health problem since pathogens would not be expected to regrow under these conditions.

The influx of soluble organic matter into the distribution system could also promote the regrowth of bacteria already present in the system, especially in reservoir sediments and at dead-end locations. Regrowth would be highly undesirable since this would lead to deteriorated water quality and to possible coliform positive samples leading to noncompliance with the Safe Drinking Water Act Regulations. Coliform positive samples resulting from regrowth on nutrients leached from leaves could also lead to politically and socially unacceptable effects, including the false impression that a health hazard may exist for the consumer.

Of serious concern is the chlorine demand exerted by even low concentrations (0.05 g/liter) of leaves. Once the disinfectant becomes inactive, microorganisms in the water, including

pathogens, have access to the distribution system. The chlorine demand exerted by leaves would probably be greatest at the time of initial fall flushing of the watershed. It is at this time when the greatest coloration of distribution water is noted. It is recommended that cautions be taken during this time of the year to especially insure that free residual chlorine is present at all locations of the distribution system.

It is of course not possible to state definitively that the leaves deposited in the river cause the same magnitude of problems observed in the laboratory experiments. However, the occurrence of colored matter in tap water drawn from the distribution system, especially in the fall, clearly indicates some impact of leaves on drinking water quality. The level of DOC, the chlorine demand, and the concentration of the microbial populations actually entering the public water supply at the intake was unfortunately not monitored in this study. Procedures are readily available to establish these relevant measurements and it is recommended that some attempt be made to investigate these parameters during the time of the major watershed flushout in the fall (LeChevallier, Evans, and Seider, 1981).

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APPENDICES

Appendix 1. Stream water quality during winter 1982, Seaside Municipal Watershed, Clat-sop Co., Oregon

		Apparent ¹	True ²	÷			Dissolved	-
Date	Station #	Color (units)	Color (units)	Turbidity ⁺ (NTU)	Conductivity (µmhos/cm)	Hd	Oxygen (mg/1)	Temperature (°C)
Jan 26	1s	25	S	2.3	35	6.7	11.9	8.0
	5 S	20	S	2.2	34	6.7	12.0	8.0
	6s	20	ŝ	2.1	34	6.8	11.8	8.0
	7s	20	S	1.6	31	6.6	11.8	8.0
	8s	20	S	2.1	34	6.8	12.0	7.8
	12s	20	S	2.3	37	6.9	12.0	8.0
Feb 16	1s	30	15	3.5	30	6.6	12.1	7.8
	5s	30	15	3.2	30	6.6	12.3	7.8
	6s	25	10	2.7	29	6.6	12.1	8.0
	7s	25	15	2.0	27	6.6	12.0	8.3
	8s	25	10	3.2	28	6.6	12.3	7.8
	12s	25	10	3.3	31	6.7	12.2	7.8
Apr 4	1 s	10	:	0.56	42	6.8	12.6	6.9
	5s	10	;	0.49	41	6.9	12.6	6.9
	6s	10	;	0.57	40	6.9	12.4	7.2
	7 S	10	1	0.71	34	6.8	12.4	7.5
	8s	10	!	0.41	39	6.8	12.6	6.7
	12s	10	!	0.41	43	7.0	12.5	7.2

¹Unfiltered samples ²Filtered samples

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Water quality data for pools in direct contact with stream flow (2P,5P, 9Pa) sampled autumn 1981, Seaside Municipal Watershed, Clatsop Co., OR Appendix 2A.

					S	ampling p	oints					6	
		co	lor	Col	nduct	ivity		ци		Di	ssolve	4 0 ⁴	
		un)	its)	ت ا	umhos,	(cm)	2	цц			(mg/1)		
Date		2P 5	P 9P	a 2P	SP	9Pa	2P	SP	9Pa	2P	5P	9Pa	
Sep 9		1	- 20	1	1	51	:	:	7.0	ł	2 1 1	7.2	2
Sep 16		20 -	- 20	51	ł	52	7.0		7.2	9.9	1	9.5	
Sep 23		20 -	- 30	51	;	50	7.2	1	7.2	11.4	1	8.9	
Sep 30		2	0 20	;	40	40	1 1 1	1	7.0	10.6	10.9	11.0	- 12
0ct 6		:	:	1	1	1	1		111	1 1 1 1	t 1 1	1 1 1	
0ct 12		- 01	- 10	42	*	42	7.0	1	7.0	11.6	8 6 9	11.5	
0ct 21		5 1	5 15	46	46	47	7.1	7.1	7.1	11.6	11.5	11.3	
Oct 28		20 2	0 20	35	35	35	6.8	6.8	6.8	10.6	11.0	11.2	
Nov 4	1	10 1	0 10	44	42	45	7.1	7.1	7.1	11.9	12.0	11.8	
Nov 11		25 2	5 40	44	44	39	7.0	7.0	6.9	10.6	10.8	10.6	
Nov 18		10 1	5 15	39	39	40	6.8	6.9	7.0	11.6	11.6	11.1	
Nov 24		10 1	5 10	41	41	41	7.0	7.1^{1}	7.1	12.1	11.8	12.1	
Dec 2		- 02	- 15	32	1	34	6.7	1	6.7	11.7	1 	11.7	
¹ pH dat	a for	this	date	actually	from	sample p	oint 55	, which	1 Was	expected	to be		

nancedva Mas MILLCH sampre point LOW actually ph data for this date very similar to 5P.

Water quality data for pools with indirect contact with stream flow (9Pb, 13Pa, 16p) sampled autumn 1981, Seaside Municipal Watershed Clatsop Co., OR Appendix 2B.

			Co	lor		Cond	uctiv	npling /ity	Points	Hd		Di	ssolved	1 0 ²
Dat	e	d6	b 13	L cont	L6P	9Pb	13Pa	.m.) 16P	99b	13Pa	16P	9Ph	(13pa	1 6 n
														12-
Sep	6	10	-	0	10	51	43	44	7.0	6.5	7.0	7.4	3.4	8.5
Sep	16	15	2	0	10	49	55	45	7.1	6.8	7.1	8.1	1.4	8.9
Sep	23	20	2	0	50	51	56	45	7.2	7.0	7.0	8.4	7.2	7.9
Sep	30	20	-	5	L5 .	41	44	35	7.0	7.1	6.9	10.8	10.7	11.1
Oct	9	1	1	•	1	ł	1	1	1	1 1 1	1 1	1	1 1 1	
Oct	12	10	-	•	5	42	47	ļ	7.0	7.2	1	11.5	11.4	1 1 1 1
Oct	21	20		5 1	S	47	48	41	6.9	7.0	7.0	10.8	11.3	11.3
Oct	28	20	2	5	0	36	38	30	6.8	6.9	6.7	11.1	10.8	10.9
Nov	4	10	1	0 1	0	44	46	40	7.1	7.1	7.1	11.6	11.7	11.3
Nov	11	40	3	0 5	0	39	43	36	7.0	7.0	6.7	10.5	10.8	10.6
Nov	18	10	Ч	5 1	0	40	41	35	7.0	7.1	6.9	11.5	1 1 1 1	11.5
Nov	24	10	ī	0 1	0	41	44	36	7.1	7.2	7.0^{1}	11.9	12.0	11.8
Dec	2	15	F	0	5	34	36	:	6.7	6.9	6.61	11.7	11.7	11.4
1 pH to	data 16P.	for t	hese	date	es act	tually	from	1 16S,	which we	re exp	ected t	to be v	ery sim	ilar

Water quality data for isolated pools (13Pb, 14Pa, 14Pb) sampled during autumn 1981, Seaside Municipal Watershed, Clatsop Co., OR Appendix 2C.

					San	npling	Points					
		Colo1 (units	ر م	Conc (µn	luctiv nhos/c	/ity m)	z	Hd		Dis	solved (mg/1)	70 70
Date	13Pb	14Pa	14Pb	13Pb	14Pa	14Pb	1.3Pb	14Pa	14Pb	13Pb	14Pa	14Pb
Sep 9	15	20	50	53	57	48	6.8	6.6	6.4	3.4	3.2	1.2
Sep 16	10	20	70	41	50	55	7.0	7.2	7.1	3.5	2.8	0.1
Sep 23	15	25	40	47	64	50	6.8	6.7	6.4	6.0	2.8	3.0
Sep 30	15	25	30	47	45	45	6.9	6.7	6.5	9.8	9.4	7.1
0ct 6	;	;	1 1	1	1 1	1	1	•	1	1 1 1	1	
0ct 12	5	15	10	48	44	40	7.0	6.8	6.7	10.1	8.8	8.9
Oct 21	15	25	30	48	57	48	7.1	7.0	6.3	9.8	6.1	3.8
Oct 28	20	25	25	39	40	34	6.9	6.6	6.5	8.7	8.9	10.2
Nov 4	10	20	30	45	42	44	6.8	6.4	6.3	10.6	8.8	5.8
Nov 11	35	100	06	44	54	40	6.7	6.4	6.1	9.7	8.1	6.3
Nov 18	10	15	10	42	38	36	6.9	6.2	6.6	11.6	9.8	11.3
Nov 24	10	10	15	45	40	38	6.7	6.2	6.3	11.0	9.2	11.2
Dec 2	10	15	20	37	31	31	6.9	6.5	6.6	11.7	11.2	11.2

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		•			Sa	mplin	ng Poin	its					
Date	1S	3S ¹	5S	6S	7S	8S	10S	11S	12S	135	14S	15S	16S
Sep 9	20	15	15	10	30	15	15	15	10	10	30	S	15
Sep 16	15	15	15	15	30	20	15	10	10	10	30	S	10
Sep 23	20	20	25	20	30	20	20	20	10	10	30	10	20
Sep 30	20	20	20	20	25	20	20	15	15	15	20	10	15
0ct 6	30	;	;	;	;	;	30	20	;	;	:	25	1
0ct 12	10	10	10	10	15	10	10	10	10	10	15	S	10
0ct 21	20	15	15	15	15	15	15	15	15	10	20	S	15
Oct 28	20	1	20	20	25	20	20	20	20	20	25	20	20
Nov 4	10	1	10	10	20	10	10	10	S	S	20	0	S
Nov 11	25	1	30	35	40	50	40	40	30	30	40	35	50
Nov 18	10	1	15	10	10	15	15	10	15	10	10	10	10
Nov 24	10	1	15	10	10	10	10	ഹ	10	10	10	10	10
Dec 2	20	1	15	20	15	15	15	15	15	10	20	10	20

Water color for stream stations sampled during autumn 1981, Seaside Mu-nicipal Watershed, Clatsop Co., OR. (color given in Pt-Co units) Appendix 3A.

^{1}From October 28 on Station 3S was not sampled because it was so similar to Station 1S in water quality.

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Appendix 3	3B.	Dissolve	d oxyge	en (mg/1) of	sampled	strea	m water	during	autumn	1981.	Sea-
		side Mun	icipal	Wat	ershe	, be	Clatsop (00	R	2			1

Date					a	ampiin	g Poin	ts					
	1S	3S	5S	6S	7S -	8S	10S	11S	12S	13S	14S	15S	16S
Sep 9	10.9	9.8	10.3	9.5	8.7	9.2	9.8	9.7	9.5	1	8.5	9.9	9.7
Sep 16	10.8	11.2	9.6	11.4	9.2	10.4	11.0	11.3	10.3	9.7	10.3	10.2	10.5
Sep 23	9.9	10.8	10.3	9.6	10.4	8.7	10.1	10.8	10.0	9.6	10.6	8.4	9.8
Sep 30	10.4	11.0	10.8	10.8	10.7	11.1	11.2	11.0	11.4	11.2	10.7	10.9	10.6
0ct 6	1 1 1	 	1 1 1 1	1 1 1 1	1 1 1 1	1 1 1 1	t 1 1	 		1 1 1	1 1 1	1 1 1	111
0ct 12	11.7	11.9	11.6	11.6	12.0	11.6	11.6	11.6	11.4	11.5	12.5	11.3	11.5
0ct 21	, 11.8	11.5	11.5	11.6	11.4	11.6	11.6	11.5	11.4	11.5	11.3	11.2	11.3
Oct 28	10.4	* * *	10.8	10.6	1 1 1 1	10.8	1 1 1	1	10.9		10.6	11.0	11.0
Nov 4	11.7		12.0	11.6	11.6	11.9	1 1 1 1	1 1 1	11.8		1 1 1	11.7	11.6
Nov 11	10.5	1	10.8	10.5	10.2	10.9	L I I 1	1 1 1	10.5	1 1 1 1 1 1	1 1 1 1	10.9	10.7
Nov 18	11.6	1 1 1 1	11.6	11.4	11.1	11.6	1 1 1 1	111	11.7	1 1 1 1	1 1 1	11.7	11.6
Nov 24	12.1	1 1 1 1	12.2	12.0	11.9	12.0	1 1 1 1	1 1 1	12.0	1		11.8	11.8
Dec 2	11.5	1 1 1	11.6	11.6	11.5	11.9	1 1 1	r 1 1	11.7	1 1 1	1 1 1	11.7	11.8

the dissolved oxygen seemed to remain fairly constant among stations in the same stream reach. Therefore, Station 3S was assumed to be the same as 1S, Stations 10S and 11S the same as 8S, Station 13S the same as 12S, and Station 14S the same as 7S, From October 28 on only certain stations were sampled for dissolved oxygen because from October 28 on.

Water-
Municipal
Seaside
1981,
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water Co.,
stream Clatsop
of d,
pH she
3C.
Appendix

					Sé	ampling	g Point	S					
Date	1S	3S	5S	6S	7S_	8S	10S	11S	12S	13S	14S	15S	16S
Sep 9	7.2	7.1	7.2	1 4 1	7.1	7.1	1 1 1	:	7.2	1		7.2	7.1
Sep 16	7.1	1	7.2	:	7.0	7.2	1 1 1	1	7.2	1 1	;	7.3	7.2
Sep 23	7.2	1 1 1	7.2	1 1 1	6.9	7.2	1	1	7.3	1 1 1	1	7.2	7.1
Sep 30	6.9	1 1 1	6.9	1 1	6.8	7.0	111	1	7.1	1	1	7.1	7.0
0ct 6	6.6	1 1 1	1 1 1	111	1	:	6.6	6.7	1	1		6.8	
0ct 12	6.9	1 1 1	7.1		6.9	7.0	1	1	7.2	1 1	1 1 1	7.2	6.9
Oct 21	7.1	7.0	7.1	6.9	6.8	7.1	7.1	7.0	7.2	7.2	6.8	7.1	1 2
Oct 28	6.8	1 1 1	6.9	6.8	6.6	6.8	6.9	6.8	6.9	6.8	6.7	7.0	6.8
Nov 4	6.9	1 1 1	7.1	7.1	6.9	7.1	7.1	7.0	7.2	7.2	6.9	7.1	7.1
Nov 11	6.9	1 1 1	7.0	6.9	6.8	6.9	6.9	6.8	7.0	7.0	6.8	7.0	6.7
Nov 18	6.7	1	6.9	6.8	6.7	7.0	7.0	6.9	7.0	7.0	6.7	7.1	6.9
Nov 24	7.0	1	7.1	1	6.9	7.1	1	1	7.2	1	1	7.1	7.0
Dec 2	6.7	1	6.8	1	6.6	6.7	1 1 1	5 1 1	б.9	1 1 1	1	6.8	6.6
Becaus	e of t	imis at	ilarit)	in pł	I betwe	sen ste	ations	in the	same	stream	reach	not	a11
or dama		anaty	INT DO?	· hid	TC MG	incep o	nall nall		MOTTO	ns Sur	aLLUIS	nau	au

same pH: 1S and 3S; 5S and 6S; 7S and 14S; 8S, 10S and 11S; 12S and 13S. pH meas-urements were not begun until October and it was after a few weeks of analyzing for pH that it was decided to only analyze certain samples.

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		-			Sa	mpling	Point	ts					
Date	1S	3S ¹	5S	6S	_27	8S	10S	_11S	12S	13S	14S	15S	16S
Sep 9	54	52	51	52	49	51	51	45	52	53	50	52	44
Sep 16	48	51	50	47	50	49	51	45	51	51	50	52	44
Sep 23	52	52	51	52	51	50	50	46	52	51	51	55	45
Sep 30	42	41	41	43	41	40	41	38	44	43	42	47	34
0ct 6	30	1	;	;	;	;	28	28	;	1	1	30	1
0ct 12	42	42	42	43	39	42	42	39	46	46	37	45	37
0ct 21	46	46	46	46	42	47	47	42	48	48	41	49	41
Oct 28	34	;	35	35	36	35	35	33	38	38	34	39	30
Nov 4	44	;	43	45	37	44	42	40	50	45	37	45	40
Nov 11	46	;	43	41	38	40	39	35	44	43	37	41	37
Nov 18	38	ł	39	39	36	40	39	36	42	42	- 36	42	35
Nov 24	43	1	41	41	36	41	41	38	44	44	36	43	36
Dec 2	32	;	33	33	30	33	34	31	36	36	30	35	28

Appendix 3D.

From October 28 on Station 35 was not sampled because it was so similar to Station 1S in water quality.

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Time (hrs)	Color (units)	Conductivity (umhos/cm)	рН	Leaf Weight Change (%)
0	0	41	6.8	0
2	15	53	6.6	- 5.2
6	22	66	6.4	-10.3
12	34	72	6.3	-13.9
24	58	78	6.2	-16.6
48	90	82	6.0	-22.0
72	133	83	5.8	-22.5
96	198	89	5.9	-23.7
336	655	100	6.5	-26.4
648	1310	97	6.5	-30.7

Appendix 4. Water color, conductivity, pH, and leaf weight changes with time during leaching of red alder leaves in still water^{1,2}.

¹Leaf mass to water volume ratio was 2.2 g/1

²Values listed are means of 5 replicates. pH means obtained by converting pH to [H⁺] (antilog pH), averaging and converting back to pH.

Di	fference ± 95% C.I. ²	
Color (units)	Conductivity (µmhos/cm)	pH
n.s. ⁴	n.s.	n.s.
n.s.	n.s.	0.23
26±9	n.s.	n.s.
34±18	n.s.	n.s.
44±23	8±5	n.s.
50±26	n.s.	n.s.
	Di: Color (units) n.s. ⁴ n.s. 26±9 34±18 44±23 50±26	$\begin{array}{r c c c c c c c c c c c c c c c c c c c$

Appendix	5.	Differences in color, conductivity, and pH	
		between still and running water laboratory	
		leaching of red alder leaves ¹	

¹The leaf mass to water volume ratio in both situations was 2.2 g/1.

²Differences in means between still and running water treatments with 95% confidence interval at given times.

³Because of the log relationship between pH and [H⁺] it was not possible to convert differences with 95% confidence intervals from [H⁺] back to pH units. Therefore, confidence intervals not shown.

⁴n.s. indicates no significant difference between the two treatments (two tailed t-test, $\alpha = 0.5$).



Leaf mass to water volume ratio (g/1)

Appendix 6. Relationship between pH and mass loading of red alder leaves leached in still water (laboratory) for 48 hours





Leaf Mass to Water Vol. Ratio	Color (units)	Conductivity (umhos/cm)	рН	Leaf Weight Change (%)
0.00	0	41	6.7	0
0.25	19	49	6.6	-24.2
0.50	29	54	6.5	-23.0
1.00	55	65	6.3	-24.8
2.22	94	88	5.9	-24.0
5.56	225	170	5.3	-25.3

Appendix 8. Water color, conductivity, pH, and leaf weight changes with changes in mass loading of red alder leaves in still water¹.

 1 Values listed are means of 5 replicates. pH means obtained by converting pH to [H^+] (-antilog pH), averaging and converting back to pH.

Appendix 9.	Color/carbon and UV absorbance/carbon ratios in red
	alder leaf leachates of varying concentrations.

DOC (mg/l)	Color (units)	Absorbance (@ 254nm)	Color/Carbon Ratio	Abs/Carbon Ratio
740	305		0 //1	
493	200		0.40	
370	150		0.40	
247	100		0.40	
185	70	3.50	0.38	0.019
148	60	2.63	0.40	0.018
111	40	1.91	0.36	0.017
74.0	30	1.271	0.40	0.017
37.0	20	0.638	0.54	0.017
29.6	15	0.513	0.51	0.017
14.8	10	0.254	0.67	0.017
7.4	10	0.118	1.35	0.016
3.7	5	0.062	1.35	0.017
1.41	0 .	0.031	0	0.020

¹although shown here as platinum cobalt units, these values are directly related to absorbance at 455 nm.

Appendix 10. Estimated water color at city of Seaside diversion under conditions of moderate and low flow and high leaf input.

 Maximum travel time of in-channel water (contact time of water with leaves)

The longest stream distance in the watershed is from the diversion to the uppermost reach of the west tributary. This distance was estimated from a USGS 15' quadrangle at 6,915 m (22,680 ft).

The water velocity was taken as the average of the velocities measured at the mouths of the three main tributaries in May 1982, 0.4 m/s. This is a weighted mean using the percent of the total flow (1.0 m³/s) found in each tributary as the weights:

Ave. Velocity(V) = $\frac{(0.29 \text{ m/s})(0.1)+(0.53 \text{ m/s})(0.52)+(0.30 \text{ m/s})(0.38)}{0.1 + 0.52 + 0.38}$

 $V = 0.4 \, \text{m/s}$

Therefore,

 $\begin{array}{rcl} \max. \ travel \\ time(t) \end{array} &= (6915m)x(1s/0.4m)x(1hr/3600s) \\ t &= \underline{5 \ hr} \end{array}$

2) Leaf loading to stream

a) Stream surface area

Measurements of stream width and depth were made at the same time as the velocity measurements (May 1982, flow = $1.0 \text{ m}^3/\text{s}$).

- mean channel width, streams > 3rd order = 6.8 m
- mean channel width, streams < 3rd order = 1.8 m
- channel length, streams > 3rd order¹ = 9,453 m
- channel length, streams < 3rd order¹ = 50,122 m

Weighted mean stream width(w) = $\frac{(6.8m)(9453m) + (1.8m)(50,122m)}{(9453m) + (50,122m)}$

w = 2.6 m

¹from USGS 15' quadrangle

Total stream channel length¹ = 59,575 m Total stream surface area(a) = (2.6m)(59,575m)a = $1.55 \times 10^5 m^2$

b) Leaf input

Highest leaf input rate observed during autumn 1981 was assumed: $11.7g/m^2/day$ (Oct 21-28, 1981). Also assumed that low flows prevail for a week and leaves thus accumulate in channel for 7 days.

leaf input = $(11.7 \text{ g/m}^2/\text{day})(7 \text{ days}) = 81.9 \text{ g/m}^2$

Total Stream Leaf Loading(m) = $(81.9g/m^2)(1.55 \times 10^5 m^2)$ m = $1.27 \times 10^7 g$

3) Water volume during moderate flow

The volume of water receiving the above leaf mass was assumed to equal the volume of water flowing at the diversion over a 5 hour period. the flow during the above stream measurements was $1.0 \text{ g}^3/\text{s}$, which is similar to the flow during peak leaf fall in 1981.

Water Volume (ℓ) = (1.0m³/ ℓ)(1000 ℓ /m³)(3600s/h)(5hr) ℓ = <u>1.8 x 10⁷ ℓ </u>

Leaf mass to water volume ratio

If the leaf mass (m) is evenly distributed along the channel so that the water encounters a constant mass as it travels:

$$\frac{\text{leaf mass(m)}}{\text{water vol (l)}} = \frac{1.27 \times 10^7 \text{g}}{1.8 \times 10^7 \text{l}} = \frac{0.7 \text{ g/l}}{1.8 \times 10^7 \text{l}}$$

from USGS 15' quadrangle

5) Estimated water color at moderate flow

From the relationship in Fig. 8 (y = 39x + 8), the color generated in still water after 48 hours is:

for 0.7 g/ ℓ , y = 39(0.7) + 8 = <u>35 units</u> for 2.2 g/ ℓ , y = 39(2.2) + 8 = 94 units

From the relationship in Fig. 6 (y = 2x + 2.6), the color generated from 2.2 g/ ℓ loading after 5 hours is 12.6 units (y = 2(5) + 2.6).

However, since actual and predicted color values show a more significant disparity with shorter leaching times, Figure 7 was instead used to obtain an estimated color level of 20 units for 2.2 g/^g loading after 5 hours in still water.

Assuming a uniform relationship to color between the 0.7 g/ $_{\ell}$ and 2.2 g/ $_{\ell}$ loading levels, the estimated color generated from 0.7 g/ $_{\ell}$ after 5 hours in still water is therefore:

 $(20 \text{ units})(0.37^*) = 7.4 \text{ units}$

 $*0.37 = \frac{35 \text{ units } (0.7 \text{ g/l color } 0.48 \text{ hr})}{94 \text{ units } (2.2 \text{ g/l color } 0.48 \text{ hr})}$

Finally, since Figure 7 also shows that for 5 hours of leaching, running water produces about twice the color level of still water, the estimated color for the assumed high leaf input and moderate streamflow is:

 2×7.4 units = 15 units

This estimated color level is consistent with the stream color measured during October 1981, when the flows and leaf inputs used in the calculation actually occurred.

6) Estimated water color at low flow

In this calculation the previously-used leaf input level was assumed, as were the stream dimension and velocity values, since low flow measurements were not made.

Stream flow was assumed to be 0.1 m^3/s (4 cfs), which represents the lowest flow observed during the five years of record (Aug. 1979). This represents the following volume of water flowing past the city diversion over five hours:

$$\ell = (0.1 \text{ m}^3/\text{s})(1000 \ \ell/\text{m}^3)(3600 \text{ s/hr})(5 \text{ hr})$$

 $\ell = 2.04 \times 106 \ \ell$

The leaf mass to water volume ratio is therefore:

 $\frac{\text{leaf mass (m)}}{\text{water vol (l)}} = \frac{1.27 \times 10^7 \text{g}}{2.04 \times 10^6 \text{g}} = \frac{6.2 \text{ g/l}}{6.2 \text{ g/l}}$

Using the above procedure to estimate water color under these conditions:

6.2 g/l stil @ 48 hr (l water color = 3 Fig. 8)	9(6.2) + 8 = 250	units
6.2 g/% runn color @ 5	ing water = (hr	20*)(2.7**)(2**)	= 108 units
*20 =	2.2 g/& color @ 5	hours (Fig. 7)	
**2.7 =	250 units (6.2 g/& 94 units (2.2 g/&	color @ 48 hr) color @ 48 hr)	
***2 =	running water colo color @ 5 hr	r is 2x still wat	ter

NOTE: Since many assumptions and simplifications were made, this calculation is unlikely to be a precise prediction of color level. It is instead intended to demonstrate the potential for alder leaves to cause significant water color on the Seaside watershed.