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STATE OF WASHINGTON
John Spellman
Governor

DEPARTMENT OF ECOLOGY
7272 Cleanwater Lane, Olympia, Washington 98504

MEMORANDUM
February 9, 1981

To: John Hodgson

From: John Bernhardt and Tim Determan

Subject: Omak Groundwater Contamination

Our review of the Omak groundwater quality data submitted by your office follows.

PROBLEM DESCRIPTION

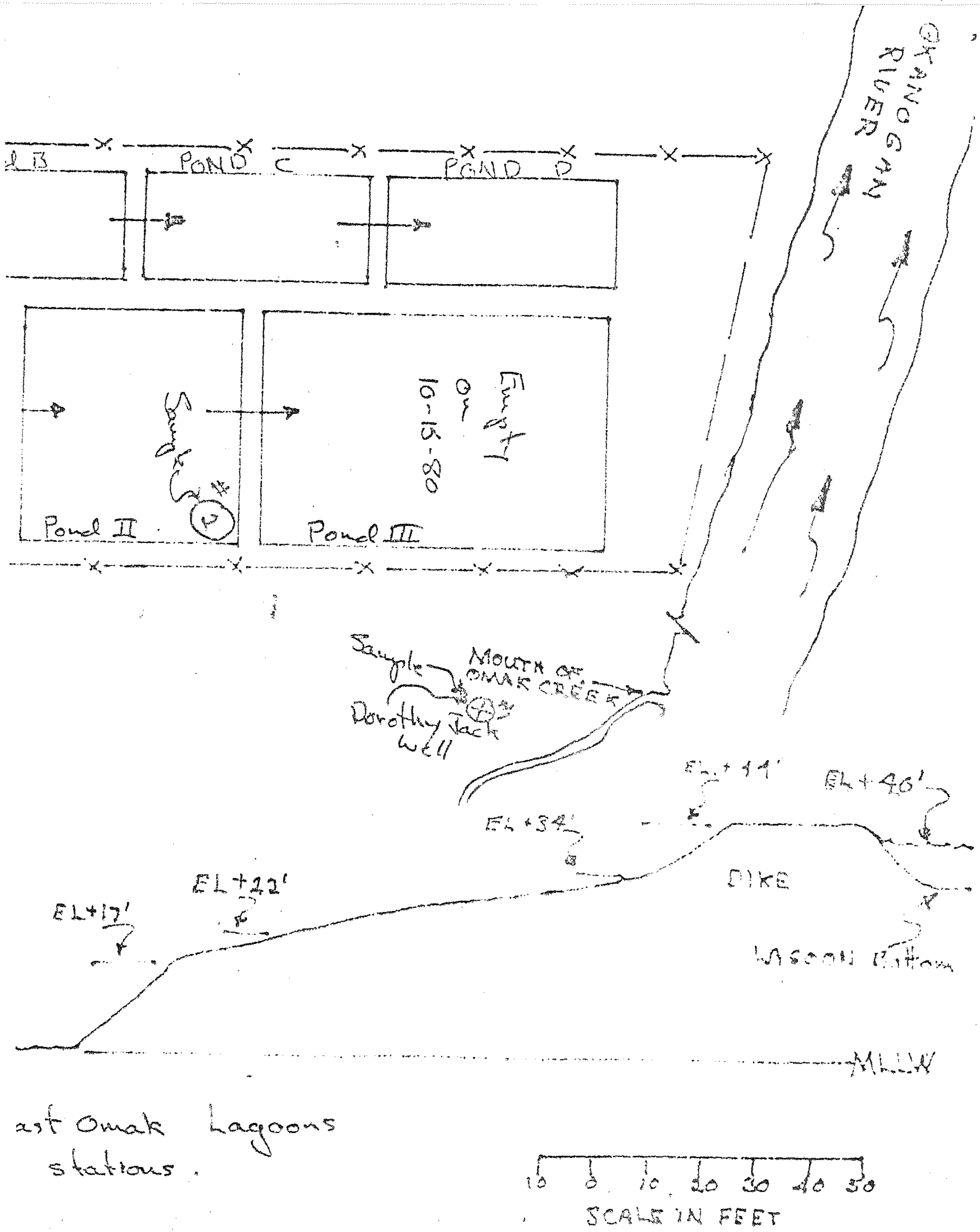
Our understanding is that Crown Zellerbach's sawmill/furniture operation in east Omak is suspected of contaminating the underlying groundwaters (Figure 1). The facility's wastewaters containing phenolic glues and other woodwaste materials are discharged to a series of earthen ponds for disposal via ground seepage. The problem is that these ponds are located within 30 feet of a private residence (Dorothy Jack). Colville Indian tribal social workers feel that Mrs. Jack's ailing health while at the residence (now at a retirement home) and the apparent poor quality of her drinking water are due to contamination by Crown Zellerbach's wastewaters. There also is concern that other wells in the area are contaminated by the same ponds.

The monitoring data submitted for review were collected by your staff and Crown Zellerbach. Some samples were split as part of the joint sampling.

WATER QUALITY DATA ANALYSIS

The sampling data thus far collected are not complete enough to statistically analyze for possible cause-and-effect relationships between reported water quality problems in Dorothy Jack's well and the Crown Zellerbach ponds. Our only recourse was to scan the pond data for "indicator" parameters which exist at high concentrations in the ponds but would not be expected to occur in nearby uncontaminated groundwaters. Woodwaste leachates are typically characterized by tannin-lignin, oxygen demanding substances, color, and odor. Sweet and Fetrow (1975) suggest that, of these parameters, tannin-lignin is the best indicator of groundwater contamination.

As shown in Tables 1 and 2, high concentrations of tannin-lignin were observed in Dorothy Jack's well waters during both of your surveys, July



ast Omak Lagoons
stations.

and October 1980. This strongly suggests contamination by a woodwaste source. The term "strongly suggests" is used simply because we do not know enough about Dorothy Jack's well and other possible sources of contamination to state, in fact, that Crown Zellerbach is the source. Crown Zellerbach is a prime suspect because of its proximity.

Dorothy Jack's water supply also contains color which also is an indicator of woodwaste contamination (Tables 1 and 2). However, manganese and iron are also elevated (Table 3). At the concentrations observed, these two constituents can cause discoloration (reddish-brown) and contribute to staining of fixtures, spotting of laundry, etc. Also, the reddish-brown iron bacteria which are bound to be present can build up many layers forming a slime that can eventually clog water lines. Many water systems statewide with elevated iron have this problem. Correspondingly, tannin-lignin concentrations as low as 0.4 mg/L impart a yellow-brown color (levels exceeding 6 mg/L were observed). In effect, the color problems associated with the well could be due to woodwaste leachate (as indicated by the tannin-lignin) or the metals, or both (probably).

The Dorothy Jack water supply is reportedly also characterized by unpleasant odors. Again, tannin-lignin may be the source since it imparts a woody taste at 2 to 4 mg/L. Manganese and iron also can impart objectionable odors at high concentrations.

The fact that your investigation initially included a wide range of chemical analyses is a good approach when not sure about the outcome.

If you wish to pursue your investigation further, the following recommendations are made. The assumption is that you want to further clarify the Dorothy Jack problem in terms of Crown Zellerbach's ponds, and determine the configuration of the groundwater plume eminating from Crown Zellerbach's ponds, if any.

1. Tannin-lignin and color are the only analyses needed for further sampling. I would probably also collect pH, manganese, and iron, but these are not mandatory. Manganese, iron, and pH are mentioned because increased acidity associated with some woodwastes and a reducing environment (some groundwaters) may dissociate these two metal constituents from the allevial substrata (Sweet and Fetrow, 1975).

2. The analyses you have had performed other than those cited above do not show much (Tables 1-3). Additional sampling would be necessary to confirm any relationships suggested. Zinc and turbidity standards appear to be exceeded in addition to the parameters other than pH cited above.

3. Your existing data have only one "control" sample, during the July run. Good control data are a must for this type of investigation; therefore, it is paramount that you include one or more control stations as part of any future sampling. Any station (well) selected must be upgradient and at least 1/4 mile from the ponds to allow for back flow during a well drawdown.

4. Your suggestion of initially encircling the ponds with stand pipes and collecting samples to determine the direction of plume migration is a good one. This also will tell a lot more about the Dorothy Jack well problem. One or two stand pipes should be placed between her well and the ponds.

5. If a contaminated groundwater plume is detected by the stand pipe sampling, the monitoring should be expanded to include all "downriver" private water supply wells within about two miles.

6. Item 3, above, should be done in the near future. Even if a plume is not evident during this effort, additional sampling should be conducted during summer 1981 when irrigation is in progress (the assumption is that irrigation is taking place sufficiently close to elevate the near-surface water).

Also attached is Table 4 which compares the Department of Social and Health Services' drinking water quality standards with the present status of Dorothy Jack's water supply.

Groundwater contamination by woodwaste materials or associated wastewaters can develop in serious problems in some cases, as demonstrated in the attached report by Sweet and Fetrow (1975). The problem documented in this report may not at all relate to the Omak area because the conditions are different; however, it provides some very good guidelines for attacking this type of problem.

We hope that any questions you have concerning your data are answered by this brief analysis and please give us a call if anything further develops.

JB:TAD:cp

Attachments

REFERENCES

McKee, J.E. and H.W. Wolf, 1963. *Water Quality Criteria.* Pul . No 3-A State Water Quality Control Board. Resources Agency of Calif., Sacramento. 548 pp.

NAS, NAE, 1973. *Water Quality Criteria.* EPA R3-73-003. U.S. Env. Protection Agency, Washington, D.C. 594 pp.

Sweet, H.R. and R.H. Tetrow, 1975. *Groundw.ter Pollution by Wood Waste Disposal.* Groundwater 13:2. 227-231 pp.

Table 1. Comparison of Water Quality Parameters from Crown Zellerbach well (Control), Crown Zellerbach Ponds and Dorothy Jack (DJ) Well in July 1980.

Parameter	Control Well	Crown Zellerbach Pond	DJ Well
pH (S.U.)	7.5	7.7	7.4
Sp. Cond. (μmhos/cm)	574	547	574
COD (mg/L)	21	82	4
BOD (mg/L)	<4	13	<4
Fecal Coliform (col/100 ml)	<1	42	<2
NO_3-N (mg/L)	.17	<.01	.21
NO_2-N (mg/L)	<.01	<.01	<.01
NH_3-N (mg/L)	.1	.06	.19
O-PO_4-P (mg/L)	<.01	.11	<.01
T-PO_4-P (mg/L)	.05	.20	.05
Total Solids (mg/L)	370	400	380
T. Non-Vol. Solids (mg/L)	260	290	270
Total Susp. Solids (mg/L)	1	7	19
T. Non-Vol. Susp. Solids (mg/L)	<1	4	13
PBI (mg/L)	0	9	0
Color (Units)	4	130	25
Tannins and Lignins (mg/L)	.9	6.0	7.2
Phenols (mg/L)	.01	.018	.005

Table 2. Results and Statistical Summary of Parameters Sampled During October, 1980

Parameter	Well (Oct. 14) Crown Zellerbach Only	Well (Oct. 15) DOE	Well (Oct. 15) Crown Zellerbach	Pond DOE	Pond Crown Zellerbach
pH (S.U.)	7.1	7.4	6.9	7.4	7.0
Turbidity (NTU)	15		3.5		4.5
Sp. Cond. (μmhos/cm)	573	550	573	510	565
COD (mg/L)	17	36	32	130	136
BOD (mg/L)	3	<4	<1	33	28
Fecal Coliform (col/100 ml)		<1		19	
NO_3-N (mg/L)	.18	<.01	<.05	<[illegible]	<.05
NO_2-N (mg/L)		<.01		<[illegible]	
NH_3-N (mg/L)	.21	.14	.07	<.1	.07
O-PO_4-P (mg/L)	.27	.20	.23	<.1	.21
T-PO_4-P (mg/L)		.24		.32	
Total Solids (mg/L)	353	380	366	420	413
T. Non-Vol. Solids (mg/L)	281	310	283	280	269
Total Susp. Solids (mg/L)	27.9	3.0	2.7	9.0	10.0
Total Non-Vol. Susp. Solids (mg/L)	18.6	1.0	.7	4.0	3.9
Cl (mg/L)	17		12		12
SO_4 (mg/L)	39		14		79
PBI (mg/L)		9		580	
Color (Units)	25	42	35	310	140
Tannins and Lignins (mg/L)	.029[1]	8.4	.045[1]	28	.216[1]
Phenols (mg/L)		005		.018	

[1]Absorbance values only reported.

Table 3. Summary of Metals Analyses on Acidified Split Samples Taken in October 1980.

Metal (mg/L)	DJ Well (Oct. 14) Crown Zellerbach Only	DJ Well (Oct. 15) DOE	DJ Well (Oct. 15) Crown Zellerbach	Pond DOE	Pond Crown Zellerbach
Al	.02		.02		.17
Ba	.43		.72		.09
Ca	40.7		53.9		48.1
Cr		<.03		<.03	
Cu	.30	.01	.03	.01	<.01
Fe	5.83		1.47		.16
K	4.2		7.6		12
Mg	13.0		25.3		29.0
Mn	3.10		7.11		.23
Na	23.7		30.3		22.8
Ni	.49	<.06	.02	<.06	.01
Pb		<.02		<.02	
Zn	6.22	.08	.07	.07	<.01

Table 4. Maximum Contaminant Limits (MCL), Rationale for Control, and Present Status of DJ Well.

Parameter	MCL[1]	Rationale for Setting MCL[2]	Above/Below MCL
Turbidity (NTU)	1.0	Limits effective Cl_2 disinfection	ABOVE[3]
Sp. Cond. (μmhos/cm^{-1})	700	Palatibility, laxative effects, corrosion	Below
NO_3-N (mg/L^{-1})	10	__________ to nitrite, interference with oxygen transport	Below
Cl^{-1} (mg/L^{-1})	250	Same as specific conductance	Below
SO_4^{-1} (mg/L^{-1})	250	Laxative effects	Below
Color (Units)	15	Aesthetics (refer to turbidity)	ABOVE
Metals			
Barium (mg/L^{-1})	1.0	Diarrhea, blood pressure, central nervous system affects	Below
Chromium (mg/L^{-1})	.05	Skin irritant, accumulation in tissue	Below
Copper (mg/L^{-1})	1.0	Taste	Below
Iron (mg/L^{-1})	.3	Taste, aesthetics	ABOVE
Manganese (mg/L^{-1})	.05	Aesthetics (reinforced affects with iron)	ABOVE
Lead (mg/L^{-1})	.05	Anemia, paralysis, infant neurological damage	Below
Zinc (mg/L^{-1})	5	Aesthetics	1 ABOVE, 3 Below

[1]DSHS. 1978. *Rules and Regulations of the State Board of Health Regarding Public Water Systems.* Health Services Division, DSHS, Olympia. 48 p.

[2]EPA. 1976. *Quality Criteria for Water.* Wash. D.C. 256 p.

[3]May be due to precipitation of metals oxides during holding time (Crown Zellerbach intra-company memo).

Ground-Water Pollution by Wood Waste Disposal

ABSTRACT

Timber production and wood products industries in the Mid-Willamette Valley of Oregon annually dispose of about 547,000 tons (500,000 tonnes) of wood and bark wastes. Land storage or disposal of these wastes can result in the generation of significant volumes of leachate.

Wood waste leachates are commonly characterized by lignin-tannin (measured as tannic acid), oxygen demanding materials, color, and odor. In this study, lignin-tannin concentrations in the ground water ranged as high as 7.5 mg/l; iron and manganese were also shown to increase markedly relative to natural background concentrations, ranging as high as 13 mg/l and 106 mg/l, respectively.

In August 1972 the area affected by the contaminated ground water covered about 4 acres (1.6 hectares) and extended nearly 1,000 feet (330 meters) downgradient from the disposal site. By late January 1973 the plume had migrated laterally to affect an area of about 15 acres (6 hectares) while extending over 1,500 feet (460 meters) downgradient. The lateral migration is attributed to a seasonal change in the local flow system. At least eleven existing domestic water-supply wells have been rendered nonpotable by this pollution.

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[b]District Engineer, Oregon Department of Environmental Quality, 2595 State Street, Salem, Oregon 97310.

Discussion open until August 1, 1975.

INTRODUCTION

Timber production and wood products rank as the Pacific Northwest's leading industries (Department of Commerce, 1968). In the process of harvesting timber and manufacturing wood products, large quantities of solid waste materials are generated. Some wood wastes have been employed in the manufacture of by-products, but as recently as the late 1960's much of the waste material was incinerated. In 1969 there were 61 wigwam burners operating in the Mid-Willamette Valley region of Oregon. These burners disposed of about 547,000 tons (500,000 tonnes) of wood and bark wastes annually (Mick and McCarger, 1969). In 1970 the Oregon Environmental Quality Commission adopted standards and regulations to control both visible and particulate air contaminant emissions. These standards resulted in the phasing out of many wigwam burners, and since 1972, less than ten have operated at any one time in the Mid-Willamette region (Mick, 1973).

The controlled burning of wood wastes as hog fuel produces steam which can subsequently be used in drying kilns or for power generation. The conversion of wood products waste materials to useful energy helps the mills to reduce their consumption of natural gas and oils. However, the conversion of existing wigwam burners to burning units which will meet current air pollution standards is costly, discouraging the wide use of these facilities. Other possible alternative methods for

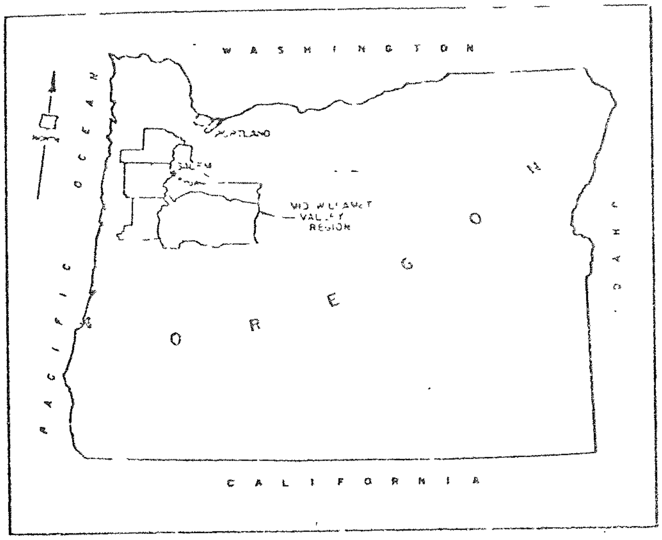

Fig. 1. Location of the Mid-Willamette region and Turner study area.

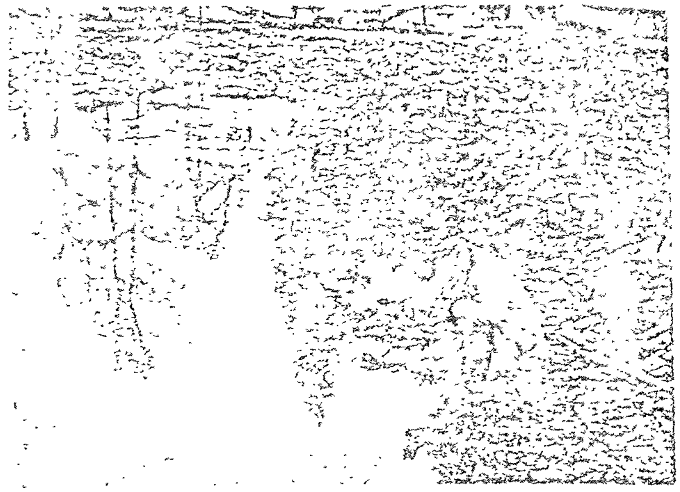

Fig. 2. Disposal site and shallow ground water with homes in the background.

disposing of wood waste include: (1) sale of residues for by-product materials, (2) sale of residues for agricultural use, (3) storage for future sales, and (4) land disposal. Obviously, the first alternative has both economic and environmental advantages. The other three alternatives have the potential for generating leachate and the latter two also pose a potential fire danger, especially during the dry season. Land disposal of wastes, especially bark, contaminated residues, broken pallets, clean-up debris, dunnage, etc., has become a very common practice in Oregon.

The potential ground-water problems resulting from wood waste landfills are exemplified by a case study in the Turner area which is located southeast of Salem, Oregon (see Figure 1). During the summer of 1972 an abandoned gravel borrow pit 10 to 12 feet (3 to 4 meters) deep and from 2 to 3 acres (about 1 hectare) in area was filled with wood wastes including approximately 3,000 tons (2,700

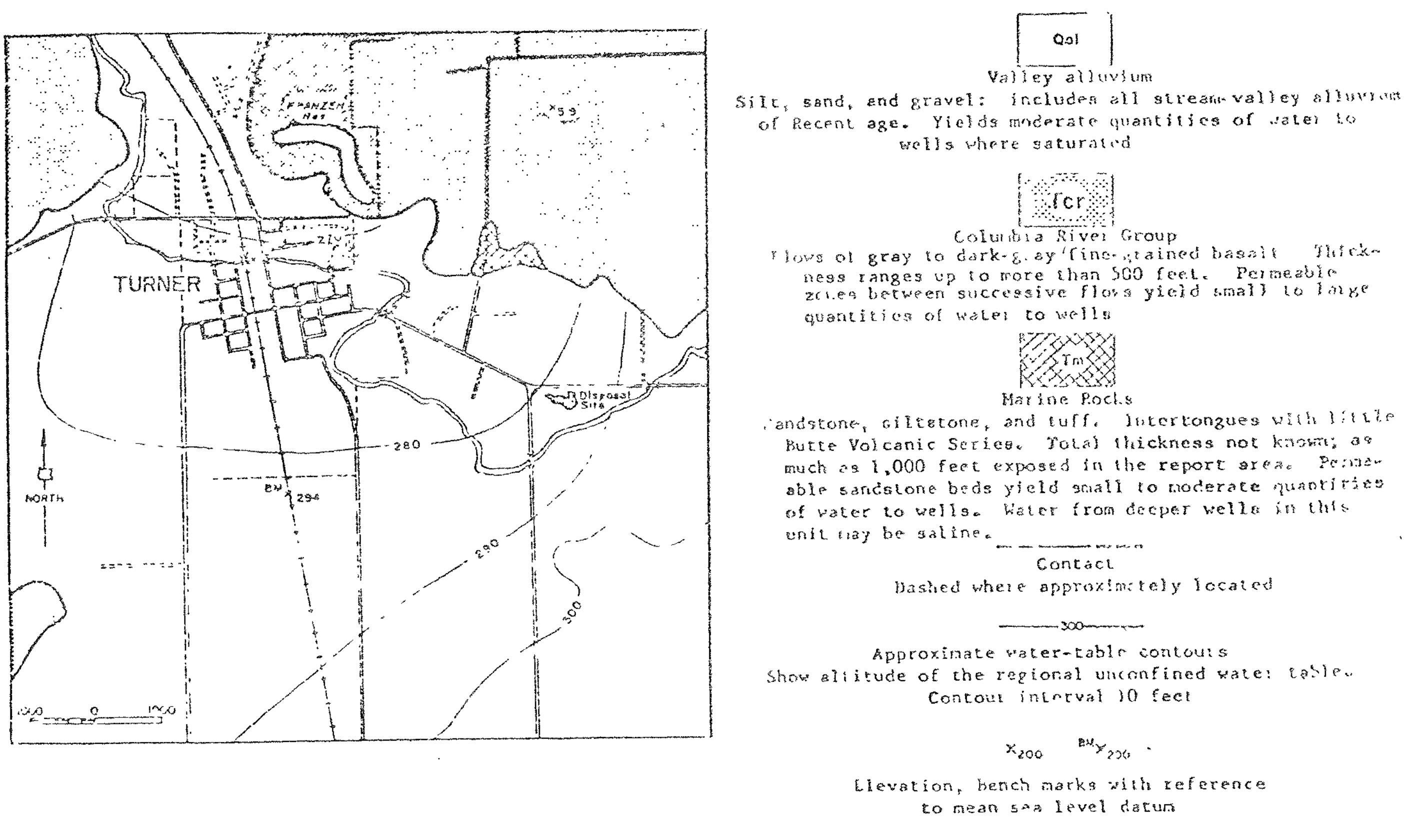

Fig. 3. Geology and water table in the Turner study area (after Hampton, 1972).

onnes) of hemlock (*Tsuga heterophyla*) bark (see Figure 2). Pollutants subsequently leached from the wood wastes and grossly contaminated a number of lowgradient domestic water supplies, rendering them nonpotable.

HYDROGEOLOGY

The hydrogeology of the Molalla-Salem slope area has been described by Hampton (1972) (see Figure 3). To the north of the problem area there are exposures of Miocene basalt flows of the Columbia River Group and some marine sedimentary rocks of Tertiary Age. Immediately underlying the area are gravelly alluvial sedimentary materials of Recent Age.

Mill Creek meanders through the region surrounding the study area. The area is generally within the zones of intermediate and intermittent or ephemeral local ground-water discharge. Mill Creek receives perennial discharge from the intermediate flow system but during the winter it is locally a gaining stream and during the late summer it is locally a losing stream.

Most of the ground water being developed in the area is extracted from the Recent alluvial deposits. The depth of the gravels ranges from about 50 feet (15 meters) at well number 12, Figures 4 and 5, to at least 100 feet (30 meters) in wells south

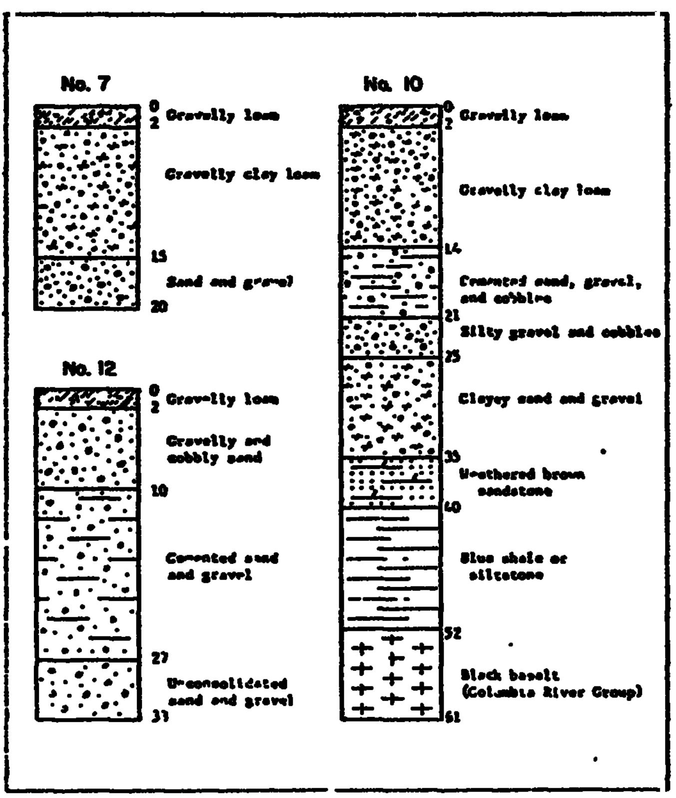

Fig. 4. Available well logs from water walls in the Turner study area.

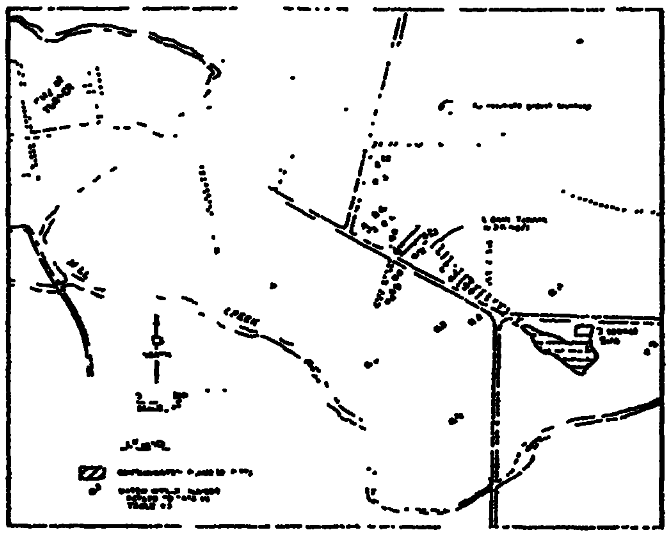

Fig. 5. Lignin-tannin contaminant plume, August 18, 1972.

of the disposal site. The preponderance of shallow driven wells, as opposed to drilled wells in the area is evidence of both the shallow depth of developable ground water and the open and unconsolidated nature of the alluvial deposits. Available well information is included in Figure 4.

The static water level in the alluvial materials ranges from at or near the land surface in low lying areas during the winter months, and from 2 to 10 feet (1 to 3 meters) below land surface during the summer. The gravelly substrata have high hydraulic conductivities. Shallow, lateral, ground-water flow rates in similar gravels in the Willamette Valley have been found to be several feet (one meter) per day (Price, 1967).

Hampton (1972) roughly mapped the surface of the water table in the problem area (see Figure 3). This map indicates a general downgradient, lateral movement of ground water from the east-southeast toward the west-northwest in the vicinity of the disposal site.

HYDROGEOCHEMISTRY

Some of the wood wastes disposed of in the borrow pit were deposited below the water table and were consequently saturated by ground water. This resulted in the relatively rapid generation of leachate at the site. Leachates derived from wood and bark have been described by several authors including Sproul and Sharpe (1968) and in Oregon by Schaumburg (1972). The leachate is reportedly characterized by color, oxygen-consuming materials potentially toxic to fish, and an odor imparted to the water.

In order to determine the extent of leachate contamination, water samples were collected from

Table 1. Summary of Turner Water Quality Data

	Well Log	pH				Total Acidity mg/l as $CaCO_3$				Lignin Tannin mg/l as tannic acid				Total Iron mg/l*				Manganese mg/l*		
		8/11/72	8/18/72	9/25/72	1/30/73	8/11/72	8/18/72	9/25/72	1/30/73	8/11/72	8/18/72	9/15/72	1/30/73	8/11/72	8/18/72	9/25/72	1/30/73	8/18/72	9/25/72	1/30/73
1		6.7	6.9		7.0	33.6	24.6		5.4	7.4	7.5		2.70	6.8	13.0		8.4	106.0		6.3
2		5.6	7.2	7.4	7.0	15.9	20.5	12.4	4.1	3.5	2.7	0.2	1.88	0.7	1.4	1.2	5.6	84.0	3.5	4.6
3		5.6	7.0			20.5	33.4		0.8	1.5	1.4			1.3	1.4			28.0		
4		6.3	7.2		7.5	7.8	5.6		0.04	<0.1	0.1		0.19	0.2	0.04		0.19	0.03		0.04
5		6.6	7.1		7.3	7.0	21.2		0.09	<0.1	<0.1		0.48	0.1	0.08		1.00	0.10		0.91
6		6.3	6.8		6.8	26.2	37.4		0.03	0.1	<0.1		0.22	0.03	0.40		<0.03	0.12		0.03
7	x	6.8	7.3	7.3	7.1	3.2	20.3	13.0	7.9	4.5	5.8	<0.1	0.17	2.3	1.9	0.22	0.07	16.2	2.6	0.2[illegible]
8		6.9	7.3			7.2	9.4		0.2	<0.1	<0.1			0.2	<0.03			0.04		
9		6.8	7.1	7.2	7.5	10.1	13.7	8.4	0.1	<0.1	0.1	<0.1	0.86	<0.03	<0.03	0.35	0.20	0.08	<0.03	3.5[illegible]
10	x	6.7	7.1	7.0	7.1	10.6	13.7	7.8	<0.03	<0.1	0.1	<0.1	0.09	<0.03	0.08	0.21	<0.03	<0.03	0.10	0.11
11		7.5	7.7		7.8	2.9	3.5		<0.03	<0.1	<0.1		0.13	<0.03	<0.03		0.12	<0.03		0.13
12	x	7.1	7.5	7.9	6.8	0.2	4.3	3.2	<0.03	<0.1	<0.1	<0.1	0.17	<0.03	<0.03	<0.03	<0.03	<0.03	0.06	<0.03
13		7.4	7.3		6.8	4.9	3.9		<0.03	<0.1	<0.1		0.13	<0.03	<0.03		<0.03	<0.03		<0.03
14			7.6		6.9		3.1				<0.1		0.17		<0.03		<0.03	<0.03		.00[illegible]
15			7.7				4.8				0.1				<0.03			0.08		
16			7.2				6.9				<0.1				<0.03			0.05		
17			6.9				10.1				<0.1				0.17			0.03		
18			7.1		7.3		20.3				0.1		0.81		0.17		2.8	0.14		4.0
19			7.8		8.0		1.9				<0.1		0.09		<0.03		<0.03	<0.03		<0.03
20			7.5				8.4				<0.1				<0.03			<0.03		
21			7.5		7.2		38.6				<0.1		0.13		0.08		0.12	<0.03		<0.03
22			6.5		6.7		30.8				0.1		0.13		<0.03		<0.03	<0.03		<0.03
23			6.7				29.4				0.5				0.60			<0.03		

* Public Health Service recommended maximum for drinking water: Manganese 0.05 mg/l; Total Iron 0.3 mg/l.

23 wells. One upgradient and one adjacent well, numbers 13 and 12 respectively, were sampled for background information. Sets of samples were collected on August 11, 18, September 25, 1972 and January 30, 1973. A summary of the water quality data is included in Table 1.

An initial drop in pH and an increase in total acidity of contaminated ground water were anticipated. These conditions were confirmed in the downgradient wells affected by the wood waste leachate. However, of the chemical constituents used to detect the movement of the leachate, lignin-tannin concentrations seemed to be the most reliable indicator. According to McKee and Wolf (1963), a tannic acid concentration of from 2 to 4 milligrams per liter (mg/l) imparts a woody taste and odor to water. Odors and a yellow-brown discoloration in the well-water samples collected in this investigation were observed to occur at levels as low as 0.4 mg/l. Therefore, the approximate areal extent of shallow ground water containing at least 0.4 mg/l of lignin-tannin, as tannic acid, was plotted. Figures 5 and 6 show the extent of the contaminated shallow ground water on August 18, 1972 and January 30, 1973 respectively. Following the initial summer (1972) sampling program, it was anticipated that as the water-table elevation rose and the local flow regimen changed during the winter months, that is as Mill Creek reversed from a losing to a gaining stream, there would be a lateral migration of the contaminants toward the stream.

The study area receives an average of over 45 inches (110 centimeters) per year of incident precipitation. More than 12 inches (30 centimeters) of rainfall occurred between the August 1972 and January 1973 surveys used in developing Figures 5 and 6. During the January 30, 1973 survey, the water table was observed to be at the land surface in the low lying areas. The change in the local flow regimen and the predicted lateral migration appeared to have occurred, as evidenced by the larger plume in late January of 1973 (see Figure 6). The area affected by the leachate contaminated ground water increased from approximately 4 acres (1.7 hectares) and 1000 feet (330 meters) downgradient from the disposal site in August 1972 to about 15 acres (6 hectares) and 1500 feet (460 meters) downgradient in January 1973.

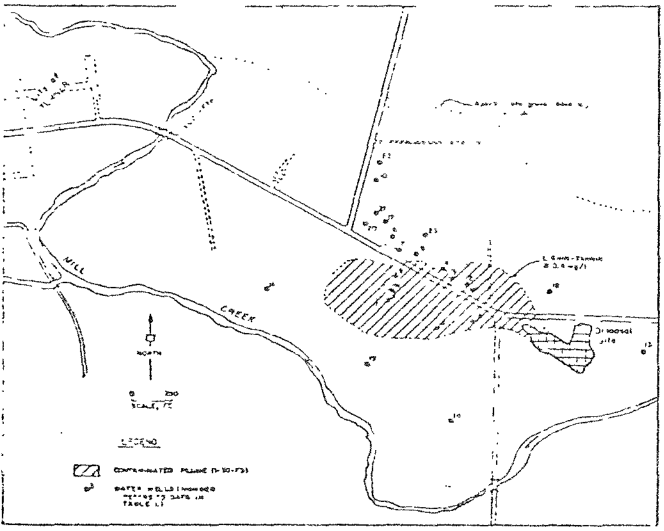

Fig. 6. Lignin-tannin contaminant plume, January 30, 1973.

Another pollution problem related to the wood vaste leachate was also measured. Total iron and nanganese levels were found to be far in excess of ıormal or background concentrations and were well bove recommended Public Health Service drinking-vater standards (see Table 1). As previously mentioned, an increase in total acidity and a decrease in H occurred due to the leaching of volatile organic cids from the wood waste. This caused the lissociation of some iron and manganese from the lluvial substrata through which the contaminated round water was passing. The presence of a educing environment resulted in higher concentraions of iron and manganese and aided in their novement by providing a medium in which they vere more soluble. Since iron may exist in a variety f forms, it is generally not a reliable constituent rom which to draw conclusions in the geochemical nterpretation of water analyses (Hem, 1959). Iowever, in this case, increased iron concentrations re indicative of the altered chemical environment ı the tested aquifer, that is, acidic reducing onditions.

SUMMARY

Wood waste containing large amounts of bark, eposited in a saturated, anaerobic, environment, ielded high concentrations of volatile organic acids. he leachate produced under these conditions is lso high in lignin-tannin content. Moreover, under educing conditions, these chemical constituents adily dissociated iron and manganese from the luvial substratum, increasing the concentrations the ground water. These environmental factors n potentially and have actually degraded the ound water to a nonpotable quality.

Care must be taken in the selection of wood waste disposal sites. Preventing these waste materials from entering developable ground- and surface water bodies is of paramount importance. A knowledge of the local and regional hydrogeologic conditions is important for properly selecting wood waste disposal sites. Improper site selection, design, and/or operation can result in the degradation of both surface- and ground-water quality. The Turner area study is an example of a poorly located disposal site which resulted in the pollution of at least eleven nearby domestic water-supply wells. The problem was finally alleviated for the people who depended on the shallow ground-water supply by extending an existing community water supply to the affected area. However, the shallow ground-water resource in the area remains degraded.

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REFERENCES

Department of Commerce. 1968. The economy and outlook. State of Oregon, Salem, Oregon.

Hampton, E. R. 1972. Geology and ground water of the Molalla-Salem slope area, northern Willamette Valley, Oregon. U.S. Geol. Survey Water-Supply Paper 1997, 83 pp.

Hem, John D. 1959. Study and interpretation of the chemical characteristics of natural water. U.S. Geol. Survey Water-Supply Paper 1473, pp. 58-68.

McKee, J. E., and H. W. Wolf. 1963. Water quality criteria, 2nd ed. The Resources Agency of Calif., State Water Resources Control Board Pub. No. 3-A, p. 281

Mick, Allan. 1973. Personal communication.

Mick, Allan and Dean McCaiger. 1969. Air pollution problems in plywood particle board and hard board mills in the Mid-Willamette Valley. Mid-Willamette Valley Air Pollution Authority, Salem, Ore., 26 pp.

Price, Don. 1967. Rate and extent of migration of a "one-shot" contaminant in an alluvial aquifer in Keizer, Oregon. U.S. Geol. Survey Prof. Paper 575-B, pp. B217-B220.

Schaumburg, Frank D. 1972. The influence of log handling on water quality. Oregon State University, Dept. of Civil Eng. Project No. WPO1320 for the Water Quality Office, Environmental Protection Agency, 115 pp.

Sproul, Otis J. and Clifford A. Sharpe. 1968. Water quality degradation by wood bark pollutants. Water Resources Center Publications Number 5, University of Maine, Orono, Maine, 53 pp.

Standard methods for the examination of water and waste water, 13th ed. 1971. American Public Health Association, 874 pp.