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Ground Water Quality Assessment
Whatcom County Dairy Lagoon #2
Lynden, Washington

by
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ABSTRACT

The Environmental Investigations and Laboratory Services Program (EILS) of Ecology monitored ground water quality for one year at a 12-year-old dairy lagoon in Whatcom County. This study was conducted at the request of the Water Quality Program as part of a larger effort to define the impact of dairy lagoons on ground water quality at several locations in Washington State. The results of these studies will be used to augment existing dairy waste management programs.

Monitoring wells were installed, and subsequently sampled quarterly. Analytes included chloride, total dissolved solids, total organic carbon, chemical oxygen demand, total phosphorus, ammonia-N, nitrite+nitrate-N, and total and fecal coliform bacteria. In downgradient wells, concentrations of total dissolved solids, chemical oxygen demand, total organic carbon, ammonia-N, total phosphorus, and chloride consistently exceeded upgradient concentrations, probably due to leakage from the lagoon. Also total and fecal coliform bacteria concentrations in downgradient wells exceeded upgradient conditions intermittently. One downgradient monitoring well showed anomalously high concentrations for one sampling event, probably due to localized leakage from the lagoon. The ground water flow conditions near the lagoon were characterized, and the mean ground water flow velocity was estimated to be about one foot per day. Additional monitoring wells are recommended downgradient of the lagoon to evaluate the fate of contaminants and the distance affected.

ACKNOWLEDGEMENTS

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INTRODUCTION

Problem Statement

Dairy lagoons temporarily store animal wastes and wastewater during winter when: 1) nutrient uptake by cover vegetation and crops is low, and 2) the potential for surface runoff and ground water contamination from land application of wastes is high. Also in summer, lagoons store dairy wastes between field spray applications. Dairy lagoons may leak if not properly sealed and may contaminate ground water. Reese and Loudon (1983) summarized past studies on dairy lagoon sealing. In general, these studies concluded that dairy lagoons are to some degree self-sealing and that leakage rates decrease substantially after lagoons are initially filled. Research into the causes and mechanisms related to self-sealing of dairy lagoons suggests that at least a partial seal, consisting of settled solids, a microbial layer or a combination of both, restricts leakage from lagoons. Also, leakage rates and the rates of sealing appear to be a function of soil texture (pore size), total solids concentration, and hydraulic head (Reese and Loudon, 1983). Although researchers agree that leakage rates decrease after lagoons first receive wastes, there is disagreement on the effectiveness of seals and whether the leakage rates pose a potentially significant threat to ground water quality.

The Ground Water Quality Unit of the Ecology Water Quality Program requested that the Toxics, Compliance, and Ground Water Investigations Section assess ground water quality near selected dairy lagoons in Washington. Four lagoons were selected: two in Whatcom County, one in Yakima County, and one in Lewis County. Monitoring at the lagoons was initiated sequentially. Whatcom County Dairy Lagoon #2 was the second lagoon monitored in Whatcom County and the third in the series of the lagoons monitored statewide. This report presents and discusses the first year of results at Whatcom County Dairy Lagoon #2. The results of the first two lagoons (Edaleen Dairy Lagoon, Whatcom County and Hornby Dairy Lagoon, Yakima County) have been described previously by Erickson (1991 and 1992).

Lagoon History and Construction

Whatcom County Dairy Lagoon #2 is located about 15 miles north of Bellingham, Washington, and about two miles northwest of Lynden, Washington. The lagoon was originally constructed in 1980. The Soil Conservation Service (SCS) assisted with the lagoon design which met the construction guidelines of that time (SCS, 1979). However, the lagoon was widened in 1989 by the dairy operator. This work was not conducted with SCS assistance and therefore the lagoon probably does not meet current SCS guidelines (SCS, 1987) for earthen liners (Bonson, 1992). The lagoon is 347 feet long and 135 feet wide with a maximum capacity of 2.5 million gallons. It is designed to handle wastewater for about 420 dairy cows. Prior to 1989, manure and wastewater were stored in the lagoon. After 1989, manure solids have been separated from the waste and are land applied.

Geology, Hydrogeology and Soils

The lagoon is situated on the Lynden Terrace which is underlain by the Sumas Outwash deposits from the most recent Pleistocene glaciation (Easterbrook,1971). The outwash deposits continuously underlie the site, and consist of stratified sand and mixtures of sand and gravel. Based on vicinity well logs, the outwash deposits range in thickness from about 40 to 50 feet and are underlain by silt and clay deposits with low permeability. The water table fluctuates seasonally about two to three feet due to variations in precipitation, irrigation, and pumping. The depth to water ranges from about five to nine feet below ground surface. Regionally, ground water flows from north to south toward the Nooksack River. The outwash deposits represent an important source of drinking and irrigation water in the Lynden area. Wells completed in the aquifer have moderate to high yields. In the immediate vicinity of the lagoon, ground water use is not well defined. Commonly, surface drainage is directed north-south by ditches that parallel the roads.

Soils developed in the Sumas Outwash at the site location consist of the Tromp and Edmonds-Tromp silt loams (Poulson and Flannery, 1953). These soils are characterized by rapid internal drainage.

METHODS

General

A ground water monitoring network was installed around the lagoon to obtain ground water quality samples and to define directions and rates of ground water flow. Wells and the lagoon were sampled quarterly from February 1991 to October 1991. Samples were tested for ammonia-N, nitrate+nitrite-N, total phosphorus, total organic carbon (TOC), chemical oxygen demand (COD), total dissolved solids (TDS), chloride, and total and fecal coliform bacteria. Lagoon samples also were tested for total suspended solids. Total persulfate nitrogen (TPN) was tested during one sampling round in February 1991. TPN was intended to be an indicator of total (inorganic and organic) nitrogen present in samples. TPN testing was stopped because TPN results were inconsistent with, and less than, total inorganic nitrogen concentrations in another lagoon study (Erickson, 1991).

The monitoring network consisted of four monitoring wells (Figure 1): one upgradient well (MW1) to define ambient ground water quality, and three downgradient wells (MW2, MW3 and MW4). Well water levels were measured during each sampling event. The water level measurements were converted to relative elevations using mean sea level as a common datum. Differences in the water level elevations were used to determine ground water gradients and flow directions. Specific capacity data for nearby private wells was used to estimate hydraulic conductivity of the aquifer. The hydraulic conductivity and ground water gradient data were combined to estimate ground water flow velocities. The study methods are described in detail below.

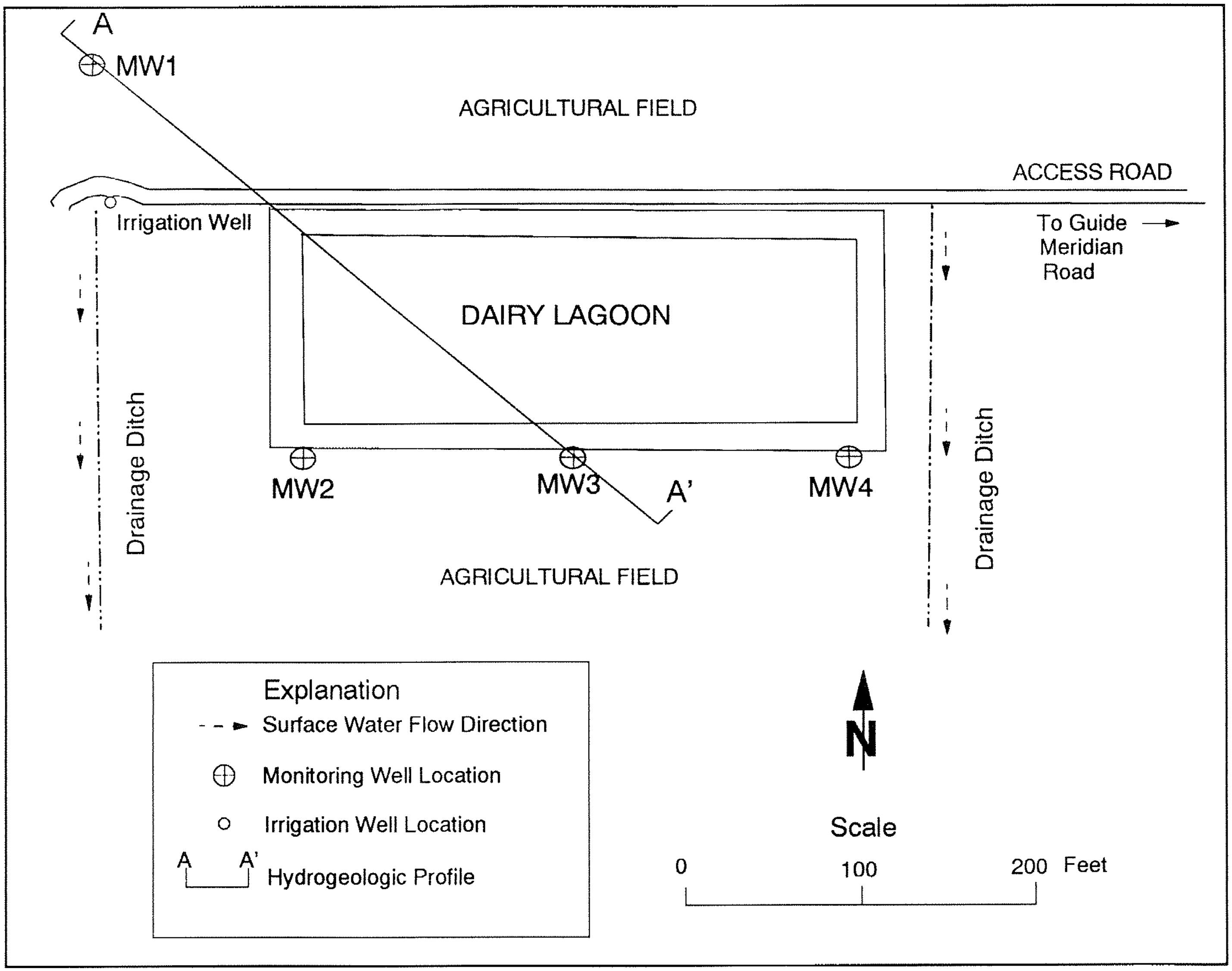

Figure 1. Well Location Map, Whatcom County Dairy Lagoon #2

Well Installation and Water Levels

Monitoring wells were constructed with 1¼-inch diameter galvanized pipe and 2-foot-long, commercial, stainless steel wellpoints. Well screens and casing were steam cleaned prior to installation. Bentonite surface seals were installed at each well by augering an oversized hole, about six inches in diameter and three feet deep, and placing hydrated 1/2-inch bentonite pellets in the annular space. After the wellpoint was driven past the bottom of the oversized hole, hydrated bentonite was added to the annular space during driving of the remaining casing to the desired well depth. As-built drawings for each well are shown in Appendix A. All wells were developed by surging with a one-way foot valve attached to 3/4-inch PVC pipe.

Water levels were obtained using a commercial electric well probe. Relative elevations of measuring points for the monitoring wells were determined using a surveyor's level and rod. All elevations were measured relative to a nearby road centerline with an assumed elevation of 100 feet (mean sea level) using a USGS 7.5 minute topographic map. Relative elevations of measuring points are considered to be accurate to 0.05 feet.

Hydraulic Conductivity

Hydraulic conductivity was estimated by using specific capacity data (the ratio of discharge rate and drawdown) and the method described by Bradbury and Rothschild (1985). This method is an iterative solution to the Theis equation with modifications for partial penetration and well loss. Results using this method are considered order-of-magnitude approximations. Specific capacity data was obtained from Ecology well records for wells within a one mile radius of the lagoon. Locations of wells used for hydraulic conductivity estimates were not field verified. On-site monitoring wells were not used to determine hydraulic conductivity because the well construction (short screen length, small slot size, and the small diameter) was not suitable for stressing the highly transmissive outwash aquifer, or for providing representative slug test results.

Sampling and Analysis

Wells were purged and sampled using a peristaltic pump attached to dedicated 3/8-inch ID polyethylene tubing. Flexible silastic tubing was used in the peristaltic pump head. Prior to sampling, a minimum of three well volumes were purged and pH, temperature, and specific conductance measurements stabilized. Measurements were considered stable if the change between well volumes was less than 0.1 Standard Units for pH, 0.2°C for temperature, and 20 micromhos/cm for specific conductance. Grab samples from the lagoon were collected just below the wastewater surface. All samples were placed in coolers at 4°C and transported to the Ecology/EPA Region X Laboratory in Manchester, Washington. The parameters tested, test methods, and method detection limits are listed in Table 1.

Table 1. Whatcom County Dairy Lagoon #2 Parameters, Test Methods, and Detection Limits.

Parameter	Method of Analysis	Reference	Detection Limit
Water Level	Electric Well Probe	NA	0.01 feet
pH	Beckman pH Meter	NA	0.1 Std Units
Specific Conductance	YSI Conductance Meter	NA	10 umhos/cm
Temperature	Beckman Temperature Probe	NA	0.1°C
Ammonia-N	EPA Method 350.1	EPA (1983)	0.01 mg/L
Nitrate+Nitrite-N	EPA Method 353.2	EPA (1983)	0.01 mg/L
Total Persulfate Nitrogen	EPA Method 353.2	EPA (1983)	0.1 mg/L
Total Phosphorus	EPA Method 365.1	EPA (1983)	0.01 mg/L
Chloride	Std Methods No. 429	APHA (1985)	0.1 mg/L
Total Dissolved Solids	Std Methods No. 209B	APHA (1985)	10 mg/L
Total Suspended Solids	Std Methods No. 205C	APHA (1985)	10 mg/L
Chemical Oxygen Demand	Std Methods No. 508C	APHA (1985)	4 mg/L
Total Organic Carbon	Std Methods No. 505	APHA (1985)	1.0 mg/L
Total Coliform	Std Methods No. 909A	APHA (1985)	1 CFU/100 ml
Fecal Coliform	Std Methods No. 909C	APHA (1985)	1 CFU/100 ml

NA= Not Applicable

CFU= Colony Forming Unit

Quality Assurance

In addition to calibration standards, spikes, and laboratory duplicates, field quality assurance samples consisted of blind duplicates and TOC transport blanks. A blind duplicate, used to estimate analytical precision, was obtained for each parameter during each sampling event. Duplicate results, relative percent differences (RPDs, the ratio of the difference of duplicate results and their mean expressed as a percent) and TOC transport results are shown in Table 2.

Overall, the quality of the data was good. RPDs were generally less than 25% for most parameters. Exceptions are chemical oxygen demand (33%), total organic carbon (28%), nitrate+nitrite - N (127%) and total phosphorus (40%) for February, and total dissolved solids (29%) for May. The high nitrate+nitrite-N RPD occurred near the method detection limit, and therefore is not necessarily representative of analytical precision at higher concentrations. August duplicate results for total coliform bacteria were inconsistent; one sample showed no bacteria and the other showed five organisms/100mL. Ammonia-N for February was estimated because testing was completed after the recommended holding time. Total persulfate nitrogen results for the February sampling were estimated because of matrix interference.

The concentrations for TOC transport blanks were less than 1 mg/L and no qualification of the data is necessary. The October result for the lagoon TOC concentration was estimated because of matrix interference.

RESULTS

Ground Water Flow

Figure 2 shows the relationship of the lagoons and the site hydrogeology. The depth to water measurements and water level elevations are listed in Table 3. Depth to the water table ranged from about five to nine feet during the study. Hydrographs for well water levels are shown in Figure 3. Water levels fluctuated two to three feet over the course of the study. Throughout the study, the fluid level in the lagoon was three to seven feet higher than the water table.

Differences in water levels between wells indicate that ground water moves generally southward. Water-table contour maps based on water level data for February, May, August, and October 1991 are shown in Figures 4 through 7. Ground water moves perpendicular to the contours from high to low elevations. In February and May, ground water was flowing toward the south and southeast. In August, the flow had a strong westward component. In October, the flow was toward the south and southwest. The variation in flow directions was likely due to changes in pumping, irrigation and possibly infiltration from ditches. Although MW1 was not always directly upgradient of the lagoon, it appears that it was never downgradient of the lagoon and therefore served adquately as an upgradient well, unaffected by leakage from the lagoon. Hydraulic gradients, measured by the change of water table elevation over distance, ranged from 0.0010 (October) to 0.0034 (February) feet/feet.

Table 2. Duplicate and Transport Blank Results, Whatcom County Dairy Lagoon #2.

(Units = mg/L unless shown otherwise)

Site Name	Date		Total Dissolved Solids	Chemical Oxygen Demand	Total Organic Carbon	Ammonia as N	Nitrate+ Nitrite as N	Total Persulfate Nitrogen	Total Phosphorus	Chloride
MW4	02/27/91		549	58	50.6	8.9 J	0.09	7.4 J	0.22	59.1
			548	81	67.1	8.8 J	0.02	7.2 J	0.33	59
		RPD=	0.2	33	28.0	1.1	130	2.7	40	0.2
MW2	05/21/91		472	53	17	31	0.01 UJ	NT	0.29	40.3
			630	58	16.7	30	0.01 UJ	NT	0.28	40.5
		RPD=	28.7	9.0	1.8	3.3	0.0	--	3.5	0.5
MW4	08/13/91		212	53	15.7	28	0.02 U	NT	4.7	7.9
			236	48	15	29	0.02 U	NT	4.9	7.7
		RPD=	10.7	9.9	4.6	3.5	--	--	4.2	2.6
MW3	10/28/91		472	52	22.7	84	0.02	NT	2.2	53.3
			488	42	22.6	83	0.02 U	NT	2.2	50.4
		RPD=	3.3	21	0.4	1.2	--	--	0.0	5.6

Site Name	Date		Total Coliform (CFU/100ml)	Fecal Coliform (CFU/100ml)	TOC Transport Blank
MW4	02/27/91		1 U	1 U	0.75
			1 U	1 U	
		RPD=	--	--	
MW2	05/21/91		1 U	1 U	1.0 U
			1 U	1 U	
		RPD=	--	--	
MW4	08/13/91		5 X	1 UX	1.0 U
			1 U	1 UX	
		RPD=	--	--	
MW3	10/28/91		1 U	1 X	1.0 U
			1 U	1 X	
		RPD=	--	0.0	

J= Estimated Value

NT= Not Tested

X= Many Background Organisms

CFU= Colony Forming Unit

U= Analyte not detected above listed detection limit

RPD= Relative percent difference (ratio of the difference of duplicate results divided by the mean expressed as percent)

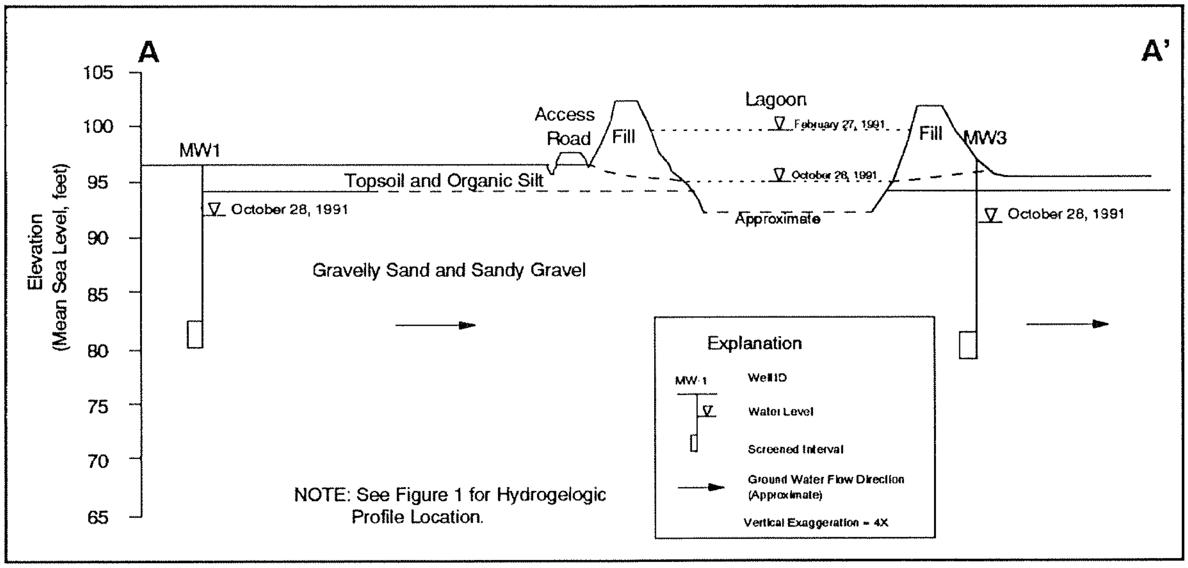

Figure 2. Hydrogeologic Profile A-A', Whatcom County Dairy Lagoon #2

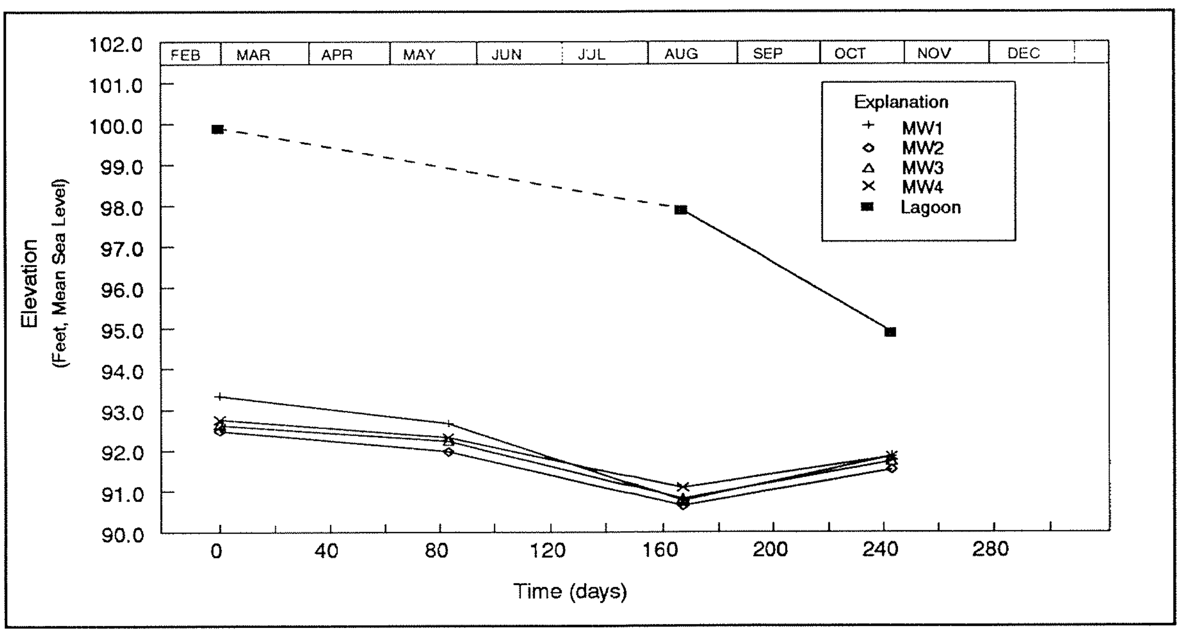

Figure 3. Hydrographs for Wells and Lagoon, Whatcom County Dairy Lagoon #2

Table 3. Depth to Water and Water-Level Elevations, Whatcom County Dairy Lagoon #2.

Site Name	Date	Top of Casing (MSL, feet)	State Plane Coordinates X	Y	Depth to Water (feet)	Water Elevation (MSL, feet)
LAGOON BERM	02/27/91	101.93	NA	NA	2	99.9
LAGOON BERM	08/13/91	101.93	NA	NA	4	97.9
LAGOON BERM	10/28/91	101.93	NA	NA	7	94.9
MW1	02/27/91	98.12	1602280	717680	4.78	93.34
MW1	05/21/91	98.12	1602280	717680	5.45	92.67
MW1	08/13/91	98.12	1602280	717680	7.35	90.77
MW1	10/28/91	98.12	1602280	717680	6.26	91.86
MW2	02/27/91	97.36	1602380	717515	4.88	92.48
MW2	05/21/91	97.36	1602380	717515	5.39	91.97
MW2	08/13/91	97.36	1602380	717515	6.72	90.64
MW2	10/28/91	97.36	1602380	717515	5.83	91.53
MW3	02/27/91	100.01	1602515	717515	7.39	92.62
MW3	05/21/91	100.01	1602515	717515	7.78	92.23
MW3	08/13/91	100.01	1602515	717515	9.19	90.82
MW3	10/28/91	100.01	1602515	717515	8.29	91.72
MW4	02/27/91	97.76	1602650	717515	5.00	92.76
MW4	05/21/91	97.76	1602650	717515	5.44	92.32
MW4	08/13/91	97.76	1602650	717515	6.67	91.09
MW4	10/28/91	97.76	1602650	717515	5.91	91.85

NA= Not Applicable
MSL= Mean Sea Level

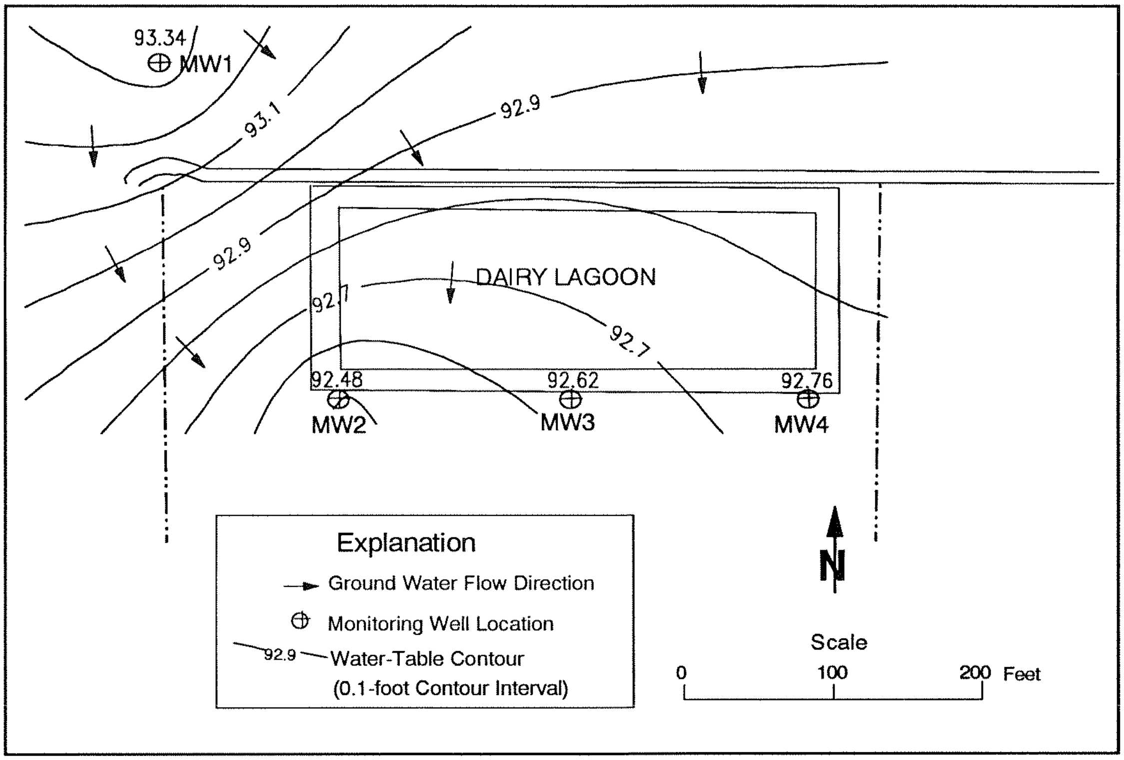

Figure 4. Water-Table Contour Map, Whatcom County Dairy Lagoon #2, February 1991.

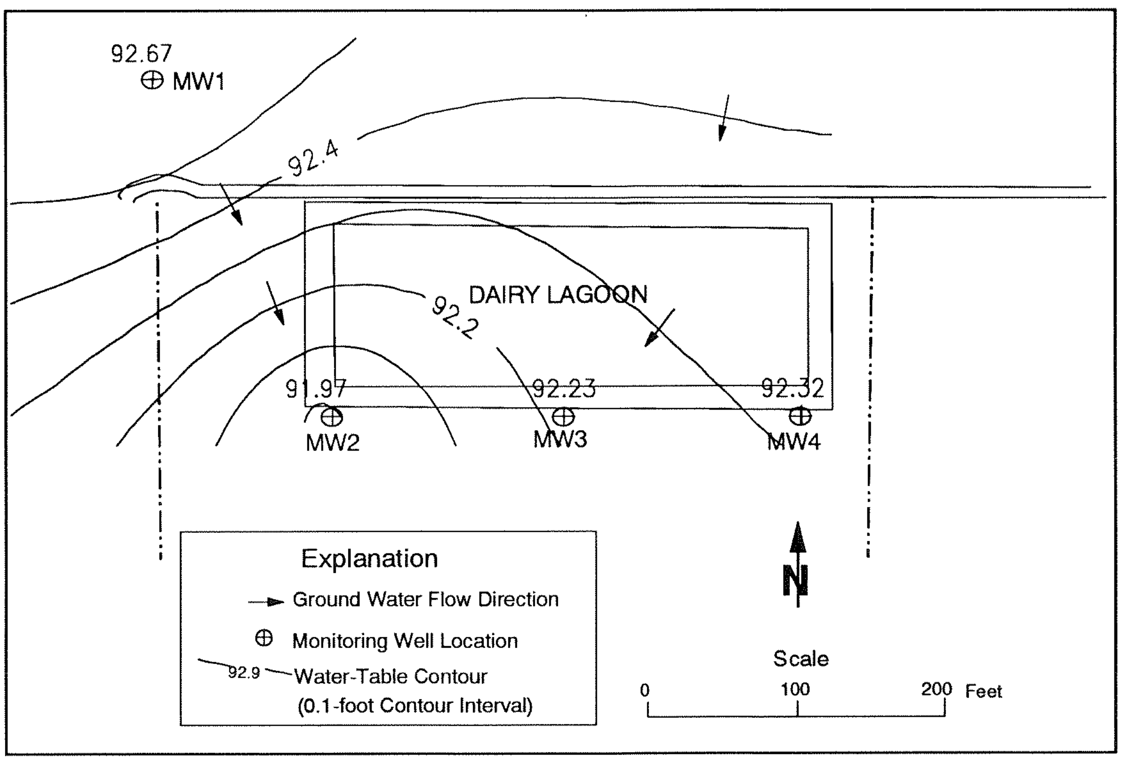

Figure 5. Water-Table Contour Map, Whatcom County Dairy Lagoon #2, May 1991

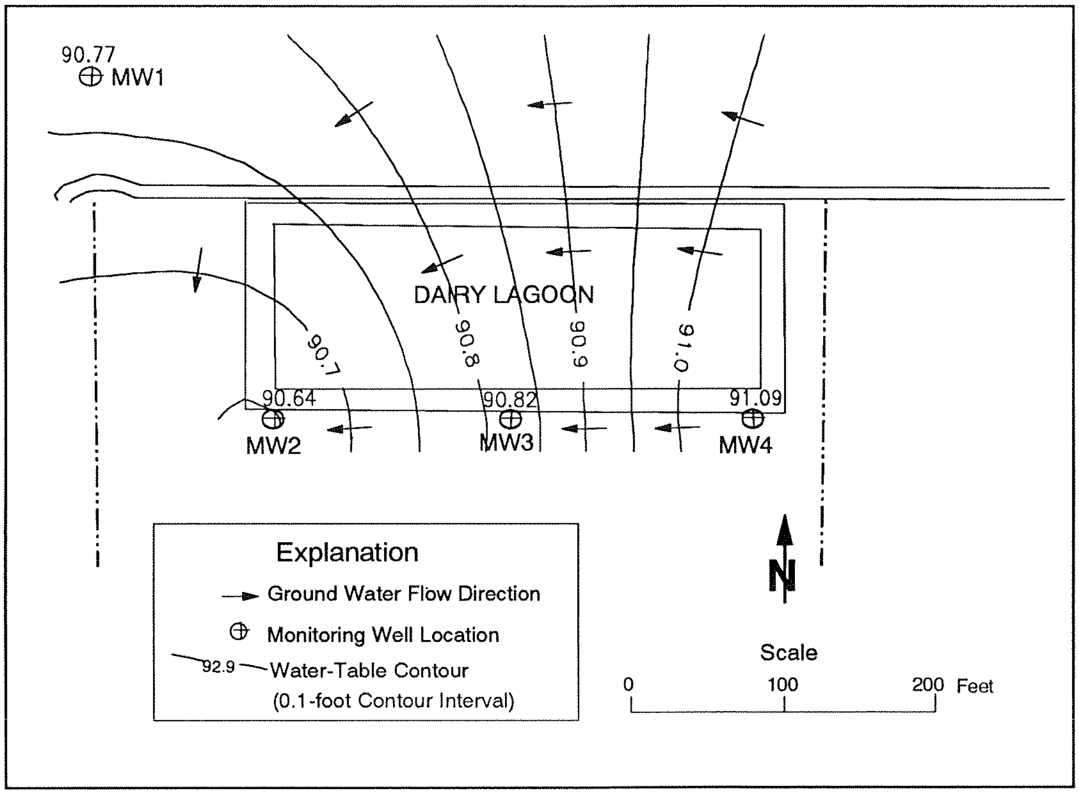

Figure 6. Water-Table Contour Map, Whatcom County Dairy Lagoon #2, August 1991

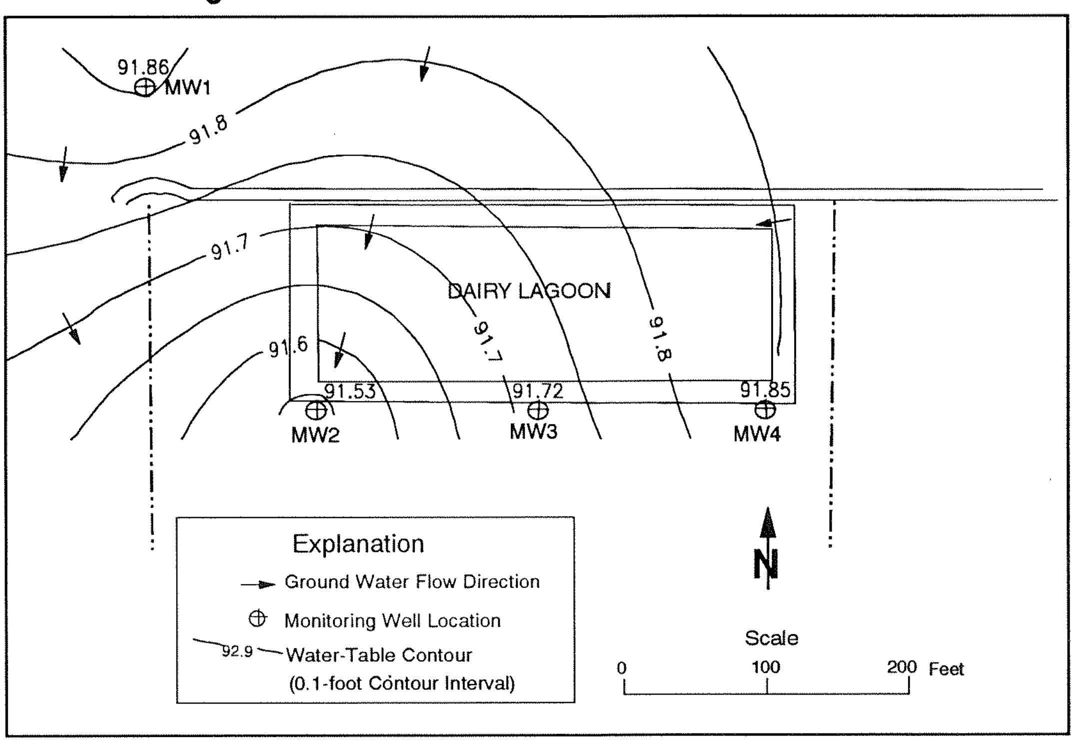

Figure 7. Water-Table Contour Map, Whatcom County Dairy Lagoon #2, October 1991

Hydraulic Conductivity

Hydraulic conductivity of the outwash aquifer was estimated using specific capacity and well construction information for 15 wells within a one mile radius of the lagoon. For these estimates the storage coefficient was assumed to be 0.25 and no corrections were made for well loss. The input data and results are listed in Table 4. Based on this method, hydraulic conductivities range from about 6 to 355 feet per day with arithmetic and geometric means of 147 and 111 feet per day, respectively. Because hydraulic conductivity is considered to be log-normally distributed (Freeze, 1986), the geometric mean is a better estimate of central tendency than the arithmetic mean. The hydraulic conductivity of the outwash aquifer near the Edaleen Dairy Lagoon, about three miles northeast of this site, ranged from 57 to 5,350 feet per day with a geometric mean of 283 feet/day (Erickson, 1991). This estimate was based on specific capacity data for eight private wells.

Ground Water Velocities

Ground water velocities can be estimated using Darcy's Law:

$$V=\frac{K_h\times\frac{dh}{dL}}{n_e}$$

where,

v = estimated average linear velocity
dh/dL = hydraulic gradient
K_h = saturated hydraulic conductivity
n_e = effective porosity

Because the aquifer is unconfined and consists of unconsolidated sand and gravel, effective porosity is assumed to range between 0.10 and 0.35. This variability, combined with the range of hydraulic conductivity and hydraulic gradient, results in a range in flow velocity of 0.02 to 12 feet per day. The results are shown in Table 5. The mean linear velocity (using a hydraulic conductivity of 111 feet per day, and effective porosity of 0.25 and a hydraulic gradient of 0.0022 (feet/feet)) is one foot per day.

Table 4. **Specific Capacity Data and Estimated Hydraulic Conductivities for Private Wells, Whatcom County Dairy Lagoon #2.**

Well ID	Diameter (inches)	Static Water Level (feet)	Test Water Level (feet)	Test Duration (hours)	Discharge Rate (GPM)	Aquifer Thickness (feet)	Open Interval (feet)	Storage Coeff.	Well Loss	Estimated Hydraulic Conductivity (feet/day)
18E1	36	6	16	2	250	30	1.5	0.25	1	300
18F1	36	6	23.85	4	182	24	9	0.25	1	73
7M1	8	10	18	1	50	15	5	0.25	1	112
23B1	18	22	27	4	12	16	6	0.25	1	28
23C1	6	30	35.5	0.5	8	9	0.25	0.25	1	165
23B2	12	13	15	0.5	60	15	8	0.25	1	355
23C2	6	3	5	4	20	20	5	0.25	1	209
23D1	6	17.75	39.75	2	7	30	5	0.25	1	6
23D2	6	7	10	4	20	17	7	0.25	1	111
23D3	36	6	13	4	80	15	9	0.25	1	90
12L1	36	5	20	4	300	26	5	0.25	1	193
12N1a	36	6	15.3	2	200	20	15	0.25	1	120
12N1b	36	6	22	2	300	20	15	0.25	1	103
12N2	36	15	18	1	12	7	1.5	0.25	1	DNC*
13J1	36	6	18	2	250	17	5	0.25	1	208
13R1a	36	6	14.4	2	200	20	15	0.25	1	136
13R1b	36	6	18	2	300	20	15	0.25	1	146
								Arithmetic Mean=		147
								Geometric Mean=		111

*DNC= Did not converge.

Table 5. Estimated Ground Water Velocities.

	Minimum	Maximum	Mean
Hydraulic Conductivity (feet/day)	6	355	111 (Geometric)
Effective Porosity (No units)	0.10	0.35	0.25
Hydraulic Gradient (feet/feet)	0.0010	0.0034	0.0022
Ground Water Velocity (feet/day)	0.02	12	1.0

These results compare well with the estimated ground water velocities for the Edaleen Dairy Lagoon site, about three miles to the northeast. The mean ground water flow velocity at the Edaleen Dairy was estimated to be about four to five feet/day using Darcy's Law and about one to two feet per day using chloride travel times (Erickson, 1991).

Water Quality

Field analytical results for pH, temperature and specific conductance are shown in Table 6. The pH of ground water ranged from 6.2 to 7.5 and was highest in downgradient wells (MW2 through MW4). Ground water temperature ranged from 9.1 to 12.1°C, and was consistently low in May, and high in August. Specific conductance for the upgradient well (MW1) ranged from 192 to 290 micromhos/cm. In comparison, specific conductance in downgradient wells, although highly variable, was substantially higher and ranged from 314 to 2080 micromhos/cm.

Chemical water quality and bacteriologic results are shown in Tables 7 and 8, respectively. The lagoon wastewater concentrations for chemical oxygen demand (COD, 540 to 21000 mg/L), total organic carbon (TOC, 1180 to 5110 mg/L), ammonia-N (400 to 1000 mg/L), total phosphorus (21 to 1900 mg/L), chloride (342 to 645 mg/L), total coliform bacteria (460,000 to 10,000,000 Colony Forming Units(CFUs)/100mL) and fecal coliform bacteria (200,000 to 9,200,000 CFUs/100mL) were substantially higher than concentrations in ground water upgradient (MW1) of the lagoon. Therefore these parameters are potential indicators of leakage from the lagoon.

In general, concentrations of most of the measured parameters were elevated in downgradient wells relative to MW1. Downgradient concentrations for total dissolved solids (TDS), COD, TOC, ammonia-N, total phosphorus, and chloride were substantially higher than upgradient concentrations. The results for TDS, chloride, TOC, and ammonia-N during the study period are shown in Figures 8 through 11. The maximum concentrations (TDS, 1420 mg/L; chloride,

Table 6. Field Analytical Results, Whatcom County Dairy Lagoon #2.

Site Name	Date	pH (Std. Units)	Temperature (°C)	Specific Conductance* (micromhos/cm, @ 25°C)
LAGOON	08/31/91	7.6	23.8	6800
LAGOON	10/28/91	7.4	6.4	8000
MW1	02/27/91	6.2	9.4	290
MW1	05/21/91	6.4	9.1	192
MW1	08/31/91	6.3	11.7	257
MW1	10/28/91	6.3	10.6	215
MW2	02/27/91	6.9	10.9	370
MW2	05/21/91	7.0	9.6	620
MW2	08/31/91	7.0	12.1	1010
MW2	10/28/91	6.9	10.6	970
MW3	02/27/91	6.9	11.8	900
MW3	05/21/91	7.0	9.8	840
MW3	08/31/91	7.3	11.7	760
MW3	10/28/91	7.0	11.3	790
MW4	02/27/91	6.8	11.8	700
MW4	05/21/91	7.5	9.8	2080
MW4	08/31/91	7.7	12.1	314
MW4	10/28/91	6.9	10.9	460

*Specific conductance readings are approximate.

Table 7. Laboratory Results, Whatcom County Dairy Lagoon #2 (mg/L).

Site Name	Date	Total Dissolved Solids	Chemical Oxygen Demand	Total Organic Carbon	Ammonia as N	Nitrate+ Nitrite as N	Total Inorganic Nitrogen	Total Persulfate Nitrogen	Total Phosphorus	Chloride	Total Solids
LAGOON	02/27/91	NT	540	3920	672 J	3.78	676	2.1 J	20.8	625	NT
LAGOON	05/21/91	NT	4200	5110	810	0.51	811	NT	1900	645	22000
LAGOON	08/13/91	NT	3700	1180	400	0.24	400	NT	46	342	5770
LAGOON	10/28/91	NT	21000	2230 J	1000	0.02 U	1000	NT	160	NT	34100
MW1	02/27/91	307	10 U	8.7	0.23 J	0.01 U	0.23	0.6 J	0.09	6.53	NT
MW1	05/21/91	289	11	3.1	0.22	0.01 UJ	0.22	NT	0.09	6.73	NT
MW1	08/13/91	287	7.2	1.7	0.21	0.02 U	0.21	NT	ND	4.0	NT
MW1	10/28/91	299	4.2	1.2	0.26	0.02 U	0.26	NT	0.03	6.7	NT
MW2	02/27/91	225	10 U	15.1	20.9 J	0.01 U	20.9	6.5 J	0.30	14.1	NT
MW2	05/21/91	551	56	16.8	30.5	0.01 UJ	30.5	NT	0.28	40.4	NT
MW2	08/13/91	661	63	24.6	53	0.02 U	53	NT	1.7	76.3	NT
MW2	10/28/91	684	78	26.4	110	0.02 U	110	NT	0.80	60.5	NT
MW3	02/27/91	492	44	53.6	64.2 J	0.07	64.3	23 J	2.3	50.6	NT
MW3	05/21/91	553	88	39.6	53	0.01 UJ	53	NT	1.9	53.9	NT
MW3	08/13/91	565	56	20.5	70	0.02 U	70	NT	3.0	43.5	NT
MW3	10/28/91	480	47	22.6	83.5	0.02 U	83.5	NT	2.2	51.8	NT
MW4	02/27/91	548	69.5	58.8	8.7 J	0.06	8.8	7.3 J	0.27	59	NT
MW4	05/21/91	1420	940	241	180	0.15 J	180	NT	20	145	NT
MW4	08/13/91	224	50.5	15.4	28.5	0.02 U	28.5	NT	4.8	7.8	NT
MW4	10/28/91	252	38	10.0	62	0.02 U	62	NT	0.86	18.3	NT

J= Estimated Value

U= Analyte Not Detected Above Listed Value.

NT= Not Tested

Table 8. Bacteriologic Results, Whatcom County Dairy Lagoon #2. (Units = Colony Forming Units/100ml)

Site Name	Date	Total Coliform		Fecal Coliform	
LAGOON	02/27/91	1,200,000		700,000	
LAGOON	05/21/91	1,500,000		1,400,000	
LAGOON	08/13/91	460,000		200,000	
LAGOON	10/28/91	10,000,000		9,200,000	
MW1	02/27/91	1	U	1	U
MW1	05/21/91	1		1	U
MW1	08/13/91	1	U	1	U
MW1	10/28/91	1	U	1	U
MW2	02/27/91	1	UX	1	U
MW2	05/21/91	1	U	1	U
MW2	08/13/91	1	U	1	U
MW2	10/28/91	1	UX	1	U
MW3	02/27/91	14		6	X
MW3	05/21/91	1	X	1	U
MW3	08/13/91	1	UX	1	U
MW3	10/28/91	1	UX	1	U
MW4	02/27/91	1	U	1	U
MW4	05/21/91	2000	J	180	J
MW4	08/13/91	3	X	1	UX
MW4	10/28/91	1	UX	1	U

J= Estimated Value

U= Analyte Not Detected Above Listed Value.

X= Many Background Organisms

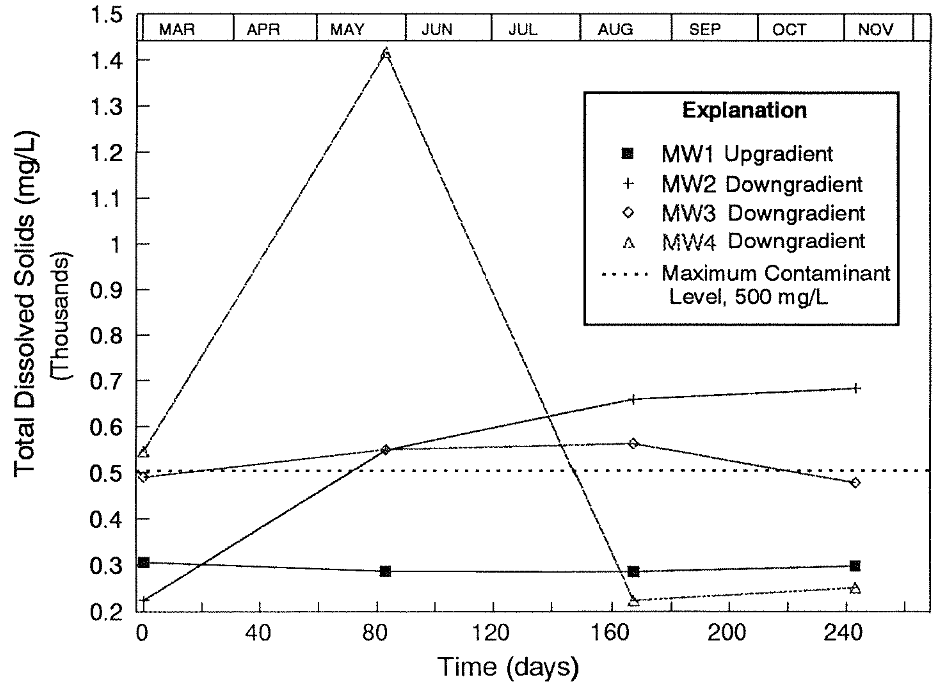

Figure 8. Total Dissolved Solids, Whatcom County Dairy Lagoon #2 February through October 1991.

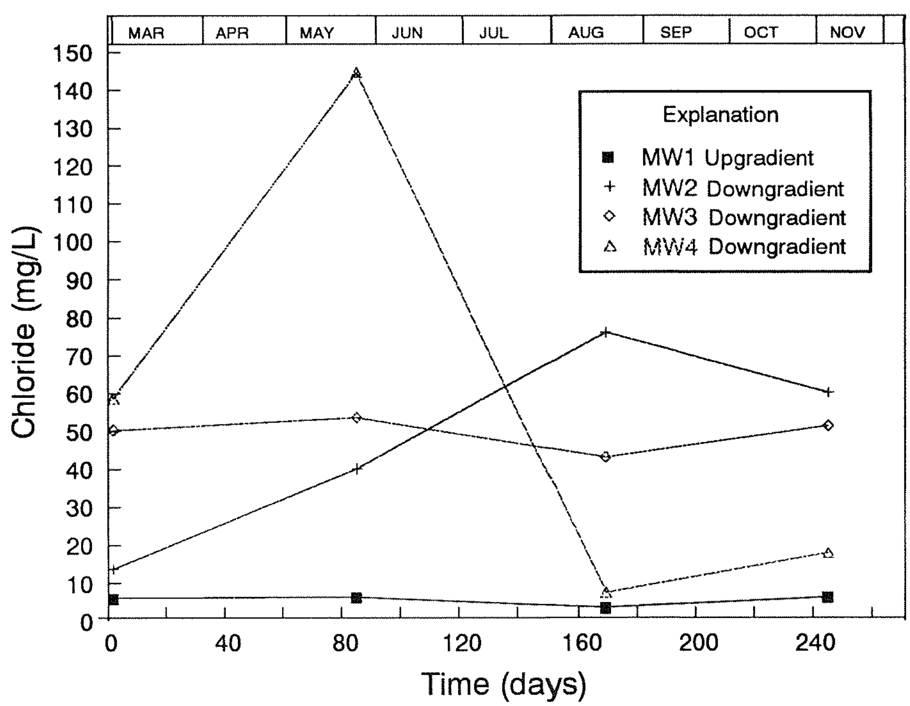

Figure 9. Chloride, Whatcom County Dairy Lagoon #2 February 1991 through October 1991.

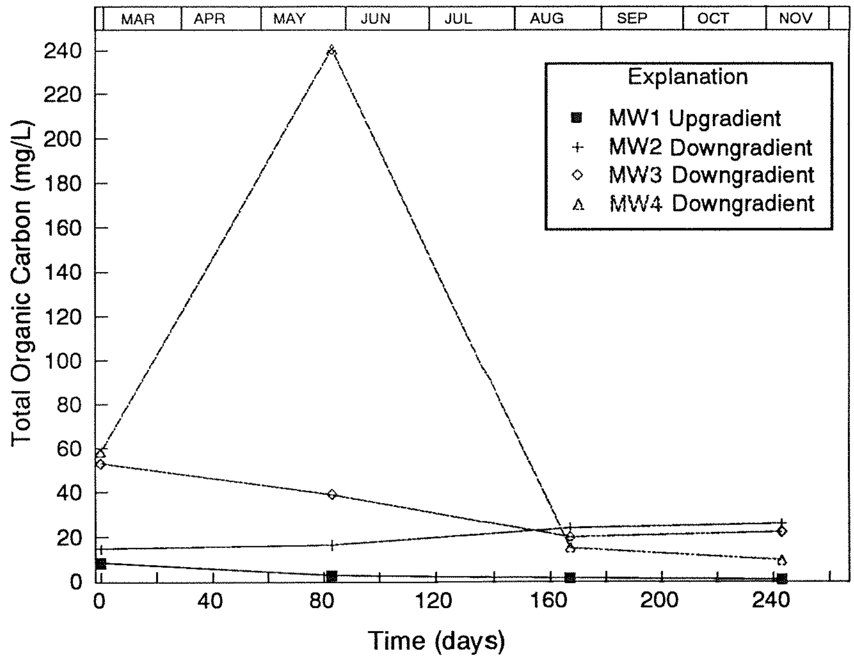

Figure 10. Total Organic Carbon (TOC), Whatcom County Dairy Lagoon #2, February through October 1991.

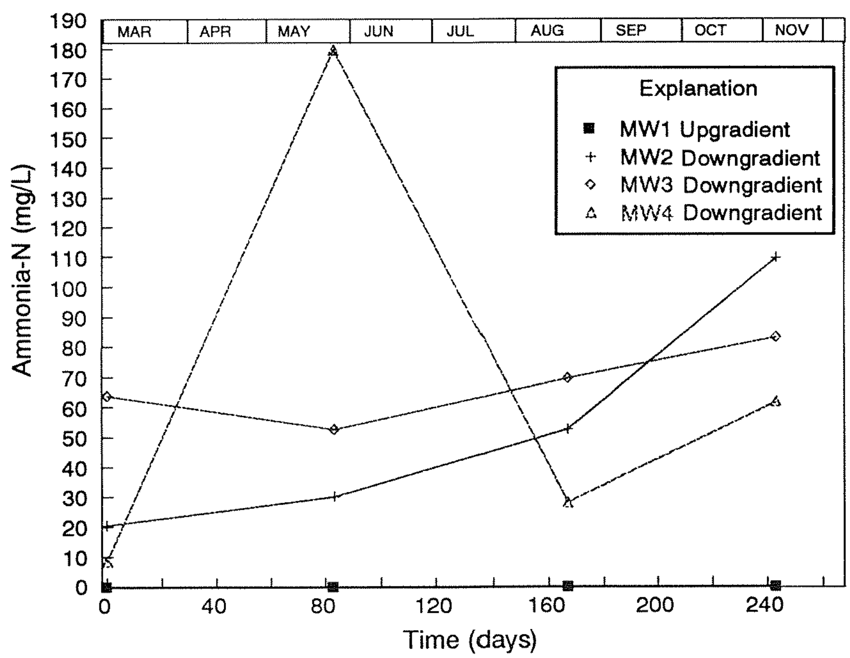

Figure 11. Ammonia-N, Whatcom County Dairy Lagoon #2 February through October 1991.

145 mg/L; TOC, 241 mg/L; and ammonia-N, 180 mg/L) were observed in MW4 in May. Concentrations in the corner downgradient wells (MW2 and MW4) showed wide variations over time. However concentrations in MW3, located downgradient of the center of the lagoon, showed relatively constant concentrations. Total coliform and fecal coliform bacteria results were highly variable, and intermittently showed elevated concentrations downgradient of the lagoon. The maximum observed total and fecal coliform counts occurred in MW4 in May and were 2000 and 180 CFUs/100mL, respectively.

DISCUSSION

Effects on Ground Water Quality

Elevated concentrations of TDS, COD, TOC, ammonia-N, total phosphorus, and chloride in downgradient wells strongly suggest that leakage from the lagoon is contaminating ground water. In particular, chloride is considered to be a good indicator of ground water contamination from lagoon leakage. Chloride was present in the wastewater at concentrations ranging from 342 mg/L to 645 mg/L while upgradient ground water concentrations (MW1) ranged from 4.0 to 6.7 mg/L. Also, it is a good tracer in ground water because it is soluble in water, does not adsorb readily to soil, and does not degrade (Davis and DeWiest, 1966; Freeze and Cherry, 1979). Chloride concentrations in downgradient wells (Figure 9) ranged from 7.8 to 145 mg/L, and were always higher than concentrations in the upgradient well.

Seasonal variation of water quality results in MW2 was probably related to changes in ground water flow direction. The highest concentrations were observed in August and October. During these months ground water flow was southwestward (Figures 6 and 7) and as a result most of the ground water flowing toward MW2 passed beneath the lagoon. In contrast, in February and May when concentrations were lower, ground water was flowing southeastward (Figures 4 and 5) and much of the ground water moving toward MW2 did not pass beneath the lagoon.

At MW4, anomalously high concentrations for most parameters were observed in May. Apparently MW4 is downgradient of a source of localized leakage from the lagoon. Based on the water-table contour maps (Figures 4 and 5), MW4 was downgradient of the east portion of the lagoon in February and May. The waste intake pipes are located beneath the east side of the lagoon. Possibly leakage is occurring along these pipes. In August and October, parameter concentrations decreased in MW4. During these months, ground water flow was primarily from east to west and MW4 was not downgradient of the lagoon.

Distance Affected Downgradient

The distance that water quality is affected downgradient of the lagoons is not known. Far-field monitoring wells were not installed as a part of this study. Contaminant concentrations are expected to decrease with distance from the lagoon due to dispersion, adsorption, degradation and volatilization. The distance affected downgradient of the Edaleen Dairy Lagoon was estimated to be on the order of a few hundred feet (Erickson, 1991). This estimate was based on only one year of monitoring and the distance affected may be substantially greater over the long term. Ground water use downgradient of the lagoon is not well known. Portions of the area are served by the Lynden Water Association and other public systems. The closest homes downgradient of the lagoon are located along Blaine-Sumas Road about 3,000 feet to the south.

Standards Exceeded

Drinking water standards (Maximum Contaminant Levels, MCLs) for public systems and ground water quality standards (Chapter 173-200 WAC) are shown in Table 9 for the parameters tested. With the exception of specific conductance, the criteria for the drinking water standards and ground water quality standards are identical. However, the ground water quality standards have narrative antidegradation standards that protect existing ground water quality and beneficial uses. Only two parameters, nitrate-N (10 mg/L) and total coliforms (one Colony Forming Unit (CFU)/100mL) have primary MCLs. Primary MCLs are maximum allowable concentrations for public water-supply systems based on potential health effects (Department of Health, 1989). Nitrogen is present in the wastewater primarily as ammonia-N. Ammonia-N concentrations in downgradient monitoring wells (Figure 11) consistently exceeded 10 mg/L and ranged from 8.7 to 180 mg/L. Because some of the ammonia in ground water will nitrify to nitrite and nitrate, the potential exists for nitrate-N concentrations to exceed 10 mg/L some distance downgradient of the lagoon. With the existing data, it is not possible to predict accurately the nitrate-N concentrations that may occur downgradient of the leaking lagoon. However, it is known that nitrate-N concentrations downgradient of the lagoon will be less than observed ammonia-N concentrations due to dispersion, volatilization, and adsorption.

Total coliform bacteria results are highly variable. Total coliform bacteria were observed intermittently in downgradient monitoring wells. Based on the concentration change between the wastewater and the monitoring wells the attenuation rate is high. One Colony Forming Unit (CFU)/100mL was detected in the upgradient well MW1, during one sampling event (May) but no coliform bacteria were detected in MW1 any other time. Downgradient of the lagoon, the maximum density was 2000 CFUs/100mL in well MW4 in May. By August, as with other elevated parameters in MW4, the density of coliform bacteria decreased to 3 CFUs/100mL. Total coliform bacteria were not detected in MW2, and the maximum concentration observed at MW3 was 14 organisms/100mL.

Secondary MCLs have been established for public drinking water systems for three of the parameters tested: specific conductance (700 micromhos/cm @ 25°C), TDS (500 mg/L), and chloride (250 mg/L). Secondary MCLs are based on aesthetics such as taste, odor, or discoloration. TDS exceeded 500 mg/L in all downgradient wells at least a portion of the time. The horizontal dotted line in Figure 8 shows the MCL relative to observed TDS concentrations in the monitoring wells. The maximum concentration was 1420 mg/L in MW4 May 1991. All chloride concentrations in monitoring wells were less than 250 mg/L.

Table 9. Whatcom County Dairy Lagoon #2, Drinking Water Standards and Ground Water Quality Standards (mg/L unless shown otherwise).

Parameter	Primary Maximum Contaminant Level(MCL)[1]	Secondary Maximum Contaminant Level(MCL)[2]	Ground Water Quality Standards[3]
Chloride	None	250	250
Total Dissolved Solids	None	500	500
Total Organic Carbon	None	None	None
Chemical Oxygen Demand	None	None	None
Ammonia-N	None	None	None
Nitrate-N	10	None	10
Total Phosphorus	None	None	None
Specific Conductance (micromhos/cm @ 25°C)	None	700	None
Total Coliform Bacteria (Colony Forming Units/100mL)	1	None	1
Fecal Coliform Bacteria (Colony Forming Units/100mL)	None	None	None

None= No standard has been established.

[1] Department of Health (1989). Primary MCLs are maximimum allowable contaminant concentrations for public water supply systems based on potential adverse health effects.

[2]Department of Health (1989). Secondary MCLs are maximum allowable contaminant concentrations for public water supply systems based on aesthetics such as taste, odor, or staining.

[3] Chapter 173-200 WAC, Water Quality Standards for Ground Waters of the State of Washington.

Note: Water Quality Standards for Ground Water have narrative antidegradation standards to protect existing ground water quality and beneficial uses.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions from the first year of monitoring at Whatcom County Dairy Lagoon #2 are discussed below.

1. Ground water immediately downgradient of the lagoon shows elevated concentrations of total dissolved solids, chemical oxygen demand, total organic carbon, ammonia-N, total phosphorus, and chloride. The increased concentrations are probably the result of leakage from the lagoon.

2. Anomalously high concentrations were observed at one downgradient monitoring well, MW4, in May. The high concentrations are likely the result of localized leakage from the lagoon. The waste intake pipe is located upgradient of MW4 during part of the study, and is a possible source of leakage.

3. Water quality results varied seasonally in downgradient corner monitoring wells, MW2 and MW4. The variations are consistent with changes in ground water flow direction.

4. Drinking water and ground water quality standards were exceeded in downgradient wells. Concentrations equaled or exceeded the Primary MCL for total coliform bacteria (one Colony Forming Unit/100mL) four times. Ammonia-N concentrations consistently exceeded 10 mg/L and ranged as high as 180 mg/L. Therefore, the potential for nitrate-N concentrations to exceed the Primary MCL (10 mg/L) downgradient of the lagoon exists. The Secondary MCL for TDS was exceeded in all downgradient wells at least some portion of the study period.

5. The lagoon is underlain by shallow ground water. Ground water flow direction varies seasonally in response to changes in pumping, irrigation and infiltration from ditches. The ground water flow velocity is estimated to range from 0.02 to 12 feet per day with a mean of about one foot per day.

6. The distance downgradient of the lagoon that water quality is affected cannot be accurately predicted with the existing data. Results from a new lagoon constructed in a similar setting about three miles to the northeast suggest that ground water quality can be affected a few hundred feet downgradient of the lagoon. The closest homes downgradient of the lagoon are about 3,000 feet from the lagoon.

Recommendations based on the first year of monitoring are described below.

1. Continue quarterly monitoring of on-site wells and the lagoon. Continued monitoring will provide additional information on the fate and transport of nitrogen species, specifically ammonia-N and nitrate-N. At least one new well should be installed downgradient of MW3 to determine contaminant concentration changes over distance. This information could be

used to estimate effects of the leakage on ground water quality at greater distances from the lagoon and could provide useful information on the fate of contaminants at other dairy lagoons in a similar setting. Continued monitoring would require authorization by Water Quality Program based on alignment with their priorities.

2. If continued monitoring is authorized and funding is available, the following additional studies should be conducted:

   a. The depth of the lagoon sounded to determine the separation distance of the bottom of the lagoon from the water table.

   b. Seepage rates estimated using short term mass balance methods.

   c. Field tests for total dissolved oxygen and Eh (measurement of redox potential), and laboratory tests for dissolved and total iron added.

These studies would provide useful information for modifying lagoon construction guidelines or for determining the fate of contaminants.

4. SCS should conduct a review of the lagoon construction to determine if it meets their standards and guidelines. In part, the review should address whether the lagoon meets earthen liner requirements. In addition, the review should consider what changes are needed to reduce/eliminate leakage from the lagoon to ground water.

5. After monitoring is terminated, on-site monitoring wells should be properly decommissioned in accordance with Chapter 173-160 WAC, Minimum Standards for the Construction and Maintenance of Wells.

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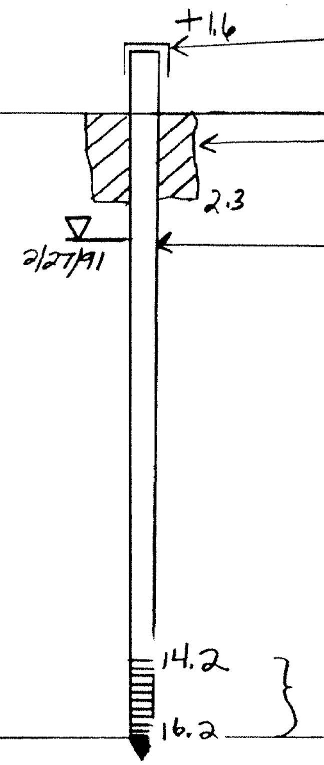
APPENDIX A

RESOURCE PROTECTION WELL REPORT

START CARD NO. 0T8211

PROJECT NAME: Timmerman's Lagoon	COUNTY: Whatcom
WELL IDENTIFICATION NO. MW-1	LOCATION: NE 1/4 SE 1/4 Sec 13 Twn 40 R 2E
DRILLING METHOD: Driving	STREET ADDRESS OF WELL: 8647 Guide
DRILLER: Denis Erickson	Lynden
FIRM: Wash. Dept. of Ecology	WATER LEVEL ELEVATION: ~96
SIGNATURE: Denis R. Erickson	GROUND SURFACE ELEVATION: ~98
CONSULTING FIRM: NONE	INSTALLED: 11/28/90
REPRESENTATIVE: NONE	DEVELOPED: 2/27/91

Depth	AS-BUILT	WELL DATA	FORMATION DESCRIPTION
	+1.6	Locking Cap	
0			Ground Surface
		Bentonite Seal, 1/2" Pellets Hydrated	TOPSOIL, Dark Brown, Organic
	2.3		Gray to Reddish Brown clayey SILT
	2/27/91 (water level)	Galvanized Casing, 1 1/4" dia.	Brown, silty, fine to medium SAND
5			
			Gray, gravelly SAND and sandy GRAVEL
10			
	14.2	Stainless Steel Well Point 30 sz., 1 1/4"	
15			
	16.2		Bottom of Hole
20			



SCALE: 1" = 5 feet

PAGE 1 OF 1

ECY 050-12 (Rev. 11/89)

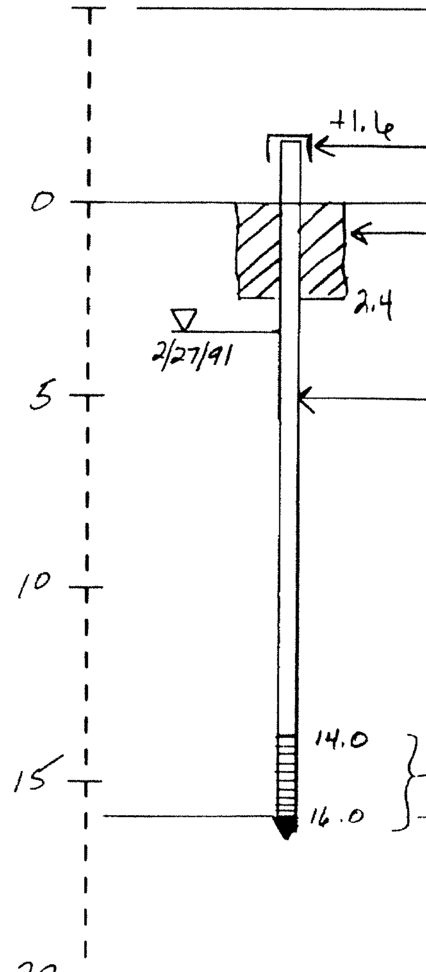
RESOURCE PROTECTION WELL REPORT

START CARD NO. 078211

PROJECT NAME: Timmerman's Lagoon
WELL IDENTIFICATION NO. MW-2
DRILLING METHOD: Driving
DRILLER: Denis Erickson
FIRM: Wash. Dept. of Ecology
SIGNATURE: Denis R. Erickson
CONSULTING FIRM: NONE
REPRESENTATIVE: NONE

COUNTY: Whatcom
LOCATION NE ¼ SE ¼ Sec 13 Twn 40 R 2E
STREET ADDRESS OF WELL: 8647 Guide
Lynden, WA
WATER LEVEL ELEVATION: ~ 92
GROUND SURFACE ELEVATION: ~ 99
INSTALLED: 11/28/90
DEVELOPED: 2/27/91

Depth (ft)	AS-BUILT	WELL DATA	FORMATION DESCRIPTION
+1.6		Locking Cap	
0			GROUND SURFACE
		Bentonite Pellet Seal (Hydrated)	Topsoil, Dark Brown, organic
			Brown and Reddish Brown clayey SILT
2.4			Brown silty fine to medium SAND
5		Galvanized Steel Casing 1¼ Diameter	
10			Gray gravelly SAND and sandy GRAVEL
14.0–16.0		Stainless Steel Screen 30 Gz	
16.0			Bottom of Hole
20			



SCALE: 1" = 5 feet PAGE 1 OF 1

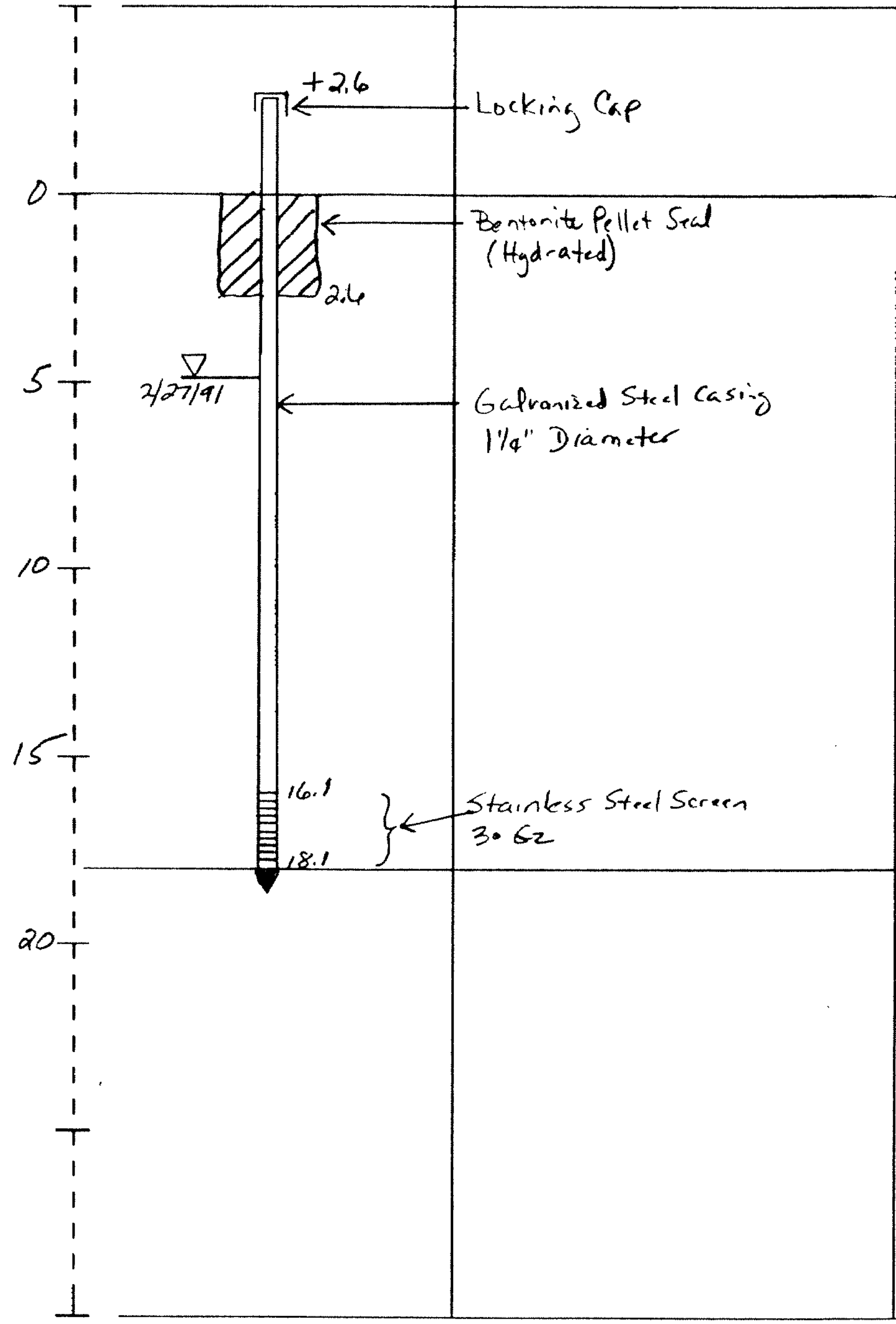
RESOURCE PROTECTION WELL REPORT

START CARD NO. 078211

PROJECT NAME: Timmerman's Lagoon
WELL IDENTIFICATION NO. MW-3
DRILLING METHOD: Driving
DRILLER: Denis Erickson
FIRM: Wash. Dept. of Ecology
SIGNATURE: Denis R. Erickson
CONSULTING FIRM: NONE
REPRESENTATIVE: NONE

COUNTY: Whatcom
LOCATION: NE ¼ SE ¼ Sec 13 Twn 40 R 2E
STREET ADDRESS OF WELL: 8647 Guide Meridian
Lynden, WA
WATER LEVEL ELEVATION: ~94
GROUND SURFACE ELEVATION: ~99
INSTALLED: 2/26/91
DEVELOPED: 2/27/91

AS-BUILT	WELL DATA	FORMATION DESCRIPTION



FORMATION DESCRIPTION

Ground Surface

TOPSOIL, Dark Brown, organic, wet

Brown and reddish brown, clayey SILT with organics

Black silty organic SAND with some gravel, fine to medium sand, wet

Gray, gravelly SAND and sandy GRAVEL

Bottom of Hole

SCALE: 1" = 5 feet

PAGE 1 OF 1

ECY 050-12 (Rev. 11/89)

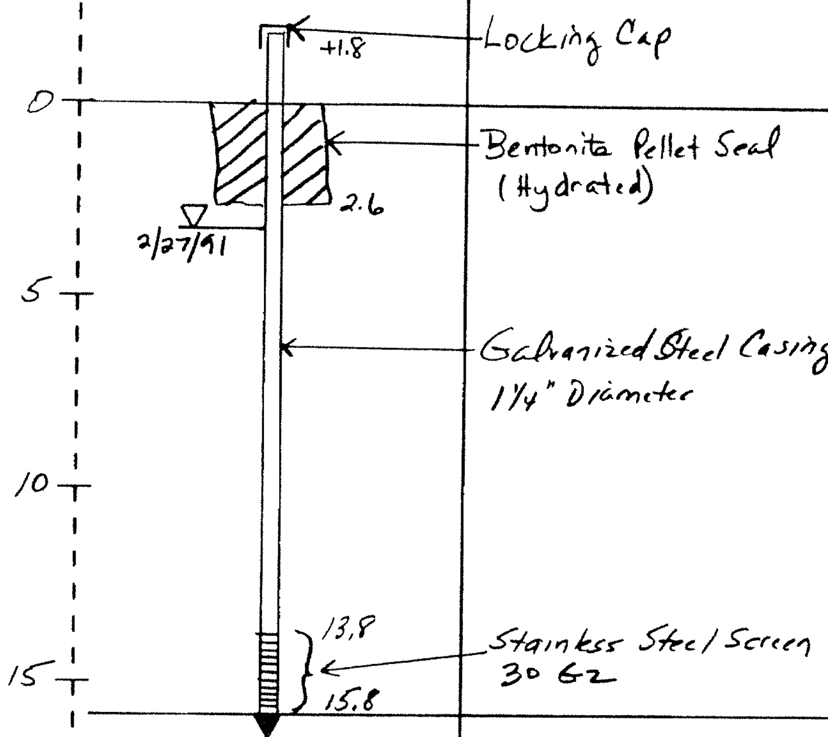
RESOURCE PROTECTION WELL REPORT

START CARD NO. 078211

PROJECT NAME: Timmerman's Lagoon
WELL IDENTIFICATION NO. MW-4
DRILLING METHOD: Driving
DRILLER: Denis Erickson
FIRM: Wash. Dept. of Ecology
SIGNATURE: Denis R. Erickson
CONSULTING FIRM: NONE
REPRESENTATIVE: NONE

COUNTY: Whatcom
LOCATION: NE 1/4 SE 1/4 Sec 13 Twn 40 R 2E
STREET ADDRESS OF WELL: 8647 Guide Meridian Lynden, WA
WATER LEVEL ELEVATION: ~91
GROUND SURFACE ELEVATION: ~99
INSTALLED: 2/26/91
DEVELOPED: 2/27/91

AS-BUILT	WELL DATA	FORMATION DESCRIPTION



Ground Surface

TOPSOIL, Dark Brown, organic

Brown clayey SILT, w/ organics

Brown to gray silty, fine to medium SAND

Gray, gravelly SAND and sandy GRAVEL

Bottom of Hole

SCALE: 1" = 5 feet

PAGE 1 OF 1

ECY 050-12 (Rev. 11/89)

40/02-13J

File Original and First Copy with Department of Ecology
Second Copy — Owner's Copy
Third Copy — Driller's Copy

40/2E/13/J

WATER WELL REPORT
STATE OF WASHINGTON

(1351)

Application No. G1-21501
Permit No. G1-21501P

(1) OWNER: Name Simon Timmerman Address 8647 Guide Meridian, Lynden, Wn.

(2) LOCATION OF WELL: County Whatcom — NE ¼ SE ¼ Sec. 13 T. ___ N., R. ___ W.M.
Bearing and distance from section or subdivision corner 400 feet west and 690 feet south of east ½ crnr

(3) PROPOSED USE: Domestic ☐ Industrial ☐ Municipal ☐ Irrigation ☒ Test Well ☐ Other ☐

(4) TYPE OF WORK: Owner's number of well (if more than one) ____
New well ☒ Method: Dug ☒ Bored ☐
Deepened ☐ Cable ☐ Driven ☐
Reconditioned ☐ Rotary ☐ Jetted ☐

(5) DIMENSIONS: Diameter of well 36 inches.
Drilled 33 ft. Depth of completed well 33 ft.

(6) CONSTRUCTION DETAILS:

Casing installed: 36" Diam. from 0 ft. to 33 ft.
Threaded ☐ ____" Diam. from ____ ft. to ____ ft.
Welded ☐ ____" Diam. from ____ ft. to ____ ft.

Perforations: Yes ☒ No ☐
Type of perforator used Perforated tile
SIZE of perforations 5/8 in. by 5/8 in.
700 perforations from 18 ft. to 33 ft.
____ perforations from ____ ft. to ____ ft.
____ perforations from ____ ft. to ____ ft.

Screens: Yes ☐ No ☒
Manufacturer's Name ____
Type ____ Model No. ____
Diam. ____ Slot size ____ from ____ ft. to ____ ft.
Diam. ____ Slot size ____ from ____ ft. to ____ ft.

Gravel packed: Yes ☒ No ☐ Size of gravel: 5/8 minus
Gravel placed from 18 ft. to 33 ft.

Surface seal: Yes ☐ No ☒ To what depth? ____ ft.
Material used in seal ____
Did any strata contain unusable water? Yes ☐ No ☒
Type of water? ____ Depth of strata ____
Method of sealing strata off ____

(7) PUMP: Manufacturer's Name Jacuzzi
Type: Centrifigal H.P. 25

(8) WATER LEVELS: Land-surface elevation above mean sea level ____ ft.
Static level 6 ft. below top of well Date 6/73
Artesian pressure ____ lbs. per square inch Date ____
Artesian water is controlled by ____ (Cap, valve, etc.)

(9) WELL TESTS: Drawdown is amount water level is lowered below static level
Was a pump test made? Yes ☒ No ☐ If yes, by whom? Self
Yield: 250 gal./min. with 12 ft. drawdown after 2 hrs.
" " " "
" " " "

Recovery data (time taken as zero when pump turned off) (water level measured from well top to water level)

Time	Water Level	Time	Water Level	Time	Water Level
	18				
1:45	7				

Date of test June, 1973
Bailer test ____ gal./min. with ____ ft. drawdown after ____ hrs.
Artesian flow ____ g.p.m. Date ____
Temperature of water ____ Was a chemical analysis made? Yes ☐ No ☐

(10) WELL LOG:

Formation: Describe by color, character, size of material and structure, and show thickness of aquifers and the kind and nature of the material in each stratum penetrated, with at least one entry for each change of formation.

MATERIAL	FROM	TO
Topsoil	0	26"
Sand & Gravel	26"	33'

Work started May, 19 73 Completed June, 19 73

WELL DRILLER'S STATEMENT:

This well was drilled under my jurisdiction and this report is true to the best of my knowledge and belief.

NAME B & K Water Wells (Person, firm, or corporation) (Type or print)

Address 432 W. King Tut Rd. B'ham, Wn. 98225

[Signed] (signature) (Well Driller)

License No. 0060-0256 Date June 20, 19 73