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STATE OF WASHINGTON

DEPARTMENT OF ECOLOGY

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MEMORANDUM

September 8, 1986

To: Carl Nuechterlein and Larry Peterson

From: Marc Heffner

Subject: Waitsburg Sewage Treatment Plant Class II Inspection, September 24-25, 1985

ABSTRACT

A Class II inspection was conducted at the Waitsburg sewage treatment plant (STP) on September 24-25, 1985. The STP is a non-discharging facility that includes a trickling filter, a lagoon, and an infiltration basin/marsh. The system seemed to be providing good treatment during the inspection. Ground water data collected during the inspection was insufficient for conclusive analysis. Developing seasonal flow nets of ground water movement in the area is suggested as part of future permit monitoring requirements.

INTRODUCTION

A class II inspection was conducted on September 24-25, 1985, at the Waitsburg (STP). Participating in the inspection were Carl Nuechterlein and Larry Peterson from the Ecology Eastern Regional Office, Marc Heffner from the Ecology Water Quality Investigations Section (WQIS), and STP operator Elmer Hayes representing Waitsburg. A concurrent water quality survey in the Touchet River and Coppei Creek was conducted by Joe Joy and Pat Crawford from the Ecology WQIS (Joy, 1986).

The Waitsburg STP is designed for zero discharge to surface waters. Treatment units include a primary clarifier, trickling filter, lagoon, and infiltration basin/marsh (Figure 1). Sludge from the primary clarifier is anaerobically digested, then spread on agricultural land. The facility is located between the Touchet River and Coppei Creek; in close proximity to both (Figure 1). Objectives of the inspection included:

1. Sample collection and flow measurement to estimate trickling filter and lagoon efficiency.

2. Sample splits for analysis by the Ecology and Walla Walla STP laboratories (the Walla Walla STP does lab work for Waitsburg).

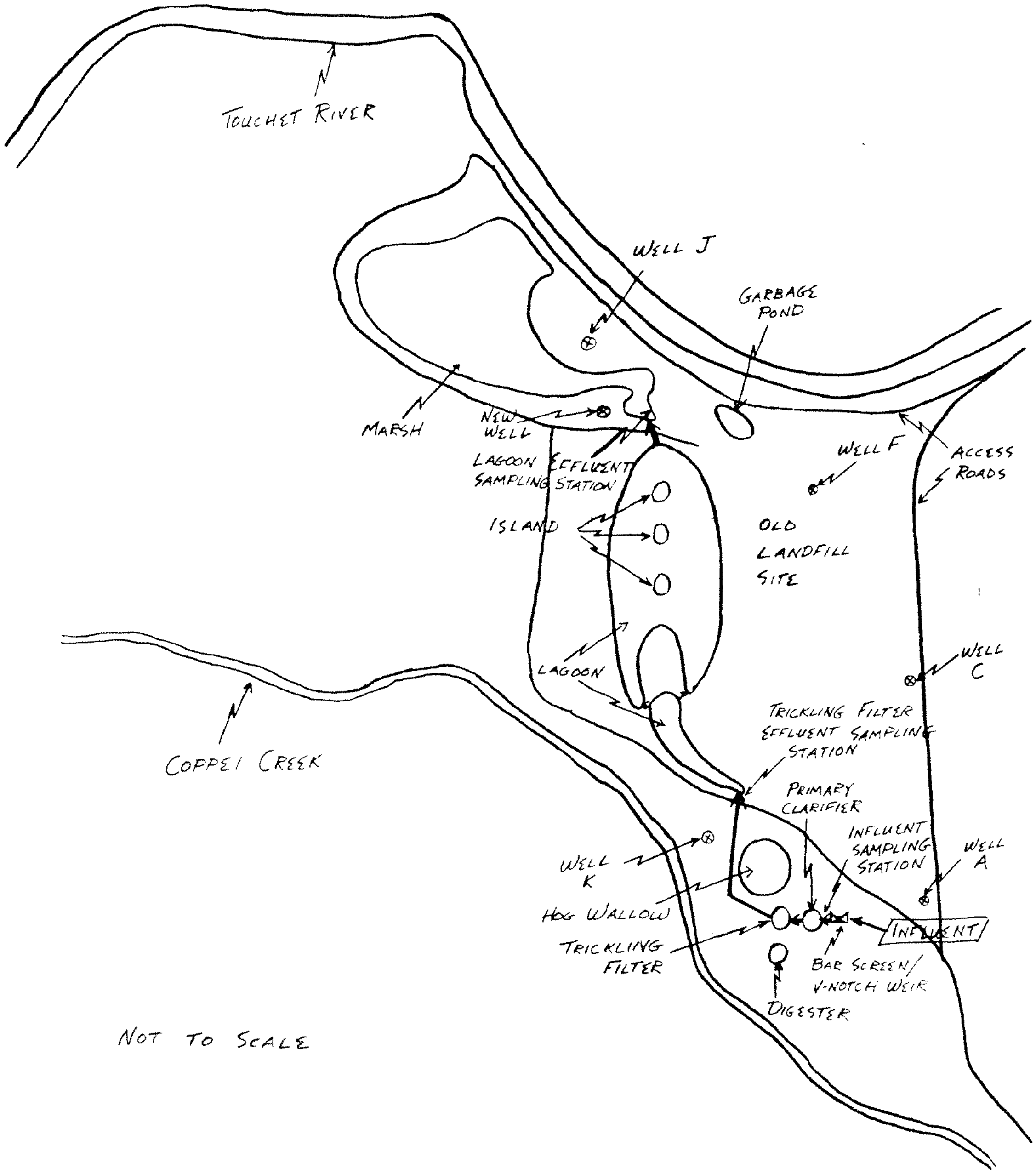


Figure 1. STP flow scheme/site map - Waitsburg, September 1985.

3. Grab sample collection from existing test wells near the STP.

4. Provide STP data for consideration when the receiving water study data are analyzed.

The zero discharge to surface water system was instituted in 1981, at which time the plant discharge to Coppei Creek was discontinued. Issuance of a state permit for operation of a non-discharging facility is pending based on several minor improvements to the system.

PROCEDURES

STP sampling included both grab and composite samples (Table 1, Figure 1). Ecology automatic Manning samplers were set up to collect approximately 200 mLs of sample every 30 minutes for 24 hours (Table 1, Figure 1). The SIP operator hand composited the Waitsburg samples, using his usual system where approximately equal aliquots of sample were collected at 0900, 1200, 1430, and 1800 hours on September 24 and at 0600 hours on September 25 at the influent and lagoon effluent stations (the 0600 aliquot is usually less than the others because flow is usually less then). All composite samples were split for analysis by Ecology and Walla Walla STP laboratories of parameters noted on Table 1. Unfortunately the sample splits for analysis by the Walla Walla lab were mixed (ie., Ecology influent mixed with Waitsburg influent, etc.) prior to analysis and laboratory results were not comparable.

Grab samples were collected by Ecology from the test wells located near the STP (Table 1, Figure 1). The operator attempted to pump the wells once or twice before the inspection to purge them. Pumping was dependant on water column depth in the well and the ability of the pump to develop suction. Inspection samples were collected using a peristaltic pump. At each well approximately one gallon of well water was pumped to purge the sampling line. Conductivity and temperature were then checked and the sample was collected. A second conductivity and temperature sample was drawn and checked to help assure water quality changes were minimal during the sampling period. Distance from the well cap to the water table was measured.

A small Ecology boat was used to collect samples from the lagoon. Dissolved oxygen (sample collected just under the duckweed; Winkler method used), sludge depth, and lagoon depth measurements were made.

Flow measurements were made at two locations; the V-notch weir located in the influent channel, and the V-notch weir at the inlet to the marsh. An Ecology-Manning dipper flow meter was set up in the influent channel. Waitsburg had a flow meter stationed at the marsh inlet, but the meter was vandalized the night before the inspection and was inoperable. Instantaneous Ecology measurements were made at the marsh inlet weir. Flow measurement accuracy was hampered by leaking around the edges of the weir plates (particularly at the influent station) and an inability to precisely measure the weir angles with the equipment available during the inspection.

Table 1. Sampling schedule - Waitsburg. September 1985.

Sample	Sampler	Laboratory	Date	Time	Field Analyses: pH	Conductivity	Temperature	Dissolved Oxygen	Sludge Depth	Water Elevation	Laboratory Analyses: Fecal Coliforms	T. Recoverable Fe	Oil & Grease	Nutrients: NH_3-N	NO_2-N	NO_3-N	O-PO_4-P	Total-P	Solids: TS	TNVS	TSS	TNVSS	Turbidity	T. Hardness	Alkalinity	Conductivity	Chloride	Color	BOD_5	COD
Ecology Grab Samples																														
Influent			9/24	1010	X	X	X																							
				1725	X	X	X																							
			9/25	1010	X	X	X					X*	X																	
Trickling Filter Efflwnt			9/24	1105	X	X	X				X																			
				1415							X																			
				1740	X	X	X																							
			9/25	0955	X	X	X				X	X*	X																	
Lagoon			9/25	0915-1015			X	X	X																					
Lagoon Effluent			9/24	1035	X	X	X				X																			
				1415							X																			
				1750	X	X	X																							
			9/25	0945	X	X	X				X	X*	X																	
Well A			9/24	1145	X	X	X			X	X	X		X	X	X	X	X			X			X		X	X	X		X
Well C			9/24	1410	X	X	X			X	X	X		X	X	X	X	X			X			X		X	X	X		X
Well F			9/24	1205	X	X	X			X	X	X		X	X	X	X	X			X			X		X	X	X		X
Well J			9/24	1300	X	X	X			X	X	X		X	X	X	X	X			X			X		X	X	X		X
Well K			9/24	1350	X	X	X				X	X		X	X	X	X	X			X			X		X	X	X		X
New Well			9/24	1235	X	X	X				X	X		X	X	X	X	X			X			X		X	X	X		X
Marsh			9/24	1340	X	X	X				X	X		X	X	X	X	X			X			X		X	X	X		X
Garbage Pond			9/24	1325	X	X	X				X	X		X	X	X	X	X			X			X		X	X	X		X
Composite Samples																														
Influent	Ecology	Ecology Walla Walla†	9/24-25	1010-1010	X	X	X							X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
																					X								X	
	Waitsburg	Ecology Walla Walla†	9/24-25	tt										X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
																					X								X	
Trickling Filter Effluent	Ecology	Ecology Walla Walla†	9/24-25	1105-1105	X	X	X							X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
																					X								X	
	Waitsburg	Walla Walla†	9/25	1030 grab																	X								X	
Lagoon Effluent	Ecology	Ecology Walla Walla†	9/24-25	1035-1035	X	X	X							X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
																					X								X	
	Waitsburg	Ecology Walla Walla†	9/24-25	tt										X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
																					X								X	

* = Grab composite collected for Fe analysis. Equal aliquots collected during first 9/24 grab sample and first 9/25 grab sample.

† = Ecology and Waitsburg composites collected at the sane sampling station were canbined by the Waitsburg STP operator prior to analysis at Walla Walla.

tt = Hand canposite collected by Waitsburg operator. Approximately equal aliquots of sanple collected on 9/24 at 0900, 1200, 1430, and 1800 hours and on 9/25 at 0600 hours.

RESULTS AND DISCUSSION

Analytical results of samples collected at Waitsburg are summarized in Table 2. Flow measurements are summarized in Table 3.

Inspection data describe fairly good treatment occurring during the sampling period. Table 4 briefly summarizes the reductions achieved for typical permit parameters in the system.

Table 4. Percent removals - Waitsburg, September 1985.

	BOD_5		TSS	
Ecology Composite Sample	Concentration (mg/L)	Percent Removal*	Concentration (mg/L)	Percent Removal*
Influent	190		68†	
Trickling filter effluent	38	80	18†	74
Lagoon effluent	14	93	7†	90

*Total percent removal to this point in the system.

†Estimated concentration. Samples sent to the Ecology laboratory were analyzed after the allowable holding time had been exceeded.

Operation of the trickling filter system was not carefully evaluated during the inspection, but several observations about the lagoon were made. Results of measurements made on the lagoon by Ecology are summarized in Figure 2. The lagoon was unusual in several ways:

1. Dissolved oxygen (D.O.) measurements in the lagoon were 0.0 mg/L. A hydrogen sulfide odor at the outlet, the relatively high NH_3-N concentration (12 mg/L), and absence of NO_3-N (0.01 mg/L) in the effluent suggested the 0.0 mg/L D.O. measurements were accurate.

2. The lagoon was unusually shaped. Three small islands and two long fingers of water were included in the lagoon. Depth was variable; in many places less than three feet.

3. Lagoon and lagoon effluent temperatures (10.9 - 13.7°C) were less than trickling filter effluent temperatures (16.3 - 17.6°C).

A thick mat of duckweed covered the entire lagoon, shading the water column and likely contributing to the low D.O. concentration and lower temperatures. The unusual shape of the lagoon likely minimizes the ability of wind action to aid oxygenation by either surface transfer or by congregating the duckweed

Table 2. Ecology results - Waitsburg, September 1985

				Field Analyses				Laboratory Analyses			Nutrients (mg/L)					Solids (mg/L)											
Sample	Sampler	Date	Time	pH (S.U.)	Conductivity (umhos/cm)	Temperature (°C)	Ground Water Elevation (ft)	Fecal Coliforms (#/100 m L)	T. Recoverable Fe (ug/L)	Oil & Grease (mg/L)	NH_3-N	NO_2-N	NO_3-N	O-PO_4-P	Total-P	TS	TNVS	TSS	TNVSS	Turbidity (NTU)	T. Hardness (mg/L as $CaCO_3$)	Alkalinity (mg/L as $CaCO_3$)	Cond. (umhos/cm)	Chloride (mg/L as Cl)	Color (units)	BOD_5 (mg/L)	COD (mg/L)
Ecology Grab Samples																											
Influent		9/24	1010	7.2	460	18.9																					
			1725	7.3	550	19.3																					
		9/25	1010	7.2	450	18.9			622*	160																	
Trickling Filter Effluent		9/24	1105	7.3	375	17.2		960,000E																			
			1415					1,600,000																			
			1740	7.3	380	17.6																					
		9/25	0955	7.4	375	16.3		410,000	249*	32																	
Lagoon Effluent		9/24	1035	6.8	370	13.0		50,000																			
			1415					66,000E																			
			1750	6.9	375	13.7																					
		9/25	0945	6.9	375	12.4		70,000	161*	24																	
Well A		9/24	1145	6.8	615	14.9	1220.6††	150	119		.25	<.01	11.0	.25	.45			4t			220		590	12	4†		9
Uell C		9/24	1410	6.6	850	15.9	1220.6††	360	3,940		3.6	<.01	8.1	.01	.95			IIt			270		650	14	17†		17
Uell F		9/24	1205	6.8	750	15.1	1219.6††	<4	12,700		1.0	<.01	.02	.01	1.0			18†			270		682	36	580†		17
Well J		9/24	1300	6.7	630	15.9	1215.4††	<4	11,400		3.2	<.01	.01	.01	1.7			26t			180		567	27	590†		17
Uell K		9/24	1350	6.7	620	13.4		1,700E	44		2.3	.25	2.9	.01	.90			2†			210		578	17	12†		9
New Well		9/24	1235	6.7	660	15.4		<4	7,010		3.0	<.01	.01	<.01	2.4			36t			200		594	26	170†		22
Marsh		9/24	1340	7.2	370	21.8		6,400	770		12	<.01	.02	5.2	7.4			20t			57		360	18	110†		55
Garbage Pond		9/24	1325	6.8	600	11.7		43	10,600		1.5	<.01	<.01	.25	.40			26t			180		573	35	92†		17
Composite Samples																											
Influent	Ecology			7.3	460	4.5					17	<.01	.08	4.6	7.8	360†	230†	68†	16†	28†	49	160	458	18	470†	190	340
	Waitsburg										21	<.01	.07	4.9	8.8	470†	230†	160†	140†	50†	58	200	444	26	500†	280	340
Trickling Filter Effluent	Ecology			7.5	365	3.9					12	.01	1.8	4.4	6.8	250†	180†	18†	2†	10†	51	130	361	13	76†	38	68
Lagoon Effluent	Ecology			7.3	375	3.6					12	<.01	.01	4.8	7.0	220†	160†	7†	4†	4†	55	120	363	17	92†	14	34
	Haitsburg										12	<.01	<.01	5.0	6.2	230†	120†	4†	1†	3†	46	120	359	16	97†	12	34

E = Estimated concentration.

* = Sample analyzed was grab composite. Equal aliquots collected during first 9/24 grab and first 9/25 grab sample.

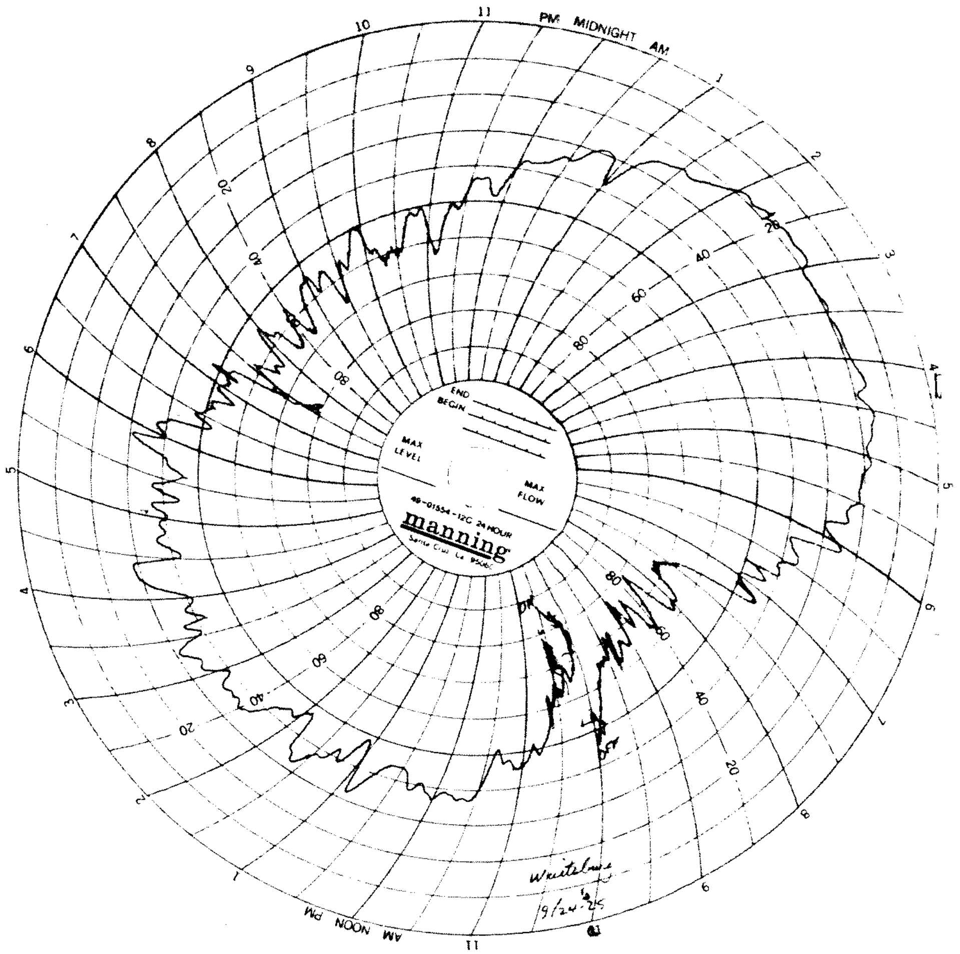
t = Estimated. Samples sent to the Ecology laboratory were analyzed after the allowable holding time had been exceeded.

†† = Estimated elevation due to possible change in well cap elevation due to fire.

Table 3. Flow measurements - Waitsburg, September 1985.

Influent Flow

Script chart from Ecology - Manning dipper flow meter:
100 percent of flow = 99 gpm = 0.14 MGD.



Flow for the day - 0.062 MGD. (NOTE: Because of a suspected totalizer malfunction during the night, flow was calculated based on chart trace.)

Lagoon Effluent Flow

Date	Time	Ecology/Instantaneous Flow Measurement (MGD)
9/24	1035	0.036
	1900	0.030
9/25	0920	0.030
Average		0.032 MGD

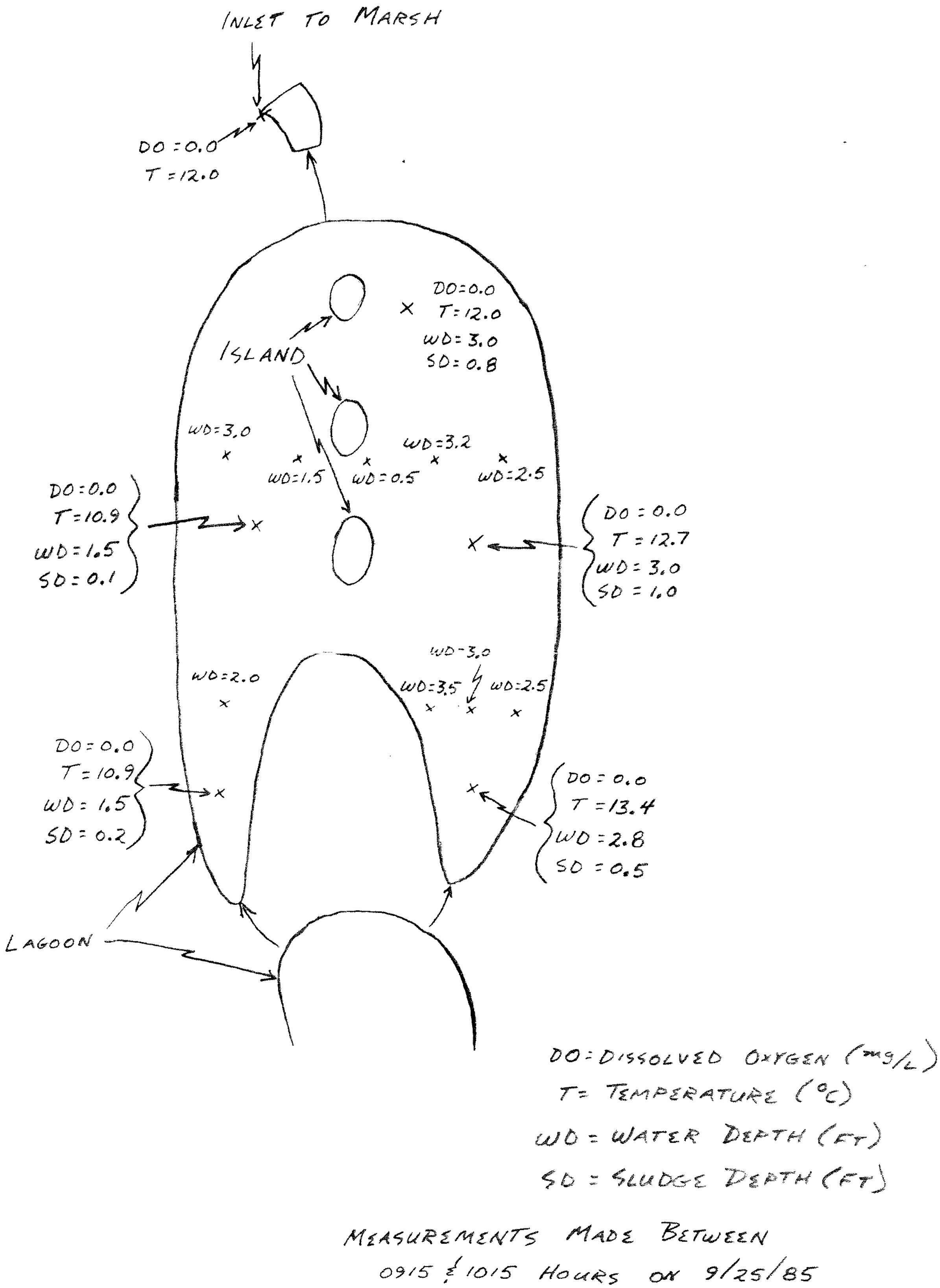


Figure 2. Lagoon rneasurements - Waitsburg, September 1985.

in an end or corner of the lagoon and allowing photosynthesis in the water column to occur in the open areas. Because of the unconventional lagoon configuration and operation, assessment of actual capacity was not attempted. Monitoring the effluent for decreased BOD_5 removal rates is suggested as an appropriate means of indicating when lagoon modification may be necessary, particularly in light of minimal anticipated future growth. This system of estimating capacity requires that both the trickling filter effluent and lagoon effluent be routinely monitored so BOD_5 removal efficiency can be calculated. Problems with excessive odors from the lagoon (H_2S or other) are another suggested means of noting a need for lagoon modification.

Flow data collected during the survey suggest exfiltration is occurring from both the lagoon and marsh. Plant influent flow was estimated to be 62,000 gallons per day (gpd), while flow to the marsh was estimated to be 32,000 gpd (Table 3). Positioning flow meters at both of these stations or using a portable meter to weekly alternate between stations is suggested for monitoring the system as a non-discharging facility. Weir angles and seals along the edges of the weir plate should be checked and modified as necessary to assure accurate measurements.

The primary concerns necessitating well sampling were: (1) the possibility that the lagoon/marsh system might directly cause unacceptable ground-water contamination, (2) the possibility that the lagoon/marsh system might alter ground-water flow patterns in such a way that the nearby closed dump site might cause unacceptable ground-water contamination, and (3) the possibility that the lagoon/marsh system might impact the Touchet River and/or Coppei Creek. Item 3 will be addressed in the receiving water survey report (Joy, 1986).

Table 5 compares the September 1985 Ecology data to the data collected just before and just after the lagoon/marsh system was set up (Gray and Osborne, 1981). Several factors make comparison difficult:

1. The data originally collected were variable at individual stations, making its use as background data difficult.

2. The 1981 study included 12 monitoring wells. Only five of the original wells plus one new well were available for monitoring in 1985.

3. Some modifications to the shape of the lagoon had been made since the 1981 study.

4. A grass fire went through the site between 1981 and 1985, damaging several well caps. Thus, present well cap elevations may be different than those measured during the original survey. The 1985 water elevation heights may be unreliable.

The 1985 data were inadequate for assessment of the ground-water concerns, but did suggest monitoring needs that should be considered when developing a permit compliance monitoring program for the system. The small number and position of wells available during the inspection did not provide adequate information to even roughly predict the direction of ground-water movement.

Table 5 - Comparison of 1985 Ecology ground water data to 1981 Gray and Osborne data** - Waitsburg, September 1985.

Parameter	Well A 9/85 In-spection	Well A 1981 5/4 - 612 Range	Well A 1981 5/4 - 612 Median	Well A 1981 619 - 7/14 Range	Well A 1981 619 - 7/14 Median	Well C 9/85 In-spection	Well C 1981 5/4 - 6/2 Range	Well C 1981 5/4 - 6/2 Median	Well C 1981 6/9 - 7/14 Range	Well C 1981 6/9 - 7/14 Median	Well F 9/85 In-spection	Well F 1981 5/4 - 6/2 Range	Well F 1981 5/4 - 6/2 Median	Well F 1981 6/9 - 7/14 Range	Well F 1981 6/9 - 7/14 Median
pH (S.U.)	6.8	6.5-7.5	7.2	7.2-7.8	7.4	6.6	7.3-7.6	*	7.0-7.4	7.2	6.8	6.2-7.5	7.0	6.8-7.2	6.9
Conductivity (umhos/cm)	615	660-900	700	480-600	560	850	540-710	*	400-550	420	750	640-910	700	580-650	620
Fecal Coliform (#/100 mL)	150	.4-.7	*	4-15	*	360	0	*	<3-<3	*	<4	0-23	*	4-23	*
T. Recoverable Fe (ug/L)††	119	<1000-<1000	*	<500-5100	<1000	3940	1800	*	800-2000	2000	12700	2800-11500	*	1500-8000	7500
NO3-N (mg/L)	11.0	9.6-144	*	28.0-180.0	*	8.1	6.0	*	23.0-83.0	*	.02	1-4.8	*	<1.0-<1.0	*
Total-P (mg/L)	.45	<.2-<.2	*	.4-.5	*	.95	<.2	*	.5-.57	*	1.0	<.2-<.2	*	.4-.52	*
Chloride (mg/L)	12	52.5-57.5	*	40.0-47.5	*	14	30.0	*	40.0-42.5	*	36	105.0-105.0	*	90.0-92.5	*
Color (units)	4†	0-0	*	0-0	*	17†	0	*	0-0	*	580†	0-0	*	1-1	*
COD (mg/L)	9	51.7-91.9	*	40.0-365.0	*	17	195.4	*	60.8-400.0	*	17	34.5-80.4	*	40.0-152.1	*

Parameter	Well J 9/85 In-spection	Well J 1981 5/4 - 6/2 Range	Well J 1981 5/4 - 6/2 Median	Well J 1981 619 - 7/14 Range	Well J 1981 619 - 7/14 Median	Well K 9/85 In-spection	Well K 1981 5/4 - 6/2 Range	Well K 1981 5/4 - 6/2 Median	Well K 1981 6/9 - 7/14 Range	Well K 1981 6/9 - 7/14 Median
pH (S.U.)	6.7	6.5-7.5	7.0	7.2-7.2	7.2	6.7	6.8-7.5	7.3	7.2-7.6	7.4
Conductivity (umhos/cm)	630	480-940	700	480-700	620	620	760-940	830	520-740	550
Fecal Coliform (#/100 mL)	<4	.9-23	*	<3-9	*	1700est.	.4-1.2	*	93-460	*
T. Recoverable Fe (ug/L)††	11400	18000-21300	*	2500-13000	5000	44	7000-8000	*	1000-4500	3500
NO3-N (mg/L)	.01	<1.0-<1.0	*	<1.0-<1.0	*	2.9	<1.0-1.2	*	<1.0-1.5	*
Total-P (mg/L)	1.7	.6-5.0	*	.4-.6	*	.90	<.2-6.0	*	.5-.57	*
Chloride (mg/L)	27	75.0-85.0	*	105.0-135.0	*	17	137.5-162.0	*	117.5-120.0	*
Color (units)	590†	2-2	*	1-4	*	12†	0-1.5	*	0-0	*
COD (mg/L)	17	120.6-132.2	*	120.0-212.9	*	9	97.7-137.9	*	100.0-167.3	*

† = Estimated. Samples sent to the Ecology laboratory were analyzed after the allowable holding time had been exceeded.

* = Two or fewer measurements; no median calculated.

** = 5/4 - 6/2 and 6/9 - 7/14 1981 data from Gray and Osborne, 1981.
5/4 - 6/2 period, effluent discharge to Coppei Creek (maximun nunber of data points: 5).
6/9 - 7/14 period, effluent sent to marsh (maximum number of data points: 6).

††Total recoverable Fe measured in 1985. The 1981 measurements are listed only as iron (Gray & Osborne, 1981).

Rough flow nets for the 1981 data are shown in Figure 3 (Gray and Osborne, 1981). The flow net drawn from the July 14, 1981, data (collected after the lagoon/marsh system had been in use for six weeks) illustrates the mounding noted in the Gray and Osborne report. The changes in flow direction in the July 14, 1981, flow net suggest that ground-water flows through the dump site may be taking a more direct path to the Touchet River than before the lagoon/marsh system was being operated. Chemical parameter measurements and bank observations of the stream did not find any apparent effects of ground water entering the surface water near the STP (Joy, 1986). Construction of monthly flow nets and intermittent chemical analysis in areas where flow nets indicate possible concern is suggested as part of the permit monitoring report. Also, late fall and early spring (when minimal foliage allows good observation) bank walks to identify any seeps are recommended.

A dye tracer study was included as part of the 1981 ground-water study (Gray and Osborne, 1981). Discovery of fairly rapid dye movement from an existing lagoon to Coppei Creek prior to the 1981 study suggested a need for further dye work as part of the 1981 study (Peterson, 1986). The leaking lagoon was drained and taken out of service. Rapid dye movement was not detected during the 1981 Gray and Osborne study,

The flow net approach for additional monitoring is suggested in preference to dye work. Firm conclusions from an additional dye study would be difficult because:

1. The STP site soil as described in the Gray and Osborne report is approximately four to six feet onyx silt loam above riverwash gravel. From Appendix A, estimates of possible flow rates range from 0.00025 to 0.025 ft/D in the silt loam and 7 to 700 ft/D in the river gravel. The time necessary for a thorough dye study could be quite long, and the potential for dye sorption to the soils or degradation increases with the extended time period.

2. The flow rate calculations assume a homogeneous soil structure. Since soil is heterogeneous, ground-water flow plumes tend to be fingered rather than smooth. The likelihood of catching a problem finger is low with a limited number of wells.

3. The 1981 data indicate that the garbage dump is upgradient from the lagoon/marsh. Thus the dye study information would probably be of little use in describing the impact of the lagoon/marsh on the garbage dump since indirect flow routing changes rather than actual flow from lagoon to dump are anticipated.

RECOMMENDATIONS AND CONCLUSIONS

During the September 1985 Class II inspection the Waitsburg STP was operating efficiently. Because it is a unique system, system capacities and operational set-points are difficult to define. Process control monitoring of the lagoon/

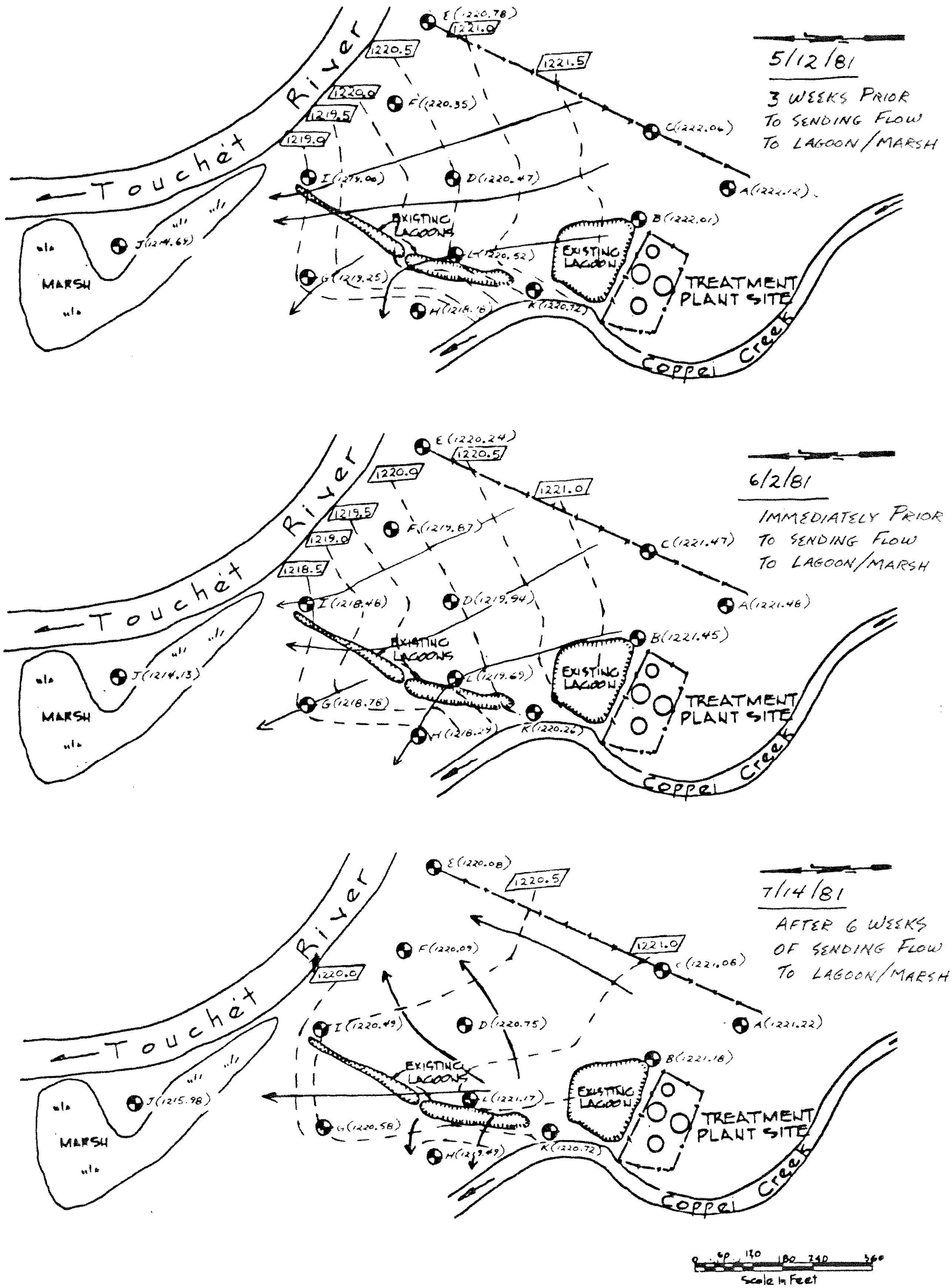


Figure 3. Flow nets for 1981 data - Waitsburg, September 1985. (NOTE: ground-water depths and well location maps are from Gray and Osborne, 1981.)

marsh system would be difficult; therefore, monitoring emphasis on performance is suggested. To monitor performance, data collected should include:

1. Flow measurements at the plant influent and lagoon effluent. Weir seals and angles should be checked and corrected as necessary. Either two fixed meters (one at each station) or one portable meter alternated weekly at each station is suggested.

2. Accurate BOD_5 and TSS monitoring of the plant influent, trickling filter effluent, and lagoon effluent is necessary to monitor system loading and performance prior to infiltration. Reduced treatment performance and increased observance of H_2S odors could be used as an indicator that system capacity under the present operational mode is being approached.

3. Ground water depth data adequate to develop monthly flow nets for the system. Developing accurate flow nets will require rehabilitation of existing wells (cleaning out sediments and re-measuring well cap elevations) and installation of additional properly sited and properly installed (with accurate well cap elevations) wells. Flow nets could be used to estimate ground-water flow patterns and suggest where intermittent chemical monitoring may be warranted. Spring and fall (when foliage is minimal) riverbank and creekbank walks to locate any seeps also are suggested. Conducting flow net and bank walk monitoring largely eliminates the need for additional dye study work.

MH:cp

Attachments

REFERENCES

EPA, 1985. Protection of Public Water Supplies from Ground-Water Contamination. Technology Transfer Seminar Publication, EPA/625/4-85/016.

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APPENDIX A - Estimation of time necessary for dye in lagoon to reach monitoring wells - Waitsburg, September 1985

Using 7/14/81 information from Gray and Osborne, 1981:

Ground water elevation at edge of lagoon (well L) approximately 1221.2
Ground water elevation at well H approximately 1219.5
Well H is approximately 80 feet from the edge of the lagoon

From EPA, 1985:

$$v = \frac{K\ dh}{n\ dl}$$

K = hydraulic conductivity
for silt K is in range of 10^{-3} - 10 ft/d
for gravel K is in range of 10^{2} - 10^{4} ft/d

n = porosity
for soil n approximately 0.55
for gravel n approximately 0.20

dh = change in height approximately 1221.5' - 1219.2' approximately 1.7'

dl = change in distance approximately 80'

Range of velocities expected

in soil: $v = \frac{10^{-3}(1.7)}{0.55(80)}$ to $\frac{10(1.7)}{0.55(80)} = 3.9 \times 10^{-5} - 0.39$ ft/d

in gravel: $v = \frac{10^{2}(1.7)}{0.20(80)}$ to $\frac{10^{4}(1.7)}{0.20(80)} = 11 - 1100$ ft/d

Travel time from lagoon to Well H (80 ft)

in soil: 2.1×10^{6} - 205 days

in gravel: 7.3 - 0.07 days