Computer Simulation of Solute Concentrations in Groundwater at the Citrus County Central Landfill

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Introduction

The Citrus County Central Landfill is located in Section 1 of Township 19 South and Range 18 East, approximately three miles east of Lecanto, Florida (Figure 1). The site consists of a closed 60-acre landfill and an active 80-acre landfill. The property is bounded on the west, south and east by the Withlacoochee State Forest and on the north by State Road 44.

Citrus County has operated leachate percolation ponds for disposal of treated landfill leachate since September 1990. The percolation ponds are located between the closed 60-acre landfill and the active 80-acre landfill. During the two year period from January 1994 through December 1995 the sodium concentration of the treated effluent averaged 380 mg/l, the chloride concentration averaged 420 mg/l, and the total dissolved solids concentration averaged 1,230 mg/l. Because this leachate exceeds the state of Florida primary drinking water standard for sodium (160 mg/l) and the secondary drinking water standard for chloride (250 mg/l) the Florida Department of Environmental Protection has requested Citrus County perform a computer simulation to predict the range of concentrations in the groundwater at the boundary of the facility. The boundary of the facility is the compliance boundary for the discharge permit, which is approximately 1,340 feet from the percolation ponds.

On November 14, 1995, Citrus County contracted with CH2M Hill to provide professional services in support of the required computer simulation. These services include a review of the pertinent hydrogeology, development of a conceptual hydrogeologic model, and the construction of a three-dimensional flow and solute transport model. This technical memorandum serves to document the details of this effort and present the results of the computer simulations.

Site Information

The surficial sediments in the vicinity of the landfill are primarily composed of interbedded, irregular deposits of sands and silts with some clays. Below these surficial sediments lie the thick sequence of carbonate rocks of the Floridan aquifer including the Suwannee, Ocala, and Avon Park Formations.

The Oligocene Suwannee Formation outcrops in the southwestern and northeastern parts of Citrus County. Borings made at the landfill site reveal that the top of the Suwannee Formation is very irregular, its top surface being encountered as high as 80 ft above mean sea level (msl) at some locations. Land surface elevations average about 120 ft above msl. At other locations it was not encountered in borings advanced as deep as 54 ft below msl. Figure 2 summarizes the approximate depths at which the top of the limestone unit was encountered at numerous borings around the site.

Hydraulic conductivity was calculated from slug tests performed by CH2M Hill on several monitoring wells located at the landfill on September 8,1995. Results of these tests suggest that the hydraulic conductivity of the surficial sediments is moderate to low and the hydraulic conductivity of the limestone is very high. Fretwell (1983) reports transmissivities of the Floridan aquifer ranging from 90,000 to 2,000,000 ft^2/day in western Citrus County.

Groundwater elevations in the vicinity of the site range from approximately 5 to 7 ft above msl (approximately 113 to 115 ft below ground surface). In those areas where the limestone surface projects above the water table, the limestone aquifer is strictly unconfined. Beneath most of the site, however, the top surface of the limestone lies 50 or more feet below saturated low to moderate permeability surficial sediments. In these areas, the limestone aquifer can be characterized as semi-confined or leaky-confined.

Regional groundwater flow in the Floridan aquifer system beneath the site is generally from east to west toward the Gulf of Mexico. The magnitude of the regional gradient is approximately 0.001 ft/ft. This gradient is similar to the gradient expressed by water levels of the on site monitoring well network. The magnitude and direction of the hydraulic gradient does not vary significantly with seasons. This is believed to be due to the general lack of intense groundwater development in the area.

Weekly chemical analysis records from the leachate treatment system were made available in order to ascertain a relationship between flowrate to the leachate percolation ponds and solute loading for sodium, chloride, and total dissolved solids (TDS). These data are provided for the period January, 1994 to December, 1995 in Appendix A. Plots of the average weighted flowrate to the percolation ponds vs. sodium, chloride, and TDS concentrations are also provided in Appendix A. The flowrates range from approximately 6,000 gallons per day (typical) to 30,000 gallons per day (maximum permitted capacity). These data were used to develop the specific scenarios to be simulated and are discussed further in the Numerical Simulation section of this technical memorandum.

Conceptual Model

The purpose of the conceptual model is to identify the factors most influential to the migration of solute from the leachate percolation ponds and to describe how these factors are anticipated to interact. The goal is to implement the conceptual model with the computer simulation. With the conceptual model approach, those factors determined to impart a significant impact to the distribution of solute are included.

The model of the site includes two fundamental hydrologic units; an upper unconfined layer of low to moderate permeability representing the surficial sediments, and a lower semi-confined layer of very high permeability representing the Floridan aquifer. Even though the top surface of the Floridan aquifer is irregular in elevation, the contact between the upper and lower layers of the conceptual model are considered to be an even level surface located 50 feet below sea level.

The western part of the property is a closed landfill that is capped with an impermeable layer. Stormwater is collected from this capped area and infiltrates into the groundwater system through a stormwater pond. The average recharge to the aquifer from the stormwater pond was estimated at 17,800 gallons per day.

In the absence of outside stresses (the leachate percolation ponds or the stormwater pond which is located southwest of the percolation ponds), water levels in the upper layer reflect water levels in the lower layer. As recharge is introduced to the upper layer from the leachate percolation ponds and stormwater pond, mounding of groundwater occurs because of the relatively low permeability (approximately 2.8 ft/day). This results in a downward gradient toward the lower layer. The expected pattern of flow will be primarily downward until the lower layer is reached. At that point flow is expected to move horizontally westward under the influence of the regional gradient.

Advection (solutes transported by the bulk movement of groundwater) rates and the degree of hydrodynamic dispersion (spreading or mixing of solutes in groundwater) are greatest in the areas of greatest groundwater velocity. In this model, groundwater velocities are largest in the lower layer and smallest in the upper layer.

Retardation of sodium and other cations is probable, but not easily predictable. Therefore retardation of cations is considered to be negligible in the conceptual model. Retardation would reduce the amount of sodium, therefore, this is a conservative assumption.

Figure 3 illustrates a representative cross section of the model with representative aquifer parameters. The aquifer parameters shown in Figure 3 are used as input for the numerical simulations of the conceptual model.

Numerical Simulations

The computer simulations were accomplished in two parts. First, the pattern of groundwater flow was modeled with MODFLOW (USGS, 1984). The flow solution obtained with MODFLOW is then used as input for the model MT3D, a particle tracking solute transport model using a modified method of characteristics (MMOC). MT3D was used to simulate the transport of sodium, chloride, and TDS.

Two different steady state flow solutions were simulated with MODFLOW. One solution was established to simulate a flowrate of 6,000 gallons per day to the leachate percolation ponds. Another solution was established to simulate a flowrate of 30,000 gallons per day to the leachate percolation ponds. These flowrates approximately bracket the actual to maximum range of flowrates to the leachate percolation ponds. In both cases the flowrate to the stormwater pond was simulated at a rate of 17,800 gallons per day. Flowrates to each of the ponds were simulated by applying the flow directly to the top layer using the recharge package in MODFLOW.

The flow model was setup with a 2 layer grid of 95 cells west to east and 48 cells south to north. The grid was constructed to include an inner finely descritized region (divided into small cells) of 25 ft by 25 ft cells between the percolation ponds and the western boundary of the landfill. Cell sizes expand in each direction from this inner finely descritized region. The limits of the grid extend to approximately 1450 ft north and south of the percolation ponds and approximately 1785 east of the percolation ponds. The western limit of the model grid extends 95,000 ft (18 miles) from the percolation ponds. This peculiar elongation of the grid in the down gradient direction was needed for the solute transport simulation to account for the large groundwater velocities in the lower model layer and the long (20 year) simulation times.

A regional east to west gradient was established using constant head boundary conditions in the lower model layer. The simulated regional gradient is 0.00095 ft/ft. The hydraulic conductivity for the top layer of the model was set at a uniform 2.8 ft/day and the transmissivity of the lower model layer was set at a uniform 280,000 ft^2/day. Vertical leakage between the two layers was set at 0.01 day^{-1} (which approximates a vertical hydraulic conductivity in the top model layer of .5 ft/day).

Figures 4 and 5 show the simulated steady state head distributions with 6,000 gallons per day discharge to the leachate percolation ponds for model layers 1 and 2 respectively. Figures 6 and 7 show the simulated steady state head distribution with 30,000 gallons per day discharge to the leachate percolation ponds for layers 1 and 2 respectively. In both simulations, the stormwater pond discharges 17,800 gallons per day.

The MT3D solute-transport package was implemented using the flow fields established by MODFLOW. Six scenarios were simulated. These include the introduction of sodium, chloride and TDS into each of the two MODFLOW flow fields. Operational data from 1994 and 1995 were analyzed by plotting average flows and laboratory testing results. The concentration of each solute for the two leachate percolation pond rates were estimated from the average flow vs. concentration plots shown in Appendix A. For the 6,000 gallon per day leachate percolation rate, sodium concentrations were simulated at 515 mg/l, chloride concentrations were simulated at 600 mg/l and TDS concentrations were simulated at 2,650 mg/l. For the 30,000 gallon per day leachate percolation rate, sodium concentrations were simulated at 460 mg/l, chloride concentrations were simulated at 470 mg/l and TDS concentrations were simulated at 1,350 mg/l. Model scenarios are summarized in Table 1.

In both the 6,000 and the 30,000 gallon per day solute transport models, background concentrations of sodium and chloride were each simulated as a concentration of 4.0 mg/l and background concentrations of TDS were simulated at a concentration 40 mg/l. Background concentrations were established from onsite monitoring wells that are not affected by the percolation ponds. The 17,800 gallon per day stormwater recharge was also simulated to occur at these background concentrations.

The model grid layout used for the MODFLOW simulation was also used for the MT3D solute-transport modeling. The model grid is shown in Appendix B. For the top layer the porosity was specified as 26%, the longitudinal dispersivity was specified as 15 ft and the traverse dispersivity was specified as 3 ft. For the bottom layer the porosity was specified as 8%, the longitudinal dispersivity was specified as 30 ft and the traverse dispersivity was specified as 6 ft. Model inputs are summarized in Table 2.

Figure 8 shows the distribution of sodium in the top layer of the model after having received 515 mg/l sodium at a rate of 30,000 gallons per day for 20 years. Figure 9 shows the corresponding distribution of sodium in the bottom layer of the model. Figure 10 shows a time series plot of the simulated sodium concentration at the down gradient boundary of the landfill in both layers of the model. For brevity, the remaining 5 solute transport simulations are included in Appendices C through G. Appendix H includes an abstract for the MT3D documentation.

Conclusions

The results of the numerical simulation suggest that leachate disposal activities at the center of the Citrus County Central Landfill are unlikely to cause sodium or chloride concentration to exceed Florida primary or secondary drinking water standards at the boundary of the landfill. Modeled groundwater concentrations at the property boundary after 20 years of operation are approximately 10 mg/l for both sodium and chloride. Model results at the property boundary after 20 years are summarized in Table 3.

The primary explanation for the low concentrations of leachate solutes at the down gradient boundary is the high degree of dilution and dispersion in the lower limestone layer below the percolation ponds. This dilution is dependent on a relatively high degree of leakance between the saturated surficial sediments and the underlying limestone. This relatively high degree of leakance is supported by the observations. If the lower limestone layer were actually tightly confined, then the mounding of groundwater in the surficial sediments beneath the percolation ponds would be expected to be much greater in magnitude. The modeled increase in water levels in the surficial layer do approximate the observed mounding, indication that the modeled leakance downward is correctly approximated.

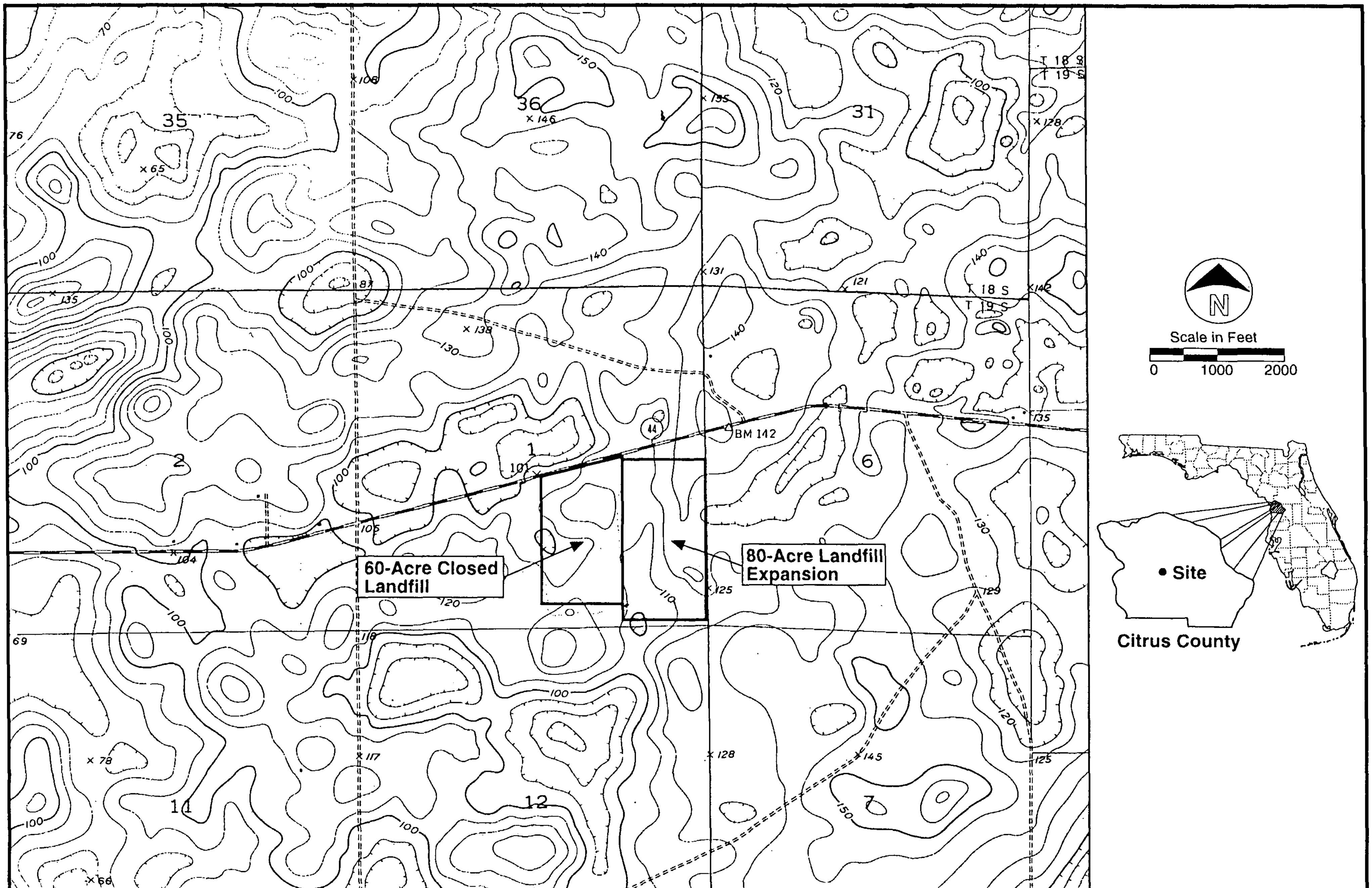
Tables

Table 1 - Model Scenarios			
Flow Rate (gpd)	**TDS (mg/l)**	**Chloride (mg/l)**	**Sodium (mg/l)**
6,000	2,650	600	515
30,000	1,350	470	460

Table 2 - Model Input	
Model Layers	2
Number of Cells	95 x 48
Gradient	0.00095 ft/ft
LAYER 1	
Hydraulic Conductivity - Kh	2.8 ft/day
Porosity - θ	0.26
Longitudinal Dispersivity - α l	15 ft
Traverse Dispersivity - α t	3 ft
Leakage Kv	0.5 ft/day
LAYER 2	
Transmissivity - T	280,000 ft^2/day
Porosity - θ	0.08
Longitudinal Dispersivity - α l	30 ft
Traverse Dispersivity - α t	6 ft

Table 3 - Model Results at Property Boundary After 20 Years				
Layer	Flow Rate (gpd)	TDS (mg/l)	Chloride (mg/l)	Sodium (mg/l)
1	6,000	43.5	4.8	4.7
2	6,000	44.6	5.0	4.9
1	30,000	52.4	8.4	8.3
2	30,000	54.8	9.3	9.2

Figures



U.S.G.S. Topographic Map
Lecanto, FL

FIGURE 1
Site Location Map

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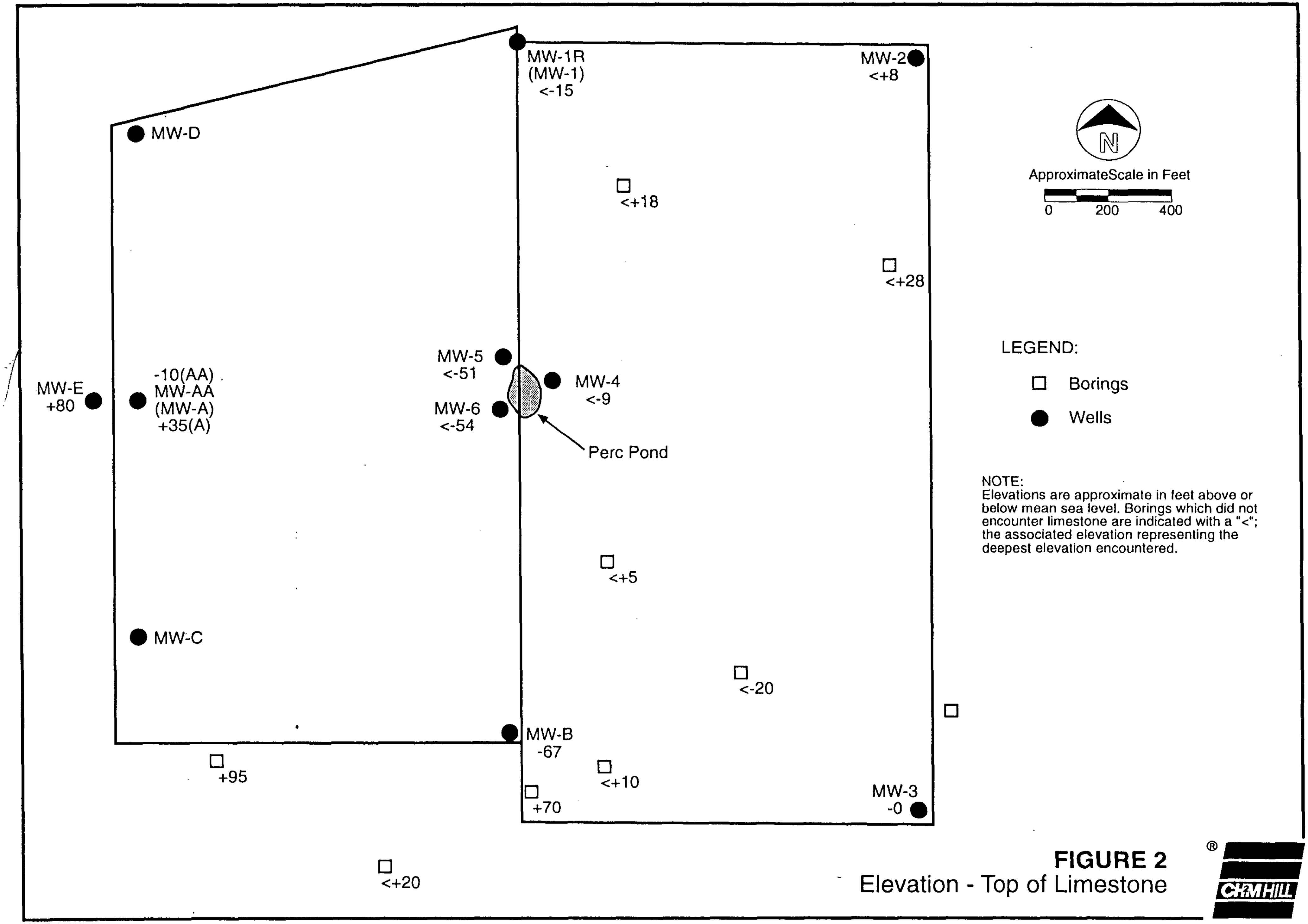

FIGURE 2
Elevation - Top of Limestone

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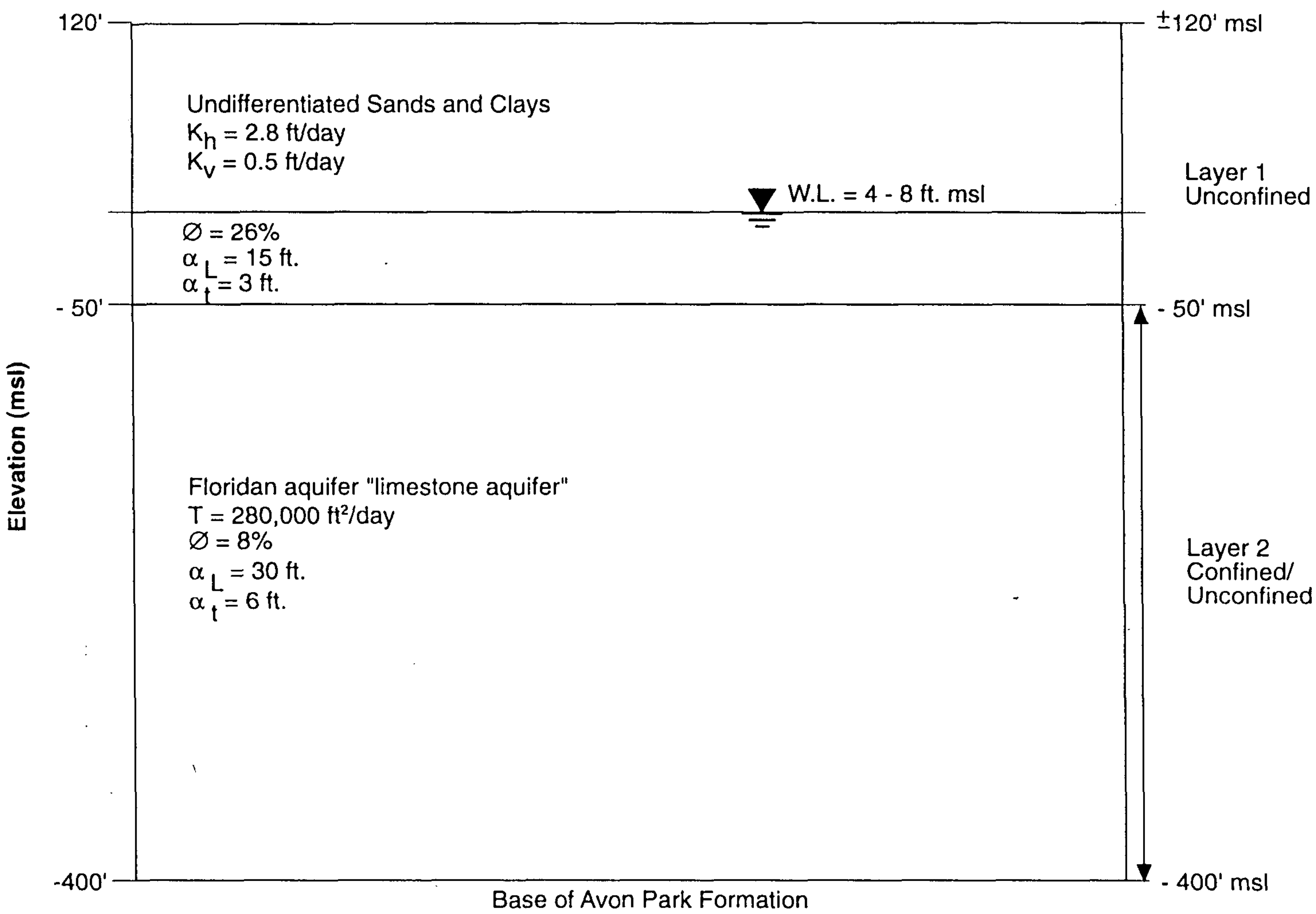

FIGURE 3
Conceptual Model Cross Section

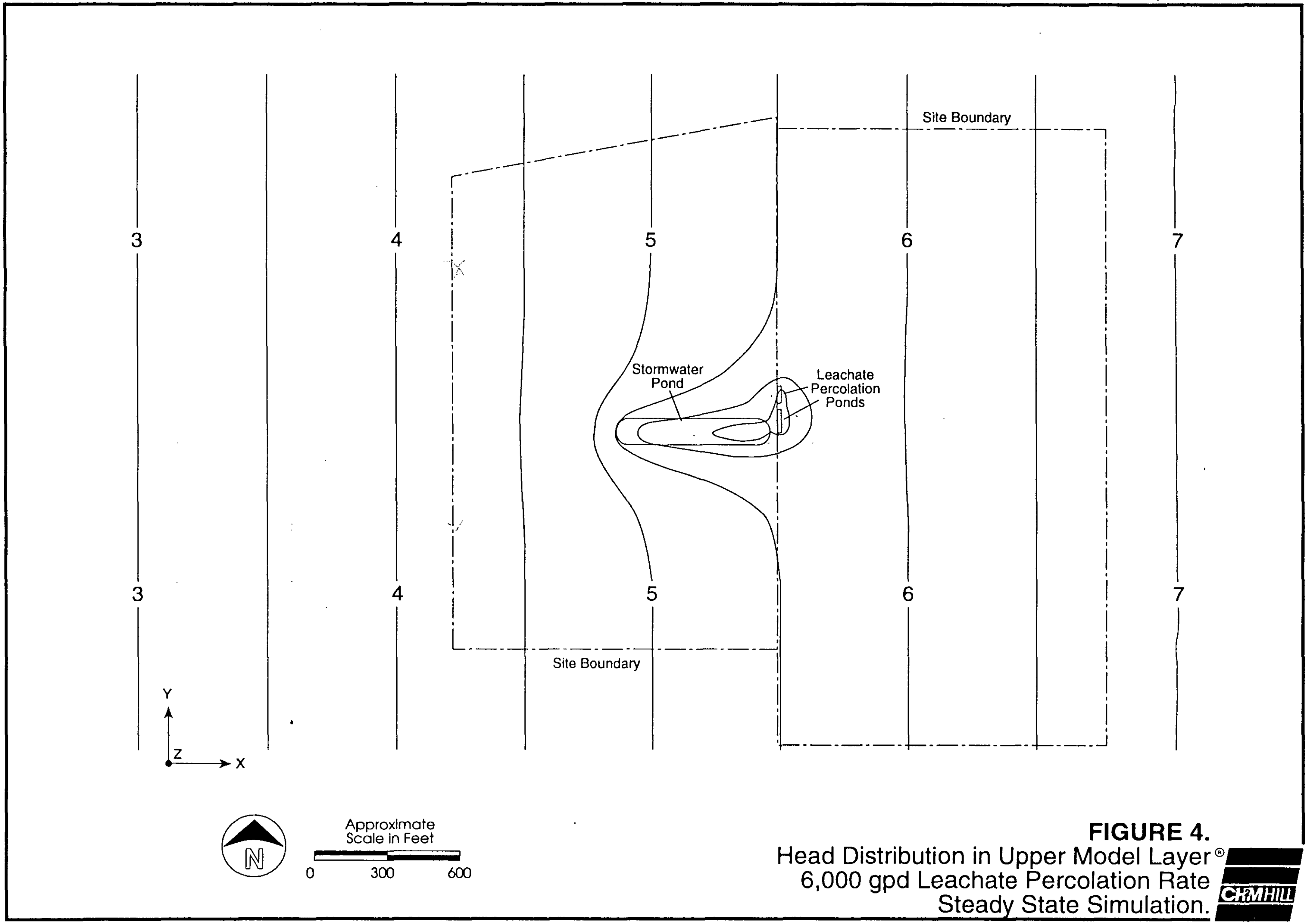

FIGURE 4.
Head Distribution in Upper Model Layer
6,000 gpd Leachate Percolation Rate
Steady State Simulation.

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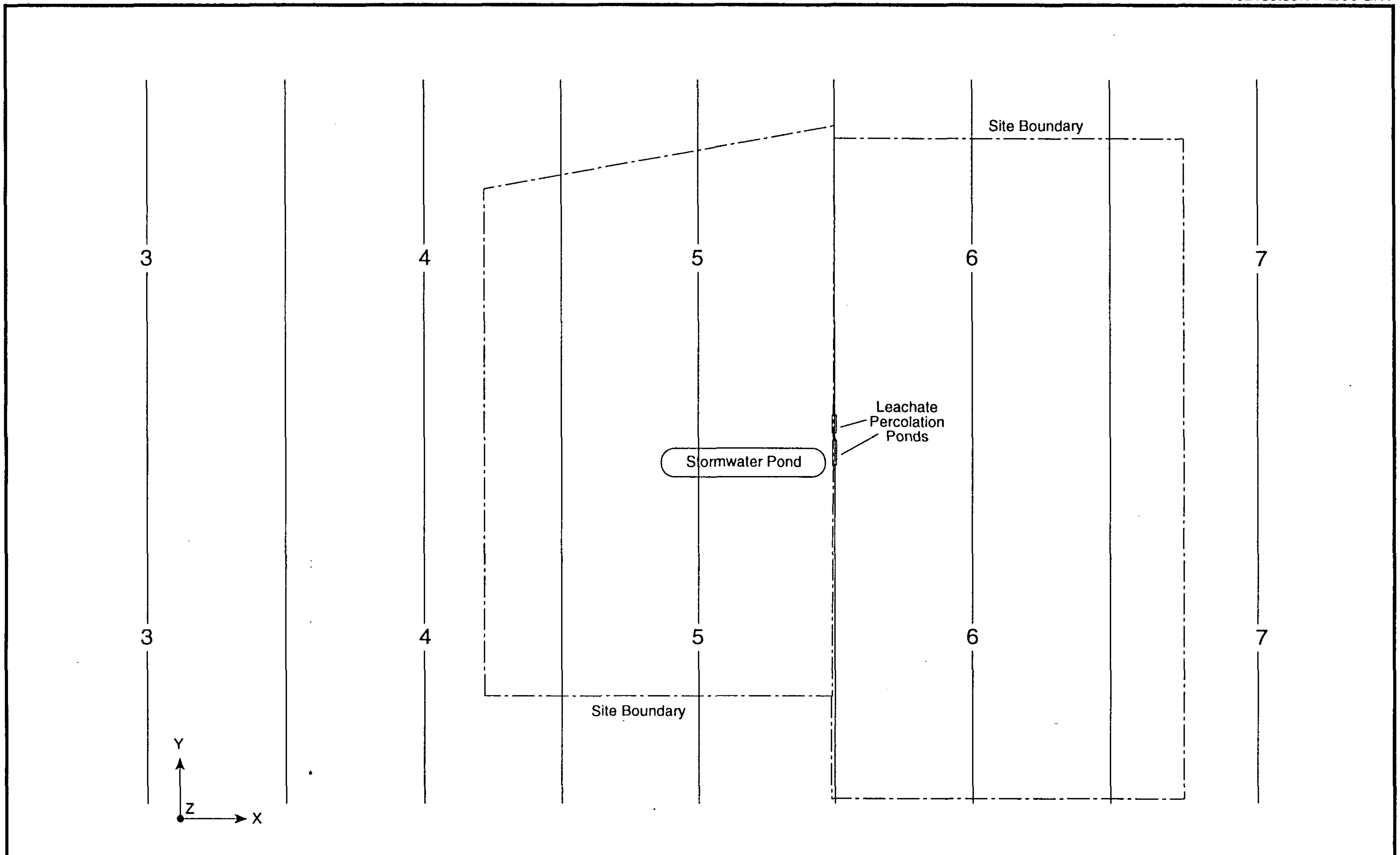

FIGURE 5.
Head Distribution in Lower Model Layer
6,000 gpd Leachate Percolation Rate
Steady State Simulation.

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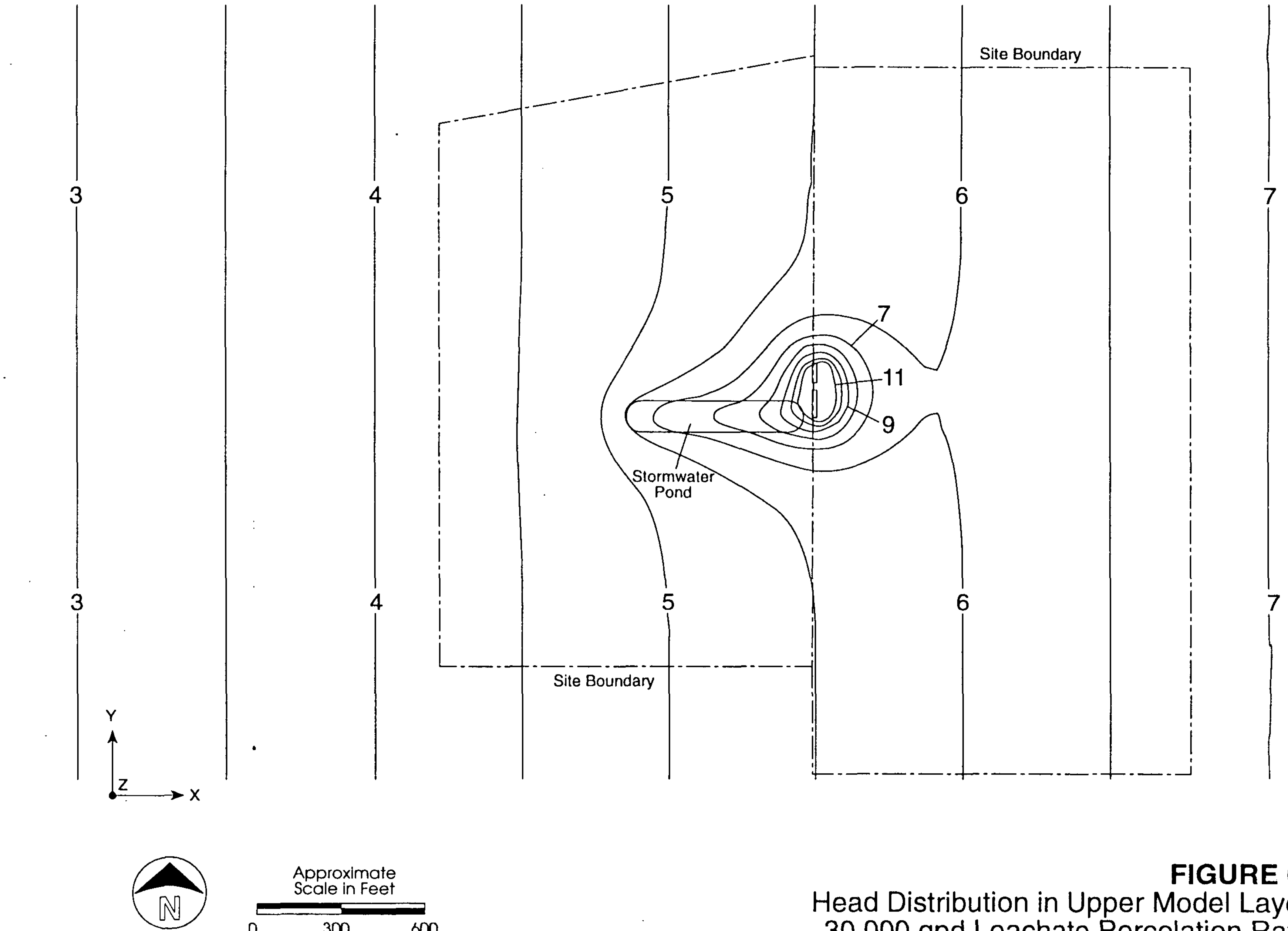

FIGURE 6.
Head Distribution in Upper Model Layer®
30,000 gpd Leachate Percolation Rate
Steady State Simulation.

CH2M HILL

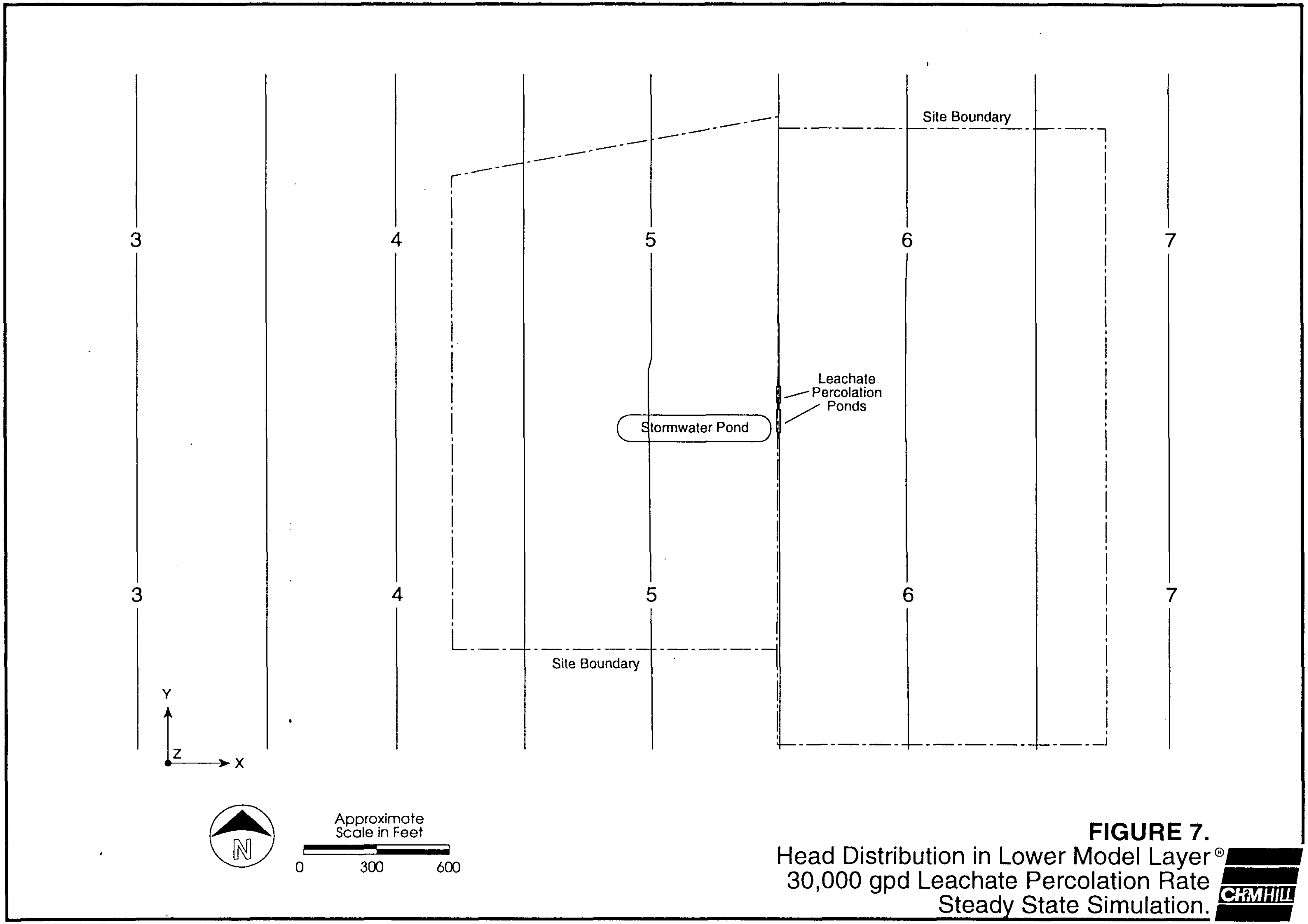

FIGURE 7.
Head Distribution in Lower Model Layer®
30,000 gpd Leachate Percolation Rate
Steady State Simulation.

CH2M HILL

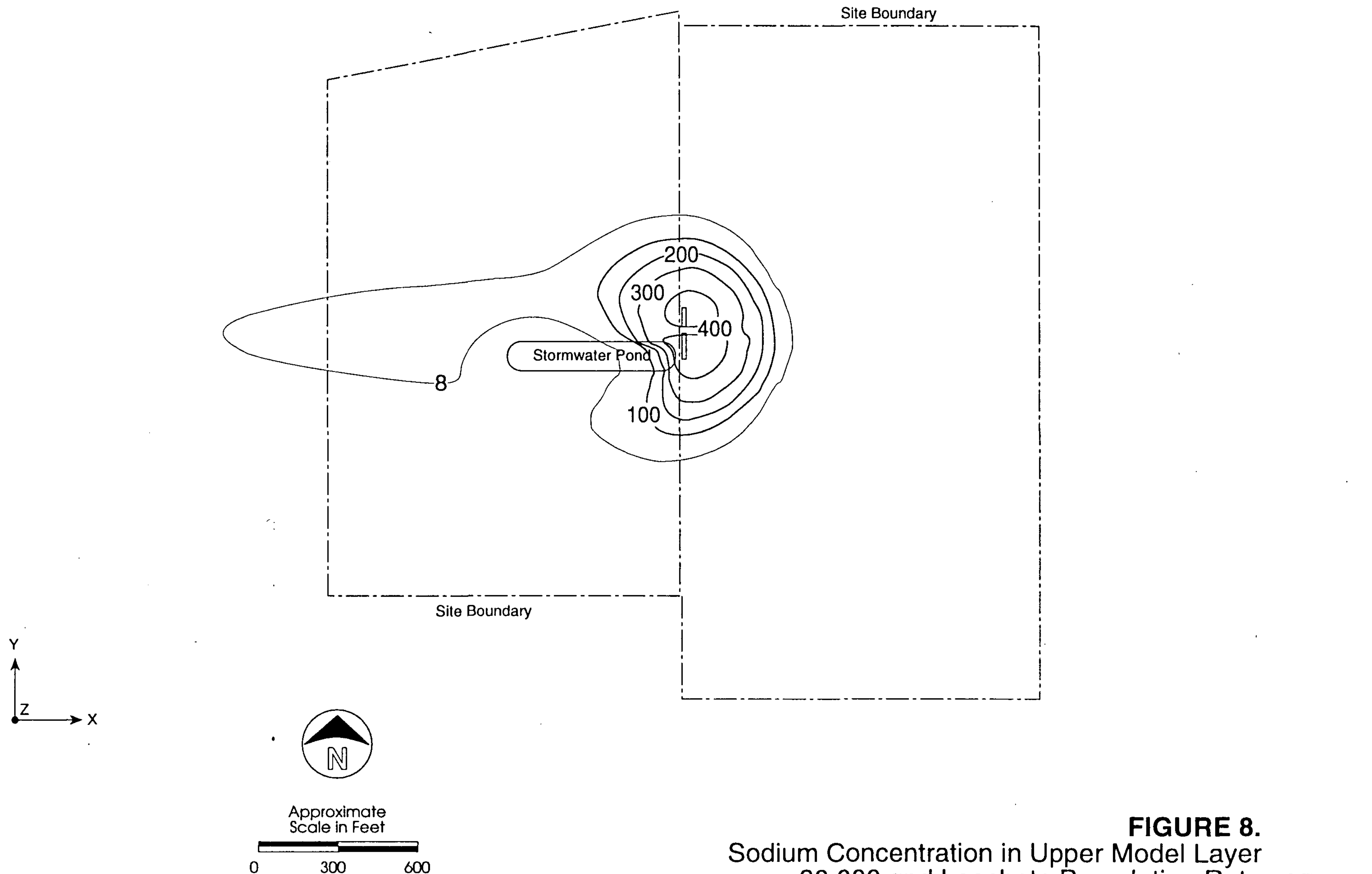

FIGURE 8.
Sodium Concentration in Upper Model Layer
30,000 gpd Leachate Percolation Rate
Sodium Concentration of Leachate: 460 mg/L
20 yr. Simulation Time.

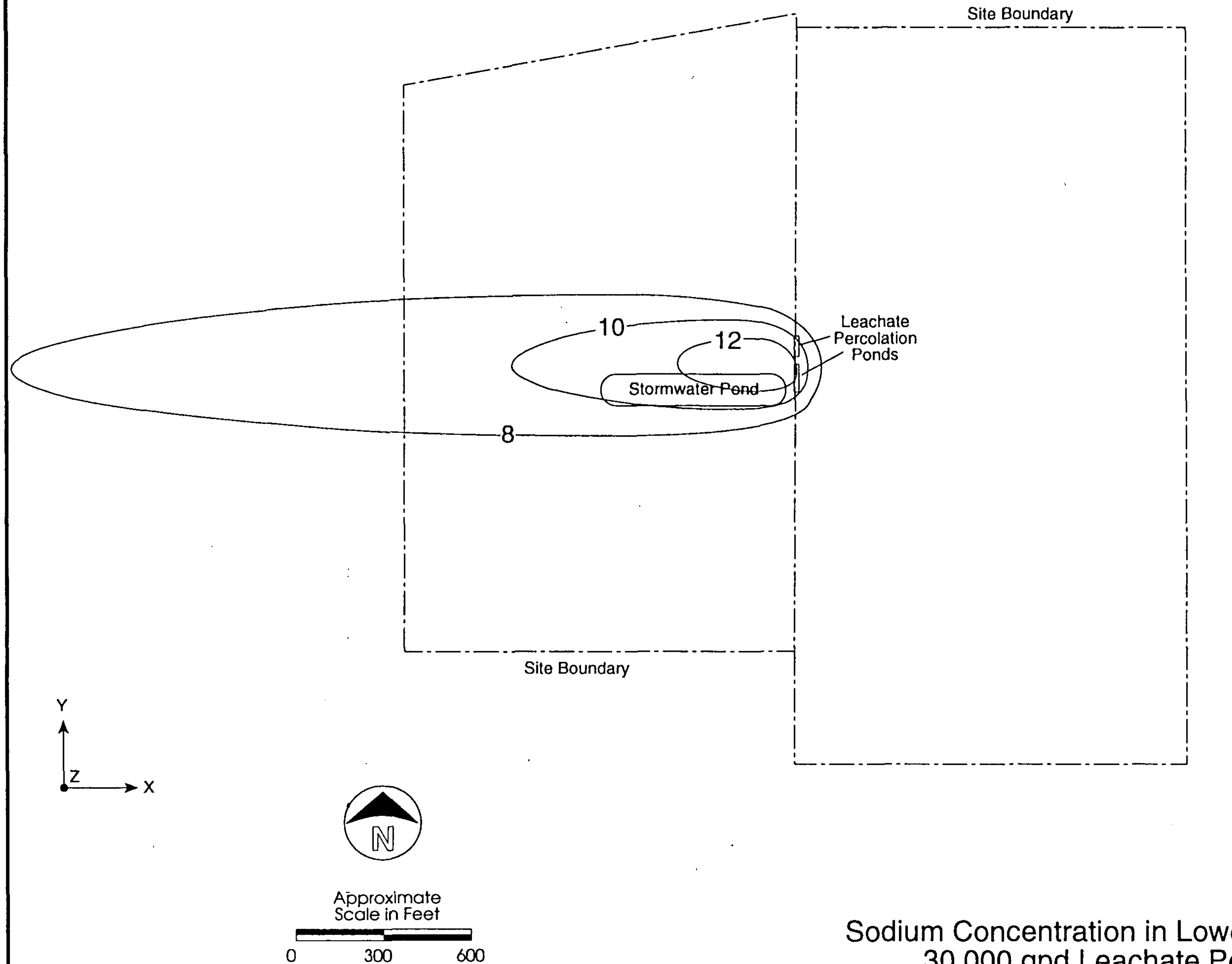

FIGURE 9.
Sodium Concentration in Lower Model Layer
30,000 gpd Leachate Percolation Rate
Sodium Concentration of Leachate: 460 mg/L
20 yr. Simulation Time.

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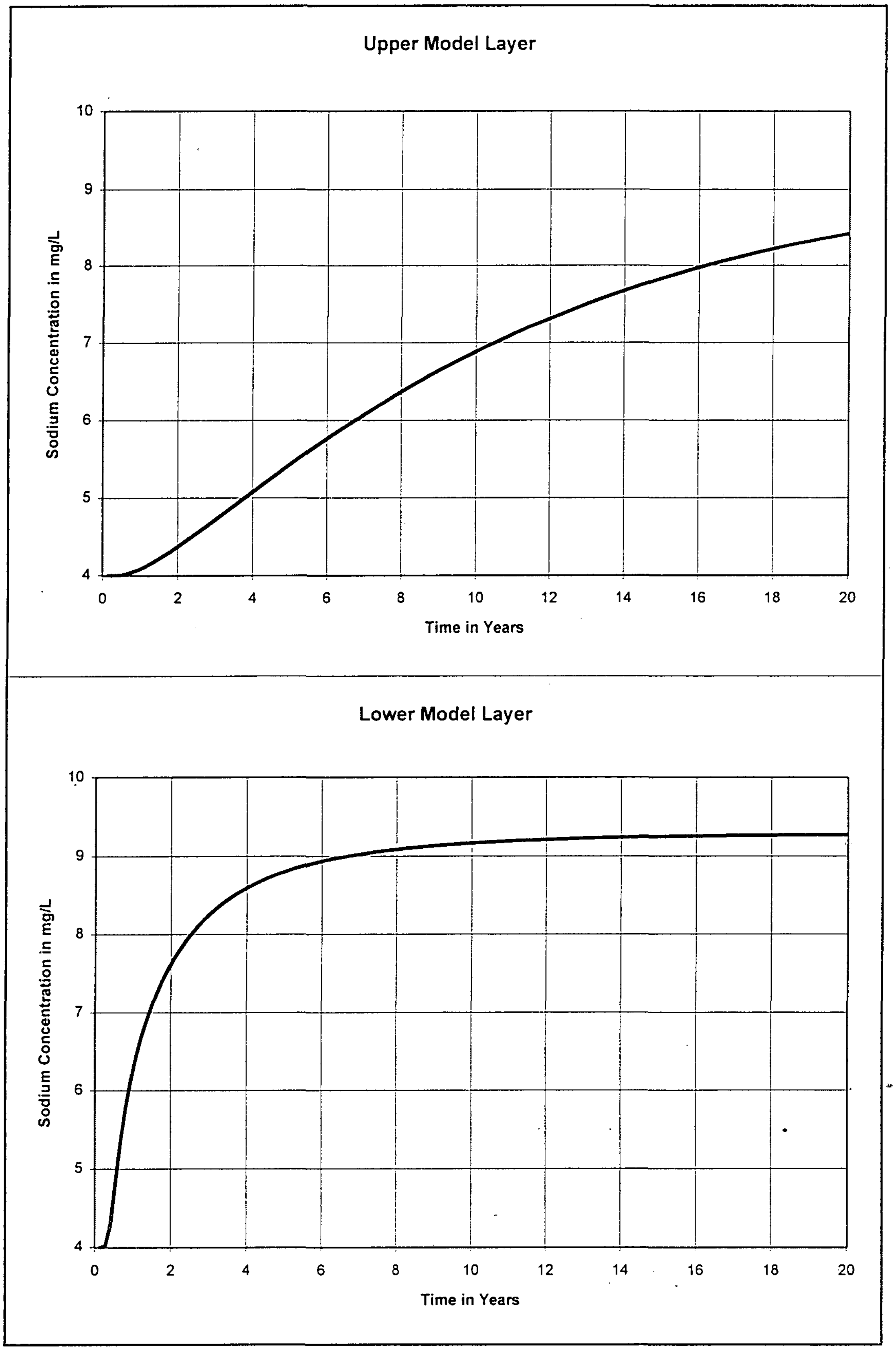
Figure 10
Simulated Sodium Concentration at the Site Boundary
Leachate Percolation Rate: 30,000 GPD



Appendix A

Leachate Characterization

Appendix A-1
Citrus County Landfill
Leachate Chariciterization Worksheet

Date		Total Influent to Plant	Day Before	Day After	Average [1] Flow	Influent Chloride	Influent Sodium	Influent TDS	Effluent Chloride	Effluent Sodium	Effluent TDS
Thursday	1/6/94	8300	6735	9200	8133.75				370	260	1500
Thursday	1/13/94	6300	5400	6200	6050				400	285	2300
Thursday	1/20/94	5900	10300	6000	7025				320	240	2100
Thursday	1/27/94	6735	5935	6735	6535				400	312	1950
Thursday	2/3/94	15475	5300	10475	11681.25				84	295	1680
Thursday	2/10/94	5475	35475	5475	12975				32	280	2260
Thursday	2/17/94	5475	5475	9000	6356.25				240	310	1220
Thursday	2/24/94	15475	35475	4200	17656.25				58	264	2420
Thursday	3/3/94	8670	8502	8670	8628				265	310	1240
Thursday	3/10/94	18610	18670	8670	16140				320	320	1200
Thursday	3/17/94	8670	9582	8670	8898				320	248	1820
Thursday	3/24/94	8934	9474	9474	9204				310	284	1240
Thursday	3/31/94	8936	8888	8139	8724.75				320	312	1210
Thursday	4/7/94	8355	7923	8139	8193				320	380	1050
Thursday	4/14/94	8355	7599	8031	8085				600	490	2800
Thursday	4/21/94	8679	8247	7815	8355				380	260	1240
Thursday	4/28/94	6519	8247	6411	6924				370	280	920
Thursday	5/5/94	7091	8027	7703	7478				310	218	3250
Thursday	5/12/94	6731	12868	6335	8166.25				318	541	2510
Thursday	5/19/94	6731	6335	5939	6434				411	504	3220
Thursday	5/26/94	6137	5939	5939	6038				450	540	3040
Thursday	6/2/94	7434	11628	12312	9702				510	318	1040
Thursday	6/9/94	9072	11988	11592	10431				420	320	2100
Thursday	6/16/94	32582	31520	14868	27888				340	315	1200
Wednesday	6/22/94	29450	33356	15534	26947.5	515	350	2780			
Thursday	6/23/94	15534	29450	23310	20957				240	260	1100
Wednesday	6/29/94	28028	29936	11394	24346.5	800	450	3240			
Thursday	6/30/94	11394	28028	0	12704				360	280	2100
Wednesday	7/6/94	20000	20000	20000	20000	170	150	750			
Thursday	7/7/94	20000	20000	0	15000				220	180	1000
Wednesday	7/13/94	20000	20000	20000	20000	350	340	1320			
Thursday	7/14/94	20000	20000	0	15000				212	210	1300
Wednesday	7/20/94	30000	20000	20000	25000	310	280	1120			
Thursday	7/21/94	20000	30000	30000	25000				205	212	870
Wednesday	7/27/94	30000	30000	30000	30000	690	675	3990			
Thursday	7/28/94	30000	30000	30000	30000				310	550	800
Wednesday	8/3/94	30000	30000	30000	30000	720	312	1280			
Thursday	8/4/94	30000	30000	30000	30000				260	420	880
Wednesday	8/10/94	30000	30000	30000	30000	380	660	1780			
Thursday	8/11/94	30000	30000	30000	30000				540	440	1460
Wednesday	8/17/94	30000	30000	30000	30000	450	390	1860			
Thursday	8/18/94	30000	30000	30000	30000				420	560	1200
Wednesday	8/24/94	30000	0	30000	22500	420	385	2220			
Thursday	8/25/94	30000	30000	0	22500				320	310	2140
Wednesday	8/31/94	10000	20000	8020	12005	790	720	2210			
Thursday	9/1/94	8020	10000	6673	8178.25				320	520	2100

Footnote:
1. Average Flowrate is weighted: (2 X flowrate on date of analysis + flowrate from day after + flowrate from the day after)/4

Appendix A-1
Citus County Landfill
Leachate Charicterization Worksheet

Date		Total Influent to Plant	Day Before	Day After	Average [1] Flow	Influent Chloride	Influent Sodium	Influent TDS	Effluent Chloride	Effluent Sodium	Effluent TDS
Thursday	9/8/94	7266	5298	5864	6423.5				400	914	2100
Wednesday	10/5/94	7561	8542	7600	7816	301					
Wednesday	10/12/94	2309	12709	14599	7981.5	405					
Tuesday	10/18/94	15137	0	8414	9672	288					
Wednesday	10/26/94	7851	8749	7119	7892.5	441					
Tuesday	11/1/94	14879	0	7448	9301.5	491					
Tuesday	11/8/94	7940	6581	7803	7566	513		1980			
Tuesday	11/15/94	7725	7127	7321	7474.5	569		2000			
Tuesday	11/22/94	6688	5148	7236	6440	498		2070			
Wednesday	11/30/94	14355	0	6055	8691.25	501		2190			
Wednesday	12/7/94	6988	3617	6783	6094	354		1630			
Tuesday	12/13/94	7455	7834	7004	7437	105		682			
Tuesday	12/20/94	7035	6981	7510	7140.25	191		976			
Tuesday	12/27/94	7262	7279	7133	7234	577		2000			
Tuesday	1/3/95	8343	7080	8637	8100.75						
Wednesday	1/11/95	6331	6958	6534	6538.5	514		2110			
Tuesday	1/17/95	6140	6583	5639	6125.5	470		1950			
Wednesday	1/25/95	11024	9103	8964	10028.75	822		1990			
Tuesday	1/31/95	7474	7882	6038	7217	525		1920			
Tuesday	2/7/95	7480	6704	6262	6981.5	501		1800			
Tuesday	2/14/95	7259	6609	6511	6909.5	582		2000			
Tuesday	2/21/95	6196	6118	6363	6218.25	492		2070			
Tuesday	2/28/95	7245	6854	8297	7410.25	503		2190			
Tuesday	3/7/95	7512	8048	7462	7633.5	420		1710			
Thursday	3/16/95	8793	14232	6582	9600	333		1480			
Tuesday	3/21/95	8064	8283	6153	7641	39.5		504			
Tuesday	3/28/95	8760	8012	7558	8272.5	548		2190			
Tuesday	4/4/95	15562	7294	7824	11560.5	584		2250			
Tuesday	4/11/95	6742	6751	6895	6782.5	582		2180			
Tuesday	4/18/95	7769	6029	7893	7365	585		2010			
Tuesday	4/25/95	8050	7098	6866	7516	718		2380			
Tuesday	5/2/95	8343	7561	8112	8089.75	590		2320			
Tuesday	5/9/95	7377	6806	12971	8632.75	403		1980			
Wednesday	5/17/95	6617	8391	1204	5707.25	649		2480			
Wednesday	5/24/95	6813	7201	5834	6665.25	471		1870			
Wednesday	5/31/95	5946	5949	5851	5923	581		2250			
Wednesday	6/7/95	7150	6972	6199	6867.75	483		2070			
Thursday	6/8/95								575	450	1720
Wednesday	6/14/95	5858	6957	5861	6133.5	435		1990			
Thursday	6/15/95								609	510	1720
Wednesday	6/21/95	7696	8821	7235	7862	457		1850			
Thursday	6/22/95								512	400	1770
Wednesday	6/28/95	7152	10728	5272	7576	326		1480			
Thursday	6/29/95								514	370	1530
Wednesday	7/5/95	17574	3970	12978	13024	508		1920			
Thursday	7/6/95								496	390	1560

Footnote:
1. Average Flowrate is weighted: (2 X flowrate on date of analysis + flowrate from day after + flowrate from the day after)/4

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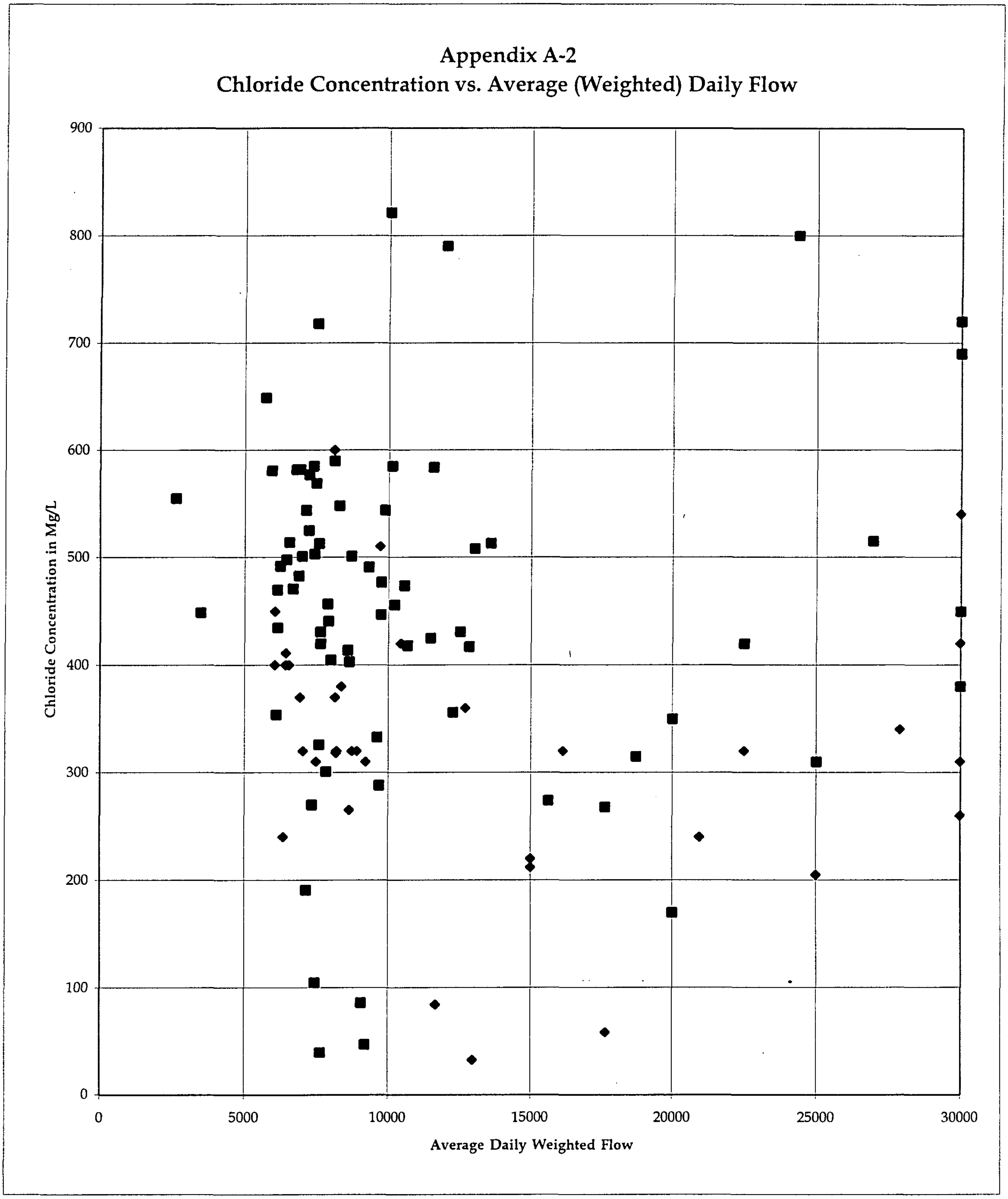
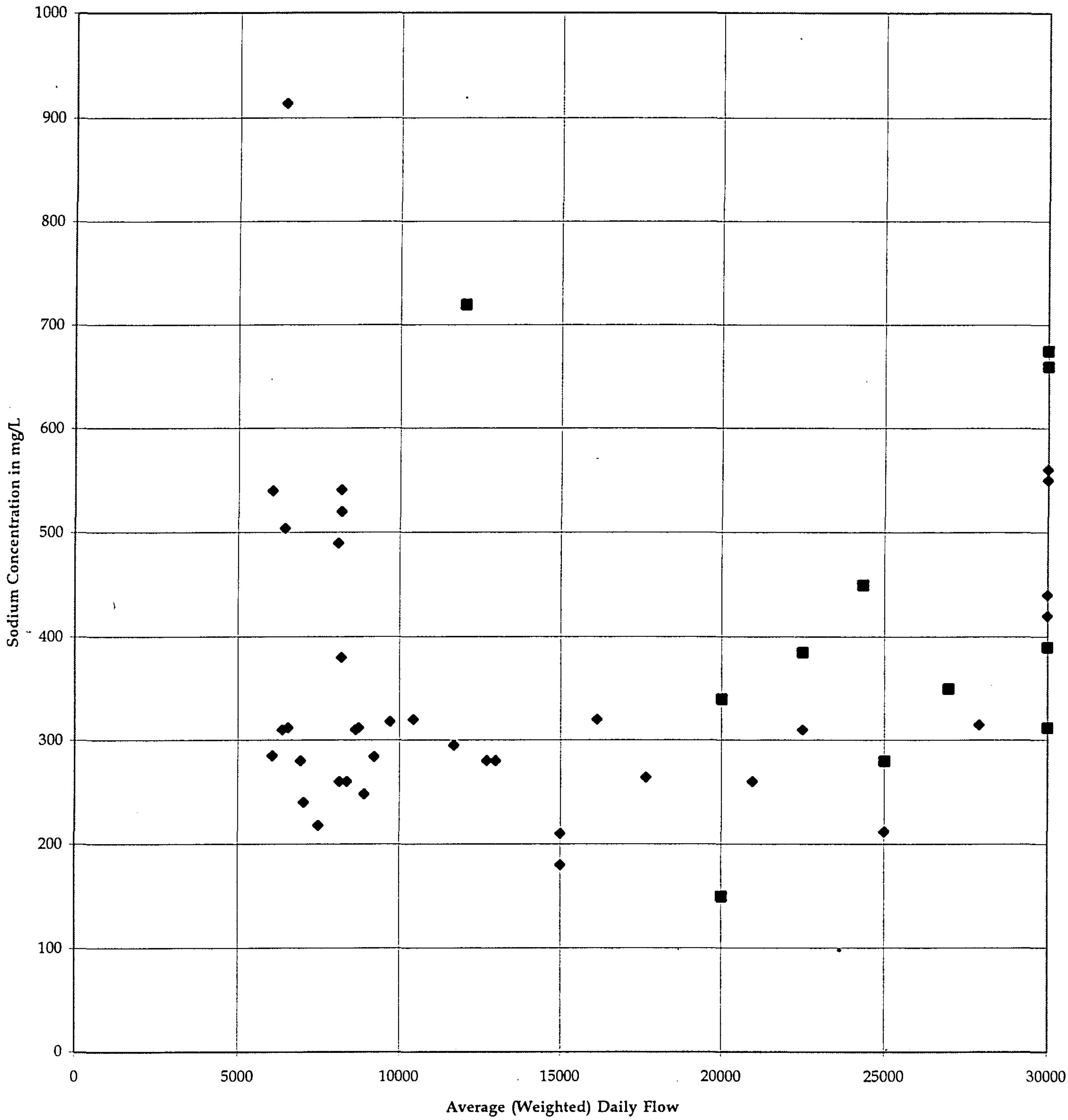
Leachate Charicterization Worksheet

Date		Total Influent to Plant	Day Before	Day After	Average [1] Flow	Influent Chloride	Influent Sodium	Influent TDS	Effluent Chloride	Effluent Sodium	Effluent TDS
Wednesday	7/12/95	7007	9426	7025	7616.25	431		1970			
Thursday	7/13/95								429	400	1360
Wednesday	7/19/95	9440	4686	5755	7330.25	270		1290			
Thursday	7/20/95								408	370	1548
Wednesday	7/26/95	10108	12361	6342	9729.75	447					
Thursday	7/27/95								462	400	1510
Thursday	8/3/95	2583	7059	30472	10674.25	418		1540			
Friday	8/4/95								406	370	1430
Wednesday	8/9/95	0	2273	11573	3461.5	449		1850			
Thursday	8/10/95								370	310	1250
Wednesday	8/16/95	8219	12043	8262	9185.75	47.1		1780			
Thursday	8/17/95								418.6	300	1270
Wednesday	8/23/95	27387	9612	6124	17627.5	268		1100			
Thursday	8/24/95								412	340	1330
Wednesday	8/30/95	11240	11792	11615	11471.75	425		1510			
Thursday	8/31/95								75.4	310	1350
Wednesday	9/6/95	10468	20184	8922	12510.5	431		1690			
Thursday	9/7/95								377	330	1510
Wednesday	9/13/95	8819	33438	11395	15617.75	274		1230			
Thursday	9/14/95								334	250	1170
Wednesday	9/20/95	11534	8631	17380	12269.75	356		1660			
Thursday	9/21/95								330	280	1120
Wednesday	9/27/95	10767	17631	12187	12838	417		1760			
Thursday	9/28/95								387	340	476
Wednesday	10/4/95	11186	7619	10843	10208.5	456		1950			
Thursday	10/5/95								400	390	1490
Wednesday	10/11/95	7028	11938	8334	8582	414		1660			
Thursday	10/12/95								434	430	1530
Wednesday	10/18/95	15668	35723	7804	18715.75	315		1590			
Thursday	10/19/95								356	320	1170
Wednesday	10/25/95	9209	9025	8807	9062.5	86		1750			
Thursday	10/26/95								417	330	1300
Wednesday	11/1/95	11757	7325	11385	10556	474		1760			
Thursday	11/2/95								452	120	1440
Wednesday	11/8/95	9871	10197	9009	9737	477		1630			
Thursday	11/9/95								472	420	1960
Wednesday	11/15/95	7013	11808	2638	7118	544		1920			
Thursday	11/16/95								609	590	1900
Monday	11/20/95	22004	0	10346	13588.5	513		1920			
Tuesday	11/21/95								543	610	1750
Wednesday	11/29/95	11105	8280	9931	10105.25	585		2070			
Thursday	11/30/95								601	480	1890
Wednesday	12/6/95	9337	9684	11101	9864.75	544		2030			
Thursday	12/7/95								572	500	1940
Wednesday	12/13/95	1692	4863	2202	2612.25	555		2130			
Thursday	12/14/95								612	540	2050

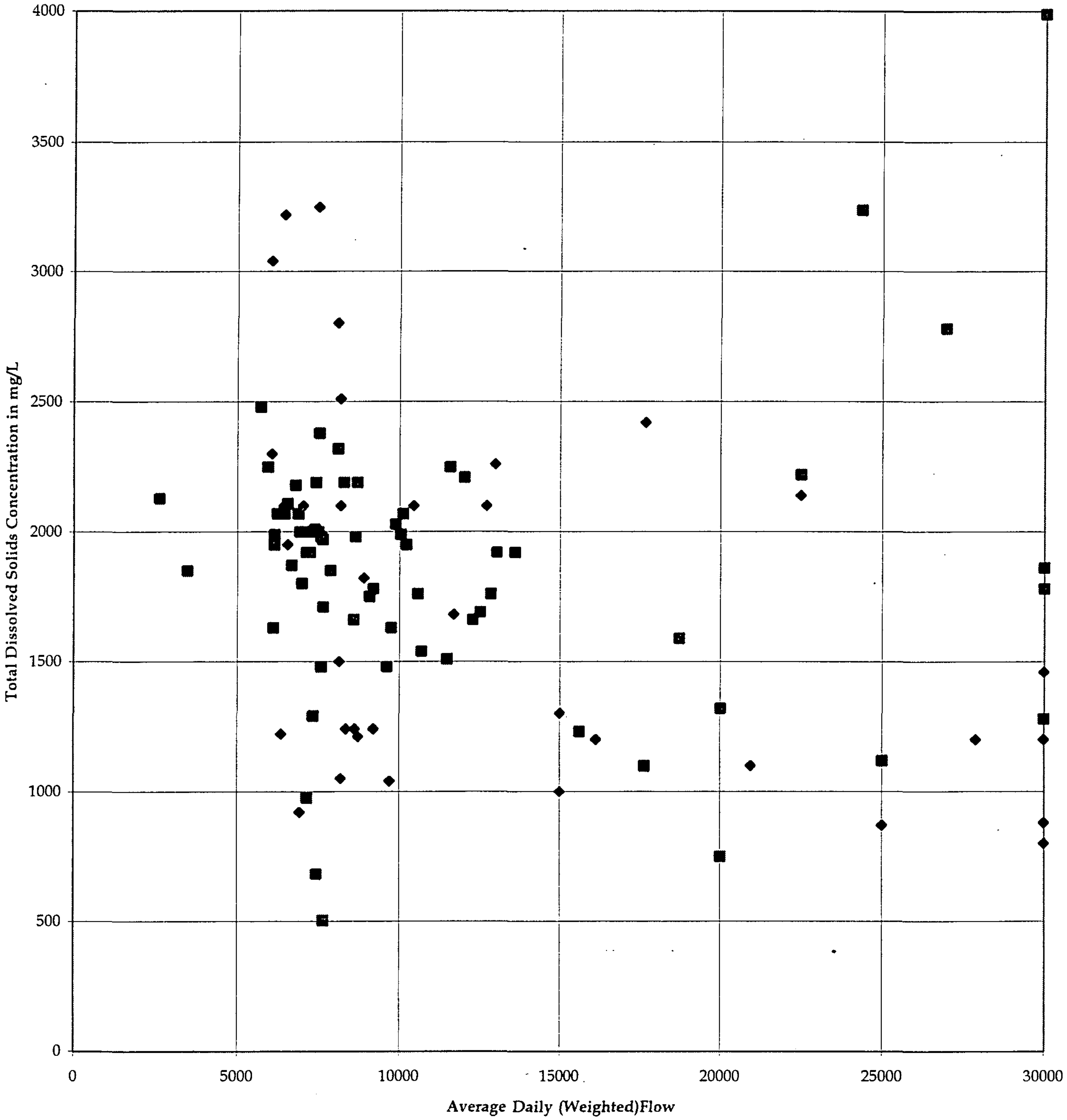
Footnote:
1. Average Flowrate is weighted: (2 X flowrate on date of analysis + flowrate from day after + flowrate from the day after)/4


Appendix A-2
Chloride Concentration vs. Average (Weighted) Daily Flow
Chloride Concentration in Mg/L
900
800
700
600
500
400
300
200
100
0
0
5000
10000
15000
20000
25000
30000
Average Daily Weighted Flow

Appendix A-2
Sodium Concentration vs. Average (Weighted) Daily Flow



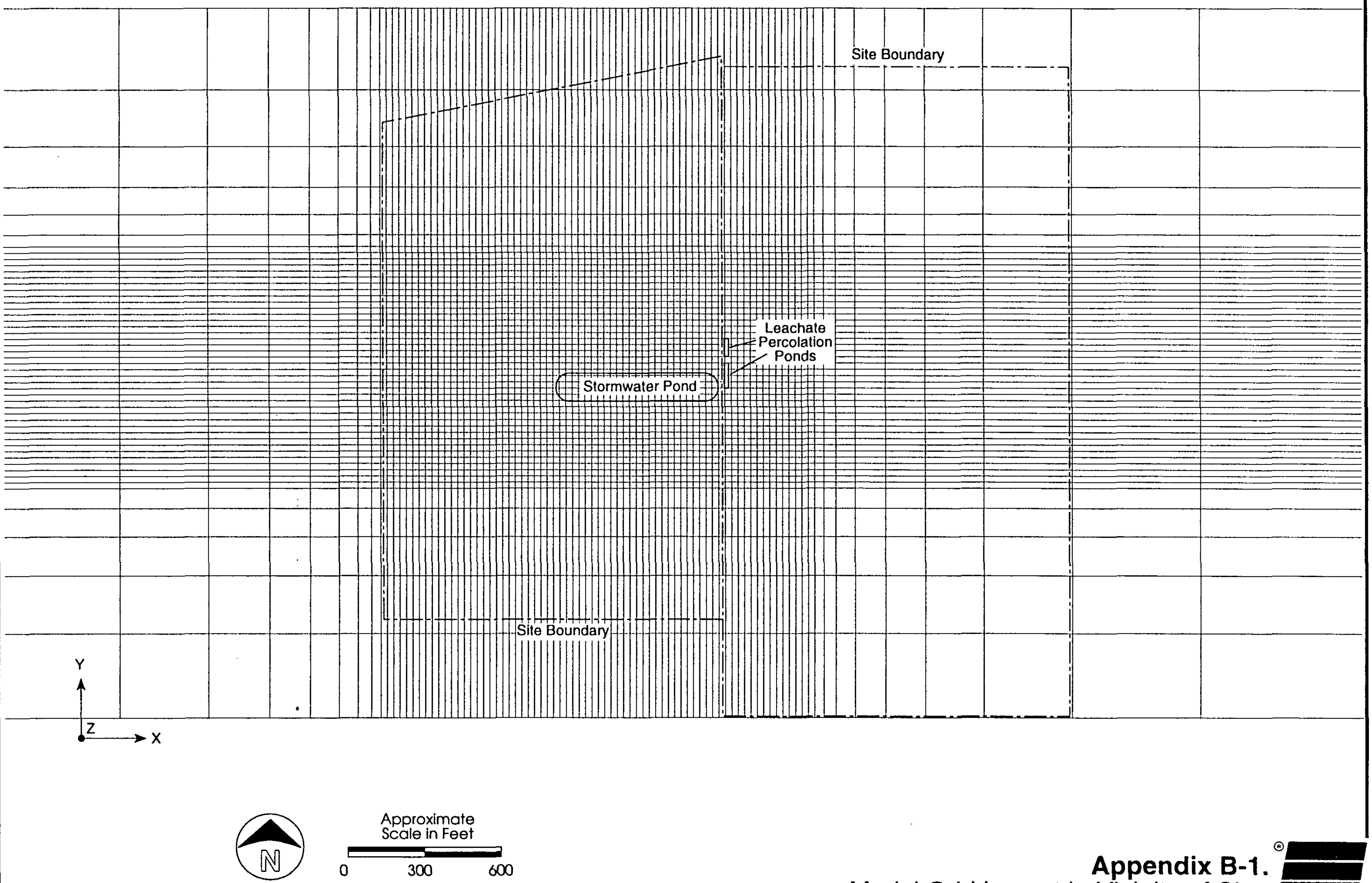
Appendix A-2
Total Dissolved Solids Concentration vs Average (Weighted) Daily Flow



Appendix A-2 Chart 3/Appendix A-2 Chart 3

Appendix B

Model Grid Layout



Appendix B-1.
Model Grid Layout in Vicinity of Site.

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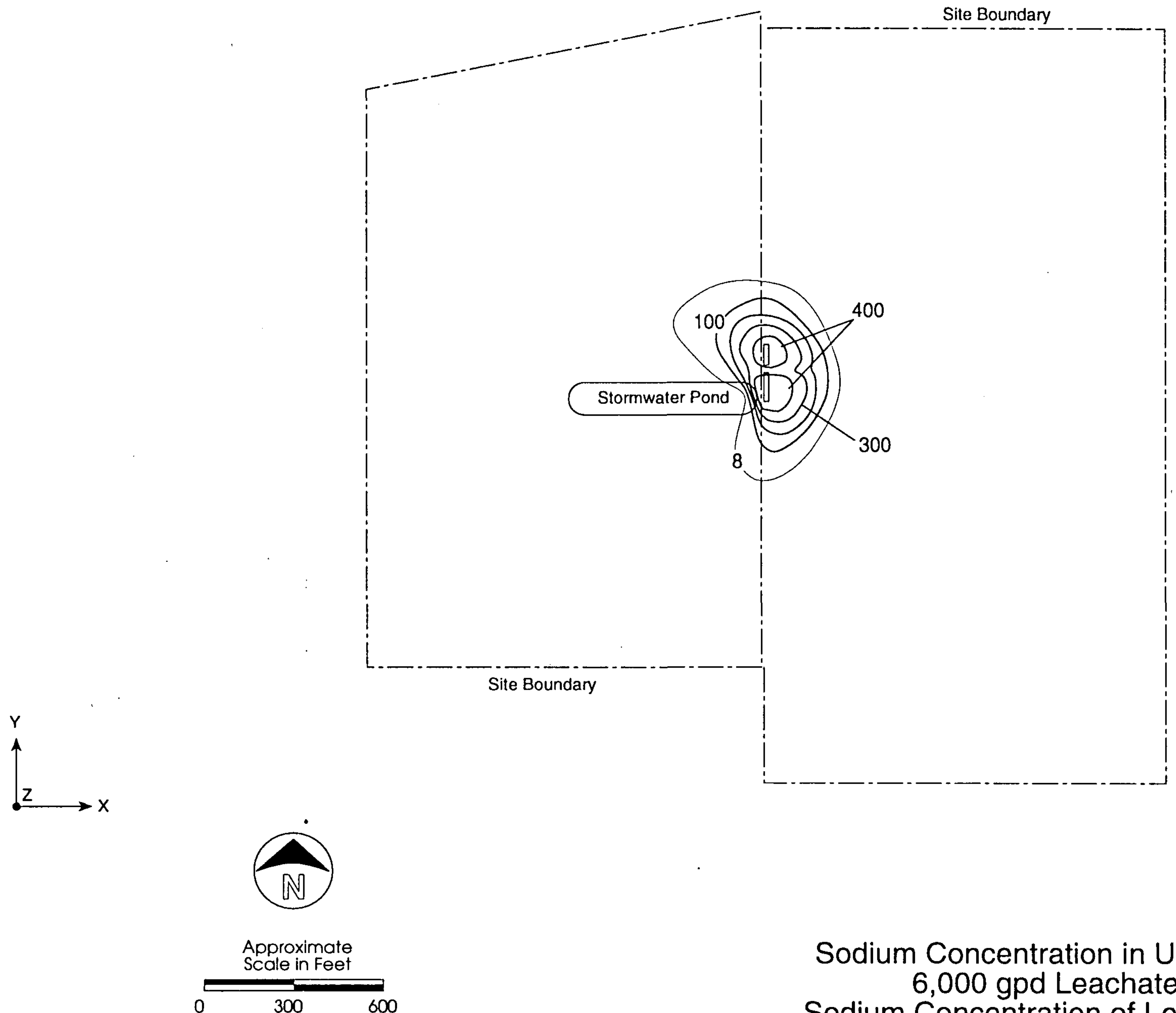
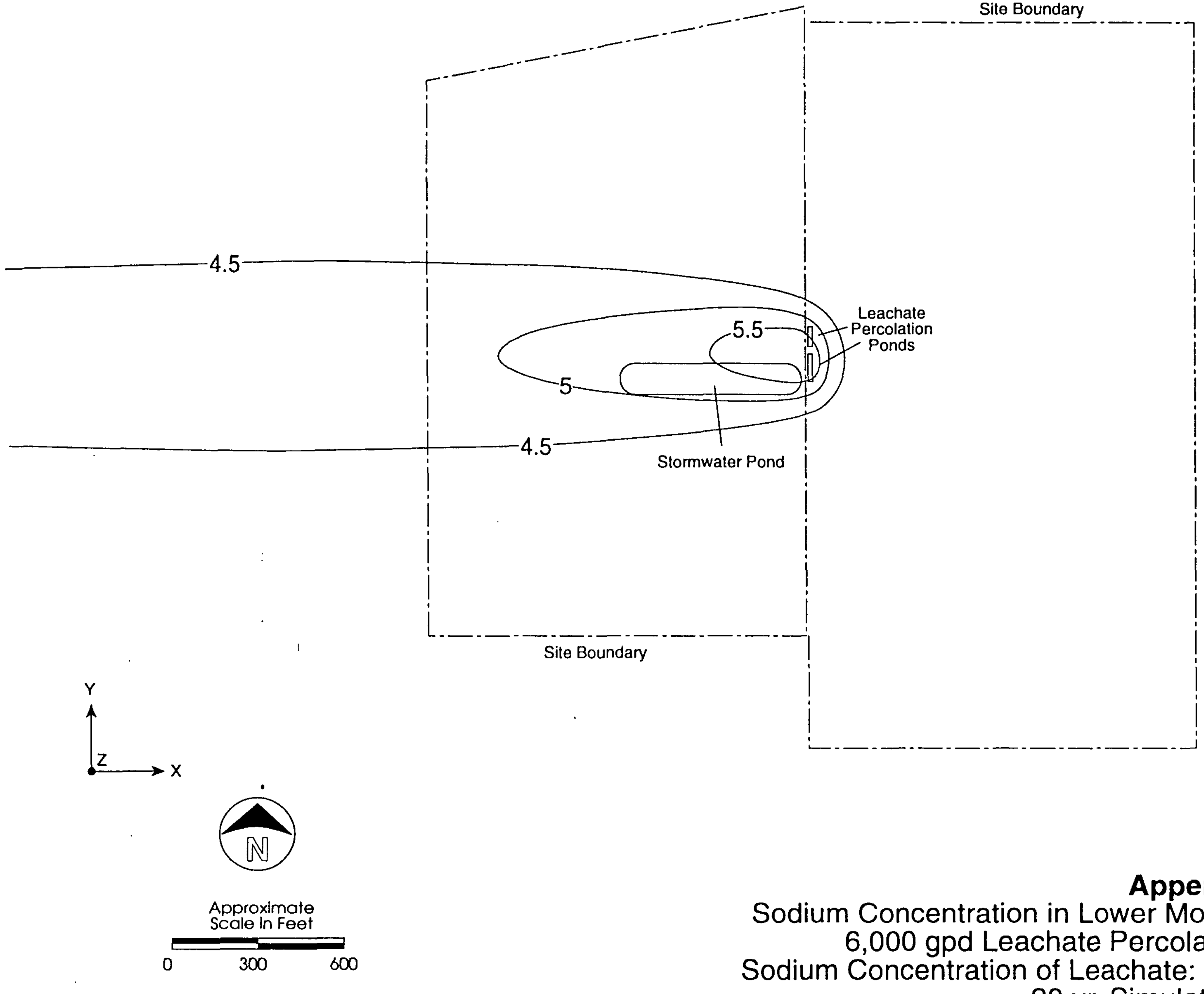
Appendix C

Sodium Concentration

6,000 gpd



Appendix C-1.
Sodium Concentration in Upper Model Layer
6,000 gpd Leachate Percolation Rate
Sodium Concentration of Leachate: 515 mg/L
20 yr. Simulation Time.



Appendix C-2.
Sodium Concentration in Lower Model Layer
6,000 gpd Leachate Percolation Rate
Sodium Concentration of Leachate: 515 mg/L
20 yr. Simulation Time.

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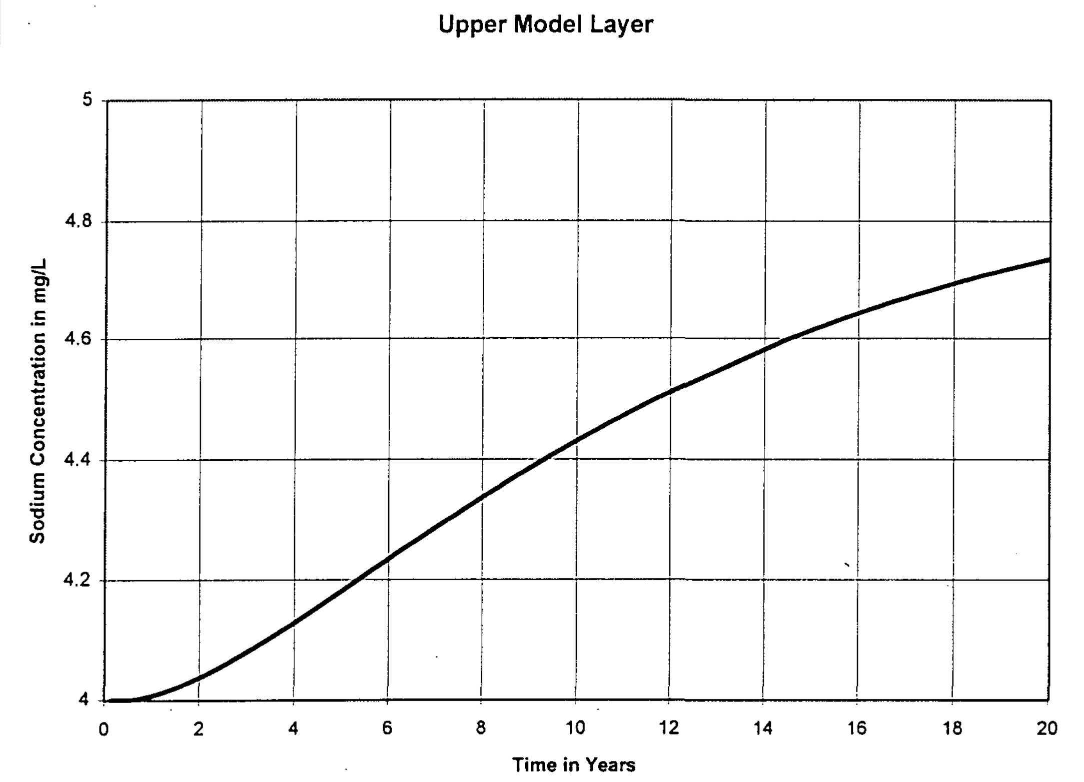
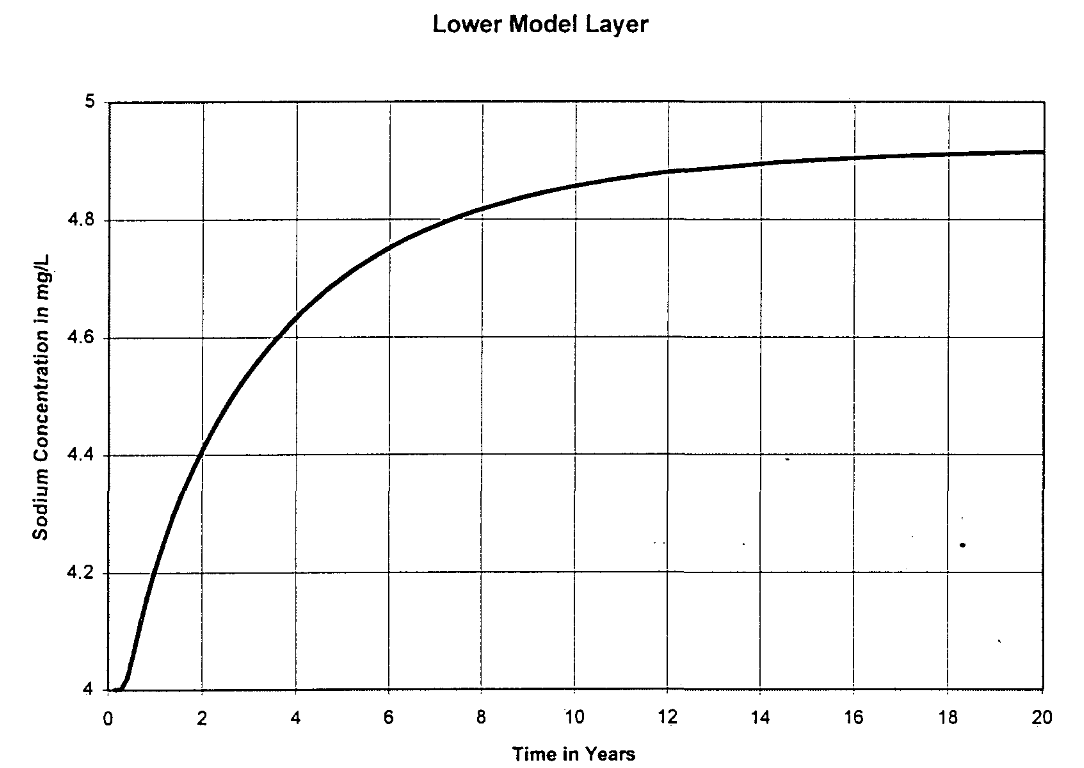
Appendix C-3
Simulated Sodium Concentrations at the Downgradient Site Boundary
@ 6000 gpd

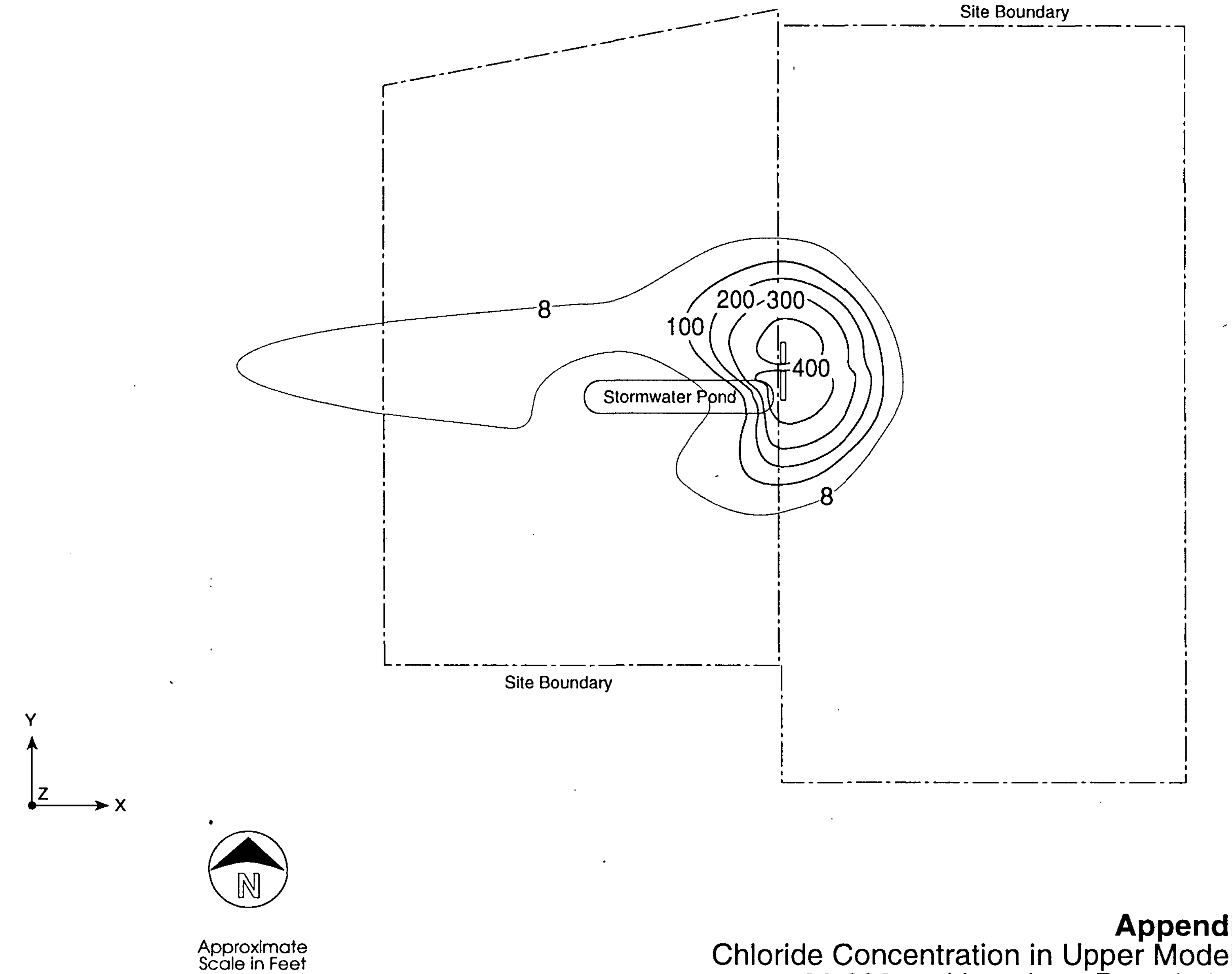




Appendix D

Chloride Concentration

30,000 gpd



Appendix D-1.
Chloride Concentration in Upper Model Layer
30,000 gpd Leachate Percolation Rate
Chloride Concentration of Leachate: 470 mg/L
20 yr. Simulation Time.

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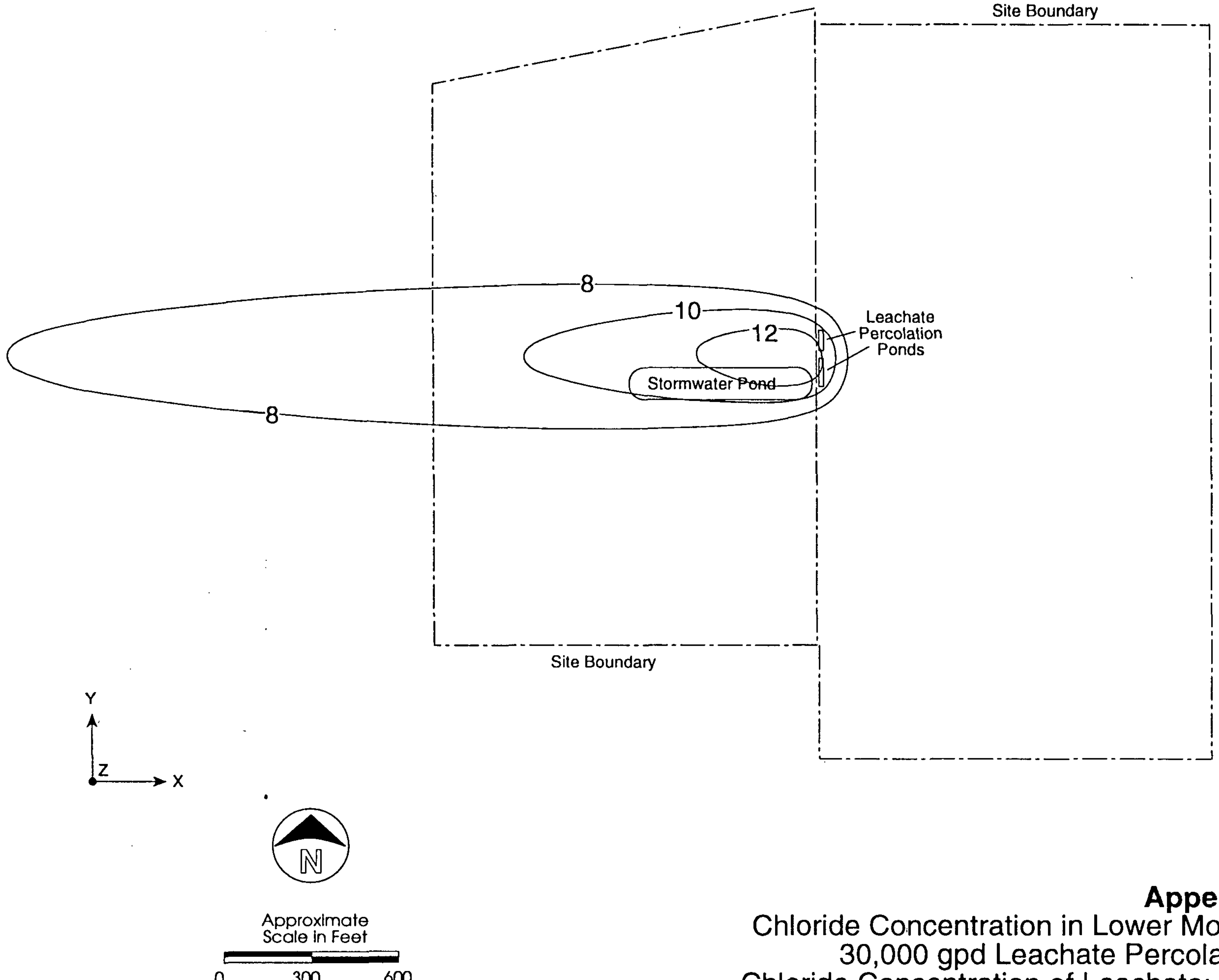
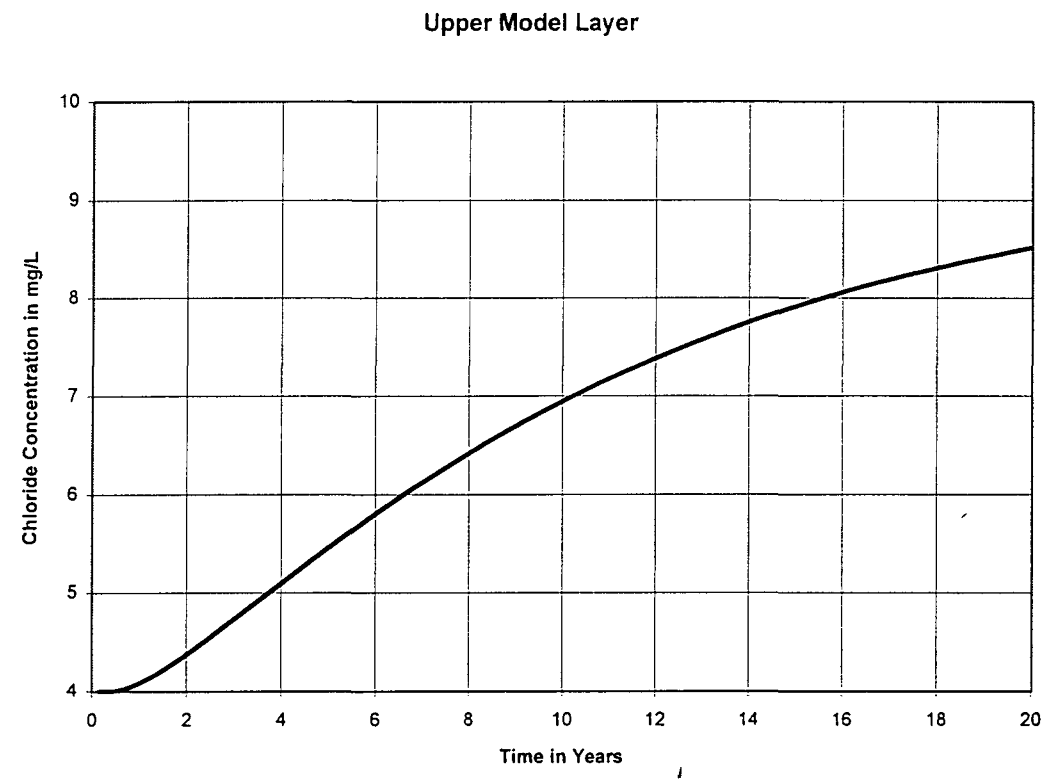
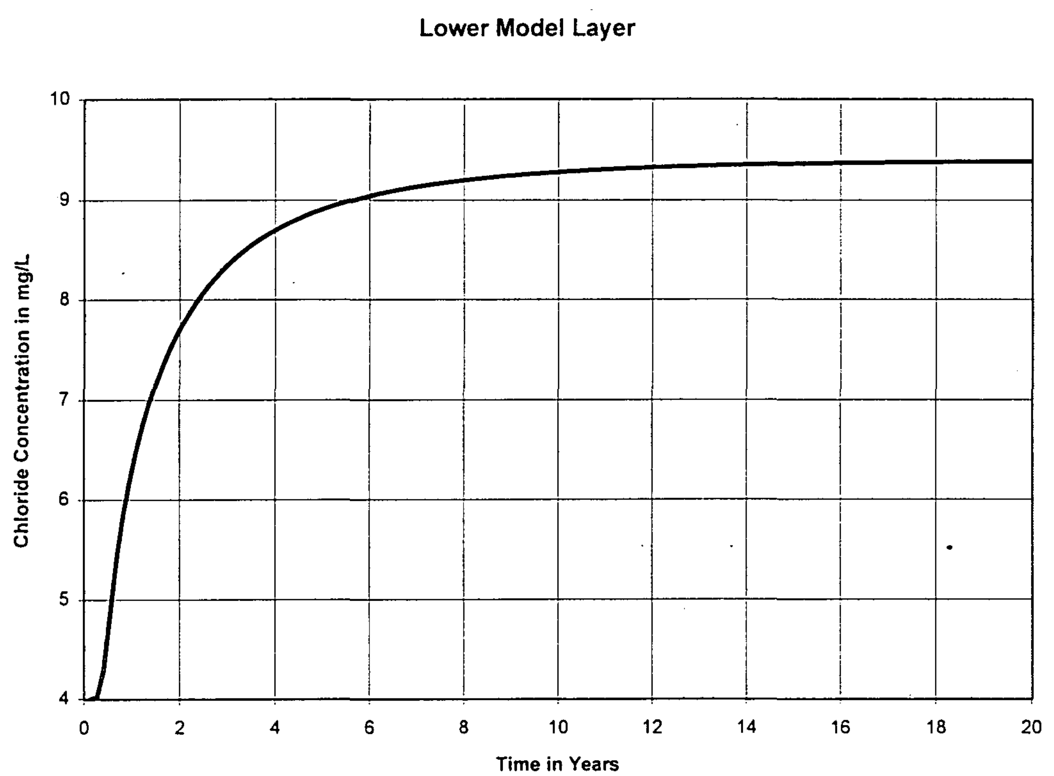


Appendix D-2.
Chloride Concentration in Lower Model Layer
30,000 gpd Leachate Percolation Rate
Chloride Concentration of Leachate: 470 mg/L
20 yr. Simulation Time.

Appendix D-3
Simulated Chloride Concentrations at the Downgradient Site Boundary

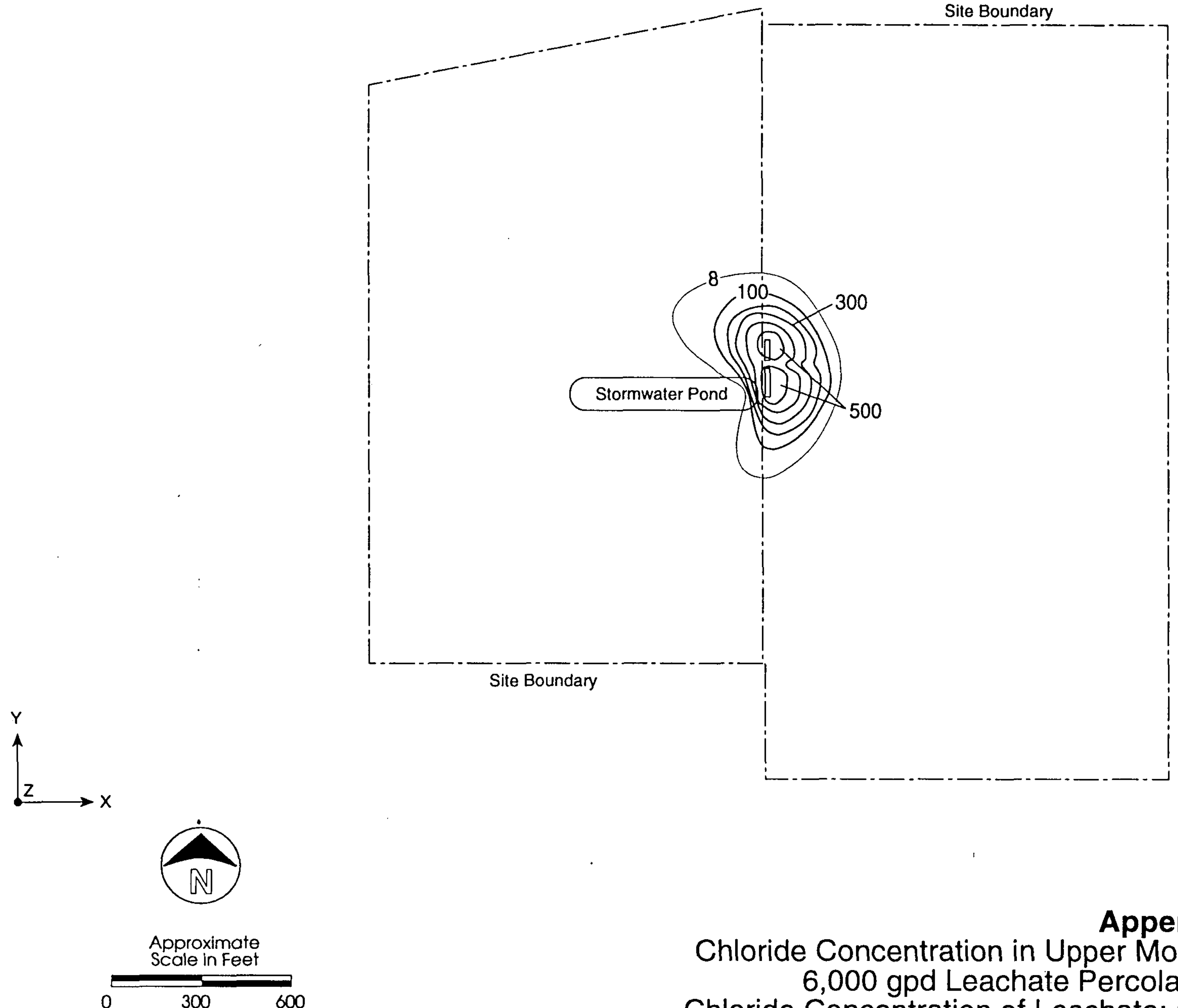




Appendix E

Chloride Concentration

6,000 gpd



Appendix E-1.
Chloride Concentration in Upper Model Layer
6,000 gpd Leachate Percolation Rate
Chloride Concentration of Leachate: 600 mg/L
20 yr. Simulation Time.

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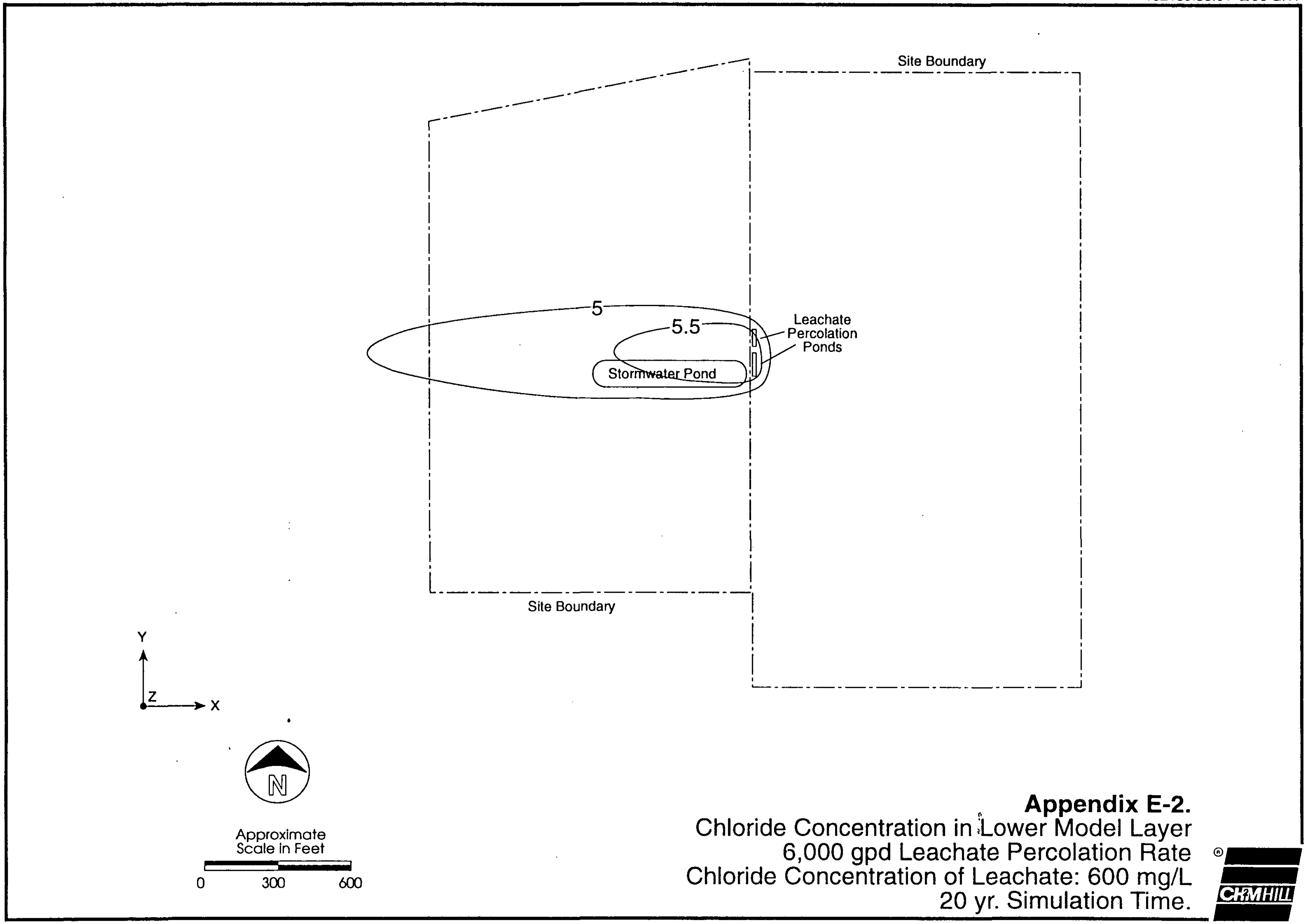
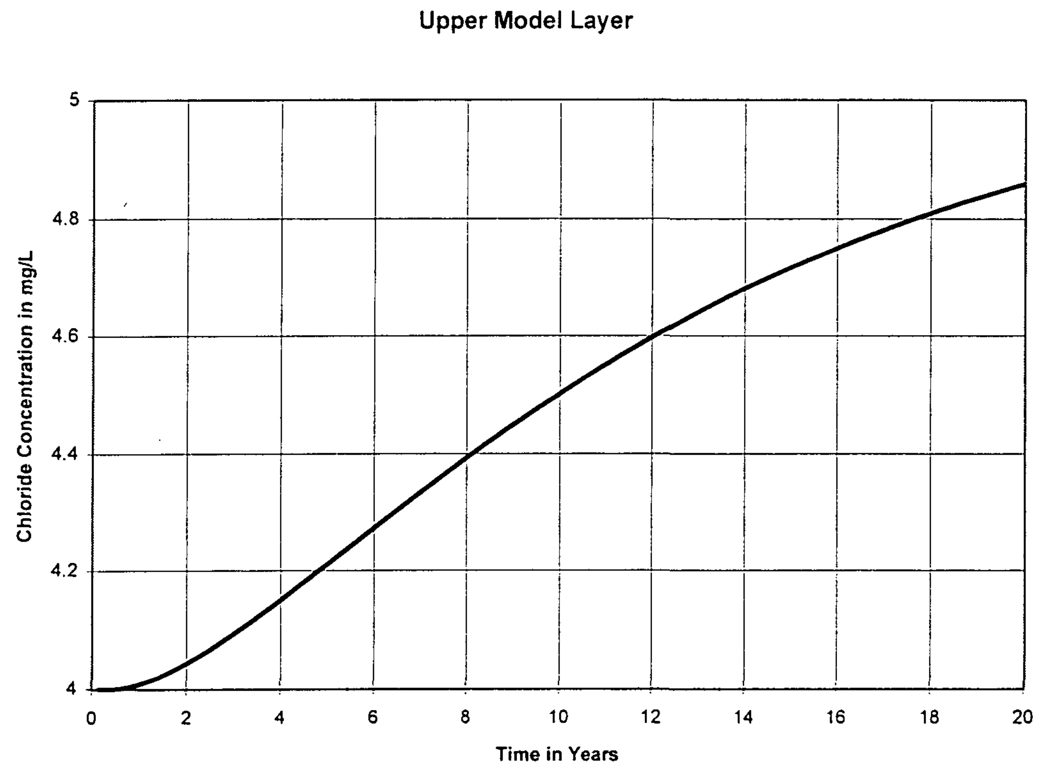
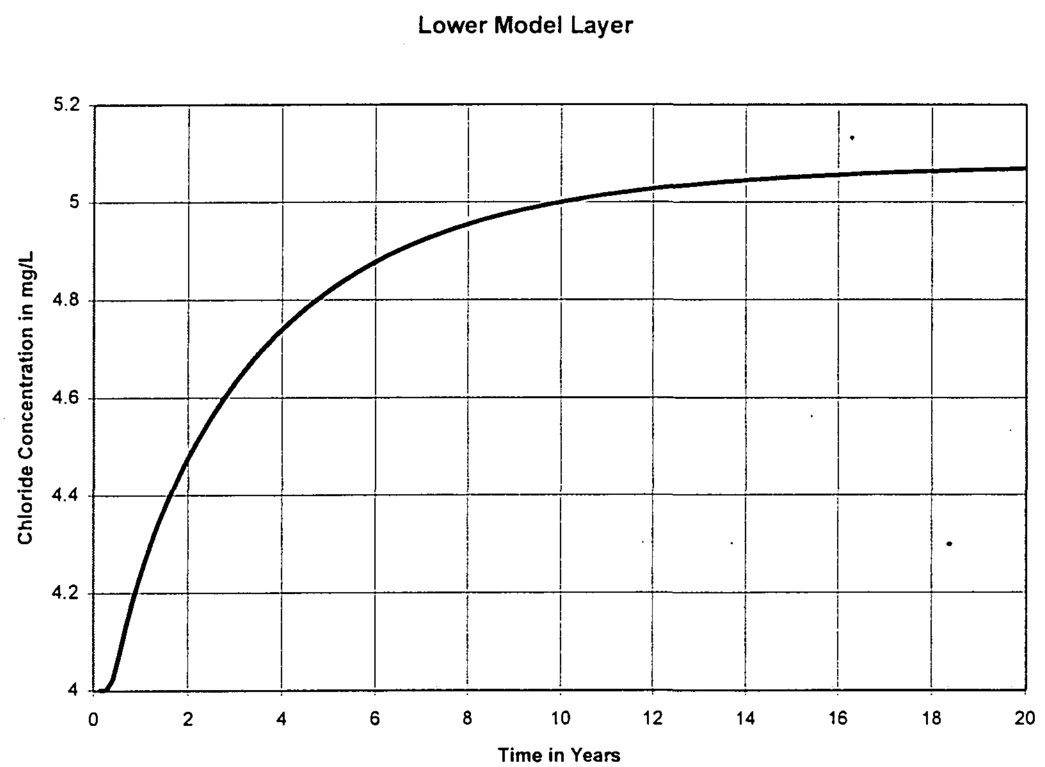


Appendix E-2.
Chloride Concentration in Lower Model Layer
6,000 gpd Leachate Percolation Rate
Chloride Concentration of Leachate: 600 mg/L
20 yr. Simulation Time.

Appendix E-3
Simulated Chloride Concentrations at the Downgradient Site Boundary

6000 gpd

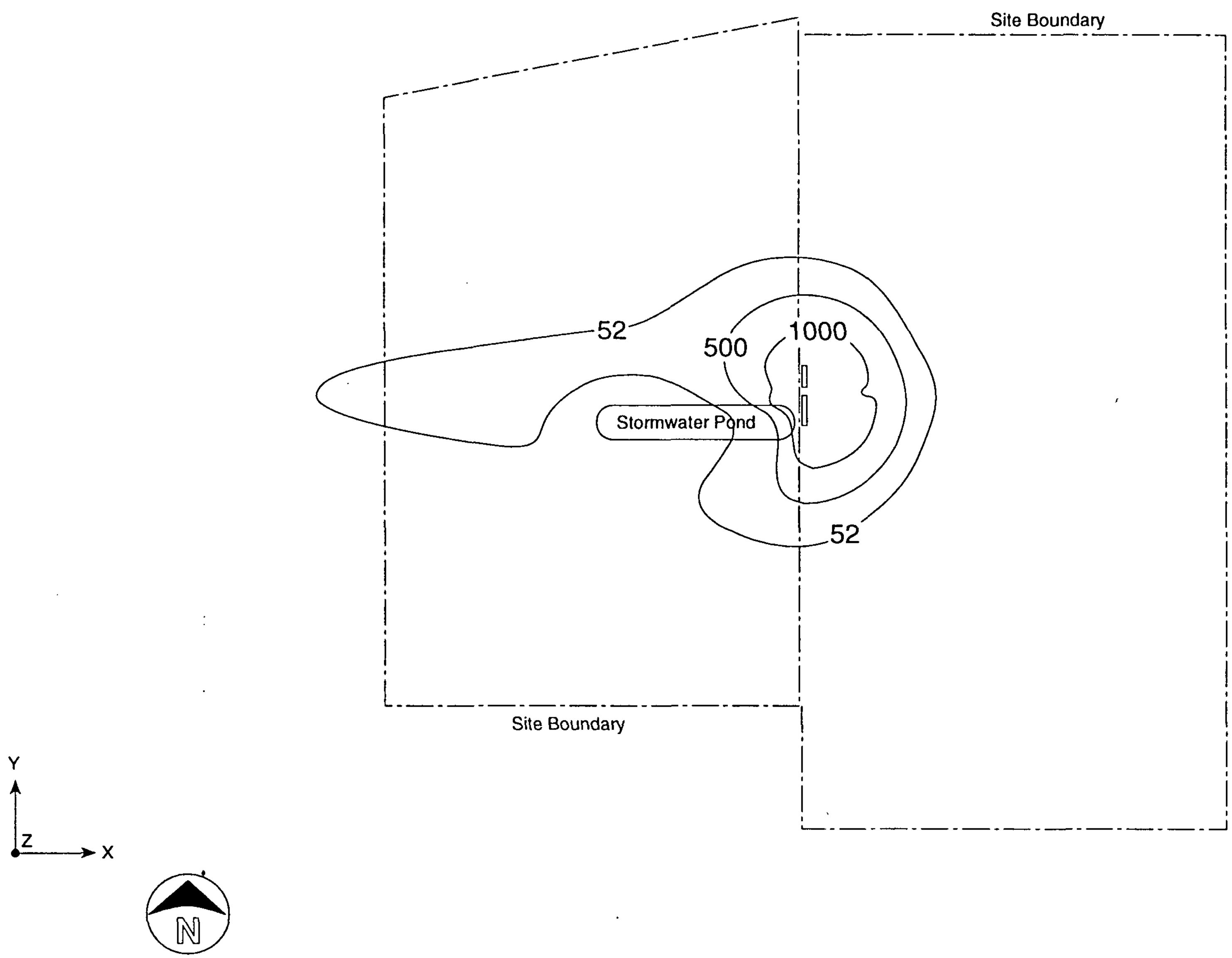


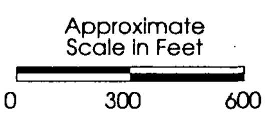


Appendix F

TDS Concentration

30,000 gpd





Appendix F-1.
Total Dissolved Solids Concentration in Upper Model Layer
30,000 gpd Leachate Percolation Rate
Total Dissolved Solids Concentration of Leachate: 1350 mg/L
20 yr. Simulation Time.

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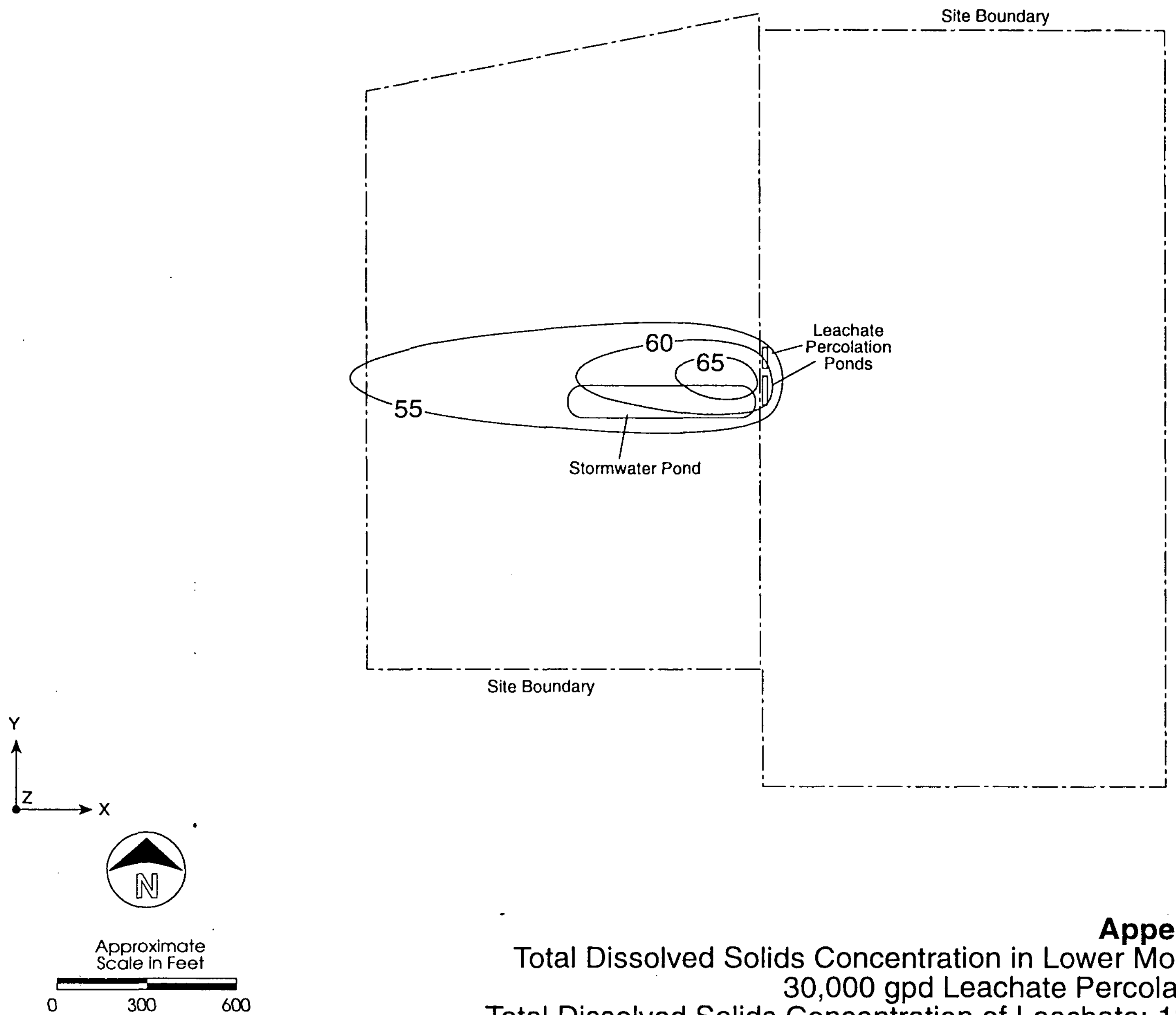

Appendix F-2.
Total Dissolved Solids Concentration in Lower Model Layer
30,000 gpd Leachate Percolation Rate
Total Dissolved Solids Concentration of Leachate: 1350 mg/L
20 yr. Simulation Time.

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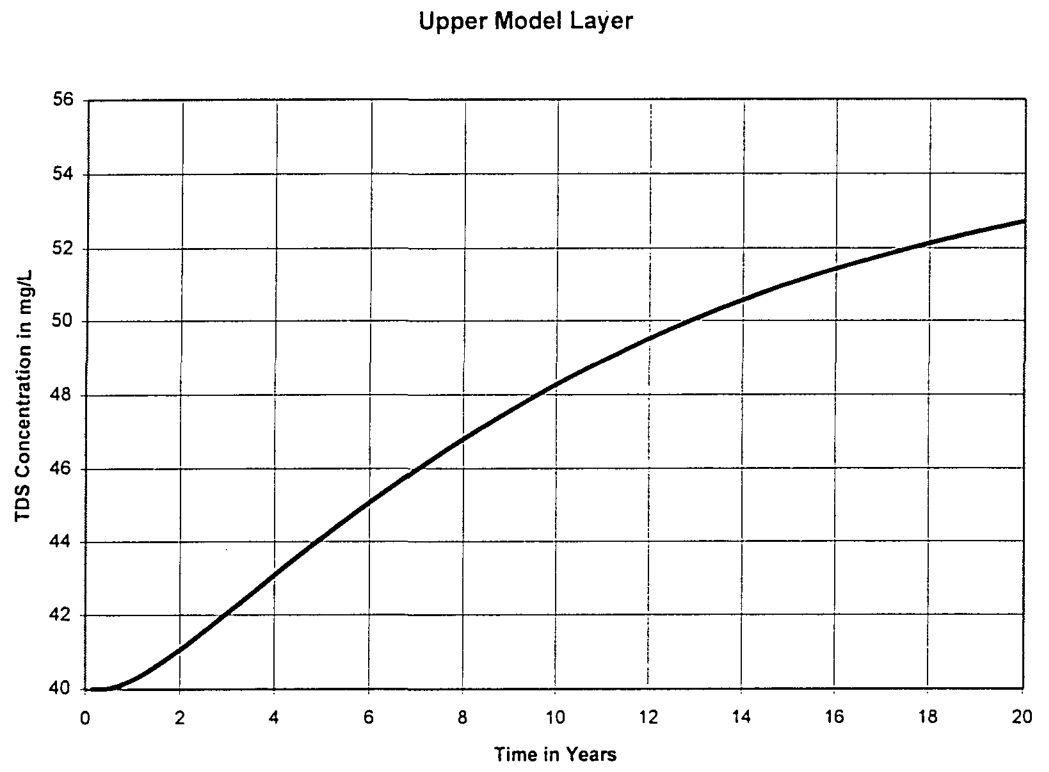
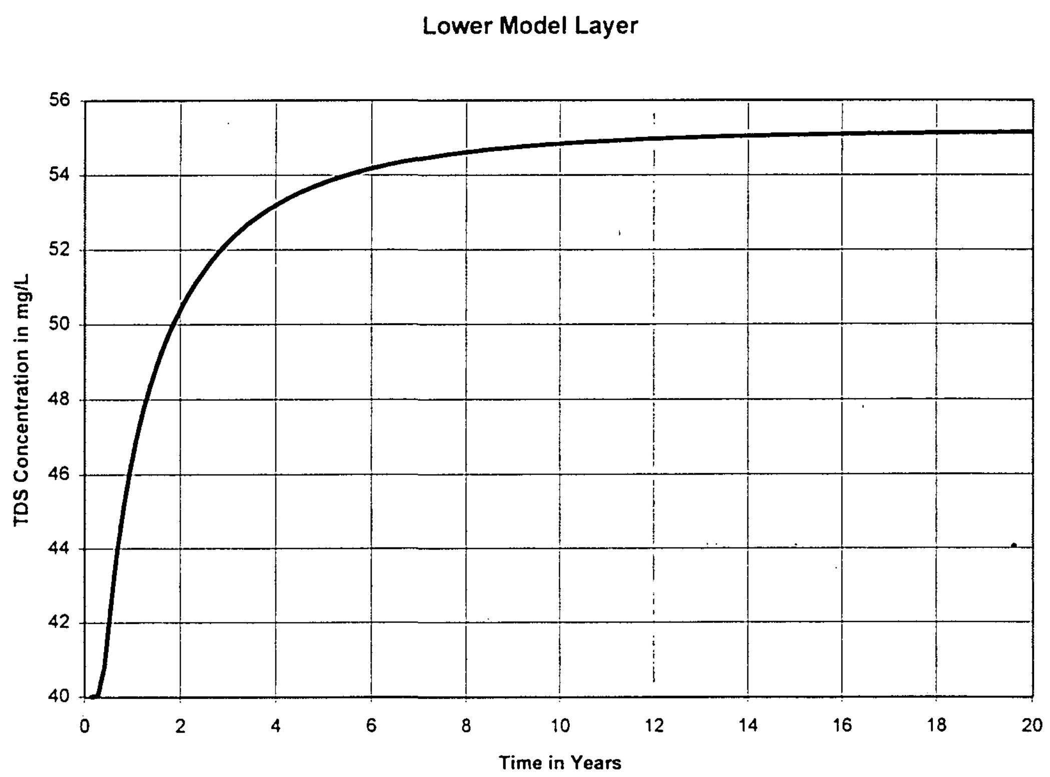
Appendix F-3
Simulated TDS Concentrations at the Downgradient Site Boundary



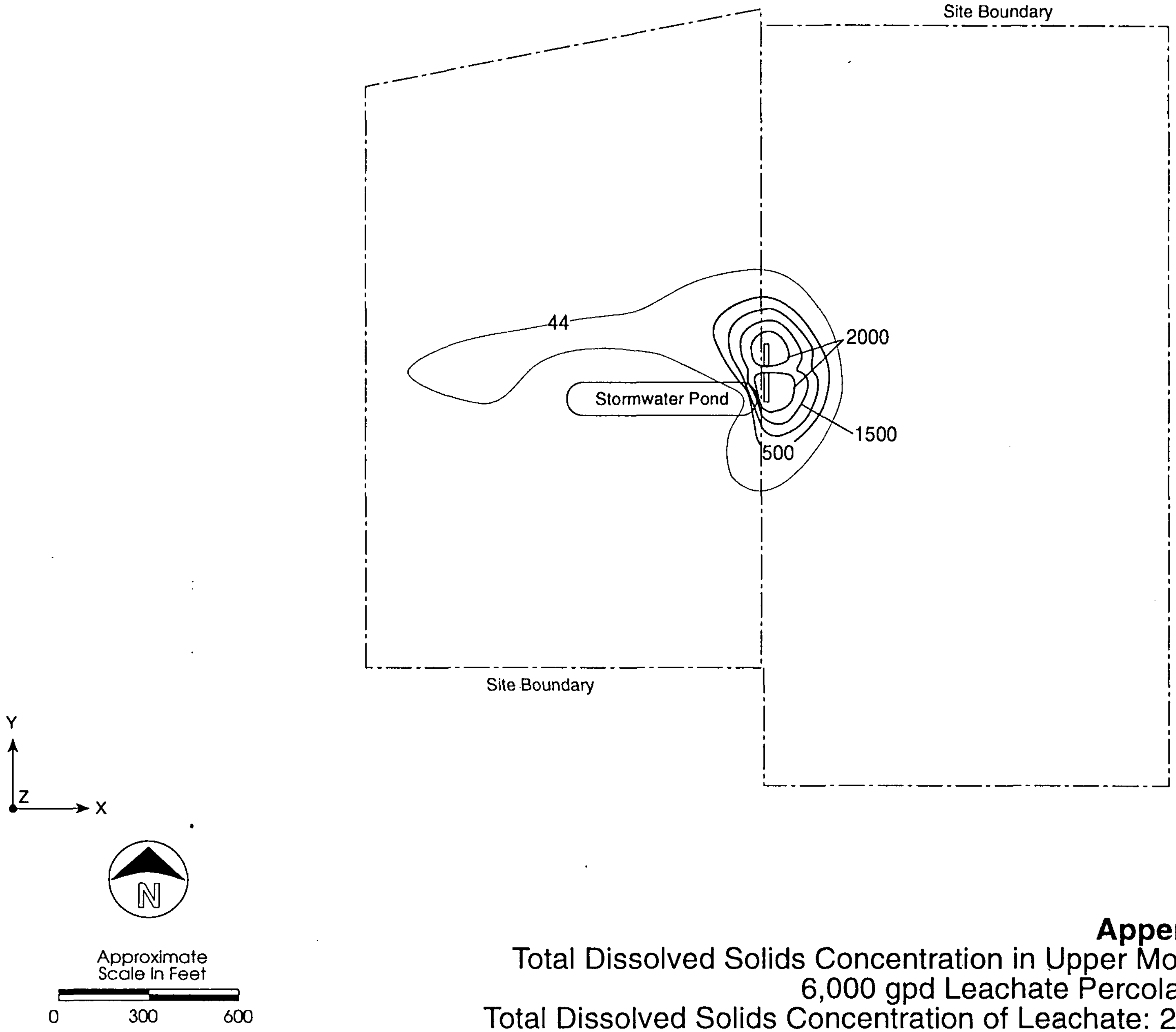


Appendix G

TDS Concentration

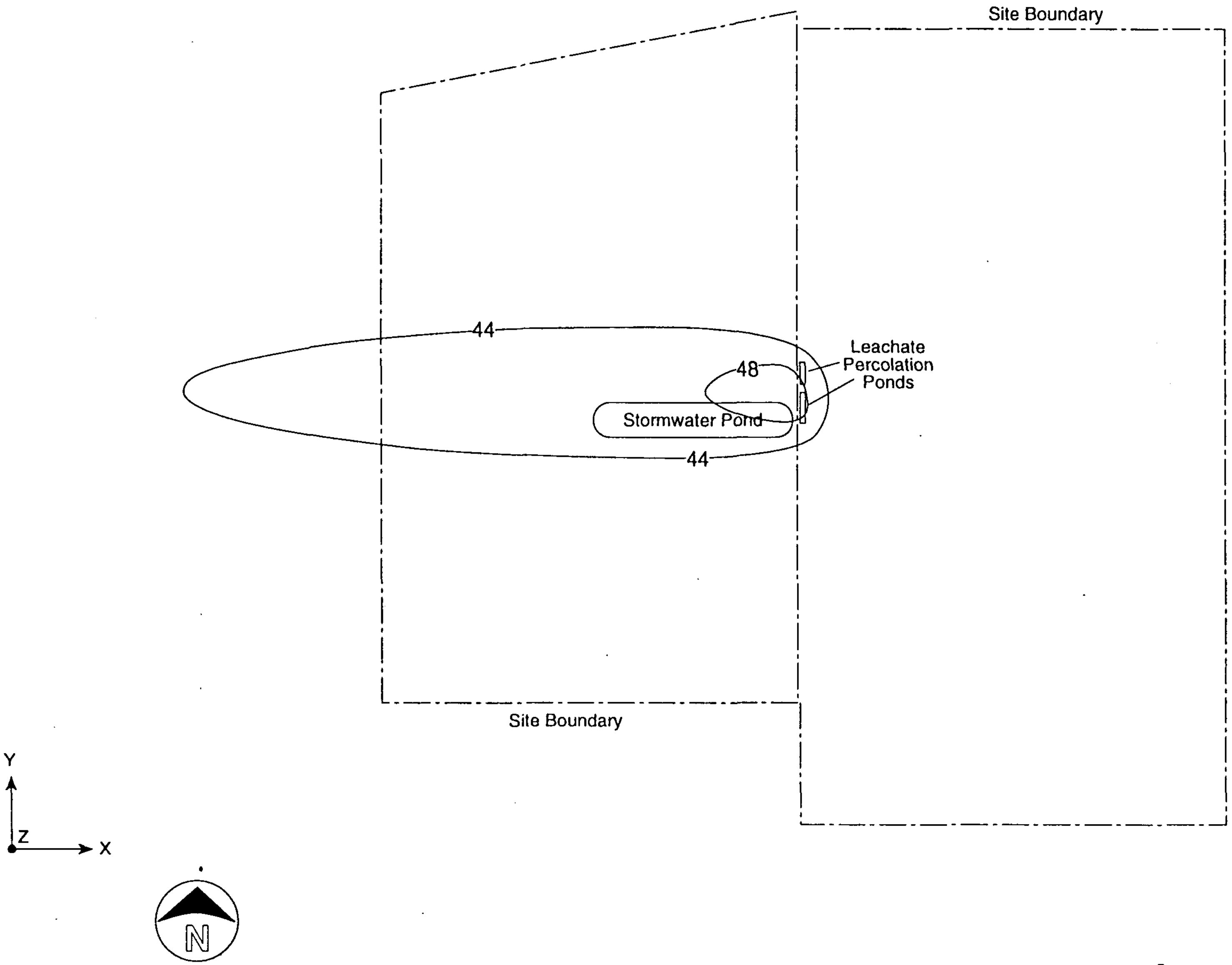
6,000 gpd

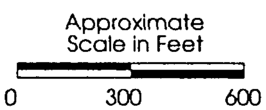
132139.33.01 2/96 GNV



Appendix G-1.
Total Dissolved Solids Concentration in Upper Model Layer
6,000 gpd Leachate Percolation Rate
Total Dissolved Solids Concentration of Leachate: 2650 mg/L
20 yr. Simulation Time.

132139.33.01 2/96 GNV





Appendix G-2.
Total Dissolved Solids Concentration in Lower Model Layer
6,000 gpd Leachate Percolation Rate
Total Dissolved Solids Concentration of Leachate: 2650 mg/L
20 yr. Simulation Time.

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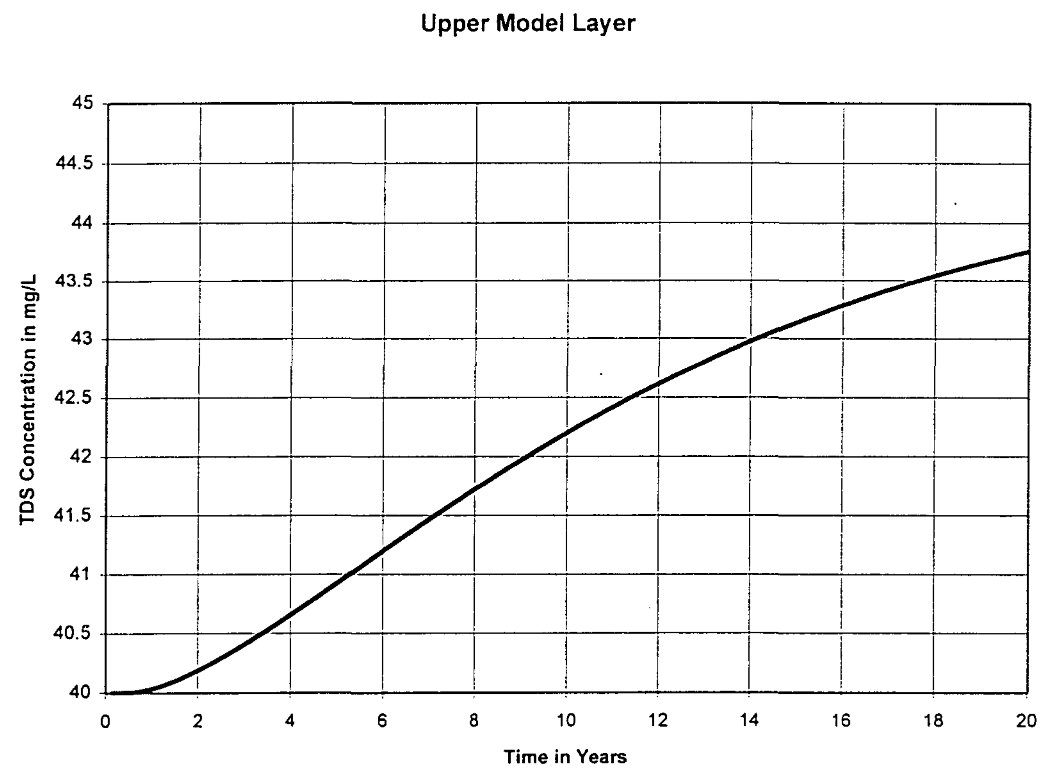
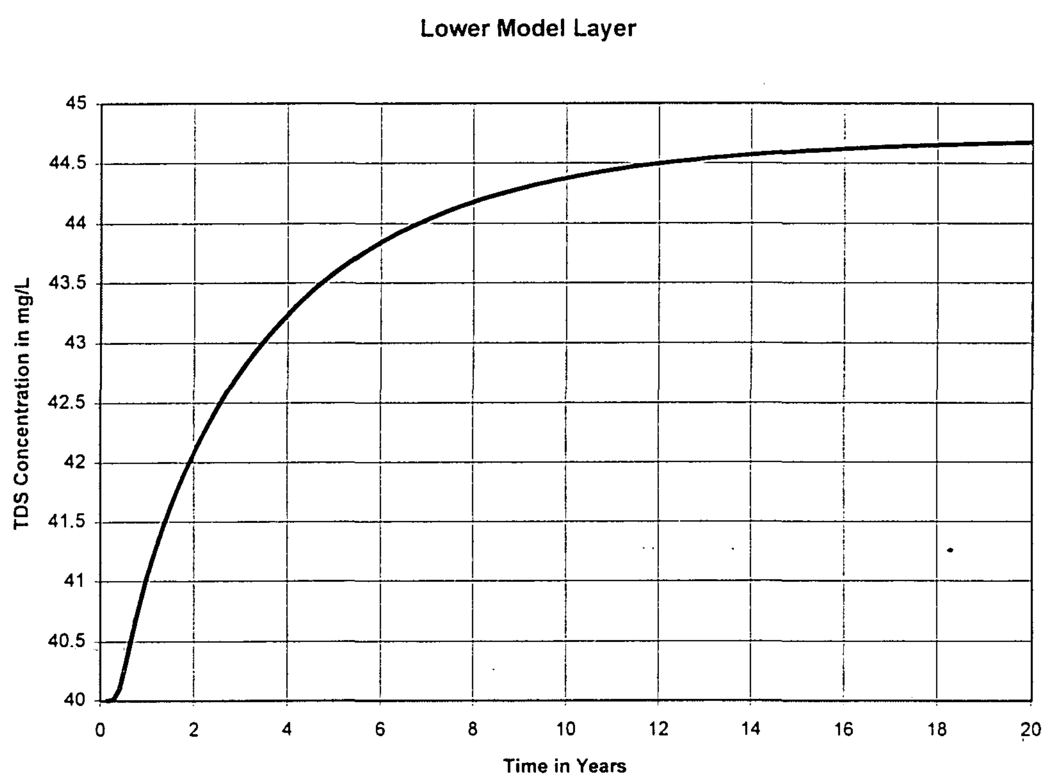
Appendix G-3
Simulated TDS Concentrations at the Downgradient Site Boundary

6000 gpd





Appendix H

Abstract for MT3D

Abstract

mt3d: a modular three-dimensional transport model

This documentation describes the theory and application of a modular three-dimensional transport model for simulation of advection, dispersion and chemical reactions of dissolved constituents in groundwater systems. The model program, referred to as MT3D, uses a modular structure similar to that implemented in MODFLOW, the U. S. Geological Survey modular three-dimensional finite-difference groundwater flow model (McDonald and Harbaugh, 1988). This modular structure makes it possible to simulate advection, dispersion, sink/source mixing, and chemical reactions independently without reserving computer memory space for unused options. New transport processes and options can be added to the model readily without having to modify the existing code.

The MT3D transport model uses a mixed Eulerian-Lagrangian approach to the solution of the three-dimensional advective-dispersive-reactive equation, in three basic options: the method of characteristics (referred to as MOC), the modified method of characteristics (referred to as MMOC), and a hybrid of these two methods (referred to as HMOC). This approach combines the strength of the method of characteristics for eliminating numerical dispersion and the computational efficiency of the modified method of characteristics. The availability of both MOC and MMOC options, and their selective use based on an automatic adaptive procedure under the HMOC option, make MT3D uniquely suitable for a wide range of field problems.

The MT3D transport model is intended to be used in conjunction with any block-centered finite-difference flow model such as MODFLOW and is based on the assumption that changes in the concentration field will not affect the flow field measurably. This allows the user to construct and calibrate a flow model independently. MT3D retrieves the hydraulic heads and the various flow and sink/source terms saved by the flow model, automatically incorporating the specified hydrologic boundary conditions. Currently, MT3D accommodates the following spatial discretization capabilities and transport boundary conditions: (1) confined, unconfined or variably confined/unconfined aquifer layers; (2) inclined model layers and variable cell thickness within the same layer; (3) specified concentration or mass flux boundaries; and (4) the solute transport effects of external sources and sinks such as wells, drains, rivers, areal recharge and evapotranspiration.