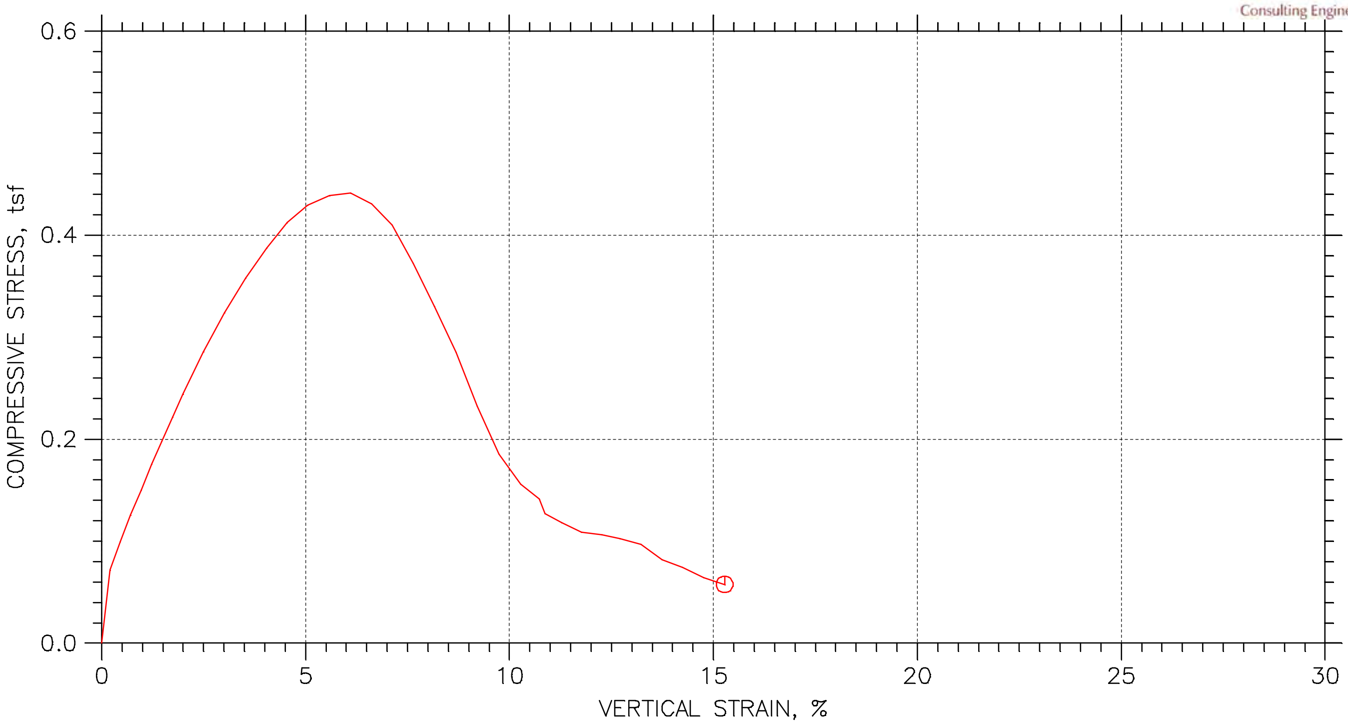
The following are attachments to the testimony of Scott M. Payne, PhD, PG and Ian Magruder, M.S..

Unconfined Compression Tests
ASTM D 2166

UNCONFINED COMPRESSION TEST
ASTM D2166



Symbol		⦶			
Test No.		HENB001S4			
Initial	Diameter, in	2.865			
	Height, in	6.0992			
	Water Content, %	17.60			
	Dry Density, pcf	108.4			
	Saturation, %	84.55			
	Void Ratio	0.56618			
Unconfined Compressive Strength, tsf		0.44114			
Undrained Shear Strength, tsf		0.22057			
Time to Failure, min		6.0041			
Strain Rate, %/min		1			
Estimated Specific Gravity		2.72			
Liquid Limit		21			
Plastic Limit		14			
Plasticity Index		7			
Failure Sketch					

Project: DYNERGY HENNEPIN
Location: HENNEPIN, IL
Project No.: MR155233
Boring No.: HENB001 S-4
Sample Type: 3.0'' ST
Description: BROWN AND GRAY LEAN CLAY WITH SAND CL SAND SEAMS NOTED
Remarks: TEST PERFORMED AS PER ASTM D2166. 408

Tue, 22-DEC-2015 14:04:16

UNCONFINED COMPRESSION TEST

Project: DYNERGY HENNEPIN
Boring No.: HENB001 S-4
Sample No.: ST-4
Test No.: HENB001S4

Location: HENNEPIN, IL
Tested By: BCM
Test Date: 12/14/15
Sample Type: 3.0" ST

Project No.: MR155233
Checked By: WPQ
Depth: 7.5'-9.5'
Elevation: -----

Soil Description: BROWN AND GRAY LEAN CLAY WITH SAND CL SAND SEAMS NOTED
Remarks: TEST PERFORMED AS PER ASTM D2166.

Specimen Height: 6.10 in
Specimen Area: 6.45 in^2
Specimen Volume: 39.32 in^3

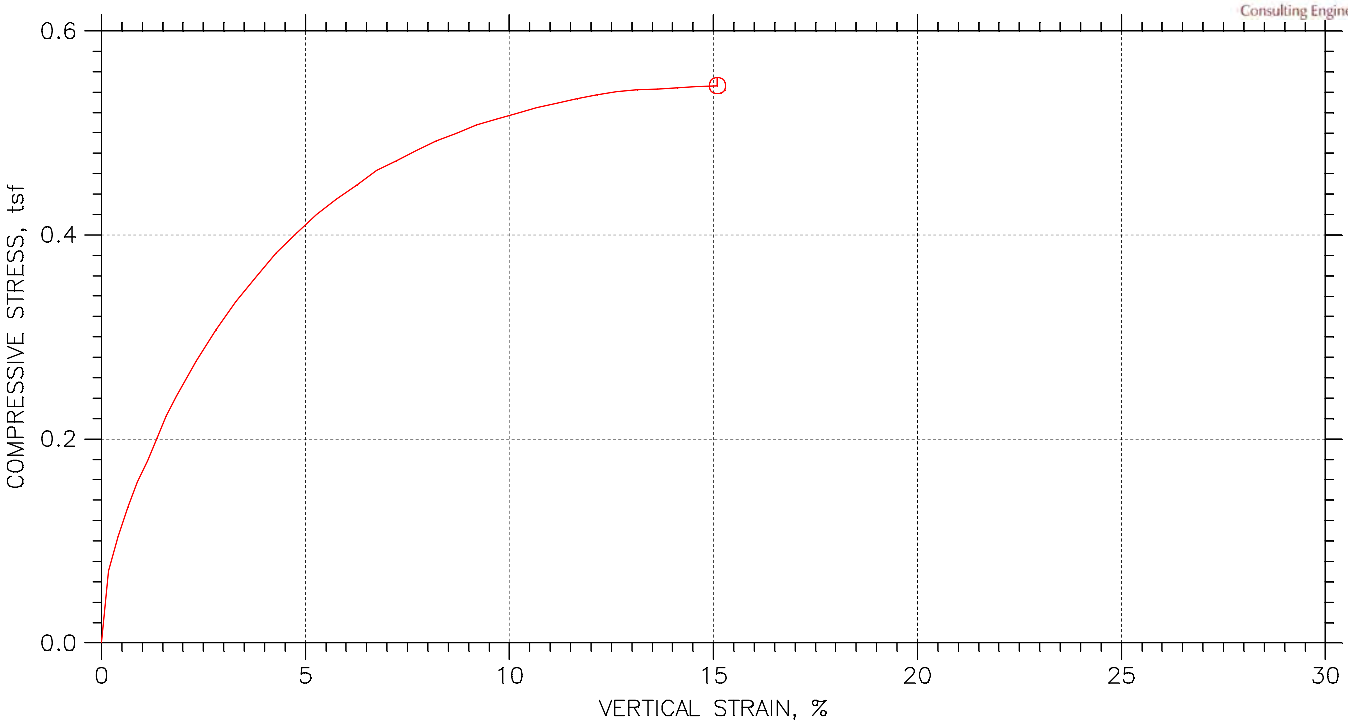
Liquid Limit: 21
Plastic Limit: 14
Estimated Specific Gravity: 2.72

Cap Mass: 0 gm

	Time min	Axial Displacement in	Axial Strain %	Load lb	Corrected Area in^2	Vertical Stress tsf	Shear Stress tsf
1	0	0	0	0	6.4465	0	0
2	0.25412	0.012269	0.20115	6.4512	6.4595	0.071907	0.035954
3	0.50388	0.027674	0.45373	8.9163	6.4759	0.099133	0.049566
4	0.75412	0.043356	0.71085	11.329	6.4927	0.12563	0.062816
5	1.0041	0.05913	0.96947	13.584	6.5097	0.15025	0.075125
6	1.2541	0.074997	1.2296	15.892	6.5268	0.17531	0.087656
7	1.5041	0.090402	1.4822	17.99	6.5435	0.19795	0.098974
8	1.7541	0.1059	1.7363	20.193	6.5605	0.22161	0.11081
9	2.0041	0.1214	1.9904	22.291	6.5775	0.24401	0.122
10	2.5041	0.15221	2.4955	26.225	6.6115	0.28559	0.14279
11	3.0041	0.18348	3.0082	29.896	6.6465	0.32386	0.16193
12	3.5041	0.2153	3.53	33.2	6.6824	0.35772	0.17886
13	4.0041	0.24667	4.0443	36.137	6.7183	0.38729	0.19364
14	4.5041	0.27739	4.5479	38.707	6.7537	0.41265	0.20633
15	5.0041	0.30847	5.0576	40.491	6.79	0.42936	0.21468
16	5.5041	0.3403	5.5794	41.592	6.8275	0.43861	0.21931
17	6.0041	0.37212	6.1012	42.064	6.8654	0.44114	0.22057
18	6.5042	0.40349	6.6154	41.277	6.9032	0.43052	0.21526
19	7.0042	0.43439	7.1221	39.547	6.9409	0.41023	0.20511
20	7.5042	0.46603	7.6409	36.085	6.9799	0.37223	0.18612
21	8.0042	0.49776	8.1611	32.204	7.0194	0.33032	0.16516
22	8.5042	0.52996	8.689	27.955	7.06	0.2851	0.14255
23	9.0042	0.5616	9.2077	22.92	7.1003	0.23242	0.11621
24	9.5042	0.59398	9.7386	18.357	7.1421	0.18506	0.09253
25	10.004	0.62673	10.276	15.577	7.1848	0.1561	0.078051
26	10.504	0.65486	10.737	14.161	7.222	0.14118	0.070591
27	11.004	0.66279	10.867	12.745	7.2325	0.12688	0.063439
28	11.5	0.6877	11.275	11.906	7.2658	0.11798	0.058991
29	12	0.71722	11.759	11.014	7.3056	0.10855	0.054275
30	12.5	0.74775	12.26	10.857	7.3473	0.10639	0.053196
31	13	0.77515	12.709	10.542	7.3851	0.10278	0.05139
32	13.5	0.80652	13.223	9.9653	7.4289	0.096583	0.048291
33	14	0.83816	13.742	8.4968	7.4736	0.081857	0.040929
34	14.5	0.86897	14.247	7.7625	7.5176	0.074345	0.037173
35	15	0.89996	14.755	6.7659	7.5624	0.064417	0.032208
36	15.5	0.93169	15.276	6.0841	7.6088	0.057572	0.028786

UNCONFINED COMPRESSION TEST
ASTM D2166

Terracon
Consulting Engineers & Scientists



Symbol		⏀			
Test No.		HEN001S7			
Initial	Diameter, in	2.8047			
	Height, in	6.0043			
	Water Content, %	37.23			
	Dry Density, pcf	81.96			
	Saturation, %	94.48			
	Void Ratio	1.0718			
Unconfined Compressive Strength, tsf		0.54628			
Undrained Shear Strength, tsf		0.27314			
Time to Failure, min		15.5			
Strain Rate, %/min		1			
Estimated Specific Gravity		2.72			
Liquid Limit		38			
Plastic Limit		22			
Plasticity Index		16			
Failure Sketch					

Project: DYNERGY HENNEPIN	
Location: HENNEPIN, IL	
Project No.: MR155233	
Boring No.: HEN001 S7	
Sample Type: 3.0" ST	
Description: DARK GRAY ORGANIC LEAN CLAY OL SHELL NOTED	
Remarks: TEST PERFORMED AS PER ASTM D2166.	410

Tue, 22-DEC-2015 14:21:51

UNCONFINED COMPRESSION TEST

Project: DYNERGY HENNEPIN
Boring No.: HEN001 S7
Sample No.: ST-7
Test No.: HEN001S7

Location: HENNEPIN, IL
Tested By: BCM
Test Date: 12/15/15
Sample Type: 3.0" ST

Project No.: MR155233
Checked By: WPQ
Depth: 20.0'-22.0'
Elevation: ----

Soil Description: DARK GRAY ORGANIC LEAN CLAY OL SHELL NOTED
Remarks: TEST PERFORMED AS PER ASTM D2166.

Specimen Height: 6.00 in
Specimen Area: 6.18 in^2
Specimen Volume: 37.10 in^3

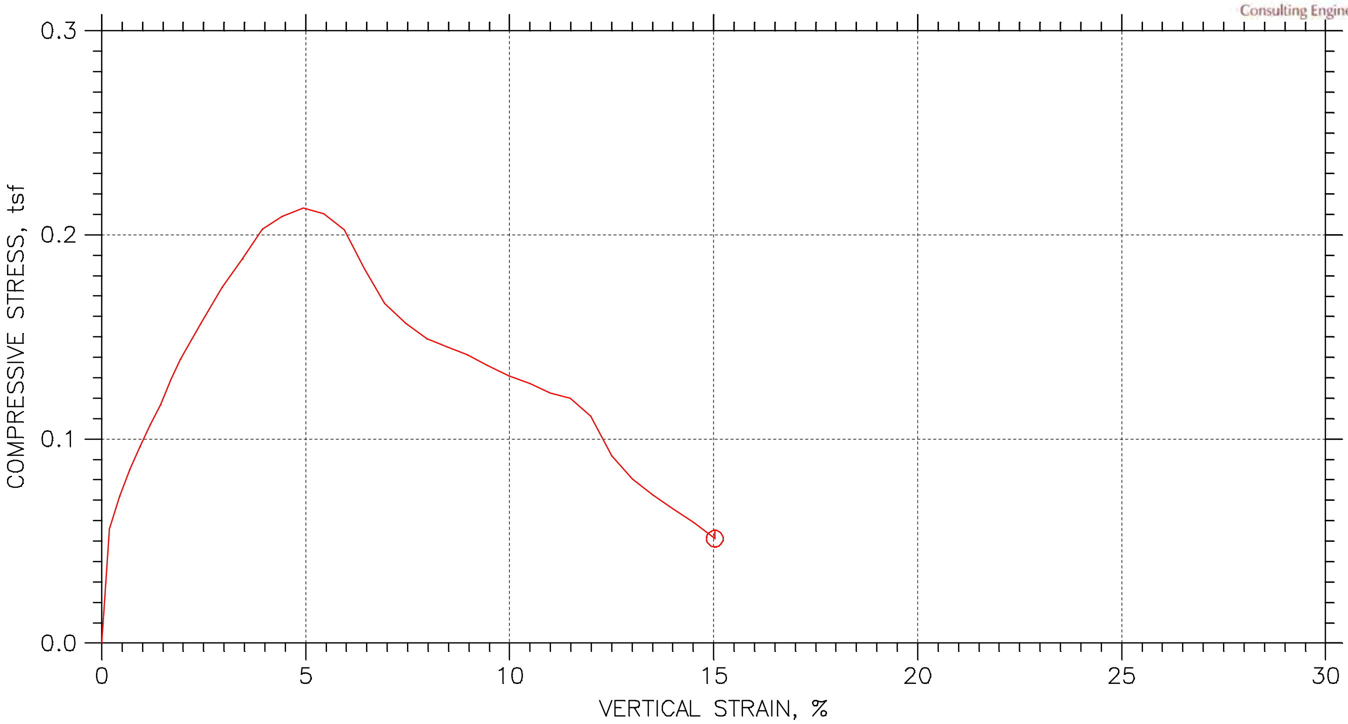
Liquid Limit: 38
Plastic Limit: 22
Estimated Specific Gravity: 2.72

Cap Mass: 0 gm

	Time min	Axial Displacement in	Axial Strain %	Load lb	Corrected Area in^2	Vertical Stress tsf	Shear Stress tsf
1	0	0	0	0	6.1783	0	0
2	0.25003	0.010322	0.1719	6.0347	6.189	0.070205	0.035102
3	0.50003	0.024571	0.40922	8.9991	6.2037	0.10444	0.052221
4	0.75003	0.038638	0.6435	11.434	6.2183	0.13239	0.066196
5	1	0.05307	0.88386	13.657	6.2334	0.15775	0.078876
6	1.25	0.067593	1.1257	15.51	6.2487	0.17871	0.089357
7	1.5	0.082299	1.3707	17.469	6.2642	0.20078	0.10039
8	1.75	0.095361	1.5882	19.374	6.278	0.2222	0.1111
9	2.0001	0.11007	1.8331	21.121	6.2937	0.24163	0.12081
10	2.5	0.13957	2.3245	24.297	6.3254	0.27657	0.13829
11	3	0.16862	2.8083	27.103	6.3568	0.30698	0.15349
12	3.5	0.19803	3.2981	29.697	6.389	0.33466	0.16733
13	4.0001	0.22781	3.7941	32.026	6.422	0.35906	0.17953
14	4.5	0.25759	4.29	34.302	6.4552	0.3826	0.1913
15	5.0001	0.28709	4.7814	36.208	6.4886	0.40178	0.20089
16	5.5001	0.31623	5.2666	38.061	6.5218	0.42019	0.21009
17	6.0001	0.34582	5.7595	39.596	6.5559	0.43486	0.21743
18	6.5001	0.3756	6.2555	41.078	6.5906	0.44876	0.22438
19	7.0001	0.40519	6.7484	42.613	6.6254	0.46309	0.23154
20	7.5001	0.43415	7.2306	43.725	6.6599	0.47271	0.23636
21	8.0001	0.46329	7.7159	44.889	6.6949	0.48276	0.24138
22	8.5001	0.49288	8.2088	46.001	6.7308	0.49207	0.24604
23	9.0001	0.52266	8.7047	46.954	6.7674	0.49955	0.24978
24	9.5001	0.55226	9.1976	48.013	6.8041	0.50806	0.25403
25	10	0.5813	9.6814	48.807	6.8406	0.51371	0.25686
26	10.5	0.6109	10.174	49.601	6.8781	0.51922	0.25961
27	11	0.64067	10.67	50.395	6.9163	0.52462	0.26231
28	11.5	0.67054	11.168	51.136	6.955	0.52937	0.26468
29	12	0.69996	11.658	51.824	6.9936	0.53353	0.26677
30	12.5	0.729	12.141	52.459	7.0321	0.53712	0.26856
31	13	0.7586	12.634	53.094	7.0718	0.54057	0.27029
32	13.5	0.78856	13.133	53.571	7.1124	0.54231	0.27115
33	14	0.81824	13.628	53.941	7.1531	0.54295	0.27147
34	14.5	0.84766	14.117	54.365	7.1939	0.54411	0.27205
35	15	0.8767	14.601	54.841	7.2347	0.54579	0.27289
36	15.5	0.90648	15.097	55.212	7.2769	0.54628	0.27314

UNCONFINED COMPRESSION TEST
ASTM D2166

Terracon
Consulting Engineers & Scientists



Symbol		⦶			
Test No.		HENB003S5			
Initial	Diameter, in	2.8394			
	Height, in	6.2583			
	Water Content, %	38.47			
	Dry Density, pcf	68.88			
	Saturation, %	72.73			
	Void Ratio	1.4017			
Unconfined Compressive Strength, tsf		0.21317			
Undrained Shear Strength, tsf		0.10659			
Time to Failure, min		5.0039			
Strain Rate, %/min		1			
Estimated Specific Gravity		2.65			
Liquid Limit		---			
Plastic Limit		---			
Plasticity Index		---			
Failure Sketch					

Project: DYNERGY HENNEPIN
Location: HENNEPIN, IL
Project No.: MR155233
Boring No.: HENB003 S-5
Sample Type: 3.0'' ST
Description: BLACK ORGANIC CLAY WITH SAND OL WOOD NOTED
Remarks: TEST PERFORMED AS PER ASTM D2166. 412

Tue, 22-DEC-2015 14:24:30

UNCONFINED COMPRESSION TEST

Project: DYNERGY HENNEPIN
Boring No.: HENB003 S-5
Sample No.: ST-5
Test No.: HENB003S5

Location: HENNEPIN, IL
Tested By: BCM
Test Date: 12/14/15
Sample Type: 3.0" ST

Project No.: MR155233
Checked By: WPQ
Depth: 10.0'-12.0'
Elevation: -----

Soil Description: BLACK ORGANIC CLAY WITH SAND OL WOOD NOTED
Remarks: TEST PERFORMED AS PER ASTM D2166.

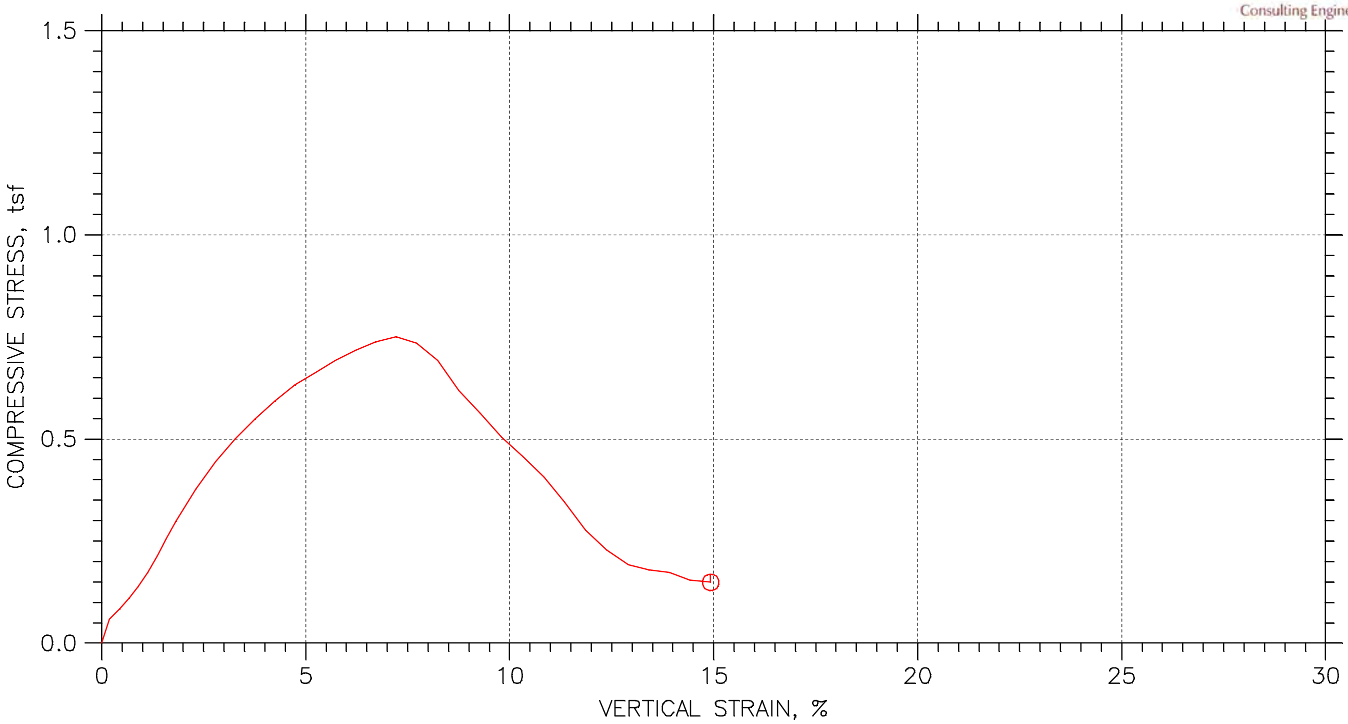
Specimen Height: 6.26 in
Specimen Area: 6.33 in^2
Specimen Volume: 39.63 in^3

Liquid Limit: ---
Plastic Limit: ---
Estimated Specific Gravity: 2.65

Cap Mass: 0 gm

	Time min	Axial Displacement in	Axial Strain %	Load lb	Corrected Area in^2	Vertical Stress tsf	Shear Stress tsf
1	0	0	0	0	6.3319	0	0
2	0.25412	0.011992	0.19162	4.9302	6.3441	0.055954	0.027977
3	0.50387	0.027951	0.44662	6.3463	6.3603	0.071842	0.035921
4	0.75387	0.043725	0.69868	7.5527	6.3764	0.085281	0.042641
5	1.0039	0.059407	0.94926	8.5492	6.3926	0.09629	0.048145
6	1.2539	0.074812	1.1954	9.5457	6.4085	0.10725	0.053623
7	1.5039	0.090125	1.4401	10.437	6.4244	0.11697	0.058487
8	1.7539	0.10562	1.6877	11.539	6.4406	0.12899	0.064497
9	2.0039	0.12121	1.9368	12.483	6.457	0.13919	0.069597
10	2.5039	0.15258	2.438	14.109	6.4901	0.15652	0.07826
11	3.0039	0.1844	2.9465	15.787	6.5241	0.17423	0.087113
12	3.5039	0.21567	3.4462	17.151	6.5579	0.1883	0.094151
13	4.0039	0.24621	3.9341	18.567	6.5912	0.20282	0.10141
14	4.5039	0.27729	4.4309	19.249	6.6255	0.20918	0.10459
15	5.0039	0.30903	4.9379	19.721	6.6608	0.21317	0.10659
16	5.5039	0.34085	5.4464	19.564	6.6966	0.21034	0.10517
17	6.0039	0.37194	5.9432	18.934	6.732	0.2025	0.10125
18	6.5039	0.40284	6.437	17.256	6.7675	0.18358	0.091792
19	7.0039	0.4343	6.9396	15.735	6.8041	0.1665	0.083252
20	7.5039	0.46659	7.4555	14.896	6.842	0.15675	0.078375
21	8.0039	0.49887	7.9714	14.266	6.8804	0.14929	0.074645
22	8.5039	0.52987	8.4667	13.951	6.9176	0.14521	0.072605
23	9.0039	0.56068	8.959	13.637	6.955	0.14117	0.070586
24	9.5039	0.59223	9.4631	13.217	6.9937	0.13607	0.068035
25	10.004	0.62451	9.979	12.798	7.0338	0.131	0.0655
26	10.504	0.65661	10.492	12.483	7.0741	0.12705	0.063525
27	11.004	0.68779	10.99	12.116	7.1137	0.12263	0.061314
28	11.504	0.71879	11.485	11.906	7.1535	0.11983	0.059917
29	12.004	0.75034	11.99	11.119	7.1945	0.11128	0.055639
30	12.504	0.78244	12.502	9.231	7.2367	0.091843	0.045921
31	13.004	0.81417	13.01	8.1296	7.2788	0.080416	0.040208
32	13.504	0.84517	13.505	7.3953	7.3205	0.072736	0.036368
33	14.004	0.87635	14.003	6.7135	7.3629	0.065649	0.032825
34	14.504	0.90817	14.512	6.0841	7.4067	0.059143	0.029571
35	15.004	0.94037	15.026	5.2974	7.4516	0.051185	0.025593

UNCONFINED COMPRESSION TEST
ASTM D2166



Symbol		⦶			
Test No.		HEN004S5			
Initial	Diameter, in	2.8673			
	Height, in	6.2728			
	Water Content, %	36.84			
	Dry Density, pcf	84.04			
	Saturation, %	98.19			
	Void Ratio	1.0205			
Unconfined Compressive Strength, tsf		0.75034			
Undrained Shear Strength, tsf		0.37517			
Time to Failure, min		7.5002			
Strain Rate, %/min		1.52			
Estimated Specific Gravity		2.72			
Liquid Limit		NP			
Plastic Limit		NP			
Plasticity Index		NP			
Failure Sketch					

Project: DYNERGY HENNEPIN,
Location: HENNEPIN, IL
Project No.: MR155233
Boring No.: HEN-004 S5
Sample Type: 3" ST
Description: BROWN BLACK AND GRAY SANDY SILT WITH GRAVEL
Remarks: TEST PERFORMED AS PER ASTM D 2166. 414

UNCONFINED COMPRESSION TEST

Project: DYNERGY HENNEPIN,
Boring No.: HEN-004 S5
Sample No.: S-5
Test No.: HEN004S5

Location: HENNEPIN, IL
Tested By: BCM
Test Date: 12/16/15
Sample Type: 3" ST

Project No.: MR155233
Checked By: WPQ
Depth: 10.0'-12.0'
Elevation: -----

Terracon Consulting Engineers & Scientists

Soil Description: BROWN BLACK AND GRAY SANDY SILT WITH GRAVEL
Remarks: TEST PERFORMED AS PER ASTM D 2166.

Specimen Height: 6.27 in
Specimen Area: 6.46 in^2
Specimen Volume: 40.50 in^3

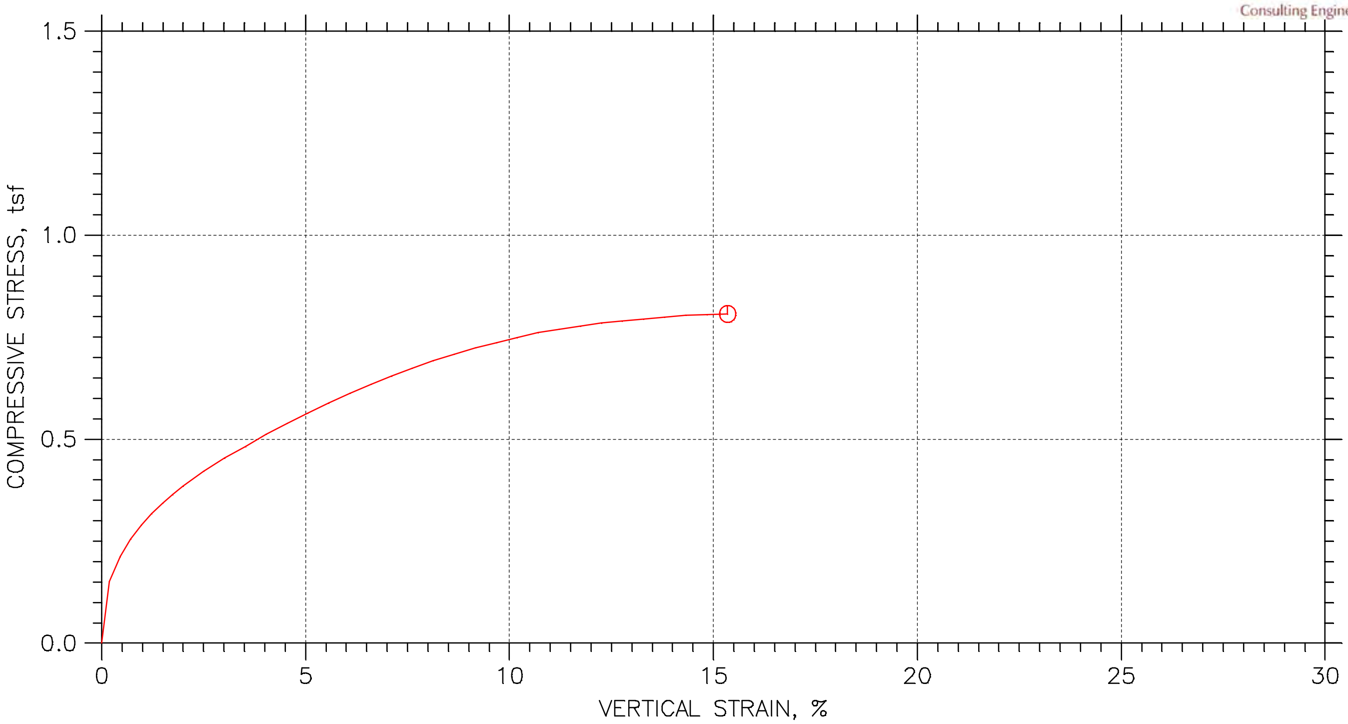
Liquid Limit: NP
Plastic Limit: NP
Estimated Specific Gravity: 2.72

Cap Mass: 0 gm

	Time min	Axial Displacement in	Axial Strain %	Load lb	Corrected Area in^2	Vertical Stress tsf	Shear Stress tsf
1	0	0	0	0	6.4572	0	0
2	0.25028	0.012177	0.19412	5.2238	6.4697	0.058134	0.029067
3	0.50028	0.027213	0.43382	7.5583	6.4853	0.083913	0.041956
4	0.75028	0.042065	0.67058	9.9187	6.5008	0.10986	0.054928
5	1.0003	0.05664	0.90294	12.595	6.516	0.13917	0.069586
6	1.2503	0.07103	1.1323	15.755	6.5311	0.17369	0.086843
7	1.5003	0.085328	1.3603	19.418	6.5462	0.21358	0.10679
8	1.7503	0.099811	1.5912	23.365	6.5616	0.25638	0.12819
9	2.0003	0.11439	1.8235	27.325	6.5771	0.29913	0.14956
10	2.5002	0.14446	2.3029	34.567	6.6094	0.37656	0.18828
11	3.0002	0.17527	2.7941	40.945	6.6428	0.4438	0.2219
12	3.5002	0.2059	3.2823	46.44	6.6763	0.50083	0.25041
13	4.0002	0.23634	3.7676	51.238	6.71	0.5498	0.2749
14	4.5002	0.26669	4.2514	55.585	6.7439	0.59344	0.29672
15	5.0002	0.29768	4.7456	59.525	6.7789	0.63223	0.31612
16	5.5002	0.32877	5.2411	62.756	6.8143	0.66308	0.33154
17	6.0002	0.35967	5.7338	65.903	6.8499	0.69271	0.34636
18	6.5002	0.39048	6.225	68.625	6.8858	0.71756	0.35878
19	7.0002	0.4212	6.7147	70.966	6.922	0.73816	0.36908
20	7.5002	0.45266	7.2161	72.527	6.9594	0.75034	0.37517
21	8.0002	0.48439	7.722	71.456	6.9975	0.73524	0.36762
22	8.5002	0.5164	8.2323	67.599	7.0364	0.69171	0.34585
23	9.0002	0.54878	8.7485	60.738	7.0762	0.618	0.309
24	9.5002	0.58153	9.2705	55.746	7.117	0.56396	0.28198
25	10	0.61492	9.8029	50.193	7.159	0.50481	0.25241
26	10.5	0.64785	10.328	45.66	7.2009	0.45654	0.22827
27	11	0.67986	10.838	40.855	7.2421	0.40618	0.20309
28	11.5	0.71141	11.341	34.915	7.2832	0.34517	0.17258
29	12	0.7437	11.856	28.086	7.3257	0.27604	0.13802
30	12.5	0.77681	12.384	23.378	7.3698	0.22839	0.1142
31	13	0.81021	12.916	19.773	7.4149	0.192	0.095999
32	13.5	0.84139	13.413	18.548	7.4575	0.17907	0.089536
33	14	0.87256	13.91	17.974	7.5005	0.17253	0.086267
34	14.5	0.9043	14.416	16.213	7.5449	0.15472	0.07736
35	15	0.93612	14.923	15.704	7.5898	0.14897	0.074485

UNCONFINED COMPRESSION TEST
ASTM D2166

Terracon Consulting Engineers & Scientists



Symbol		⏀			
Test No.		HEN004S9			
Initial	Diameter, in	2.7551			
	Height, in	6.0059			
	Water Content, %	33.62			
	Dry Density, pcf	85.2			
	Saturation, %	92.10			
	Void Ratio	0.99292			
Unconfined Compressive Strength, tsf		0.80682			
Undrained Shear Strength, tsf		0.40341			
Time to Failure, min		15.004			
Strain Rate, %/min		1.14			
Estimated Specific Gravity		2.72			
Liquid Limit		43			
Plastic Limit		22			
Plasticity Index		21			
Failure Sketch					

Project: DYNERGY HENNEPIN
Location: HENNEPIN, IL
Project No.: MR155233
Boring No.: HEN004 S-9
Sample Type: 3.0'' ST
Description: BROWN AND GRAY LEAN CLAY CL
Remarks: TEST PERFORMED AS PER ASTM D2166. 416

Tue, 22-DEC-2015 14:31:30

UNCONFINED COMPRESSION TEST

Project: DYNERGY HENNEPIN
Boring No.: HEN004 S-9
Sample No.: ST-9
Test No.: HEN004S9

Location: HENNEPIN, IL
Tested By: BCM
Test Date: 12/15/15
Sample Type: 3.0" ST

Project No.: MR155233
Checked By: WPQ
Depth: 30.0'-32.0'
Elevation: ----

Soil Description: BROWN AND GRAY LEAN CLAY CL
Remarks: TEST PERFORMED AS PER ASTM D2166.

Specimen Height: 6.01 in
Specimen Area: 5.96 in^2
Specimen Volume: 35.81 in^3

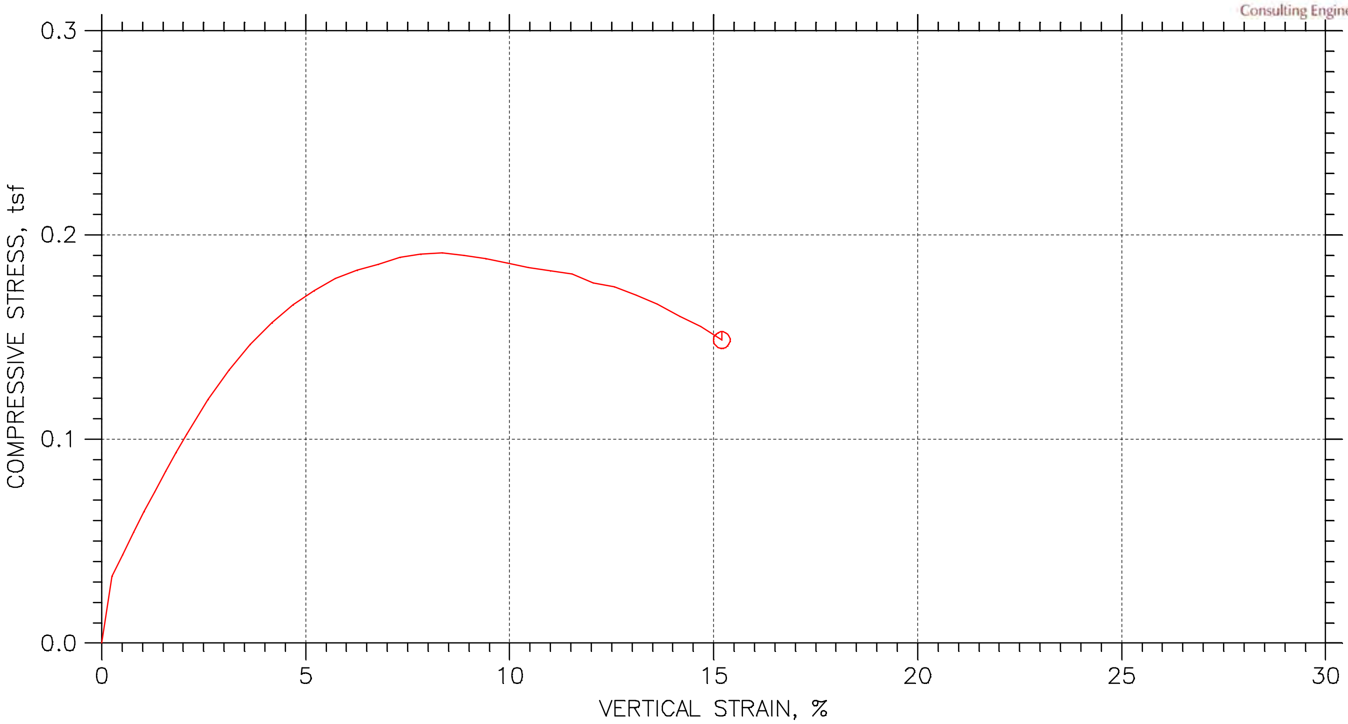
Liquid Limit: 43
Plastic Limit: 22
Estimated Specific Gravity: 2.72

Cap Mass: 0 gm

	Time min	Axial Displacement in	Axial Strain %	Load lb	Corrected Area in^2	Vertical Stress tsf	Shear Stress tsf
1	0	0	0	0	5.9617	0	0
2	0.25398	0.01157	0.19265	12.53	5.9732	0.15103	0.075517
3	0.50398	0.027058	0.45052	17.637	5.9887	0.21204	0.10602
4	0.75398	0.04291	0.71446	21.269	6.0046	0.25504	0.12752
5	1.004	0.058397	0.97233	24.165	6.0202	0.289	0.1445
6	1.254	0.073885	1.2302	26.639	6.036	0.31777	0.15888
7	1.504	0.089281	1.4866	28.798	6.0517	0.34262	0.17131
8	1.754	0.10477	1.7444	30.746	6.0675	0.36484	0.18242
9	2.004	0.11989	1.9962	32.483	6.0831	0.38447	0.19224
10	2.504	0.15005	2.4983	35.695	6.1145	0.42032	0.21016
11	3.004	0.18093	3.0126	38.696	6.1469	0.45325	0.22663
12	3.504	0.21163	3.5238	41.433	6.1795	0.48276	0.24138
13	4.004	0.24252	4.038	44.118	6.2126	0.5113	0.25565
14	4.504	0.27322	4.5492	46.698	6.2458	0.53832	0.26916
15	5.004	0.30374	5.0573	49.172	6.2793	0.56382	0.28191
16	5.504	0.33453	5.57	51.647	6.3134	0.589	0.2945
17	6.004	0.36542	6.0843	53.963	6.3479	0.61207	0.30603
18	6.504	0.3963	6.5985	56.174	6.3829	0.63366	0.31683
19	7.004	0.42691	7.1082	58.333	6.4179	0.65441	0.32721
20	7.504	0.45734	7.6148	60.386	6.4531	0.67375	0.33688
21	8.004	0.48831	8.1306	62.334	6.4893	0.69161	0.3458
22	8.504	0.51938	8.6478	64.124	6.5261	0.70746	0.35373
23	9.004	0.55045	9.1651	65.914	6.5632	0.72309	0.36155
24	9.504	0.58088	9.6717	67.546	6.6	0.73686	0.36843
25	10.004	0.6114	10.18	69.02	6.6374	0.74871	0.37435
26	10.504	0.64246	10.697	70.547	6.6758	0.76086	0.38043
27	11.004	0.67362	11.216	71.758	6.7148	0.76943	0.38471
28	11.504	0.70478	11.735	72.969	6.7543	0.77784	0.38892
29	12.004	0.73557	12.247	74.022	6.7938	0.78448	0.39224
30	12.504	0.76636	12.76	74.917	6.8337	0.78932	0.39466
31	13.004	0.79761	13.28	75.917	6.8747	0.79509	0.39755
32	13.504	0.82886	13.801	76.707	6.9162	0.79854	0.39927
33	14.004	0.86002	14.32	77.602	6.9581	0.803	0.4015
34	14.504	0.8909	14.834	78.339	7.0001	0.80576	0.40288
35	15.004	0.92178	15.348	78.918	7.0426	0.80682	0.40341

UNCONFINED COMPRESSION TEST
ASTM D2166

Terracon
Consulting Engineers & Scientists



Symbol		⏀			
Test No.		HENB005S2			
Initial	Diameter, in	2.8366			
	Height, in	6.0217			
	Water Content, %	59.63			
	Dry Density, pcf	60.38			
	Saturation, %	91.85			
	Void Ratio	1.688			
Unconfined Compressive Strength, tsf		0.19114			
Undrained Shear Strength, tsf		0.095571			
Time to Failure, min		8.0034			
Strain Rate, %/min		1			
Estimated Specific Gravity		2.60			
Liquid Limit		---			
Plastic Limit		---			
Plasticity Index		---			
Failure Sketch					

Project: DYNERGY HENNEPIN
Location: HENNEPIN, IL
Project No.: MR155233
Boring No.: HENB005 S-2
Sample Type: 3.0'' ST
Description: BLACK TO VERY DARK GRAY ORGANIC CLAY OL
Remarks: TEST PERFORMED AS PER ASTM D2166.

Tue, 22-DEC-2015 14:34:51

UNCONFINED COMPRESSION TEST

Project: DYNERGY HENNEPIN
Boring No.: HENB005 S-2
Sample No.: ST-2
Test No.: HENB005S2

Location: HENNEPIN, IL
Tested By: BCM
Test Date: 12/14/15
Sample Type: 3.0" ST

Project No.: MR155233
Checked By: WPQ
Depth: 7.5'-9.5'
Elevation: -----

Terracon Consulting Engineers & Scientists

Soil Description: BLACK TO VERY DARK GRAY ORGANIC CLAY OL
Remarks: TEST PERFORMED AS PER ASTM D2166.

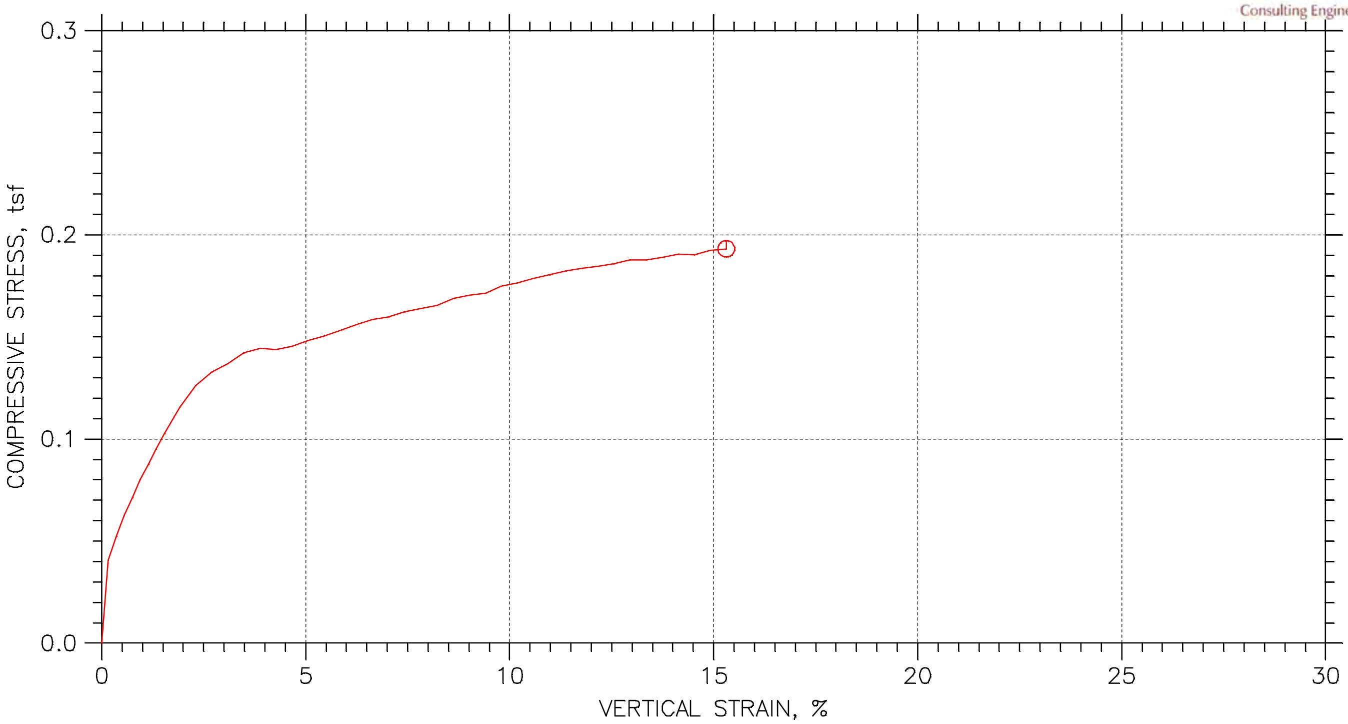
Specimen Height: 6.02 in
Specimen Area: 6.32 in^2
Specimen Volume: 38.05 in^3

Liquid Limit: ---
Plastic Limit: ---
Estimated Specific Gravity: 2.60

Cap Mass: 0 gm

	Time min	Axial Displacement in	Axial Strain %	Load lb	Corrected Area in^2	Vertical Stress tsf	Shear Stress tsf
1	0	0	0	0	6.3196	0	0
2	0.25025	0.015497	0.25736	2.8847	6.3359	0.032781	0.016391
3	0.50417	0.031272	0.51932	3.8288	6.3526	0.043395	0.021698
4	0.75417	0.046861	0.77822	4.8253	6.3692	0.054548	0.027274
5	1	0.062267	1.034	5.717	6.3856	0.06446	0.03223
6	1.2539	0.078318	1.3006	6.6086	6.4029	0.074313	0.037157
7	1.5037	0.094092	1.5626	7.5002	6.4199	0.084116	0.042058
8	1.7534	0.10977	1.823	8.3394	6.437	0.09328	0.04664
9	2.0034	0.12555	2.0849	9.1786	6.4542	0.10239	0.051196
10	2.5034	0.15673	2.6027	10.752	6.4885	0.11931	0.059656
11	3.0034	0.18791	3.1205	12.116	6.5232	0.13373	0.066864
12	3.5034	0.21946	3.6444	13.322	6.5586	0.14625	0.073124
13	4.0034	0.25119	4.1714	14.371	6.5947	0.1569	0.078451
14	4.5034	0.28264	4.6938	15.263	6.6309	0.16573	0.082864
15	5.0034	0.31373	5.2101	15.997	6.667	0.17276	0.08638
16	5.5034	0.3451	5.7309	16.626	6.7038	0.17857	0.089285
17	6.0034	0.37674	6.2564	17.098	6.7414	0.18262	0.091308
18	6.5034	0.40847	6.7833	17.466	6.7795	0.18549	0.092744
19	7.0034	0.43983	7.3042	17.885	6.8176	0.18888	0.094442
20	7.5034	0.47092	7.8205	18.147	6.8558	0.19059	0.095293
21	8.0034	0.50256	8.3459	18.305	6.8951	0.19114	0.095571
22	8.5034	0.53494	8.8836	18.305	6.9358	0.19002	0.095011
23	9.0034	0.56713	9.4183	18.252	6.9767	0.18836	0.094182
24	9.5034	0.59878	9.9437	18.147	7.0174	0.1862	0.093098
25	10.003	0.63023	10.466	18.042	7.0583	0.18405	0.092023
26	10.503	0.66187	10.992	17.99	7.1	0.18243	0.091217
27	11.003	0.69416	11.528	17.938	7.143	0.18081	0.090403
28	11.503	0.7258	12.053	17.623	7.1857	0.17658	0.08829
29	12.003	0.75707	12.572	17.518	7.2284	0.17449	0.087246
30	12.503	0.78853	13.095	17.203	7.2719	0.17033	0.085167
31	13.003	0.82035	13.623	16.889	7.3163	0.1662	0.0831
32	13.503	0.85255	14.158	16.364	7.3619	0.16004	0.080021
33	14.003	0.8841	14.682	15.945	7.4071	0.15499	0.077493
34	14.503	0.91518	15.198	15.368	7.4522	0.14847	0.074237

UNCONFINED COMPRESSION TEST
ASTM D2166



Symbol		⦶			
Test No.		HENB012S7			
Initial	Diameter, in	2.8343			
	Height, in	6.0142			
	Water Content, %	38.30			
	Dry Density, pcf	73.56			
	Saturation, %	79.62			
	Void Ratio	1.3083			
Unconfined Compressive Strength, tsf		0.19314			
Undrained Shear Strength, tsf		0.09657			
Time to Failure, min		19.5			
Strain Rate, %/min		1			
Estimated Specific Gravity		2.72			
Liquid Limit		---			
Plastic Limit		---			
Plasticity Index		---			
Failure Sketch					

Project: DYNERGY HENNEPIN
Location: HENNEPIN, IL
Project No.: MR155233
Boring No.: HENB012 S-7
Sample Type: 3.0'' ST
Description: VERY DARK GRAY LEAN CLAY CL ORGANICS NOTED
Remarks: TEST PERFORMED AS PER ASTM D2166. 420

UNCONFINED COMPRESSION TEST

Project: DYNERGY HENNEPIN
Boring No.: HENB012 S-7
Sample No.: S-7
Test No.: HENB012S7

Location: HENNEPIN, IL
Tested By: BCM
Test Date: 12/14/15
Sample Type: 3.0" ST

Project No.: MR155233
Checked By: WPQ
Depth: 20.0'-22.0'
Elevation: -----

Soil Description: VERY DARK GRAY LEAN CLAY CL ORGANICS NOTED
Remarks: TEST PERFORMED AS PER ASTM D2166.

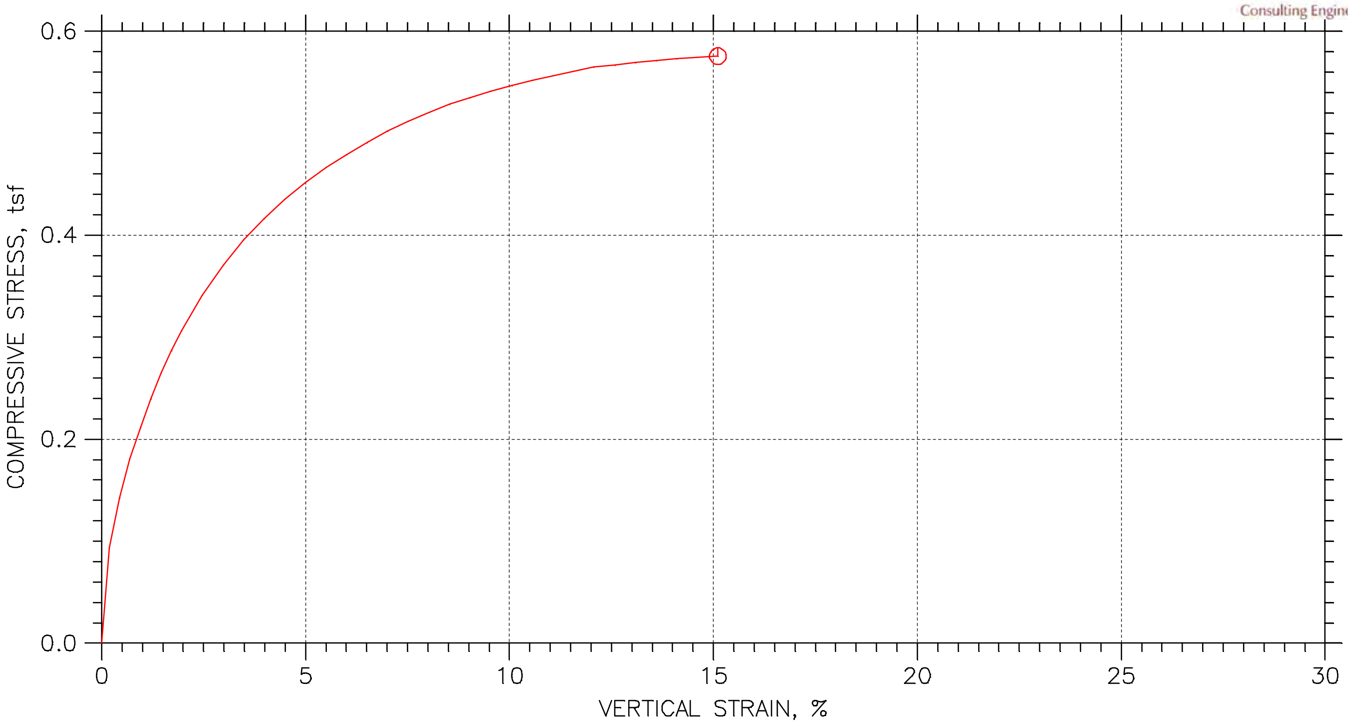
Specimen Height: 6.01 in
Specimen Area: 6.31 in^2
Specimen Volume: 37.94 in^3

Liquid Limit: ---
Plastic Limit: ---
Estimated Specific Gravity: 2.72

Cap Mass: 0 gm

	Time min	Axial Displacement in	Axial Strain %	Load lb	Corrected Area in^2	Vertical Stress tsf	Shear Stress tsf
1	0	0	0	0	6.3091	0	0
2	0.25005	0.0095937	0.15952	3.5665	6.3192	0.040637	0.020318
3	0.50007	0.021309	0.35431	4.6155	6.3315	0.052486	0.026243
4	0.75007	0.033117	0.55064	5.5072	6.344	0.062502	0.031251
5	1.0001	0.045017	0.74851	6.2939	6.3567	0.071289	0.035644
6	1.2501	0.056824	0.94484	7.0806	6.3693	0.080041	0.040021
7	1.5001	0.068724	1.1427	7.7625	6.382	0.087574	0.043787
8	1.7501	0.080532	1.339	8.4443	6.3947	0.095077	0.047538
9	2.0001	0.092247	1.5338	9.1261	6.4074	0.10255	0.051276
10	2.5001	0.1154	1.9188	10.332	6.4325	0.11565	0.057826
11	3.0001	0.13865	2.3053	11.329	6.458	0.12631	0.063154
12	3.5001	0.16208	2.6949	11.958	6.4838	0.13279	0.066396
13	4.0001	0.18579	3.0891	12.378	6.5102	0.1369	0.068448
14	4.5001	0.20977	3.4879	12.902	6.5371	0.14211	0.071054
15	5.0001	0.23366	3.8852	13.165	6.5641	0.1444	0.0722
16	5.5001	0.257	4.2732	13.165	6.5907	0.14382	0.071909
17	6.0001	0.28025	4.6598	13.375	6.6174	0.14552	0.07276
18	6.5001	0.30377	5.0509	13.689	6.6447	0.14833	0.074166
19	7.0001	0.32748	5.4451	13.951	6.6724	0.15055	0.075273
20	7.5001	0.35165	5.8469	14.266	6.7009	0.15329	0.076644
21	8.0001	0.37591	6.2503	14.581	6.7297	0.156	0.077999
22	8.5001	0.39952	6.643	14.896	6.758	0.1587	0.079349
23	9.0001	0.42277	7.0295	15.053	6.7861	0.15971	0.079855
24	9.5001	0.44611	7.4176	15.368	6.8146	0.16237	0.081184
25	10	0.46991	7.8133	15.577	6.8438	0.16388	0.08194
26	10.5	0.49417	8.2167	15.787	6.8739	0.16536	0.082681
27	11	0.51861	8.6232	16.207	6.9045	0.169	0.084502
28	11.5	0.54278	9.025	16.417	6.935	0.17044	0.08522
29	12	0.56594	9.41	16.574	6.9644	0.17134	0.085672
30	12.5	0.589	9.7935	16.994	6.9941	0.17494	0.08747
31	13	0.61252	10.185	17.203	7.0245	0.17633	0.088165
32	13.5	0.63632	10.58	17.518	7.0556	0.17877	0.089383
33	14	0.66058	10.984	17.78	7.0876	0.18062	0.090311
34	14.5	0.68466	11.384	18.042	7.1196	0.18246	0.091231
35	15	0.70827	11.777	18.252	7.1513	0.18377	0.091883
36	15.5	0.73133	12.16	18.41	7.1825	0.18455	0.092273
37	16	0.75467	12.548	18.619	7.2144	0.18582	0.092912
38	16.5	0.77847	12.944	18.882	7.2472	0.18759	0.093794
39	17	0.80264	13.346	18.987	7.2808	0.18776	0.09388
40	17.5	0.82681	13.748	19.196	7.3147	0.18895	0.094477
41	18	0.85043	14.14	19.459	7.3481	0.19066	0.095332
42	18.5	0.87367	14.527	19.511	7.3814	0.19032	0.095158
43	19	0.89701	14.915	19.826	7.415	0.19251	0.096254
44	19.5	0.92063	15.308	19.983	7.4494	0.19314	0.09657

UNCONFINED COMPRESSION TEST
ASTM D2166



Symbol		⦶			
Test No.		HEN014S8			
Initial	Diameter, in	2.8339			
	Height, in	6.0764			
	Water Content, %	32.54			
	Dry Density, pcf	89.48			
	Saturation, %	98.61			
	Void Ratio	0.89757			
Unconfined Compressive Strength, tsf		0.57547			
Undrained Shear Strength, tsf		0.28774			
Time to Failure, min		15			
Strain Rate, %/min		1.14			
Estimated Specific Gravity		2.72			
Liquid Limit		43			
Plastic Limit		20			
Plasticity Index		23			
Failure Sketch					

Project: DYNERGY HENNEPIN
Location: HENNEPIN, IL
Project No.: MR155233
Boring No.: HEN014 S-8
Sample Type: 3.0" ST
Description: BROWN AND GRAY LEAN CLAY CL
Remarks: TEST PERFORMED AS PER ASTM D2166.

Tue, 22-DEC-2015 14:47:46

UNCONFINED COMPRESSION TEST

Project: DYNERGY HENNEPIN
Boring No.: HEN014 S-8
Sample No.: ST-8
Test No.: HEN014S8

Location: HENNEPIN, IL
Tested By: BCM
Test Date: 12/15/15
Sample Type: 3.0" ST

Project No.: MR155233
Checked By: WPQ
Depth: 25.0'-27.0'
Elevation: ----

Soil Description: BROWN AND GRAY LEAN CLAY CL
Remarks: TEST PERFORMED AS PER ASTM D2166.

Specimen Height: 6.08 in
Specimen Area: 6.31 in^2
Specimen Volume: 38.33 in^3

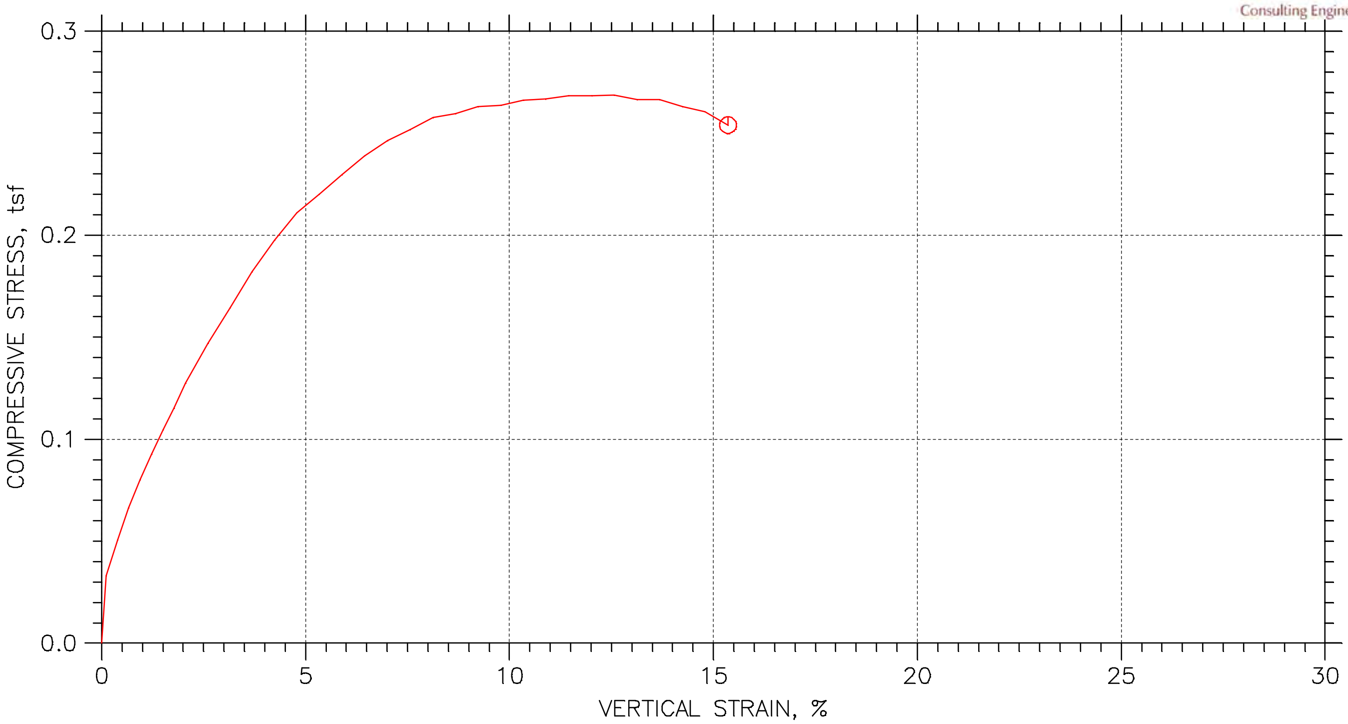
Liquid Limit: 43
Plastic Limit: 20
Estimated Specific Gravity: 2.72

Cap Mass: 0 gm

	Time min	Axial Displacement in	Axial Strain %	Load lb	Corrected Area in^2	Vertical Stress tsf	Shear Stress tsf
1	0	0	0	0	6.3073	0	0
2	0.25018	0.011388	0.18741	8.2129	6.3192	0.093577	0.046789
3	0.50018	0.026876	0.44229	12.53	6.3354	0.1424	0.0712
4	0.75018	0.042363	0.69718	15.952	6.3516	0.18083	0.090414
5	1.0002	0.057942	0.95356	18.742	6.3681	0.21191	0.10595
6	1.2502	0.073429	1.2084	21.269	6.3845	0.23986	0.11993
7	1.5002	0.088644	1.4588	23.533	6.4007	0.26472	0.13236
8	1.7502	0.10395	1.7107	25.586	6.4171	0.28708	0.14354
9	2.0002	0.11925	1.9626	27.376	6.4336	0.30638	0.15319
10	2.5002	0.15014	2.4709	30.641	6.4671	0.34113	0.17056
11	3.0002	0.18102	2.9791	33.431	6.501	0.37025	0.18513
12	3.5002	0.21209	3.4904	35.905	6.5355	0.39556	0.19778
13	4.0002	0.24243	3.9897	37.958	6.5694	0.41602	0.20801
14	4.5002	0.27285	4.4904	39.906	6.6039	0.43509	0.21754
15	5.0002	0.30347	4.9942	41.644	6.6389	0.45163	0.22582
16	5.5002	0.33417	5.4995	43.223	6.6744	0.46627	0.23314
17	6.0002	0.36487	6.0047	44.645	6.7103	0.47903	0.23951
18	6.5002	0.39566	6.5115	46.013	6.7466	0.49105	0.24553
19	7.0002	0.42627	7.0152	47.33	6.7832	0.50238	0.25119
20	7.5002	0.45707	7.522	48.435	6.8204	0.51131	0.25566
21	8.0002	0.48786	8.0288	49.541	6.8579	0.52012	0.26006
22	8.5002	0.51865	8.5355	50.594	6.8959	0.52825	0.26412
23	9.0002	0.54935	9.0408	51.489	6.9343	0.53462	0.26731
24	9.5002	0.57969	9.5401	52.384	6.9725	0.54093	0.27046
25	10	0.61058	10.048	53.226	7.0119	0.54654	0.27327
26	10.5	0.64128	10.554	54.068	7.0515	0.55207	0.27603
27	11	0.67189	11.057	54.806	7.0915	0.55644	0.27822
28	11.5	0.7025	11.561	55.543	7.1319	0.56073	0.28037
29	12	0.73311	12.065	56.28	7.1727	0.56494	0.28247
30	12.5	0.76408	12.575	56.806	7.2145	0.56692	0.28346
31	13	0.79506	13.084	57.385	7.2569	0.56936	0.28468
32	13.5	0.82603	13.594	57.912	7.2997	0.57121	0.2856
33	14	0.85665	14.098	58.438	7.3425	0.57304	0.28652
34	14.5	0.88717	14.6	58.912	7.3857	0.57431	0.28716
35	15	0.91814	15.11	59.386	7.43	0.57547	0.28774

UNCONFINED COMPRESSION TEST
ASTM D2166

Terracon
Consulting Engineers & Scientists



Symbol		⦶			
Test No.		HENB015S4			
Initial	Diameter, in	2.7992			
	Height, in	5.6701			
	Water Content, %	131.90			
	Dry Density, pcf	50.83			
	Saturation, %	155.02			
	Void Ratio	2.2547			
Unconfined Compressive Strength, tsf		0.26878			
Undrained Shear Strength, tsf		0.13439			
Time to Failure, min		11.5			
Strain Rate, %/min		1			
Estimated Specific Gravity		2.65			
Liquid Limit		48			
Plastic Limit		25			
Plasticity Index		23			
Failure Sketch					

Project: DYNERGY HENNEPIN
Location: HENNEPIN, IL
Project No.: MR155233
Boring No.: HENB015 S-4
Sample Type: 3.0'' ST
Description: BLACK AND DARK GRAY ORGANIC CLAY WITH SAND AND GRAVEL OL
Remarks: TEST PERFORMED AS PER ASTM D2166.

Tue, 22-DEC-2015 14:50:01

UNCONFINED COMPRESSION TEST

Project: DYNERGY HENNEPIN
Boring No.: HENB015 S-4
Sample No.: ST-4
Test No.: HENB015S4

Location: HENNEPIN, IL
Tested By: BCM
Test Date: 12/14/15
Sample Type: 3.0" ST

Project No.: MR155233
Checked By: WPQ
Depth: 7.5'-9.5'
Elevation: -----

Soil Description: BLACK AND DARK GRAY ORGANIC CLAY WITH SAND AND GRAVEL OL
Remarks: TEST PERFORMED AS PER ASTM D2166.

Specimen Height: 5.67 in
Specimen Area: 6.15 in^2
Specimen Volume: 34.89 in^3

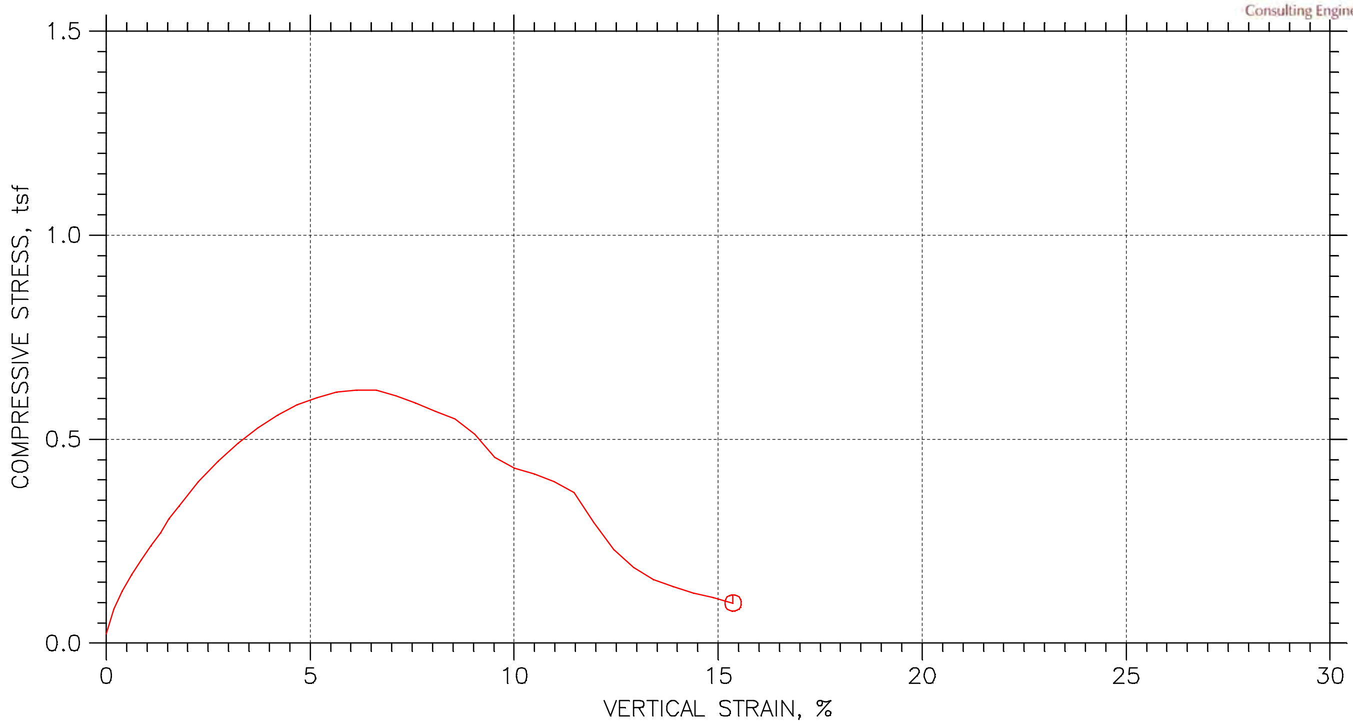
Liquid Limit: 48
Plastic Limit: 25
Estimated Specific Gravity: 2.65

Cap Mass: 0 gm

	Time min	Axial Displacement in	Axial Strain %	Load lb	Corrected Area in^2	Vertical Stress tsf	Shear Stress tsf
1	0	0	0	0	6.1541	0	0
2	0.25005	0.006365	0.11226	2.8323	6.161	0.033099	0.016549
3	0.50005	0.022047	0.38883	4.3533	6.1781	0.050734	0.025367
4	0.75005	0.037821	0.66703	5.717	6.1954	0.06644	0.03322
5	1.0001	0.053503	0.94361	6.9233	6.2127	0.080235	0.040118
6	1.2501	0.069278	1.2218	8.0247	6.2302	0.092739	0.046369
7	1.5001	0.085144	1.5016	9.0737	6.2479	0.10456	0.052282
8	1.7501	0.10073	1.7766	10.018	6.2654	0.11512	0.057561
9	2.0001	0.11623	2.0499	11.119	6.2829	0.12742	0.063712
10	2.5001	0.14741	2.5998	12.902	6.3183	0.14703	0.073515
11	3.0001	0.17841	3.1464	14.528	6.354	0.16463	0.082314
12	3.5001	0.20912	3.6882	16.154	6.3897	0.18203	0.091014
13	4.0001	0.2404	4.2397	17.623	6.4265	0.19744	0.09872
14	4.5001	0.27158	4.7896	18.934	6.4636	0.21091	0.10546
15	5.0001	0.30285	5.3411	19.878	6.5013	0.22015	0.11007
16	5.5001	0.3343	5.8959	20.875	6.5396	0.22983	0.11491
17	6.0001	0.36567	6.4491	21.819	6.5783	0.23881	0.1194
18	6.5001	0.39722	7.0055	22.658	6.6177	0.24652	0.12326
19	7.0001	0.42886	7.5635	23.287	6.6576	0.25185	0.12592
20	7.5001	0.4604	8.1199	23.969	6.6979	0.25766	0.12883
21	8.0001	0.49186	8.6747	24.284	6.7386	0.25947	0.12973
22	8.5001	0.52323	9.2278	24.756	6.7797	0.26291	0.13145
23	9.0001	0.55468	9.7826	24.966	6.8214	0.26352	0.13176
24	9.5001	0.58605	10.336	25.385	6.8634	0.2663	0.13315
25	10	0.61769	10.894	25.595	6.9064	0.26683	0.13342
26	10.5	0.64942	11.453	25.91	6.9501	0.26842	0.13421
27	11	0.68124	12.015	26.067	6.9944	0.26833	0.13417
28	11.5	0.71279	12.571	26.277	7.0389	0.26878	0.13439
29	12	0.74416	13.124	26.225	7.0837	0.26655	0.13327
30	12.5	0.7758	13.682	26.382	7.1295	0.26643	0.13321
31	13	0.80744	14.24	26.225	7.1759	0.26312	0.13156
32	13.5	0.83917	14.8	26.12	7.2231	0.26036	0.13018
33	14	0.87081	15.358	25.648	7.2707	0.25398	0.12699

UNCONFINED COMPRESSION TEST
ASTM D2166

Terracon
Consulting Engineers & Scientists



Symbol		⦶			
Test No.		HEN015S8			
Initial	Diameter, in	2.8402			
	Height, in	6.0898			
	Water Content, %	148.86			
	Dry Density, pcf	39.26			
	Saturation, %	121.79			
	Void Ratio	3.3248			
Unconfined Compressive Strength, tsf		0.62021			
Undrained Shear Strength, tsf		0.31011			
Time to Failure, min		7.0003			
Strain Rate, %/min		1			
Estimated Specific Gravity		2.72			
Liquid Limit		74			
Plastic Limit		37			
Plasticity Index		37			
Failure Sketch					

Project: DYNERGY HENNEPIN
Location: HENNEPIN, IL
Project No.: MR155233
Boring No.: HEN015 S8
Sample Type: 3.0'' ST
Description: BLACK ORGANIC SILT WITH SAND OH
Remarks: TEST PERFORMED AS PER ASTM D2166.

Tue, 22-DEC-2015 14:52:19

UNCONFINED COMPRESSION TEST

Project: DYNERGY HENNEPIN
Boring No.: HEN015 S8
Sample No.: S-8
Test No.: HEN015S8

Location: HENNEPIN, IL
Tested By: BCM
Test Date: 12/15/15
Sample Type: 3.0" ST

Project No.: MR155233
Checked By: WPQ
Depth: 25.0'-27.0'
Elevation: ----

Soil Description: BLACK ORGANIC SILT WITH SAND OH
Remarks: TEST PERFORMED AS PER ASTM D2166.

Specimen Height: 6.09 in
Specimen Area: 6.34 in^2
Specimen Volume: 38.58 in^3

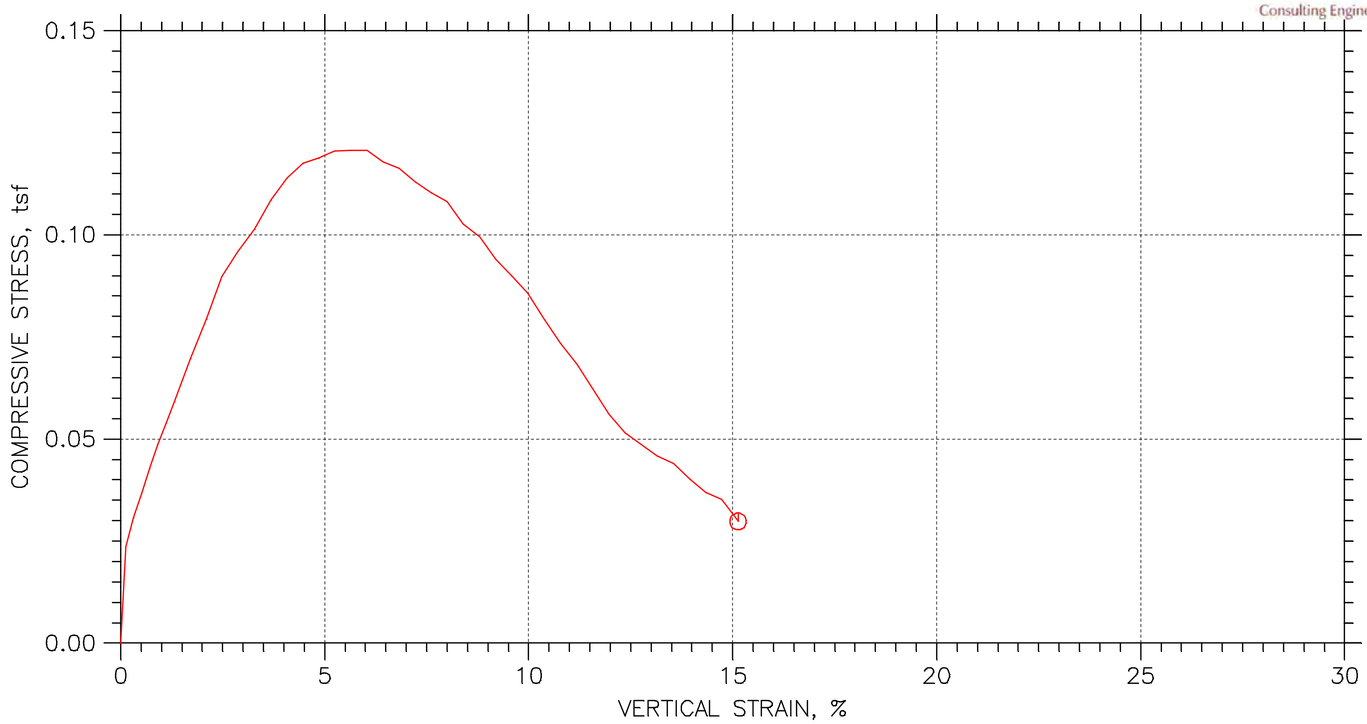
Liquid Limit: 74
Plastic Limit: 37
Estimated Specific Gravity: 2.72

Cap Mass: 0 gm

	Time min	Axial Displacement in	Axial Strain %	Load lb	Corrected Area in^2	Vertical Stress tsf	Shear Stress tsf
1	0	0	0	1.9586	6.3354	0.022259	0.01113
2	0.25022	0.011144	0.18299	7.358	6.347	0.083469	0.041734
3	0.50022	0.024023	0.39448	11.328	6.3605	0.12823	0.064117
4	0.75023	0.037907	0.62247	14.928	6.3751	0.16859	0.084297
5	1.0002	0.052156	0.85646	18.21	6.3901	0.20518	0.10259
6	1.2502	0.06668	1.0949	21.227	6.4055	0.2386	0.1193
7	1.5002	0.081021	1.3304	24.139	6.4208	0.27068	0.13534
8	1.7502	0.093991	1.5434	27.262	6.4347	0.30504	0.15252
9	2.0002	0.1087	1.7849	30.173	6.4505	0.33679	0.16839
10	2.5002	0.13793	2.2649	35.679	6.4822	0.39629	0.19815
11	3.0002	0.16725	2.7464	40.337	6.5143	0.44583	0.22291
12	3.5002	0.19684	3.2324	44.625	6.547	0.49075	0.24538
13	4.0002	0.22625	3.7153	48.224	6.5799	0.52769	0.26385
14	4.5002	0.25585	4.2013	51.295	6.6133	0.55846	0.27923
15	5.0002	0.28517	4.6828	53.941	6.6467	0.58432	0.29216
16	5.5002	0.31467	5.1673	55.847	6.6806	0.60189	0.30094
17	6.0002	0.34409	5.6502	57.329	6.7148	0.61472	0.30736
18	6.5003	0.37359	6.1347	58.123	6.7495	0.62003	0.31002
19	7.0003	0.403	6.6177	58.441	6.7844	0.62021	0.31011
20	7.5003	0.43241	7.1007	57.382	6.8197	0.60583	0.30291
21	8.0003	0.46183	7.5836	56.112	6.8553	0.58933	0.29467
22	8.5003	0.49115	8.0651	54.471	6.8912	0.56912	0.28456
23	9.0003	0.52065	8.5496	52.883	6.9277	0.54961	0.27481
24	9.5003	0.55025	9.0356	49.548	6.9647	0.51222	0.25611
25	10	0.57993	9.5231	44.36	7.0022	0.45613	0.22806
26	10.5	0.60953	10.009	41.925	7.0401	0.42878	0.21439
27	11	0.63885	10.491	40.707	7.0779	0.4141	0.20705
28	11.5	0.66863	10.979	39.066	7.1168	0.39523	0.19762
29	12	0.69804	11.462	36.631	7.1556	0.36859	0.18429
30	12.5	0.72763	11.948	29.538	7.1951	0.29558	0.14779
31	13	0.75741	12.437	23.08	7.2353	0.22967	0.11484
32	13.5	0.78728	12.928	18.686	7.2761	0.18491	0.092455
33	14	0.81706	13.417	15.828	7.3171	0.15574	0.077872
34	14.5	0.84656	13.901	14.134	7.3583	0.1383	0.069149
35	15	0.87634	14.39	12.705	7.4003	0.12361	0.061803
36	15.5	0.90602	14.878	11.646	7.4427	0.11266	0.05633
37	16	0.93562	15.364	10.217	7.4855	0.09827	0.049135

UNCONFINED COMPRESSION TEST
ASTM D2166

Terracon
Consulting Engineers & Scientists



Symbol		○			
Test No.		HENB017S3			
Initial	Diameter, in	2.8169			
	Height, in	5.9768			
	Water Content, %	36.89			
	Dry Density, pcf	81.7			
	Saturation, %	93.06			
	Void Ratio	1.0783			
Unconfined Compressive Strength, tsf		0.1207			
Undrained Shear Strength, tsf		0.060351			
Time to Failure, min		8.004			
Strain Rate, %/min		1			
Estimated Specific Gravity		2.72			
Liquid Limit		39			
Plastic Limit		21			
Plasticity Index		18			
Failure Sketch					

Project: DYNERGY HENNEPIN
Location: HENNEPIN, IL
Project No.: MR155233
Boring No.: HENB017 S-3
Sample Type: 3.0'' ST
Description: VERY DARK GRAY LEAN CLAY WITH SAND
Remarks: TEST PERFORMED AS PER ASTM D2166. 428

UNCONFINED COMPRESSION TEST

Project: DYNERGY HENNEPIN
Boring No.: HENB017 S-3
Sample No.: ST-3
Test No.: HENB017S3

Location: HENNEPIN, IL
Tested By: BCM
Test Date: 12/14/15
Sample Type: 3.0" ST

Project No.: MR155233
Checked By: WPQ
Depth: 5.0'-7.0'
Elevation: -----

Soil Description: VERY DARK GRAY LEAN CLAY WITH SAND
Remarks: TEST PERFORMED AS PER ASTM D2166.

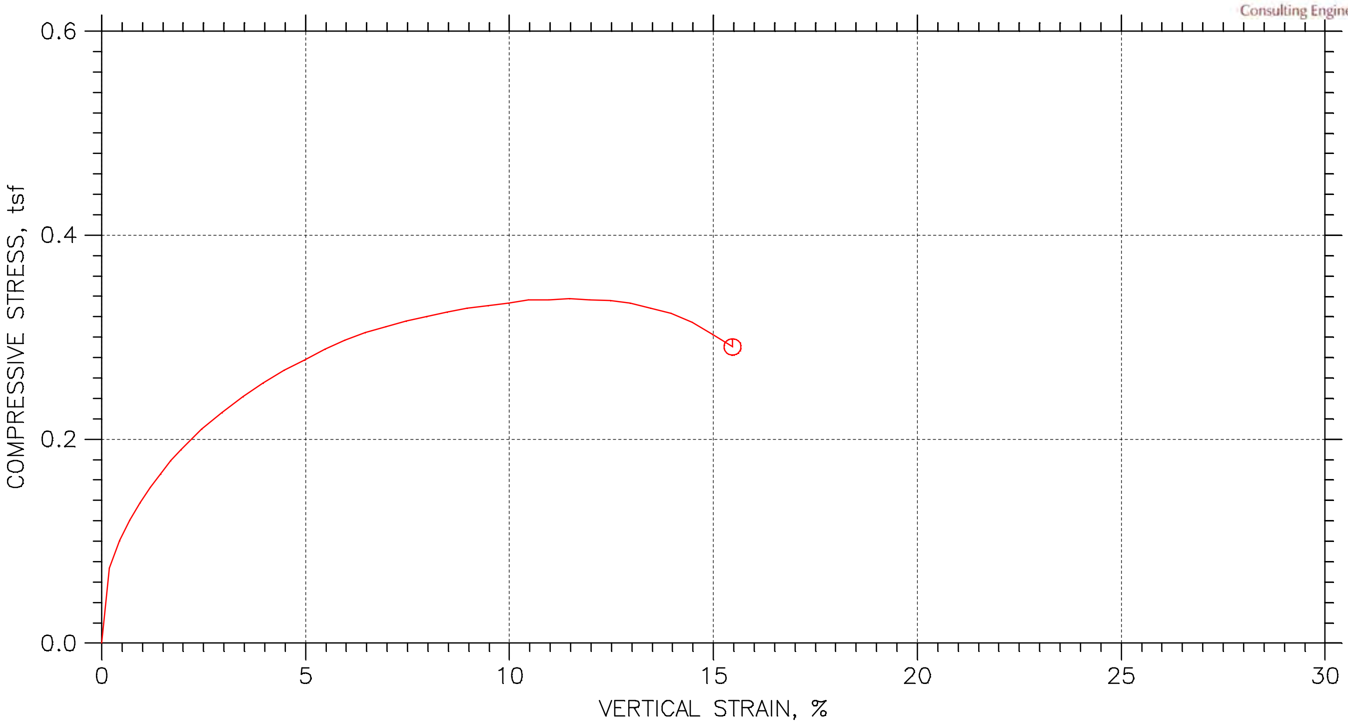
Specimen Height: 5.98 in
Specimen Area: 6.23 in^2
Specimen Volume: 37.25 in^3

Liquid Limit: 39
Plastic Limit: 21
Estimated Specific Gravity: 2.72

Cap Mass: 0 gm

	Time min	Axial Displacement in	Axial Strain %	Load lb	Corrected Area in^2	Vertical Stress tsf	Shear Stress tsf
1	0	0	0	0	6.2322	0	0
2	0.50395	0.0072875	0.12193	2.0455	6.2398	0.023603	0.011801
3	0.75395	0.019095	0.31949	2.6749	6.2522	0.030804	0.015402
4	1.004	0.030903	0.51705	3.1994	6.2646	0.036771	0.018386
5	1.254	0.04271	0.71461	3.7239	6.2771	0.042714	0.021357
6	1.504	0.054702	0.91525	4.2484	6.2898	0.048632	0.024316
7	1.754	0.066695	1.1159	4.7204	6.3025	0.053926	0.026963
8	2.004	0.078687	1.3165	5.1925	6.3153	0.059198	0.029599
9	2.504	0.10221	1.7101	6.1365	6.3406	0.069682	0.034841
10	3.004	0.12546	2.0991	7.0282	6.3658	0.079491	0.039746
11	3.504	0.14861	2.4865	7.9723	6.3911	0.089813	0.044906
12	4.004	0.17204	2.8785	8.5492	6.4169	0.095925	0.047963
13	4.504	0.19584	3.2767	9.0737	6.4433	0.10139	0.050696
14	5.004	0.22001	3.6811	9.7555	6.4704	0.10856	0.054278
15	5.504	0.24399	4.0824	10.28	6.4975	0.11392	0.056958
16	6.004	0.26724	4.4713	10.647	6.5239	0.11751	0.058753
17	6.504	0.29021	4.8556	10.805	6.5503	0.11876	0.059381
18	7.004	0.31336	5.243	11.014	6.577	0.12058	0.060288
19	7.504	0.33689	5.6366	11.067	6.6045	0.12065	0.060323
20	8.004	0.36087	6.0379	11.119	6.6327	0.1207	0.060351
21	8.504	0.38476	6.4376	10.909	6.661	0.11792	0.058961
22	9.004	0.40819	6.8297	10.805	6.689	0.1163	0.058149
23	9.504	0.43135	7.2171	10.542	6.717	0.113	0.056502
24	10.004	0.45459	7.606	10.332	6.7452	0.11029	0.055145
25	10.504	0.47802	7.998	10.175	6.774	0.10815	0.054075
26	11.004	0.50192	8.3978	9.7031	6.8036	0.10268	0.051342
27	11.504	0.5259	8.7991	9.4408	6.8335	0.099472	0.049736
28	12.004	0.54979	9.1988	8.9688	6.8636	0.094084	0.047042
29	12.504	0.57341	9.5939	8.6017	6.8936	0.08984	0.04492
30	13.004	0.59675	9.9844	8.2345	6.9235	0.085634	0.042817
31	13.504	0.62036	10.38	7.6576	6.954	0.079285	0.039642
32	14.004	0.64416	10.778	7.1331	6.985	0.073526	0.036763
33	14.504	0.66805	11.177	6.661	7.0165	0.068353	0.034176
34	15.004	0.69194	11.577	6.0841	7.0482	0.062151	0.031076
35	15.504	0.71547	11.971	5.5072	7.0797	0.056007	0.028004
36	16.004	0.73871	12.36	5.0876	7.1111	0.051511	0.025756
37	16.504	0.76224	12.753	4.8253	7.1432	0.048637	0.024318
38	17.004	0.78594	13.15	4.5631	7.1758	0.045784	0.022892
39	17.504	0.80984	13.55	4.4057	7.209	0.044002	0.022001
40	18.004	0.83373	13.949	4.0386	7.2425	0.040149	0.020074
41	18.504	0.85734	14.345	3.7239	7.2759	0.03685	0.018425
42	19.004	0.88077	14.737	3.5665	7.3094	0.035132	0.017566
43	19.504	0.90448	15.133	3.042	7.3435	0.029826	0.014913

UNCONFINED COMPRESSION TEST
ASTM D2166



Symbol		○			
Test No.		HEN017S6			
Initial	Diameter, in	2.7764			
	Height, in	6.1713			
	Water Content, %	34.15			
	Dry Density, pcf	88.			
	Saturation, %	99.92			
	Void Ratio	0.9296			
Unconfined Compressive Strength, tsf		0.33759			
Undrained Shear Strength, tsf		0.16879			
Time to Failure, min		11.504			
Strain Rate, %/min		1.14			
Estimated Specific Gravity		2.72			
Liquid Limit		45			
Plastic Limit		24			
Plasticity Index		21			
Failure Sketch					

Project: DYNERGY HENNEPIN
Location: HENNEPIN, IL
Project No.: MR155233
Boring No.: HEN017 S-6
Sample Type: 3.0'' ST
Description: BROWN AND GRAY LEAN CLAY CL
Remarks: TEST PERFORMED AS PER ASTM D2166. 430

Tue, 22-DEC-2015 14:58:59

UNCONFINED COMPRESSION TEST

Project: DYNERGY HENNEPIN
Boring No.: HEN017 S-6
Sample No.: ST-6
Test No.: HEN017S6

Location: HENNEPIN, IL
Tested By: BCM
Test Date: 12/15/15
Sample Type: 3.0" ST

Project No.: MR155233
Checked By: WPQ
Depth: 15.0'-17.0'
Elevation: ----

Soil Description: BROWN AND GRAY LEAN CLAY CL
Remarks: TEST PERFORMED AS PER ASTM D2166.

Specimen Height: 6.17 in
Specimen Area: 6.05 in^2
Specimen Volume: 37.36 in^3

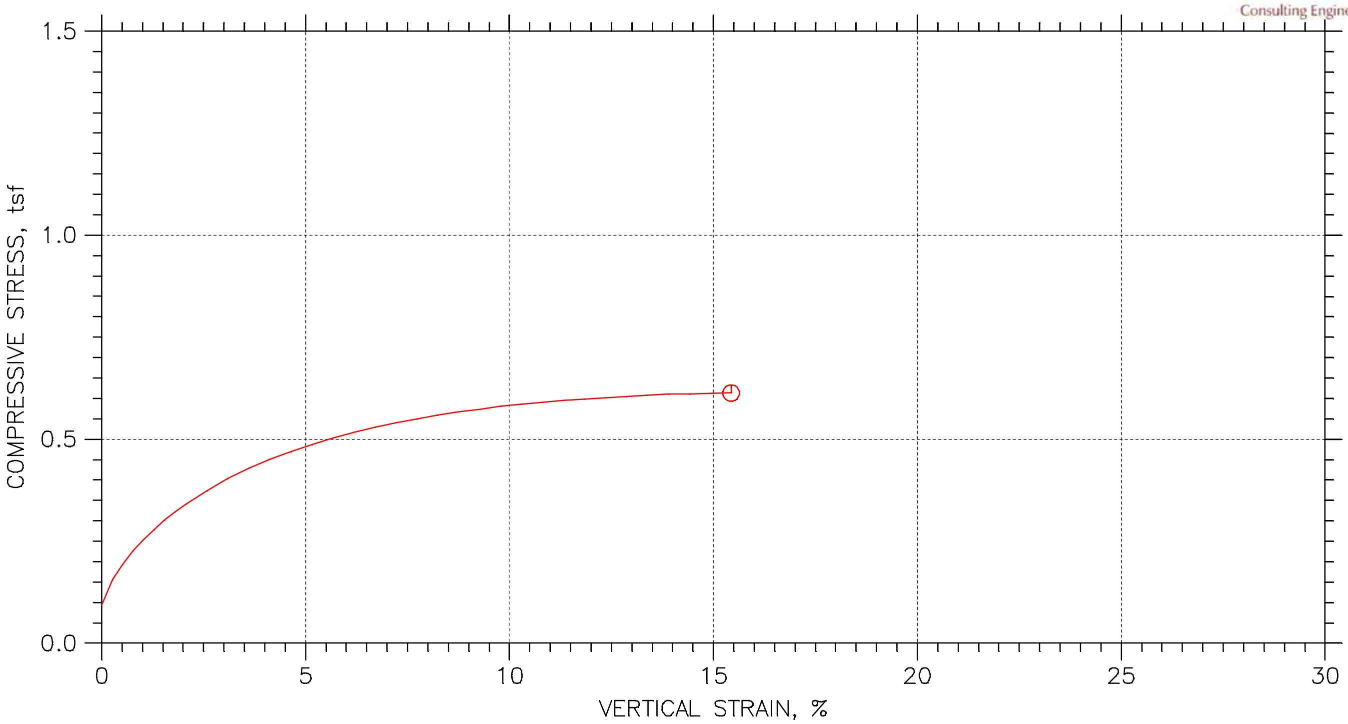
Liquid Limit: 45
Plastic Limit: 24
Estimated Specific Gravity: 2.72

Cap Mass: 0 gm

	Time min	Axial Displacement in	Axial Strain %	Load lb	Corrected Area in^2	Vertical Stress tsf	Shear Stress tsf
1	0	0	0	0	6.0541	0	0
2	0.25403	0.011661	0.18896	6.2123	6.0655	0.073743	0.036871
3	0.50403	0.02724	0.4414	8.4762	6.0809	0.10036	0.05018
4	0.75403	0.042636	0.69089	10.214	6.0962	0.12063	0.060314
5	1.004	0.057942	0.9389	11.688	6.1114	0.13769	0.068847
6	1.254	0.073429	1.1899	13.004	6.127	0.15281	0.076406
7	1.504	0.088735	1.4379	14.162	6.1424	0.16601	0.083003
8	1.754	0.10431	1.6903	15.32	6.1582	0.17912	0.089561
9	2.004	0.11998	1.9442	16.268	6.1741	0.18971	0.094855
10	2.504	0.15123	2.4506	18.058	6.2062	0.2095	0.10475
11	3.004	0.18248	2.9569	19.585	6.2385	0.22603	0.11302
12	3.504	0.21355	3.4603	21.059	6.2711	0.24178	0.12089
13	4.004	0.24443	3.9608	22.322	6.3037	0.25496	0.12748
14	4.5041	0.27559	4.4657	23.533	6.3371	0.26738	0.13369
15	5.0041	0.30665	4.9691	24.534	6.3706	0.27727	0.13864
16	5.5041	0.33754	5.4695	25.639	6.4044	0.28824	0.14412
17	6.0041	0.36815	5.9655	26.534	6.4381	0.29674	0.14837
18	6.5041	0.39903	6.466	27.376	6.4726	0.30453	0.15227
19	7.0041	0.43019	6.9709	28.061	6.5077	0.31046	0.15523
20	7.5041	0.46107	7.4713	28.693	6.5429	0.31574	0.15787
21	8.0041	0.49187	7.9703	29.272	6.5784	0.32038	0.16019
22	8.5041	0.52248	8.4663	29.798	6.614	0.32438	0.16219
23	9.0041	0.55327	8.9653	30.325	6.6503	0.32831	0.16416
24	9.5041	0.58443	9.4702	30.746	6.6874	0.33103	0.16551
25	10.004	0.6154	9.9721	31.167	6.7247	0.3337	0.16685
26	10.504	0.64592	10.467	31.588	6.7618	0.33635	0.16818
27	11.004	0.67663	10.964	31.799	6.7996	0.33671	0.16836
28	11.504	0.7076	11.466	32.062	6.8381	0.33759	0.16879
29	12.004	0.73876	11.971	32.167	6.8773	0.33676	0.16838
30	12.504	0.76955	12.47	32.273	6.9166	0.33595	0.16798
31	13.004	0.79998	12.963	32.22	6.9557	0.33351	0.16676
32	13.504	0.83086	13.463	31.904	6.996	0.32835	0.16417
33	14.004	0.86202	13.968	31.588	7.037	0.3232	0.1616
34	14.504	0.89336	14.476	30.956	7.0788	0.31486	0.15743
35	15.004	0.92406	14.974	29.956	7.1202	0.30292	0.15146
36	15.504	0.95449	15.467	28.903	7.1618	0.29058	0.14529

UNCONFINED COMPRESSION TEST
ASTM D2166

Terracon
Consulting Engineers & Scientists



Symbol		◐			
Test No.		HEN018S8			
Initial	Diameter, in	2.8083			
	Height, in	6.0094			
	Water Content, %	31.88			
	Dry Density, pcf	90.04			
	Saturation, %	97.88			
	Void Ratio	0.8859			
Unconfined Compressive Strength, tsf		0.61328			
Undrained Shear Strength, tsf		0.30664			
Time to Failure, min		15.004			
Strain Rate, %/min		1.14			
Estimated Specific Gravity		2.72			
Liquid Limit		43			
Plastic Limit		22			
Plasticity Index		21			
Failure Sketch					

Project: DYNERGY HENNEPIN
Location: HENNEPIN, IL
Project No.: MR155233
Boring No.: HEN018 S-8
Sample Type: 3.0" ST
Description: DARK BROWNISH GRAY LEAN CLAY CL
Remarks: TEST PERFORMED AS PER ASTM D2166. 432

Tue, 22-DEC-2015 15:00:59

UNCONFINED COMPRESSION TEST

Project: DYNERGY HENNEPIN
Boring No.: HEN018 S-8
Sample No.: ST-8
Test No.: HEN018S8

Location: HENNEPIN, IL
Tested By: BCM
Test Date: 12/15/15
Sample Type: 3.0" ST

Project No.: MR155233
Checked By: WPQ
Depth: 25.0'-27.0'
Elevation: ----

Soil Description: DARK BROWNISH GRAY LEAN CLAY CL
Remarks: TEST PERFORMED AS PER ASTM D2166.

Specimen Height: 6.01 in
Specimen Area: 6.19 in^2
Specimen Volume: 37.22 in^3

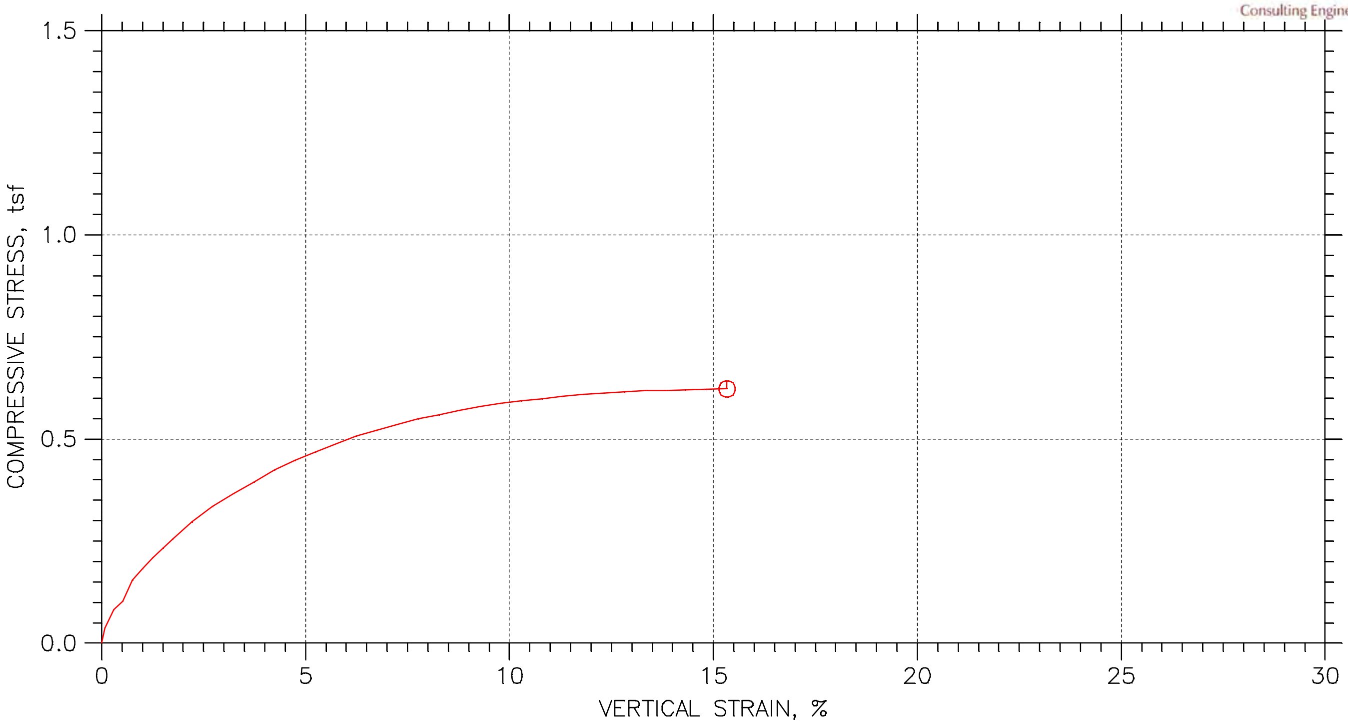
Liquid Limit: 43
Plastic Limit: 22
Estimated Specific Gravity: 2.72

Cap Mass: 0 gm

	Time min	Axial Displacement in	Axial Strain %	Load lb	Corrected Area in^2	Vertical Stress tsf	Shear Stress tsf
1	0	0	0	7.9497	6.1939	0.092409	0.046205
2	0.25402	0.015943	0.2653	13.478	6.2104	0.15625	0.078126
3	0.50403	0.031431	0.52302	16.794	6.2265	0.1942	0.097101
4	0.75403	0.046554	0.77468	19.585	6.2423	0.22589	0.11295
5	1.004	0.061768	1.0279	22.059	6.2583	0.25379	0.12689
6	1.254	0.077165	1.2841	24.27	6.2745	0.2785	0.13925
7	1.504	0.092743	1.5433	26.376	6.291	0.30187	0.15094
8	1.754	0.10841	1.804	28.219	6.3077	0.32211	0.16105
9	2.004	0.12408	2.0648	30.009	6.3245	0.34163	0.17081
10	2.504	0.15524	2.5833	33.062	6.3582	0.3744	0.1872
11	3.004	0.18594	3.0942	35.8	6.3917	0.40327	0.20164
12	3.504	0.21664	3.6051	38.274	6.4256	0.42887	0.21444
13	4.004	0.24807	4.1281	40.38	6.4606	0.45001	0.22501
14	4.504	0.27923	4.6465	42.328	6.4958	0.46917	0.23459
15	5.004	0.30993	5.1574	44.171	6.5308	0.48697	0.24349
16	5.5041	0.34027	5.6623	45.803	6.5657	0.50228	0.25114
17	6.0041	0.37116	6.1762	47.33	6.6017	0.51619	0.2581
18	6.5041	0.40268	6.7007	48.751	6.6388	0.52872	0.26436
19	7.0041	0.43402	7.2222	50.067	6.6761	0.53996	0.26998
20	7.5041	0.46435	7.7271	51.278	6.7126	0.55001	0.27501
21	8.0041	0.4946	8.2304	52.436	6.7494	0.55937	0.27968
22	8.5041	0.52539	8.7428	53.489	6.7873	0.56741	0.28371
23	9.0041	0.55701	9.2688	54.384	6.8267	0.57358	0.28679
24	9.5041	0.58825	9.7888	55.332	6.866	0.58023	0.29012
25	10.004	0.61887	10.298	56.122	6.905	0.58519	0.2926
26	10.504	0.64939	10.806	56.964	6.9443	0.59061	0.29531
27	11.004	0.68063	11.326	57.701	6.9851	0.59477	0.29738
28	11.504	0.71206	11.849	58.333	7.0265	0.59773	0.29887
29	12.004	0.74286	12.361	59.07	7.0676	0.60177	0.30088
30	12.504	0.77301	12.863	59.702	7.1083	0.60472	0.30236
31	13.004	0.80362	13.373	60.333	7.1501	0.60755	0.30377
32	13.504	0.83496	13.894	60.965	7.1934	0.61021	0.30511
33	14.004	0.86658	14.42	61.439	7.2376	0.6112	0.3056
34	14.504	0.89719	14.93	61.966	7.281	0.61277	0.30638
35	15.004	0.92743	15.433	62.387	7.3243	0.61328	0.30664

UNCONFINED COMPRESSION TEST
ASTM D2166

Terracon
Consulting Engineers & Scientists



Symbol		⏀			
Test No.		HEN019S2			
Initial	Diameter, in	2.848			
	Height, in	5.8406			
	Water Content, %	33.10			
	Dry Density, pcf	89.03			
	Saturation, %	99.24			
	Void Ratio	0.90719			
Unconfined Compressive Strength, tsf		0.62255			
Undrained Shear Strength, tsf		0.31128			
Time to Failure, min		15.503			
Strain Rate, %/min		1			
Estimated Specific Gravity		2.72			
Liquid Limit		41			
Plastic Limit		22			
Plasticity Index		19			
Failure Sketch					

Project: DYNERGY HENNEPIN
Location: HENNEPIN, IL
Project No.: MR155233
Boring No.: HEN019 S2
Sample Type: 3.0'' ST
Description: DARK BROWN LEAN CLAY WITH SAND CL
Remarks: TEST PERFORMED AS PER ASTM D2166.

Tue, 22-DEC-2015 15:04:02

UNCONFINED COMPRESSION TEST

Project: DYNERGY HENNEPIN
Boring No.: HEN019 S2
Sample No.: S-2
Test No.: HEN019S2

Location: HENNEPIN, IL
Tested By: BCM
Test Date: 12/15/15
Sample Type: 3.0" ST

Project No.: MR155233
Checked By: WPQ
Depth: 7.5'-9.5'
Elevation: ----

Soil Description: DARK BROWN LEAN CLAY WITH SAND CL
Remarks: TEST PERFORMED AS PER ASTM D2166.

Specimen Height: 5.84 in
Specimen Area: 6.37 in^2
Specimen Volume: 37.21 in^3

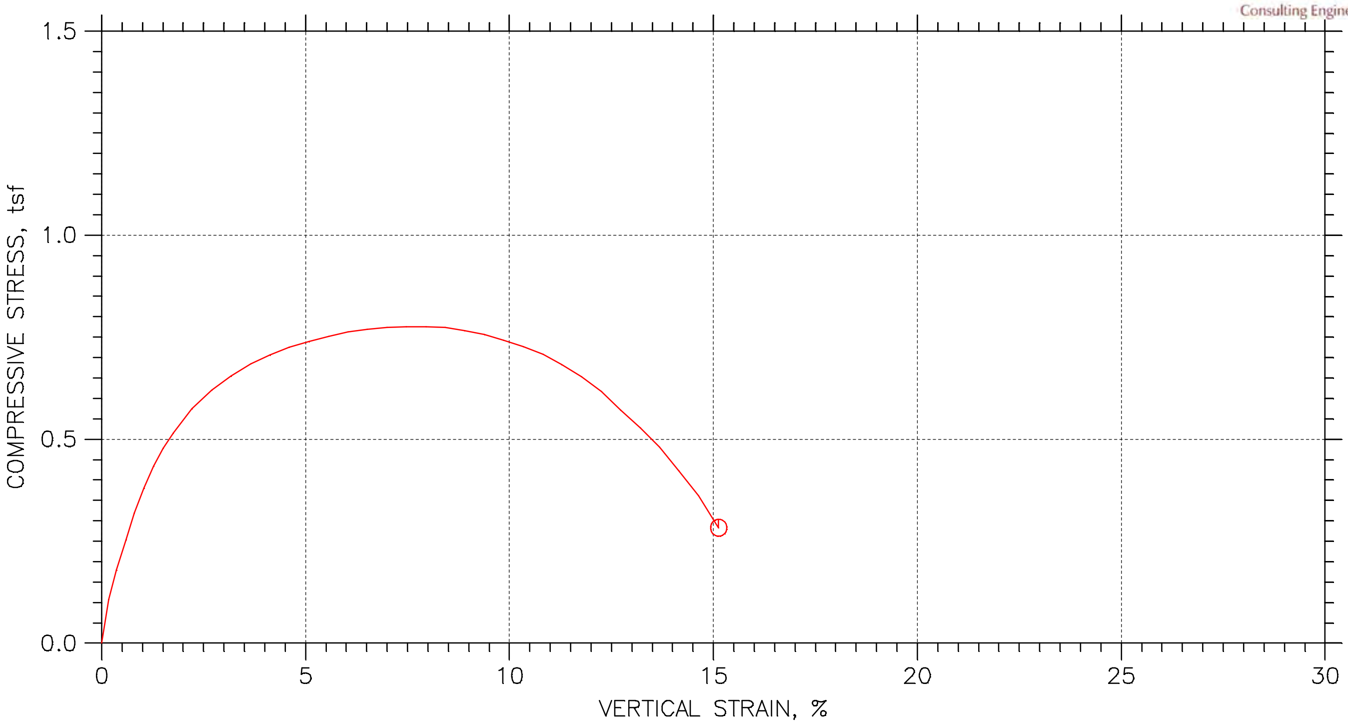
Liquid Limit: 41
Plastic Limit: 22
Estimated Specific Gravity: 2.72

Cap Mass: 0 gm

	Time min	Axial Displacement in	Axial Strain %	Load lb	Corrected Area in^2	Vertical Stress tsf	Shear Stress tsf
1	0	0	0	0	6.3706	0	0
2	0.25415	0.0046585	0.079761	3.282	6.3757	0.037063	0.018532
3	0.50415	0.01772	0.3034	7.358	6.39	0.082908	0.041454
4	0.75388	0.0306	0.52392	9.1049	6.4041	0.10236	0.051182
5	1.0039	0.044301	0.75851	13.816	6.4193	0.15497	0.077483
6	1.2534	0.058916	1.0087	16.357	6.4355	0.183	0.091501
7	1.5034	0.073439	1.2574	18.686	6.4517	0.20854	0.10427
8	1.7534	0.08778	1.5029	20.91	6.4678	0.23277	0.11638
9	2.0034	0.10203	1.7469	22.921	6.4839	0.25453	0.12726
10	2.5034	0.12925	2.213	26.891	6.5148	0.2972	0.1486
11	3.0034	0.15884	2.7197	30.385	6.5487	0.33407	0.16704
12	3.5034	0.18853	3.228	33.455	6.5831	0.3659	0.18295
13	4.0034	0.21803	3.7331	36.314	6.6176	0.3951	0.19755
14	4.5034	0.24717	4.232	39.172	6.6521	0.42399	0.21199
15	5.0034	0.27658	4.7356	41.554	6.6873	0.44741	0.2237
16	5.5034	0.30645	5.247	43.778	6.7234	0.46881	0.23441
17	6.0034	0.33605	5.7537	45.842	6.7595	0.4883	0.24415
18	6.5034	0.36509	6.251	47.854	6.7954	0.50703	0.25352
19	7.0034	0.39387	6.7437	49.495	6.8313	0.52166	0.26083
20	7.5034	0.42355	7.252	51.136	6.8687	0.53602	0.26801
21	8.0034	0.45351	7.7649	52.671	6.9069	0.54906	0.27453
22	8.5034	0.48293	8.2685	53.994	6.9448	0.55978	0.27989
23	9.0034	0.51206	8.7674	55.265	6.9828	0.56984	0.28492
24	9.5034	0.54111	9.2647	56.482	7.0211	0.57922	0.28961
25	10.003	0.5708	9.773	57.541	7.0606	0.58677	0.29338
26	10.503	0.60094	10.289	58.6	7.1012	0.59415	0.29707
27	11.003	0.63063	10.797	59.394	7.1417	0.59879	0.29939
28	11.503	0.65995	11.299	60.347	7.1821	0.60497	0.30248
29	12.003	0.68936	11.803	61.088	7.2231	0.60892	0.30446
30	12.503	0.71905	12.311	61.776	7.265	0.61223	0.30612
31	13.003	0.74901	12.824	62.464	7.3078	0.61543	0.30771
32	13.503	0.77842	13.328	63.152	7.3502	0.61862	0.30931
33	14.003	0.8071	13.819	63.576	7.3921	0.61924	0.30962
34	14.503	0.83596	14.313	64.052	7.4347	0.6203	0.31015
35	15.003	0.86592	14.826	64.581	7.4795	0.62168	0.31084
36	15.503	0.89543	15.331	65.058	7.5241	0.62255	0.31128

UNCONFINED COMPRESSION TEST
ASTM D2166

Terracon
Consulting Engineers & Scientists



Symbol		⦶			
Test No.		HEN019S4			
Initial	Diameter, in	2.7374			
	Height, in	6.1728			
	Water Content, %	34.87			
	Dry Density, pcf	86.39			
	Saturation, %	98.22			
	Void Ratio	0.96564			
Unconfined Compressive Strength, tsf		0.77617			
Undrained Shear Strength, tsf		0.38809			
Time to Failure, min		8.5033			
Strain Rate, %/min		1			
Estimated Specific Gravity		2.72			
Liquid Limit		45			
Plastic Limit		24			
Plasticity Index		21			
Failure Sketch					

Project: DYNERGY HENNEPIN
Location: HENNEPIN, IL
Project No.: MR155233
Boring No.: HEN019 S4
Sample Type: 3.0'' ST
Description: GRAY AND BROWN LEAN CLAY CL
Remarks: TEST PERFORMED AS PER ASTM D2166.

Tue, 22-DEC-2015 15:07:07

UNCONFINED COMPRESSION TEST

Project: DYNERGY HENNEPIN
Boring No.: HEN019 S4
Sample No.: ST-4
Test No.: HEN019S4

Location: HENNEPIN, IL
Tested By: BCM
Test Date: 12/15/15
Sample Type: 3.0" ST

Project No.: MR155233
Checked By: WPQ
Depth: 12.5'-14.5'
Elevation: ----

Soil Description: GRAY AND BROWN LEAN CLAY CL
Remarks: TEST PERFORMED AS PER ASTM D2166.

Specimen Height: 6.17 in
Specimen Area: 5.89 in^2
Specimen Volume: 36.33 in^3

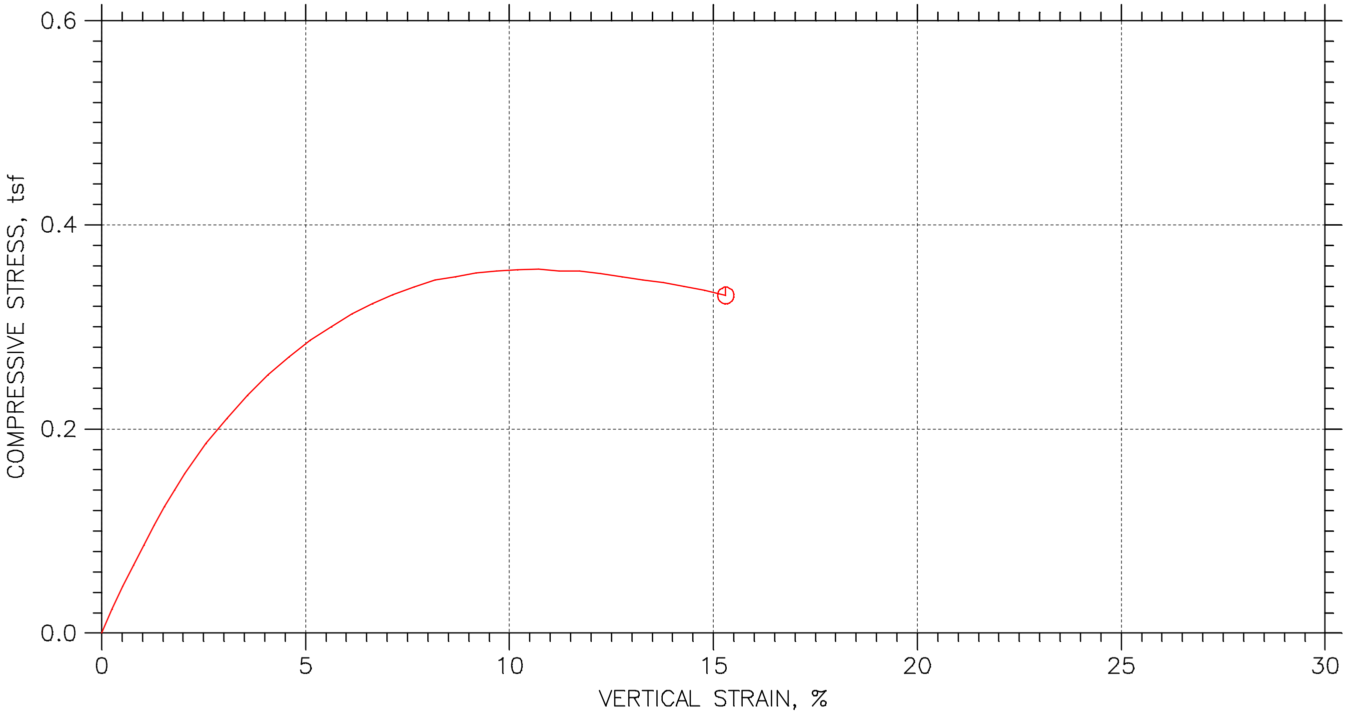
Liquid Limit: 45
Plastic Limit: 24
Estimated Specific Gravity: 2.72

Cap Mass: 0 gm

	Time min	Axial Displacement in	Axial Strain %	Load lb	Corrected Area in^2	Vertical Stress tsf	Shear Stress tsf
1	0	0	0	0	5.8853	0	0
2	0.25017	0.010413	0.16869	8.7873	5.8952	0.10732	0.053661
3	0.50018	0.022288	0.36106	14.716	5.9066	0.17939	0.089693
4	0.75357	0.036628	0.59338	20.751	5.9204	0.25236	0.12618
5	1.0033	0.049233	0.79758	26.309	5.9326	0.31929	0.15965
6	1.2533	0.06394	1.0358	31.391	5.9469	0.38005	0.19003
7	1.5033	0.078828	1.277	35.837	5.9614	0.43283	0.21642
8	1.7533	0.093443	1.5138	39.649	5.9757	0.47772	0.23886
9	2.0033	0.10806	1.7505	42.878	5.9901	0.51538	0.25769
10	2.5033	0.13701	2.2196	48.013	6.0189	0.57434	0.28717
11	3.0033	0.16633	2.6946	52.089	6.0483	0.62008	0.31004
12	3.5033	0.19593	3.1741	55.318	6.0782	0.65527	0.32764
13	4.0033	0.22562	3.655	58.07	6.1085	0.68446	0.34223
14	4.5033	0.25475	4.127	60.241	6.1386	0.70656	0.35328
15	5.0033	0.28407	4.602	62.199	6.1692	0.72592	0.36296
16	5.5033	0.31367	5.0814	63.629	6.2003	0.73887	0.36944
17	6.0033	0.34336	5.5624	65.111	6.2319	0.75225	0.37613
18	6.5033	0.37286	6.0403	66.328	6.2636	0.76244	0.38122
19	7.0033	0.40227	6.5168	67.281	6.2955	0.76947	0.38474
20	7.5033	0.4315	6.9903	67.969	6.3276	0.7734	0.3867
21	8.0033	0.461	7.4683	68.552	6.3603	0.77602	0.38801
22	8.5033	0.4906	7.9477	68.922	6.3934	0.77617	0.38809
23	9.0033	0.5201	8.4257	69.081	6.4268	0.77392	0.38696
24	9.5033	0.54942	8.9007	68.71	6.4603	0.76578	0.38289
25	10.003	0.57884	9.3771	68.287	6.4943	0.75708	0.37854
26	10.503	0.60852	9.8581	67.281	6.5289	0.74197	0.37098
27	11.003	0.63839	10.342	66.222	6.5641	0.72637	0.36319
28	11.503	0.66771	10.817	64.899	6.5991	0.70809	0.35404
29	12.003	0.69648	11.283	62.94	6.6338	0.68313	0.34156
30	12.503	0.72617	11.764	60.558	6.6699	0.65371	0.32686
31	13.003	0.75604	12.248	57.541	6.7067	0.61773	0.30887
32	13.503	0.78563	12.727	53.518	6.7435	0.5714	0.2857
33	14.003	0.81496	13.202	49.707	6.7805	0.52782	0.26391
34	14.503	0.844	13.673	45.472	6.8174	0.48024	0.24012
35	15.003	0.87369	14.154	40.284	6.8556	0.42308	0.21154
36	15.503	0.90392	14.644	34.567	6.8949	0.36096	0.18048
37	16.003	0.93379	15.127	27.262	6.9343	0.28307	0.14153

UNCONFINED COMPRESSION TEST
ASTM D2166

Terracon
Consulting Engineers & Scientists



Symbol		⦶			
Test No.		HENB019S6			
Initial	Diameter, in	2.798			
	Height, in	6.1795			
	Water Content, %	33.84			
	Dry Density, pcf	86.79			
	Saturation, %	96.23			
	Void Ratio	0.9565			
Unconfined Compressive Strength, tsf		0.3564			
Undrained Shear Strength, tsf		0.1782			
Time to Failure, min		10.504			
Strain Rate, %/min		1			
Estimated Specific Gravity		2.72			
Liquid Limit		38			
Plastic Limit		22			
Plasticity Index		16			
Failure Sketch					

Project: DYNERGY HENNEPIN
Location: HENNEPIN, IL
Project No.: MR155233
Boring No.: HENB019 S-6
Sample Type: 3.0'' ST
Description: BROWN AND GRAY LEAN CLAY CL
Remarks: TEST PERFORMED AS PER ASTM D2166.

Tue, 22-DEC-2015 15:09:43

Project: DYNERGY HENNEPIN
Boring No.: HENB019 S-6
Sample No.: ST-6
Test No.: HENB019S6

Location: HENNEPIN, IL
Tested By: BCM
Test Date: 12/14/15
Sample Type: 3.0" ST

Project No.: MR155233
Checked By: WPQ
Depth: 20.0'-22.0'
Elevation: -----

Soil Description: BROWN AND GRAY LEAN CLAY CL
Remarks: TEST PERFORMED AS PER ASTM D2166.

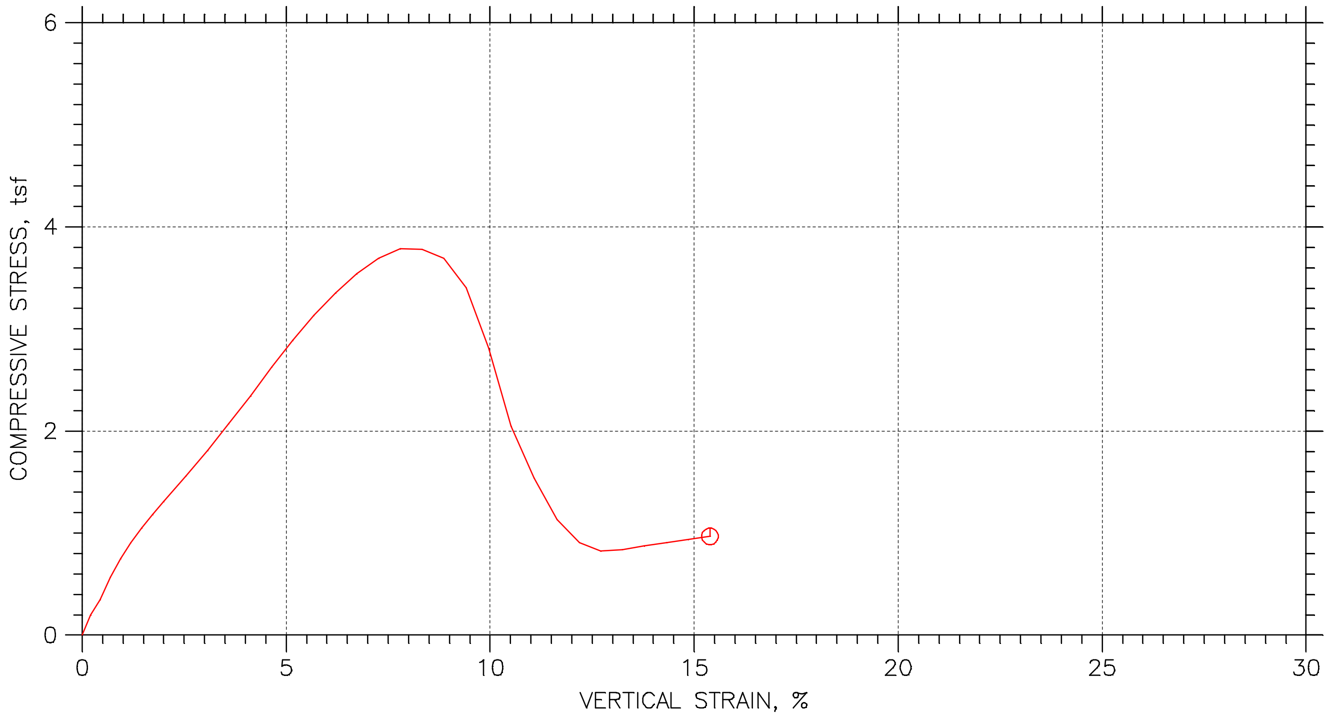
Specimen Height: 6.18 in
Specimen Area: 6.15 in^2
Specimen Volume: 38.00 in^3

Liquid Limit: 38
Plastic Limit: 22
Estimated Specific Gravity: 2.72

Cap Mass: 0 gm

	Time min	Axial Displacement in	Axial Strain %	Load lb	Corrected Area in^2	Vertical Stress tsf	Shear Stress tsf
1	0	0	0	0	6.1489	0	0
2	0.25378	0.016051	0.25974	1.9931	6.1649	0.023277	0.011639
3	0.50378	0.032102	0.51949	3.9337	6.181	0.045822	0.022911
4	0.75378	0.048153	0.77923	5.7694	6.1972	0.06703	0.033515
5	1.0038	0.064019	1.036	7.4478	6.2132	0.086306	0.043153
6	1.2538	0.079517	1.2868	9.1261	6.229	0.10549	0.052744
7	1.5038	0.095014	1.5376	10.752	6.2449	0.12397	0.061983
8	1.7538	0.1106	1.7898	12.168	6.2609	0.13993	0.069966
9	2.0038	0.12619	2.0421	13.637	6.2771	0.15642	0.078209
10	2.5038	0.15783	2.5542	16.312	6.31	0.18612	0.093061
11	3.0038	0.18984	3.0722	18.567	6.3438	0.21073	0.10537
12	3.5038	0.22149	3.5842	20.665	6.3774	0.2333	0.11665
13	4.0038	0.25248	4.0858	22.553	6.4108	0.2533	0.12665
14	4.5038	0.28375	4.5918	24.231	6.4448	0.27071	0.13535
15	5.0038	0.31567	5.1083	25.805	6.4799	0.28673	0.14336
16	5.5038	0.34786	5.6293	27.169	6.5157	0.30022	0.15011
17	6.0038	0.37914	6.1353	28.427	6.5508	0.31245	0.15622
18	6.5038	0.40995	6.6339	29.529	6.5858	0.32283	0.16141
19	7.0038	0.44113	7.1385	30.473	6.6215	0.33135	0.16568
20	7.5038	0.47295	7.6535	31.365	6.6585	0.33915	0.16958
21	8.0038	0.50505	8.173	32.151	6.6961	0.34571	0.17285
22	8.5038	0.53632	8.679	32.623	6.7332	0.34885	0.17442
23	9.0038	0.56713	9.1776	33.2	6.7702	0.35308	0.17654
24	9.5038	0.59822	9.6807	33.515	6.8079	0.35445	0.17723
25	10.004	0.63032	10.2	33.882	6.8473	0.35627	0.17814
26	10.504	0.66252	10.721	34.092	6.8873	0.3564	0.1782
27	11.004	0.69351	11.223	34.144	6.9262	0.35494	0.17747
28	11.504	0.72442	11.723	34.302	6.9654	0.35457	0.17728
29	12.004	0.75587	12.232	34.302	7.0058	0.35253	0.17626
30	12.504	0.78788	12.75	34.197	7.0474	0.34937	0.17469
31	13.004	0.81998	13.269	34.039	7.0896	0.34569	0.17285
32	13.504	0.85079	13.768	33.987	7.1306	0.34318	0.17159
33	14.004	0.88188	14.271	33.83	7.1724	0.3396	0.1698
34	14.504	0.91361	14.785	33.672	7.2157	0.33599	0.168
35	15.004	0.94553	15.301	33.358	7.2597	0.33083	0.16542

UNCONFINED COMPRESSION TEST
ASTM D2166



Symbol		⏀			
Test No.		HENB021S3			
Initial	Diameter, in	2.8783			
	Height, in	5.8752			
	Water Content, %	15.80			
	Dry Density, pcf	116.7			
	Saturation, %	94.44			
	Void Ratio	0.45507			
Unconfined Compressive Strength, tsf		3.7833			
Undrained Shear Strength, tsf		1.8917			
Time to Failure, min		7.5002			
Strain Rate, %/min		1			
Estimated Specific Gravity		2.72			
Liquid Limit		---			
Plastic Limit		---			
Plasticity Index		---			
Failure Sketch					

Project: DYNERGY HENNEPIN
Location: HENNEPIN, IL
Project No.: MR155233
Boring No.: HENB021 S-3
Sample Type: 3.0" ST
Description: BROWN TO BROWNISH GRAY LEAN CLAY WITH SAND AND GRAVEL CL
Remarks: TEST PERFORMED AS PER ASTM D2166. 440

UNCONFINED COMPRESSION TEST

Project: DYNERGY HENNEPIN
Boring No.: HENB021 S-3
Sample No.: ST-3
Test No.: HENB021S3

Location: HENNEPIN, IL
Tested By: BCM
Test Date: 12/14/15
Sample Type: 3.0" ST

Project No.: MR155233
Checked By: WPQ
Depth: 5.0'-6.0'
Elevation: -----

Terracon Consulting Engineers & Scientists

Soil Description: BROWN TO BROWNISH GRAY LEAND CLAY WITH SAND AND GRAVEL CL
Remarks: TEST PERFORMED AS PER ASTM D2166.

Specimen Height: 5.88 in
Specimen Area: 6.51 in^2
Specimen Volume: 38.23 in^3

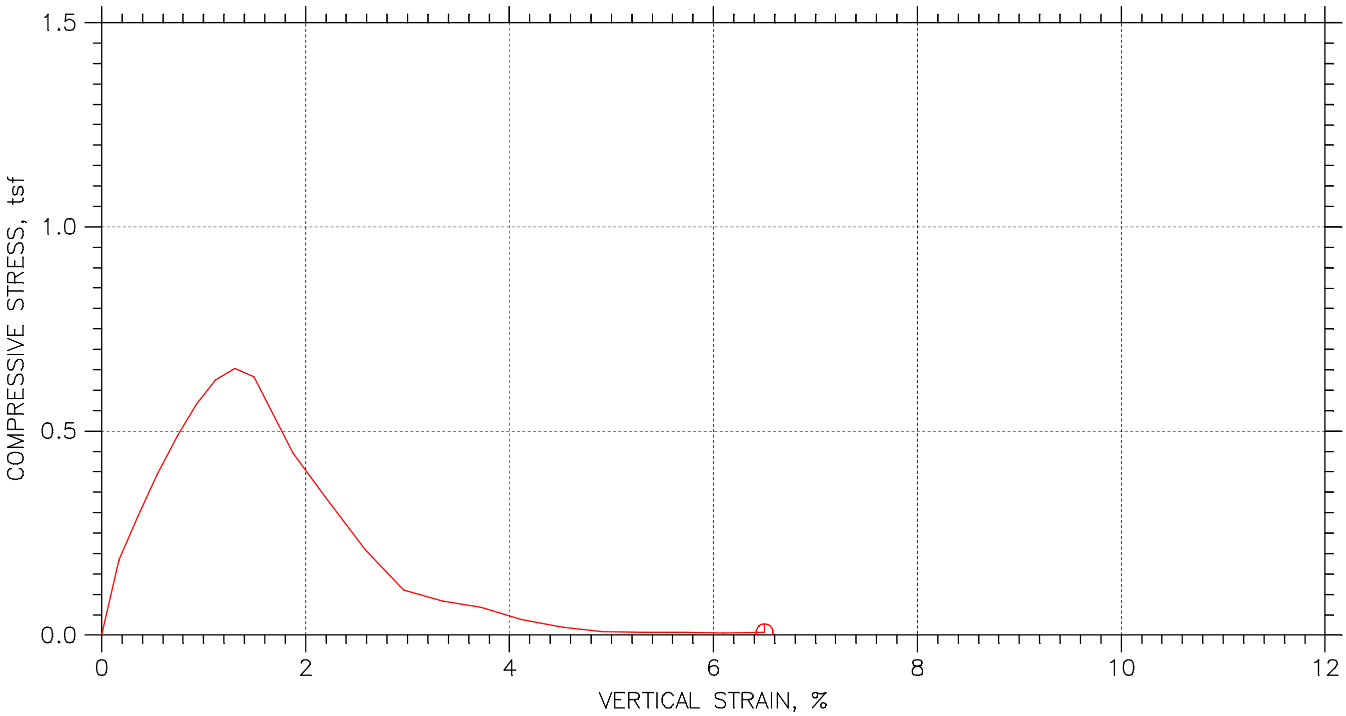
Liquid Limit: ---
Plastic Limit: ---
Estimated Specific Gravity: 2.72

Cap Mass: 0 gm

	Time min	Axial Displacement in	Axial Strain %	Load lb	Corrected Area in^2	Vertical Stress tsf	Shear Stress tsf
1	0	0	0	0	6.5069	0	0
2	0.2502	0.012177	0.20725	17.57	6.5204	0.19402	0.097008
3	0.5002	0.026198	0.44591	31.627	6.5361	0.34839	0.1742
4	0.7502	0.040496	0.68928	51.453	6.5521	0.56541	0.2827
5	1.0002	0.055625	0.94678	68.499	6.5691	0.75077	0.37538
6	1.2502	0.070384	1.198	82.607	6.5858	0.90311	0.45156
7	1.5002	0.085882	1.4618	96.192	6.6035	1.0488	0.52441
8	1.7502	0.10156	1.7287	108.52	6.6214	1.18	0.59
9	2.0002	0.11734	1.9972	120.58	6.6395	1.3076	0.6538
10	2.5002	0.14898	2.5357	144.34	6.6762	1.5566	0.77832
11	3.0002	0.18034	3.0696	168.57	6.713	1.808	0.904
12	3.5002	0.21125	3.5956	194.22	6.7496	2.0718	1.0359
13	4.0002	0.24206	4.12	221.02	6.7865	2.3449	1.1724
14	4.5002	0.27277	4.6428	248.71	6.8237	2.6243	1.3121
15	5.0002	0.30331	5.1625	275.1	6.8611	2.8868	1.4434
16	5.5002	0.33403	5.6854	300.38	6.8992	3.1347	1.5674
17	6.0002	0.36484	6.2098	322.93	6.9377	3.3514	1.6757
18	6.5002	0.39583	6.7373	343.07	6.977	3.5404	1.7702
19	7.0002	0.42683	7.2649	359.91	7.0167	3.6931	1.8465
20	7.5002	0.45791	7.794	370.82	7.0569	3.7833	1.8917
21	8.0002	0.48937	8.3294	372.39	7.0982	3.7773	1.8887
22	8.5002	0.5211	8.8695	366.3	7.1402	3.6937	1.8469
23	9.0002	0.55311	9.4144	339.24	7.1832	3.4004	1.7002
24	9.5002	0.58522	9.9608	282.54	7.2268	2.815	1.4075
25	10	0.6175	10.51	206.7	7.2711	2.0468	1.0234
26	10.5	0.65071	11.076	156.61	7.3174	1.541	0.77051
27	11	0.68355	11.635	115.91	7.3637	1.1334	0.56668
28	11.5	0.71584	12.184	93.15	7.4097	0.90513	0.45256
29	12	0.74665	12.708	85.282	7.4542	0.82373	0.41187
30	12.5	0.77792	13.241	87.013	7.5	0.83533	0.41766
31	13	0.80947	13.778	91.629	7.5467	0.87419	0.4371
32	13.5	0.84129	14.319	95.3	7.5944	0.90351	0.45175
33	14	0.87275	14.855	99.811	7.6422	0.94036	0.47018
34	14.5	0.90402	15.387	103.38	7.6902	0.96787	0.48394

UNCONFINED COMPRESSION TEST
ASTM D2166

Terracon
Consulting Engineers & Scientists



Symbol					
Test No.		HENB021S8			
Initial	Diameter, in	2.8717			
	Height, in	6.0697			
	Water Content, %	31.90			
	Dry Density, pcf	65.24			
	Saturation, %	61.09			
	Void Ratio	1.201			
Unconfined Compressive Strength, tsf		0.65256			
Undrained Shear Strength, tsf		0.32628			
Time to Failure, min		1.7542			
Strain Rate, %/min		1			
Estimated Specific Gravity		2.30			
Liquid Limit		NP			
Plastic Limit		NP			
Plasticity Index		NP			
Failure Sketch					

Project: DYNERGY HENNEPIN
Location: HENNEPIN, IL
Project No.: MR155233
Boring No.: HENB021 S-8
Sample Type: 3.0" ST
Description: DARK GRAY VARVED FLY ASH
Remarks: TEST PERFORMED AS PER ASTM D2166.

Tue, 22-DEC-2015 15:16:20

Project: DYNERGY HENNEPIN
Boring No.: HENB021 S-8
Sample No.: S-8
Test No.: HENB021S8

Location: HENNEPIN, IL
Tested By: BCM
Test Date: 12/14/15
Sample Type: 3.0" ST

Project No.: MR155233
Checked By: WPQ
Depth: 22.0'-24.0'
Elevation: -----

Soil Description: DARK GRAY VARVED FLY ASH
Remarks: TEST PERFORMED AS PER ASTM D2166.

Specimen Height: 6.07 in
Specimen Area: 6.48 in^2
Specimen Volume: 39.31 in^3

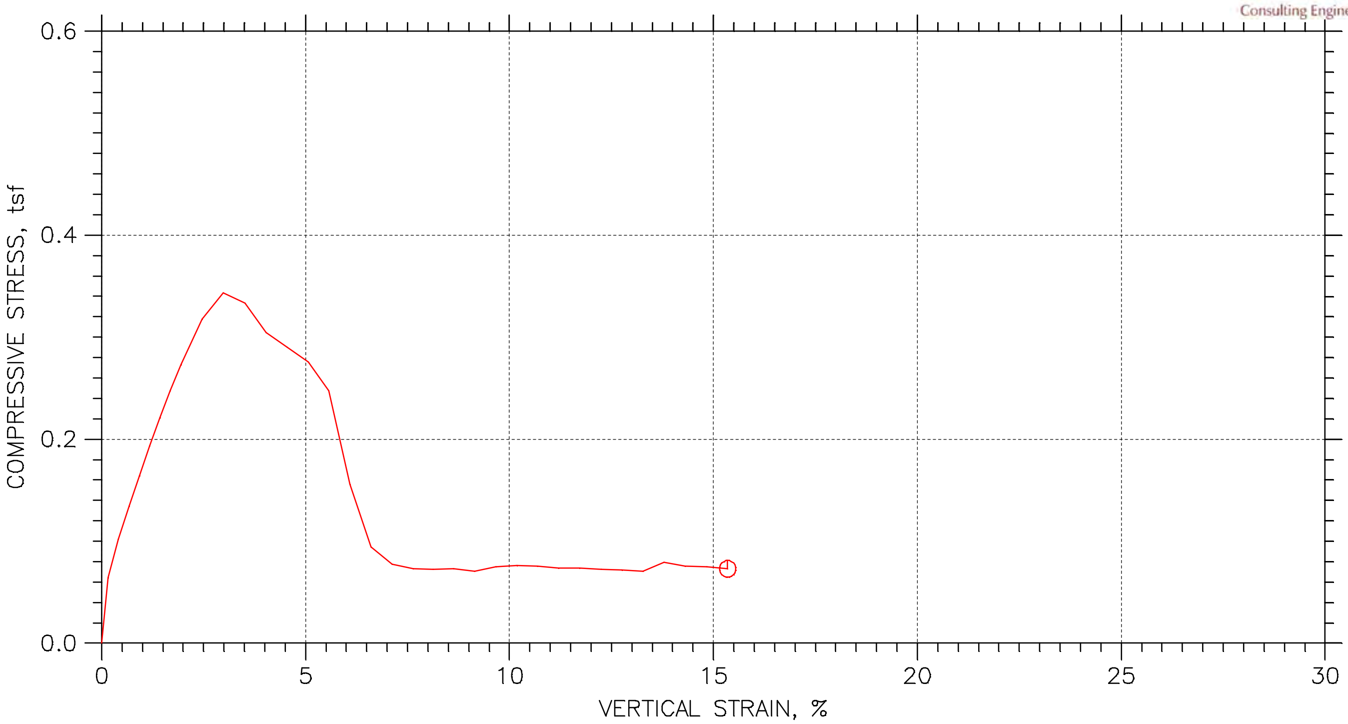
Liquid Limit: NP
Plastic Limit: NP
Estimated Specific Gravity: 2.30

Cap Mass: 0 gm

	Time min	Axial Displacement in	Axial Strain %	Load lb	Corrected Area in^2	Vertical Stress tsf	Shear Stress tsf
1	0	0	0	0	6.4767	0	0
2	0.25415	0.010239	0.1687	16.626	6.4876	0.18452	0.09226
3	0.50415	0.02177	0.35867	26.434	6.5	0.29281	0.14641
4	0.75415	0.033301	0.54865	35.665	6.5124	0.39431	0.19715
5	1.0042	0.044832	0.73862	44.11	6.5249	0.48674	0.24337
6	1.2542	0.056363	0.9286	51.348	6.5374	0.56552	0.28276
7	1.5042	0.067894	1.1186	56.802	6.55	0.6244	0.3122
8	1.7542	0.07924	1.3055	59.477	6.5624	0.65256	0.32628
9	2.0042	0.090587	1.4924	57.799	6.5748	0.63295	0.31647
10	2.5042	0.11402	1.8785	40.963	6.6007	0.44682	0.22341
11	3.0042	0.13311	2.1931	31.155	6.6219	0.33874	0.16937
12	3.5042	0.15691	2.5852	19.354	6.6486	0.20959	0.10479
13	4.0042	0.17988	2.9636	10.228	6.6745	0.11033	0.055164
14	4.5042	0.20276	3.3405	7.7625	6.7005	0.083411	0.041705
15	5	0.22591	3.722	6.2939	6.7271	0.067364	0.033682
16	5.5	0.24999	4.1187	3.5141	6.7549	0.037456	0.018728
17	6	0.27425	4.5184	1.8882	6.7832	0.020042	0.010021
18	6.5	0.29833	4.915	0.73429	6.8115	0.0077617	0.0038808
19	7	0.3224	5.3117	0.68184	6.84	0.0071772	0.0035886
20	7.5	0.34657	5.7099	0.62939	6.8689	0.0065973	0.0032986
21	8	0.3701	6.0974	0.47204	6.8973	0.0049276	0.0024638
22	8.5	0.39463	6.5017	0.73429	6.9271	0.0076322	0.0038161

UNCONFINED COMPRESSION TEST REPORT

Terracon
Consulting Engineers & Scientists



Symbol		①			
Test No.		HENB022S2			
Initial	Diameter, in	2.8346			
Initial	Height, in	6.0874			
Initial	Water Content, %	26.87			
Initial	Dry Density, pcf	84.39			
Initial	Saturation, %	88.11			
Initial	Void Ratio	0.70142			
Unconfined Compressive Strength, tsf		0.34367			
Undrained Shear Strength, tsf		0.17183			
Time to Failure, min		3.0002			
Strain Rate, %/min		1			
Estimated Specific Gravity		2.30			
Liquid Limit		NP			
Plastic Limit		NP			
Plasticity Index		NP			
Failure Sketch					

Project: DYNERGY HENNEPIN
Location: HENNEPIN, IL
Project No.: MR155233
Boring No.: HENB022 S-2
Sample Type: 3.0'' ST
Description: VERY DARK GRAY VARVED FLY ASH WITH SAND AND GRAVEL
Remarks: TEST PERFORMED AS PER ASTM D2166. 444

UNCONFINED COMPRESSION TEST

Project: DYNERGY HENNEPIN
Boring No.: HENB022 S-2
Sample No.: ST-2
Test No.: HENB022S2

Location: HENNEPIN, IL
Tested By: BCM
Test Date: 12/14/15
Sample Type: 3.0" ST

Project No.: MR155233
Checked By: WPQ
Depth: 2.5'-4.5'
Elevation: -----

Soil Description: VERY DARK GRAY VARVED FLY ASH WITH SAND AND GRAVEL
Remarks: TEST PERFORMED AS PER ASTM D2166.

Specimen Height: 6.09 in
Specimen Area: 6.31 in^2
Specimen Volume: 38.42 in^3

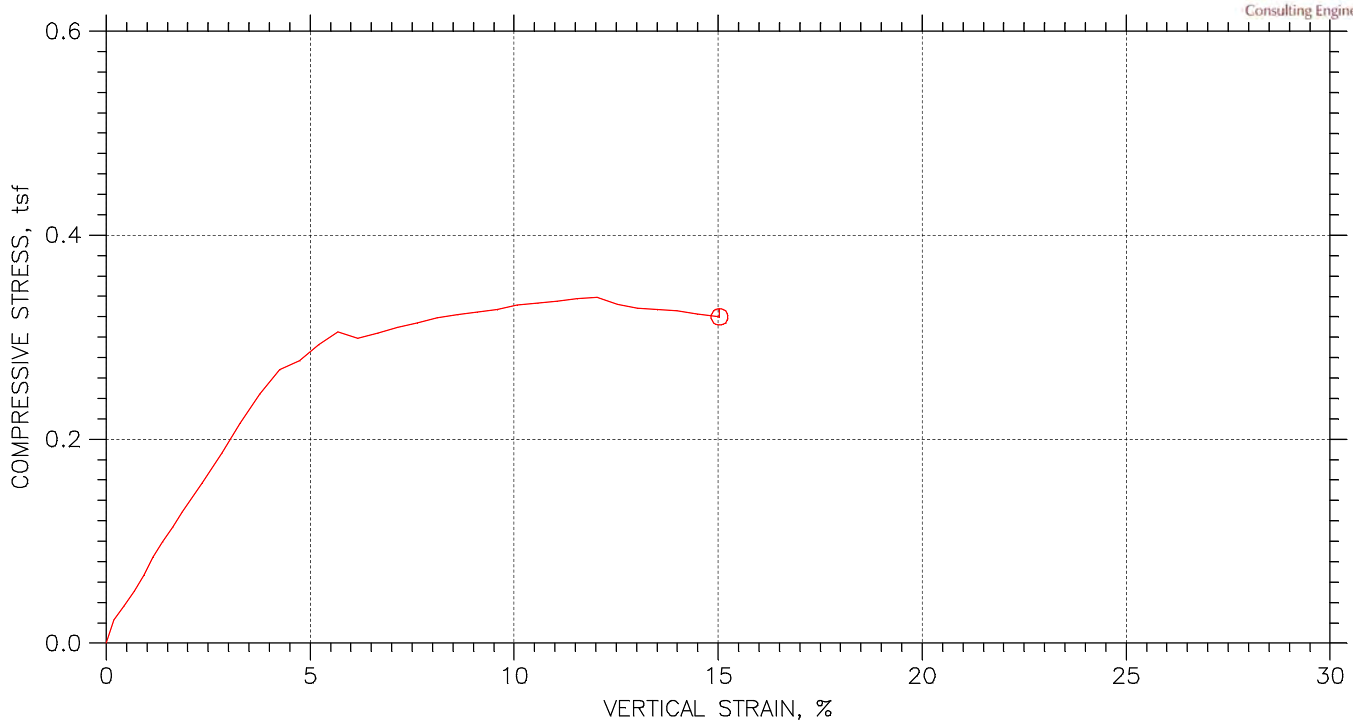
Liquid Limit: NP
Plastic Limit: NP
Estimated Specific Gravity: 2.30

Cap Mass: 0 gm

	Time min	Axial Displacement in	Axial Strain %	Load lb	Corrected Area in^2	Vertical Stress tsf	Shear Stress tsf
1	0	0	0	0	6.3108	0	0
2	0.2502	0.0095937	0.1576	5.6121	6.3208	0.063927	0.031963
3	0.5002	0.025183	0.4137	8.9688	6.3371	0.1019	0.050951
4	0.7502	0.040681	0.66828	11.853	6.3533	0.13433	0.067166
5	1.0002	0.056086	0.92135	14.528	6.3695	0.16423	0.082113
6	1.2502	0.071491	1.1744	17.151	6.3858	0.19337	0.096687
7	1.5002	0.086804	1.426	19.668	6.4021	0.2212	0.1106
8	1.7502	0.10267	1.6866	22.081	6.4191	0.24767	0.12384
9	2.0002	0.11854	1.9473	24.441	6.4362	0.27342	0.13671
10	2.5002	0.15027	2.4685	28.532	6.4706	0.31749	0.15874
11	3.0002	0.18182	2.9868	31.05	6.5051	0.34367	0.17183
12	3.5041	0.21392	3.5142	30.263	6.5407	0.33314	0.16657
13	4.0041	0.24547	4.0324	27.798	6.576	0.30436	0.15218
14	4.5041	0.27665	4.5446	26.644	6.6113	0.29017	0.14508
15	5.0041	0.30811	5.0614	25.438	6.6473	0.27553	0.13776
16	5.5041	0.3391	5.5705	22.973	6.6831	0.24749	0.12375
17	6.0041	0.37028	6.0827	14.528	6.7196	0.15567	0.077836
18	6.5041	0.40192	6.6025	8.8639	6.757	0.094451	0.047225
19	7.0041	0.43365	7.1238	7.2904	6.7949	0.077251	0.038625
20	7.5041	0.46465	7.6329	6.9233	6.8324	0.072958	0.036479
21	8.0041	0.49491	8.13	6.9233	6.8693	0.072566	0.036283
22	8.5041	0.52535	8.6301	6.9757	6.9069	0.072717	0.036359
23	9.0041	0.5568	9.1468	6.8184	6.9462	0.070675	0.035338
24	9.5041	0.58798	9.659	7.238	6.9856	0.074601	0.037301
25	10.004	0.61962	10.179	7.4478	7.026	0.076322	0.038161
26	10.504	0.65071	10.689	7.3953	7.0662	0.075354	0.037677
27	11.004	0.68189	11.202	7.2904	7.1069	0.073859	0.036929
28	11.504	0.71362	11.723	7.2904	7.1489	0.073425	0.036713
29	12.004	0.74554	12.247	7.238	7.1916	0.072464	0.036232
30	12.504	0.77681	12.761	7.238	7.234	0.07204	0.03602
31	13.004	0.8079	13.272	7.1331	7.2766	0.07058	0.03529
32	13.504	0.83917	13.785	8.0772	7.3199	0.079448	0.039724
33	14.004	0.87127	14.313	7.71	7.365	0.075373	0.037687
34	14.504	0.90328	14.839	7.71	7.4104	0.074911	0.037455
35	15.004	0.93437	15.349	7.5527	7.4552	0.072942	0.036471

Terracon
Consulting Engineers & Scientists

UNCONFINED COMPRESSION TEST REPORT



Symbol		⦶			
Test No.		HEN025S9			
Initial	Diameter, in	2.8591			
	Height, in	6.0091			
	Water Content, %	36.14			
	Dry Density, pcf	75.78			
	Saturation, %	92.89			
	Void Ratio	0.89482			
Unconfined Compressive Strength, tsf		0.33892			
Undrained Shear Strength, tsf		0.16946			
Time to Failure, min		12.504			
Strain Rate, %/min		1			
Estimated Specific Gravity		2.30			
Liquid Limit		NP			
Plastic Limit		NP			
Plasticity Index		NP			
Failure Sketch					

Project: DYNERGY HENNEPIN
Location: HENNEPIN, IL
Project No.: MR155233
Boring No.: HEN025 S9
Sample Type: 3.0'' ST
Description: DARK GRAY TO GRAY FLY ASH WITH SAND
Remarks: TEST PERFORMED AS PER ASTM D2166.

UNCONFINED COMPRESSION TEST

Project: DYNERGY HENNEPIN
Boring No.: HEN025 S9
Sample No.: S-9
Test No.: HEN025S9

Location: HENNEPIN, IL
Tested By: BCM
Test Date: 12/15/15
Sample Type: 3.0" ST

Project No.: MR155233
Checked By: WPQ
Depth: 25.0'-27.0'
Elevation: ----

Soil Description: DARK GRAY TO GRAY FLY ASH WITH SAND
Remarks: TEST PERFORMED AS PER ASTM D2166.

Specimen Height: 6.01 in
Specimen Area: 6.42 in^2
Specimen Volume: 38.58 in^3

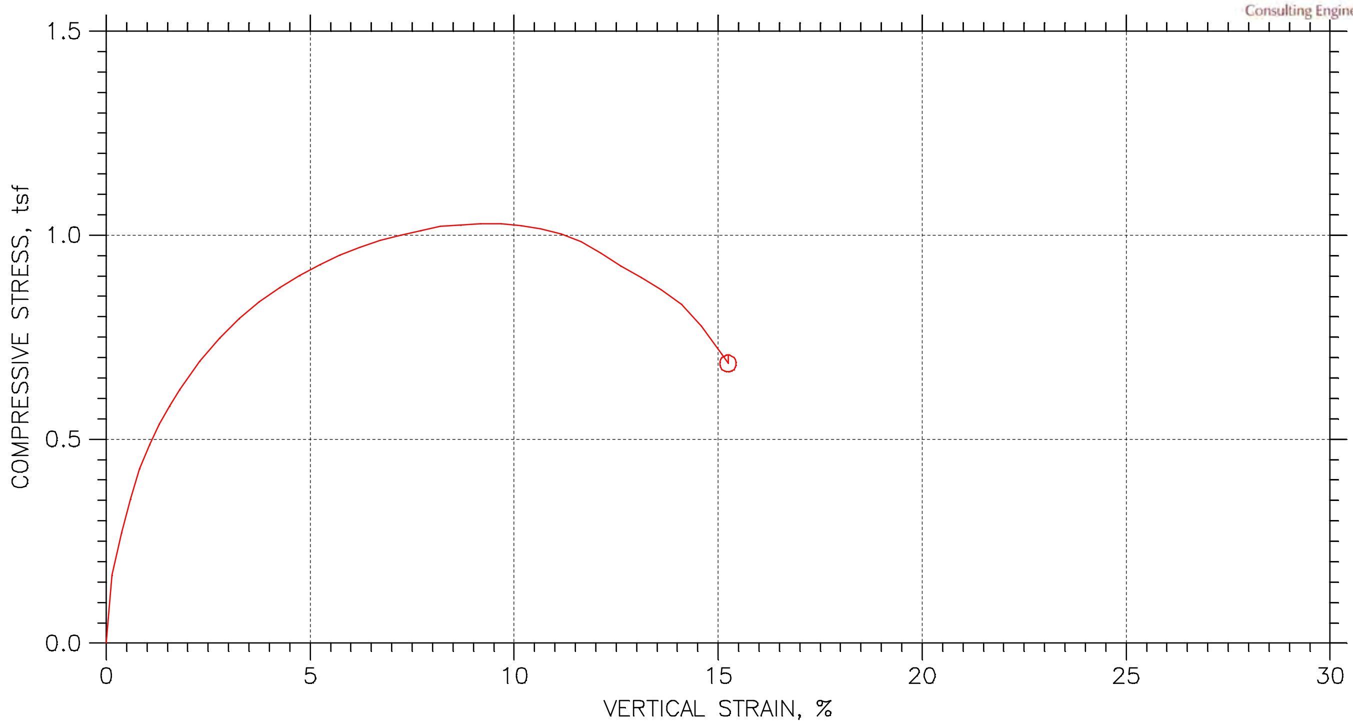
Liquid Limit: NP
Plastic Limit: NP
Estimated Specific Gravity: 2.30

Cap Mass: 0 gm

	Time min	Axial Displacement in	Axial Strain %	Load lb	Corrected Area in^2	Vertical Stress tsf	Shear Stress tsf
1	0	0	0	0	6.42	0	0
2	0.25405	0.011783	0.19609	2.0116	6.4326	0.022515	0.011258
3	0.50407	0.026307	0.43778	3.282	6.4482	0.036646	0.018323
4	0.75407	0.041104	0.68403	4.6054	6.4642	0.051296	0.025648
5	1.0041	0.055536	0.92421	6.0347	6.4799	0.067053	0.033526
6	1.2538	0.068507	1.1401	7.6227	6.494	0.084514	0.042257
7	1.5038	0.083304	1.3863	8.9991	6.5103	0.099525	0.049762
8	1.7538	0.097919	1.6295	10.322	6.5263	0.11388	0.05694
9	2.0038	0.11253	1.8727	11.699	6.5425	0.12874	0.064372
10	2.5038	0.14158	2.3561	14.346	6.5749	0.15709	0.078547
11	3.0038	0.17063	2.8395	17.151	6.6076	0.18689	0.093444
12	3.5038	0.19712	3.2803	19.851	6.6377	0.21532	0.10766
13	4.0038	0.22635	3.7667	22.656	6.6713	0.24452	0.12226
14	4.5038	0.25521	4.2471	24.986	6.7048	0.26831	0.13416
15	5.0038	0.28444	4.7335	25.938	6.739	0.27713	0.13856
16	5.5038	0.3134	5.2154	27.527	6.7732	0.29261	0.1463
17	6.0038	0.34116	5.6775	28.85	6.8064	0.30518	0.15259
18	6.5038	0.37048	6.1654	28.426	6.8418	0.29915	0.14957
19	7.0038	0.39971	6.6519	29.009	6.8775	0.30369	0.15185
20	7.5038	0.42885	7.1368	29.75	6.9134	0.30983	0.15492
21	8.0038	0.45836	7.6277	30.332	6.9501	0.31423	0.15711
22	8.5038	0.48777	8.1172	30.967	6.9872	0.31911	0.15955
23	9.0038	0.51736	8.6097	31.444	7.0248	0.32228	0.16114
24	9.5038	0.54687	9.1007	31.814	7.0628	0.32432	0.16216
25	10.004	0.576	9.5856	32.291	7.1006	0.32743	0.16371
26	10.504	0.60533	10.074	32.873	7.1392	0.33153	0.16577
27	11.004	0.63492	10.566	33.244	7.1785	0.33343	0.16672
28	11.504	0.66451	11.059	33.614	7.2182	0.33529	0.16765
29	12.004	0.69393	11.548	34.038	7.2582	0.33765	0.16882
30	12.504	0.72316	12.034	34.355	7.2983	0.33892	0.16946
31	13.004	0.75284	12.528	33.879	7.3395	0.33235	0.16617
32	13.504	0.78235	13.019	33.667	7.381	0.32842	0.16421
33	14.004	0.81158	13.506	33.72	7.4225	0.32709	0.16355
34	14.503	0.84099	13.995	33.773	7.4647	0.32575	0.16288
35	15.003	0.8704	14.485	33.667	7.5074	0.32288	0.16144
36	15.503	0.90009	14.979	33.561	7.5511	0.32001	0.16
37	15.558	0.90328	15.032	33.561	7.5558	0.31981	0.1599

UNCONFINED COMPRESSION TEST REPORT

Terracon
Consulting Engineers & Scientists



Symbol		⦶			
Test No.		HEN027S2			
Initial	Diameter, in	2.8106			
	Height, in	5.9756			
	Water Content, %	36.30			
	Dry Density, pcf	84.59			
	Saturation, %	98.00			
	Void Ratio	1.0075			
Unconfined Compressive Strength, tsf		1.0288			
Undrained Shear Strength, tsf		0.51438			
Time to Failure, min		10			
Strain Rate, %/min		1			
Estimated Specific Gravity		2.72			
Liquid Limit		---			
Plastic Limit		---			
Plasticity Index		---			
Failure Sketch					

Project: DYNERGY HENNEPIN
Location: HENNEPIN, IL
Project No.: MR155233
Boring No.: HEN027 S2
Sample Type: 3.0'' ST
Description: GRAY LEAN CLAY WITH SAND AND GRAVEL CL
Remarks: TEST PERFORMED AS PER ASTM D2166.

Tue, 22-DEC-2015 15:22:36

UNCONFINED COMPRESSION TEST

Project: DYNERGY HENNEPIN
Boring No.: HEN027 S2
Sample No.: ST-2
Test No.: HEN027S2

Location: HENNEPIN, IL
Tested By: BCM
Test Date: 12/15/15
Sample Type: 3.0" ST

Project No.: MR155233
Checked By: WPQ
Depth: 10.0'-12.0'
Elevation: ----

Soil Description: GRAY LEAN CLAY WITH SAND AND GRAVEL CL
Remarks: TEST PERFORMED AS PER ASTM D2166.

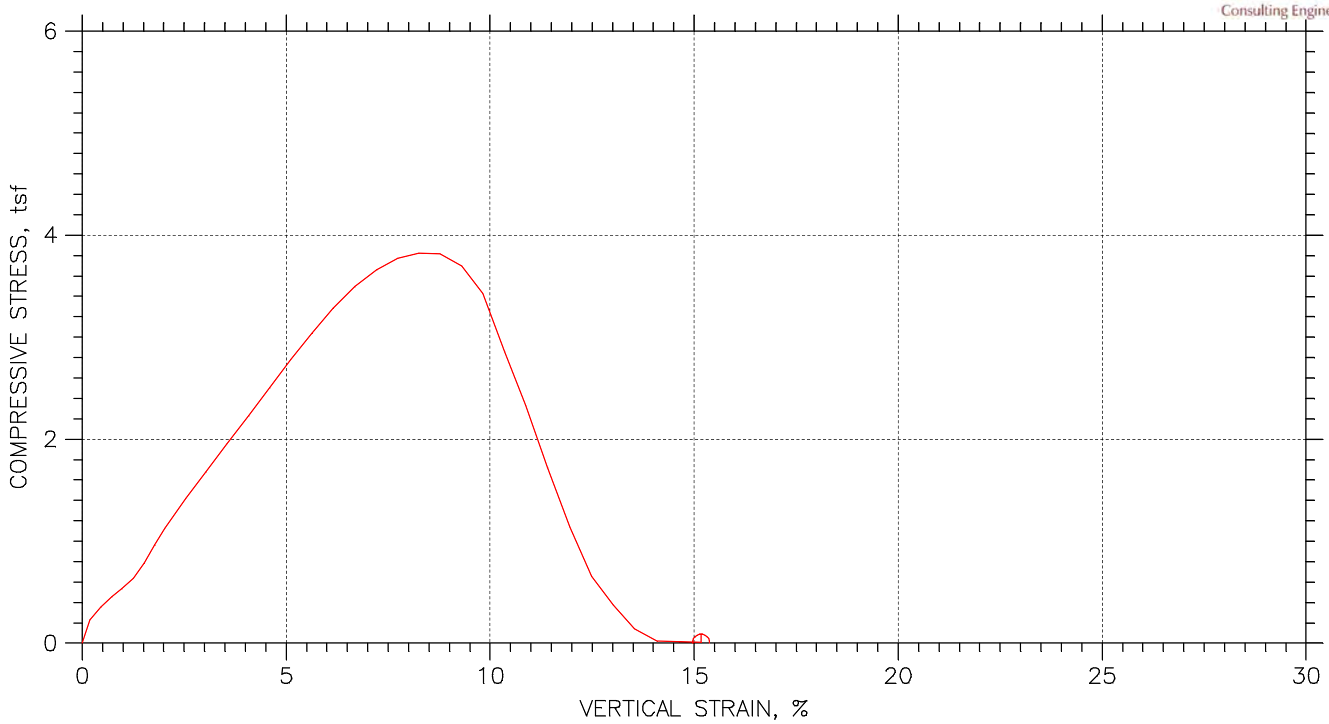
Specimen Height: 5.98 in
Specimen Area: 6.20 in^2
Specimen Volume: 37.07 in^3

Liquid Limit: ---
Plastic Limit: ---
Estimated Specific Gravity: 2.72

Cap Mass: 0 gm

	Time min	Axial Displacement in	Axial Strain %	Load lb	Corrected Area in^2	Vertical Stress tsf	Shear Stress tsf
1	0	0	0	0	6.2044	0	0
2	0.2501	0.0081295	0.13604	14.346	6.2128	0.16625	0.083125
3	0.5001	0.022196	0.37145	23.345	6.2275	0.2699	0.13495
4	0.7501	0.035806	0.59921	30.597	6.2418	0.35294	0.17647
5	1.0001	0.048959	0.81932	37.055	6.2556	0.42649	0.21324
6	1.2501	0.063392	1.0608	42.348	6.2709	0.48623	0.24311
7	1.5001	0.078098	1.3069	46.954	6.2865	0.53777	0.26888
8	1.7501	0.092895	1.5546	50.871	6.3023	0.58117	0.29058
9	2.0001	0.1076	1.8007	54.63	6.3181	0.62255	0.31127
10	2.5001	0.13729	2.2975	60.876	6.3503	0.69022	0.34511
11	3.0001	0.16633	2.7836	66.222	6.382	0.7471	0.37355
12	3.5001	0.19529	3.2681	70.934	6.414	0.79626	0.39813
13	4.0001	0.22443	3.7557	74.851	6.4465	0.836	0.418
14	4.5001	0.25411	4.2525	78.451	6.4799	0.87168	0.43584
15	5.0001	0.28353	4.7447	81.574	6.5134	0.90173	0.45086
16	5.5001	0.31266	5.2324	84.326	6.5469	0.92738	0.46369
17	6.0001	0.34189	5.7215	86.867	6.5809	0.9504	0.4752
18	6.5001	0.37158	6.2183	89.144	6.6158	0.97016	0.48508
19	7.0001	0.40136	6.7166	91.155	6.6511	0.98678	0.49339
20	7.5001	0.43095	7.2119	92.849	6.6866	0.99978	0.49989
21	8.0001	0.46018	7.701	94.437	6.722	1.0115	0.50576
22	8.5001	0.48941	8.1902	95.972	6.7578	1.0225	0.51126
23	9.0001	0.51892	8.6839	96.66	6.7944	1.0243	0.51215
24	9.5001	0.54851	9.1792	97.56	6.8314	1.0282	0.51412
25	10	0.57801	9.6729	98.143	6.8688	1.0288	0.51438
26	10.5	0.60733	10.164	98.09	6.9063	1.0226	0.51131
27	11	0.63675	10.656	97.878	6.9443	1.0148	0.50741
28	11.5	0.66625	11.15	97.296	6.9829	1.0032	0.5016
29	12	0.69557	11.64	95.919	7.0217	0.98355	0.49177
30	12.5	0.72507	12.134	93.749	7.0612	0.95592	0.47796
31	13	0.75412	12.62	91.155	7.1004	0.92433	0.46217
32	13.5	0.78353	13.112	88.826	7.1407	0.89564	0.44782
33	14	0.81313	13.608	86.444	7.1816	0.86665	0.43333
34	14.5	0.84254	14.1	83.321	7.2227	0.83058	0.41529
35	15	0.87214	14.595	78.345	7.2646	0.77648	0.38824
36	15.504	0.90191	15.093	71.834	7.3073	0.70779	0.3539
37	15.654	0.91086	15.243	69.716	7.3202	0.68572	0.34286

UNCONFINED COMPRESSION TEST REPORT



Symbol		①			
Test No.		HEN032S3			
Initial	Diameter, in	2.8303			
	Height, in	5.85			
	Water Content, %	14.10			
	Dry Density, pcf	115.8			
	Saturation, %	82.27			
	Void Ratio	0.46619			
Unconfined Compressive Strength, tsf		3.8231			
Undrained Shear Strength, tsf		1.9116			
Time to Failure, min		8.0041			
Strain Rate, %/min		1.14			
Estimated Specific Gravity		2.72			
Liquid Limit		35			
Plastic Limit		18			
Plasticity Index		17			
Failure Sketch					

Project: DYNERGY HENNEPIN
Location: HENNEPIN, IL
Project No.: MR155233
Boring No.: HEN032 S-3
Sample Type: 3.0'' ST
Description: DARK BROWNISH GRAY LEAN CLAY WITH SAND AND GRAVEL CL
Remarks: TEST PERFORMED AS PER ASTM D2166. 450

UNCONFINED COMPRESSION TEST

Project: DYNERGY HENNEPIN
Boring No.: HEN032 S-3
Sample No.: ST-3
Test No.: HEN032S3

Location: HENNEPIN, IL
Tested By: BCM
Test Date: 12/15/15
Sample Type: 3.0" ST

Project No.: MR155233
Checked By: WPQ
Depth: 5.0'-7.0'
Elevation: ----

Soil Description: DARK BROWNISH GRAY LEAN CLAY WITH SAND AND GRAVEL CL
Remarks: TEST PERFORMED AS PER ASTM D2166.

Specimen Height: 5.85 in
Specimen Area: 6.29 in^2
Specimen Volume: 36.81 in^3

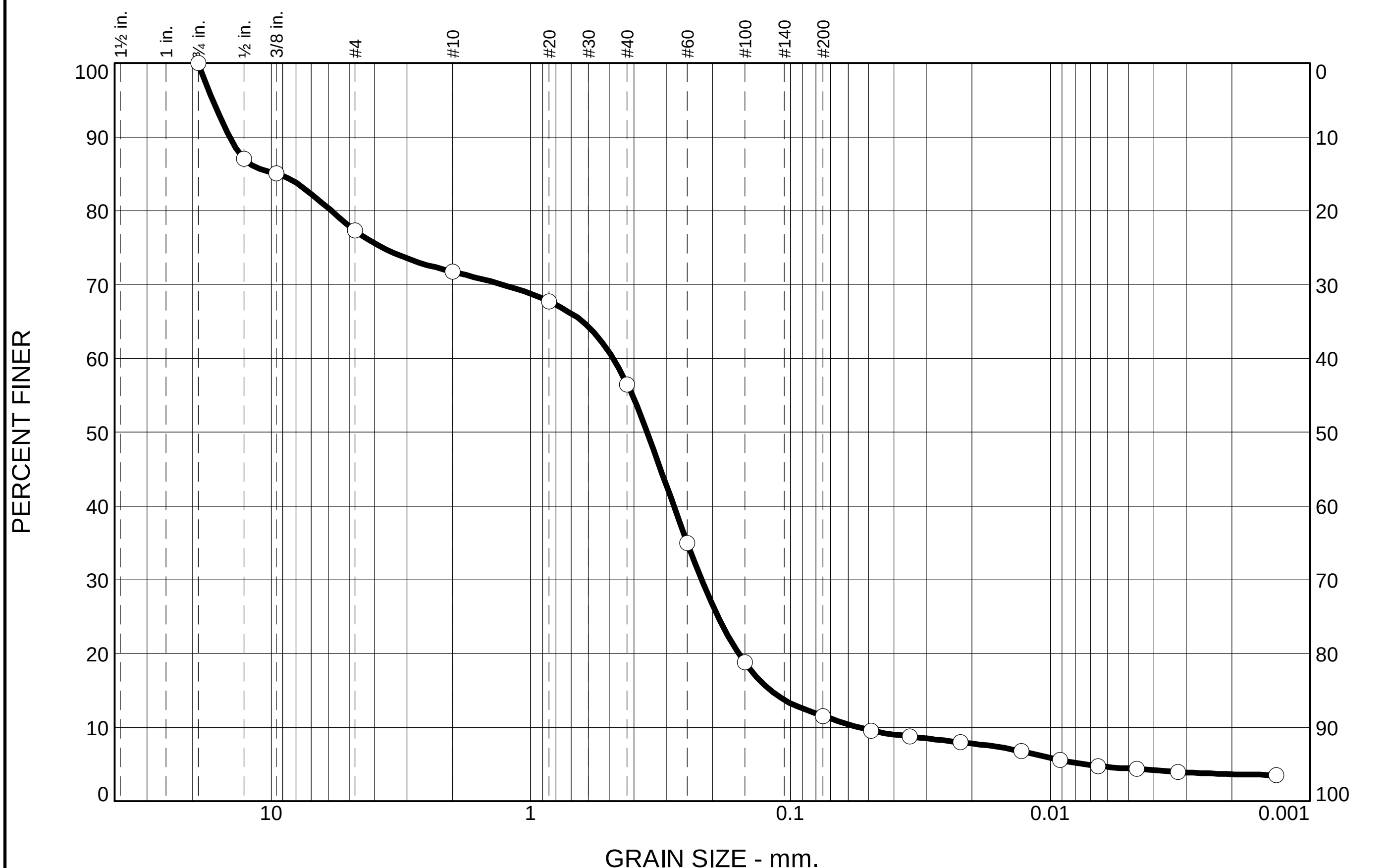
Liquid Limit: 35
Plastic Limit: 18
Estimated Specific Gravity: 2.72

Cap Mass: 0 gm

	Time min	Axial Displacement in	Axial Strain %	Load lb	Corrected Area in^2	Vertical Stress tsf	Shear Stress tsf
1	0	0	0	0	6.2916	0	0
2	0.25403	0.011115	0.18999	20.059	6.3036	0.22911	0.11456
3	0.50403	0.026602	0.45474	30.798	6.3203	0.35085	0.17543
4	0.75403	0.041999	0.71793	39.748	6.3371	0.45161	0.22581
5	1.004	0.057395	0.98111	47.382	6.3539	0.53692	0.26846
6	1.254	0.073065	1.249	56.543	6.3711	0.63899	0.31949
7	1.504	0.088735	1.5168	69.915	6.3885	0.78796	0.39398
8	1.7541	0.10358	1.7707	85.657	6.405	0.96289	0.48144
9	2.0041	0.11853	2.0261	100.35	6.4217	1.1251	0.56254
10	2.504	0.14841	2.5369	127.09	6.4553	1.4175	0.70875
11	3.004	0.17738	3.0321	151.41	6.4883	1.6802	0.8401
12	3.5041	0.20726	3.5429	176.95	6.5227	1.9532	0.97661
13	4.0041	0.23833	4.074	203.01	6.5588	2.2285	1.1143
14	4.5041	0.26903	4.5988	229.49	6.5949	2.5055	1.2527
15	5.0041	0.29937	5.1174	256.29	6.6309	2.7828	1.3914
16	5.5041	0.32943	5.6313	281.66	6.667	3.0418	1.5209
17	6.0041	0.36004	6.1545	305.56	6.7042	3.2816	1.6408
18	6.5041	0.39092	6.6825	327.41	6.7421	3.4965	1.7482
19	7.0041	0.42172	7.2089	344.52	6.7804	3.6584	1.8292
20	7.5041	0.45215	7.729	357.32	6.8186	3.773	1.8865
21	8.0041	0.48248	8.2476	364.11	6.8571	3.8231	1.9116
22	8.5041	0.51319	8.7724	365.79	6.8966	3.8189	1.9094
23	9.0041	0.54443	9.3066	356.58	6.9372	3.7009	1.8504
24	9.5041	0.57495	9.8283	332.2	6.9773	3.428	1.714
25	10.004	0.60556	10.352	278.29	7.0181	2.8551	1.4275
26	10.504	0.63636	10.878	228.38	7.0595	2.3293	1.1646
27	11.004	0.66724	11.406	169.79	7.1016	1.7214	0.8607
28	11.504	0.69895	11.948	113.14	7.1453	1.14	0.57002
29	12.004	0.73056	12.488	65.651	7.1894	0.65748	0.32874
30	12.504	0.76144	13.016	37.169	7.233	0.36999	0.185
31	13.004	0.79242	13.546	14.32	7.2773	0.14168	0.070839
32	13.504	0.82403	14.086	2.3165	7.3231	0.022775	0.011388
33	14.004	0.85619	14.636	1.5794	7.3703	0.015429	0.0077146
34	14.503	0.88735	15.168	0.7897	7.4165	0.0076665	0.0038332

Particle Size Analysis of Soils
ASTM D 422

PARTICLE SIZE ANALYSIS OF SOILS ASTM D422



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	22.7	5.6	15.2	44.9	7.2	4.4

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
.75	100.0		
.5	87.0		
.375	85.1		
#4	77.3		
#10	71.7		
#20	67.7		
#40	56.5		
#60	35.0		
#100	18.8		
#200	11.6		

* (no specification provided)

BROWN POORLY GRADED SAND WITH SILT AND GRAVEL

Atterberg Limits

PL= LL= PI=

Coefficients

D_{90}= 14.4606 D_{85}= 9.3898 D_{60}= 0.4813
D_{50}= 0.3560 D_{30}= 0.2199 D_{15}= 0.1189
D_{10}= 0.0546 C_u= 8.82 C_c= 1.84

Classification

USCS= SP-SM AASHTO=

Remarks

F.M.=2.70

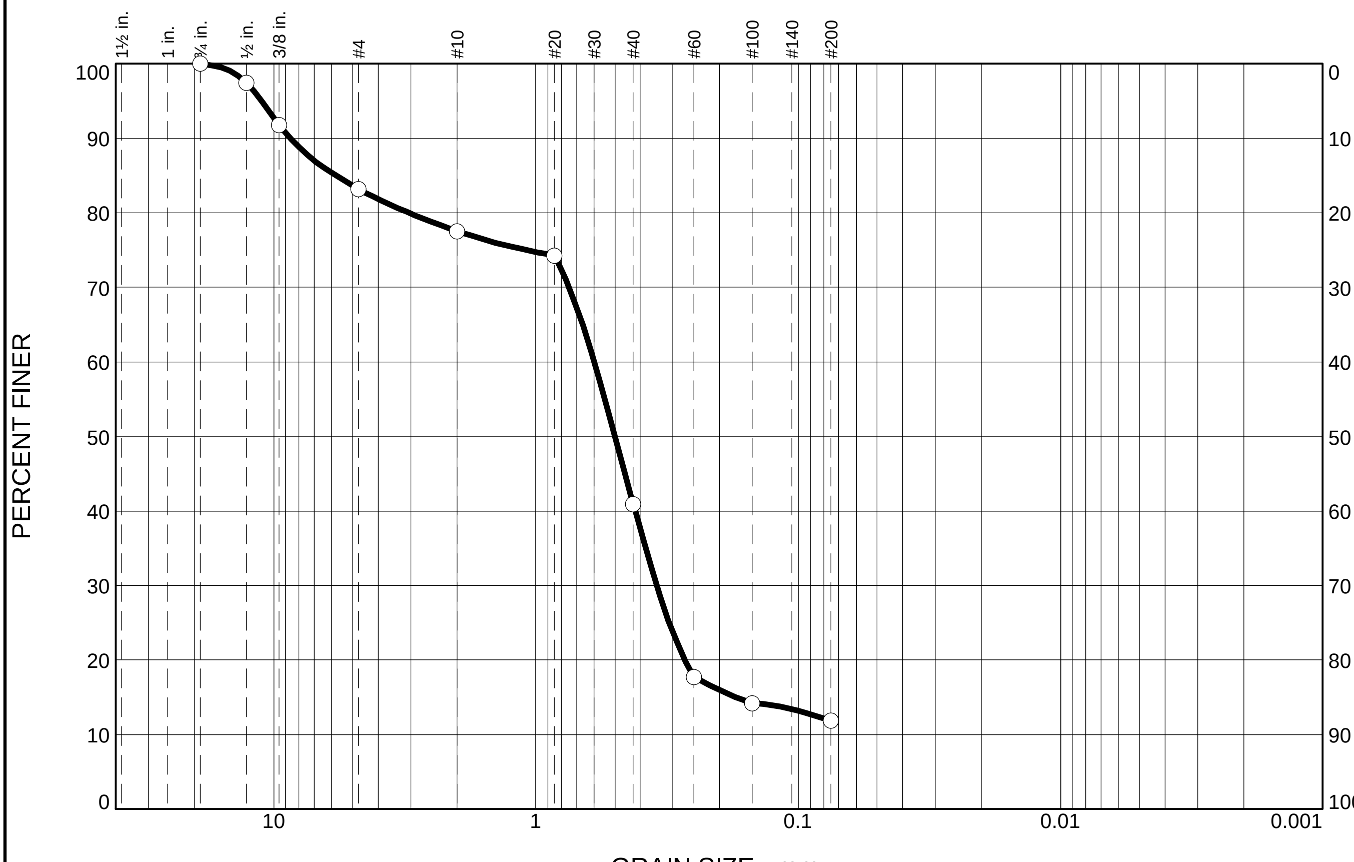
Source of Sample: HEN-B002 **Depth:** 15.0'-16.5'
Sample Number: S-6 **Date:** 12-4-15

Terracon

Client: AECOM
Project: DYNERGY - HENNEPIN
Project No: MR155233 **Figure**

Tested By: SJH **Checked By:** WPQ

PARTICLE SIZE ANALYSIS OF SOILS ASTM D422



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	16.8	5.7	36.6	29.0	11.9	

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
.75	100.0		
.5	97.4		
.375	91.8		
#4	83.2		
#10	77.5		
#20	74.3		
#40	40.9		
#60	17.7		
#100	14.2		
#200	11.9		

* (no specification provided)

BROWN POORLY GRADED SAND WITH SILT AND GRAVEL

Atterberg Limits

PL= LL= PI=

Coefficients

D_{90}= 8.6465 D_{85}= 5.7731 D_{60}= 0.6002
D_{50}= 0.4992 D_{30}= 0.3457 D_{15}= 0.1731
D_{10}= C_u= C_c=

Classification

USCS= SP-SM AASHTO=

Remarks

F.M.=2.74

Source of Sample: HEN-B002 **Depth:** 55.0'-56.5'
Sample Number: S-14 **Date:** 11-25-15

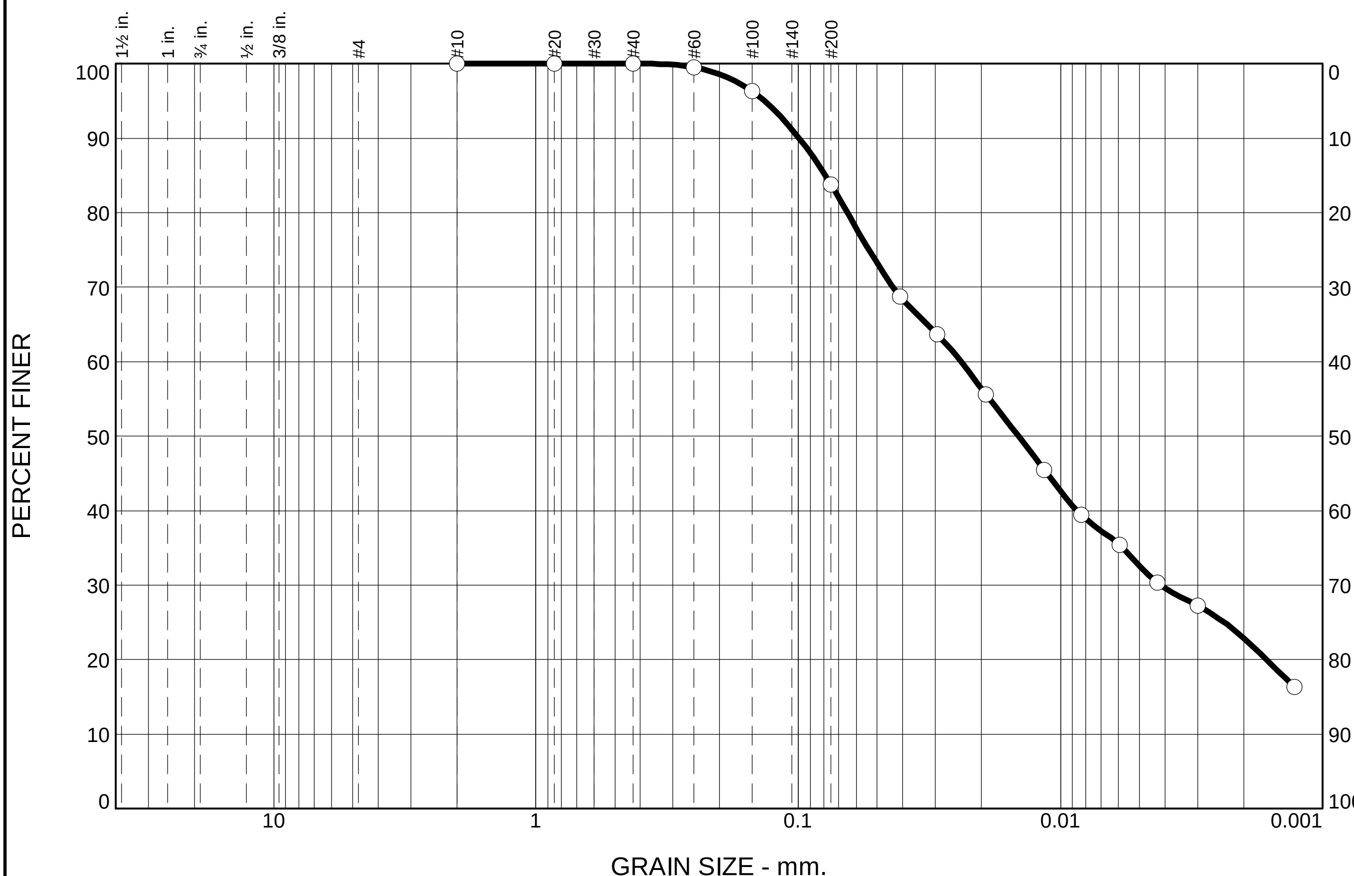
Terracon

Client: AECOM
Project: DYNERGY - HENNEPIN

Project No: MR155233 **Figure**

Tested By: SJH **Checked By:** WPQ

PARTICLE SIZE ANALYSIS OF SOILS ASTM D422



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	0.0	0.0	0.0	16.2	51.2	32.6

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
#10	100.0		
#20	100.0		
#40	100.0		
#60	99.5		
#100	96.3		
#200	83.8		

* (no specification provided)

DARK GRAY LEAN CLAY WITH SAND AND FLY ASH

Atterberg Limits

PL= 24 LL= 43 PI= 19

Coefficients

D_{90}= 0.0992 D_{85}= 0.0788 D_{60}= 0.0240
D_{50}= 0.0145 D_{30}= 0.0042 D_{15}=
D_{10}= C_u= C_c=

Classification

USCS= CL AASHTO= A-7-6(17)

Remarks

F.M.=0.04

Source of Sample: HEN-B005 **Depth:** 12.5'-14.5'
Sample Number: S-4

Date: 12-17-15

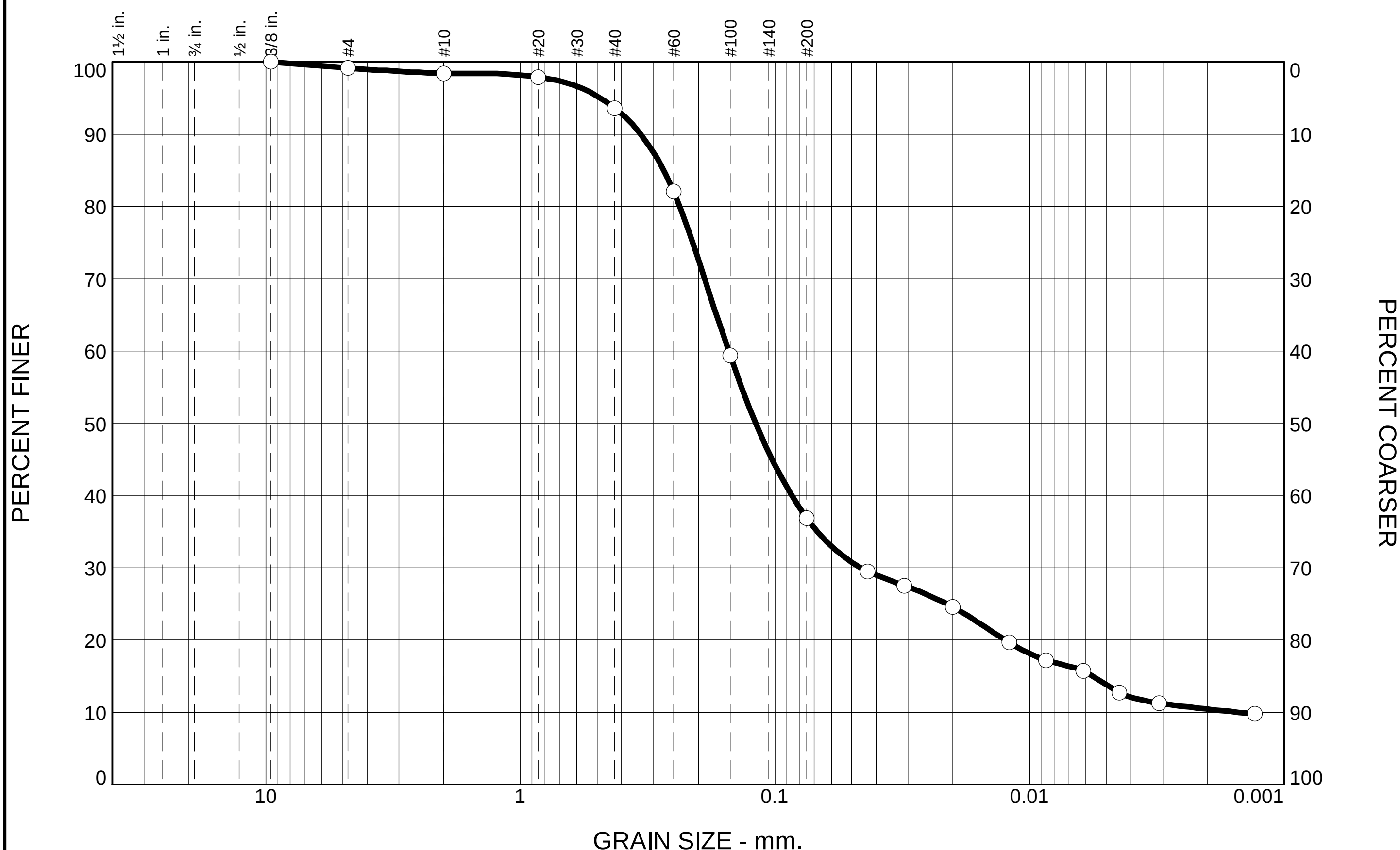
Terracon

Client: AECOM
Project: DYNERGY - HENNEPIN

Project No: MR155233 **Figure**

Tested By: SJH **Checked By:** WPQ

PARTICLE SIZE ANALYSIS OF SOILS ASTM D422



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	0.8	0.8	4.8	56.7	23.1	13.8

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
.375	100.0		
#4	99.2		
#10	98.4		
#20	97.9		
#40	93.6		
#60	82.0		
#100	59.4		
#200	36.9		

* (no specification provided)

BROWN SILTY SAND

Atterberg Limits

PL= LL= PI=

Coefficients

D_{90}= 0.3360 D_{85}= 0.2738 D_{60}= 0.1522
D_{50}= 0.1189 D_{30}= 0.0460 D_{15}= 0.0056
D_{10}= 0.0015 C_u= 99.90 C_c= 9.12

Classification

USCS= SM AASHTO=

Remarks

F.M.=0.61

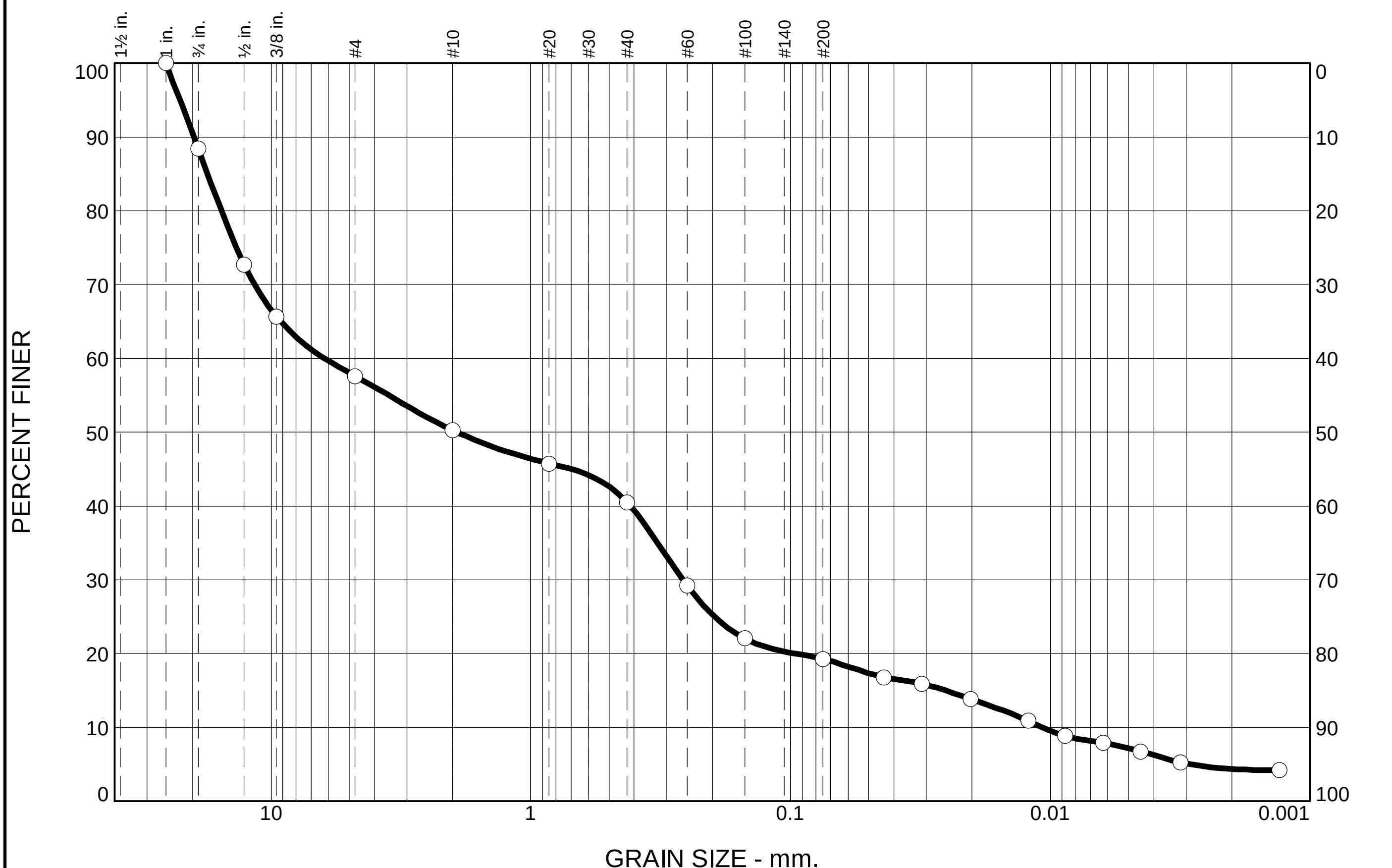
Source of Sample: HEN-B006 **Depth:** 15.0'-16.5'
Sample Number: S-6 **Date:** 12-4-15

Terracon

Client: AECOM
Project: DYNERGY - HENNEPIN
Project No: MR155233 **Figure**

Tested By: SJH **Checked By:** WPQ

PARTICLE SIZE ANALYSIS OF SOILS ASTM D422



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	11.6	30.8	7.3	9.8	21.2	12.1	7.2

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
1	100.0		
.75	88.4		
.5	72.7		
.375	65.7		
#4	57.6		
#10	50.3		
#20	45.7		
#40	40.5		
#60	29.2		
#100	22.1		
#200	19.3		

* (no specification provided)

LIGHT BROWN SILTY GRAVEL WITH SAND

Atterberg Limits

PL= LL= PI=

Coefficients

D_{90}= 19.7935 D_{85}= 17.5429 D_{60}= 6.2349
D_{50}= 1.9279 D_{30}= 0.2598 D_{15}= 0.0252
D_{10}= 0.0107 C_u= 583.74 C_c= 1.01

Classification

USCS= GM AASHTO=

Remarks

F.M.=3.90

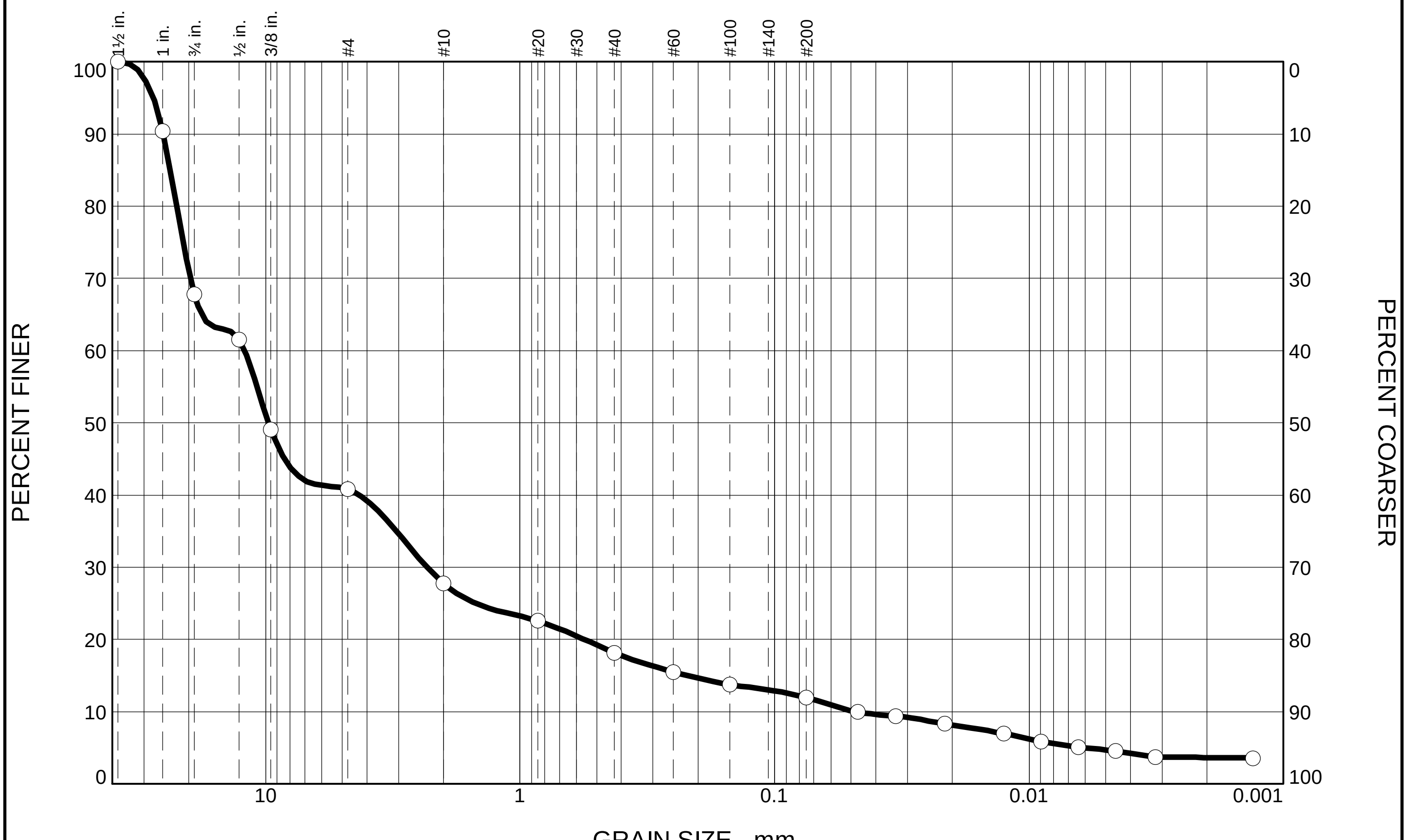
Source of Sample: HEN-B006 **Depth:** 30.0'-31.5'
Sample Number: S-9 **Date:** 12-9-15

Terracon

Client: AECOM
Project: DYNERGY - HENNEPIN
Project No: MR155233 **Figure**

Tested By: SJH **Checked By:** WPQ

PARTICLE SIZE ANALYSIS OF SOILS ASTM D422



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	32.2	27.0	13.0	9.6	6.3	7.2	4.7

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
1.50	100.0		
1	90.4		
.75	67.8		
.5	61.5		
.375	49.0		
#4	40.8		
#10	27.8		
#20	22.6		
#40	18.2		
#60	15.5		
#100	13.8		
#200	11.9		

* (no specification provided)

BROWN GRAVEL WITH POORLY GRADED SAND AND SILT

Atterberg Limits

PL= LL= PI=

Coefficients

D_{90}= 25.2429 D_{85}= 23.6694 D_{60}= 12.0960
D_{50}= 9.7410 D_{30}= 2.3148 D_{15}= 0.2213
D_{10}= 0.0481 C_u= 251.61 C_c= 9.21

Classification

USCS= GP AASHTO=

Remarks

F.M.=5.38

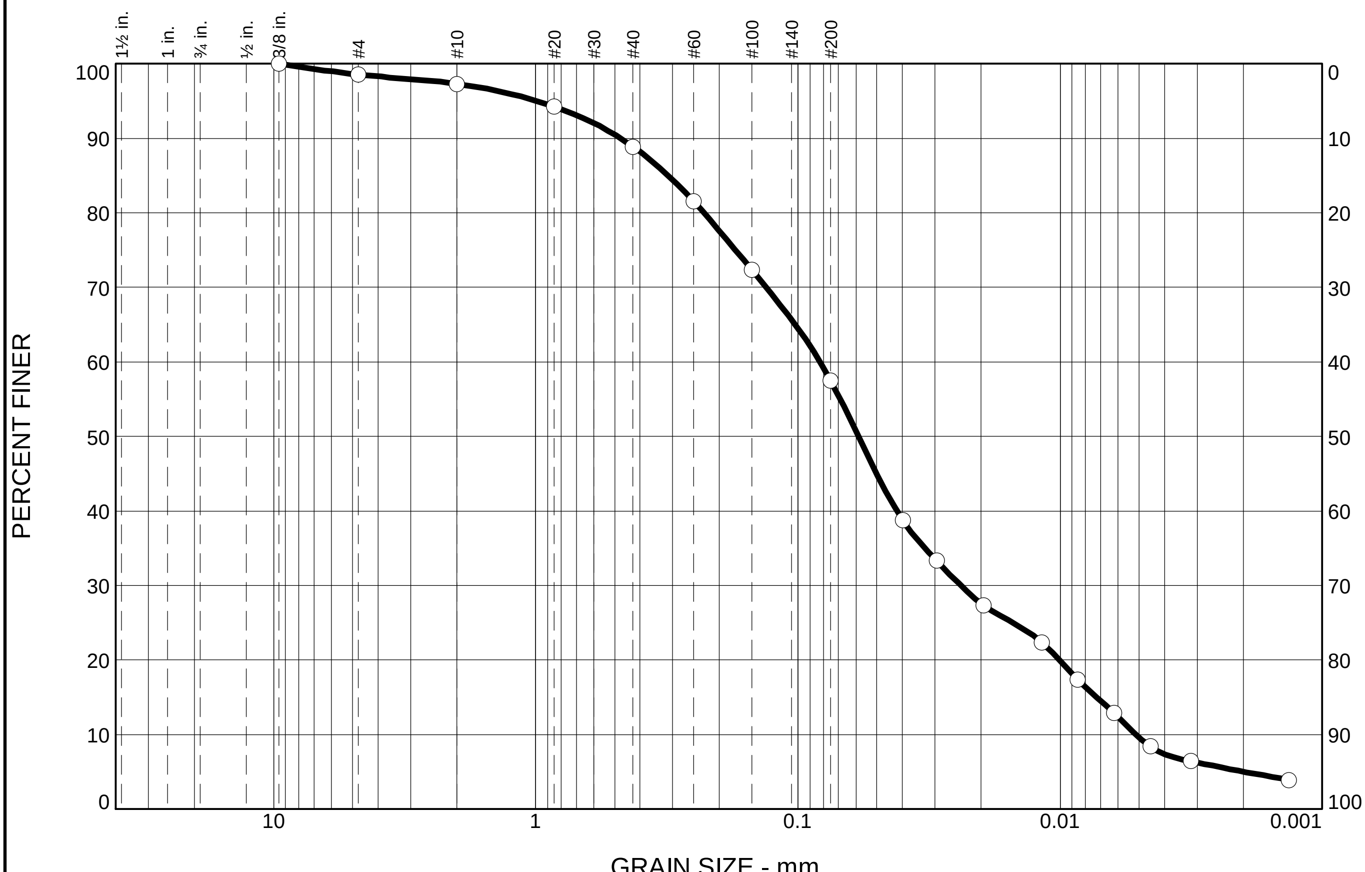
Source of Sample: HEN-B007 **Depth:** 15.0'-16.5'
Sample Number: S-6 **Date:** 12-9-15

Terracon

Client: AECOM
Project: DYNERGY - HENNEPIN
Project No: MR155233 **Figure**

Tested By: SJH **Checked By:** WPQ

PARTICLE SIZE ANALYSIS OF SOILS ASTM D422



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	1.5	1.2	8.4	31.4	47.9	9.6

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
.375	100.0		
#4	98.5		
#10	97.3		
#20	94.2		
#40	88.9		
#60	81.6		
#100	72.3		
#200	57.5		

* (no specification provided)

DARK GRAY TO BLACK SANDY SILT

Atterberg Limits

PL= LL= PI=

Coefficients

D_{90}= 0.4739 D_{85}= 0.3125 D_{60}= 0.0824
D_{50}= 0.0587 D_{30}= 0.0239 D_{15}= 0.0073
D_{10}= 0.0051 C_u= 16.02 C_c= 1.35

Classification

USCS= ML AASHTO=

Remarks

F.M.=0.59

Source of Sample: HEN-B008 **Depth:** 5.0'-6.5'
Sample Number: S-3 **Date:** 12-4-15

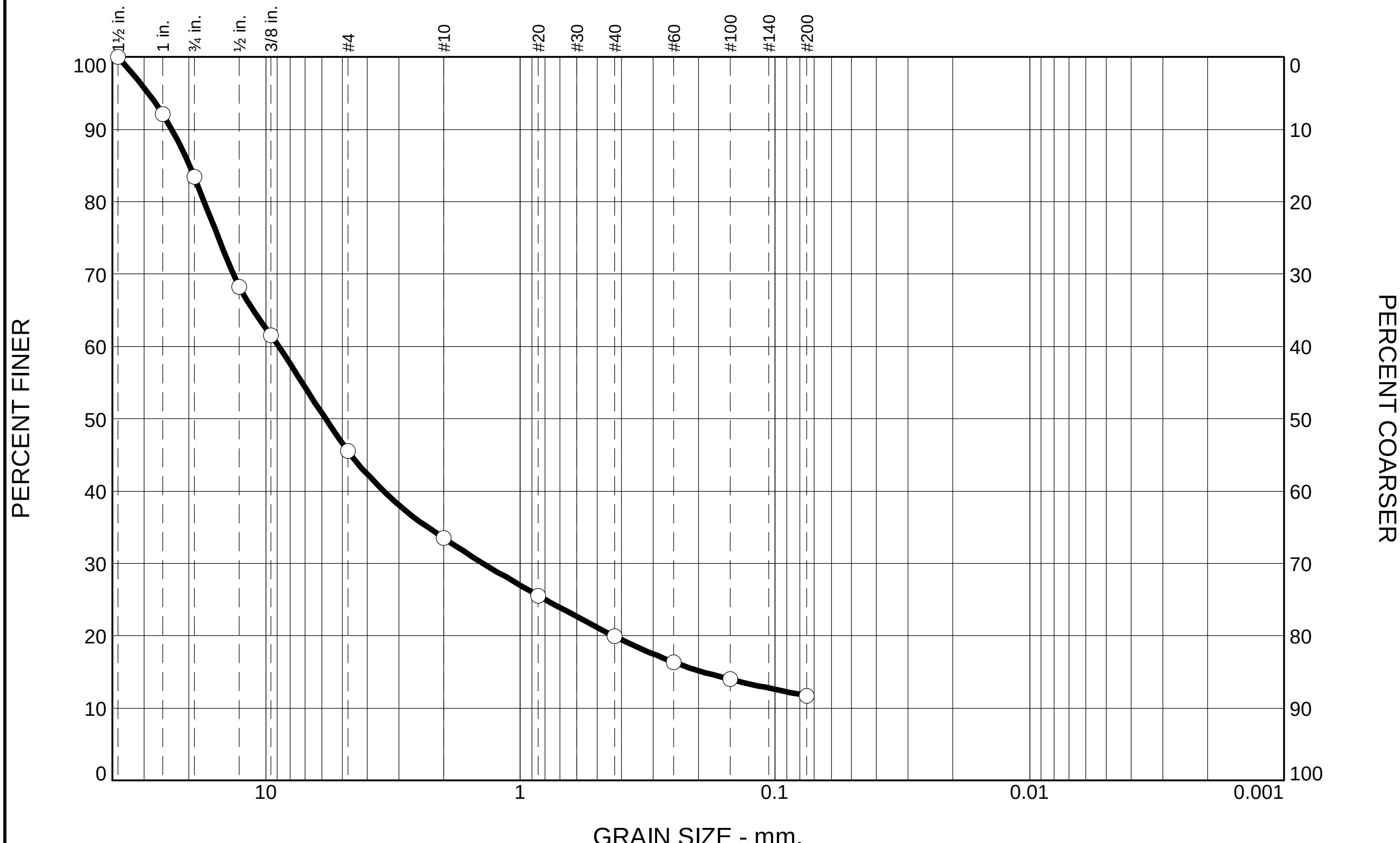
Terracon

Client: AECOM
Project: DYNERGY - HENNEPIN

Project No: MR155233 **Figure**

Tested By: SJH **Checked By:** WPQ

PARTICLE SIZE ANALYSIS OF SOILS ASTM D422



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	16.6	37.8	12.1	13.6	8.2	11.7	

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
1.5	100.0		
1	92.1		
.75	83.4		
.5	68.3		
.375	61.5		
#4	45.6		
#10	33.5		
#20	25.6		
#40	19.9		
#60	16.3		
#100	14.0		
#200	11.7		

* (no specification provided)

BROWN POORLY GRADED GRAVEL WITH SILT AND SAND

Atterberg Limits

PL= LL= PI=

Coefficients

D_{90}= 23.4043 D_{85}= 19.9202 D_{60}= 8.8946
D_{50}= 5.8205 D_{30}= 1.3976 D_{15}= 0.1913
D_{10}= C_u= C_c=

Classification

USCS= GP-GM AASHTO=

Remarks

F.M.=4.92

Source of Sample: HEN-B008 **Depth:** 20.0'-21.5'
Sample Number: S-7

Date: 11-25-15

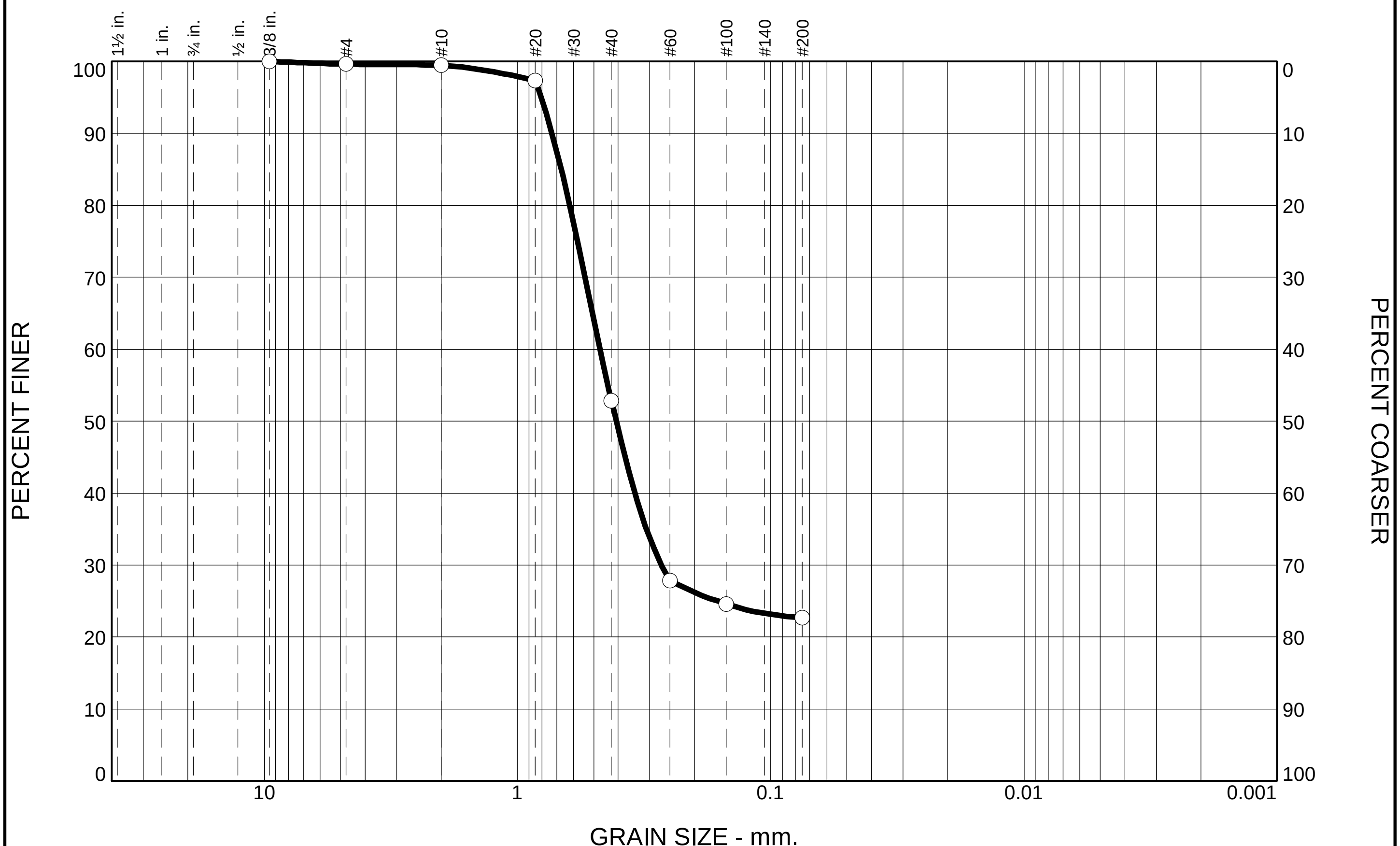
Terracon

Client: AECOM
Project: DYNERGY - HENNEPIN

Project No: MR155233 **Figure**

Tested By: SJH **Checked By:** WPQ

PARTICLE SIZE ANALYSIS OF SOILS ASTM D422



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	0.4	0.1	46.7	30.1	22.7	

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
.375	100.0		
#4	99.6		
#10	99.5		
#20	97.4		
#40	52.8		
#60	27.9		
#100	24.6		
#200	22.7		

* (no specification provided)

BROWN SILTY SAND

Atterberg Limits

PL= LL= PI=

Coefficients

D_{90}= 0.7292 D_{85}= 0.6712 D_{60}= 0.4713
D_{50}= 0.4071 D_{30}= 0.2705 D_{15}=
D_{10}= C_u= C_c=

Classification

USCS= SM AASHTO=

Remarks

F.M.=1.67

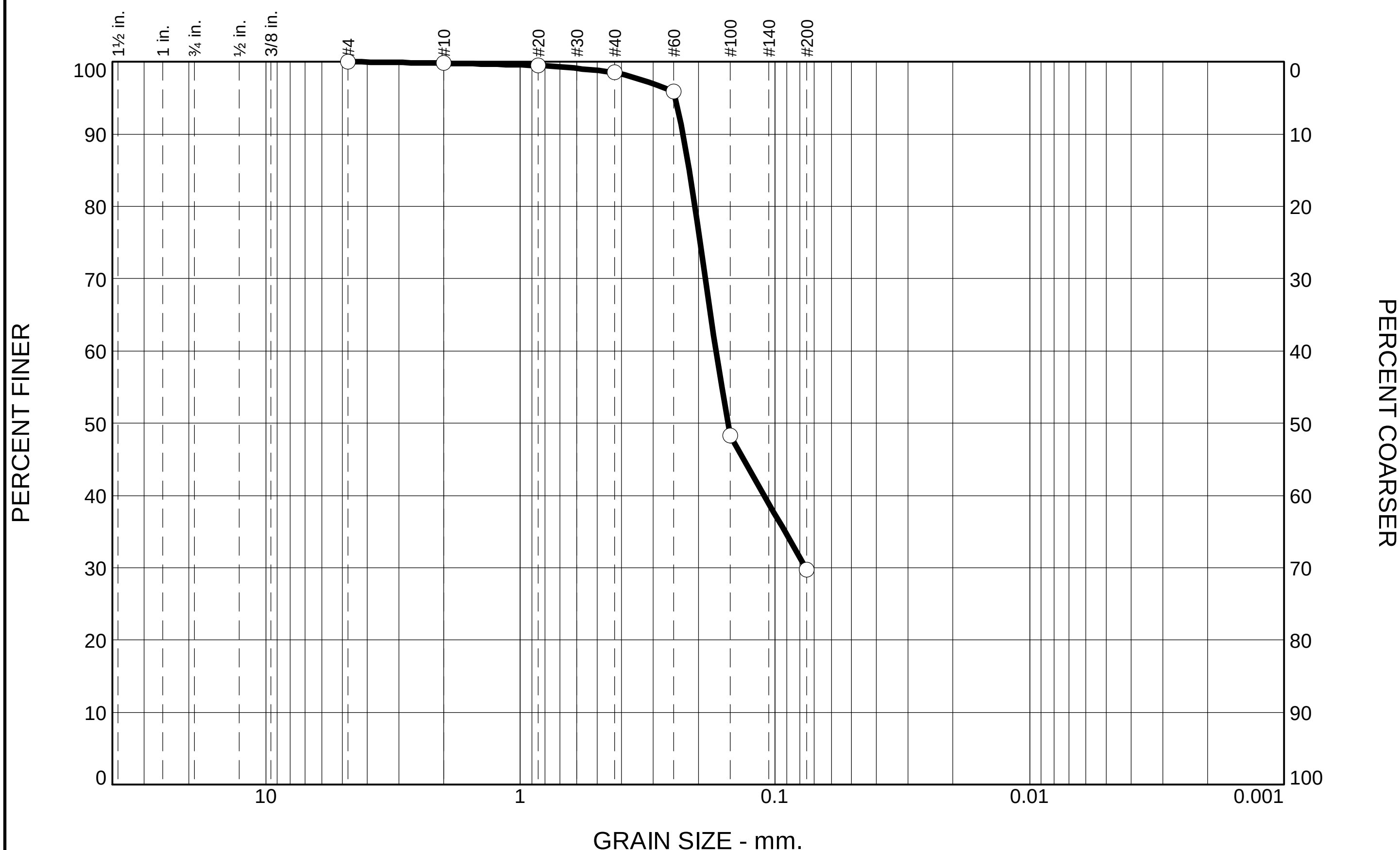
Source of Sample: HEN-B009 **Depth:** 25.0'-26.5'
Sample Number: S-8 **Date:** 11-25-15

Terracon

Client: AECOM
Project: DYNERGY - HENNEPIN
Project No: MR155233 **Figure**

Tested By: SJH **Checked By:** WPQ

PARTICLE SIZE ANALYSIS OF SOILS ASTM D422



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	0.0	0.2	1.3	68.8	29.7	

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
#4	100.0		
#10	99.8		
#20	99.5		
#40	98.5		
#60	95.9		
#100	48.3		
#200	29.7		

* (no specification provided)

BROWN SILTY SAND

Atterberg Limits

PL= LL= PI=

Coefficients

D_{90}= 0.2298 D_{85}= 0.2170 D_{60}= 0.1702
D_{50}= 0.1531 D_{30}= 0.0759 D_{15}=
D_{10}= C_u= C_c=

Classification

USCS= SM AASHTO=

Remarks

F.M.=0.56

Source of Sample: HEN-B009 **Depth:** 40.0'-41.5'
Sample Number: S-11

Date: 11-25-15

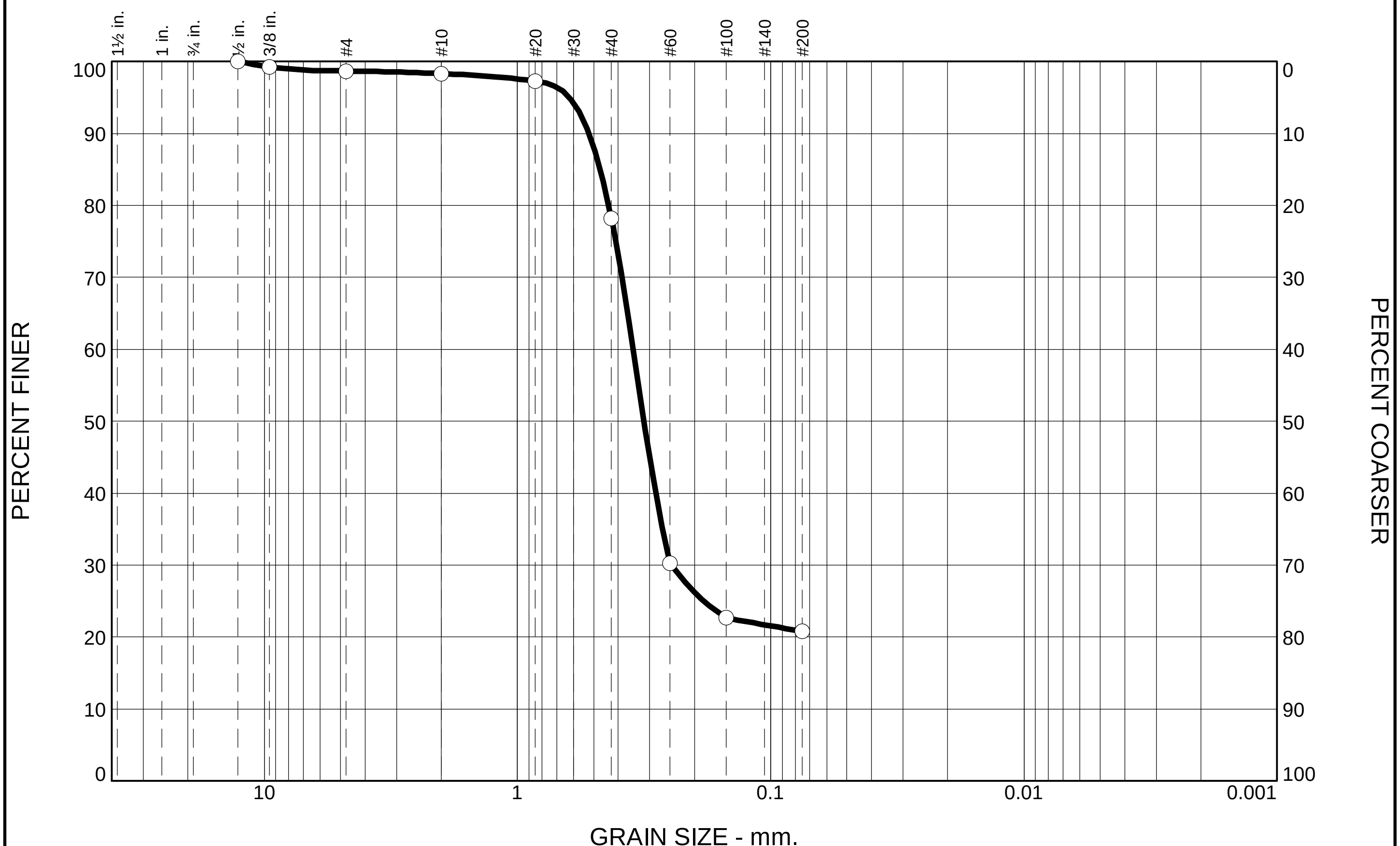
Terracon

Client: AECOM
Project: DYNERGY - HENNEPIN

Project No: MR155233 **Figure**

Tested By: SJH **Checked By:** WPQ

PARTICLE SIZE ANALYSIS OF SOILS ASTM D422



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	1.3	0.4	20.1	57.4	20.8	

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
.50	100.0		
.375	99.2		
#4	98.7		
#10	98.3		
#20	97.3		
#40	78.2		
#60	30.2		
#100	22.7		
#200	20.8		

* (no specification provided)

BROWN AND DARK BROWN SILTY SAND

Atterberg Limits

PL= LL= PI=

Coefficients

D_{90}= 0.5217 D_{85}= 0.4703 D_{60}= 0.3489
D_{50}= 0.3162 D_{30}= 0.2471 D_{15}=
D_{10}= C_u= C_c=

Classification

USCS= SM AASHTO=

Remarks

F.M.=1.44

Source of Sample: HEN-B010 **Depth:** 7.5'-9.0'
Sample Number: S-4

Date: 11-25-15

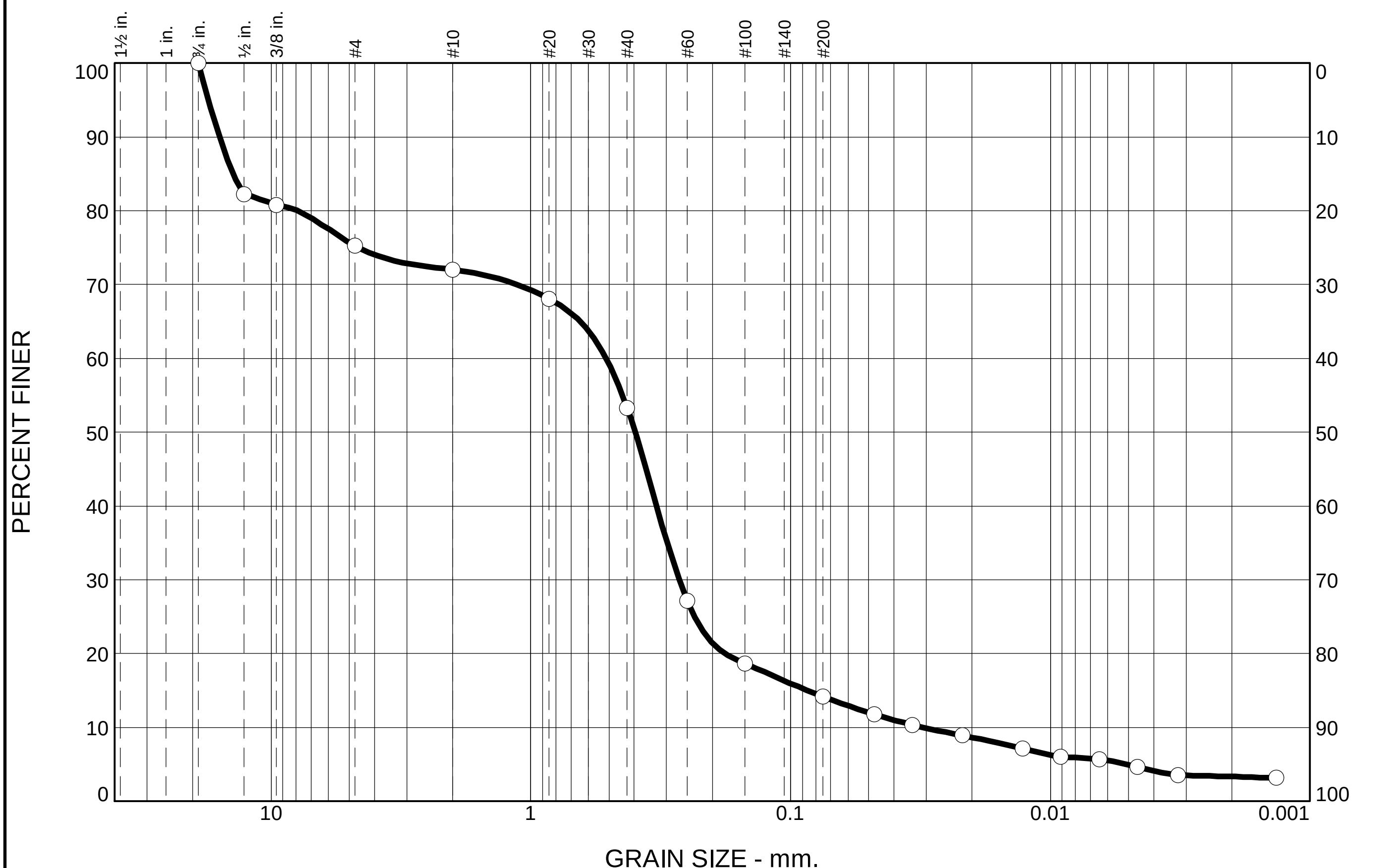
Terracon

Client: AECOM
Project: DYNERGY - HENNEPIN

Project No: MR155233 **Figure**

Tested By: SJH **Checked By:** WPQ

PARTICLE SIZE ANALYSIS OF SOILS ASTM D422



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	24.8	3.2	18.7	39.1	9.3	4.9

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
.75	100.0		
.5	82.2		
.375	80.7		
#4	75.2		
#10	72.0		
#20	68.1		
#40	53.3		
#60	27.1		
#100	18.7		
#200	14.2		

* (no specification provided)

BROWN TO DARK BROWN POORLY GRADED SAND WITH SILT AND GRAVEL

Atterberg Limits

PL= LL= PI=

Coefficients

D_{90}= 15.7800 D_{85}= 14.0146 D_{60}= 0.5125
D_{50}= 0.3959 D_{30}= 0.2684 D_{15}= 0.0861
D_{10}= 0.0310 C_u= 16.55 C_c= 4.54

Classification

USCS= SP-SM AASHTO=

Remarks

F.M.=2.84

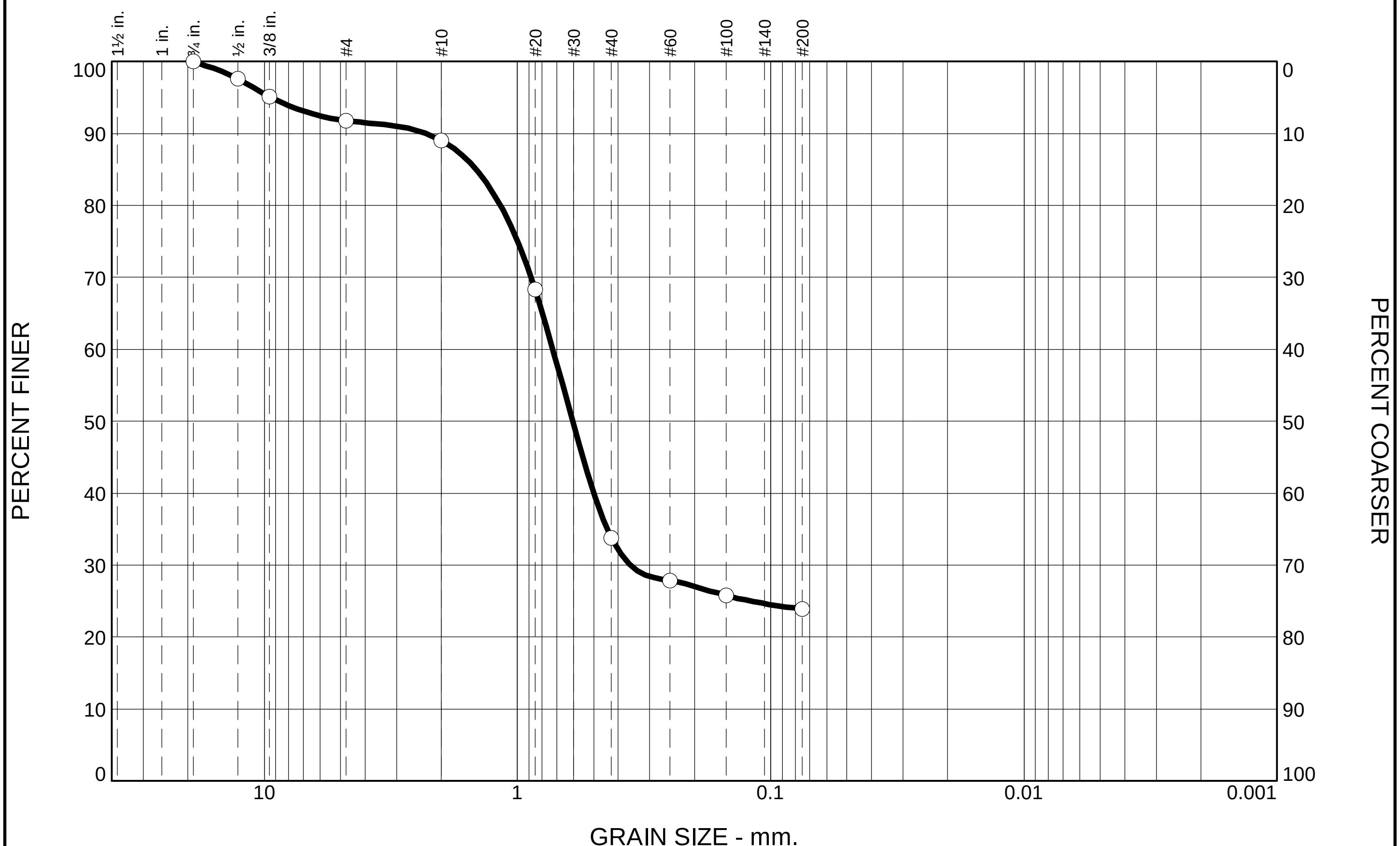
Source of Sample: HEN-B010 **Depth:** 20.0'-21.5'
Sample Number: S-7 **Date:** 12-4-15

Terracon

Client: AECOM
Project: DYNERGY - HENNEPIN
Project No: MR155233 **Figure**

Tested By: SJH **Checked By:** WPQ

PARTICLE SIZE ANALYSIS OF SOILS ASTM D422



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	8.2	2.8	55.2	9.9	23.9	

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
.75	100.0		
.5	97.6		
.375	95.1		
#4	91.8		
#10	89.0		
#20	68.3		
#40	33.8		
#60	27.9		
#100	25.8		
#200	23.9		

* (no specification provided)

BROWN SILTY SAND WITH GRAVEL

Atterberg Limits

PL= LL= PI=

Coefficients

D_{90}= 2.3059 D_{85}= 1.4549 D_{60}= 0.7240
D_{50}= 0.6053 D_{30}= 0.3582 D_{15}=
D_{10}= C_u= C_c=

Classification

USCS= SM AASHTO=

Remarks

F.M.=2.39

Source of Sample: HEN-B010 **Depth:** 40.0'-41.5'
Sample Number: S-11

Date: 11-25-15

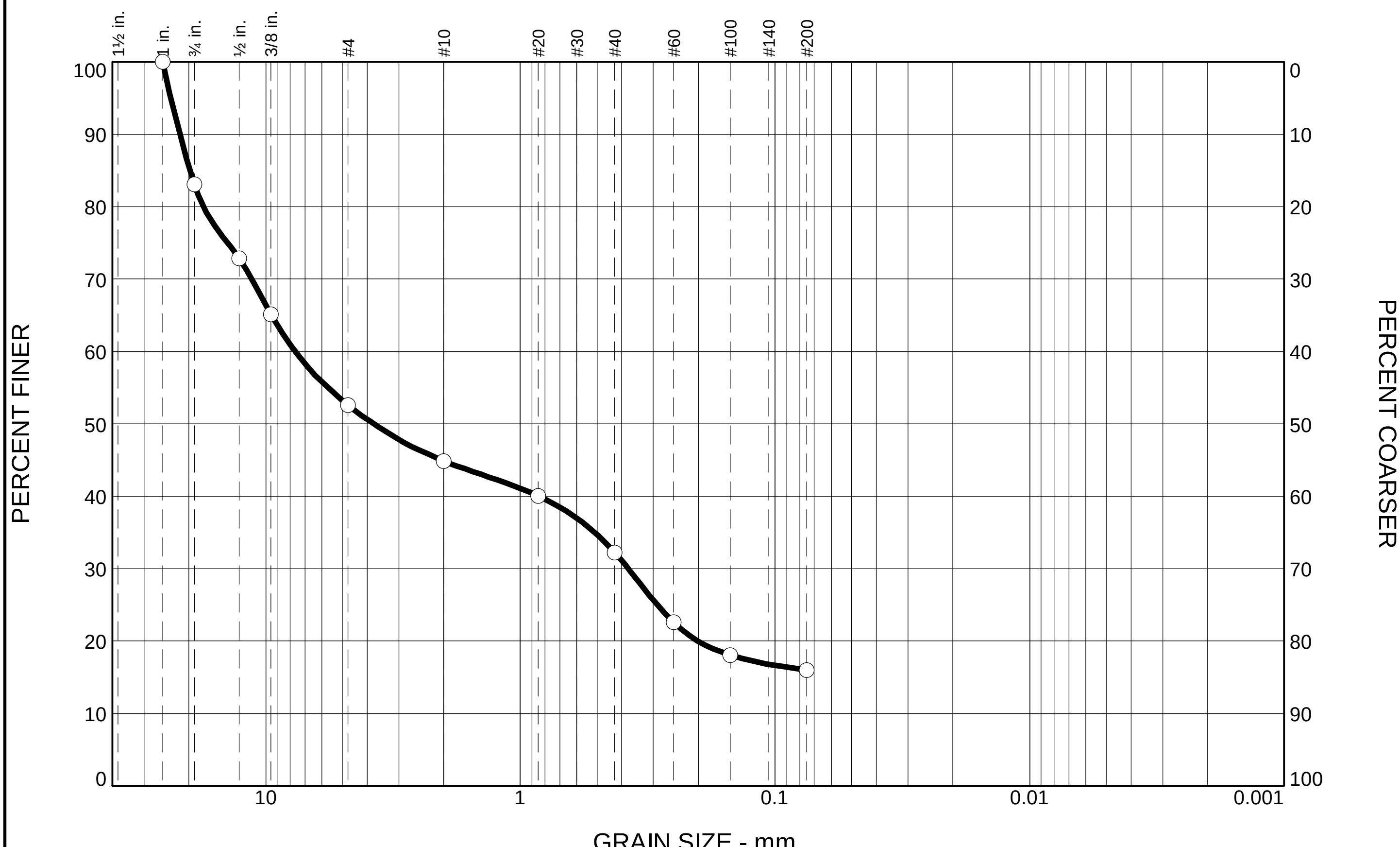
Terracon

Client: AECOM
Project: DYNERGY - HENNEPIN

Project No: MR155233 **Figure**

Tested By: SJH **Checked By:** WPQ

PARTICLE SIZE ANALYSIS OF SOILS ASTM D422



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	16.9	30.5	7.7	12.7	16.2	16.0	

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
1	100.0		
.75	83.1		
.5	72.9		
.375	65.1		
#4	52.6		
#10	44.9		
#20	40.0		
#40	32.2		
#60	22.6		
#100	18.1		
#200	16.0		

* (no specification provided)

BROWN SILTY GRAVEL WITH SAND

Atterberg Limits

PL= LL= PI=

Coefficients

D_{90}= 21.7378 D_{85}= 19.8442 D_{60}= 7.6494
D_{50}= 3.7604 D_{30}= 0.3762 D_{15}=
D_{10}= C_u= C_c=

Classification

USCS= GM AASHTO=

Remarks

F.M.=4.30

Source of Sample: HEN-B011 **Depth:** 15.0'-16.5'
Sample Number: S-6 **Date:** 11-25-15

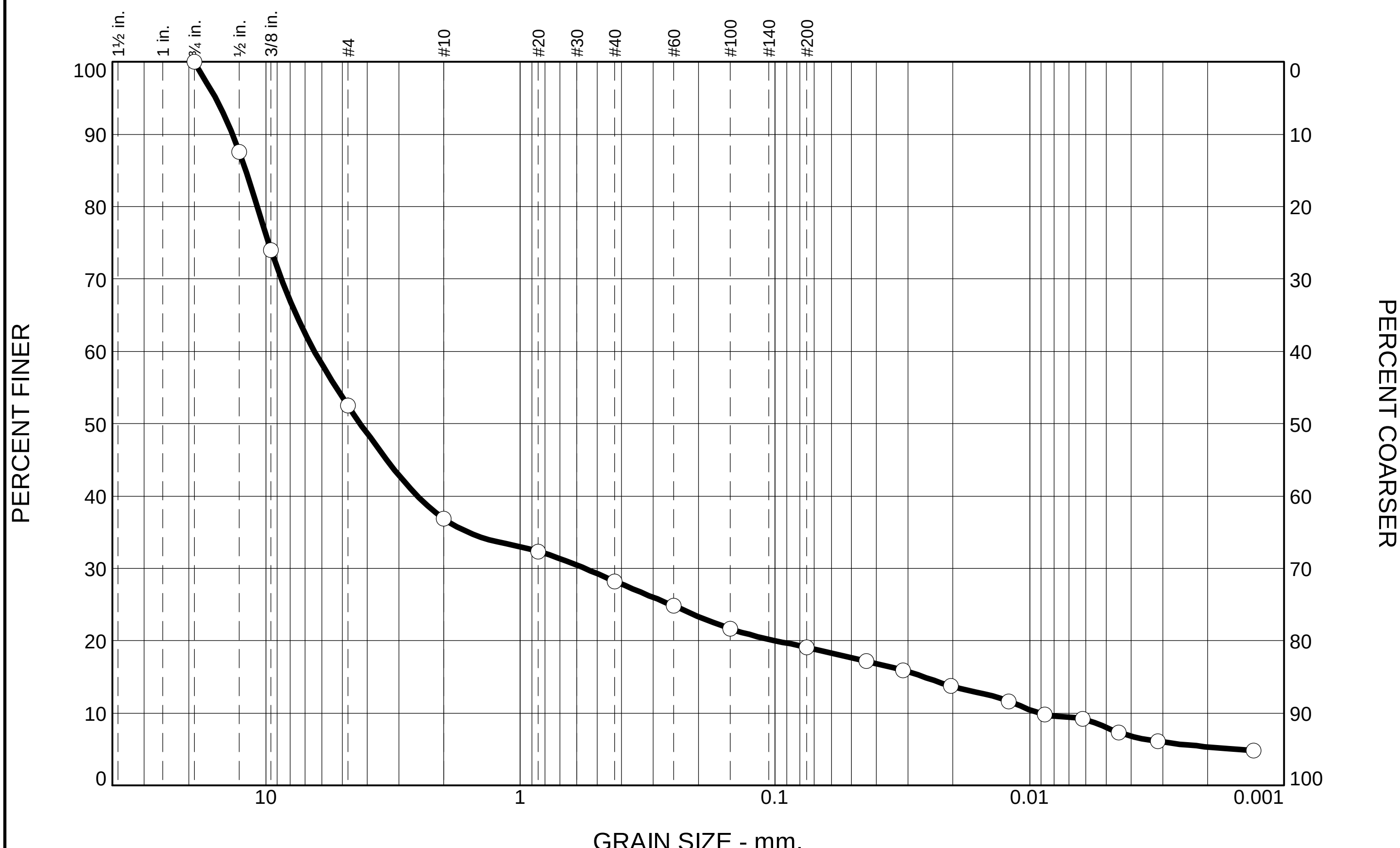
Terracon

Client: AECOM
Project: DYNERGY - HENNEPIN

Project No: MR155233 **Figure**

Tested By: SJH **Checked By:** WPQ

PARTICLE SIZE ANALYSIS OF SOILS ASTM D422



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	47.5	15.6	8.7	9.1	11.1	8.0

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
.75	100.0		
.5	87.6		
.375	74.0		
#4	52.5		
#10	36.9		
#20	32.3		
#40	28.2		
#60	24.8		
#100	21.7		
#200	19.1		

* (no specification provided)

LIGHT BROWN AND LIGHT GRAY SILTY GRAVEL WITH SAND

Atterberg Limits

PL= LL= PI=

Coefficients

D_{90}= 13.5067 D_{85}= 11.9845 D_{60}= 6.4325
D_{50}= 4.2474 D_{30}= 0.5575 D_{15}= 0.0261
D_{10}= 0.0092 C_u= 701.49 C_c= 5.27

Classification

USCS= GM AASHTO=

Remarks

F.M.=4.23

Source of Sample: HEN-B012 **Depth:** 2.5'-4.0'
Sample Number: S-2 **Date:** 12-4-15

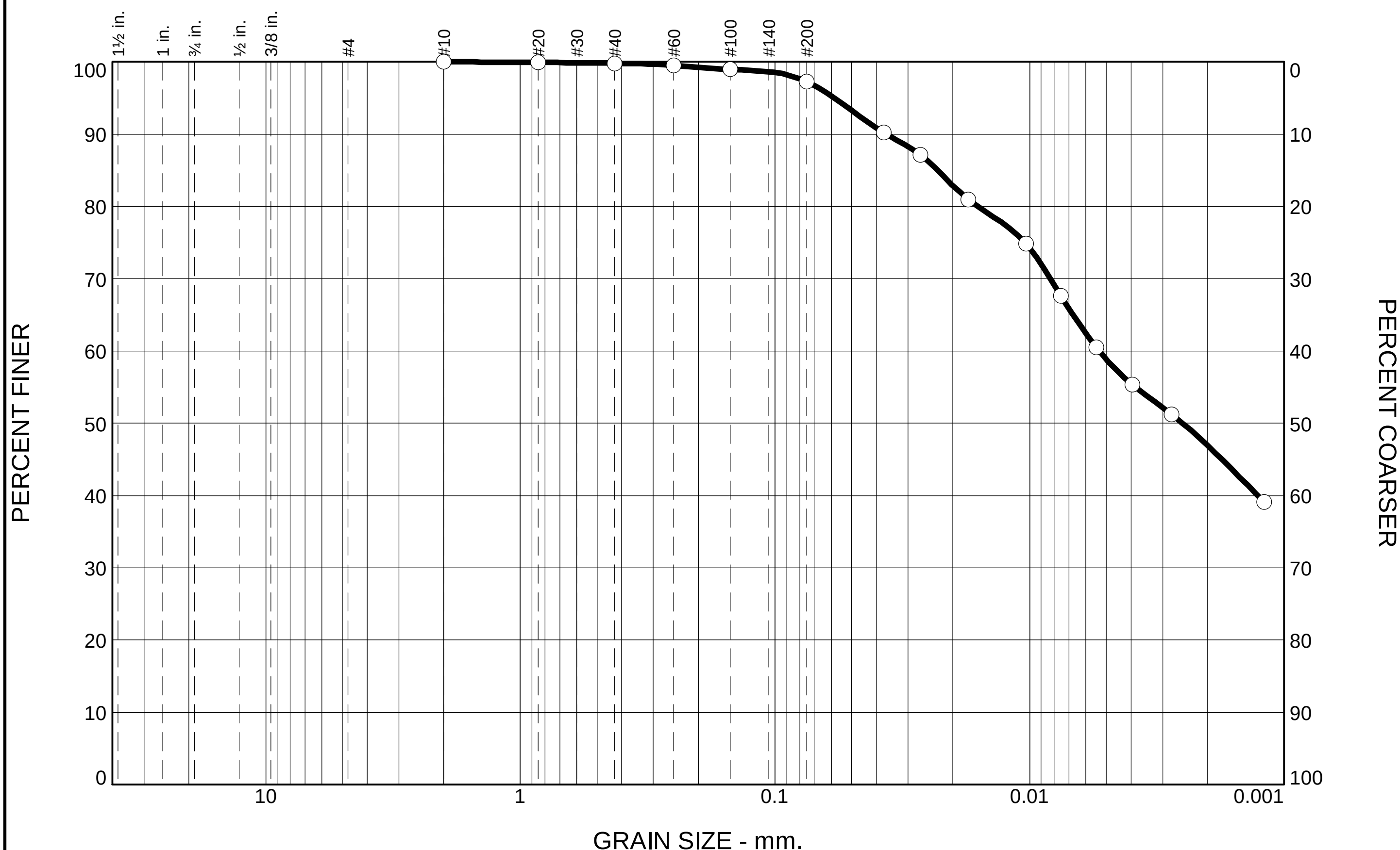
Terracon

Client: AECOM
Project: DYNERGY - HENNEPIN

Project No: MR155233 **Figure**

Tested By: SJH **Checked By:** WPQ

PARTICLE SIZE ANALYSIS OF SOILS ASTM D422



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	0.0	0.0	0.2	2.5	38.5	58.8

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
#10	100.0		
#20	99.9		
#40	99.8		
#60	99.5		
#100	98.9		
#200	97.3		

* (no specification provided)

VERY DARK GRAY LEAN CLAY - ORGANICS NOTED

Atterberg Limits

PL= LL= PI=

Coefficients

D_{90}= 0.0366 D_{85}= 0.0230 D_{60}= 0.0053
D_{50}= 0.0025 D_{30}= D_{15}=
D_{10}= C_u= C_c=

Classification

USCS= CL AASHTO=

Remarks

F.M.=0.02

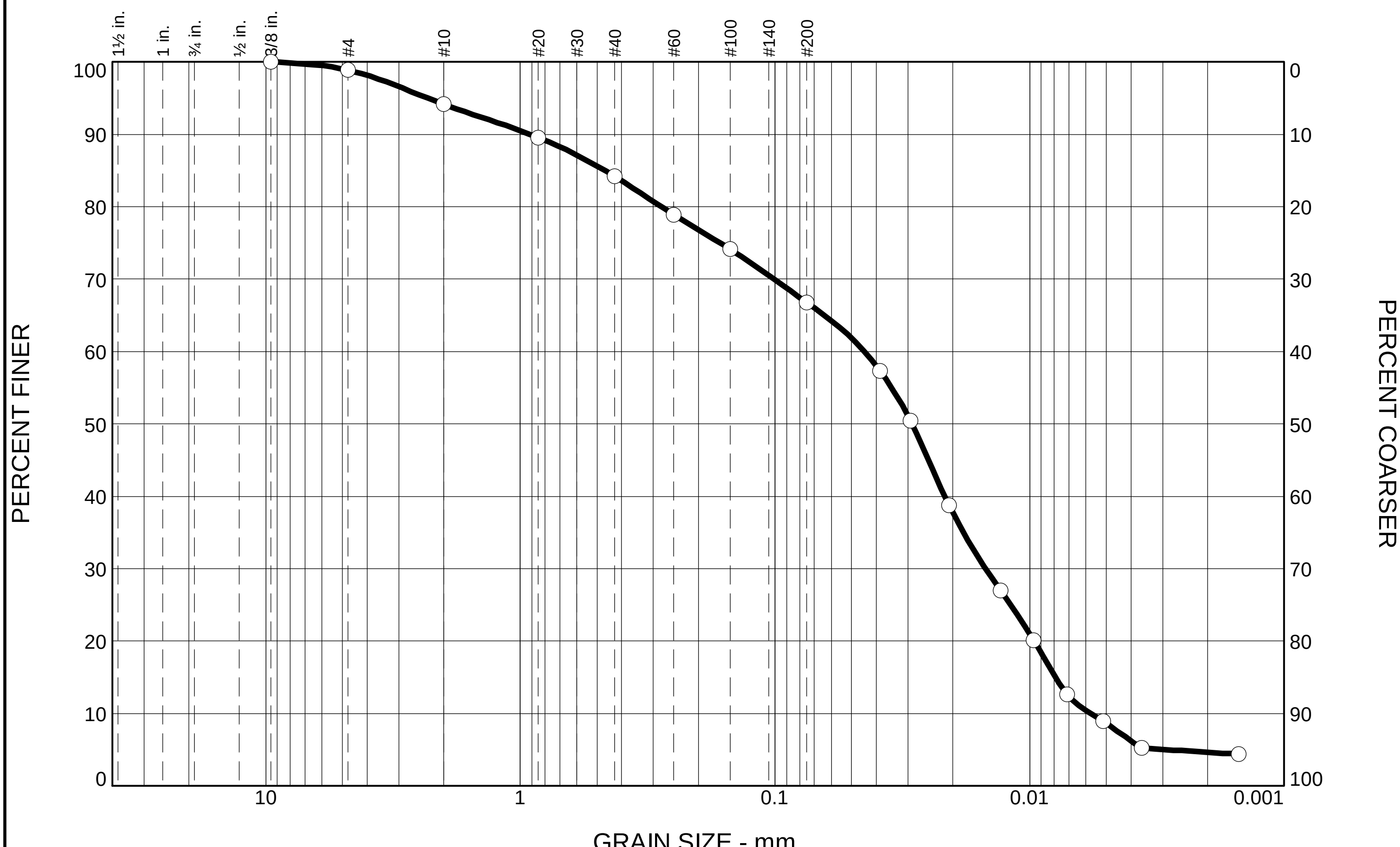
Source of Sample: HEN-B012 **Depth:** 20.0'-22.0'
Sample Number: S-7 **Date:** 12-17-15

Terracon

Client: AECOM
Project: DYNERGY - HENNEPIN
Project No: MR155233 **Figure**

Tested By: SJH **Checked By:** WPQ

PARTICLE SIZE ANALYSIS OF SOILS ASTM D422



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	1.1	4.7	10.0	17.4	58.1	8.7

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
.375	100.0		
#4	98.9		
#10	94.2		
#20	89.5		
#40	84.2		
#60	78.9		
#100	74.1		
#200	66.8		

* (no specification provided)

DARK GRAY FLY ASH

Atterberg Limits

PL= LL= PI=

Coefficients

D_{90}= 0.9160 D_{85}= 0.4652 D_{60}= 0.0445
D_{50}= 0.0290 D_{30}= 0.0149 D_{15}= 0.0079
D_{10}= 0.0058 C_u= 7.71 C_c= 0.86

Classification

USCS= AASHTO=

Remarks

F.M.=0.73

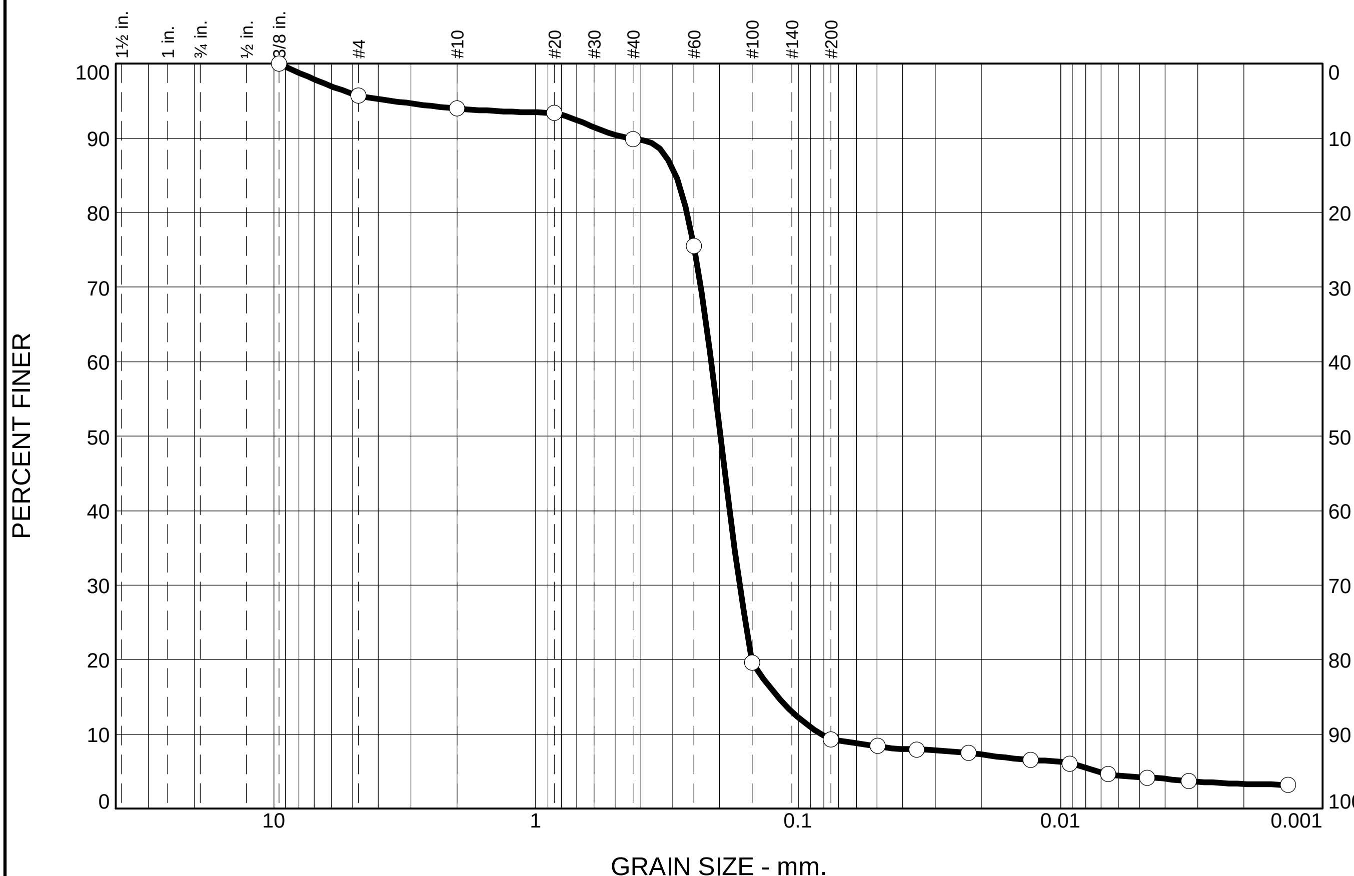
Source of Sample: HEN-B014 **Depth:** 7.5'-9.0'
Sample Number: S-4
Date: 12-9-15

Terracon

Client: AECOM
Project: DYNERGY - HENNEPIN
Project No: MR155233 **Figure**

Tested By: SJH **Checked By:** WPQ

PARTICLE SIZE ANALYSIS OF SOILS ASTM D422



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	4.3	1.7	4.1	80.6	5.1	4.2

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
.375	100.0		
#4	95.7		
#10	94.0		
#20	93.4		
#40	89.9		
#60	75.6		
#100	19.6		
#200	9.3		

* (no specification provided)

GRAY POORLY GRADED SAND WITH SILT

Atterberg Limits

PL= LL= PI=

Coefficients

D_{90}= 0.4408 D_{85}= 0.2931 D_{60}= 0.2146
D_{50}= 0.1976 D_{30}= 0.1670 D_{15}= 0.1195
D_{10}= 0.0819 C_u= 2.62 C_c= 1.59

Classification

USCS= SP-SM AASHTO=

Remarks

F.M.=1.20

Source of Sample: HEN-B014 **Depth:** 45.0'-46.5'
Sample Number: S-12

Date: 12-4-15

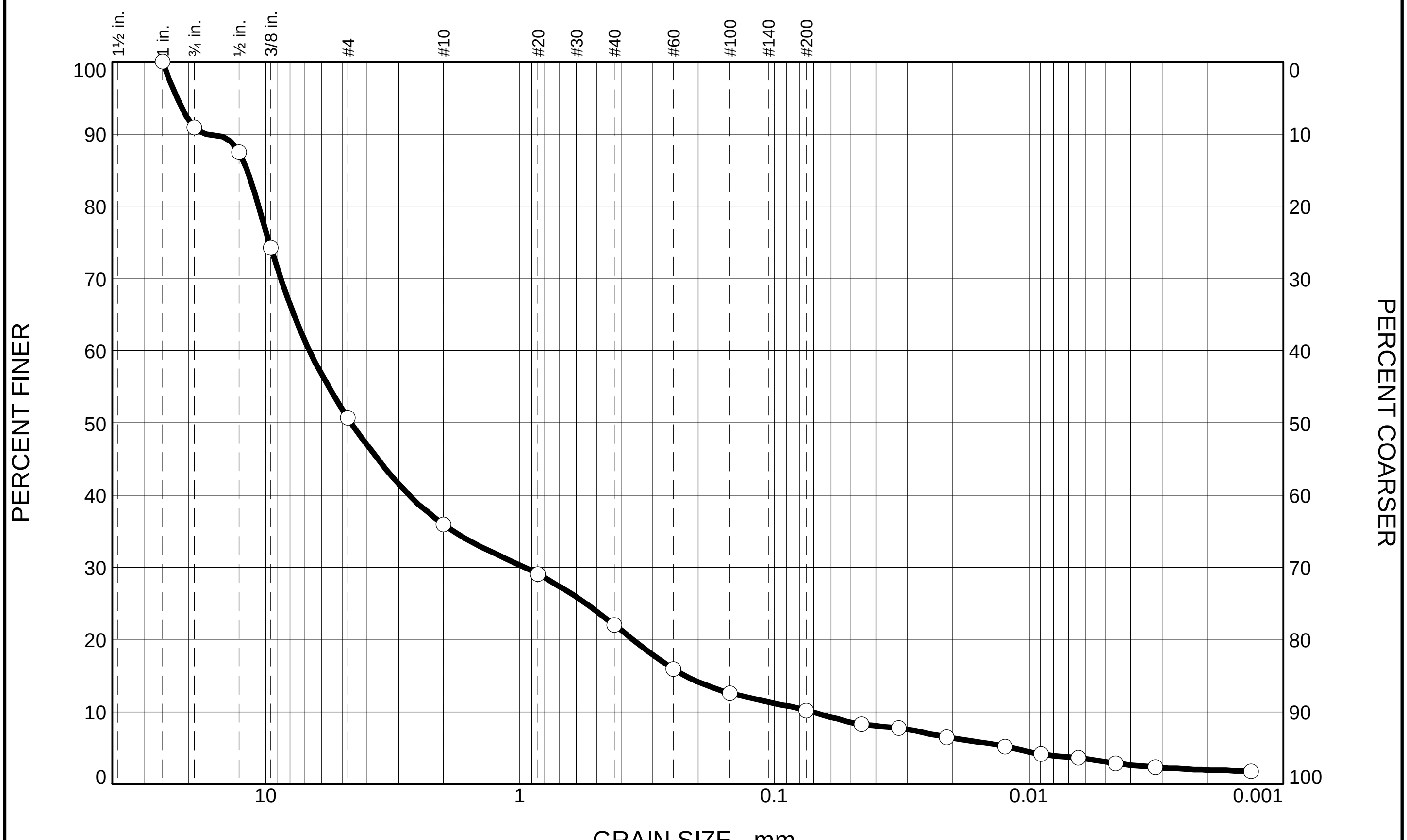
Terracon

Client: AECOM
Project: DYNERGY - HENNEPIN

Project No: MR155233 **Figure**

Tested By: SJH **Checked By:** WPQ

PARTICLE SIZE ANALYSIS OF SOILS ASTM D422



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	9.1	40.2	14.8	13.9	11.8	7.1	3.1

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
1	100.0		
.75	90.9		
.5	87.5		
.375	74.2		
#4	50.7		
#10	35.9		
#20	29.1		
#40	22.0		
#60	15.9		
#100	12.6		
#200	10.2		

* (no specification provided)

GRAY AND BROWN POORLY GRADED GRAVEL WITH SILT AND SAND

Atterberg Limits

PL= LL= PI=

Coefficients

D_{90}= 17.2255 D_{85}= 11.8295 D_{60}= 6.7167
D_{50}= 4.6068 D_{30}= 0.9599 D_{15}= 0.2250
D_{10}= 0.0718 C_u= 93.58 C_c= 1.91

Classification

USCS= GP-GM AASHTO=

Remarks

F.M.=4.59

Source of Sample: HEN-B015 **Depth:** 45.0'-46.5'
Sample Number: S-12 **Date:** 12-4-15

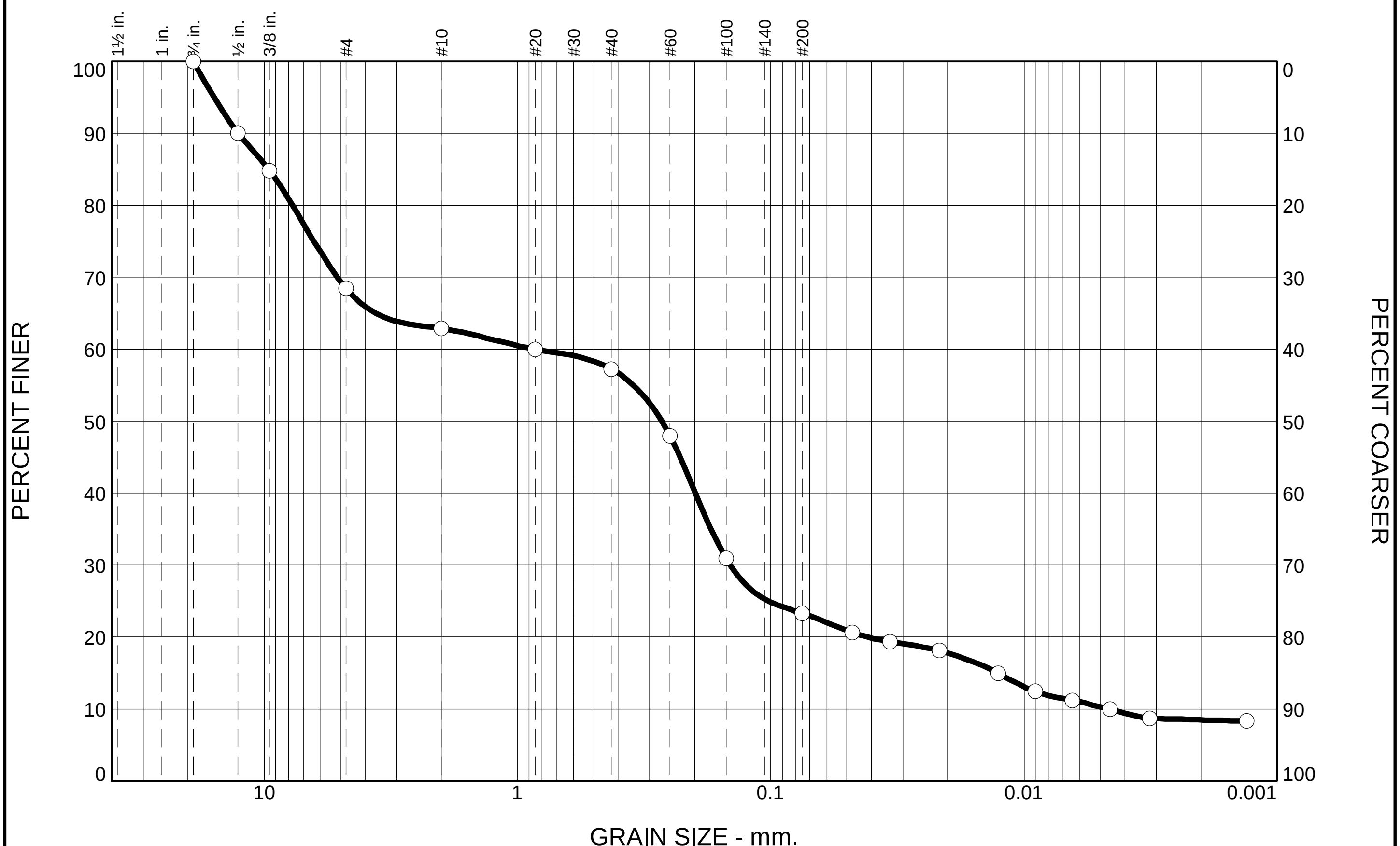
Terracon

Client: AECOM
Project: DYNERGY - HENNEPIN

Project No: MR155233 **Figure**

Tested By: SJH **Checked By:** WPQ

PARTICLE SIZE ANALYSIS OF SOILS ASTM D422



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	31.5	5.6	5.7	33.9	13.0	10.3

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
.75	100.0		
.5	90.1		
.375	84.8		
#4	68.5		
#10	62.9		
#20	60.0		
#40	57.2		
#60	48.0		
#100	30.9		
#200	23.3		

* (no specification provided)

DARK BROWN AND BROWN SILTY SAND WITH GRAVEL

Atterberg Limits

PL= LL= PI=

Coefficients

D_{90}= 12.6514 D_{85}= 9.6003 D_{60}= 0.8530
D_{50}= 0.2690 D_{30}= 0.1447 D_{15}= 0.0127
D_{10}= 0.0046 C_u= 183.51 C_c= 5.28

Classification

USCS= AASHTO=

Remarks

F.M.=2.80

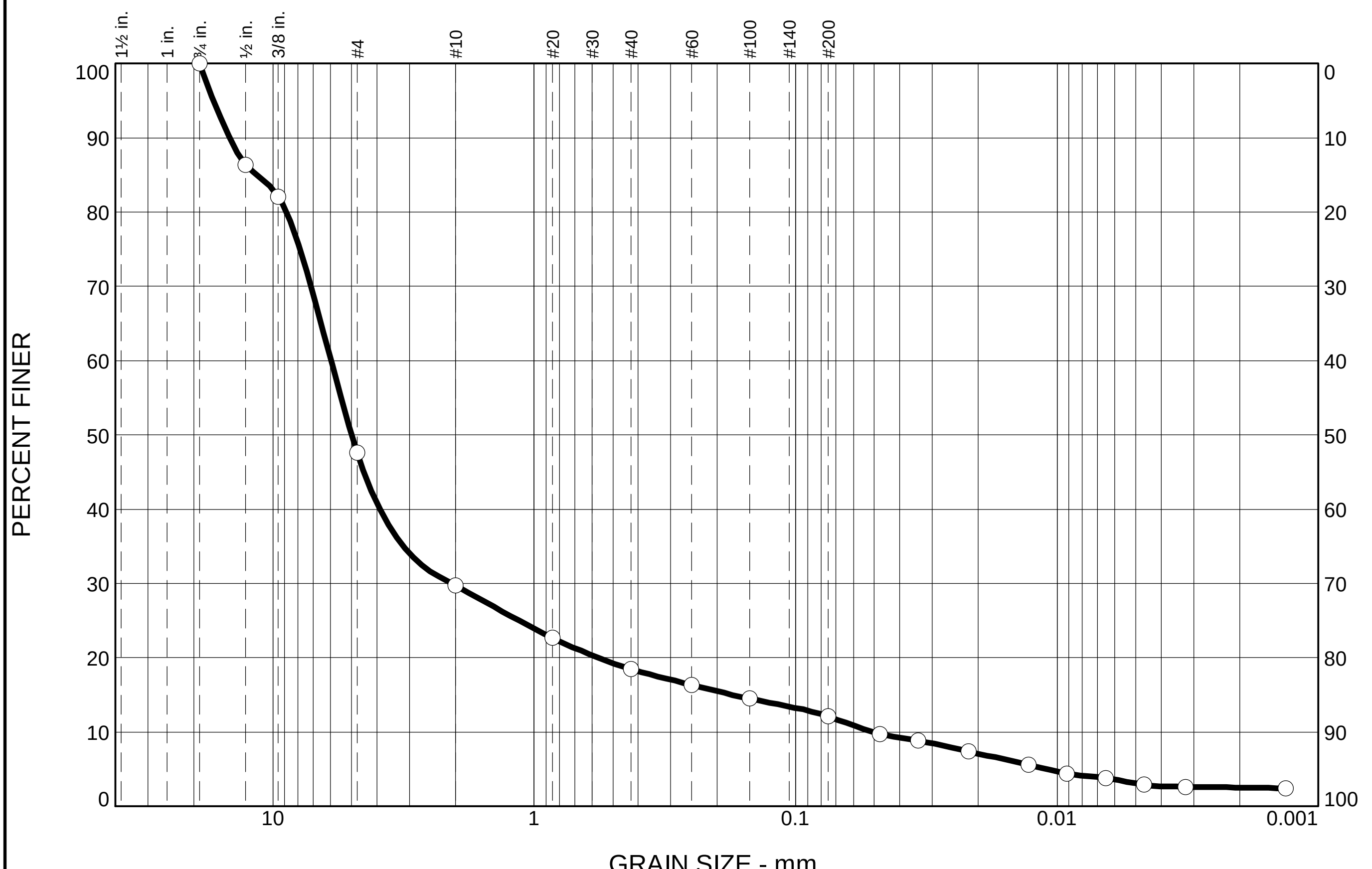
Source of Sample: HEN-B016 **Depth:** 5.0'-6.5'
Sample Number: S-3 **Date:** 12-9-15

Terracon

Client: AECOM
Project: DYNERGY - HENNEPIN
Project No: MR155233 **Figure**

Tested By: SJH **Checked By:** WPQ

PARTICLE SIZE ANALYSIS OF SOILS ASTM D422



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	52.4	17.9	11.2	6.4	9.0	3.1

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
.75	100.0		
.5	86.4		
.375	82.1		
#4	47.6		
#10	29.7		
#20	22.7		
#40	18.5		
#60	16.3		
#100	14.5		
#200	12.1		

* (no specification provided)

BROWNISH GRAY GRAVEL WITH SILT AND SAND

Atterberg Limits

PL= LL= PI=

Coefficients

D_{90}= 14.6414 D_{85}= 11.5354 D_{60}= 5.9837
D_{50}= 4.9929 D_{30}= 2.0751 D_{15}= 0.1743
D_{10}= 0.0507 C_u= 117.95 C_c= 14.19

Classification

USCS= GP-GM AASHTO=

Remarks

F.M.=4.62

Source of Sample: HEN-B016 **Depth:** 70.0'-71.5'
Sample Number: S-17

Date: 12-9-15

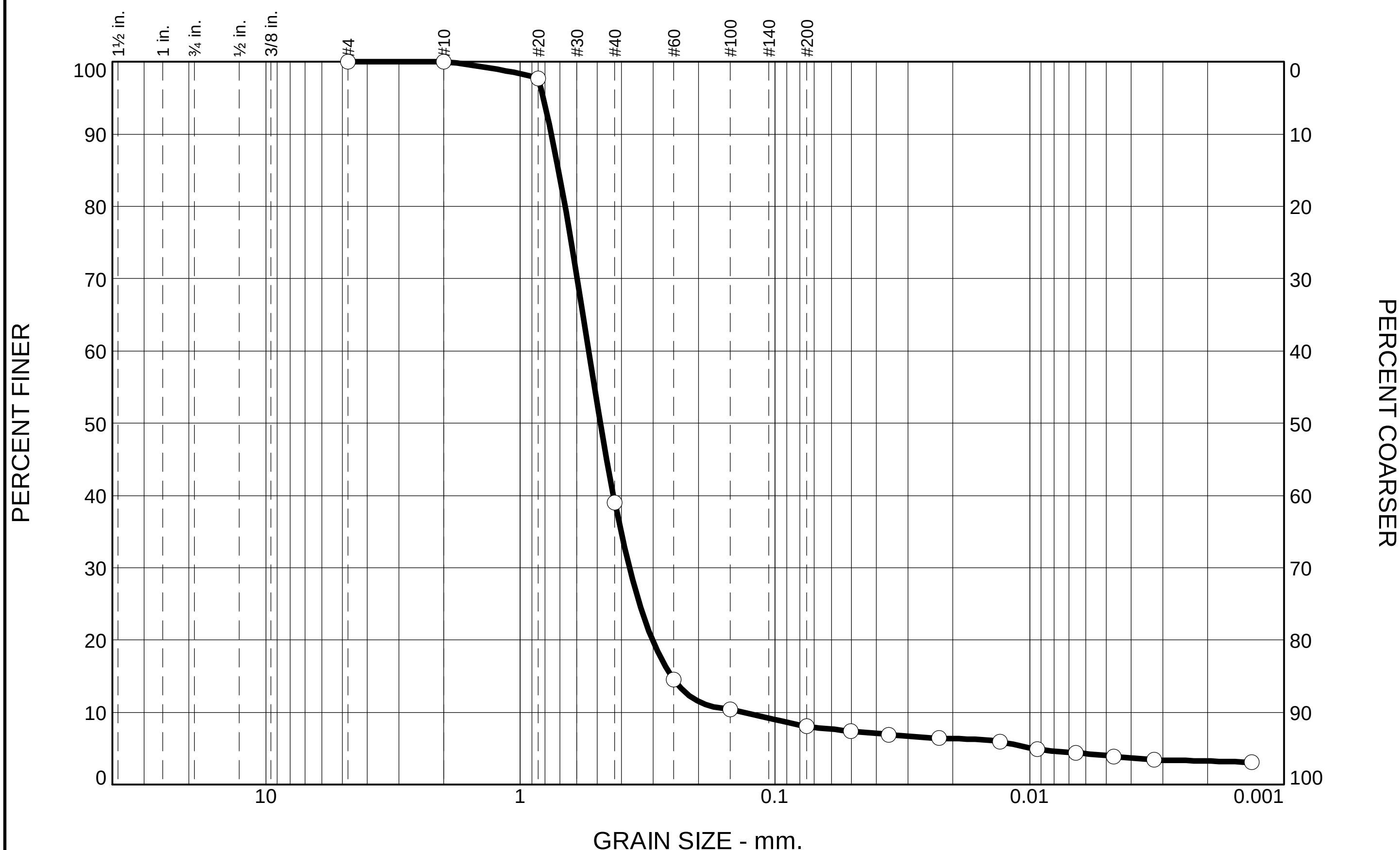
Terracon

Client: AECOM
Project: DYNERGY - HENNEPIN

Project No: MR155233 **Figure**

Tested By: SJH **Checked By:** WPQ

PARTICLE SIZE ANALYSIS OF SOILS ASTM D422



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	0.0	0.0	60.9	31.0	4.1	4.0

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
#4	100.0		
#10	100.0		
#20	97.7		
#40	39.1		
#60	14.5		
#100	10.4		
#200	8.1		

* (no specification provided)

DARK GRAY SAND WITH SILT

Atterberg Limits

PL= LL= PI=

Coefficients

D_{90}= 0.7541 D_{85}= 0.7076 D_{60}= 0.5389
D_{50}= 0.4840 D_{30}= 0.3721 D_{15}= 0.2553
D_{10}= 0.1325 C_u= 4.07 C_c= 1.94

Classification

USCS= SM AASHTO=

Remarks

F.M.=2.01

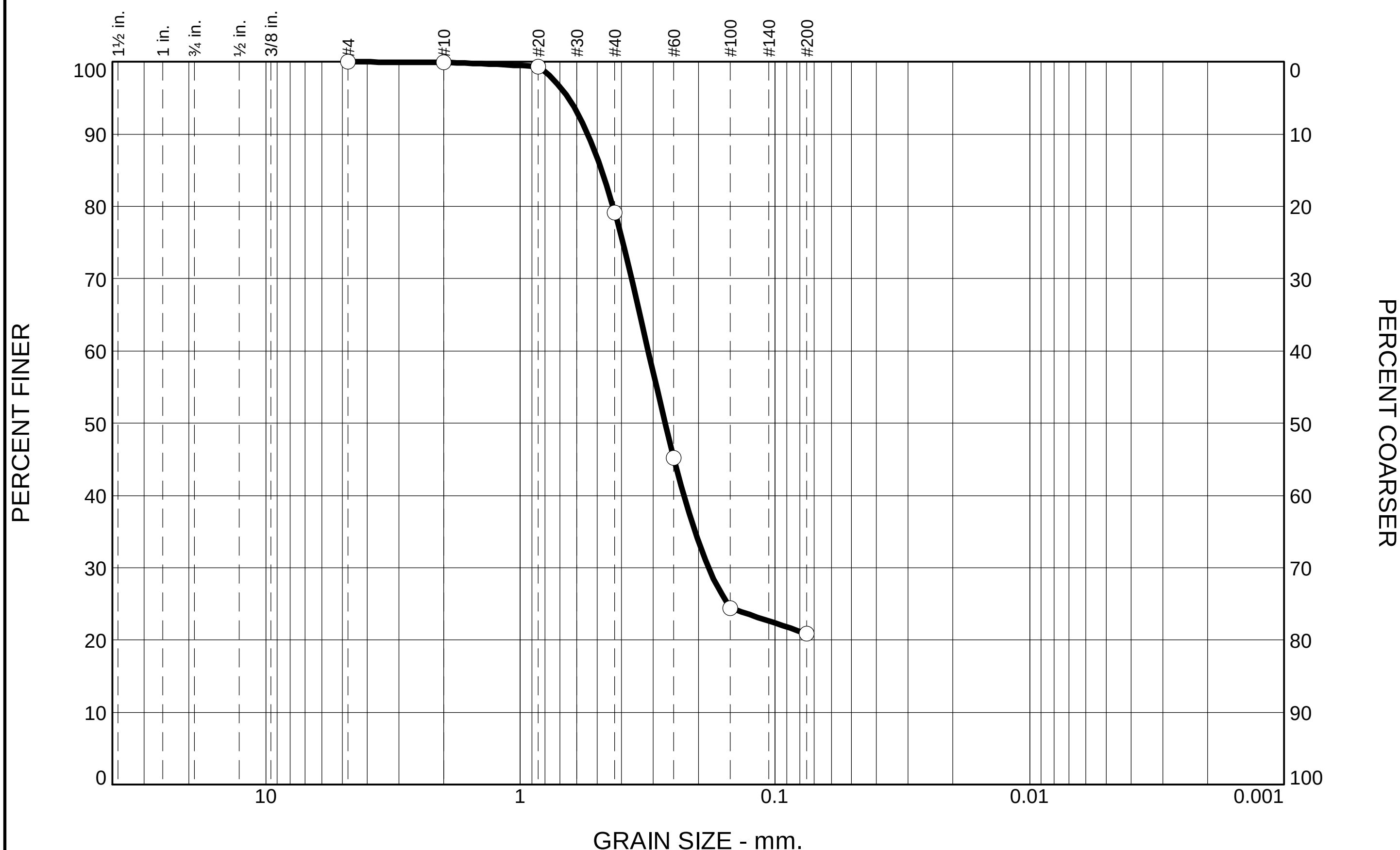
Source of Sample: HEN-B017 **Depth:** 45.0'-46.5'
Sample Number: S-12 **Date:** 12-9-15

Terracon

Client: AECOM
Project: DYNERGY - HENNEPIN
Project No: MR155233 **Figure**

Tested By: SJH **Checked By:** WPQ

PARTICLE SIZE ANALYSIS OF SOILS ASTM D422



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	0.0	0.1	20.7	58.3	20.9	

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
#4	100.0		
#10	99.9		
#20	99.3		
#40	79.2		
#60	45.2		
#100	24.4		
#200	20.9		

* (no specification provided)

GRAY AND BROWN SILTY SAND

Atterberg Limits

PL= LL= PI=

Coefficients

D_{90}= 0.5438 D_{85}= 0.4786 D_{60}= 0.3142
D_{50}= 0.2703 D_{30}= 0.1817 D_{15}=
D_{10}= C_u= C_c=

Classification

USCS= SM AASHTO=

Remarks

F.M.=1.26

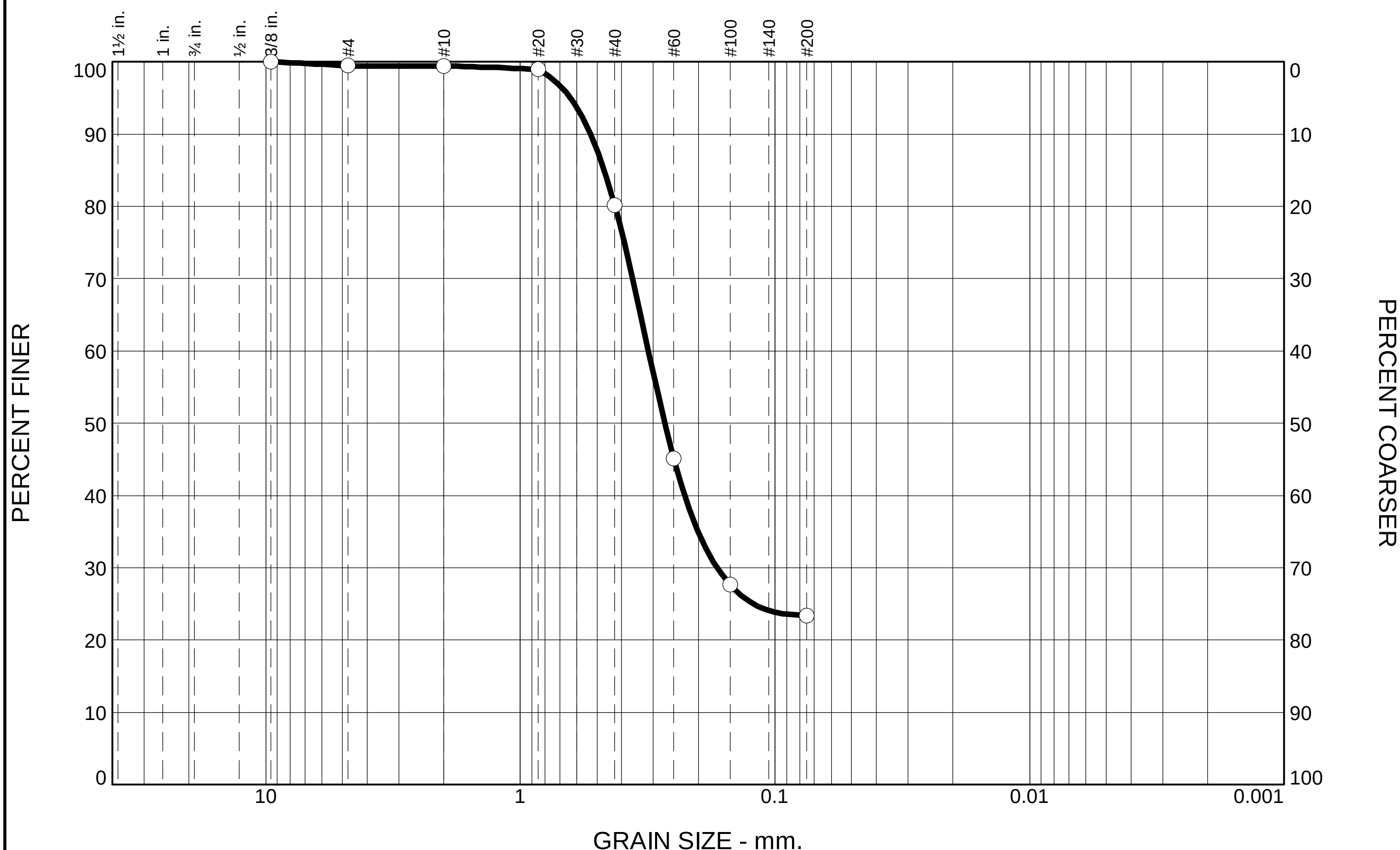
Source of Sample: HEN-B018 **Depth:** 55.0'-56.5'
Sample Number: S-14 **Date:** 12-7-15

Terracon

Client: AECOM
Project: DYNERGY - HENNEPIN
Project No: MR155233 **Figure**

Tested By: SJH **Checked By:** WPQ

PARTICLE SIZE ANALYSIS OF SOILS ASTM D422



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	0.5	0.1	19.3	56.7	23.4	

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
.375	100.0		
#4	99.5		
#10	99.4		
#20	99.0		
#40	80.1		
#60	45.2		
#100	27.7		
#200	23.4		

* (no specification provided)

BROWN AND GRAY SILTY SAND

Atterberg Limits

PL= LL= PI=

Coefficients

D_{90}= 0.5299 D_{85}= 0.4677 D_{60}= 0.3138
D_{50}= 0.2709 D_{30}= 0.1686 D_{15}=
D_{10}= C_u= C_c=

Classification

USCS= SM AASHTO=

Remarks

F.M.=1.24

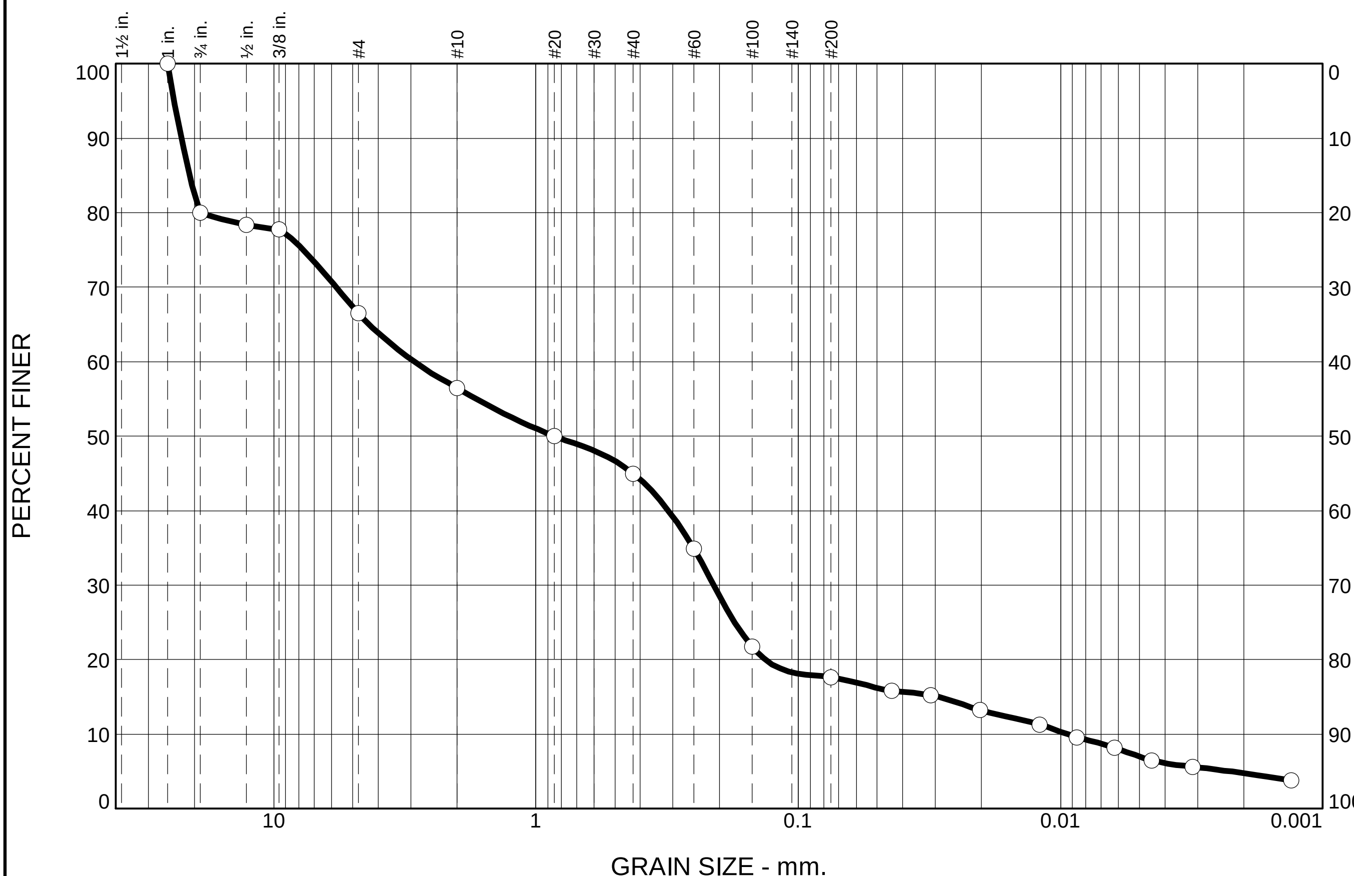
Source of Sample: HEN-B019 **Depth:** 40.0'-41.5'
Sample Number: S-10 **Date:** 12-7-15

Terracon

Client: AECOM
Project: DYNERGY - HENNEPIN
Project No: MR155233 **Figure**

Tested By: SJH **Checked By:** WPQ

PARTICLE SIZE ANALYSIS OF SOILS ASTM D422



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	20.0	13.5	10.0	11.5	27.4	10.6	7.0

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
1	100.0		
.75	80.0		
.5	78.4		
.375	77.7		
#4	66.5		
#10	56.5		
#20	50.0		
#40	45.0		
#60	34.8		
#100	21.7		
#200	17.6		

* (no specification provided)

BROWN AND REDDISH BROWN SILTY SAND WITH GRAVEL

Atterberg Limits

PL= LL= PI=

Coefficients

D_{90}= 22.4706 D_{85}= 20.9381 D_{60}= 2.9071
D_{50}= 0.8484 D_{30}= 0.2097 D_{15}= 0.0290
D_{10}= 0.0094 C_u= 309.22 C_c= 1.61

Classification

USCS= SM AASHTO=

Remarks

F.M.=3.57

Source of Sample: HEN-B020 **Depth:** 20.0'-21.4'
Sample Number: S-7

Date: 12-9-15

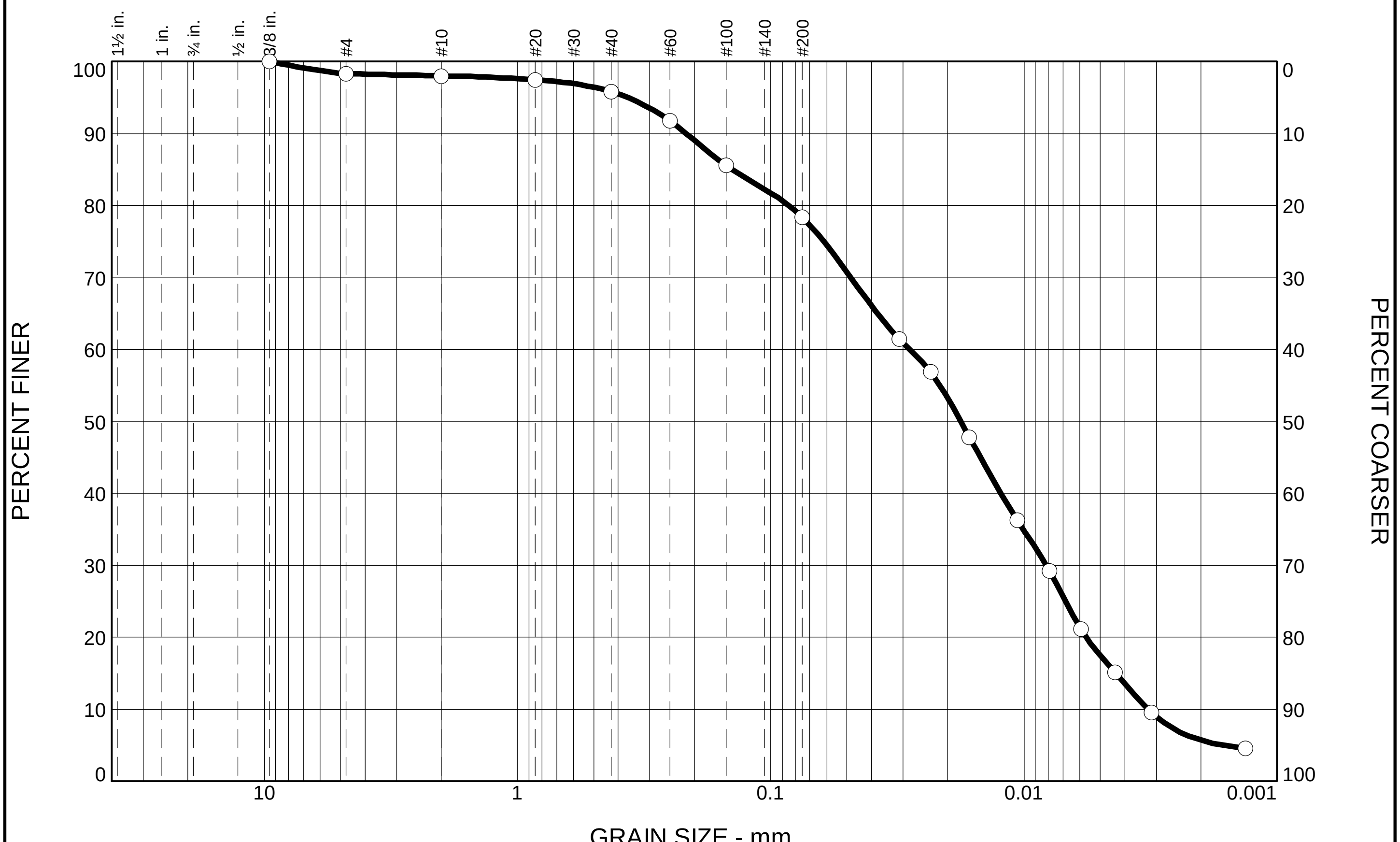
Terracon

Client: AECOM
Project: DYNERGY - HENNEPIN

Project No: MR155233 **Figure**

Tested By: SJH **Checked By:** WPQ

PARTICLE SIZE ANALYSIS OF SOILS ASTM D422



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	1.7	0.3	2.2	17.5	60.8	17.5

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
.375	100.0		
#4	98.3		
#10	98.0		
#20	97.5		
#40	95.8		
#60	91.7		
#100	85.5		
#200	78.3		

* (no specification provided)

DARK GRAY VARVED FLY ASH

Atterberg Limits

PL= LL= PI=

Coefficients

D_{90}= 0.2157 D_{85}= 0.1423 D_{60}= 0.0283
D_{50}= 0.0178 D_{30}= 0.0082 D_{15}= 0.0043
D_{10}= 0.0032 C_u= 8.74 C_c= 0.73

Classification

USCS= AASHTO=

Remarks

F.M.=0.30

Source of Sample: HEN-B021 **Depth:** 22.0'-24.0'
Sample Number: S-8

Date: 12-17-15

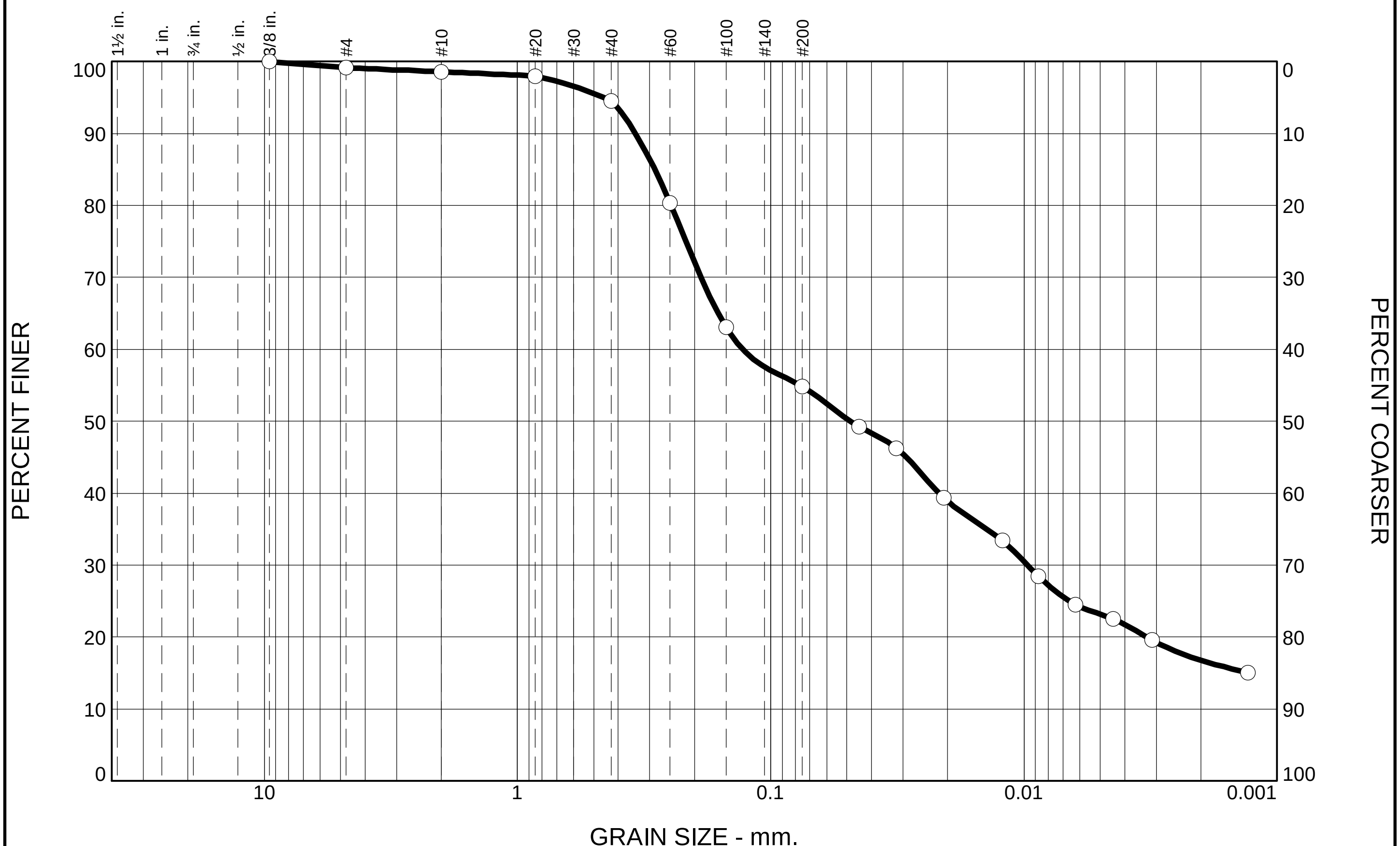
Terracon

Client: AECOM
Project: DYNERGY - HENNEPIN

Project No: MR155233 **Figure**

Tested By: SJH **Checked By:** WPQ

PARTICLE SIZE ANALYSIS OF SOILS ASTM D422



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	0.9	0.5	4.1	39.7	31.6	23.2

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
.375	100.0		
#4	99.1		
#10	98.6		
#20	98.0		
#40	94.5		
#60	80.4		
#100	63.1		
#200	54.8		

* (no specification provided)

DARK GRAY AND BLACK SILTY SAND WITH CLAY

Atterberg Limits

PL= LL= PI=

Coefficients

D_{90}= 0.3417 D_{85}= 0.2870 D_{60}= 0.1290
D_{50}= 0.0484 D_{30}= 0.0097 D_{15}=
D_{10}= C_u= C_c=

Classification

USCS= SM AASHTO=

Remarks

F.M.=0.58

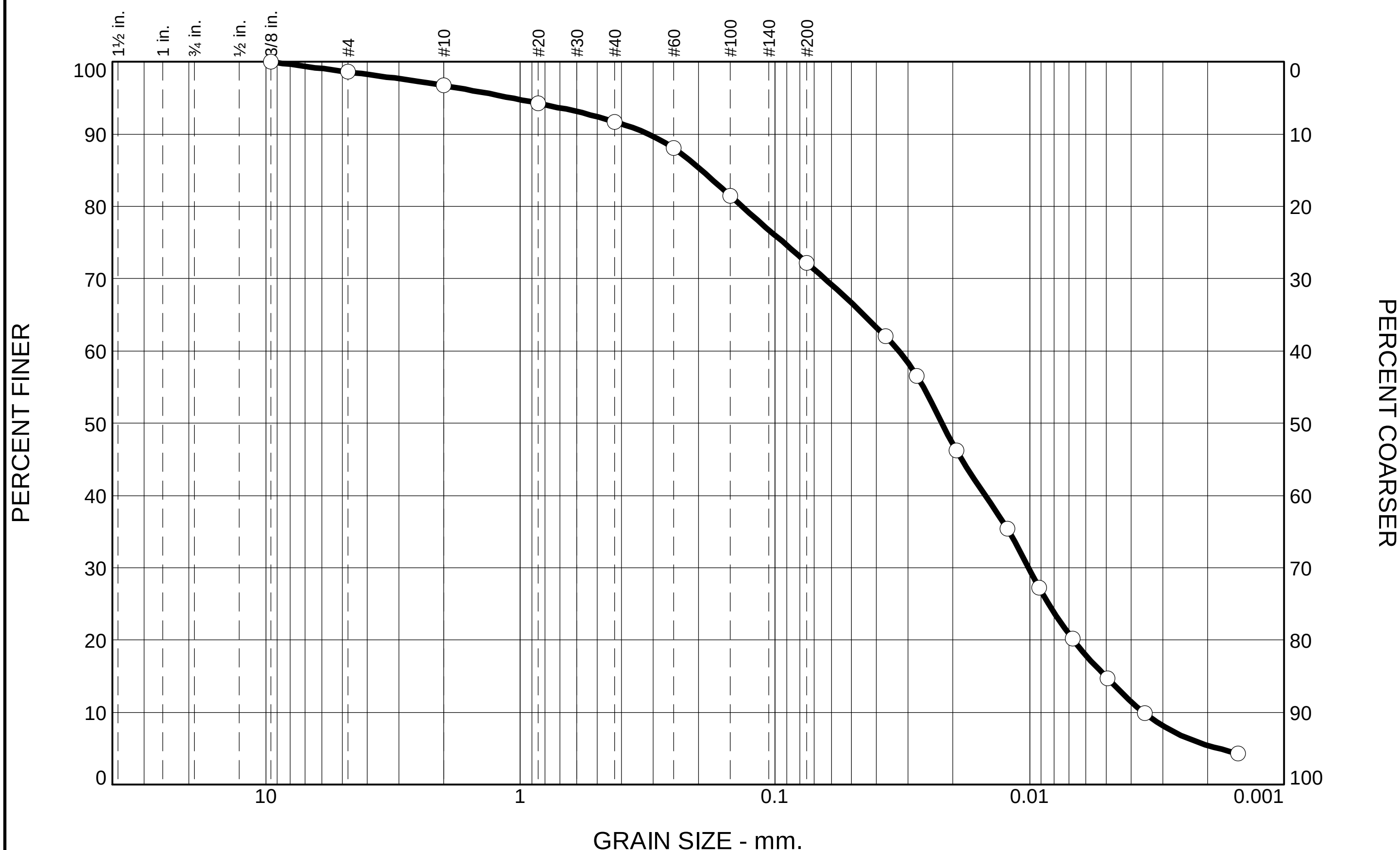
Source of Sample: HEN-B021 **Depth:** 35.0'-36.5'
Sample Number: S-11 **Date:** 12-9-15

Terracon

Client: AECOM
Project: DYNERGY - HENNEPIN
Project No: MR155233 **Figure**

Tested By: SJH **Checked By:** WPQ

PARTICLE SIZE ANALYSIS OF SOILS ASTM D422



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	1.4	1.9	5.0	19.5	57.3	14.9

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
.375	100.0		
#4	98.6		
#10	96.7		
#20	94.2		
#40	91.7		
#60	88.0		
#100	81.5		
#200	72.2		

* (no specification provided)

VERY DARK GRAY VARVED FLY ASH WITH SAND - SAND SEAMS NOTED

Atterberg Limits

PL= LL= PI=

Coefficients

D_{90}= 0.3145 D_{85}= 0.1939 D_{60}= 0.0327
D_{50}= 0.0221 D_{30}= 0.0101 D_{15}= 0.0050
D_{10}= 0.0036 C_u= 9.15 C_c= 0.88

Classification

USCS= AASHTO=

Remarks

F.M.=0.45

Source of Sample: HEN-B022 **Depth:** 7.5'-9.0'
Sample Number: S-4

Date: 12-15-15

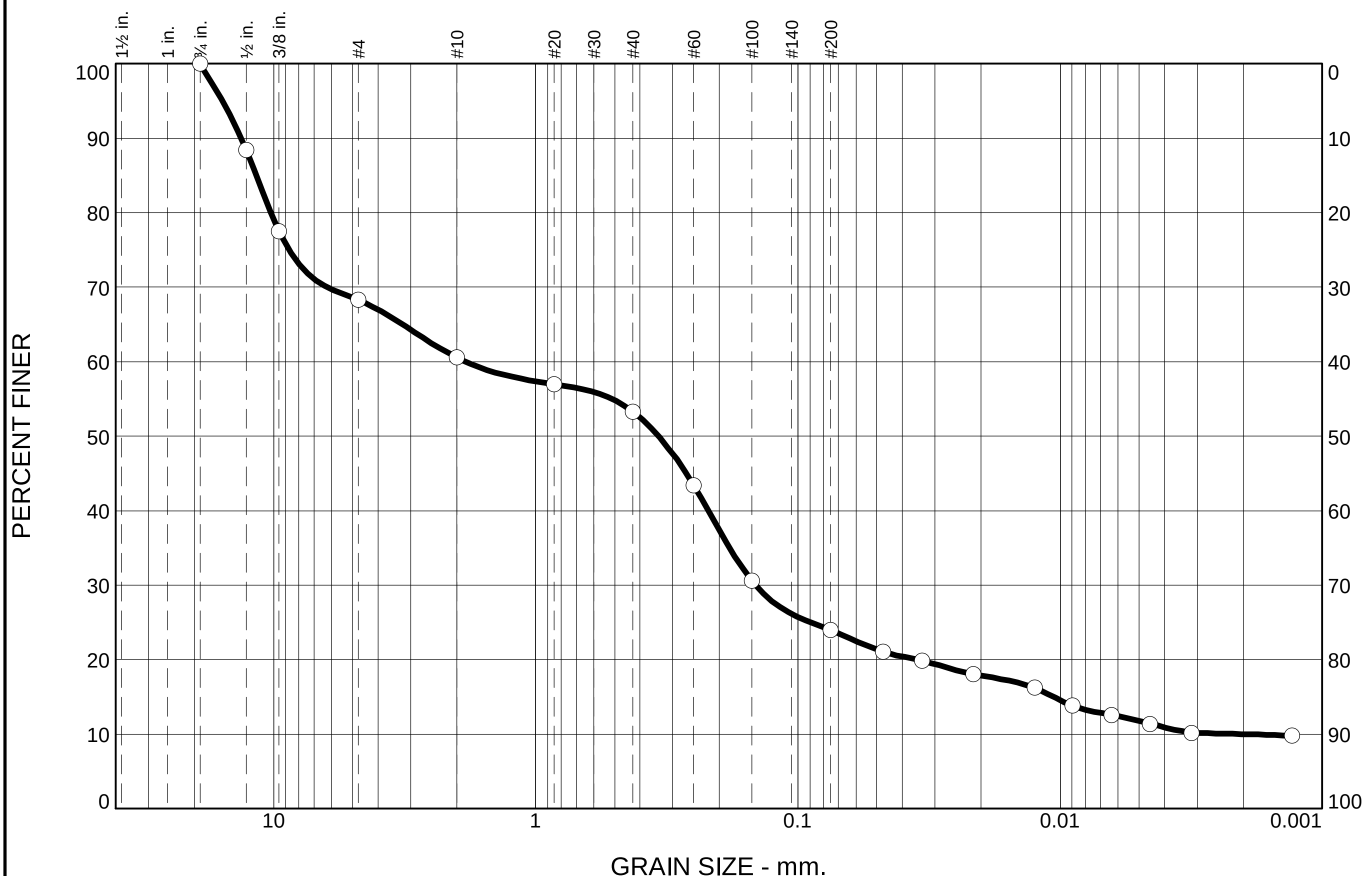
Terracon

Client: AECOM
Project: DYNERGY - HENNEPIN

Project No: MR155233 **Figure**

Tested By: SJH **Checked By:** WPQ

PARTICLE SIZE ANALYSIS OF SOILS ASTM D422



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	31.7	7.8	7.2	29.3	12.2	11.8

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
.75	100.0		
.5	88.4		
.375	77.5		
#4	68.3		
#10	60.5		
#20	57.0		
#40	53.3		
#60	43.4		
#100	30.6		
#200	24.0		

* (no specification provided)

BROWN AND TAN SILTY SAND WITH GRAVEL

Atterberg Limits

PL= LL= PI=

Coefficients

D_{90}= 13.2956 D_{85}= 11.6290 D_{60}= 1.8552
D_{50}= 0.3396 D_{30}= 0.1452 D_{15}= 0.0106
D_{10}= 0.0021 C_u= 894.27 C_c= 5.48

Classification

USCS= SM AASHTO=

Remarks

F.M.=3.00

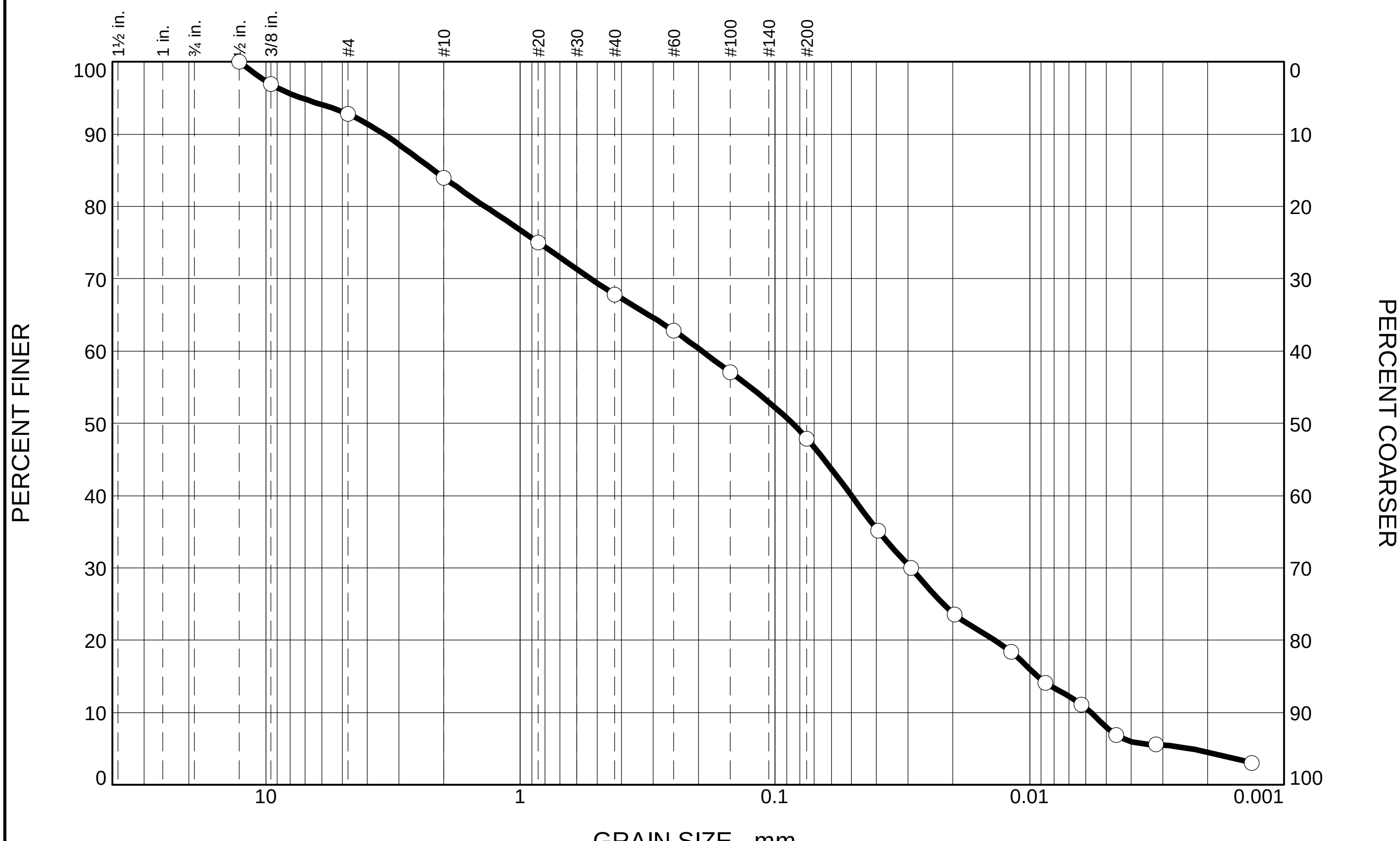
Source of Sample: HEN-B023 **Depth:** 2.5'-4.0'
Sample Number: S-2 **Date:** 12-9-15

Terracon

Client: AECOM
Project: DYNERGY - HENNEPIN
Project No: MR155233 **Figure**

Tested By: SJH **Checked By:** WPQ

PARTICLE SIZE ANALYSIS OF SOILS ASTM D422



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	7.2	8.8	16.2	19.9	39.9	8.0

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
0.5	100.0		
.375	96.9		
#4	92.8		
#10	84.0		
#20	75.0		
#40	67.8		
#60	62.8		
#100	57.1		
#200	47.9		

* (no specification provided)

DARK GRAY AND BLACK SILTY SAND AND FLY ASH - CINDERS NOTED

Atterberg Limits

PL= LL= PI=

Coefficients

D_{90}= 3.4369 D_{85}= 2.1877 D_{60}= 0.1934
D_{50}= 0.0854 D_{30}= 0.0293 D_{15}= 0.0093
D_{10}= 0.0058 C_u= 33.63 C_c= 0.77

Classification

USCS= SM AASHTO=

Remarks

F.M.=1.53

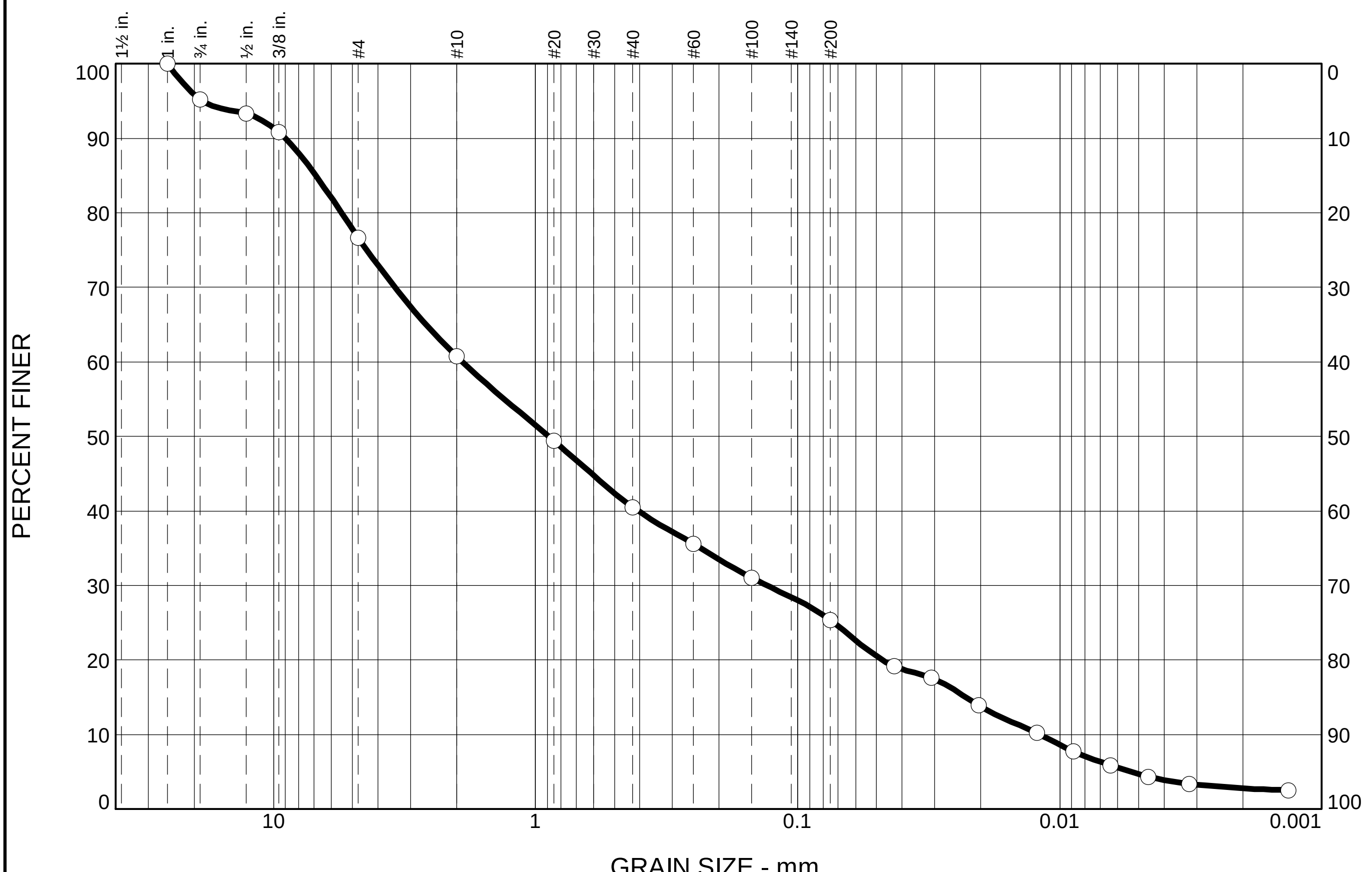
Source of Sample: HEN-B023 **Depth:** 20.0'-21.5'
Sample Number: S-7 **Date:** 12-17-15

Terracon

Client: AECOM
Project: DYNERGY - HENNEPIN
Project No: MR155233 **Figure**

Tested By: SJH **Checked By:** WPQ

PARTICLE SIZE ANALYSIS OF SOILS ASTM D422



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	4.8	18.5	16.0	20.2	15.2	20.6	4.7

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
1	100.0		
.75	95.2		
.5	93.3		
.375	90.8		
#4	76.7		
#10	60.7		
#20	49.4		
#40	40.5		
#60	35.6		
#100	31.0		
#200	25.3		

* (no specification provided)

DARK GRAY FLY ASH WITH SAND AND CINDERS

Atterberg Limits

PL= LL= PI=

Coefficients

D_{90}= 9.0077 D_{85}= 6.8824 D_{60}= 1.9019
D_{50}= 0.8884 D_{30}= 0.1309 D_{15}= 0.0229
D_{10}= 0.0119 C_u= 159.31 C_c= 0.75

Classification

USCS= AASHTO=

Remarks

F.M.=3.07

Source of Sample: HEN-B023 **Depth:** 35.0'-36.5'
Sample Number: S-11

Date: 12-17-15

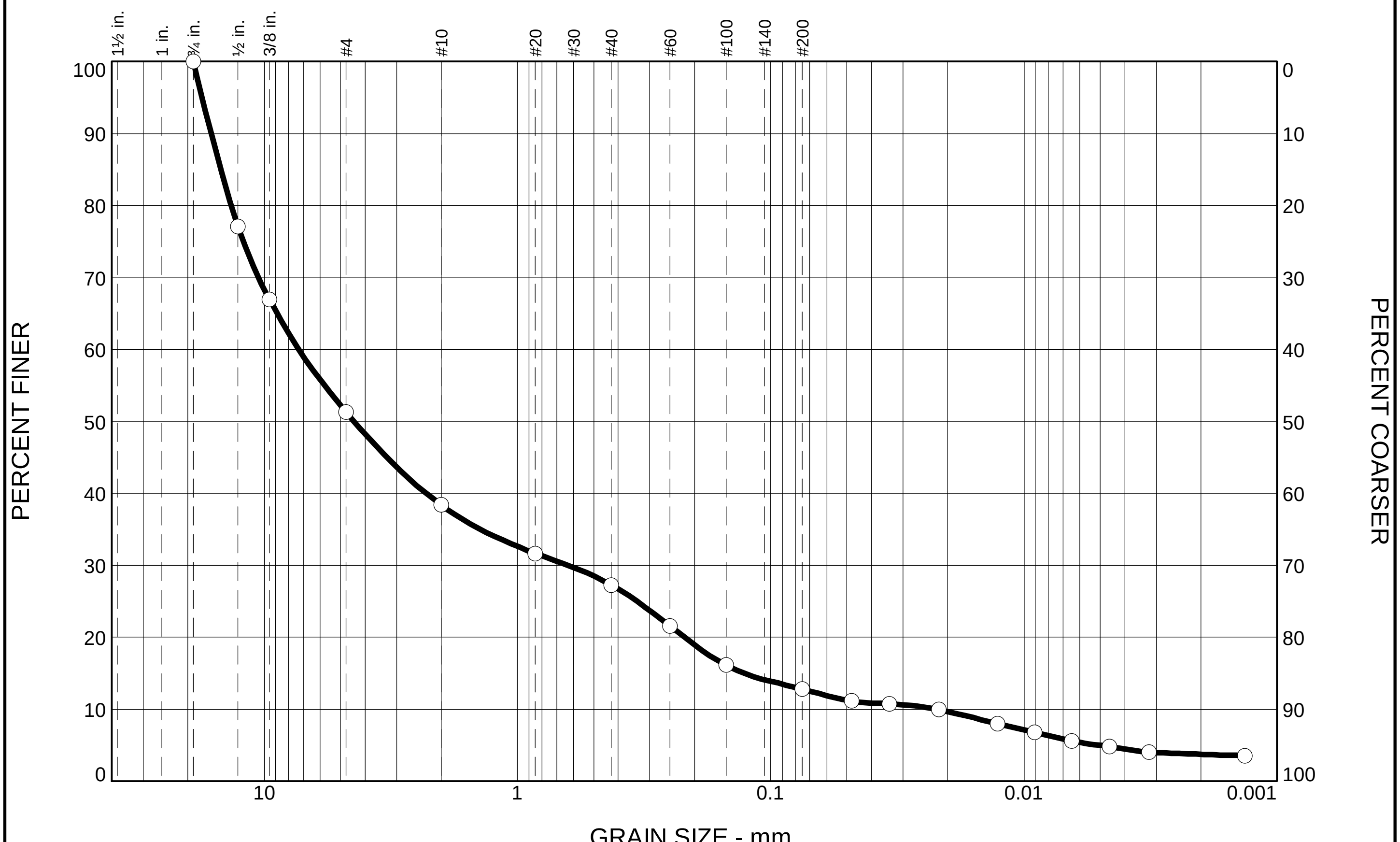
Terracon

Client: AECOM
Project: DYNERGY - HENNEPIN

Project No: MR155233 **Figure**

Tested By: SJH **Checked By:** WPQ

PARTICLE SIZE ANALYSIS OF SOILS ASTM D422



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	48.7	12.9	11.1	14.5	7.8	5.0

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
.75	100.0		
.5	77.1		
.375	66.9		
#4	51.3		
#10	38.4		
#20	31.7		
#40	27.3		
#60	21.6		
#100	16.1		
#200	12.8		

* (no specification provided)

LIGHT BROWN POORLY GRADED GRAVEL WITH SAND AND SILT

Atterberg Limits

PL= LL= PI=

Coefficients

D_{90}= 16.1906 D_{85}= 14.8494 D_{60}= 7.2956
D_{50}= 4.4253 D_{30}= 0.6301 D_{15}= 0.1271
D_{10}= 0.0221 C_u= 330.63 C_c= 2.47

Classification

USCS= GP-GM AASHTO=

Remarks

F.M.=4.38

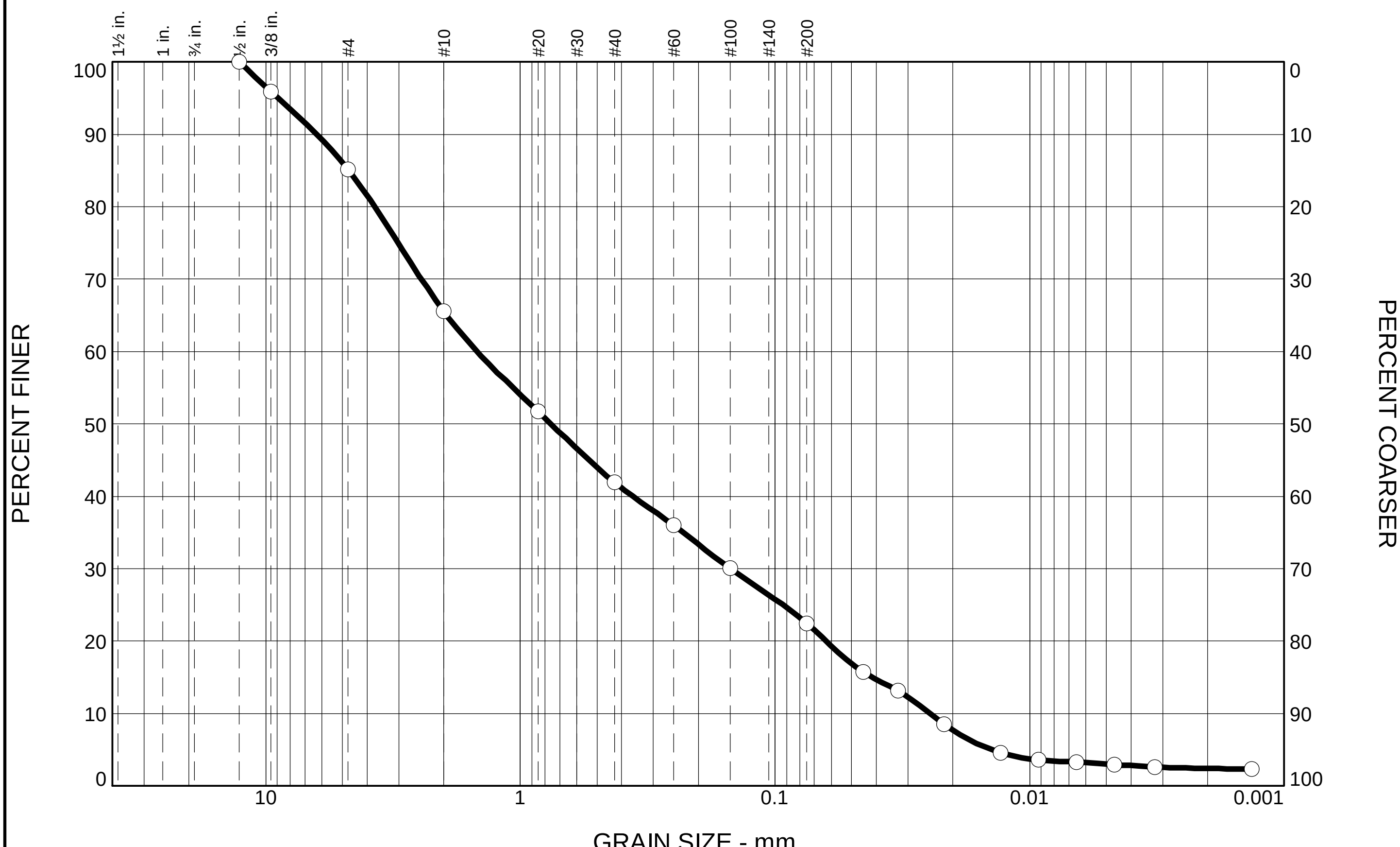
Source of Sample: HEN-B023 **Depth:** 50.0'-51.0'
Sample Number: S-14
Date: 12-15-15

Terracon

Client: AECOM
Project: DYNERGY - HENNEPIN
Project No: MR155233 **Figure**

Tested By: SJH **Checked By:** WPQ

PARTICLE SIZE ANALYSIS OF SOILS ASTM D422



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	14.8	19.6	23.7	19.5	19.4	3.0

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
.50	100.0		
.375	95.9		
#4	85.2		
#10	65.6		
#20	51.7		
#40	41.9		
#60	36.0		
#100	30.0		
#200	22.4		

* (no specification provided)

BLACK FLY ASH WITH CINCERS AND SAND

Atterberg Limits

PL= LL= PI=

Coefficients

D_{90}= 6.3009 D_{85}= 4.7122 D_{60}= 1.4780
D_{50}= 0.7577 D_{30}= 0.1495 D_{15}= 0.0415
D_{10}= 0.0247 C_u= 59.92 C_c= 0.61

Classification

USCS= AASHTO=

Remarks

F.M.=2.79

Source of Sample: HEN-B024 **Depth:** 15.0'-16.5'
Sample Number: S-6 **Date:** 12-17-15

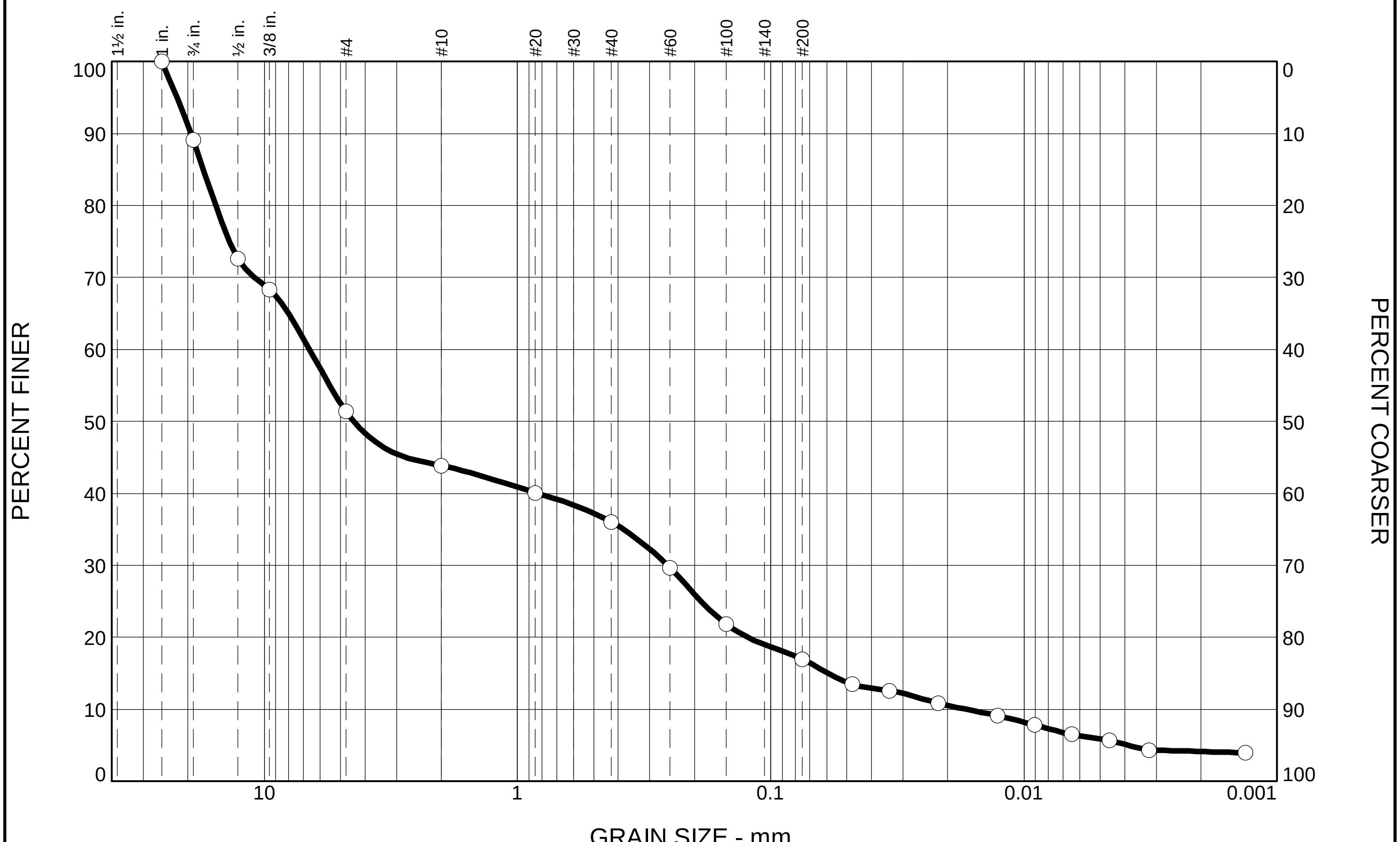
Terracon

Client: AECOM
Project: DYNERGY - HENNEPIN

Project No: MR155233 **Figure**

Tested By: SJH **Checked By:** WPQ

PARTICLE SIZE ANALYSIS OF SOILS ASTM D422



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	10.9	37.7	7.5	7.9	19.0	11.1	5.9

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
1	100.0		
.75	89.1		
.5	72.6		
.375	68.3		
#4	51.4		
#10	43.9		
#20	40.1		
#40	36.0		
#60	29.6		
#100	21.8		
#200	17.0		

* (no specification provided)

BROWN AND DARK BROWN SILTY GRAVEL WITH SAND

Atterberg Limits

PL= LL= PI=

Coefficients

D_{90}= 19.4555 D_{85}= 17.3788 D_{60}= 6.6192
D_{50}= 4.4334 D_{30}= 0.2558 D_{15}= 0.0594
D_{10}= 0.0170 C_u= 390.47 C_c= 0.58

Classification

USCS= GM AASHTO=

Remarks

F.M.=4.13

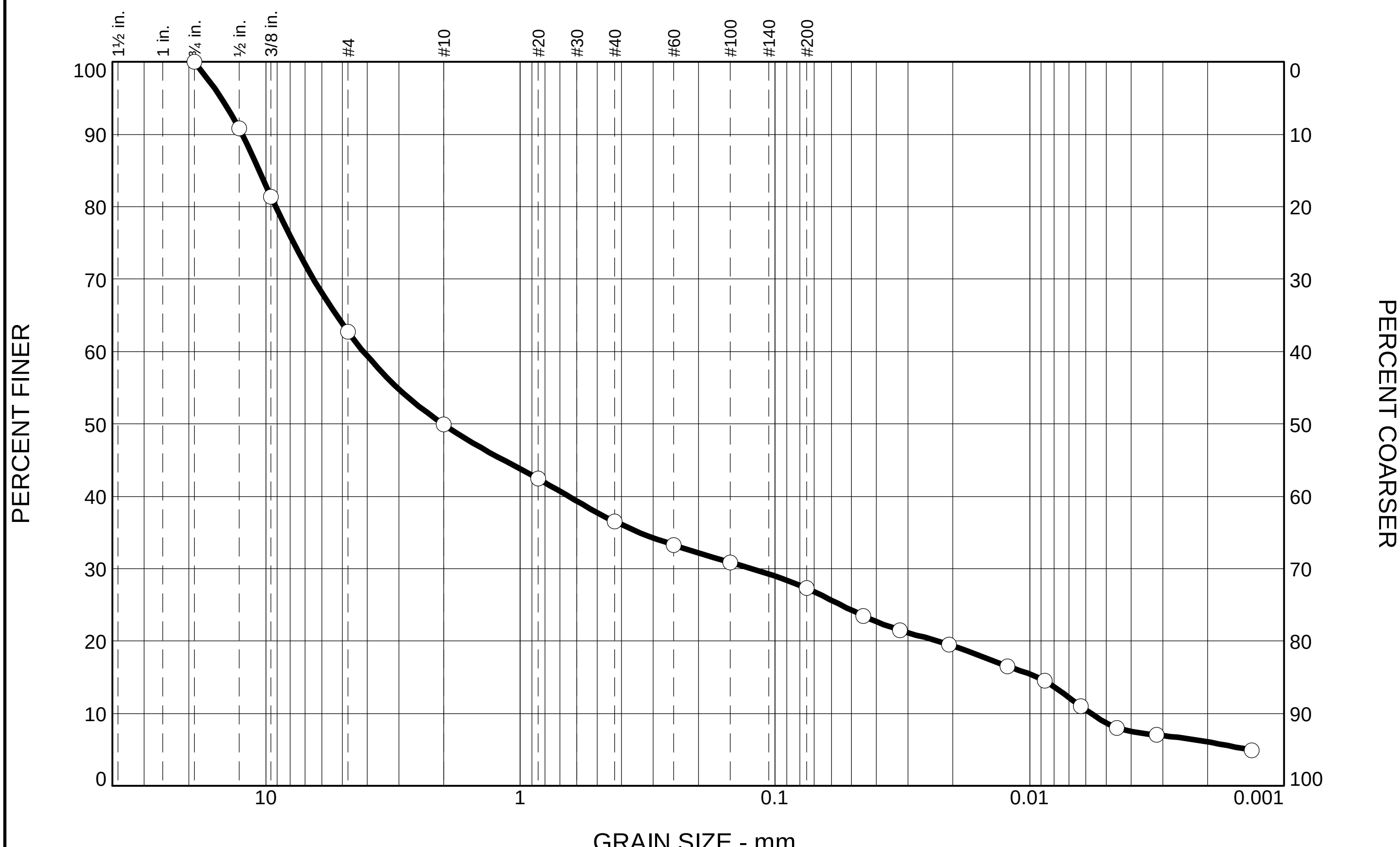
Source of Sample: HEN-B024 **Depth:** 45.0'-46.5'
Sample Number: S-13
Date: 12-17-15

Terracon

Client: AECOM
Project: DYNERGY - HENNEPIN
Project No: MR155233 **Figure**

Tested By: SJH **Checked By:** WPQ

PARTICLE SIZE ANALYSIS OF SOILS ASTM D422



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	37.3	12.8	13.4	9.2	18.6	8.7

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
.75	100.0		
.5	90.8		
.375	81.4		
#4	62.7		
#10	49.9		
#20	42.4		
#40	36.5		
#60	33.3		
#100	30.9		
#200	27.3		

* (no specification provided)

BROWN AND GRAY SILTY GRAVEL WITH SAND

Atterberg Limits

PL= LL= PI=

Coefficients

D_{90}= 12.3694 D_{85}= 10.6049 D_{60}= 4.1296
D_{50}= 2.0193 D_{30}= 0.1239 D_{15}= 0.0093
D_{10}= 0.0057 C_u= 719.10 C_c= 0.65

Classification

USCS= GM AASHTO=

Remarks

F.M.=3.55

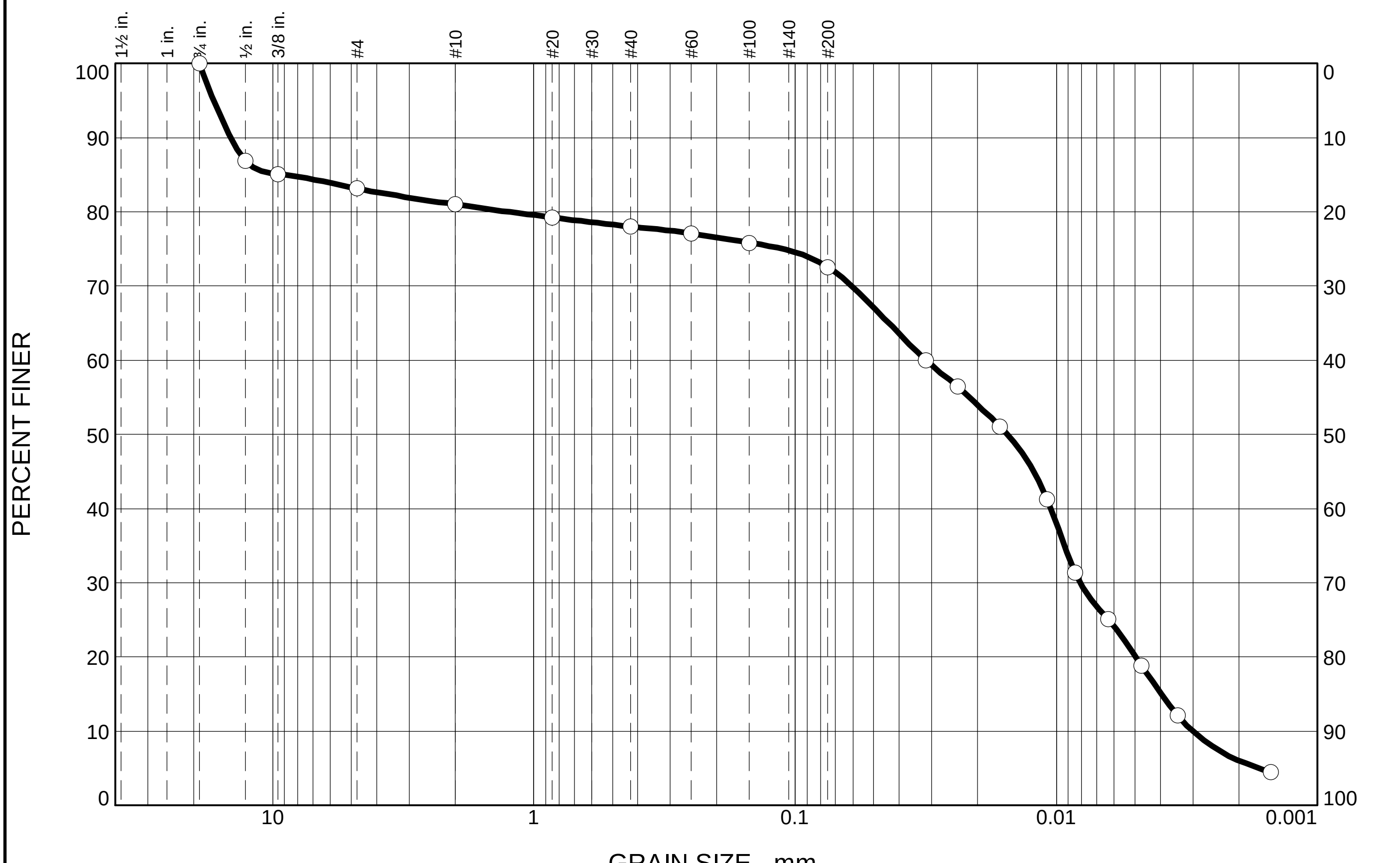
Source of Sample: HEN-B025 **Depth:** 5.0'-6.5'
Sample Number: S-3 **Date:** 12-15-15

Terracon

Client: AECOM
Project: DYNERGY - HENNEPIN
Project No: MR155233 **Figure**

Tested By: SJH **Checked By:** WPQ

PARTICLE SIZE ANALYSIS OF SOILS ASTM D422



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	16.8	2.2	3.0	5.5	52.3	20.2

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
.75	100.0		
.5	86.9		
.375	85.1		
#4	83.2		
#10	81.0		
#20	79.2		
#40	78.0		
#60	77.1		
#100	75.8		
#200	72.5		

* (no specification provided)

VERY DARK GRAY FLY ASH WITH SAND

Atterberg Limits

PL= LL= PI=

Coefficients

D_{90}= 14.4848 D_{85}= 9.0363 D_{60}= 0.0315
D_{50}= 0.0154 D_{30}= 0.0081 D_{15}= 0.0040
D_{10}= 0.0030 C_u= 10.52 C_c= 0.70

Classification

USCS= AASHTO=

Remarks

F.M.=1.39

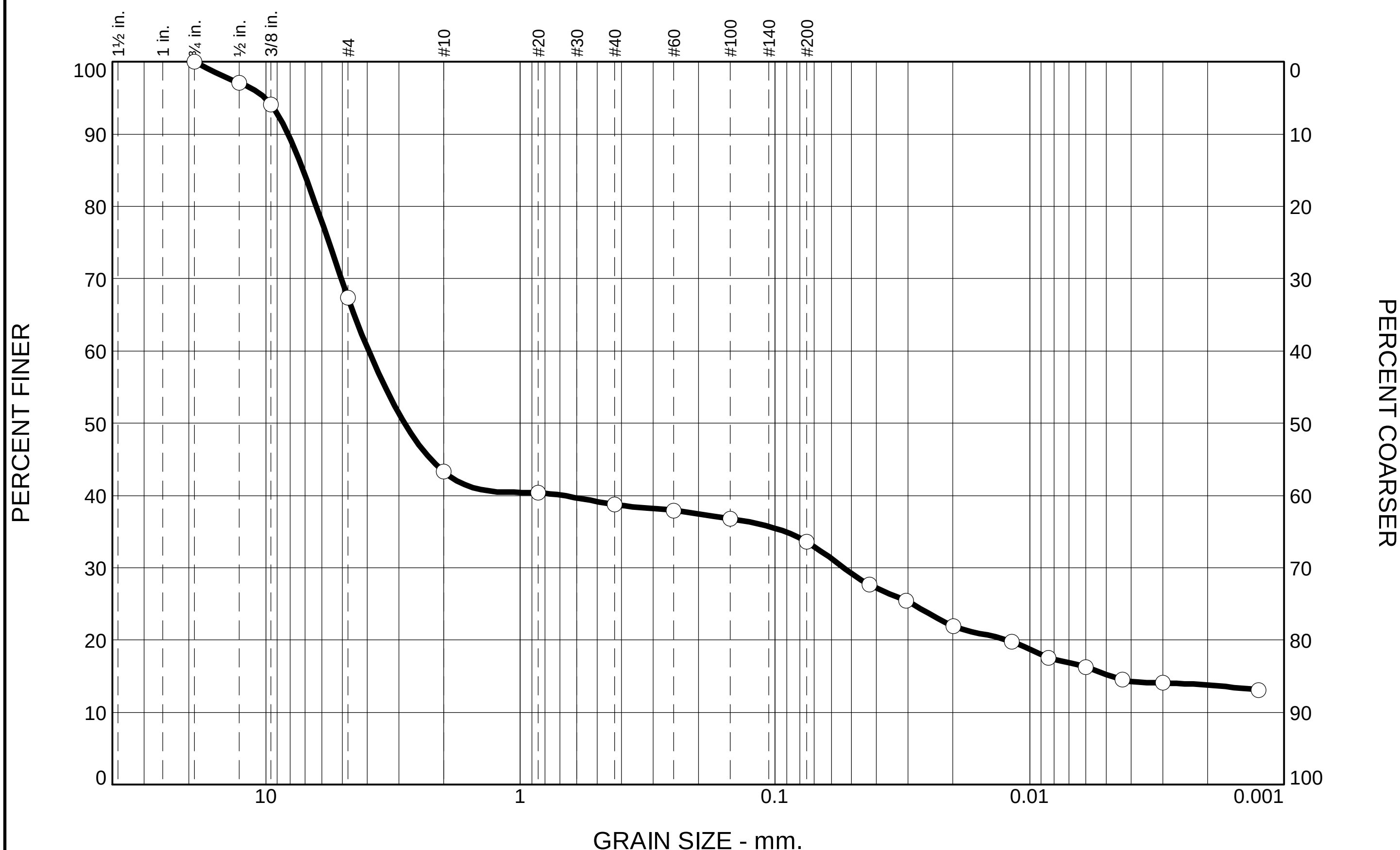
Source of Sample: HEN-B025 **Depth:** 11.5'-14.0'
Sample Number: S-6 **Date:** 12-15-15

Terracon

Client: AECOM
Project: DYNERGY - HENNEPIN
Project No: MR155233 **Figure**

Tested By: SJH **Checked By:** WPQ

PARTICLE SIZE ANALYSIS OF SOILS ASTM D422



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	32.6	24.1	4.6	5.1	18.4	15.2

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
.75	100.0		
.5	97.1		
.375	94.1		
#4	67.4		
#10	43.3		
#20	40.4		
#40	38.7		
#60	37.9		
#100	36.8		
#200	33.6		

* (no specification provided)

BROWN SILTY SAND WITH GRAVEL

Atterberg Limits

PL= LL= PI=

Coefficients

D_{90}= 8.1578 D_{85}= 7.1123 D_{60}= 3.9390
D_{50}= 2.8475 D_{30}= 0.0538 D_{15}= 0.0048
D_{10}= C_u= C_c=

Classification

USCS= SM AASHTO=

Remarks

F.M.=3.38

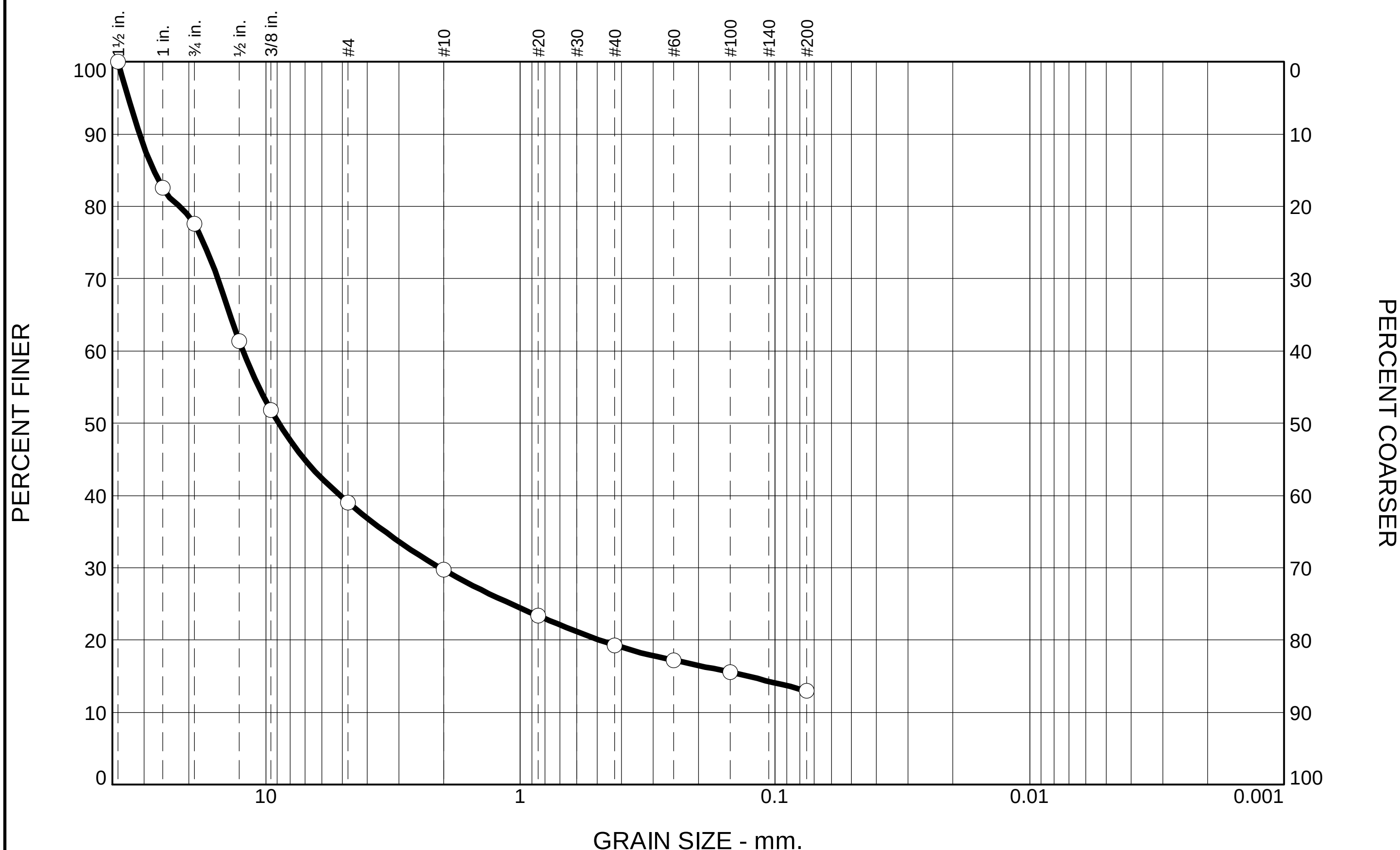
Source of Sample: HEN-B026A **Depth:** 13.5'-15.0'
Sample Number: S-2 **Date:** 12-15-15

Terracon

Client: AECOM
Project: DYNERGY - HENNEPIN
Project No: MR155233 **Figure**

Tested By: SJH **Checked By:** WPQ

PARTICLE SIZE ANALYSIS OF SOILS ASTM D422



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	22.4	38.6	9.3	10.4	6.3	13.0	

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
1.5	100.0		
1	82.5		
.75	77.6		
.5	61.4		
.375	51.8		
#4	39.0		
#10	29.7		
#20	23.4		
#40	19.3		
#60	17.2		
#100	15.6		
#200	13.0		

* (no specification provided)

LIGHT BROWN POORLY GRADED GRAVEL WITH SAND AND CLAY

Atterberg Limits

PL= LL= PI=

Coefficients

D_{90}= 31.2310 D_{85}= 27.6077 D_{60}= 12.2743
D_{50}= 8.8861 D_{30}= 2.0649 D_{15}= 0.1281
D_{10}= C_u= C_c=

Classification

USCS= GP-GC AASHTO=

Remarks

F.M.=5.20

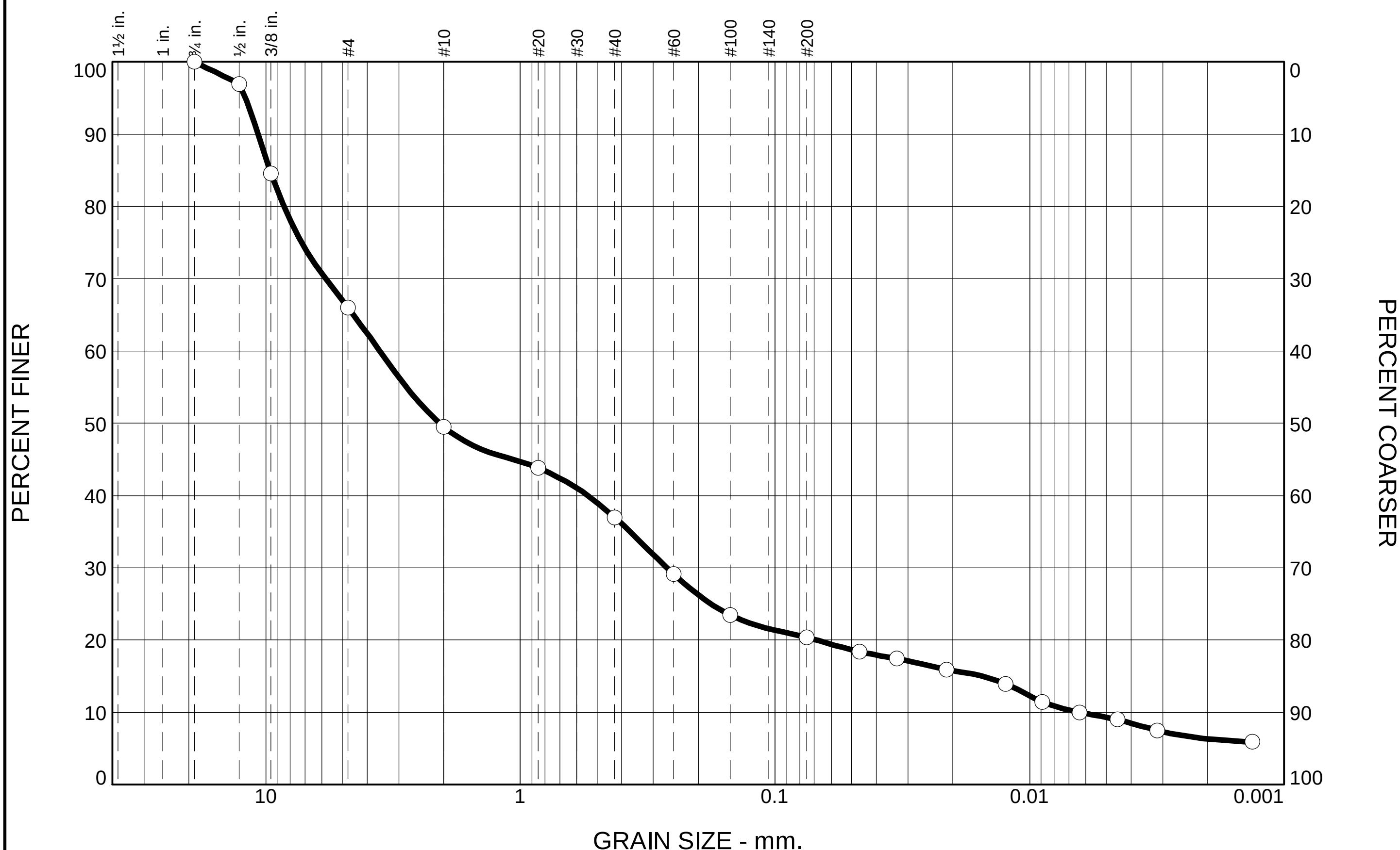
Source of Sample: HEN-B029 **Depth:** 35.0'-36.5'
Sample Number: S-10 **Date:** 12-10-15

Terracon

Client: AECOM
Project: DYNERGY - HENNEPIN
Project No: MR155233 **Figure**

Tested By: SJH **Checked By:** WPQ

PARTICLE SIZE ANALYSIS OF SOILS ASTM D422



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	34.0	16.5	12.6	16.6	11.0	9.3

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
.75	100.0		
.5	97.0		
.375	84.6		
#4	66.0		
#10	49.5		
#20	43.8		
#40	36.9		
#60	29.1		
#100	23.5		
#200	20.3		

* (no specification provided)

BROWN AND LIGHT BROWN SILTY SAND WITH GRAVEL

Atterberg Limits

PL= LL= PI=

Coefficients

D_{90}= 10.7082 D_{85}= 9.6174 D_{60}= 3.5682
D_{50}= 2.0785 D_{30}= 0.2659 D_{15}= 0.0154
D_{10}= 0.0064 C_u= 557.69 C_c= 3.10

Classification

USCS= SM AASHTO=

Remarks

F.M.=3.56

Source of Sample: HEN-B030 **Depth:** 2.5'-4.0'
Sample Number: S-2 **Date:** 12-15-15

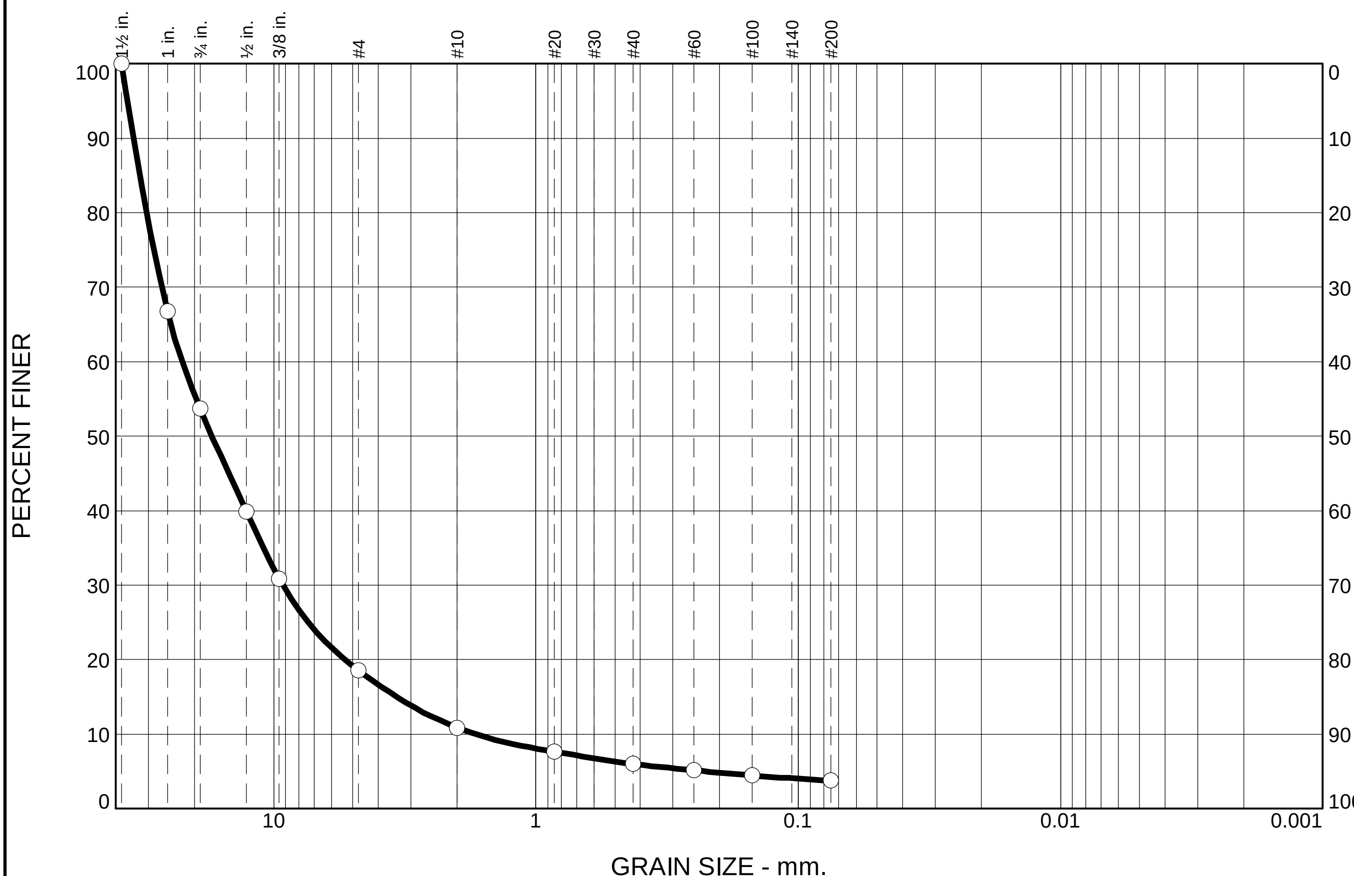
Terracon

Client: AECOM
Project: DYNERGY - HENNEPIN

Project No: MR155233 **Figure**

Tested By: SJH **Checked By:** WPQ

PARTICLE SIZE ANALYSIS OF SOILS ASTM D422



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	46.3	35.1	7.7	4.9	2.2	3.8	

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
1.5	100.0		
1	66.8		
.75	53.7		
.5	39.9		
.375	30.9		
#4	18.6		
#10	10.9		
#20	7.6		
#40	6.0		
#60	5.1		
#100	4.4		
#200	3.8		

* (no specification provided)

LIGHT BROWN AND TAN WELL GRADED GRAVEL WITH SAND

Atterberg Limits

PL= LL= PI=

Coefficients

D_{90}= 34.1590 D_{85}= 32.2869 D_{60}= 22.3306
D_{50}= 17.1780 D_{30}= 9.2189 D_{15}= 3.3953
D_{10}= 1.7025 C_u= 13.12 C_c= 2.24

Classification

USCS= GW AASHTO=

Remarks

F.M.=6.60

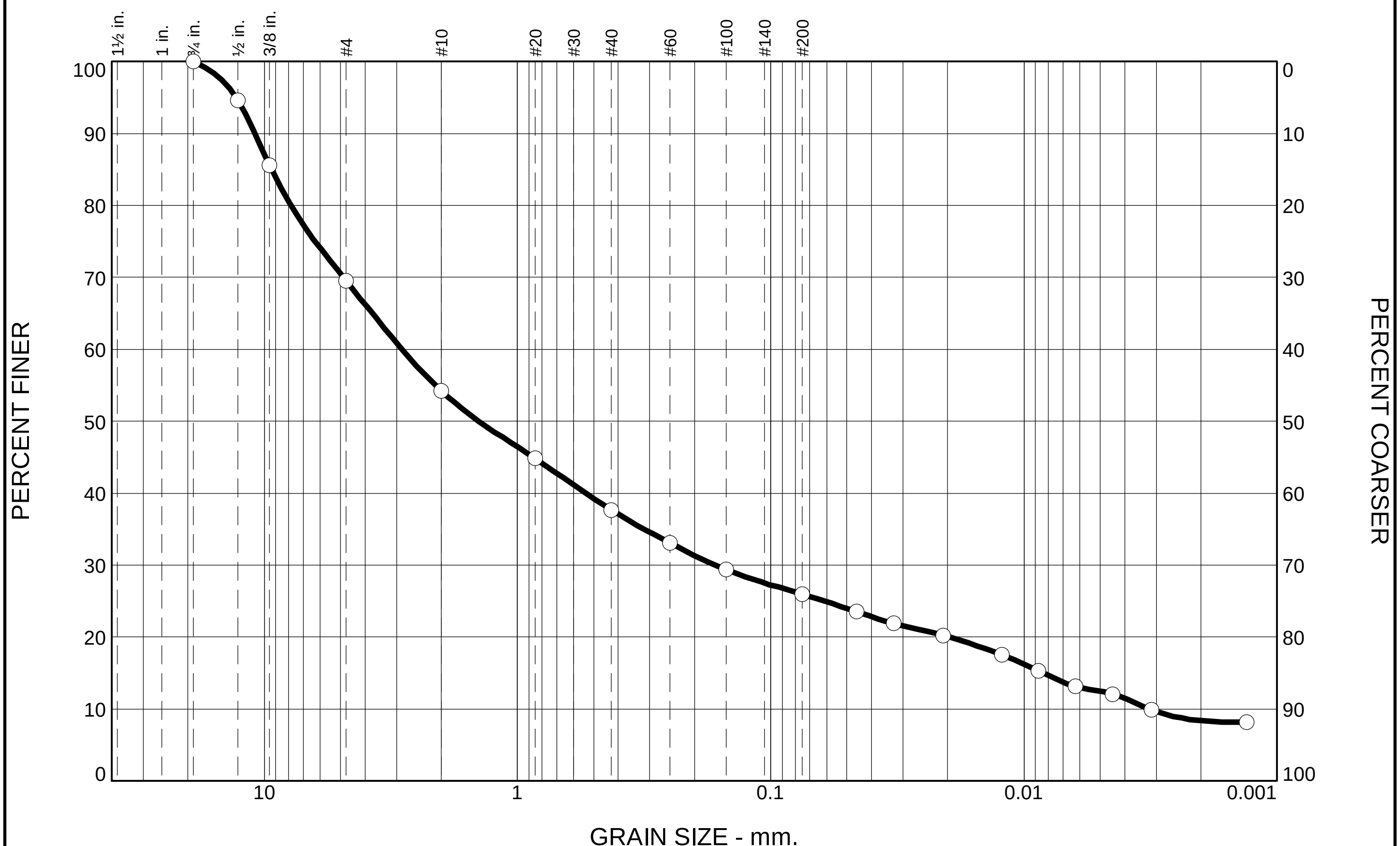
Source of Sample: HEN-B030 **Depth:** 15.0'-16.5'
Sample Number: S-6
Date: 12-10-15

Terracon

Client: AECOM
Project: DYNERGY - HENNEPIN
Project No: MR155233 **Figure**

Tested By: SJH **Checked By:** WPQ

PARTICLE SIZE ANALYSIS OF SOILS ASTM D422



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	30.5	15.3	16.5	11.8	13.4	12.5

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
.75	100.0		
.5	94.6		
.375	85.6		
#4	69.5		
#10	54.2		
#20	44.8		
#40	37.7		
#60	33.1		
#100	29.4		
#200	25.9		

* (no specification provided)

BROWN SILTY SAND WITH GRAVEL

Atterberg Limits

PL= LL= PI=

Coefficients

D_{90}= 10.8888 D_{85}= 9.3568 D_{60}= 2.8565
D_{50}= 1.4206 D_{30}= 0.1654 D_{15}= 0.0084
D_{10}= 0.0032 C_u= 894.95 C_c= 3.00

Classification

USCS= SM AASHTO=

Remarks

F.M.=3.35

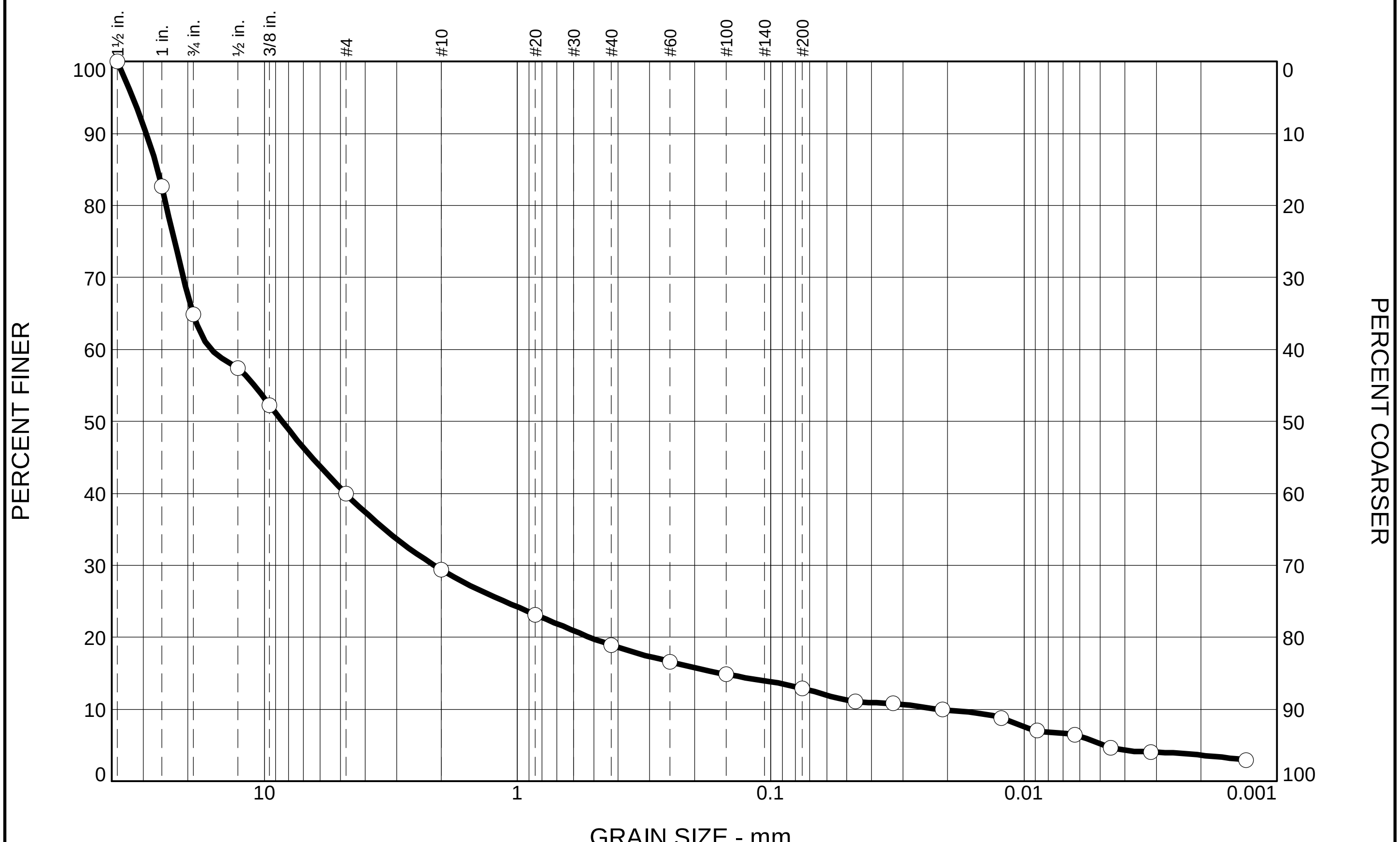
Source of Sample: HEN-B032 **Depth:** 20.0'-21.5'
Sample Number: S-7
Date: 12-15-15

Terracon

Client: AECOM
Project: DYNERGY - HENNEPIN
Project No: MR155233 **Figure**

Tested By: SJH **Checked By:** WPQ

PARTICLE SIZE ANALYSIS OF SOILS ASTM D422



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	35.1	25.0	10.5	10.5	6.0	7.7	5.2

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
1.5	100.0		
1	82.7		
.75	64.9		
.5	57.4		
.375	52.3		
#4	39.9		
#10	29.4		
#20	23.2		
#40	18.9		
#60	16.6		
#100	14.8		
#200	12.9		

* (no specification provided)

BROWN AND LIGHT BROWN POORLY GRADED GRAVEL WITH SILT AND SAND

Atterberg Limits

PL= LL= PI=

Coefficients

D_{90}= 29.2016 D_{85}= 26.4297 D_{60}= 16.1803
D_{50}= 8.4958 D_{30}= 2.1337 D_{15}= 0.1581
D_{10}= 0.0218 C_u= 742.74 C_c= 12.92

Classification

USCS= GP-GM AASHTO=

Remarks

F.M.=5.34

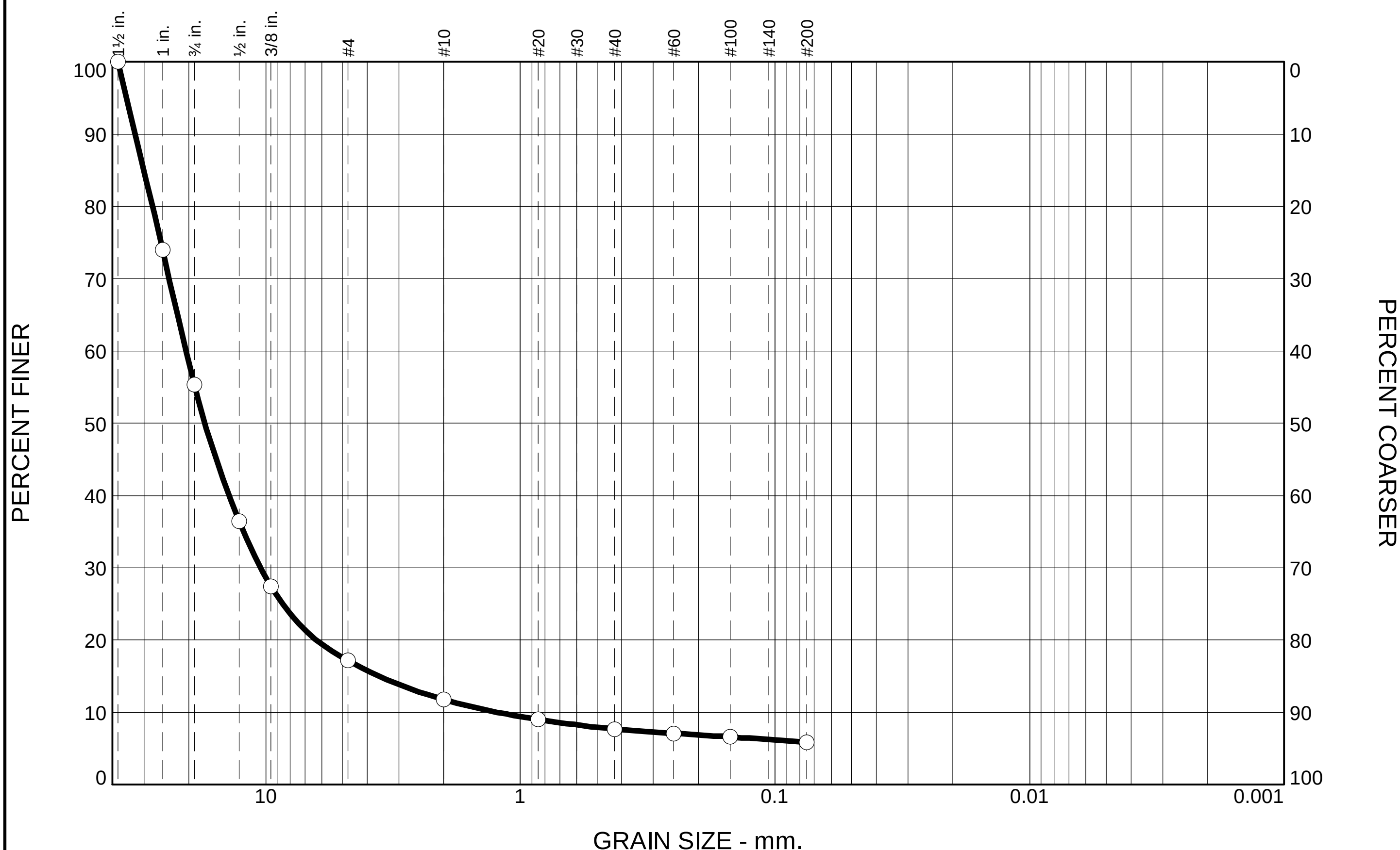
Source of Sample: HEN-B034 **Depth:** 10.0'-11.5'
Sample Number: S-5 **Date:** 12-17-15

Terracon

Client: AECOM
Project: DYNERGY - HENNEPIN
Project No: MR155233 **Figure**

Tested By: SJH **Checked By:** WPQ

PARTICLE SIZE ANALYSIS OF SOILS ASTM D422



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	44.7	38.1	5.4	4.1	1.8	5.9	

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
1.5	100.0		
1	74.0		
.75	55.3		
.5	36.4		
.375	27.4		
#4	17.2		
#10	11.8		
#20	9.0		
#40	7.7		
#60	7.1		
#100	6.6		
#200	5.9		

* (no specification provided)

LIGHT BROWN AND TAN POORLY GRADED GRAVEL WITH SAND AND SILT

Atterberg Limits

PL= LL= PI=

Coefficients

D_{90}= 32.5083 D_{85}= 30.0560 D_{60}= 20.5658
D_{50}= 17.3171 D_{30}= 10.4646 D_{15}= 3.5815
D_{10}= 1.2300 C_u= 16.72 C_c= 4.33

Classification

USCS= GP-GM AASHTO=

Remarks

F.M.=6.56

Source of Sample: HEN-B034 **Depth:** 35.0'-36.5'
Sample Number: S-10 **Date:** 12-10-15

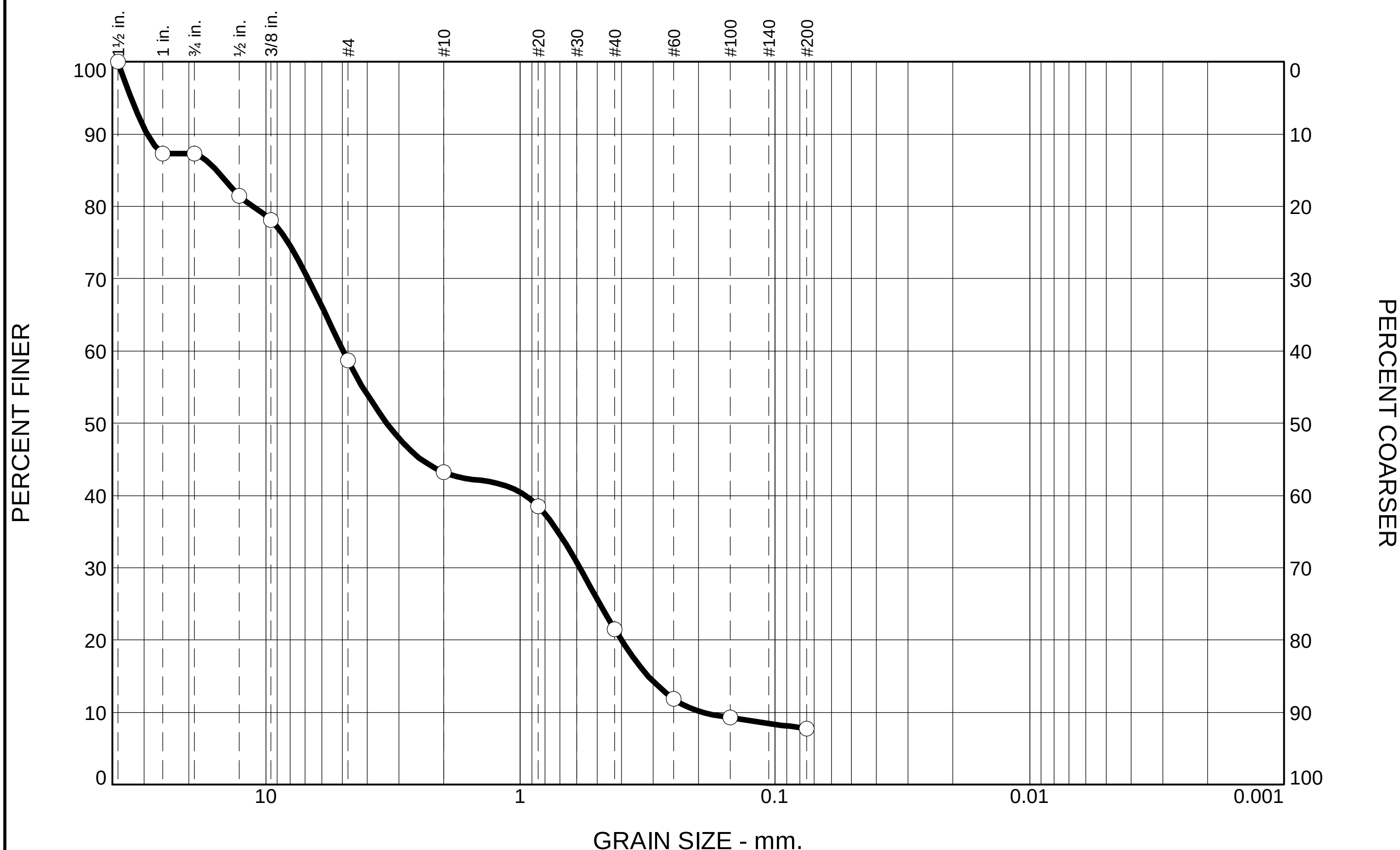
Terracon

Client: AECOM
Project: DYNERGY - HENNEPIN

Project No: MR155233 **Figure**

Tested By: SJH **Checked By:** WPQ

PARTICLE SIZE ANALYSIS OF SOILS ASTM D422



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	12.7	28.6	15.5	21.8	13.7	7.7	

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
1.5	100.0		
1	87.3		
.75	87.3		
.5	81.5		
.375	78.1		
#4	58.7		
#10	43.2		
#20	38.5		
#40	21.4		
#60	11.8		
#100	9.2		
#200	7.7		

* (no specification provided)

BROWN AND DARK BROWN SILTY SAND WITH GRAVEL

Atterberg Limits

PL= LL= PI=

Coefficients

D_{90}= 29.1386 D_{85}= 15.6078 D_{60}= 4.9602
D_{50}= 3.3485 D_{30}= 0.5840 D_{15}= 0.3138
D_{10}= 0.1928 C_u= 25.73 C_c= 0.36

Classification

USCS= SM AASHTO=

Remarks

F.M.=4.36

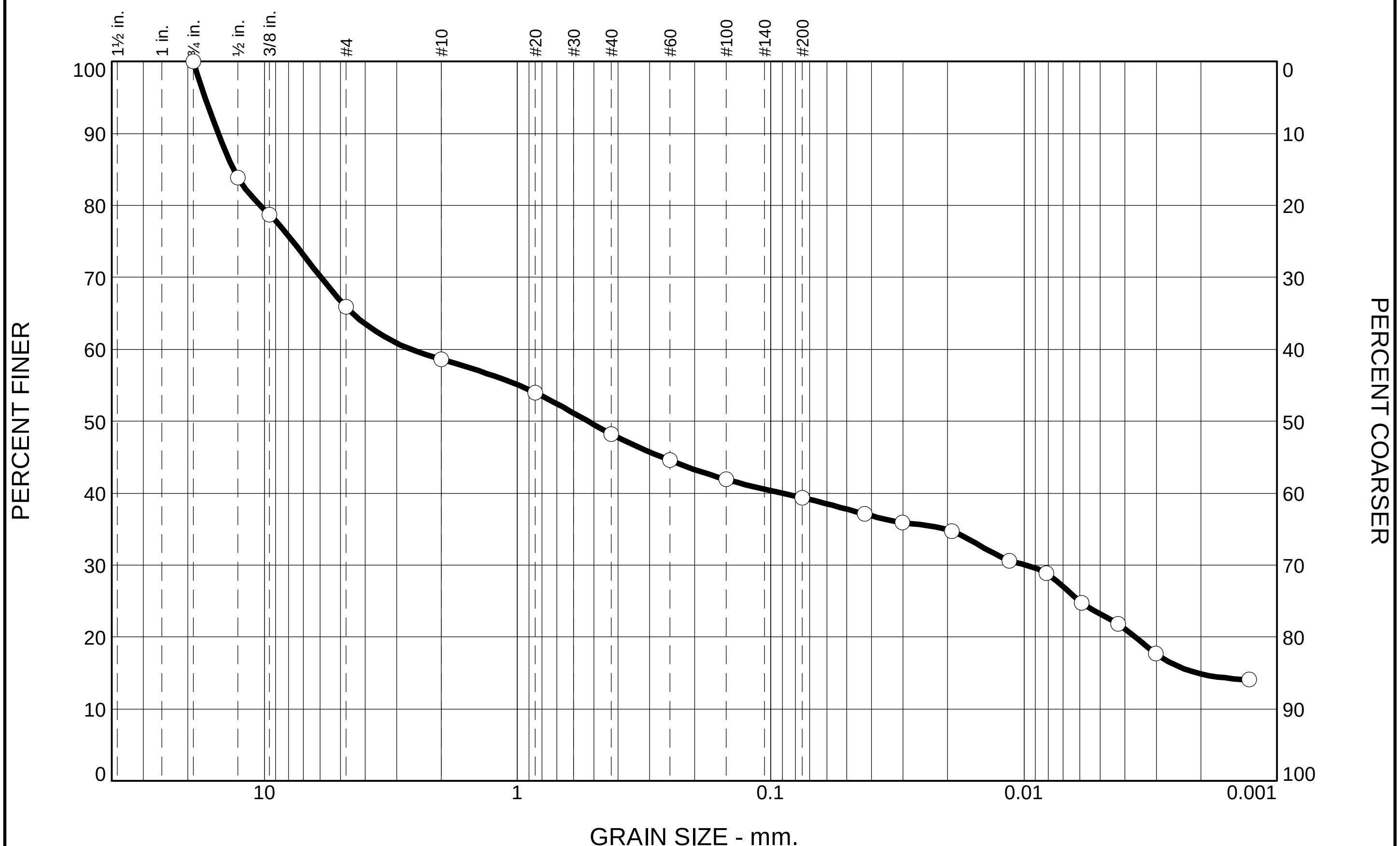
Source of Sample: HEN-B037 **Depth:** 5.0'-6.5'
Sample Number: S-3 **Date:** 12-10-15

Terracon

Client: AECOM
Project: DYNERGY - HENNEPIN
Project No: MR155233 **Figure**

Tested By: SJH **Checked By:** WPQ

PARTICLE SIZE ANALYSIS OF SOILS ASTM D422



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	34.1	7.3	10.4	8.8	16.2	23.2

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
.75	100.0		
.5	83.9		
.375	78.7		
#4	65.9		
#10	58.6		
#20	54.0		
#40	48.2		
#60	44.6		
#100	41.9		
#200	39.4		

* (no specification provided)

BROWN AND LIGHT BROWN CLAYEY GRAVEL WIRTH SAND

Atterberg Limits

PL= LL= PI=

Coefficients

D_{90}= 15.2090 D_{85}= 13.2128 D_{60}= 2.6302
D_{50}= 0.5271 D_{30}= 0.0099 D_{15}= 0.0021
D_{10}= C_u= C_c=

Classification

USCS= GC AASHTO=

Remarks

F.M.=3.01

Source of Sample: HEN-B037 **Depth:** 15.0'-16.5'
Sample Number: S-6

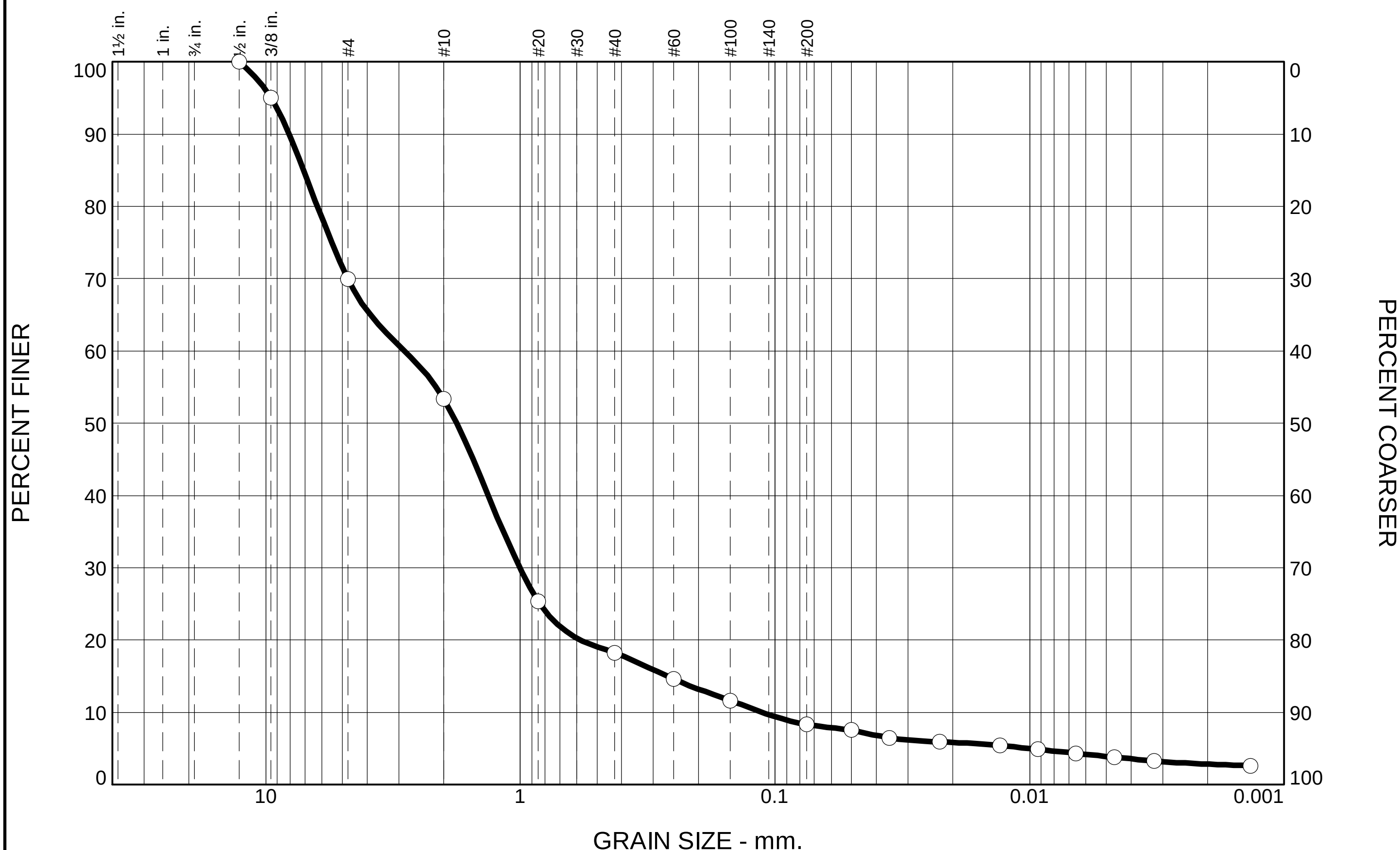
Date: 12-15-15

Terracon

Client: AECOM
Project: DYNERGY - HENNEPIN
Project No: MR155233 **Figure**

Tested By: SJH **Checked By:** WPQ

PARTICLE SIZE ANALYSIS OF SOILS ASTM D422



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	30.1	16.5	35.2	9.9	4.4	3.9

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
.50	100.0		
.375	95.0		
#4	69.9		
#10	53.4		
#20	25.4		
#40	18.2		
#60	14.6		
#100	11.6		
#200	8.3		

* (no specification provided)

TAN POORLY GRADED SAND WITH GRAVEL AND SILT

Atterberg Limits

PL= LL= PI=

Coefficients

D_{90}= 8.0898 D_{85}= 7.0874 D_{60}= 2.8508
D_{50}= 1.7783 D_{30}= 1.0044 D_{15}= 0.2652
D_{10}= 0.1120 C_u= 25.46 C_c= 3.16

Classification

USCS= SP-SM AASHTO=

Remarks

F.M.=3.95

Source of Sample: HEN-B038 **Depth:** 5.0'-5.9'
Sample Number: S-3

Date: 12-15-15

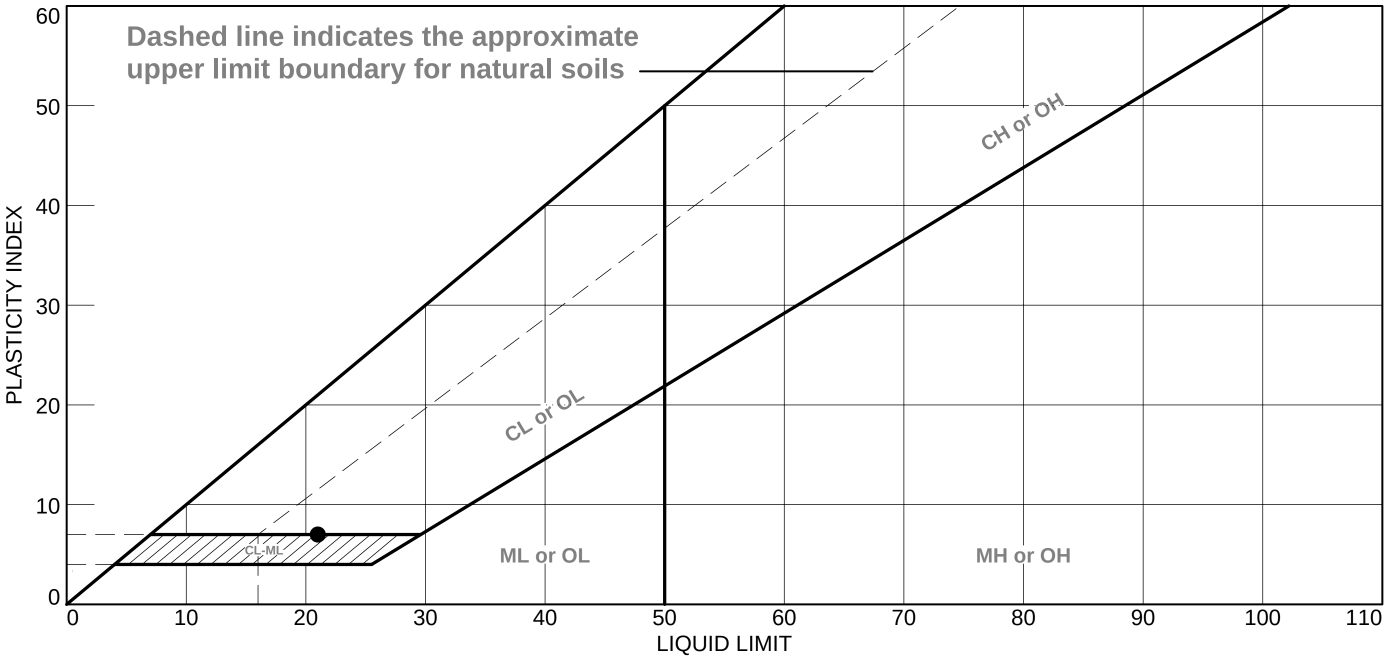
Terracon

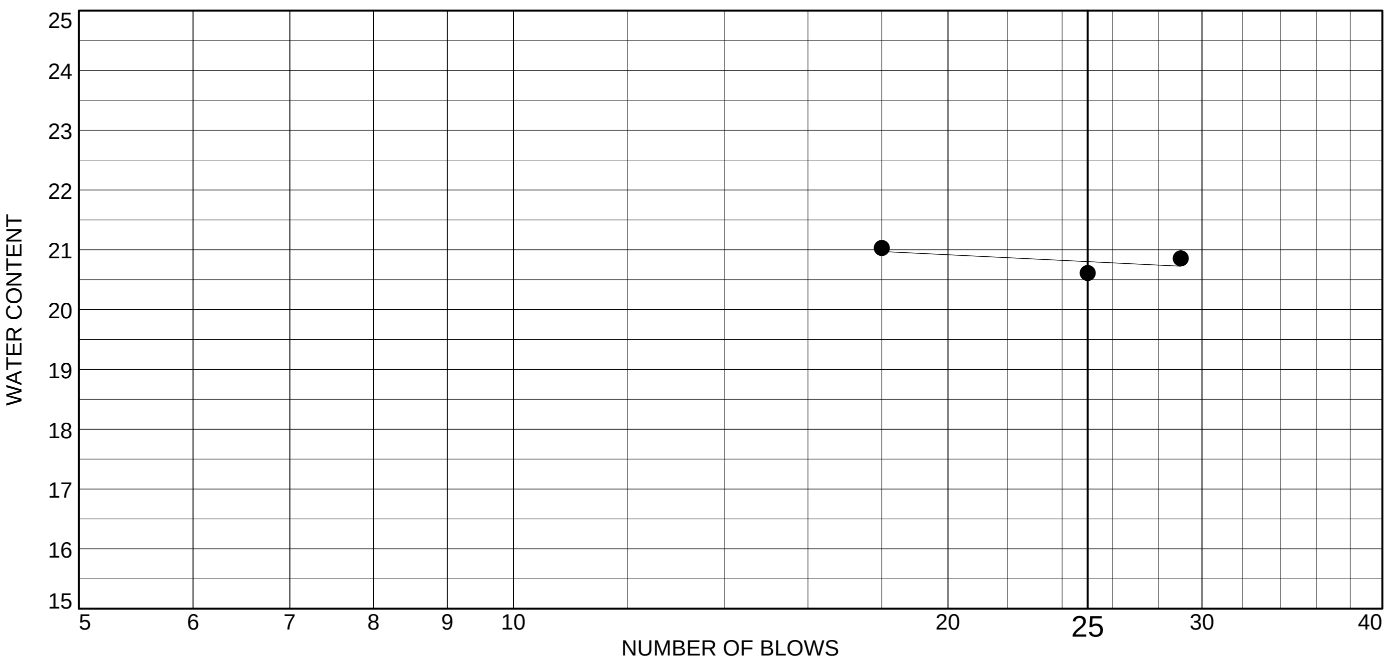
Client: AECOM
Project: DYNERGY - HENNEPIN
Project No: MR155233 **Figure**

Tested By: SJH **Checked By:** WPQ

Liquid Limit, Plastic Limit and Plasticity Index of Soils ASTM D 4318

LIQUID AND PLASTIC LIMITS ASTM D4318





	MATERIAL DESCRIPTION	LL	PL	PI	%<#40	%<#200	USCS
●	BROWN AND GRAY LEAN CLAY WITH SAND - SAND SEAMS NOTED	21	14	7			CL

Project No. MR155233 **Client:** AECOM

Project: DYNERGY - HENNEPIN

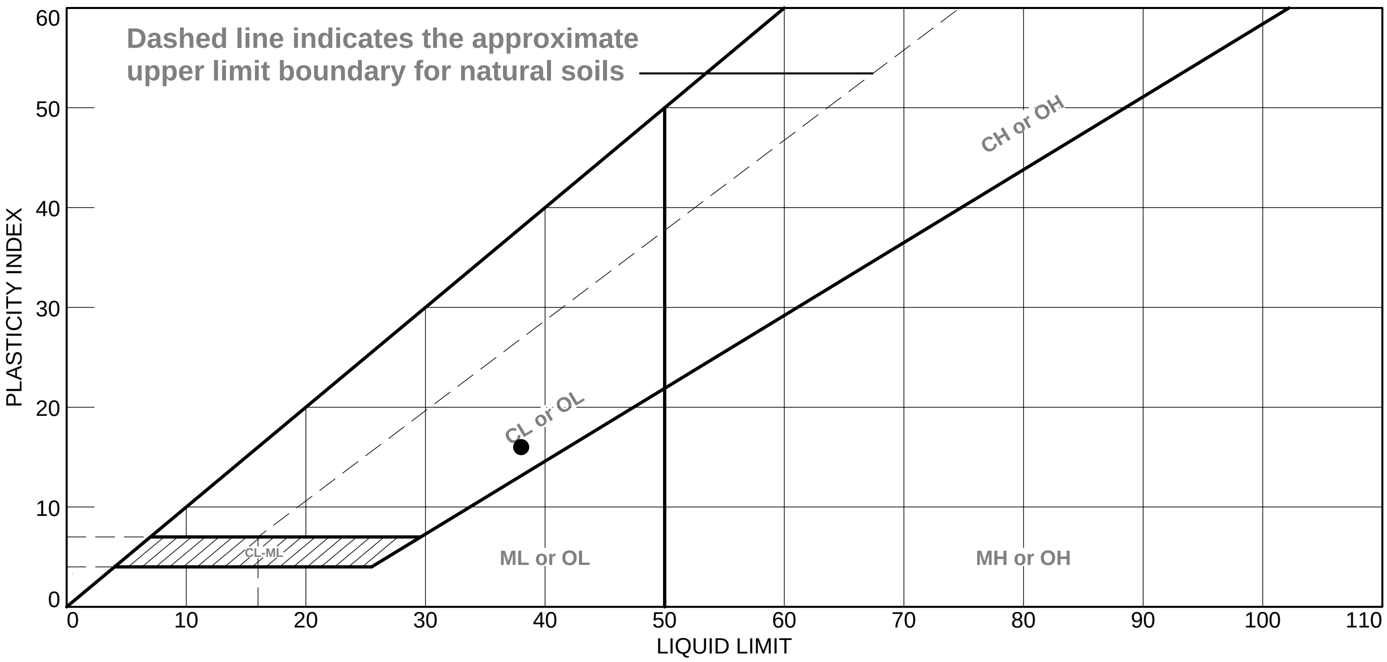
Source of Sample: HEN-B001 **Depth:** 7.5'-9.5'
Sample Number: S-4

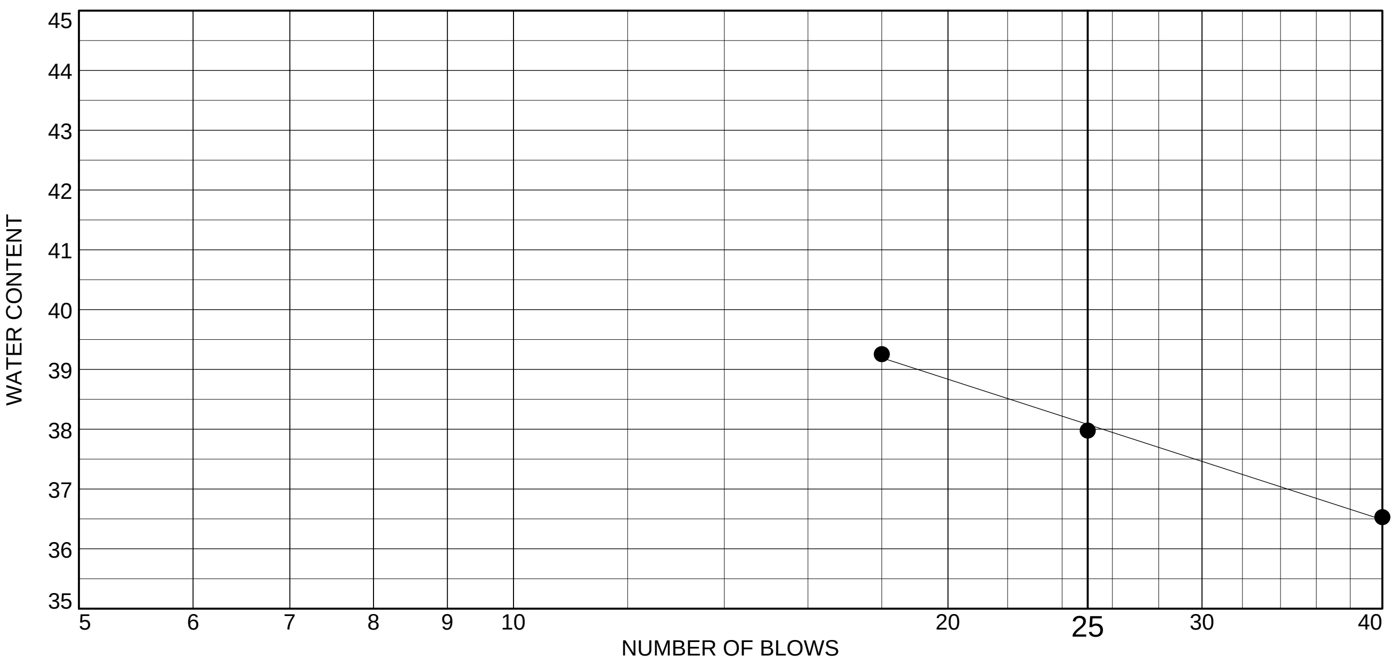
Remarks:

Figure

Tested By: BCM **Checked By:** WPQ

LIQUID AND PLASTIC LIMITS ASTM D4318





	MATERIAL DESCRIPTION	LL	PL	PI	%<#40	%<#200	USCS
●	GRAY ORGANIC LEAN CLAY - SHELL NOTED	38	22	16			CL

Project No. MR155233 **Client:** AECOM

Project: DYNERGY - HENNEPIN

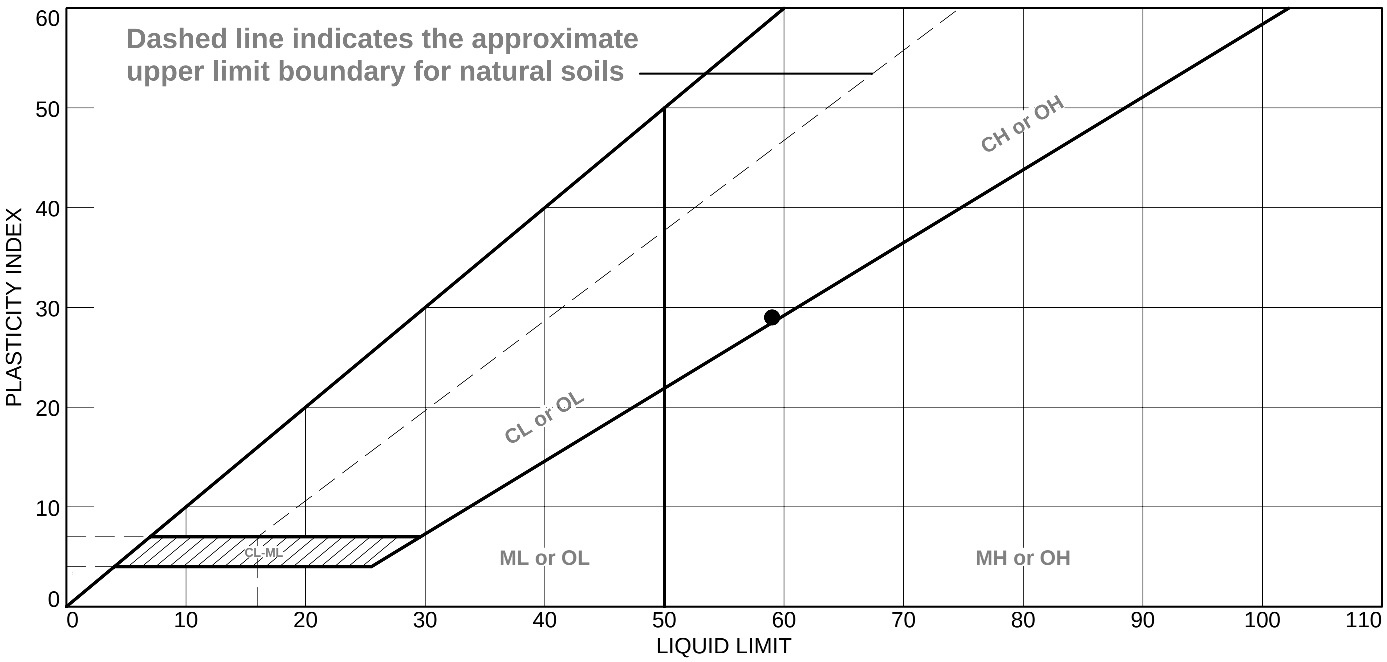
Source of Sample: HEN-B001 **Depth:** 20.0'-22.0'
Sample Number: S-7

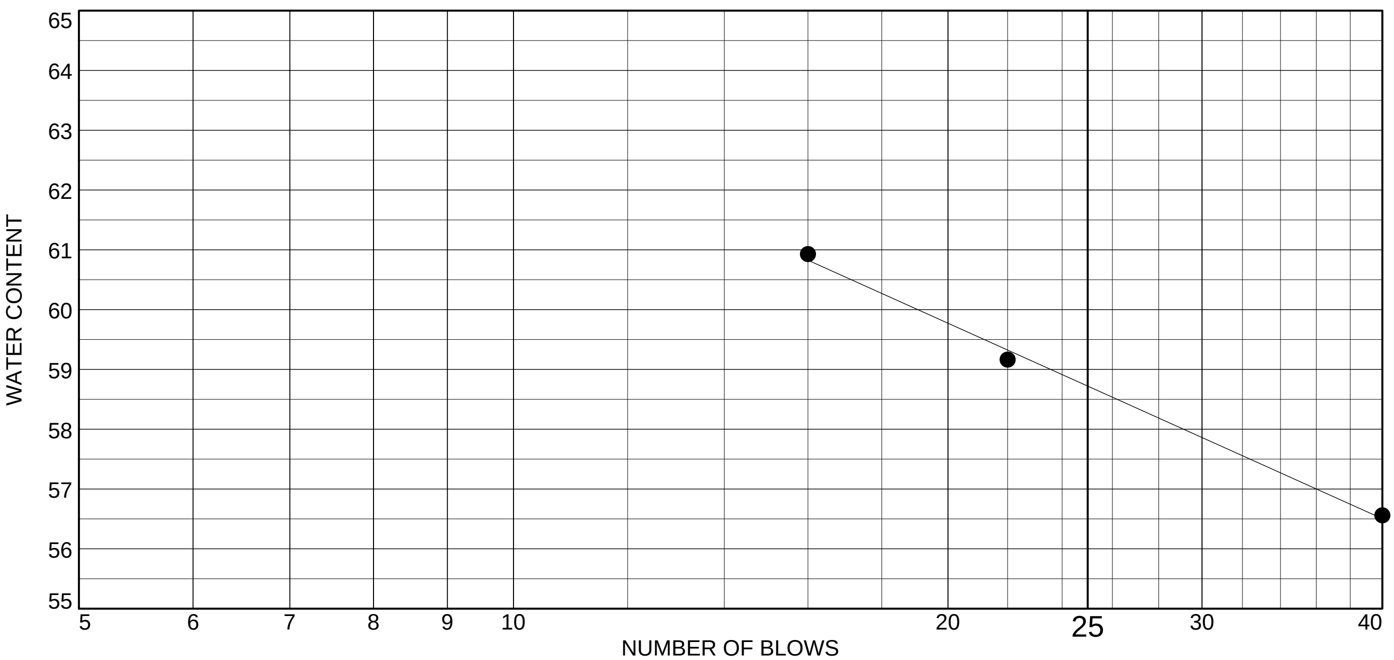
Remarks:

Figure

Tested By: HP **Checked By:** WPQ

LIQUID AND PLASTIC LIMITS ASTM D4318





	MATERIAL DESCRIPTION	LL	PL	PI	%<#40	%<#200	USCS
●	DARK GRAY FAT CLAY	59	30	29			CH

Project No. MR155233 **Client:** AECOM

Project: DYNERGY - HENNEPIN

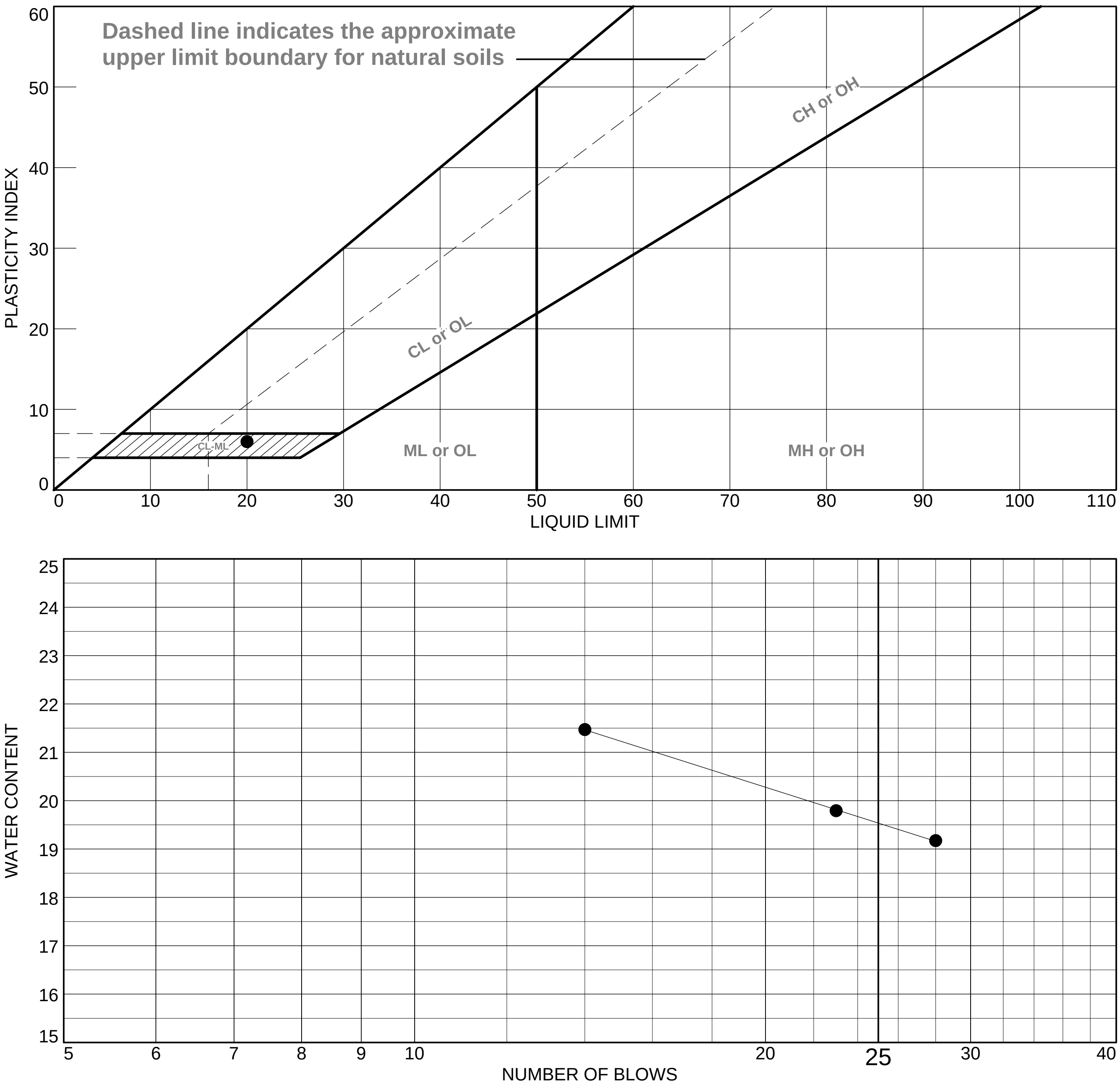
Source of Sample: HEN-B001 **Depth:** 40.0'-41.5'
Sample Number: S-11

Remarks:

Figure

Tested By: HP **Checked By:** WPQ

LIQUID AND PLASTIC LIMITS ASTM D4318



	MATERIAL DESCRIPTION	LL	PL	PI	%<#40	%<#200	USCS
●	BROWN SILT WITH CLAY	20	14	6			ML

Project No. MR155233 **Client:** AECOM

Project: DYNERGY - HENNEPIN

Source of Sample: HEN-B002 **Depth:** 7.5'-9.0'
Sample Number: S-4

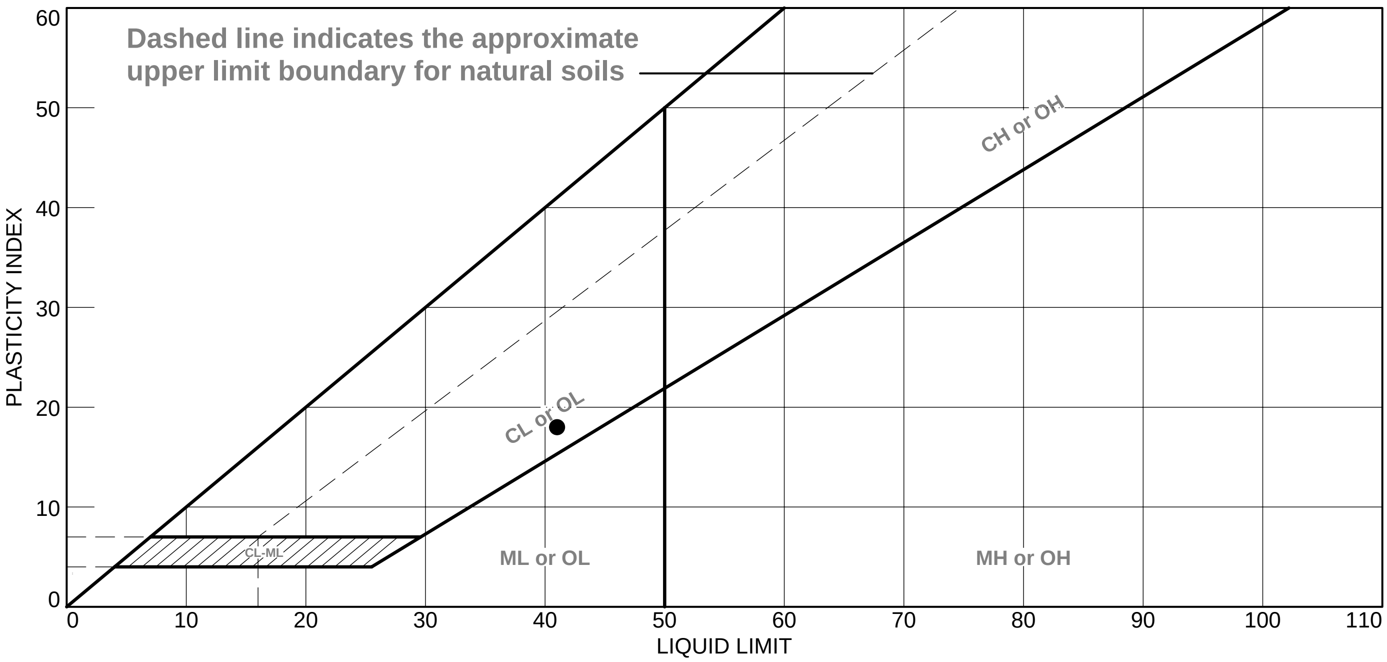
Terracon

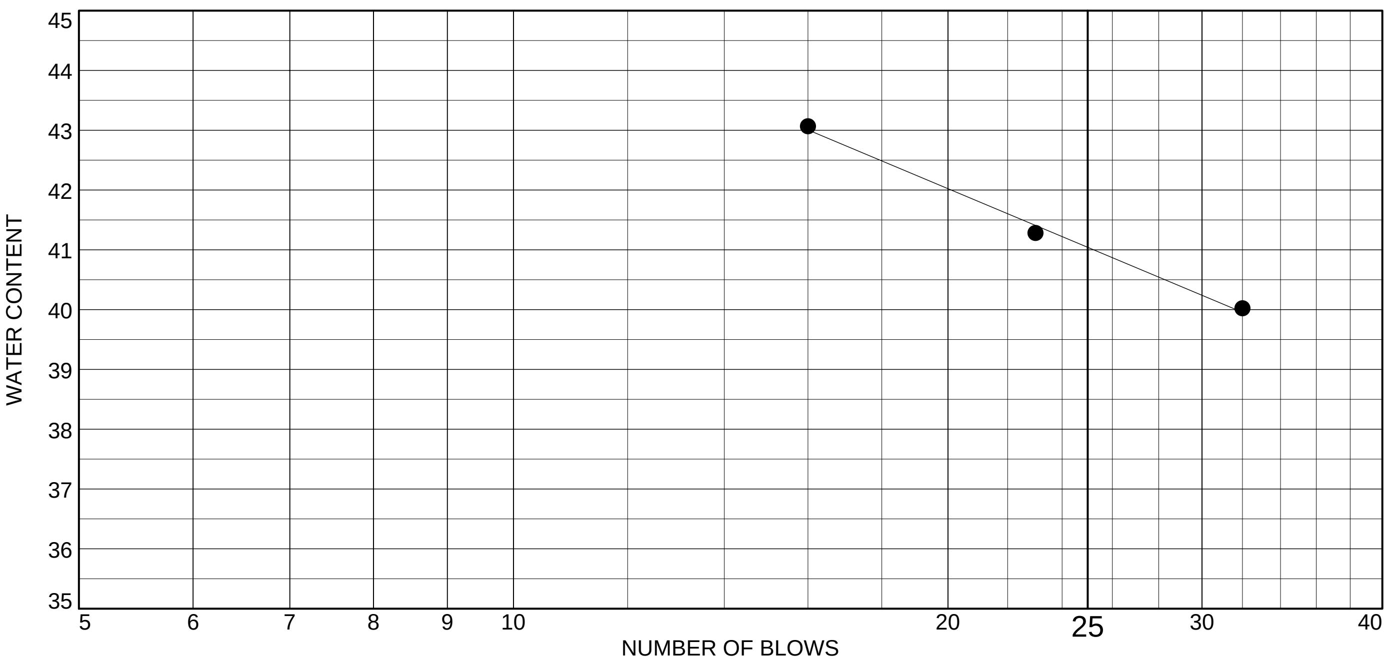
Remarks:

Figure

Tested By: DT **Checked By:** WPQ

LIQUID AND PLASTIC LIMITS ASTM D4318





	MATERIAL DESCRIPTION	LL	PL	PI	%<#40	%<#200	USCS
●	DARK GRAY LEAN CLAY WITH SAND AND GRAVEL - FLY ASH NOTED	41	23	18			OL

Project No. MR155233 **Client:** AECOM

Project: DYNERGY - HENNEPIN

Source of Sample: HEN-B002 **Depth:** 25.0'-27.0'
Sample Number: S-8

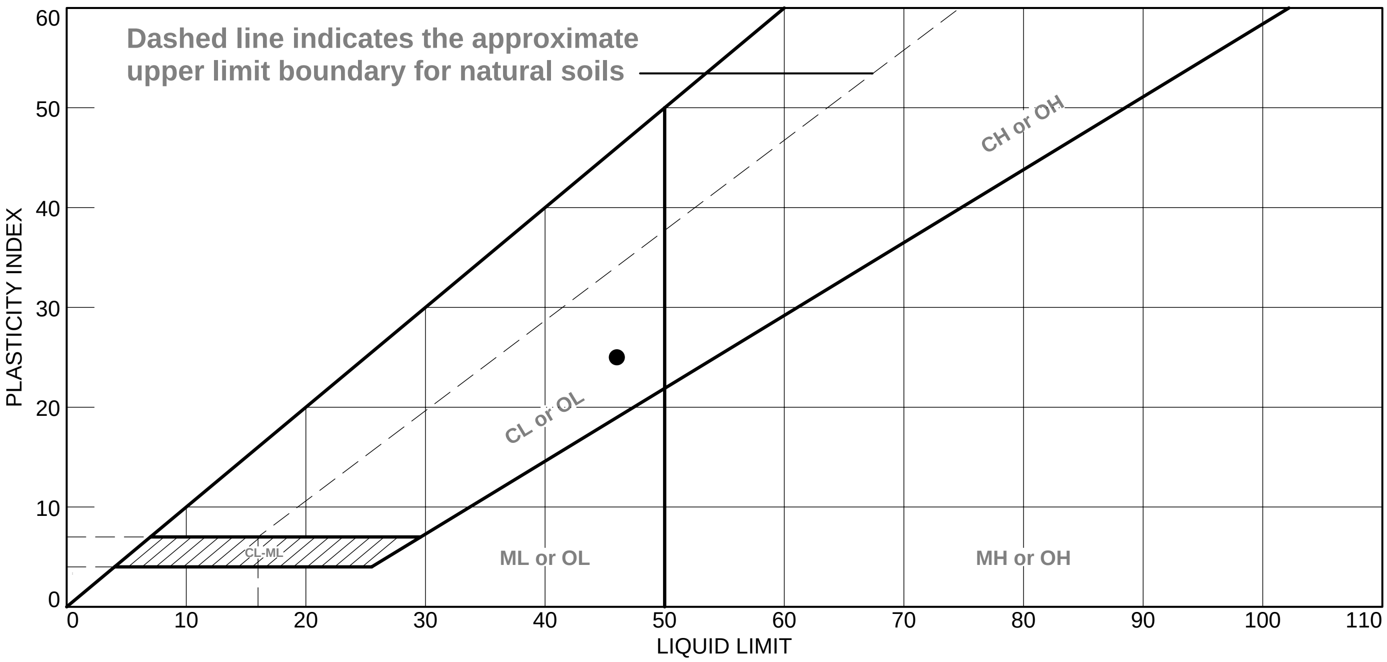
Terracon

Remarks:

Figure

Tested By: BCM **Checked By:** WPQ

LIQUID AND PLASTIC LIMITS ASTM D4318



	MATERIAL DESCRIPTION	LL	PL	PI	%<#40	%<#200	USCS
●	GRAY LEAN CLAY	46	21	25			CL

Project No. MR155233 **Client:** AECOM

Project: DYNERGY - HENNEPIN

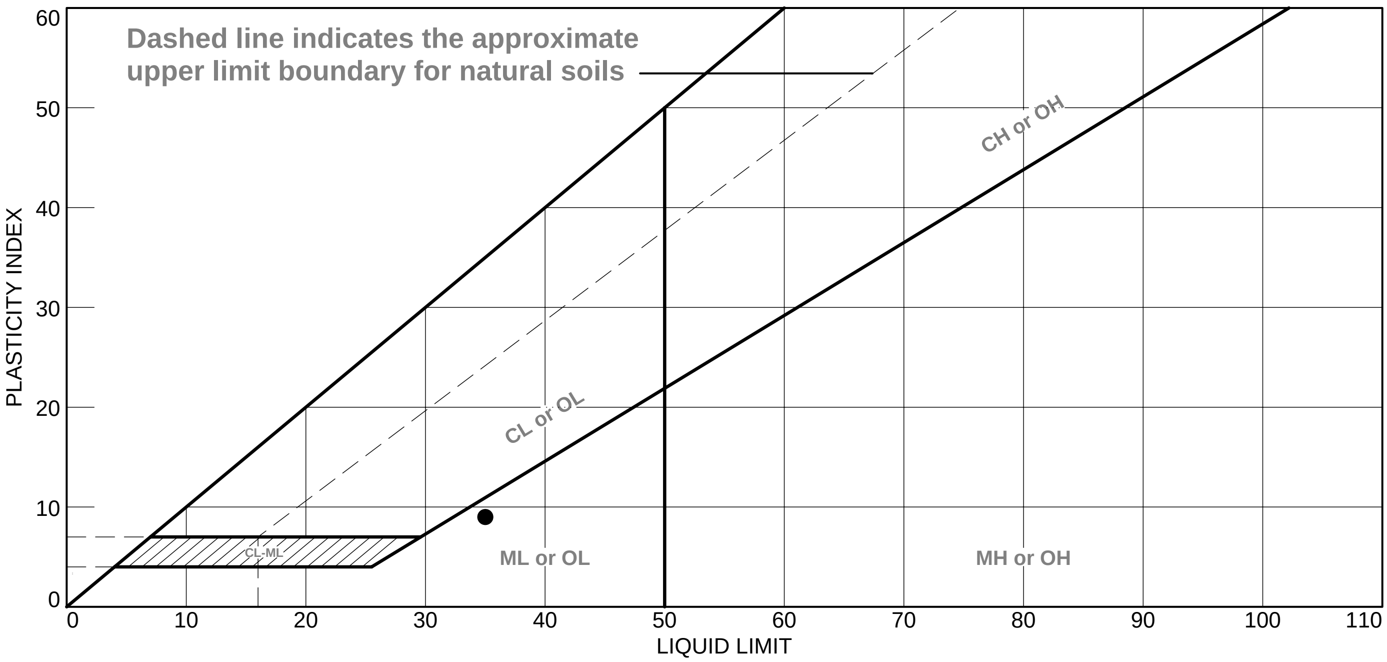
Source of Sample: HEN-B002 **Depth:** 35.0'-37.0'
Sample Number: S-10

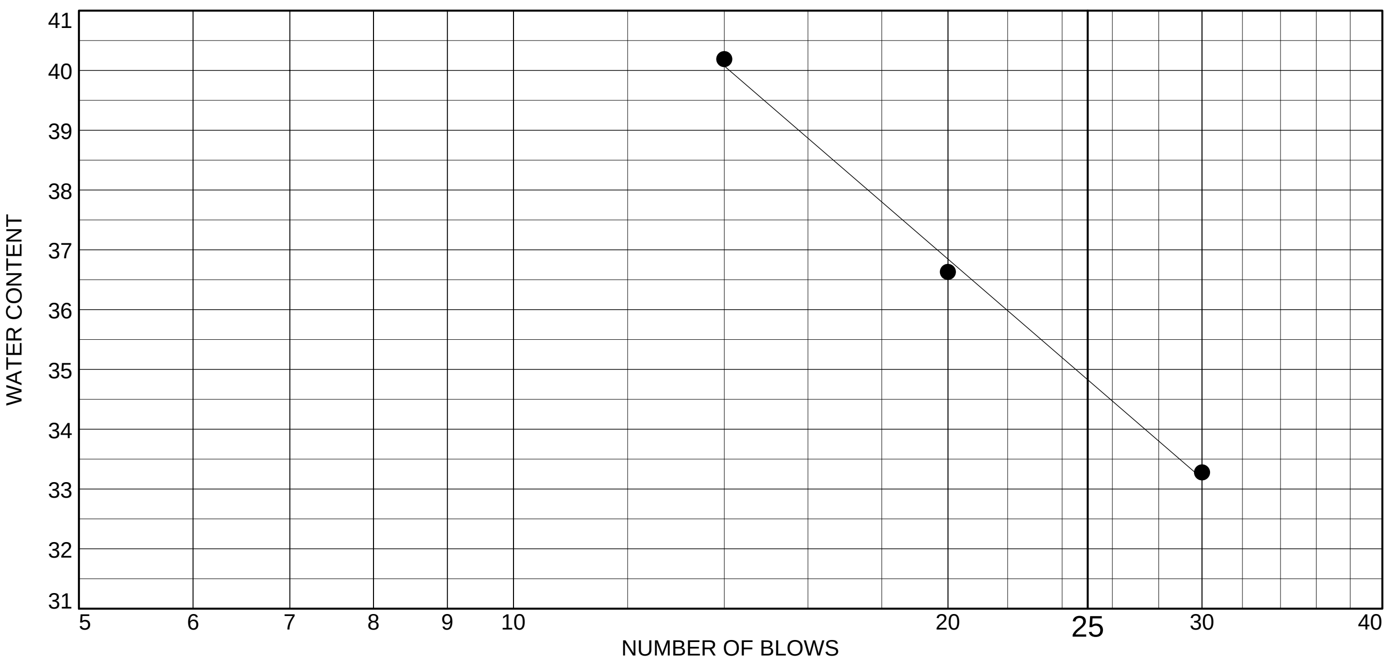
Remarks:

Figure

Tested By: BCM **Checked By:** WPQ

LIQUID AND PLASTIC LIMITS ASTM D4318





	MATERIAL DESCRIPTION	LL	PL	PI	%<#40	%<#200	USCS
●	BLACK ORGANIC CLAY WITH SAND - WOOD NOTED	35	26	9			OL

Project No. MR155233 **Client:** AECOM

Project: DYNERGY - HENNEPIN

Source of Sample: HEN-B003 **Depth:** 10.0'-12.0'

Sample Number: S-5

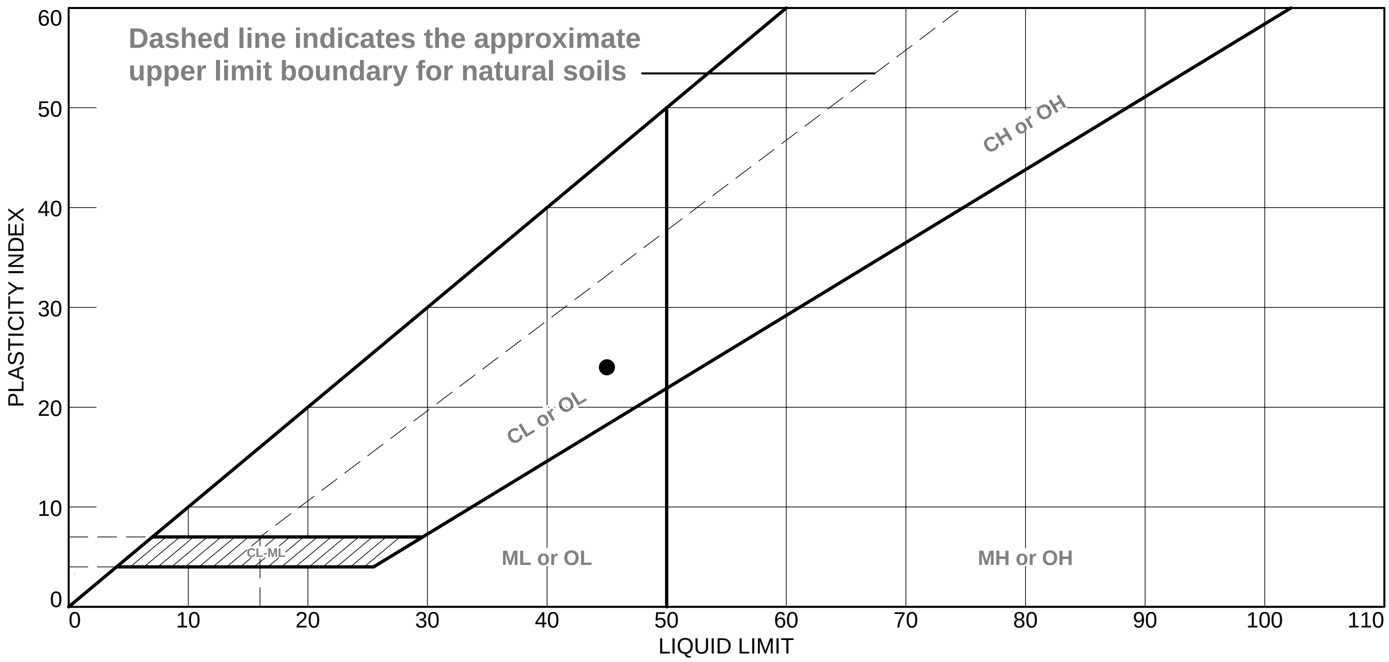
Terracon

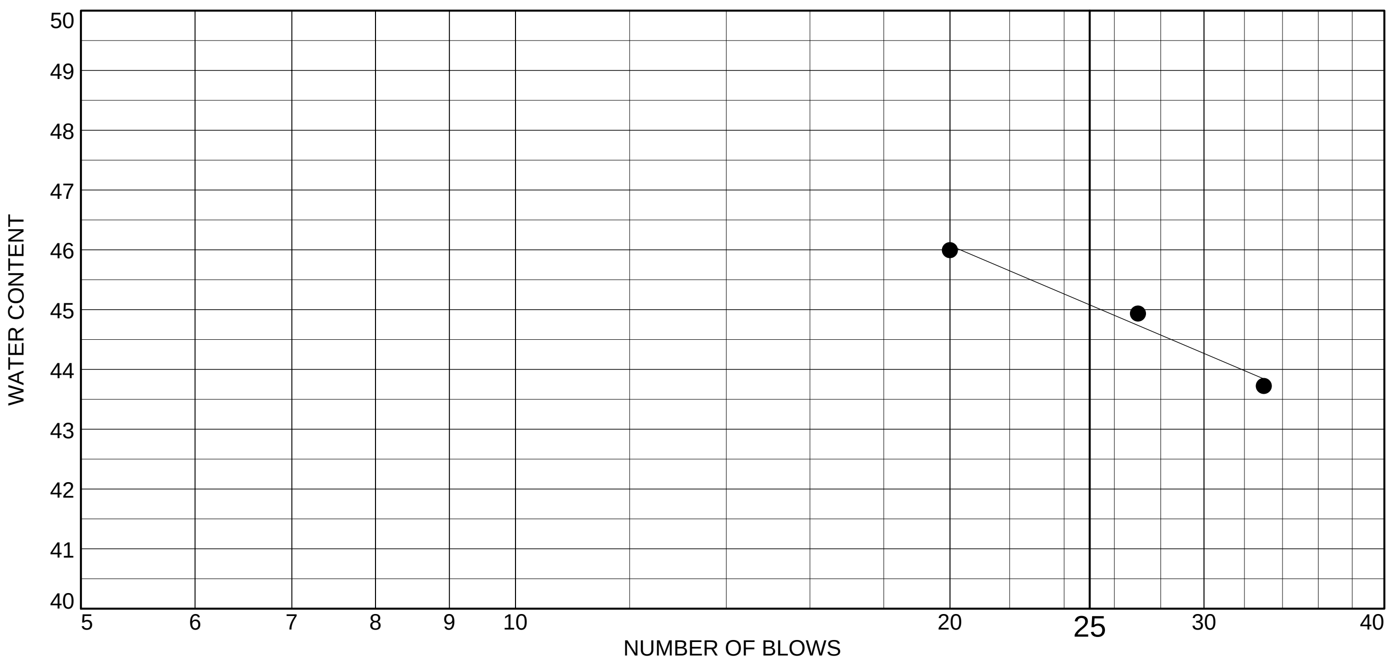
Remarks:

Figure

Tested By: BCM **Checked By:** WPQ

LIQUID AND PLASTIC LIMITS ASTM D4318





	MATERIAL DESCRIPTION	LL	PL	PI	%<#40	%<#200	USCS
●	DARK GRAY LEAN CLAY	45	21	24			CL

Project No. MR155233 **Client:** AECOM

Project: DYNERGY - HENNEPIN

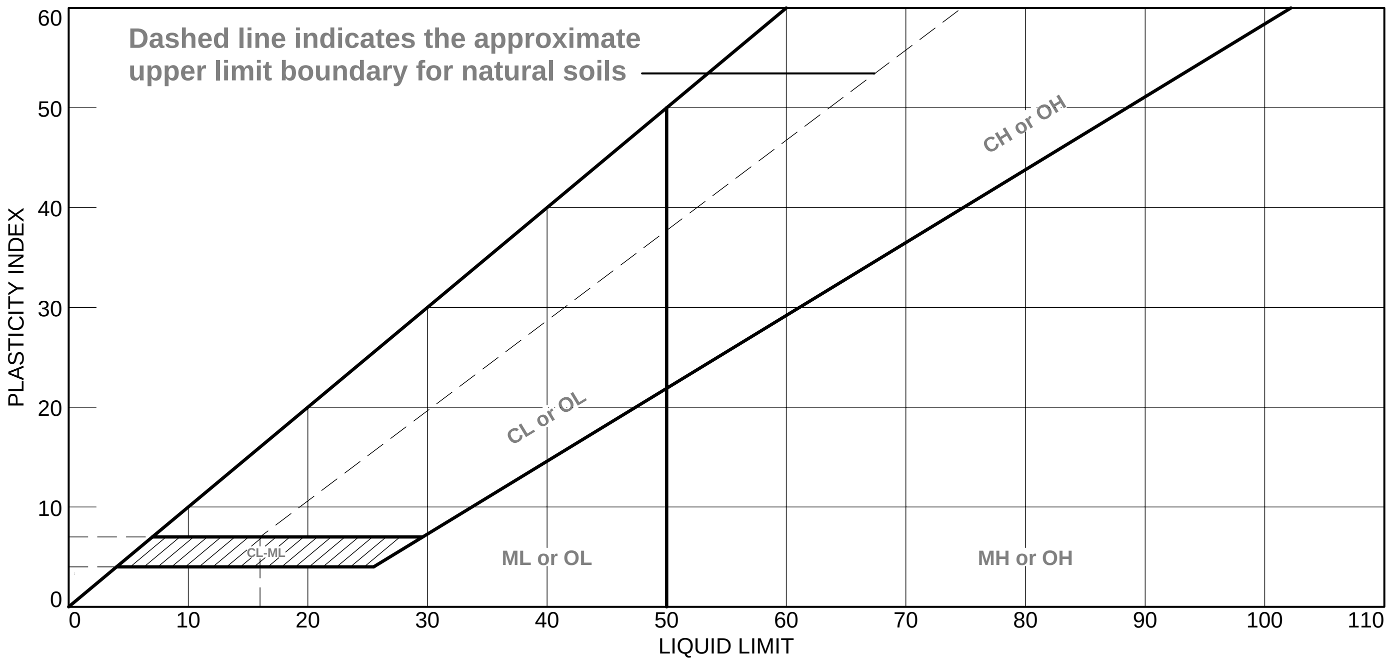
Source of Sample: HEN-B003 **Depth:** 25.0'-27.5'
Sample Number: S-8

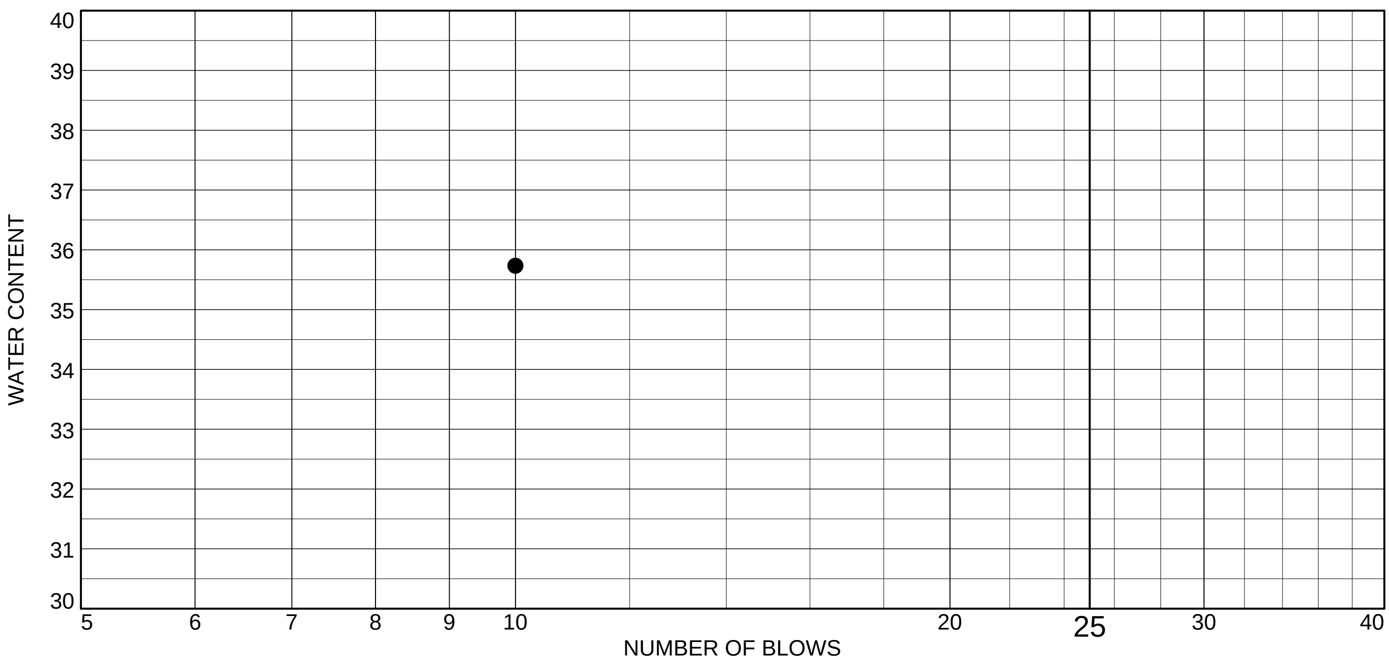
Remarks:

Figure

Tested By: BCM **Checked By:** WPQ

LIQUID AND PLASTIC LIMITS ASTM D4318





	MATERIAL DESCRIPTION	LL	PL	PI	%<#40	%<#200	USCS
●	BROWN BLACK AND GRAY SANDY SILT WITH GRAVEL	32	35	NP			ML

Project No. MR155233 **Client:** AECOM

Project: DYNERGY - HENNEPIN

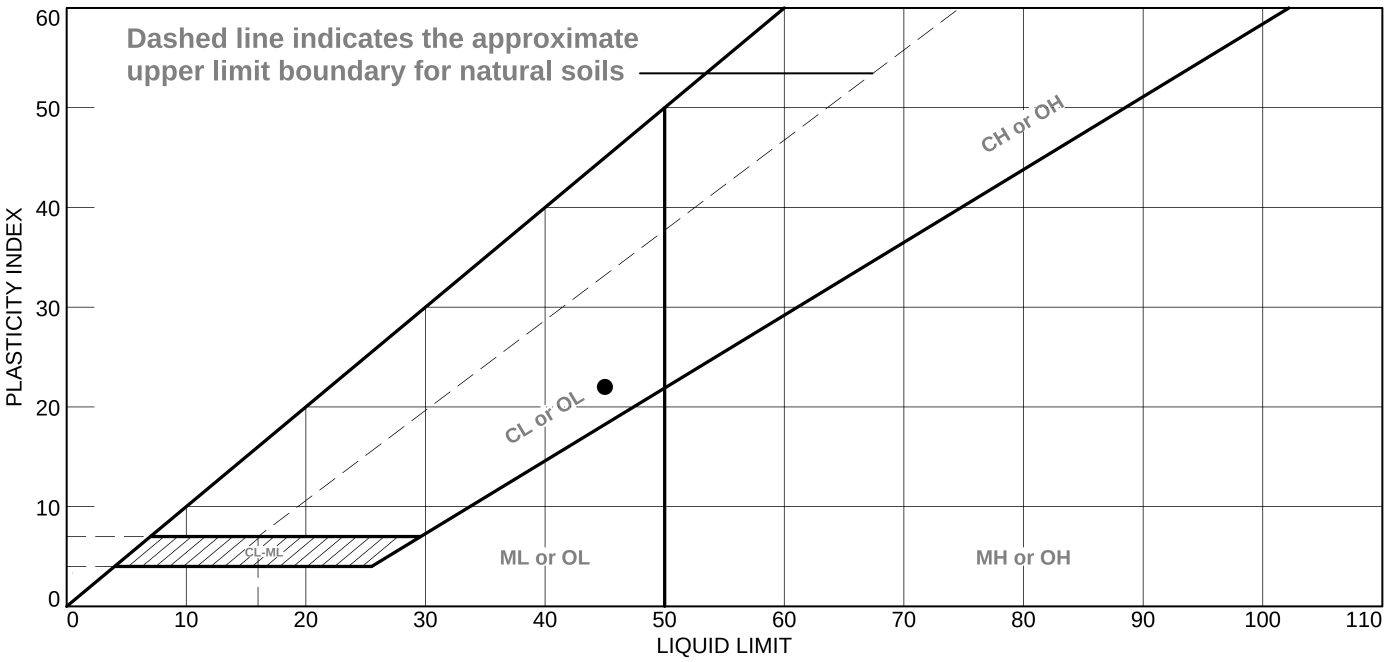
Source of Sample: HEN-B004 **Depth:** 10.0'-12.0'
Sample Number: S-5

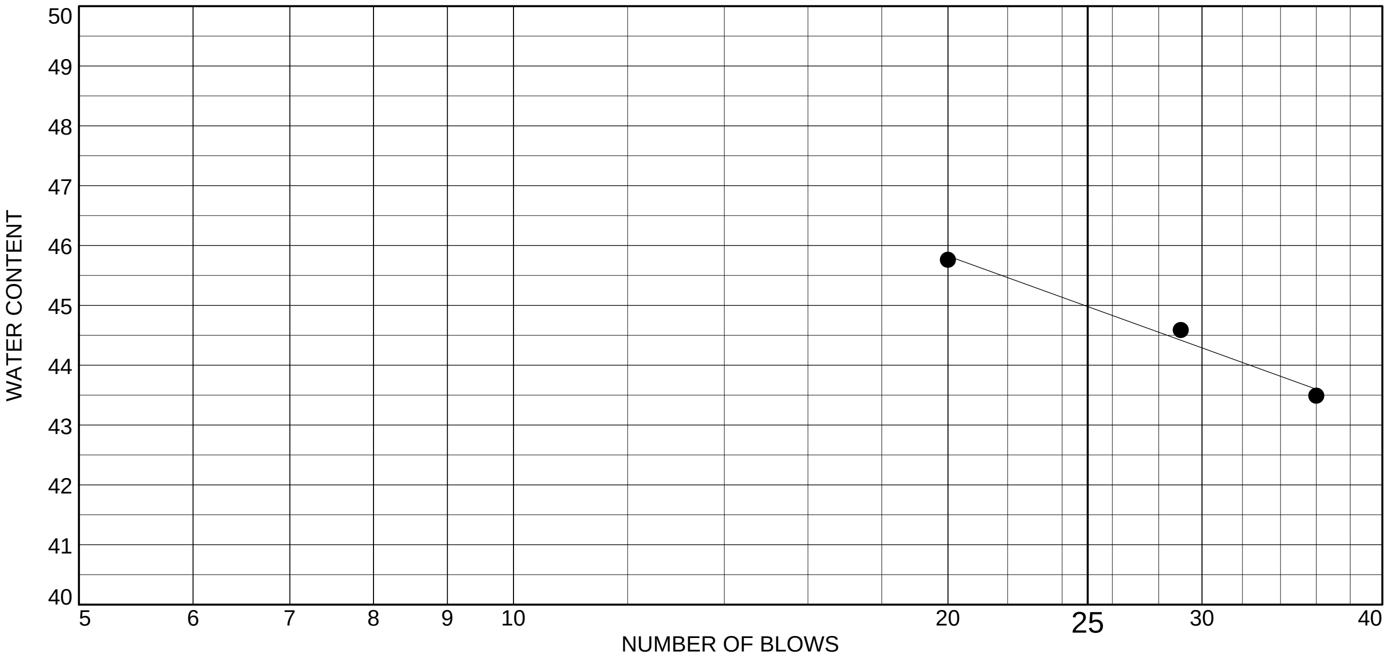
Remarks:
● A single point test was performed because of difficultly obtaining high blow counts due to type of material.

Figure

Tested By: BCM **Checked By:** WPQ

LIQUID AND PLASTIC LIMITS ASTM D4318





	MATERIAL DESCRIPTION	LL	PL	PI	%<#40	%<#200	USCS
●	VERY DARK GRAY LEAN CLAY - ORGANICS NOTED	45	23	22			CL

Project No. MR155233 **Client:** AECOM

Project: DYNERGY - HENNEPIN

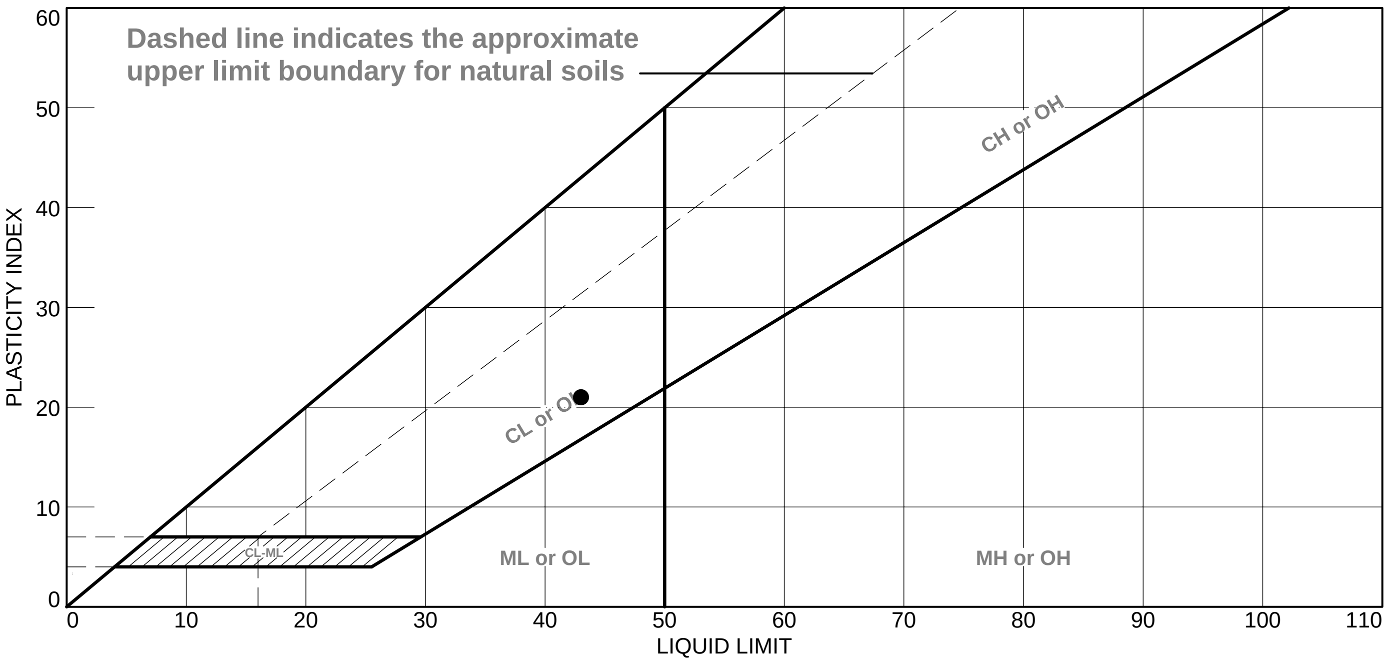
Source of Sample: HEN-B004 **Depth:** 20.0'-22.0'
Sample Number: S-7

Remarks:

Figure

Tested By: BCM **Checked By:** WPQ

LIQUID AND PLASTIC LIMITS ASTM D4318



	MATERIAL DESCRIPTION	LL	PL	PI	%<#40	%<#200	USCS
●	BROWN AND GRAY LEAN CLAY	43	22	21			CL

Project No. MR155233 **Client:** AECOM

Project: DYNERGY - HENNEPIN

Source of Sample: HEN-B004 **Depth:** 30.0'-32.0'
Sample Number: S-9

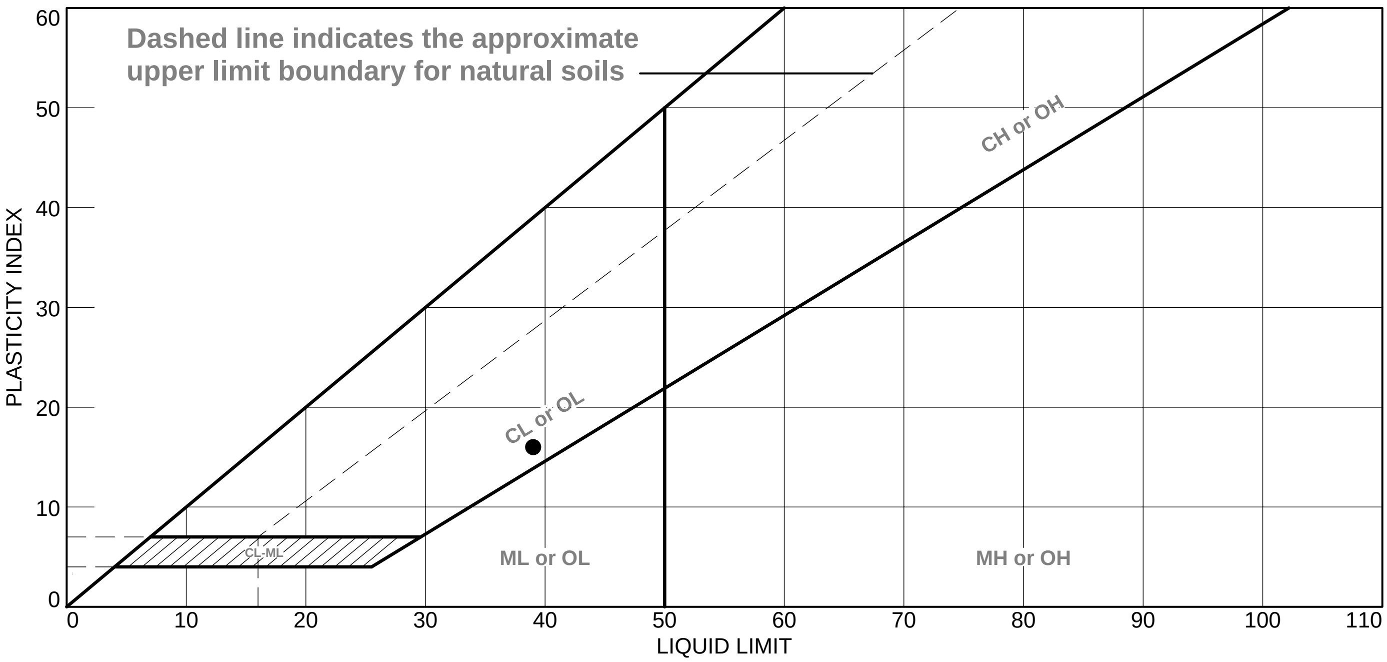
Terracon

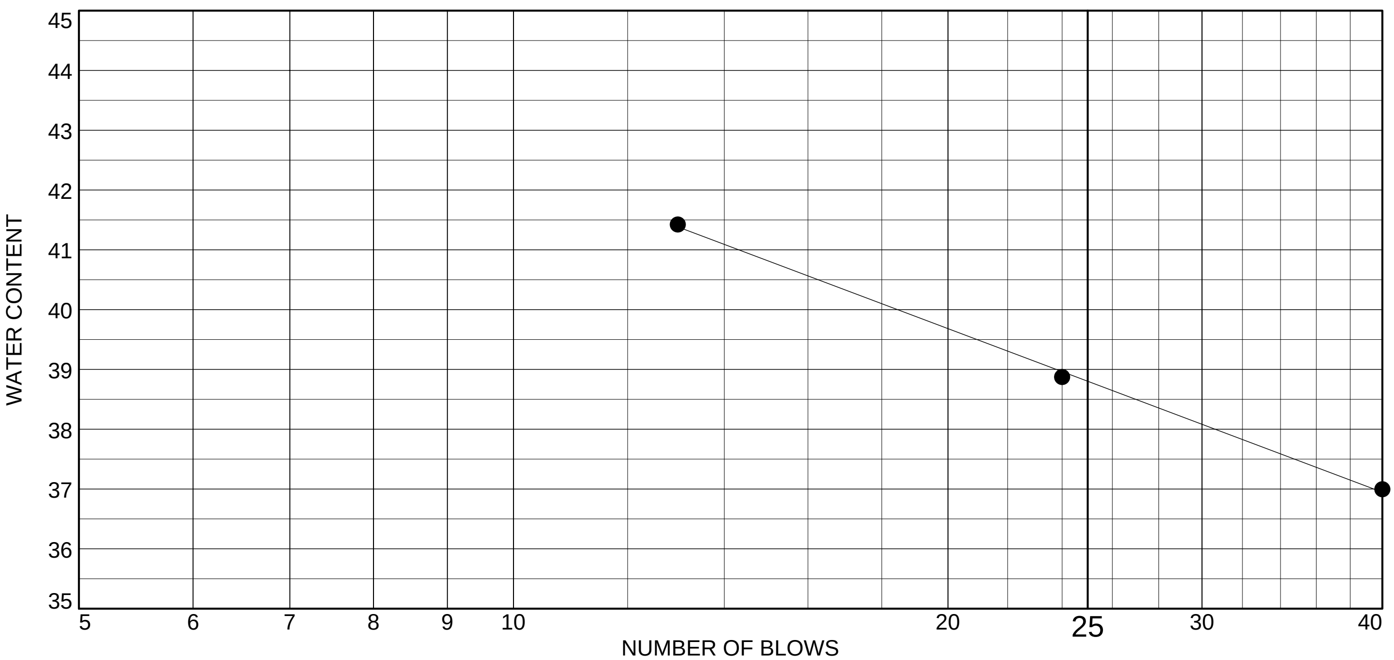
Remarks:

Figure

Tested By: BCM **Checked By:** WPQ

LIQUID AND PLASTIC LIMITS ASTM D4318





	MATERIAL DESCRIPTION	LL	PL	PI	%<#40	%<#200	USCS
●	BLACK TO VERY DARK GRAY ORGANIC CLAY	39	23	16			OL

Project No. MR155233 **Client:** AECOM

Project: DYNERGY - HENNEPIN

Source of Sample: HEN-B005 **Depth:** 7.5'-9.5'
Sample Number: S-2

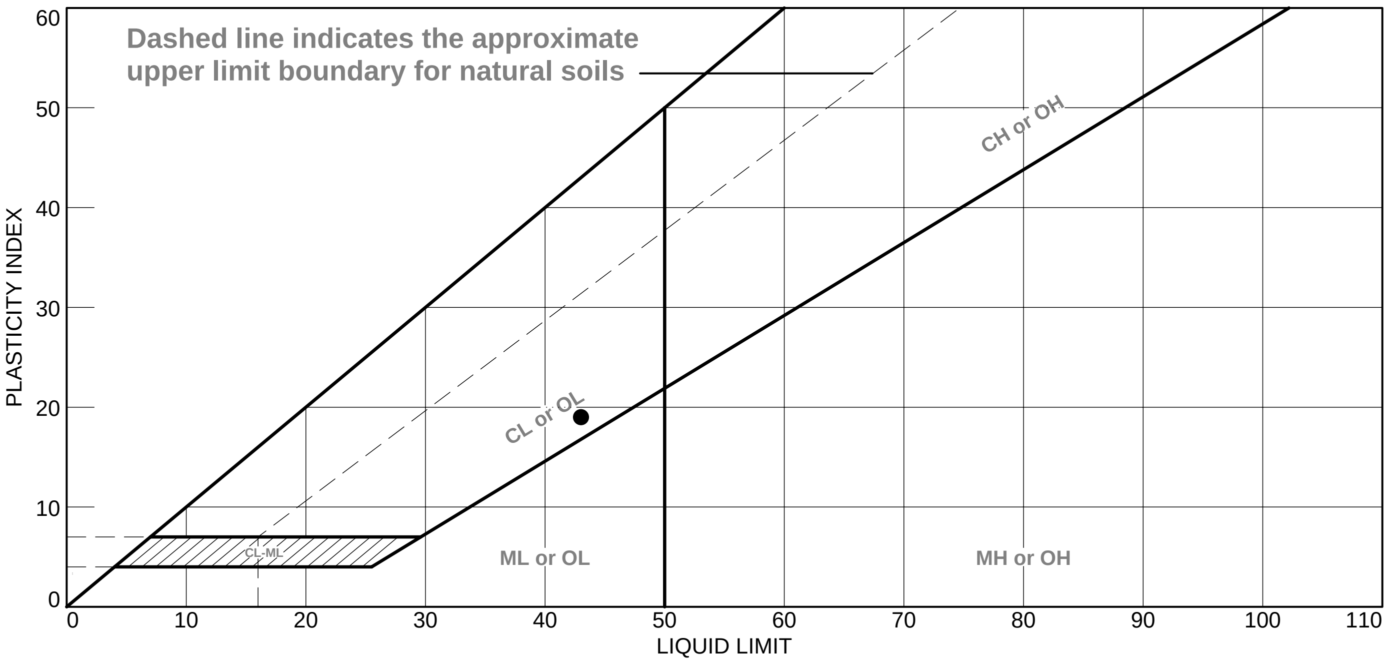
Terracon

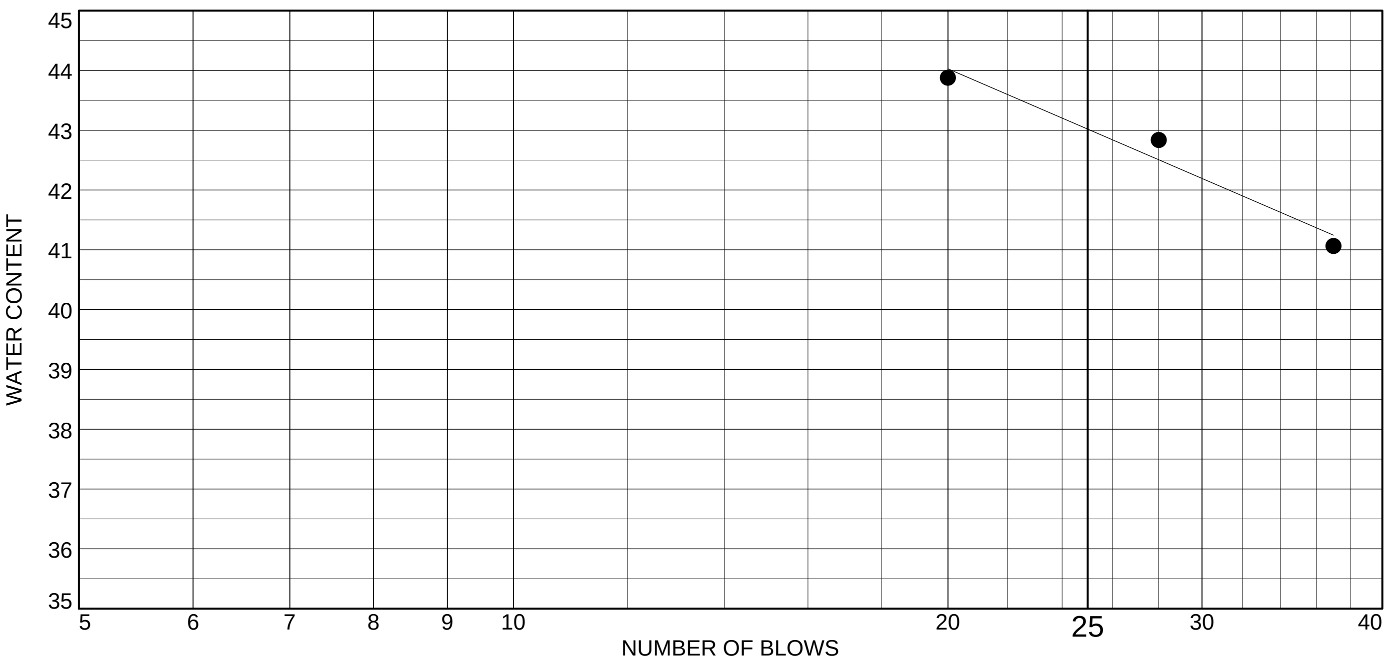
Remarks:

Figure

Tested By: BCM **Checked By:** WPQ

LIQUID AND PLASTIC LIMITS ASTM D4318





	MATERIAL DESCRIPTION	LL	PL	PI	%<#40	%<#200	USCS
●	DARK GRAY LEAN CLAY WITH SAND AND FLY ASH	43	24	19	100.0	83.8	CL

Project No. MR155233 **Client:** AECOM

Project: DYNERGY - HENNEPIN

Source of Sample: HEN-B005 **Depth:** 12.5'-14.5'
Sample Number: S-4

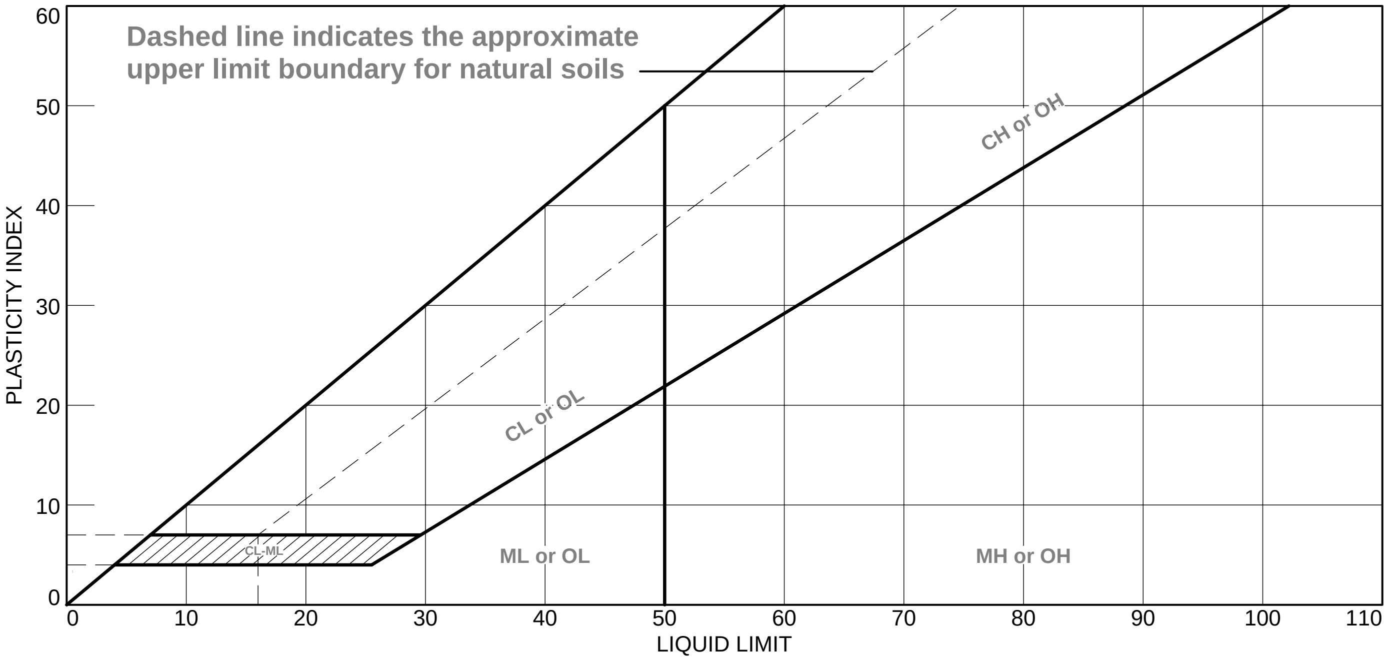
Terracon

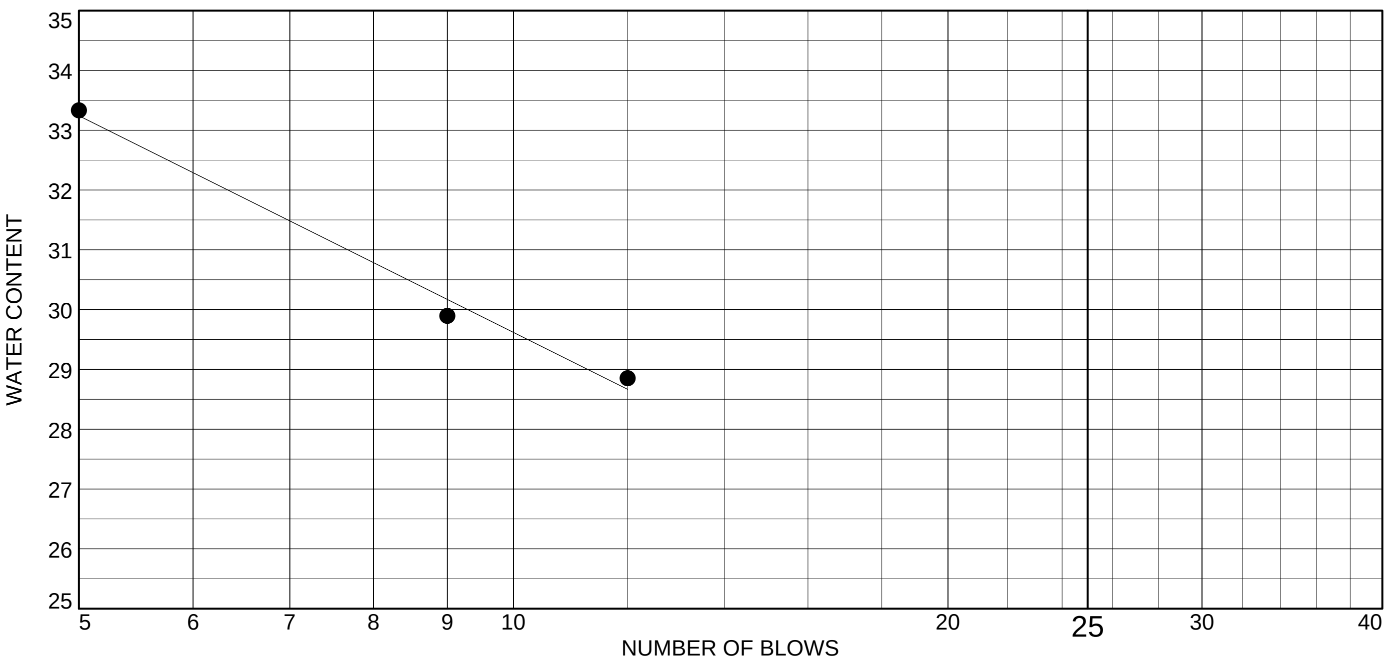
Remarks:

Figure

Tested By: DT **Checked By:** WPQ

LIQUID AND PLASTIC LIMITS ASTM D4318





	MATERIAL DESCRIPTION	LL	PL	PI	%<#40	%<#200	USCS
●	MULTI STRATA SAMPLE: TOP, FLY ASH - MIDDLE, FLY ASH LEAN CLAY WITH SAND MIX - BOTTOM, BROWN SANDY CLAY	25	28	NP			

Project No. MR155233 **Client:** AECOM

Project: DYNERGY - HENNEPIN

Source of Sample: HEN-B008 **Depth:** 7.5'-9.5'
Sample Number: S-4

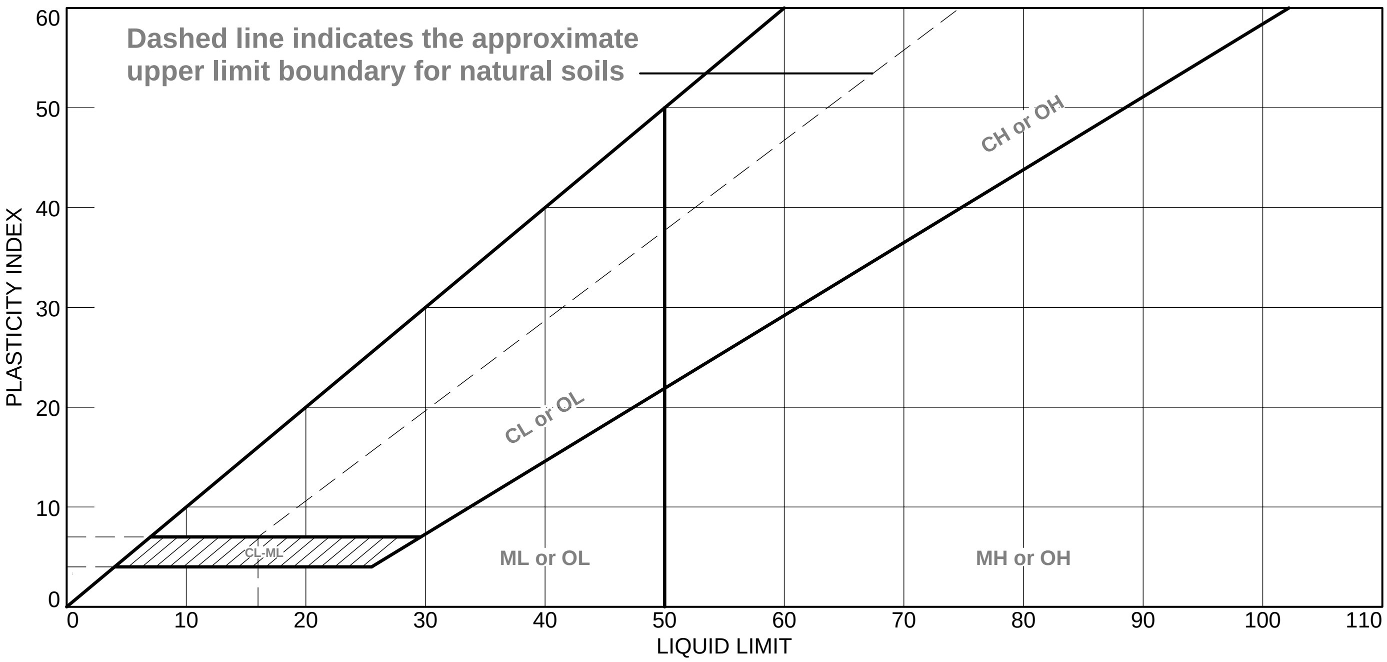
Terracon

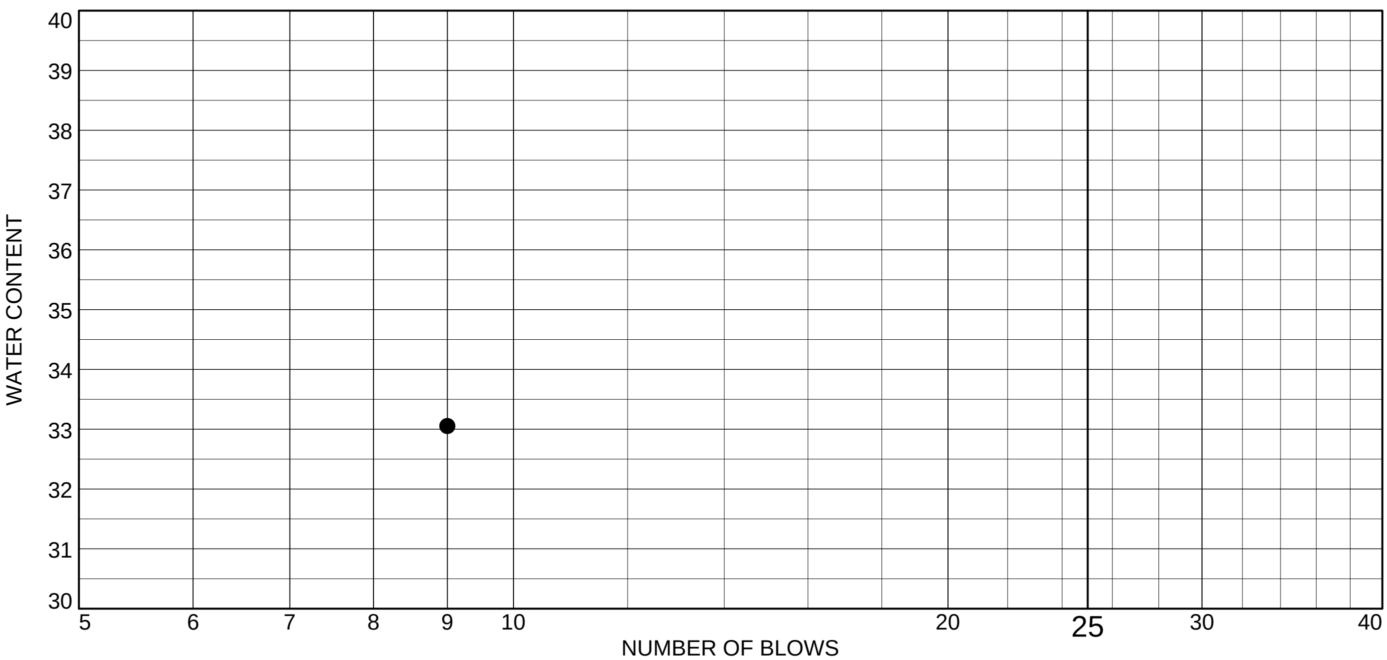
Remarks:

Figure

Tested By: BCM **Checked By:** WPQ

LIQUID AND PLASTIC LIMITS ASTM D4318





	MATERIAL DESCRIPTION	LL	PL	PI	%<#40	%<#200	USCS
●	VERY DARK GRAY FLY ASH WITH SAND AND GRAVEL	29	33	NP			

Project No. MR155233 **Client:** AECOM

Project: DYNERGY - HENNEPIN

Source of Sample: HEN-B010 **Depth:** 10.0'-11.5'

Sample Number: S-5

Terracon

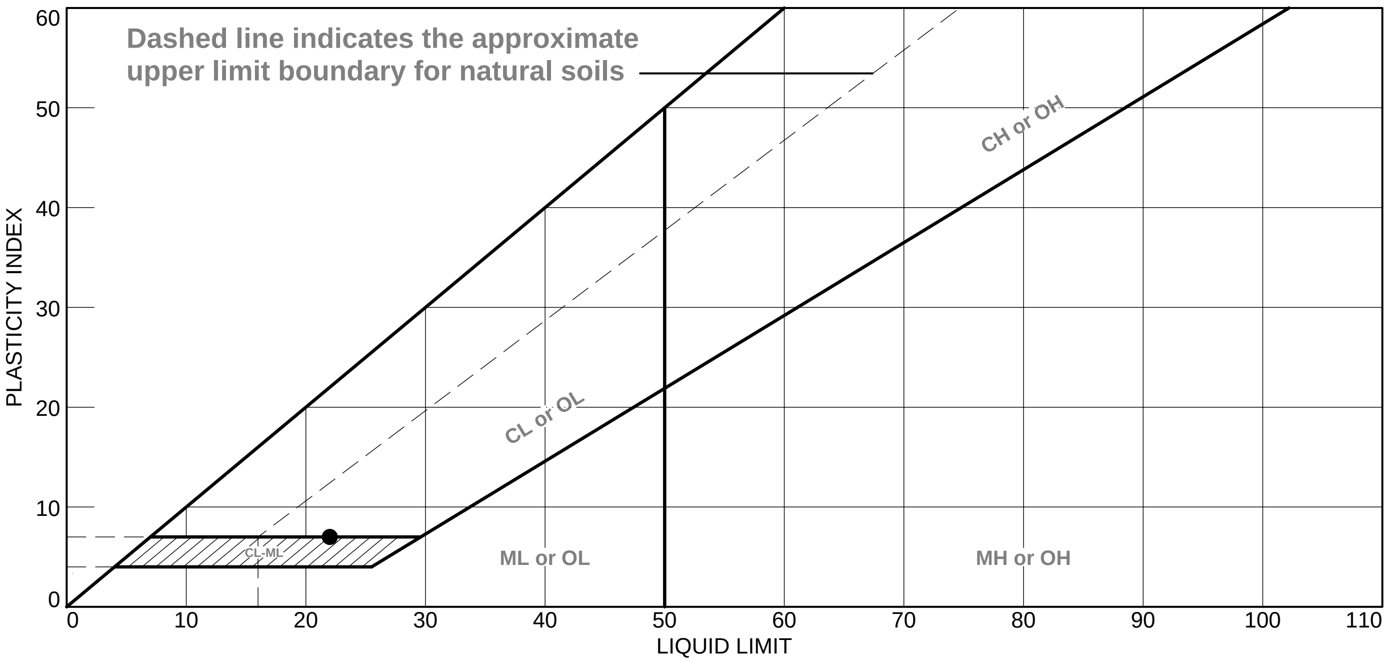
Remarks:

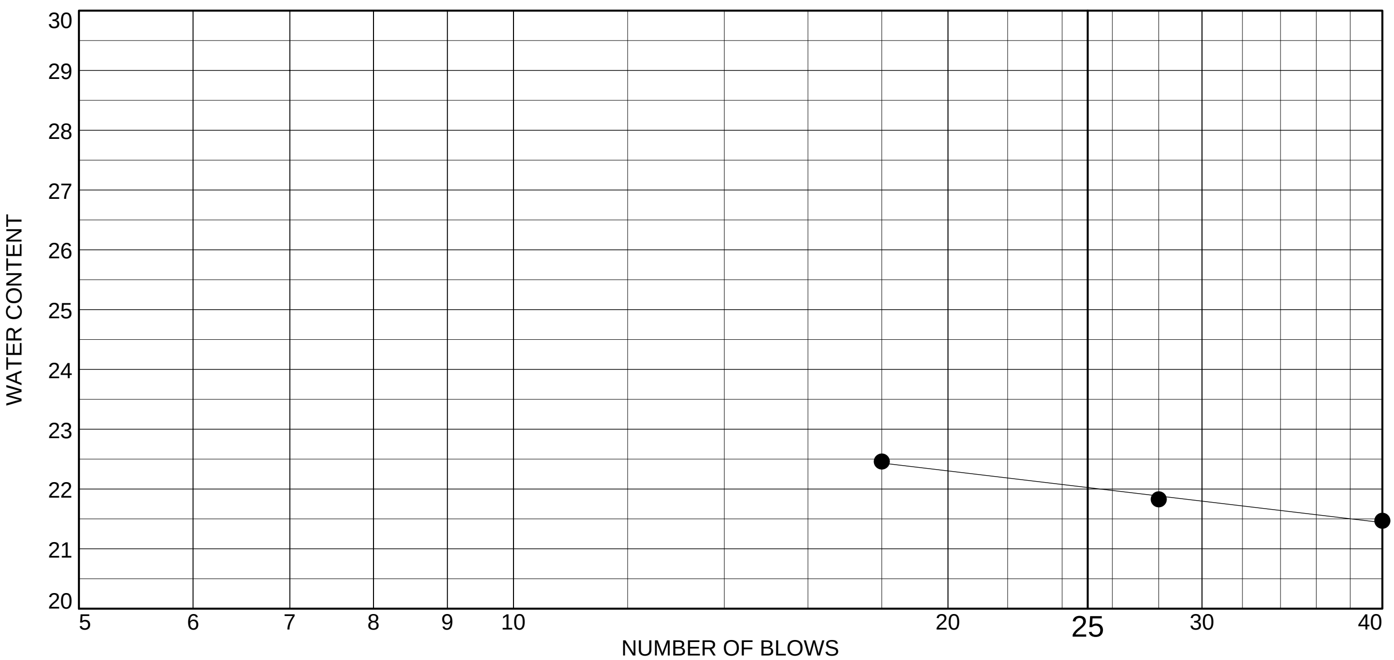
● A single point test was performed because of difficultly obtaining high blow counts due to type of material.

Figure

Tested By: BCM **Checked By:** WPQ

LIQUID AND PLASTIC LIMITS ASTM D4318





	MATERIAL DESCRIPTION	LL	PL	PI	%<#40	%<#200	USCS
●	RUST BROWN SANDY LEAN CLAY	22	15	7			CL

Project No. MR155233 **Client:** AECOM

Project: DYNERGY - HENNEPIN

Source of Sample: HEN-B011 **Depth:** 2.5'-4.0'
Sample Number: S-2

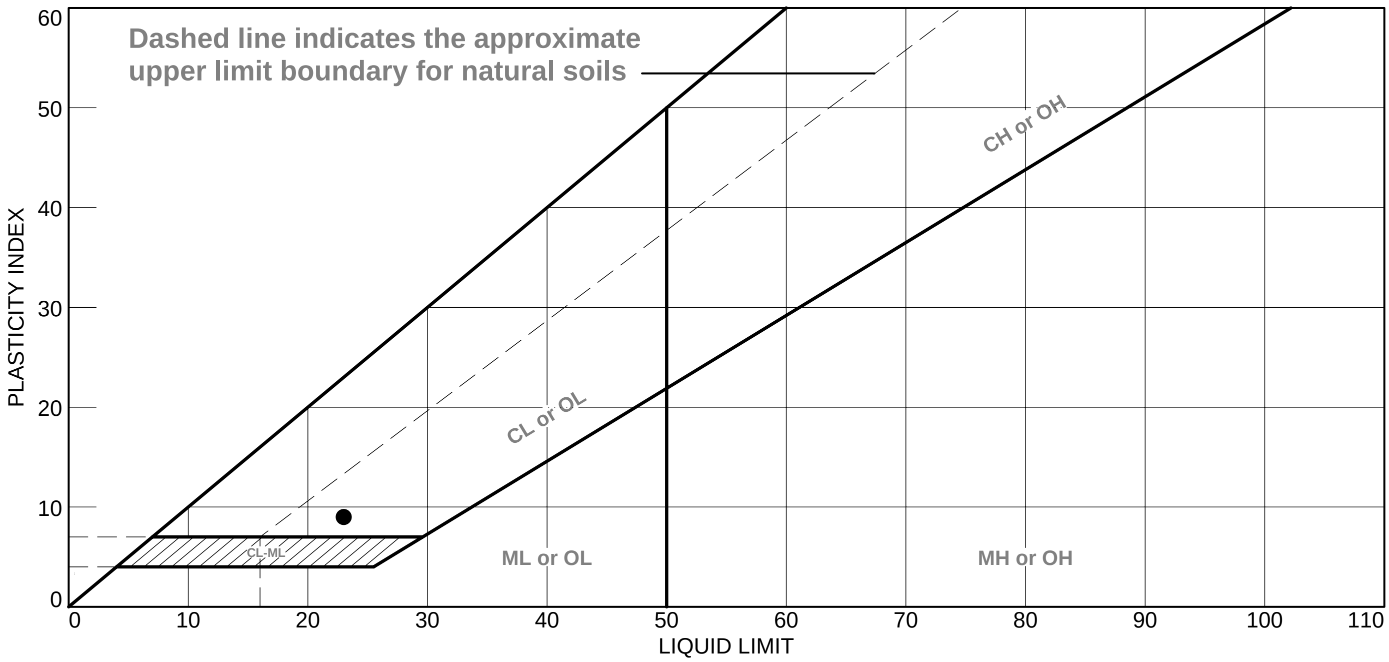
Terracon

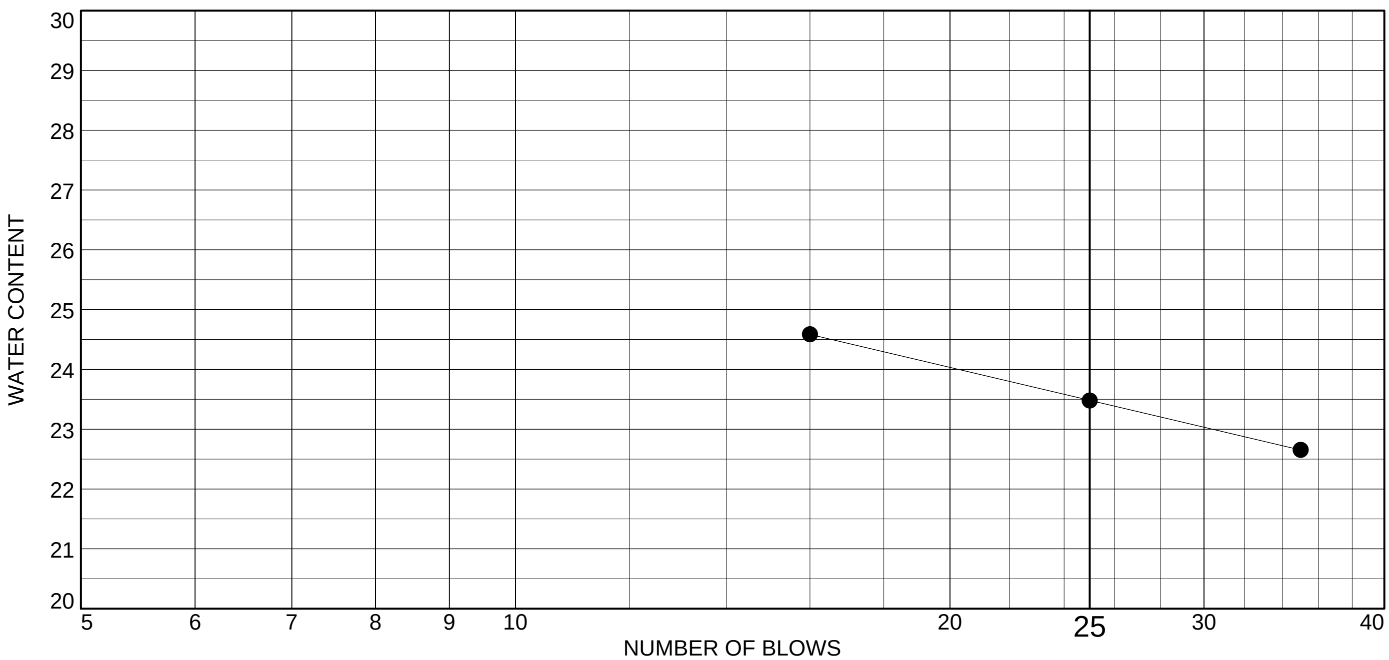
Remarks:

Figure

Tested By: HP **Checked By:** WPQ

LIQUID AND PLASTIC LIMITS ASTM D4318





	MATERIAL DESCRIPTION	LL	PL	PI	%<#40	%<#200	USCS
●	DARK BROWN LEAN CLAY WITH SILT AND SAND - SILT AND SAND SEAM NOTED	23	14	9			CL

Project No. MR155233 **Client:** AECOM

Project: DYNERGY - HENNEPIN

Source of Sample: HEN-B012 **Depth:** 10.0'-11.5'
Sample Number: S-5

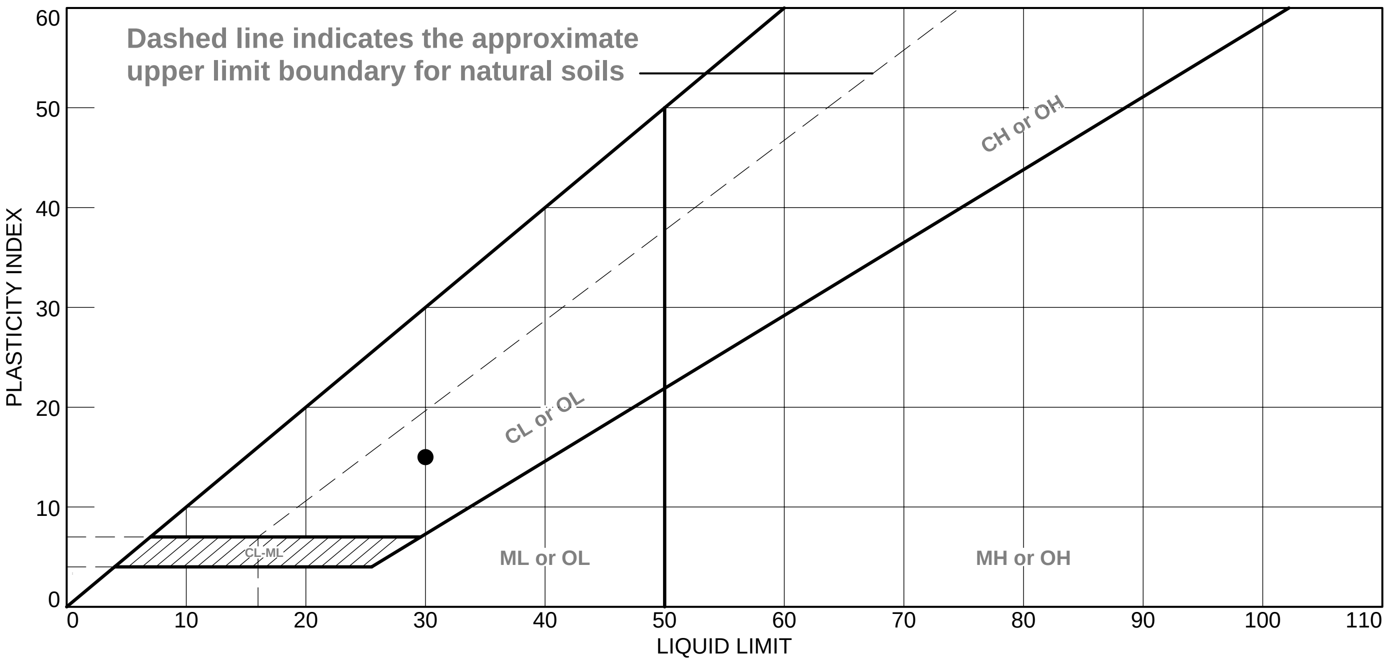
Terracon

Remarks:

Figure

Tested By: DT **Checked By:** WPQ

LIQUID AND PLASTIC LIMITS ASTM D4318



	MATERIAL DESCRIPTION	LL	PL	PI	%<#40	%<#200	USCS
●	BROWN AND GRAYISH BROWN LEAN CLAY WITH SAND	30	15	15			CL

Project No. MR155233 **Client:** AECOM

Project: DYNERGY - HENNEPIN

Source of Sample: HEN-B012 **Depth:** 30.0'-32.0'
Sample Number: S-9

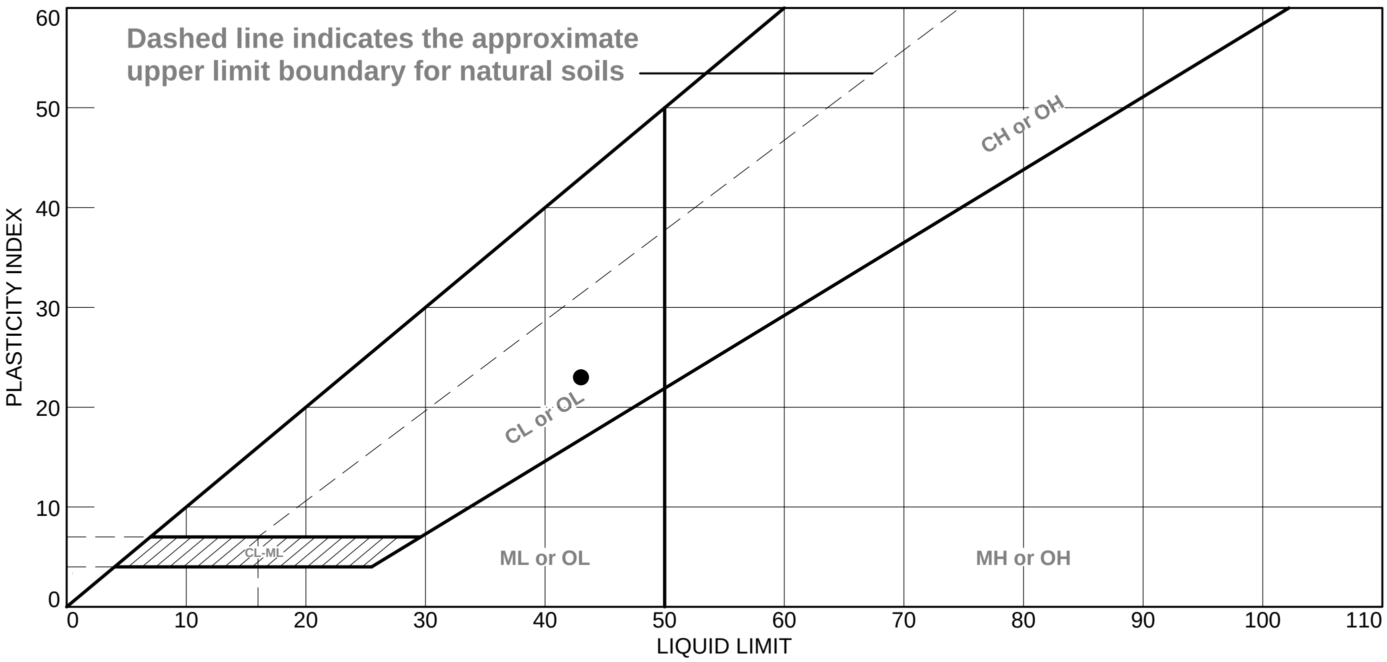
Terracon

Remarks:

Figure

Tested By: HP **Checked By:** WPQ

LIQUID AND PLASTIC LIMITS ASTM D4318



	MATERIAL DESCRIPTION	LL	PL	PI	%<#40	%<#200	USCS
●	BROWN AND GRAY LEAN CLAY	43	20	23			CL

Project No. MR155233 **Client:** AECOM

Project: DYNERGY - HENNEPIN

Source of Sample: HEN-B014 **Depth:** 25.0'-27.0'
Sample Number: S-8

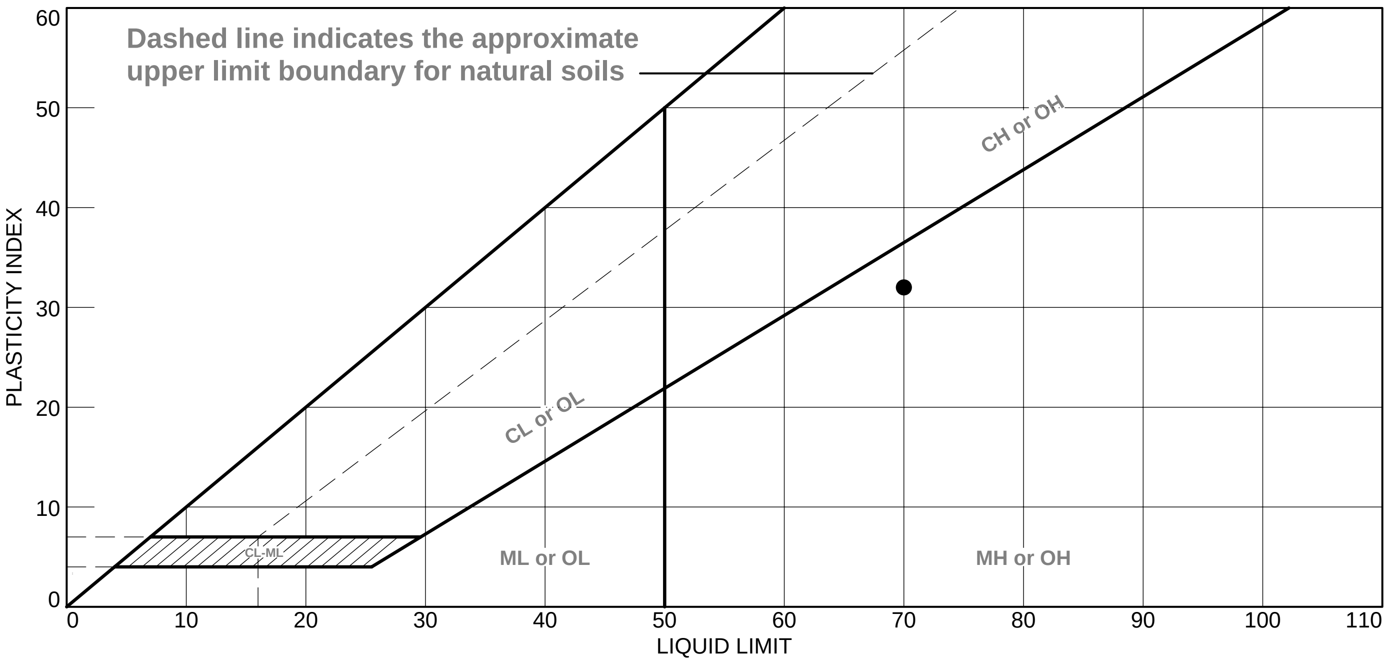
Terracon

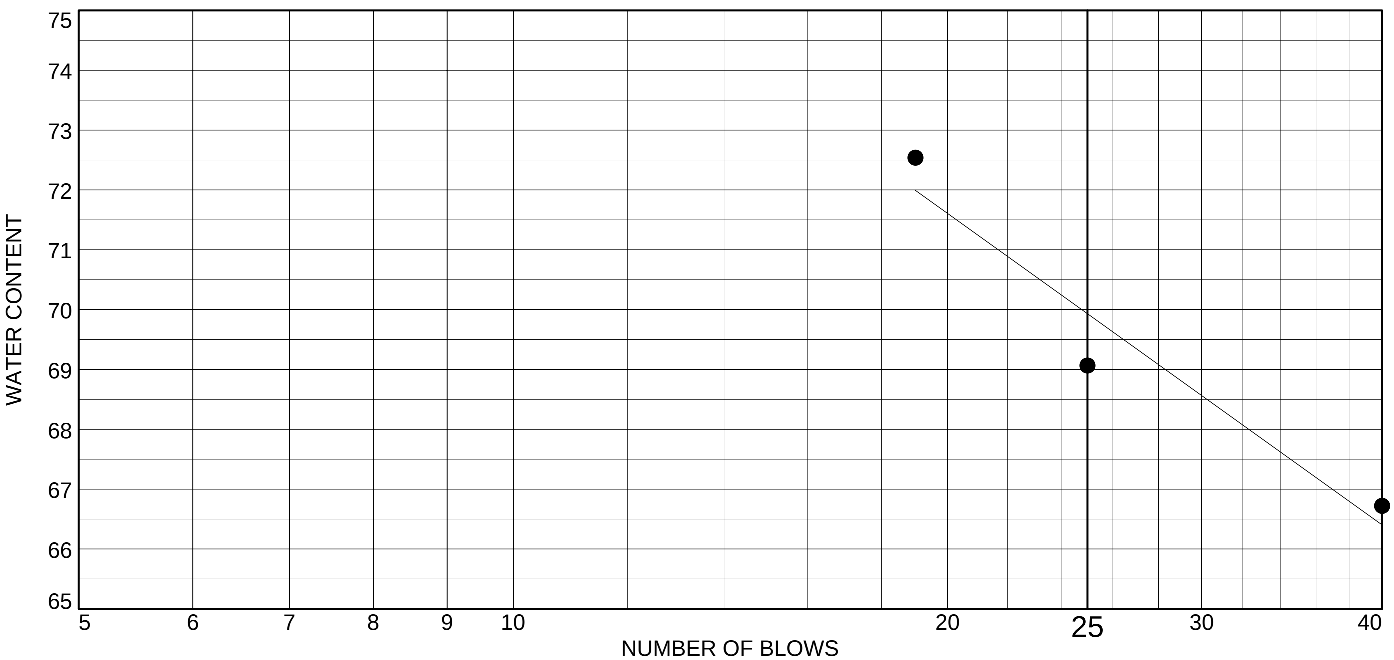
Remarks:

Figure

Tested By: BCM **Checked By:** WPQ

LIQUID AND PLASTIC LIMITS ASTM D4318





	MATERIAL DESCRIPTION	LL	PL	PI	%<#40	%<#200	USCS
●	VERY DARK BROWNISH GRAY ORGANIC SILT	70	38	32			OH

Project No. MR155233 **Client:** AECOM

Project: DYNERGY - HENNEPIN

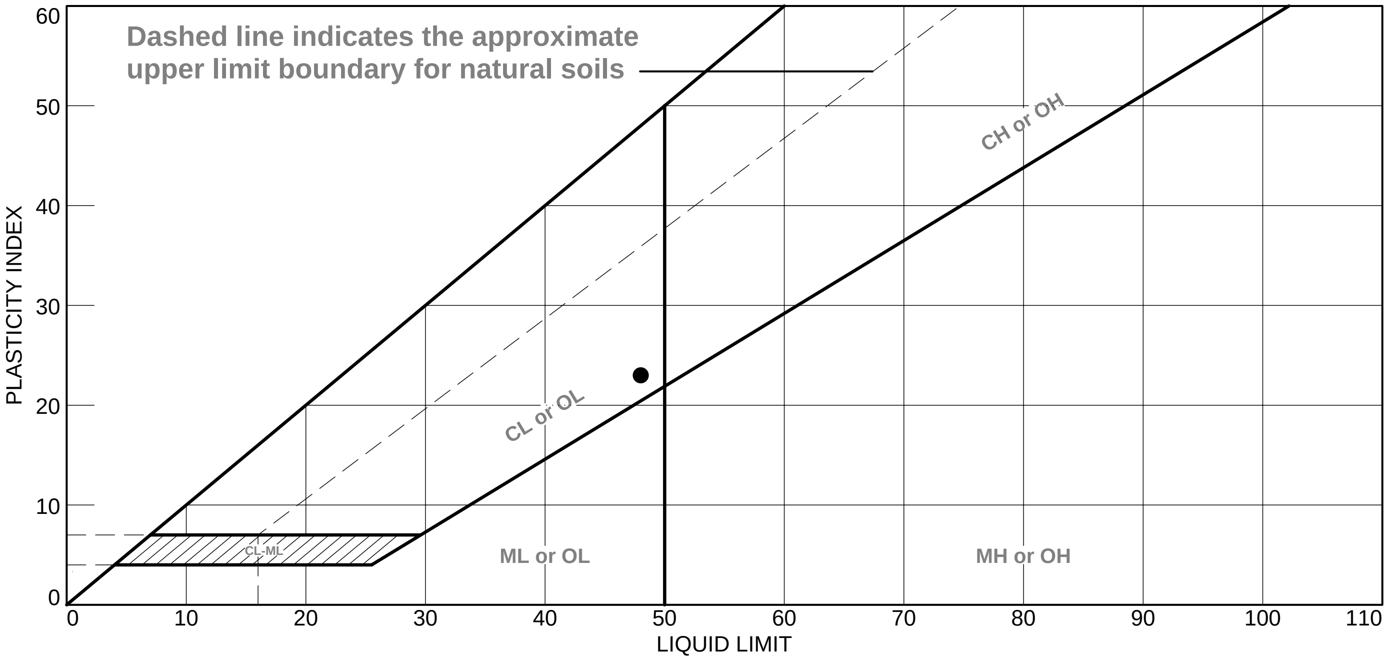
Source of Sample: HEN-B014 **Depth:** 35.0'-37.0'
Sample Number: S-10

Remarks:

Figure

Tested By: BCM **Checked By:** WPQ

LIQUID AND PLASTIC LIMITS ASTM D4318



	MATERIAL DESCRIPTION	LL	PL	PI	%<#40	%<#200	USCS
●	BLACK AND DARK GRAY ORGANIC LEAN CLAY WITH SAND AND GRAVEL	48	25	23			OL

Project No. MR155233 **Client:** AECOM

Project: DYNERGY - HENNEPIN

Source of Sample: HEN-B015 **Depth:** 7.5'-9.5'
Sample Number: S-4

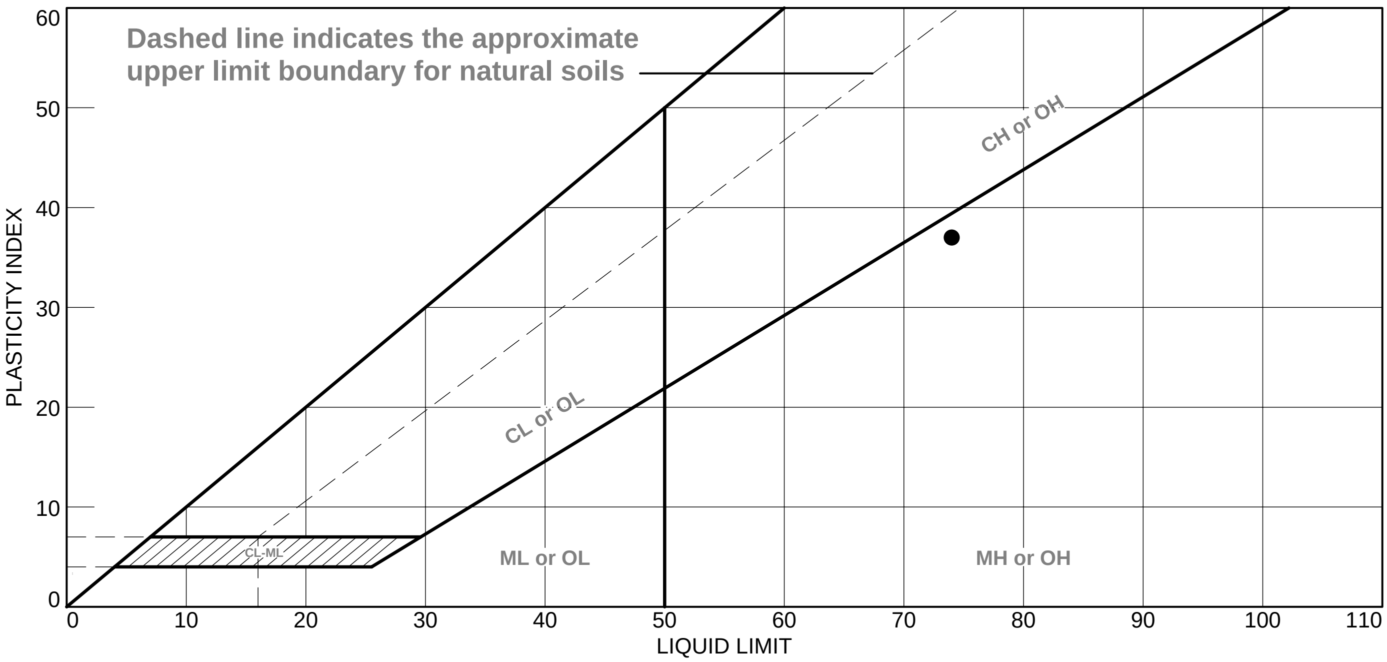
Terracon

Remarks:

Figure

Tested By: BCM **Checked By:** WPQ

LIQUID AND PLASTIC LIMITS ASTM D4318



	MATERIAL DESCRIPTION	LL	PL	PI	%<#40	%<#200	USCS
●	BLACK ORGANIC SILT WITH SAND	74	37	37			OH

Project No. MR155233 **Client:** AECOM

Project: DYNERGY - HENNEPIN

Source of Sample: HEN-B015 **Depth:** 25.0'-27.0'
Sample Number: S-8

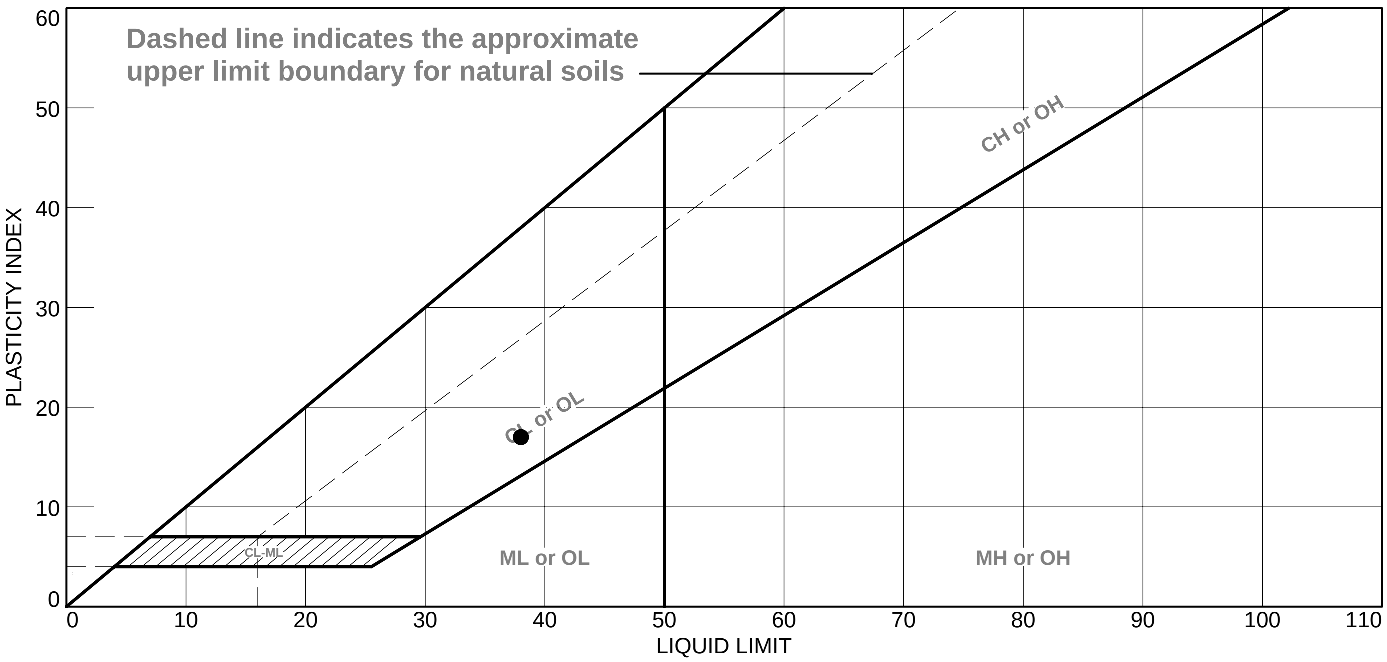
Remarks:

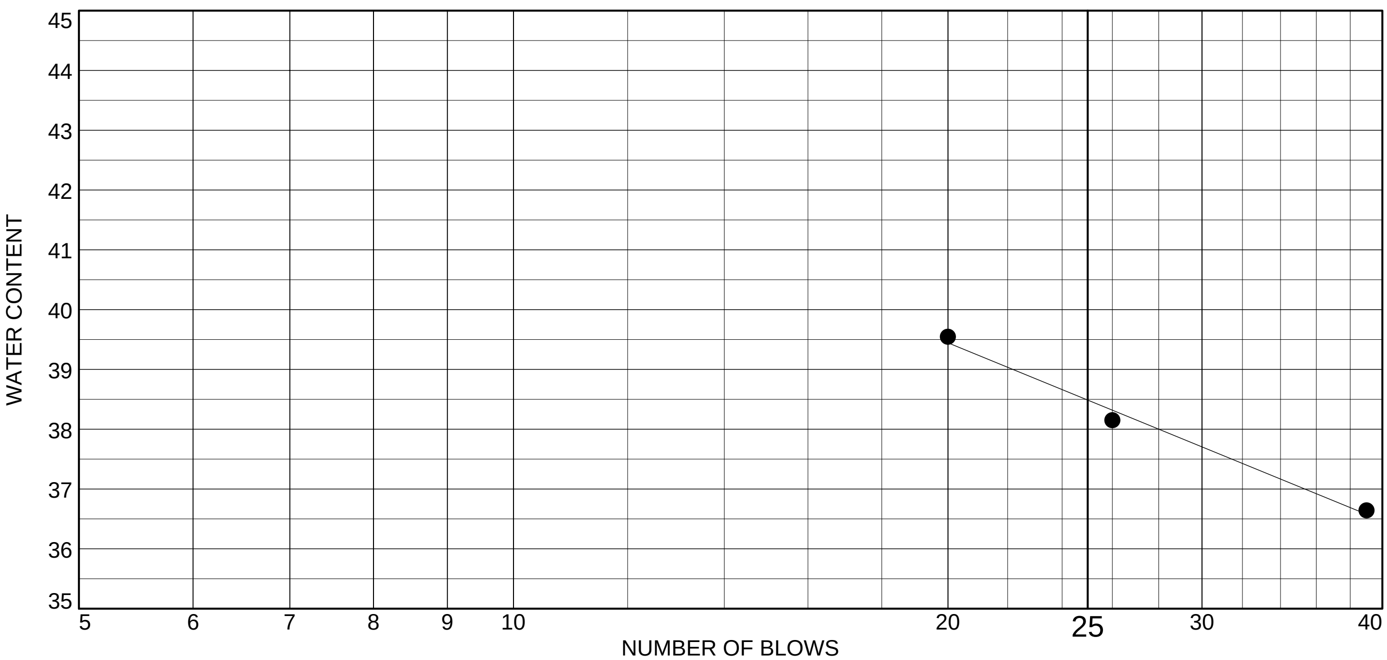
Terracon

Figure

Tested By: BCM **Checked By:** WPQ

LIQUID AND PLASTIC LIMITS ASTM D4318





	MATERIAL DESCRIPTION	LL	PL	PI	%<#40	%<#200	USCS
●	VERY DARK GRAY CLAY WITH SAND AND GRAVEL - ORGANICS AND ASH NOTED	38	21	17			CL

Project No. MR155233 **Client:** AECOM

Project: DYNERGY - HENNEPIN

Source of Sample: HEN-B016 **Depth:** 20.0'-22.0'
Sample Number: S-7

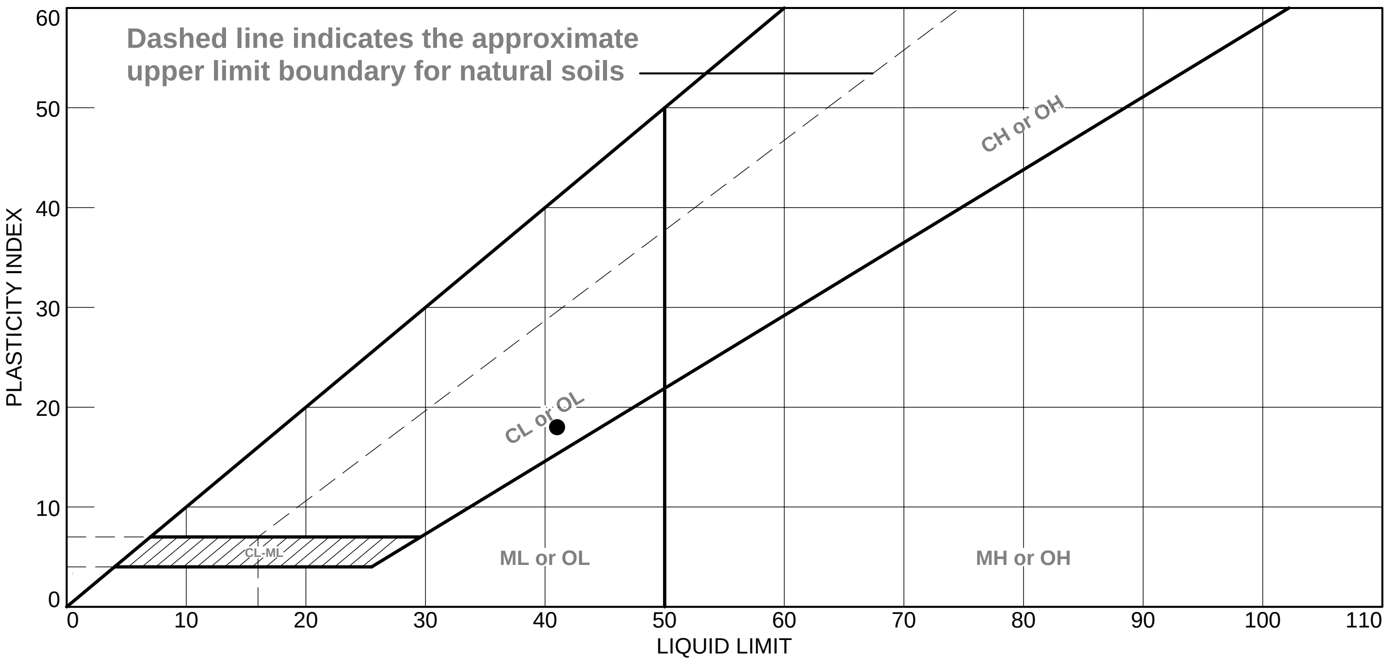
Terracon

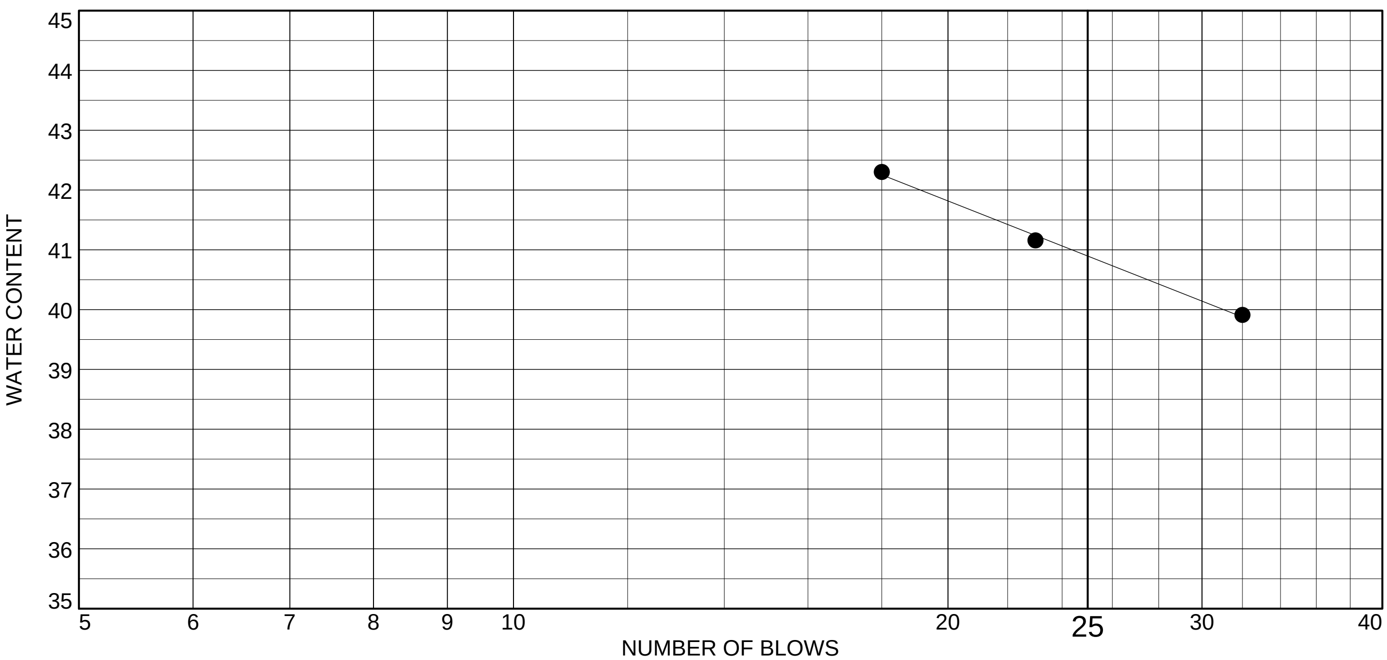
Remarks:

Figure

Tested By: BCM **Checked By:** WPQ

LIQUID AND PLASTIC LIMITS ASTM D4318





	MATERIAL DESCRIPTION	LL	PL	PI	%<#40	%<#200	USCS
●	DARK GRAY LEAN CLAY WITH SAND - FLY ASH AND ORGANICS NOTED	41	23	18			CL

Project No. MR155233 **Client:** AECOM

Project: DYNERGY - HENNEPIN

Source of Sample: HEN-B016 **Depth:** 35.0'-37.0'
Sample Number: S-10

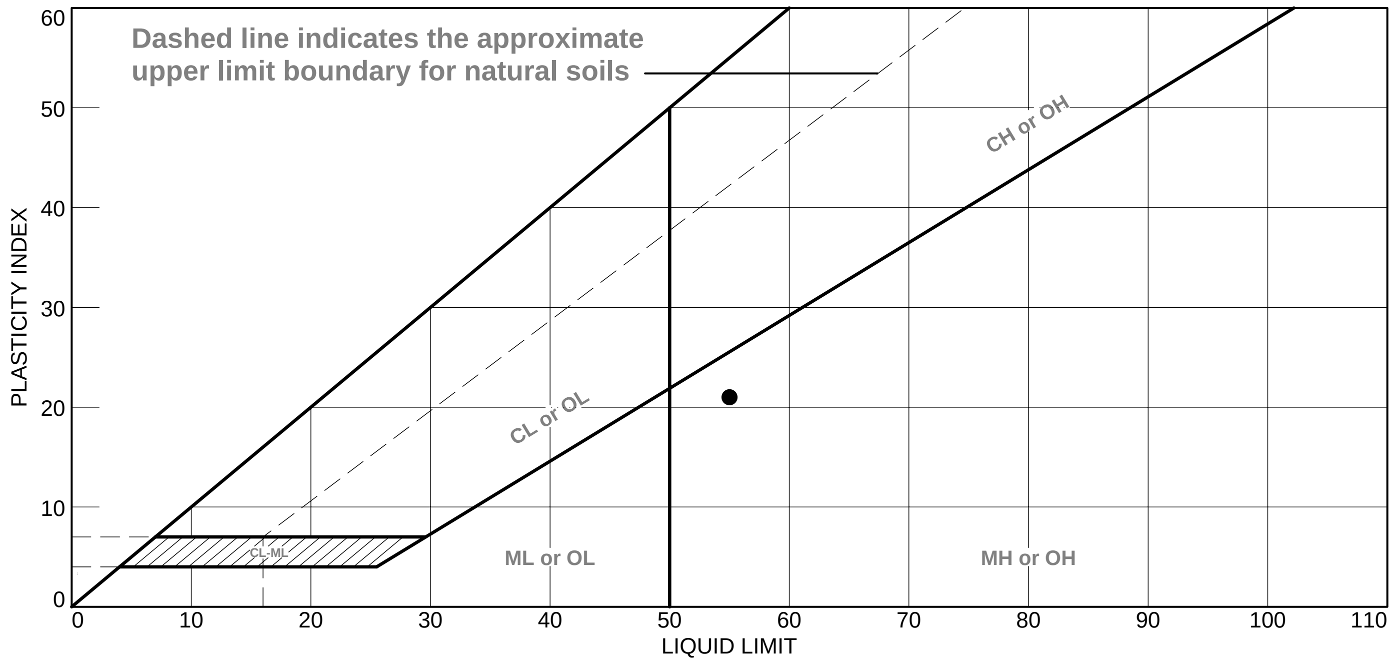
Terracon

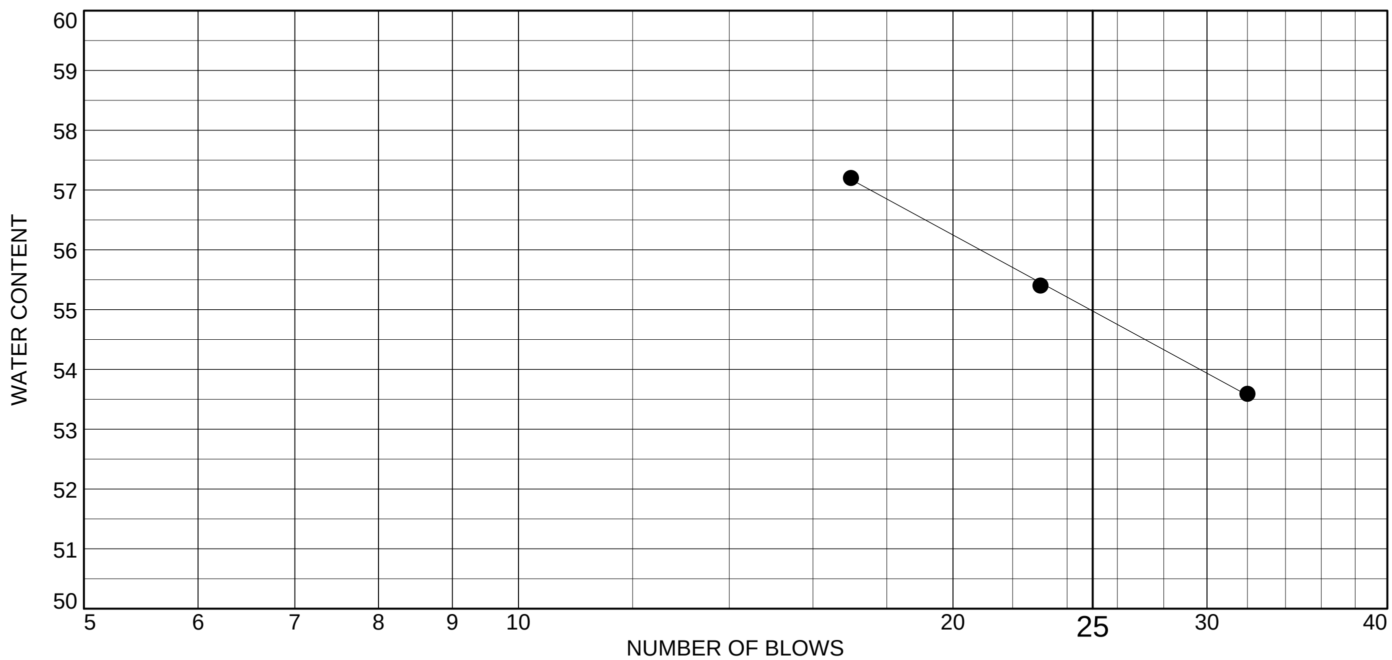
Remarks:

Figure

Tested By: BCM **Checked By:** WPQ

LIQUID AND PLASTIC LIMITS ASTM D4318





	MATERIAL DESCRIPTION	LL	PL	PI	%<#40	%<#200	USCS
●	DARK GRAY LEAN CLAY WITH SILT	55	34	21			CL

Project No. MR155233 **Client:** AECOM

Project: DYNERGY - HENNEPIN

Source of Sample: HEN-B016 **Depth:** 60.0'-61.5'
Sample Number: S-15

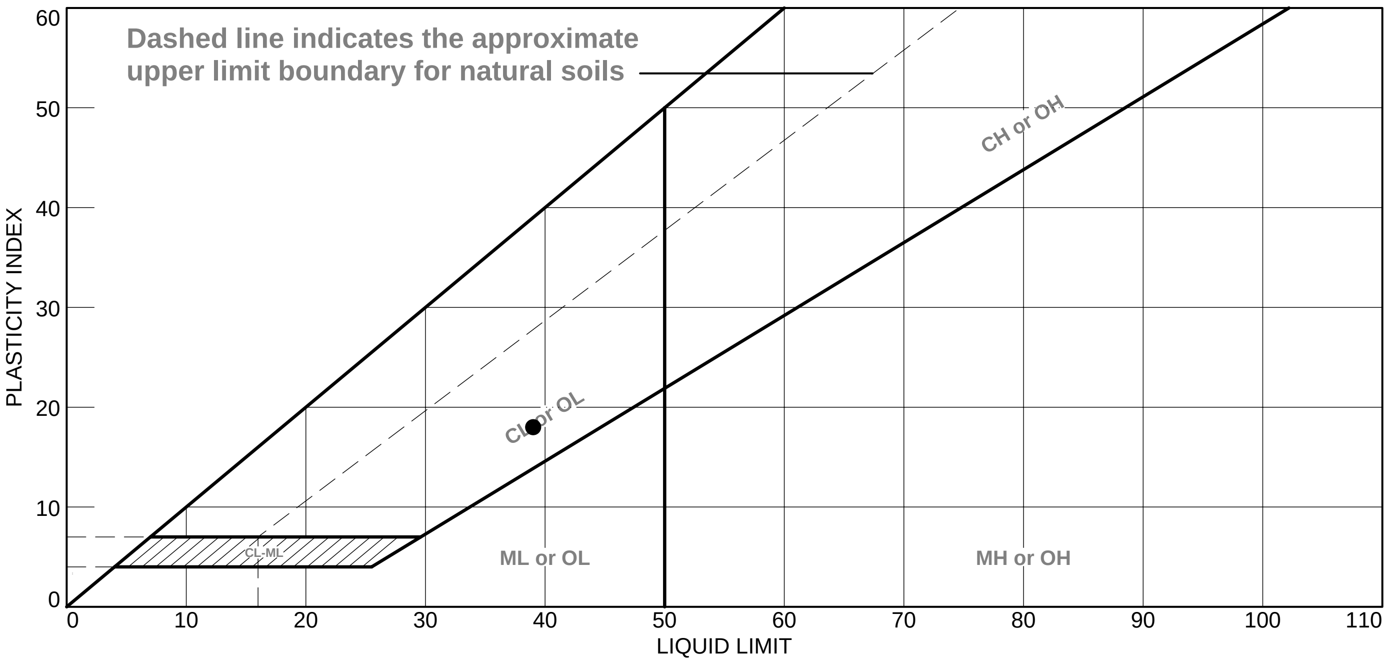
Terracon

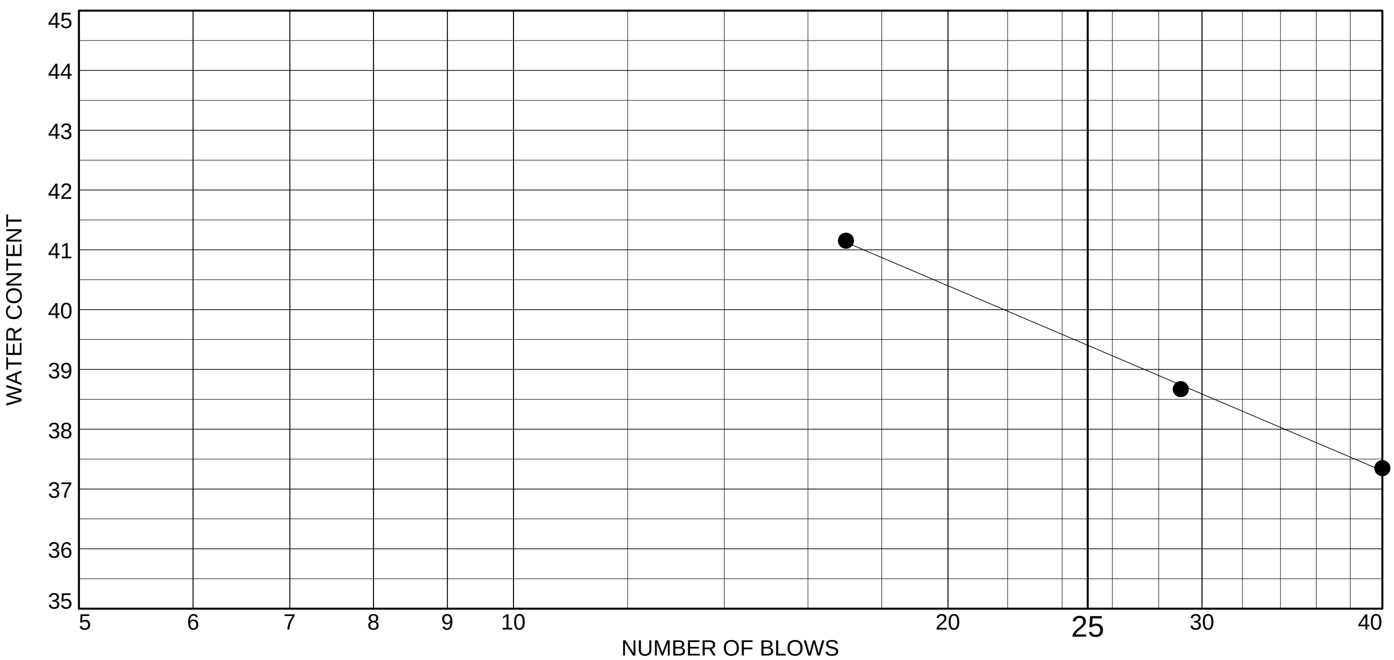
Remarks:

Figure

Tested By: HP **Checked By:** WPQ

LIQUID AND PLASTIC LIMITS ASTM D4318





	MATERIAL DESCRIPTION	LL	PL	PI	%<#40	%<#200	USCS
●	VERY DARK GRAY LEAN CLAY WITH SAND	39	21	18			CL

Project No. MR155233 **Client:** AECOM

Project: DYNERGY - HENNEPIN

Source of Sample: HEN-B017 **Depth:** 5.0'-7.0'

Sample Number: S-3

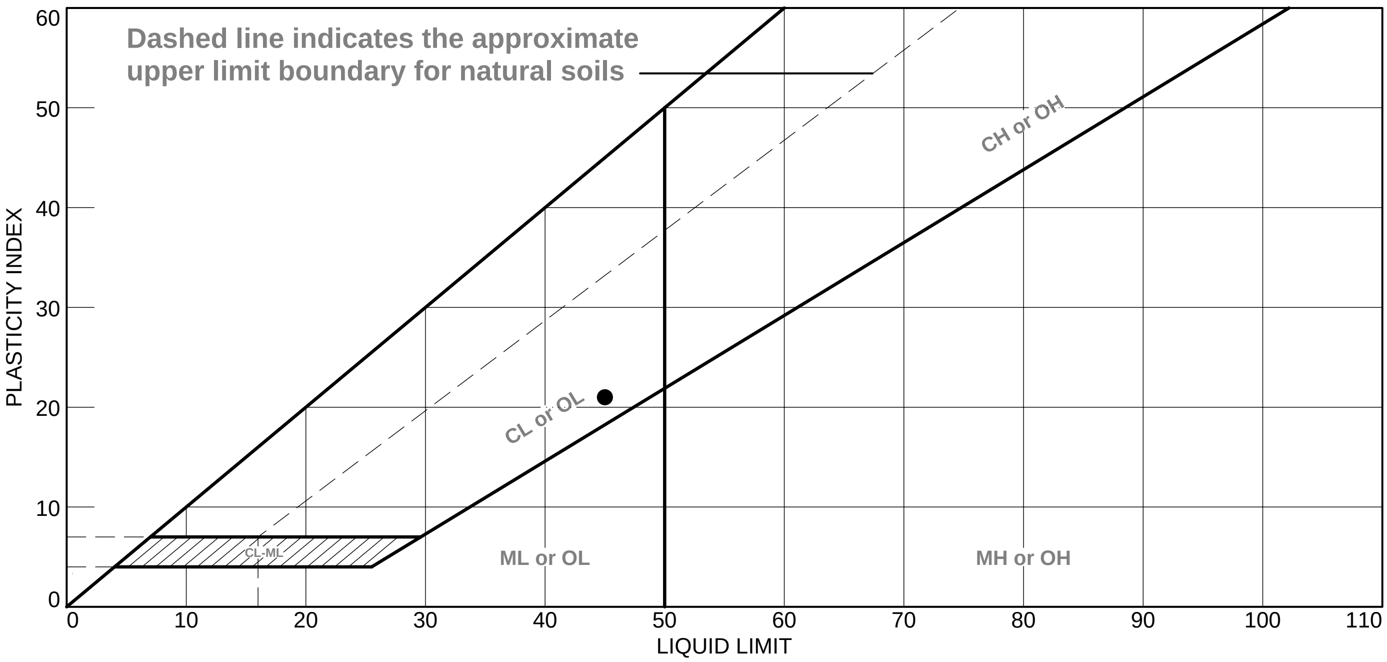
Terracon

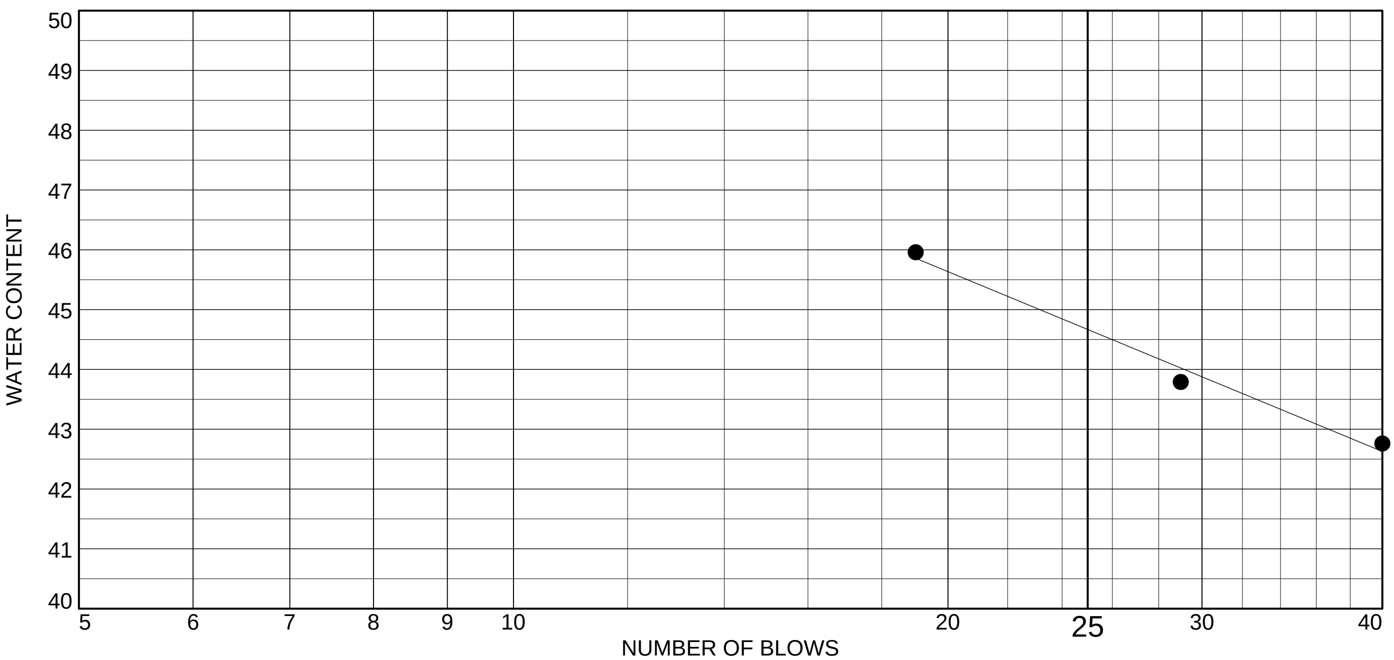
Remarks:

Figure

Tested By: BCM **Checked By:** WPQ

LIQUID AND PLASTIC LIMITS ASTM D4318





	MATERIAL DESCRIPTION	LL	PL	PI	%<#40	%<#200	USCS
●	BROWN AND GRAY LEAN CLAY	45	24	21			CL

Project No. MR155233 **Client:** AECOM

Project: DYNERGY - HENNEPIN

Source of Sample: HEN-B017 **Depth:** 15.0'-17.0'
Sample Number: S-6

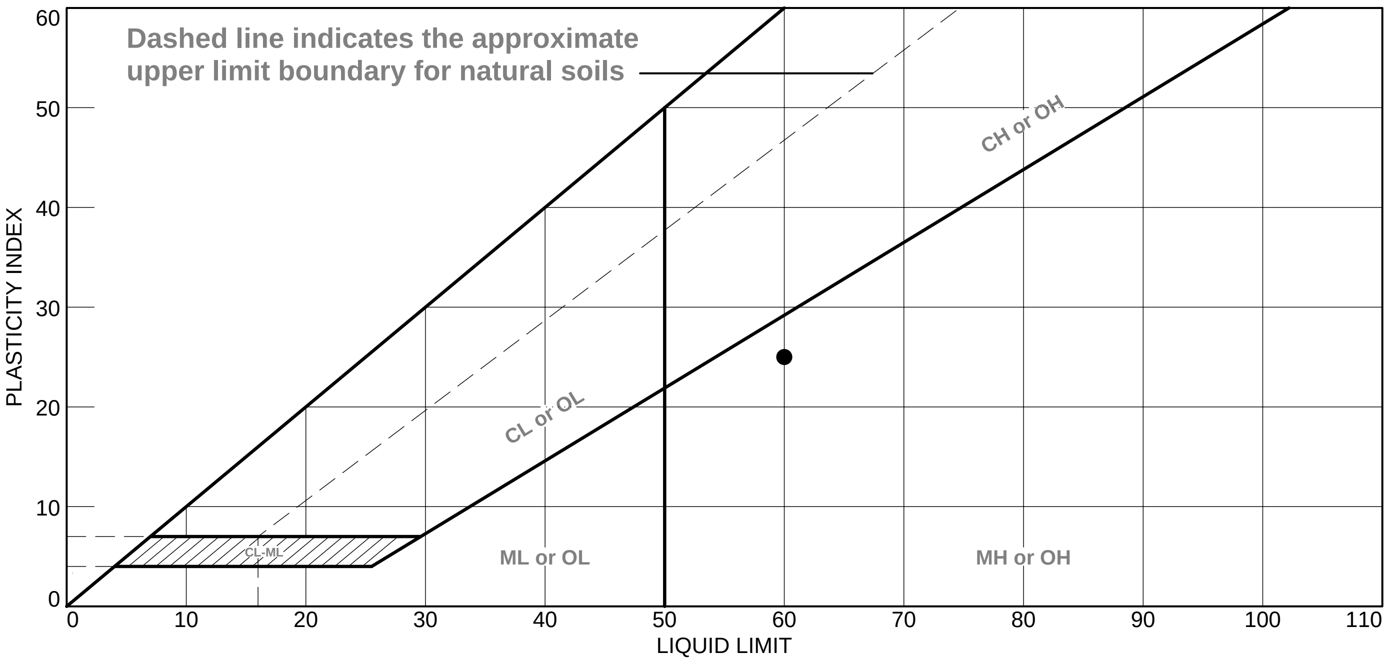
Terracon

Remarks:

Figure

Tested By: HP **Checked By:** WPQ

LIQUID AND PLASTIC LIMITS ASTM D4318



	MATERIAL DESCRIPTION	LL	PL	PI	%<#40	%<#200	USCS
●	DARK BROWNISH GRAY ORGANIC CLAY WITH SAND - SAND SEAMS AND SHELL NOTED	60	35	25			OL

Project No. MR155233 **Client:** AECOM

Project: DYNERGY - HENNEPIN

Source of Sample: HEN-B017 **Depth:** 30.0'-32.0'
Sample Number: S-9

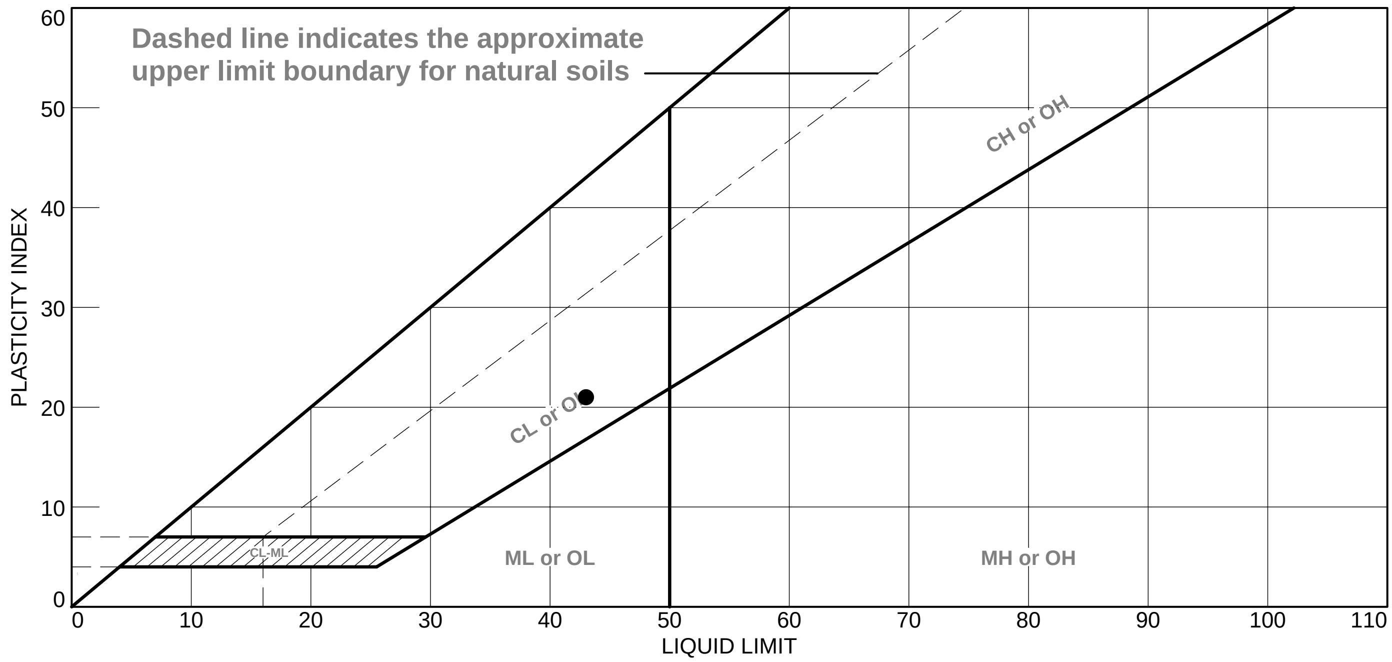
Terracon

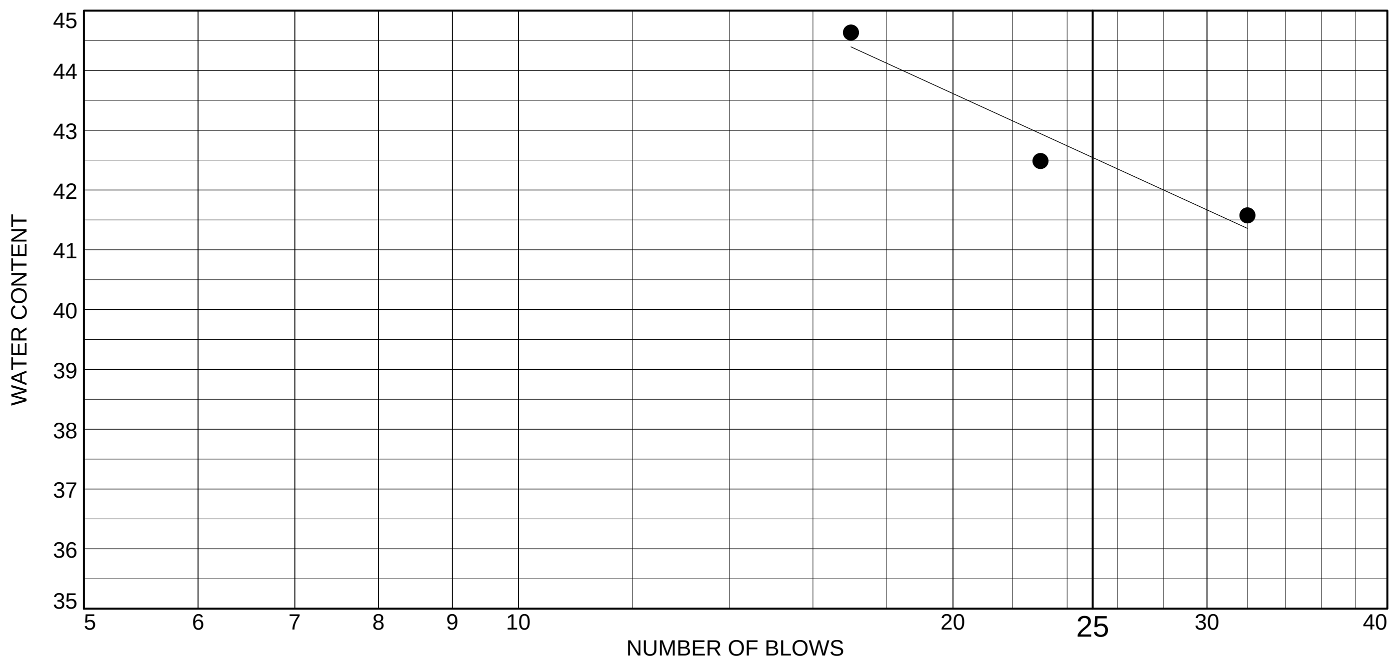
Remarks:

Figure

Tested By: BCM **Checked By:** WPQ

LIQUID AND PLASTIC LIMITS ASTM D4318





	MATERIAL DESCRIPTION	LL	PL	PI	%<#40	%<#200	USCS
●	DARK BROWNISH GRAY LEAN CLAY	43	22	21			CL

Project No. MR155233 **Client:** AECOM

Project: DYNERGY - HENNEPIN

Source of Sample: HEN-B018 **Depth:** 25.0'-27.0'
Sample Number: S-8

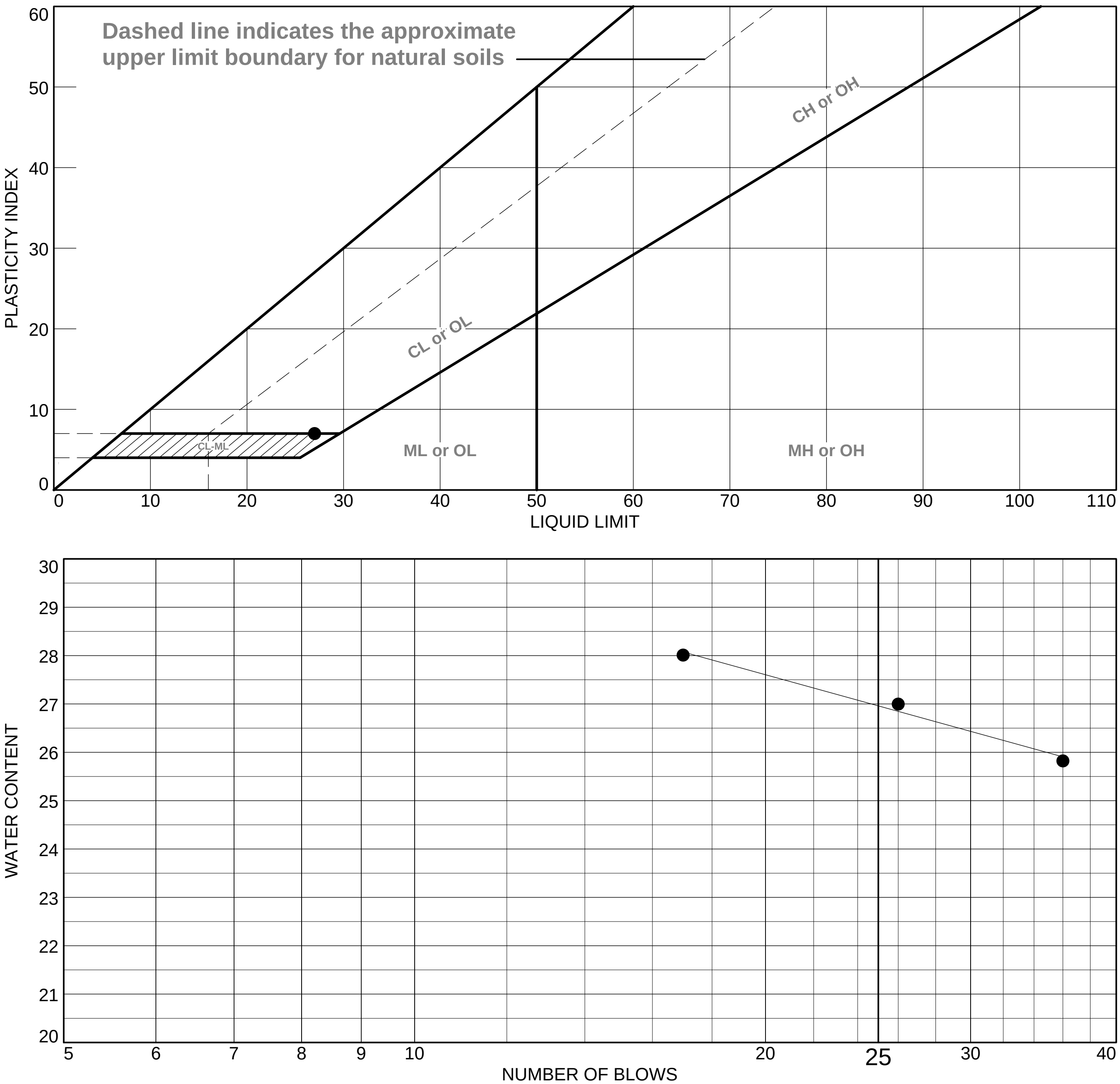
Terracon

Remarks:

Figure

Tested By: BCM **Checked By:** WPQ

LIQUID AND PLASTIC LIMITS ASTM D4318



	MATERIAL DESCRIPTION	LL	PL	PI	%<#40	%<#200	USCS
●	DARK BROWN AND GRAY ORGANIC CLAY WITH SAND - SAND SEAMS AND SHELL NOTED	27	20	7			OL

Project No. MR155233 **Client:** AECOM

Project: DYNERGY - HENNEPIN

Source of Sample: HEN-B018 **Depth:** 40.0'-42.0'
Sample Number: S-11

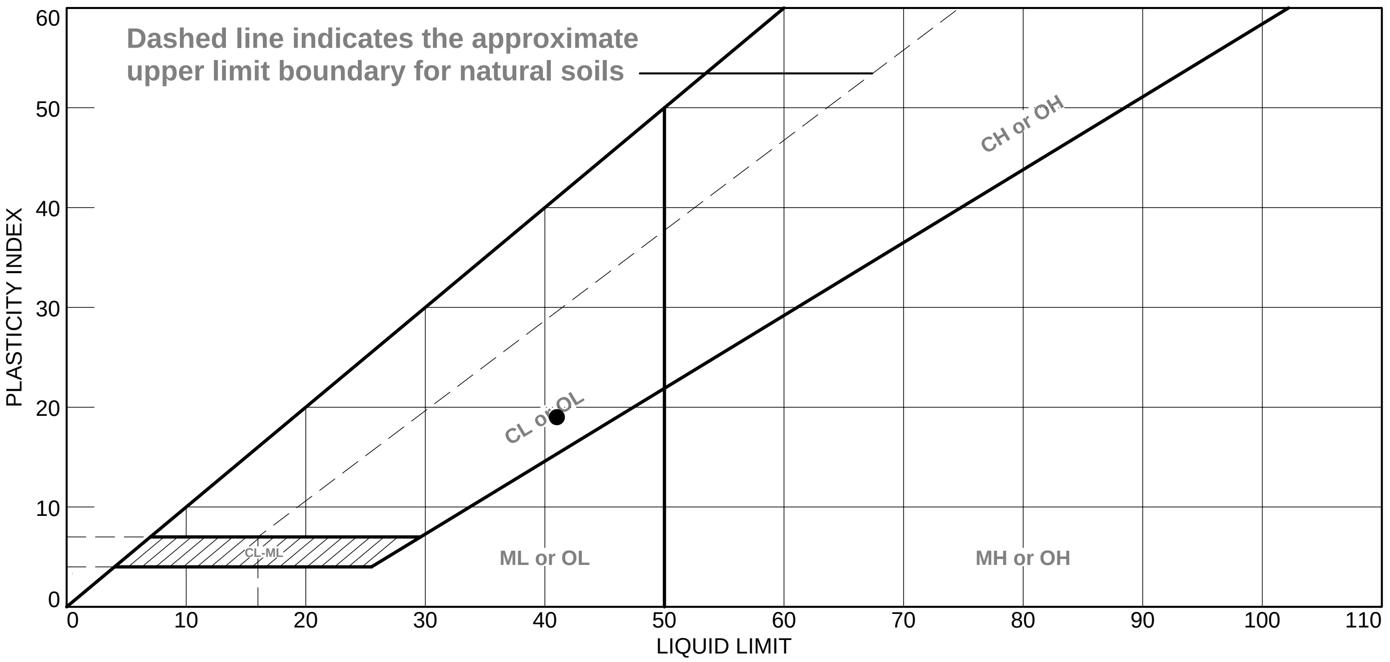
Terracon

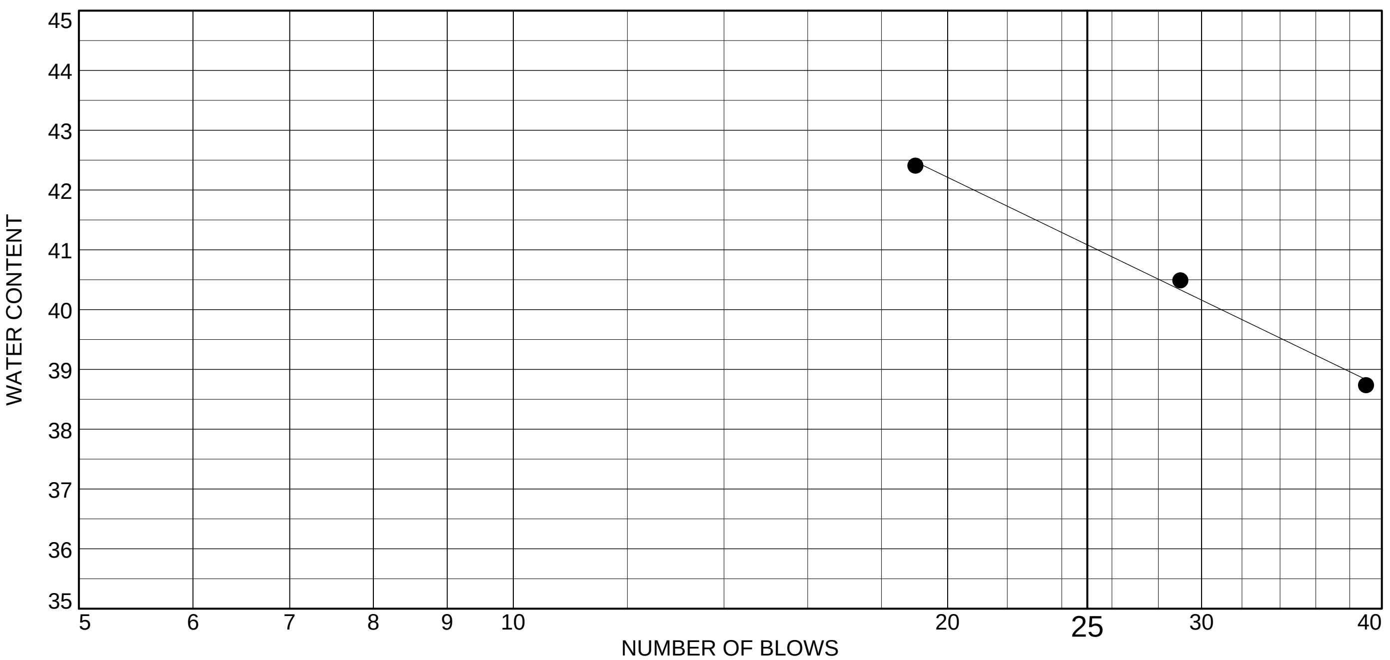
Remarks:

Figure

Tested By: BCM **Checked By:** WPQ

LIQUID AND PLASTIC LIMITS ASTM D4318





	MATERIAL DESCRIPTION	LL	PL	PI	%<#40	%<#200	USCS
●	DARK BROWN LEAN CLAY WITH SAND	41	22	19			CL

Project No. MR155233 **Client:** AECOM

Project: DYNERGY - HENNEPIN

Source of Sample: HEN-B019 **Depth:** 7.5'-9.5'
Sample Number: S-2

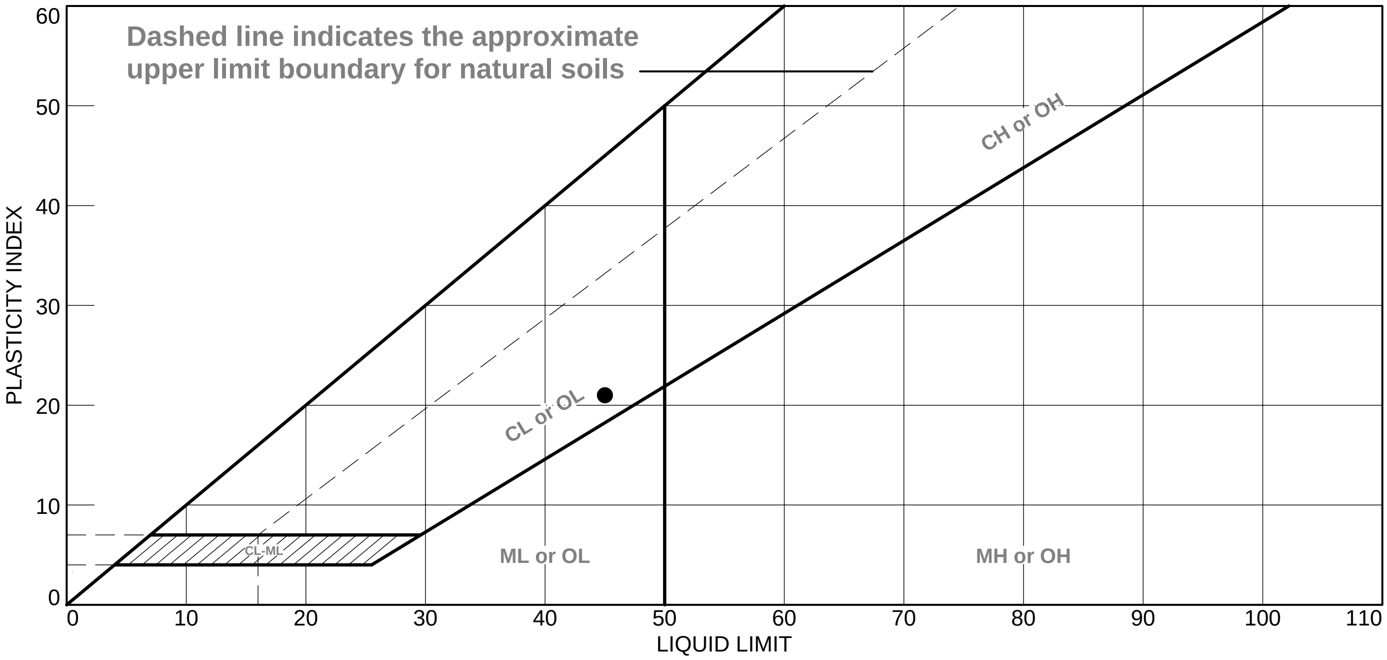
Terracon

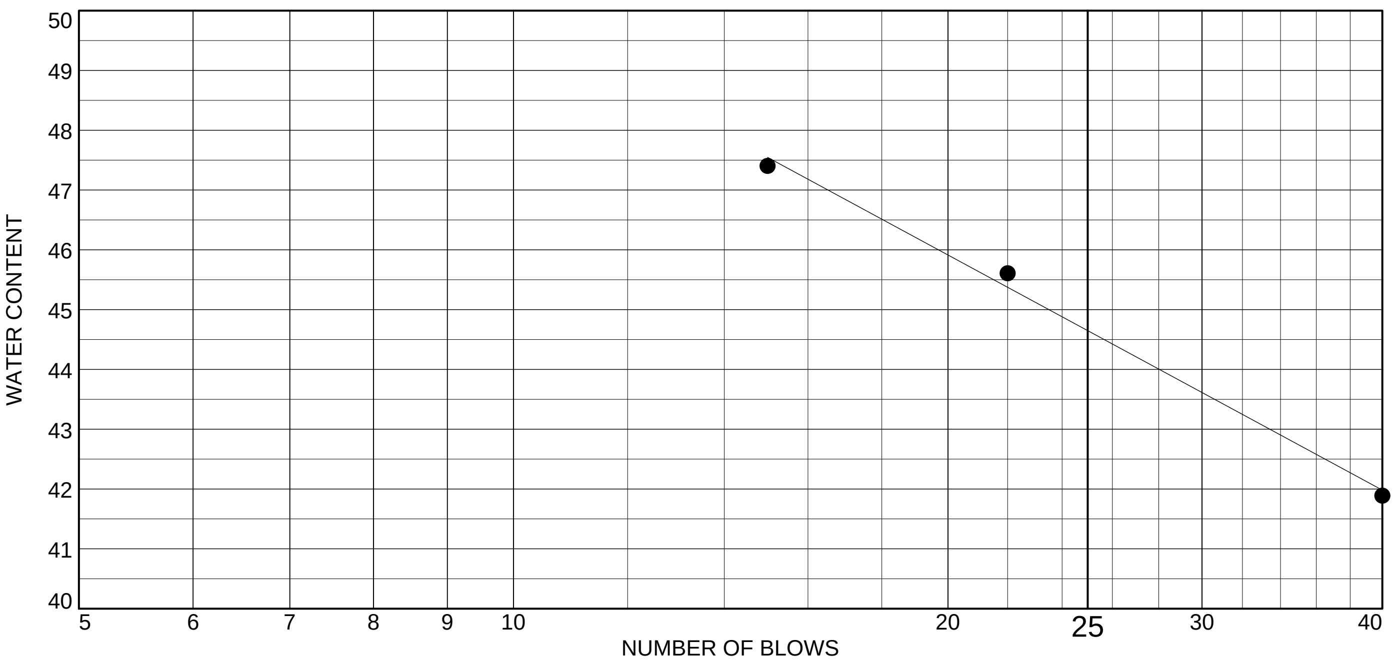
Remarks:

Figure

Tested By: HP **Checked By:** WPQ

LIQUID AND PLASTIC LIMITS ASTM D4318





	MATERIAL DESCRIPTION	LL	PL	PI	%<#40	%<#200	USCS
●	GRAY AND BROWN LEAN CLAY	45	24	21			CL

Project No. MR155233 **Client:** AECOM

Project: DYNERGY - HENNEPIN

Source of Sample: HEN-B019 **Depth:** 12.5'-14.5'

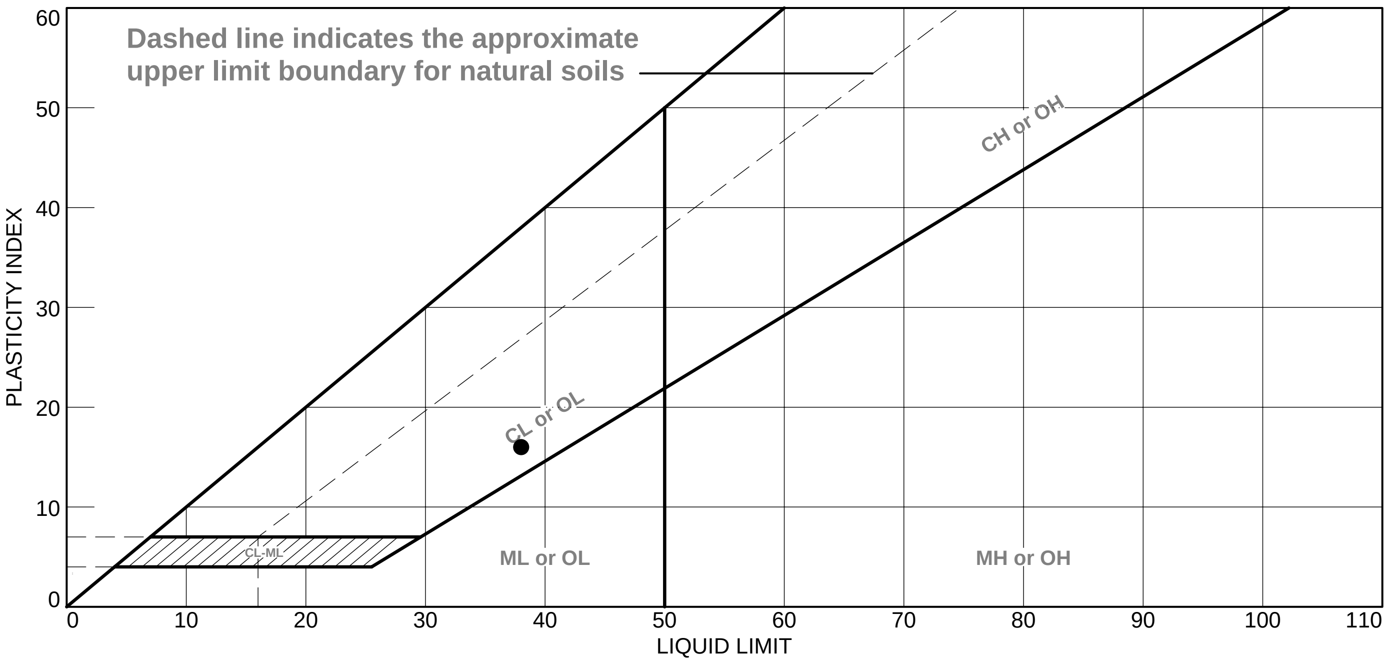
Sample Number: S-4

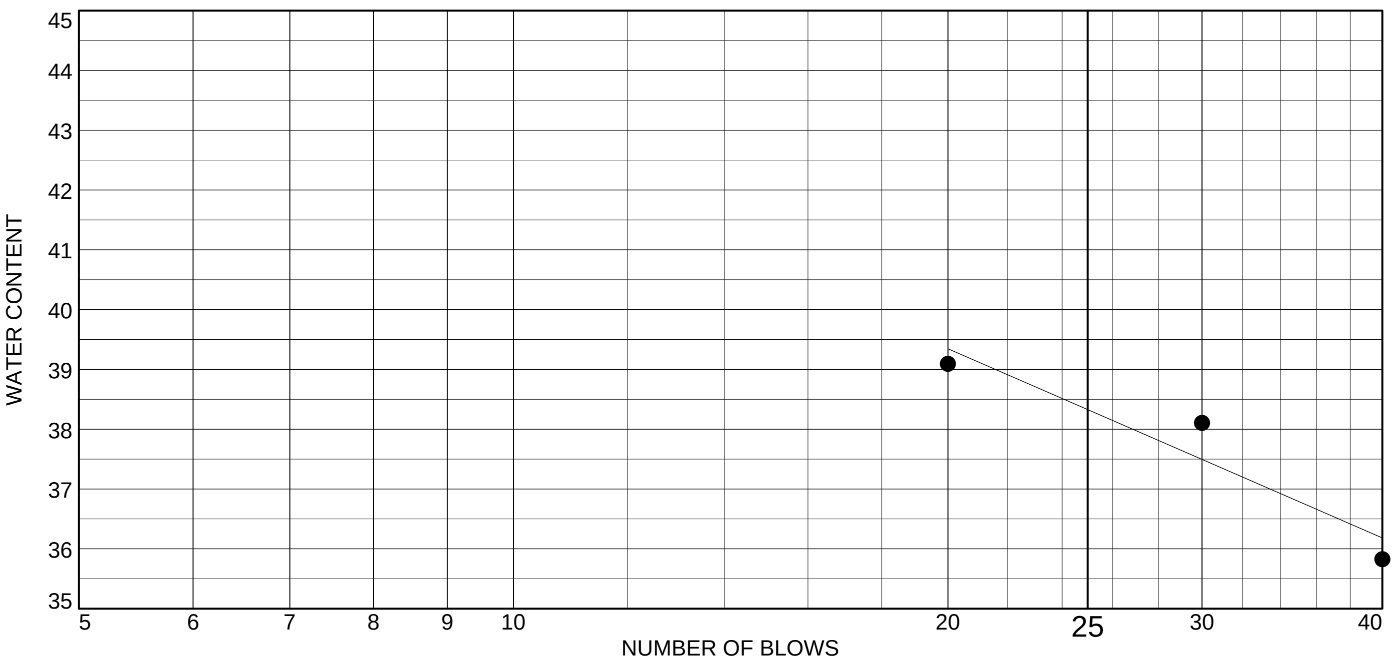
Remarks:

Figure

Tested By: HP **Checked By:** WPQ

LIQUID AND PLASTIC LIMITS ASTM D4318





	MATERIAL DESCRIPTION	LL	PL	PI	%<#40	%<#200	USCS
●	BROWN AND GRAY LEAN CLAY	38	22	16			CL

Project No. MR155233 **Client:** AECOM

Project: DYNERGY - HENNEPIN

Source of Sample: HEN-B019 **Depth:** 20.0'-22.0'
Sample Number: S-6

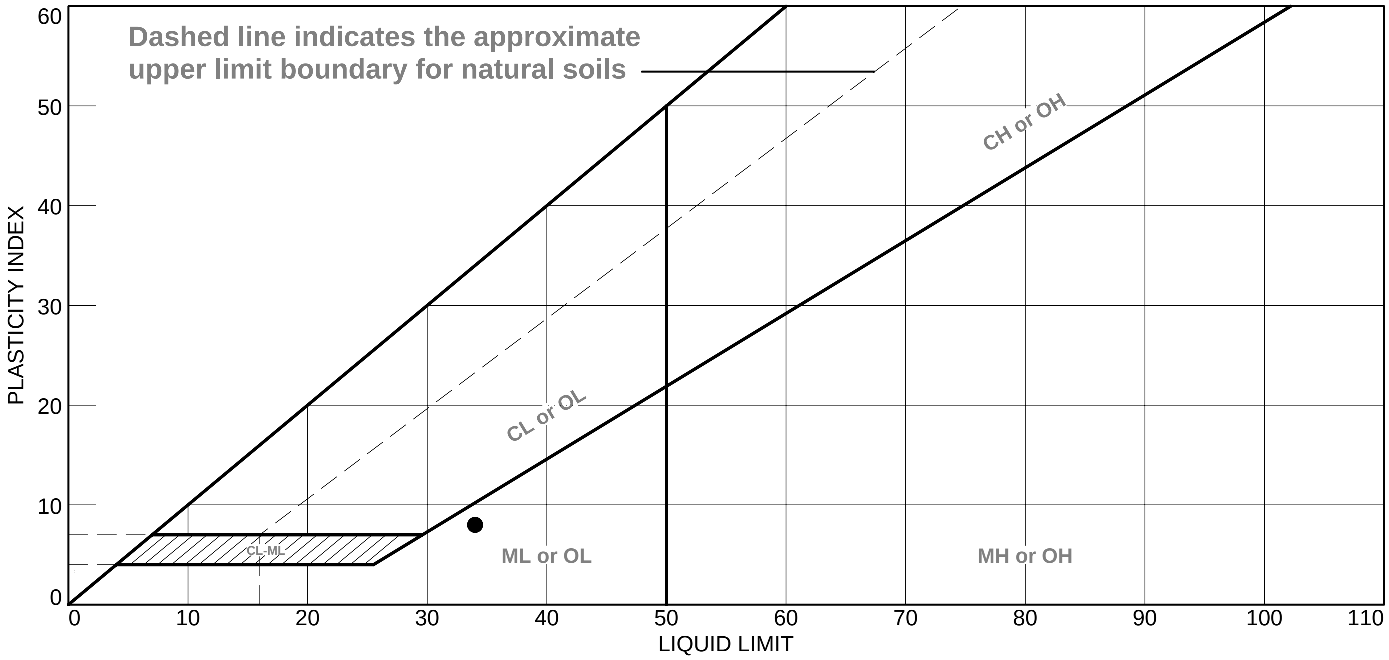
Terracon

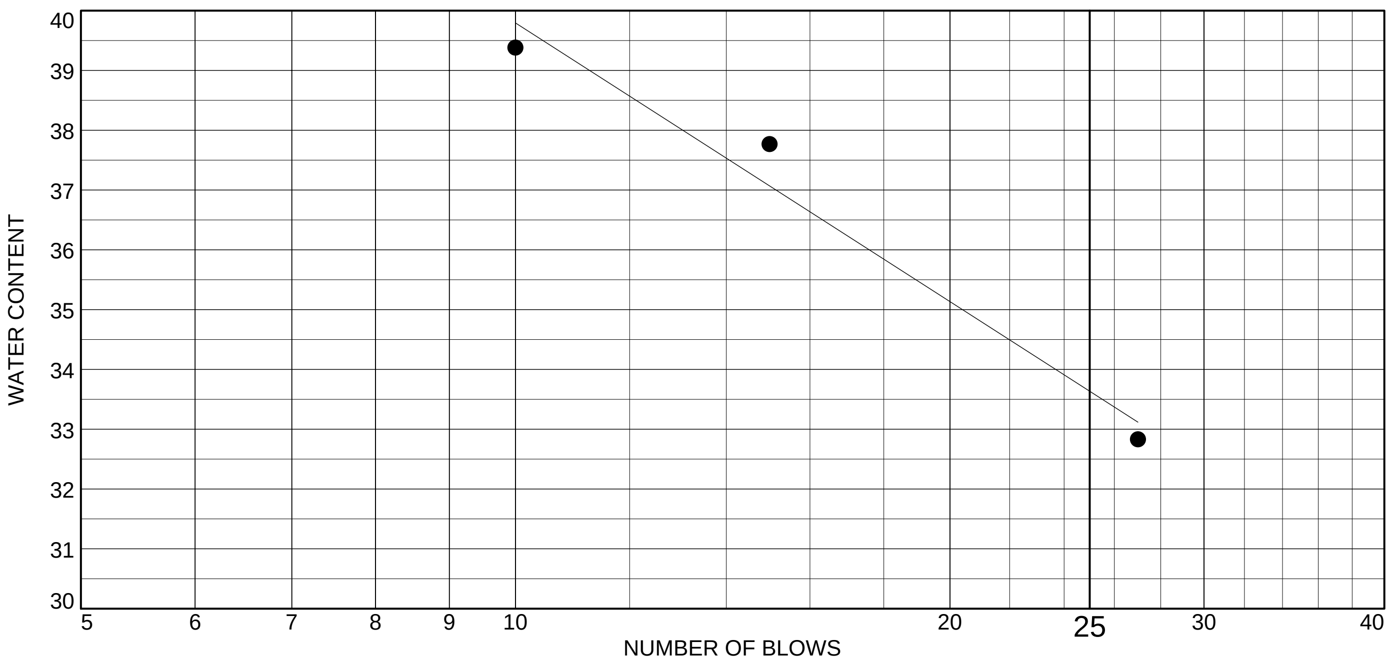
Remarks:

Figure

Tested By: BCM **Checked By:** WPQ

LIQUID AND PLASTIC LIMITS ASTM D4318





	MATERIAL DESCRIPTION	LL	PL	PI	%<#40	%<#200	USCS
●	VERY DARK GRAY ORGANIC SILT WITH SAND - SHELL NOTED	34	26	8			ML

Project No. MR155233 **Client:** AECOM

Project: DYNERGY - HENNEPIN

Source of Sample: HEN-B019 **Depth:** 25.0'-27.0'
Sample Number: S-7

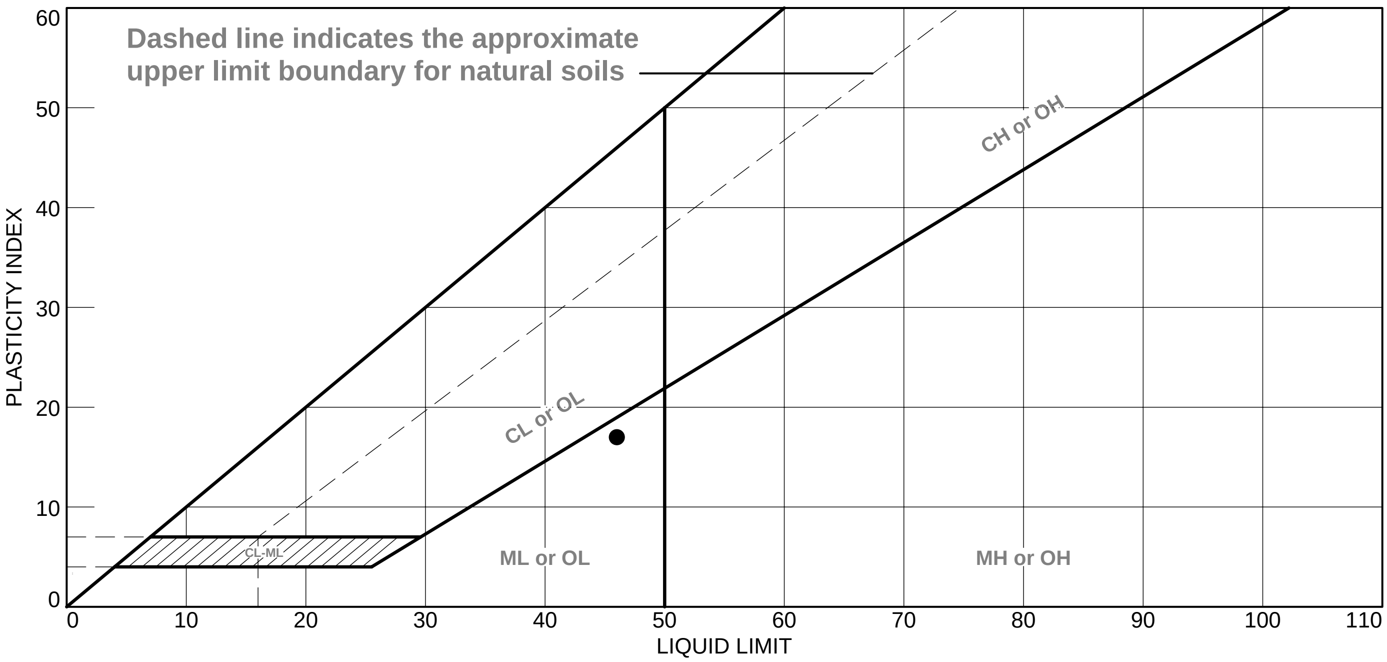
Terracon

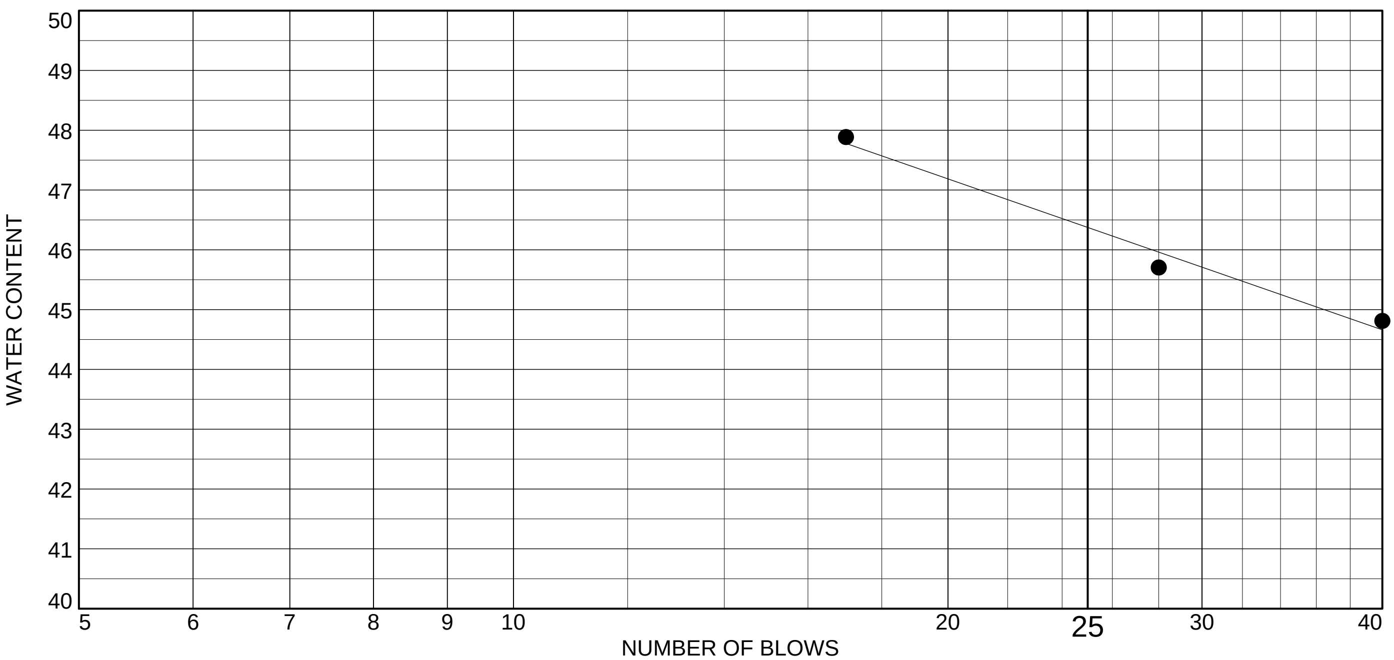
Remarks:

Figure

Tested By: BCM **Checked By:** WPQ

LIQUID AND PLASTIC LIMITS ASTM D4318





	MATERIAL DESCRIPTION	LL	PL	PI	%<#40	%<#200	USCS
●	GRAY LEAN CLAY WITH SILT	46	29	17			CL

Project No. MR155233 **Client:** AECOM

Project: DYNERGY - HENNEPIN

Source of Sample: HEN-B019 **Depth:** 50.0'-51.5'
Sample Number: S-12

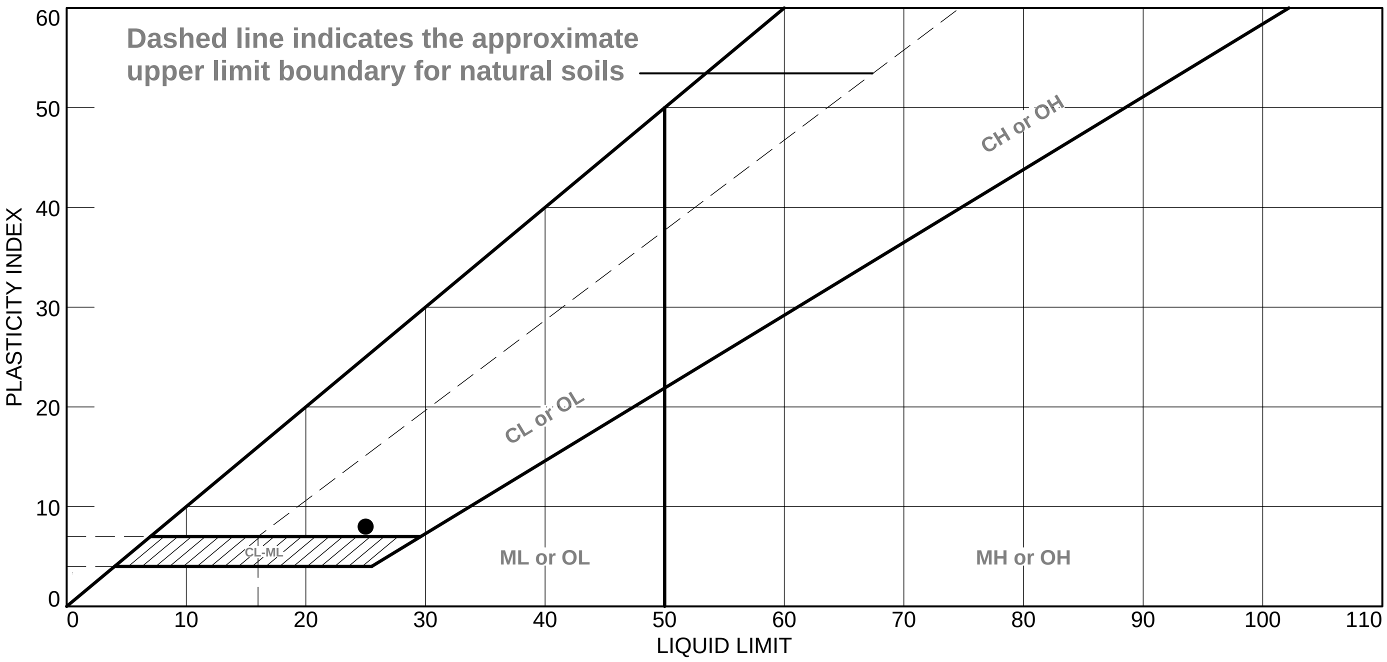
Terracon

Remarks:

Figure

Tested By: HP **Checked By:** WPQ

LIQUID AND PLASTIC LIMITS ASTM D4318



	MATERIAL DESCRIPTION	LL	PL	PI	%<#40	%<#200	USCS
●	BROWN AND DARK BROWN LEAN CLAY WITH SILT AND GRAVEL	25	17	8			CL

Project No. MR155233 **Client:** AECOM

Project: DYNERGY - HENNEPIN

Source of Sample: HEN-B020 **Depth:** 0.0'-1.5'
Sample Number: S-1

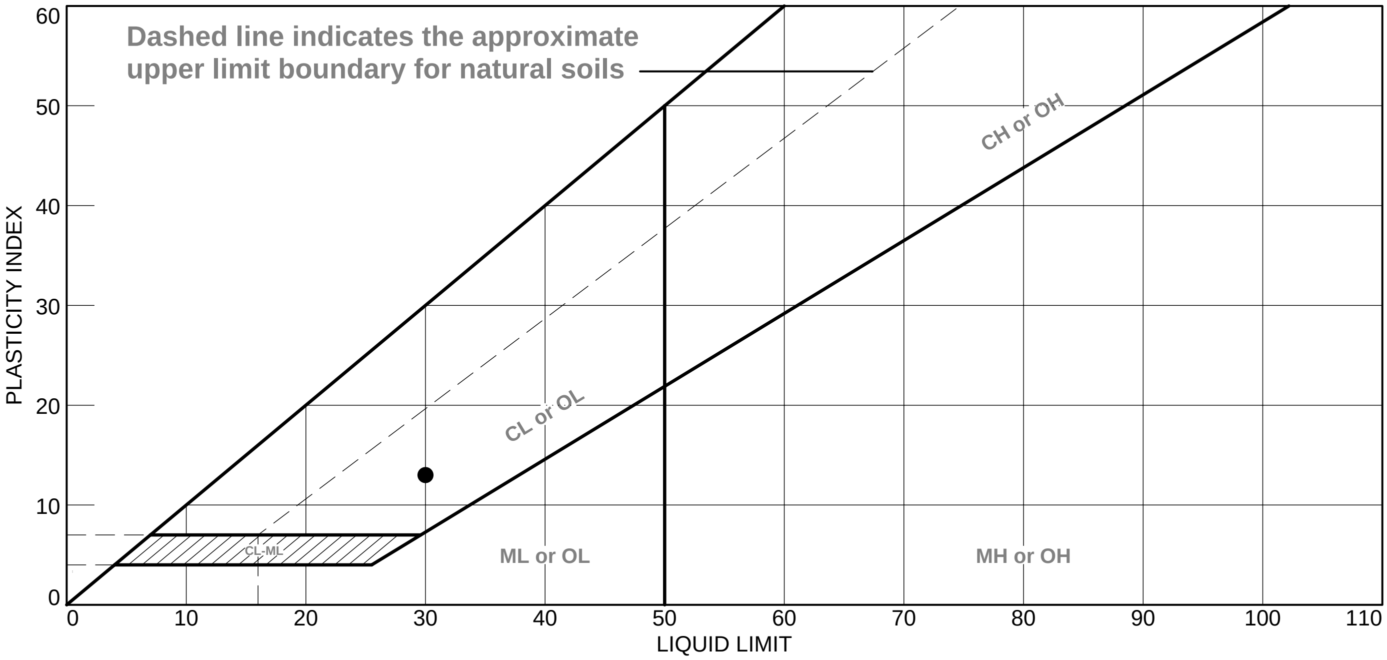
Terracon

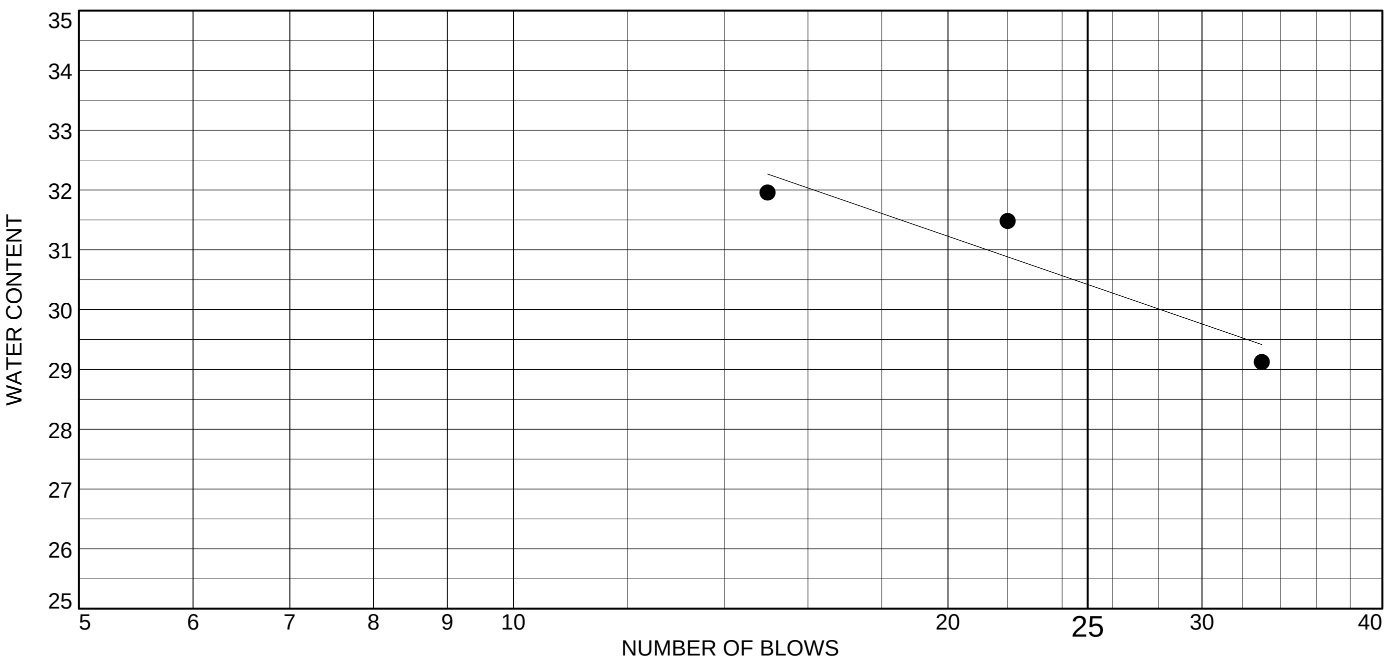
Remarks:

Figure

Tested By: DT **Checked By:** WPQ

LIQUID AND PLASTIC LIMITS ASTM D4318





	MATERIAL DESCRIPTION	LL	PL	PI	%<#40	%<#200	USCS
●	BROWN SANDY LEAN CLAY WITH GRAVEL	30	17	13			CL

Project No. MR155233 **Client:** AECOM

Project: DYNERGY - HENNEPIN

Source of Sample: HEN-B020 **Depth:** 9.5'-11.5

Sample Number: S-5

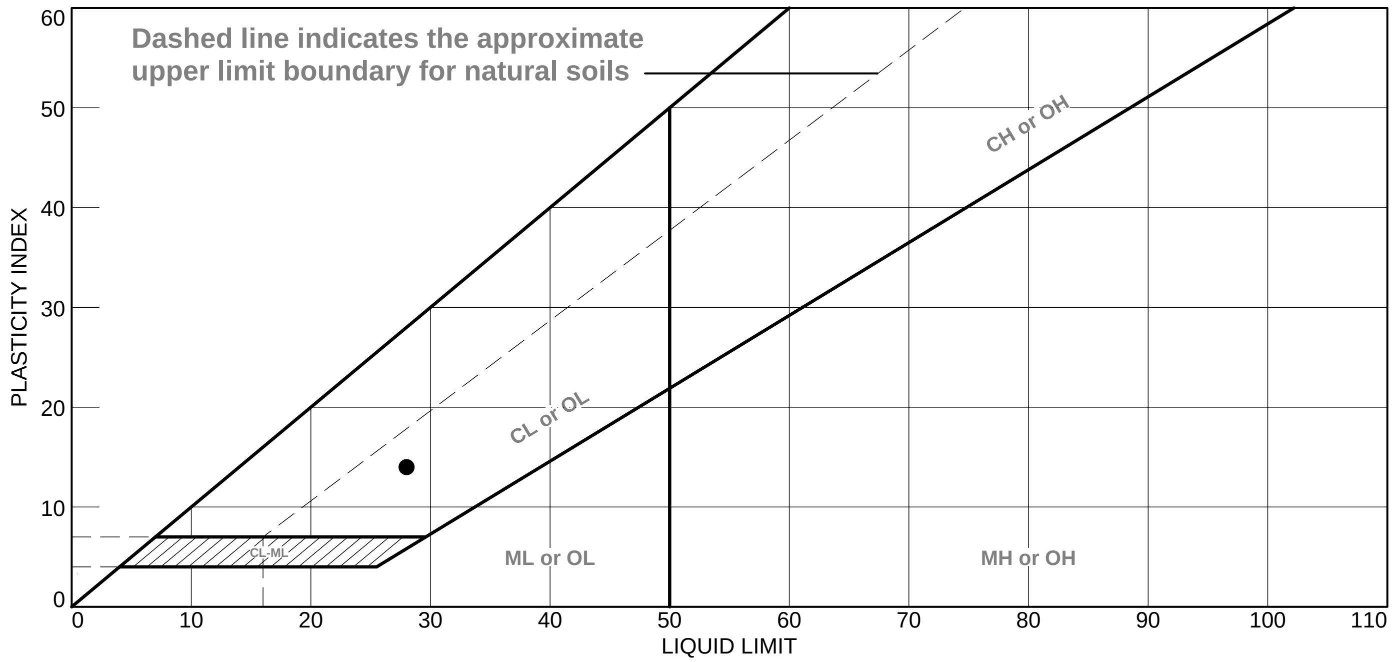
Remarks:

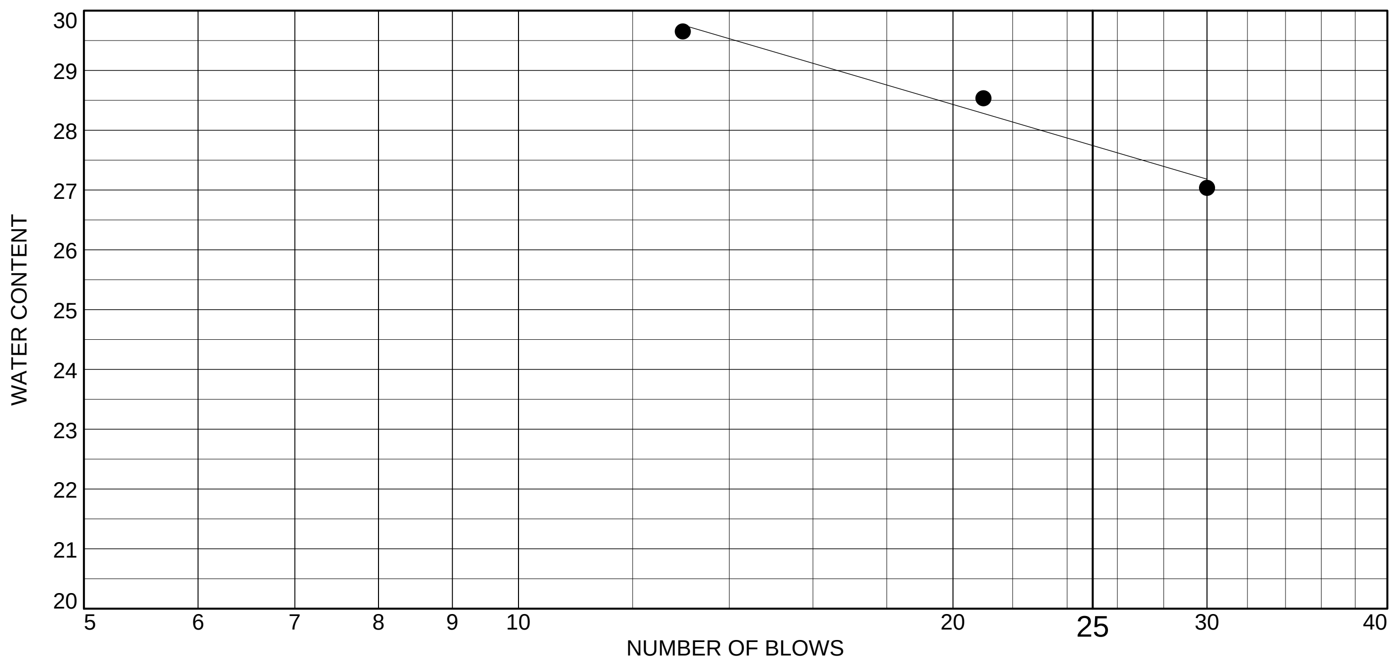
Terracon

Figure

Tested By: BCM **Checked By:** WPQ

LIQUID AND PLASTIC LIMITS ASTM D4318





	MATERIAL DESCRIPTION	LL	PL	PI	%<#40	%<#200	USCS
●	BROWN LEAN CLAY WITH SAND AND GRAVEL	28	14	14			CL

Project No. MR155233 **Client:** AECOM

Project: DYNERGY - HENNEPIN

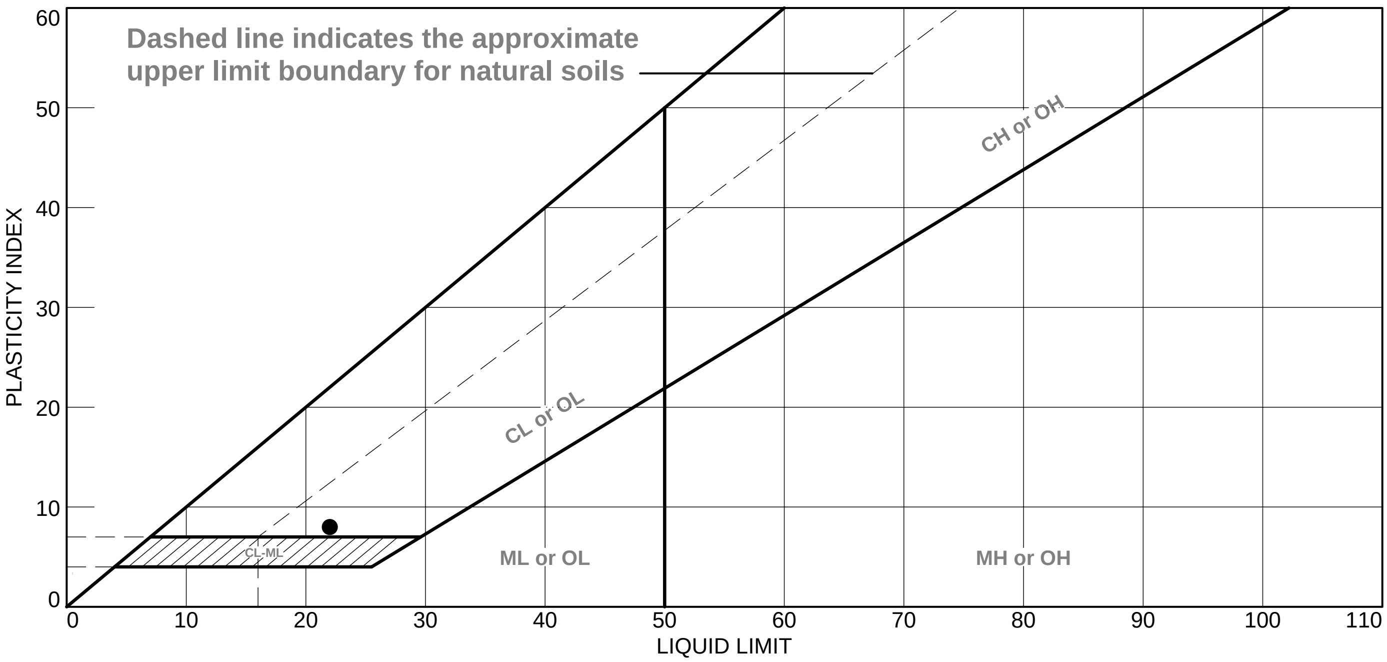
Source of Sample: HEN-B021 **Depth:** 5.0'-6.0'
Sample Number: S-3

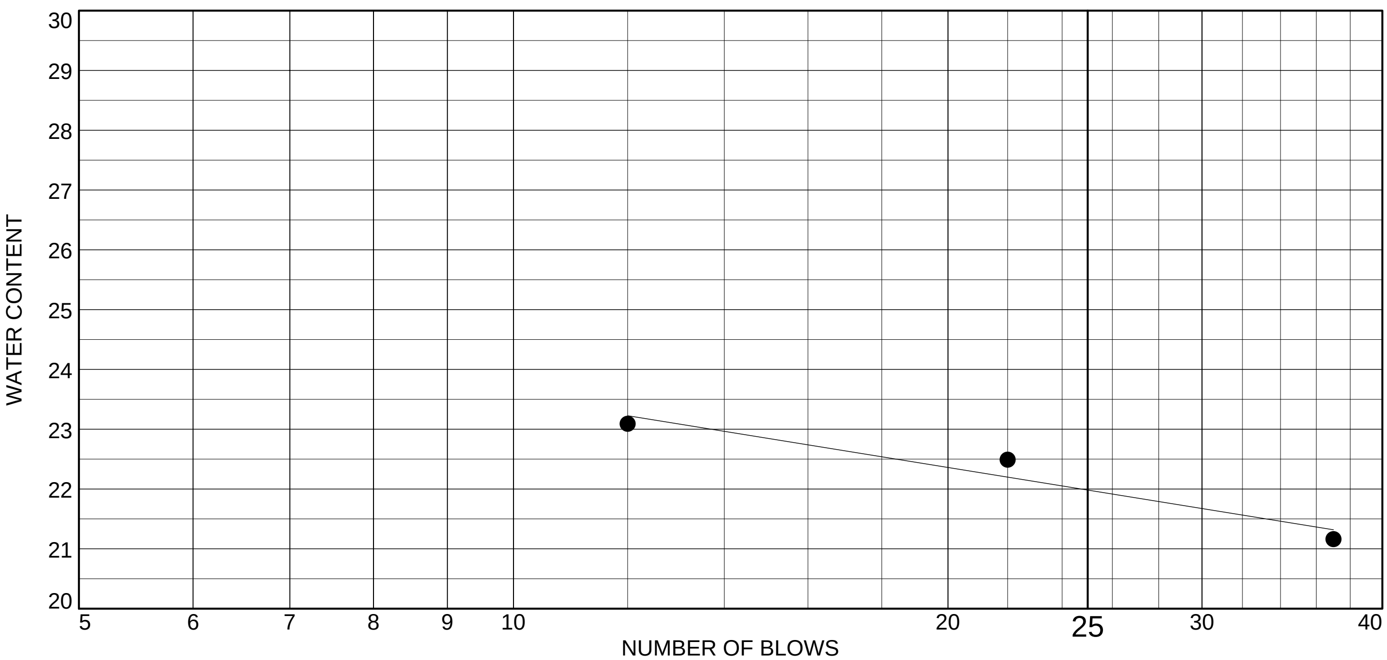
Remarks:

Figure

Tested By: BCM **Checked By:** WPQ

LIQUID AND PLASTIC LIMITS ASTM D4318





	MATERIAL DESCRIPTION	LL	PL	PI	%<#40	%<#200	USCS
●	BROWN LEAN CLAY WITH SAND - ROOTS NOTED	22	14	8			CL

Project No. MR155233 **Client:** AECOM

Project: DYNERGY - HENNEPIN

Source of Sample: HEN-B021 **Depth:** 15.0'-16.5'
Sample Number: S-6

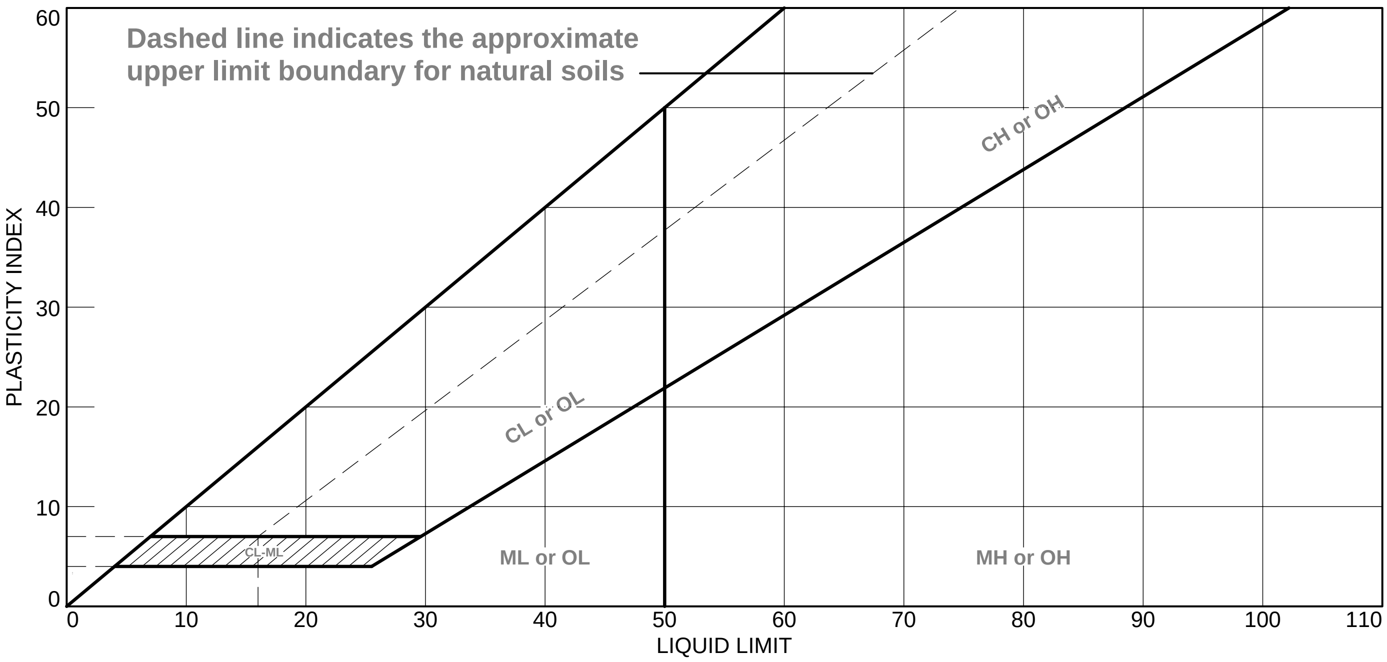
Terracon

Remarks:

Figure

Tested By: HP **Checked By:** WPQ

LIQUID AND PLASTIC LIMITS ASTM D4318



	MATERIAL DESCRIPTION	LL	PL	PI	%<#40	%<#200	USCS
●	VERY DARK GRAY VARVED FLY ASH	36	42	NP			

Project No. MR155233 **Client:** AECOM

Project: DYNERGY - HENNEPIN

Source of Sample: HEN-B022 **Depth:** 2.5'-4.5'

Sample Number: S-2

Terracon

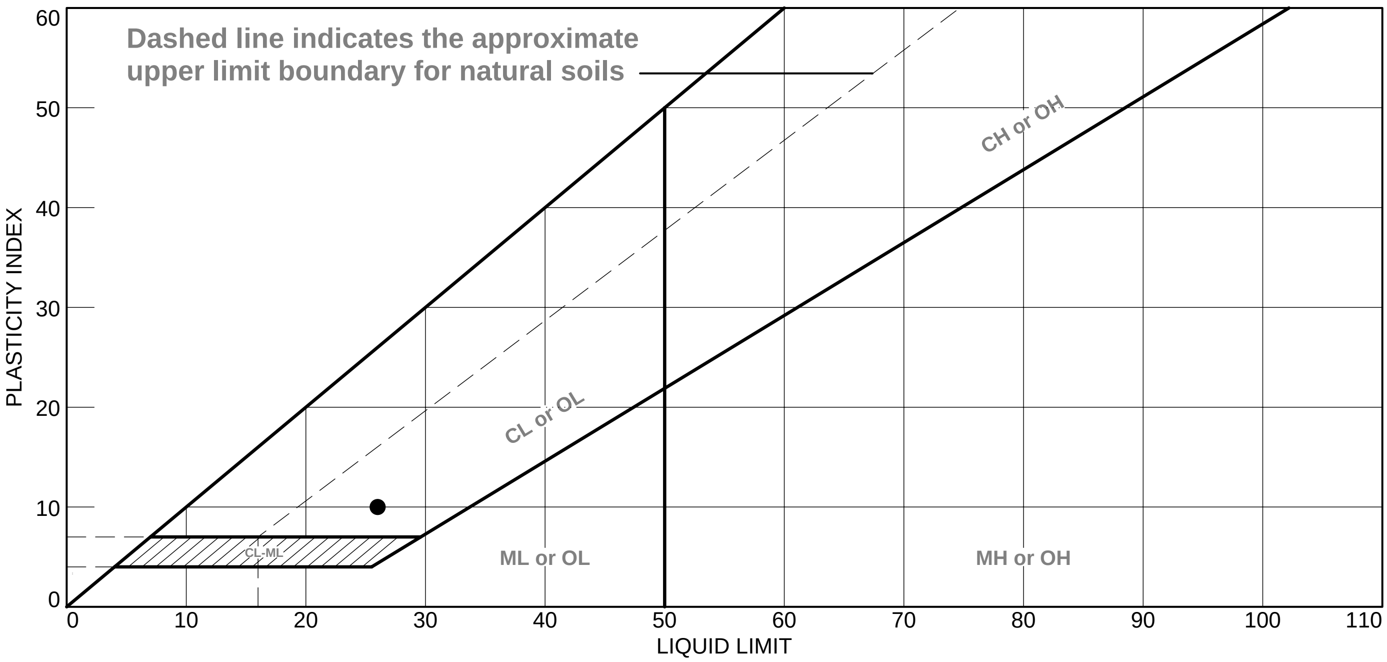
Remarks:

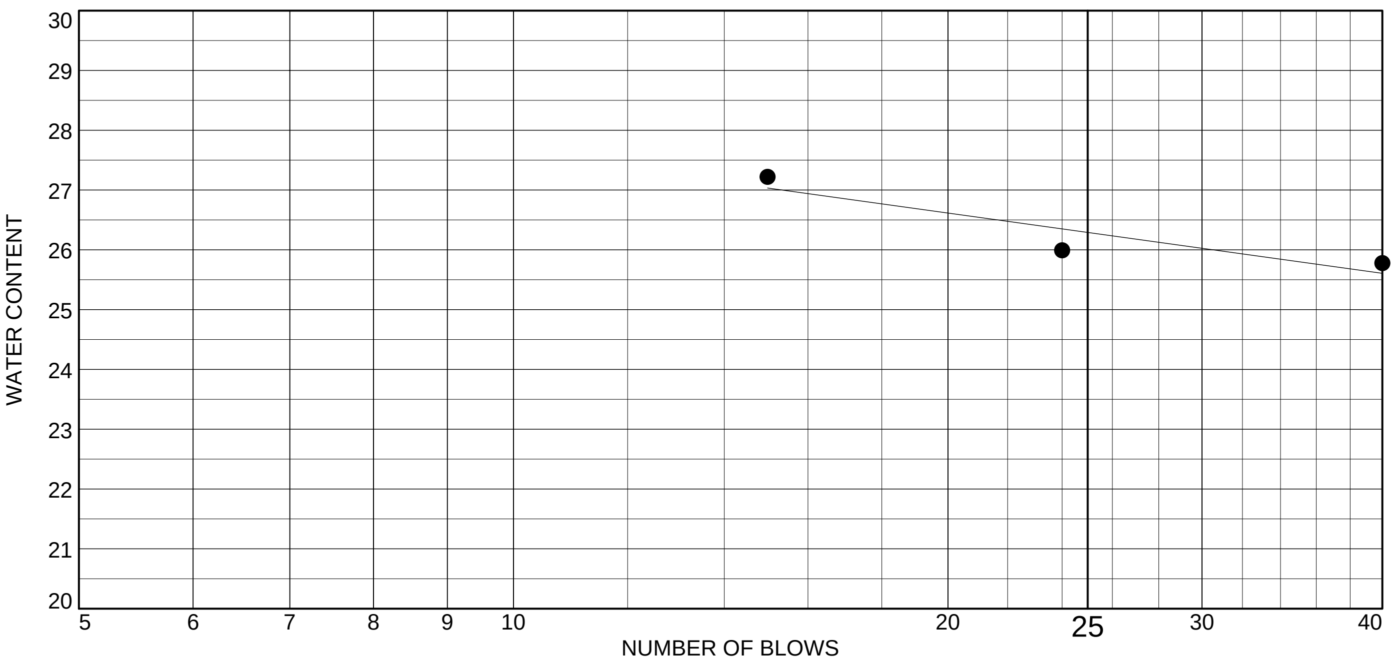
● A single point test was performed because of difficultly obtaining high blow counts due to type of material.

Figure

Tested By: HP **Checked By:** WPQ

LIQUID AND PLASTIC LIMITS ASTM D4318





	MATERIAL DESCRIPTION	LL	PL	PI	%<#40	%<#200	USCS
●	REDDISH BROWN SANDY LEAN CLAY	26	16	10			CL

Project No. MR155233 **Client:** AECOM

Project: DYNERGY - HENNEPIN

Source of Sample: HEN-B022 **Depth:** 20.0'-21.5'
Sample Number: S-7

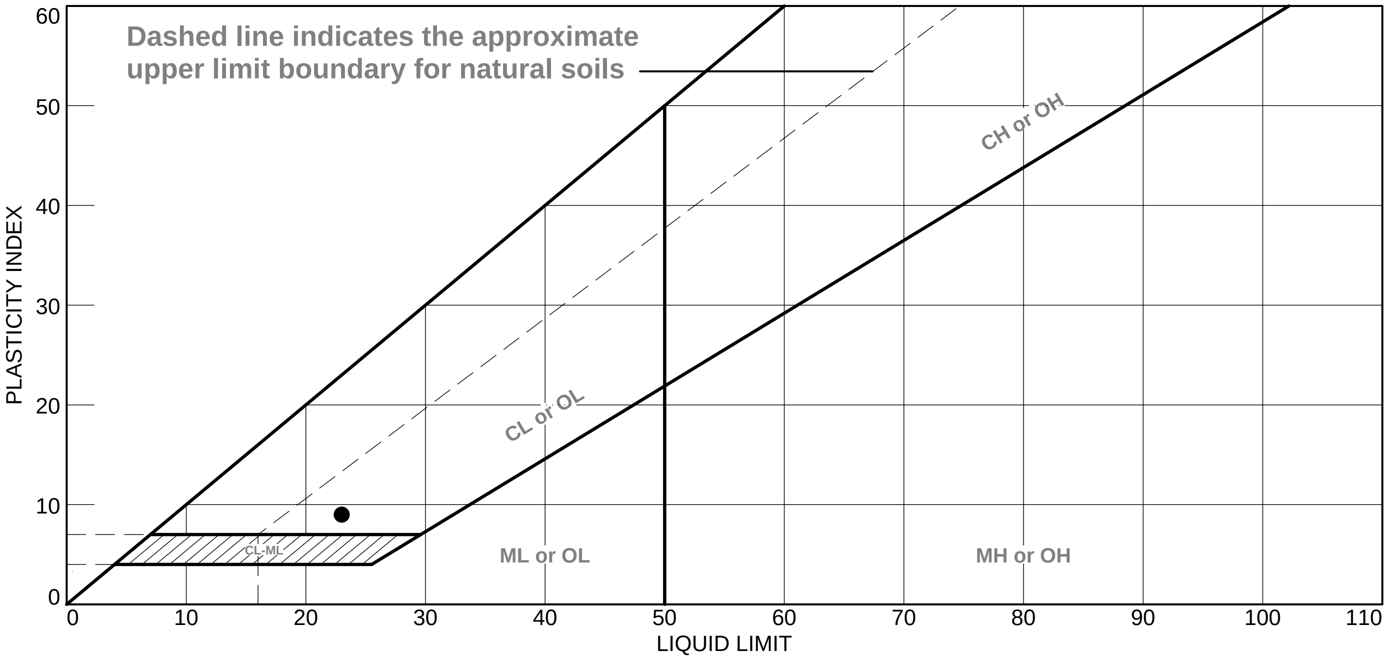
Terracon

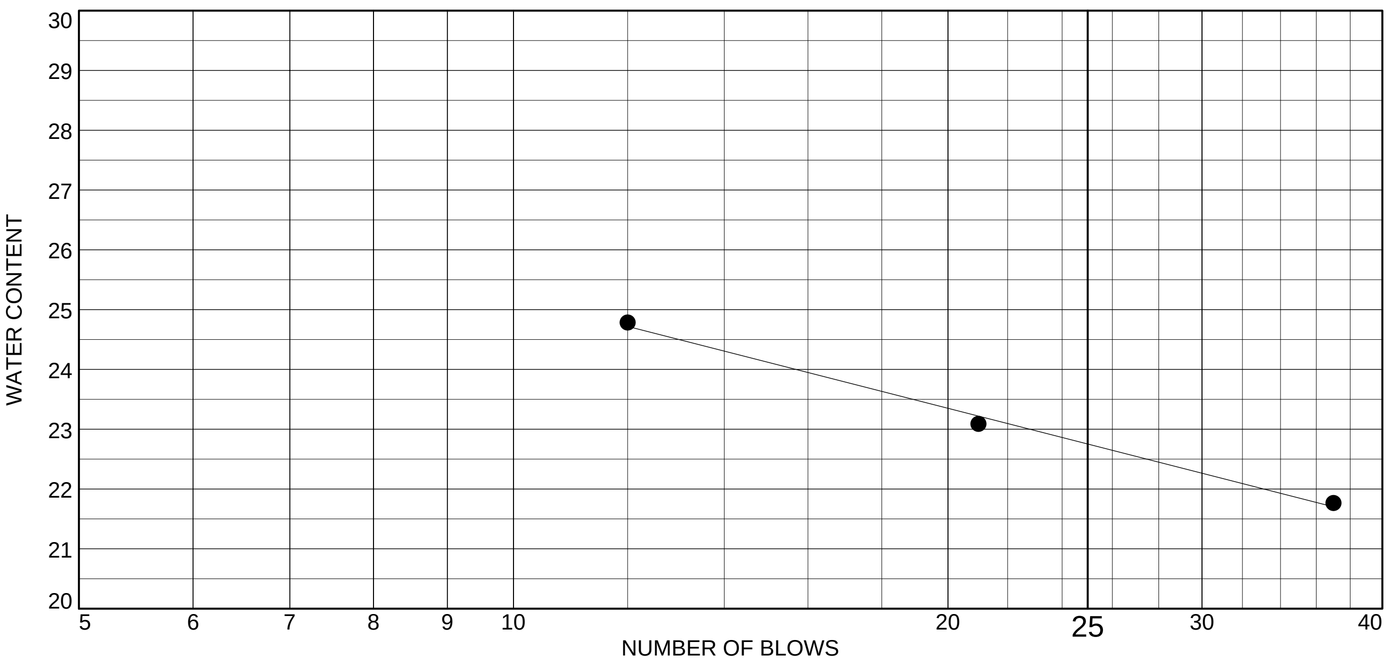
Remarks:

Figure

Tested By: HP **Checked By:** WPQ

LIQUID AND PLASTIC LIMITS ASTM D4318





	MATERIAL DESCRIPTION	LL	PL	PI	%<#40	%<#200	USCS
●	BROWN LEAN CLAY WITH GRAVEL	23	14	9			CL

Project No. MR155233 **Client:** AECOM

Project: DYNERGY - HENNEPIN

Source of Sample: HEN-B024 **Depth:** 10.0'-11.5'
Sample Number: S-5

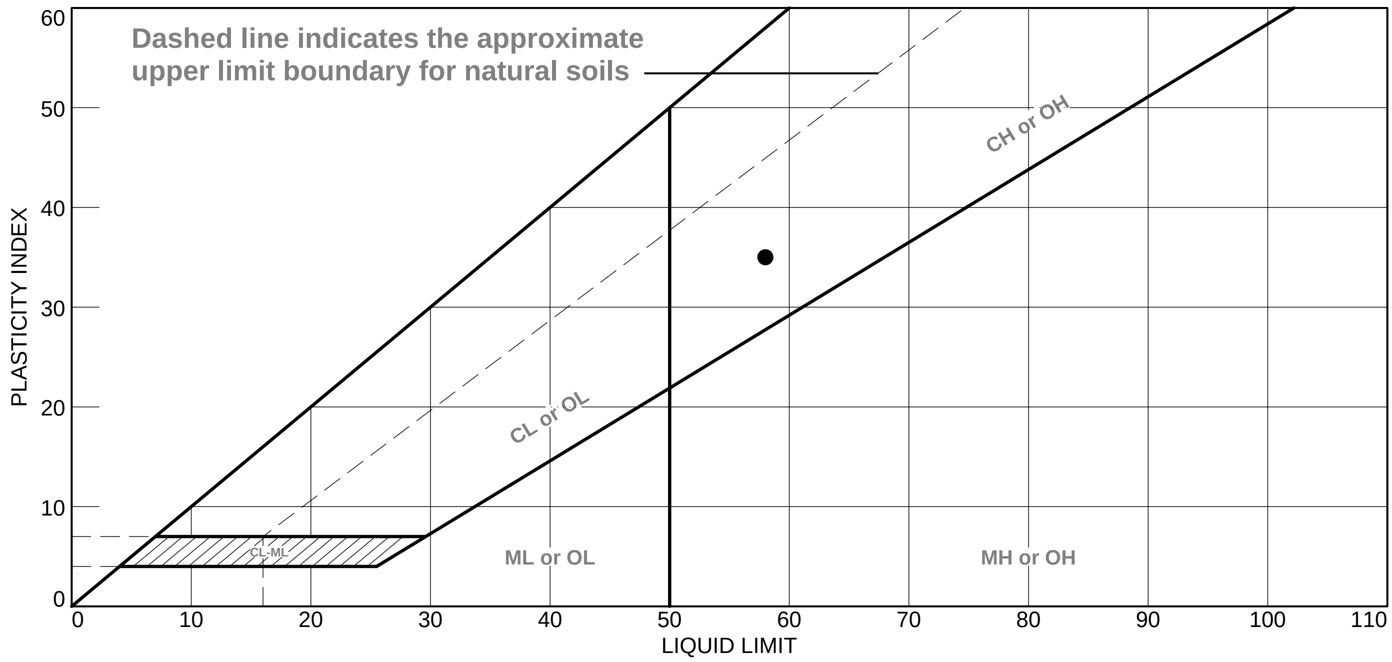
Terracon

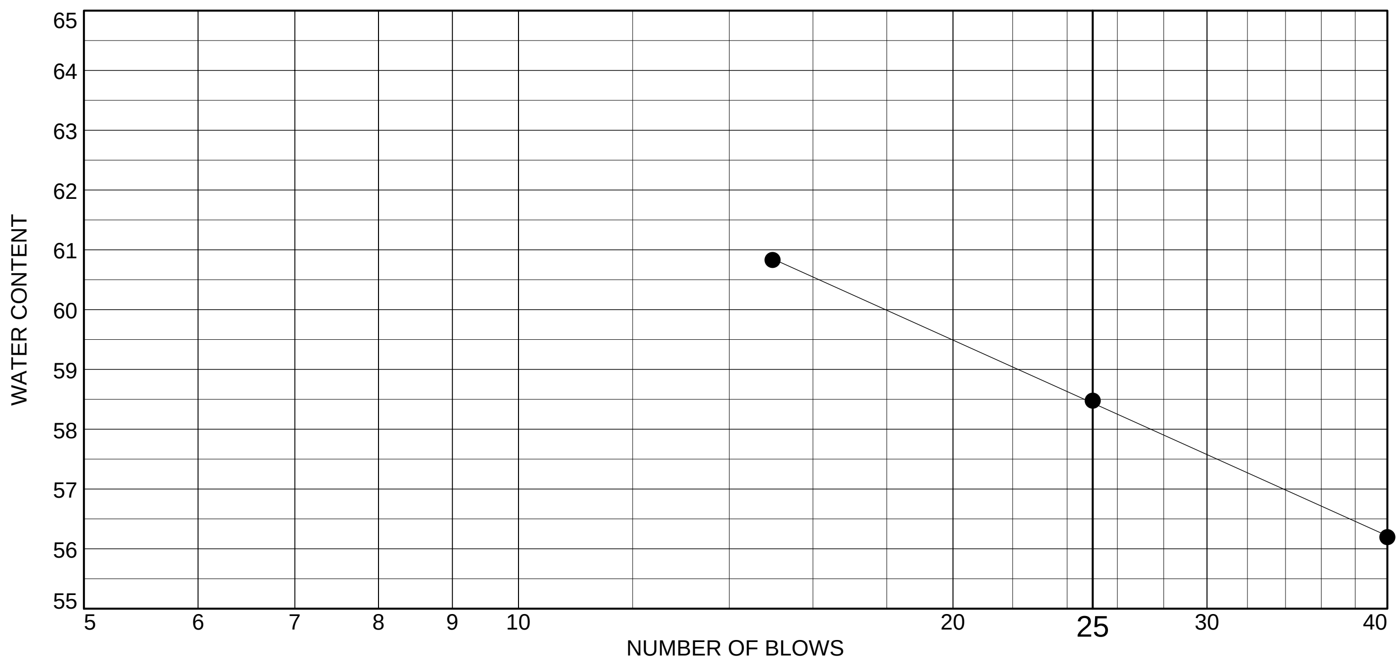
Remarks:

Figure

Tested By: SJH **Checked By:** WPQ

LIQUID AND PLASTIC LIMITS ASTM D4318





	MATERIAL DESCRIPTION	LL	PL	PI	%<#40	%<#200	USCS
●	DARK GRAY ORGANIC CLAY WITH SAND	58	23	35			0H

Project No. MR155233 **Client:** AECOM

Project: DYNERGY - HENNEPIN

Source of Sample: HEN-B024 **Depth:** 26.5'-28.5'
Sample Number: S-9

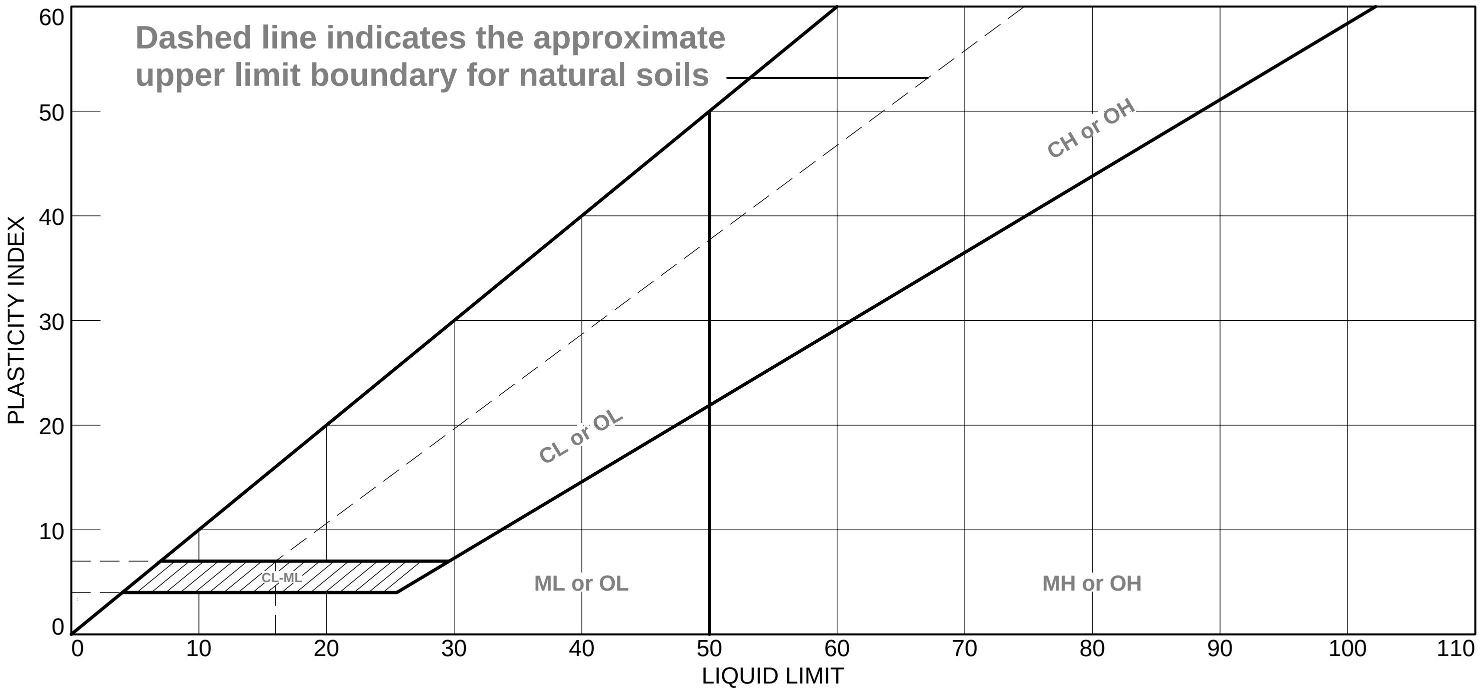
Terracon

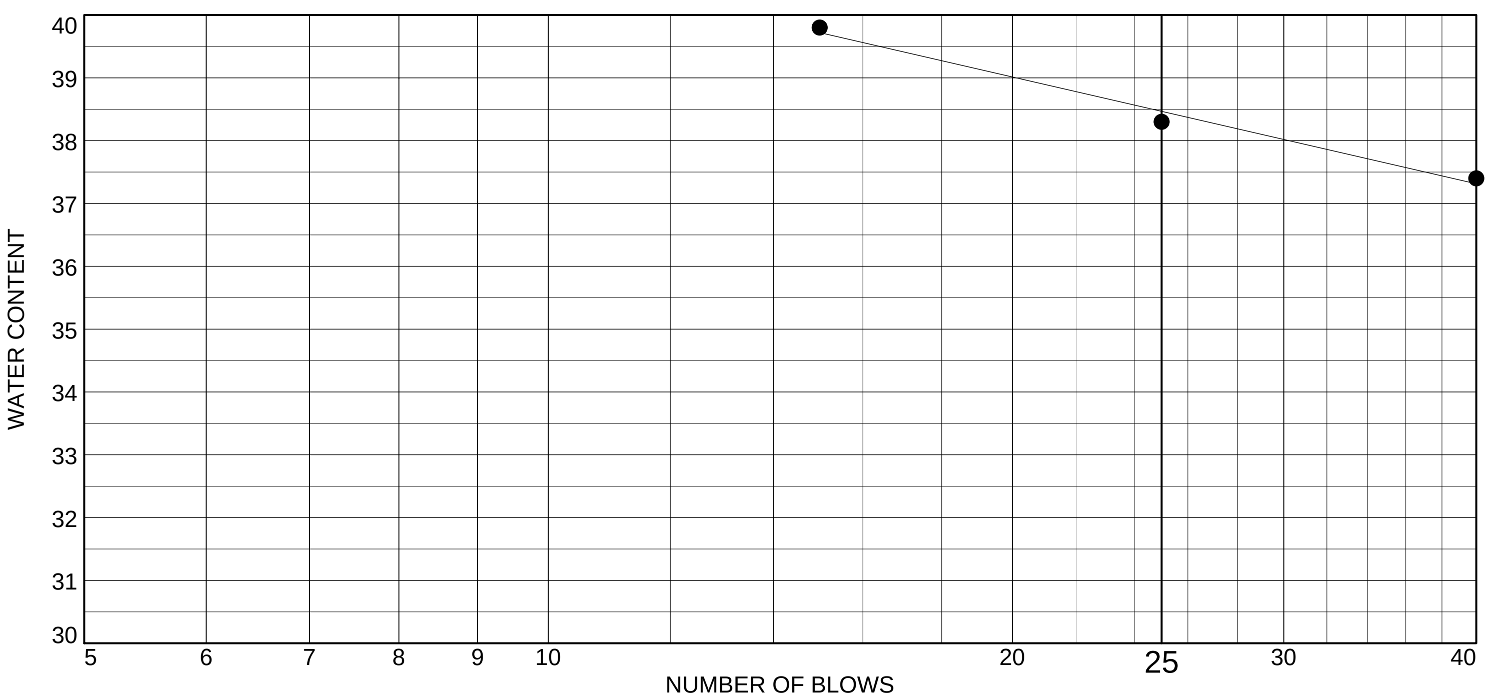
Remarks:

Figure

Tested By: BCM **Checked By:** WPQ

LIQUID AND PLASTIC LIMITS ASTM D4318





	MATERIAL DESCRIPTION	LL	PL	PI	%<#40	%<#200	USCS
●	VERY DARK GRAY FLY ASH WITH SAND	38	38	NP	78.0	72.5	ML

Project No. MR155233 **Client:** AECOM

Project: DYNERGY - HENNEPIN

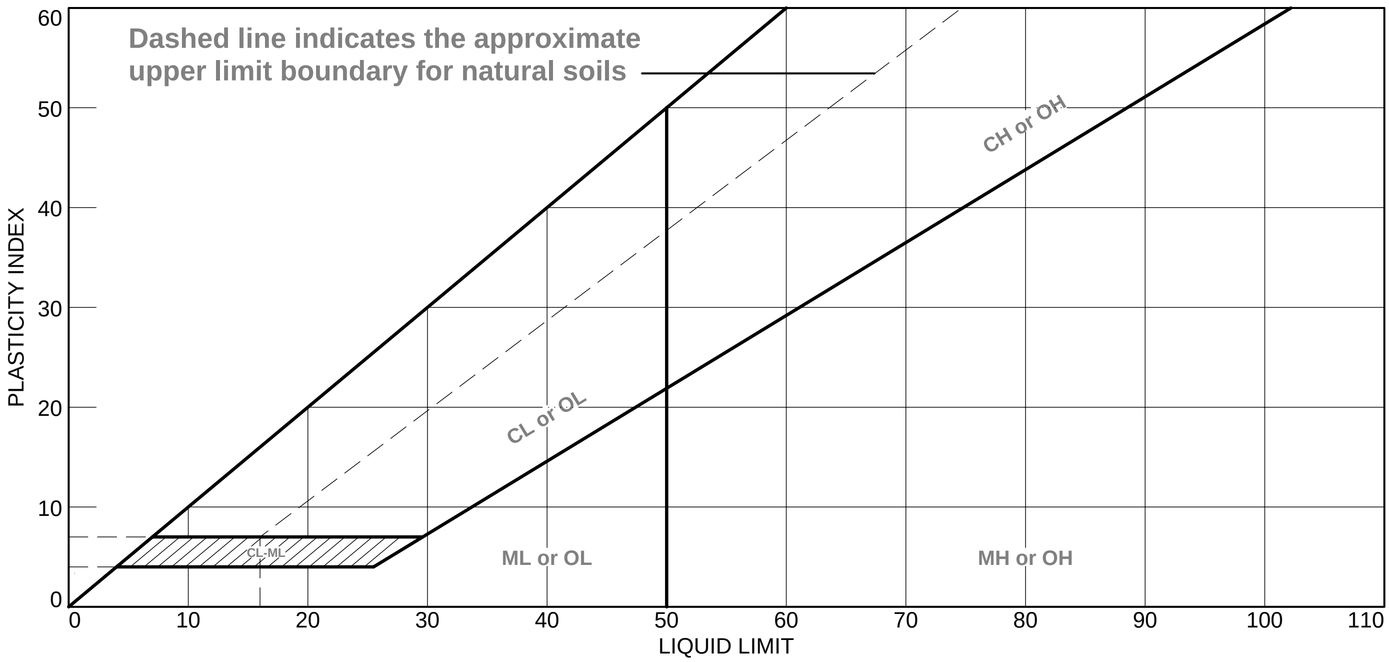
Source of Sample: HEN-B025 **Depth:** 11.5'-14.0'
Sample Number: S-6

Remarks:

Figure

Tested By: BCM **Checked By:** WPQ

LIQUID AND PLASTIC LIMITS ASTM D4318



	MATERIAL DESCRIPTION	LL	PL	PI	%<#40	%<#200	USCS
●	VERY DARK GRAY TO GRAY FLY ASH WITH SAND	32	34	NP			

Project No. MR155233 **Client:** AECOM

Project: DYNERGY - HENNEPIN

Source of Sample: HEN-B025 **Depth:** 25.0'-27.0'
Sample Number: S-9

Terracon

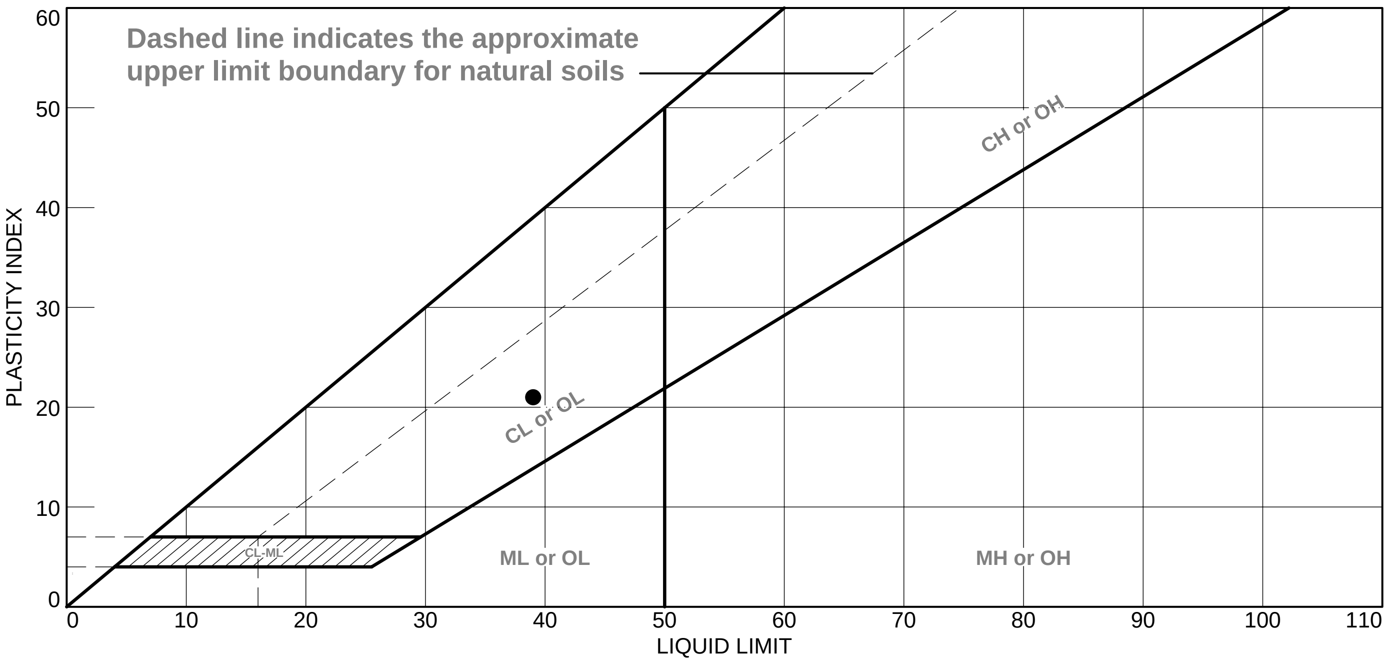
Remarks:

● A single point test was performed because of difficultly obtaining high blow counts due to type of material.

Figure

Tested By: BCM **Checked By:** WPQ

LIQUID AND PLASTIC LIMITS ASTM D4318



	MATERIAL DESCRIPTION	LL	PL	PI	%<#40	%<#200	USCS
●	BROWN LEAN CLAY WITH GRAVEL	39	18	21			CL

Project No. MR155233 **Client:** AECOM

Project: DYNERGY - HENNEPIN

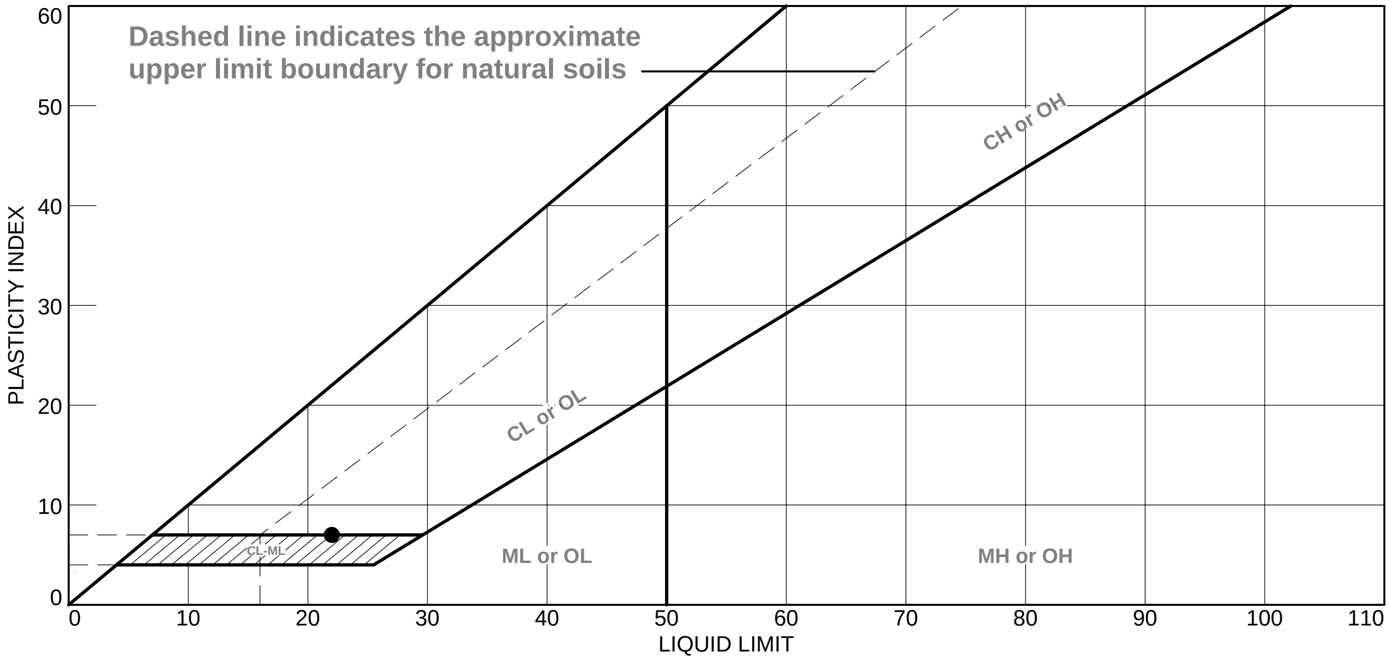
Source of Sample: HEN-B027 **Depth:** 15.0'-16.5'
Sample Number: S-4

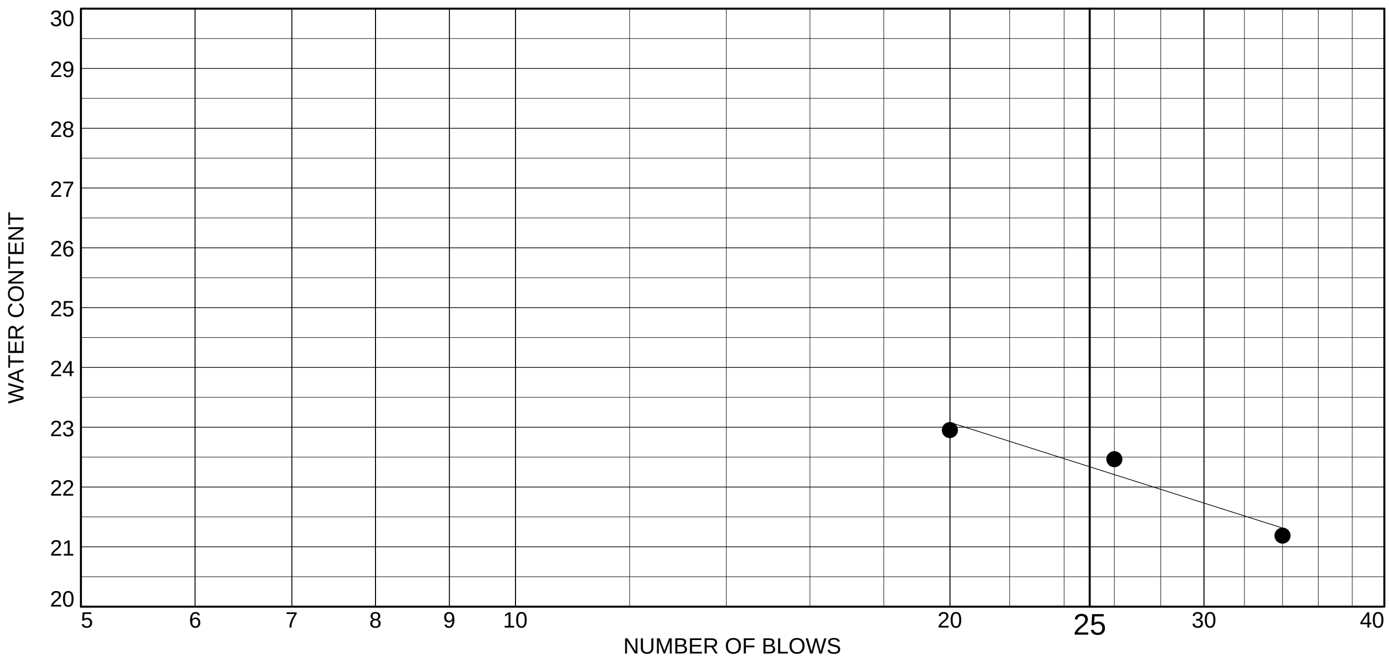
Remarks:

Figure

Tested By: SJH **Checked By:** WPQ

LIQUID AND PLASTIC LIMITS ASTM D4318





	MATERIAL DESCRIPTION	LL	PL	PI	%<#40	%<#200	USCS
●	BROWN LEAN CLAY WITH SAND AND GRAVEL	22	15	7			CL

Project No. MR155233 **Client:** AECOM

Project: DYNERGY - HENNEPIN

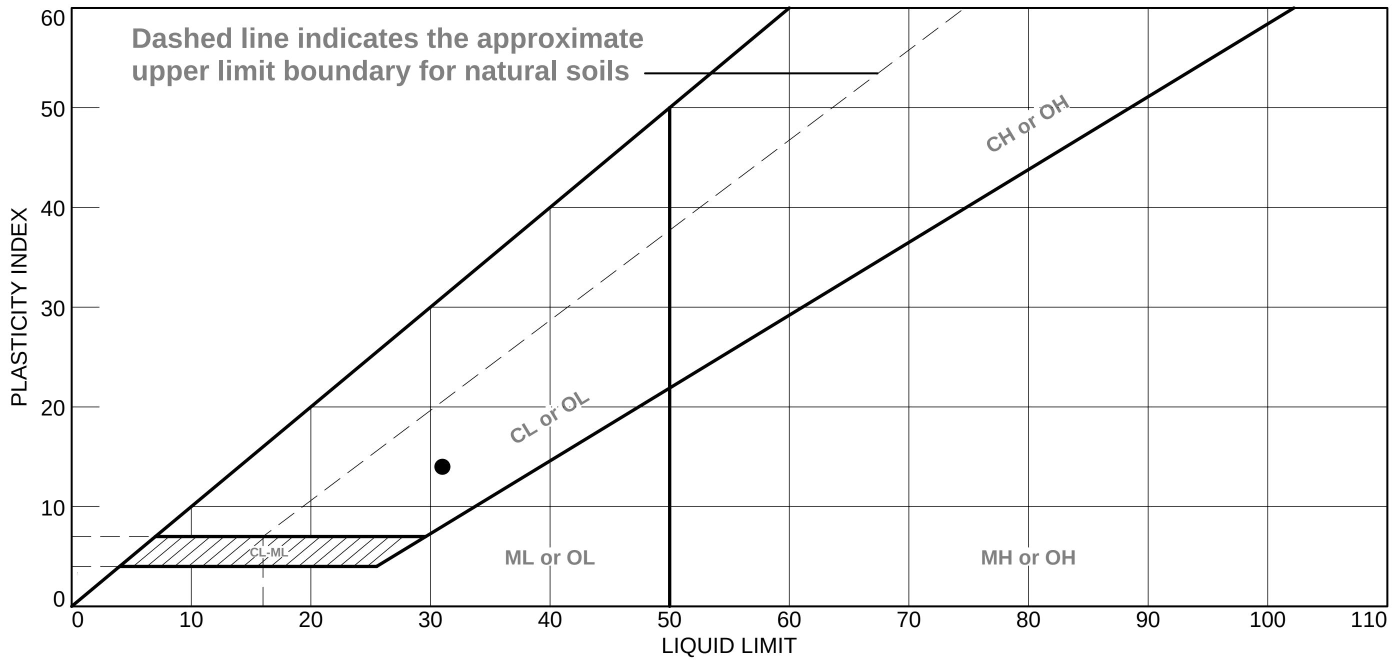
Source of Sample: HEN-B029 **Depth:** 5.0'-7.0'
Sample Number: S-3

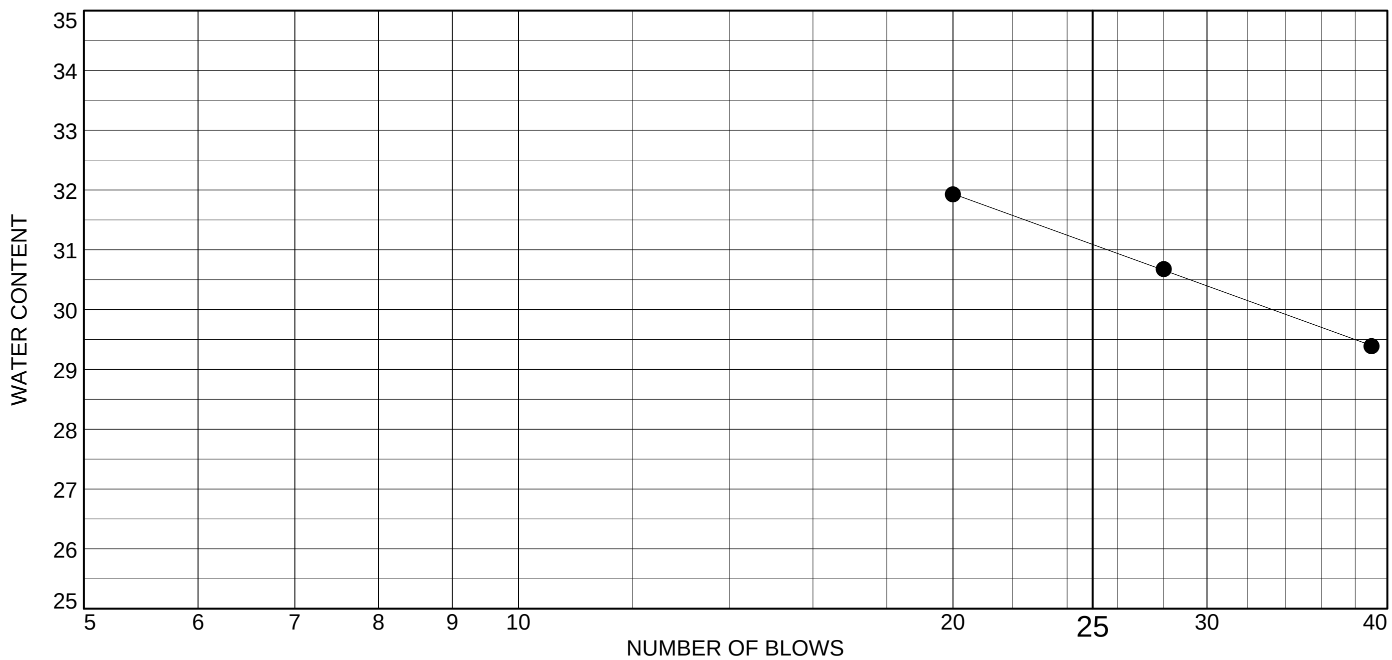
Remarks:

Figure

Tested By: BCM **Checked By:** WPQ

LIQUID AND PLASTIC LIMITS ASTM D4318





	MATERIAL DESCRIPTION	LL	PL	PI	%<#40	%<#200	USCS
●	VERY DARK BROWN AND GRAY SLIGHTLY ORGANIC LEAN CLAY WITH SAND AND GRAVEL	31	17	14			CL

Project No. MR155233 **Client:** AECOM

Project: DYNERGY - HENNEPIN

Source of Sample: HEN-B029 **Depth:** 10.0'-12.0'

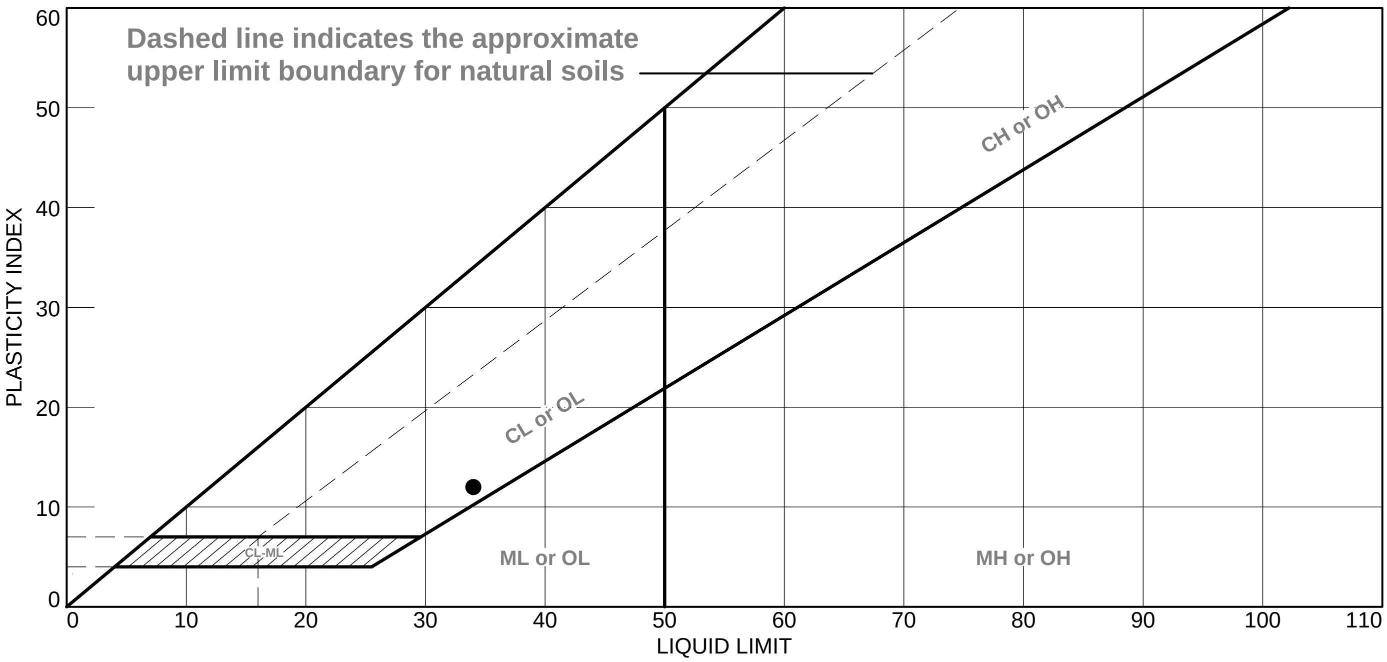
Sample Number: S-5

Remarks:

Figure

Tested By: BCM **Checked By:** WPQ

LIQUID AND PLASTIC LIMITS ASTM D4318



	MATERIAL DESCRIPTION	LL	PL	PI	%<#40	%<#200	USCS
●	DARK BROWN AND BLACK ORGANIC CLAY WITH GRAVEL - WOOD NOTED	34	22	12			OL

Project No. MR155233 **Client:** AECOM

Project: DYNERGY - HENNEPIN

Source of Sample: HEN-B030 **Depth:** 21.5'
Sample Number: S-7

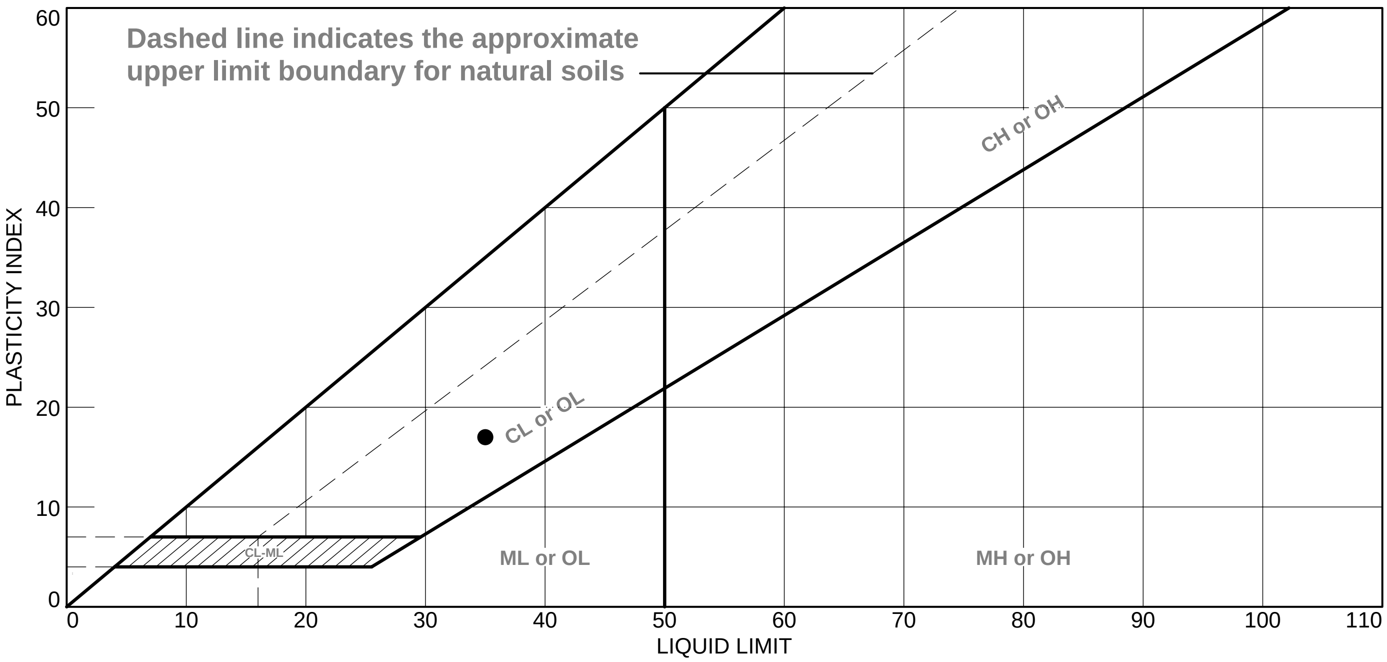
Terracon

Remarks:

Figure

Tested By: SJH **Checked By:** WPQ

LIQUID AND PLASTIC LIMITS ASTM D4318



	MATERIAL DESCRIPTION	LL	PL	PI	%<#40	%<#200	USCS
●	DARK BROWNISH GRAY LEAN CLAY WITH SAND AND GRAVEL	35	18	17			CL

Project No. MR155233 **Client:** AECOM

Project: DYNERGY - HENNEPIN

Source of Sample: HEN-B032 **Depth:** 5.0'-7.0'
Sample Number: S-3

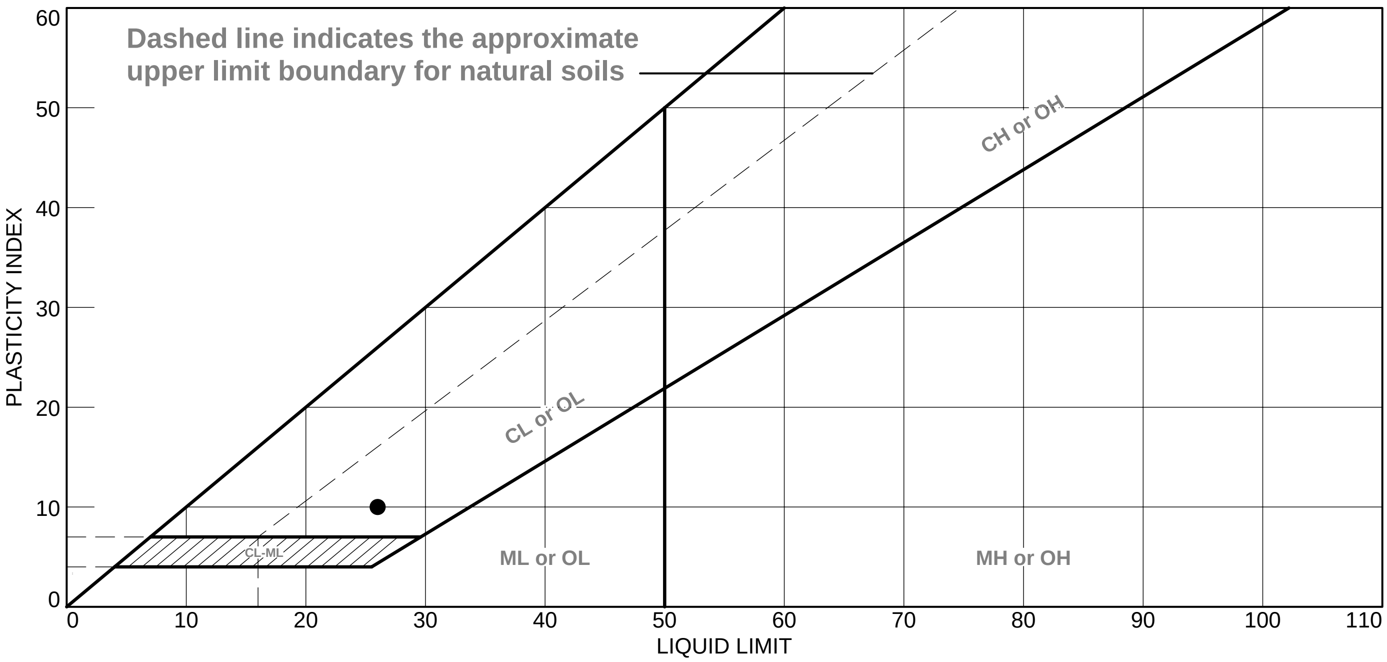
Terracon

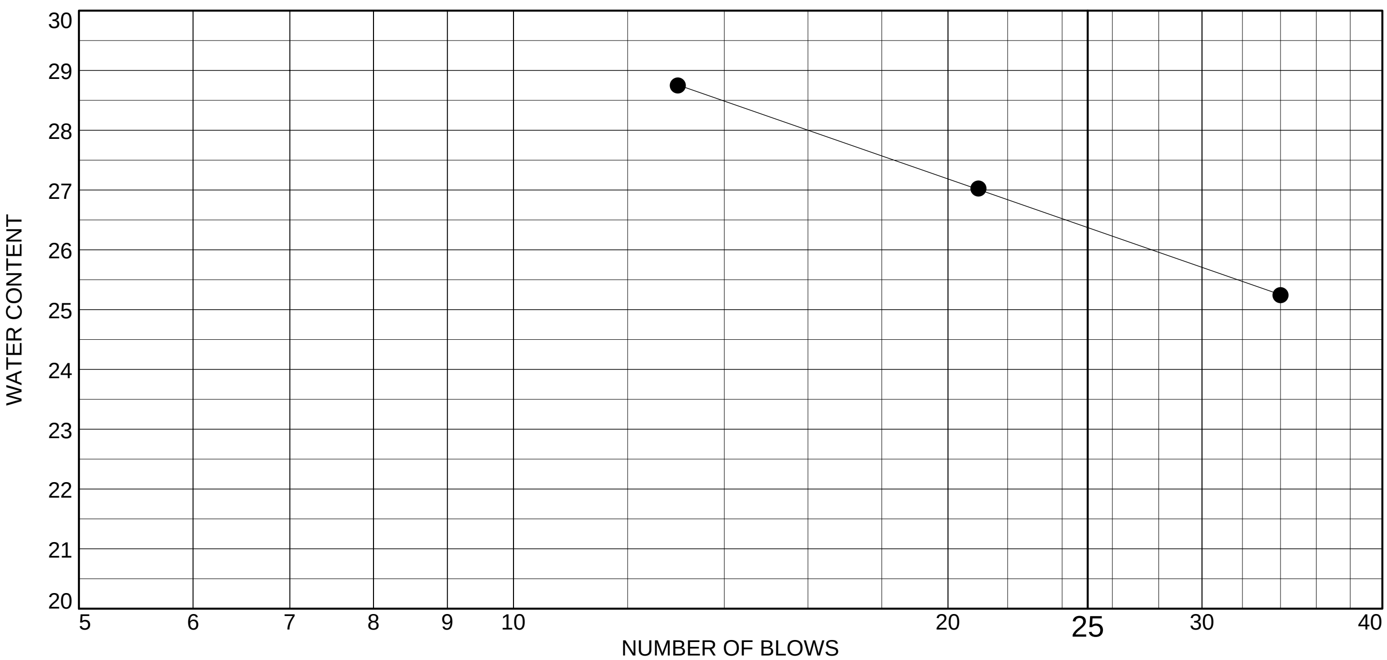
Remarks:

Figure

Tested By: HP **Checked By:** WPQ

LIQUID AND PLASTIC LIMITS ASTM D4318





	MATERIAL DESCRIPTION	LL	PL	PI	%<#40	%<#200	USCS
●	DARK BROWN AND DARK GRAY LEAN CLAY WITH GRAVEL	26	16	10			CL

Project No. MR155233 **Client:** AECOM

Project: DYNERGY - HENNEPIN

Source of Sample: HEN-B032 **Depth:** 10.0'-11.5'
Sample Number: S-5

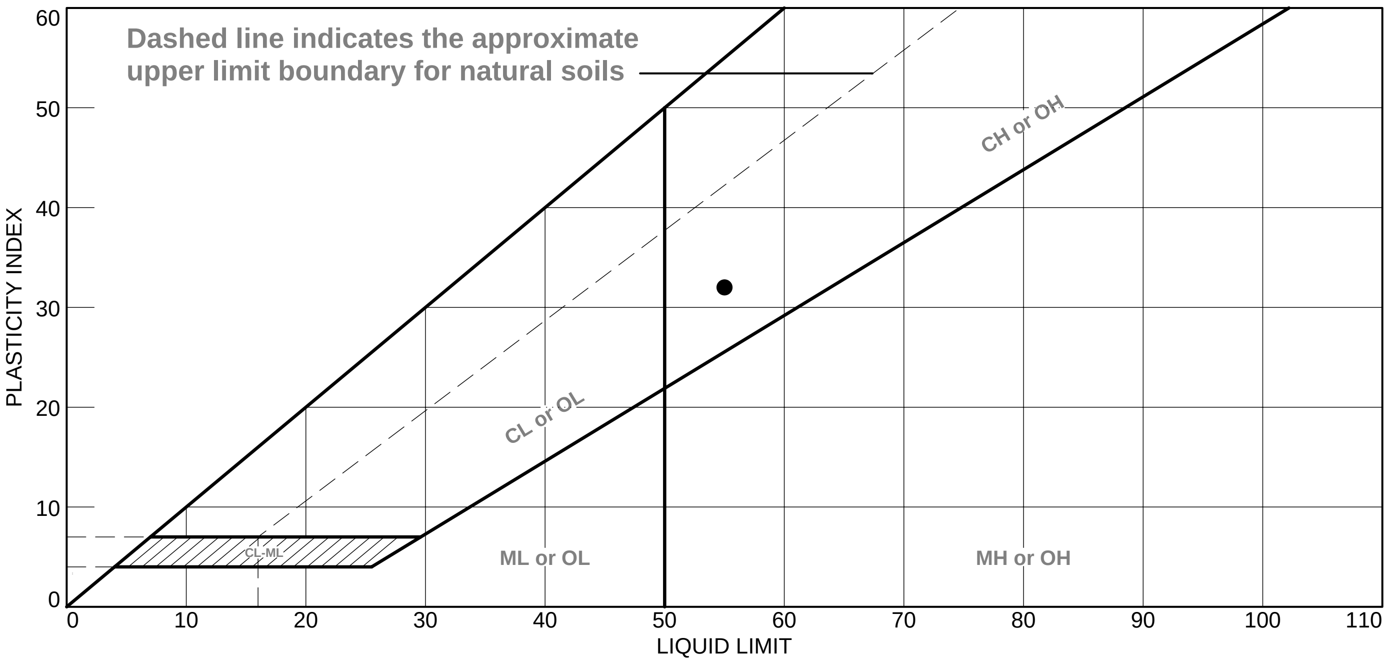
Terracon

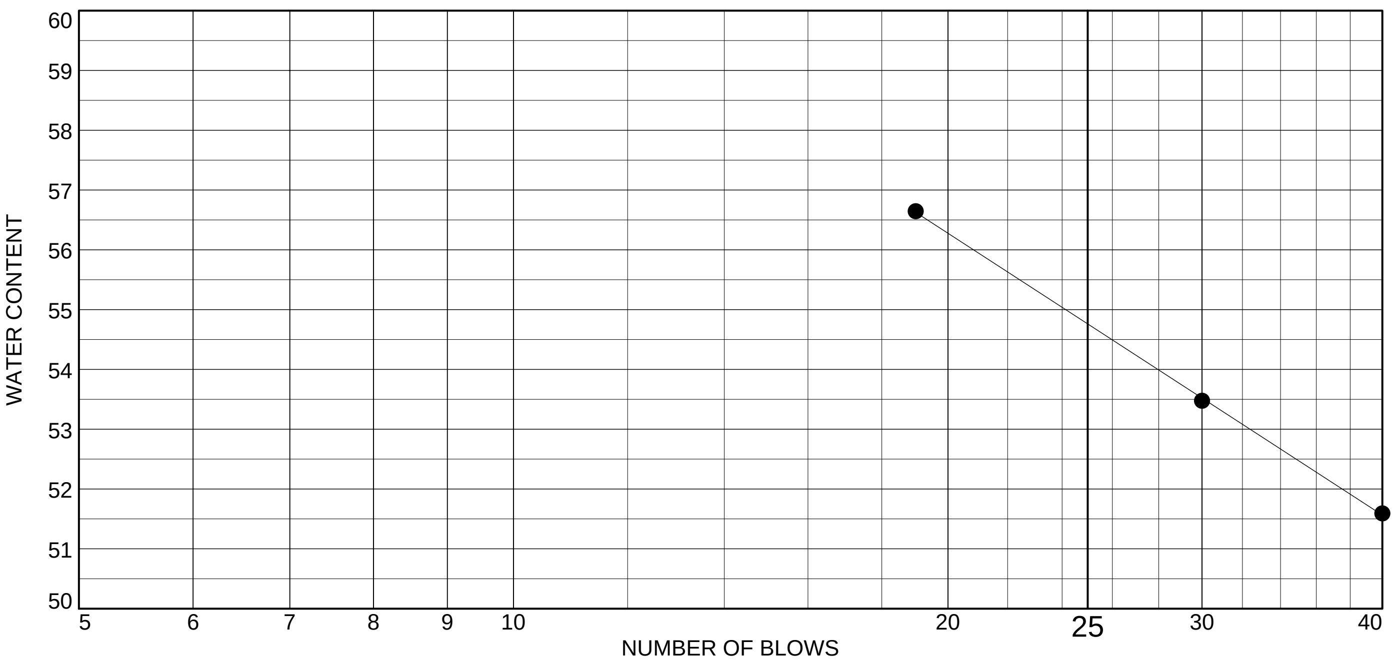
Remarks:

Figure

Tested By: SJH **Checked By:** WPQ

LIQUID AND PLASTIC LIMITS ASTM D4318





	MATERIAL DESCRIPTION	LL	PL	PI	%<#40	%<#200	USCS
●	GREENISH GRAY FAT CLAY	55	23	32			CH

Project No. MR155233 **Client:** AECOM

Project: DYNERGY - HENNEPIN

Source of Sample: HEN-B038 **Depth:** 10.5-11.5'

Sample Number: S-5B

Terracon

Remarks:

Figure

Tested By: HP **Checked By:** WPQ

Specific Gravity of Soils
ASTM D 854

Terracon
Consulting Engineers & Scientists

SPECIFIC GRAVITY OF SOIL SOLIDS
ASTM D-854

Project Number: MR155233
Project Name: Dynergy Hennepin
Test Date: 12/11/2015

Results Summary

Boring / Sample	Sample Description	USCS	Sample Number	Depth (ft)	Passing #4	Specific Gravity (Gs)
HEN-B002	BROWN SAND WITH CLAY	CL	S-2	2.50'-4.0'	100.00%	2.680
HEN-B004	BROWN, TAN AND GRAY GRAVEL WITH SAND	GP	S-2	2.5'-4.0'	100.00%	2.746
HEN-B006	BROWN AND LIGHT BROWN SAND WITH GRAVEL	SP	S-2	2.5'-4.0'	100.00%	2.665
HEN-B009	DARK BROWN SILT WITH SAND	ML	S-4	8.0'-9.0'	100.00%	2.672
HEN-B010	BROWN AND DARK BROWN SILTY SAND	SM	S-4	7.5'-9.0'	100.00%	2.723
HEN-B011	RUST BROWN SANDY LEAN CLAY	CL	S-2	2.5'-4.0'	100.00%	2.693
HEN-B018	BROWN, TAN AND GRAY SILT WITH CLAY AND GRAVEL	ML	S-3	5.0'-6.5'	100.00%	2.700
HEN-B020	BROWN SILT WITH CLAY, SAND AND GRAVEL	ML	S-3	5.0'-6.5'	100.00%	2.672
HEN-B023	FILL: BROWN AND DARK BROWN SILT WITH CLAY SAND AND GRAVEL	ML	S-3	5.0'-6.5'	100.00%	2.701
HEN-B024	BROWN AND GRAY SAND WITH SILT, CLAY AND GRAVEL	SM	S-2	2.5'-4.5'	100.00%	2.756
HEN-B025	BROWN LEAN CLAY WITH SILT AND SAND	CL	S-2	2.5'-4.5'	100.00%	2.708
HEN-B030	FILL: BROWN AND GRAY LEAN CLAY WITH SILT, SAND AND GRAVEL	CL	S-3	5.0'-6.5'	100.00%	2.746
HEN-B034	DARK BROWN LEAN CLAY WITH SILT AND SAND	CL	S-2	2.5'-4.0'	100.00%	2.704
HEN-B034	BROWN AND LIGHT BROWN GRAVEL WITH CLAY AND SAND	GP-GC	S-6	15.0'-16.5'	100.00%	2.808
HEN-B037	BROWN SAND WITH SILT AND GRAVEL	SP-SM	S-2	2.5'-4.0'	100.00%	2.685
HEN-B038	BROWN GRAVEL WITH CLAY AND SILT	GP-GC	S-6	15.0'-16.5'	100.00%	2.763

Corrosion Series of Tests
ASTM G 51
ASTM G 57
DIPRA Methods

Soil Resistivity	**ASTM G 57**
Soil pH	**ASTM G 51**
Soil REDOX	**DIPRA**
Soil Sulfides	**DIPRA**
Water Content	**ASTM D 2216**

Laboratory Services *750 Corporate Woods Parkway* *Vernon Hills, Illinois 60061* *Phone: (224) 352-7000* *Fax: (224) 352-7024*

Soil Corrosivity Indication Series

Project No.: **MR155233**
Project Name: Dynegy Hennepin
Client Name: AECOM
Test Date: **12/15/2015**

Boring / Sample No.	Resistivity Natural Soil Box (ohm-cm)	Resistivity Saturated Soil Box (ohm-cm)	pH Soil Water Slurry	REDOX Soil Water Slurry (mV)	Sulfides Reaction (pos/neg)	As Received WC (%)	Saturated WC (%)	Total Points
HEN-B003 Sample 5 10.0'-12.0'	400,000	3680	9.22	70	NEG	2.1	45.7	
Points	-	0	3	3.5	0	-	-	**6.5**
HEN-B009 Sample 2 2.5'-4.0'	16,000	4,400	8.39	65	NEG	11.0	28.5	
Points	-	0	0	3.5	0	-	-	**3.5**
HEN-B023 Sample 4 7.5'-9.0'	13,600	3,940	8.19	80	NEG	8.0	24.7	
Points	-	0	0	3.5	0	-	-	**3.5**
HEN-B025 Sample 2 2.5'-4.0'	10,600	3,680	8.26	85	NEG	9.3	22.5	
Points	-	0	0	3.5	0	-	-	**3.5**

Resistivity:	Points:	pH:	Points:	Redox:	Points:	Sulfides:	Points:	†
<1500 ohms	10	0.0-2.0	5	Negative	5	Positive	3.5	
1500-1800	8	2.0-4.0	3	0 - 50mV	4	Trace	2	
1800-2100	5	4.0-6.5	0	50 - 100mV	3.5	Negative	0	
2100-2500	2	6.5-7.5	0*	100mV+	0			
2500-3000	1	7.5-8.5	0					
3000+	0	8.5 +	3					

*- If Sulfides are present and a low or neg. ReDox, add 3 points

† - THIS SYSTEM IS BASED ON A 25.5 POINT CORROSIVITY RATING SYSTEM DEVELOPED BY THE AMERICAN NATIONAL STANDARDS FOR POLYETHYLENE ENCASEMENT AND DUCTILE-IRON PIPE SYSTEMS. IT SHOULD BE NOTED THAT THESE TEST RESULTS ARE AN INDICATION OF SOIL CHEMISTRY AND SHOULD BE USED AS A INDICATION OF POSSIBLE CORROSIVE CONDITIONS. TERRACON IS NOT LIABLE FOR ANY REMEDIAL MEASURES TAKEN ON THE BASIS OF THESE RESULTS.

Tested by: WPQ Checked By: BCM

Organic Content Test by Loss on Ignition ASTM D 2974 Method C

ORGANIC CONTENT TEST
ASTM D-2974
Method C

Laboratory Services Group | **750 Corporate Woods Parkway** | **Vernon Hills, Illinois 60061** | **Ph. (224)352-7000** | **fax (224)352-7024**

Project No.: MR155233
Project Name: DYNEGY HENNEPIN
Date Tested: 12/14/15

Sample Information

Boring / Source:	HEN-B019
Sample No.:	S-2
Depth (ft.):	7.5'-8.5'

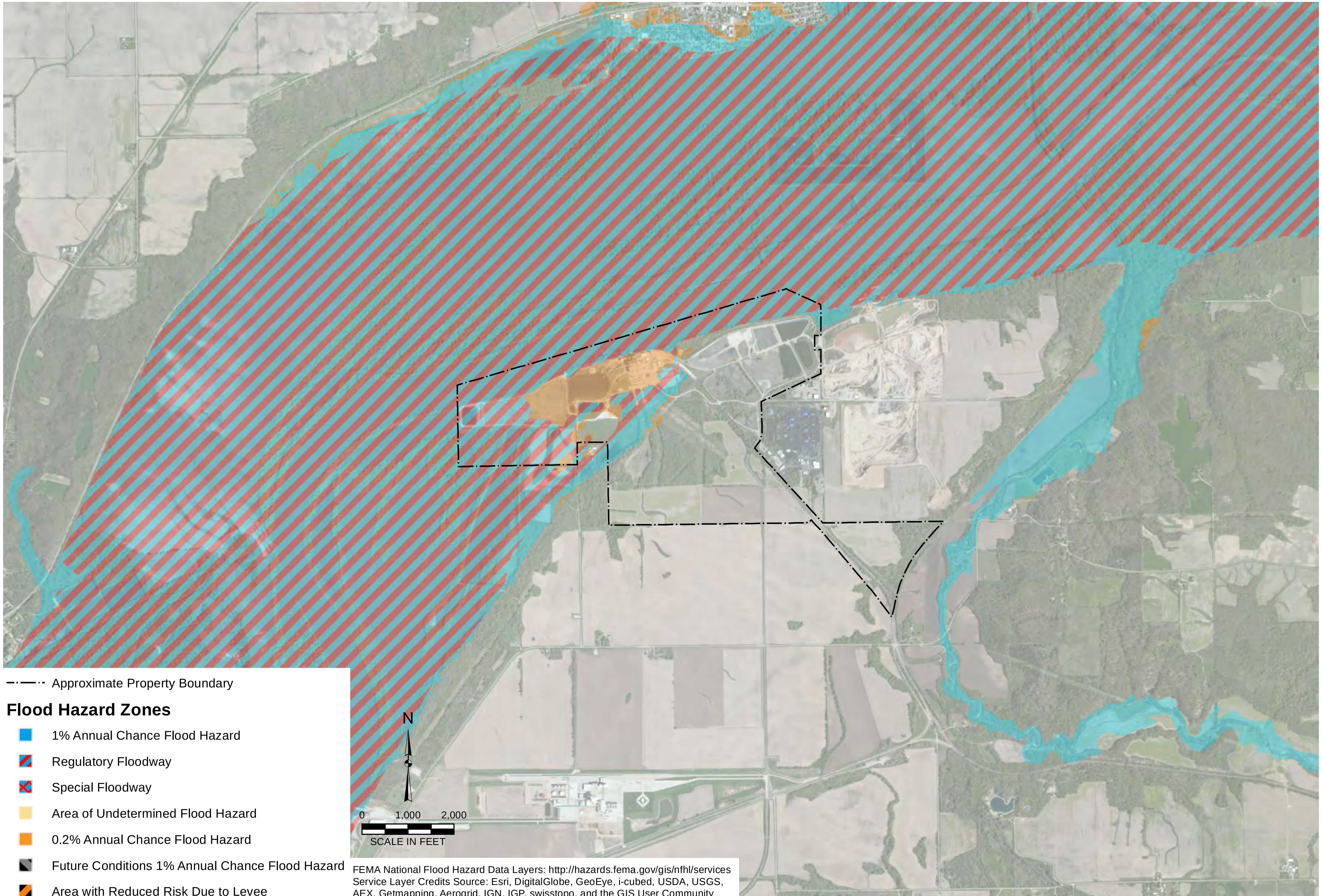
Organic Content Test Data

Tare No.:	F
Tare Wt. (gm): T	19.63
Wet Wt. + Tare (gm): A+T	59.14
Dry Wt. + Tare (gm): B+T	49.34
Moisture Content (%):	**32.99**
Wt. of Ash + Tare (gm): D+T	48.36
Percent Ash: (D-T/B-T)x100 = E	96.70
Organic Content (%):	**3.30**

** Note: Test performed by heating the sample to 440 degrees centigrade for a period of three hours.

Appendix F

FEMA National Flood Hazard Map



FEMA National Flood Hazard Data Layers: http://hazards.fema.gov/gis/nfhl/services
Service Layer Credits Source: Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

DRAWN BY/DATE: TDC 11/11/13
REVIEWED BY/DATE: BRH 11/18/13
APPROVED BY/DATE: SJC 5/14/14

FEMA NATIONAL FLOOD HAZARD MAP

HYDROGEOLOGICAL SUMMARY AND GROUNDWATER QUALITY ASSESSMENT
WEST ASH POND SYSTEM
DYNEGY MIDWEST GENERATION, LLC
HENNEPIN POWER STATION, HENNEPIN, ILLINOIS

PROJECT NO: 2140

APPENDIX: A

NATURAL RESOURCE TECHNOLOGY

Y:\Mapping\Projects\21\2140\MXD\Appendix A_FEMA National Flood Hazard Map.mxd Author: mmejac; Date/Time: 5/14/2014, 10:48:38 AM

Appendix G

Water Wells Survey
NRT/Kelron, June 3, 2009

Water Well Survey

Dynegy Midwest Generation
Hennepin Power Station
Hennepin, Illinois

June 3, 2009

Project No: 1957

TABLE OF CONTENTS

REPORT CERTIFICATION

1 OVERVIEW 1-1

2 WATER WELL DATABASE AND ALTERNATE SEARCH RESULTS 2-1

2.1 Illinois State Geological Survey (ISGS) 2-1
2.2 Illinois State Water Survey (ISWS) 2-2
2.3 Illinois Environmental Protection Agency (Illinois EPA) 2-2
2.4 Illinois Department of Public Health (IDPH) 2-4
2.5 Putnam County Health Department 2-4
2.6 Visual Survey 2-4

3 CONCLUSIONS 3-1

FIGURES

Figure 1 Water Well Location Map (1957-1-B01C)
Figure 2 Aerial Photograph with Water Wells (1957-1-B02C)

TABLES

Table 1 Water Well Records within 2,500 Foot Radius of Property Boundary

APPENDICES

Appendix A: Illinois State Geological Survey Well Locations and Data
Appendix B: Illinois State Water Survey Private Well Database Well Data
Appendix C: Illinois Environmental Protection Agency Web-Based GIS Files
Appendix D: Record of Communications

REPORT CERTIFICATION

Certification of document preparation and supervision for the following:

Water Well Survey for Hennepin Power Station
Hennepin, Illinois

June 3, 2009

Professional Geologist Name:	Stuart J. Cravens
License Number:	196-000108
Expiration Date:	March 31, 2011

Illinois Licensed Professional Geologist

Signature: ______________________________

Date: ______________________________ (June 3, 2009)

Seal:

1 OVERVIEW

This report has been prepared for Dynegy Midwest Generation, Inc. (DMG) by Kelron Environmental and Natural Resource Technology, Inc. (NRT) and is intended to meet well survey procedures in relevant Illinois and federal regulations[1], including the "Right to Know" Potable Water Well Survey procedures of 35 Illinois Administrative Code 1600.210(b)(1) and 1600.210(b)(2). The purpose of this survey is to identify all existing water wells located within 2,500 feet of the property boundary of DMG's Hennepin Power Station (HPS or Facility), located within the Village of Hennepin's northern municipal limits in Putnam County, Illinois. The HPS property boundary (Figure 1) is located in:

- The north half of the southeast quarter and the south half of the northeast quarter of Section 27; and
- The north half of the northwest quarter of the southeast quarter; the north half of the northwest quarter of the southwest quarter; and, the north half of the northeast quarter of the southwest quarter of Section 26.

A non-community wellhead protection area (WHPA) has been designated by the Illinois Environmental Protection Agency (Illinois EPA) and Illinois Department of Public Health (IDPH) south of the East Ash Pond System and property boundary (Figures 1 and 2). A total of 11 water supply wells were identified within the search radius outside of the HPS property boundary using Illinois EPA, Illinois State Geological Survey (ISGS), Illinois State Water Survey (ISWS) information, and a visual survey. Additionally, four water wells owned by DMG are located within the HPS property boundary. Within the search radius, one well (Well #4) is located east of the Facility, one well (Well #3) is located west of the Facility, and nine wells are located south of the Facility (Well numbers 5 through 11, 14, and 15). One well (Well #7) is designated as a non-community water supply well (non-CWS). All these wells are either upgradient or side gradient from the active and out-of-service ash pond systems of the HPS.

[1] Leaking Underground Storage Tank regulations (35 Ill. Adm. Code 732); Leaking Underground Storage Tank regulations (35 Ill. Adm. Code 734); Site Remediation Program (35 Ill. Adm. Code 740.425(b)(2)(D)); RCRA Permit regulations (35 Ill. Adm. Code 703.183(s)(9); 35 Ill. Adm. Code 703.184(a)(3)); and the National Contingency Plan (40 CFR 300.430(d)).

2 WATER WELL DATABASE AND ALTERNATE SEARCH RESULTS

The following databases and sources of information were utilized in order to determine community water source and potable water well locations and construction in the vicinity of the HPS property boundary:

- Illinois State Geological Survey -Water Well Database Query;
- Illinois State Water Survey private well database;
- Illinois EPA web-based Geographic Information System (GIS) files;
- Illinois Department of Public Health;
- Putnam County Health Department; and
- Field observation of wells from visual survey.

2.1 Illinois State Geological Survey (ISGS)

The ISGS website provided an ArcIMS Viewer Map as well as a database query. According to the ISGS ArcIMS Viewer Map, 11 water wells are located within a 2,500-foot radius of the HPS property boundary (Figures 1 and 2). The wells are numbered 1, 2, 4 through 9, 12, and 13 on the map. Each map location number represents one well identification, with the exception of map Well #6, which appears to have two listings for the same well (Table 1). The ISGS database information, including any boring log and well construction information, is provided in Appendix A. Four mapped well numbers occur on the Facility property as follows:

- Well #1, located southwest of the main plant near the front entrance gate; and,
- Wells #2, #12, and #13 located south of the main plant and midway between the East and West Ash Pond Systems.

Well #1 was located incorrectly on the original driller's log and this error has been propagated through the ISGS (and ISWS and IEPA) databases. This well is used for irrigation of the coal pile and is not a potable source.

The depths of the wells in the ISGS database ranged from 64 to 128 feet deep. All wells, where lithology information is provided, obtain water from unconsolidated sand and gravel deposits. The ISGS water well database also contained test borings for DMG's Facility; none of these borings were for potable wells and were not included within the search results presented in this report.

2.2 Illinois State Water Survey (ISWS)

The ISWS database of well records included records for the wells identified in the ISGS database, with the exception of well numbers 4 and 12, for which there were no ISWS records. There were also two ISWS Private Well Database records that did not appear in any other databases: well numbers 3 and 14, both of which are very old wells with only approximate locations and unknown ownership. Wells #3 and #14 are dug wells with recorded construction dates of 1844 and 1922, respectively, and were most likely abandoned decades ago.

A number of well records from the ISWS contained minimal information for mapping; therefore, these wells are not included in this report as sufficient information was provided to determine the wells are not within the 2,500 feet search radius. A copy of the ISWS Private Well database records is included in Appendix B.

2.3 Illinois Environmental Protection Agency (Illinois EPA)

The Illinois EPA Database website provided ArcIMS Viewer Maps (Appendix C). The database provides information on community, non-community, and public water supply wells as defined on the Illinois EPA website:

- Community Water Supply: *a public water supply that serves or is intended to serve at least 15 service connections used by residents or regularly serves at least 25 residents.*
- Non-community Water Supply: *a public water supply that is not a community water supply.*
- Public Water Supply: *all mains, pipes and structures through which water is obtained and distributed to the public, including wells and well structures, intakes and cribs, pumping stations, treatment plants, reservoirs, storage tanks and appurtenances, collectively or severally, actually used or intended for use for the purpose of furnishing water for drinking or general domestic use and which serve at least 15 service connections or which regularly serve at least 25 persons at least 60 days per year. A public water supply is either a community water supply or a non-community water supply.*

Based on the Illinois EPA maps, community water systems (CWS) are not present within a 2,500 feet radius of the HPS property boundary. The nearest CWS wells and system details, included in Appendix C, are:

- Village of Depue (Facility Number 0110300) located approximately 1.5 miles north of the Facility;
- Village of Hennepin (Facility Number 1555100) located approximately 3 miles south of the Facility;
- Village of Bureau Junction (Facility Number 0110150) located approximately 3 miles southwest of the Facility; and
- Village of Granville (Facility Number 1550050) located approximately 3.5 miles southeast of the Facility.

According to Illinois EPA records, the HPS property boundary is located greater than 1-mile from the Minimum Setback Zones, Existing or Potential Maximum Setback Zones, and /or Recharge Areas for the CWS systems.

Based on the Illinois EPA maps, there is one non-community supply (non-CWS) well, 6 industrial / commercial wells, and 2 farm/domestic water wells located within the 2,500 feet radius of the HPS property boundary (Figures 1 and 2). All wells identified on Illinois EPA maps were also identified in ISGS and/or ISWS records. The non-CWS water supply system (Appendix C) is identified as the Exolon ESK System #0117408, which consists of one well (Map Well #7). The WHPA for this system lies within the 2,500-foot search radius (Figures 1 and 2) but south of the Hennepin Power Station's property boundary.

A wellhead protection area (WHPA) is the surface and subsurface area surrounding a water well or well field supplying a CWS or non-CWS water system through which contaminants from a source are theoretically likely to move and reach the water well or well field. All CWS and non-CWS systems utilizing groundwater in Illinois have a 1,000-foot wellhead / source water protection radius, also referred to as a Phase I WHPA.

2.4 Illinois Department of Public Health (IDPH)

The IDPH was contacted for confirmation information on the Exolon non-CWS system. J. Scott Bell with the IDPH confirmed the system is the only non-CWS within the search radius. Mr. Bell also stated the system is now identified as the Washington Mills non-CWS (Appendix D).

2.5 Putnam County Health Department

Personnel from the Bureau-Putnam County Health Department were not able to confirm or provide additional data on the non-CWS well system (Appendix D).

2.6 Visual Survey

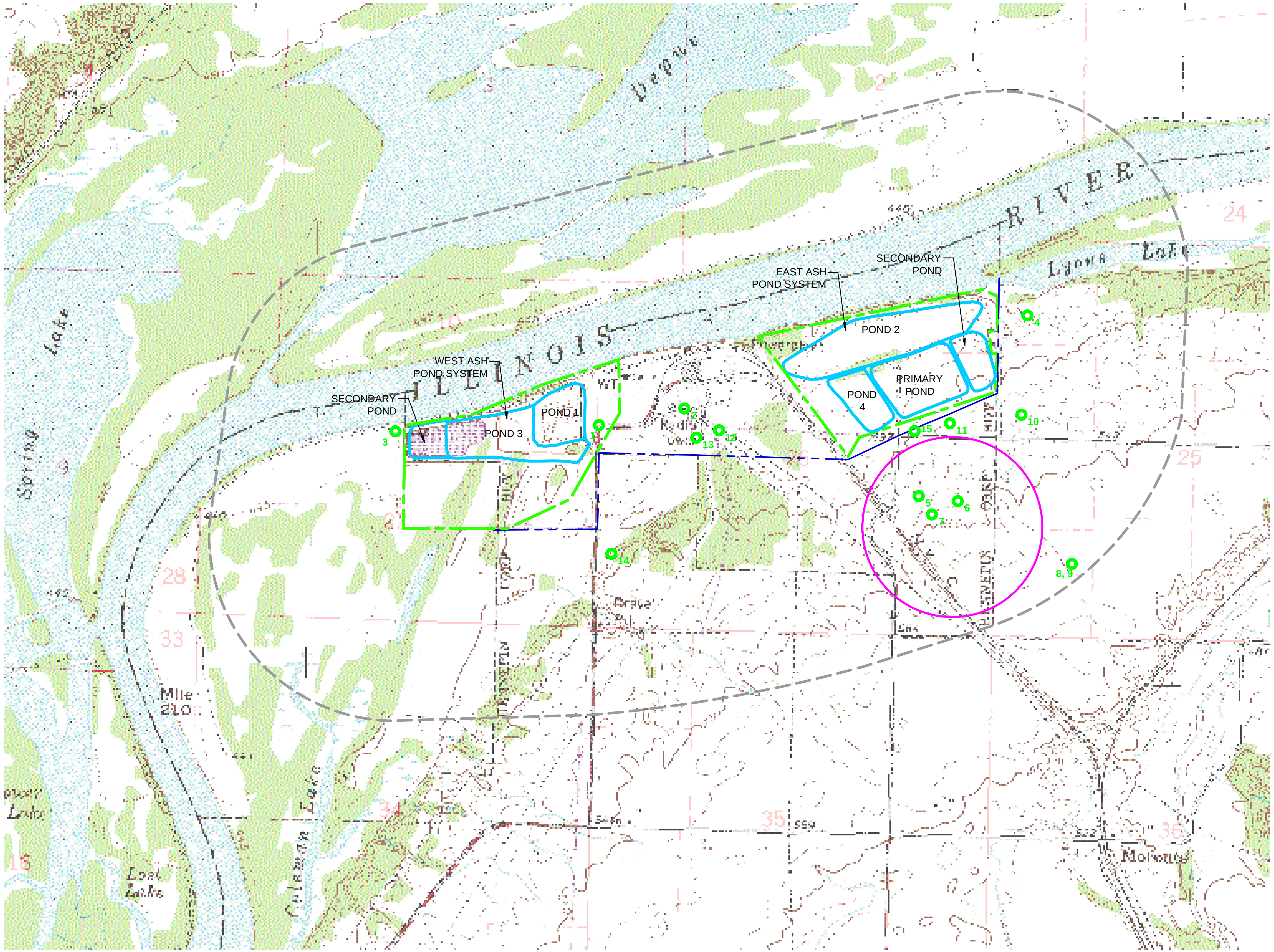
A visual survey, also referred to as a windshield survey, was conducted on April 14, 2009 to verify some well locations listed in the databases and also to locate wells not identified by ISGS, ISWS, Illinois EPA or DMG sources. Three wells were field identified (Table 1; Figures 1 and 2) that did not have corresponding well logs in any of the database sources: Well #10, located on property owned by Tri-Con Materials; and Wells #11 and #15, located on property that appears to be owned by Advanced Asphalt. All three of these wells are industrial-commercial wells with unknown operational status as to whether they are active or inactive.

3 CONCLUSIONS

According to database records of the ISGS, ISWS, and Illinois EPA, there are eight water wells (assumed to be potable) owned by private residences or companies within a 2,500 feet radius of the HPS property boundary and four water wells owned by DMG are located on the HPS property (Table 1). Three additional undocumented industrial-commercial wells were identified at locations south and southeast of the Facility during a visual (windshield) survey. A total of 15 water wells have been identified both on DMG's HPS property and within a 2,500-foot radius of the Facility property boundary.

In addition to the above sources of water well information provided by State agencies, Kelron obtained information from DMG personnel and the IDPH. Personnel with both these entities had no knowledge or information of any additional wells within a 2,500 feet radius of the HPS property boundary beyond those identified within the State databases.

The results of the water well survey are provided in Appendices A through D for each of the sources of information contacted. Based on all of the well information acquired from the listed sources, water supply wells within at least 2,500 feet of the HPS property boundary were placed on a topographic map (Figure 1) and aerial photograph (Figure 2) and shown in relation to the HPS property boundary. The current status of some of these wells (i.e., operational, abandoned, or sealed) is not known.



LEGEND

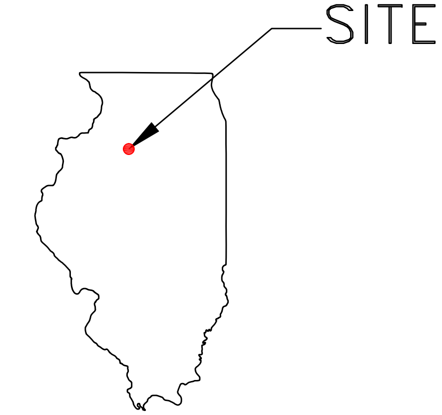
4 (green circle)	WATER WELL LOCATION
light blue line	ASH POND
dark blue dash-dot line	APPROXIMATE PROPERTY BOUNDARY
green dash-dot line	GROUNDWATER MANAGEMENT ZONE
gray dashed line	2,500 FOOT RADIUS FROM PROPERTY BOUNDARY
magenta line	NON–CWS WELLHEAD PROTECTION AREA

SOURCE:
USGS DIGITAL RASTER GRAPHICS FILES FROM ILLINOIS NATURAL RESOURCES GEOSPATIAL DATA CLEARINGHOUSE (http://www.isgs.uiuc.edu)

ILLINOIS ENVIRONMENTAL PROTECTION AGENCY SOURCE WATER ASSESSMENT PROGRAM (SWAP) ArcIMS MAPPING TOOL (http://maps.epa.state.il.us/website/swap/intro.html).

ILLINOIS STATE GEOLOGICAL SURVEY, DIGITAL WATER WELL RECORDS INTERACTIVE MAP (http://www.isgs.illinois.edu/maps-data-pub/wwdb/wwdb.shtml).

2009 KELRON/NRT FIELD OBSERVATIONS.
2009 DYNEGY MIDWEST GENERATION PERSONNEL CORRESPONDENCE.



N

0 750 1500
SCALE IN FEET

DRAWN BY: RLH DATE: 06/01/09
CHECKED BY: RJC DATE: 06/01/09
APPROVED BY: RJC DATE: 06/01/09
DRAWING NO: 1957–1–B01C
REFERENCE: o41089c3.tiff

WATER WELL LOCATION MAP

WATER WELL SURVEY
HENNEPIN POWER STATION
HENNEPIN, ILLINOIS

NATURAL RESOURCE TECHNOLOGY

PROJECT NO.
1957/1.0

FIGURE NO.
1

KELRON environmental

LEGEND

12	WATER WELL LOCATION
	ASH POND
	APPROXIMATE PROPERTY BOUNDARY
	GROUNDWATER MANAGEMENT ZONE
	2500 FT. RADIUS, FROM PROPERTY BOUNDARY
	NON-CWS WELLHEAD PROTECTION AREA

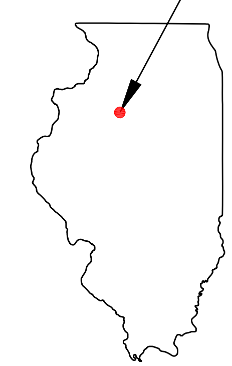
SOURCE NOTES:
2005 DIGITAL ORTHOPHOTO FROM ILLINOIS NATURAL RESOURCES GEOSPATIAL DATA CLEARINGHOUSE (http://www.isgs.uiuc.edu).

ILLINOIS ENVIRONMENTAL PROTECTION AGENCY SOURCE WATER ASSESSMENT PROGRAM (SWAP) ArcIMS MAPPING TOOL (http://maps.epa.state.il.us/website/swap/intro.html).

ILLINOIS STATE GEOLOGICAL SURVEY, DIGITAL WATER WELL RECORDS INTERACTIVE MAP (http://www.isgs.illinois.edu/maps-data-pub/wwdb/wwdb.shtml).

2009 KELRON/NRT FIELD OBSERVATIONS.
2009 DYNEGY MIDWEST GENERATION PERSONNEL CORRESPONDENCE.

SITE



N

0 750 1500
SCALE IN FEET

DRAWN BY: RLH DATE: 06/01/09
CHECKED BY: RJC DATE: 06/01/09
APPROVED BY: RJC DATE: 06/01/09
DRAWING NO: 1957-1-B02C
REFERENCE: 41089c31.sid, 41089c32.sid, 41089c33.sid, 41089c34.sid

AERIAL PHOTOGRAPH WITH WATER WELLS

WATER WELL SURVEY
HENNEPIN POWER STATION
HENNEPIN, ILLINOIS

NATURAL RESOURCE TECHNOLOGY

PROJECT NO. 1957/1.0

FIGURE NO. 2

KELRON environmental

Table 1. Water Well Records Within 2,500-Foot Radius of Property Boundary
Hennepin Power Station; Hennepin, Illinois

Map	Source of Well Information				Location Name	Well		Location				Year	Aquifer		Well
Well #	ISGS	ISWS	IEPA	Other	at Time of Well Completion	Depth	County	Township	Range	Section	Subsection	Drilled	Type	Formation	Use
1*	121552070200	155-12-04	20702	DMG	Hennepin Power Station (DMG)	83	Putnam	33N	02W	27	SE/SE/NE	2004	Unconsolidated	Sand and Gravel	IC
2	121550012800	P403409	00128	DMG	Illinois Power Co., No. 5	113	Putnam	33N	02W	26	NE/NE/NW	1968	Unconsolidated	Sand and Gravel	IC
3	- -	125917	- -	- -	- -	30	Putnam	33N	02W	27	NE/NW/SW	1844	- -	- -	FD
4	121552045800	- -	20458	- -	Advanced Asphalt Co.	114	Putnam	33N	02W	25	SW/NW/NW	1995	Unconsolidated	Sand and Gravel	IC
5	121552029200	79101 P403400	20292	- -	Exolon, Well No. 1	109	Putnam	33N	02W	26	SW/NE/SE	1978	Unconsolidated	Sand and Gravel	IC
6	121552049700 121552047700	155-011-96 P405443	20497 20477	- -	Exolon, Well No. 3	124	Putnam	33N	02W	26	SE/NE/SE	1996	Unconsolidated	Sand and Gravel	IC
7	121552025800	76743	20258	SWA	Exolon, Well No. 2 (ID 15500143)	128	Putnam	33N	02W	26	SW/NE/SE	1978	Unconsolidated	Sand and Gravel	NCWS
8	121552051800	314693	20518	- -	Kenneth Brown	72	Putnam	33N	02W	25	NE/SW/SW	1999	Unconsolidated	Sand and Gravel	FD
9	121552068500	359951	20685	- -	Kenneth Brown	64	Putnam	33N	02W	25	NE/SW/SW	2002	Unconsolidated	Sand and Gravel	FD
10	- -	- -	- -	Visual	Tri-Con Materials	--	Putnam	33N	02W	25	SW/SW/NW	- -	- -	- -	IC
11	- -	- -	- -	Visual	Potentially Advanced Asphalt	--	Putnam	33N	02W	26	SE/SW/NE	- -	- -	- -	IC
12	121552043500	- -	20435	DMG	Illinos Power Co., No. 1A/6	125	Putnam	33N	02W	26	NE/NE/NW	1993	Unconsolidated	Sand and Gravel	IC
13	121552059800	176545 P403406	20598	DMG	Illinois Power Co., No. 4	114	Putnam	33N	02W	26	NE/NE/NW	1969	Unconsolidated	Sand and Gravel	IC
14	- -	125916	- -	- -	- -	17	Putnam	33N	02W	26	NW/SW/SW	1922	Unconsolidated	Sand and Gravel	FD
15	- -	- -	- -	Visual	Potentially Advanced Asphalt	--	Putnam	33N	02W	26	SW/SE/NE	- -	- -	- -	IC

Sources of Information

DMG Dyngey Midwest Generation
IEPA Illinois Environmental Protection Agency
ISGS Illinois State Geological Survey
ISWS Illinois State Water Survey
SWA IEPA Source Water Assessment

Well Use

FD Farm and/or Domestic Water Well
IC Industrial/Commercial Water Well
CWS Community Water Supply
NCWS Non-Community Water Supply

Notes

- - Not applicable or no information available.
* Used for irrigation of coal pile only.

APPENDIX A

ILLINOIS STATE GEOLOGICAL SURVEY WELL LOCATIONS AND DATA

ILLINOIS STATE GEOLOGICAL SURVEY

MAP # 1
ISWS # 155-12-04
P 411819

Irrigation Well	Top	Bottom
gravel	0	4
gravel & boulders	4	18
12-25 slot sand	18	26
gravel & boulders	26	33
1/8" - 1" gravel, no fines	33	80
20-60 slot sand	80	83
shale at	83	83
Total Depth		83

Casing: 12" STEEL from 0' to 62'
12" STAINLESS STL SCREEN from 62' to 82'

Screen: 20' of 12" diameter 80 slot
Grout: BENTONITE from 0 to 20.
Grout: #2 MUSCATINE from 20 to 82.
Water from sand at 33' to 82'.
Static level 13' below casing top which is 2' above GL
Pumping level 20' when pumping at 50 gpm for 1 hour

Permanent pump installed at 60'

Address of well: same as above

Location source: Location from permit

Permit Date: August 9, 2004 **Permit #:**

COMPANY Harold Dean Albrecht
FARM Dynegy Midwest-Hennepin Power
DATE DRILLED August 11, 2004 **NO.**
ELEVATION 0 **COUNTY NO.** 20702
LOCATION NE NW SW
LATITUDE 41.296294 **LONGITUDE** -89.335163
COUNTY Putnam **API 121552070200** **27 - 33N - 2W**

ILLINOIS STATE GEOLOGICAL SURVEY

Water Well	Top	Bottom
Total Depth		113
Driller's Log filed		

MAP #2
ISWS # P403409

Permit Date: **Permit #:**

COMPANY Layne Western Co., Inc.
FARM Illinois Power
DATE DRILLED September 1, 1968 **NO.** 5
ELEVATION 0 **COUNTY NO.** 00128
LOCATION NE NE NW
LATITUDE 41.304882 **LONGITUDE** -89.31122
COUNTY Putnam **API** 121550012800 26 - 33N - 2W

ILLINOIS STATE GEOLOGICAL SURVEY

Semi-Private Water Well	Top	Bottom
yellow rocky sand & gravel	0	75
very fine Sankoty sand	75	114
blue shale at	114	114
Total Depth		114

MAP #4

Casing: 6" BLACK STEEL from 3' to 109'
Screen: 4' of 6" diameter 10 slot
Grout: BENTONITE from 0 to 90.
Size hole below casing: 6"

Water from Sankoty at 109' to 113'.
Static level 75' below casing top which is 1' above GL
Pumping level 105' when pumping at 10 gpm for 2 hours

Permanent pump installed at 112' on June 29, 1995, with a capacity of 10 gpm

Address of well: R.R. #1
Hennepin, IL

Location source: Location from permit

Permit Date: May 31, 1995 **Permit #:**

COMPANY Lutes, George W.
FARM Advanced Asphalt Co.
DATE DRILLED June 12, 1995 **NO.**
ELEVATION 0 **COUNTY NO.** 20458
LOCATION SW NW NW
LATITUDE 41.30505 **LONGITUDE** -89.299075
COUNTY **Putnam** **API 121552045800** **25 - 33N - 2W**

ILLINOIS STATE GEOLOGICAL SURVEY

Water Well	Top	Bottom
Total Depth		109
Driller's Log filed		
Sample set # 61998 (0' - 105') Received: June 15, 1979		

MAP # 5

ISWS # 79101
P403400

Permit Date: **Permit #:**

COMPANY Layne Western Co., Inc.
FARM Esk Corporation
DATE DRILLED September 1, 1978 **NO.** 1
ELEVATION 0 **COUNTY NO.** 20292
LOCATION 1830'S line, 1070'E line of SE
LATITUDE 41.298332 **LONGITUDE** -89.304115
COUNTY Putnam **API** 121552029200 26 - 33N - 2W

ILLINOIS STATE GEOLOGICAL SURVEY

Noncommunity - Public Water Well	Top	Bottom
SS #68792 (0-120')	0	0
fine brown sand	0	4
gray clay	4	5
coarse sand & gravel with boulders	5	79
brown clay with gravel	79	81
fine sand with gravel	81	117
gray shale	117	124
Total Depth		124

Casing: 12" STEEL .375" from 0' to 102'
Screen: 15' of 12" diameter .13 slot
Grout: CEMENT from 0 to 20.
Size hole below casing: 38"

Water from sand & gravel at 102' to 117'.

Sample set # 68792 (0' - 120') Received: March 6, 2000

Location source: Location from permit

MAP #6
ISWS # 155-011-96
P 403400

Permit Date: September 5, 1996 **Permit #:** 155-011

COMPANY Buffington, G.
FARM Exolon - ESK Company
DATE DRILLED October 1, 1997 **NO.** 3
ELEVATION 0 **COUNTY NO.** 20497
LOCATION 1775'N 550'W SE/c
LATITUDE 41.298186 **LONGITUDE** -89.302211
COUNTY **Putnam** **API 121552049700** **26 - 33N - 2W**

ILLINOIS STATE GEOLOGICAL SURVEY

Private Water Well	Top	Bottom
fine brown sand	0	4
gray clay	4	5
coarse sand & gravel	5	79
brown clay with gravel	79	81
fine sand with gravel	81	117
gray shale	117	124
Total Depth		124

MAP #6

Casing: 12" STEEL .375" from 0' to 102'
Screen: 15' of 12" diameter .13 slot
Grout: CEMENT from 0 to 20.
Size hole below casing: 38"

Water from sand & gravel at 102' to 117'.
Permanent pump installed at 80' on , with a capacity of 300 gpm

Location source: Location from permit

Permit Date: September 5, 1996 **Permit #:**

COMPANY Buffington, G.
FARM Exolon - ESK Company #3
DATE DRILLED October 1, 1996 **NO.**
ELEVATION 0 **COUNTY NO.** 20477
LOCATION 1775'N 550'W SE/c SE
LATITUDE 41.298186 **LONGITUDE** -89.302211
COUNTY **Putnam** **API 121552047700** **26 - 33N - 2W**

ILLINOIS STATE GEOLOGICAL SURVEY

Water Well	Top	Bottom
Total Depth		128
Driller's Log filed		
Sample set # 61999 (0' - 130') Received: June 15, 1979		

MAP # 7

Permit Date: **Permit #:**

COMPANY Layne Western Co., Inc.
FARM Esk Corporation
DATE DRILLED July 1, 1978 **NO.** 2
ELEVATION 0 **COUNTY NO.** 20258
LOCATION 1590'S line, 890'E line of SE
LATITUDE 41.297672 **LONGITUDE** -89.303448
COUNTY **Putnam** **API 121552025800** **26 - 33N - 2W**

ILLINOIS STATE GEOLOGICAL SURVEY

MAP # 8

Private Water Well	Top	Bottom
dirty sand	0	8
gravel	8	18
clay	18	36
yellow gravel (a lot of water loss)	36	50
gray gravel (a lot of water loss)	50	72
shale at	72	72
Total Depth		72

Casing: 4" PVC SCH 40 from -1' to 51'
Screen: 4' of 4" diameter 15 slot
Grout: BENT GROUT MIX from 0 to 46.
Water from sand & gravel at 0' to 0'.
Static level 18' below casing top which is 1' above GL
Pumping level 0' when pumping at 50 gpm for 3 hours

Address of well: R.R. #1
Hennepin, IL

Location source: Location from permit

Permit Date: August 3, 1999 **Permit #:**

COMPANY Jet Hall
FARM Brown, Kenneth
DATE DRILLED August 25, 1999 **NO.**
ELEVATION 0 **COUNTY NO.** 20518
LOCATION NE SW SW
LATITUDE 41.296001 **LONGITUDE** -89.296594
COUNTY **Putnam** **API 121552051800** **25 - 33N - 2W**

ILLINOIS STATE GEOLOGICAL SURVEY

MAP # 9

Private Water Well	Top	Bottom
sandy brown clay	0	12
gravel	12	20
pinkish gray clay	20	28
yellow gravel (lots of water loss)	28	50
fine sand	50	64
Total Depth		64

Casing: 6" PVC from 0' to 42'
6" SS SCREEN 18/20 SLOT from 42' to 50'
Screen: 8' of 6" diameter slot
Grout: BENT CLAY SLRY from 0 to 40.
Grout: MUSCATINE #1 from 40 to 50.
Water from sand & gravel at 28' to 64'.
Static level 5' below casing top which is 1' above GL
Pumping level 7' when pumping at 12 gpm for 2 hours

Address of well: same as above

Location source: Location from permit

Permit Date: October 4, 2002 **Permit #:**

COMPANY Jet Hall/Lutes H2o Well Drlg.
FARM Brown, Kenneth
DATE DRILLED November 15, 2002 **NO.**
ELEVATION 0 **COUNTY NO.** 20685
LOCATION NE SW SW
LATITUDE 41.296001 **LONGITUDE** -89.296594
COUNTY **Putnam** **API 121552068500** **25 - 33N - 2W**

ILLINOIS STATE GEOLOGICAL SURVEY

MAP #12

Noncommunity - Public Water Well	Top	Bottom
SS #68242 (0'-120')	0	0
black topsoil	0	2
brown clay, a little clayey	2	7
yellow-brown coarse gravel & boulders	7	27
brown coarse sand to coarse gravel	27	41
gray & brown soft silty clay	41	43
brn med sand to coarse gravel & boulders	43	50
reddish brown coarse gravel & boulders	50	67
multi-colored boulders	67	73
conglomerate clay & boulders /trace lime	73	82
light gray silty clay	82	84
hard tight coarse gravel	84	86
brn med sand to coarse gravel & boulders	86	96
boulder	96	98
fn brn snd; coarse gravel w/finer layers	98	112
brown fine sand to medium gravel	112	118
firm gray shale	118	125
Total Depth		120

Casing: 36" STEEL from 12' to 62'
18" STEEL 70.59#/FT. from -2' to 90'
Screen: 25' of 18" diameter .1 slot
Grout: CONCRETE from 0 to 20.
Water from sand & gravel at 90' to 115'.
Static level 17' below casing top which is 3' above GL
Pumping level 31' when pumping at 1086 gpm for 8 hours
Permanent pump installed at 50' on October 31, 1993, with a

Permit Date: August 31, 1993 **Permit #:**

COMPANY Buffington, G.
FARM Illinois Power Co.
DATE DRILLED September 30, 1993 **NO.** 1A/5 (6?)
ELEVATION 0 **COUNTY NO.** 20435
LOCATION NE NE NW
LATITUDE 41.304882 **LONGITUDE** -89.31122
COUNTY **Putnam** **API 121552043500** **26 - 33N - 2W**

MAP #12
PAGE 2

capacity of 500 gpm

Sample set # 68242 (10' - 120') Received: July 14, 1994

Location source: Location from permit

ILLINOIS STATE GEOLOGICAL SURVEY

Water Well	Top	Bottom
Total Depth		114
Sample set # 56227 (65' - 114') Received: May 16, 1969		

MAP #13

ISWS# 176545

P403406

Permit Date: **Permit #:**

COMPANY Layne-Western Drlg

FARM Il. Power Co.

DATE DRILLED **NO.** 4

ELEVATION 0GL **COUNTY NO.** 20598

LOCATION NE NE NW

LATITUDE 41.304882 **LONGITUDE** -89.31122

COUNTY **Putnam** **API 121552059800** **26 - 33N - 2W**

APPENDIX B

ILLINOIS STATE WATER SURVEY PRIVATE WELL DATABASE WELL DATA

Illinois Department of Public Health
WATER WELL CONS' ICTION REPORT

Date 8-31-04

TYPE OR PRESS FIRMLY WITH BLACK INK PEN. COMPLETE WITHIN 30 DAYS OF WELL COMPLETION AND SEND TO THE APPROPRIATE HEALTH DEPARTMENT.

RECEIVED 10/1/04

(Dynegy Midwest Gen - Hennepin Power

GEOLOGICAL AND WATER SURVEY WELL RECORD

13. Property Owner Dynegy Midwest Well # 4521
14. Driller Harold D. Albrecht License # 102-002466
15. Name of Drilling Co. Albrecht Well Drilling, Inc.
16. Permit No. 155-12-04 Date Issued 8-9-04
17. Date Drilling Started August 10, 2004
18. Well SITE address R.R.#1 Hennepin, IL
19. Township Name Hennepin Land ID #01-27-100-OCC
20. Subdivision Name n/a Lot # n/a
21. Location a. County Putnam
b. Township 33N Range 2W Section 27 7d
c. NE Quarter NW Quarter SW Quarter
d. Coordinates ______ Site Elevation ______ ft. (msl)

For Survey Use

1. Type of Well a. Driven Well Casing diam. ______ in. Depth ______ ft.
b. Bored Well Buried Slab [ ] Yes [ ] No
Hole Diameter ____ in. to ______ ft.; ____ in. to ______ ft.; ____ in. to ______ ft.
c. Drilled Well PVC casing Formation packer set at depth of ______ ft.
Hole Diameter ____ in. to ______ ft. ____ in. to ______ ft. ____ in. to ______ ft.

Type of Grout	# of Bags	Grout Weight	From (ft.)	To (ft.)	Tremie Depth (ft.)

d. Drilled Well Steel Casing- - - Mechanically Driven [ ] Yes [ ] No
Hole Diameter 19 in. to 82 ft. ____ in. to ______ ft. ____ in. to ______ ft.

Type of Grout	# of Bags	Grout Weight	From (ft.)	To (ft.)	Tremie Depth (ft.)
bentonite			0	20	20

e. Well finished within [X] Unconsolidated Materials [ ] Bedrock

f. Kind of Gravel Sand Pack	Grain Size/Supplier #	From (ft.)	To (ft.)
#2 Muscatine		20	82

2 Well Use [ ] Domestic [x] Irrigation [ ] Commercial [ ] Livestock
[ ] Monitoring [ ] Other
3 Date Well Completed 8-11-04 Well Disinfected [x] Yes [ ] No
Driller's estimated well yield 50 gpm w/air
4 Date Permanent Pump Installed 8-16-04
5 Pump Capacity ______ gpm Set at (depth) 60 ft.
6 Pitless Adapter Model and Manufacturer ______
7 Well Cap Type and Manufacturer Weld-on Top Plate
8 Pressure Tank Working Cycle ______ gals. Captive Air [ ] Yes [ ] No
9 Pump System Disinfected [x] Yes [ ] No
10 Name of Pump Company Albrecht Well Drilling, Inc,
11 Pump Installer Harold D. Albrecht License # 102-002466
12 Harold D Albrecht License # 102-002466
Licensed Pump Contractor Signature

PICS 155342260,#7 P# 411819

Illinois Department of Public Health
Division of Environmental Health
525 W. Jefferson St.
Springfield, IL 62761

DO NOT write on these lines

X11819

22. Casings, Liners* and Screen Information

Diam. (in.)	Material	Joint	Slot Size	From (ft.)	To (ft.)
12	steel			0	62
12"	SS		80	62	82

(*) ______
(List reason for liner, type of upper and lower seals installed)

23. Water from sand at a depth of 33 ft. to 82 ft.
a. Static water level 13 ft. below casing which is 18 in. above ground
b. Pumping level is 20 ft. pumping 50 gpm after pumping for 1/2 hours
w/air

24. Earth Materials Passed Through	From (ft.)	To (ft.)
gravel	0	4
gravel & boulders	4	18
12-25 slot sand	18	26
gravel & boulders	26	33
1/8" - 1" gravel [no fines]	33	80
20-60 slot sand	80	83
shale	83	

(If dry hole, fill out log and indicate how hole was sealed.)

Harold D Albrecht
25. Licensed Water Well Contractor Signature

102-002466
License Number

MAP #1

IMPORTANT NOTICE: This state agency is requesting disclosure of information that is necessary to accomplish the statutory purpose as outlined under Public Act 85-0863. DISCLOSURE OF THIS INFORMATION IS MANDATORY. This form has been approved by the Forms Management Center.

ISGS # 121552070200

SEE REVERSE SIDE FOR ADDITIONAL INFORMATION)

ILLINOIS DEPARTMENT OF PUBLIC HEALTH
WELL CONSTRUCTION REPORT

1. Type of Well
   a. Dug ____. Bored ____. Hole Diam. ____ in. Depth ____ ft.
      Curb material ____. Buried Slab: Yes ____ No ____
   b. Driven ____. Drive Pipe Diam. ____ in. Depth ____ ft.
   c. Drilled ✓. Finished in Drift ✓. In Rock ____.
      Tubular ____. Gravel Packed ✓.
   d. Grout:

(KIND)	FROM (Ft.)	TO (Ft.)
None		

2. Distance to Nearest:
   Building ____ Ft. Seepage Tile Field ____
   Cess Pool ____ Sewer (non Cast iron) ____
   Privy ____ Sewer (Cast iron) ____
   Septic Tank ____ Barnyard ____
   Leaching Pit ____ Manure Pile ____
3. Is water from this well to be used for human consumption?
   Yes ____ No ✓
4. Date well completed Aug 27, 68
5. Permanent Pump Installed? Yes ✓ No ____
   Manufacturer Layne Type Line shaft
   Capacity 1000 gpm. Depth of setting 60 ft.
6. Well Top Sealed? Yes ✓ No ____
7. Pitless Adaptor Installed? Yes ____ No ✓
8. Well Disinfected? Yes ✓ No ____
9. Water Sample Submitted? Yes ____ No ✓

REMARKS:

P 408409

GEOLOGICAL WATER SURVEYS WATER WELL RECORD

10. Dept. Mines and Minerals permit No. N-4409 Year 1968
11. Property owner Ill. Power Co. Well No. 5
    Address Hennepin, Ill
    Driller Layne-Western Co. License No. 92-14
12. Water from Drift (Formation) at depth 0 to 112 ft.
13. County Putnam
    Sec. 26.5A
    Twp. 33N
    Rng. 2W
    Elev.
14. Screen: Diam. 18 in.
    Length: 30 ft. Slot 0.080"
15. Casing and Liner Pipe

Diam. (in.)	Kind and Weight	From (Ft.)	To (Ft.)
30"	3/8" steel	0	63'-6"
18"	3/8" steel	0	63'-6"
18"	3/8" steel	73'-6"	73'-6"

SHOW LOCATION IN SECTION PLAT
NE NE NW

16. Size Hole below casing: 30 in.
17. Static level 13'4" ft. below casing top which is 0 ft. above ground level. Pumping level 33 ft. when pumping at 157 gpm for 6 hours.

18. FORMATIONS PASSED THROUGH	THICKNESS	DEPTH OF BOTTOM
Drift	112	112
Shale	?	?
(CONTINUE ON SEPARATE SHEET IF NECESSARY)		

SIGNED D. L. [illegible] DATE Nov 2, 68

MAP # 2
ISGS # 121550012800

Whi[illegible]py — Ill. Dept. of Public Health
Yellow Copy — Well Contractor
Blue Copy — Well Owner

INSTRUCTIONS TO DRILLERS

FILL IN ALL PERTINENT INFORMATION REQUESTED AND MAIL ORIGINAL TO STATE DEPARTMENT OF PUBLIC HEALTH, ROOM 616, STATE OFFICE BUILDING, SPRINGFIELD, ILLINOIS, 62706. DO NOT DETACH GEOLOGICAL / WATER SURVEYS SECTION. BE SURE TO PROVIDE PROPER WELL LOCATION.

ILLINOIS DEPARTMENT OF PUBLIC HEALTH
WELL CONSTRUCTION REPORT

1. Type of Well
   a. Dug ____. Bored ____. Hole Diam. ____ in. Depth 104 ft.
      Curb material ____. Buried Slab: Yes ____ No ____
   b. Driven ____. Drive Pipe Diam. ____ in. Depth ____ ft.
   c. Drilled x. Finished in Drift x. In Rock ____.
      Tubular ____. Gravel Packed x.
   d. Grout:

(KIND)	FROM (Ft.)	TO (Ft.)
ready mix	7	20

2. Distance to Nearest:
   Building ____ Ft. Seepage Tile Field ____
   Cess Pool ____ Sewer (non Cast iron) ____
   Privy ____ Sewer (Cast iron) ____
   Septic Tank ____ Barnyard ____
   Leaching Pit ____ Manure Pile ____
3. Is water from this well to be used for human consumption?
   Yes ____ No x
4. Date well completed 10/2/78
5. Permanent Pump Installed? Yes ____ No x
   Manufacturer ____ Type ____
   Capacity ____ gpm. Depth of setting ____ ft.
6. Well Top Sealed? Yes x No ____
7. Pitless Adaptor Installed? Yes ____ No x
8. Well Disinfected? Yes x No ____
9. Water Sample Submitted? Yes x No ____

REMARKS:

County # 20292

ISGS
121552029200

IDPH 4.065
10/68

P403400

PLC, 15534255, #1

GEOLOGICAL AND WATER SURVEYS WELL RECORD
(Industrial)

10. Property owner ESK Corporation Well No. 1
    Address Hennepin IL
    Driller Layne-Western Co. License No. 102-13
11. Permit No. 79101 Date 9/6/78
12. Water from drift (Formation) 13. County Putnam
    at depth 89 to 104 ft. Sec. 26 Uc
14. Screen: Diam. 12 in (Tele) Twp. 33N
    Length: 15 ft. Slot 40 Rge. 2W
    Elev. ____

SHOW LOCATION IN SECTION PLAT
1830'N, 1070'W, SE/c, (Industrial)

15. Casing and Liner Pipe

Diam. (in.)	Kind and Weight	From (Ft.)	To (Ft.)
12	steel 0.330"	89	+2

16. Size Hole below casing: 38 in.
17. Static level 72 ft. below casing top which is 2 ft. above ground level. Pumping level 85 ft. when pumping at 530 gpm for 8 hours.

18. FORMATIONS PASSED THROUGH	THICKNESS	DEPTH OF BOTTOM
Fine sand to coarse gravel/boulders	0	6
Fine brown sand	6	8
Fine sand to coarse gravel/boulders	8	64
Fine to coarse sand	64	105
Fine sand to coarse gravel, boulders & traces of clay	105	109

(CONTINUE ON SEPARATE SHEET IF NECESSARY)

SIGNED D. G. Lohmeier DATE 10/3/78
D. G. Lohmeier, P.E.

MAP #5

White & Pink Copies:
Ill. [illegible]t. of Public Health
Yellow [illegible]opy: Well Contractor
Golden Copy: Well Owner

Well Construction Report

MAP #6
1565 #121552049700

THIS FORM MUST BE COMPLETED WITHIN 30 DAYS
OF WELL COMPLETION AND SENT TO
THE ILLINOIS DEPARTMENT OF PUBLIC HEALTH
DIVISION OF ENVIRONMENTAL HEALTH
525 WEST JEFFERSON STREET
SPRINGFIELD, ILLINOIS 62761

GEOLOGICAL AND WATER SURVEYS WELL RECORD

Project Driller, MIKE RIFE & MARV MICHELS

9. Driller Layne-Western License No. 102-003241
10. Well Site Address HENNEPIN, IL
11. Property Owner Exolon-ESK Well No. 3
12. Permit No. 155-011-96 Date Issued 9/5/96
13. Location: 550'W & 1775'N of S.E. corner County Putnam
Sec. 26,4c, Twp. 33N Rge. 2W

1. Type of Well
   a. Bored_____ Hole Diam._____in. Depth_____ft
      Buried Slab: Yes_____ No_____
   b. Driven_____ Drive Pipe Diam._____in. Depth_____ft
   c. Drilled X Finished in Drift X In Rock_____
   d. Grout:

(KIND)	FROM (Ft.)	TO (Ft.)
cement	0	20

2. Well furnishes water for human consumption? Yes X No_____
3. Date well drilled October 1
4. Permanent pump installed? Yes_____ Date in future No X
   Manufacturer Layne & Bowler Type VTP
   Location_____
   Capacity 300 gpm. Depth of setting 80 ft.
5. Well top sealed? Yes X No_____ Type steel plate
6. Pitless adapter installed? Yes_____ No X
   Manufacturer_____ Model No._____
   How attached to casing? -
7. Well disinfected? Yes X No_____
8. Pump and equipment disinfected Yes_____ No_____

14. Water from sand & gravel at depth 102 ft to 117 ft

15. Casing and Liner Pipe

Diam.(in)	Kind and Weight	From (ft)	To (ft)
12	steel-.375"	0	102

Show location in section plat

SW NW SE

16. Screen: Diam. 12 in, Length 15' ~~XX~~, Slot Size .130"
17. Size hole below casing 38 in. 18. Ground Elev._____ ft msl.
19. Static level_____ft below casing top which is _____ft. above ground level. Pumping level _____ft, pumping gpm for _____ hours.

20. Earth Materials Passed Through	Depth of Top	Depth of Bottom
Fine brown sand	0	4
Gray clay	4	5
Coarse sand & gravel with boulders	5	79
Brown clay with gravel	79	81
Fine sand with gravel	81	117
Gray shale	117	124

Continue on separate sheet if necessary.

IMPORTANT NOTICE

This State Agency is requesting disclosure of information that is necessary to accomplish the statutory purpose as outlined under Public Act 85-0863. Disclosiure of this information is mandatory. This form has been approved by the Forms Management Center.

PRESS FIRMLY WITH BLACK PEN OR TYPE
Do Not Use Felt Pen

P# 405443

CO#20497

Signed GREGORY D. BUFFINGTON, P.E. Date 11/5/96

IL482-0126

PICS 15534255, #3

Wh[illegible] opy — Ill. Dept. of Public Health
Yellow Copy — Well Contractor
Blue Copy — Well Owner

INSTRUCTIONS TO DRILLERS

FILL IN ALL PERTINENT INFORMATION REQUESTED AND MAIL ORIGINAL TO STATE DEPARTMENT OF PUBLIC HEALTH, ROOM 616, STATE OFFICE BUILDING, SPRINGFIELD, ILLINOIS, 62706. DO NOT DETACH GEOLOGICAL / WATER SURVEYS SECTION. BE SURE TO PROVIDE PROPER WELL LOCATION.

MAP # 7
ISGS # 20258

ILLINOIS DEPARTMENT OF PUBLIC HEALTH
WELL CONSTRUCTION REPORT

1. Type of Well
   a. Dug ____. Bored ____. Hole Diam. ____ in. Depth 128 ft.
   Curb material ____. Buried Slab: Yes ____ No ____
   b. Driven ____. Drive Pipe Diam. ____ in. Depth ____ ft.
   c. Drilled x. Finished in Drift x. In Rock ____.
   Tubular ____. Gravel Packed x.
   d. Grout:

(KIND)	FROM (Ft.)	TO (Ft.)
Grout	7	20

2. Distance to Nearest:
   Building ____ Ft. Seepage Tile Field ____
   Cess Pool ____ Sewer (non Cast iron) ____
   Privy ____ Sewer (Cast iron) ____
   Septic Tank ____ Barnyard ____
   Leaching Pit ____ Manure Pile ____
3. Is water from this well to be used for human consumption?
   Yes x No ____
4. Date well completed 8/15/78
5. Permanent Pump Installed? Yes ____ No x
   Manufacturer ____ Type ____
   Capacity ____ gpm. Depth of setting ____ ft.
6. Well Top Sealed? Yes x No ____
7. Pitless Adaptor Installed? Yes ____ No x
8. Well Disinfected? Yes x No ____
9. Water Sample Submitted? Yes x No ____

REMARKS: County # 20258

116
12
128

IDPH 4.065
10/68

GEOLOGICAL AND WATER SURVEYS WELL RECORD
(Potable)

10. Property owner ESK Corporation Well No. 2
    Address Hennepin, Illinois
    Driller Layne-Western Co. Inc. License No. 102-13
11. Permit No. 76743 Date 7/12/78
12. Water from drift (Formation) at depth 116 to 128 ft.
13. County Putnam
    Sec. 26.2c
    Twp. 33N
    Rge. 2W
    Elev. ____
14. Screen: Diam. 12 in (Tele)
    Length: 12 ft. Slot 40

SHOW LOCATION IN SECTION PLAT

1590'N 890'W, SE/c, (Industrial)

15. Casing and Liner Pipe

Diam. (in.)	Kind and Weight	From (Ft.)	To (Ft.)
12	steel 0.330"	0	116

16. Size Hole below casing: 20 in.
17. Static level 90 ft. below casing top which is 2 ft. above ground level. Pumping level 112 ft. when pumping at 261 gpm for 8 hours.

18. FORMATIONS PASSED THROUGH	THICKNESS	DEPTH OF BOTTOM
Gravel, boulders	0	82
Brown clay	82	88
Med. sand, gravel, fine sand	88	128

(CONTINUE ON SEPARATE SHEET IF NECESSARY)

SIGNED D. G. Lohmeier DATE 10/3/78
D. G. Lohmeier, P.E.

PICS 155342255 #2 P403401

MAP # 12

ISGS #121552043500

PAGE 1

WELL INFORMATION – DRIFT WELLS

Layne-Western Company, Inc.

PROFESSIONAL SERVICES FOR WATER SYSTEMS

721 West Illinois Avenue • Aurora, Illinois 60506-2892 • Phone: 708/897-6941

Name of Job: Illinois Power Company — Date: 10/05/93

City or Village: Hennepin — State: IL

Well No.: ~~5~~ 6 (Local 1A) — Drillers: Glidewell, Will, Rife

Well Location: ______ ft. (____) and ______ ft. (____) of the ______ corner of

Section 26 SE, Twp. 33 (N), Range 2 (W) Putnam County.

Otherwise located as fractional section

Work Began: 8-24-93 — Work Completed: 10-07-93 — Well Depth: 115'

All measurements made from existing ground level at time well was drilled.

Casing Record:

Amount	Dia.	Wt. or Thickness	Material			joints from		to
92'	18"	0.375"	Steel	with	Welded	joints from	90'	to +2'
50'	36"	0.375'	Steel	with	Welded	joints from	12'	to 62'

Screen Record: Type Houston

Amount	Dia.	Opening	Material			joints from		to
25'	18"	0.100	S.Steel	with	Welded	joints from	115'	to 90'
				with		joints from		to

Type of Seal at Bottom: Stainless Steel Plate

Hole Record:

38" min. inch from 0 to 118'

______ inch from ______ to ______

Gravel Pack Record:

Amount	Size	Source	From	To
47 Tons	#3	Northern	118"	70'

Cementing Record: Ready Mix Concrete - 20' to 9'

Backfill Record: Bentonite Seat at 62 ft.

Backfill Sand 62 to 20

P404906

MAP #12
PAGE 2

WELL LOG

Feet		Feet	Description
0	to	2	Black topsoil
2	to	7	Brown sand, a little clayey
7	to	27	Yellow brown coarse gravel&boulders
27	to	41	Brown coarse sand to coarse gravel
41	to	43	Gray & brown soft silty clay
43	to	50	Brown medium sand to coarse gravel & boulders
50	to	67	Reddish brown coarse gravel & boulders
67	to	73	Multi-colored boulders
73	to	82	Conglomerate clay & boulders traces of weathered lime
82	to	84	Light gray silty clay
84	to	86	Hard tight coarse gravel
86	to	96	Brown jagged medium sand to coarse gravel & boulders
96	to	98	Boulder
98	to	112	Brown fine sand to coarse gravel with finer layers
112	to	118	Brown fine sand to medium gravel
118	to	125	Firm gray shale
	to		
	to		
	to		
	to		
	to		
	to		
	to		

Well Test Data: Static Level 17 ; pumping level 31' after 8 hours pumping at 1086 g.p.m.

Length of test 8 hrs. See Well Test Data Sheet Dated October 4, 1993

REMARKS:

MAP #12
PAGE 3

WELL TEST DATA SHEET

Layne-Western Company

A Layne Company

PROFESSIONAL SERVICES FOR WATER SYSTEMS

721 West Illinois Avenue • Aurora, Illinois 60506-2892 • Phone: 708/897-6941

Job: Illinois Power Company
Well No.: ~~5~~ 6
Date Tested: 10/4/93
Location: Hennepin, IL
Tested By: C. Glidewell
Dia. of Well: 18"
Driver: 671 Engine
Depth of Well: 115' from G.L.
Pump Used:
Column and Shaft: 8 x 1-11/16"
Length of Airline: 85'
Bowls:
Non-Pumping Level: 17'
Manufacturer: Layne
Orifice Size: 10" x 8"
Serial No.: Test Pump

Time	Piezometer Reading (in.)	G.P.M.	Air Gauge Reading (feet)	Pumping Level	Drawdown	Disch. Pressure		Total Pumping Head	Remarks
						Lbs.	Feet		
9:30		0	68	17'	SWL				
10:00	13.5	1086	56	29	12				Cloudy
10:30	13.5	1086	56	29					Clear
11:00	13.5	1086	56	29					No Sand
11:30	13.5	1086	56	29					
12:00	13.5	1086	54	31	14				
12:30	13.5	1086	54	31					
1:00	13.5	1086	54	31					
1:30	13.5	1086	54	31					
2:00	13.5	1086	54	31					
2:30	13.5	1086	54	31					
3:00	13.5	1086	54	31					
3:30	13.5	1086	54	31					
4:00	13.5	1086	54	31					
4:30	13.5	1086	54	31					
5:00	13.5	1086	54	31					
5:30	13.5	1086	54	31	14				

Final Specific Capacity = 77.6 GAL/FT.

MAP #12
PAGE 4

WELL TEST DATA SHEET

Layne-Western Company

A Layne Company

PROFESSIONAL SERVICES FOR WATER SYSTEMS

721 West Illinois Avenue • Aurora, Illinois 60506-2892 • Phone: 708/897-6941

Job Illinois Power

Well No. #6 (1A)

Date Tested 10/27/93

Location Hennepin, IL.

Tested By Marvin Michelson

Dia. of Well 18"

Driver 60 HP Westinghouse

Depth of Well 115' (from G.L.)

Pump Used:

Column and Shaft 8"x1 11/16"x2 1/2"

Length of Airline 50'

Bowls 11 stage - 12 RKMC

Non-Pumping Level 29' (Direct)

Manufacturer Layne-Western

Orifice Size IP Tripod - 6 x 5

Serial No. 22200

Time	Piezometer Reading (in.)	G.P.M.	Air Gauge Reading (feet)	Pumping Level	Drawdown	Disch. Pressure		Total Pumping Head	Remarks
						Lbs.	Feet		
7:00		0	29						
1:15	14.3	466	35	35	6	120			cloudy 78/78/80
1:20	17.3	513	35	35	6	115			78/78/79
1:25	19	543	35	35	6	100			clear
	21	570	36	36	7	105			clear
	22.8	597	36	36	7	100			clear
	24.5	616	36	36	7	95			clear
	26.8	641	37	37	8	90			clear
	28.3	659	37	37	8	85			77/77/78
	30.3	682	37	37	8	80			77/77/78
	32.3	704	38	38	9	75			77/77/78
	34	726	38	38	9	70			77/77/78
	36	747	38	38	9	65			77/77/78
	37.3	757	38	38	9	60			77/77/78
	39.3	777	39	39	10	55			77/77/78
	41	797	39	39	10	50			77/77/78
1:40	43	816	40	40	11	45			77/77/78
	44.8	826	40	40	11	40			77/77/78
	46.5	849	40	40	11	35			77/77/78
	48	862	41	41	12	30			77/77/78
	49.8	876	42	42	13	25			Sp Q =67.4

ISGS # 121552059800 #4 MIAF AGET 7/7/65 Sp Mu No 3 #5

City Hennepin Township Location County Putnam

Section 26 5 Twp. No. 33N Range 2W

Location (in feet from section corner) NE¼, NE¼, NW¼

Owner Illinois Power Co. Authority

Contractor Layne-Western Co. Address 721 West Illinois Ave., Aurora, Ill. 60507

Date drilled Aug 26, 68 Elev. above sea level top of well

Depth ~~116'~~ 113.5

Log Sand and gravel

Were drill cuttings saved Yes Where filed State of Illinois

Size hole 30" If reduced, where and how much

Casing record 18" to 93'-6"; 18" stainless screen to 116'

Distance to water when not pumping 13'-4" Distance to water is 24

feet after pumping at 1080 G. P. M. for 8 hours.

Reference point for above measurements Top of casing

Type of pump Test pump Distance to cylinder

Length of cylinder Length of suction pipe below cylinder

Length stroke Speed

Hours used per day Type of power

Rating of motor Rating of pump in G. P. M.

Can following be measured: (1) Static water level

(2) Pumping level (3) Discharge

(4) Influence on other wells

Temperature of water Was water sample collected Yes

Date Effect of water on meters, hot water

coils, etc.

Date of Analysis Analysis No.

Recorder

Date

2807-22617 12

April 1, 1969

WELL PRODUCTION TEST
ILLINOIS POWER COMPANY, WELL NO. 4
PUTNAM COUNTY
by

Layne-Western

MAP #13
PAGE 2

ISGS #
121552059800

Owner:	Illinois Power Company
Location:	NE 1/4, NE 1/4, NW 1/4, Sec. 26, T. 33N., R. 2W.
Date of Test:	8/27/68
Date Completed:	August 1968
Length of Test:	6 hours
Aquifer:	Sand & gravel

WELL DATA

PUMPED WELL

Well No:	4
Driller:	Layne-Western
Depth:	113.5
Hole Record:	48" 0-15'; 42" 15-30'; 34" 30-60'; 30" 60-113.5'
Casing Record:	30" 0-62'; 18" 0-63.5 and 73.5-93.5' (gravel packed, 2-113.5')
Screen Record:	10' of 18" #6 slot S.S. 63.5-73.5'; 20' of 18" #6 slot S. S. 93.5-113.5'
Pump and Power:	Test pump; 100 hp motor
Measuring Point:	18" above GL, top of casing
Measuring Equipment:	10x8" orifice, steel tape
Static Level:	13'4"

R-403404

MAP #13
PAGE 3

MEASUREMENTS

PUMPED WELL

Date 1968	Hour	Time (min)	Alt. gage (ft)	Depth to water (ft)	Draw-down (ft)	Piez. tube (in)	Pump. rate (gpm)	Remarks
8/27	7:50A		13.33					FPNR*
	8:45		17.58					Fire pump running (on at 8:37)
	8:59		13.58					FPNR*
	9:00	0				24.5	1543	Pump on
	9:15	15	31.17	31.17	17.82	25	1557	FPNR*
	9:30	30	33.42	33.42	20.08	25.5	1571	Fire pump running
	10:00	60	33.58	33.58	20.25	25.5	1571	Fire pump running
	10:30	90	33.58	33.58	20.25	25.5	1571	Fire pump running
	11:00	120	31.42	31.42	18.08	25.5	1571	Fire pump running
	11:30	150	33	33	19.67	25.5	1571	Fire pump running
	12:00N	180	33.33	33.33	20	25.5	1571	Fire pump running
	12:30P	210	33.08	33.08	19.75	25.5	1571	Fire pump running
	1:00	240	33.25	33.25	19.75	25.5	1571	Fire pump running
	1:30	270	33.82	33.82	20.50	25.5	1571	Fire pump running
	2:00	300	32.92	32.92	19.58	25.5	1571	Fire pump running
	2:30	330	33	33	19.67	25.5	1571	Fire pump running
	3:00	360	33	33	19.67	25.5	1571	Fire pump running
	3:05	365						Reduced capacity to 1080 gpm
	3:30	390	26.17	26.17	12.67	11	1080	Fire pump running
	4:00	420	24.08	24.08	10.75	11	1080	FPNR* (off at 3:33)
	4:30	450	24.08	24.08	10.75	11	1080	FPNR*
	5:00	480	24.08	24.08	10.75	11	1080	FPNR*
								End of Test

*FPNR=Fire pump not running

MAP #13
PAGE 4

DRILLER'S LOG
WELL NO. 4

Formation	From	To
Brown sandy soil	0'	8"
Brown med. sand to coarse gravel with boulders	8"	22 1/2'
Black silty soil	22 1/2'	23 1/2
Brown med. sand to coarse gravel with trace of clay and silt	23 1/2	26 1/2
Light gray silty clay, soft	26 1/2	28
Brown med. sand	28	29 1/2
Multi-colored clay silt, soft, soft sandstone boulder at 30'	29 1/2	32
Brown med. sand to coarse gravel, trace of rusty colored sandy silt, some boulders	32	49 1/2
Gray sandy clay	49 1/2	50 1/2
Brown and gray med. sand to coarse gravel	50 1/2	58
Light gray silty clay	58	59
Med. sand to coarse gravel, multi-colored	59	67
Light gray silty clay	67	67 1/2
Med. sand to coarse gravel, multi-colored	67 1/2	79
Fine to med. sand, gray	79	87
Limestone boulder	87	88
Brown med. sand to coarse gravel	88	97
Brown fine to med. sand, trace of gravel	97	106 1/2
Brown med. sand to coarse gravel	106 1/2	112 1/2
Gray shale	112 1/2	

Location.

NE 1/4, NE 1/4, NW 1/4, S.26
T.33N., R.2W.

P Number: 431044 | NEW | SAVE | CANCEL | DELETE

Data Set Location: 1 OF 9 | > | >|

Entered By: tbryant 10/31/2007

Last User: tbryant 10/31/2007

SUMMARY | POINT INFO | IWIP INFO | LOCATION VERIFICATION | OBSERVATION | PAPER FILES | QA / QC

Well Type:
Total Depth: 44.00 (ft.)
AQ Code:

Aquifer Type:
Well Use: RE
Date Completed: <1991

Owner: DYNEGY MIDWEST GEN - HENNEPIN POWER

Facility Point Number: 8
IWIP Facility ID: 15534260

Driller:

Drilling Company:

Permit #:
VALID #
VALID LOCATION

Address:

City:
State:
Zip:

Land ID:
Lot #:

Subdivision:

FIPS: 155 TWN: 33N RNG: 02W SEC: 26 QQQ: SE NE NW Plot: 5G VALID LOC.

PLSS Source: CR Principal Meridian: 3

	Decimal Degrees		Deg.	Min.	Sec.	Decimal Minutes
Latitude: N	41.3032333	CALC	41	18	11.64	
Longitude: W	39.3162167		39	18	58.38	

Lat-Lon Source: GPS

LS Elevation: (ft.) Elevation Method: Elevation Source:

Casing Dia.: (in.) Variable: Casing Depth: (ft.) Slotted:

Screen Length: (ft.)

Water From: depth of: (ft.) to: (ft.)

Static Level Below Casing Top: (ft.)

Inches Casing Above Ground Level: (in.)

Pumping Level Below Casing Top: CALC

Static Water Level: Pumping Level:

Pumping: gpm for hours

General Remarks: USED 1991-1993 AS PART OF A LEAKING UNDERGROUND TANK REMEDIATION PER JOHN AUGSPOLS 10-31-07 TB.

Record Type: SIC: 4911 SIC Source: 1

Record Type Remarks:

Previous Owners:

Date Sealed: 08/16/2007 SGS Number:

Lambert X: 3051710 Lambert Y: 3011702 CALC

Lambert Method:

Lambert Method Remarks:

Lambert Accuracy:

Lambert Source:

Database Data
Date Completed:
Date Sealed: 20070816

RECORD FILTER | FIND NUMBER | VIEW PUMPAGE | VIEW SC | VIEW FACILITY | VIEW PERMIT | PRINT SCREEN

NO MAP #
TEST WELLS

P431044
Facility 15534260, #8

SCANNED

Private Well Database

Illinois State Water Survey
Address / Phone Information

Records for **Putnam** county, **33N** township, **01W** range, **30** section.

Well ID	Plot	Depth	Record Type	Well Use	Well Type	Aquifer Type	ISGS No.
125859	1G	119	RG	DO	~~	~~	00173

Driller	Date Drilled	Static Level	Pumping Level	Pumping GPM	Pumping Hours
S DEAN ALBRECHT	07/06/1973				

Well ID	Plot	Depth	Record Type	Well Use	Well Type	Aquifer Type	ISGS No.
125860	2H	100	RG	DO	~~	~~	00127

Driller	Date Drilled	Static Level	Pumping Level	Pumping GPM	Pumping Hours
S DEAN ALBRECHT	10/15/1968				

Well ID	Plot	Depth	Record Type	Well Use	Well Type	Aquifer Type	ISGS No.
125861	2H	100	RG	DO	~~	~~	

Driller	Date Drilled	Static Level	Pumping Level	Pumping GPM	Pumping Hours
S DEAN ALBRECHT	07/31/1969				

Well ID	Plot	Depth	Record Type	Well Use	Well Type	Aquifer Type	ISGS No.
314745	8A	170	RGCP	DO	DL	UN	20515

Driller	Date Drilled	Static Level	Pumping Level	Pumping GPM	Pumping Hours
COUNTRY WELL & PUMP	10/02/1997				

Well ID	Plot	Depth	Record Type	Well Use	Well Type	Aquifer Type	ISGS No.
329423	5B	26	RGP	DO	BD	UN	20541

Driller	Date Drilled	Static Level	Pumping Level	Pumping GPM	Pumping Hours
ROY THORNE	03/28/2000	13			

Well ID	Plot	Depth	Record Type	Well Use	Well Type	Aquifer Type	ISGS No.
348053	3H	65	RGP	DO	BD	UN	20670

Driller	Date Drilled	Static Level	Pumping Level	Pumping GPM	Pumping Hours
THORNE WELL DRILLING/MIKE DRYDEN	03/07/2003				

View the results in "Table Format" Search for a different Section

If this page does not print correctly, change your browser's layout mode to landscape.

Please view our **Data Disclaimer**, Water Well Records Policies and Procedures, and **Plot Location System**

Column headings link to data explanations.

Home | Highlights | Staff | Data | Information | Centers | Site Map | Search

ISWS

Private Well Database

Illinois State Water Survey
Address / Phone Information

Records for **Putnam** county, **33N** township, **01W** range, **31** section.

Well ID	Plot	Depth	Record Type	Well Use	Well Type	Aquifer Type	ISGS No.
125862	1A	201	RG	DO	~~	~~	00180

Driller	Date Drilled	Static Level	Pumping Level	Pumping GPM	Pumping Hours
S DEAN ALBRECHT	06/12/1973				

Well ID	Plot	Depth	Record Type	Well Use	Well Type	Aquifer Type	ISGS No.
125863	1F	200	RG	DO	~~	~~	20256

Driller	Date Drilled	Static Level	Pumping Level	Pumping GPM	Pumping Hours
K & K WELL DRILLING	07/11/1977				

Well ID	Plot	Depth	Record Type	Well Use	Well Type	Aquifer Type	ISGS No.
125864	2F	4	RG	DO	~~	~~	

Driller	Date Drilled	Static Level	Pumping Level	Pumping GPM	Pumping Hours
	03/12/1934				

Well ID	Plot	Depth	Record Type	Well Use	Well Type	Aquifer Type	ISGS No.
125865	5F	200	RG	DO	~~	~~	00164

Driller	Date Drilled	Static Level	Pumping Level	Pumping GPM	Pumping Hours
S DEAN ALBRECHT	11/17/1972				

Well ID	Plot	Depth	Record Type	Well Use	Well Type	Aquifer Type	ISGS No.
296155	8H	213	RG	DO	DL	UN	

Driller	Date Drilled	Static Level	Pumping Level	Pumping GPM	Pumping Hours
KEITH THIERY	04/30/1997	134	136	20	2

Well ID	Plot	Depth	Record Type	Well Use	Well Type	Aquifer Type	ISGS No.
358239	8H	241	RG	DO	DL	UN	20698

Driller	Date Drilled	Static Level	Pumping Level	Pumping GPM	Pumping Hours
COMPLETE WELL DRILLING/DARREL DOBER	06/19/2003	179	189	12	2

View the results in "Table Format" Search for a different Section

If this page does not print correctly, change your browser's layout mode to landscape.

Please view our **Data Disclaimer**, Water Well Records Policies and Procedures, and **Plot Location System**

Column headings link to data explanations.

| PWD Home | Meta Data | Location System | Disclaimer | Contact Us | Help |

ISWS

Private Well Database

Illinois State Water Survey
Address / Phone Information

Records for **Putnam** county, **33N** township, **02W** range, **24** section.

Well ID	Plot	Depth	Record Type	Well Use	Well Type	Aquifer Type	ISGS No.
343982	5D	303	RGP	DO	DL	UN	20622

Driller	Date Drilled	Static Level	Pumping Level	Pumping GPM	Pumping Hours
LUTES H2O DRILLING/G.DELHOTEL	07/30/2001	229		30	2

View the results in "Table Format" Search for a different Section

If this page does not print correctly, change your browser's layout mode to landscape.

Please view our **Data Disclaimer**, Water Well Records Policies and Procedures, and **Plot Location System**

Column headings link to data explanations.

Illinois State Water Survey, Contact Information
University of Illinois at Urbana-Champaign

Private Well Database

Illinois State Water Survey
Address / Phone Information

Records for **Putnam** county, **33N** township, **02W** range, **25** section.

Well ID	Plot	Depth	Record Type	Well Use	Well Type	Aquifer Type	ISGS No.
125915	3F	196	RG	DO	~~	~~	

Driller	Date Drilled	Static Level	Pumping Level	Pumping GPM	Pumping Hours
EGART	1922				

Well ID	Plot	Depth	Record Type	Well Use	Well Type	Aquifer Type	ISGS No.
314693	7B	72	RGCP	DO	DL	UN	20518

Driller	Date Drilled	Static Level	Pumping Level	Pumping GPM	Pumping Hours
LUTES DRILLING	09/14/1999	17		50	3

MAP # 8

Well ID	Plot	Depth	Record Type	Well Use	Well Type	Aquifer Type	ISGS No.
359951	7B	64	RG	DO	DL	UN	20685

Driller	Date Drilled	Static Level	Pumping Level	Pumping GPM	Pumping Hours
LUTES H2O DRILLING/JET HALL	11/15/2002	4	6	12	2

Well ID	Plot	Depth	Record Type	Well Use	Well Type	Aquifer Type	ISGS No.
382144	1A	158	RG	DO	DL	UN	20747

Driller	Date Drilled	Static Level	Pumping Level	Pumping GPM	Pumping Hours
LUTES H2O DRILLING/KEITH THIERRY	04/10/2006	100		15	1

View the results in "Table Format" Search for a different Section

If this page does not print correctly, change your browser's layout mode to landscape.

Please view our **Data Disclaimer**, Water Well Records Policies and Procedures, and **Plot Location System**

Column headings link to data explanations.

Illinois State Water Survey, Contact Information
University of Illinois at Urbana-Champaign

ISWS

Private Well Database

Illinois State Water Survey
Address / Phone Information

Records for **Putnam** county, **33N** township, **02W** range, **26** section.

Well ID	Plot	Depth	Record Type	Well Use	Well Type	Aquifer Type	ISGS No.
125916	8B	17	RG	DO	~~	~~	

Driller	Date Drilled	Static Level	Pumping Level	Pumping GPM	Pumping Hours
	1922				

MAP # 14

View the results in "Table Format" Search for a different Section

If this page does not print correctly, change your browser's layout mode to landscape.

Please view our **Data Disclaimer**, Water Well Records Policies and Procedures, and **Plot Location System**

Column headings link to data explanations.

Illinois State Water Survey, Contact Information
University of Illinois at Urbana-Champaign

ISWS

Private Well Database

Illinois State Water Survey
Address / Phone Information

Records for **Putnam** county, **33N** township, **02W** range, **27** section.

Well ID	Plot	Depth	Record Type	Well Use	Well Type	Aquifer Type	ISGS No.
125917	5D	30	RG	DO	~~	~~	

Driller	Date Drilled	Static Level	Pumping Level	Pumping GPM	Pumping Hours
	1884				

OUT OF RADIUS

View the results in "Table Format" Search for a different Section

If this page does not print correctly, change your browser's layout mode to landscape.

Please view our **Data Disclaimer**, Water Well Records Policies and Procedures, and **Plot Location System**

Column headings link to data explanations.

Illinois State Water Survey, Contact Information
University of Illinois at Urbana-Champaign

Home | Highlights | Staff | Data | Information | Centers | Site Map | Search

ISWS

Private Well Database

Illinois State Water Survey
Address / Phone Information

Records for **Putnam** county, **33N** township, **02W** range, **34** section.

Well ID	Plot	Depth	Record Type	Well Use	Well Type	Aquifer Type	ISGS No.
125918	1D	300	RG	DO	~~	~~	

Driller	Date Drilled	Static Level	Pumping Level	Pumping GPM	Pumping Hours
	1848				

View the results in "Table Format" Search for a different Section

If this page does not print correctly, change your browser's layout mode to landscape.

Please view our **Data Disclaimer**, Water Well Records Policies and Procedures, and **Plot Location System**

Column headings link to data explanations.

| PWD Home | Meta Data | Location System | Disclaimer | Contact Us | Help |

| Home | Highlights | Staff | Data | Information | Centers | Site Map |

Illinois State Water Survey, Contact Information
University of Illinois at Urbana-Champaign

ISWS

Private Well Database

Illinois State Water Survey
Address / Phone Information

Records for **Putnam** county, **33N** township, **02W** range, **35** section.

Well ID	Plot	Depth	Record Type	Well Use	Well Type	Aquifer Type	ISGS No.
125919	1E	127	RG	DO	~~	~~	

Driller	Date Drilled	Static Level	Pumping Level	Pumping GPM	Pumping Hours
BICKERMAN	1909				

OUT OF RADIUS

Well ID	Plot	Depth	Record Type	Well Use	Well Type	Aquifer Type	ISGS No.
125920	3A	75	RG	DO	~~	~~	

Driller	Date Drilled	Static Level	Pumping Level	Pumping GPM	Pumping Hours
BICKERMAN	1895				

Well ID	Plot	Depth	Record Type	Well Use	Well Type	Aquifer Type	ISGS No.
125921	7D	110	RG	DO	~~	~~	

Driller	Date Drilled	Static Level	Pumping Level	Pumping GPM	Pumping Hours
	1904				

Well ID	Plot	Depth	Record Type	Well Use	Well Type	Aquifer Type	ISGS No.
125922	8E	160	RG	DO	~~	~~	

Driller	Date Drilled	Static Level	Pumping Level	Pumping GPM	Pumping Hours
BICKERMAN	1920				

View the results in "Table Format" Search for a different Section

If this page does not print correctly, change your browser's layout mode to landscape.

Please view our **Data Disclaimer**, Water Well Records Policies and Procedures, and **Plot Location System**

Column headings link to data explanations.

Illinois State Water Survey, Contact Information
University of Illinois at Urbana-Champaign

Home | Highlights | Staff | Data | Information | Centers | Site Map | Search

ISWS

Private Well Database

Illinois State Water Survey
Address / Phone Information

Records for **Putnam** county, **33N** township, **02W** range, **36** section.

Well ID	Plot	Depth	Record Type	Well Use	Well Type	Aquifer Type	ISGS No.
125160	7A	155	RG	DO	~~	~~	00118

Driller	Date Drilled	Static Level	Pumping Level	Pumping GPM	Pumping Hours
S DEAN ALBRECHT	01/12/1968				

Well ID	Plot	Depth	Record Type	Well Use	Well Type	Aquifer Type	ISGS No.
125923	1G	186	RG	DO	~~	~~	20286

Driller	Date Drilled	Static Level	Pumping Level	Pumping GPM	Pumping Hours
S D ALBRECHT	08/18/1977				

Well ID	Plot	Depth	Record Type	Well Use	Well Type	Aquifer Type	ISGS No.
125924	1H	155	RG	DO	~~	~~	00107

Driller	Date Drilled	Static Level	Pumping Level	Pumping GPM	Pumping Hours
S DEAN ALBRECHT	1966				

Well ID	Plot	Depth	Record Type	Well Use	Well Type	Aquifer Type	ISGS No.
125925	5E	35	RG	DO	~~	~~	

Driller	Date Drilled	Static Level	Pumping Level	Pumping GPM	Pumping Hours
	1874				

Well ID	Plot	Depth	Record Type	Well Use	Well Type	Aquifer Type	ISGS No.
125926	6D	105	RG	DO	~~	~~	

Driller	Date Drilled	Static Level	Pumping Level	Pumping GPM	Pumping Hours
BICKERMAN	1898				

Well ID	Plot	Depth	Record Type	Well Use	Well Type	Aquifer Type	ISGS No.
125927	8E	85	RG	DO	~~	~~	

Driller	Date Drilled	Static Level	Pumping Level	Pumping GPM	Pumping Hours
	1874				

Well ID	Plot	Depth	Record Type	Well Use	Well Type	Aquifer Type	ISGS No.
359954	4E	67	RGP	DO	DL	UN	20688

Driller	Date Drilled	Static Level	Pumping Level	Pumping GPM	Pumping Hours
LUTES H2O DRILLING/JET HALL	05/08/2003	19		50	2

View the results in "Table Format" Search for a different Section

If this page does not print correctly, change your browser's layout mode to landscape.

Please view our **Data Disclaimer**, Water Well Records Policies and Procedures, and **Plot Location System**

Column headings link to data explanations.

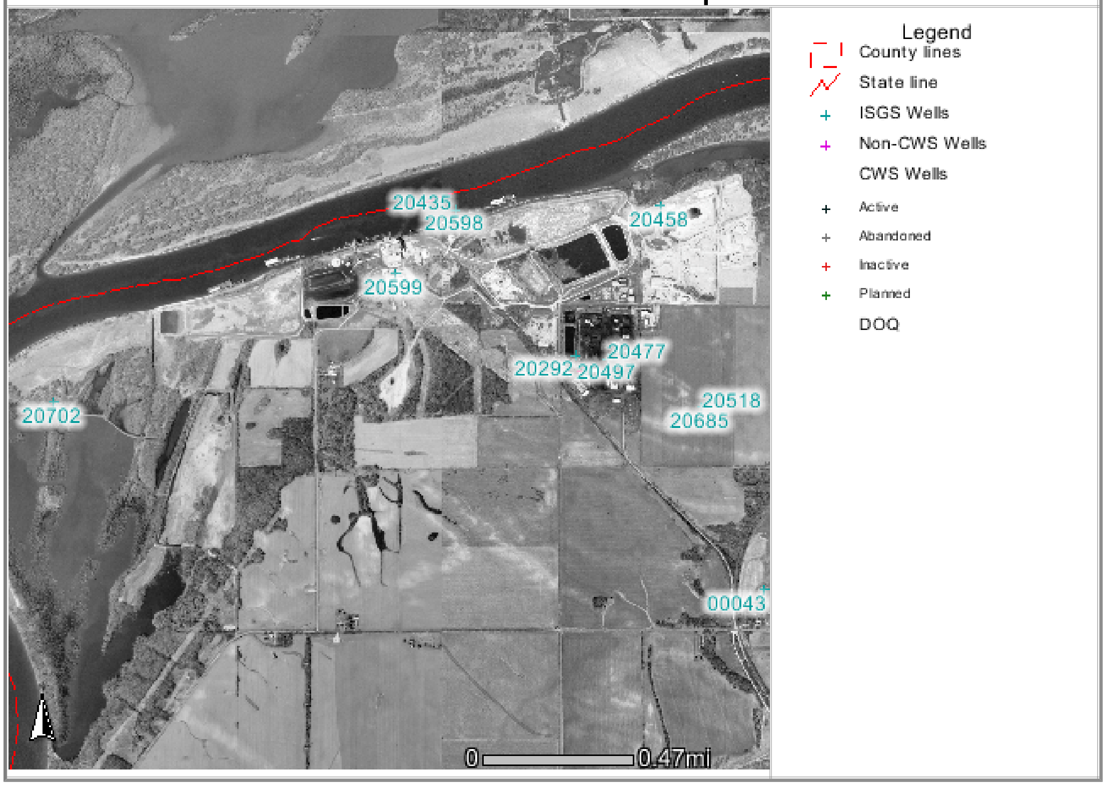
| PWD Home | Meta Data | Location System | Disclaimer | Contact Us | Help |

APPENDIX C

ILLINOIS ENVIRONMENTAL PROTECTION AGENCY
WEB-BASED GIS FILES

Information and data presented were obtained from various Federal, State, and local agencies and are subject to revision.

ArcIMS HTML Viewer Map

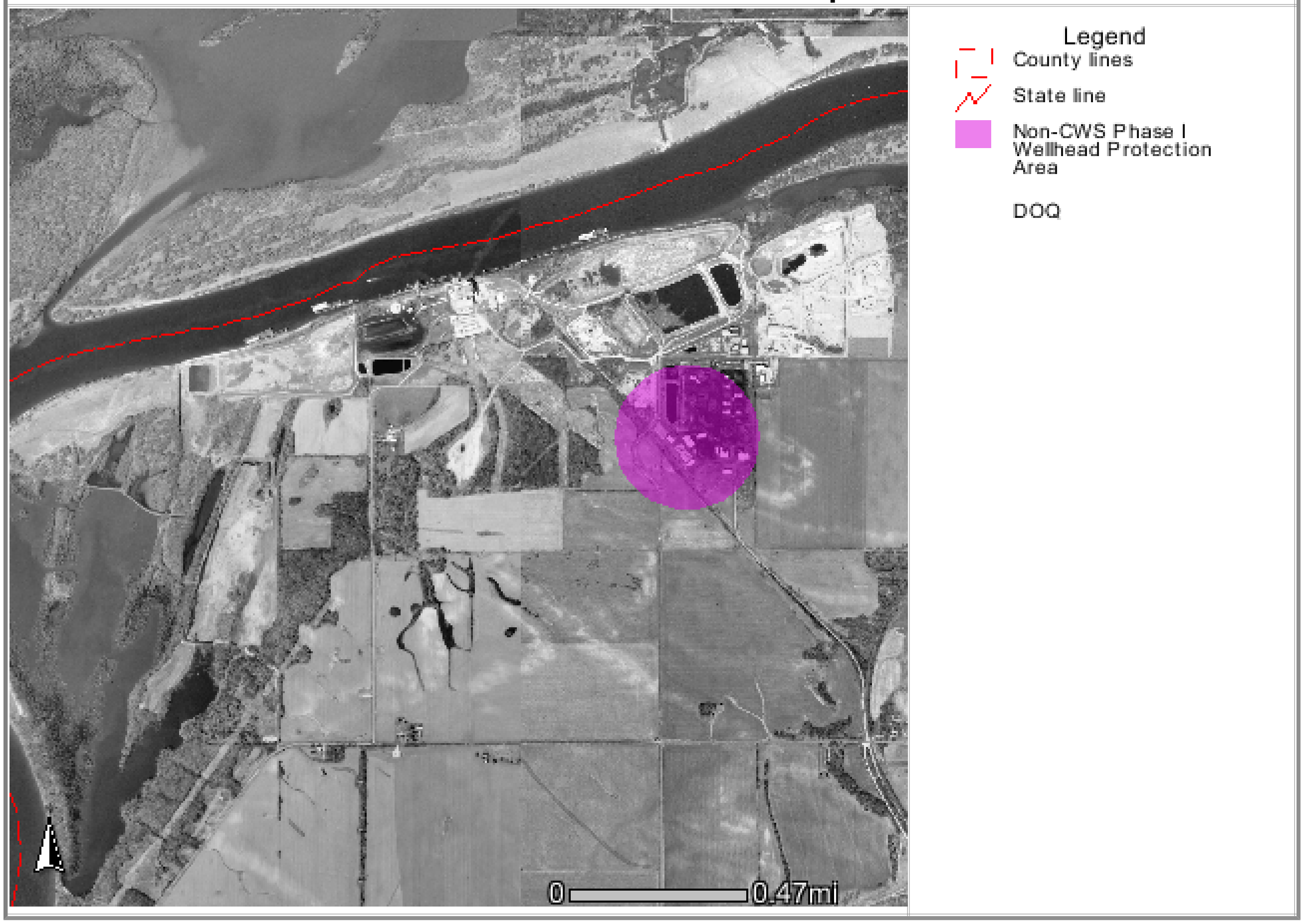


ISGS Wells

Rec	API_NUMBER	TOTAL_DEPT	FARM_NAME	ELEVATION	STATUS	LAM_X	LAM_Y	LATITUDE	LONGITUDE	COUNTY_NO
1	121552070200	83	Dynegy Midwest-Hennepin Power	0	WATER	3045102	3008480	41.296270	89.335096	20702

Information and data presented were obtained from various Federal, State, and local agencies and are subject to revision.

ArcIMS HTML Viewer Map



Non-CWS Phase I Wellhead Protection Area

Rec	area	perimeter	buff1000_	buff1000_i	inside
1	3125482.25000	6275.02881	1420	1419	100

Source Water Assessment Summary

0117408 - EXOLON ESK

Last Updated on 2/3/2006

Source of Groundwater
The Exolon Company water supply system consists of one well. The well draws its water supply from an unconfined aquifer, which consists of sand.

Source Water Quality
The well at the Exolon Company is sampled for bacteria, nitrate/nitrites and lead and copper. In addition the Exolon Company is also required to sample for inorganic compounds (IOC), volatile compounds (VOC), and synthetic compounds (SOC).

On review of the geological composition, land-use practices, and well construction it was found that the well is susceptible to VOC, SOC, IOC, nitrate/nitrites, and bacteria.

Construction/Treatment
The Exolon Company has a 12-inch drilled well with steel casing. The well has an estimated depth of 130 feet. The well has a turbine pump and a 1,000 pressurized storage tank. The well receives no treatment.

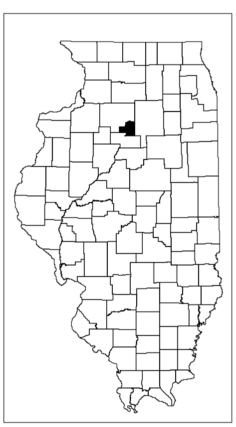
Finished Water Quality
A review of the Exolon Company water supply at this time shows that the system is in compliance with the groundwater quality standards established under 35 Illinois Administrative Code Part 620.

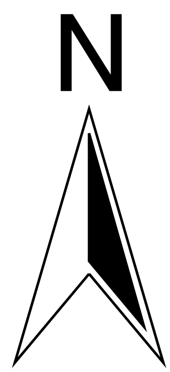
Potential Sources of Contamination
The following sites are listed as potential sources of contamination due to the nature of their activity and their geographic proximity (within a 1,000 foot buffer) to the source water protection area.

See Table on Topographic Map Coverage(Second Map)

Susceptibility to Contamination
The Illinois Department of Public Health has determined that the Exolon Company water supply has a high susceptibility to contamination. This determination is based on a number of criteria including: available geological data, land-use practices, and well depth.

Aerial Photograph Coverage
Exolon Non-Community Well





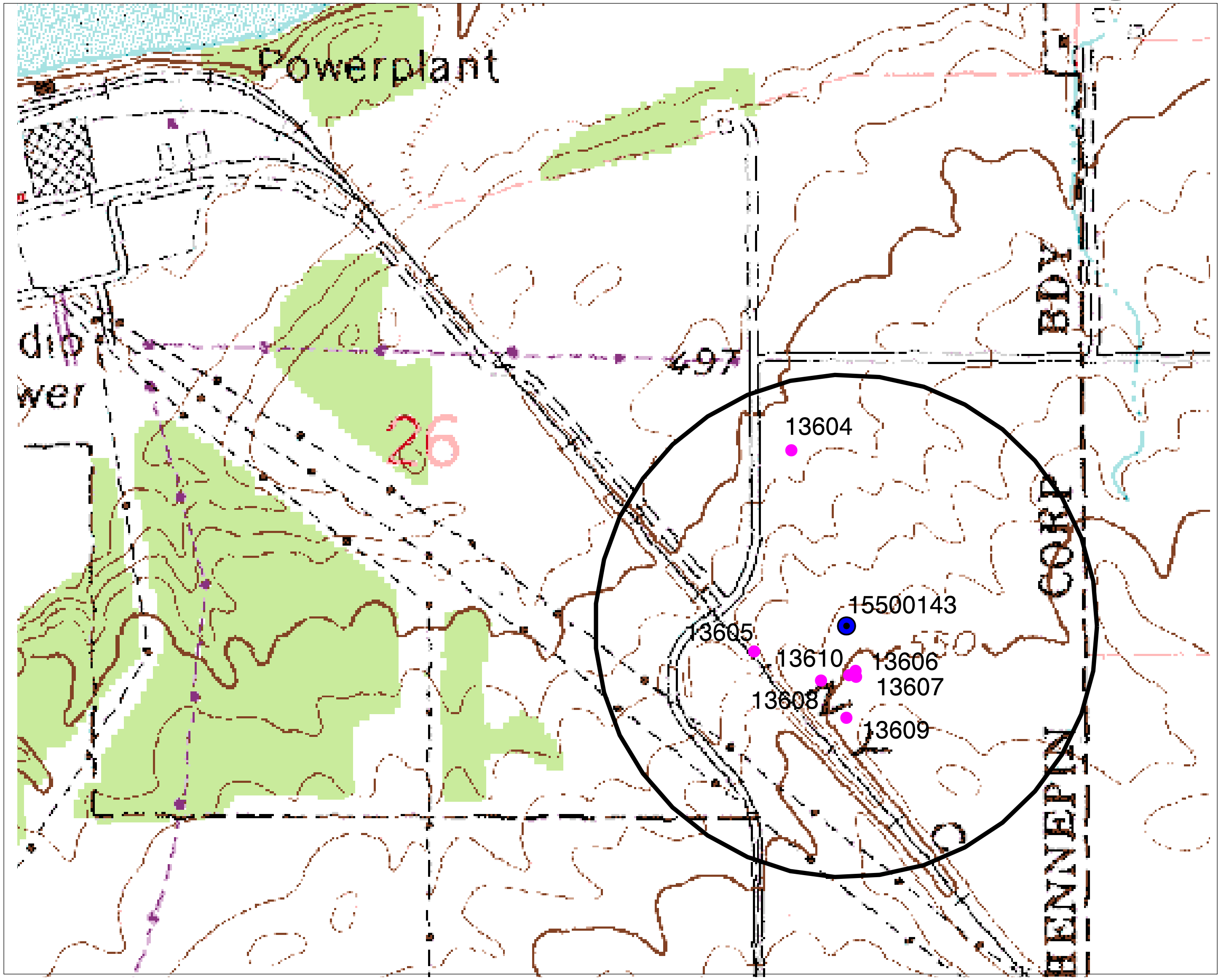
1000 0 1000 Feet

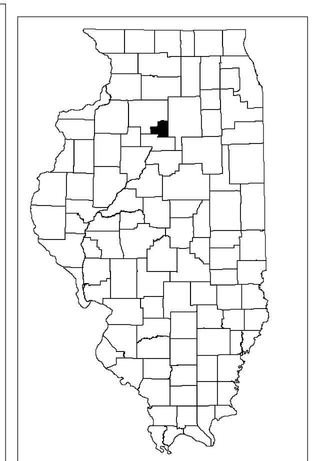
Non-Community Water Supply Wells

Illinois Environmental Protection Agency
Division of Public Water Supplies
Groundwater Section

Illinois Department of Public Health

Topographic Map Coverage
Exolon Non-Community Well





N

Potential_	Potential_	Source_id_
Exolon	Lagoon on-site	13604
Exolon	Single Unit Septic	13605
Exolon	A.G. L.P. < 25000 gal.	13606
Exolon	A.G. Pet Stor < 25000 gal.	13607
Exolon	Electrical Generator/Subs	13608
Exolon	A.G. Pet Stor	13609
Exolon	B.G. Pet Stor > 500 gal	13610

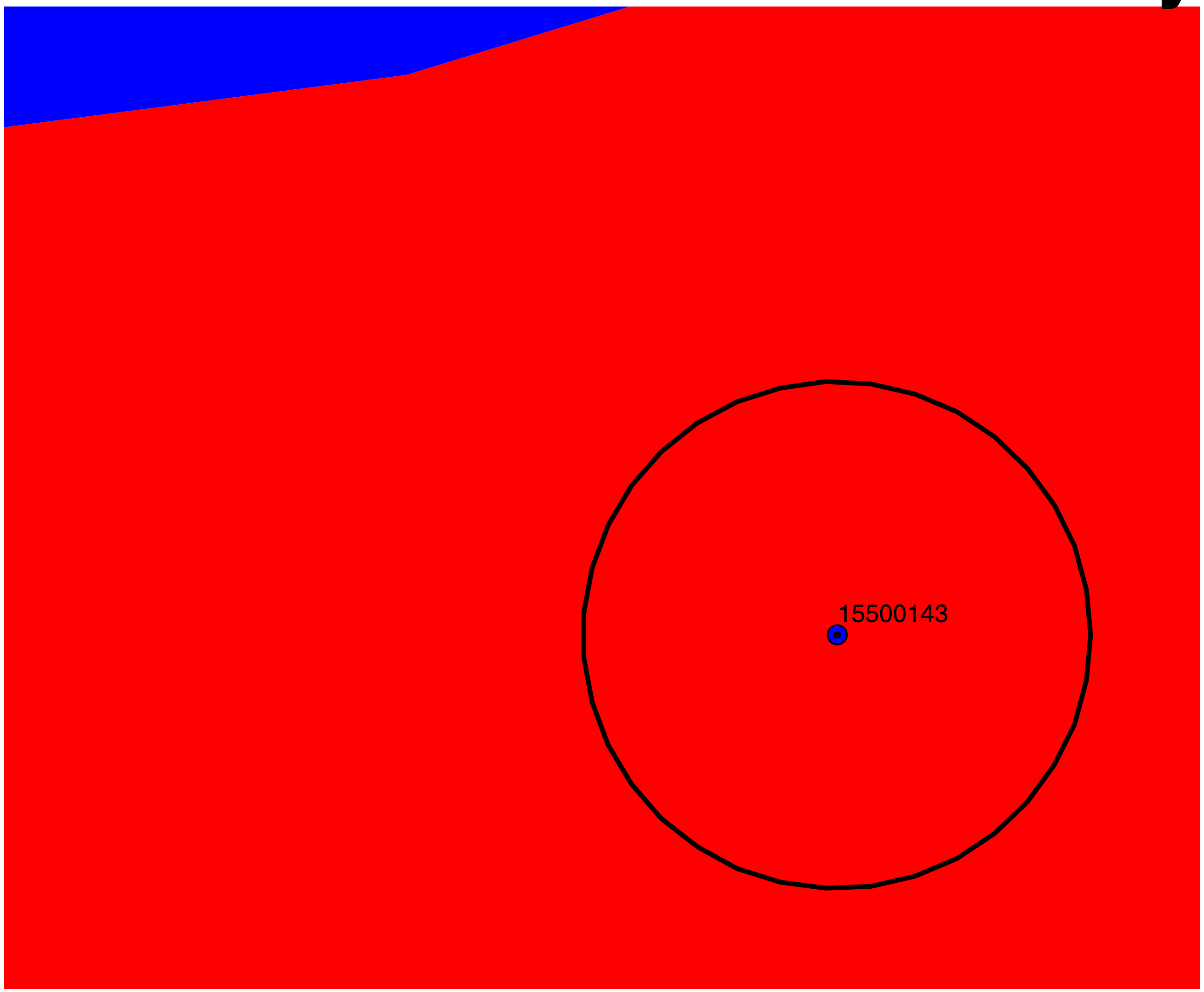
- Non-Community Water Supply Wells
- Potential Sources of Contamination

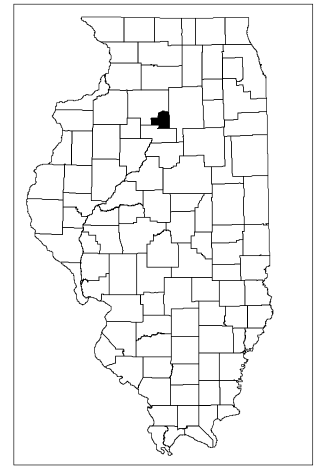
Illinois Environmental Protection Agency
Division of Public Water Supplies
Groundwater Section

Illinois Department of Public Health

1000 0 1000 2000 3000 4000 Feet

Nitrate Sensitivity
Exolon Non-Community Well





N

Disclaimer: This nitrate sensitivity data is being used at a scale smaller than at which it was digitized. This may make features look angular or rasterized, or may make them appear to be out of place. This map should be used as a general reference only, and a smaller scale assessment should be performed for further evaluation of this site.

Non-Community Water Supply Wells

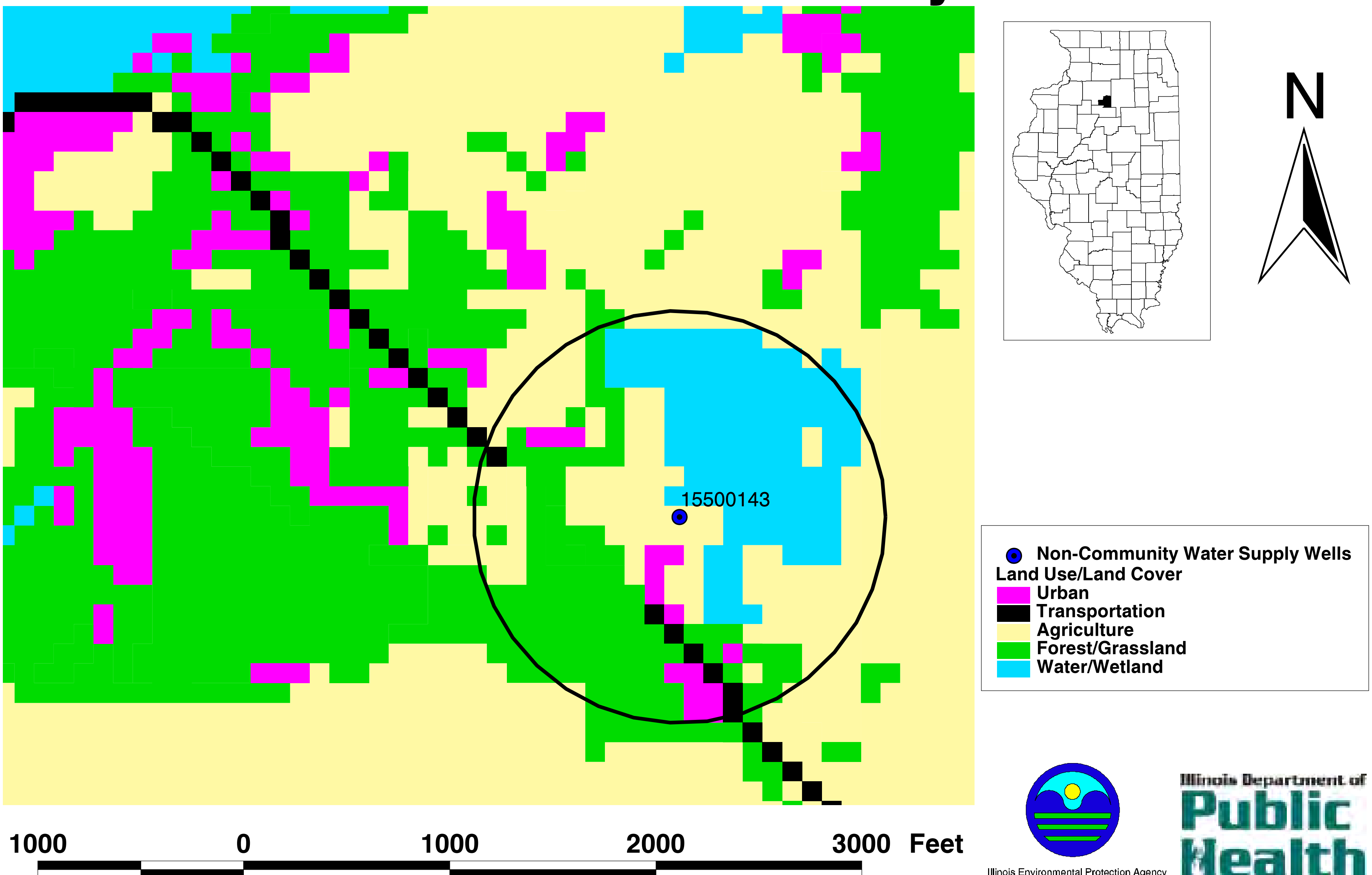
Nitrate Sensitivity
- **Excessive**
- **High**
- **Moderate**
- **Somewhat Limited**
- **Limited**
- **Very Limited**
- **Disturbed Land**
- **Surface Water**

1000 0 1000 2000 3000 Feet

Illinois Environmental Protection Agency
Division of Public Water Supplies
Groundwater Section

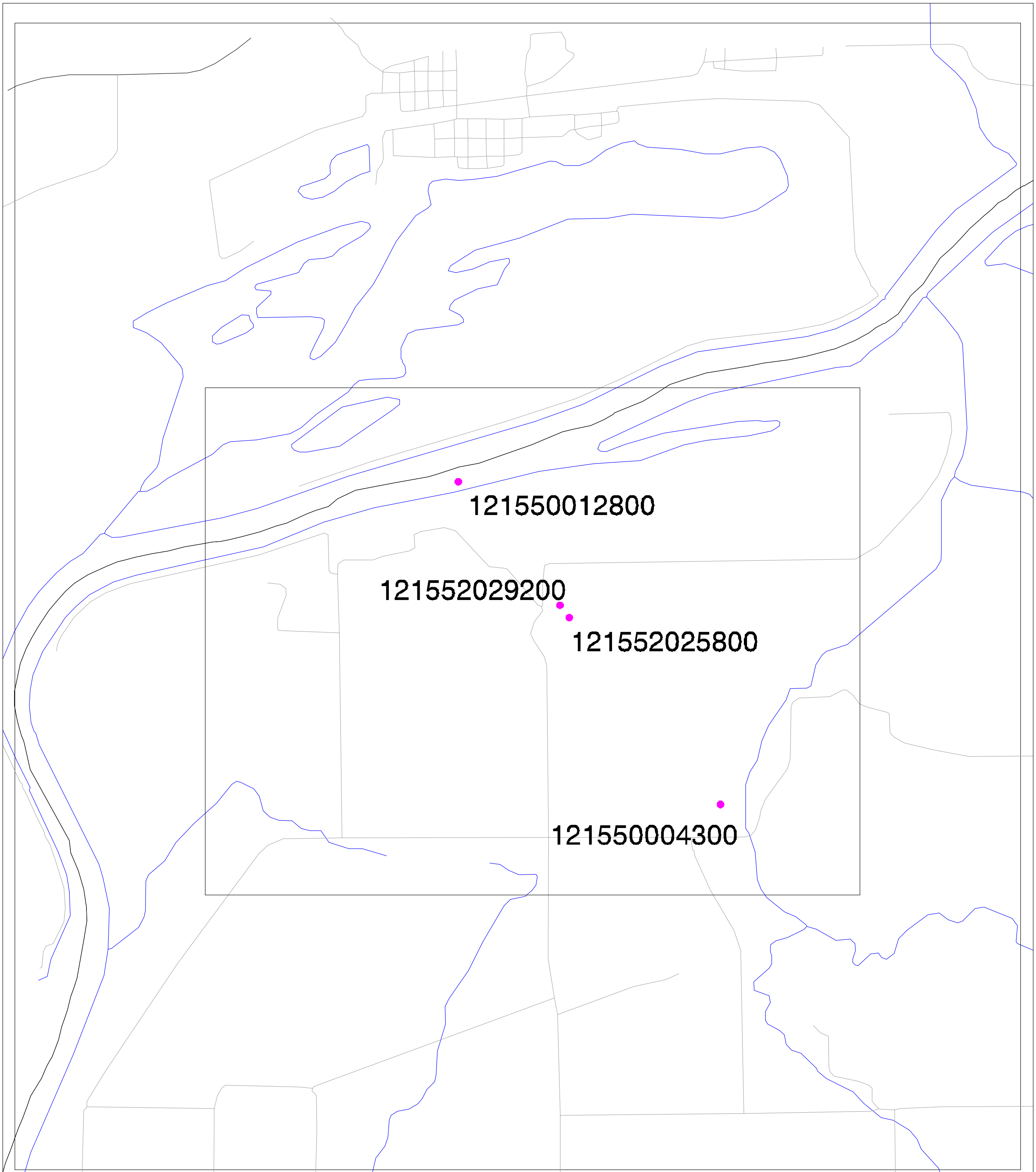
Illinois Department of Public Health

Land Use/Land Cover
Exolon Non-Community Well



Illinois Environmental Protection Agency
Division of Public Water Supplies
Groundwater Section

Illinois Department of Public Health



N

Scale

1:30011

Illinois Geographic-Lithologic Analysis Support System

I-GLASS

Use of this map is restricted to Illinois EPA Staff.
The IEPA is not liable for any misinterpretation of these data by non-IEPA staff.

This map contains information derived from tabular and spatial datasets obtained from the Illinois State Geological Survey, the Illinois State Water Survey, the Illinois Department of Natural Resources, and the United States Geological Survey.

Illinois EPA
Division of Public Water Supplies
Groundwater Section

Illinois Department of Public Health

Illinois Environmental Protection Agency

Source Water Assessment Program

FACT SHEET

DE PUE

BUREAU COUNTY

Prepared in cooperation with the U.S. Geological Survey.

Information and data used in the preparation of this Fact Sheet are provided by the Illinois EPA and are subject to revision.

IMPORTANCE OF SOURCE WATER:

The Village of DePue (Facility Number 0110300) has two public water supply wells. Wells #2 and #3 (IEPA #11336 and #11337) produce 176,300 gallons per day on average to an estimated population of 1729 through 710 service connections.

WATER SUPPLIES THAT OBTAIN SOURCE WATER FROM THIS FACILITY:

As of January 2001, no other facilities purchase water from this community water supply.

SOURCE OF WATER SUPPLY:

Wells #2 and #3 are located behind the waterworks on 2nd Street. Wells #2 and #3 pump 220 and 250 gallons per minute, respectively, and have a production capacity of 288,000 gallons per day. Wells #2 and #3 are 1487 and 1490 feet deep, respectively, and utilize a deep bedrock aquifer. The bedrock is overlain by permeable river deposits and impermeable bedrock. The aquifer utilized is considered confined by the Illinois EPA, therefore is not considered geologically sensitive.

WELL DATA FOR THIS FACILITY:

Well ID	Well Description	Status	Depth (Feet)	Min Setback (Feet)	Aquifer Description
11336	WELL 2	A	1487	200	DEEP BEDROCK
11337	WELL 3	A	1490	200	DEEP BEDROCK

SOURCE WATER QUALITY:

The public water supply wells at DePue were sampled as part of a Statewide Groundwater Monitoring Network on March 12, 1987. The well samples were analyzed for volatile organic compounds (VOC) and inorganic chemicals (IOC). The analyses detected no quantifiable levels of VOC in either well. The inorganic analyses performed found the water from both wells to meet all groundwater quality standards established in 35 Illinois Administrative Code Part 620.410.

FINISHED WATER QUALITY:

Finished water quality data tables of monitored parameters, contaminants detected, health advisory information, drinking water standards or maximum contaminant levels are available at http//www.epa.gov/ogwdw. Similar information is also available in the Consumer Confidence Report supplied by the water supply to its customers. A review of this information does not indicate levels of organic or inorganic compounds which exceed the drinking water quality standards. Radium and Alpha emitters were detected in radionuclide analyses done in 1999. Alpha emitters were detect at a level of 15 pCi/l and combined radium was detected at a level of 6.9 pCi/l, the maximum contaminant levels (MCL) are 15 and 5 pCi/l respectively.

POTENTIAL SOURCES OF CONTAMINATION:

The site labeled on the Wellhead Protection Planning Map and described in the following table is considered a "potential" source of contamination. (Maps and tables are not available in the Visually Impaired version. However, the information presented in these maps and tables is summarized within the following text sections of this fact sheet.) The Illinois EPA performed a detailed well Site Survey in 1989 to identify potential sources of contamination to the village's wells. These sources are identified based on the nature of its activity, the availability of data in the electronic data bases, and its geographical proximity to the source water protection area. In addition, the Illinois EPA made use of its information from the its leaking underground storage tank database (http://epadata.epa.state.il.us/land/ust/search.asp) and site remediation program database (http://epadata.epa.state.il.us/land/srp/search.asp) to further assess potential sources of contamination to the community's source water. These databases include information from the Illinois EPA Division of Land Pollution Control (LPC) and the Illinois Emergency Management Agency (IEMA). The following list of facilities contained within these databases. As a result of multiple possible contamination sources, individual sites may be listed on the table more than once in relation to the wells.

IEMA #900361 - LPC #0110300003 - Mobil Chemical Company, Depot & Marquette Streets., Depue 61322

SITE DATA FOR THIS FACILITY:

Well ID	Map Code	Site Name	Site Description	Distance (Feet)
11336	02556	CASEY'S GENERAL STORE	BELOW GROUND STORAGE (PET	975
11337	02556	CASEY'S GENERAL STORE	BELOW GROUND STORAGE (PET	975

OTHER IDENTIFIED POTENTIAL SOURCES:

For this community water supply, no additional potential sources of contamination have been identified beyond those in Illinois EPA databases.

SUSCEPTIBILITY TO CONTAMINATION:

Based on information obtained in a Well Site Survey published in 1989 by the Illinois EPA, one "potential" source is located within 1,000 feet of the wells.

The Illinois EPA has determined that the Depue Community Water Supply's source water is not suspectibile to contamination. This determination is based on a number of including: monitoring conducted at the wells; monitoring conducted at the entry point to the distribution system; available hydrogeologic data on the wells; and land use proximite to the wells.

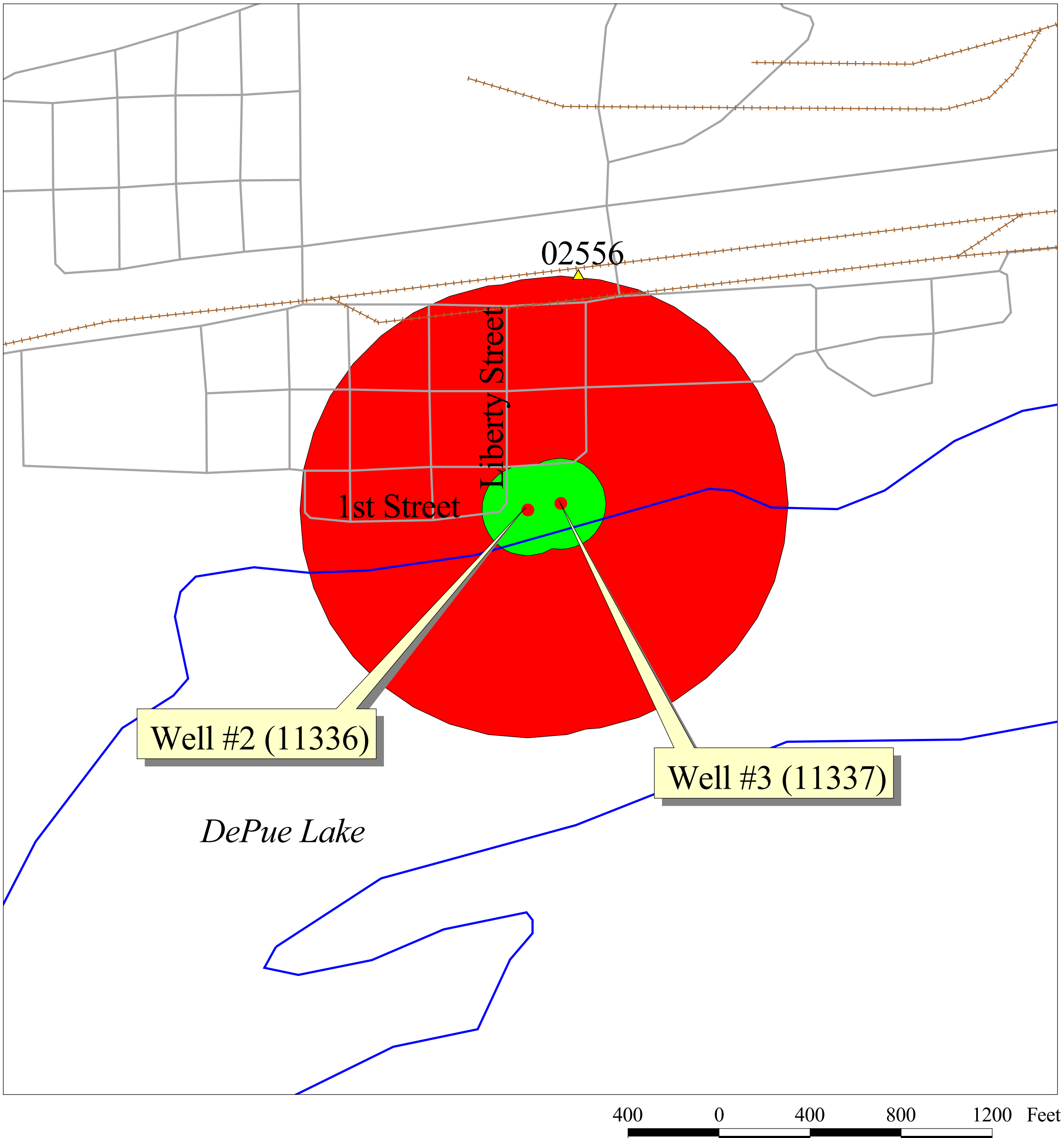
Furthermore, in anticipation of the U.S. EPA's proposed Ground Water Rule, the Illinois EPA has determined that the Depue Community Water Supply is not vulneraible to viral contamination. This determination is based upon the evaluation of the following criteria during the Vulnerability Waiver Process: the community's wells are properly constructed with sound integrity and proper siting conditions; a hydrogeologic barrier exists which should prevent pathogen movement; all potential routes and sanitary defects have been mitigated such that the source water is adequately protected; monitoring data did not indicate a history of disease outbreak; and the sanitary survey of the water supply did not indicate a viral contamination threat. Because the community's wells are constructed in a confined aquifer, which should prevent the movement of pathogens into the wells, well hydraulics was not considered to be a significant factor in the susceptibility determination.

SOURCE WATER PROTECTION EFFORTS:

The Ilinois Environmental Protection Act provides minimum protection zones of 200 feet for your wells. These minimum protection zones are regulated by the Illinois EPA. To further reduce the risk to source water, the water supply has implemented a wellhead protection program which includes the proper abandonment of potential routes of groundwater contamination and correction of sanitary defects at the water treatment facility. This effort resulted in the community water supply receiving a special exception permit from the Illinois EPA which allows a reduction in monitoring. The outcome of this monitoring reduction has saved the community considerable laboratory analysis costs.

To further minimize the risk to the community's groundwater supply, the Illinois EPA recommends that three additional activities be assessed. First, the facility may wish to enact a "maximum setback zone" ordinance. These ordinances are authorized by the Illinois Environmental Protection Act and allow county and municipal officials the opportunity to provide additional protection up to a fixed distance, normally 1,000 feet from their wells. Second, the water supply staff may wish to revisit their contingency planning documents. Contingency planning documents are a primary means to ensure that, through emergency preparedness, a community will minimize their risk of being without safe and adequate water. Finally, the water supply staff is encouraged to review their cross connection control program to ensure that it remains current and viable. Cross connections to either the water treatment plant (for example, at bulk water loading stations) or in the distribution system may negate all source water protection initatives provided by the community.

WELLHEAD PROTECTION PLANNING MAP FOR DEPUE (FACILITY #0110300)



Legend

- CWS Wells
- Potential Sources Of Contamination
- Rails
- Roads
- Streams
- Minimum Setback Zone
- Existing or Potential Maximum Setback Zone

FOR MORE INFORMATION CONTACT:

Groundwater Section, Bureau of Water
Illinois Environmental Protection Agency
1021 North Grand Avenue East
Springfield, IL 62794-9276
Ph# (217)785-4787

Source Information
Roads, Rails, and Streams from Illinois DNR.
CWS Wells and Potential Sources from Illinois EPA.
Map compiled by Groundwater Section, Illinois EPA.

Illinois Environmental Protection Agency

Source Water Assessment Program

FACT SHEET

HENNEPIN PWD

PUTNAM COUNTY

Prepared in cooperation with the U.S. Geological Survey.

Information and data used in the preparation of this Fact Sheet are provided by the Illinois EPA and are subject to revision.

IMPORTANCE OF SOURCE WATER:

The Village of Hennepin (Facility Number 1555100) obtains its water from three active community water supply wells. Wells #3, #4, and #5 (Illinois EPA #11602, 11603, and 11604, respectively) supply an average of 149,600 gallons per day (gpd) to 312 services or a population of 750.

WATER SUPPLIES THAT OBTAIN SOURCE WATER FROM THIS FACILITY:

No connected water supplies existed at the time this Source Water Assessment fact sheet was completed.

SOURCE OF WATER SUPPLY:

Wells #3 and #4 are located at the central and southern end of Hennepin, respectively, and well #5 is located north of Hennepin. They produce 250, 400, and 650 gallons per minute (gpm), respectively and are operated for a combined maximum output of roughly 341,900 gpd. Wells #3, #4, and #5 are 100, 107, and 135 feet in depth, respectively. All three wells obtain their source water from a shallow, permeable sand and gravel aquifer overlain by materials of variable permeability. Permeability is a measure of the capability of a soil or sediment to transmit fluids. The Illinois EPA considers these wells to be geologically sensitive.

WELL DATA FOR THIS FACILITY:

Well ID	Well Description	Status	Depth (Feet)	Min Setback (Feet)	Aquifer Description
11602	WELL 3	A	100	400	Sand & Gravel
11603	WELL 4	A	107	400	Sand & Gravel
11604	WELL 5	A	135	400	Sand & Gravel

SOURCE WATER QUALITY:

Hennepin's wells have been sampled since January 20, 1981 for inorganic chemicals (IOC), volatile organic compounds (VOC), and synthetic organic compounds (SOC) as part of a Statewide Groundwater Monitoring Program. The VOC and SOC analyses did not detect quantifiable levels of any organic compounds. IOC analyses indicate that concentrations of these chemicals are consistent with other sand and gravel aquifers of similar character in Illinois. It is important to note that the IOC results were below the groundwater quality standards established under 35 Illinois Administrative Code Part 620.410, with the exception of manganese concentrations. Manganese concentrations range from 15 to 339 parts per billion (ppb). The groundwater quality standard for manganese, as established under Part 620.410, is 150 ppb. However, the Illinois EPA considers the elevated level of manganese to be the result of natural mineralization of the aquifer. Hence, the level of manganese is not considered a violation due to the stipulation in Part 620.410 that no violation occurs as a result of a natural occurrence of an IOC.

FINISHED WATER QUALITY:

As referenced in the Source Water Quality Section of this report, Hennepin has mineralized groundwater. Sampling performed after treatment indicates that levels of manganese in the source water have been reduced to below the drinking water standards. Further information on finished water quality data tables of monitored parameters, contaminants detected, health advisory information, drinking water standards and maximum contaminant levels are available at http://www.epa.gov/ogwdw/. Similar information is also available in the Consumer Confidence Report supplied by the Village of Hennepin to their customers.

POTENTIAL SOURCES OF CONTAMINATION:

The sites labeled on the Wellhead Protection Planning Map and described in the following tables are considered "potential" sources of contamination. (Maps and tables are not available in the Visually Impaired Accessible version. However, the information presented in the maps and tables is summarized within the following text sections of this fact sheet.) These sites are predominantly identified through the Illinois EPA's Well Site Survey program based on the nature of their activity, the availability of data in electronic databases, and their geographic proximity to the source water protection area. In addition, the Illinois EPA made use of the information from its leaking underground storage tank database (http://epadata.epa.state.il.us/land/ust/search.asp) and site remediation program database (http://epadata.epa.state.il.us/land/srp/search.asp) to further assess potential sources of contamination to the village's source water. These databases include information from the Illinois EPA Division of Land Pollution Control (LPC) and the Illinois Emergency Management Agency (IEMA). The following is a list of facilities contained within these databases. As a result of multiple possible contamination sources, individual sites may be listed in the table more than once in relation to a well.

IEMA # Site Name Street City ZIP Code
902789 Illinois Power Co. Power Station, 2 miles north of Hennepin 61327
921595 Putnam County C.U.S.D. #535 South 5th St., Elemetary School Hennepin 61327
923676 Illinois Power Co. Power Plant Rd. Hennepin 61327

SITE DATA FOR THIS FACILITY:

Well ID	Map Code	Site Name	Site Description	Distance (Feet)
11602	23251	PUTNAM COUNTY SHERIFF'S OF	ABOVE GROUND STORAGE (PET	350
11602	23250	JUDD CONSTRUCTION COMPAN	ABOVE GROUND STORAGE (PET	1800
11602	23252	HENNEPIN MARINE	BOAT YARD	800
11602	23253	HENNEPIN HARDWARE	STORE/SALES	900
11602	23254	HENNEPIN BOAT MARKET	ABOVE GROUND STORAGE (PET	750
11603	23250	JUDD CONSTRUCTION COMPAN	ABOVE GROUND STORAGE (PET	1300
11603	23254	HENNEPIN BOAT MARKET	ABOVE GROUND STORAGE (PET	1650
11603	23251	PUTNAM COUNTY SHERIFF'S OF	ABOVE GROUND STORAGE (PET	800
11603	23252	HENNEPIN MARINE	BOAT YARD	1450
11603	23253	HENNEPIN HARDWARE	STORE/SALES	1750
11604	23255	MODERN HARD CHROME	MANUFACTURING PROCESS (e.g.	500
11604	23256	AIR PRODUCTS	CHEMICAL HANDLING (i.e. MANU	1400
11604	23249	INTERNATIONAL STEEL GROUP	WATER TREATMENT PLANT	1600
11604	23248	INTERNATIONAL STEEL GROUP	INJECTION WELL (ROUTE)	1200
11604	23247	INTERNATIONAL STREEL GROU	SLUDGE DISPOSAL ON-SITE	650
11604	01434	LTV STEEL CO	SLUDGE DISPOSAL ON-SITE	650
11604	01435	LTV STEEL CO	INJECTION WELL (ROUTE)	1200
11604	22477	LTV STEEL WWTP	WATER TREATMENT PLANT	1600

OTHER IDENTIFIED POTENTIAL SOURCES:

For this community water supply, no additional potential sources of contamination have been identified beyond those in Illinois EPA databases.

SUSCEPTIBILITY TO CONTAMINATION:

To determine Hennepin's susceptibility to groundwater contamination, the Illinois Rural Water Association conducted a well site survey in October, 2002. Based on the information obtained in this document, there are 13 potential sources of groundwater contamination that could pose a hazard to groundwater utilized by Hennepin's community water supply. These include 1 chemical handling facility, 1 manufacturing process, 1 boat yard, 1 sales store, 2 onsite sludge disposals, 2 injection wells, 2 water treatment plants, and 3 above ground fuel storage tanks. In addition, information provided by the Leaking Underground Storage Tank and Remedial Project Management Sections of the Illinois EPA indicated sites with on-going remediation that might be of concern.

According to the Hennepin PWD facility, LTV Steel Co. and the associated injection well and water treatment plant have been sold to the International Steel Group. However, the sludge disposal associated with this site is no longer active.

Based upon this information, the Illinois EPA has determined that the Hennepin Community Water Supply's source water is susceptible to contamination. As such, the Illinois EPA has provided 5-year recharge area calculations for the wells. The land use within the recharge areas of the wells was analyzed as part of this susceptibility determination. This land use includes residential, commercial and agricultural properties.

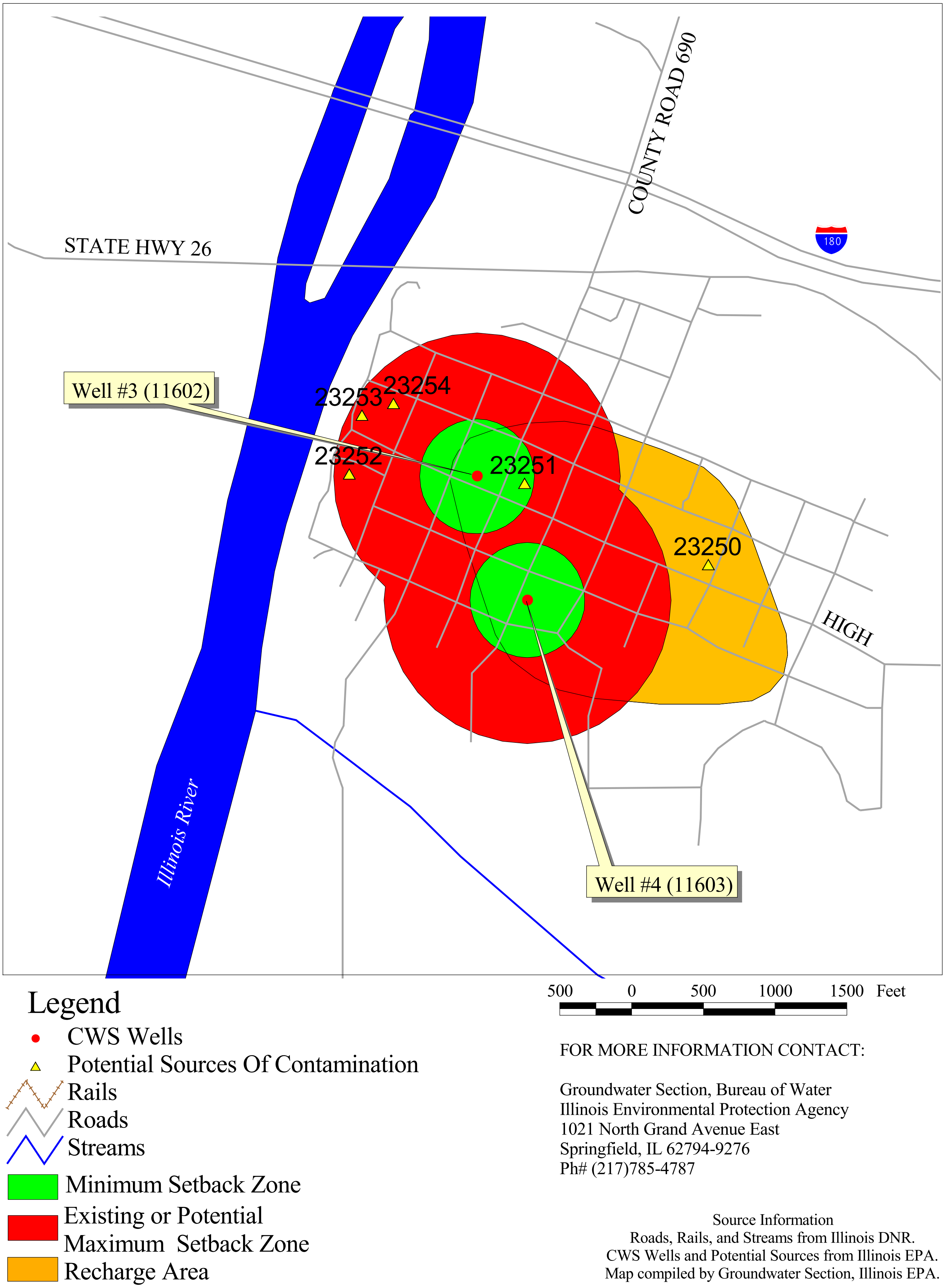
SOURCE WATER PROTECTION EFFORTS:

The Illinois Environmental Protection Act provides minimum protection zones of 400 feet for Hennepin's wells. These minimum protection zones are regulated by the Illinois EPA. To further reduce the risk to the source water, a maximum protection zone may be established, which is authorized by the Illinois Environmental Protection Act and allows county and municipal officials the opportunity to provide additional potential source prohibitions up to 1,000 feet from their wells.

To further minimize the risk to the village's groundwater supply, the Illinois EPA recommends the following additional activities be considered. First, the water supply staff may wish to conduct contingency planning. Contingency planning documents are a primary means to ensure that, through emergency preparedness, a community will minimize their risk of being without safe or adequate water. Second, the water supply staff is encouraged to conduct a biennial cross connection survey of the distribution system as outlined in the cross connection control ordinance [Section 18 of the Environmental Protection Act 415 ILCS 5/1 et seq. (Act); 35 Illinois Act Code, Sections 607.104d, 653.801c] and to review their cross connection control ordinance to ensure that it remains current and viable. Cross connections to either the water treatment plant (for example, at bulk water loading stations) or in the distribution system may negate all source water protection initiatives. Finally, the Illinois EPA recommends that the village investigate additional source water protection management options to address the land use activities within the wells' recharge area. Specifically, these management options should address potential impacts from non-point sources related to agricultural land uses.

To further reduce the risk to source water, Hennepin may wish to implement a wellhead protection program, which includes the proper abandonment of potential routes of groundwater contamination within the recharge area, management of potential sources of contamination and correction of any sanitary defects that might be present at the water treatment facility. This effort may result in the community water supply receiving a special exception permit from the Illinois EPA, which allows a reduction in monitoring and laboratory analysis costs.

FIGURE 1: WELLHEAD PROTECTION PLANNING MAP FOR HENNEPIN (FACILITY #1555100)

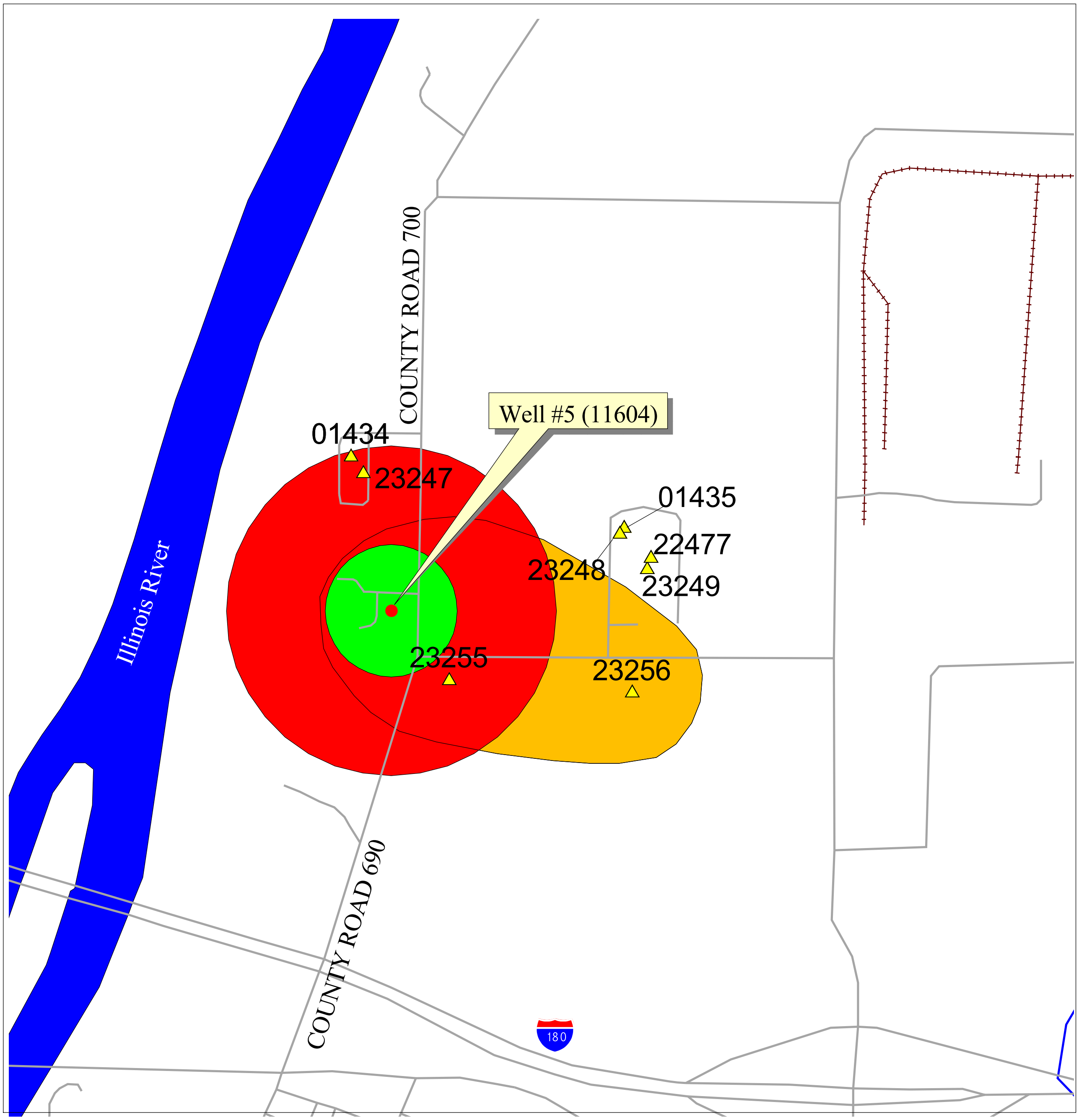


FOR MORE INFORMATION CONTACT:

Groundwater Section, Bureau of Water
Illinois Environmental Protection Agency
1021 North Grand Avenue East
Springfield, IL 62794-9276
Ph# (217)785-4787

Source Information
Roads, Rails, and Streams from Illinois DNR.
CWS Wells and Potential Sources from Illinois EPA.
Map compiled by Groundwater Section, Illinois EPA.

FIGURE 2: WELLHEAD PROTECTION PLANNING MAP
FOR HENNEPIN (FACILITY #1555100)



Legend
- CWS Wells
- Potential Sources Of Contamination
- Rails
- Roads
- Streams
- Minimum Setback Zone
- Existing or Potential Maximum Setback Zone
- Recharge Area

500 0 500 1000 1500 Feet

FOR MORE INFORMATION CONTACT:

Groundwater Section, Bureau of Water
Illinois Environmental Protection Agency
1021 North Grand Avenue East
Springfield, IL 62794-9276
Ph# (217)785-4787

Source Information
Roads, Rails, and Streams from Illinois DNR.
CWS Wells and Potential Sources from Illinois EPA.
Map compiled by Groundwater Section, Illinois EPA.

Illinois Environmental Protection Agency

Source Water Assessment Program

FACT SHEET

BUREAU JUNCTION

BUREAU COUNTY

Prepared in cooperation with the U.S. Geological Survey.

Information and data used in the preparation of this Fact Sheet are provided by the Illinois EPA and are subject to revision.

IMPORTANCE OF SOURCE WATER:

The Village of Bureau Junction (Facility Number 0110150) has two public water supply wells. Wells #4 (Illinois EPA #11327) and #5 (Illinois EPA #00729) produce 32,088 gallons per day on average to an estimated population of 340 through 131 service connections.

WATER SUPPLIES THAT OBTAIN SOURCE WATER FROM THIS FACILITY:

No connected water supplies existed at the time this Source Water Assessment fact sheet was completed.

SOURCE OF WATER SUPPLY:

Well #4 is located on Kansas Street between Miller and North Streets. Well #5 is located 300 feet northeast of Well #4. The water from both wells is blended and treated before distribution. Wells #4 and #5 pump 50 and 190 gallons per minute, respectively and the facility has a production capacity of 345,600 gallons per day. Well #4 is 334 feet deep and utilizes a shallow bedrock aquifer and Well #5 is 1,545 feet deep and utilizes a deep bedrock aquifer which are overlain by permeable alluvial deposits and bedrock formations of variable permeability. Permeability is the ability of a soil or sediment to transmit fluids. Permeability is a measure of the ability of a soil or sediment to transmit fluids. Both aquifers utilized are considered confined by the Illinois EPA, therefore are not considered geologically sensitive.

WELL DATA FOR THIS FACILITY:

Well ID	Well Description	Status	Depth (Feet)	Min Setback (Feet)	Aquifer Description
00729	WELL 5	A	1545	200	Cambrian/Ordovician
11326	WELL 2	B	305	400	Devonian/Silurian
11327	WELL 4	A	334	200	Devonian/Silurian

SOURCE WATER QUALITY:

The Well #4 at Bureau Junction has been sampled regularly as part of a Statewide Ambient Groundwater Monitoring Program since March 1, 1994. Well #5 was sampled in 1997. The samples were analyzed for volatile organic compounds (VOC) and inorganic chemicals (IOC). Well #4 has been sampled for synthetic organic chemical and pesticides (SOC). The VOC analyses detected no contaminants. The IOC analyses have indicated a elevated level of chlorides, which is naturally occurring. The IOC results show levels up to 796 part per billion (ppb) in Well #4, and 201 in Well #5, which is above the groundwater standard of 200 ppb. At this time there is no drinking water standard for chlorides established in 35 Illinois Administrative Code Part 620.410. The Illinois EPA considers these chlorides concentrations the result of natural mineralization in the aquifer.

FINISHED WATER QUALITY:

Further information on finished water quality, including data tables of monitored parameters, contaminants detected, health advisory information, drinking water standards and maximum contaminant levels is available at http//www.epa.gov/ogwdw. Similar information is also available in the Consumer Confidence Report supplied by the water supply to its customers. A review of this information does not indicate levels of organic compounds or inorganic chemicals which exceed the drinking water quality standards. Radium were detected in radio nuclide analyses done in 1999. Alpha emitters were detected at a levels ranging from 20 to 23 picoCuries per liter (pCi/l), the maximum contaminant levels (MCL) for combined Alpha emitters is 15 pCi/l. Combined radium was detected at a levels ranging from 4.7 to 8.8 picoCuries per liter (pCi/l), the maximum contaminant levels (MCL) for combined Radium is 5 pCi/l.

POTENTIAL SOURCES OF CONTAMINATION:

The sites labeled on the Wellhead Protection Planning Map and described in the following tables are considered "potential" sources of contamination. (Maps and tables are not available in the Visually Impaired Accessible version. However, the information presented in the maps and tables is summarized within the following text sections of this fact sheet.) The Illinois EPA performed a detailed Well Site Survey in 1994 to identify potential sources of contamination to the water supply's wells. These sources are identified based on the nature of their activity, the availability of data in electronic databases, and their geographic proximity to the source water protection area. In addition, the Illinois EPA made use of information from its leaking underground storage tank database (http://epadata.epa.state.il.us/land/ust/search.asp) and site remediation program database (http://epadata.epa.state.il.us/land/srp/search.asp) to further assess potential sources of contamination to the water supply's source water. These databases include information from the Illinois EPA Division of Land Pollution Control (LPC) and the Illinois Emergency Management Agency (IEMA). The following is a list of facilities contained within these databases. As a result of multiple possible contamination sources, individual sites may be listed in the table more than once in relation to a well.

IEMA # LPC # Site Name Address City ZIP Code
920807 0118995005 Bureau, Village of 101 East Nebraska St. Bureau 61315
992314 0118995011 Bureau Service Co. 107 North Main Bureau 61315

SITE DATA FOR THIS FACILITY:

Well ID	Map Code	Site Name	Site Description	Distance (Feet)
00729	02912	BILL'S GAS & GENERAL STORE	BELOW GROUND STORAGE (PET	650
00729	02913	VILLAGE OF BUREAU VILLAGE H	BELOW GROUND STORAGE (PET	550
00729	02914	UNKNOWN ABANDONED GAS ST	BELOW GROUND STORAGE (PET	750
11327	02913	VILLAGE OF BUREAU VILLAGE H	BELOW GROUND STORAGE (PET	700
11327	02914	UNKNOWN ABANDONED GAS ST	BELOW GROUND STORAGE (PET	850
11327	02912	BILL'S GAS & GENERAL STORE	BELOW GROUND STORAGE (PET	600

OTHER IDENTIFIED POTENTIAL SOURCES:

For this community water supply, no additional potential sources of contamination have been identified beyond those in Illinois EPA databases.

SUSCEPTIBILITY TO CONTAMINATION:

Based on information obtained in a Well Site Survey published in 1994 by the Illinois EPA, several potential secondary sources are located within 1,000 feet of the wells.

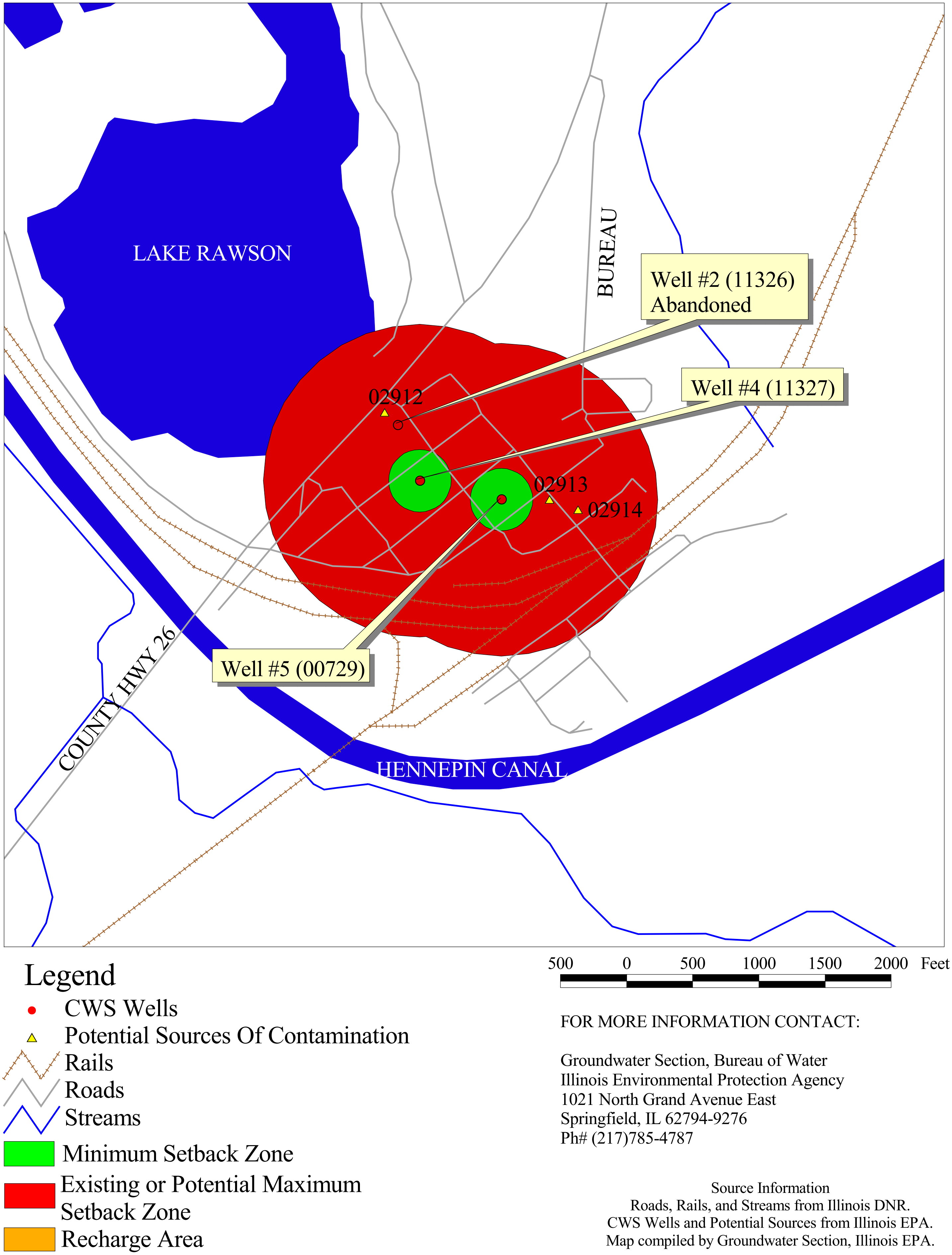
The Illinois EPA has determined that the Bureau Junction Community Water Supply's source water is not susceptible to contamination. This determination is based on a number of criteria including; monitoring conducted at the wells; monitoring conducted at the entry point to the distribution system; and available hydro geologic data on the wells.

SOURCE WATER PROTECTION EFFORTS:

The Illinois Environmental Protection Act provides minimum protection zones of 200 feet for Wells #4 and #5. These minimum protection zones are regulated by the Illinois EPA.

To further minimize the risk to the facility's groundwater supply, the Illinois EPA recommends that three additional activities be assessed. First, the water supply may wish to work with village officials to enact a "maximum setback zone" ordinance. These ordinances are authorized by the Illinois Environmental Protection Act and allow county and municipal officials the opportunity to provide additional protection up to a fixed distance, normally 1,000 feet from their wells. Second, the water supply staff may wish to revisit their contingency planning documents. Contingency planning documents are a primary means to ensure that, through emergency preparedness, a community will minimize their risk of being without safe and adequate water. Finally, the water supply staff is encouraged to review their cross connection control program to ensure that it remains current and viable. Cross connections to either the water treatment plant (for example, at bulk water loading stations) or in the distribution system may negate all source water protection initiatives provided by the community..

FIGURE 1: WELLHEAD PROTECTION PLANNING MAP FOR BUREAU JUNCTION (FACILITY #0110150)



FOR MORE INFORMATION CONTACT:

Groundwater Section, Bureau of Water
Illinois Environmental Protection Agency
1021 North Grand Avenue East
Springfield, IL 62794-9276
Ph# (217)785-4787

Source Information
Roads, Rails, and Streams from Illinois DNR.
CWS Wells and Potential Sources from Illinois EPA.
Map compiled by Groundwater Section, Illinois EPA.

Illinois Environmental Protection Agency

Source Water Assessment Program

FACT SHEET

GRANVILLE

PUTNAM COUNTY

Prepared in cooperation with the U.S. Geological Survey.

Information and data used in the preparation of this Fact Sheet are provided by the Illinois EPA and are subject to revision.

IMPORTANCE OF SOURCE WATER:

The Viallage of Granville (Facility #1550050) has two public water supply wells. Well #1 (IEPA #11590) and Well #2 (IEPA #11591) produce 186,500 gallons per day to an estimated population of 1,402 through 644 service connections. The facility provides water to the Village of Mark and Oak Park Estates MHP.

WATER SUPPLIES THAT OBTAIN SOURCE WATER FROM THIS FACILITY:

Facility Number	Facility Name	Status	Population
1550010	OAK PARK ESTATES	A	150
1550250	MARK	A	500

SOURCE OF WATER SUPPLY:

Well #1 is located at the village garage at the southeast corner of Main and High Streets. Well #2 is located on the south of the intersection of Tomlinson and Colby Streets. Wells #1 and #2 pump 135 and 170 gallons per minute and have a production capacity of 439,200 gallons per day. The wells are 1,742 and 1,782 feet deep and utilize deep bedrock aquifer, which are overlain by relatively impermeable till interbedded within sand and gravel. Permeability is the ability of a soil or sediment to transmit fluids. The aquifer utilized is considered confined by the Illinois EPA, therefore is not considered geologically sensitive.

WELL DATA FOR THIS FACILITY:

Well ID	Well Description	Status	Depth (Feet)	Min Setback (Feet)	Aquifer Description
11590	WELL NO 1 IN CITY GARAGE	A	1742	200	DEEP BEDROCK
11591	WELL NO 2	A	1782	200	DEEP BEDROCK

SOURCE WATER QUALITY:

The public water supply wells at Granville were sampled as part of the Statewide Groundwater Monitoring Network on June 9, 1987. The well samples were analyzed for volatile organic compounds (VOC) and inorganic chemicals (IOC). The VOC analyses performed detected no quantifiable levels of organic chemicals in either well. The IOC analyses performed found the water from both wells to have an elevated level of total chlorides, which is naturally occurring. Total Chloride was detected at a level of 304 and 308 parts per billion (ppb), in Wells #1 and #2, respectively which is above the Groundwater Quality Standards of 200 ppb for chloride established in 35 Illinois Administrative Code Part 620.410.

FINISHED WATER QUALITY:

Finished water quality data tables of monitored parameters, contaminants detected, health advisory information, drinking water standards or maximum contaminant levels are available at http//www.epa.gov/ogwdw. Similar information is also available in the Consumer Confidence Report supplied by the water supply to its customers. A review of this information does not indicate levels of organic or inorganic compounds which exceed the drinking water quality standards. Radium and Alpha emitters were detected in radionuclide analyses done in 1999. Alpha emitters were detect at a level of 39 picoCuries per liter (pCi/l) and combined radium was detected at a level of 12.2 pCi/l, the maximum contaminant levels (MCL) are 15 and 5 pCi/l respectively.

POTENTIAL SOURCES OF CONTAMINATION:

The sites labeled on the Wellhead Protection Planning Map and described in the following tables are considered "potential" sources of contamination. (Maps and tables are not available in the Visually Impaired Accessible version. However, the information presented in the maps and tables is summarized within the following text sections of this fact sheet.) The Illinois EPA performed a detailed Well Site Survey in 1992 to identify potential sources of contamination to the community's wells. These sources are identified based on the nature of their activity, the availability of data in electronic databases, and their geographic proximity to the source water protection area. In addition, the Illinois EPA made use of information from its leaking underground storage tank database (http://epadata.epa.state.il.us/land/ust/search.asp) and site remediation program database (http://epadata.epa.state.il.us/land/srp/search.asp) to further assess potential sources of contamination to the community's source water. These databases include information from the Illinois EPA Division of Land Pollution Control (LPC) and the Illinois Emergency Management Agency (IEMA). The following is a list of facilities contained within these databases. As a result of multiple possible contamination sources, individual sites may be listed in the table more than once in relation to a well.

IEMA # - LPC # - Site Name Address City ZIP Code
20002181 - 1550055009 - Maupin Trucking & Excavating Rt. 71 Granville 61326
901786 - 1550050001 - Salsman, Coy 102 McCoy St. Granville 61326
921597 - 1550055002 - Putnam County C.U.S.D. #535 400 East Silverspoon St. Granville 61326
930911 - 1550050001 - Salsman, Coy 101 South McCoy St. Granville 61326
932022 - 1550055003 - Petro-Line Rt. 89, R.R. 1, Box 36 Granville 61326
941345 - 1550055001 - Mid-American Growers Inc. R.R. 1, Rt. 89 Granville 61326
972212 - 1550055007 - Toedter Oil Co. RFD Rt. 89 1 1/4 Mile South Spring Valley Granville 61326

SITE DATA FOR THIS FACILITY:

Well ID	Map Code	Site Name	Site Description	Distance (Feet)
11590	07317	COYE'S SUNOCO SERVICE	BELOW GROUND STORAGE (PET	350
11590	07318	DONALDSON BUSINESS FORMS	PRINTING	800
11590	07321	OSSOLA CONSTRUCTION CO.	PILES OF MATERIAL (e.g. SAND A	2300
11590	07320	UNKNOWN FORMER GAS STATI	BELOW GROUND STORAGE (PET	2100
11590	07319	UNKNOWN FORMER GAS STATI	BELOW GROUND STORAGE (PET	1000
11591	07318	DONALDSON BUSINESS FORMS	PRINTING	1500
11591	07321	OSSOLA CONSTRUCTION CO.	PILES OF MATERIAL (e.g. SAND A	300
11591	07320	UNKNOWN FORMER GAS STATI	BELOW GROUND STORAGE (PET	775
11591	07319	UNKNOWN FORMER GAS STATI	BELOW GROUND STORAGE (PET	1580
11591	07317	COYE'S SUNOCO SERVICE	BELOW GROUND STORAGE (PET	2000

OTHER IDENTIFIED POTENTIAL SOURCES:

For this community water supply, no additional potential sources of contamination have been identified beyond those in Illinois EPA databases.

SUSCEPTIBILITY TO CONTAMINATION:

Based on information obtained in a Well Site Survey published in 1992 by the Illinois EPA, several potential sources are located within 1,000 feet of the wells.

The Illinois EPA has determined that the Granville Community Water Supply's source water is not suspectibile to contamination. This determination is based on a number of criteria including; monitoring conducted at the wells; monitoring conducted at the entry point to the distribution system; and available hydrogeologic data on the wells.

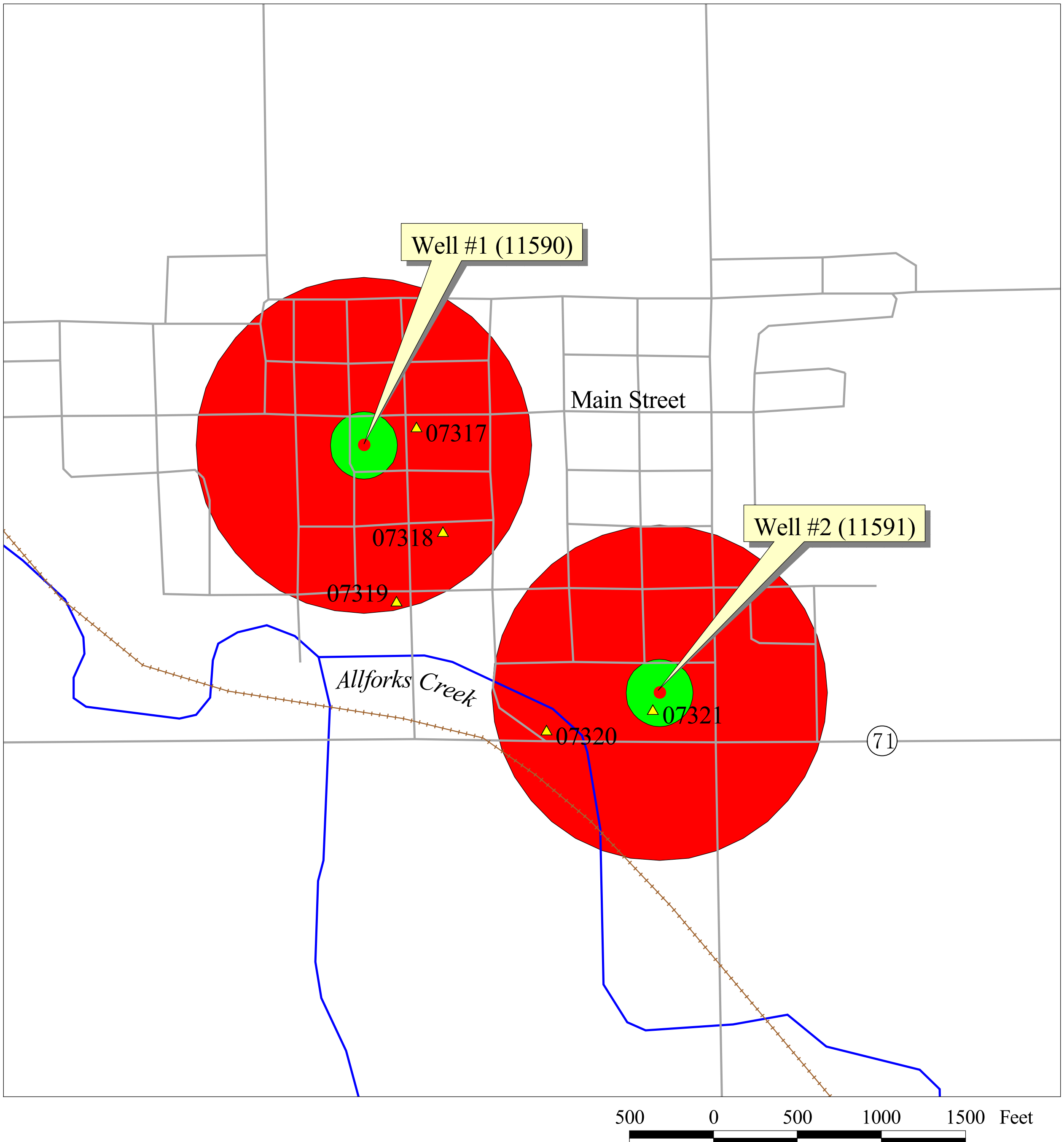
Furthermore, in anticipation of the U.S. EPA's proposed Ground Water Rule, the Illinois EPA has determined that the Granville Community Water Supply is not vulnerable to viral contamination. This determination is based upon the evaluation of the following criteria during the Vulnerability Waiver Process: the community's wells are properly constructed with sound integrity and proper siting conditions; a hydraulic barrier exists which should prevent pathogen movement; all potential routes and sanitary defects have been mitigated such that the source water is adequately protected; monitoring data did not indicate a history of disease outbreak; and the sanitary survey of the water supply did not indicate a viral contamination threat. Because the community's wells are constructed in a confined aquifer, which should prevent the movement of pathogens into the wells, well hydraulics were not considered to be a significant factor in the susceptibility determination. Hence, well hydraulics were not evaluated for this system ground water supply.

SOURCE WATER PROTECTION EFFORTS:

The Illinois Environmental Protection Act provides minimum protection zones of 200 feet for your wells. These minimum protection zones are regulated by the Illinois EPA. To further reduce the risk to source water, the Facility has implemented a wellhead protection program which includes the proper abandonment of potential routes of groundwater contamination and correction of sanitary defects at the water treatment facility. This effort resulted in the community water supply receiving a special exception permit from the Illinois EPA which allows a reduction in monitoring. The outcome of this monitoring reduction has saved the community considerable laboratory analysis costs.

To further minimize the risk to the facility's groundwater supply, the Illinois EPA recommends that three additional activities be assessed. First, the water supply may wish to enact a "maximum setback zone" ordinance. These ordinances are authorized by the Illinois Environmental Protection Act and allow county and municipal officials the opportunity to provide additional protection up to a fixed distance, normally 1,000 feet from their wells. Second, the water supply staff may wish to revisit their contingency planning documents. Contingency planning documents are a primary means to ensure that, through emergency preparedness, a community will minimize their risk of being without safe and adequate water. Finally, the water supply staff is encouraged to review their cross connection control program to ensure that it remains current and viable. Cross connections to either the water treatment plant (for example, at bulk water loading stations) or in the distribution system may negate all source water protection initatives provided by the community.

WELLHEAD PROTECTION PLANNING MAP FOR GRANVILLE (FACILITY #1550050)



Legend

- CWS Wells
- Potential Sources Of Contamination
- Rails
- Roads
- Streams
- Minimum Setback Zone
- Existing or Potential Maximum Setback Zone

FOR MORE INFORMATION CONTACT:

Groundwater Section, Bureau of Water
Illinois Environmental Protection Agency
1021 North Grand Avenue East
Springfield, IL 62794-9276
Ph# (217)785-4787

Source Information
Roads, Rails, and Streams from Illinois DNR.
CWS Wells and Potential Sources from Illinois EPA.
Map compiled by Groundwater Section, Illinois EPA.

Illinois Environmental Protection Agency

Source Water Assessment Program

FACT SHEET

MARK

PUTNAM COUNTY

Prepared in cooperation with the U.S. Geological Survey.

Information and data used in the preparation of this Fact Sheet are provided by the Illinois EPA and are subject to revision.

Illinois EPA PWS Number: **1550250**

For the purpose of the Source Water Assessment Program (SWAP), this community water supply (CWS) purchases water from another CWS. The current procedure for a purchasing water supply indicates that the source water information for this CWS is presented in the SWAP Fact Sheet of the parent supply (the water supply from which the water originates). Therefore, please refer to the parent supply's SWAP Fact Sheet for an assessment of this CWS's source water. The parent CWS for the supply you requested is listed below with its source water type and county. Some CWSs that purchase their water have wells as back-up supplies; however, these wells are not the primary source of water supply and are not considered as part of this assessment program.

INFORMATION FOR THE SOURCE OF THIS FACILITY'S WATER

Parent IEPA Number:	**1550050**
Parent Name:	**GRANVILLE**
Parent Water Type:	**GROUND**
Parent Supply County:	**PUTNAM**

APPENDIX D

RECORD OF COMMUNICATIONS

Stuart Cravens

From: "Bell, Scott S." <Scott.S.Bell@Illinois.gov>
To: <kelron@egix.net>
Cc: "Smet, John" <John.Smet@Illinois.gov>
Sent: Wednesday, March 18, 2009 12:18 PM
Subject: attn Stuart Cravens

According to our records, the only active NCPWS within one mile of Dynegy Hennepin Power Station is Washington Mills (fka Exolon, Esk).

J. Scott Bell, LEHP
Illinois Department of Public Health
Peoria Regional Office
5415 N. University
Peoria, IL 61614
309 693 5373
fax 309 693 5118
scott.s.bell@illinois.gov

Stuart Cravens

From: "Andrea Gress" <agress@bchealthdepartment.org>
To: "Stuart Cravens" <kelron@egix.net>
Sent: Tuesday, March 17, 2009 2:26 PM
Subject: RE: Community and Non-Community Water Supplies - Putnam Counry

Dear Stu,

As far as the non-communities we are responsible for at the local level, none of them are located in that area. However, the state also covers non-community wells in our area because they fall in a different category so I am forwarding this email to our Regional State Health Department in Peoria, IL. The contact is John Smet. Email: john.smet@illinois.gov. Hopefully he will get back to you regarding the non-community wells the state is responsible for.

Sincerely,

Andrea Gress

Andrea Gress, BS, LEHP, REHS/RS
Environmental Health Sanitarian
Bureau-Putnam County Health Department
526 Bureau Valley Parkway
Princeton, IL 61356
Phone: 815-872-5091
Fax: 815-872-5092

From: Stuart Cravens [mailto:kelron@egix.net]
Sent: Thursday, March 12, 2009 9:05 AM
To: Andrea Gress
Subject: Community and Non-Community Water Supplies - Putnam Counry

To: Bureau and Putnam County Health Department

As required by the IEPA, and on behalf of the Hennepin Power Station, located in Putnam County, Illinois (Township 33 North, Range, 2 West, Section 26) Kelron Environmental is conducting a water well survey of potable wells within 1 mile of the property.

I have done the web database searches and obtained information from the IEPA, ISGS, and ISWS and wanted to confirm that there are no community water supply wells within 1 mile of the Hennepin Power Station and the only non-community water supply well(s) are located at the Exolon Corporation in the southeast quarter of Section 26. The IEPA website showed there to be one non-community water supply well on Exolon property used for potable purposes, although there are apparently at least two other wells which may be active or inactive for industrial (non-potable) use.

I would appreciate it if you could confirm this information or provide me with a contact person in your office with whom I can communicate via mail or phone.

Thank you very much.

Stu Cravens, Senior Hydrogeologist

Stuart J. Cravens
Kelron Environmental
kelron@egix.net
217-390-1503 phone

Stuart Cravens

From: "Stuart Cravens" <kelron@egix.net>
To: "John P Augspols" <john_augspols@dynegy.com>
Sent: Tuesday, February 03, 2009 3:12 PM
Attach: Hen Power Plant 2.jpg
Subject: Industrial Well locations

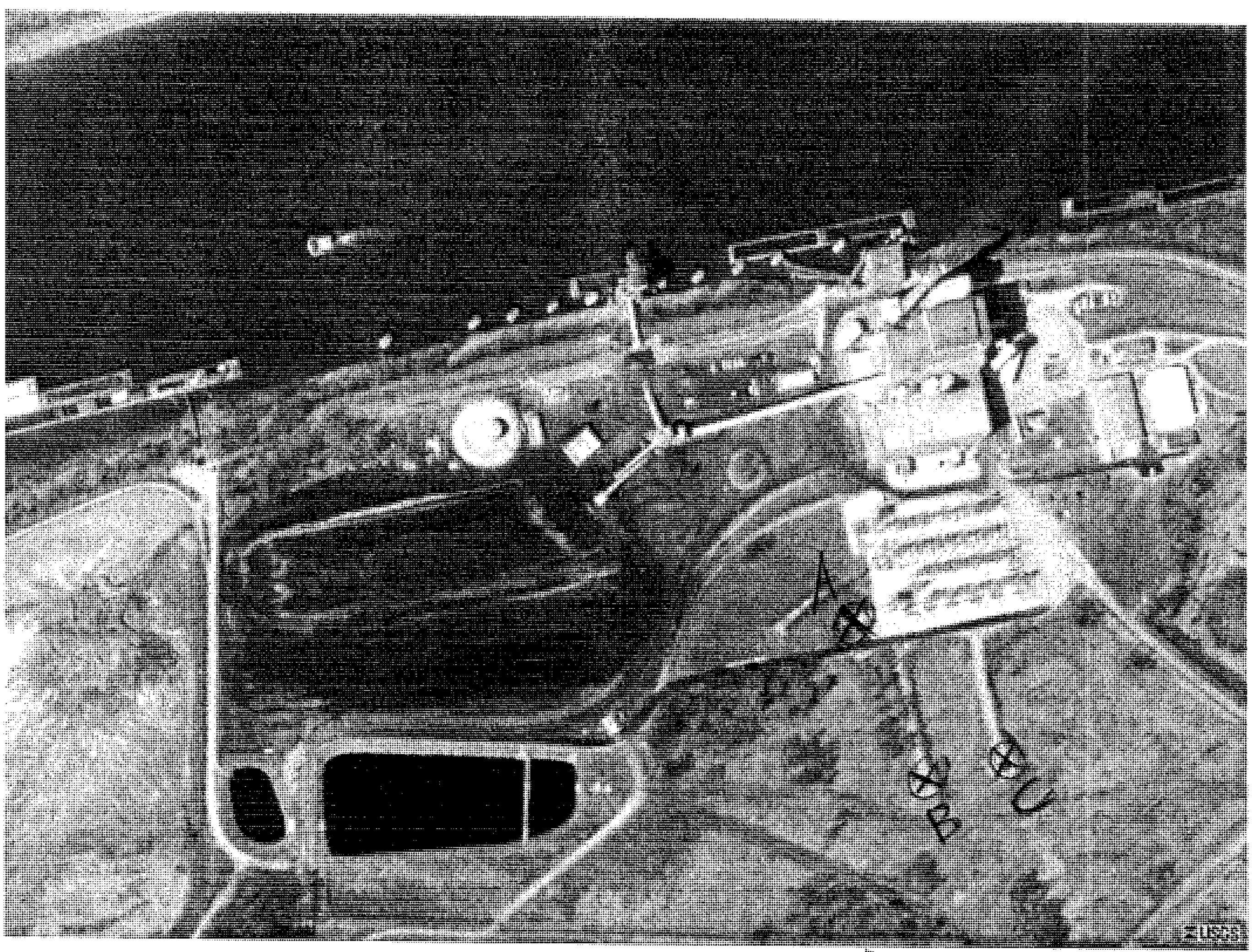
In process!

John,

Are any of your industrial water wells at Hennepin active? Can you show on the attached jpeg map the locations of those wells and their designations? Call if this is a problem or any questions.

Thanks. Stu

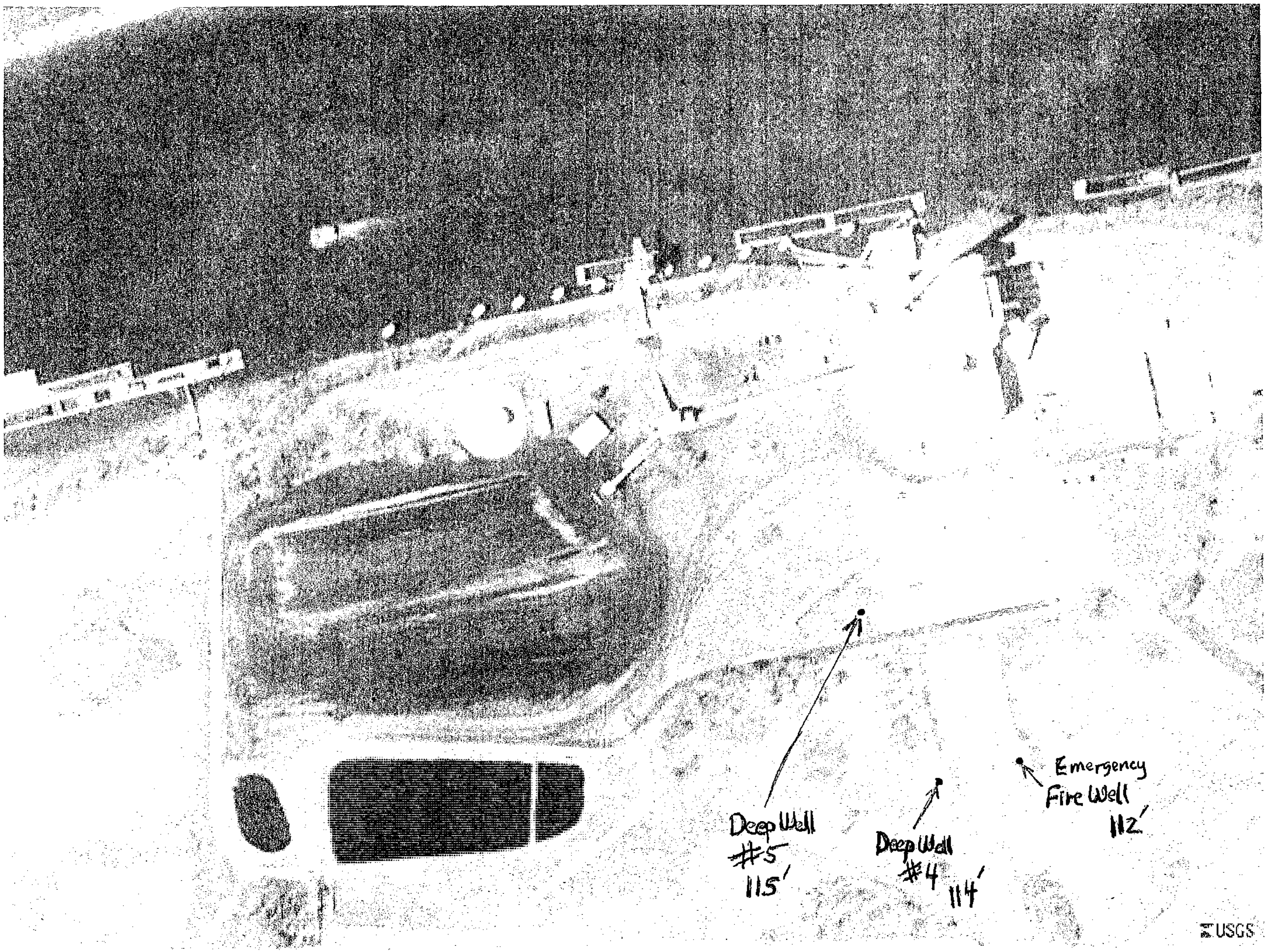
Stuart J. Cravens
Kelron Environmental
kelron@egix.net
217-390-1503 phone



A = Dep well #5 (115') #28

B = Dep well #4 (114') #26

C = Firewell (112') ?#29?


Emergency Fire Well 112'
Deep Well #5 115'
Deep Well #4 114'
USGS

Appendix H

Groundwater Quality Monitoring Results

Appendix H1

Illinois EPA Program Monitoring Results

Appendix H1: Illinois EPA Program Monitoring Results
Inorganic Parameters - Downgradient Wells
Hydrogeologic Site Characterization Report
Ash Pond No. 2, Hennepin Power Station

Legend:
Value exceeds 35 IAC 620 Class I groundwater standard
Value below detection limit

Well No	sample date	Nitrate nitrogen, total (mg/L)	Cyanide, total (mg/L)	Chloride, total (mg/L)	Chloride, dissolved (mg/L)	Sulfate, total (mg/L)	Sulfate, dissolved (mg/L)	Fluoride, dissolved (mg/L)	Fluoride, total (mg/L)	Boron, dissolved (mg/L)	Boron, total (mg/L)	Iron, total (mg/L)	Iron, dissolved (mg/L)	Manganese, total (mg/L)	Manganese, dissolved (mg/L)	pH (field) (SU)	Residue, total filtrable (mg/L)
3	3/26/2008									1.1						7.15	
3	5/15/2008									0.93						7	
3	8/25/2008									1.5						6.9	
3	10/27/2008									1.2						6.85	
3	12/29/2008	9.94	0.056							0.935	0.956	0.388	0.044	0.01	0.013		633
3	12/29/2008			88	97	79	80	0.148	0.152							7.12	
3	3/25/2009	7.49	0.07							0.822	0.872	0.109	0.035	0.008	0.006		
3	3/25/2009			80	75	90	90.3	0.12	0.11							6.91	635
3	6/18/2009	14.70	0.098							0.766	0.804	8.9	0.052	0.3	0.009		
3	6/18/2009			92	92.6	109	117.2	0.133	0.105							6.72	735
3	9/29/2009	8.84	0.044							1.23	1.31	0.158	0.025	0.012	0.005		
3	9/29/2009			62	89	109	109.1	0.162	0.194							7.15	627
3	12/22/2009	8.86	0.056							0.706	0.724	0.034	0.02	0.007	0.006		
3	12/22/2009			82	83	95	94.7	0.099	0.089							6.5	596
3	3/16/2010	9.62	0.043							0.725	0.769	0.129	0.028	0.007	0.006		
3	3/16/2010			103	99.2	86	93.6	0.081	0.098							7.23	568
3	6/7/2010		0.124														
3	8/31/2010	11.00	0.052	89		130		0.14		1.1			0.025		0.006	7.11	690
3	12/28/2010	10.00	0.1	100		100		0.16		0.73			0.045		0.01	7.11	710
3	3/16/2011									0.73						7.13	
3	6/29/2011	13.00	0.06		97		100	0.138		0.58			0.025		0.01	7.02	710
3	8/23/2011	13.00	0.048		79		140	0.141		0.99			0.028		0.01	6.79	700
3	10/18/2011	9.10	0.045		77		130	0.106		1.1			0.025		0.009	6.92	690
3	3/1/2012	11.00	0.069		120		110	0.124		0.54			0.036		0.012	7.23	730
3	5/30/2012	8.60	0.058		110		100	0.128		0.67			0.028		0.011	6.73	730
3	8/29/2012	7.10	0.063		110		120	0.138		0.93			0.03		0.009	7.13	730
3	11/27/2012	9.16	0.075		94		109	0.14		0.826			0.046		0.014	7.26	714
3	3/7/2013	10.80	0.072		104		110	0.14		0.561			0.049		0.016	7.13	734
3	6/6/2013	9.23	0.045		88		78	0.15		0.632			0.053		0.009	7.23	628
3	9/3/2013	6.96	0.045		73		188	0.16		1.26			0.039		0.009	7.2	758
3	12/11/2013	10.30	0.034		78		65	0.14		1.04			0.033		0.009	7.2	744
3	3/26/2014	8.32	0.027		69		87	0.11		0.863			0.034		0.008	7.11	632
3	6/17/2014	6.90	0.032		88		108	0.18		0.721			0.029		0.01	7.98	728
3	8/20/2014	9.71	0.021		75		142	0.19		1.16			0.024		0.009	7.17	644
03R	3/18/2015	2.78	0.007		77		93	0.23		0.947			0.02		0.017	7.29	556
03R	6/23/2015	3.07	0.007		69		113	0.26		0.866			0.02		0.01	7.28	518
03R	9/16/2015	4.61	0.007		77		131	0.27		1.56			0.02		0.006	7.23	560
03R	12/9/2015	3.50	0.007		71		84	0.25		1.18			0.02		0.005	7.23	572
03R	3/9/2016	1.83	0.007		72		122	0.26		1.3			0.02		0.005	7.26	476
03R	6/8/2016	3.42	0.005		77		108	0.3		1.33			0.02		0.005	7.27	562
03R	8/31/2016	3.66	0.005		89		100	0.26		0.938			0.02		0.005	7.5	476
03R	12/8/2016	2.31	0.005		67		95	0.29		1.24			0.02		0.005	7.25	464
6	3/26/2008									0.69						6.98	
6	5/15/2008									0.59						6.91	
6	8/25/2008									1.1						6.77	
6	10/27/2008									0.71						6.41	
6	12/29/2008	13.30	0.102							1.02	1.05	0.081	0.053	0.005	0.005	6.66	
6	12/29/2008			77	77	126	139	0.159	0.167								736
6	3/25/2009	9.33	0.098							0.724	0.736	0.058	0.046	0.005	0.005		
6	3/25/2009			101	96	103	98.8		0.142							6.74	692
6	6/18/2009	18.00	0.121							0.644	0.672	0.158	0.055	0.005	0.005		
6	6/18/2009			118	119.1	138	144.4	0.18	0.161							6.57	794
6	9/29/2009	9.91	0.065							1.17	1.24	0.066	0.036	0.005	0.005		
6	9/29/2009			73	94.7	128	124.4	0.199	0.224							6.98	674
6	12/22/2009	10.20	0.101							0.761	0.796	0.078	0.037	0.005	0.005		
6	12/22/2009			116	113	110	109	0.119	0.119							6.86	699
6	3/16/2010	12.00	0.108							0.653	0.739	0.076	0.042	0.005	0.005		
6	3/16/2010			121	118.9	122	120.5	0.11	0.124							6.99	735
6	6/7/2010		0.051														
6	8/31/2010	16.00	0.061	100		160		0.18		0.75			0.025		0.005	6.89	750
6	12/28/2010	11.00	0.093	110		120		0.2		0.72			0.046		0.005	6.97	760
6	3/16/2011									0.63						6.98	
6	6/29/2011	13.00	0.064		109		120	0.193		0.55			0.031		0.005	6.79	740
6	8/23/2011	13.00	0.054		79		150	0.195		0.72			0.03		0.005	6.61	730
6	10/18/2011	13.00	0.059		91		130	0.143		0.9			0.028		0.005	6.61	730
6	3/1/2012	7.40	0.067		130		120	0.171		0.57			0.03		0.005	7.3	760
6	5/30/2012	7.80	0.077		120		120	0.195		0.58			0.033		0.005	6.66	770

Appendix H1: Illinois EPA Program Monitoring Results
Inorganic Parameters - Downgradient Wells
Hydrogeologic Site Characterization Report
Ash Pond No. 2, Hennepin Power Station

Legend:
Value exceeds 35 IAC 620 Class I groundwater standard
Value below detection limit

Well No	sample date	Nitrate nitrogen, total (mg/L)	Cyanide, total (mg/L)	Chloride, total (mg/L)	Chloride, dissolved (mg/L)	Sulfate, total (mg/L)	Sulfate, dissolved (mg/L)	Fluoride, dissolved (mg/L)	Fluoride, total (mg/L)	Boron, dissolved (mg/L)	Boron, total (mg/L)	Iron, total (mg/L)	Iron, dissolved (mg/L)	Manganese, total (mg/L)	Manganese, dissolved (mg/L)	pH (field) (SU)	Residue, total filtrable (mg/L)
6	8/29/2012	8.50	0.083		120		120	0.168		0.6			0.037		0.005	6.96	760
6	11/27/2012	9.79	0.076		115		112	0.21		0.62			0.05		0.005	7.19	752
6	3/7/2013	11.20	0.066		108		118	0.22		0.508			0.058		0.005	7.1	750
6	6/6/2013	9.94	0.067		108		88	0.21		0.41			0.05		0.005	7.15	754
6	9/3/2013	11.60	0.053		84		154	0.24		0.812			0.039		0.005	7.07	876
6	12/11/2013	10.60	0.031		76		110	0.21		0.884			0.026		0.005	7.18	688
6	3/26/2014	9.15	0.039		93		94	0.18		0.685			0.03		0.005	6.97	680
6	6/17/2014	7.84	0.045		112		125	0.26		0.552			0.034		0.005	7.39	802
6	8/20/2014	9.03	0.031		92		184	0.23		0.84			0.027		0.005	7.01	748
6	12/9/2014	3.99	0.007		85		86	0.27		0.418			0.02		0.005	7.09	562
6	3/18/2015	4.27	0.007		80		79	0.28		0.428			0.02		0.005	7.27	480
6	3/19/2015	11.00	0.007		46		61	0.1		0.059			0.02		0.005	7.26	564
6	6/22/2015	5.23	0.007		52		46	0.32		0.292			0.02		0.005	7.19	364
6	9/16/2015	5.97	0.007		82		103	0.31		0.639			0.02		0.005	7.32	546
6	12/9/2015	3.79	0.007		73		69	0.32		0.47			0.02		0.005	7.03	510
6	3/9/2016	4.35	0.007		80		93	0.32		0.551			0.02		0.005	7.2	512
6	6/8/2016	4.79	0.015		99		103	0.37		0.458			0.02		0.005	7.32	610
6	8/31/2016	5.20	0.006		93		89	0.34		0.417			0.02		0.005	7.2	526
6	12/8/2016	3.25	0.005		64		66	0.39		0.354			0.02		0.005	6.88	482
18D	6/18/2009	10.60	0.167							3.51	3.76	7.49	0.082	0.827	0.659		
18D	6/18/2009			93	94.9	169	180.2	0.152	0.141							6.79	737
18D	9/29/2009	7.95	0.161							3.5	4.03	0.644	0.064	0.313	0.281		
18D	9/29/2009			81	97.4	164	162	0.182	0.207							7.15	756
18D	12/22/2009	7.52	0.165							3.37	3.69	0.208	0.058	0.299	0.255		
18D	12/22/2009			98	97	152	154	0.099	0.103							6.5	696
18D	3/16/2010	3.37	0.053							1.38	1.11	0.561	0.025	0.082	0.079		
18D	3/16/2010			31	48.4	63	83.5	0.088	0.093							7.26	474
18D	6/7/2010		0.078														
18D	8/31/2010	4.70	0.112	79		150		0.16		3.2			0.043		0.18	7.04	730
18D	12/28/2010	5.90	0.09	98		160		0.17		3.5			0.055		0.21	7.19	640
18D	6/29/2011	1.50	0.008		20		68	0.126		1.3			0.069		0.12	7.22	400
18D	8/23/2011	4.20	0.059		57		150	0.187		2.8			0.044		0.16	7.09	610
18D	10/18/2011	5.80	0.072		71		160	0.138		2.9			0.045		0.23	6.98	680
18D	3/1/2012	5.00	0.007		83		160	0.158		2.9			0.027		0.19	7.27	640
18D	5/30/2012	4.50	0.046		72		130	0.171		2.3			0.025		0.13	6.84	600
18D	8/29/2012	4.60	0.044		80		150	0.16		2.7			0.046		0.2	7.1	670
18D	11/27/2012	6.50	0.068		81		134	0.15		2.17			0.038		0.171	7.2	720
18D	3/7/2013	5.54	0.06		74		139	0.16		1.75			0.047		0.09	7.13	592
18D	6/6/2013	5.30	0.076		75		105	0.16		1.69			0.032		0.149	7.16	696
18D	9/3/2013	4.02	0.038		72		135	0.2		2.23			0.033		0.186	7.38	718
18D	12/11/2013	5.77	0.049		68		162	0.16		2.6			0.023		0.181	7.28	618
18D	3/26/2014	0.27	0.007		11		40	0.1		1.96			0.025		0.011	7.18	252
18D	6/17/2014	2.76	0.046		66		123	0.17		2.2			0.079		0.291	7.58	750
18D	8/20/2014	5.30	0.053		74		140	0.16		2.18			0.092		0.212	7.12	728
18D	3/18/2015	3.65	0.011		83		134	0.16		1.86			0.024		0.124	7.16	702
18D	6/23/2015	4.06	0.039		84		115	0.14		1.58			0.026		0.077	7.1	640
18D	9/16/2015	4.71	0.039		80		138	0.15		1.94			0.038		0.156	7.19	648
18D	12/9/2015	4.23	0.037		82		132	0.14		1.73			0.022		0.107	7.2	650
18D	3/9/2016	3.88	0.03		84		134	0.14		1.79			0.025		0.131	7.17	622
18D	6/8/2016	3.46	0.027		82		141	0.16		1.95			0.028		0.164	7.17	672
18D	8/31/2016	2.89	0.027		86		136	0.14		1.76			0.02		0.103	7.43	654
18D	12/8/2016	2.41	0.026		85		143	0.17		1.9			0.025		0.158	7.16	592
18S	6/18/2009	11.50	0.101							2.33	2.51	1.19	0.059	0.101	0.054		
18S	6/18/2009			95	93.3	170	164.1	0.109	0.097							6.73	770
18S	9/29/2009	8.17	0.067							2.97	3.17	0.955	0.039	0.072	0.037		
18S	9/29/2009			77	92.4	178	170.8	0.142	0.15							7.15	719
18S	12/22/2009	8.30	0.066							2.99	3.19	0.233	0.022	0.047	0.033		
18S	12/22/2009			89	89	169	166	0.077	0.079							6.8	679
18S	3/16/2010	7.46	0.038							2.43	2.59	0.199	0.021	0.029	0.021		
18S	3/16/2010			103	103.4	113	105.8	0.079	0.08							7.23	586
18S	6/7/2010		0.048														
18S	8/31/2010	10.00	0.039	89		220		0.12		3.6			0.025		0.017	7.18	840
18S	12/28/2010	8.60	0.082	110		150		0.13		2.2			0.036		0.027	7.08	740
18S	6/29/2011	9.60	0.055		98		190	0.1		2.5			0.03		0.025	6.98	760
18S	8/23/2011	8.90	0.048		79		210	0.139		3.4			0.046		0.13	6.93	780
18S	10/18/2011	9.50	0.049		83		190	0.104		2.9			0.031		0.024	6.83	770
18S	3/1/2012	7.00	0.062		110		130	0.116		1.6			0.029		0.023	7.22	740

Natural Resource Technology

Appendix H1: Illinois EPA Program Monitoring Results
Inorganic Parameters - Downgradient Wells
Hydrogeologic Site Characterization Report
Ash Pond No. 2, Hennepin Power Station

Legend:
- (pink) Value exceeds 35 IAC 620 Class I groundwater standard
- (blue) Value below detection limit

Well No	sample date	Nitrate nitrogen, total (mg/L)	Cyanide, total (mg/L)	Chloride, total (mg/L)	Chloride, dissolved (mg/L)	Sulfate, total (mg/L)	Sulfate, dissolved (mg/L)	Fluoride, dissolved (mg/L)	Fluoride, total (mg/L)	Boron, dissolved (mg/L)	Boron, total (mg/L)	Iron, total (mg/L)	Iron, dissolved (mg/L)	Manganese, total (mg/L)	Manganese, dissolved (mg/L)	pH (field) (SU)	Residue, total filtrable (mg/L)
18S	5/30/2012	7.20	0.05		110		170	0.135		2.4			0.025		0.021	6.78	750
18S	8/29/2012	7.00	0.056		100		130	0.124		1.9			0.025		0.024	7.04	740
18S	11/27/2012	8.71	0.06		93		136	0.13		2.03			0.031		0.024	7.23	762
18S	3/7/2013	9.94	0.074		98		141	0.15		1.45			0.079		0.027	7.14	738
18S	6/6/2013	7.33	0.025		61		129	0.15		2.92			0.036		0.012	7.3	648
18S	9/3/2013	8.71	0.048		77		224	0.16		4.38			0.029		0.017	7.1	930
18S	12/11/2013	8.08	0.041		77		188	0.15		2.97			0.03		0.016	7.23	750
18S	3/26/2014	8.26	0.031		76		134	0.1		2.39			0.043		0.016	7.12	702
18S	6/17/2014	8.43	0.028		77		186	0.15		2.81			0.03		0.016	7.45	858
18S	8/20/2014	9.63	0.025		77		192	0.14		3.24			0.023		0.014	7.17	790
18S	3/18/2015	4.77	0.026		74		161	0.13		2.87			0.02		0.009	7.31	644
18S	6/23/2015	3.84	0.007		72		159	0.13		3.01			0.02		0.009	7.33	634
18S	9/16/2015	4.71	0.007		64		238	0.14		5.34			0.02		0.007	7.4	640
18S	12/9/2015	4.40	0.007		74		163	0.15		3.46			0.02		0.007	7.47	538
18S	3/9/2016	4.23	0.007		71		206	0.14		4.44			0.02		0.007	7.37	628
18S	6/8/2016	3.80	0.005		67		213	0.15		4.56			0.02		0.006	7.58	660
18S	8/31/2016	3.92	0.005		69		188	0.12		4.57			0.02		0.005	7.5	668
18S	12/8/2016	3.11	0.005		71		180	0.15		3.49			0.02		0.008	7.28	546
Class I Standard	--	10.00	2	200	200	400	400	4	4	2	2	5	5	0.15	0.15	9	1200
Class I Standard (pH Lower Limit)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	6.5	--
# of Exceedances	--	22	0	0	0	0	0	0	0	40	7	2	0	4	17	0	0
# of Exceedances (pH Lower Limit)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1	--
Minimum Value	--	0.27	0.005	31	11	63	40	0.077	0.079	0.059	0.67	0.034	0.02	0.005	0.005	6.41	252
Maximum Value	--	18.00	0.17	121	130	220	238	0.39	0.22	5.34	4.03	8.90	0.09	0.83	0.66	7.98	930
# of Samples Analyzed	--	118	122	28	110	28	110	117	20	128	20	20	118	20	118	128	118

Natural Resource Technology

Appendix H1: Illinois EPA Program Monitoring Results
Inorganic Parameters - Upgradient Wells
Hydrogeologic Site Characterization Report
Ash Pond No. 2, Hennepin Power Station

Legend:
Value exceeds 35 IAC 620 Class I groundwater standard
Value below detection limit

Well No.	sample date	Nitrate nitrogen, total (mg/L)	Cyanide, total (mg/L)	Chloride, total (mg/L)	Chloride, dissolved (mg/L)	Sulfate, total (mg/L)	Sulfate, dissolved (mg/L)	Fluoride, dissolved (mg/L)	Fluoride, total (mg/L)	Boron, dissolved (mg/L)	Boron, total (mg/L)	Iron, total (mg/L)	Iron, dissolved (mg/L)	Manganese, total (mg/L)	Manganese, dissolved (mg/L)	pH (field) (SU)	Residue, total filtrable (mg/L)
7	3/27/2008									0.05						6.89	
7	5/15/2008									0.05						6.7	
7	8/25/2008									0.05						6.54	
7	10/27/2008									0.052						6.51	
7	12/29/2008	9.54	0.007							0.04	0.04	0.026	0.02	0.005	0.01		615
7	12/29/2008			30	33	67	71	0.113	0.115							6.52	
7	3/25/2009	9.21	0.007							0.041	0.046	0.02	0.02	0.005	0.005		
7	3/25/2009			33	31	61	63.6	0.091	0.086							6.74	638
7	6/18/2009	9.70	0.007							0.036	0.037	0.658	0.02	0.031	0.005		
7	6/18/2009			35	36.8	64	62	0.101	0.089							6.3	680
7	9/29/2009	9.63	0.007							0.035	0.038	0.063	0.02	0.005	0.005		
7	9/29/2009			33	46.3	75	72.2	0.121	0.147							6.66	628
7	12/29/2009	10.40	0.007							0.048	0.051	0.046	0.02	0.005	0.005		
7	12/29/2009			42	42	75	76.5	0.078	0.073							7	624
7	3/16/2010	10.50	0.007							0.052	0.058	0.021	0.02	0.005	0.005		
7	3/16/2010			43	41.4	76	71.5	0.07	0.081							6.82	587
7	6/7/2010		0.007														
7	8/31/2010	11.00	0.007	29		85		0.1		0.05			0.025		0.005	6.57	660
7	12/29/2010	6.80	0.007	46		80		0.13		0.05			0.025		0.005	6.98	790
7	3/16/2011									0.054						6.92	
7	6/29/2011	7.50	0.007		37		94	0.1		0.05			0.025		0.005	6.85	660
7	8/24/2011	14.00	0.007		29		94	0.128		0.05			0.025		0.005	6.58	660
7	10/19/2011	8.10	0.007		27		170	0.088		0.05			0.025		0.005	6.61	700
7	3/1/2012	13.00	0.007		41		89	0.106		0.05			0.025		0.005	6.9	560
7	5/31/2012	12.00	0.007		39		78	0.122		0.05			0.025		0.005	7.16	610
7	8/29/2012	12.00	0.007		35		80	0.107		0.05			0.025		0.005	6.84	650
7	11/27/2012	12.20	0.007		34		101	0.12		0.052			0.02		0.005	7.15	672
7	3/7/2013	9.62	0.007		30		118	0.12		0.045			0.02		0.005	7.02	588
7	6/6/2013	10.30	0.009		36		63	0.13		0.026			0.02		0.005	7.04	576
7	9/4/2013	6.15	0.007		18		61	0.13		0.034			0.02		0.005	7.19	692
7	12/11/2013	8.23	0.008		25		56	0.1		0.037			0.02		0.005	7.24	592
7	3/26/2014	7.51	0.007		22		49	0.1		0.043			0.02		0.005	6.96	576
7	6/18/2014	6.48	0.007		21		57	0.12		0.037			0.02		0.005	7.22	674
7	8/20/2014	11.00	0.007		38		63	0.1		0.037			0.02		0.005	6.81	670
7	12/9/2014	10.20	0.007		48		67	0.1		0.052			0.02		0.005	6.89	718
7	3/19/2015	7.44	0.007		47		68	0.1		0.056			0.02		0.005	7.06	638
7	6/23/2015	7.35	0.007		53		69	0.11		0.067			0.02		0.005	6.78	552
7	9/17/2015	7.92	0.007		43		69	0.12		0.059			0.02		0.005	7.06	560
7	12/9/2015	7.89	0.007		44		76	0.11		0.068			0.02		0.005	6.99	662
7	3/10/2016	9.21	0.007		47		69	0.1		0.055			0.02		0.005	6.9	504
7	6/8/2016	14.20	0.005		57		77	0.11		0.07			0.02		0.005	6.64	728
7	9/1/2016	9.65	0.005		49		71	0.1		0.066			0.02		0.005	6.94	572
7	12/9/2016	14.80	0.005		62		89	0.1		0.067			0.02		0.005	6.75	682
8	3/26/2008									0.14						6.83	
8	5/15/2008									0.095						6.68	
8	8/25/2008									0.099						6.49	
8	10/27/2008									0.083						6.53	
8	12/29/2008	8.31	0.007							0.078	0.079	0.02	0.02	0.005	0.005		779
8	12/29/2008			80	83	83	79	0.114	0.117							6.64	
8	3/25/2009	6.92	0.007							0.081	0.087	0.02	0.02	0.005	0.005		
8	3/25/2009			109	107	84	82.2	0.094	0.09							6.5	800
8	6/18/2009	4.24	0.01							0.054	0.055	0.169	0.02	0.005	0.005		
8	6/18/2009			32	32.2	82	88.6	0.107	0.098							6.27	718
8	9/29/2009	6.81	0.009							0.071	0.075	0.033	0.02	0.005	0.005		
8	9/29/2009			66	82.7	117	117.5	0.123	0.146							6.6	822
8	12/29/2009	9.58	0.023							0.113	0.116	0.021	0.02	0.005	0.005		
8	12/29/2009			140	140	140	134	0.078	0.074							7.07	945
8	3/16/2010	7.91	0.022							0.086	0.096	0.024	0.02	0.005	0.005		
8	3/16/2010			131	130.6	113	116.1	0.071	0.079							6.74	856
8	6/7/2010		0.029														
8	8/31/2010	7.20	0.011	65		110		0.11		0.055			0.025		0.005	6.49	750
8	12/29/2010	7.40	0.007	170		130		0.12		0.097			0.025		0.005	6.72	860
8	3/16/2011	8.90	0.008			110		0.13		0.14						6.83	1100
8	6/29/2011	2.60	0.026	120	130	110	130	0.1	0.1	0.11	0.1	0.025	0.025		0.005	6.76	980
8	8/24/2011	6.30	0.017		100		110	0.126		0.077			0.025		0.005	6.98	860
8	10/19/2011	8.10	0.007		170		130	0.09		0.087			0.025		0.005	6.56	950
8	3/1/2012	7.70	0.009		210		120	0.106		0.11			0.025		0.005	6.95	960
8	5/30/2012	8.30	0.007	190	220	130	120	0.121	0.134	0.11	0.12	0.025	0.025		0.005	6.68	1100

Natural Resource Technology
AN OBG COMPANY

Appendix H1: Illinois EPA Program Monitoring Results
Inorganic Parameters - Upgradient Wells
Hydrogeologic Site Characterization Report
Ash Pond No. 2, Hennepin Power Station

Legend:
- (pink) Value exceeds 35 IAC 620 Class I groundwater standard
- (blue) Value below detection limit

Well No.	sample date	Nitrate nitrogen, total (mg/L)	Cyanide, total (mg/L)	Chloride, total (mg/L)	Chloride, dissolved (mg/L)	Sulfate, total (mg/L)	Sulfate, dissolved (mg/L)	Fluoride, dissolved (mg/L)	Fluoride, total (mg/L)	Boron, dissolved (mg/L)	Boron, total (mg/L)	Iron, total (mg/L)	Iron, dissolved (mg/L)	Manganese, total (mg/L)	Manganese, dissolved (mg/L)	pH (field) (SU)	Residue, total filtrable (mg/L)
8	8/29/2012	9.60	0.008		280		120	0.107		0.12			0.025		0.005	6.71	1100
8	11/27/2012	10.60	0.012		321		155	0.1		0.13			0.02		0.005	6.99	1230
8	3/7/2013	12.20	0.008		351		149	0.11		0.148			0.02		0.005	7.02	1200
8	6/6/2013	3.26	0.007	92	89	73	67	0.16	0.15	0.113	0.126	0.025	0.02		0.005	7.75	832
8	9/3/2013	7.41	0.007		186		127	0.12		0.087			0.02		0.005	7.05	1100
8	12/11/2013	9.66	0.015		220		118	0.12		0.111			0.02		0.005	7.06	996
8	3/26/2014	9.70	0.008		173		105	0.1		0.139			0.02		0.005	7.15	968
8	6/18/2014	7.04	0.008	127	129	137	120	0.12	0.11	0.095	0.09	0.031	0.02		0.005	7.08	958
8	8/20/2014	7.34	0.017		146		164	0.1		0.096			0.02		0.005	6.8	1010
8	12/9/2014	15.90	0.08		228		218	0.1		0.095			0.026		0.005	6.78	1230
8	3/19/2015	9.01	0.011		216		120	0.1		0.113			0.02		0.005	6.9	1110
8	6/22/2015	7.20	0.024	269	245	108	107	0.1	0.1	0.124	0.141	0.034	0.02		0.003	6.74	1080
8	9/16/2015	8.56	0.021		162		145	0.1		0.093			0.02		0.005	6.84	978
8	12/8/2015	14.60	0.066		220		177	0.1		0.116			0.023		0.005	6.82	1080
8	3/10/2016	10.20	0.04		142		141	0.1		0.077			0.02		0.005	6.73	896
8	6/7/2016	6.68	0.034	170	178	129	142	0.1	0.1	0.081	0.089	0.044	0.02		0.003	6.6	1030
8	9/1/2016	17.30	0.1		304		196	0.1		0.117			0.034		0.005	6.69	1420
8	12/9/2016	14.60	0.08		242		198	0.1		0.099			0.027		0.005	6.63	1230
08D	6/18/2009	11.50	0.025							0.141	0.15	5.48	0.02	0.396	0.206		
08D	6/18/2009			159	162.1	133	129.5	0.158	0.143							6.27	1004
08D	9/29/2009	6.74	0.016							0.132	0.135	0.301	0.02	0.154	0.107		
08D	9/29/2009			130	182.2	118	126.2	0.142	0.164							6.7	978
08D	12/29/2009	8.16	0.02							0.16	0.178	0.051	0.02	0.108	0.11		
08D	12/29/2009			166	169	120	118	0.094	0.096							6.76	1008
08D	3/16/2010	8.65	0.019							0.154	0.161	0.02	0.02	0.09	0.092		
08D	3/16/2010			184	182.1	113	104	0.094	0.106							6.69	1001
08D	6/7/2010		0.034														
08D	8/31/2010	6.70	0.009	180		120		0.15		0.12			0.025		0.043	6.57	1000
08D	12/29/2010	8.30	0.013	170		130		0.15		0.12			0.025		0.033	6.6	970
08D	3/16/2011	7.60	0.014			110		0.16		0.14						6.68	1000
08D	6/29/2011	9.90	0.022	210	230	120	130	0.1	0.112	0.12	0.12	0.26	0.025		0.044	6.67	1100
08D	8/23/2011	8.60	0.007		240		120	0.158		0.13			0.025		0.028	6.51	1100
08D	10/19/2011	8.60	0.007		190		130	0.111		0.13			0.025		0.029	6.6	1100
08D	3/1/2012	7.50	0.007		270		120	0.114		0.084			0.025		0.023	7.02	930
08D	5/30/2012	8.30	0.01	240	290	130	130	0.122	0.135	0.084	0.092	0.31	0.025		0.016	6.69	1000
08D	8/29/2012	9.00	0.007		340		120	0.115		0.082			0.025		0.009	6.86	1100
08D	11/27/2012	6.22	0.007		296		146	0.11		0.094			0.02		0.011	7.01	1080
08D	3/7/2013	10.80	0.01		245		147	0.12		0.098			0.02		0.022	7.05	1020
08D	6/6/2013	8.44	0.075	250	262	126	127	0.16	0.17	0.124	0.136	0.5	0.045		0.053	6.95	1130
08D	9/4/2013	5.88	0.007		180		130	0.14		0.105			0.071		0.054	7.15	1040
08D	12/11/2013	7.05	0.014		154		118	0.14		0.11			0.032		0.032	7.33	948
08D	3/26/2014	8.71	0.029		140		99	0.1		0.119			0.02		0.012	6.96	1010
08D	6/18/2014	10.70	0.026	189	206	143	168	0.14	0.13	0.113	0.128	0.965	0.02		0.015	7.61	1200
08D	8/20/2014	8.83	0.021		215		173	0.12		0.105			0.02		0.017	6.69	1190
08D	12/10/2014	9.31	0.081		204		142	0.12		0.142			0.047		0.066	6.69	1060
08D	3/19/2015	8.95	0.079		223		143	0.1		0.186			0.047		0.053	6.87	1190
08D	6/22/2015	9.62	0.034	236	238	142	155	0.12	0.11	0.133	0.13	0.25	0.03		0.012	6.71	1090
08D	9/16/2015	8.17	0.011		114		103	0.11		0.102			0.02		0.018	6.82	1040
08D	12/8/2015	7.84	0.03		211		124	0.11		0.124			0.02		0.021	6.89	1090
08D	3/10/2016	8.48	0.019		238		128	0.11		0.11			0.02		0.013	6.73	1040
08D	6/7/2016	7.78	0.016	231	228	118	129	0.11	0.11	0.107	0.106	0.02	0.02		0.027	6.64	1020
08D	9/1/2016	13.00	0.058		317		155	0.11		0.123			0.029		0.01	6.63	1380
08D	12/9/2016	9.87	0.031		325		171	0.1		0.103			0.02		0.005	6.59	1340
Class I Standard	--	10.00	2	200	200	400	400	4	4	2	2	5	5	0.15	0.15	9	1200
Class I Standard (pH Lower Limit)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	6.5	--
# of Exceedances	--	24	0	6	30	0	0	0	0	0	0	1	0	2	1	0	6
# of Exceedances (pH Lower Limit)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	5	--
Minimum Value	--	2.60	0.005	29.00	18.00	61.00	49.00	0.070	0.073	0.026	0.037	0.02	0.02	0.005	0.003	6.270	504
Maximum Value	--	17.30	0.10	269.00	351.00	####	#####	0.16	0.17	0.19	0.18	5.48	0.07	0.40	0.21	7.75	1420
# of Samples Analyzed	--	93	96	34	85	36	85	93	28	102	28	28	91	16	91	102	93

Appendix H1: Illinois EPA Program Monitoring Results
Trace Metal Parameters - Downgradient Wells
Hydrogeologic Site Characterization Report
Ash Pond No. 2, Hennepin Power Station

Legend:
Value exceeds 35 IAC 620 Class I groundwater standard
Value below detection limit

Well No.	sample date	Antimony, dissolved (mg/L)	Antimony, total (mg/L)	Arsenic, dissolved (mg/L)	Arsenic, total (mg/L)	Barium, dissolved (mg/L)	Barium, total (mg/L)	Beryllium, dissolved (mg/L)	Beryllium, total (mg/L)	Cadmium, dissolved (mg/L)	Cadmium,total (mg/L)	Chromium, dissolved (mg/L)	Chromium, total (mg/L)	Cobalt, dissolved (mg/L)	Cobalt, total (mg/L)	Copper, dissolved (mg/L)	Copper, total (mg/L)	Lead, dissolved (mg/L)	Lead, total (mg/L)	Mercury, dissolved (mg/L)	Mercury, total (mg/L)	Nickel, dissolved (mg/L)	Nickel, total (mg/L)	Selenium, dissolved (mg/L)	Selenium, total (mg/L)	Silver, dissolved (mg/L)	Silver, total (mg/L)	Thallium, dissolved (mg/L)	Thallium, total (mg/L)	Vanadium, dissolved (mg/L)	Vanadium, total (mg/L)	Zinc, dissolved (mg/L)	Zinc, total (mg/L)
3	12/29/2008	0.005	0.005	0.003	0.003	0.077	0.082	0.001	0.001	0.004	0.005	0.01	0.01	0.0164	0.013	0.016	0.018	0.002	0.002	0.0002	0.0002	0.039	0.039	0.006	0.006	0.01	0.01	0.002	0.002	0.01	0.01	0.016	0.017
3	3/25/2009	0.005	0.005	0.003	0.003	0.085	0.09	0.001	0.001	0.007	0.006	0.01	0.01	0.0126	0.013	0.024	0.024	0.002	0.002	0.0002	0.0002	0.049	0.051	0.006	0.006	0.01	0.01	0.002	0.002	0.01	0.01	0.016	0.018
3	6/18/2009	0.005	0.005	0.003	0.004	0.098	0.133	0.001	0.001	0.006	0.007	0.01	0.014	0.0186	0.022	0.024	0.038	0.002	0.008	0.0002	0.0002	0.073	0.087	0.006	0.006	0.01	0.01	0.002	0.002	0.01	0.012	0.018	0.064
3	9/29/2009	0.005	0.005	0.003	0.003	0.084	0.089	0.001	0.001	0.006	0.006	0.01	0.01	0.0129	0.012	0.023	0.026	0.002	0.002	0.0002	0.0002	0.043	0.045	0.007	0.006	0.01	0.01	0.002	0.002	0.01	0.01	0.018	0.02
3	12/22/2009	0.005	0.005	0.003	0.003	0.083	0.085	0.001	0.001	0.005	0.006	0.01	0.01	0.0117	0.013	0.019	0.021	0.002	0.002	0.0002	0.0002	0.039	0.038	0.006	0.006	0.01	0.01	0.002	0.002	0.01	0.01	0.015	0.017
3	3/16/2010	0.005	0.005	0.003	0.003	0.084	0.086	0.001	0.001	0.005	0.005	0.01	0.01	0.0115	0.012	0.024	0.023	0.002	0.002	0.0002	0.0002	0.052	0.05	0.006	0.008	0.01	0.01	0.002	0.002	0.01	0.01	0.016	0.018
3	8/31/2010	0.005		0.005		0.074		0.002		0.002		0.01		0.005		0.029		0.005		0.0002		0.051		0.016		0.002				0.002		0.021	
3	12/28/2010	0.005		0.007		0.096		0.002		0.009		0.01		0.011		0.046		0.005		0.0002		0.059		0.01		0.002				0.002		0.031	
3	6/29/2011	0.005		0.01		0.076		0.004		0.005		0.005		0.005		0.005		0.005		0.002		0.054		0.014		0.002		0.002				0.026	
3	8/23/2011	0.005		0.01		0.08		0.004		0.006		0.005		0.01		0.033		0.005		0.0002		0.054		0.012		0.002		0.002				0.025	
3	10/18/2011	0.005		0.003		0.085		0.004		0.007		0.005		0.01		0.031		0.004		0.0002		0.046		0.013		0.002		0.002				0.023	
3	3/1/2012	0.005		0.003		0.086		0.004		0.007		0.005		0.01		0.034		0.004		0.0002		0.062		0.011		0.002		0.002				0.023	
3	5/30/2012	0.005		0.003		0.089		0.004		0.007		0.005		0.01		0.037		0.004		0.0002		0.058		0.015		0.002		0.002				0.023	
3	8/29/2012	0.005		0.003		0.083		0.004		0.009		0.005		0.012		0.043		0.004		0.0002		0.062		0.014		0.002		0.002				0.032	
3	11/27/2012	0.005		0.003		0.093		0.001		0.01		0.005		0.0112		0.052		0.002		0.0002		0.066		0.006		0.002		0.002				0.036	
3	3/7/2013	0.005		0.003		0.104		0.001		0.011		0.005		0.014		0.058		0.002		0.0002		0.086		0.006		0.002		0.002				0.036	
3	6/6/2013	0.005		0.003		0.072		0.001		0.006		0.005		0.0102		0.027		0.002		0.0002		0.06		0.006		0.002		0.002				0.021	
3	9/3/2013	0.005		0.003		0.093		0.001		0.009		0.005		0.011		0.042		0.002		0.0002		0.07		0.011		0.002		0.002				0.033	
3	12/11/2013	0.005		0.003		0.096		0.001		0.007		0.005		0.0081		0.035		0.002		0.0002		0.057		0.006		0.002		0.002				0.027	
3	3/26/2014	0.005		0.003		0.093		0.001		0.006		0.005		0.0093		0.034		0.002		0.0002		0.051		0.006		0.002		0.002				0.024	
3	6/17/2014	0.005		0.003		0.094		0.001		0.007		0.005		0.0106		0.035		0.002		0.0002		0.06		0.006		0.002		0.002				0.026	
3	8/20/2014	0.001		0.001		0.084		0.001		0.006		0.005		0.0067		0.029		0.001		0.0002		0.041		0.004		0.002		0.001				0.026	
03R	3/18/2015	0.001		0.001		0.063		0.001		0.003		0.005		0.005		0.012		0.001		0.0002		0.007		0.003		0.002		0.001				0.013	
03R	6/23/2015	0.001		0.001		0.072		0.001		0.002		0.005		0.005		0.012		0.001		0.0002		0.011		0.006		0.002		0.001				0.011	
03R	9/16/2015	0.001		0.001		0.073		0.001		0.002		0.005		0.005		0.007		0.001		0.0002		0.009		0.005		0.002		0.001				0.008	
03R	12/9/2015	0.001		0.001		0.063		0.001		0.002		0.005		0.005		0.008		0.001		0.0002		0.004		0.005		0.002		0.001				0.007	
03R	3/9/2016	0.001		0.001		0.062		0.001		0.002		0.005		0.005		0.006		0.001		0.0002		0.005		0.005		0.002		0.001				0.006	
03R	6/8/2016	0.001		0.001		0.064		0.001		0.002		0.005		0.005		0.005		0.001		0.0002		0.008		0.007		0.002		0.001				0.005	
03R	8/31/2016	0.001		0.001		0.061		0.001		0.002		0.005		0.005		0.005		0.001		0.0002		0.005		0.006		0.002		0.001				0.005	
03R	12/8/2016	0.001		0.001		0.056		0.001		0.002		0.005		0.005		0.005		0.001		0.0002		0.002		0.005		0.002		0.001				0.005	
6	12/29/2008	0.005	0.005	0.003	0.003	0.083	0.089	0.001	0.001	0.005	0.006	0.01	0.01	0.0181	0.018	0.028	0.029	0.002	0.002	0.0002	0.0002	0.059	0.064	0.006	0.006	0.01	0.01	0.002	0.002	0.01	0.01	0.032	0.033
6	3/25/2009	0.005	0.005	0.003	0.003	0.078	0.085	0.001	0.001	0.004	0.004	0.01	0.01	0.0177	0.018	0.019	0.018	0.002	0.002	0.0002	0.0002	0.064	0.064	0.006	0.006	0.01	0.01	0.002	0.002	0.01	0.01	0.03	0.033
6	6/18/2009	0.005	0.005	0.003	0.003	0.085	0.087	0.001	0.001	0.005	0.005	0.01	0.01	0.0238	0.024	0.022	0.028	0.002	0.002	0.0002	0.0002	0.086	0.088	0.006	0.006	0.01	0.01	0.002	0.002	0.01	0.01	0.034	0.034
6	9/29/2009	0.005	0.005	0.003	0.003	0.069	0.073	0.001	0.001	0.005	0.005	0.01	0.01	0.0205	0.022	0.026	0.029	0.002	0.002	0.0002	0.0002	0.065	0.061	0.006	0.006	0.01	0.01	0.002	0.002	0.01	0.01	0.036	0.031
6	12/22/2009	0.005	0.005	0.003	0.003	0.073	0.078	0.001	0.001	0.006	0.006	0.01	0.01	0.029	0.031	0.03	0.029	0.002	0.002	0.0002	0.0002	0.082	0.085	0.006	0.006	0.01	0.01	0.002	0.002	0.01	0.01	0.04	0.044
6	3/16/2010	0.005	0.005	0.003	0.003	0.079	0.087	0.001	0.001	0.007	0.008	0.01	0.01	0.0282	0.032	0.036	0.041	0.002	0.002	0.0002	0.0002	0.101	0.114	0.006	0.006	0.01	0.01	0.002	0.002	0.01	0.01	0.047	0.051
6	8/31/2010	0.005		0.005		0.065		0.002		0.006		0.01		0.016		0.033		0.005		0.0002		0.06		0.005		0.002				0.002		0.044	
6	12/28/2010	0.005		0.005		0.079		0.002		0.009		0.01		0.018		0.05		0.005		0.0002		0.074		0.005		0.002				0.002		0.063	
6	6/29/2011	0.005		0.01		0.063		0.004		0.006		0.005		0.014		0.036		0.005		0.002		0.061		0.01		0.002		0.002				0.05	
6	8/23/2011	0.005		0.01		0.066		0.004		0.005		0.005		0.012		0.031		0.005		0.0002		0.054		0.01		0.002		0.002				0.042	
6	10/18/2011	0.005		0.003		0.067		0.004		0.005		0.005		0.01		0.032		0.004		0.0002		0.053		0.01		0.002		0.002				0.041	
6	3/1/2012	0.005		0.003		0.064		0.004		0.005		0.005		0.011		0.033		0.004		0.0002		0.066		0.01		0.002		0.002				0.041	
6	5/30/2012	0.005		0.003		0.069		0.004		0.006		0.005		0.013		0.036		0.004		0.0002		0.078		0.01		0.002		0.002				0.043	
6	8/29/2012	0.005		0.003		0.063		0.004		0.007		0.005		0.014		0.04		0.004		0.0002		0.071		0.01		0.002		0.002				0.052	
6	11/27/2012	0.005		0.003		0.071		0.001		0.011		0.005		0.0145		0.063		0.002		0.0002		0.078		0.006		0.002		0.002				0.075	
6	3/7/2013	0.005		0.003		0.076		0.001		0.011		0.005		0.0157		0.061		0.002		0.0002		0.085		0.006		0.002		0.002				0.071	
6	6/6/2013	0.005		0.003		0.073		0.001		0.009		0.005		0.0177		0.043		0.002		0.0002		0.089		0.006		0.002		0.002				0.054	
6	9/3/2013	0.005		0.003		0.078		0.001		0.009		0.005		0.0128		0.044		0.002		0.0002		0.076		0.006		0.002		0.002				0.059	
6	12/11/2013	0.005		0.003		0.072		0.001		0.007		0.005		0.0093		0.039		0.002		0.0002		0.051		0.006		0.002		0.002				0.05	
6	3/26/2014	0.005		0.003		0.074		0.001		0.007		0.005		0.0123		0.038		0.002		0.0002		0.059		0.006		0.002		0.002				0.048	
6	6/17/2014	0.005		0.003		0.076		0.001		0.008		0.005		0.0142		0.04		0.002		0.0002		0.075		0.006		0.002		0.002				0.055	
6	8/20/2014	0.001		0.001		0.073		0.001		0.007		0.005		0.0112		0.036		0.001		0.0002		0.06		0.002		0.002		0.001				0.051	
6	12/9/2014	0.001		0.001		0.054		0.001		0.004		0.005		0.005		0.018		0.001		0.0002		0.007		0.001		0.002		0.001				0.032	
6	3/18/2015	0.001		0.001		0.053		0.001		0.004		0.005		0.005		0.016		0.001		0.0002		0.009		0.001		0.002		0.001				0.026	
6	3/19/2015	0.001		0.001		0.066		0.001		0.002		0.005		0.005		0.005		0.001		0.0002		0.002		0.001		0.002		0.001				0.005	
6	6/22/2015	0.001		0.001		0.04		0.001		0.002		0.005		0.005		0.005		0.001		0.0002		0.006		0.001		0.002		0.001				0.01	
6	9/16/2015	0.001		0.001		0.066		0.001		0.003		0.005		0.005		0.012		0.001		0.0002		0.013		0.003		0.002		0.001				0.019	
6	12/9/2015	0.001		0.001		0.057		0.001		0.002		0.005		0.005		0.009		0.001		0.0002		0.005		0.001		0.002		0.001				0.016	
6	3/9/2016	0.001		0.001		0.064		0.001		0.002		0.005		0.005		0.008		0.001		0.0002		0.007		0.003		0.002		0.001				0.013	
6	6/8/2016	0.001		0.001		0.068		0.001		0.002		0.005		0.0066		0.008		0.001		0.0002		0.026		0.001		0.002		0.001				0.014	
6	8/31/2016	0.001		0.001		0.058		0.001		0.002		0.005		0.005		0.007		0.001		0.0002		0.01		0.001		0.002		0.001				0.01	
6	12/8/2016	0.001		0.001		0.052		0.001		0.002		0.005		0.005		0.005		0.001		0.0002		0.003		0.001		0.002		0.001				0.007	

Natural Resource Technology
AN OBG COMPANY

Appendix H1: Illinois EPA Program Monitoring Results
Trace Metal Parameters - Downgradient Wells
Hydrogeologic Site Characterization Report
Ash Pond No. 2, Hennepin Power Station

Legend:
Value exceeds 35 IAC 620 Class I groundwater standard
Value below detection limit

Well No.	sample date	Antimony, dissolved (mg/L)	Antimony, total (mg/L)	Arsenic, dissolved (mg/L)	Arsenic, total (mg/L)	Barium, dissolved (mg/L)	Barium, total (mg/L)	Beryllium, dissolved (mg/L)	Beryllium, total (mg/L)	Cadmium, dissolved (mg/L)	Cadmium,total (mg/L)	Chromium, dissolved (mg/L)	Chromium, total (mg/L)	Cobalt, dissolved (mg/L)	Cobalt, total (mg/L)	Copper, dissolved (mg/L)	Copper, total (mg/L)	Lead, dissolved (mg/L)	Lead, total (mg/L)	Mercury, dissolved (mg/L)	Mercury, total (mg/L)	Nickel, dissolved (mg/L)	Nickel, total (mg/L)	Selenium, dissolved (mg/L)	Selenium, total (mg/L)	Silver, dissolved (mg/L)	Silver, total (mg/L)	Thallium, dissolved (mg/L)	Thallium, total (mg/L)	Vanadium, dissolved (mg/L)	Vanadium, total (mg/L)	Zinc, dissolved (mg/L)	Zinc, total (mg/L)
18D	6/18/2009	0.005	0.005	0.003	0.004	0.103	0.127	0.001	0.001	0.002	0.002	0.01	0.012	0.0139	0.016	0.01	0.014	0.002	0.007	0.0002	0.0002	0.078	0.088	0.006	0.006	0.01	0.01	0.002	0.002	0.01	0.01	0.01	0.039
18D	9/29/2009	0.005	0.005	0.003	0.003	0.08	0.087	0.001	0.001	0.002	0.002	0.01	0.01	0.0125	0.014	0.01	0.01	0.002	0.002	0.0002	0.0002	0.071	0.08	0.006	0.006	0.01	0.01	0.002	0.002	0.01	0.01	0.01	0.01
18D	12/22/2009	0.005	0.005	0.003	0.003	0.095	0.1	0.001	0.001	0.002	0.002	0.01	0.01	0.0129	0.015	0.01	0.01	0.002	0.002	0.0002	0.0002	0.063	0.067	0.006	0.006	0.01	0.01	0.002	0.002	0.01	0.01	0.01	0.01
18D	3/16/2010	0.005	0.005	0.003	0.003	0.088	0.086	0.001	0.001	0.002	0.002	0.01	0.01	0.01	0.01	0.01	0.01	0.002	0.002	0.0002	0.0002	0.032	0.025	0.006	0.006	0.01	0.01	0.002	0.002	0.01	0.01	0.01	0.01
18D	8/31/2010	0.005		0.005		0.092		0.002		0.002		0.01		0.0096		0.01		0.005		0.0002		0.049		0.005		0.002				0.002		0.005	
18D	12/28/2010	0.005		0.005		0.076		0.002		0.002		0.01		0.012		0.004		0.005		0.0002		0.056		0.009		0.002				0.002		0.006	
18D	6/29/2011	0.005		0.01		0.066		0.004		0.005		0.005		0.005		0.005		0.005		0.002		0.016		0.01		0.002		0.002				0.005	
18D	8/23/2011	0.005		0.01		0.08		0.004		0.005		0.005		0.0094		0.005		0.005		0.0002		0.046		0.013		0.002		0.002				0.005	
18D	10/18/2011	0.005		0.003		0.091		0.004		0.005		0.005		0.012		0.005		0.004		0.0002		0.055		0.01		0.002		0.002				0.006	
18D	3/1/2012	0.005		0.003		0.071		0.004		0.005		0.005		0.0094		0.005		0.004		0.0002		0.045		0.01		0.002		0.002				0.005	
18D	5/30/2012	0.005		0.003		0.091		0.004		0.005		0.005		0.0094		0.005		0.004		0.0002		0.046		0.01		0.002		0.002				0.005	
18D	8/29/2012	0.005		0.003		0.089		0.004		0.005		0.005		0.01		0.005		0.004		0.0002		0.05		0.01		0.002		0.002				0.005	
18D	11/27/2012	0.005		0.003		0.094		0.001		0.002		0.005		0.0129		0.006		0.002		0.0002		0.059		0.006		0.002		0.002				0.012	
18D	3/7/2013	0.005		0.003		0.094		0.001		0.002		0.005		0.0117		0.007		0.002		0.0002		0.057		0.006		0.002		0.002				0.01	
18D	6/6/2013	0.005		0.003		0.104		0.001		0.002		0.005		0.0114		0.008		0.002		0.0002		0.064		0.006		0.002		0.002				0.011	
18D	9/3/2013	0.005		0.003		0.097		0.001		0.002		0.005		0.0134		0.007		0.002		0.0002		0.061		0.006		0.002		0.002				0.009	
18D	12/11/2013	0.005		0.003		0.096		0.001		0.002		0.005		0.0093		0.005		0.002		0.0002		0.042		0.006		0.002		0.002				0.005	
18D	3/26/2014	0.005		0.003		0.086		0.001		0.002		0.005		0.0118		0.005		0.002		0.0002		0.044		0.006		0.002		0.002				0.005	
18D	6/17/2014	0.005		0.003		0.106		0.001		0.002		0.005		0.0149		0.005		0.002		0.0002		0.064		0.006		0.002		0.002				0.007	
18D	8/20/2014	0.001		0.001		0.099		0.001		0.002		0.005		0.016		0.005		0.001		0.0002		0.059		0.001		0.002		0.001				0.01	
18D	3/18/2015	0.001		0.001		0.091		0.001		0.002		0.005		0.0103		0.006		0.001		0.0002		0.056		0.001		0.002		0.001				0.011	
18D	6/23/2015	0.001		0.001		0.093		0.001		0.002		0.005		0.008		0.007		0.001		0.0002		0.049		0.001		0.002		0.001				0.011	
18D	9/16/2015	0.001		0.001		0.091		0.001		0.002		0.005		0.0126		0.005		0.001		0.0002		0.05		0.001		0.002		0.001				0.008	
18D	12/9/2015	0.001		0.001		0.082		0.001		0.002		0.005		0.0087		0.005		0.001		0.0002		0.043		0.001		0.002		0.001				0.008	
18D	3/9/2016	0.001		0.001		0.085		0.001		0.002		0.005		0.0091		0.005		0.001		0.0002		0.043		0.001		0.002		0.001				0.006	
18D	6/8/2016	0.001		0.001		0.088		0.001		0.002		0.005		0.0112		0.005		0.001		0.0002		0.045		0.001		0.002		0.001				0.006	
18D	8/31/2016	0.001		0.001		0.084		0.001		0.002		0.005		0.0078		0.005		0.001		0.0002		0.039		0.001		0.002		0.001				0.005	
18D	12/8/2016	0.001		0.001		0.083		0.001		0.002		0.005		0.0089		0.005		0.001		0.0002		0.039		0.001		0.002		0.001				0.005	
18S	6/18/2009	0.005	0.005	0.003	0.003	0.108	0.121	0.001	0.001	0.005	0.005	0.01	0.01	0.0192	0.021	0.024	0.033	0.002	0.002	0.0002	0.0002	0.081	0.089	0.006	0.006	0.01	0.01	0.002	0.002	0.01	0.012	0.015	0.021
18S	9/29/2009	0.005	0.005	0.003	0.003	0.098	0.111	0.001	0.001	0.004	0.005	0.01	0.01	0.0112	0.012	0.018	0.022	0.002	0.002	0.0002	0.0002	0.059	0.06	0.008	0.009	0.01	0.01	0.002	0.002	0.01	0.012	0.011	0.016
18S	12/22/2009	0.005	0.005	0.003	0.003	0.095	0.106	0.001	0.001	0.004	0.004	0.01	0.01	0.0118	0.014	0.02	0.02	0.002	0.002	0.0002	0.0002	0.046	0.05	0.009	0.01	0.01	0.01	0.002	0.002	0.01	0.01	0.01	0.017
18S	3/16/2010	0.005	0.005	0.003	0.003	0.081	0.087	0.001	0.001	0.003	0.003	0.01	0.01	0.01	0.01	0.012	0.013	0.002	0.002	0.0002	0.0002	0.033	0.033	0.006	0.008	0.01	0.01	0.002	0.002	0.01	0.01	0.01	0.01
18S	8/31/2010	0.005		0.005		0.089		0.002		0.004		0.01		0.0093		0.024		0.005		0.0002		0.046		0.029		0.002				0.009		0.013	
18S	12/28/2010	0.005		0.005		0.085		0.002		0.006		0.01		0.01		0.041		0.005		0.0002		0.06		0.014		0.002				0.008		0.021	
18S	6/29/2011	0.005		0.01		0.077		0.004		0.005		0.005		0.0093		0.034		0.005		0.002		0.006		0.024		0.002		0.002				0.02	
18S	8/23/2011	0.005		0.01		0.098		0.004		0.005		0.005		0.0081		0.026		0.005		0.0002		0.053		0.045		0.002		0.002				0.015	
18S	10/18/2011	0.005		0.003		0.099		0.004		0.005		0.005		0.0092		0.029		0.004		0.0002		0.057		0.026		0.002		0.002				0.016	
18S	3/1/2012	0.005		0.003		0.087		0.004		0.005		0.005		0.0084		0.035		0.004		0.0002		0.054		0.017		0.002		0.002				0.019	
18S	5/30/2012	0.005		0.003		0.098		0.004		0.005		0.005		0.008		0.032		0.004		0.0002		0.056		0.041		0.002		0.002				0.016	
18S	8/29/2012	0.005		0.003		0.092		0.004		0.005		0.005		0.01		0.036		0.004		0.0002		0.063		0.031		0.002		0.002				0.021	
18S	11/27/2012	0.005		0.003		0.1		0.001		0.006		0.005		0.0105		0.041		0.002		0.0002		0.069		0.018		0.002		0.002				0.023	
18S	3/7/2013	0.005		0.003		0.11		0.001		0.007		0.005		0.013		0.053		0.002		0.0002		0.087		0.01		0.002		0.002				0.028	
18S	6/6/2013	0.005		0.003		0.072		0.001		0.003		0.005		0.0069		0.014		0.002		0.0002		0.035		0.02		0.002		0.002				0.007	
18S	9/3/2013	0.005		0.003		0.113		0.001		0.006		0.009		0.0095		0.035		0.002		0.0002		0.077		0.079		0.002		0.002				0.02	
18S	12/11/2013	0.005		0.003		0.108		0.001		0.005		0.005		0.0077		0.033		0.002		0.0002		0.062		0.033		0.002		0.002				0.019	
18S	3/26/2014	0.005		0.003		0.102		0.001		0.005		0.005		0.0087		0.032		0.002		0.0002		0.061		0.019		0.002		0.002				0.02	
18S	6/17/2014	0.005		0.003		0.104		0.001		0.005		0.005		0.009		0.03		0.002		0.0002		0.06		0.028		0.002		0.002				0.019	
18S	8/20/2014	0.001		0.001		0.1		0.001		0.004		0.005		0.0078		0.027		0.001		0.0002		0.055		0.034		0.002		0.001				0.019	
18S	3/18/2015	0.001		0.001		0.086		0.001		0.003		0.005		0.005		0.017		0.001		0.0002		0.024		0.035		0.002		0.001				0.011	
18S	6/23/2015	0.001		0.001		0.086		0.001		0.002		0.005		0.005		0.013		0.001		0.0002		0.017		0.034		0.002		0.001				0.008	
18S	9/16/2015	0.001		0.001		0.082		0.001		0.002		0.005		0.005		0.008		0.001		0.0002		0.011		0.059		0.002		0.001				0.005	
18S	12/9/2015	0.001		0.001		0.078		0.001		0.002		0.005		0.005		0.009		0.001		0.0002		0.012		0.033		0.002		0.001				0.006	
18S	3/9/2016	0.001		0.001		0.079		0.001		0.002		0.005		0.005		0.006		0.001		0.0002		0.009		0.056		0.002		0.001				0.005	
18S	6/8/2016	0.001		0.001		0.079		0.001		0.002		0.005		0.005		0.005		0.001		0.0002		0.006		0.059		0.002		0.001				0.005	
18S	8/31/2016	0.001		0.001		0.076		0.001		0.002		0.005		0.005		0.005		0.001		0.0002		0.005		0.045		0.002		0.001				0.005	
18S	12/8/2016	0.001		0.001		0.067		0.001		0.002		0.005		0.005		0.005		0.001		0.0002		0.004		0.051		0.002		0.001				0.005	
Class I Standard		0.006	0.006	0.01	0.01	2	2	0.004	0.004	0.005	0.005	0.1	0.1	1	1	0.65	0.65	0.0075	0.0075	0.002	0.002	0.1	0.1	0.05	0.05	0.05	0.05	0.002	0.002	0.049	0.049	5	5
# of Exceedances		0	0	0	0	0	0	0	0	36	7	0	0	0	0	0	0	0	1	0	0	1	1	5	0	0	0	0	0	0	0	0	0
Minimum Value		0.001	0.005	0.001	0.003	0.040	0.073	0.001	0.001	0.002	0.002	0.005	0.010	0.005	0.010	0.004	0.010	0.001	0.002	0.0002	0.0002	0.002	0.025	0.001	0.006	0.002	0.010	0.001	0.002	0.002	0.010	0.005	0.010
Maximum Value		0.005	0.005	0.010	0.004	0.113	0.127	0.004	0.001	0.011	0.008	0.010	0.012	0.029	0.032	0.063	0.041	0.005	0.007	0.0020	0.0002	0.101	0.114	0.079	0.010	0.010	0.010	0.002	0.002	0.010	0.012	0.075	0.051
# of Samples Analyzed		118	20	118	20	118	20	118	20	118	20	118	20	118	20	118	20	118	20	118	20	118	20	118	20	118	20	110	20	28	20	118	20

Natural Resource Technology
AN OBG COMPANY

Appendix H1: Illinois EPA Program Monitoring Results
Trace Metal Parameters - Upgradient Wells
Hydrogeologic Site Characterization Report
Ash Pond No. 2, Hennepin Power Station

Legend:
- (pink) Value exceeds 35 IAC 620 Class I groundwater standard
- (blue) Value below detection limit

Well No.	sample_date	Antimony, dissolved (mg/L)	Antimony, total (mg/L)	Arsenic, dissolved (mg/L)	Arsenic, total (mg/L)	Barium, dissolved (mg/L)	Barium, total (mg/L)	Beryllium, dissolved (mg/L)	Beryllium, total (mg/L)	Cadmium, dissolved (mg/L)	Cadmium,total (mg/L)	Chromium, dissolved (mg/L)	Chromium, total (mg/L)	Cobalt, dissolved (mg/L)	Cobalt, total (mg/L)	Copper, dissolved (mg/L)	Copper, total (mg/L)	Lead, dissolved (mg/L)	Lead, total (mg/L)	Mercury, dissolved (mg/L)	Mercury, total (mg/L)	Nickel, dissolved (mg/L)	Nickel, total (mg/L)	Selenium, dissolved (mg/L)	Selenium, total (mg/L)	Silver, dissolved (mg/L)	Silver, total (mg/L)	Thallium, dissolved (mg/L)	Thallium, total (mg/L)	Vanadium, dissolved (mg/L)	Vanadium, total (mg/L)	Zinc, dissolved (mg/L)	Zinc, total (mg/L)
7	12/29/2008	0.005	0.005	0.003	0.003	0.09	0.094	0.001	0.001	0.002	0.002	0.01	0.01	0.01	0.01	0.01	0.01	0.002	0.002	0.0002	0.0002	0.01	0.01	0.006	0.006	0.01	0.01	0.002	0.002	0.01	0.01	0.01	0.01
7	3/25/2009	0.005	0.005	0.003	0.003	0.106	0.112	0.001	0.001	0.002	0.002	0.01	0.01	0.01	0.01	0.01	0.01	0.002	0.002	0.0002	0.0002	0.01	0.01	0.006	0.006	0.01	0.01	0.002	0.002	0.01	0.01	0.01	0.01
7	6/18/2009	0.005	0.005	0.003	0.003	0.095	0.102	0.001	0.001	0.002	0.002	0.01	0.01	0.01	0.01	0.01	0.01	0.002	0.002	0.0002	0.0002	0.01	0.01	0.006	0.006	0.01	0.01	0.002	0.002	0.01	0.01	0.01	0.01
7	9/29/2009	0.005	0.005	0.003	0.003	0.088	0.096	0.001	0.001	0.002	0.002	0.01	0.01	0.01	0.01	0.01	0.01	0.002	0.002	0.0002	0.0002	0.01	0.01	0.006	0.006	0.01	0.01	0.002	0.002	0.01	0.01	0.01	0.01
7	12/29/2009	0.005	0.005	0.003	0.003	0.091	0.099	0.001	0.001	0.002	0.002	0.01	0.01	0.01	0.01	0.01	0.01	0.002	0.002	0.0002	0.0002	0.01	0.01	0.006	0.006	0.01	0.01	0.002	0.002	0.01	0.01	0.01	0.01
7	3/16/2010	0.005	0.005	0.003	0.003	0.088	0.095	0.001	0.001	0.002	0.002	0.01	0.01	0.01	0.01	0.01	0.01	0.002	0.002	0.0002	0.0002	0.01	0.01	0.006	0.006	0.01	0.01	0.002	0.002	0.01	0.01	0.01	0.01
7	8/31/2010	0.005		0.005		0.079		0.002		0.002		0.01		0.005		0.01		0.005		2		0.005		0.005		0.002				0.002		0.005	
7	12/29/2010	0.005		0.005		0.087		0.002		0.002		0.01		0.005		0.008		0.005		2		0.002		0.008		0.002				0.002		0.015	
7	6/29/2011	0.005		0.01		0.075		0.004		0.005		0.005		0.005		0.005		0.005		0.002		0.005		0.01		0.002		0.002				0.005	
7	8/24/2011	0.005		0.01		0.079		0.004		0.005		0.005		0.005		0.005		0.005		0.0002		0.005		0.01		0.002		0.002				0.005	
7	10/19/2011	0.005		0.003		0.092		0.004		0.005		0.005		0.005		0.005		0.004		0.0002		0.002		0.01		0.002		0.002				0.005	
7	3/1/2012	0.005		0.003		0.067		0.004		0.005		0.005		0.005		0.005		0.004		0.0002		0.002		0.01		0.002		0.002				0.005	
7	5/31/2012	0.005		0.003		0.038		0.004		0.005		0.005		0.005		0.005		0.004		0.0002		0.002		0.01		0.002		0.002				0.005	
7	8/29/2012	0.005		0.003		0.072		0.004		0.005		0.005		0.005		0.005		0.004		0.0002		0.002		0.01		0.002		0.002				0.005	
7	11/27/2012	0.005		0.003		0.082		0.001		0.002		0.005		0.005		0.005		0.002		0.0002		0.002		0.006		0.002		0.002				0.005	
7	3/7/2013	0.005		0.003		0.089		0.001		0.002		0.005		0.005		0.005		0.002		0.0002		0.002		0.006		0.002		0.002				0.005	
7	6/6/2013	0.005		0.003		0.071		0.001		0.002		0.005		0.005		0.005		0.002		0.0002		0.002		0.006		0.002		0.002				0.005	
7	9/4/2013	0.005		0.003		0.089		0.001		0.002		0.005		0.005		0.005		0.002		0.0002		0.002		0.006		0.002		0.002				0.005	
7	12/11/2013	0.005		0.003		0.087		0.001		0.002		0.005		0.005		0.005		0.002		0.0002		0.002		0.006		0.002		0.002				0.005	
7	3/26/2014	0.005		0.003		0.087		0.001		0.002		0.005		0.005		0.005		0.002		0.0002		0.002		0.006		0.002		0.002				0.005	
7	6/18/2014	0.005		0.003		0.092		0.001		0.002		0.005		0.005		0.005		0.002		0.0002		0.003		0.006		0.002		0.002				0.005	
7	8/20/2014	0.001		0.001		0.092		0.001		0.002		0.005		0.005		0.005		0.001		0.0002		0.002		0.001		0.002		0.001				0.005	
7	12/9/2014	0.001		0.001		0.108		0.001		0.002		0.005		0.005		0.005		0.001		0.0002		0.005		0.001		0.002		0.001				0.005	
7	3/19/2015	0.001		0.001		0.095		0.001		0.002		0.005		0.005		0.005		0.001		0.0002		0.002		0.001		0.002		0.001				0.005	
7	6/23/2015	0.001		0.001		0.093		0.001		0.002		0.005		0.005		0.005		0.001		0.0002		0.002		0.001		0.002		0.001				0.005	
7	9/17/2015	0.001		0.001		0.095		0.001		0.002		0.005		0.005		0.005		0.001		0.0002		0.002		0.001		0.002		0.001				0.005	
7	12/9/2015	0.001		0.001		0.132		0.001		0.002		0.005		0.005		0.005		0.001		0.0002		0.006		0.001		0.002		0.001				0.005	
7	3/10/2016	0.001		0.001		0.098		0.001		0.002		0.005		0.005		0.005		0.001		0.0002		0.002		0.001		0.002		0.001				0.005	
7	6/8/2016	0.001		0.001		0.129		0.001		0.002		0.005		0.005		0.005		0.001		0.0002		0.002		0.001		0.002		0.001				0.005	
7	9/1/2016	0.001		0.001		0.106		0.001		0.002		0.005		0.005		0.005		0.001		0.0002		0.002		0.001		0.002		0.001				0.014	
7	12/9/2016	0.001		0.001		0.124		0.001		0.002		0.005		0.005		0.005		0.001		0.0002		0.017		0.001		0.002		0.001				0.005	
8	12/29/2008	0.005	0.005	0.003	0.003	0.131	0.132	0.001	0.001	0.002	0.002	0.01	0.01	0.01	0.01	0.01	0.01	0.002	0.002	0.0002	0.0002	0.01	0.012	0.006	0.006	0.01	0.01	0.002	0.002	0.01	0.01	0.01	0.01
8	3/25/2009	0.005	0.005	0.003	0.003	0.143	0.153	0.001	0.001	0.002	0.002	0.01	0.01	0.01	0.01	0.01	0.01	0.002	0.002	0.0002	0.0002	0.011	0.011	0.006	0.006	0.01	0.01	0.002	0.002	0.01	0.01	0.01	0.01
8	6/18/2009	0.005	0.005	0.003	0.003	0.141	0.147	0.001	0.001	0.002	0.002	0.01	0.01	0.01	0.01	0.01	0.01	0.002	0.002	0.0002	0.0002	0.013	0.013	0.006	0.006	0.01	0.01	0.002	0.002	0.01	0.01	0.01	0.01
8	9/29/2009	0.005	0.005	0.003	0.003	0.124	0.13	0.001	0.001	0.002	0.002	0.01	0.01	0.01	0.01	0.01	0.01	0.002	0.002	0.0002	0.0002	0.01	0.012	0.006	0.006	0.01	0.01	0.002	0.002	0.01	0.01	0.01	0.01
8	12/29/2009	0.005	0.005	0.003	0.003	0.134	0.141	0.001	0.001	0.002	0.002	0.01	0.01	0.01	0.01	0.01	0.01	0.002	0.002	0.0002	0.0002	0.038	0.039	0.006	0.006	0.01	0.01	0.002	0.002	0.01	0.01	0.01	0.01
8	3/16/2010	0.005	0.005	0.003	0.003	0.114	0.123	0.001	0.001	0.002	0.002	0.01	0.01	0.01	0.01	0.01	0.01	0.002	0.002	0.0002	0.0002	0.019	0.023	0.006	0.006	0.01	0.01	0.002	0.002	0.01	0.01	0.01	0.01
8	8/31/2010	0.005		0.005		0.11		0.002		0.002		0.01		0.005		0.01		0.005		2		0.013		0.008		0.002				0.002		0.005	
8	12/29/2010	0.005		0.008		0.12		0.002		0.002		0.01		0.005		0.001		0.005		2		0.007		0.008		0.002				0.002		0.005	
8	3/16/2011			0.005		0.15				0.002		0.01						0.005		2				0.016								0.005	
8	6/29/2011	0.005		0.01	0.01	0.11	0.11	0.004		0.005	0.005	0.005	0.005	0.005		0.005	0.005	0.005	0.005	0.002	0.002	0.037		0.01	0.01	0.002		0.002		0.005	0.005	0.005	0.005
8	8/24/2011	0.005		0.01		0.12		0.004		0.005		0.005		0.005		0.005		0.005		0.0002		0.021		0.01		0.002		0.002				0.005	
8	10/19/2011	0.005		0.003		0.13		0.004		0.005		0.005		0.005		0.005		0.004		0.0002		0.009		0.01		0.002		0.002				0.005	
8	3/1/2012	0.005		0.003		0.12		0.004		0.005		0.005		0.005		0.005		0.004		0.0002		0.021		0.01		0.002		0.002				0.005	
8	5/30/2012	0.005		0.005	0.003	0.15	0.13	0.004		0.005	0.005	0.005	0.005	0.005		0.005	0.005	0.004	0.004	0.0002	0.0002	0.019		0.01	0.01	0.002		0.002		0.005	0.005	0.005	0.005
8	8/29/2012	0.005		0.004		0.13		0.004		0.005		0.005		0.005		0.005		0.004		0.0002		0.021		0.01		0.002		0.002				0.005	
8	11/27/2012	0.005		0.003		0.161		0.001		0.002		0.005		0.005		0.005		0.002		0.0002		0.032		0.006		0.002		0.002				0.005	
8	3/7/2013	0.005		0.003		0.173		0.001		0.002		0.005		0.005		0.005		0.002		0.0002		0.032		0.006		0.002		0.002				0.005	
8	6/6/2013	0.005		0.003	0.003	0.11	0.127	0.001		0.002	0.002	0.005	0.005	0.005		0.005	0.005	0.002	0.002	0.0002	0.0002	0.01		0.006	0.006	0.003		0.002		0.01	0.01	0.005	0.007
8	9/3/2013	0.005		0.003		0.165		0.001		0.002		0.005		0.005		0.005		0.002		0.0002		0.037		0.006		0.002		0.002				0.005	
8	12/11/2013	0.005		0.003		0.167		0.001		0.002		0.005		0.005		0.005		0.002		0.0002		0.03		0.006		0.002		0.002				0.005	
8	3/26/2014	0.005		0.003		0.154		0.001		0.002		0.005		0.005		0.005		0.002		0.0002		0.024		0.006		0.002		0.002				0.005	
8	6/18/2014	0.005		0.003	0.003	0.146	0.164	0.001		0.002	0.002	0.005	0.005	0.005		0.005	0.005	0.002	0.002	0.0002	0.0002	0.024		0.006	0.006	0.003		0.002		0.01	0.01	0.005	0.005
8	8/20/2014	0.001		0.001		0.142		0.001		0.002		0.005		0.005		0.005		0.001		0.0002		0.048		0.001		0.002		0.001				0.007	
8	12/9/2014	0.001		0.001		0.126		0.001		0.002		0.005		0.005		0.005		0.001		0.0002		0.121		0.001		0.002		0.001				0.005	
8	3/19/2015	0.001		0.001		0.119		0.001		0.002		0.005		0.005		0.005		0.001		0.0002		0.04		0.001		0.002		0.001				0.005	
8	6/22/2015	0.001		0.001	0.001	0.125	0.136	0.0005		0.002	0.002	0.005	0.005	0.005		0.005	0.005	0.001	0.001	0.0002	0.0002	0.051		0.001	0.001	0.003		0.001		0.01	0.01	0.005	0.005
8	9/16/2015	0.001		0.001		0.124		0.001		0.002		0.005		0.005		0.005		0.001		0.0002		0.055		0.001		0.002		0.001				0.005	
8	12/8/2015	0.001		0.001		0.111		0.001		0.002		0.005		0.005		0.005		0.001		0.0002		0.104		0.001		0.002		0.001				0.005	
8	3/10/2016	0.001		0.001		0.132		0.001		0.002		0.005		0.005		0.005		0.001		0.0002		0.066		0.001		0.002		0.001				0.005	
8	6/7/2016	0.001		0.001	0.001	0.115	0.123	0.0005		0.002	0.002	0.005	0.005	0.005		0.005	0.005	0.001	0.001	0.0002	0.0002	0.086		0.001	0.001	0.003		0.001		0.01	0.01	0.005	0.005
8	9/1/2016	0.001		0.001		0.144		0.001		0.002		0.005		0.0244		0.005		0.001		0.0002		0.234		0.001		0.002		0.001				0.005	
8	12/9/2016	0.001		0.001		0.109		0.001		0.002		0.005		0.0205		0.005		0.001		0.0002		0.183		0.001		0.002		0.001				0.005	

Appendix H1: Illinois EPA Program Monitoring Results
Trace Metal Parameters - Upgradient Wells
Hydrogeologic Site Characterization Report
Ash Pond No. 2, Hennepin Power Station

Legend:
- (pink) Value exceeds 35 IAC 620 Class I groundwater standard
- (blue) Value below detection limit

Well No.	sample_date	Antimony, dissolved (mg/L)	Antimony, total (mg/L)	Arsenic, dissolved (mg/L)	Arsenic, total (mg/L)	Barium, dissolved (mg/L)	Barium, total (mg/L)	Beryllium, dissolved (mg/L)	Beryllium, total (mg/L)	Cadmium, dissolved (mg/L)	Cadmium,total (mg/L)	Chromium, dissolved (mg/L)	Chromium, total (mg/L)	Cobalt, dissolved (mg/L)	Cobalt, total (mg/L)	Copper, dissolved (mg/L)	Copper, total (mg/L)	Lead, dissolved (mg/L)	Lead, total (mg/L)	Mercury, dissolved (mg/L)	Mercury, total (mg/L)	Nickel, dissolved (mg/L)	Nickel, total (mg/L)	Selenium, dissolved (mg/L)	Selenium, total (mg/L)	Silver, dissolved (mg/L)	Silver, total (mg/L)	Thallium, dissolved (mg/L)	Thallium, total (mg/L)	Vanadium, dissolved (mg/L)	Vanadium, total (mg/L)	Zinc, dissolved (mg/L)	Zinc, total (mg/L)
08D	6/18/2009	0.005	0.005	0.003	0.003	0.117	0.143	0.001	0.001	0.002	0.002	0.01	0.01	0.01	0.01	0.01	0.01	0.002	0.004	0.0002	0.0002	0.029	0.035	0.006	0.006	0.01	0.01	0.002	0.002	0.01	0.01	0.01	0.024
08D	9/29/2009	0.005	0.005	0.003	0.003	0.095	0.098	0.001	0.001	0.002	0.002	0.01	0.01	0.01	0.01	0.01	0.01	0.002	0.002	0.0002	0.0002	0.025	0.026	0.006	0.006	0.01	0.01	0.002	0.002	0.01	0.01	0.01	0.01
08D	12/29/2009	0.005	0.005	0.003	0.003	0.121	0.135	0.001	0.001	0.002	0.002	0.01	0.01	0.01	0.01	0.01	0.01	0.002	0.002	0.0002	0.0002	0.027	0.03	0.006	0.006	0.01	0.01	0.002	0.002	0.01	0.01	0.01	0.01
08D	3/16/2010	0.005	0.005	0.003	0.003	0.125	0.131	0.001	0.001	0.002	0.002	0.011	0.01	0.01	0.01	0.01	0.01	0.002	0.002	0.0002	0.0002	0.027	0.028	0.006	0.006	0.01	0.01	0.002	0.002	0.01	0.01	0.01	0.01
08D	8/31/2010	0.005		0.005		0.098		0.002		0.002		0.01		0.005		0.01		0.005		2		0.012		0.01		0.002				0.002		0.005	
08D	12/29/2010	0.005		0.008		0.1		0.002		0.002		0.01		0.005		0.001		0.005		2		0.02		0.01		0.002				0.002		0.005	
08D	3/16/2011			0.005		0.11				0.002		0.01						0.005		2				0.016								0.005	
08D	6/29/2011	0.005		0.01	0.01	0.1	0.11	0.004		0.005	0.005	0.005	0.005	0.005		0.005	0.005	0.005	0.005	0.002	0.002	0.026		0.01	0.01	0.002		0.002		0.005	0.005	0.005	0.007
08D	8/23/2011	0.005		0.01		0.11		0.004		0.005		0.005		0.005		0.005		0.005		0.0002		0.013		0.014		0.002		0.002				0.005	
08D	10/19/2011	0.005		0.003		0.11		0.004		0.005		0.005		0.005		0.005		0.004		0.0002		0.011		0.01		0.002		0.002				0.005	
08D	3/1/2012	0.005		0.003		0.077		0.004		0.005		0.005		0.005		0.005		0.004		0.0002		0.012		0.01		0.002		0.002				0.005	
08D	5/30/2012	0.005		0.003	0.003	0.1	0.092	0.004		0.005	0.005	0.005	0.005	0.005		0.005	0.005	0.004	0.004	0.0002	0.0002	0.024		0.01	0.01	0.002		0.002		0.005	0.005	0.005	0.005
08D	8/29/2012	0.005		0.003		0.11		0.004		0.005		0.005		0.005		0.005		0.004		0.0002		0.019		0.01		0.002		0.002				0.005	
08D	11/27/2012	0.005		0.003		0.104		0.001		0.002		0.005		0.005		0.005		0.002		0.0002		0.015		0.006		0.002		0.002				0.005	
08D	3/7/2013	0.005		0.003		0.105		0.001		0.002		0.005		0.005		0.005		0.002		0.0002		0.029		0.006		0.002		0.002				0.005	
08D	6/6/2013	0.005		0.003	0.003	0.116	0.13	0.001		0.002	0.002	0.005	0.005	0.0324		0.015	0.017	0.002	0.002	0.0002	0.0002	0.139		0.006	0.006	0.003		0.002		0.01	0.01	0.018	0.028
08D	9/4/2013	0.005		0.003		0.106		0.001		0.002		0.005		0.005		0.005		0.002		0.0002		0.039		0.006		0.002		0.002				0.005	
08D	12/11/2013	0.005		0.003		0.117		0.001		0.002		0.005		0.005		0.005		0.002		0.0002		0.032		0.006		0.002		0.002				0.005	
08D	3/26/2014	0.005		0.003		0.121		0.001		0.002		0.005		0.005		0.005		0.002		0.0002		0.044		0.006		0.002		0.002				0.008	
08D	6/18/2014	0.005		0.003	0.003	0.143	0.164	0.001		0.002	0.002	0.005	0.005	0.005		0.005	0.005	0.002	0.002	0.0002	0.0002	0.061		0.006	0.006	0.003		0.002		0.01	0.01	0.005	0.01
08D	8/20/2014	0.001		0.001		0.134		0.001		0.002		0.005		0.005		0.005		0.001		0.0002		0.056		0.001		0.002		0.001				0.011	
08D	12/10/2014	0.001		0.001		0.119		0.001		0.002		0.005		0.0188		0.035		0.001		0.0002		0.11		0.001		0.002		0.001				0.018	
08D	3/19/2015	0.001		0.001		0.127		0.001		0.002		0.005		0.0264		0.047		0.001		0.0002		0.144		0.001		0.002		0.001				0.02	
08D	6/22/2015	0.001		0.001	0.001	0.137	0.144	0.0005		0.002	0.002	0.005	0.005	0.0223		0.017	0.012	0.001	0.001	0.0002	0.0002	0.095		0.001	0.001	0.003		0.001		0.01	0.01	0.013	0.012
08D	9/16/2015	0.001		0.001		0.141		0.001		0.002		0.005		0.005		0.005		0.001		0.0002		0.028		0.001		0.002		0.001				0.006	
08D	12/8/2015	0.001		0.001		0.128		0.001		0.002		0.005		0.0149		0.01		0.001		0.0002		0.066		0.001		0.002		0.001				0.011	
08D	3/10/2016	0.001		0.001		0.142		0.001		0.002		0.005		0.005		0.005		0.001		0.0002		0.05		0.001		0.002		0.001				0.006	
08D	6/7/2016	0.001		0.001	0.001	0.134	0.138	0.0005		0.002	0.002	0.005	0.005	0.005		0.005	0.005	0.001	0.001	0.0002	0.0002	0.062		0.001	0.001	0.003		0.001		0.01	0.01	0.005	0.006
08D	9/1/2016	0.001		0.001		0.175		0.001		0.002		0.005		0.0123		0.009		0.001		0.0002		0.113		0.001		0.002		0.001				0.012	
08D	12/9/2016	0.001		0.001		0.168		0.001		0.002		0.005		0.0102		0.005		0.001		0.0002		0.089		0.001		0.002		0.001				0.008	
Class I Standard		0.006	0.006	0.01	0.01	2	2	0.004	0.004	0.005	0.005	0.1	0.1	1	1	0.65	0.65	0.0075	0.0075	0.002	0.002	0.1	0.1	0.05	0.05	0.05	0.05	0.002	0.002	0.049	0.049	5	5
# of Exceedances		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	0	8	0	0	0	0	0	0	0	0	0	0	0
Minimum Value		0.001	0.005	0.001	0.001	0.038	0.092	0.0005	0.001	0.002	0.002	0.005	0.005	0.0050	0.010	0.001	0.005	0.001	0.001	0.0002	0.0002	0.002	0.010	0.001	0.001	0.002	0.010	0.001	0.002	0.002	0.005	0.005	0.005
Maximum Value		0.005	0.005	0.010	0.010	0.175	0.164	0.0040	0.001	0.005	0.005	0.011	0.010	0.0324	0.010	0.047	0.017	0.005	0.005	2.0	0.002	0.234	0.039	0.016	0.010	0.010	0.010	0.002	0.002	0.010	0.010	0.020	0.028
# of Samples Analyzed		91	16	93	28	93	28	91	16	93	28	93	28	91	16	91	28	93	28	93	28	91	16	93	28	91	16	85	16	34	28	93	28

Appendix H2

CCR Rule Monitoring Results

Appendix H2: CCR Rule Program Monitoring Results
Hydrogeologic Site Characterization Report
Ash Pond No. 2, Hennepin Power Station

Parameters (total)			**Wells**	**Upgradient**											
				07				**08**				**08D**			
Appendix III	**Units**	**Class I Standard**	**Sample Date**	not sampled first round	3/10/2016	6/7/2016	9/1/2016	12/8/2015	3/9/2016	6/7/2016	9/1/2016	12/8/2015	3/9/2016	6/7/2016	9/1/2016
Boron	mg/L	2.0		- - - -	0.0629	0.0673	0.0697	0.0972	0.0878	0.075	0.142	0.109	0.122	0.111	0.139
Calcium	mg/L	NS		- - - -	126	154	150	198	213	191	299	174	187	177	287
Chloride	mg/L	200		- - - -	51	55	49	**216**	145	**202**	**312**	184	**209**	**217**	**325**
Fluoride	mg/L	4.0		- - - -	0.10	0.10	0.10	0.09	0.09	0.09	0.09	0.12	0.10	0.10	0.12
Sulfate	mg/L	400		- - - -	70	82	75	164	133	129	209	119	130	113	161
TDS	mg/L	1,200		- - - -	536	758	574	1170	918	1060	**1370**	1050	1060	1090	**1340**
pH-Field	S.U.	6.5-9.0		- - - -	6.90	6.64	6.94	6.82	6.73	6.60	6.69	6.89	6.73	6.64	6.63
Appendix IV															
Antimony	mg/L	0.006		- - - -	<0.0002	0	<0.0002	<0.0002	0.0003	0.0003	<0.0002	<0.0002	0.0003	0.0003	<0.0002
Arsenic	mg/L	0.010		- - - -	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002
Barium	mg/L	2.0		- - - -	0.104	0.13	0.13	0.118	0.148	0.127	0.146	0.133	0.155	0.138	0.23
Beryllium	mg/L	0.004		- - - -	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
Cadmium	mg/L	0.005		- - - -	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	0.0005	0.0005	0.0003	0.0011
Chromium	mg/L	0.1		- - - -	0.0005	0.0005	0.0005	0.0004	<0.0003	<0.0003	<0.0003	0.0004	<0.0003	<0.0003	<0.0003
Cobalt	mg/L	1.0		- - - -	<0.0002	<0.0002	<0.0002	0.0029	0.0017	0.0034	0.0285	0.0122	0.0036	0.0028	0.013
Fluoride	mg/L	4.0		- - - -	0.10	0.10	0.1	0.09	0.09	0.09	0.09	0.12	0.10	0.10	0.12
Lead	mg/L	0.0075		- - - -	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	0.0003	<0.0002	0.0005
Lithium	mg/L	NS		- - - -	0.0079	0.0085	0.0091	0.01	0.0091	0.0092	0.0127	0.0121	0.0143	0.0108	0.0164
Mercury	mg/L	0.002		- - - -	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005
Molybdenum	mg/L	NS		- - - -	0.0008	0.0006	0.0008	0.0015	0.0016	0.0013	0.0014	0.0014	0.0013	0.0011	0.0014
Selenium	mg/L	0.05		- - - -	0.001	0.0011	0.0014	<0.0009	<0.0009	<0.0009	<0.0009	<0.0009	<0.0009	<0.0009	<0.0009
Thallium	mg/L	0.002		- - - -	<0.0002	<0.0002	<0.0002	0.0004	<0.0002	<0.0002	<0.0002	0.0003	<0.0002	<0.0002	<0.0002
Radium 226/228	pCi/L	20		- - - -	0.12	1.09	0.36	0.89	0.72	0.74	0.33	0.94	0.12	0.35	0.55
Groundwater Elevation	feet			- - - -	451.59	452.75	453.4	449.20	447.80	448.93	450.35	447.92	447.52	447.60	450.19

Parameters (total)	**Downgradient**								**Downgradient**							
	03R				**18D**				**18S**				**45S**			
Appendix III	12/9/2015	3/9/2016	6/8/2016	8/31/2016	12/9/2015	3/9/2016	6/8/2016	8/31/2016	12/9/2015	3/9/2016	6/8/2016	8/31/2016	12/9/2015	3/9/2016	6/8/2016	8/31/2016
Boron	1.24	1.38	1.25	1.03	1.98	1.93	1.82	1.86	**3.40**	**4.74**	**4.18**	**5.11**	0.400	0.436	0.544	0.497
Calcium	82.4	84.6	85.6	85.8	114	116	110	108	99.7	101	98.3	118	87.8	97.2	97.2	95.4
Chloride	66	78	84	89	74	81	90	83	68	69	70	70	70	80	104	96
Fluoride	0.20	0.26	0.26	0.27	0.13	0.15	0.14	0.14	0.14	0.13	0.13	0.12	0.29	0.33	0.33	0.34
Sulfate	85	136	107	101	133	141	136	123	153	229	204	187	83	93	99	98
TDS	548	566	532	560	680	686	648	608	656	670	654	678	534	594	574	542
pH-Field	7.23	7.26	7.27	7.50	7.20	7.17	7.17	7.43	7.47	7.37	7.58	7.5	7.00	7.15	7.26	7.31
Appendix IV																
Antimony	0.0004	0.0004	0.0006	<0.0002	0.0003	0.0003	0.0003	<0.0002	0.0005	0.0005	0.0006	0.0004	0.0003	0.0003	0.0004	<0.0002
Arsenic	0.0005	0.0005	0.0006	0.0003	0.0005	0.0006	0.0005	0.0004	0.0007	0.0006	0.0007	0.0007	0.0007	0.0004	0.0004	0.0003
Barium	0.0656	0.067	0.0658	0.0617	0.0891	0.0937	0.0875	0.0873	0.0833	0.0813	0.0768	0.0861	0.0664	0.0709	0.0717	0.0691
Beryllium	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
Cadmium	0.0016	0.0013	0.001	0.0008	0.0011	0.0011	0.001	0.0008	0.0018	0.0014	0.0011	0.0007	0.0023	0.0022	0.0021	0.002
Chromium	0.0006	0.0008	0.0008	<0.0003	0.0004	<0.0003	<0.0003	<0.0003	0.0016	0.0029	0.0014	0.0009	0.0013	0.0004	0.0004	<0.0003
Cobalt	0.0007	0.0007	0.0011	0.0007	0.0093	0.0106	0.0088	0.008	0.0016	0.0012	0.0008	0.0006	0.0024	0.0028	0.006	0.0041
Fluoride	0.20	0.26	0.26	0.27	0.13	0.15	0.14	0.14	0.14	0.13	0.13	0.12	0.29	0.33	0.33	0.34
Lead	<0.0002	0.0004	0.0003	<0.0002	<0.0002	0.0003	<0.0002	<0.0002	0.0004	<0.0002	<0.0002	<0.0002	0.001	0.0007	0.0005	0.0004
Lithium	0.0239	0.0289	0.0278	0.0219	0.0318	0.0306	0.0293	0.0317	0.0711	0.0806	0.0797	0.0844	0.0175	0.0165	0.0169	0.0178
Mercury	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005
Molybdenum	0.208	0.22	0.212	0.15	0.0299	0.0312	0.0292	0.0281	0.315	0.32	0.333	0.354	0.0972	0.0911	0.0847	0.0847
Selenium	0.0055	0.0054	0.0075	0.0071	<0.0009	<0.0009	<0.0009	<0.0009	0.0338	**0.0596**	**0.0506**	0.0462	<0.0009	<0.0009	<0.0009	<0.0009
Thallium	0.0004	<0.0002	0.0003	0.0004	0.0003	<0.0002	<0.0002	0.0003	0.0004	<0.0002	0.0003	0.0004	0.0004	0.0003	0.0003	0.0003
Radium 226/228	0.68	0.392	2.45	-0.05	0.41	0.388	0.64	0.44	0.91	0	1.22	0.75	1.09	0.706	1.27	0.37
Groundwater Elevation	448.75	447.33	448.25	450.05	448.78	447.23	448.05	450.12	448.84	447.32	448.22	450.13	448.85	447.62	448.37	450.07

[O: KLT 7/11/16, C: ANS 7/12/16, U: ANS 8/8/16, C: KLT 8/8/16, U: ANS 10/6/16, C: KJS 10/7/16, U: Y_Z 11/3/16, C: DLB 11/9/16]

Notes:
All parameters collected and measured as totals
NS — no USEPA MCL established for parameter
pCi/L — pico Curies per Liter
S.U. — Standard Units
TDS — Total Dissolved Solids
Red Value — Parameter concentration exceeds USEPA MCL
< — Below reporting limit for parameter
- - - - — not sampled
Groundwater level data as collected on December 8, 2015 for R1,
March 8, 2016 for R2, June 7, 2016 for R3, and August 31, 2016 for R4

OBG

THERE'S A WAY

Natural Resource Technology

AN OBG COMPANY

The following are attachments to the testimony of Scott M. Payne, PhD, PG and Ian Magruder, M.S..

ATTACHMENT 24

APPENDIX D

GROUNDWATER MODEL REPORT

OBG

Groundwater Model Report

Hennepin East Ash Pond No. 2

Hennepin, Illinois

Dynegy Midwest Generation, LLC

FINAL

December 20, 2017

Natural Resource Technology
AN OBG COMPANY

DECEMBER 20, 2017 | FINAL | PROJECT #2414

Groundwater Model Report

Hennepin East Ash Pond No. 2
Hennepin, Illinois

Prepared for:

Dynegy Midwest Generation, LLC
1500 Eastport Plaza Drive
Collinsville, IL 62234

STUART J. CRAVENS, PG
Principal Hydrogeologist

MENG WANG, PHD, PE
Data Innovation Engineer

TABLE OF CONTENTS

LIST OF TABLES ii
LIST OF FIGURES ii
LIST OF APPENDICES ii
ACRONYMS AND ABBREVIATIONS i
1 INTRODUCTION 1
1.1 Overview 1
1.2 Background 1
1.2.1 Site History 1
1.2.2 Hydrogeology 2
1.2.3 Ash Saturation 2
1.2.4 Groundwater Quality 3
1.3 Conceptual Model 3
2 MODEL ESTABLISHMENT 4
2.1 MODEL Background 4
2.2 MODEL Approach 4
2.3 MODEL Description 5
2.4 MODEL Setup 5
2.4.1 Grid and Boundary Conditions 5
2.4.2 Flow Model Input Values and Sensitivity 6
2.4.3 Transport Model Input Values and Sensitivity 7
3 MODEL RESULTS 9
3.1 Flow and Transport Model Assumptions and Limitations 9
3.2 Calibration Flow and Transport Model Results 9
3.3 Model Prediction 10
3.3.1 Baseline 10
3.3.2 Capping Scenario 10
4 SUMMARY 11
REFERENCES 12

LIST OF TABLES

Table 1-1 Flow Model Stress Period Establishment
Table 2-1a Flow Model Input Values (Steady-State Calibration)
Table 2-1b Flow Model Input Values (Transient Calibration)
Table 2-1c Flow Model Input Values (Prediction)
Table 2-2 Transport Model Input Values

LIST OF FIGURES

Figure 1-1 Site Location Map
Figure 1-2 Ash Impoundment Location Map
Figure 1-3 Monitoring Well Location Map
Figure 2-1 MODFLOW Grid and Boundary Conditions
Figure 2-2 Hydraulic Conductivity (ft/d) Array
Figure 2-3 Effective Porosity and Specific Yield Array
Figure 2-4 Recharge (ft/d) Array (Steady State Model)
Figure 2-5 Recharge (ft/d) Array (Transient Model)
Figure 2-6 Recharge (ft/d) Array (Prediction Model for Capping Scenario)
Figure 3-1 Comparison of Calibration Heads to Observations from 1994 through 2016
Figure 3-2 Comparison of Calibration Boron Concentrations to Observations from 1994 through 2016
Figure 3-3 Comparison of Predicted Heads between Baseline and Capping Scenarios
Figure 3-4 Comparison of Predicted Boron Concentrations between Baseline and Capping Scenario
Figure 3-5 Footprint of Boron Plume over 2 mg/L in Year 2019
Figure 3-6 Footprint of Boron Plume over 2 mg/L in Year 2037

LIST OF APPENDICES

Appendix A MODFLOW MODELING FILES (on CD)

ACRONYMS AND ABBREVIATIONS

CCR	coal combustion residual
CEC	Civil & Environmental Consultants, Inc.
DMG	Dynegy Midwest Generation, LLC
in/yr	inches per year
ft	feet
HELP	Hydrologic Evaluation of Landfill Performance
IAC	Illinois Administrative Code
IDNR	Illinois Department of Natural Resources
K_d	distribution coefficient
mg/L	milligrams per liter
mL/g	milliliters per gram
MW	megawatt
NRT	Natural Resource Technology, an OBG Company
yr	year

1 INTRODUCTION

1.1 OVERVIEW

This Groundwater Model Report has been prepared by Natural Resource Technology (NRT), an OBG company, on behalf of Dynegy Midwest Generation, LLC (DMG) to document the impact of proposed capping system for closure of Ash Pond No. 2 within the East Ash Pond System at the Hennepin Power Station, Hennepin, Illinois. The East Ash Pond System is located in the northeast quarter of Section 27, Township 33 North, Range 2 West, Putnam County, Illinois (Figure 1-1). Former impoundments are situated less than 200 feet south of the Illinois River and approximately one mile east of the Big Bend, where the river shifts course from predominantly west to predominantly south. Existing ash impoundments border Ash Pond No. 2 to the east and south. Surrounding areas include industrial properties to the east and south of the East Ash Pond System, agricultural land to the southwest, and the Hennepin Power Station to the west (Figure 1-2).

Site hydrogeology, and groundwater quality are summarized in Section 1, and described in detail in a separate *Hydrogeologic Investigation Report* (NRT, 2017b). The Hydrogeologic Investigation Report was completed to summarize data collected to comply with Federal Coal Combustion Residual (CCR) Rule (40 CFR Part 257) as well as comprehensive data collection and evaluations from prior hydrogeologic investigation reports completed at the East Ash Pond System. A *Groundwater Monitoring Plan* (NRT, 2017c) and a *Groundwater Management Zone Application* (NRT, 2017d) are also being prepared to support the closure of the Ash Pond No. 2 within the East Ash Pond System. Hydrologic Evaluation of Landfill Performance (HELP) modeling has been conducted to estimate the time required for hydrostatic equilibrium of groundwater to be achieved beneath Ash Pond No.2. The HELP modeling also provided percolation rates for existing conditions and predicted cap scenario that were used as inputs in the groundwater flow and transport model. Description of the HELP model inputs and results are found in the *Hydrostatic Modeling Report* (NRT, 2017a).

Groundwater transport modeling was established to assess the effects of the proposed capping system on surrounding groundwater quality, and is documented in Section 2. The model calibration and prediction results are presented in Sections 3 and 4, respectively. The report is summarized in Section 5.

1.2 BACKGROUND

1.2.1 Site History

The Hennepin Power Station has two coal-fired units constructed in 1953 and 1959 with a capacity of 210 MW. As shown in Figure 1-2, the Hennepin East Ash Pond System consists of: (1) Old Ash Pond No. 2 (including current Ash Pond No. 2, Landfill and Leachate Pond (Pond 2 East) which were constructed over the eastern portion of Old Ash Pond No. 2), (2) East Ash Pond, (3) Ash Pond No. 4 (by definition a non-CCR unit, designated capped or otherwise maintained), and (4) the Polishing pond (Secondary Pond). Detailed history of the East Ash Pond System is presented in the *Hydrogeologic Investigation Report* (NRT, 2017b). Significant operational changes and activities are listed in Table 1-1 and described below.

Ash Pond No. 2 was constructed in 1958 and used to store fly ash, bottom ash, and other non-CCR waste streams (e.g., coal pile runoff). The pond was removed from service in 1996. The easternmost portion of Ash Pond No. 2 was removed in 2009 to 2010 to facilitate construction of the Leachate Pond. The Leachate Pond is lined with 60-mil HDPE overlying two feet of compacted clay with a vertical hydraulic conductivity of 1×10^{-7} cm/sec. Between the Leachate Pond and the inactive unlined Ash Pond No. 2 is Landfill Phase I, an overfill with geomembrane liner and leachate collection system that was completed in 2010. The Landfill (Figure 1-2) became operational in February 2011 with placement of 7,500 cubic yards of bottom ash to protect the liner, but no other material has been placed in the Landfill since that time. Although additional landfill cells (i.e., Phases II, III, IV) and a future bottom ash pond were planned in 2009, it was subsequently decided that no further construction of lined ash disposal units (landfill or bottom ash pond) would be undertaken because of decreased ash disposal due to beneficial reuse of CCRs. The Landfill Phase I cell will be further utilized in 2019 when CCR placement will be required to cease in the East (Primary) Ash Pond.

A notice of intent to close the remaining uncapped portion of Ash Pond No. 2, encompassing approximately 25.5 acres, was submitted in November 2015. The cap system, as designed by Civil & Environmental Consultants, Inc. (CEC), is proposed to be implemented on the remaining areas of Ash Pond No. 2 (Landfill Phases II, III and IV, and bottom ash pond, that will not be completed). This modeling report evaluates the proposed capping system that will replace construction of the remaining landfill phases over the area identified as Ash Pond No. 2 on Figure 1-2. Henceforth, all references to Ash Pond No. 2 refer only to the current uncovered area of ash located west of Landfill Phase I that is proposed for capping.

The East Ash (Primary) Pond, completed in 1996 with a 4-foot clay liner, has been used to store bottom ash, fly ash, and other non-CCR waste; and, to clarify process water prior to discharge in accordance with the station's NPDES permit. This pond remains in service for the treatment of bottom ash transport waters, miscellaneous low volume wastewater streams, and unsold fly ash. Ash Pond No. 4 is a former unlined impoundment which is now dry and classified as a non-CCR pond (capped or otherwise maintained). The Polishing Pond was constructed in 1995 with a 48-inch thick compacted clay liner having a vertical hydraulic conductivity of 1×10^{-7} cm/sec.

1.2.2 Hydrogeology

Principal stratigraphic layers (from top to bottom) encountered at the East Ash Pond System and adjacent areas are:

- Fill - CCRs fly ash, bottom ash, and other non-CCR waste streams including coal pile runoff.
- Alluvial fine grained silts and clays, classified as Cahokia Alluvium.
- Sand and gravel with boulders, deposited by glacial meltwaters and classified as Henry Formation.

The river is immediately adjacent to the lower terrace, east of the East Ash Pond System, and there is minimal alluvium between the pond system and the river. The highly permeable Henry Formation sands and gravels make up the upper and lower terraces, and fill the valley beneath the alluvium. The sand and gravels of the two terraces are indistinguishable, consisting of a heterogeneous mixture of silty-sandy gravel, with cobble zones and with boulders up to several feet in diameter. The Henry formation is more than 100 feet thick in the river valley and at least 130 feet thick on the upper terrace.

The Henry Formation and alluvium comprise the uppermost aquifer at the East Ash Pond System and extend from the water table to the bedrock. This uppermost aquifer extends about 7,000 feet upgradient from the pond system to the south where clay-rich glacial till is encountered. Clay-rich glacial tills typically yield little water, especially compared with the high permeability Henry Formation.

The Henry Formation deposits are underlain by shale bedrock. The Pennsylvanian-age bedrock consists of interbedded layers of shale with thin limestone, sandstone, and coal beds. The shale bedrock unit has low hydraulic conductivity and defines the lower boundary of the uppermost aquifer.

Regional groundwater flow in the unlithified deposits above the shale bedrock discharges into the Illinois River. The primary flow direction of groundwater flow beneath the East Ash Pond System is north (NRT, 2017b). Depth to the water table is typically greater than 20 feet below ground surface around the site. The water table elevation can vary significantly, depending on the river stage. During flood stages, exfiltration from the river may temporarily recharge groundwater close to the river and the water table beneath the East Ash Pond System and adjacent areas of the floodplain may rise to levels mimicking river elevations.

1.2.3 Ash Saturation

Soil boring logs performed within Ash Pond No. 2 indicate the base grade elevation of ash is as low as 451 feet (NRT, 2017b). Groundwater elevations measured quarterly between the period of September 2007 and December 2015 showed typical groundwater elevations in wells surrounding Ash Pond No. 2 below 450 feet. Therefore, currently the CCRs at Ash Pond No. 2 are unsaturated for most time. However, as groundwater elevations respond rapidly to river flood events that recharge the aquifer, it is likely that ash within Ash Pond

No. 2 may occasionally become partially saturated for short periods during high precipitation and/or flood events when river elevations exceed an elevation of at least 451 feet.

1.2.4 Groundwater Quality

Groundwater sampling at the East Ash Pond System was initiated in 1994 around Ash Pond No. 2. All existing well locations are shown on Figure 1-3. Boron is a primary indicator parameter for CCR leachate impacts on groundwater quality, which have significantly decreased in surrounding wells since Ash Pond No. 2 was removed from service and dewatered in 1996. However, occasional increases in boron concentrations were observed to coincide with the precipitation/flood events and localized saturation of the ash. There were no exceedances of groundwater quality standards for cyanide, sulfate or fluoride in upgradient or downgradient wells. The details of groundwater monitoring results are presented in the *Hydrogeologic Investigation Report* (NRT, 2017b).

1.3 CONCEPTUAL MODEL

The primary direction of groundwater flow is north, discharging into the Illinois River, a regional groundwater sink (Figure 1-3). There are three sources of water: natural recharge within the model domain, leachate seepage from the East Ash Pond System, and groundwater flow from the south. Due to the presence of clay-rich glacial till to the south, groundwater flow from the south primarily originates as recharge on the sand and gravel deposits.

Ash Pond No.2 is underlain by a highly permeable sand and gravel aquifer (Henry Formation). Leachate released from the pond infiltrates vertically to the sand and gravel, and then flows horizontally with groundwater toward the north and the Illinois River. Seepage through the Landfill (Phase I) and Leachate Pond liners (as the condition for the lined eastern portion of Ash Pond No. 2) assumes percolation of leachate occurs through small (<1 cm^2) holes in the geomembrane, which are distributed evenly over the footprint of the liner. Leachate that seeps through these holes migrates vertically through the liner and unsaturated zone until it intersects the water table. Once leachate reaches the water table, it mixes with groundwater and is advectively transported northward by the groundwater. The concentration and areal distribution of the mixed leachate in groundwater is further affected by dispersion and diffusion as it migrates north toward its discharge point at the Illinois River.

Ash fill is modeled as unsaturated throughout the modeling duration to capture the pond condition during normal flow conditions. Boron was modeled because it is a primary indicator of coal ash leachate, exceeds the Groundwater Class I standard (2 mg/L), is mobile in groundwater, and is more representative of coal ash leachate than sulfate, which may originate from other anthropogenic or natural sources. Sulfate is also not present above groundwater quality standards. The groundwater monitoring network is shown in Figure 1-3. Since the ash fill is modeled as unsaturated throughout the simulated timeframe, the conceptual model for transport assumes the only source of boron to the system originates from boron that leaches to recharge water during percolation through ash above the water table. The boron mass is discharged at the model representation of the Illinois River. The conceptual transport model assumes that boron concentration in leachate does not vary as a function of time, although the volume of leachate decreases over time as a function of pond dewatering and capping. There is no removal of mass from the groundwater system via adsorption or decay.

2 MODEL ESTABLISHMENT

2.1 MODEL BACKGROUND

The 2017 model is an update to, and was derived from, a model developed for the Site in 2010 (NRT, 2010). The specific updates include following:

- The transient calibration period was extended through December 2017.
- New stress periods were added to the transient calibration period to represent the completion of the Leachate Pond construction and Phase I landfill cell construction over the eastern portions of Ash Pond No. 2. Modeling stress periods are listed in Table 1-1.
- Recently installed monitoring well MW-40S and MW-05DR were added to the monitoring network for calibration.
- Recharge rates were revised or assigned to improve calibration results.
- The river stage and constant head boundary condition were revised to improve calibration results.
- The recalibrated model was then used to simulate closure action. Closure action was modeled over a period of 20 years, beginning in January 2018.

2.2 MODEL APPROACH

Three modeling codes were used to model groundwater flow and contaminant transport: 1) percolation through the cap system was modeled using the Hydrologic Evaluation of Landfill Performance (HELP) model. Details regarding closure configurations and HELP model establishment are presented in a separate Hydrostatic Equilibrium Report (NRT, 2017a); 2) groundwater flow was modeled in three dimensions using MODFLOW; and, 3) contaminant transport was modeled in three dimensions using MT3DMS.

A three-dimensional groundwater flow and transport model was calibrated to represent the conceptual flow system described above. The model was calibrated in multiple stages:

- **Stage 1**: A steady-state flow model was calibrated to approximate head distributions observed while Ash Pond No. 2 was in service, based on heads measured in September 1995.
- **Stage 2**: The steady state transport model was calibrated to approximate concentrations observed while Ash Pond No. 2 was in service during the same period.
- **Stage 3**: The steady state flow model was converted to a transient flow model. The model was then verified by matching modeled output to groundwater elevation data collected since dewatering of Ash Pond No. 2. The transient flow model (12/15/1996 -12/31/2017) was divided into two transient stress periods to characterize the specific hydrogeological changes due to site constructions. Details are presented in Table 1-1.
- **Stage 4**: The transport model was calibrated to approximate boron concentration trends observed since dewatering of Ash Pond No. 2, using heads from the transient flow calibration model.

Each subsequent calibration stage required changes to and recalibration of previous stages. The calibration was judged based on the comparison between simulated results and field measurements throughout the monitoring period (1995 – 2017) instead of a single time point. The results provide a representative simulation of groundwater flow and transport conditions near Ash Pond No.2.

The calibrated model was then used as a starting point for the prediction model to predict changes in boron concentrations over a transport period of 20 years under a baseline scenario and a closure configuration:

- Baseline: assumes no action is undertaken.

- Closure Configuration: The remaining areas of Ash Pond No. 2 that were not covered by the Landfill or the Leachate Pond are covered by a clay cap that consists of a 6-inch surface layer and an 18-inch compact soil barrier with a hydraulic conductivity of 1 x 10^{-5} cm/s.

According to the HELP model results (NRT, 2017b), the hydraulic head within the proposed capping system and the percolation rates through the cover will stabilize (reach equilibrium) rapidly (< 2 years) following cap installation. Therefore, only one transient stress period was used in the prediction model for the closure scenario. The stabilized percolation rate was used over the entire duration of the closure scenario.

2.3 MODEL DESCRIPTION

MODFLOW uses a finite difference approximation to solve a three-dimensional head distribution in a transient, multi-layer, heterogeneous, anisotropic, variable-gradient, variable-thickness, confined or unconfined flow system. User-supplied inputs are hydraulic conductivity, aquifer/layer thickness, recharge, wells and boundary conditions. The program also calculates water balance at wells, rivers and drains.

MODFLOW was developed by the United States Geological Survey (McDonald and Harbaugh, 1988) and has been updated several times since. Major assumptions of the code are: 1) groundwater flow is governed by Darcy's law; 2) the formation behaves as a continuous porous medium; 3) flow is not affected by chemical, temperature, or density gradients; and 4) hydraulic properties are constant within a grid cell. Other assumptions concerning the finite difference equation can be found in McDonald and Harbaugh (1988).

MT3DMS (Zheng and Wang, 1998) is an update of MT3D. It calculates concentration distribution for a single dissolved solute as a function of time and space. Concentration is distributed over a three-dimensional, non-uniform, transient flow field. Solute mass may be input at discrete points (wells, drains, river nodes, constant head cells), or distributed evenly or unevenly over the land surface (recharge).

MT3DMS accounts for advection, dispersion, diffusion, first-order decay and sorption. Sorption can be calculated using linear, Freundlich, or Langmuir isotherms. First-order decay terms may be differentiated for the adsorbed and dissolved phases.

The program uses the standard finite difference method, the particle-tracking-based Eulerian-Lagrangian methods and the higher-order finite-volume TVD method for the solution schemes. The finite difference solution can be prone to numerical dispersion for low-dispersivity transport scenarios, and the particle-tracking method has problems in conserving mass-balance. The TVD solution is not subject to numerical dispersion and conserves mass well, but is computationally intensive. For this modeling, the TVD solution was used.

Major assumptions are: 1) changes in the concentration field do not affect the flow field; 2) changes in the concentration of one solute do not affect the concentration of another solute; 3) chemical and hydraulic properties are constant within a grid cell; and 4) sorption is instantaneous and fully reversible, while decay is not reversible.

2.4 MODEL SETUP

2.4.1 Grid and Boundary Conditions

A four layer, 112 by 157 node grid was established with variable grid spacing ranging from 25 to 500 feet (Figure 2-1). The largest grid spacings were near the upgradient and lateral model boundaries, and the finest grid spacings were along the river near Ash Pond No. 2.

The upgradient edge of the model was a constant head boundary. The downgradient edge of the model was a no-flow boundary. The cells approximating the bank of the river were MODFLOW river boundary cells. The upper boundary was a time-dependent specified flux boundary, with specified flux rates equal to the recharge rate or the rate of seepage from the proposed capping option or the East Ash Pond System, depending on model node position and time step.

The specified mass flux boundary condition assigns a specified concentration to recharge water entering a model cell, and the resulting concentration in the cell is a function of the relative rate and concentration of recharge water and the rate of dilution induced by other water (representing lateral groundwater flow) entering the cell.

2.4.2 Flow Model Input Values and Sensitivity

Flow model input values and results of sensitivity analyses are listed in Table 2-1 and described below.

Layer Top/Bottom

The top of layer 1 was the water table, therefore the bottom of model layer 1 was set at 430 feet, a value lower than the maximum water table elevation (in the impoundment). The bottom elevations of the following layers were set at 422 feet, 414 feet and 406 feet, respectively. The top of layers 2 through 4 were set to the base of the overlying layer. The saturated thickness of layer 1 depended on modeled water table elevation.

Hydraulic Conductivity

Saturated geologic materials were represented using different hydraulic conductivity zones (Figure 2-2). The hydraulic conductivity values were based on the 2010 model. The sand and gravel deposits beneath the site were modeled using hydraulic conductivity values of 100, 500, and 1,000 ft/d. Alluvium and riverbed sediments immediately adjacent to the river were modeled using hydraulic conductivity values of 7 and 0.75 ft/d. The area of moderate hydraulic conductivity at the upgradient (south) end of the model, representing the more finely-grained sands was assigned a hydraulic conductivity value of 35 ft/d. No vertical or horizontal anisotropy was assumed. Measured hydraulic conductivities of the Henry Formation sands and gravels range from 1×10^{-4} to 3×10^{0} cm/s [0.3 to 8,503 feet/day] which are consistent with pump test data from high capacity wells in the area that ranged from 5×10^{-2} to 3×10^{-1} cm/sec (NRT, 2017b). The assigned hydraulic conductivity values in the model are within observed ranges.

The model had moderately high to high sensitivity to the horizontal hydraulic conductivity used over most of the domain, with the exception of the alluvium and riverbed, Layer 2 west (Zone 5) and Sand and Gravel, Layer 4 north (Zone 6), which have low sensitivity. Sensitivity to vertical hydraulic conductivity varied, with the low permeability zones being most sensitive.

Storage and Effective Porosity

Storage and effective porosity zones were based on a simplified representation of the hydraulic conductivity zones (Figure 2-3). Specific yield values ranged from 0.18 to 0.25, and were adopted from the 2010 model. The input values and sensitivity of effective porosity (Table 2-2) are discussed in the transport section 2.4.3 below.

Upgradient Flux

The head value for the upgradient constant head boundary was modified from the 2010 model during calibration. The model displayed moderate to high sensitivity to changes in head at the upgradient constant head boundary.

Recharge

Several recharge values were used in the model. The recharge rates are presented in Table 2-2 while the associated concentration rates are presented in Table 2-3. The zoning and values of recharge inputs were based on the 2010 model, and calibrated to fit the additional monitoring data collected since 2010. Ambient recharge for this area with sandy soils and former gravel quarries were determined to be 14.0 inches per year and 20.1 in/yr, respectively, as in previous models.

For the steady state model, a high recharge rate was modeled to simulate seepage of water from the active unlined Ash Pond No. 2 (Figure 2-4). The model was used to calibrate the hydraulic gradients and boron concentrations while the Ash Pond No. 2 was in service, which served as the initial point for the following transient model.

The transient model calibration represented the period from the construction completion of the East Ash Pond and the Polishing Pond (1996 to 2017), including two stress periods of site configuration used to capture the changes in site use at the East Ash Pond System during this time. Recharge values for the Ash Ponds No. 2 and No. 4 as well as the Polishing Pond were revised from the 2010 model to match concentrations observed after 2010 (Figure 2-5). During Stress Period 1 (i.e., Phase 1) of the transient modeling, a band of focused recharge across the east-central portion of Ash Pond No. 2 was established in the model (zones 10 and 13) to simulate the bowl-like topographic contours of the dewatered Ash Pond No. 2. The conceptual model for this area of focused recharge is that runoff collects and infiltrates in the deepest portion of the dewatered pond. The recharge rate for this area was established with the limitation that total annual recharge averaged over the entire area of the Ash Pond No. 2 had to be less than 80% of average annual precipitation. During Stress Period 2 (i.e., Phase 2) of the transient modeling, the eastern end of Ash Pond No. 2 has been covered with the lined Leachate Pond (Figure 2-5, zone 12) and the east-central portion of Ash Pond No. 2 has been covered with the lined Landfill Phase I cell (Figure 2-5, zone 11).

The prediction modeling for the capping scenario assumed that the proposed clay cover would cover the landfill that will not be constructed over Ash Pond No. 2 (Figure 2-6, zones 3, 5, and 13). The recharge value for the proposed capping system is the stabilized percolation rate estimated by the HELP model as detailed in the *Hydrostatic Modeling Report* (NRT, 2017a). Zone 7 of Ash Pond No. 2 was also removed from the prediction model (both no action and capping scenarios) because the berm has been extensively reworked in this area, which improved drainage and reduced infiltration along the Illinois River. Groundwater quality in this area also does not exceed the standard so the area was simulated using the same parameters as the surrounding terrace materials (Henry Formation).

The model displayed moderate to high sensitivity to changes in recharge rates with the exception of the northern corner of Ash Pond No. 2 (Zone 7), which had negligible sensitivity, and Ash Pond No. 4 (Zone 8), which had low sensitivity.

River Parameters

River input parameters (Table 2-1) were adjusted from the 2010 model to improve the match between modeling results and field measurements of groundwater elevations collected from 1995 to 2017. The calibrated river stage of 444.0 feet is within observed surface water elevations at the site. The river nodes were run as steady state; therefore, no seasonal fluctuations were accounted for by the river cells.

Sensitivity analysis showed that the model was highly sensitive to river stage and conductance values.

2.4.3 Transport Model Input Values and Sensitivity

Transport model input values and sensitivity analyses are presented in Table 2-2 and described below.

Initial Concentration

Initial concentrations were set to zero for the steady-state model. Initial concentrations for the transient calibration model were the final concentrations of the steady-state model. Similarly, initial concentrations for the prediction scenarios were the final concentrations of the transient calibration model.

Source Concentration

During steady and transient calibration stress periods, leachate concentrations between 5 and 22 mg/L were used to represent boron percolation from Ash Pond No. 2 (including the Leachate Pond and Landfill cell), Ash Pond No. 4, East (Primary) Ash Pond and the Polishing Pond (Figures 2-4 to2-5). Using only recharge inputs for simulating the East Ash Pond System ensures the only source concentration entering the model from the pond system is in the form of leachate through the base of the unsaturated ash.

Leachate source concentrations were lower in the western half of Ash Pond No. 2, all of Ash Pond No. 4, and the East (Primary) Ash Pond and Polishing Pond, where a significant volume of the material managed was bottom ash. The highest concentrations were modeled in the eastern half of Ash Pond No. 2, where most of the material is fly ash. The leachate source concentrations were revised from the 2010 model during calibration to improve results.

In the prediction model, the percolation concentrations of capped areas (Zones 3, 5, and 13), ranging from 8 to 16 mg/L, were carried over from the calibration model to predict the effectiveness of the capping system. As described in the recharge section above, zone 7 adjacent to Ash Pond No. 2 was removed in the prediction models because the berm has been reworked in recent years, which has improved drainage of this area.

Effective Porosity

Effective porosity values ranged from 0.10 to 0.20 based on the 2010 model. These values were not changed during calibration and had negligible sensitivity in the model (Table 2-2).

Dispersivity

Longitudinal dispersivity was set at 35 feet based on the 2010 model. Transverse and vertical dispersion coefficients were estimated assuming a ratio of 1/10 and 1/100, respectively (Gelhar et al., 1992). The model displayed negligible sensitivity to changes in dispersion coefficients, except the vertical dispersivity, which had low sensitivity.

Retardation and Decay

A distribution coefficient of zero was selected to yield a retardation factor of 1.0. A decay coefficient of zero was modeled, as is appropriate for inorganic constituents. Therefore, this modeling assumed no adsorption and no decay. Sensitivity analysis was not performed on the retardation coefficient.

Diffusion

Diffusion was also set to 0 for the entire model domain.

3 MODEL RESULTS

3.1 FLOW AND TRANSPORT MODEL ASSUMPTIONS AND LIMITATIONS

Simplifying assumptions are necessary when numerically representing the natural environment in a groundwater flow and transport model. Outside of assumptions inherent to the codes used to develop the model, several simplifying assumptions were made, including:

- Leachate instantaneously migrates to groundwater (e.g., rapid migration through the unsaturated zone).
- Fluctuations in river stage are short in duration and do not affect groundwater flow and transport. Therefore, the ash fill within the East Ash Pond System were maintained as unsaturated (above the water table) throughout the modeling period.
- Hydraulic parameters such as hydraulic conductivity, storage, and recharge, can be represented using homogeneous zones that cover large areas of the model domain.
- Recharge rate outside the impoundment is constant over time.
- Source concentrations remain constant over time.
- Boron minimally adsorbs and does not decay, and mixing and dispersion are the primary attenuation mechanisms.
- Cap construction has an instantaneous effect on recharge and percolation because it is constructed over a brief period relative to the length of the model simulation.

The model is limited by the data used for calibration, which adequately define the local groundwater flow system and the source and extent of the plume. These data, collected from 1996 through 2017, are from points near the East Ash Pond System. Model predictions of transport distant from the impoundment will not be as reliable as predictions of transport near the impoundment, and the reliability of model predictions decreases with increasing time because changes to the system may occur that the model does not account for.

3.2 CALIBRATION FLOW AND TRANSPORT MODEL RESULTS

Results of the MODFLOW/MT3DMS modeling are presented below. A CD containing the model files is attached to this report (Appendix A).

Figure 3-1 compares modeled versus observed heads for the period 1996 through 2016 at Wells 02, 03R, 04R, 05R, 06, 07, 08, 10, 11, 12, 13, 15, 16, 17, 18S, 18D, 19S, 19D, and 40S. Modeled heads at all monitoring wells fall within the range of observed values. The hydraulic model was calibrated based on the comparison between simulated and monitoring data collected throughout the entire simulation period (~20 years) instead of a single point; therefore, the calibrated heads for the steady state (initial point of the time-series plot) were slightly higher than the observed heads for most wells; also, the simulated data did not capture the rising water elevations after year 2007. However, these discrepancies were not considered significant as long as the predicted heads fell in the range of monitoring data for each of the wells in the monitoring network. The consistency between modeled and observed heads indicate that this model provides a reasonable simulation of the effects of the East Ash Pond System on groundwater flow.

The simulated boron concentrations are compared to observed data in Figure 3-2. The simulated boron concentrations reasonably match the observed concentrations. The model successfully simulates the decreasing trends of boron after Ash Pond No. 2 was removed from service, and captures the boron levels at wells surrounding Ash Pond No. 2, including 06, 03R, 18S/18D, 05R/05DR, 10, 12, 13 and 40S. The model underestimates the boron concentrations in wells 04R, 19S, and 19D, located in the berm between the Leachate Pond and the Illinois River (Figure 1-3), approximately 750 feet east of the area that is to be capped in the prediction scenario. The simulated boron concentration in Well 15, located on the south side of the Leachate Pond is consistent with the model prediction. The agreement between modeled and predicted concentrations demonstrates the capability of the transport model for the prediction of contaminant transport in groundwater at the East Ash Pond System.

3.3 MODEL PREDICTION

As stated in the previous sections, the prediction model was extended 20 years following the cap completion (2018 to 2038) to evaluate boron concentrations in groundwater under a baseline (no action) scenario and the closure configuration. The short duration was chosen because the time was sufficient to show the effect of the capping system. Predicted hydraulic heads under the two scenarios are compared in Figure 3-3. The predicted boron concentrations under the two scenarios are compared in Figure 3-4.

3.3.1 Baseline

Under the baseline scenario, it was assumed that no action was taken to cover or remove existing ash. As shown in Figures 3-3 and 3-4, both hydraulic head and boron concentrations are predicted to remain stable. The boron concentration at well 18S remains at a constant level above the Illinois Class I groundwater protection standard (2 mg/L) during the modeling duration.

Figure 3-5 depicts the predicted boron plume where it exceeds the Illinois Class I groundwater protection standard 20 years after cap completion. The boron plume is predicted to extend north beneath the Illinois River in the proximity of well 18S. No further reduction is expected with time.

3.3.2 Capping Scenario

Under the capping scenario, it was assumed that all of Ash Pond No.2 to the west of the current Landfill (i.e., Phase I) would be capped in place with a clay cover that is predicted to yield a percolation rate of 5.9 inch/yr (NRT, 2017a).

Comparing the baseline to the capping option, reduction in boron concentrations is predicted in monitoring wells downgradient of Ash Pond No. 2 (Figure 3-4). Well 18S would reach a boron concentration of 1.5 mg/L, which is less than the Class I Standard of 2 mg/L, in two years following cap completion. Minimal drops in hydraulic heads at monitoring wells are observed after the cap is in place because the decreased percolation rate within the capped impoundment is not significant relative to precipitation over the entire model domain.

As shown in Figure 3-5 (2-year plume) and Figure 3-6 (20-year plume), the footprint of the plume under the capping scenario diminished and groundwater impacts beneath Ash Pond No. 2 are attenuated within two years, while the plume in the baseline scenario remains unchanged through Year 20. Groundwater protection standards are predicted to be met in monitoring wells downgradient of Ash Pond No. 2 within two years after capping.

4 SUMMARY

A 3-dimensional groundwater flow and transport model was established to evaluate the effectiveness of the proposed closure plan on Ash Pond No. 2 within the East Ash Pond System at the Hennepin Power Station. The proposed closure configuration includes capping the remaining uncovered footprint of Ash Pond No. 2 located west of the Landfill (Phase I), which encompasses the area originally proposed for future landfill expansion Phases II, III and IV, and future bottom ash pond, which are no longer planned for completion on top of the pond. The closure configuration will occur in place with a clay cover, which consists of a 6-inch surface layer and an 18-inch compact soil barrier with a hydraulic conductivity of 1×10^{-5} cm/s. The model was developed based on a previous 2010 model with incorporation of new field and laboratory measurements, and was recalibrated to fit additional monitoring data. In summary, the results of the modeling are:

- The consistency between modeling results and the observable data collected from 1996 through 2017 exhibits a successful calibration of the updated model, demonstrating the model's capability for the prediction of hydraulic flow and contaminant transport in groundwater at the site.
- When no action is taken, groundwater impacts will not be contained within the property and groundwater protection standards will not be met for boron. Boron concentrations remain asymptotic during the 20-year modeling timeframe (Year 2037) and no further reduction is expected with time.
- Of the wells located between Ash Pond No. 2 and the Illinois River (06, 03R, 18S, and18D), well 18S is the only location that currently contains boron in excess of the Class I Standard. Under the proposed closure scenario, further reduction of groundwater impacts is expected and boron concentrations are predicted to meet the groundwater protection standard at well 18S within two years upon cap completion (Year 2019).
- CCRs at Ash Pond No. 2 are typically unsaturated during most of the year. However, as groundwater elevations respond rapidly to river flood events that recharge the aquifer, it is likely that ash within Ash Pond No. 2 occasionally becomes partially saturated for short periods during high precipitation and/or flood events. These short-term flooding events were not simulated in the groundwater transport model; therefore, boron concentrations at well 18S may not respond as quickly as predicted in the model.
- The modeling indicates the proposed capping scenario and reduced mass flux is expected to be protective of groundwater.

REFERENCES

Anderson, Mary P., and Woessner, William W., 1992, Applied groundwater modeling: simulation of flow and advective transport, Academic Press, Inc., San Diego, CA.

Civil & Environmental Consultants, Inc., 2017. Closure and Post Closure Care Plan, Ash Pond No. 2, Dynegy Midwest Generation, LLC, Hennepin Power Station, Hennepin, IL.

Fetter, C. W., 1988, Applied Hydrogeology, Merrill Publishing Company, Columbus Ohio.

McDonald, M.G., and A.W. Harbaugh, 1988, A Modular Three-Dimensional Finite-Difference Ground-Water Flow Model: Techniques of Water-Resources Investigations, Techniques of Water-Resources of the United States Geological Survey, Book 6, Chapter A1.

Mercer, J.W., and R.K. Waddell, 1993, Contaminant Transport in Groundwater, in Handbook of Hydrology, D.R. Maidment (ed.), McGraw-Hill Inc., pp. 16.1-16.41, New York, NY.

Natural Resource Technology, Inc. (NRT), 2010. Groundwater Impact Assessment, Section 27 GIA; Hennepin Power Station Putnam County, East Ash Impoundment, Illinois. October, 2010.

Natural Resource Technology, Inc. (NRT), 2016. 2016 Closure Work Plan Annual Report; Hennepin Power Station Putnam County, East Ash Impoundment, Illinois. 2016.

Natural Resource Technology, Inc. (NRT), 2017. Hydrostatic Modeling Report; Hennepin Power Station Putnam County, East Ash Impoundment, Illinois. September, 2017a.

Natural Resource Technology, Inc. (NRT), 2017. Hydrogeologic Site Characterization Report; Hennepin Power Station Putnam County, East Ash Impoundment, Illinois. September, 2017b.

Natural Resource Technology, Inc. (NRT), 2017c. Groundwater Monitoring Plan; Hennepin Power Station Putnam County, East Ash Impoundment, Illinois. September, 2017.

Natural Resource Technology, Inc. (NRT), 2017d. Groundwater Management Zone Application; Hennepin Power Station Putnam County, East Ash Impoundment, Illinois. September, 2017.

Zheng, Z., and P.P. Wang, 1998, MT3DMS, a Modular Three-Dimensional Multispecies Transport Model, Model documentation and user's guide prepared by the University of Alabama Hydrogeology Group for the US Army Corps of Engineers.

Tables

Table 1-1. Flow Model Stress Period Establishment
Groundwater Model Report
East Ash Pond No. 2, Hennepin Power Station

Date	Operational Change or Activity	Model Simulation
1958	• Construction of Ash Pond No. 2	Steady State (12/25/1959 - 12/15/1996)
1978	• Embankment raise of Ash Pond No. 2	
1985	• Embankment raise of Ash Pond No. 2 to elevation 484 feet	
1989	• Embankment raise of Ash Pond No. 2 to elevation 494 feet	
1996	• Completion of East Ash Pond Construction: Primary East Ash Pond with 4-foot clay liner was Phase I constructed in 1995-1996.	Calibration Simulation - Stress Period 1 (12/15/1996 -12/1/2010)
2010/2011	• Eastern portion of Ash Pond No. 2 was removed; Construction on the Leachate Pond was completed in December 2010. 25.5 acre-foot pond lined with 2 feet of compacted clay, 60-mil HDPE geomembrane liner. • Landfill was constructed over placed CCR in Ash Pond No. 2; completed in 2010. In February 2011, 7,500 cubic yards of bottom ash was placed into the Phase I cell as a post-construction freeze-protection measure to protect the leachate collection system and geomembrane liner. However, no other material (fly ash or bottom ash) has been placed in the landfill since then.	Calibration Simulation - Stress Period 2 (12/1/2010 - 12/31/2017)

Notes
1. Ash Pond No. 2: no liner; lowermost bottom elevation = 451 feet (variable base depth of ash)

Table 2-1a. Flow Model Input Values (Steady-State Calibration)
Groundwater Model Report
East Ash Pond No. 2, Hennepin Power Station

Horizontal Hydraulic Conductivity	**Zone**	**ft/d**	**cm/s**	**Sensitivity[1]**
Alluvium and Riverbed, Layer 1	3	7.0	2.5E-03	high
Alluvium and Riverbed, Layer 2 East	3	7.0	2.5E-03	high
Alluvium and Riverbed, Layer 2 West	5	0.75	2.6E-04	low
Sand and Gravel, North, Layer 1	4	500	1.8E-01	moderately high
Sand and Gravel, North, Layers 2 & 3	1	1,000	3.5E-01	high
Sand and Gravel, North, Layer 4	6	100	3.5E-02	low
Sand and Gravel, South, all layers	2	35.0	1.2E-02	moderately high
Vertical Hydraulic Conductivity		**ft/d**	**Kh/Kv**	**Sensitivity[1]**
Alluvium and Riverbed, Layer 1	3	7.0	1.0	high
Alluvium and Riverbed, Layer 2 East	3	7.0	1.0	high
Alluvium and Riverbed, Layer 2 West	5	0.8	1.0	moderate
Sand and Gravel, North, Layer 1	4	500	1.0	negligible
Sand and Gravel, North, Layers 2 & 3	1	1,000	1.0	negligible
Sand and Gravel, North, Layer 4	6	100	1.0	negligible
Sand and Gravel, South, all layers	2	35.0	1.0	negligible
Recharge[2]		**ft/d**	**in/yr**	**Sensitivity[1]**
General	1	3.2E-03	14.0	high
Quarry	6	4.6E-03	20.1	moderate
Ash Pond No. 2	2	2.0E-01	867	moderate
Ash Pond No. 2	3	2.0E-01	867	high
Ash Pond No. 2	4	2.0E-01	867	high
Ash Pond No. 2	5	2.0E-01	867	high
Ash Pond No. 2	7	3.6E-03	15.8	negligible
Ash Pond No. 4	8	3.6E-03	15.8	low
Storage		**S_S**	**S_Y**	**Sensitivity[1]**
Alluvium and Riverbed	3	1.0E-03	0.18	-
Sand and Gravel, North, Layer 1	4	1.0E-04	0.20	-
Sand and Gravel, North, Layers 2 & 3	1	1.0E-05	0.25	-
Sand and Gravel, North, Layer 4	4	1.0E-04	0.20	-
Sand and Gravel, South, all layers	2	1.0E-03	0.18	-
River Parameters/Constant Head		**Illinois Riv.**	**Constant Head**	**Sensitivity[1]**
Stage/Head (ft)		444	458	high/moderately high
Bed Thickness (ft)		5	-	not tested
Hydraulic Conductivity (ft/d)		0.85	-	not tested
Conductance (ft^2/d, normalized per ft^2 area)		6.06E+04	-	high
River Width (ft)		850	-	not tested
River Cell Length (ft)		419.19	-	not tested

Notes:

1 - Sensitivity Explanation, based on maximum change in Sum of Squared Residuals (SSR)

Negligible - SSR changed by less than 1%

Natural Resource Technology AN OBG COMPANY

Table 2-1b. Flow Model Input Values (Transient Calibration)
Groundwater Model Report
East Ash Pond No. 2, Hennepin Power Station

		Calibration	
Stress Periods[1]		**Days, #TS**	**Dates**
Stress Period 1		**5099, 10**	**12/15/1996 -12/1/2010**
Stress Period 2		**2587, 6**	**12/1/2010 - 12/31/2017**
Recharge[2] **(Calibration SP1)**	**Zone**	**ft/d**	**in/yr**
General	1	3.2E-03	14.0
Quarry	6	4.6E-03	20.1
Ash Pond No. 2	5	3.6E-03	15.8
Ash Pond No. 2	3	3.6E-03	15.8
Ash Pond No. 2 - High Recharge Area	13	4.5E-02	197.1
Ash Pond No. 2 - High Recharge Area (northeast corne	10	4.5E-02	197.1
Ash Pond No. 4	8	3.6E-03	15.8
New Primary/Secondary Ponds	9	4.0E-03	17.5
Ash Pond No. 2	7	4.5E-03	19.7
Recharge[2] **(Calibration SP2)**	**Zone**	**ft/d**	**in/yr**
General	1	3.2E-03	14.0
Quarry	6	4.6E-03	20.1
Ash Pond No. 2	5	3.6E-03	15.8
Ash Pond No. 2	3	3.6E-03	15.8
Ash Pond No. 2 - High Recharge Area	13	4.5E-02	197.1
Ash Pond No. 4	8	3.6E-03	15.8
New Primary/Secondary Ponds	9	4.0E-03	17.5
Ash Pond No. 2	7	4.5E-03	19.7
Leachate Pond Cap (Phases 2 and 3)	12	4.6E-07	0.0
Phase 1 Ash Pond No. 2 Landfill (Phase 3)	11	6.8E-05	0.3

Notes:

1 - First column is model days and number of time steps, second column is approximate dates in mm/yy format.

2 - See figures for delineation of model zones; recharge values outside ash pond are same as Table 2-1a.

Natural Resource Technology
AN OBG COMPANY

Table 2-1c. Flow Model Input Values (Prediction)
Groundwater Model Report
East Ash Pond No. 2, Hennepin Power Station

		Prediction	
Simulated Period[1]		**Days, #TS**	**Dates**
		8035, 16	**1/1/2018-1/1/2038**
	Zone		
Recharge[2] (Closure Scenarios)		**ft/d**	**in/yr**
Clay Cap	3	1.3E-03	5.9
Clay Cap	5	1.3E-03	5.9
Clay Cap	13	1.3E-03	5.9

Notes:

1 - First column is model days and number of time steps, second column is approximate dates in mm/yy format.

2 - See figures for delineation of model zones; recharge values outside ash pond are same as Table 2-1b (SP2).

3 - Cap percolation rate is applied to the impoundment, with coverage area dependent on closure scenario.

Natural Resource Technology AN OBG COMPANY

Table 2-2. Transport Model Input Values
Groundwater Model Report
East Ash Pond No. 2, Hennepin Power Station

Initial Concentration	Zone	Base Case (mg/L)	Alternatives	Sensitivity[1]
Entire Domain		0	not tested	-

Percolation Concentration (mg/L)	Zone	Base Case (mg/L)	Alternatives	Sensitivity[1]
All Simulations				
General	1	0	not tested	high[2]
Quarry	6	0	not tested	moderate[2]
Steady State Model				
Ash Pond No. 2	2	22	not tested	moderate[2]
Ash Pond No. 2	3	16	not tested	high[2]
Ash Pond No. 2	4	13	not tested	high[2]
Ash Pond No. 2	5	9	not tested	high[2]
Ash Pond No. 2	7	5	not tested	negligible[2]
Ash Pond No. 4	8	5	not tested	low[2]
Calibration Model				
Ash Pond No. 2	5	9	not tested	-
Ash Pond No. 2	3	16	not tested	-
Ash Pond No. 2 - High Recharge Area	13	10	not tested	-
Ash Pond No. 2 - High Recharge Area (northeast corner)	10	20	not tested	-
Ash Pond No. 4	8	5	not tested	-
New Primary/Secondary Ponds	9	4	not tested	-
Ash Pond No. 2	7	5	not tested	-
Leachate Pond Cap (SPs 2 and 3)	12	16	not tested	-
Phase 1 Ash Pond No. 2 Landfill (SP 3)	11	16	not tested	-
Prediction Model				
Ash Pond No. 2 Cap	5	9	not tested	-
Ash Pond No. 2 Cap	3	16	not tested	-
Ash Pond No. 2 Cap	13	10	not tested	-

Effective Porosity	Zone	Base Case	Alternatives	Sensitivity[1]
Alluvium and Riverbed	3	0.10	0.05, 0.15	negligible
Sand and Gravel, North, Layers 1 & 4	4	0.15	0.10, 0.20	negligible
Sand and Gravel, North, Layers 2 & 3	1	0.20	0.16, 0.24	negligible
Sand and Gravel, South, All Layers	2	0.10	0.05, 0.15	negligible

Dispersivity (ft)	Base Case	Alternatives	Sensitivity[1]
Entire Domain Longitudinal	35	25, 50	negligible
Entire Domain Transverse	3.5	2.5, 5	negligible
Entire Domain Vertical	0.3	0.25, 0.5	low

Notes:

1 - Sensitivity Explanation

Negligible - little effect on concentrations

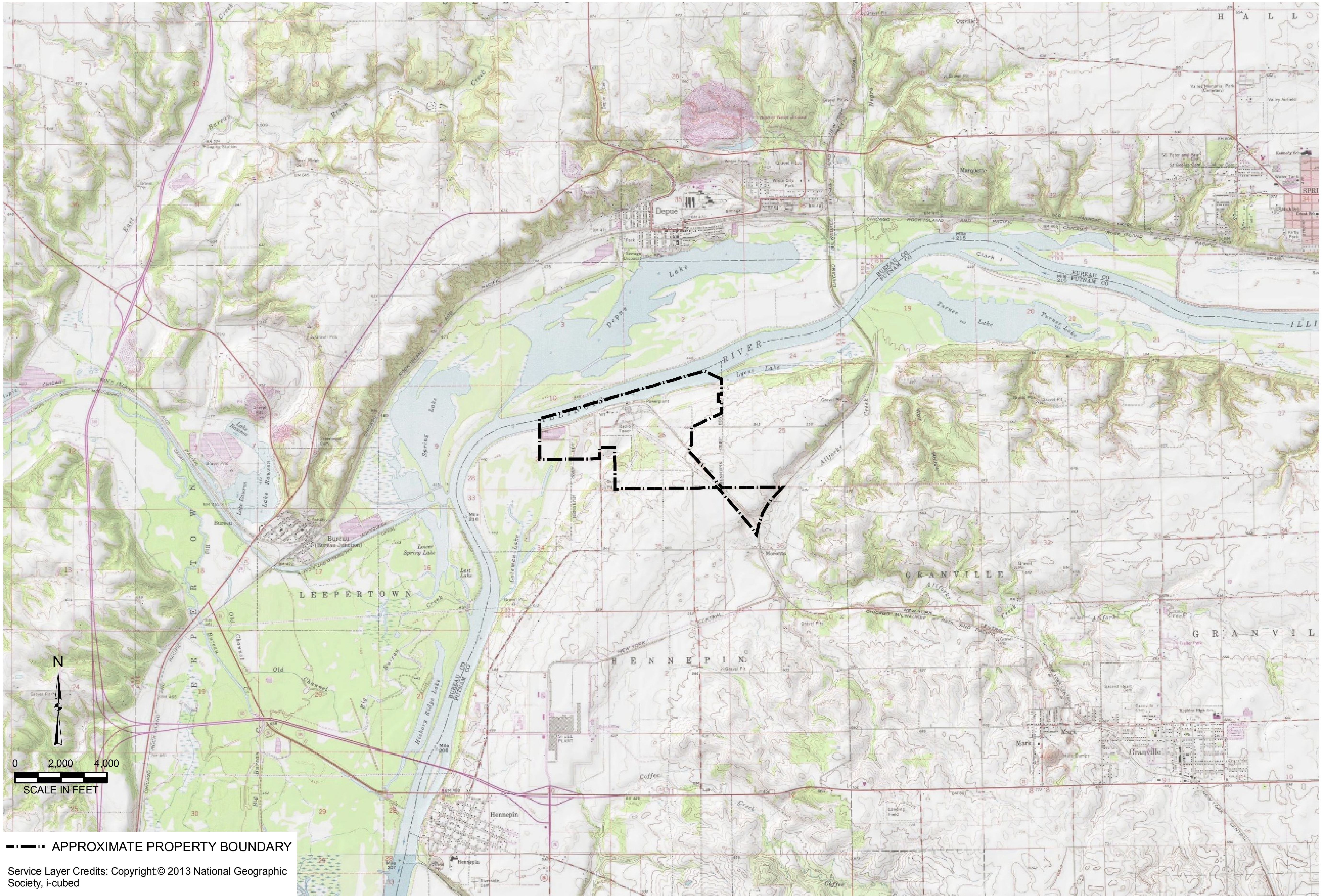
Low - concentrations at two or more wells changed by 2 to 10 percent

Moderate - concentrations at two or more wells changed by 10 to 20 percent

High - concentration at two or more wells changed by more than 20 percent

2 - Determined to be highly sensitive during transport model calibration

Figures



Y:\Mapping\Projects\24\2414\MXD\GWMR\Figure 1-1_Site Location Map.mxd Author: stolzsd; Date/Time: 1/3/2018, 1:49:46 PM

DRAWN BY/DATE: SDS 8/29/17
REVIEWED BY/DATE: RJK 8/30/17
APPROVED BY/DATE: SJC 9/5/17

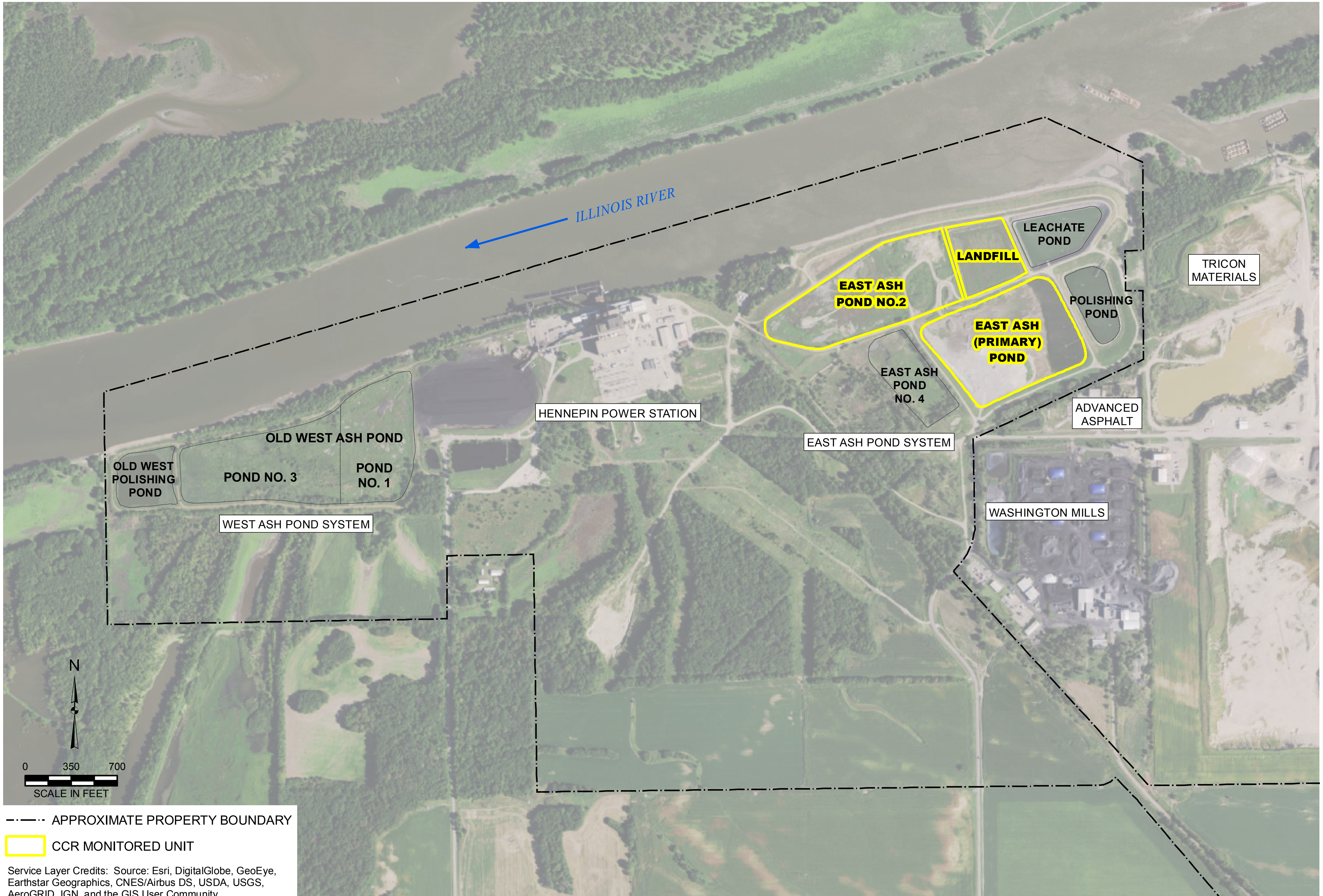
SITE LOCATION MAP

GROUNDWATER MODEL REPORT
EAST ASH POND NO. 2
DYNEGY MIDWEST GENERATION, LLC
HENNEPIN POWER STATION, HENNEPIN, ILLINOIS

PROJECT NO: 2414

FIGURE NO: 1-1

Natural Resource Technology
AN OBG COMPANY



DRAWN BY/DATE: SDS 8/29/17
REVIEWED BY/DATE: RJK 8/30/17
APPROVED BY/DATE: SJC 9/6/17

ASH IMPOUNDMENT LOCATION MAP

GROUNDWATER MODEL REPORT
EAST ASH POND NO. 2
DYNEGY MIDWEST GENERATION, LLC
HENNEPIN POWER STATION, HENNEPIN, ILLINOIS

PROJECT NO: 2414

FIGURE NO: 1-2

Natural Resource Technology
AN OBG COMPANY

Y:\Mapping\Projects\24\2414\MXD\GWMR\Figure 1-2_Ash Impound Loc.mxd Author: stolzsd; Date/Time: 1/8/2018, 11:39:39 AM

DRAWN BY/DATE: SDS 8/29/17
REVIEWED BY/DATE: RJK 8/30/17
APPROVED BY/DATE: SJC 9/6/17

MONITORING WELL LOCATION MAP

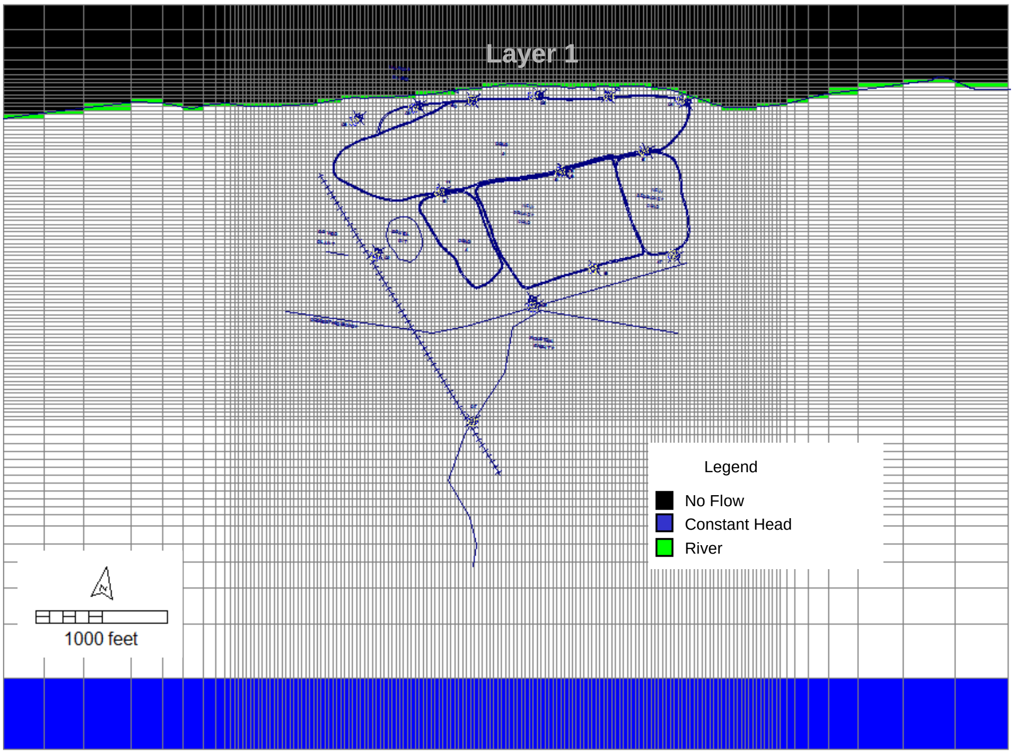
GROUNDWATER MODEL REPORT
EAST ASH POND NO. 2
DYNEGY MIDWEST GENERATION, LLC
HENNEPIN POWER STATION, HENNEPIN, ILLINOIS

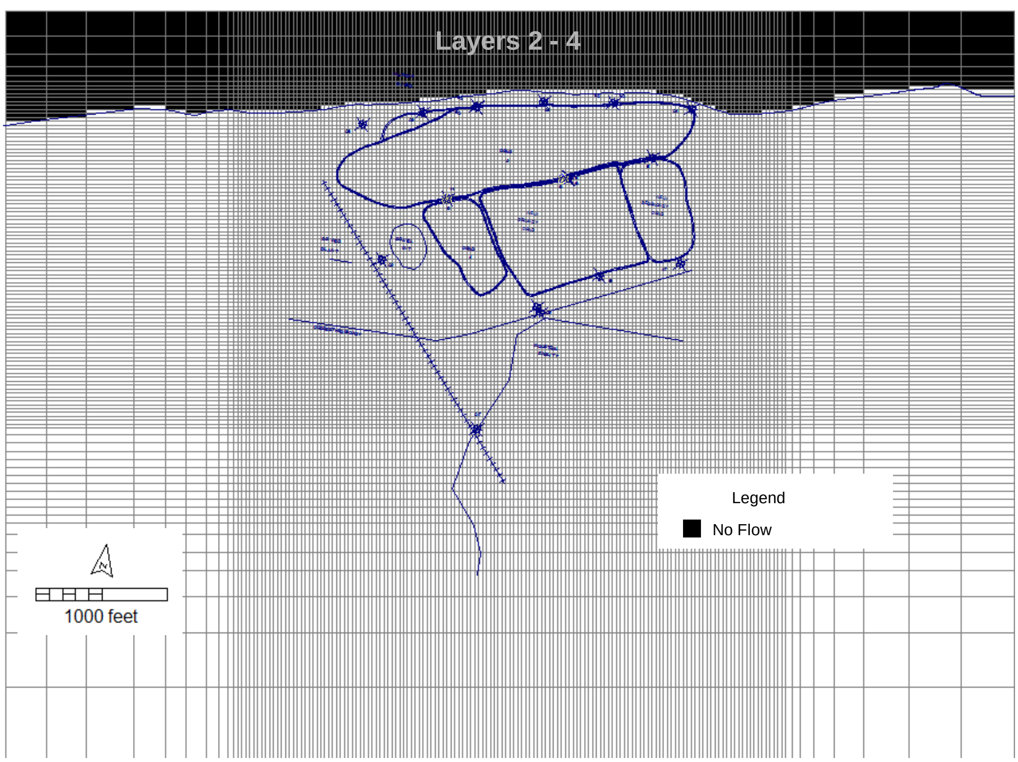
PROJECT NO: 2414

FIGURE NO: 1-3

Natural Resource Technology
AN OBG COMPANY

Y:\Mapping\Projects\24\2414\MXD\GWMR\Figure 1-3_Monitoring Well Location Map.mxd Author: stolzsd; Date/Time: 1/3/2018, 1:59:11 PM





PREPARED BY/DATE:
M_W 08/14/2017
REVIEWED BY/DATE:
BGH 09/07/2017

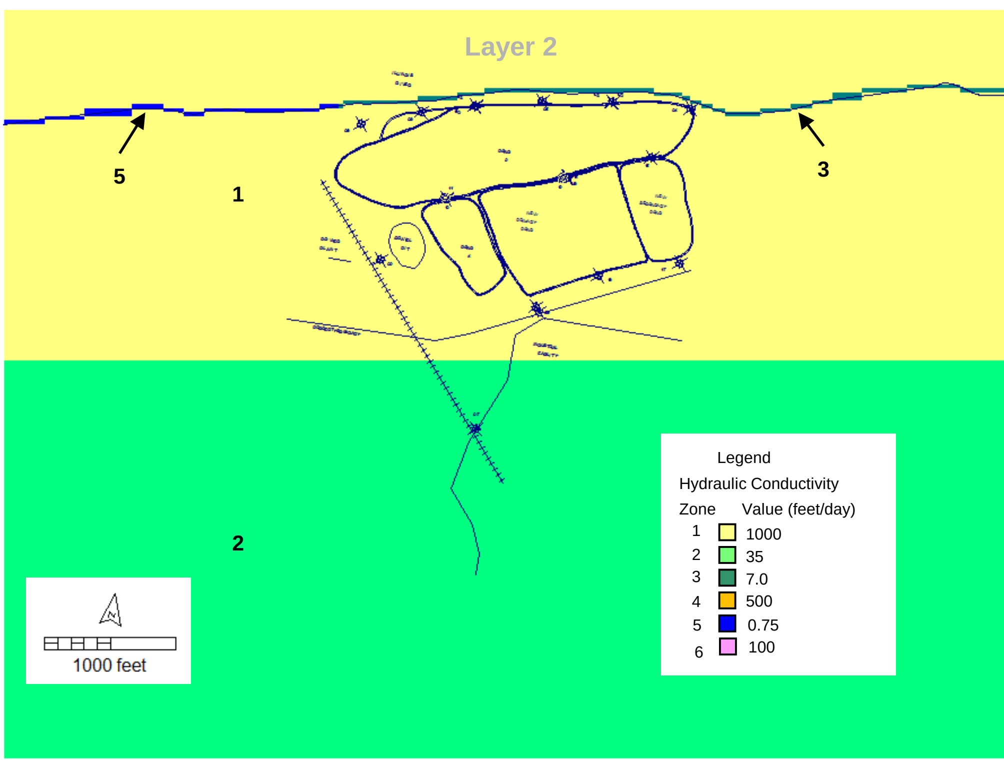
MODFLOW Grid and Boundary Conditions for Layers 1 (top) and 2-4 (bottom).

GROUNDWATER MODEL REPORT
EAST ASH POND NO. 2, HENNEPIN POWER STATION

PROJECT NO: 2414

FIGURE NO: 2-1

Natural Resource Technology
AN OBG COMPANY



PREPARED BY/DATE:
M_W 08/14/2017
REVIEWED BY/DATE:
BGH 09/07/2017

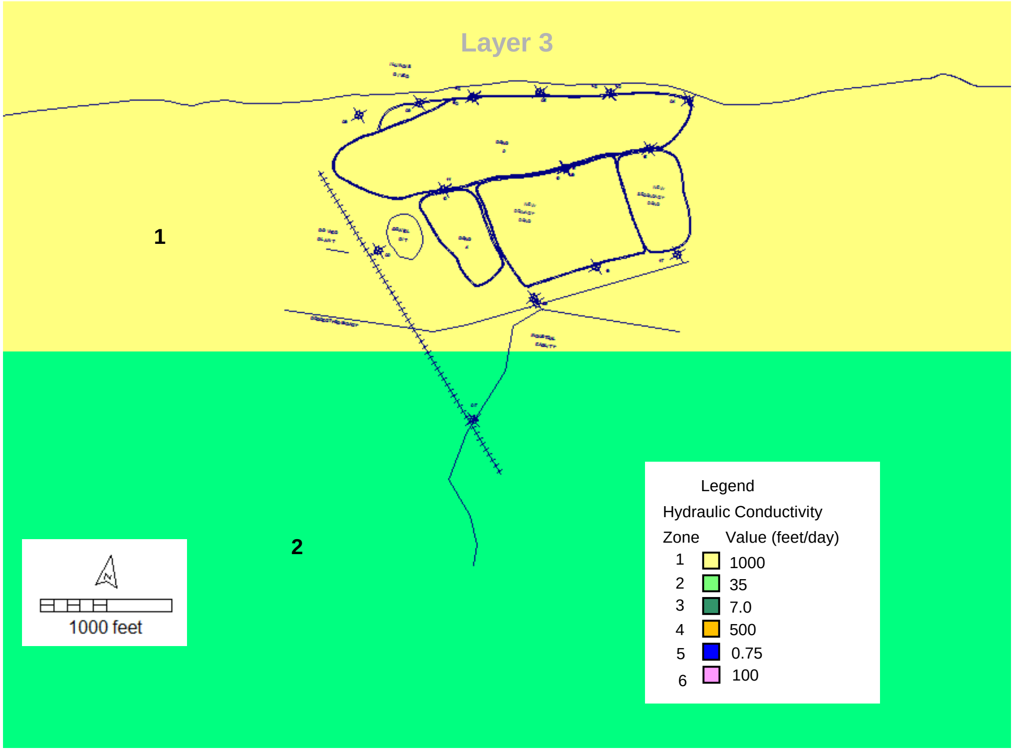
Hydraulic Conductivity (ft/d) Array - Layers 1 (top) and 2 (bottom)

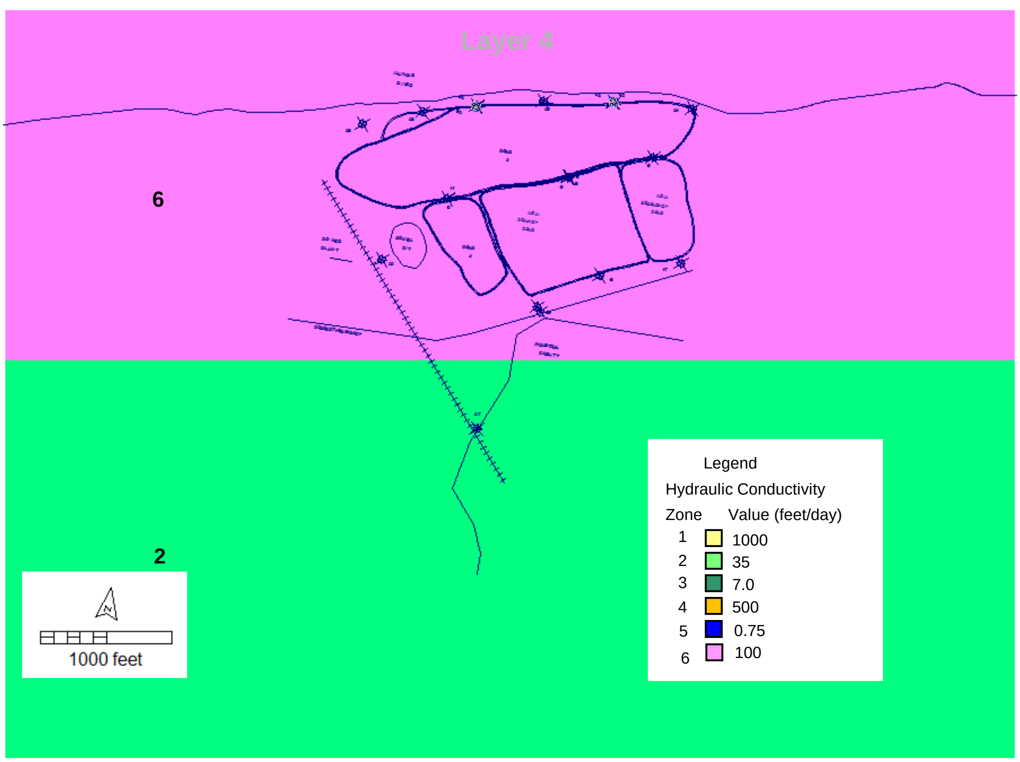
GROUNDWATER MODEL REPORT
EAST ASH POND NO. 2, HENNEPIN POWER STATION

PROJECT NO: 2414

FIGURE NO: 2-2

Natural Resource Technology
AN OBG COMPANY





PREPARED BY/DATE:
M_W 08/14/2017
REVIEWED BY/DATE:
BGH 09/07/2017

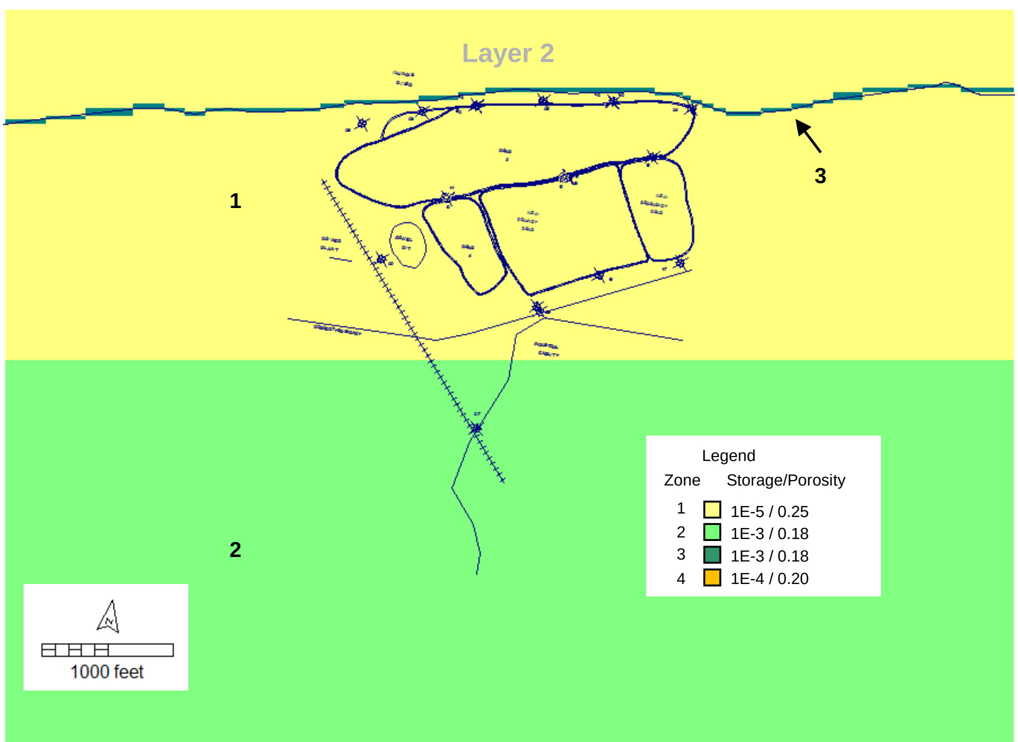
Hydraulic Conductivity (ft/d) Array - Layers 3 (top) and 4 (bottom)

GROUNDWATER MODEL REPORT
EAST ASH POND NO. 2, HENNEPIN POWER STATION

PROJECT NO: 2414

FIGURE NO: 2-2

Natural Resource Technology
AN OBG COMPANY



PREPARED BY/DATE:
M_W 08/14/2017
REVIEWED BY/DATE:
BGH 09/07/2017

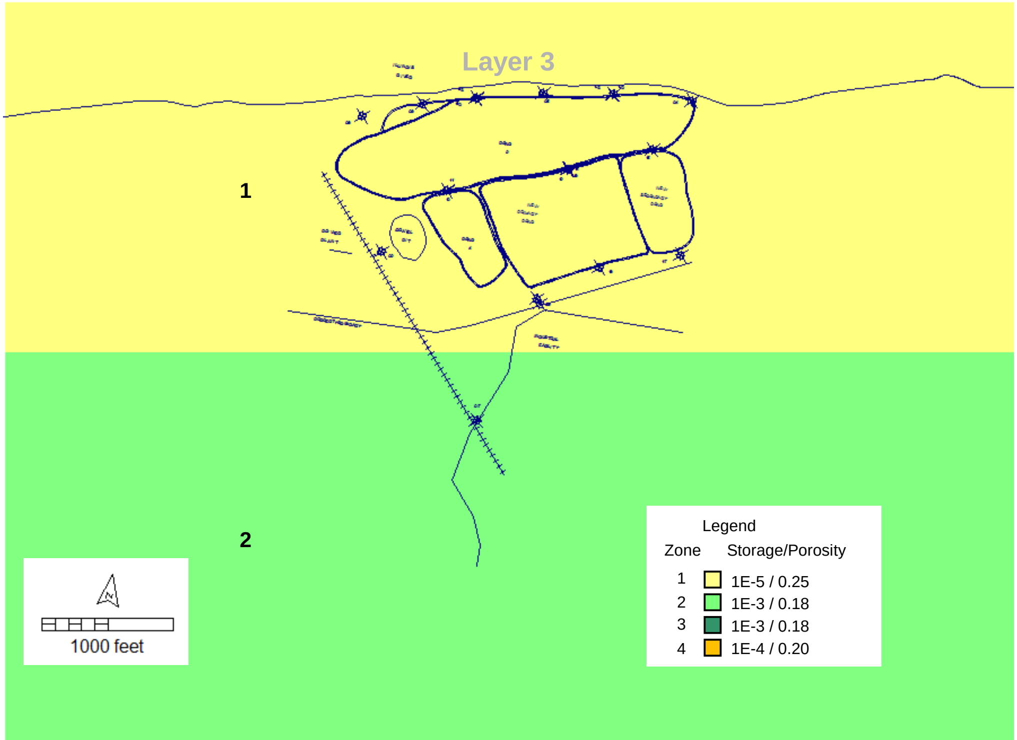
Effective Porosity and Specific Yield Array - Layers 1 (top) and 2 (bottom)

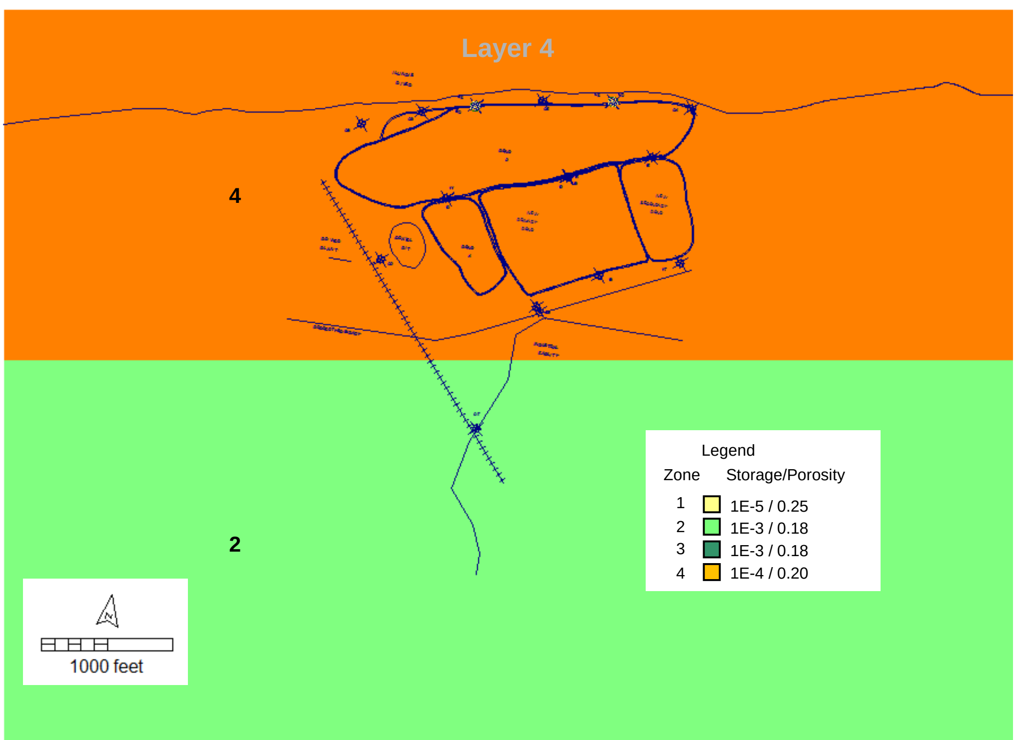
GROUNDWATER MODEL REPORT
EAST ASH POND NO. 2, HENNEPIN POWER STATION

PROJECT NO: 2414

FIGURE NO: 2-3

Natural Resource Technology
AN OBG COMPANY





PREPARED BY/DATE:
M_W 08/14/2017
REVIEWED BY/DATE:
BGH 09/07/2017

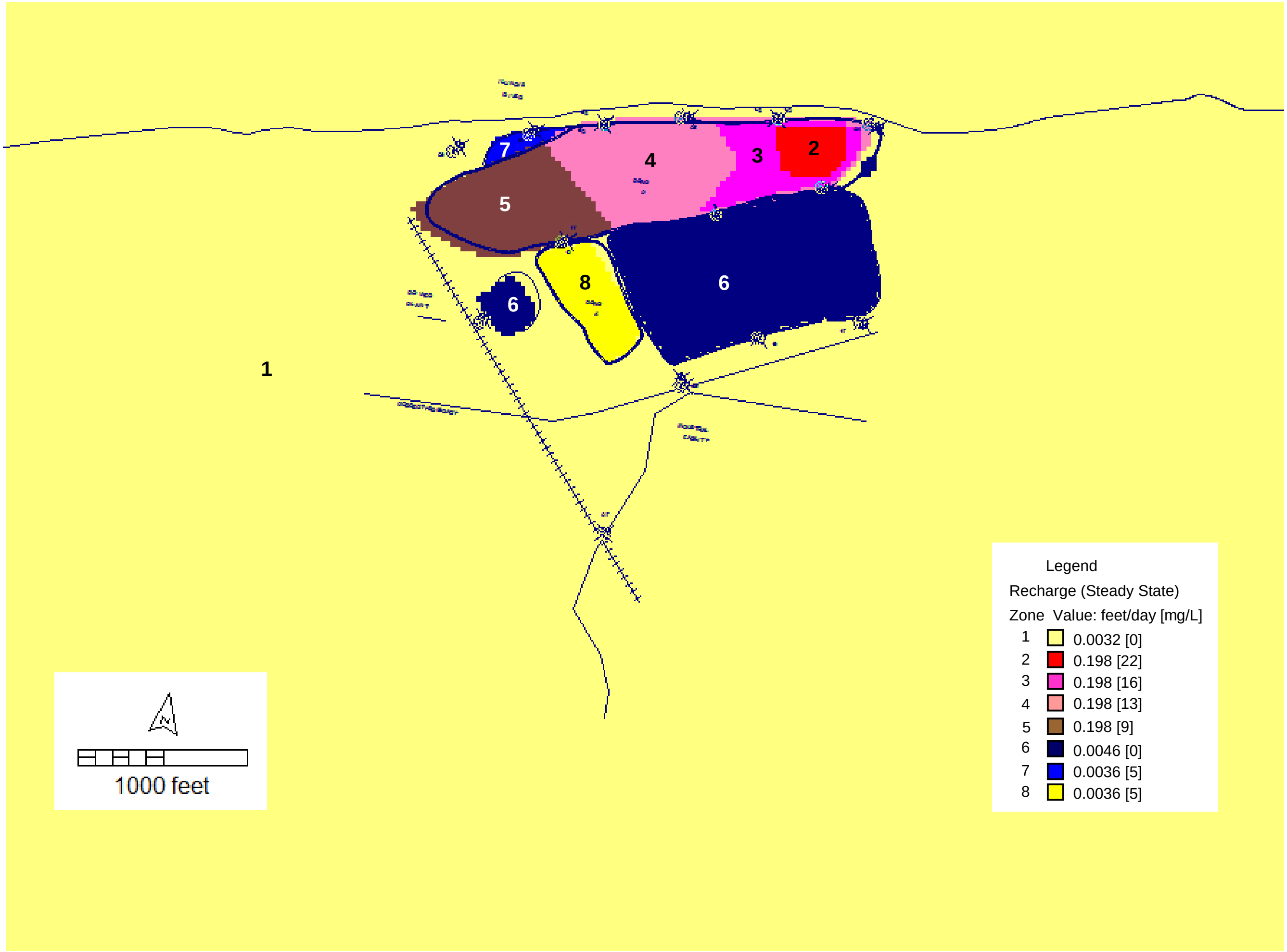
Effective Porosity and Specific Yield Array - Layers 3 (top) and 4 (bottom)

GROUNDWATER MODEL REPORT
EAST ASH POND NO. 2, HENNEPIN POWER STATION

PROJECT NO: 2414

FIGURE NO: 2-3

Natural Resource Technology
AN OBG COMPANY



PREPARED BY/DATE:
M_W 08/14/2017
REVIEWED BY/DATE:
BGH 09/07/2017

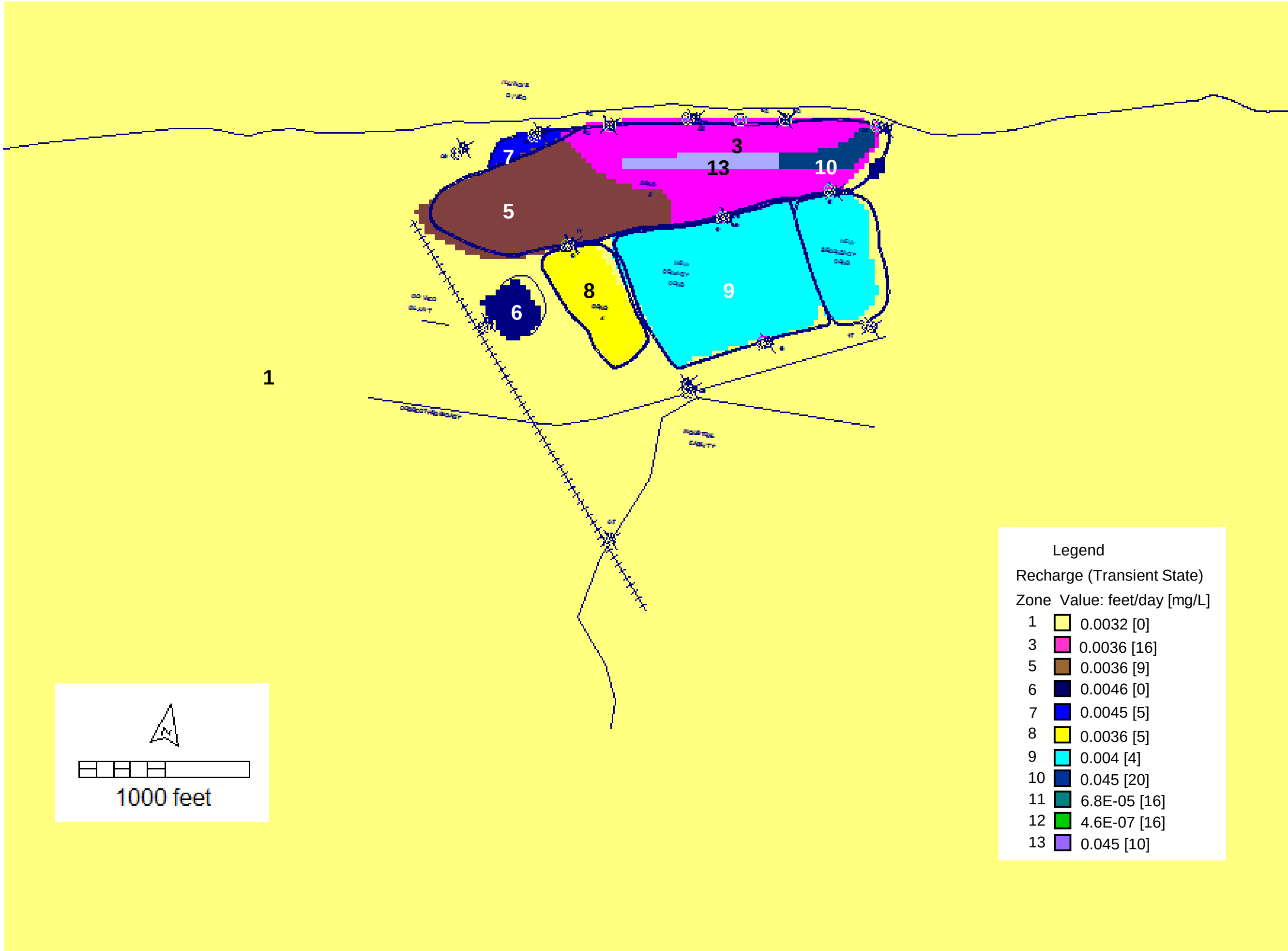
Recharge (ft/d) Array (Steady State Model)

GROUNDWATER MODEL REPORT
EAST ASH POND NO. 2, HENNEPIN POWER STATION

PROJECT NO: 2414

FIGURE NO: 2-4

Natural Resource Technology
AN OBG COMPANY



PREPARED BY/DATE:
M_W 08/14/2017
REVIEWED BY/DATE:
BGH 09/07/2017

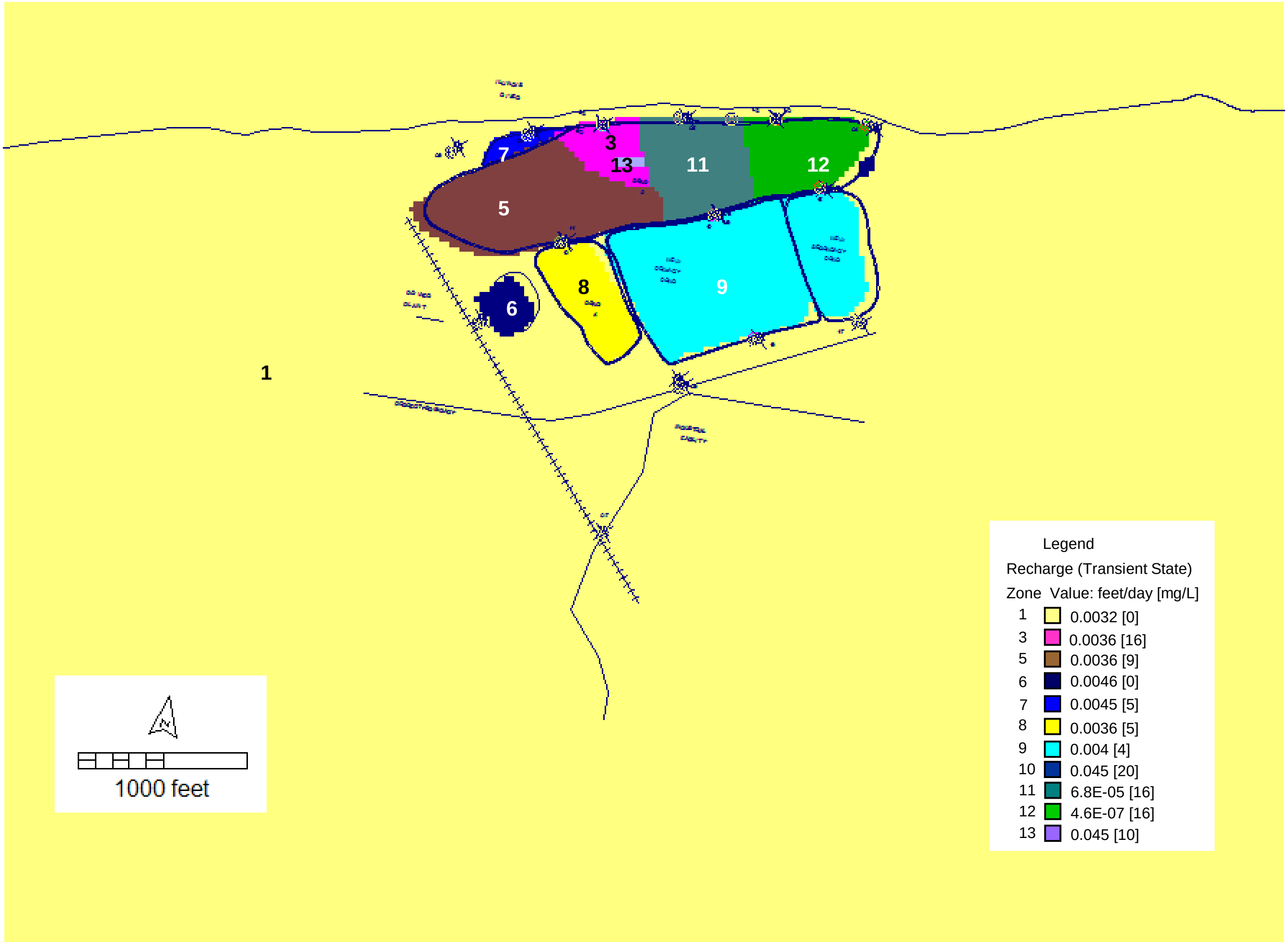
Recharge (ft/d) Array
(Transient Model, Phase 1)

GROUNDWATER MODEL REPORT
EAST ASH POND NO. 2, HENNEPIN POWER STATION

PROJECT NO: 2414

FIGURE NO: 2-5

Natural Resource Technology
AN OBG COMPANY



PREPARED BY/DATE:
M_W 08/14/2017
REVIEWED BY/DATE:
BGH 09/07/2017

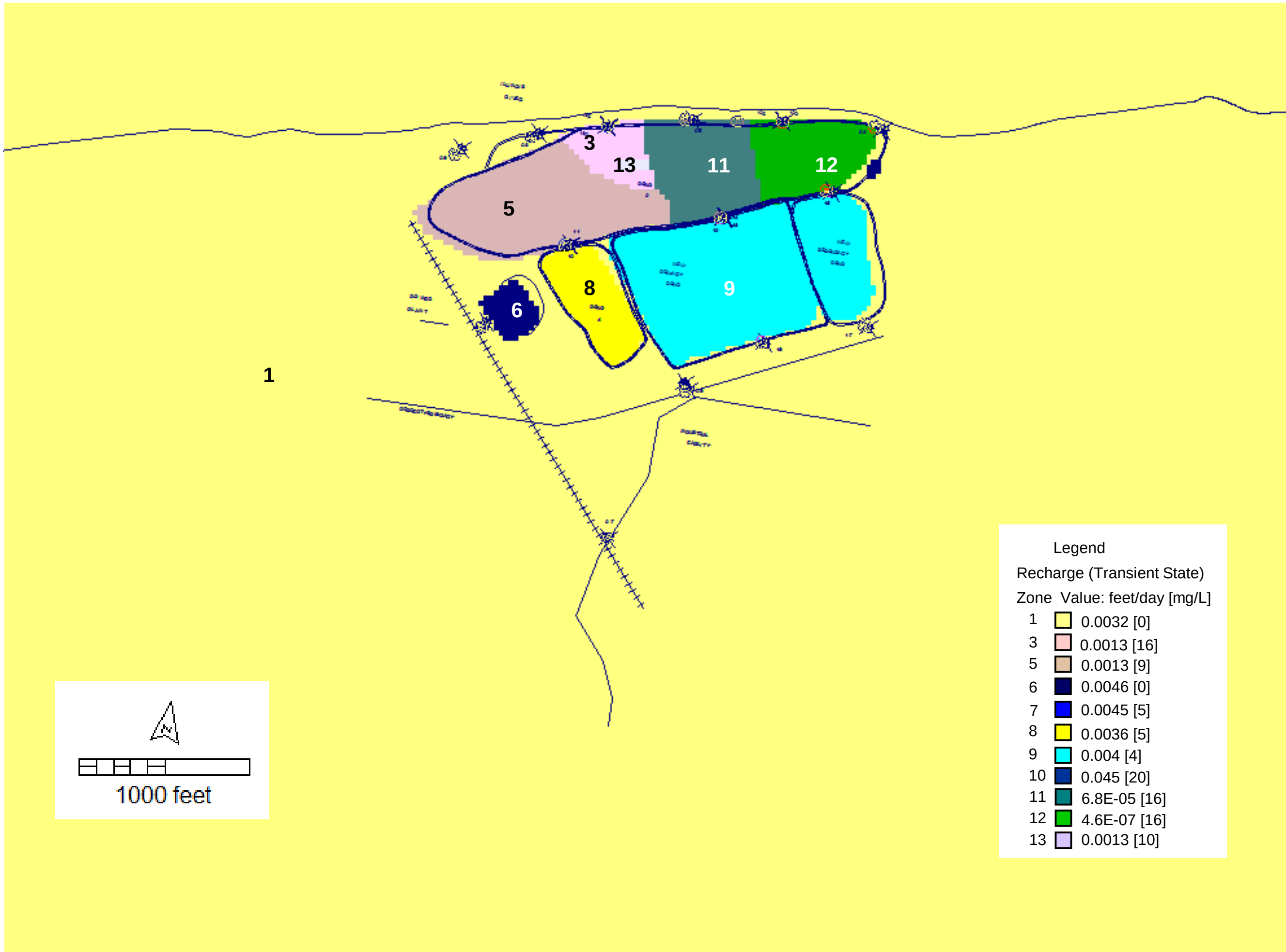
Recharge (ft/d) Array
(Transient Model, Phase 2)

GROUNDWATER MODEL REPORT
EAST ASH POND NO. 2, HENNEPIN POWER STATION

PROJECT NO: 2414

FIGURE NO: 2-5

Natural Resource Technology
AN OBG COMPANY



PREPARED BY/DATE:
M_W 08/14/2017
REVIEWED BY/DATE:
BGH 09/07/2017

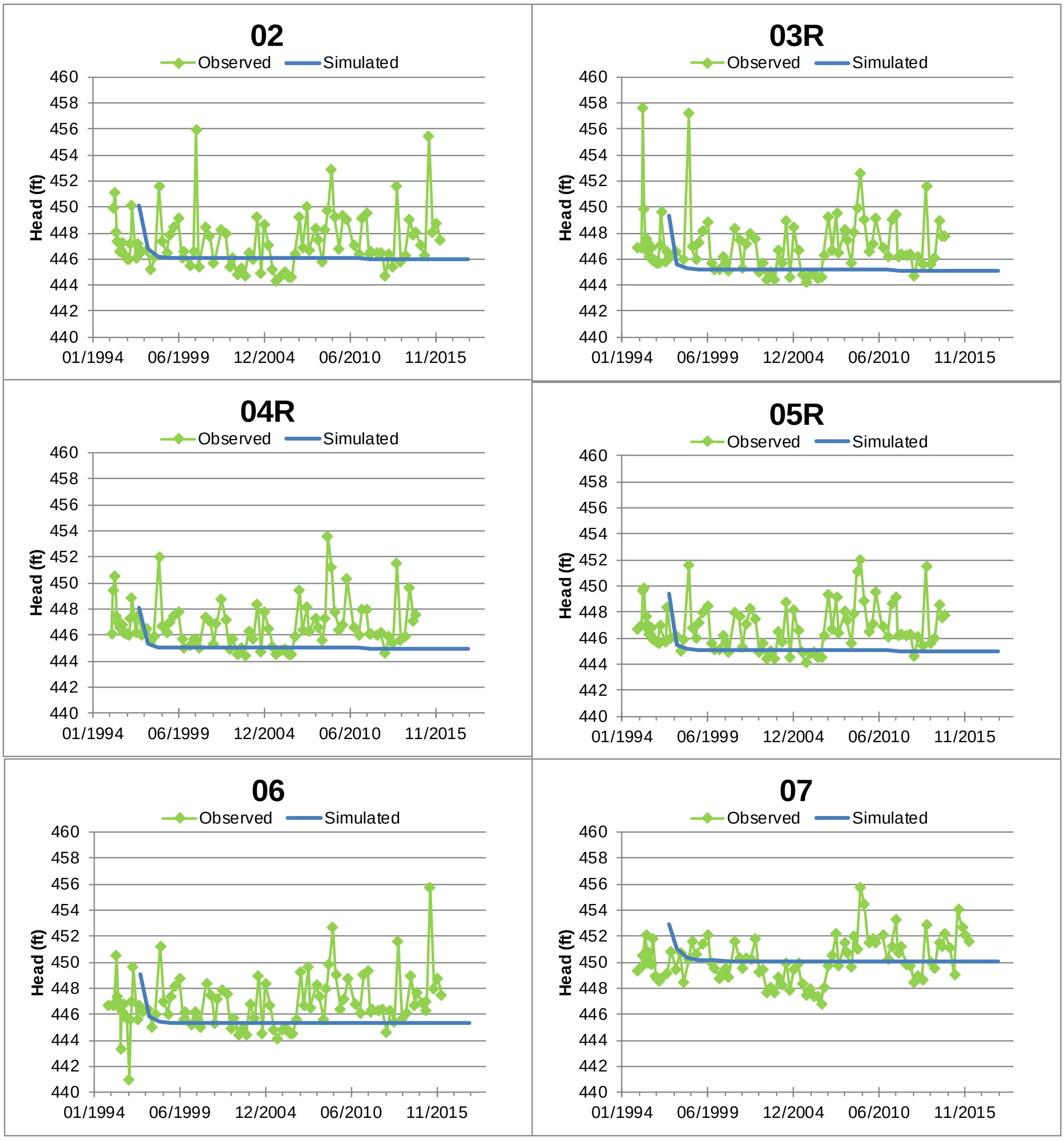
Recharge (ft/d) Array
(Prediction Model for Capping Scenario)

GROUNDWATER MODEL REPORT
EAST ASH POND NO. 2, HENNEPIN POWER STATION

PROJECT NO: 2414

FIGURE NO: 2-6

Natural Resource Technology
AN OBG COMPANY



PREPARED BY/DATE:
M_W 08/14/2017
REVIEWED BY/DATE:
BGH 09/07/2017

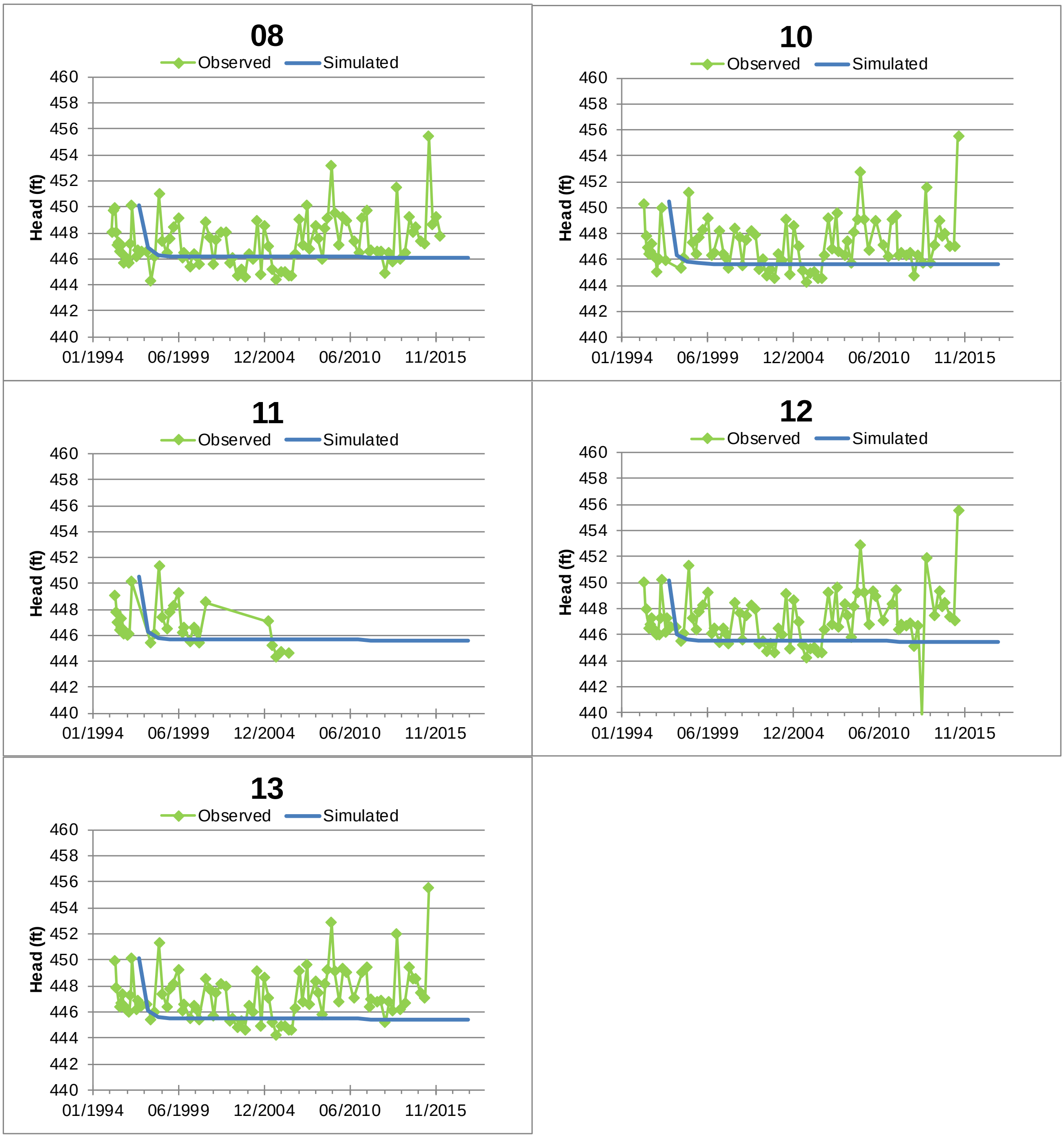
Comparison of Calibration Heads to Observations from 1994 through 2016

GROUNDWATER MODEL REPORT
EAST ASH POND NO. 2, HENNEPIN POWER STATION

PROJECT NO: 2414

FIGURE NO: 3-1

Natural Resource Technology
AN OBG COMPANY



PREPARED BY/DATE:
M_W 08/14/2017
REVIEWED BY/DATE:
BGH 09/07/2017

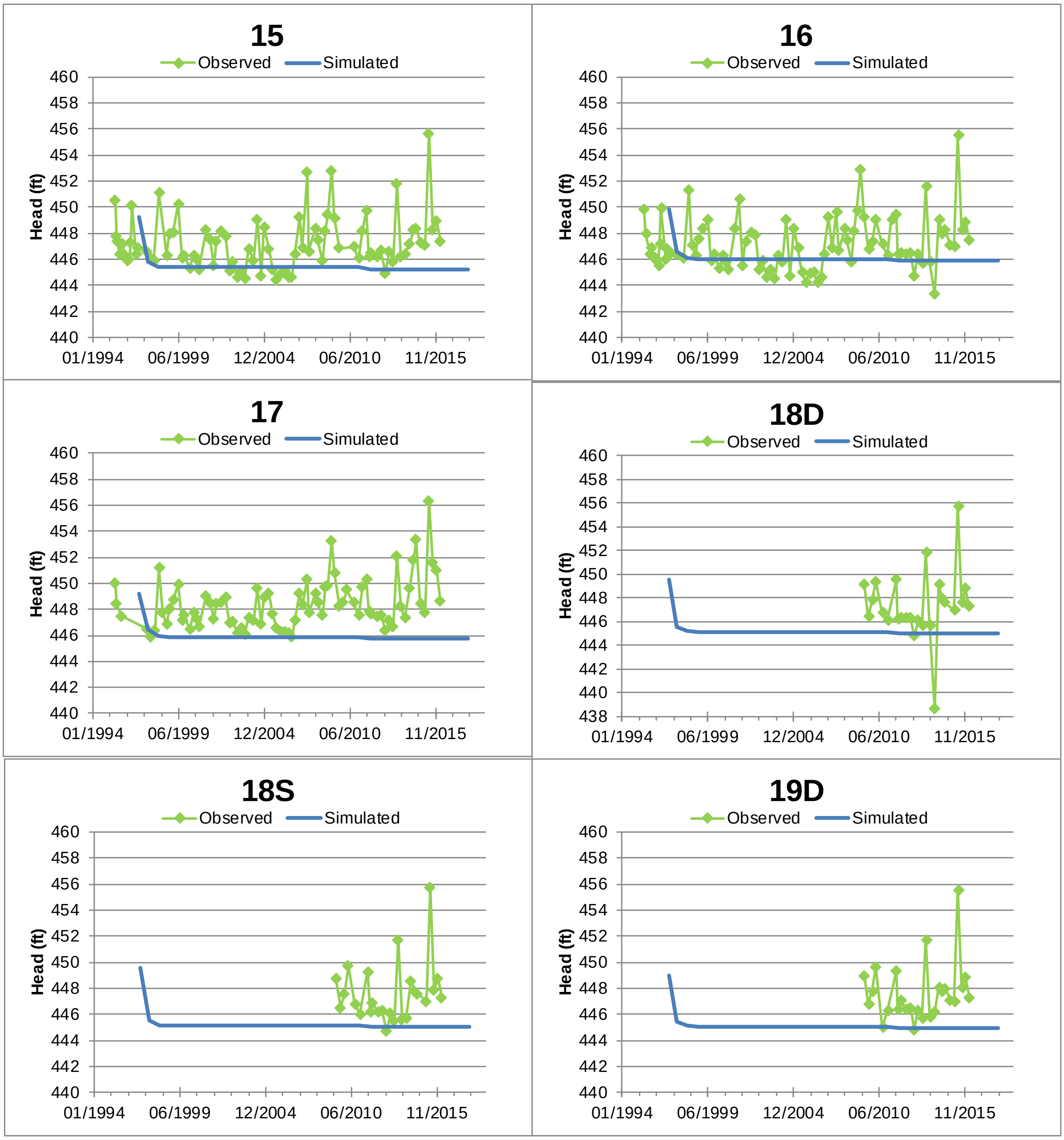
Comparison of Calibration Heads to Observations from 1994 through 2016

GROUNDWATER MODEL REPORT
EAST ASH POND NO. 2, HENNEPIN POWER STATION

PROJECT NO: 2414

FIGURE NO: 3-1

Natural Resource Technology
AN OBG COMPANY



PREPARED BY/DATE:
M_W 08/14/2017
REVIEWED BY/DATE:
BGH 09/07/2017

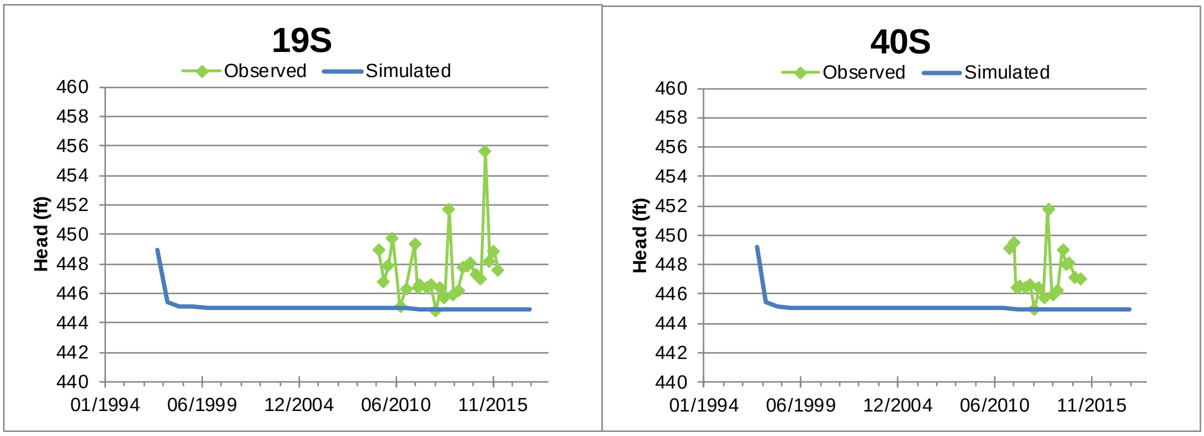
Comparison of Calibration Heads to Observations from 1994 through 2016

GROUNDWATER MODEL REPORT
EAST ASH POND NO. 2, HENNEPIN POWER STATION

PROJECT NO: 2414

FIGURE NO: 3-1

Natural Resource Technology
AN OBG COMPANY



PREPARED BY/DATE:
M_W 08/14/2017
REVIEWED BY/DATE:
BGH 09/07/2017

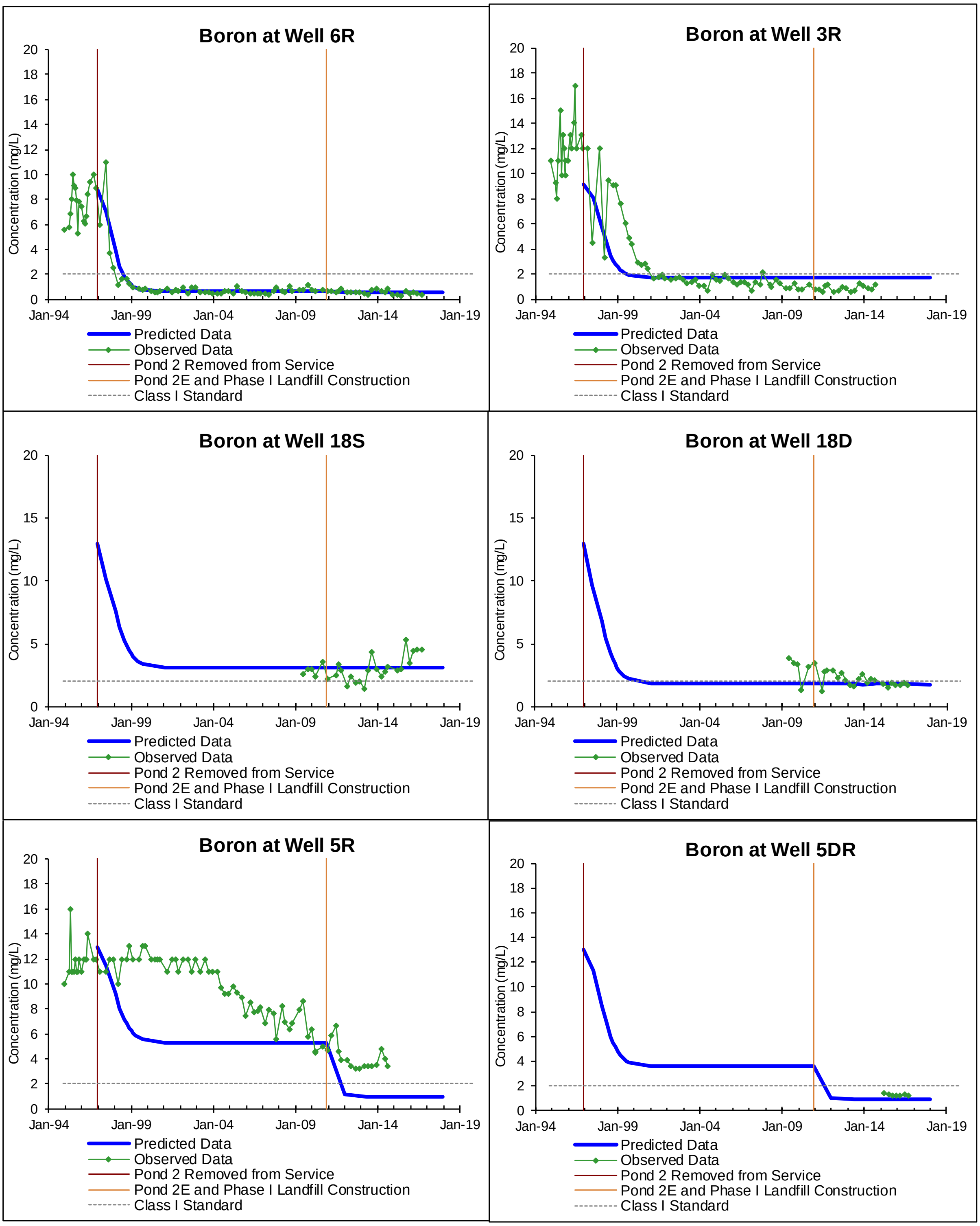
Comparison of Calibration Heads to Observations from 1994 through 2016

GROUNDWATER MODEL REPORT
EAST ASH POND NO. 2, HENNEPIN POWER STATION

PROJECT NO: 2414

FIGURE NO: 3-1

Natural Resource Technology
AN OBG COMPANY



PREPARED BY/DATE:
M_W 08/14/2017
REVIEWED BY/DATE:
BGH 09/07/2017

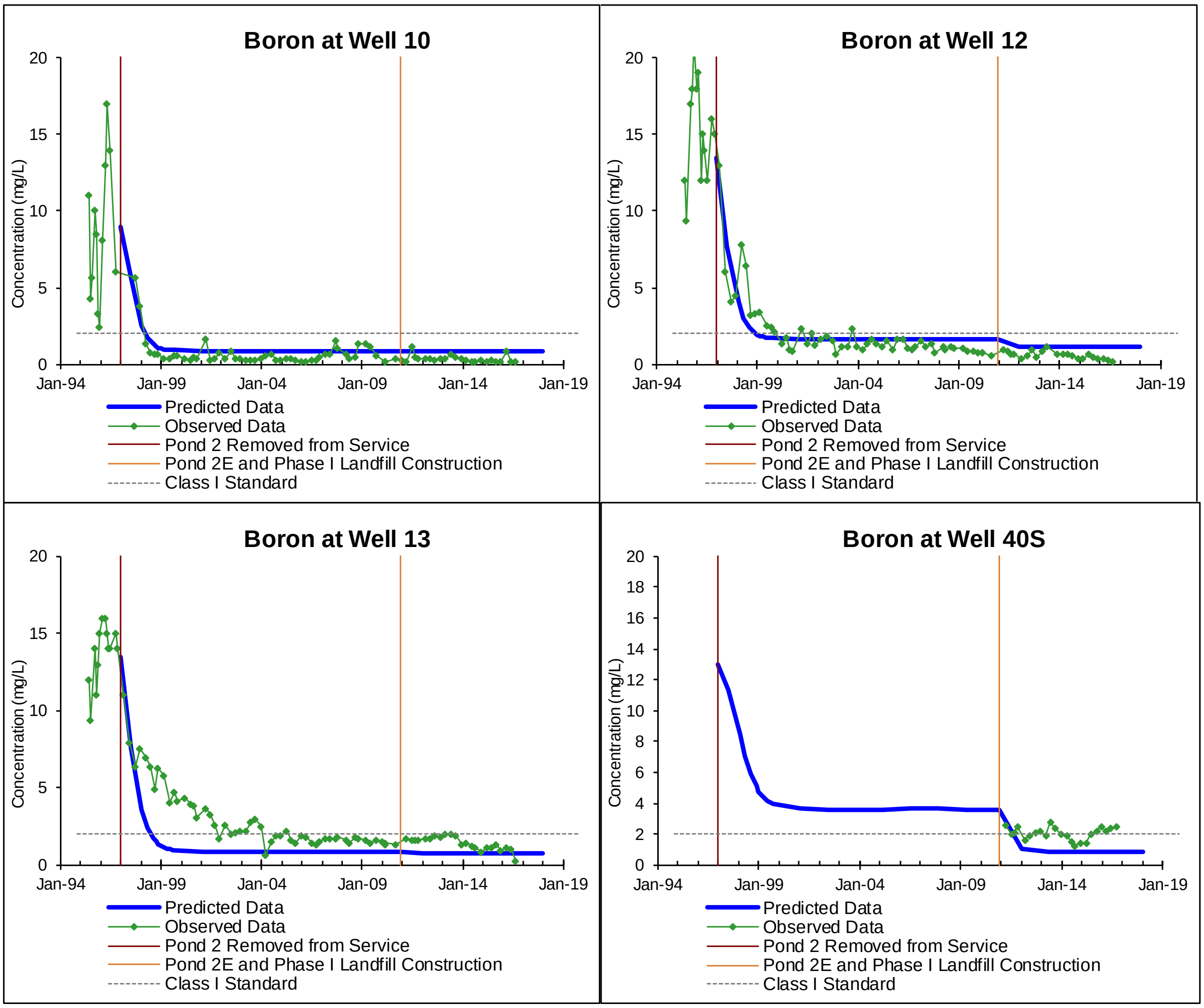
Comparison of Calibration Boron Concentrations to Observations from 1994 through 2016

GROUNDWATER MODEL REPORT
EAST ASH POND NO. 2, HENNEPIN POWER STATION

PROJECT NO: 2414

FIGURE NO: 3-2

Natural Resource Technology
AN OBG COMPANY



PREPARED BY/DATE:
M_W 08/14/2017
REVIEWED BY/DATE:
BGH 09/07/2017

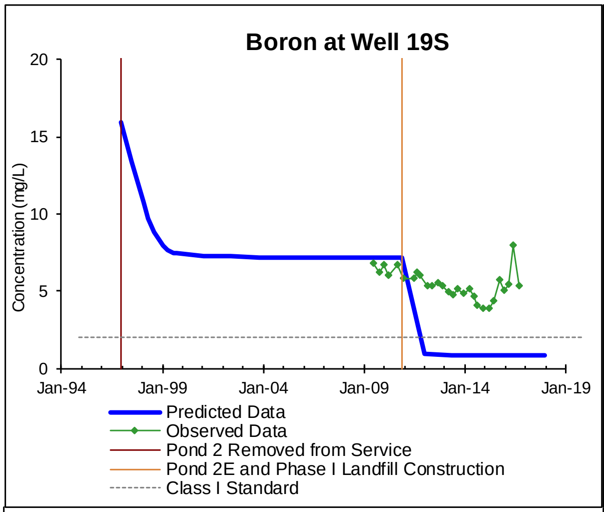
Comparison of Calibration Boron Concentrations to Observations from 1994 through 2016

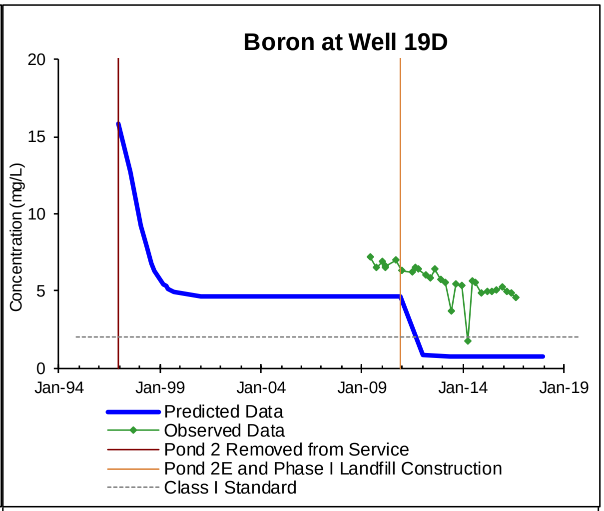
GROUNDWATER MODEL REPORT
EAST ASH POND NO. 2, HENNEPIN POWER STATION

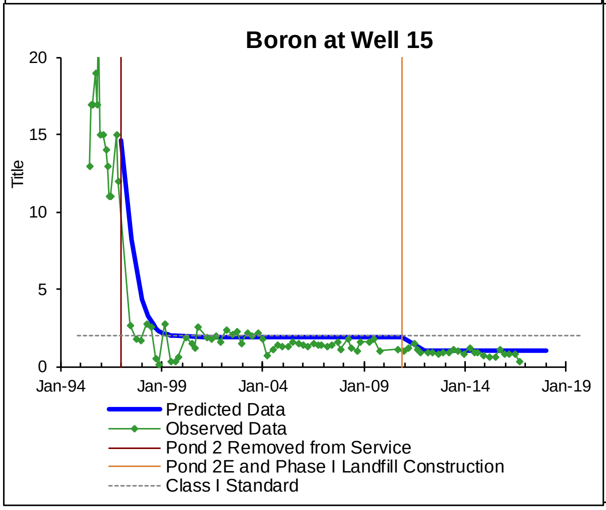
PROJECT NO: 2414

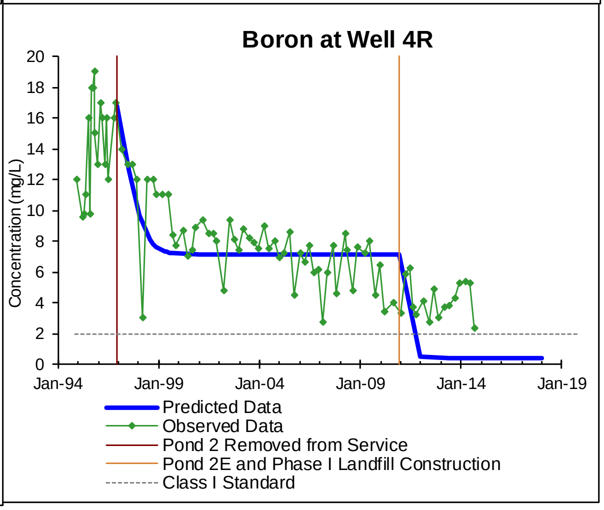
FIGURE NO: 3-2

Natural Resource Technology
AN OBG COMPANY

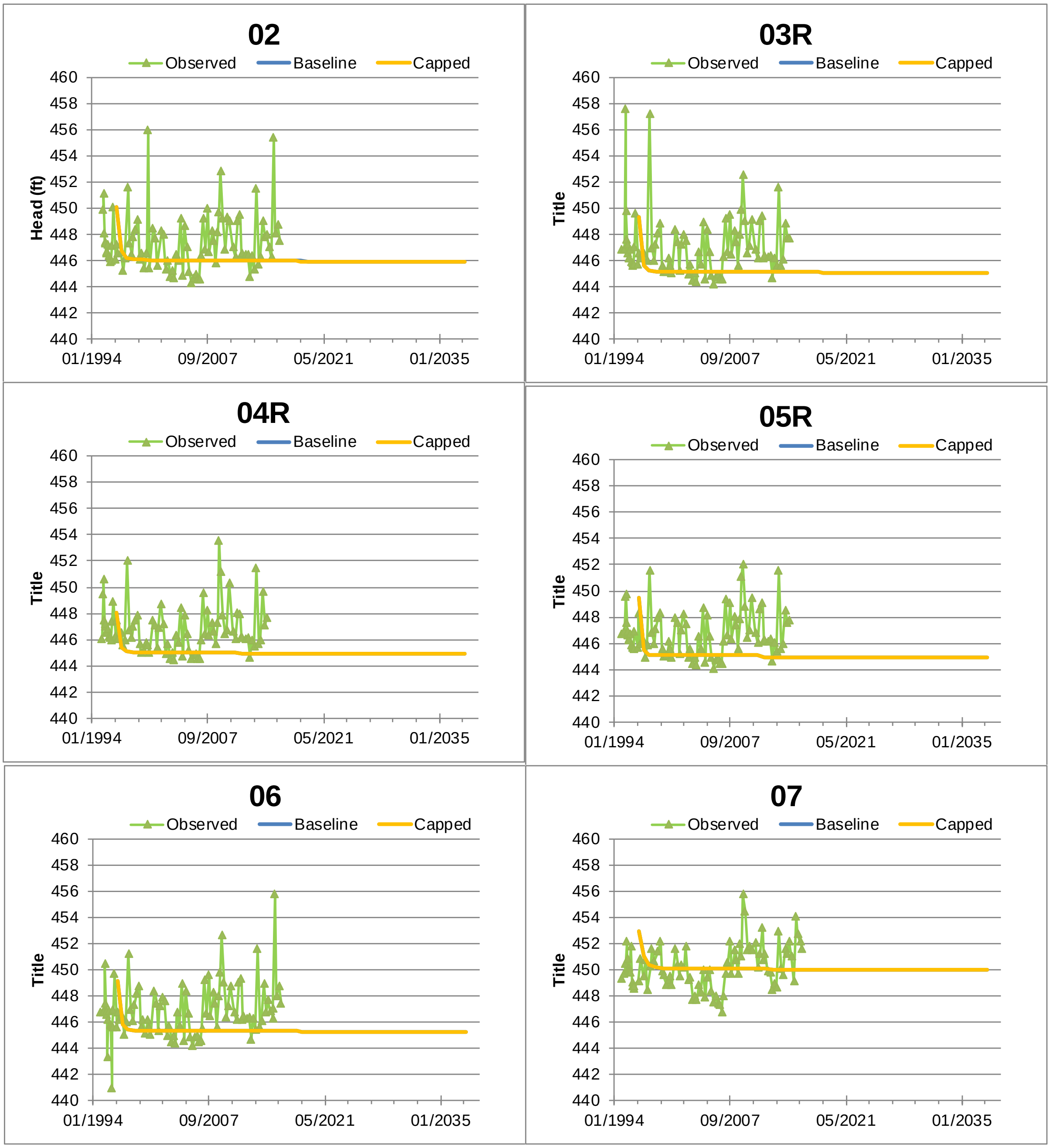








PREPARED BY/DATE: M_W 08/14/2017 REVIEWED BY/DATE: BGH 09/07/2017	**Comparison of Calibration Boron Concentrations to Observations from 1994 through 2016** GROUNDWATER MODEL REPORT EAST ASH POND NO. 2, HENNEPIN POWER STATION	**PROJECT NO: 2414** **FIGURE NO: 3-2** Natural Resource Technology AN OBG COMPANY



PREPARED BY/DATE:
M_W 08/14/2017
REVIEWED BY/DATE:
BGH 09/07/2017

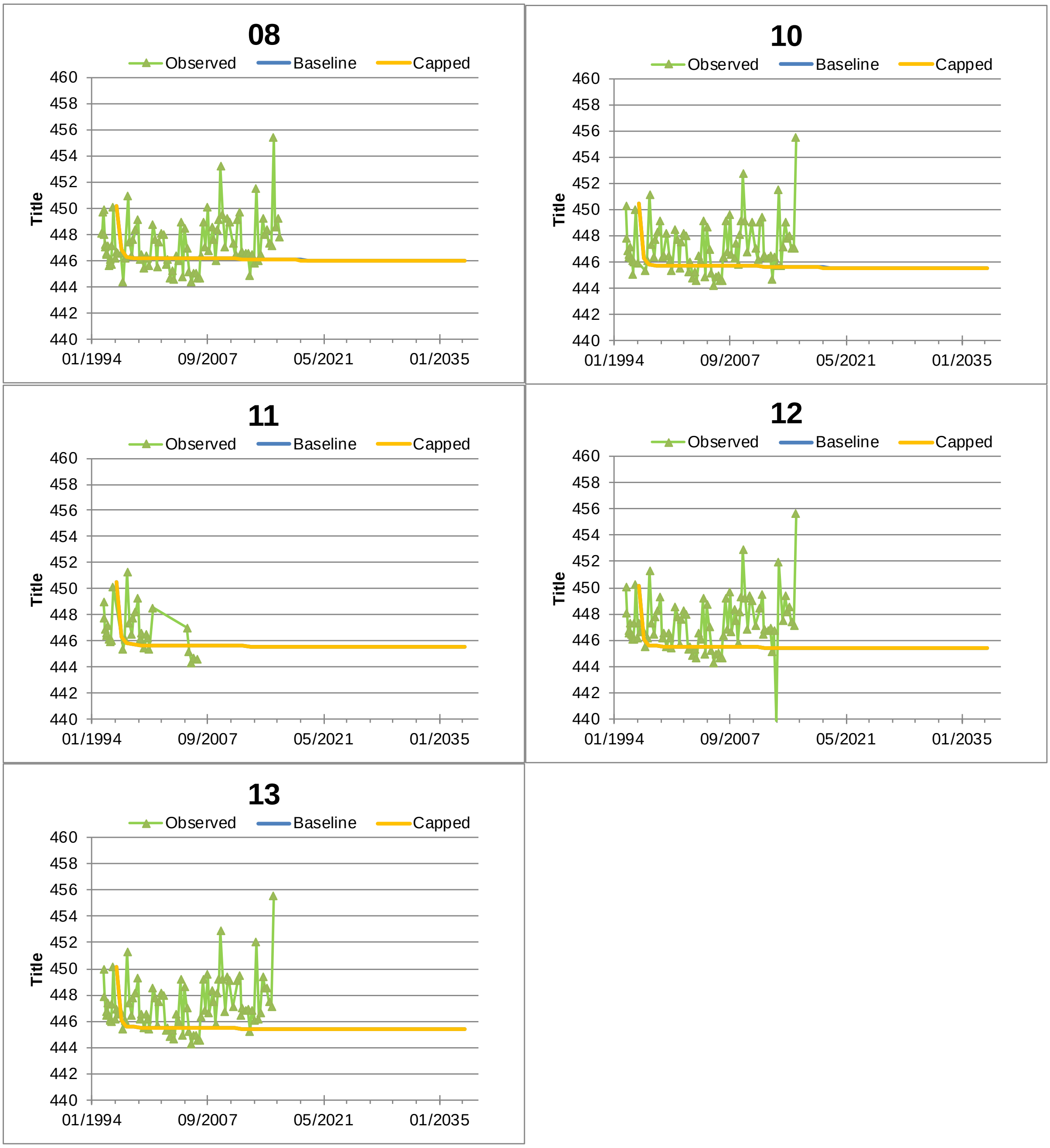
Comparison of Predicted Heads between Baseline and Capping Scenarios

GROUNDWATER MODEL REPORT
EAST ASH POND NO. 2, HENNEPIN POWER STATION

PROJECT NO: 2414

FIGURE NO: 3-3

Natural Resource Technology
AN OBG COMPANY



PREPARED BY/DATE:
M_W 08/14/2017
REVIEWED BY/DATE:
BGH 09/07/2017

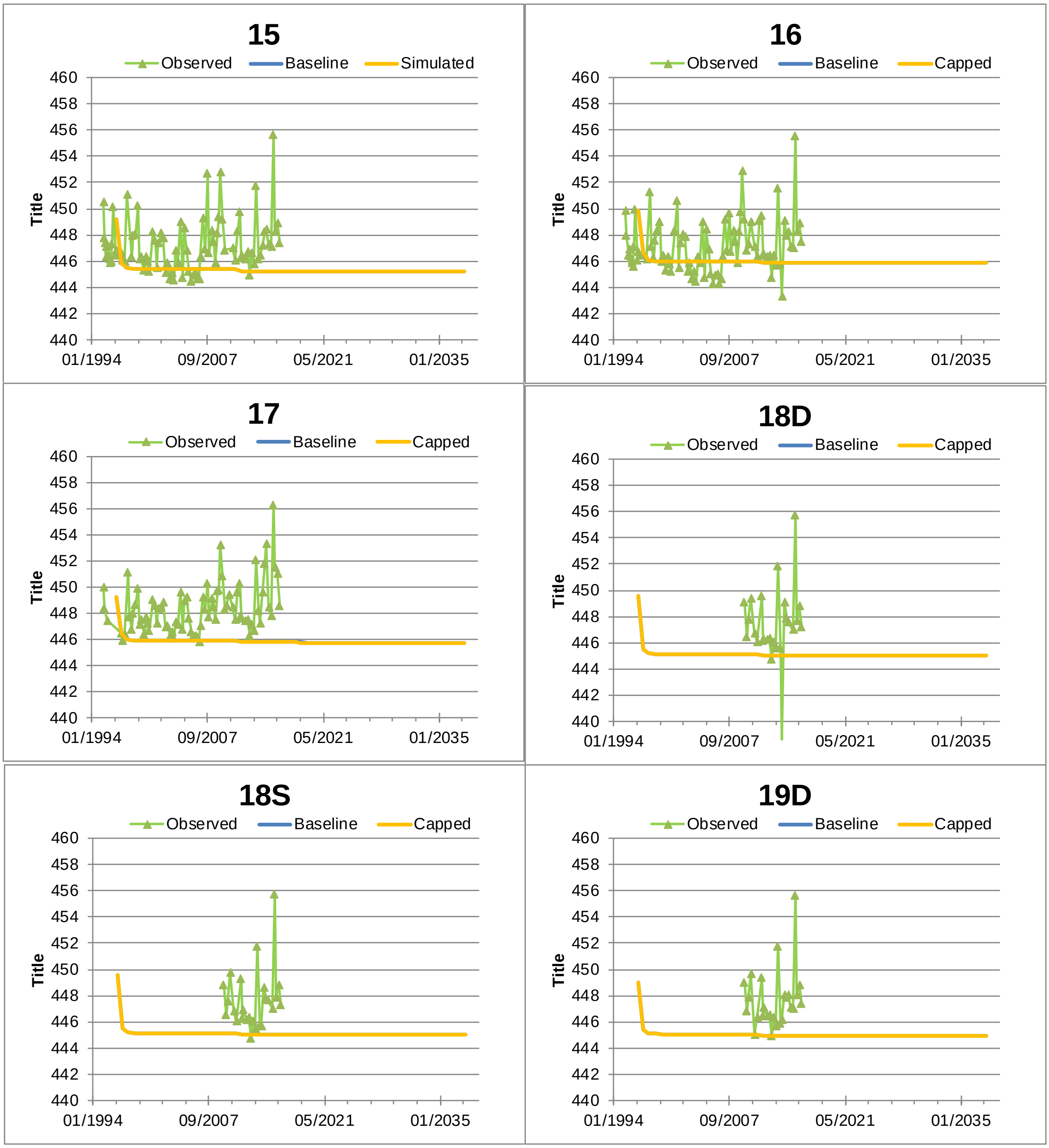
Comparison of Predicted Heads between Baseline and Capping Scenarios

GROUNDWATER MODEL REPORT
EAST ASH POND NO. 2, HENNEPIN POWER STATION

PROJECT NO: 2414

FIGURE NO: 3-3

Natural Resource Technology
AN OBG COMPANY



PREPARED BY/DATE:
M_W 08/14/2017
REVIEWED BY/DATE:
BGH 09/07/2017

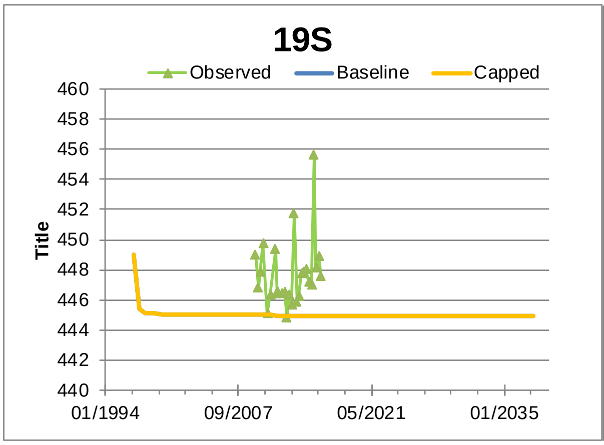
Comparison of Predicted Heads between Baseline and Capping Scenarios

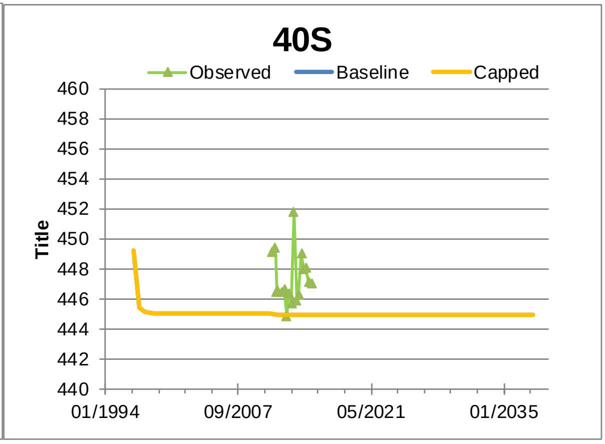
GROUNDWATER MODEL REPORT
EAST ASH POND NO. 2, HENNEPIN POWER STATION

PROJECT NO: 2414

FIGURE NO: 3-3

Natural Resource Technology
AN OBG COMPANY





PREPARED BY/DATE:
M_W 08/14/2017
REVIEWED BY/DATE:
BGH 09/07/2017

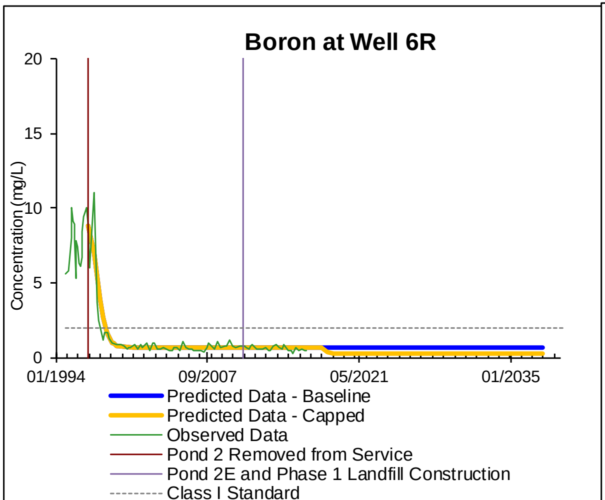
Comparison of Predicted Heads between Baseline and Capping Scenarios

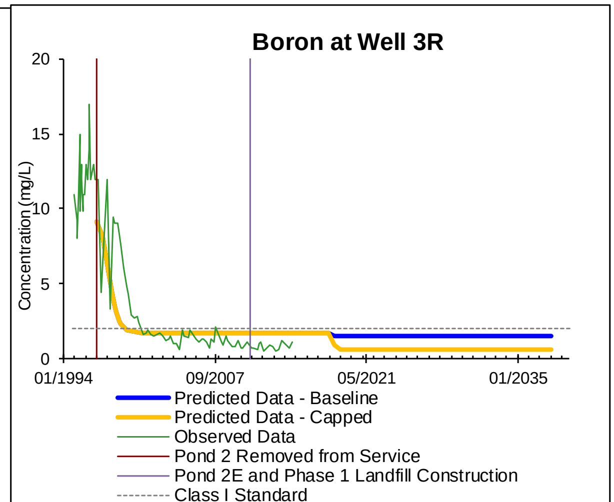
GROUNDWATER MODEL REPORT
EAST ASH POND NO. 2, HENNEPIN POWER STATION

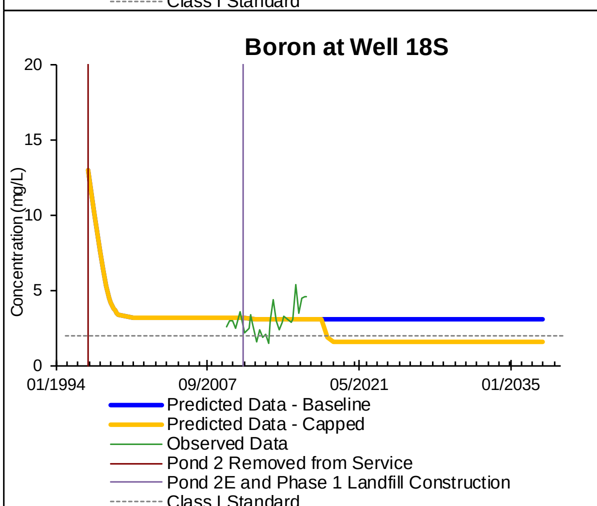
PROJECT NO: 2414

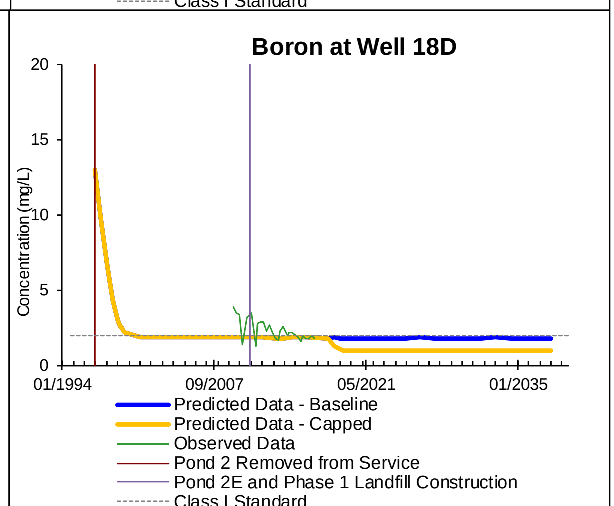
FIGURE NO: 3-3

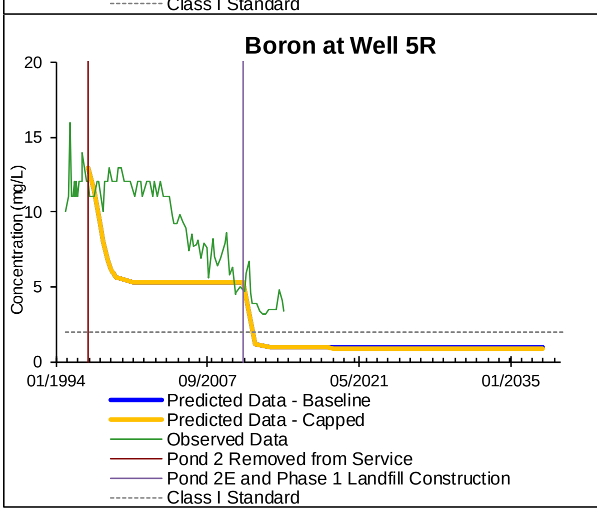
Natural Resource Technology
AN OBG COMPANY

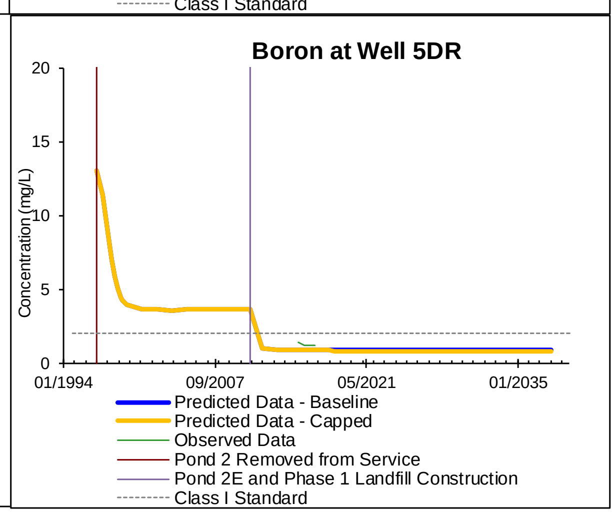












PREPARED BY/DATE:
M_W 08/14/2017
REVIEWED BY/DATE:
BGH 09/07/2017

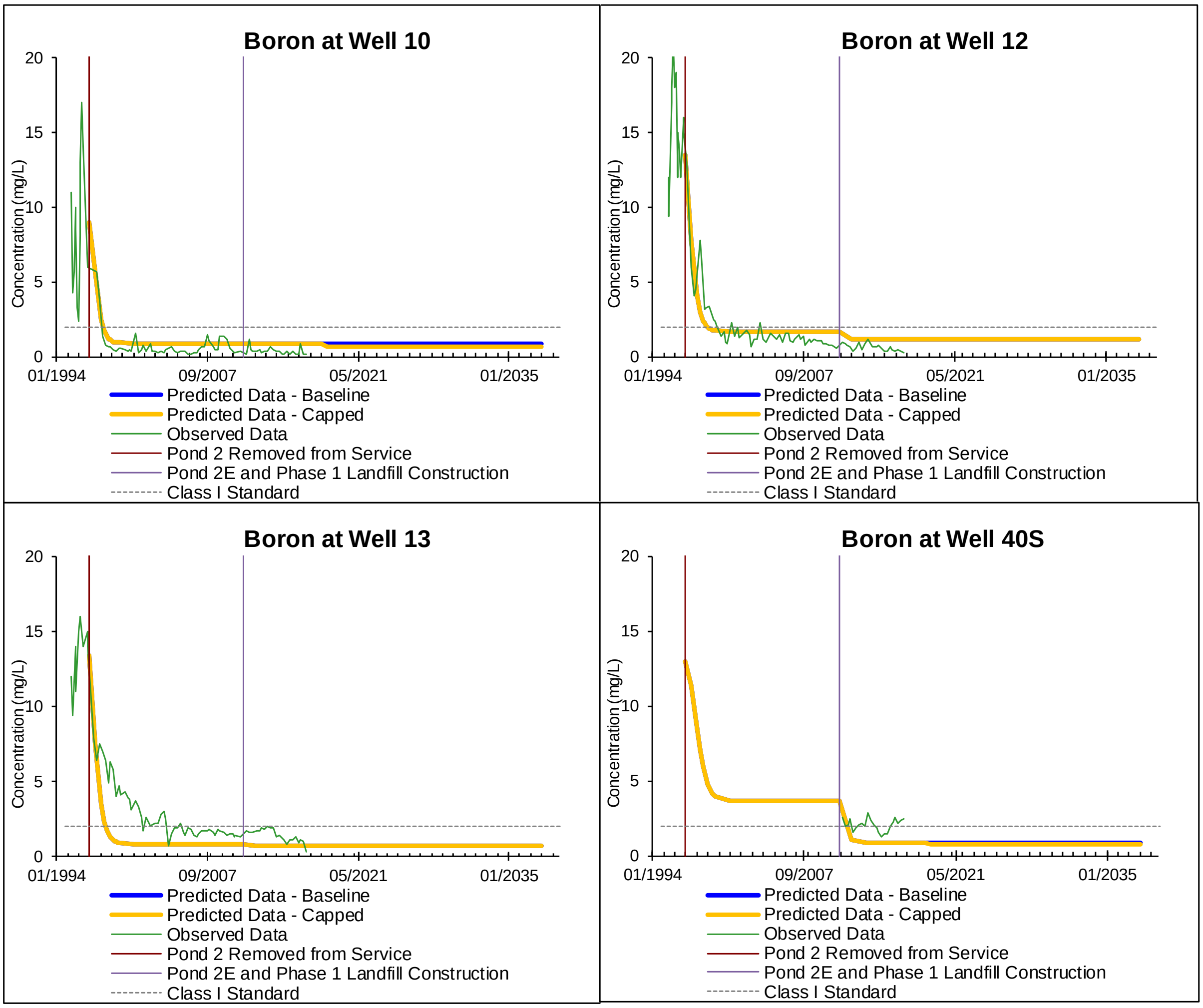
Comparison of Predicted Boron Concentrations between Baseline and Capping Scenario

GROUNDWATER MODEL REPORT
EAST ASH POND NO. 2, HENNEPIN POWER STATION

PROJECT NO: 2414

FIGURE NO: 3-4

Natural Resource Technology
AN OBG COMPANY



PREPARED BY/DATE:
M_W 08/14/2017
REVIEWED BY/DATE:
BGH 09/07/2017

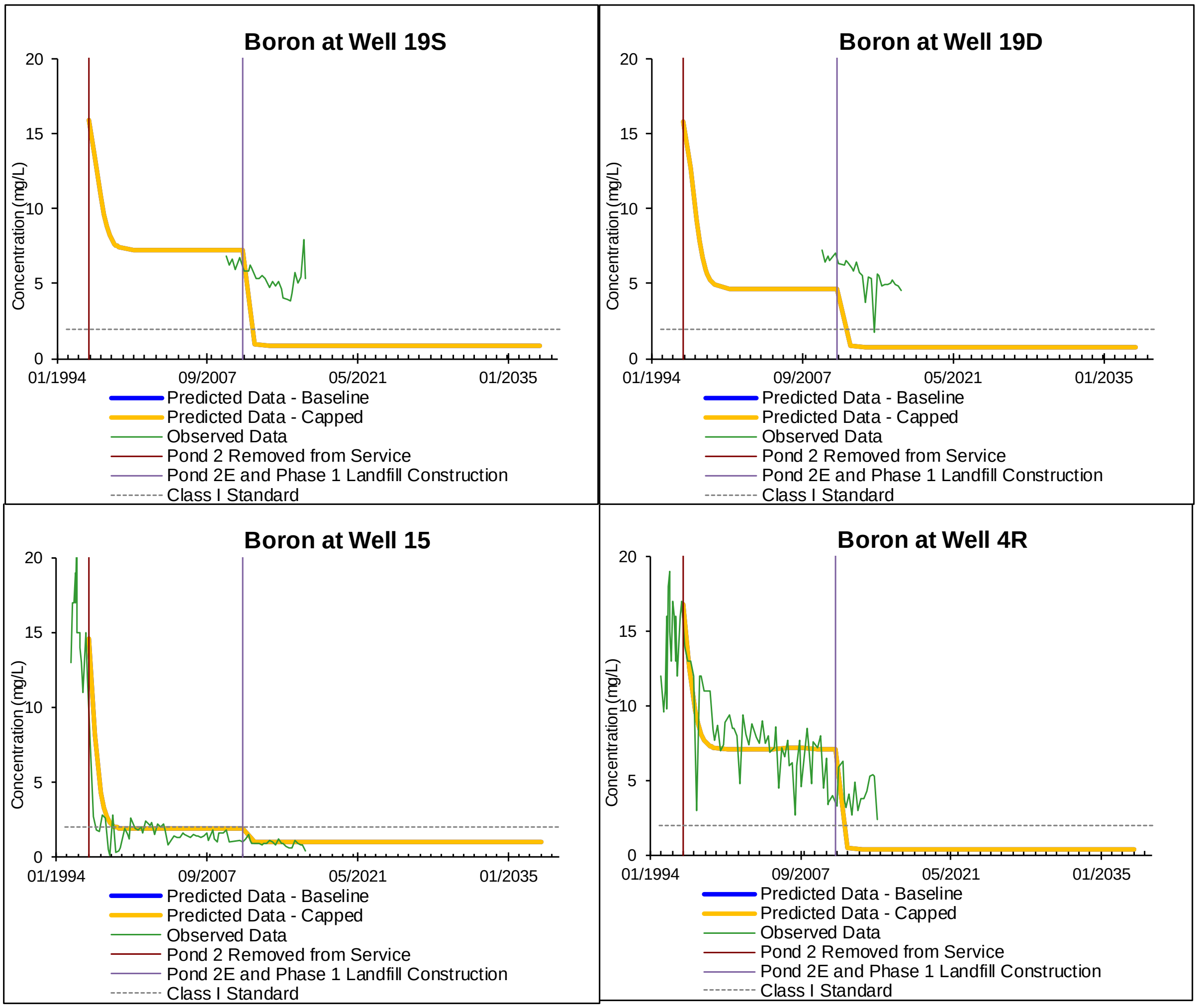
Comparison of Predicted Boron Concentrations between Baseline and Capping Scenario

GROUNDWATER MODEL REPORT
EAST ASH POND NO. 2, HENNEPIN POWER STATION

PROJECT NO: 2414

FIGURE NO: 3-4

Natural Resource Technology
AN OBG COMPANY



PREPARED BY/DATE:
M_W 08/14/2017
REVIEWED BY/DATE:
BGH 09/07/2017

Comparison of Predicted Boron Concentrations between Baseline and Capping Scenario

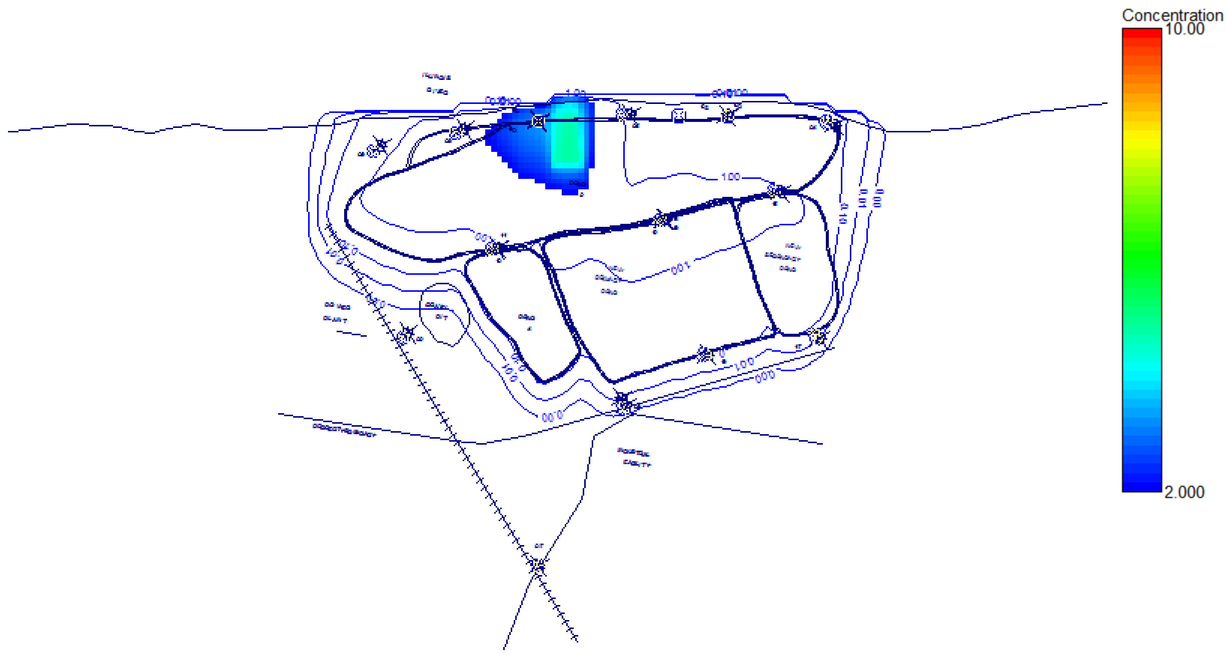
GROUNDWATER MODEL REPORT
EAST ASH POND NO. 2, HENNEPIN POWER STATION

PROJECT NO: 2414

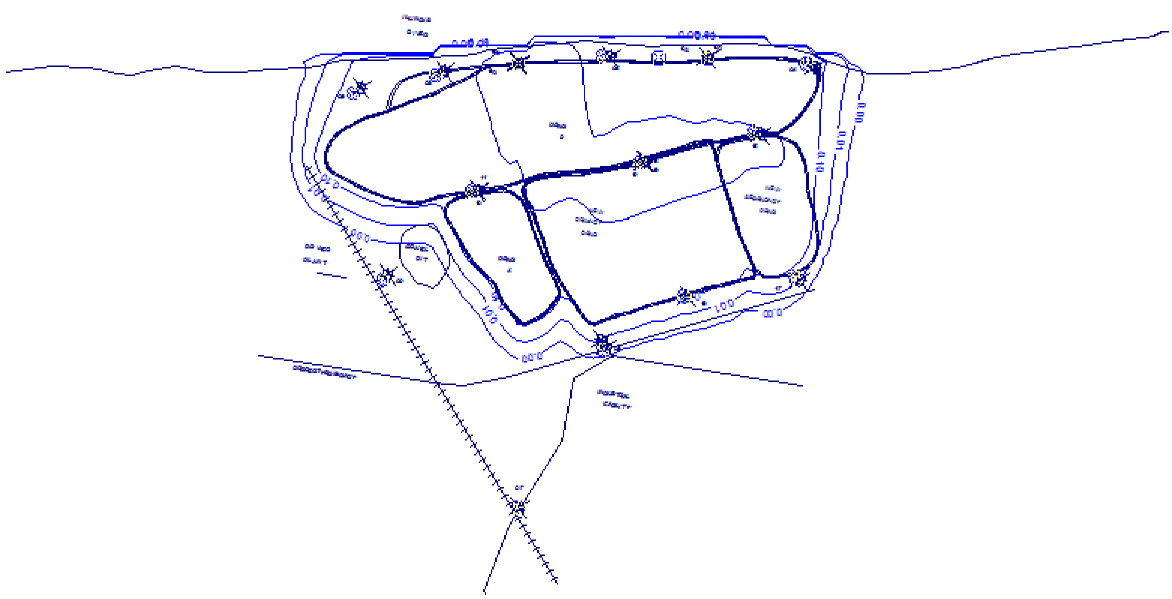
FIGURE NO: 3-4

Natural Resource Technology
AN OBG COMPANY

Baseline Scenario



Capping Scenario



PREPARED BY/DATE:
M_W 08/14/2017
REVIEWED BY/DATE:
BGH 09/07/2017

Footprint of Boron Plume over 2 mg/L in Year 2019

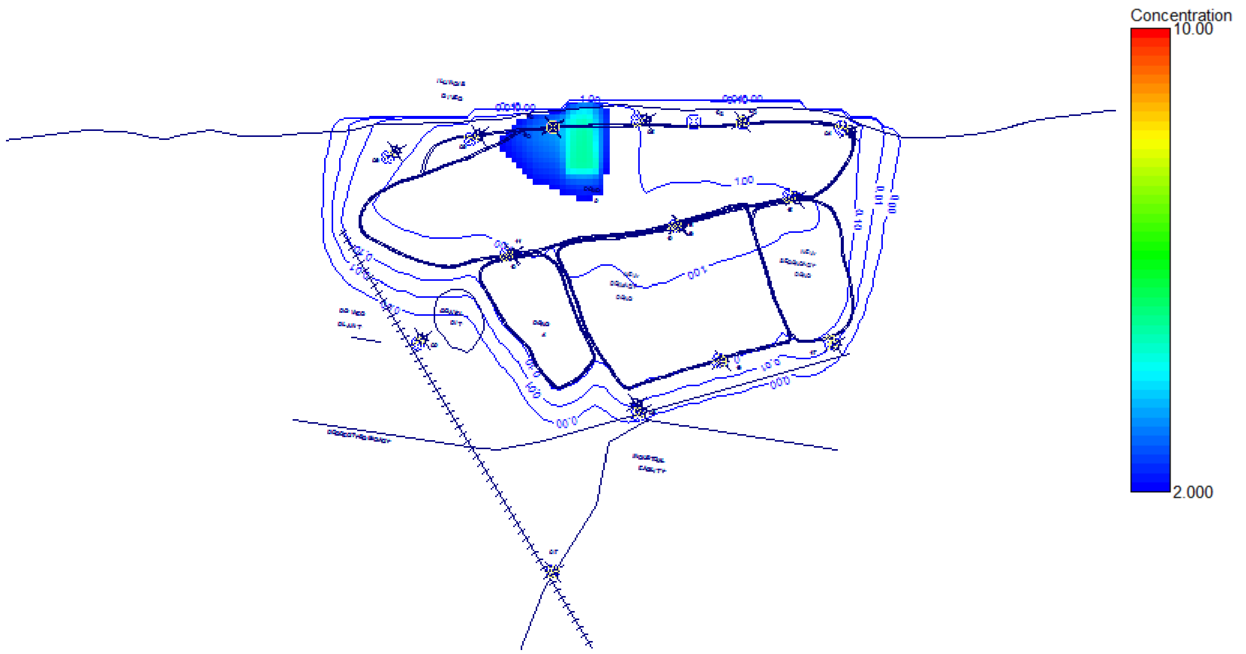
GROUNDWATER MODEL REPORT
EAST ASH POND NO. 2, HENNEPIN POWER STATION

PROJECT NO: 2414

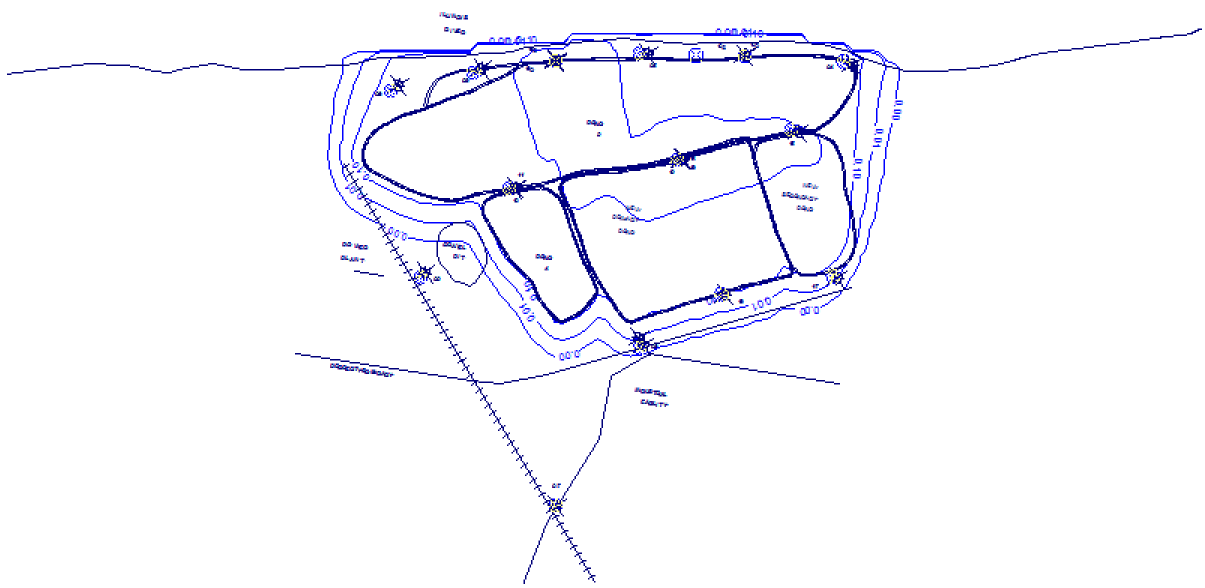
FIGURE NO: 3-5

Natural Resource Technology
AN OBG COMPANY

Baseline Scenario



Capping Scenario



PREPARED BY/DATE:
M_W 08/14/2017
REVIEWED BY/DATE:
BGH 09/07/2017

Footprint of Boron Plume over 2 mg/L in Year 2037

GROUNDWATER MODEL REPORT
EAST ASH POND NO. 2, HENNEPIN POWER STATION

PROJECT NO: 2414

FIGURE NO: 3-6

Natural Resource Technology
AN OBG COMPANY

Appendix A

MODFLOW MODELING FILES

(on CD)

OBG

THERE'S A WAY

Natural Resource Technology
AN OBG COMPANY

ATTACHMENT 25

APPENDIX C

HYDROSTATIC MODELING REPORT

OBG

Hydrostatic Modeling Report

Hennepin East Ash Pond No. 2

Hennepin, Illinois

Dynegy Midwest Generation, LLC

FINAL

December 20, 2017

Natural Resource Technology
AN OBG COMPANY

DECEMBER 20, 2017 | FINAL | PROJECT #2414

Hydrostatic Modeling Report

Hennepin East Ash Pond No. 2
Hennepin, Illinois

Prepared for:

Dynegy Midwest Generation, LLC
1500 Eastport Plaza Drive
Collinsville, IL 62234

STUART J. CRAVENS, PG
Principal Hydrogeologist

MENG WANG, PHD, PE
Data Innovation Engineer

TABLE OF CONTENTS

LIST OF TABLES ii
LIST OF FIGURES ii
LIST OF APPENDICES ii
ACRONYMS AND ABBREVIATIONS iii
1 BACKGROUND 1
1.1 Introduction 1
1.2 30% Cap Design 1
1.3 Objective 1
2 HELP MODEL SET-UP 3
2.1 Model Description 3
2.2 Input Data 3
2.3 Types of Analysis 4
3 HELP MODEL RESULTS 5
3.1 Percolation Calculation 5
3.2 Prediction Analysis 5
3.3 Sensitivity Analysis 5
4 SUMMARY 7
REFERENCES 8

LIST OF TABLES

Table 1 HELP Input Parameters
Table 2 HELP Sensitivity Analyses

LIST OF FIGURES

Figure 1 Hydraulic Head and Percolation Rate Modeled by HELP
Figure 2 Sensitivity Analysis - Hydraulic Conductivity of Barrier Layer
Figure 3 Sensitivity Analysis - Thickness of Barrier Layer
Figure 4 Sensitivity Analysis - Initial Saturation Thickness
Figure 5 Sensitivity Analysis - Thickness of Fly Ash layer
Figure 6 Sensitivity Analysis - Foundation Soil Conductivity

LIST OF APPENDICES

Appendix A HELP Model Files (on CD)

ACRONYMS AND ABBREVIATIONS

cm/s	centimeters per second
mil	millimeters
DMG	Dynegy Midwest Generation, Inc.
in	inch
ft/ft	feet per feet
vol/vol	volume per volume
in/yr	inch per year
yr	year
NRT	Natural Resource Technology, an OBG Company
HELP	Hydrologic Evaluation of Landfill Performance
U.S. EPA	United States Environmental Protection Agency
WAPS	West Ash Pond System

1 BACKGROUND

1.1 INTRODUCTION

This Hydrostatic Modeling Report has been prepared by Natural Resource Technology (NRT), an OBG company, on behalf of Dynegy Midwest Generation, LLC (DMG) to estimate percolation from the Ash Pond No. 2 within the East Ash Pond System at the Hennepin Power Station, Hennepin, Illinois, beneath the proposed pond cap. Former impoundments are situated less than 200 feet south of the Illinois River and approximately one mile east of the Big Bend, where the river shifts course from predominantly west to predominantly south. The Hennepin East Ash Pond System consists of: (1) East Ash Pond No. 2 (including current Ash Pond No. 2, Landfill and Leachate Pond which were constructed over the eastern portion of Ash Pond No. 2); (2) East Ash Pond; (3) Ash Pond No. 4 (by definition, Non-CCR unit, capped or otherwise maintained); and (4) the Polishing Pond. The easternmost portion of Ash Pond No. 2 was removed in 2009 to 2010 to facilitate construction of the Leachate Pond. The Leachate Pond is lined with 60-mil HDPE overlying two feet of compacted clay with a vertical hydraulic conductivity of 1×10^{-7} cm/sec. Between the Leachate Pond and the inactive unlined Ash Pond No. 2 is Landfill Phase I, an overfill with geomembrane liner and leachate collection system that was completed in 2010. The Landfill became operational in February 2011 with placement of 7,500 cubic yards of bottom ash to protect the liner, but no other material has been placed in the Landfill since that time. Although additional landfill cells (i.e., Phases II, III, IV) and a future bottom ash pond were planned in 2009, it was subsequently decided that no further construction of lined ash disposal units (landfill or bottom ash pond) would be undertaken because of decreased ash disposal due to beneficial reuse of CCRs.

A notice of intent to close the remaining uncapped portion of Ash Pond No. 2, encompassing approximately 25.5 acres, was submitted in November 2015. The cap system, as designed by Civil & Environmental Consultants, Inc. (CEC), is proposed to be implemented on the remaining areas of Ash Pond No. 2 (Landfill Phases II, III and IV, and bottom ash pond, that will not be completed). The Hydrologic Evaluation of Landfill Performance (HELP) model was used to predict percolation and to evaluate hydrostatic conditions in response to the proposed cap system. Henceforth, all references to Ash Pond No. 2 refer only to the current uncovered area of ash located west of Landfill Phase I.

1.2 30% CAP DESIGN

The preferred cover system for Ash Pond No. 2, provided to NRT by CEC, is comprised of a 6-inch vegetative cover layer (topsoil) overlying an 18-inch compact soil barrier with a hydraulic conductivity of 1×10^{-5} cm/s. The borrow source of the soil is considered to be located within existing Dynegy property based on current design.

HELP model input assumes the proposed cover systems are properly constructed and maintained to allow 100% stormwater runoff; i.e., the cover has positive drainage to prevent standing water, and vegetation consists of a fair stand of grass.

1.3 OBJECTIVE

- The purpose of this report is to estimate percolation through the ponds upon cap completion and to evaluate the design of the cap system on the hydrostatic conditions within the system. The time for the capped pond to reach hydrostatic equilibrium is also assessed. This modeling report addresses the following:
- Predict the percolation rates through the basal component of the pond when the designed cap is implemented for the remaining uncovered area of Ash Pond No.2. The percolation rates serve as input data for recharge rates in the MODFLOW model to predict pond hydraulics and leachate transport when the cap is in-place.
- Assess whether the capped pond could reach hydrostatic equilibrium conditions for the proposed design of the cap system, when applied with site-specific parameters, which means minimal water head fluctuation beneath the cap system on the foundation soil following the completion of cap construction (i.e., flow rate in

equals flow rate out). If modeling indicates hydrostatic equilibrium is achievable, then the time it will take the pond to reach hydrostatic equilibrium status is estimated.

2 HELP MODEL SET-UP

2.1 MODEL DESCRIPTION

The Hydrologic Evaluation of Landfill Performance (HELP) model was developed by the U.S. Environmental Protection Agency (Schroeder et al., 1994). HELP is a one-dimensional hydrologic model of water movement across, into, through and out of a landfill or soil column based on precipitation, evapotranspiration, runoff, and the geometry and hydrogeologic properties of a layered soil and waste profile.

For this investigation, HELP Version 3.07 (Schroeder et al., 1994) was selected to estimate the hydraulic conditions beneath the cap system implemented on Phases II, III and IV areas of Ash Pond No. 2 as prescribed by CEC. The hydrologic data entered into HELP are listed in Table 1 and described in the following paragraphs.

2.2 INPUT DATA

Table 1 presents all input data to configure the HELP model. Climatic input variables were synthetically generated by the HELP model using modified default values for Chicago and a latitude of 41.30° N for the Hennepin Power Station. Rainfall frequency and temperature patterns for more than 100 cities are programmed into HELP. Chicago was selected as the closest city to the site. The model used Chicago precipitation and temperature patterns with default Chicago precipitation and temperature data to generate daily precipitation and temperature data. A 25-year simulation period was selected, which provided a sufficient duration to review the impact of precipitation variance on outputs for models and indicate the trend for the designed cap to reach equilibrium.

Physical input data were based on the actual and proposed capped configurations of the pond, measured soil properties, and in the absence of site specific measurements, assumed soil properties (NRT, 2017b). The coal ash was subdivided into several 160-inch thick sublayers in the models. Coal ash thickness was obtained from soil borings conducted in the pond (NRT, 2017b). Specifically, the HELP model soil layout includes (from top to bottom):

- Layer 1: 6 inches of vegetative cover
- Layer 2: 18 inches of soil (barrier layer)
- Layers 3-5: 480 inches of fly ash divided into three 160 inch layers
- Layer 6: 240 inches of sand and gravel layer
- Layer 7: 420 inches of silty sand layer

The HELP modeling assumed that cap materials and ash had uniform texture and hydraulic properties during the simulation period. Cap material for Layer 1 and fly ash for Layers 3-5 were chosen from the HELP database to match the conceptual design. Hydraulic properties of the cap materials, including hydraulic conductivity, porosity, field capacity, and wilting point, were the default database values. For Layer 2, the hydraulic properties of the cap material were chosen as HELP material #16 (Barrier Soil) except the hydraulic conductivity, which was specified by CEC as 1×10^{-5} cm/s.

The coal ash was modeled as unsaturated according to the soil boring records (NRT, 2017b), the initial moisture content of which was set as 0.3, which represents the equilibrium state of coal ash before the cap is placed (Appendix A). The cap was assumed to allow 100% surface water runoff provided the cap drainage is properly maintained.

Material layers 6 and 7 were assumed to be homogenous; that is, the material layers have uniform texture and hydraulic properties. Hydraulic properties of materials, including hydraulic conductivity, porosity, field capacity, and wilting point, were the default HELP database values.

2.3 TYPES OF ANALYSIS

Two types of HELP simulations were performed: prediction analysis and sensitivity analysis.

The prediction analysis was conducted to estimate the percolation rate through the basal soil, which was later input to the groundwater flow model. The prediction analysis was also performed to estimate the hydraulic head on the basal soil, which was used to evaluate the hydrostatic status over time for the newly capped areas of Ash Pond No. 2 and to estimate the time for the hydraulic head to reach equilibrium.

Sensitivity analysis was used to determine the significance of input parameters for Ash Pond No. 2 to reach hydrostatic equilibrium. Sensitivity analysis was performed for parameters potentially influencing the capped impoundment hydrostatic conditions, including:

- Hydraulic conductivity of the clay cap, Layer 2 (barrier layer)
- Thickness of the clay cap, Layer 2 (barrier layer)
- Initial saturation thickness
- Thickness of Layers 3-5 (fly ash)
- Hydraulic conductivity of Layer 7 (basal soil)

3 HELP MODEL RESULTS

3.1 PERCOLATION CALCULATION

HELP input and output files are included as Appendix A on the attached CD. Calculated percolation rates through the foundation soil fluctuated with changes in precipitation and evaporation conditions. The average percolation rates though foundation soil estimated for the cap during the stable phase is 5.9 inch/yr (Figure 1), and was used in the groundwater prediction models (NRT, 2017a).

3.2 PREDICTION ANALYSIS

The HELP model was run for 25 years after cap construction completion, applying the input parameters listed in Section 2.2 and Table 1.

Figure 1 illustrates the predicted hydraulic heads and percolation rates through the basal soil. As shown on Figure 1, the hydraulic head on the foundation soil and percolation rate through the system behave in a similar manner, both of which decrease dramatically and reach equilibrium in the first 2 years following cap completion. The value of hydraulic head on the basal soil is expected to be very low after Year 2 (approximately 0.008 inches with fluctuations within 0.006 inches). Therefore, under this model setting the hydrostatic equilibrium is expected to be realized soon after cap completion and the hydraulic head will remain at a low level. The percolation rates are also expected to reach equilibrium soon after cap completion and will stabilize at around 5.9 in/yr. The percolation rates have a higher range of fluctuations (about 4 to 10 in/yr), which is the result of the annual variance in the synthetic precipitation input.

3.3 SENSITIVITY ANALYSIS

Sensitivity analyses were performed on select layer parameters as summarized in Table 2 and described in the following paragraphs. The changes in hydraulic heads under sensitivity analyses are shown on Figures 2 through 6.

Hydraulic Conductivity of the Clay Cap Layer 2 (barrier layer)

The hydraulic heads on the basal soil were simulated under a range of hydraulic conductivity values for the clay cap (barrier layer) and the results are shown on Figure 2. The range of hydraulic conductivity values chosen for the clay cap barrier layer range from 1 x 10^{-3} cm/s to 1 x 10^{-7} cm/s, which almost covers the entire range of available soil values provided by CEC. Despite the fluctuation due to the annual variance in precipitation, the hydraulic heads remain below 0.01 inches from Year 2 to Year 25 for all conditions. The results indicate that hydrostatic equilibrium can be attained under a wide range of clay cover hydraulic conductivity values representing available soils.

Thickness of the Clay Cap Layer 2 (barrier layer)

The hydraulic heads on the basal soil were simulated under a range of clay cap thicknesses (12, 18 and 24 inches) and the results are shown on Figure 3. The hydraulic heads predicted under all three scenarios are nearly identical, indicating that attainment of hydrostatic equilibrium is not sensitive to the thickness of the clay cap.

Initial Saturation Thickness

The hydraulic heads on the foundation soil were simulated under three different initial thicknesses of saturated layers: a lower end of 35 feet where only the basal layer is saturated; the base case of 55 feet where the basal layer and the overlying layer are saturated; and, an upper end of 68 feet where the basal layer and the two overlying layers (including the bottom layer of ash) are saturated. As shown in Figure 4, hydraulic heads calculated by HELP were sensitive to the initial saturation thickness in the first 2 years of the simulations. Starting from Year 3 all scenarios resulted in the same hydraulic heads, suggesting hydrostatic equilibrium can be rapidly attained under a wide range initial saturation thickness conditions.

Thickness of Layers 3-5 (fly ash)

The hydraulic heads on basal soil were predicted under a range of fly ash thicknesses and the results are shown on Figure 5. According to the Hydrogeologic Report (NRT, 2017b), the ash layer within Ash Pond No. 2 has a thickness of approximately 10 to 45 feet. The sensitivity analysis was performed for the scenarios with fly ash thickness ranging from 1 x 160 inch layer (total of 13 feet) to 5 x 160 inch (total of 65 feet). The hydraulic heads predicted under all three scenarios reach equilibrium after Year 2. Although the hydraulic heads fluctuate slightly from each other, the magnitude and variance of hydraulic heads remain similar and they are all below 0.01 inches. Therefore, attainment of hydrostatic equilibrium was not sensitive to the range of fly ash layer thickness.

Hydraulic Conductivity of Layer 7 (basal soil)

The hydraulic heads on basal soil were predicted under a range of hydraulic conductivity values for the basal soil and the results are shown on Figure 6. According to the Hydrogeologic Investigation Report (NRT, 2017b), the Henry Formation sands and gravels at the site are highly permeable with measured hydraulic conductivity ranging from 3×10^{0} cm/s to 1×10^{-4} cm/s and a geometric mean of 5.6×10^{-2} cm/s. The range of hydraulic conductivity chosen for sensitivity testing of the basal soil was from 5×10^{-4} cm/s to 1×10^{-6} cm/s as a conservative test. The results indicate hydraulic equilibrium can be attained by Year 7 for all tested values. When the conductivity is assumed at 1×10^{-6} cm/s the hydraulic head slowly decreases until Year 7, when it reaches equilibrium and matches the hydraulic heads predicted by the other scenarios. The results indicate that for higher basal soil conductivities the system will reach equilibrium more rapidly. Therefore, the results show that hydrostatic equilibrium can be attained under a wide range of basal soil hydraulic conductivities, including the range of values observed beneath Ash Pond No. 2.

4 SUMMARY

The HELP model was used to estimate percolation rate within Ash Pond No.2 (located west of the Phase I Landfill) and to evaluate the hydrostatic conditions following implementation of the proposed cap system. Input parameters were chosen based on site specific configurations, and a range of parameters were tested for sensitivity to the hydraulic head accumulated beneath the cap system in the 25 years following closure completion (construction of the cap system). The results of the modeling indicate:

- Hydrostatic equilibrium can be attained for the remaining uncovered portion of Ash Pond No. 2 under the current hydrogeological conditions with the proposed cap system.
- Hydraulic head in the proposed cap system is expected to decrease to near-zero level for equilibrium after 2 years upon completion of cap construction (Figure 1).
- The hydrostatic condition of the capped impoundment is moderately sensitive to the basal soil hydraulic conductivity (Figure 6). The higher hydraulic conductivities (i.e., 1.0 x 10^{-5} or greater) for the basal soil result in the hydraulic head decreasing rapidly within 2 years. Alternatively, when the foundation soil hydraulic conductivity is extremely low, as demonstrated with the 1.0 x 10^{-6} cm/s case, the calculated hydraulic head still demonstrates a decreasing trend and equilibrium will be realized approximately 7 years following cap completion.
- The proposed compacted clay cap with a permeability of 1.0 x 10^{-5} cm/s is lower than the measured hydraulic conductivities of deposits underlying Ash Pond No. 2 (NRT, 2017b) and meets the criteria of 40 CFR Part 257.102 (U.S. EPA, 2015).

The proposed capping system - a 6-inch surface soil layer and 18-inch compacted soil layer, is a feasible design on the remaining uncovered areas of Ash Pond No. 2 from the hydrostatic equilibrium perspective. The hydraulic head within the impoundment will decrease following cap construction and hydrostatic equilibrium will be attained.

REFERENCES

Civil & Environmental Consultants, Inc. 2017. Communication on Draft Closure Options for the West Ash Impoundment; Hennepin Power Station Putnam County, Illinois. August, 2017.

Natural Resource Technology, Inc. (NRT), 2017a. Groundwater Model Report; Hennepin Power Station Putnam County, East Ash Impoundment, Illinois. September, 2017.

Natural Resource Technology, Inc. (NRT), 2017b. Hydrogeologic Investigation Report; Hennepin Power Station Putnam County, East Ash Impoundment, Illinois. September, 2017.

Schroeder, P.R., T.S. Dozier, P.A. Zappi, B.M. McEnroe, J.W. Sjostrom, and R.L. Peyton. 1994. The Hydrologic Evaluation of Landfill Performance (HELP) Model: Engineering Documentation for Version 3. EPA/600/R-94/168b. U.S. Environmental Protection Agency Office of Research and Development, Washington, D.C.

U.S. EPA, 2015. 40 CFR Parts 257 and 261 – Hazardous and Solid Waste Management System; Disposal of Coal Ash Residuals from Electric Utilities. Federal Register vol. 80, no. 74, April 17, 2015. 21467-21501.

Tables

Table 1. HELP Input Parameters
Hydrostatic Modeling Report
East Ash Pond No. 2, Hennepin Power Station

Parameter						Notes
Climate Data						
City	Chicago, IL					Nearby city to the Site within HELP database
Latitude	41.30° N					Power station latitude
Evaporation Zone Depth (in)	20					4- bare ground, 20 - fair grass
Leaf Index	2					1 - poor stand of grass (Schroeder, 1994)
Growing Season Period, Average Wind Speed, and Quarterly Relative Humidity.	HELP model defaults					See HELP output in Appendix A
Number of Years for Synthetic Data Generation	25					25-year period is applied to determine time to reach equilibrium.
Temperature, Evapotranspiration, and Precipitation	synthetically generated using Chicago, IL defaults.					--
Soil Layer Data						
Soil-general						
% Where Runoff Possible	100					--
Area (acres)	1					Unit area
Specify Initial moisture content	Y					--
Initial Surface Water/Snow (in)	0					--
Soil Layers						
1	Vegetative Cover					--
2	Clay Cap					
3	Fly Ash					
4	Fly Ash					
5	Fly Ash					
6	Sand and Gravel					
7	Sandy Silt					
Layer Parameter						
Layer #	**1**	**2**	**3-5**	**6**	**7**	
Type	1	3	1	1	3	1 = vertical percolation layer; 2 = lateral drainage layer; 3 = barrier soil layer
Thickness Per Layer (in)	6	18	160 X 3	240	420	-
Material Texture Number	9	16	30	6	9	6 = sandy loam; 9 = silt loam; 20 = drainage net; 30 = fly ash; 16 = barrier soil
Porosity (vol/vol)	0.501	0.427	0.541	0.453	0.501	Default value for selected soil texture
Field Capacity (vol/vol)	0.284	0.418	0.187	0.19	0.284	Default value for selected soil texture
Wilting Point (vol/vol)	0.135	0.367	0.047	0.085	0.135	Default value for selected soil texture
Initial Moisture Content (vol/vol)	0.284*	0.427*	0.300**	0.453*	0.501*	*Default values, unsaturated materials use field capacity, saturated materials use porosity. **Chosen value to match the moisture content of ash that reaches equilibrium when no cap is implemented.
Hydraulic Conductivity (cm/s)	1.90E-04*	1E-5**	5E-5*	7.2E-4*	1.9E-4*	* - default value in HELP database ** - self-chosen values; default value is 1E-7
Soils-runoff						
SCS Runoff Curve Number	x					HELP Calculated
Slope	2.0%					Based on the CEC design
Length (ft)	1100					Estimated values based on the CEC design figure
Texture	6					Based on uppermost soil type (silt loam)
Vegetation	1					1 - bare ground; 3 - fair stand of grass

Table 2. HELP Sensitivity Analyses
Hydrostatic Modeling Report
East Ash Pond No. 2, Hennepin Power Station

Parameter	Base Value	Tested Range	Sensitivity to Hydrostatic Equilibrium[1]
Soil Parameters--barrier soil			
Hyraulic conductivity (cm/s)	1.0E-05	1.0E-03, 1.0E-04, 1.0E-05, 1.0E-06, 1.0E-07	Negligible
Thickness (in)	18	12, 18, 24	Negligible
Soil Layers			
Initial Saturation Thickness (ft)	55	35, 55, 68	Negligible
Soil Parameters--fly ash			
Layers x Thickness (in)	3 x 160	1 x 160, 3 x 160, 5 x 160	Negligible
Soil Parameters--underlying soil			
Hyraulic conductivity (cm/s)	1.90E-04	5.0E-04, 1.9E-04, 1.0E-05, 1.0E-06	Moderate

Notes:

1. Sensitivity Explanation

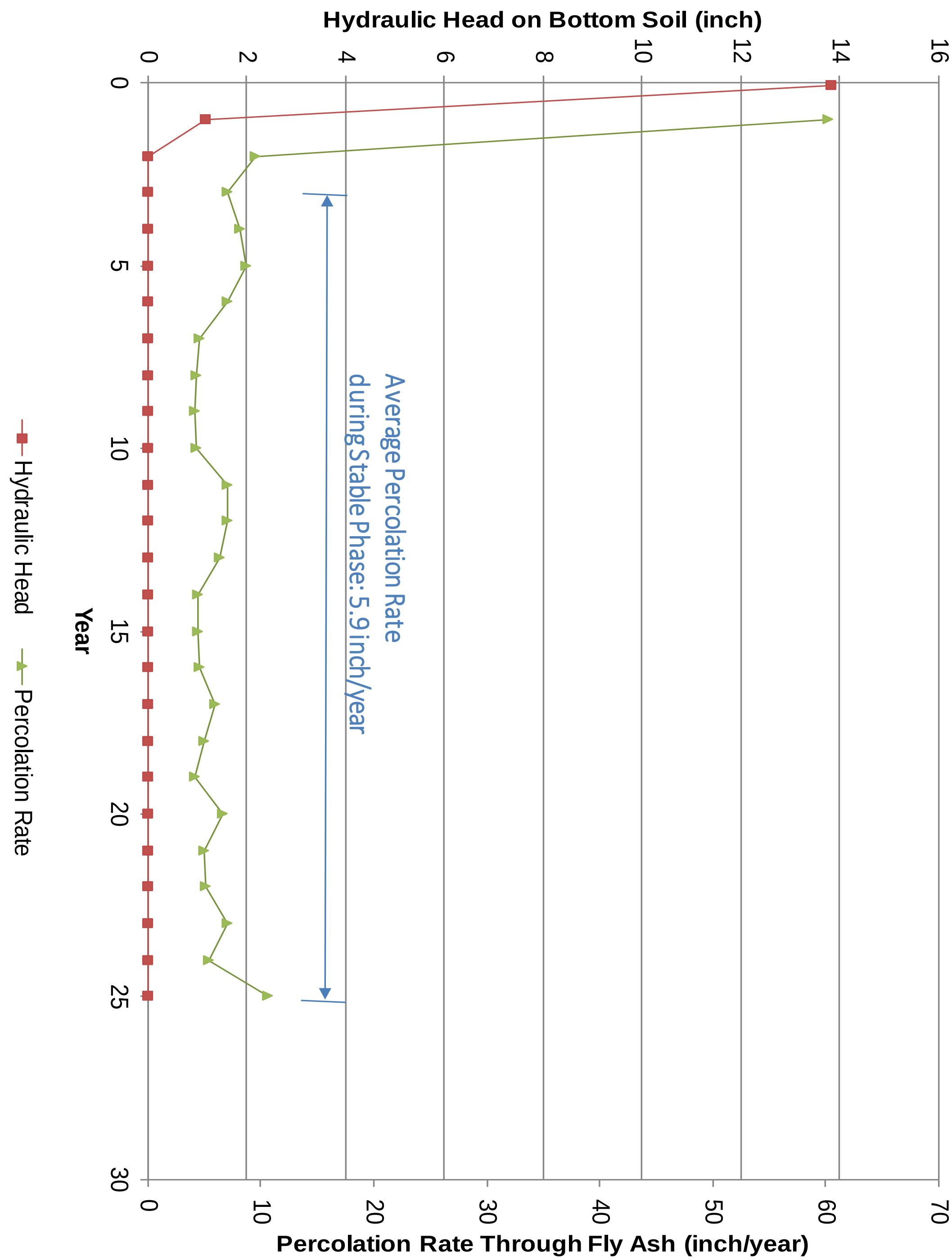
Negligible - Hydraulic head changes within 1 inch and hydrostatic equilibrium can be attained.

Low - Hydraulic head changes within 10 inch and hydrostatic equilibrium can be attained.

Moderate - Hydraulic head changes higher than 10 inch and hydrostatic equilibrium can be attained.

High - Hydrostatic equilibrium cannot be attained.

Figures



PROJECT NO: 2414

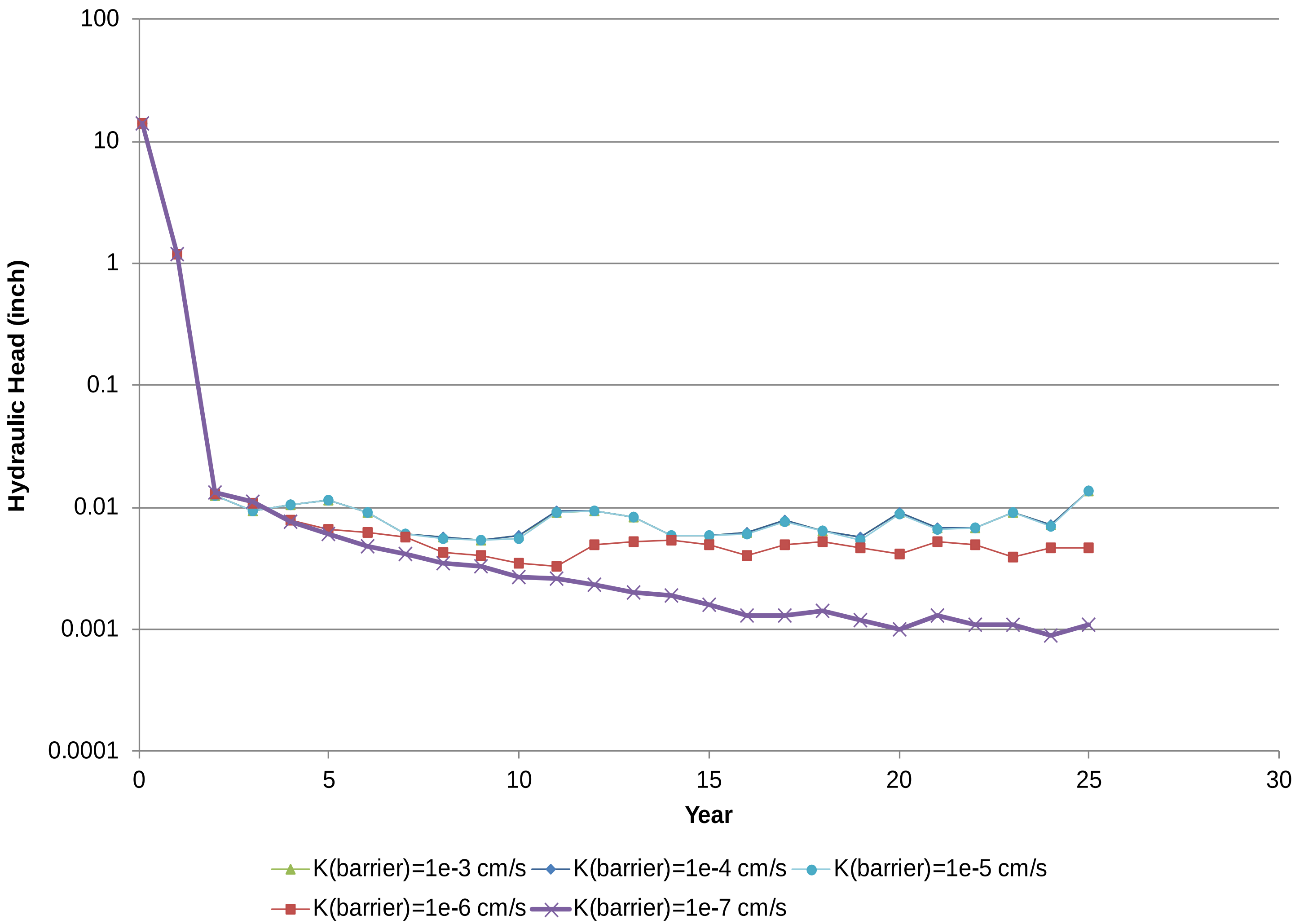
FIGURE NO: 1

Natural Resource Technology
AN OBG COMPANY

Hydraulic Head and Percolation Rate Modeled by HELP

HYDROSTATIC MODELING REPORT
HENNEPIN EAST ASH POND NO. 2
DYNEGY MIDWEST GENERATION, LLC

PREPARED BY/DATE
M_W 07/31/2017
REVIEWED BY/DATE
BGH 09/08/2017



Sensitivity Explanation
Negligible - Hydraulic head changes within 1 inch and hydrostatic equilibrium can be attained.
Low - Hydraulic head changes within 10 inch and hydrostatic equilibrium can be attained.
Moderate - Hydraulic head changes higher than 10 inch and hydrostatic equilibrium can be attained.
High - Hydrostatic equilibrium cannot be attained.

PREPARED BY/DATE
M_W 07/31/2017
REVIEWED BY/DATE
BGH 09/08/2017

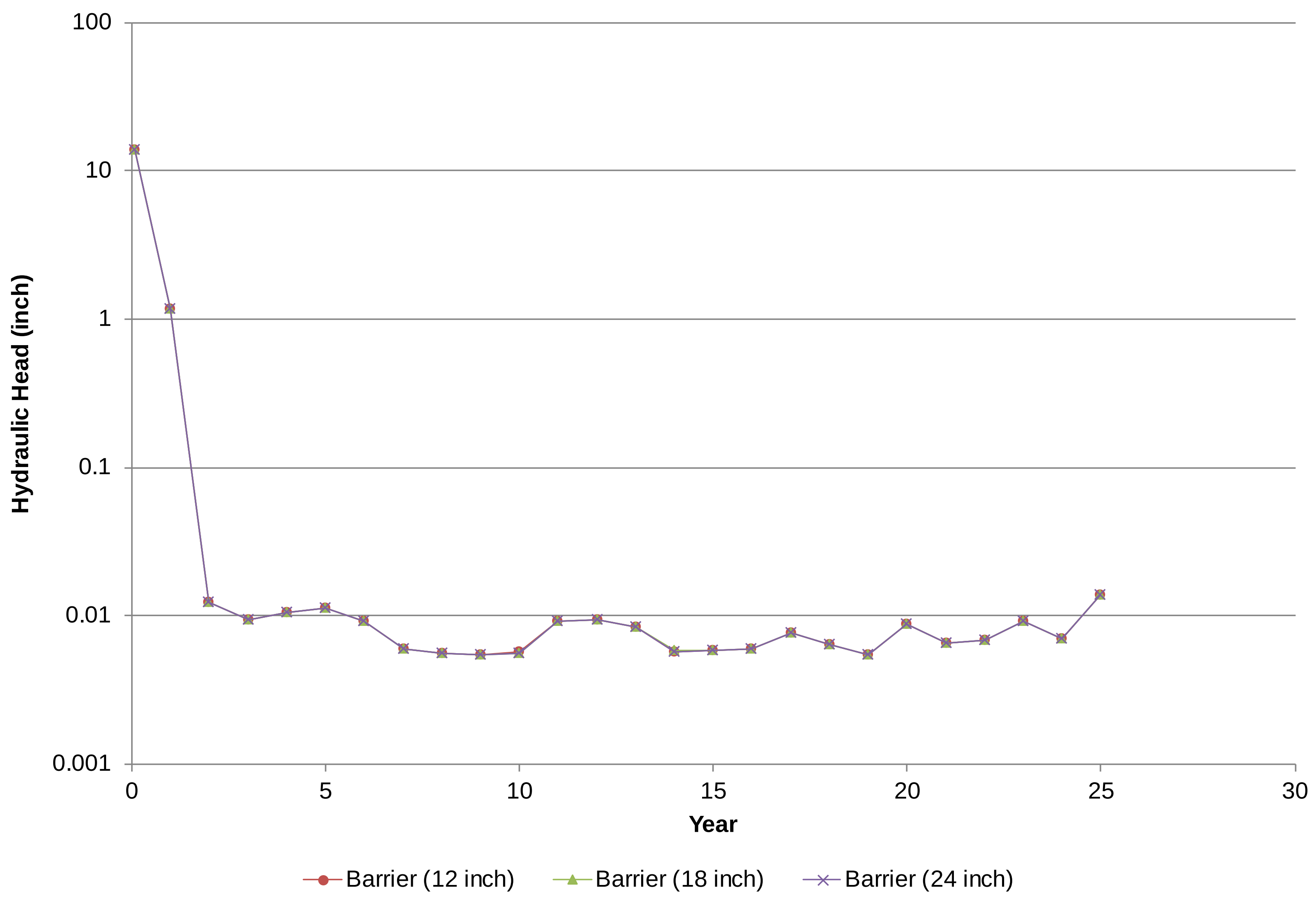
Sensitivity Analysis - Hydraulic Conductivity of Barrier Layer

HYDROSTATIC MODELING REPORT
HENNEPIN EAST ASH POND NO. 2
DYNEGY MIDWEST GENERATION, LLC

PROJECT NO: 2414

FIGURE NO: 2

Natural Resource Technology
AN OBG COMPANY



Sensitivity Explanation
Negligible - Hydraulic head changes within 1 inch and hydrostatic equilibrium can be attained.
Low - Hydraulic head changes within 10 inch and hydrostatic equilibrium can be attained.
Moderate - Hydraulic head changes higher than 10 inch and hydrostatic equilibrium can be attained.
High - Hydrostatic equilibrium cannot be attained.

PREPARED BY/DATE
M_W 07/31/2017
REVIEWED BY/DATE
BGH 09/08/2017

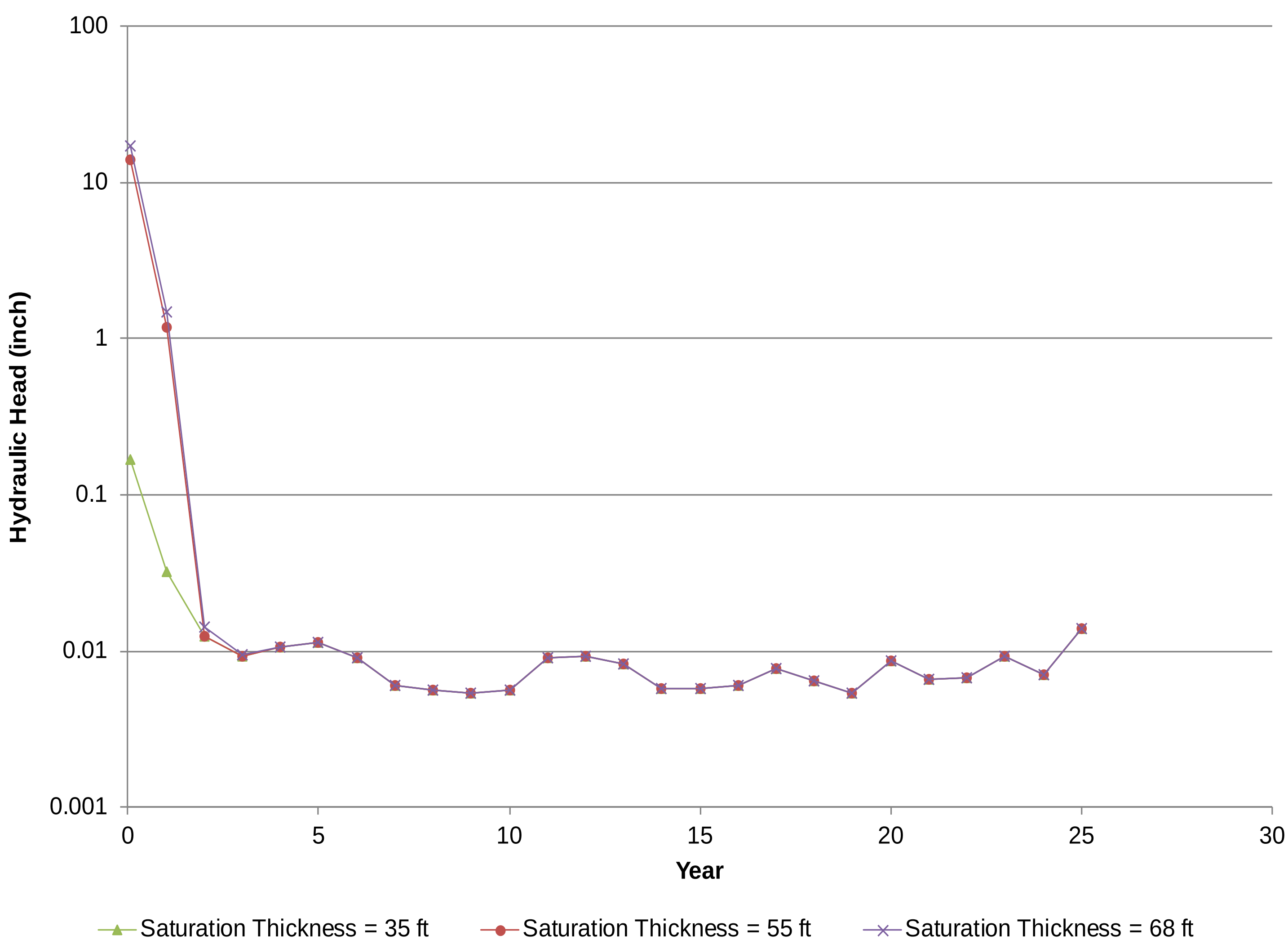
Sensitivity Analysis - Thickness of Barrier Layer

HYDROSTATIC MODELING REPORT
HENNEPIN EAST ASH POND NO. 2
DYNEGY MIDWEST GENERATION, LLC

PROJECT NO: 2414

FIGURE NO: 3

Natural Resource Technology
AN OBG COMPANY



Sensitivity Explanation
Negligible - Hydraulic head changes within 1 inch and hydrostatic equilibrium can be attained.
Low - Hydraulic head changes within 10 inch and hydrostatic equilibrium can be attained.
Moderate - Hydraulic head changes higher than 10 inch and hydrostatic equilibrium can be attained.
High - Hydrostatic equilibrium cannot be attained.

PREPARED BY/DATE
M_W 07/31/2017
REVIEWED BY/DATE
BGH 09/08/2017

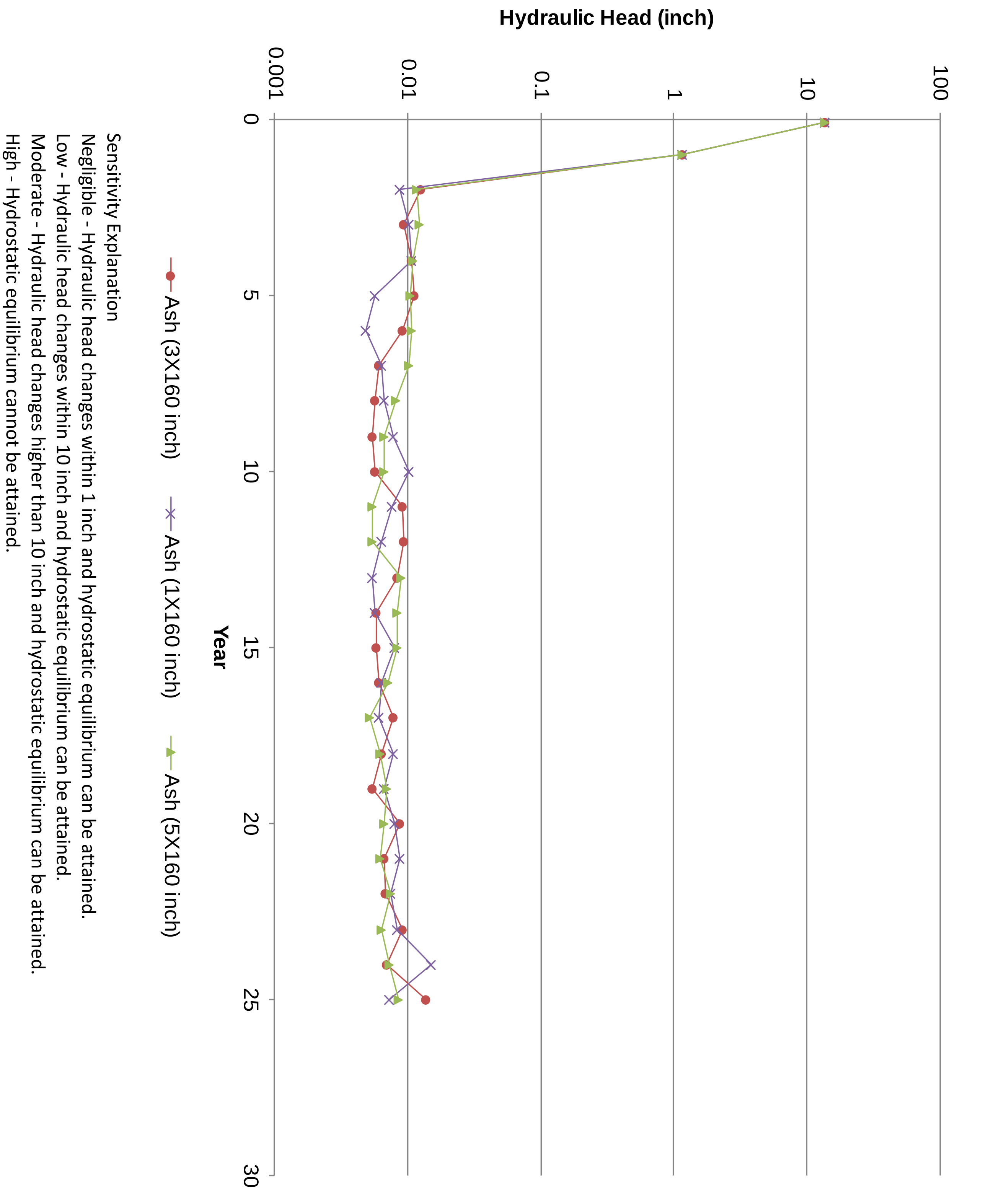
Sensitivity Analysis - Initial Saturation Thickness

HYDROSTATIC MODELING REPORT
HENNEPIN EAST ASH POND NO. 2
DYNEGY MIDWEST GENERATION, LLC

PROJECT NO: 2414

FIGURE NO: 4

Natural Resource Technology
AN OBG COMPANY



PROJECT NO: 2414

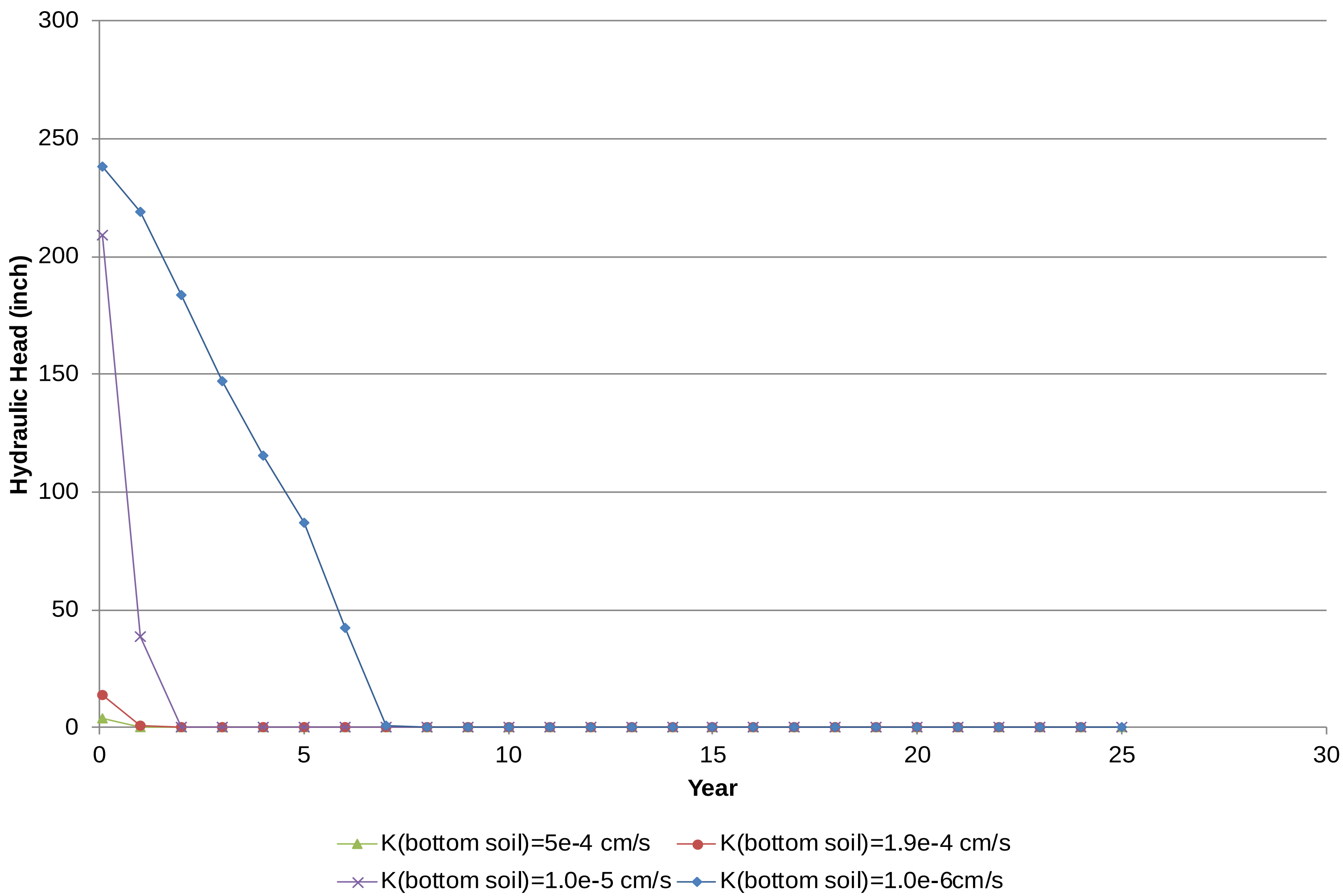
FIGURE NO: 5

Natural Resource Technology
AN OBG COMPANY

Sensitivity Analysis - Thickness of Fly Ash layer

HYDROSTATIC MODELING REPORT
HENNEPIN EAST ASH POND NO. 2
DYNEGY MIDWEST GENERATION, LLC

PREPARED BY/DATE
M_W 07/31/2017
REVIEWED BY/DATE
BGH 09/08/2017



Sensitivity Explanation

Negligible - Hydraulic head changes within 1 inch and hydrostatic equilibrium can be attained.

Low - Hydraulic head changes within 10 inch and hydrostatic equilibrium can be attained.

Moderate - Hydraulic head changes higher than 10 inch and hydrostatic equilibrium can be attained.

High - Hydrostatic equilibrium cannot be attained.

PREPARED BY/DATE
M_W 07/31/2017
REVIEWED BY/DATE
BGH 09/08/2017

Sensitivity Analysis - Foundation Soil Conductivity

HYDROSTATIC MODELING REPORT
HENNEPIN EAST ASH POND NO. 2
DYNEGY MIDWEST GENERATION, LLC

PROJECT NO: 2414

FIGURE NO: 6

Natural Resource Technology
AN OBG COMPANY

Appendix A

HELP Model Files

(on CD)

OBG

THERE'S A WAY

Natural Resource Technology
AN OBG COMPANY

The following are attachments to the testimony of Scott M. Payne, PhD, PG and Ian Magruder, M.S..

ATTACHMENT 26

Guidelines for Evaluating Ground-Water Flow Models

By Thomas E. Reilly and Arlen W. Harbaugh

Abstract

Ground-water flow modeling is an important tool frequently used in studies of ground-water systems. Reviewers and users of these studies have a need to evaluate the accuracy or reasonableness of the ground-water flow model. This report provides some guidelines and discussion on how to evaluate complex ground-water flow models used in the investigation of ground-water systems. A consistent thread throughout these guidelines is that the objectives of the study must be specified to allow the adequacy of the model to be evaluated.

Introduction

The simulation of ground-water flow systems using computer models is standard practice in the field of hydrology. Models are used for a variety of purposes that include education, hydrologic investigation, water management, and legal determination of responsibility. In the most general terms, a model is a simplified representation of the appearance or operation of a real object or system. Ground-water flow models represent the operation of a real ground-water system with mathematical equations solved by a computer program. A difficulty that faces all individuals attempting to use the results of a model is the development of an understanding of the strengths and limitations of a model analysis without having to reproduce the entire analysis.

The primary purpose of this report is to help users of reports that document ground-water flow models evaluate the adequacy or appropriateness of a model. A secondary purpose for this report is to provide for model developers a guide to the information that should be included in model documentation. The information in this report is mainly qualitative. It reflects the views developed by the authors on the basis of over 50 years combined experience with ground-water modeling. The authors have used models, reviewed modeling studies and reports, provided modeling advice, taught modeling courses, and developed computer model programs.

It is important to distinguish among three terms we use to discuss the modeling process: conceptual model, computer model program, and model. A “conceptual model” is the hydrologist’s concept of a ground-water system. A “computer model program” is a computer program that solves ground-water equations. Computer model programs are general purpose in that they can be used to simulate a variety of specific systems by varying input data. A “model” is the application of a computer model program to simulate a specific system. Thus, a model incorporates the model program and all of the input data required to represent a ground-water system. The modeler attempts to incorporate what he or she believes to be the most important aspects of the conceptual model into a model so that the model will provide useful information about the system.

The information provided in this report is generally relevant to all types of ground-water flow model programs; however, the examples cited throughout the report use the model program MODFLOW (Harbaugh and others, 2000).

This report reviews the important aspects of simulating a ground-water flow system using a computer model program and explains the ramifications of various design decisions. An important part of the information necessary for evaluating a model is the intended use of a model, because it is impossible to develop a model that will fulfill all purposes. Further, the intended use must be specific as opposed to general. For example, saying that a model will be used to evaluate water-management alternatives is inadequate. Specific information about the alternatives to be considered also would be necessary. Thus, a consistent thread throughout this report is the need to consider the purpose of a model when evaluating the appropriateness of the model.

Appropriateness of the Computer Model Program

Many computer model programs are available for simulating ground-water systems. Each computer model program can be characterized by the mathematical method used to represent ground-water equations (Konikow and Reilly, 1999), assumptions, and the range of simulation capabilities. For example, the mathematical method in MODFLOW is finite difference in space and time, with backward difference for time. Major assumptions are (1) confined three-dimensional flow with water-table approximations, and (2) principal directions of hydraulic conductivity are aligned with the coordinate axes. A variety of hydrologic capabilities are included, for example, the simulation of wells, rivers, recharge, and ground-water evapotranspiration. There also are simple analytical models that assume homogeneous conditions for one or two dimensions that can be used to solve some problems. The tool or computer model program used can be as simple or as complex as required for the problem, but the method, assumptions, and capabilities must be evaluated to assure that the tool is appropriate and can provide scientifically defensible results.

Questions to be answered in the evaluation of the appropriateness of the modeling program are:

1. Are the objectives of the study clearly stated?
2. Is the mathematical method used in the computer model program appropriate to address the problem?
3. Does the numerical or analytical model selected for use simulate the important physical processes needed to adequately represent the system?

Different Modeling Approaches to Address a Problem

A general-purpose computer model program such as MODFLOW can be used in many ways to address a problem as illustrated in table 1. Approaches to a problem that are commonly used are: calibrated model, hypothetical system model, sensitivity analysis, superposition, and particle tracking. Frequently, several approaches are combined to address a problem.

A Calibrated Model

A model that is "calibrated" is required to address many hydrologic problems. Model calibration in its most limited meaning is the modification of model input data for the purpose of making the model more closely match observed heads and flows. Adjustment of parameters can be done manually or automatically by using nonlinear regression statistical techniques. In the broader meaning of model calibration, parameter adjustment is only one aspect of model calibration. Key aspects of the model, such as the conceptualization of the flow system, that influence the capability of the model to meet the problem objectives also are evaluated and adjusted as needed during calibration. For example, it may be noticed that some of the parameters that result in the best match to observations are not reasonable based on other knowledge of their values. This may indicate that there is a conceptualization problem with the model. Thus, the closeness of fit between the simulated and observed conditions, and the extent to which important aspects of the simulation are incorporated in the model are both important in evaluating how well a model is calibrated. In practice, calibration is conducted differently by each investigator; some examples that discuss calibrated models are Luckey and others (1986), Buxton and Smolensky (1999), and Anderson and Woessner (1992, section 8.3 and 8.4).

The amount of effort that is required in calibrating a ground-water flow model is dependent upon the intended use of the model (that is, the objective of the investigation). Most models of specific ground-water systems that are used to estimate aquifer properties, understand the past, understand the present, or to forecast the future are calibrated by matching observed heads and flows. Determining if the calibration is sufficient for the intended use of the model is very important in evaluating whether the model has been constructed appropriately. (See later section for more on evaluating the adequacy of model calibration.)

A Hypothetical Model

A hypothetical model is a model of an idealized or representative system as opposed to a model of a specific system. In an attempt to understand the basic operation of a ground-water system, the determination of whether to develop a model of a hypothetical idealized system or a model of an actual system greatly affects the amount of data needed to construct the model. Hypothetical models are not calibrated, but input data are frequently adjusted during model development to make the model fit the idealized system or to test how the model responds. The utility of hypothetical models is that the system can be defined exactly and the cause and effect processes under investigation can be clearly identified with minimal cost. The input data needed to define the hypothetical system can be as simple or as complex as required to investigate the processes of interest. No effort is required to collect and interpret data from an actual ground-water system and no uncertainty exists in the ability of the model to represent the system, which results in substantial cost savings compared to making a model of a specific system. Hypothetical models have been used to examine various processes that affect or are affected by ground-water flow, for example: boundary conditions (Franke and Reilly, 1987), contributing areas to wells (Morrissey, 1989; Reilly and Pollock, 1993), and model calibration (Hill and others, 1998).

Sensitivity Analysis

Sensitivity analysis is the evaluation of model input parameters to see how much they affect model outputs, which are heads and flows. The relative effect of the parameters helps to provide fundamental understanding of the simulated system. Sensitivity analysis also is inherently part of model calibration. The most sensitive parameters will be the most important parameters for causing the model to match observed values. For example, an area in which the model is insensitive to hydraulic conductivity generally indicates an area where there is relatively little water flowing. If the model is being calibrated, then changing the value of hydraulic conductivity in this area will

Table 1. Types of problems that may initiate a hydrologic study involving a ground-water flow model.

Problem Type	Reason for Undertaking Study	Approach to Model the Problem
Basic Understanding of Ground-Water System	Investigation of hydrologic processes	• Hypothetical system model • Superposition • Particle Tracking
	Determination of effective data collection network	• Calibrated model • Hypothetical system model • Superposition • Sensitivity analysis
	Preliminary model to determine current level of understanding	• Calibrated model • Hypothetical system model • Superposition • Sensitivity analysis
Estimation of Aquifer Properties	Aquifer test analysis	• Calibrated model • Superposition
	Determination of aquifer properties	• Calibrated model
Understanding the Past	Understanding historical development of an aquifer system	• Calibrated model
	Estimation of predevelopment conditions	• Calibrated model
Understanding the Present	Determination of the effect of ground-water pumpage on surface-water bodies	• Calibrated model • Superposition • Particle Tracking
	Determination of sources of water to wells	• Calibrated model • Particle Tracking
	Determination of responsible parties causing impacts on the system	• Calibrated model • Particle Tracking
Forecasting the Future	Management of a system	• Calibrated model • Superposition • Particle Tracking

not help much in causing the model to match observations. The calibration will not provide much certainty about the value of the parameter, but the uncertainty will not matter provided the model is not used in situations where large amounts of water will flow in that area. Such a model, however, would probably not be suitable for evaluation of recharge or withdrawal in this area because the amount of flow in the area would be much greater than it was when the model was calibrated, and the uncertainty from the calibration would be unacceptable. Anderson and Woessner (1992, p. 246-257) provide some examples of sensitivity analyses.

Sensitivity analysis can be conducted manually or automatically. In the manual approach, multiple model simulations are made in which ideally a single parameter is adjusted by an arbitrary amount. The changes to the model output for all of the parameter changes may be displayed in tables or graphs for evaluation. The automatic approach directly computes parameter sensitivity, which is the change in head or flow divided by the change in a parameter. Automatic sensitivity analysis is inherently part of automatic parameter adjustment for model calibration. The automatic parameter adjustment algorithm uses parameter sensitivity to compute the parameter values that cause the model to best match observed heads and flows.

Superposition

Superposition (Reilly and others, 1987) is a modeling approach that is useful in saving time and effort and eliminating uncertainty in some model evaluations. Models that are designed to use superposition evaluate only changes in stress and changes in responses. Most aquifer tests that analyze drawdown use superposition. Only the change in heads (the drawdown) and change in flows are analyzed, which assumes the response of the system is only due to the stress imposed and is not due to other processes in the system. The absolute value of the head and a quantification of the actual regional flows are not needed. In the past, superposition was frequently used with analog model analysis of ground-water systems because electrical simulation of areal stresses and boundary conditions was extremely difficult. As modern numerical computer models made simulation of all stress conditions easier, superposition was used less frequently in areal models. If the problem to be solved involves only the evaluation of a change due to some change in stress, however, the application of superposition can greatly simplify the data needs for model development. Superposition is strictly applicable to linear problems only, that is, constant saturated thickness and linear boundary conditions. If the system is relatively linear, however, for example the saturated thickness does not change by a significant portion (no absolute guidance can be given, but some investigators have used a 10 percent change in thickness as a rule of thumb), superposition can still provide reasonably accurate answers. Currently, superposition is used primarily in the simulation of aquifer tests, in that only changes due to the imposed change in stress (that is, the well discharge) are simulated and zero drawdowns are specified as the initial and boundary conditions; example simulations are presented in Prince and Schneider (1989) and McAda (2001).

Particle Tracking

Particle tracking (Pollock, 1989) is the determination of the path a particle will take through a three-dimensional ground-water flow system. The determination of the paths of water in the flow system aids in conceptualizing and quantifying the sources of water in a modeled system. For example, Buxton and others (1991) used particle-tracking analysis to determine recharge areas on Long Island, New York, and Modica and others (1997) made use of particle tracking in the context of a ground-water flow model to understand the patterns and age distribution of ground-water flow to streams of the Atlantic Coastal Plain. Although particle tracking is useful in determining advective transport, this report does not address the use of models to determine transport of chemicals, but rather refers to the approach of using particle tracking to understand the flow system.

Spatial and Temporal Approaches

In addition to the overall modeling approaches discussed above, many model programs can be used in one, two, or three dimensions, and they can be applied as transient or steady state. The simplification of the model domain to one or two dimensions, either in plan view or cross section, is used to minimize the cost of constructing a model. The simplification of the system to one or two dimensions, however, must be consistent with the flow field under investigation and consistent with the objectives of the study. Consistent with the flow field, means that there is no or negligible flow orthogonal to the line or plane of the one- or two-dimensional system being simulated.

Steady-state models are used widely, although true steady-state conditions do not exist in natural systems. All natural systems fluctuate in response to climatic variations that can be seasonal, annual, decadal or longer. In steady-state models, an assumption is made that a system can be represented by a state of dynamic equilibrium or an approximate equilibrium condition. If the objectives of the investigation do not require information on the time it takes for a system to respond to new stresses or the response of the system between periods of relative equilibrium, then simulation of the system as a steady-state system may be a reasonable approach. However, if the system is not at a period of equilibrium or approximate equilibrium during the periods of interest, then a transient analysis is required.

Questions to be answered in the evaluation of the appropriateness of the modeling approach to analyze the problem are:

1. Is the overall approach (calibrated model, hypothetical system model, sensitivity analysis, superposition, and particle tracking) for using simulation in addressing the objectives clearly stated and appropriate?
2. If the analysis is not three dimensional, is the representation of the system using one or two dimensions appropriate to meet the objectives of the study and justified in the report?
3. If the model is steady state, is adequate information provided to justify that the system is reasonably close to a steady-state condition?

Models of ground-water systems may be very different in their level of complexity. Whether the model design and approach are appropriate for the problem being investigated must be evaluated. This evaluation requires a clear statement of the problem to be investigated and the modeling approach. A further requirement is an understanding of the model design. The remainder of this report focuses on specific aspects of model design that should be examined in determining the worth of a particular model. These aspects are: discretization and representation of the hydrogeologic framework, boundary conditions, initial conditions, accuracy of the numerical solution, and accuracy of calibration for the intended use of the model.

Discretization and Representation of the Hydrogeologic Framework

A fundamental aspect of numerical models is the representation of the real world by discrete volumes of material. The volumes are called cells in the finite-difference method, and the volumes are called elements in the finite-element method. The accuracy of the model is limited by the size of the discrete volumes. Further, for transient models, time is represented by discrete increments of time called time steps in most model programs. The size of the time steps also has an impact on the accuracy of a model. The issue of the size of the discrete volumes and time steps is discussed for the finite-difference method.

Cell Size

The size of cells determines the extent to which hydraulic properties and stresses can vary throughout the modeled region. Hydraulic properties and stresses are specified for each cell, so the more cells in a model, the greater the ability to vary hydraulic properties and stresses. If the cell size is too large, important features of the framework may be left out or poorly represented. Accordingly, it is important to evaluate the known (or assumed) variation of hydraulic properties and stresses of the system being simulated compared to the size of the cells. For example, the differences in the representation of a confining unit in a regional ground-water flow model and a sub-regional model of Long Island, New York (Buxton and Reilly, 1987) are substantial (fig. 1), and the locations where the clay is absent is much better represented at the finer scale. In a parallel sense, the representation of the streams and shoreline are different depending on the scale (fig. 2). The intended use of the model and the importance of the features being discretized affect both the evaluation of whether the model is discretized appropriately and whether important features are missing that would cause a systematic error or bias in the simulation results.

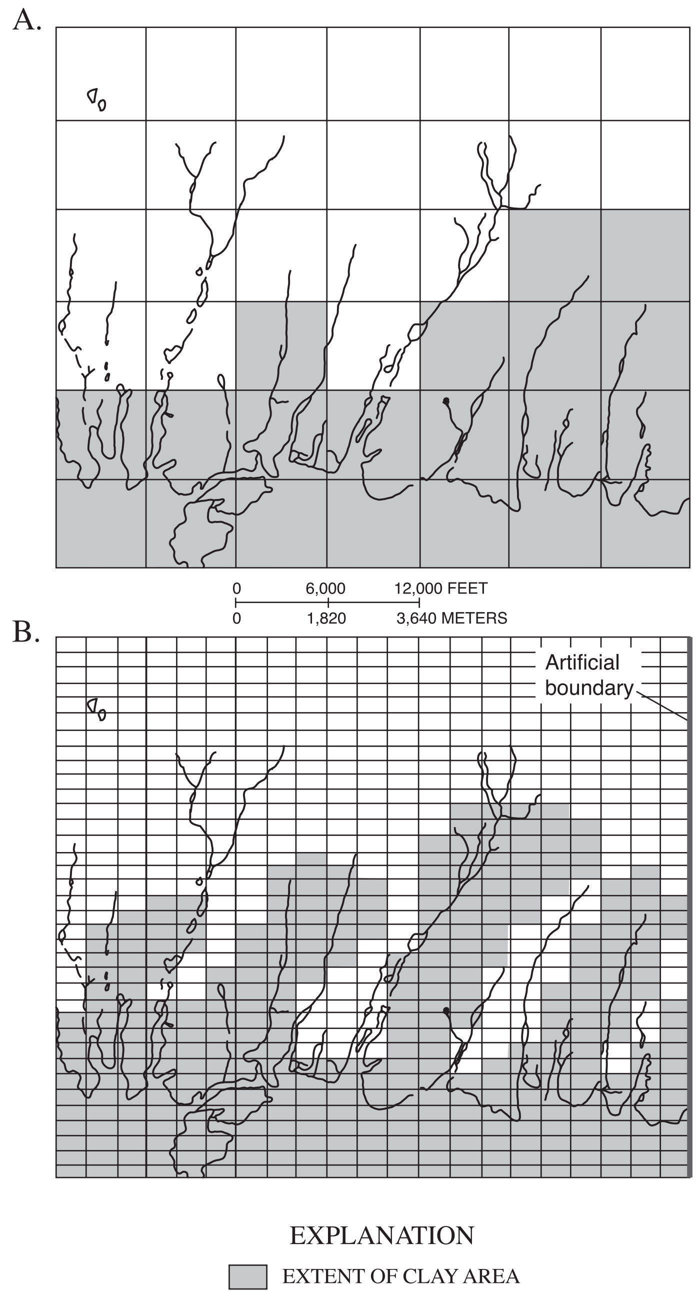


Figure 1. Extent of the south-shore confining unit on Long Island, New York, (A) as represented in a regional ground-water flow model grid, and (B) as represented in a sub-regional ground-water flow model grid. (Modified from Buxton and Reilly, 1987.)

Figure 3 shows the difference in simulated drawdown when different cell sizes are used to simulate pumping from two wells in a one-layer model. The 3,300 ft by 3,300 ft system is confined with a uniform transmissivity of 10,000 ft^2/d. No-flow boundaries surround all sides except the northern boundary, which has a specified head of 0 ft. The wells are 200 ft apart, and each is pumped at a constant rate of 100,000 ft^3/d. Figure 3A shows drawdown with a grid spacing of 300 ft. With this grid spacing, the two wells are located in a single cell, so the model "sees" the two wells as a single well pumping at 200,000 ft^3/d. Figure 3B shows the same system using a 100-ft grid spacing; this spacing allows each well to be represented separately. Both grids result in nearly identical drawdown for distances greater than 500 ft from the wells, but the drawdown is quite different close to the well.

Continuity of geologic deposits can be disrupted when cells are too large; for example, isolated cells, unintended holes in confining units, and breaks in channels with high conductivity can occur. An example of this is shown in figure 4 where a high hydraulic-conductivity channel becomes discontinuous when discretized with finite-difference cells that are too large to accurately define the important feature of the framework. The effect of the high hydraulic-conductivity channel is not adequately represented in a model with this discretization because it is not represented as a channel but rather as a set of discontinuous pockets of high hydraulic conductivity.

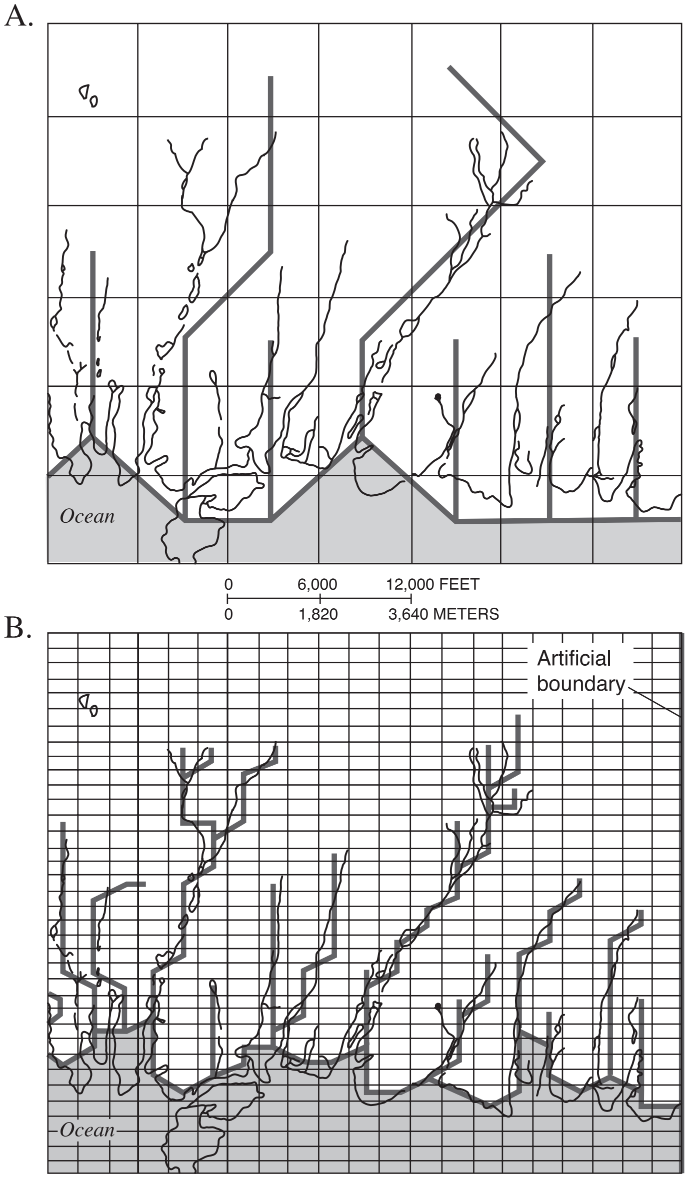


Figure 2. Representation of stream and shoreline boundaries on Long Island, New York, (A) as represented in a regional ground-water flow model grid, and (B) as represented in a sub-regional ground-water flow model grid. (Modified from Buxton and Reilly, 1987.)

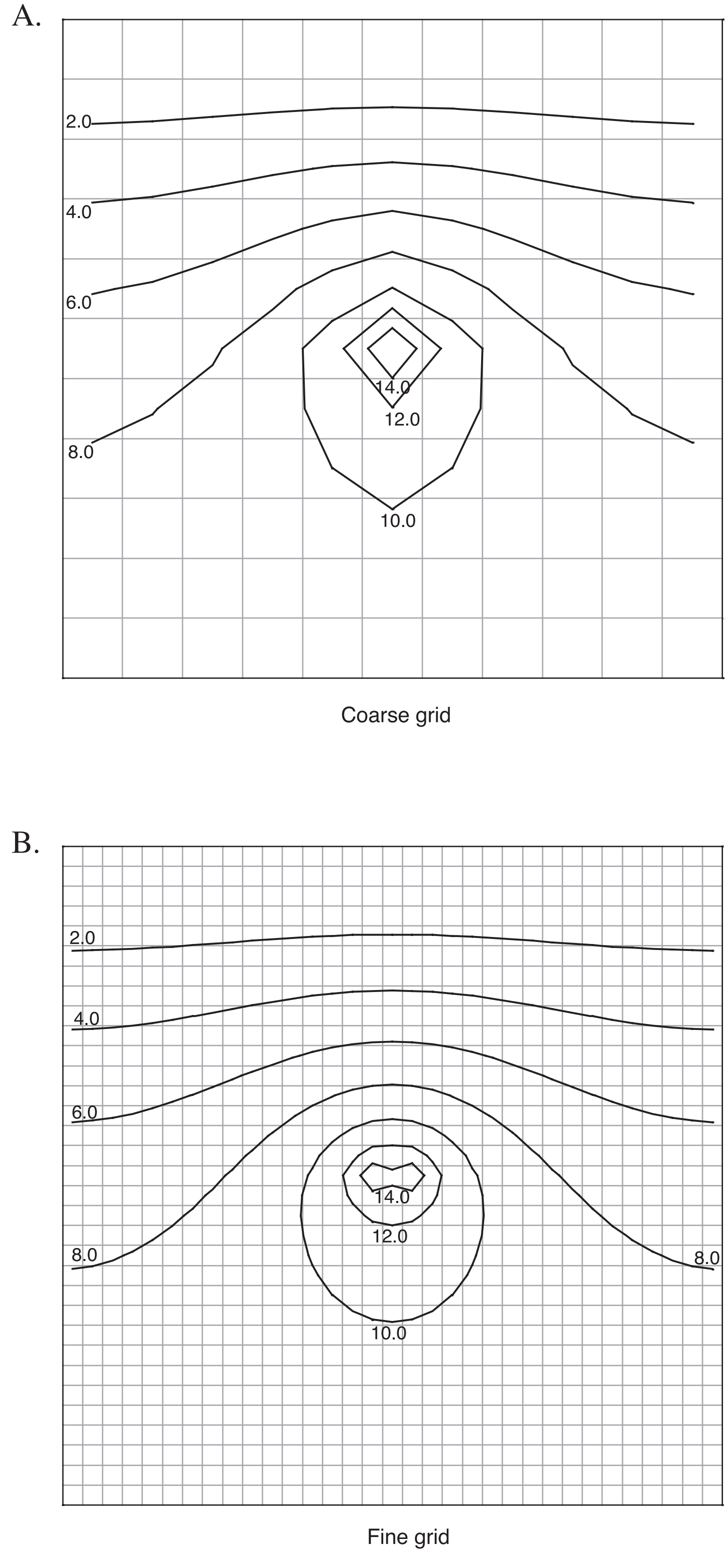


Figure 3. Simulated drawdown from two wells using different grid spacings.

Further, selecting a cell size that is just adequate to represent the variation of hydraulic properties and stresses generally is inadequate. A change in a property or stress in a system has an effect on the computed head some distance away. A complex distribution of hydraulic properties and stresses results in a complex head distribution. Many cells are needed to simulate a complex head distribution because the finite-difference method computes a single value of head for each cell. Many single values are required to approximate a complex distribution. Thus, it is important to incorporate a sufficient number of cells to allow the complexity of head distribution to be simulated. A simple example is shown in figure 5. A system is simulated with two different grid spacings, as described for figure 3, except that a single well pumping 200,000 ft^3/d is being simulated. The figure shows a cross section of head along the row containing the well. The head distribution is most complex near the well, and accordingly, there is noticeable difference in drawdown for the two grid spacings near the well. If accuracy of head near the well is not important to the problem, then the coarse grid is probably acceptable. But, if accuracy is needed near the well, then the finer grid would be necessary.

Some of the examples in this report have used uniform horizontal grid spacing; however, finite-difference models generally allow the widths of rows and columns to vary, which is called variable grid spacing. The use of variable grid spacing allows some flexibility to make cells smaller in some areas and coarser in other areas. Another approach to allowing cell sizes to vary, called telescopic refinement, is to couple a finer grid model to a subregion of a coarser grid model. This approach can avoid having the elongated cells, which are characteristic of using variable grid spacing. An approach for implementing telescopic refinement with MODFLOW is documented in Leake and Claar (1999).

In the vertical direction, two approaches commonly are used to represent the hydrogeologic framework in the model—uniform model layers (a rectilinear grid) and deformed model layers (fig. 6). Deformed model layers allow horizontal

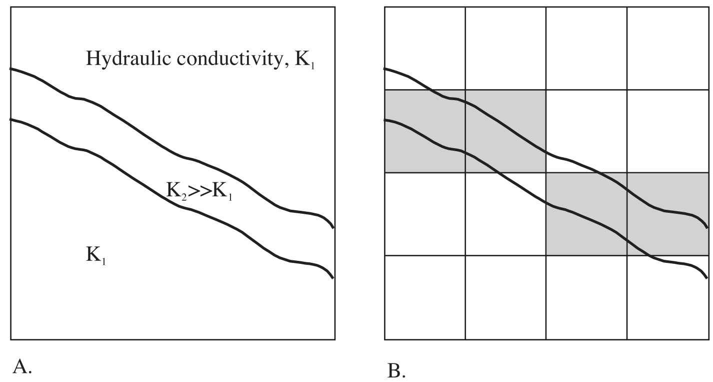


Figure 4. Large finite-difference cells may be inadequate to represent some important features of a ground-water system. (A) Map of the distribution of horizontal hydraulic conductivity showing a channel of high hydraulic conductivity. (B) Finite-difference cells representing the high hydraulic-conductivity channel are no longer continuous, because there is no direct connection between diagonal cells in the finite-difference method.

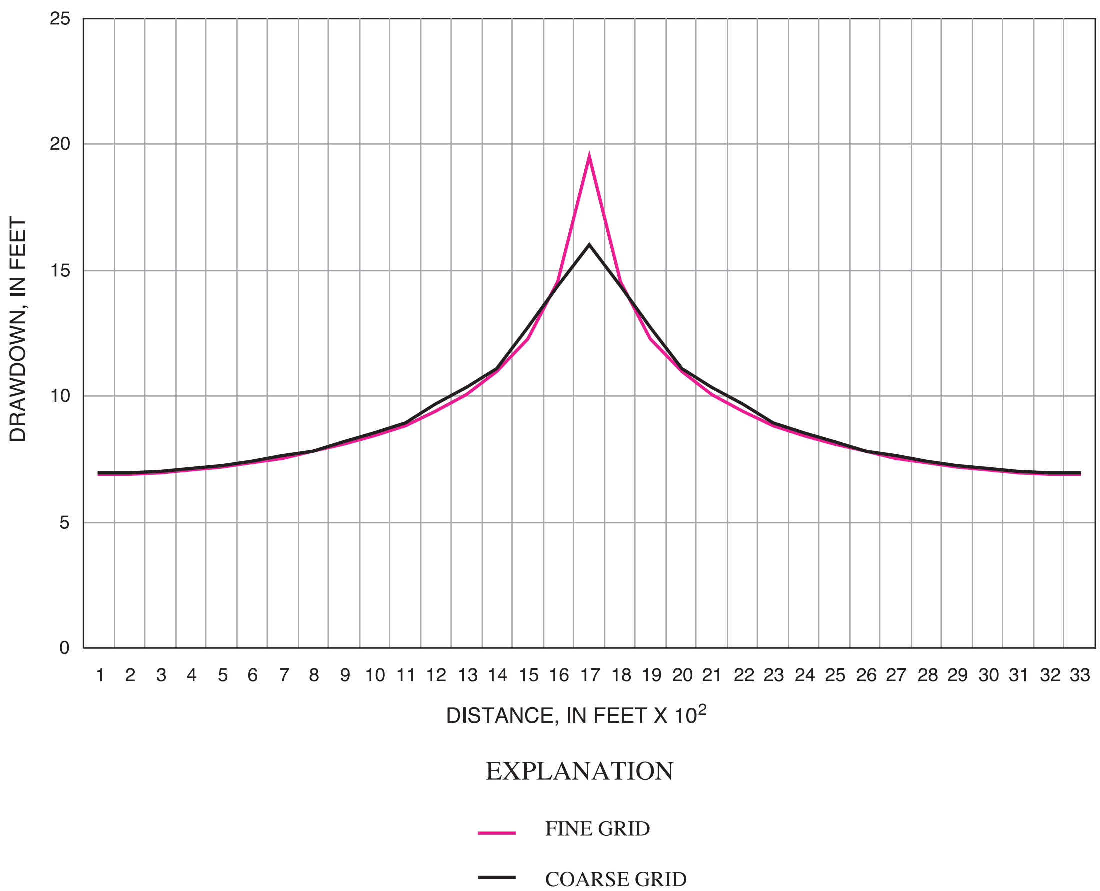


Figure 5. Cross section of drawdown showing the effect of grid spacing.

continuity to be maintained with fewer cells at the expense of introducing some error in the finite-difference method. As examples, the discretization of the geologic framework into uniform model layers was used in the simulation of ground-water flow on Cape Cod, Massachusetts as shown in figure 7 (modified from Masterson and others, 1997), and the discretization of the geologic framework by deformed or hydrogeologic model layers was used in the simulation of ground-water flow on Long Island, New York as shown in figure 8 (modified from Buxton and others, 1999).

A two-dimensional (single-layer) model and a three-dimensional (eight-layer) model of Cape Cod, Massachusetts, provide an example of the effect of vertical discretization on model results. The number of layers used to discretize the aquifer affects the resultant flow field and estimation of the area contributing recharge to pumping wells. The ground-water flow system in the example consists of a thick (250–500 ft) multilayered sequence of unconsolidated deposits or materials that range in grain size from gravel and sand to silt and clay and includes numerous overlying ponds and streams and variable

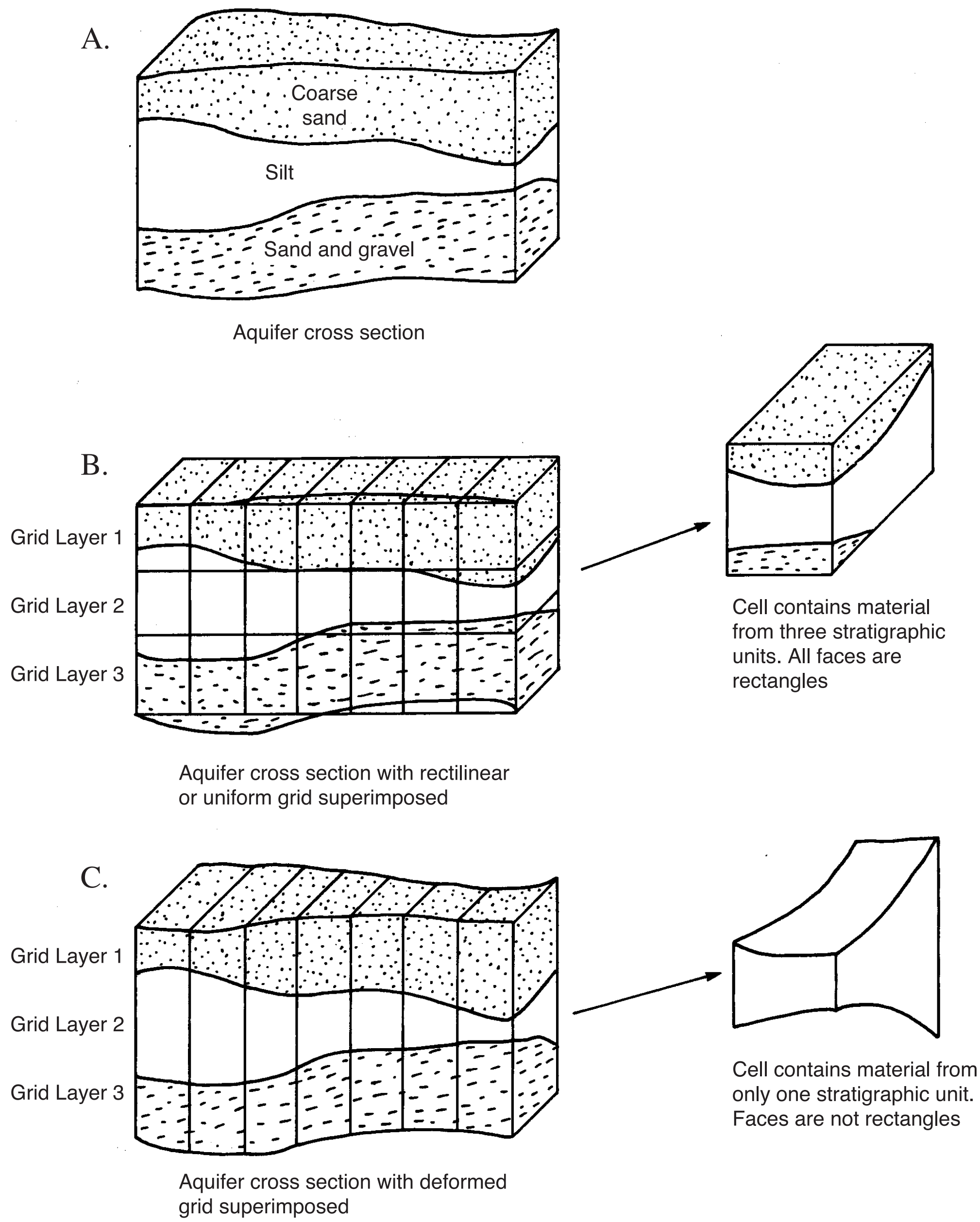


Figure 6. Schemes of vertical discretization for (A) aquifer cross section, (B) aquifer cross section with rectilinear or uniform grid superimposed, and (C) aquifer cross section with deformed grid superimposed.

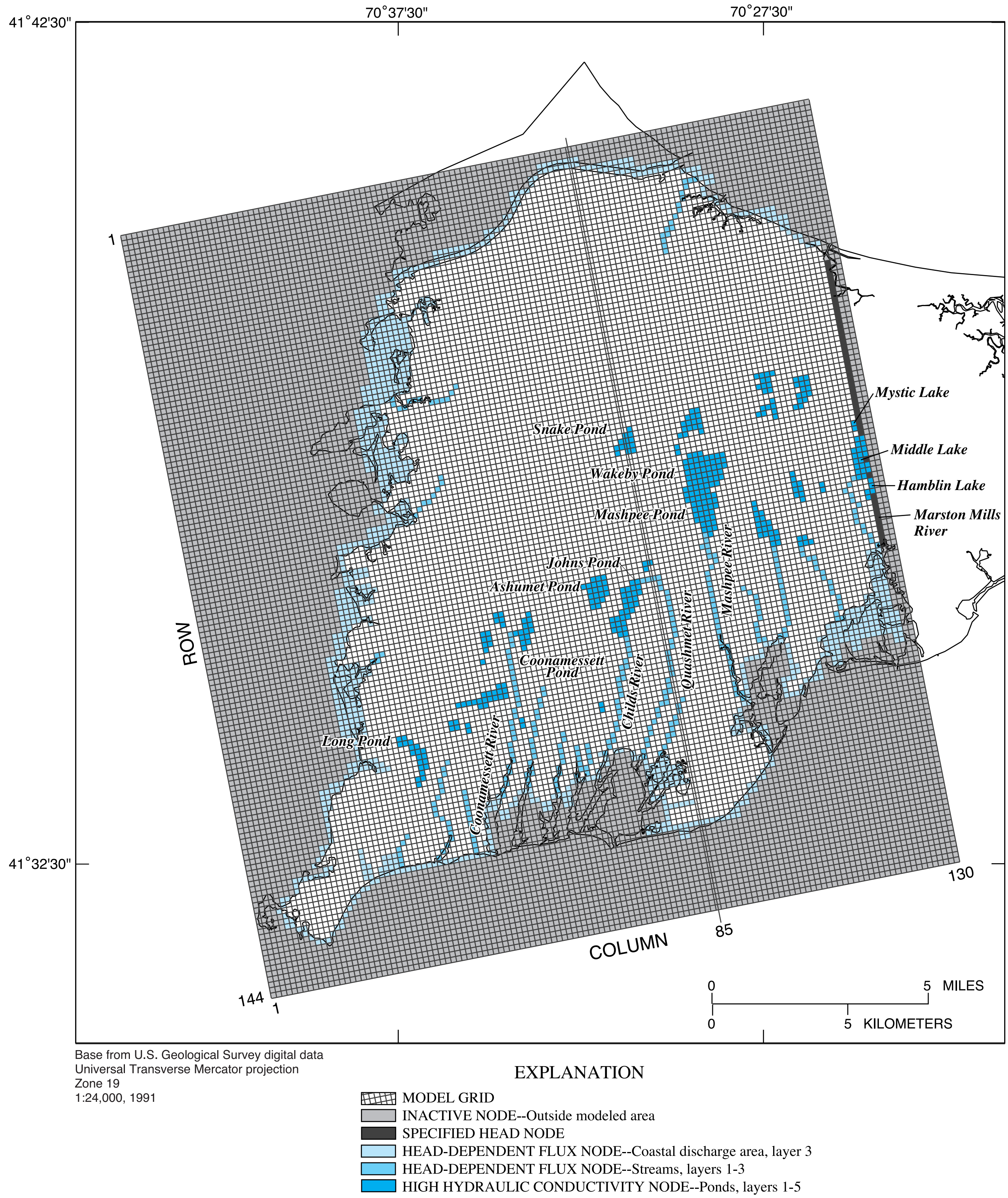


Figure 7A. Horizontal and vertical discretization using uniform layers for the model simulating ground-water flow on Cape Cod, Massachussetts. Horizontal grid. (Modified from Masterson and others, 1997.)

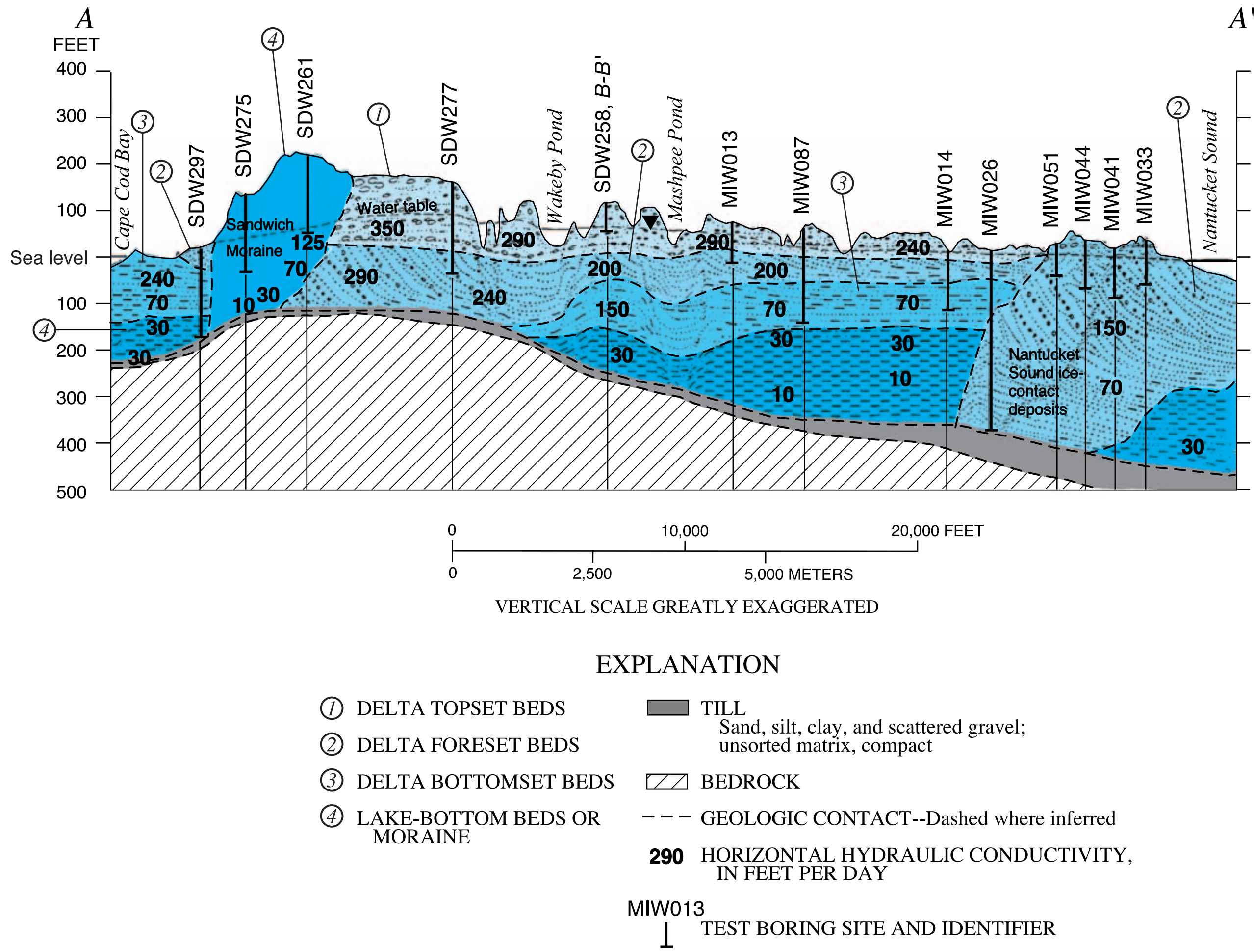


Figure 7B. Horizontal and vertical discretization using uniform layers for the model simulating ground-water flow on Cape Cod, Massachussetts. Hydrogeologic cross section near column 85. (Modified from Masterson and others, 1997.)

recharge rates from precipitation. More than 30 public-supply wells, screened at various depths, withdraw water from the system at widely differing rates. The three-dimensional model was developed first and then simplified into a two-dimensional model that was calibrated independently; consequently, the total transmissivities of the two models are not identical. The contributing recharge areas for the two-dimensional model and three-dimensional model (fig. 9) are different, however, even though both models represent the flow field on Cape Cod, Massachusetts. In the two-dimensional model (fig. 9A), the contributing areas are fairly typical of the simple ellipsoidal shapes that are delineated by two-dimensional analytical and numerical modeling techniques. In comparison, however, the shapes of the contributing recharge areas using the multilayer three-dimensional model (fig. 9B) are more complex (Barlow, 1994; Franke and others, 1998).

In evaluating a ground-water flow simulation, the proper or sufficient discretization is not straightforward to determine. Enough detail is required to represent the hydraulic properties, stresses, and complexities of the flow field for the objectives of the study; yet, the cost will be less if the model is kept as simple as possible so that data entry, computer resources, and analysis of model output are as minimal as possible. Thus, the determination of the proper discretization is always a compromise. Ideally, the modeler would test the effect of grid spacing on a model to help determine the optimal grid spacing; however, the authors have not seen this done with any frequency. The model documentation should justify the discretization that is used.

Specifying Properties of Cells

A second aspect of representing the hydrogeologic framework is the choice of the hydraulic properties assigned to the cells. When simulating an actual system (as opposed to a hypothetical system), the properties of a system are generally not known at every cell in the grid; therefore, interpolation from limited real-world data must be done. Given the uncertainty of knowledge of the distribution of hydraulic properties, groups of cells are sometimes given a uniform value rather than attempting to define an individual value for every cell. Interpolation schemes, such as distance weighting and various geostatistical

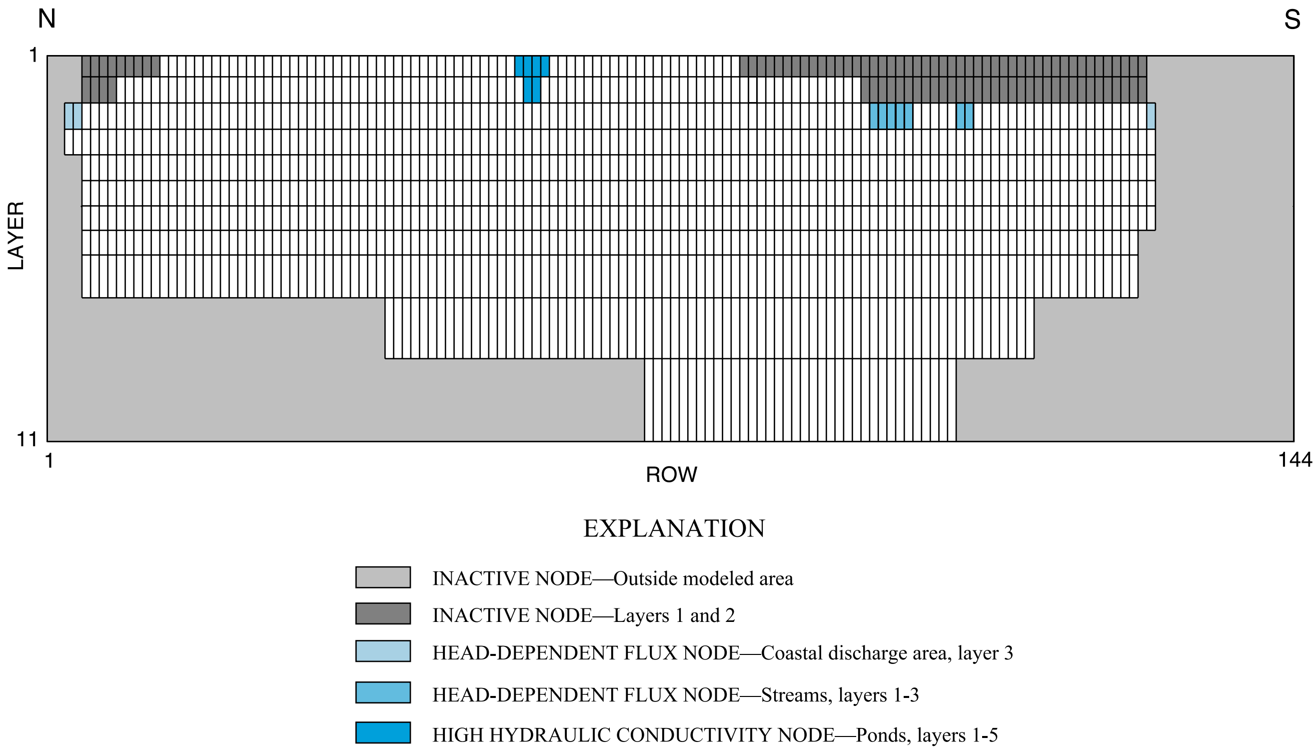


Figure 7C. Horizontal and vertical discretization using uniform layers for the model simulating ground-water flow on Cape Cod, Massachussetts. Vertical grid using uniform layers along column 85. (Modified from Masterson and others, 1997.)

methods, also are used. The user of a model should evaluate the appropriateness of the interpolation scheme. To make such evaluation possible, the model documentation should specify the interpolation method used and include the rationale for using that interpolation method.

Three examples of interpolated hydraulic conductivity data for a hypothetical system are shown in figure 10. All three examples are based upon the assumption that values are known (presumably from aquifer tests) at four points. Figure 10A shows the use of the nearest-neighbor method. For every cell, the data point that is closest to the center of a cell is used as the cell value. An even simpler approach would be to use a single value for all the cells that is the average of the four known values. This simpler approach could be justified if the known values are not considered to be accurate. Figure 10B shows grid values determined by using a weighted average of the four known values based on the inverse distance squared from the center of a cell to the four points. Finally, figure 10C shows grid values determined from the hydraulic conductivity of the two adjacent contours. The value for a cell is the distance-weighted average of the two contour values. Contours were drawn based on the four known points plus additional geologic information about the types of sediments throughout the area (which was made up for this example). The three distributions shown in figure 10 differ significantly even though they are all based on the same four data points. There are many other methods available for interpolation that would each produce different parameter distributions.

The authors are aware of only one general guideline to help determine the best interpolation method to use in a particular situation. This guideline states that it is best to use the simplest interpolation method that is consistent with the known data. The rationale for this guideline is that unwarranted complexity in the discretized values builds a bias into a model that affects all future use. Ideally the model developer would evaluate the importance of the interpolation method by testing different methods and comparing the effect on model results. Such testing is not always practical depending on the resources available for model development.

The chosen interpolation method is often implemented by a computer program. The model documentation should reference the program that is used. Some model programs incorporate interpolation capabilities. For example, the Hydrogeologic-Unit Flow (HUF) Package (Anderman and Hill, 2000) in MODFLOW vertically averages hydraulic properties for cells based on real-world geometry of hydrogeologic units.

The discretization of the storage properties of the ground-water system has some intricacies of its own. The two main types of aquifer storativity are confined storage (specific storage) and unconfined storage (specific yield). Unconfined storage is related to the release of water as the water table lowers (dewatering of the aquifer material); thus, it occurs only along the top boundary of the saturated flow system. Confined storage is related to the release of water as the head drops because of expansion of the water itself as the pressure changes and changes in the solid framework of the aquifer (no dewatering

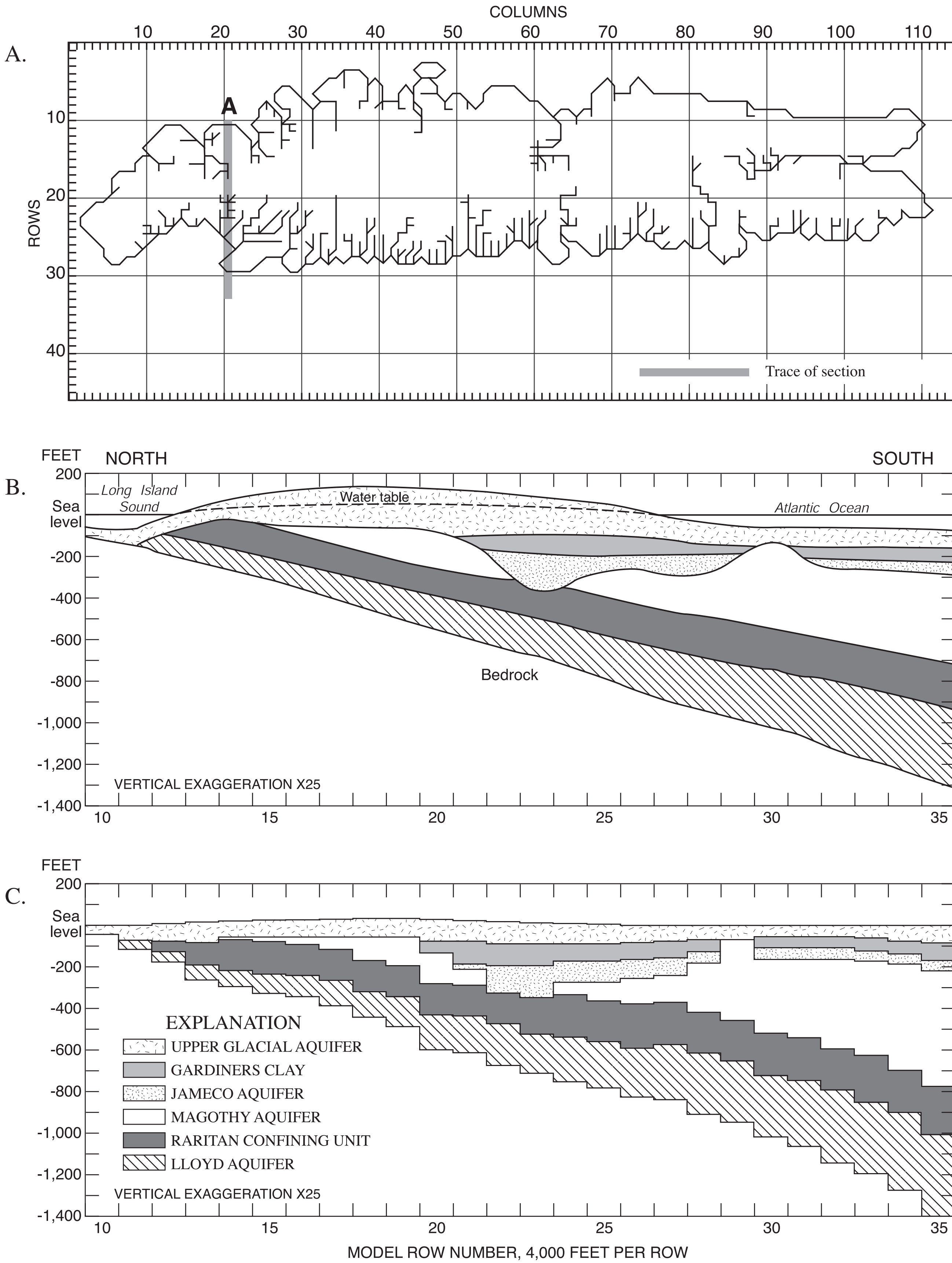


Figure 8. Horizontal and vertical discretization using deformed layers for the model simulating ground-water flow on Long Island, New York: (A) horizontal grid, (B) hydrogeologic cross section, and (C) vertical grid using deformed layers. (Modified from Buxton and others, 1999.)

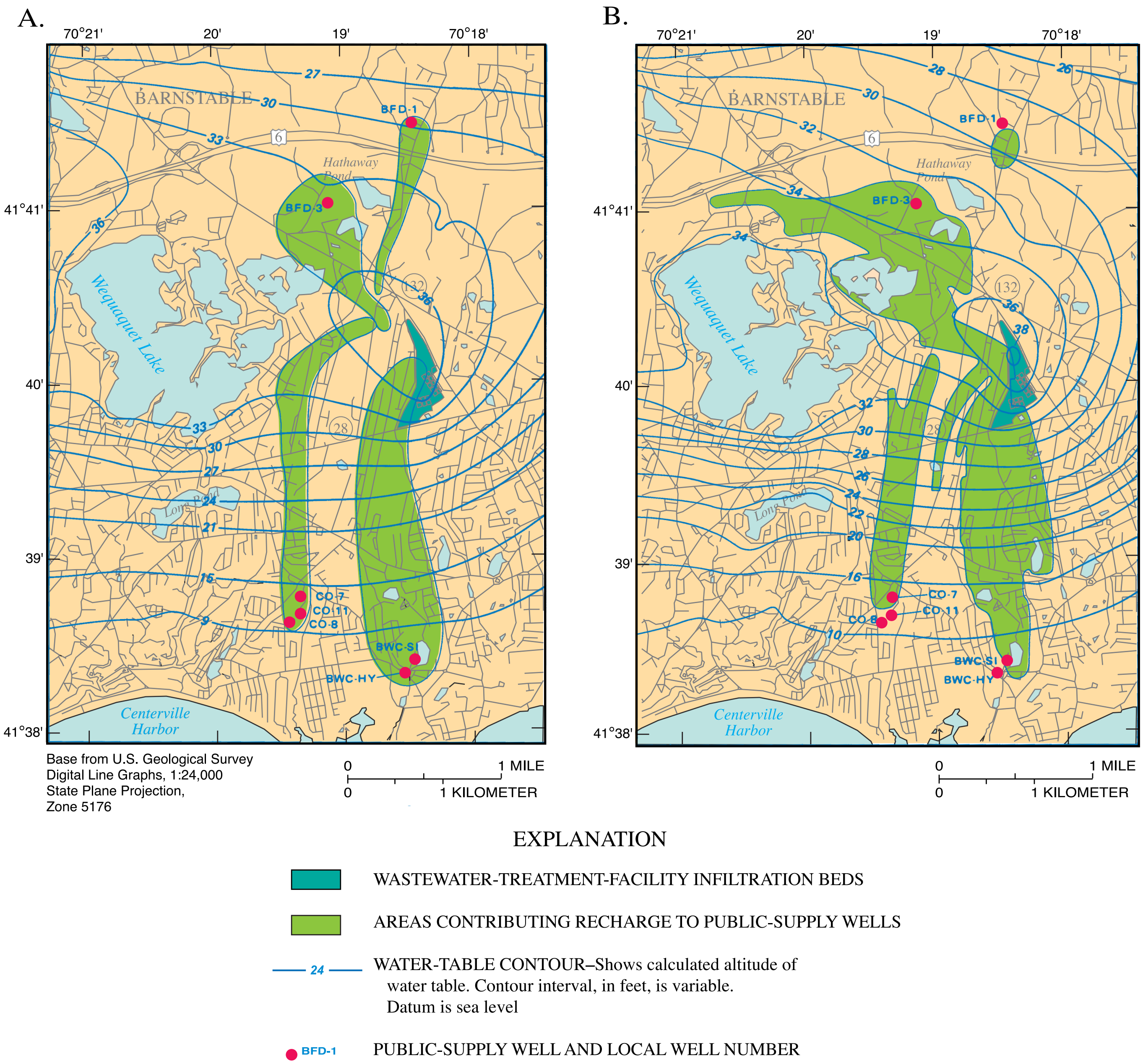


Figure 9. Comparison of areas contributing recharge to seven public-supply wells as determined by two different numerical models, Cape Cod, Massachusetts: (A) results from a two-dimensional single-layer model, and (B) results from a three-dimensional eight-layer model. (Modified from Barlow, 1994; and Franke and others, 1998.)

occurs). In simulating the changes in storage for transient systems, it is important that the unconfined storage occurs only at the top boundary (or top active layer), even if the water-table aquifer is divided into many layers. Some model programs, such as MODFLOW, control which storage coefficient is used based on the layer geometries and heads, thus ensuring that the proper (either the specific storage or the specific yield) coefficient is used. Other model programs require the user to specify the coefficient for each cell. Some investigators have erroneously specified specific yield for all layers in an unconfined aquifer, when it should be specified only for the uppermost active layer, causing incorrect quantities of water to be simulated from storage. Thus, care must be taken in determining if the proper storativity is simulated in a model.

Models that simulate a water table also can have a uniqueness problem related to the representation of the hydrogeologic framework by discrete volumes. Ground-water model programs such as MODFLOW allow cells representing the water table to go dry (desaturate) so that ground-water flow is not simulated in those cells. Cells also can convert from dry to wet in some situations. Cell wetting and drying depends on a variety of factors such as initial conditions, the iterative solution process, and

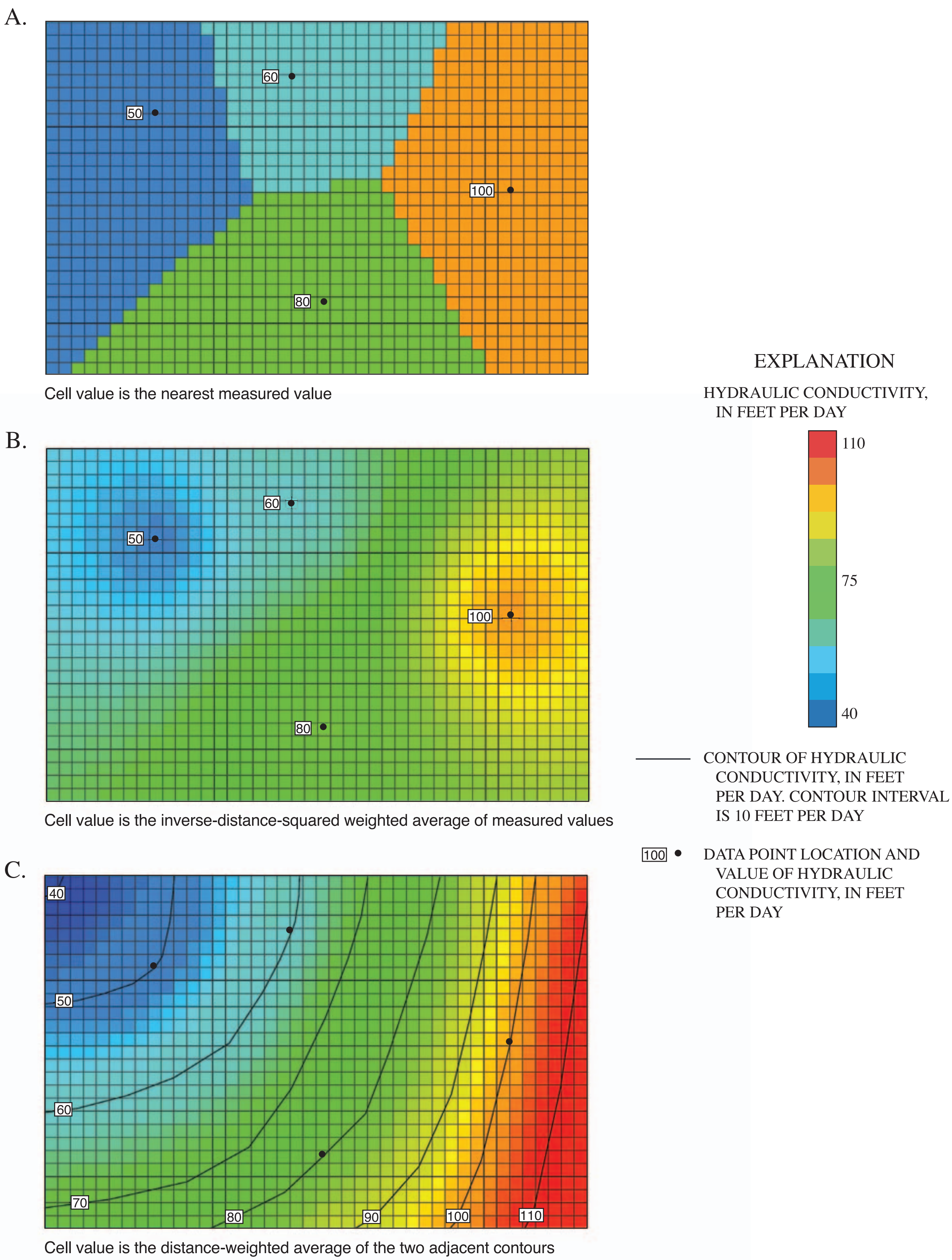


Figure 10. Examples of interpolating data for cells from measured data. (A) Cell value is the nearest measured value, (B) cell value is the inverse-distance-squared weighted average of measured values, and (C) cell value is the distance-weighted average of the two adjacent contours.

user-specified options to control wetting and drying. By varying these factors, it is possible to change the number of dry cells, and thus the head will vary. Careful evaluation is required to detect the potential for nonuniqueness and reject solutions that are unreasonable.

To avoid solver convergence problems that sometimes occur when cells can convert between wet and dry, some investigators have resorted to specifying cells representing the water table as having a constant saturated thickness. It is important to evaluate the extent to which this has been done and the degree to which the thickness represented by the simulated heads varies from the assumed specified thickness. For steady-state models, the following process can be repeated until the simulated saturated thickness is reasonably close to the specified saturated thickness:

1. Run the model.
2. Compare the simulated saturated thickness (head minus bottom elevation) to the specified saturated thickness.
3. Adjust the specified saturated thickness to match the simulated thickness.

For transient models, the changes in saturated thickness throughout the simulation can be compared to the specified saturated thickness to insure that the change is small compared to the total saturated thickness.

Time Steps

Transient models simulate the impact of stresses over time. In MODFLOW, time is divided into time steps, and head is computed at the end of each time step. Many time steps are required to simulate a complex distribution of head over time. This is similar to the need for many cells to represent the spatial distribution of head. It is important to incorporate enough time steps to allow the temporal complexity of head distribution to be simulated.

Figure 11 shows the effect of using different numbers of time steps to simulate the drawdown of a well. The system is the same as that used for the fine-grid simulation in figure 3, with a dimensionless storage coefficient of 0.01 and a well located in the cell at row 17 and column 17. The hydrographs are for the cell at row 17, column 13, which is the 4th cell directly to the left of the pumping cell. At the start of the simulation, the well is turned on with a pumping rate of 100,000 ft^3/d. Each time step is 1.5 times longer than the previous time step, which results in more time steps in early time when head is changing most rapidly. Use of six or more time steps in this model produces nearly the same results, but four or less time steps produces much different results, especially in early time.

MODFLOW also makes use of stress periods to facilitate specification of stress data. A stress period is a group of one or more time steps in which stress input data are constant. In many situations, it is appropriate to maintain the same stresses for multiple time steps, so combining time steps into a stress period for the purposes of data input minimizes the data preparation effort. A new stress period must start whenever it becomes necessary to change stress input data. If stress periods are too long, important dynamics of the stresses may be left out or poorly represented. For example, the Well Package of MODFLOW (Harbaugh and others, 2000) allows pumping rates for wells to change every stress period, and within a stress period the pumping is constant. If the simulation is broken into stress periods of one year, for example, but the actual pumping rate changes more frequently, then stress periods may need to be shorter.

The intended use of the model is also an important factor in evaluating whether the size of stress periods and time steps is appropriate. Considering again the simulation of wells, if a model is used to analyze the average response of a system over many years, then pumping might be represented as yearly averages using yearly stress periods. There would likely be multiple time steps in each yearly stress period, but the stress would remain constant for each year. Thus, hourly, daily, and seasonal variations in pumping would be ignored. But, if a model is used to simulate seasonal system response, then pumping should be represented with shorter stress periods – perhaps monthly.

Questions to be answered in evaluating the appropriateness of the discretization and the representation of the hydrogeologic framework in the simulation of the ground-water system are:

1. Does the horizontal discretization represent the important features of the hydrogeologic framework to meet the objectives of the study?

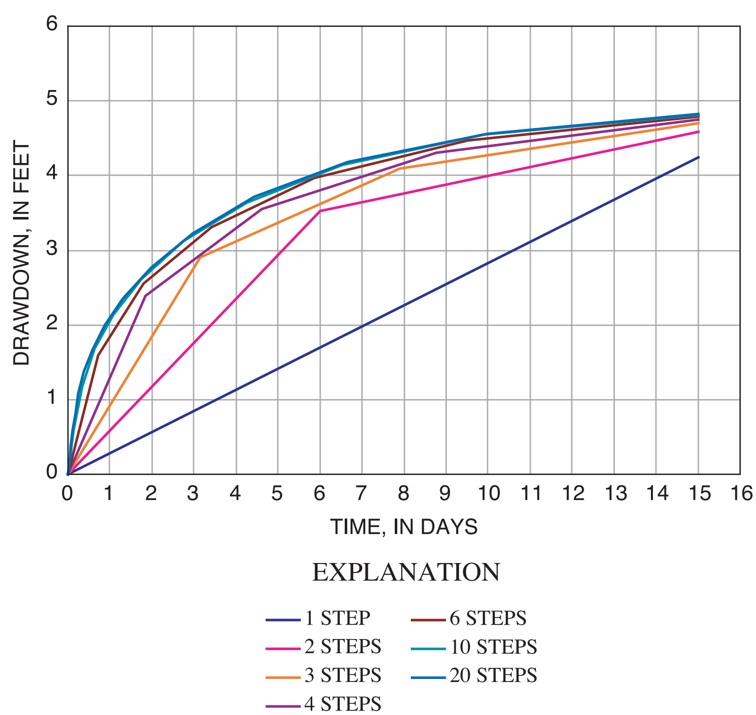


Figure 11. Drawdown versus time for different numbers of time steps.

2. Are the physical boundaries represented appropriately in space by the discretized representation?
3. Is the horizontal discretization appropriate to represent the degree of complexity in the aquifer properties and head distribution (flow system)?
4. Does the vertical discretization adequately represent the vertical connectivity and transmitting properties of the hydrogeologic framework to meet the objectives of the study? Does the method of vertical discretization, either a rectilinear grid or deformed grid, introduce any bias into the representation of the hydrogeologic framework?
5. Is the method of assigning parameter values to individual cells explicitly explained? Is the method appropriate for the objectives of the study and the geologic environment?
6. If the ground-water system is transient, then is the specification of storage coefficients appropriate?
7. If the ground-water system is unconfined in some areas, then is the treatment of changes in saturated thickness and the potential for cells to go dry explained and appropriate? If cells have gone dry, does the resultant solution seem appropriate?
8. Is the time discretization fine enough to represent the degree of complexity in stresses and head distribution over time?

The evaluation of the proper or sufficient discretization of the hydrogeologic framework of a ground-water flow simulation is not straightforward to determine. The continuity of deposits and the reasonableness of the specification of values for each cell in light of the depositional environment of the hydrogeologic framework must be considered. As always, the objectives of the study also determine which features must be represented in the model and the level of detail required to adequately represent their effect on the flow system.

Representation of Boundary Conditions

Boundary conditions are a key component of the conceptualization of a ground-water system. The topic of boundary conditions in the simulation of ground-water flow systems has been discussed in Franke and others (1987) and Reilly (2001).

As discussed in Reilly (2001), computer simulations of ground-water flow systems numerically evaluate the mathematical equation governing the flow of fluids through porous media. This equation is a second-order partial differential equation with head as the dependent variable. In order to determine a unique solution of such a mathematical problem, it is necessary to specify boundary conditions around the flow domain for head (the dependent variable) or its derivatives (Collins, 1961). These mathematical problems are referred to as boundary-value problems. Thus, a requirement for the solution of the mathematical equation that describes ground-water flow is that boundary conditions must be prescribed over the boundary of the domain. Boundary conditions also represent any flow or head constraints within the flow domain. For example, recharge from percolation of precipitation, river interaction, and pumping from wells are simulated as boundary conditions. Three types of boundary conditions—specified head, specified flow, and head-dependent flow—are commonly specified in mathematical analyses of ground-water flow systems. The values of head (the dependent function) in the flow domain must satisfy the preassigned boundary conditions to be a valid solution.

In solving a ground-water flow problem, however, the boundary conditions are not simply mathematical constraints; they generally represent the sources and sinks of water within the system. Furthermore, their selection is critical to the development of an accurate model (Franke and others, 1987). Not only is the location of the boundaries important, but also their numerical or mathematical representation in the model. This is because many physical features that are hydrologic boundaries can be mathematically represented in more than one way. The determination of an appropriate mathematical representation of a boundary condition is dependent upon the objectives of the study. For example, if the objective of a model study is to understand the present and no estimate of future conditions is planned, then local surface-water bodies may be simulated as known constant-head boundaries; however, if the model is intended to forecast the response of the system to additional withdrawals that may affect the stage of the surface-water bodies, then a constant head is not appropriate and a more complex boundary is required. A model of a particular area developed for one study with a particular set of objectives may not necessarily be appropriate for another study in the same area, but with different objectives. All of these aspects of boundary conditions must be considered in evaluating the strengths and weaknesses of a ground-water flow model.

In the ground-water flow modeling process (fig. 12), boundary conditions have an important influence on the areal extent of the model. Ideally in developing a conceptual model, the extent of the model is expanded outward from the area of concern both vertically and horizontally so that the physical extent coincides with physical features of the ground-water system that can be represented as boundaries. The effect of these boundaries on heads and flows must then be conceptualized, and the best or most appropriate mathematical representation of this effect is selected for use in the model.

When physical hydrologic features that can be used as boundary conditions are far from the area of interest, artificial boundaries are sometimes used. The use of an artificial boundary should be evaluated carefully to determine whether its use would cause unacceptable errors in the model. For example, a no-flow boundary might be specified along an approximated flow line at the edge of a modeled area even though the aquifer extends beyond the modeled area. The rationale might be that the artificial boundary is positioned far enough from the area of interest that whatever is simulated in the area of interest would not cause significant flow across that area of the system. The rationale for artificial boundaries can generally be tested using the model. In the example of an artificial no-flow boundary, the

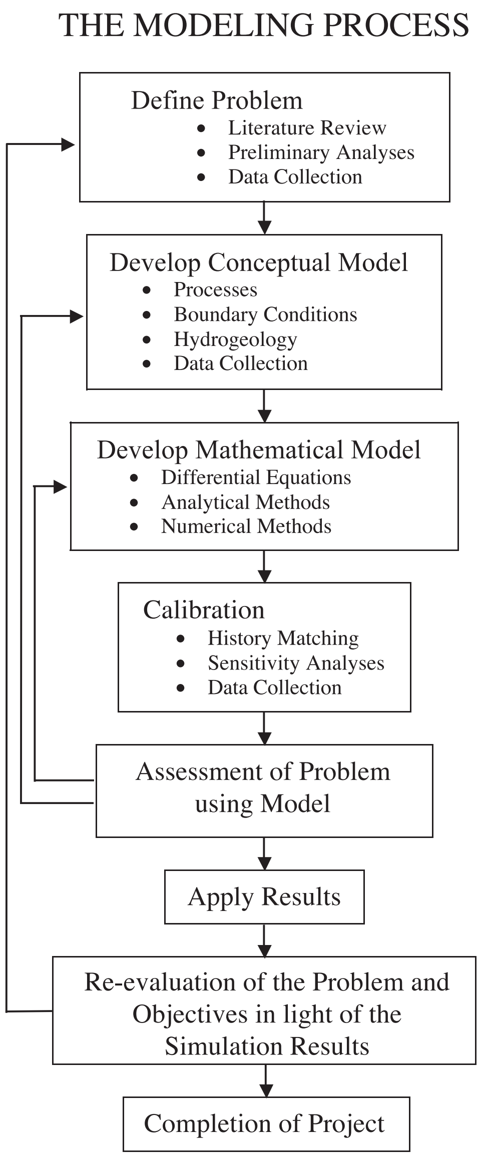


Figure 12. Flow chart of the ground-water flow modeling process. (From Reilly, 2001.)

appropriateness can be tested by looking at how much the head changes near the boundary when the model is used for its intended purpose. Substantial change in heads near the boundary is an indication that significant flow across the region would occur if the artificial boundary were not imposed.

Another example of an artificial boundary is a specified-head boundary at a location where there is no source of water to maintain the head at its specified value. The appropriateness of this boundary can be tested by evaluating the flow from the boundary and the change in flow due to changes in parameter values or stresses within the model. If a stress causes a large change in flow from the boundary, then the head would probably change at the boundary if it were not artificially fixed. Artificial boundaries, if applied improperly and not evaluated, can overly constrain the response of the system and bias the results of an analysis. A frequently observed example is when the area of interest for a study is artificially bounded by specified heads, without regard to the flow being simulated from this boundary into the study area. In this case, the model may not be sensitive to parameter values and stresses because the specified heads artificially keep the simulated heads from deviating much. For further discussion of this topic, see Franke and Reilly (1987).

The objective of the modeling analysis and the magnitude of the stresses to be simulated also influence the selection of the appropriate approach to simulate the physical features that bound the ground-water system. When ground-water systems are heavily stressed, the physical features that bound the system can change in response to the stress. Any representation of these features must account for these potential changes, either by understanding the limitations of the simulation or by representing the physical feature as realistically as possible.

In evaluating the appropriateness of a ground-water flow model, the boundary conditions are key because they determine where the water enters and leaves the system. If the boundaries are inappropriate, the model will be a poor representation of the actual ground-water flow system. Questions to be used in evaluating the boundary conditions of a ground-water flow model are:

1. Are all the external boundaries of the model associated with a definable physical feature?

If no –

A. Why not?

B. Is sufficient justification provided to warrant the use of artificial boundaries?

C. Are the effects of the “artificial” boundaries tested in the calibration of the model and documented in the report? Does the documentation of their use and their testing make a convincing argument for their reasonableness?

If yes –

A. Is the mathematical representation of the physical feature appropriate?

B. Are there conditions under which the representation of the boundary used in the model would become invalid? Are these conditions discussed?

2. Do the boundary conditions of the model overly constrain the model results so that the calibration is insensitive and the predictions are not realistic?

Representation of Initial Conditions in Transient Simulations

Initial conditions represent the heads at the beginning of a transient simulation. Thus, initial conditions serve as a boundary condition in time for the transient head response of a ground-water model solution. Initial conditions are used only in transient simulations, and are different from starting heads (or the initial guess) in steady state solutions. In steady-state solutions, the starting heads can and do affect the efficiency of the matrix solution, but the final correct solution should not be affected by different starting heads. In transient solutions, however, the initial conditions are the heads from which the model calculates changes in the system due to the stresses applied. Thus, the response of the system is directly related to the initial conditions used in the simulation.

The changes in head that occur in the transient model due to any applied stress will be a combination of the effect of the change in stress on the system and any adjustments in heads as a result of errors in the initial head configuration (the initial conditions). Adjustments in heads resulting from errors in the initial head configuration do not reflect changes that would occur in the actual system, but rather occur because the heads specified as the initial condition are not a valid solution to the numerical model. Because errors in the initial head conditions cause changes in head over time during the simulation, it is best to begin all transient simulations with a head distribution that is a valid solution for the model. This ensures that there are no discrepancies (or errors) between the specified initial conditions and a valid head solution for the model.

For simulations that start from a period when the aquifer system was in a steady-state equilibrium, the development of appropriate initial conditions is straightforward. A simulation of the steady-state period should be made. The results of this simulation should then be used as the initial conditions for the transient simulation.

Sometimes, however, it is not possible to start a simulation from a point in time where the aquifer was in steady-state equilibrium. This condition could occur if the simulation is intended to simulate seasonal or other cyclic conditions where the system is never at steady state, or in instances where there is a period of unknown stress that cannot be reproduced accurately, or when it is not feasible to simulate the entire period of record from a time of steady state because of time and money constraints. Under these conditions, it is important that the initial conditions used do not bias the results for the period of interest. Some rules of thumb for the evaluation of the appropriateness of the initial conditions in these non-ideal situations are to evaluate the time constant of the system under investigation and to test the effect of different initial conditions on the results of the model.

The time constant for a ground-water system is derived from a dimensionless form of the ground-water flow equation and is defined as (Domenico and Schwartz, 1998, p. 73):

$$T = \frac{S_s L^2}{K},$$

where T is the time constant (T), S_s is the specific storage of a confined aquifer (L^{-1}), L is a characteristic length of the system (L), and K is the hydraulic conductivity (LT^{-1}). The effect of any transient condition will not be observable if the time after the condition occurs is significantly larger than the time constant for the aquifer (T) (Domenico and Schwartz, 1998). Thus, the effect of a poor or erroneous initial condition (assuming the rest of the model including boundary conditions is correct) should not be observable in model results that are for periods of time significantly larger than the time constant for the aquifer. The time constant is developed from the ground-water flow equation for a confined system with homogeneous hydraulic conductivity. Thus, its application in actual systems is not always exact. The appropriate characteristic length (L) of the system is usually chosen to represent the distance between major boundaries. The specific storage (S_s) represents the compressible storage characteristics of the system; however, an equivalent storativity for unconfined aquifers could be calculated as the specific yield (S_y) divided by the thickness (b) of the unconfined aquifer. For unconfined aquifers, an approximate time constant would be:

$$T = \frac{S_y L^2}{bK}.$$

The determination of the importance and duration of effects of erroneous or imperfect initial conditions can also be accomplished by testing the effect of different initial conditions on the model under study. This test is accomplished by simulating the same system with the stresses and different initial conditions. When the simulations for all the different initial conditions produce the same result, then one can assume the influence of the inaccurate initial conditions is negligible at all following time periods.

A simulation of a simple transient ground-water system can illustrate some of these points. In the illustrative simulation, the simple transient ground-water system is 20,000 ft long and 20,000 ft wide with two aquifers separated by a confining unit, and bounded by no-flow boundaries with a stream along one edge. The aquifer has uniform areal recharge of 0.003 ft/d. The upper aquifer is unconfined and both aquifers have a horizontal hydraulic conductivity of 50 ft/d and a vertical hydraulic conductivity of 5 ft/d. The confining bed is 10-ft thick with a vertical hydraulic conductivity of 0.001 ft/d. The system is discretized as shown in figure 13, and simulated using the finite-difference model MODFLOW. The areal grid size is 1,000 ft by 1,000 ft, and the two aquifers are each represented by two layers; the bottom aquifer is represented by a lower layer (layer 4) 50-ft thick overlain by a 40-ft thick layer (layer 3), and the unconfined aquifer is represented by a 50-ft thick layer (layer 2) overlain by a layer (layer 1) with a uniform bottom at –50 ft, which allows changes in thickness as a function of the head. The stream is represented as a constant head of 0 ft along the right-hand boundary in the top layer. The specific yield for the top layer is 0.2 and the specific storage for the entire model domain is 1.0 x 10^{-6} 1/ft.

The steady-state head distribution for the simple system in layer 1 is symmetric perpendicular to the stream and varies from 67.94 ft at the ground-water divide to 0.0 ft at the stream (fig. 14). A transient simulation is run from the initial steady state to examine the effect of a well discharging 100,000 ft^3/d from layer 3 in cell 10, 10 (9,500 ft from the divide). The correct simulation has as the initial condition the steady-state head

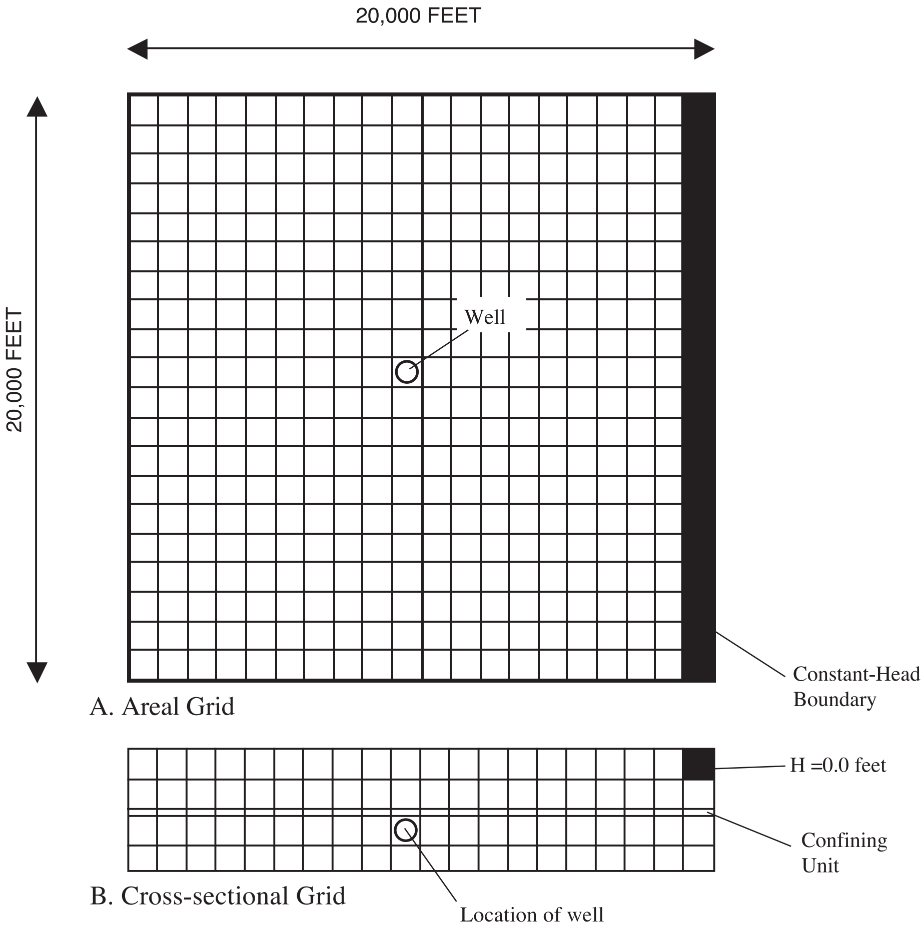


Figure 13. Extent and model grid of the finite-difference model used to illustrate initial conditions: (A) areal grid, and (B) cross-sectional grid.

distribution before the well began discharging; the response of the system through time is shown at the divide in layer 1 (fig. 15A) and at the cell containing the well in layer 3 (fig. 15B). The effect of inaccurate initial conditions can be observed in the response of the aquifer at these same locations. Two different initial conditions, as shown on figure 14, are used to test the response of the system to inaccurate initial conditions. These two other conditions are a uniform head of 100 ft everywhere (all layers), except at the stream, and a linearly changing initial head ranging from 95 ft to 0 ft at the stream. The response of the system over time in response to the pumping well compared to the correct response that used the steady-state head distribution is shown in figure 15 for a cell in layer 1 at the divide and for the cell containing the well in layer 3. The time constant can also be calculated for this system, although some approximations must be made to estimate a saturated thickness. If the saturated thickness of the unconfined aquifer is assumed to be 100 ft (the thickness at the stream), then the time constant is calculated as:

$$T = \frac{0.2(20,000\text{ft})^2}{100.\text{ft}(50\ \text{ft/d})} = 1.6 \times 10^4 \text{ days} = 44 \text{ years}.$$

As shown in figure 15, the curves for the two inaccurate initial conditions do not approach the correct transient response until about 20 to 40 years after the start of pumping. Thus, inaccurate initial conditions can cause errors for a significant time period in transient simulations.

Examination of the simulated response through time from 0-5 years in the finite-difference cell containing the well illustrates some interesting points. The correct response of the system is simulated for the case with the steady-state heads as the initial conditions (fig. 16); the initial value for the head is 50.09 ft in the cell containing the well. The case with the linearly varying heads as initial conditions has the initial value for the cell containing the well equal to 50.0 ft, which is almost the same as the correct steady-state value. Even though the initial conditions in the individual cell are almost the same, the response is different, because the initial conditions over the entire model domain affect the head response. The response of the system with the linearly varying initial conditions is obviously in error because the response of the system shows an increase in head after the first time step in response to pumping, which is not physically reasonable.

Questions to be used in evaluating the initial conditions of a ground-water flow model are:

1. Does the transient model simulation start from a steady-state condition?

If yes –

A. Were the initial conditions generated from a steady-state simulation of the period of equilibrium, which is the preferred method?

B. If the initial conditions were not generated from a steady-state simulation of the period of equilibrium, then is there a compelling reason why they were not generated, or are the initial conditions invalid?

If no –

A. Was it possible to select a period of equilibrium to start the simulation and make the determination of initial conditions more straightforward? If it is possible, then the model should have simulated the transient period from the period of equilibrium.

B. If it was not possible to select a period of equilibrium to start the simulation, then what was the justification for selecting the starting time and the initial conditions for the simulation? How was it shown that the initial conditions used did not bias the result of the simulation?

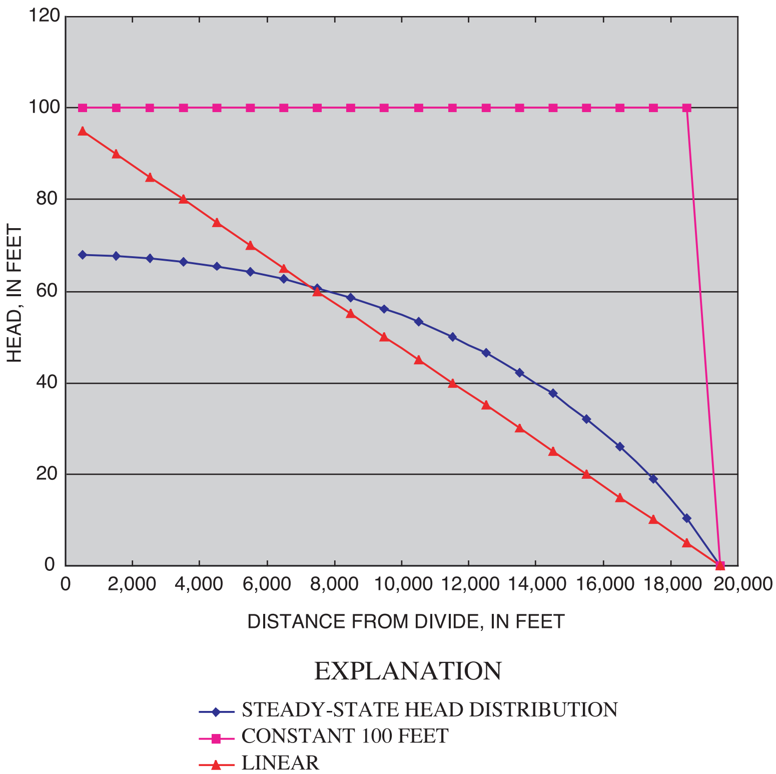


Figure 14. Head distribution along a model row from the divide to the constant-head node for three different initial conditions used for a transient simulation.

Accuracy of the Matrix Solution

Discrete numerical models involve the solution of large sets of simultaneous algebraic equations (Harbaugh and others, 2000). This solution of large sets of algebraic equations usually involves the use of sophisticated matrix solution techniques. Most of the solution techniques are iterative in nature whereby the solution is obtained through successive approximation, which is stopped when it is determined that a "good" solution has been obtained (Bennett, 1976). The criterion used in most iterative solution techniques is called the "head change criterion." When the maximum absolute value of head change from all nodes during an iteration is less than or equal to the selected head change criterion, then iteration stops.

When evaluating a ground-water flow model, even if the computer model has output results, one must check to determine if indeed a solution has been obtained by the matrix solution technique. The first check is to evaluate the head change criterion. Was the head change criterion set small enough to obtain a model solution with minimal error? One means of evaluating the head change criterion is to examine the global mass balance for the model. If the error in the mass balance (for example, total inflow minus total outflow divided by one half the sum of the inflow and outflow) over the entire model domain is small, usually less than

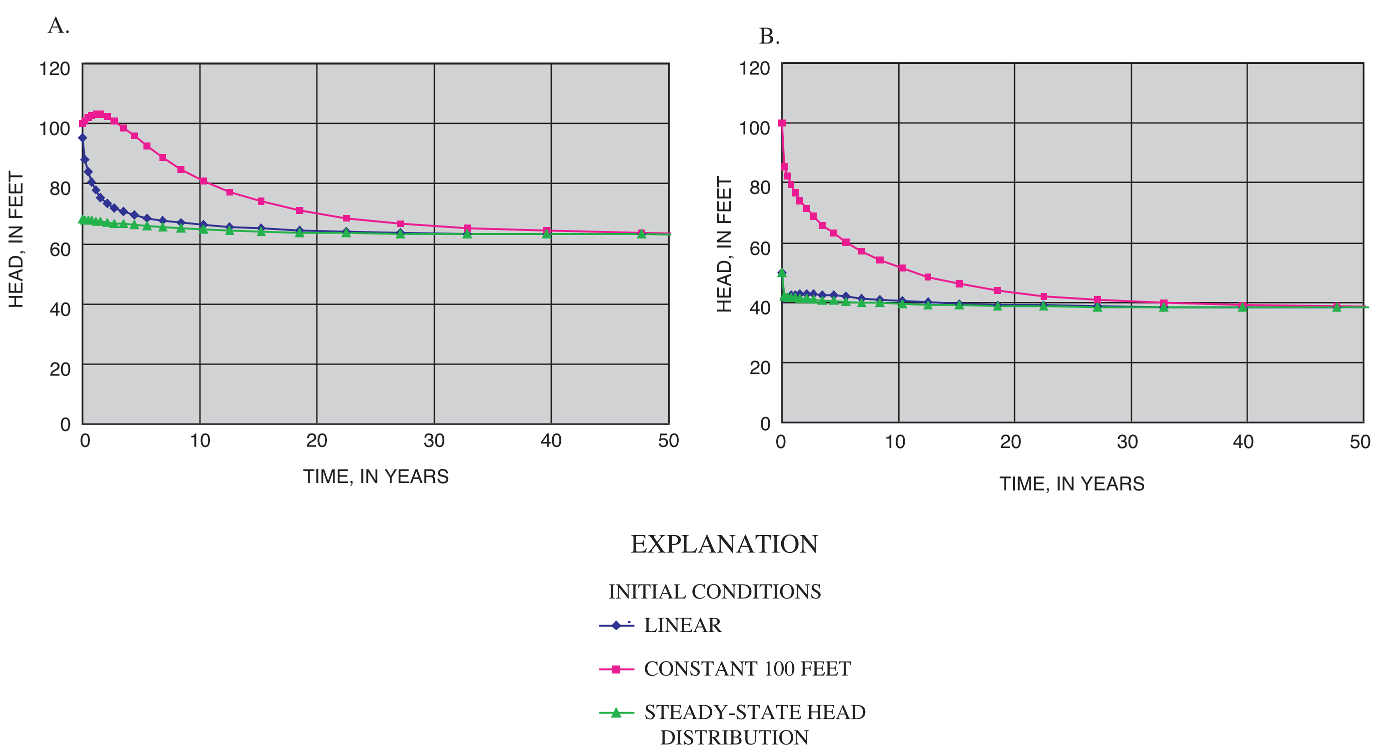


Figure 15. Head in a cell through time in response to a well discharging at a rate of 100,000 ft^3/d: (A) the head in layer 1 at the divide, and (B) the head in the cell with the discharging well in layer 3.

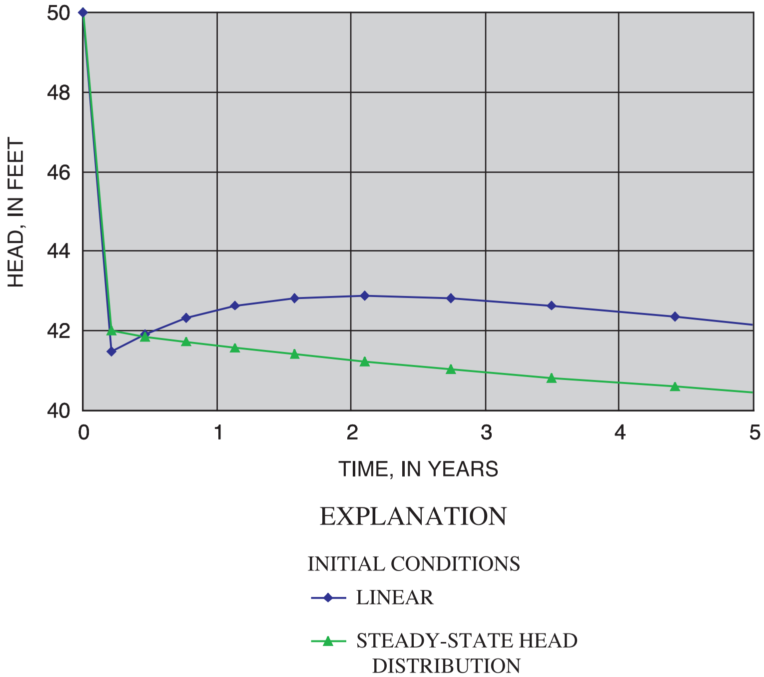


Figure 16. Head in the well for the first 5 years after the start of pumping for the cases using the initial conditions of the steady-state head distribution and the linearly varying head distribution.

0.5 percent, then the head change criterion is assumed to have been sufficient. If the error in the mass balance calculations is significant, then the matrix solution was not good and the model should be corrected by improving the matrix solution. The matrix solution can be improved by lowering the head change criterion, adjusting iteration parameters (if the solution techniques use iteration parameters), using different starting heads for steady-state simulations, or using a different solution technique.

Even if the head change criterion is met and the global mass balance error is small, the model solution may not be appropriate for the system under investigation. Two potential reasons are that some models can either be mathematically nonunique or very nonlinear. The mathematically nonunique problem usually is a poorly posed problem where a model has only specified-flow boundary conditions and no other boundary condition that specifies a head or datum (such as, constant head, river stage, general head boundary, etc.). In this type of problem, there is a family of solutions all with the same gradients but different absolute heads. The matrix solution technique may not converge or it may converge to one of the infinite number of possible solutions.

In nonlinear problems, the solution affects the coefficients of the matrix being solved; thus, the solution affects the problem being solved. As a result, the manner in which the iterative solution technique approaches a solution can affect the final solution. An example from Reilly (2001) illustrates this point. Consider a one-dimensional water-table system with a sloping impermeable bottom that contains a specified head and extends 5,000 m, with an areal recharge rate of 0.5 m/yr. The starting head for the equation solution is specified at 20 m, which is above all the bottom elevations of the cells but yet close to the magnitude of the expected results. Figure 17A is a cross-sectional view of a finite-difference representation of the steady-state solution. The cell farthest from the specified head is simulated as being dry. The total recharge flowing to the specified head cell for a 500-m width is 2,740 m^3/d. The convergence criterion of the model was met and the mass balance was excellent (showing 0.00 percent budget discrepancy). Now consider figure 17B, which is the result of a simulation of the same problem, except the starting head for the matrix solution was set at 100 m. As is shown in figure 17 and table 2, three cells are now simulated as being dry. The result is that less recharge is simulated as entering the model and the heads and water budgets are reduced accordingly, with only 2,055 m^3/d being represented as recharge entering the system for a 500-m width. Although both solutions converged and had excellent mass balances, at least one of them is incorrect. Because it is a nonlinear problem, it is not easy to determine which solution is correct. The rate of convergence and the method of making cells inactive must be considered and evaluated. After evaluating these aspects, and noting that the head in cell 7 (table 2 and fig. 17) of the second model is above the bottom elevation of cell 8, which was converted to dry during the iterative process, it seems that the first model most likely is correct. In the second model, the iterative solution, in attempting to converge, apparently overshot the bottom of some of the cells, which prematurely or erroneously truncated the area from the active model domain,

Table 2. Heads calculated for the same system with areal recharge and two different intitial heads.

[m, meters]

Cell number	Bottom elevation of cell	Head calculated with the initial head at 20 m	Head calculated with the initial head at 100 m
1	-30.0	0.00	0.00
2	-25.0	1.93	1.46
3	-20.0	3.83	2.86
4	-15.0	5.68	4.17
5	-10.0	7.49	5.38
6	-5.0	9.24	6.42
7	0.0	10.90	7.20
8	5.0	12.45	Dry
9	10.0	13.81	Dry
10	15.0	Dry	Dry

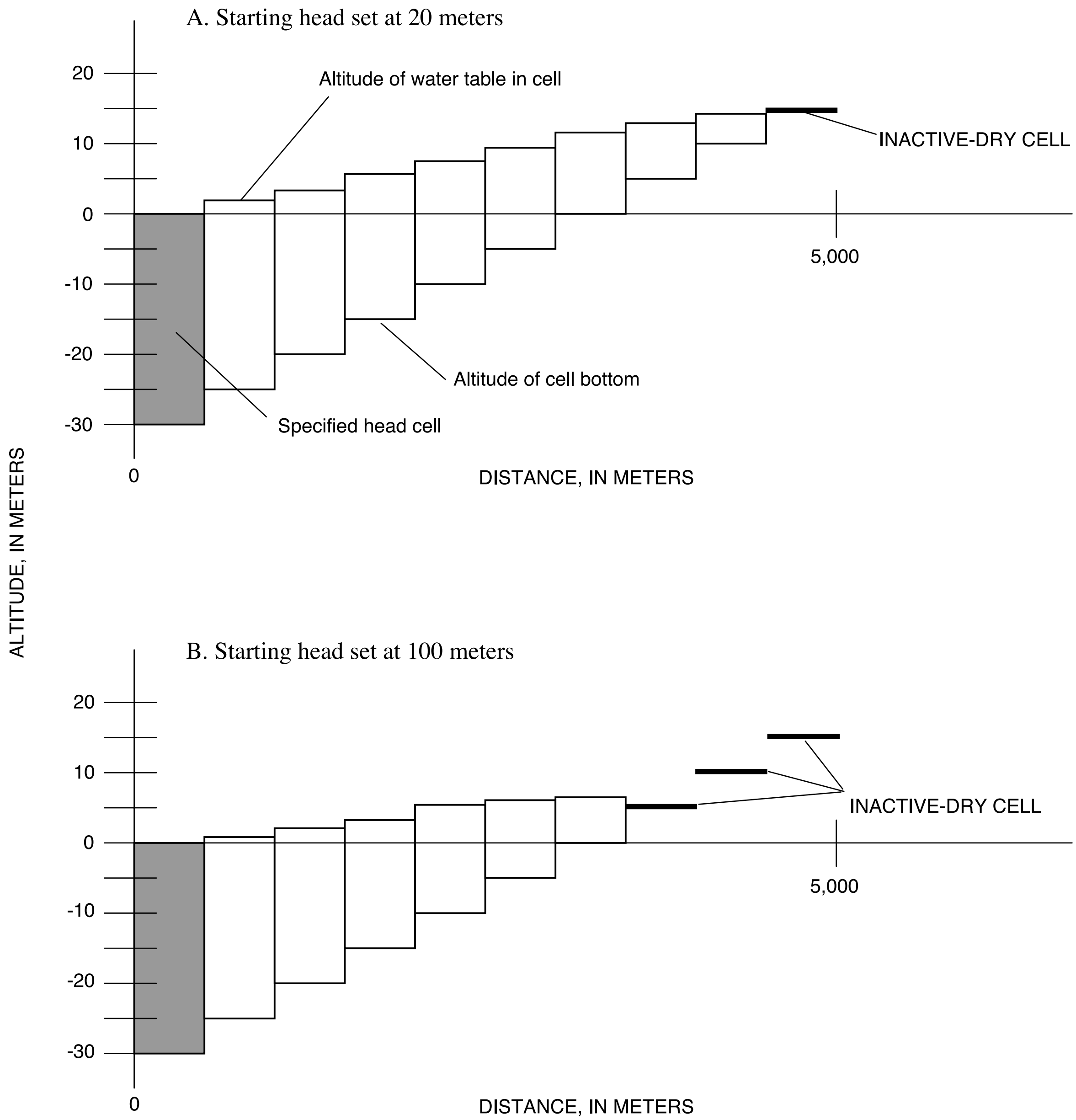


Figure 17. Cross-sectional view of a finite-difference representation simulating a variable thickness ground-water system with flow to a specified head due to areal recharge: (A) starting head set at 20 meters, and (B) starting head set at 100 meters. (From Reilly, 2001.)

and resulted in the wrong problem being solved. The model developer or user must carefully evaluate nonlinear problems and monitor the rate of convergence to ensure that cells that should be part of the active problem domain are not removed.

The accuracy of the matrix solution usually is not an issue with ground-water models that meet the head change criterion and have small mass balance errors. It is important when using models and especially nonlinear models, however, to keep in mind that the accuracy of the solution is not assured, which is another aspect for continued evaluation. Some models do not converge smoothly, and investigators use non-standard methods (tricks) to obtain a model solution. For example, some non-standard methods that have been used include: the saving of intermediate solutions that have not yet converged and changing matrix solution parameters when restarting the model; making a nonlinear water-table simulation linear by fixing the saturated thickness of the model; and obtaining a steady-state solution by using storage to slow convergence and damp the approach to the solution through simulating a long transient time period. As long as the non-standard method does not violate any important hydrologic process, they are usually transparent to the final solution and are appropriate. However, these non-standard techniques should be evaluated to determine whether they cause potential errors to be introduced to the model solution.

Questions to be addressed when evaluating the adequacy of the matrix solution in the simulation of a ground-water system are:

1. Is the ground-water system and set of matrix equations linear or nonlinear?

If linear –

A. Was the head change criterion met and was it sufficiently small to obtain an acceptable (that is, less than 0.05 percent error) global mass balance?

If nonlinear –

A. Was a nonlinear matrix solution technique used?

B. Was the head change criterion met and was it sufficiently small to obtain an acceptable (that is, less than 0.05 percent error) global mass balance?

C. Did the nonlinear terms, such as cells going dry or drains turning off, behave smoothly during the iteration process? Or were there large oscillations that would indicate a potential for convergence to an incorrect solution?

D. Were any "tricks" used to smooth convergence, such as setting saturated thickness as a constant in water-table simulations, and are the assumptions used in defining these artificially constrained features reasonable for the solution obtained?

2. Does the solution seem reasonable for the problem posed? If it is not and there are no input data errors, then another matrix solution technique should be tried to determine whether it is a matrix-solution issue or some other problem.

Adequacy of Calibration for Intended Use of Model Results

As discussed previously, not all objectives of using a ground-water model require calibration. For models that require calibration, however, an evaluation of the adequacy of the calibration is another difficult task. There are different quantitative measures that investigators use to show the accuracy of the calibration of a ground-water flow model. Some of these are: the mean error, the mean absolute error, and the root mean squared error (Anderson and Woessner, 1992). The areal distribution of residuals (differences between measured and simulated values) also is important to determine whether some areas of the model are biased either too high or too low. The difficulty that arises, however, is how to determine what is good enough.

As stated previously, key aspects of the model, such as the conceptualization of the flow system, that influence the appropriateness of the model to address the problem objectives, are often not considered during calibration by many investigators; their focus is on the quantitative measures of goodness of fit. However, the appropriateness of the conceptualization of the ground-water system and processes should always be evaluated during calibration. Thus, the method of calibration, the closeness of fit between the simulated and observed conditions, and the extent to which important aspects of the simulation were considered during the calibration process are all important in evaluating the appropriateness of the model to address the problem objectives.

Freyberg (1988) reported on a class exercise where different models were calibrated by students using the same model and identical sets of data. Freyberg's observations of the exercise showed that "success in prediction was unrelated to success in matching observed heads under premodification conditions." He concluded, "good calibration did not lead to good prediction." This is not to imply that matching heads is unimportant, only that there are other factors that need to be considered in determining the "goodness" of a model. Put in terms of logic, a good match between calculated and observed heads and flow is a necessary condition for a reasonable model, but it is not sufficient. The conceptual model and the mathematical representation of all the important processes must also be appropriate for the model to accurately represent the system under investigation. Thus, a model that matches heads and flows well must also be evaluated to determine if it is a reasonable representation of the system under study. As stated by Bredehoeft (2003), "A wrong conceptual model invariably leads to poor predictions, no matter how well the model is fit to the data."

Thus, the evaluation of the adequacy of the calibration of a model should be based more on the insight of the investigators and the appropriateness of the conceptual model rather than the exact value of the various measures of goodness of fit. For example, it would be possible to specify every cell in a model that had an observation associated with it as a specified head cell in the model. This would produce a perfect match between simulated and observed heads, however, it is conceptually unreasonable to simulate random cells as specified heads that could serve as sources and sinks of water. Thus, although the measures of calibration might make it appear to be a well-calibrated model, in effect the violation of a reasonable conceptual model makes it a poor model. A model developed according to a well-argued conceptual model with minor adjustments, in our opinion, is generally superior to a model that has a smaller discrepancy between simulated and observed heads because of unjustified manipulation of the parameter values. A reasonable representation of the conceptual model and sources of water is more important than blindly minimizing the discrepancy between simulated and observed heads.

Models can be calibrated by trial and error or by automatic parameter estimation techniques, such as nonlinear regression to minimize some measure of goodness of fit between the simulated and observed values. A key concept in automatic parameter estimation methods is that a limited set of parameters used in the model is designated to be automatically adjusted. These parameters usually are identified for specific regions (or zones) of the model that are determined before the calibration process (a priori). An example of parameter zones for hydraulic conductivity is shown in figure 18 for the top two layers of a model of the Albuquerque Basin, New Mexico (Tiedeman and others, 1998). In this example, the zones represent different hydrogeologic units. The areal extent of these units remains fixed during automatic calibration, and the conceptualization of the location and extent of these zones is part of the information specified before the automatic calibration process. The parameters and boundary conditions that are not identified for automatic calibration either remain fixed at their initial values or must be calibrated by trial and error. In addition, most automatic calibration methods weight observations according to the investigators insight into the reliability of the observations. Obviously, if the model is conceptualized incorrectly, the parameter zones are not representative of the actual parameter distribution, the fixed parameters and boundary conditions are poorly chosen, or the weighting functions are not appropriate, then the resultant estimates of the parameter values will be inaccurate even if the residual between observed and simulated conditions is automatically minimized.

If there are errors in the model conceptualization, the parameter zones selected, and the weighting functions defined for observed values, then the parameter estimation methods will provide the best parameters for the poorly defined model. This does not mean that the model will be an accurate representation of the system or will produce reasonable predictions. Perhaps the best use of the formal parameter estimation methods is to test different model, zone, and weighting function conceptualizations and determine which conceptualizations are most reasonable. In testing alternative models, Hill (1998) states that better models will have “three attributes: better fit, weighted residuals that are more randomly distributed, and more realistic optimal parameter values.” This approach was used by Yager (1996) to test three different model conceptualizations for the Niagara Falls area in New York and by Tiedeman and others (1998) to test six different system conceptualizations of the Albuquerque Basin system. This use of parameter estimation provides a quantitative means (although some subjectivity comes into determining which model is good enough) to test different conceptualizations.

In trial and error calibration, investigators have the ability to continuously change their conceptualization of the system and parameter distributions in order to improve the calibration fit, although the benefits of these changes are frequently difficult to quantify. It is the insight and skill of the investigator during a trial and error calibration that will control how well a model represents the ground-water system under investigation. In evaluating the adequacy of a model calibration, the conceptual model and the insight of the investigators generally are more important than just an evaluation of quantitative measures of goodness of fit.

Questions to be addressed in evaluating the adequacy of calibration of a model using either trial and error or automatic methods are:

1. Is the conceptual model of the system under investigation reasonable?
2. Are the mathematical representations of the boundary conditions reasonable for the objectives of the study?
3. Does the simulated head and flow distribution mimic the important aspects of the flow system, such as magnitude and direction of the head contours?
4. Does some quantitative measure of head and flow differences between the simulated and observed values seem reasonable for the objectives of the investigation?
5. Does the distribution of areas where simulated heads are too high and areas where simulated heads are too low seem randomly distributed? If they are not randomly distributed, then is there a hydrogeologic justification to change the model and make the residuals more random areally?

Just because a model is constructed and calibrated, does not ensure that it is an accurate representation of the system. The appropriateness of the boundaries and the system conceptualization is frequently more important than achieving the smallest differences between simulated and observed heads and flows.

Model Input Data, Output Listing, and Report Consistency Check

In evaluating the adequacy of a model, the input data, output listing, and report ideally should be compared with each other to ensure that they all represent the same analysis. Depending on the level of evaluation being undertaken, this comparison can vary greatly in its thoroughness. Many times the output listing and input data sets are not available to the person evaluating the model, so there is nothing that can be checked.

If the listing file is available, then it is useful as a minimum to compare some of the model output to information in the report. The simulated water budget in the output listing can be compared to budget values determined from the system conceptualization and real-world measurements provided in the report. For example, if the areal recharge rate is specified in the report, the total recharge over the modeled area can be calculated and compared to the reported recharge in the model budget. Heads or drawdowns in the model output listing can be compared to values in the report.

If a more thorough evaluation is required, then the input data can also be checked. Although it is impossible to ensure that all the preprocessor steps and manual data entry were undertaken correctly, data checking can increase confidence that the model is consistent with the description in the report. Whether the model data files were constructed by manually entering information into files or by using a graphical user interface, there is the possibility that the data files contain errors.

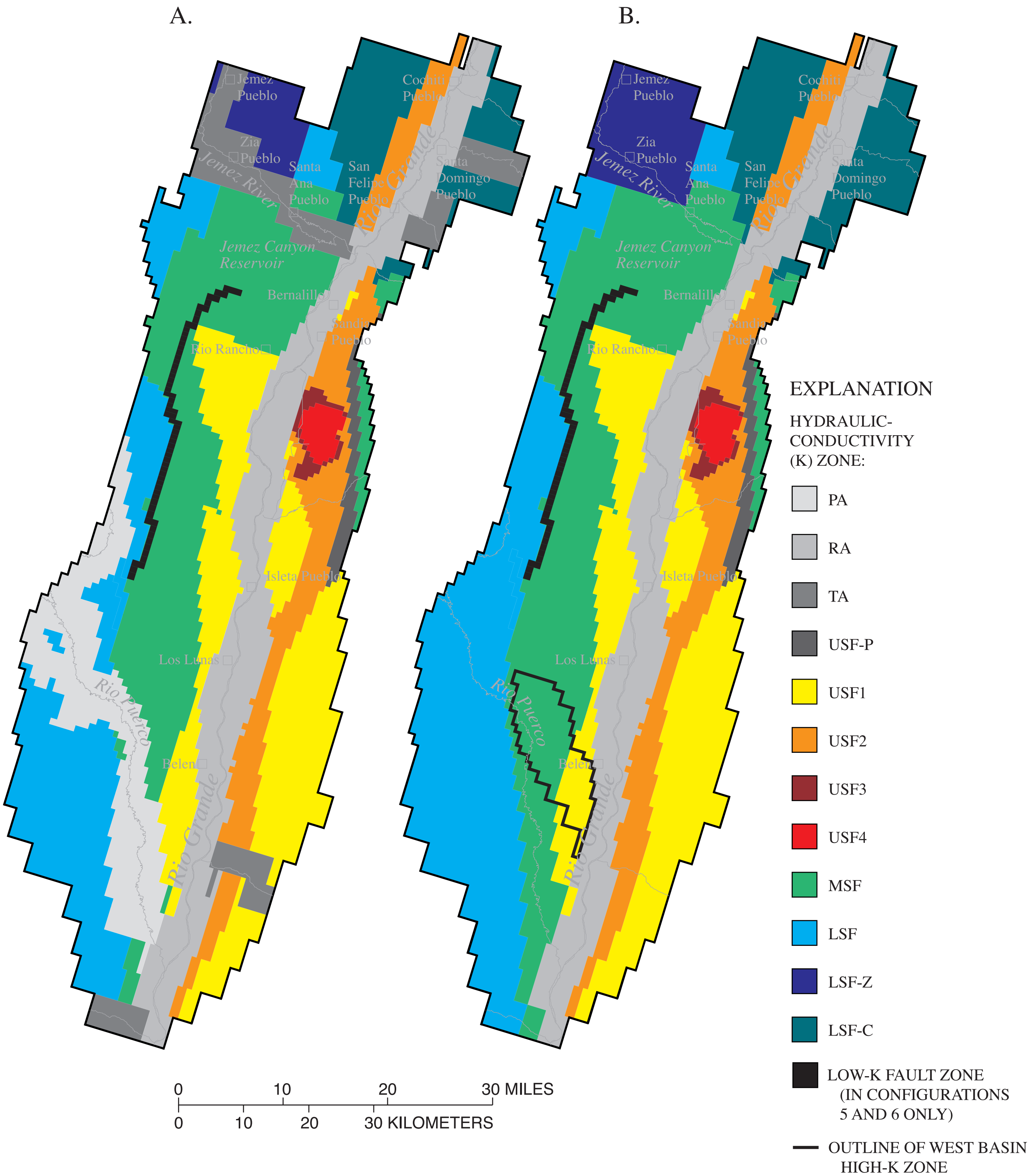


Figure 18. Hydraulic-conductivity zones identified for automatic parameter estimation in a ground-water flow model of the Albuquerque Basin, New Mexico: (A) zones in model layer 1, and (B) zones in model layer 2. (From Tiedeman and others, 1998.)

Examples of possible errors are: numbers scaled improperly, inconsistent data, data entered into incorrect fields, data assigned to incorrect cells, typographical errors, and many others. An example of inconsistent data is the use of inconsistent time or space units for different parts of the data. For example, pumping might be entered in cubic feet per second (ft^3/s) and hydraulic conductivity in feet per day (ft/d). An example of data assigned to incorrect cells is the specification of stress data, for example pumping wells located in inactive cells.

The extent to which the input data can be checked depends on the size of the model, available resources, and how the data were entered. Typical models vary in size from several thousand cells to over a hundred thousand cells. There are multiple data values per cell, so it is impractical to check every input value in even the smaller models. Thus, data scanning is a better term to describe the data-checking process. If data files are available, then they can be checked or scanned directly. If the output listing is available and if this listing contains an echo of the input data, then usually it is easier to examine the output listing than the input files. Also, seeing the data in the output listing provides added confirmation that the data files have been properly read by the model program.

Some checks that can be considered are:

1. Do the model water-budget quantities seem appropriate for the values described for the actual system in the report?
2. Are the input data the same as those described in the report?
3. Are data values consistent and assigned to appropriate cells?

Checking the information that is read directly by the model increases confidence that the simulation is indeed a solution to the problem described. The level of evaluation required determines the thoroughness of the consistency check that should be undertaken.

Model Reporting and Archiving

Because models are embodiments of scientific hypotheses, a clear and complete documentation of the model development is required for individuals to understand the hypotheses, to understand the methods used to represent the actual system with a mathematical counterpart, and to determine if the model is sufficiently accurate for the objectives of the investigation. As stated in U.S. Geological Survey Office of Ground Water Technical Memorandum 96.04 (see appendix), there is no rigid checklist or recipe for reporting on the use of simulation in a ground-water study. The appropriate level of documentation will vary depending on the study objectives and the complexity of the simulations. A valuable result of the ground-water modeling effort is the insight gained by the investigator during the modeling process about the functioning of the flow system. This understanding of the flow system gained during the modeling process can be an important product of the study and should be appropriately discussed and documented in the modeling report.

The general structure of a well-constructed report describing simulation is much the same as that for any investigative study. It should present (1) the objectives of the study, (2) a description of the work that was done, (3) logical arguments to convince the reader that the methods and analyses used in the study are valid, and (4) results and conclusions.

Ten specific topics that should be addressed in reports that describe studies in which simulation is used are listed and explained in U.S. Geological Survey Office of Ground Water Technical Memorandum 96.04 to aid individuals in documenting their model studies. These 10 topics are:

1. Describe the purpose of the study and the role that simulation plays in addressing that purpose.
2. Describe the hydrologic system under investigation.
3. Describe the mathematical methods used and their appropriateness to the problem being solved.
4. Describe the hydrogeologic character of the boundary conditions used in the simulation of the system.
5. If the method of simulation involves discretizing the system (finite-difference and finite-element methods for example), describe and justify the discretized network used.
6. Describe the aquifer system properties that are modeled.
7. Describe all the stresses modeled such as pumpage, evapotranspiration from ground water, recharge from infiltration, river stage changes, leakage from other aquifers, and source concentrations in transport models.
8. For transient models, describe the initial conditions that are used in the simulations.
9. If a model is calibrated, present the calibration criteria, procedure, and results.
10. Discuss the limitations of the model's representation of the actual system and the impact those limitations have on the results and conclusions presented in the report.

Once the study is finished, it is always useful to organize and archive the model files. The purpose of the archive is to ensure that the results are reproducible in the future either by the model developer or other interested parties. Thus, the archive should reference any published reports on the model and provide enough explanation in a text "readme" file for the model to be used by others. The archival of the model provides good scientific practice and reproducibility of results.

Summary

Ground-water models are designed and built to meet specific objectives. Models must be critically evaluated to ensure that there are no data input errors and that the conceptual model does indeed accurately represent the actual ground-water system sufficiently to meet the objectives of the study. The items to be evaluated are: the appropriateness of the model program, the discretization and representation of the geologic framework, the representation of the boundary conditions, the representation of the initial conditions, and the accuracy of the matrix solution.

Ground-water flow models attempt to reproduce, or simulate, the operation of a real ground-water system using a mathematical counterpart (a mathematical model). Thus, the evaluation of the model is intended to ensure that the model program and numerical representation of the important aspects of the system are sufficient to meet the objectives of the study. The guidelines presented in this report raise some of the important aspects of model evaluation.

Acknowledgments

The technical review and improvement of the report by William Alley, James Bartolino, William Cunningham, and Keith Prince are gratefully acknowledged. Sandra Cooper provided editorial review and assistance. The final report and illustrations were prepared by E.G. Baker and K.A. Waltenbaugh, and J.E. Banton, respectively.

References

Anderman, E.R., and Hill, M.C., 2000, MODFLOW-2000, the U.S. Geological Survey Modular Ground-Water Model—Documentation of the hydrogeologic-unit flow (HUF) package: U.S. Geological Survey Open-File Report 00-342, 89 p.

Anderson, M.P., and Woessner, W.W., 1992, Applied Groundwater Modeling—Simulation of flow and advective transport: Academic Press, Inc., San Diego, Calif., 381 p.

Barlow, P.M., 1994, Two- and three-dimensional pathline analysis of contributing areas to public-supply wells of Cape Cod, Massachusetts: Ground Water, v. 32, no. 3, p. 399–410.

Bennett, G.D., 1976, Introduction to ground-water hydraulics—A programmed text for self-instruction: Techniques of Water-Resources Investigations of the United States Geological Survey, Book 3, Chapter B2, 172 p.

Bredehoeft, J.D., 2003, From models to performance assessment: The conceptualization problem: Ground Water, v. 41, no. 5, p. 571-577.

Buxton, H.T., and Reilly, T.E., 1987, A technique for analysis of ground-water systems at regional and subregional scales, applied on Long Island, New York: U.S. Geological Survey Water-Supply Paper 2310, p. 129-142.

Buxton, H.T., Reilly, T.E., Pollock, D.W., and Smolensky, D.A., 1991, Particle tracking analysis of recharge areas on Long Island, New York: Ground Water, v. 29, no. 1, p. 63-71.

Buxton, H.T., and Smolensky, D.A., 1999, Simulation of the effects of development of the ground-water flow system of Long Island, New York: U.S. Geological Survey Water-Resources Investigations Report 98-4069, 57 p.

Buxton, H.T., Smolensky, D.A., and Shernoff, P.K., 1999, Feasibility of using ground water as a supplemental supply for Brooklyn and Queens, New York: U.S. Geological Survey Water-Resources Investigations Report 98-4070, 33 p.

Collins, R.E., 1961, Flow of fluids through porous materials: Reinhold Publishing Corp., N.Y., 270 p.

Domenico, P.A., and Schwartz, F.W., 1998, Physical and Chemical Hydrogeology (Second Edition): John Wiley and Sons, New York, N.Y., 506 p.

Franke, O.L., and Reilly, T.E., 1987, The effects of boundary conditions on the steady-state response of three hypothetical ground-water systems—Results and implications of numerical experiments: U.S. Geological Survey Water-Supply Paper 2315, 19 p.

Franke, O.L., Reilly, T.E., and Bennett, G.D., 1987, Definition of boundary and initial conditions in the analysis of saturated ground-water flow systems—An introduction: U.S. Geological Survey Techniques of Water-Resources Investigations 3-B5, 15 p.

Franke, O.L., Reilly, T.E., Pollock, D.W., and LaBaugh, J.W., 1998, Estimating areas contributing recharge to wells—Lessons from previous studies: U.S. Geological Survey Circular 1174, 14 p. (Third printing, 1999.)

Freyberg, David L., 1988, An exercise in ground-water model calibration and prediction: Ground Water, v. 26, no. 3, p. 350-360.

Harbaugh, A.W., Banta, E.R., Hill, M.C., and McDonald, M.G., 2000, MODFLOW-2000, The U.S. Geological Survey Modular Ground-Water Model—User guide to modularization concepts and the ground-water flow process: U.S. Geological Survey Open-File Report 00-92, 121 p.

Hill, M.C., 1998, Methods and guidelines for effective model calibration: U.S. Geological Survey Water-Resources Investigations Report 98-4005, 90 p.

Hill, M.C., Cooley, R.L., and Pollock, D.W., 1998, A controlled experiment in ground-water flow model calibration: Ground Water, v. 36, no. 3, p. 520-535.

Konikow, L.F., and Reilly, T.E., 1999, Groundwater modeling: *in* Delleur, J.W. (ed.), The handbook of groundwater engineering: CRC Press, Boca Raton, Fla., 40 p.

Leake, S.A., and Claar, D.V., 1999, Procedures and computer programs for telescopic mesh refinement using MODFLOW: U.S. Geological Survey Open-File Report 99-238, 53 p.

Luckey, R.R., Gutentag, E.D., Heimes, F.J., and Weeks, J.B., 1986, Digital simulation of ground-water flow in the High Plains aquifer in parts of Colorado, Kansas, Nebraska, New

Mexico, Oklahoma, South Dakota, Texas, and Wyoming: U.S. Geological Survey Professional Paper 1400-D, 57 p.

Masterson, J.P., Walter, D.A., and Savoie, Jennifer, 1997, Use of particle tracking to improve numerical model calibration and to analyze ground-water flow and contaminant migration, Massachusetts Military Reservation, western Cape Cod, Massachusetts: U.S. Geological Survey Water-Supply Paper 2482, 50 p.

McAda, D.P., 2001, Simulation of a long-term aquifer test conducted near the Rio Grande, Albuquerque, New Mexico: U.S. Geological Survey Water-Resources Investigations Report 99-4260, 66 p.

McDonald, M.G., and Harbaugh, A.W., 1988, A modular three-dimensional finite-difference ground-water flow model: Techniques of Water-Resources Investigations of the United States Geological Survey, Book 6, Chapter A1, 586 p.

Modica, Edward, Reilly, T.E., and Pollock, D.W., 1997, Patterns and age distribution of ground-water flow to streams: Ground Water, v. 35, no. 3, p. 523-537.

Morrissey, D.J., 1989, Estimation of the recharge area contributing water to a pumped well in a glacial-drift, river-valley aquifer: U.S. Geological Survey Water-Supply Paper 2338, 41 p.

Pollock, D.W., 1989, Documentation of computer programs to compute and display pathlines using results from the U.S. Geological Survey modular three-dimensional finite-difference ground-water flow model: U.S. Geological Survey Open-File Report 89-381, 188 p.

Prince, K.R., and Schneider, B.J., 1989, Estimation of hydraulic characteristics of the Upper Glacial and Magothy aquifers at East Meadow, New York, by use of aquifer tests: U.S. Geological Survey Water-Resources Investigations Report 87-4211, 43 p.

Reilly, T.E., 2001, System and boundary conceptualization in ground-water flow simulation: U.S. Geological Survey Techniques of Water-Resources Investigations, Book 3, Chapter B8, 26 p.

Reilly, T.E., Franke, O.L., and Bennett, G.D., 1987, The principle of superposition and its application in ground-water hydraulics: U.S. Geological Survey Techniques of Water-Resources Investigations 3-B6, 28 p.

Reilly, T.E., and Pollock, D.W., 1993, Factors affecting areas contributing recharge to wells in shallow aquifers: U.S. Geological Survey Water-Supply Paper 2412, 21 p.

Tiedeman, C.R., Kernodle, J.M., and McAda, D.P., 1998, Application of nonlinear-regression methods to a ground-water flow model of the Albuquerque Basin, New Mexico: U.S. Geological Survey Water-Resources Investigations Report 98-4172, 90 p.

Yager, R.M., 1996, Simulated three-dimensional ground-water flow in the Lockport Group, a fractured-dolomite aquifer near Niagara Falls, New York: U.S. Geological Survey Water-Supply Paper 2487, 42 p.

Appendix

April 24, 1996

OFFICE OF GROUND WATER TECHNICAL MEMORANDUM NO. 96.04

Subject: PUBLICATIONS—Policy on documenting the use of ground-water simulation in project reports

It has been more than two decades since Ground Water Branch Technical Memorandum No. 75.11 was released on the subject of documenting the use of ground-water simulation in project reports. Because of the time lapse, changes in modeling techniques, and the frequency of problems found when reports are reviewed, a revisit to policy on this subject is appropriate.

There is no rigid checklist or recipe for reporting on the use of simulation in a ground-water study. The appropriate level of documentation will vary depending on the project objectives and the complexity of the simulations. The general structure of a well-constructed report describing simulation is much the same as that for any investigative study. It should present (1) the objectives of the study, (2) a description of the work that was done, (3) logical arguments to convince the reader that the methods and analyses used in the study are valid, and (4) results and conclusions.

Specific topics that should be addressed in reports that describe studies in which simulation is used include the following.

1. Describe the purpose of the study and the role that simulation plays in addressing that purpose.

   The objective of the simulation must be clearly stated. The model should be represented as a tool to help solve specific problems or answer specific questions rather than as an end product.

2. Describe the hydrologic system under investigation.

   The extent, nature of boundaries, transmitting properties, storage properties, sources of water, discharge mechanisms and other relevant components of the ground-water system should be described as known or conceptualized. Usually this can be accomplished in part by referencing previous works, but major relevant system characteristics should be summarized in the report that describes the simulation.

3. Describe the mathematical methods used and their appropriateness to the problem being solved.

   In most cases, a reference to a readily available publication will be sufficient to document mathematical details; however, it will usually be desirable to briefly summarize the methods that are used. For a well-documented computer program, this will often require only a paragraph or two. If a documented computer program is modified such that computed values are affected, the modifications should be documented and evidence that the modifications are correct should be supplied.

4. Describe the hydrogeologic character of the boundary conditions used in the simulation of the system.

   In many cases, the model boundaries are placed where the aquifer terminates against relatively impermeable rocks or is intersected by a perennial stream whose head variation in time and space is known. In other cases, the aquifer may be so extensive relative to the area of interest that the modeled area may need to extend beyond the project area to accurately simulate the natural boundaries of the aquifer system. If the modeled area is arbitrarily truncated at some distance from the area of interest, it should be shown that the selection of the arbitrary boundary condition does not materially affect the ability of the model to simulate the system for the purposes of the study. Internal boundaries such as streams, lakes, and pinchouts of important hydrogeologic zones should be identified and their representation in the model should be described in the report. A clear, convincing argument of the appropriateness of the boundary conditions used in the model to represent the actual system should be made for the entire bounding surface of the modeled volume or cross section, as well as for any internal boundaries.

5. If the method of simulation involves discretizing the system (finite-difference and finite-element methods for example), describe and justify the discretized network used.

   The spacing and distribution of the blocks, elements, or subregions should reflect, in part, the spatial variability of the hydraulic parameters and the location of boundaries (for example streams, lakes, bed pinchouts), human-made features (for example wells and dams), and stresses. In most cases, a map showing the discretized network superimposed on the study area is required. Vertical discretization should be described and/or shown on illustrations. The manner in which time is discretized for transient models also should be described. If a steady-state model is used to simulate an average or approximate steady-state condition, discuss the errors that could be introduced in the study results as a consequence of using a steady-state model.

6. Describe the aquifer system properties that are modeled.

   Explain whatever inferences are made from field data and previous studies as to the spatial variation of hydraulic properties of aquifers and confining beds and how discretized values are computed throughout the simulated area. During model calibration (see item 9), modeled values are often changed; the final aquifer system properties that are modeled should be described in the report. This can be through maps or descriptions in the text. Lists of model arrays do not generally provide much understanding of the model and accordingly should not be included in the report unless it is expected that readers will want to repeat the simulations. If lists of arrays are included, they should usually be provided on electronic media. Note that Office of Ground Water Technical Memorandum No. 93.01 describes the separate requirement for archiving the complete model data sets used in ground-water projects.

7. Describe all the stresses modeled such as pumpage, evapotranspiration from ground water, recharge from infiltration, river stage changes, leakage from other aquifers, and source concentrations in transport models.

   The relations between observed and modeled stresses should be described. For example, it usually is desirable to provide a representative sample of actual pumping histories and the corresponding modeled pumping histories, although such information would not necessarily be provided for every pumped well. The manner in which stresses are averaged within the discretized time and space scheme should also be described. If a steady-state model is used to simulate an average or approximate steady-state condition, describe how the average stresses representing this system are calculated.

8. For transient models, describe the initial conditions that are used in the simulations.

   Ideally, a transient simulation will start from a steady-state condition, and the steady-state initial conditions will be generated by a steady-state simulation using the same model. In this case, the steady-state simulation must use the same hydraulic and stress parameters that are used in the transient simulation, except that the transient stresses are removed. In situations where it is not possible to start a transient model from a simulated steady-state condition, it is necessary to describe how the initial conditions were derived. It is also important to estimate the error in the derived values and the possible impact on the model results.

9. If a model is calibrated, present the calibration criteria, procedure, and results.

   Describe the source of the observed data to which model results are compared. Explain the appropriateness of using these data for model comparisons and the rationale for any adjustments made to actual observations when making the comparisons. For example, when steady-state models are used to simulate an approximate steady-state condition, it is important to explain to what extent the observations that have been made at specific points in time correspond to the approximate steady-state condition being simulated. Give a representative sample of the actual comparisons used for calibration, and show the locations of the observation points on maps. When the number of observations is extensive, locations of representative points can be shown. It is important to report and use as many types of data as possible for calibration. For example, in a flow model, both head and flow observations are desirable for use in calibration.

10. Discuss the limitations of the model's representation of the actual system and the impact those limitations have on the results and conclusions presented in the report.

    Evaluating the sensitivity of the computed model responses to changes in parameter values that reflect plausible parameter uncertainty helps to assess the model reliability. If the model is to be used to make specific projections, it is useful to estimate the impacts of the uncertainty of parameter values on the projections. In calibrated models, a concern is nonuniqueness, which is the extent to which other combinations of parameter values or configurations may result in an equally good fit to the observed data. Discuss the extent to which nonuniqueness may affect the use of the model in the study.

In summary, a report describing a study in which simulation is used should address the above topics; however, there is considerable flexibility in the form of such a report. The report should describe the purpose of the simulation and convince the reader that the use of simulation is credible. The report should further describe the system being simulated, the methods of simulation, and the data that are used.

William M. Alley
Chief, Office of Ground Water

Distribution: A, B, S, FO, PO

This memorandum supersedes Ground Water Branch Technical Memorandum No. 75.11

ATTACHMENT 27

ENVIRONMENTAL ENGINEERING SCIENCE
Volume 00, Number 00, 2018
Mary Ann Liebert, Inc.
DOI: 10.1089/ees.2017.0347

ORGINAL ARTICLE

Ranking Coal Ash Materials for Their Potential to Leach Arsenic and Selenium: Relative Importance of Ash Chemistry and Site Biogeochemistry

Grace E. Schwartz,[1,*,†,‡] James C. Hower,[2] Allison L. Phillips,[3] Nelson Rivera,[1]
Avner Vengosh,[4] and Heileen Hsu-Kim[1,*,‡]

[1]Department of Civil and Environmental Engineering, Duke University, Durham, North Carolina.
[2]Center for Applied Energy Research, University of Kentucky, Lexington, Kentucky.
[3]Levine Science Research Center, Nicholas School of the Environment, Duke University, Durham, North Carolina.
[4]Division of Earth and Ocean Sciences, Nicholas School of the Environment, Duke University, Durham, North Carolina.

Received: September 1, 2017 Accepted in revised form: December 15, 2017

Abstract

The chemical composition of coal ash is highly heterogeneous and dependent on the origin of the source coal, combustion parameters, and type and configuration of air pollution control devices. This heterogeneity results in uncertainty in the evaluation of leaching potential of contaminants from coal ash. The goal of this work was to identify whether a single leaching protocol could roughly group high-leaching potential coal ash from low-leaching potential coal ash, with respect to arsenic (As) and selenium (Se). We used four different leaching tests, including the Toxicity Characteristic Leaching Protocol (TCLP), natural pH, aerobic sediment microcosms, and anaerobic sediment microcosms on 10 different coal ash materials, including fly ash, lime-treated ash, and flue gas desulfurization materials. Leaching tests showed promise in categorizing high and low-leaching potential ash materials, indicating that a single point test could act as a first screening measure to identify high-risk ash materials. However, the amount of contaminant leached varied widely across tests, reflecting the importance of ambient conditions (pH, redox state) on leaching. These results demonstrate that on-site geochemical conditions play a critical role in As and Se mobilization from coal ash, underscoring the need to develop a situation-based risk assessment framework for contamination by coal ash pollutants.

Keywords: arsenic; biogeochemistry; coal ash; disposal; leaching potential; selenium

Introduction

Coal ash is composed primarily of three major solid waste streams: bottom ash, fly ash, and flue gas desulfurization (FGD) solids, and consists of a heterogeneous mixture of poorly to highly crystalline oxide phases of silicon, aluminum, calcium, and iron (Vejahati *et al.*, 2010). Both the major and minor elemental composition of coal ash are fundamentally determined by coal type and source, but combustion parameters and the configuration of air pollution control devices also influence how trace elements partition onto ash particles during combustion and particle capture processes (Vejahati *et al.*, 2010). Trace elements may either coprecipitate with the crystalline oxide matrices of the ash or condense from the flue gas onto the ash particles (Meij, 1994; Vejahati *et al.*, 2010).

The ability of fly ash particles to capture trace elements varies with particle surface area and flue gas temperature, with lower flue gas temperatures and high particle surface areas tending to increase trace element sorption or deposition on fly ash (Meij, 1994; Hower *et al.*, 1999). Trace element concentrations in the ash materials vary according to the point of collection in the combustion process. Volatile trace elements, such as cadmium, chromium, lead, nickel, zinc, copper, vanadium, mercury, arsenic, and selenium are one to two orders of magnitude more concentrated in fly ash relative to bottom ash (Meij, 1994). FGD processes also efficiently capture water-soluble species, and the waste slurry from FGD is enriched in the most volatile elements, which include boron, carbon, sulfur, chlorine, bromine, nitrogen, mercury, and selenium (Meij, 1994; Vejahati *et al.*, 2010; Córdoba *et al.*, 2012).

**Corresponding authors:* Grace E. Schwartz, Oak Ridge National Laboratory, PO Box 2008 MS6036, Oak Ridge, TN 37831-6036. *Phone:* (865) 241-2678; *Fax:* (865) 576-8646; *E-mail:* schwartzge@ornl.gov or Heileen Hsu-Kim, Department of Civil and Environmental Engineering, Duke University, 121 Hudson Hall, Durham, NC 27708. *Phone:* (919) 660-5109; *Fax:* (919) 660-5219; *E-mail:* hsukim@duke.edu

†*Current affiliation:* Oak Ridge National Laboratory, Environmental Sciences Division, Oak Ridge, Tennessee.

‡Member of the Association of Environmental Engineering and Science Professors.

The trace element content in coal ash is most fundamentally linked to the source, type, and chemistry of the feed coal. Coal chemistry varies by coal basin and also within coal basins and formations. In the United States, western coals, such as those from the Powder River Basin, are known for their low sulfate (<1% total sulfur) and low trace element content, whereas eastern coals tend to have higher sulfur content (Chou, 2012). Many trace elements in coal, such as arsenic (As), selenium (Se), antimony (Sb), mercury (Hg), and lead (Pb), are associated with sulfide minerals, particularly with pyrite (Finkelman, 1995; Kolker, 2012). Therefore, coals with high sulfur content also tend to have higher trace element content. Environmental damages have been reported for many trace element contaminants in coal ash due to improper disposal or ash spills (United States Environmental Protection Agency [US EPA], 2007). However, As and Se are of particular concern because of their propensity to leach during typical disposal scenarios and their potential for biomagnification in the food web of receiving water bodies (Luoma and Presser, 2009; Sharma and Sohn, 2009).

Previous studies show that the leachability of As and Se varies with the heterogeneity of ash material composition (Wang *et al.*, 2009; Hutchinson *et al.*, 2012; Izquierdo and Querol, 2012), and many leaching tests have been developed for coal ash in an attempt to account for diversity in leaching behavior for various contaminants. State and federal regulations guiding coal ash disposal have relied heavily on single point leaching tests, such as the EPA's Toxicity Characteristic Leaching Protocol (TCLP) (US EPA, 1992). With TCLP, the solid waste sample is leached overnight in an acidic solution (pH = 2.9 or 5.0), and then the supernatant is analyzed for target contaminants of concern. While this test might be appropriate for many cationic metals and for landfill waste disposal, due to its single point acidic assessment, it can greatly underestimate the leaching potential of oxyanion contaminants such as arsenate [As(V)] and selenite [Se(IV)] (Thorneloe *et al.*, 2010).

The Leaching Environmental Assessment Framework (LEAF) has been proposed as an alternative to TCLP, to better capture the pH-dependent leaching of oxyanion contaminants. The LEAF considers a range of pH values (2–13), liquid-to-solid ratios, and mass transfer rates of contaminants over compacted media (US EPA, 2012a, 2012b, 2013a, 2013b). Several leaching studies have also been conducted at the natural pH of ash materials in an attempt to better mimic the conditions found in coal ash impoundments (Catalano *et al.*, 2012; Izquierdo and Querol, 2012; Liu *et al.*, 2013). In sum, these leaching tests provide valuable information about the leaching behavior of contaminants under very specific conditions, but their applicability to field management scenarios is limited. The limitations of leaching tests are openly acknowledged by the EPA, which calls for the use of leaching tests in conjunction with field monitoring and geochemical modeling in formulating disposal plans (Kosson *et al.*, 2009, 2014). Nevertheless, regulations guiding disposal continue to heavily rely on leaching tests for solid waste classification.

With this research, we sought to determine whether coal ash materials could be grouped into high- and low-leaching potential categories based on ash material chemistry. We subjected 10 different coal ash materials to four different leaching tests: in deionized (DI) water at the natural pH of the coal ash, the TCLP, and aerobic and anaerobic sediment slurry microcosm tests. The natural pH and TCLP tests were chosen to represent established protocols for determining leaching potential, while the anaerobic and aerobic microcosm tests were chosen, based on previous work (Schwartz *et al.*, 2016a, 2016b), to be a closer representation of complex environmental conditions relevant for Se and As mobilization. The goal of this study was to determine whether these four leaching tests, which entailed a variety of leaching conditions and time points for assessment, could agree on the same high- and low-leaching potential rankings of the ash materials. The materials tested included seven fly ashes, one lime-treated fly ash sample, and two FGD samples. The leaching potential of the ash materials was then ranked for each test based on the amount of contaminant leached in 24 h per g of coal ash test.

Materials and Methods

Coal ash samples

Ash materials (summarized in Table 1) were collected from various power plants across the United States between 2012 and 2013. The samples were selected to represent a range of coal sources and chemical characteristics, including CaO, SO_3, Fe_2O_3, and trace element content. The samples represented the three major coal basins in the United States (~70–80% of annual coal production) (United States Energy Information Administration [US EIA], 2014) and a variety of common air pollution control devices and ash collection methods (US EPA, 2013c). The major mineral oxide content in the ash was characterized via X-ray fluorescence following the ASTM standard method for ash analysis (Table 1). Trace element content was determined via heated nitric acid digestion followed by inductively coupled plasma-mass spectrometry (ICP-MS) (Agilent 7700). Details on the sample preparation method can be found in the Supplemental Data section.

Natural pH leaching

Natural pH leaching procedure was adapted from LEAF Protocol Method 1316 (United States Environmental Protection Agency, 2012b). Each coal ash material was mixed with Milli-Q water (2 g dry ash to 30 mL Milli-Q water) and tumbled end over end at 28 RPM for 24 h. The samples were then centrifuged at 4,000 RPM for 10 min and the supernatant was decanted and a portion was measured for pH. The remaining supernatant was filtered through a 0.45-μm nylon syringe filter (VWR) and diluted and acidified for ICP-MS analysis with 1–2% nitric acid to ensure that pH <2. The ash materials were extracted in triplicate.

TCLP procedures

The TCLP testing procedure was adapted from EPA Method 1311 (US EPA, 1992). To determine which TCLP extraction fluid to use, 5 g of ash material was vigorously stirred in 96.5 mL of DI water for 5 min. The pH was measured and recorded and 3.5 mL of 1 M HCl (Trace metal grade; Fisher) was added to the mixture. The solution was stirred briefly, heated to 50°C, and held at 50°C for 10 min. The solution was allowed to cool to room temperature and the pH was measured. For pH <5, TCLP extraction fluid #1 was selected. For pH >5, TCLP extraction fluid #2 was selected. Supplementary Table S1 lists the TCLP extraction fluid used for each ash sample.

TABLE 1. ASH MATERIAL ORIGIN AND CHEMICAL CHARACTERISTICS

Sample code	Plant location	Collection year	Sample type	Coal source	Natural pH[a]	SiO_2%[b]	Al_2O_3%[b]	Fe_2O_3%[b]	CaO%[b]	SO_3%[b]	C%[b]	As (μg/g)[c]	Se (μg/g)[c]
FA1	Kentucky Plant #1	2013	Fly ash (ESP)	Illinois Basin	9.23	45.71	21.17	26.38	1.87	0.34	4.46	123	6
FA2	Tennessee Plant #1	2011	Fly ash (ESP)	Appalachian Basin	10.28	56.46	28.77	6.67	1.40	0.02	11.1	44	19
FA3	Kentucky Plant #2	2013	Fly ash	Appalachian Basin (Southeastern Kentucky)	8.70	51.84	29.61	10.85	1.24	<0.01	8.33	111	8.7
FA4	Missouri Plant #1	2013	Fly ash	Powder River Basin	11.96	29.49	16.56	4.80	31.1	3.93	2.85	8.6	6.0
FA5	Kentucky Plant #3	2012	Fly ash (Baghouse)	Wyoming Powder River Basin/western bituminous	11.51	44.94	25.29	5.51	14.1	1.49	4.82	9.26	5.21
FA6	New Mexico Plant #1	2013	Fly ash	Powder River Basin	12.24	62.30	23.14	5.64	4.57	0.19	2.71	22.8	5.5
FA7	Kentucky Plant #4	2012	Fly ash	Illinois Basin	10.85	49.54	21.78	17.32	5.22	3.10	<0.10	135	17
FA + L	Kentucky Plant #1	2013	Fly ash+lime	Illinois Basin	12.66	37.45	16.54	23.40	13.01	4.97	6.48	70	44
FGD1	Kentucky Plant #2	2013	FGD (Dry)	Appalachian Basin (Southeastern Kentucky)	11.93	28.76	15.11	6.74	25.23	22.56	4.93	74	12.9
FGD2	Kentucky Plant #5	2012	FGD (Wet)	Illinois Basin (Western Kentucky)	8.71	4.34	1.70	0.98	39.21	51.76	0.06	2.5	3.1

[a]Natural pH was determined by leaching the ash material at a 1:15 solid:liquid ratio in Milli-Q water for 24 h.
[b]Total element content as measured by X-Ray Fluorescence and reported as oxides.
[c]Measured by nitric acid digestion followed by ICP-MS.
ESP, electrostatic precipitator; FGD, flue gas desulfurization; ICP-MS, inductively coupled plasma-mass spectrometry.

TCLP extraction fluid #1 (pH 4.93 ± 0.05) was prepared with 5.7-mL glacial acetic acid (Fisher) and 64.3 mL of 1-M NaOH added to 1-L Milli-Q water. TCLP extraction fluid #2 (pH 2.88 ± 0.05) was comprised of 5.7-mL glacial acetic acid in 1-L of Milli-Q water. Each coal ash sample was leached at 2 g of dry fly ash to 40-mL extraction fluid. The mixtures were tumbled end over end at 30 ± 2 RPM for 18 h. The samples were then centrifuged at 4,000 RPM for 10 min. The supernatant was filtered through a 0.45-μm nylon syringe filter. The pH of the filtrate was measured, and the filtrate was parsed and preserved for ICP-MS analysis. The ash materials were extracted in triplicate.

Sediment/ash slurry microcosms

Microcosm experiment overview. The experiment entailed two sets of sediment incubation experiments: first under anaerobic conditions and next under aerobic conditions. The incubations ran 2 weeks with samples collected at 24 h and 14 days incubation time points. For both aerobic and anaerobic experiments, a sediment-water microcosm was prepared for each type of coal ash, which was added to a concentration of 25% (w/w) relative to sediment (dry weight basis). This concentration of coal ash was chosen to represent a realistic sediment-ash mixture from an ash spill scenario (Deonarine *et al.*, 2013). For each coal ash type, single slurries were prepared for anaerobic and aerobic experiments. Triplicate microcosms were prepared for the no-ash controls (sediment and water only) and for fly ash from Kentucky Plant #2 (FA3). The FA3 sample was chosen for the triplicate preparation due to the abundance of our supply.

Sediment and water for microcosms. Surface water and bulk sediment were collected for microcosm construction from Jordan Lake near Pittsboro, NC (35.705004°, −79.047544°) in October 2014. This sediment was selected because Jordan Lake was used as a reference lake in our previous field study on the impact of coal ash pond effluents in North Carolina lakes and rivers (Ruhl *et al.*, 2012).

Surface water was collected from the top 0.15 m and was stored in acid-clean plastic jugs. Bulk sediment was collected by hand from the top layer of sediment (approximately top 15 cm) and placed in a soap-cleaned (Micro-90) plastic bucket with screw top. The sediment and water were transported immediately to Duke University (<45 min) and stored at 4°C in the laboratory. The sediment and water were used to construct microcosms within 1 week of sampling. Major and trace elements in the sediments and water were quantified by nitric acid digestion followed by ICP-MS. The sediment As concentration was 3.58 μg/g and the Se concentration was 0.31 μg/g. Further sediment chemistry is shown in Supplementary Table S2.

Microcosm preparation. Sediment was thoroughly homogenized by stirring before microcosm construction. The surface water was amended with a carbon source (0.5-mM pyruvate and 0.5-mM acetate; Sigma-Aldrich), which was used to maintain microbial activity. For both the aerobic and anaerobic experiments, an extra sediment-only microcosm was prepared and amended with 6-mg/L resazurin (Sigma-Aldrich) to serve as an indicator of redox conditions for all of the microcosms in the respective experiments.

Anaerobic microcosms were constructed in 250-mL acid-washed and autoclaved glass jars with air-tight screw top lids. These microcosms were prepared by combining 68 g of wet sediment and 170 mL of N_2-purged surface water in an anaerobic chamber (Coy Labs) containing an ambient atmosphere of 90% $N_{2(g)}$, 5% $CO_{2(g)}$, and 5% $H_{2(g)}$. The microcosms were then sealed in the anaerobic chamber but were stored outside the chamber at room temperature (∼22°C) and were exposed to ambient laboratory light throughout the experiment. Anaerobic conditions ($E_H < -50$ mV) were achieved ∼7 days after microcosm construction, as indicated by the resazurin indicator turning from pink to a clear color (Tratnyek *et al.*, 2001). At this time, 11 g of coal ash sample was added to a designated microcosm, and the 2-week incubation with the ash was initiated. The microcosms were mixed end-over-end once every 1–2 days and before each sampling time point.

Aerobic microcosms contained the same amount of sediment and water as the anaerobic experiments, but were continuously purged with hydrated air inserted into the slurries through Teflon tubing. After 7 days of preincubation, coal ash was added to the aerobic microcosms. The microcosms were gently swirled to mix every 1–2 days.

Microcosm sampling after ash addition. Overlying water was collected from the microcosms at time points before (−1 h) and after the ash material addition (24 h, 14 days). For aerobic microcosms, the air bubblers were turned off during sampling, and the supernatant samples were immediately centrifuged at 3,000 RPM for 5 min and then filtered through a 0.2-μm nylon syringe filter (VWR). For anaerobic microcosms, the supernatant was sampled in an anaerobic glove box and directly filtered (no centrifugation).

The sample filtrate was split and preserved for analysis of major and trace elements via ICP-MS, major anions via Ion Chromatography (Dionex), Dissolved Organic Carbon (Shimadzu TOC-L), and pH. Whole slurry samples (4 mL) were taken at the 14-day time point for analysis of acid volatile sulfide. These aliquots were frozen at −20°C immediately after sampling. Further details on sample preservation and analysis can be found in the Supplementary Data section.

Statistical analyses

Linear correlation analyses were performed using the statistical software package *R* (GNU General Public License). For the microcosm linear correlations, the data sets (dissolved element concentrations and ash material total element concentrations) were assessed for normality using the Shapiro–Wilks test (significance cut off of $p = 0.05$) and $\log_{10}$ transformed as necessary. Linear correlations between microcosm data sets (Supplementary Table S1) were deemed significant if the model obtained a *p*-value of 0.05 or less.

Results and Discussion

Natural pH leaching

Natural pH (ash material leached with DI water) of the ash materials ranged between 8.7 and 12.7 (Table 1). Dissolved As and Se concentrations varied widely between the ash samples and were observed to range from less than the method detection limit (0.008 μg/L for As and 0.016 μg/L for Se) and up to 324 mg/L for As and 565 μg/L for Se (Fig. 1a). The percent of total As leached was very low—under 5% for all samples (Fig. 1b). The percent of total Se leached was much greater, with the majority of the materials leaching between 4% and 45% of total Se (Fig. 1b). There were no correlations between dissolved As and total As concentration in the ash materials or between dissolved Se and total Se concentration in the ash materials (Supplementary Fig. S1a, b).

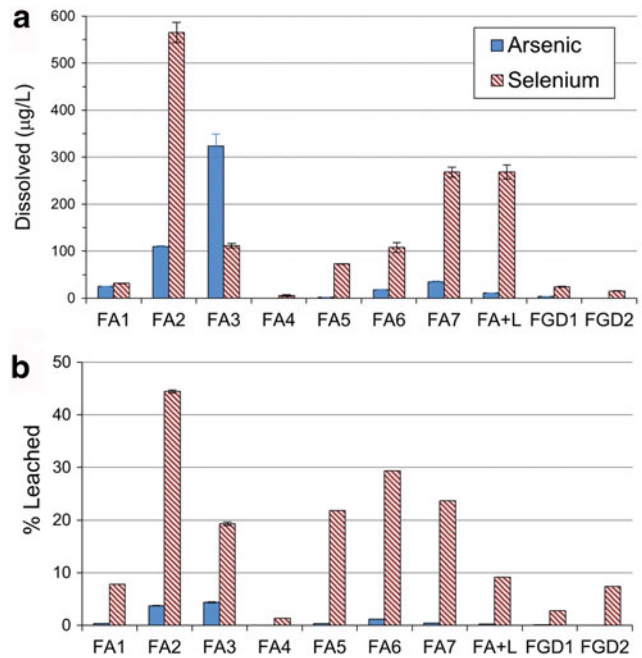


FIG. 1. Natural pH leaching results for ash materials mixed in Milli-Q water for 24 h: **(a)** dissolved arsenic and selenium. Each bar represents the average ± 1 standard deviation of triplicate leachates; **(b)** percent of the total As or Se leached from the ash material. Error bars represent the propagated standard error of measurements of leached As or Se and the total ash material As or Se. Bars with no error bars represent instances of a single measurement of total As or Se in the ash material.

Dissolved As and dissolved Se concentrations did not increase with the pH of the leachate. Arsenic was poorly correlated with pH, while Se showed no correlation ($R^2 = 0.29$ and 0.0031 for As and Se, respectively) (Supplementary Fig. S2). The CaO/SO_3 ratio in the ash material did correlate strongly with the natural pH of the fly ash samples (Supplementary Fig. S3a). However, there were no strong correlations between CaO/SO_3 ratio and dissolved As and Se concentrations in the natural pH leachate (Supplementary Fig. S3b, c).

Previous studies have shown that oxyanion leaching from ash materials is highly pH-dependent, with pH typically predicted by the Ca/S ratio (reported as CaO/SO_3) in the ash. CaO-rich ash materials generally produce alkaline waters (pH 11–13), which can enhance desorption of oxyanions such as As and Se from ash particles but also decrease dissolved As and Se concentrations through incorporation into secondary calcium precipitates (e.g., ettringite) (Wang *et al.*, 2009; Izquierdo and Querol, 2012). Ash materials with balanced CaO/SO_3 ratios produced mildly alkaline waters (pH 8–9) and may release some of the highest concentrations of As and Se due to pH-induced desorption from metal-oxide mineral phases

(Izquierdo and Querol, 2012). Ash materials with low CaO/SO_3 ratios would produce acidic waters and generally display lower As and Se leaching due to the strong sorption of As and Se oxyanions to metal-oxide mineral phases in the ash (Catalano *et al.*, 2012; Izquierdo and Querol, 2012).

Though the sorption affinity of As and Se to the fly ash particles generally decreases with solution pH when comparing sorption trends for a single sorbent, the same expectation may not necessarily hold when comparing across different sorbent types. The surface composition of the fly ash particles would also influence sorption/desorption processes. Moreover, secondary precipitates (such as Ca-arsenates) could be forming at high pH values, and the potential for these processes would also depend on fly ash composition.

TCLP leaching

All of the coal ash materials remained well under the maximum regulatory threshold limit for toxicity characteristic as defined by the TCLP test (5,000 μg/L for As and 1,000 μg/L for Se) (Fig. 2a). In general, more than 10% of the total Se in the ash materials leached during the TCLP test while As leaching was mostly below 10% (Fig. 2b). There was little correlation ($R^2 = 0.27$, $p = 0.13$) between the total amount of As in the ash materials and the amount leached by TCLP (Fig. 2c). The total amount of Se in the ash material was a much better predictor ($R^2 = 0.81$, $p = 0.0004$) of the amount of Se leached by TCLP (Fig. 2d).

Sediment/ash microcosms

Concentration of dissolved As in the microcosms varied considerably by ash material (Fig. 3a), with concentrations ranging from 2 to 72 μg/L at 24 h and 1 to 61 μg/L at 14 days in the anaerobic microcosms and 0.5 to 111 μg/L at 24 h and 0.7 to 41 μg/L at 14 days in the aerobic microcosms (Fig. 3a). The percentage of total As leached in the microcosms (Fig. 3b) was generally less than the %leached in both the Natural pH and TCLP tests. This result is likely due to re-adsorption of dissolved As onto sediment particles in the microcosm. Dissolved As generally increased over time in the anaerobic microcosm, while the trend was mixed in the aerobic microcosms. For some materials, dissolved As concentrations were greater in the anaerobic microcosms than the aerobic microcosms [consistent with our previous work (Schwartz *et al.*, 2016b)], but for other ash materials the opposite was observed (Supplementary Fig. S4). Thus, the

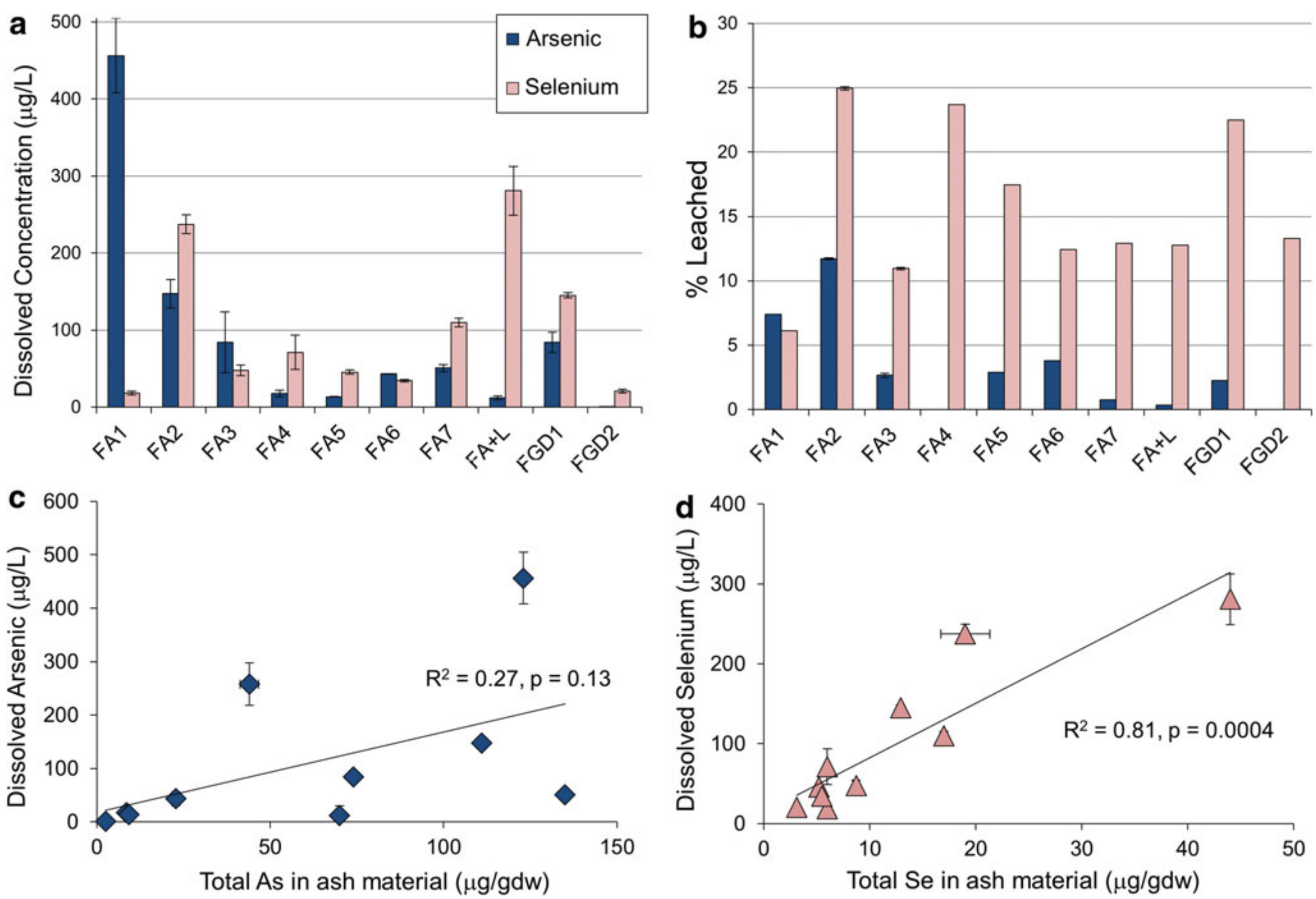


FIG. 2. TCLP leaching results for ash materials: **(a)** dissolved arsenic and selenium in TCLP leachate; **(b)** percent of total arsenic or selenium leached from ash material; **(c)** correlation between the total arsenic in ash material and the dissolved As in the TCLP leachate; and **(d)** correlation between the total Se in ash material and dissolved Se in TCLP leachate. Each bar and data point represents the average ± 1 standard deviation of triplicate leachates. Bars or data points with no error bars represent instances of a single measurement of total As or Se in the ash material. TCLP, Toxicity Characteristic Leaching Protocol.

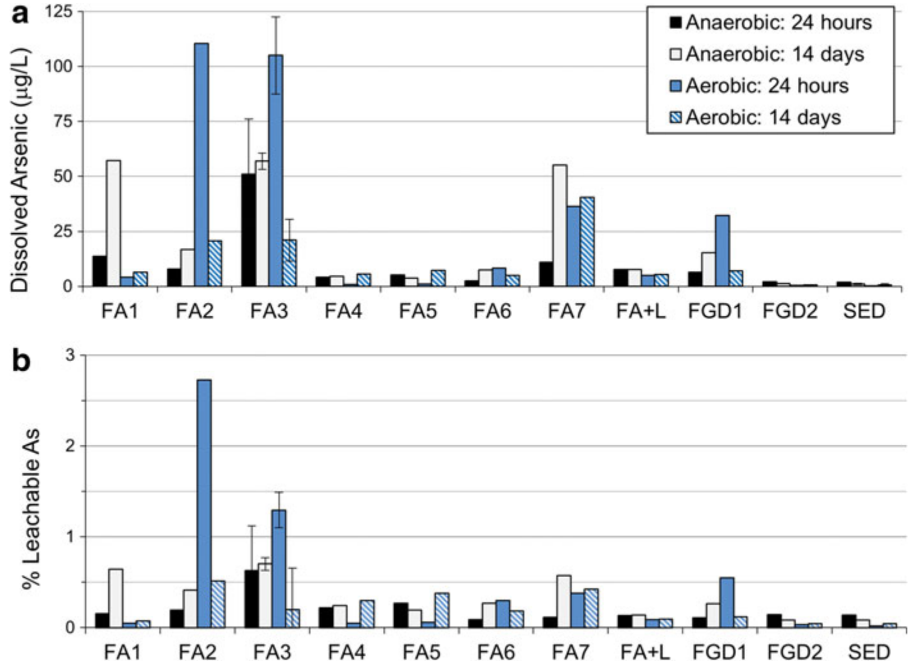


FIG. 3. **(a)** Total dissolved arsenic (0.2 μm filtered fraction) in sediment-ash microcosms. Bars represent single microcosms with exception of FA3 and SED (sediment only microcosm, no ash) where bars represent the average $\pm$ 1 standard deviation of triplicate microcosms; **(b)** percent of total As (sediment As+Ash As) leached. Bars with no error bars represent instances of a single measurement of total As or Se in ash material.

leaching of dissolved As in the microcosms could not be predicted solely by aerobic and anaerobic conditions.

Dissolved Se concentrations also varied between different ash materials. Values ranged from 4 to 123 μg/L at 1 day and 0.7 to 17 μg/L at 14 day in the anaerobic microcosms and 6 to 249 μg/L at 1 day and 5 to 99 μg L^{-1} at 14 d in the aerobic microcosms (Fig. 4a). The Se %leached in the microcosms was also generally lower than the %leached in the Natural pH and TCLP tests. This is again likely due to Se re-adsorption onto microcosm sediment particles. Selenium concentrations generally declined over time in both the anaerobic and aerobic microcosms. However, at both the 24-h and 14-day time points, dissolved Se concentration was generally greater in the aerobic microcosms relative to the anaerobic microcosms (Supplementary Fig. S5). In the anaerobic microcosms, the ash materials produced a pulse of Se at 24 h, which decreased to less than 20 μg/L at 14 days, suggesting that regardless of ash chemistry, anaerobic conditions were effective in limiting selenium solubility.

In the anaerobic microcosms, total dissolved As was generally correlated with the total arsenic content in the coal ash at both the 24-h and 14-day time points ($R^2 = 0.62$, $p = 0.007$ and $R^2 = 0.87$, $p < 0.001$, respectively; Fig. 5a). This relationship was even stronger at the 14 days time point when only fly ash samples with no lime treatment were considered ($R^2 = 0.98$, $p < 0.001$). In anaerobic microcosms, there was a

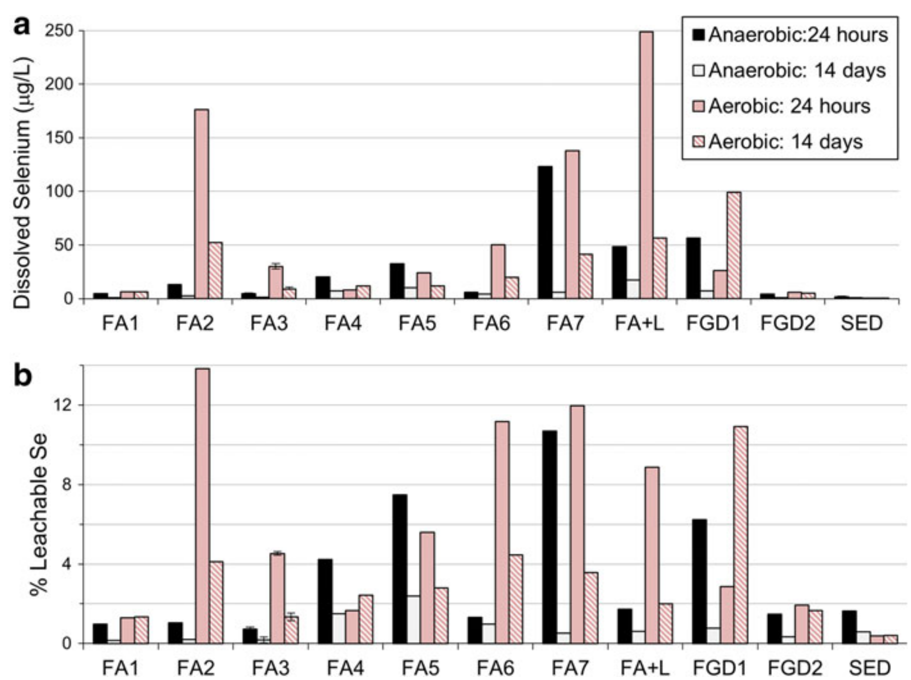


FIG. 4. **(a)** Total dissolved selenium (0.2 μm filtered fraction) in sediment-ash microcosms.. Bars represent single microcosms with the exception of FA3 and SED (sediment only microcosm, no ash) where bars represent the average $\pm$ 1 standard deviation of triplicate microcosms; **(b)** percent of the total Se (sediment Se+Ash Se) leached. Bars with no error bars represent instances of a single measurement of total As or Se in ash material.

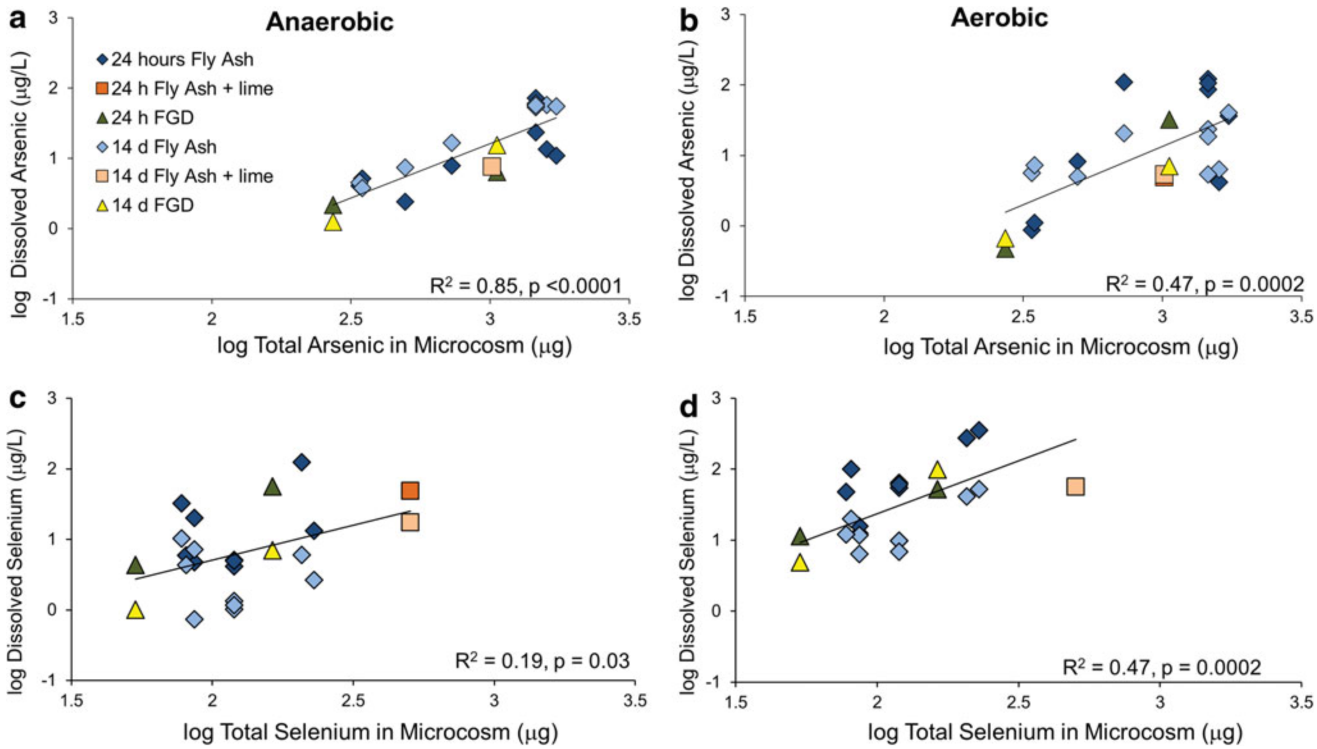


FIG. 5. Correlations between total element content in ash material and dissolved element content in sediment/ash slurry microcosms: **(a)** arsenic in anaerobic microcosms; **(b)** arsenic in aerobic microcosms; **(c)** selenium in anaerobic microcosms; and **(d)** selenium in aerobic microcosms. Each data point represents a single microcosm.

weak correlation between the percentage of the total As leached at 14 days in the microcosms and the total Fe content of the ash materials ($R^2=0.41$, $p=0.05$) (Supplementary Table S3). Yet, there was no correlation between dissolved As and dissolved Fe concentrations at either time point (Supplementary Table S3) as might be expected if the mechanism of As leaching occurred through the reductive dissolution of Fe oxides. The lack of correlation between dissolved As and dissolved Fe concentrations may be due to Fe precipitation reactions in the microcosms or Fe adsorption to the solid phase following reductive dissolution. Dissolved Se in the aerobic microcosms could generally be correlated with the total Se content of the ash material at both the 24-h and 14-day time points ($R^2=0.73$, $p=0.002$ and $R^2=0.64$, $p=0.005$, respectively; Fig. 5d). This relationship was not found in the anaerobic microcosms (Fig. 5c). No correlations were found between the dissolved Se content of the aerobic and anaerobic microcosms and Fe content.

The pH values in the microcosms varied with ash material, with the highest pH observed in the microcosm amended with lime-treated fly ash (FA+L) (Supplementary Fig. S6). In our microcosms, no significant correlations between CaO/SO_3 ratio and As and Se leaching magnitude were observed, likely due to pH buffering by the sediment/water in the slurries that maintained the pH at neutral to moderately alkaline conditions for most microcosms. The microcosm amended with lime-treated ash was the one exception to this buffering, and a high dissolved Se concentration was observed at the 24 h time point when the pH was highly alkaline (pH 12.29). Overall, pH did not appear to affect the percentage of arsenic and selenium leached from the ash materials (Supplementary Fig. S7).

Dissolved Ca concentrations in the microcosms varied by ash material, and with the exception of the microcosm amended with FA4, dissolved Ca concentrations were higher in aerobic microcosms compared to anaerobic microcosms (Supplementary Fig. S8). High Ca content in the ash material did not result in higher concentrations of dissolved calcium in either the aerobic or anaerobic microcosms (Supplementary Fig. S9). Furthermore, given similar concentrations of Ca in the ash material, FGD and lime-treated fly ash microcosms leached more calcium than fly ash-amended samples (FA4 and FA5). Calcium content of the ash material did not correlate with the percent leached for either As or Se (Supplementary Table S3).

Interaction between ash chemistry and redox conditions in microcosms

Measurements of dissolved sulfate and Fe in the microcosms indicated a clear difference in redox potential between the anaerobic and aerobic microcosms. Dissolved sulfate concentrations varied widely across ash material. Over 14 days, sulfate reduction appeared to occur in some microcosms but not in others (Supplementary Fig. S10). However, acid volatile sulfide concentrations in aerobic microcosms were one to two orders-of-magnitude lower relative to concentrations in the anaerobic microcosms, which ranged from 0.01 to 0.7 μmol/g of slurry (data not shown), confirming that there was a difference in redox potential between the aerobic and anaerobic microcosms.

Total dissolved Fe concentrations also varied by ash material and according to the redox condition in the microcosms. At the preamendment time point (−1 h), the anaerobic microcosms contained an average of 4.60 mg/L total dissolved Fe while the aerobic microcosms contained an average of 0.033 mg/L total dissolved Fe, indicating that Fe-reduction and Fe(II) release was occurring in the anaerobic microcosms (data not shown). At both 24 h and 14 days after ash addition, the anaerobic microcosms generally contained higher levels of total dissolved Fe (0.002–37 mg/L) than the aerobic microcosms (0.001–0.007 mg/L) (Supplementary Fig. S11a). The total Fe content of the ash material did not appear to correspond to the magnitude of iron released in either the anaerobic (Supplementary Fig. S11b) or the aerobic (Supplementary Fig. S11c) microcosms.

In these sediment/ash microcosms, changes in redox potential did not impact the mobility of As and Se to the same degree. In contrast to As, dissolved Se decreased over time in both the aerobic and anaerobic microcosms, indicative of different geochemical reaction pathways for the two elements. With Se, much greater amounts were leached under aerobic conditions, as would be expected from previous research (Schwartz *et al.*, 2016b). In anaerobic microcosms, an initial pulse of Se was released and then immobilized over the 14 days incubation. In general, anaerobic conditions appear effective in immobilizing Se, though an initial release of Se may still be a concern, depending on the flow dynamics of the system. Ash chemistry parameters, such as Fe and Ca contents, did not correlate with the amount of Se leached in the microcosms. Total Se in the ash material did correlate with dissolved Se in the aerobic microcosms, yet the strength of the correlation ($R^2 = 0.64$ at 14 days), indicates that other factors in addition to redox and total element content were influencing Se leaching potential in the microcosms.

Arsenic leaching could not be predicted based on redox potential. The lack of a consistent pattern in As leaching based on redox potential is different than the results of our previous work involving fly ash from Tennessee Plant #1 (FA2) (Schwartz *et al.*, 2016b). This previous study showed greater amounts of As leaching under anaerobic conditions and greater amounts of Se leaching under aerobic conditions. While the experimental designs in both studies were nearly identical, this study utilized sediment with an observable red color (37.1 mg/gdw Fe), whereas the microcosms in our previous study contained sediment with much lower Fe content (3.64 mg/gdw) and an observable brown color (suggesting greater organic carbon content).

The differences in sediment chemistry may have affected sorption of dissolved arsenic and selenium in the microcosms. Certain forms of As and Se such as arsenate and selenite species have a high affinity for Fe-oxide minerals (Balistrieri and Chao, 1990; Smedley and Kinniburgh, 2002), which could explain some differences with our previous experiment. Natural organic matter (NOM) can also impact As and Se solubility through competition for sorption sites, formation of oxyanion-NOM colloids that would fall in the ''dissolved'' fraction, direct oxidation/reduction reactions with As and Se, and indirect effects such as organic substrate type and availability that could influence redox potential (Redman *et al.*, 2002; Gadd, 2004; Wang and Mulligan, 2006; Sharma *et al.*, 2015). Differences in the sediment microbial community structure impact contaminant mobility as microbes can mobilize contaminants either through direct oxidation and reduction reactions or indirectly through the reduction of iron oxides and minerals (Gadd, 2004). Together these results highlight the complexities associated with using sediment microcosms for leaching assessments.

In our limited dataset, the As leaching results from our microcosms showed that ash chemistry, particularly the total arsenic content of the material might be used to predict As leaching potential from coal ash in anaerobic scenarios. Previous leaching studies utilizing the LEAF tests and mimicking ash impoundment leaching scenarios have not observed a relationship between total element concentration in coal ash and the magnitude of element leaching—perhaps because they were conducted under aerobic conditions (Thorneloe *et al.*, 2010; Catalano *et al.*, 2012). During coal combustion, As is volatilized into the flue gas stream and then condenses on the surface of aluminosilicate particles as the flue gas cools (Hulett *et al.*, 1980). These aluminosilicate phases can have Fe microdomains. Since As has a high affinity for iron oxide minerals (Smedley and Kinniburgh, 2002), association with Fe-rich aluminosilicates is possible (Veselská *et al.*, 2013). When the ash material is exposed to anaerobic conditions, it could result in the reductive dissolution of Fe phases and the release of As into solution. This would explain the much higher concentrations of dissolved As in our anaerobic microcosms compared with the aerobic microcosms and would explain the correlation between total As content in the ash and dissolved As in the leachates under anaerobic conditions. The much greater concentrations of dissolved Fe in the anaerobic microcosms also provide further evidence for As release by reductive dissolution of Fe phases. The correlation between total As content in fly ash and dissolved As under anaerobic conditions ($R^2 = 0.98$ at 14 days) in our dataset indicates that total As content of the fly ash might be used as a first approximation of As leaching risk from fly ash in an ash spill situation where the ash may mix with anaerobic sediments.

In sum, As leaching chemistry from coal ash appears to be very complex and highly influenced by environmental parameters, such as sediment organic content, pH, redox state, and soil microbial community, which drives soil redox conditions. It would be difficult to construct leaching models to predict As mobilization for a generalized ash spill and/or disposal situations. More information is needed regarding ambient conditions at the site such as the mixing of ash materials with sediments as well as the sediment types and their levels of organic carbon. Arsenic also undergoes multiple sorption and desorption reactions and precipitation reactions. These reactions can occur at different timescales and cause increases and decreases of dissolved concentrations, which brings into question whether coal ash leaching potential can reasonably be assessed by single time point leaching protocols under environmentally relevant conditions. The maximum dissolved As concentrations were typically observed after 24 h in most of the aerobic microcosms, but maximum dissolved concentrations were observed at 14 days for most of the anaerobic microcosms. If leaching potential is assessed at only 24 h, the risk of As leaching may be underestimated in some scenarios.

Ranking leaching potential

To assess leaching potential, we compared the results of the four leaching tests in two ways: (1) comparing the amount of leached As or Se per g of ash tested, and (2) comparing the percent leached of the total As and total Se. The amount of leachable As or Se per g of ash for any given ash material varied widely across tests, indicating the important role of geochemical conditions in leaching (Supplementary Fig. S12). The percent of contaminant leached for each ash also varied across tests, and the percent of Se leached was noticeably higher than As, as noted in the previous section. This result suggests that Se on the ash is more reactive and susceptible to leaching regardless of the geochemical conditions.

Comparative leaching potentials were evaluated by ranking the 10 ash samples based on their leachable As and Se contents (per g ash) in each assay. In this respect, the materials were assigned an integer from 1 to 10, with 10 corresponding to the highest amount leached per g ash (defined as the highest leaching potential) and 1 corresponding to the lowest amount leached per g ash (i.e., the smallest leaching potential) for each test (Fig. 6). The four leaching tests gave reasonably good agreement in categorizing the ash materials. For As, three out of four tests agreed in ranking FA2, FA3, and FA7 as having the highest leaching potential, and FA4, FA5, and FGD2 as having the lowest leaching potential (Supplementary Fig. S13). For Se, three out of four tests agreed in ranking FA2, FA7, and FA + L as having the highest leaching potential, and FA1 and FGD2 as having the lowest leaching potential (Supplementary Fig. S13). Only one ash material, FGD1, was categorized by the tests as having both a high and low leaching potential. Two ash materials (FA2 and FA7) were predicted to be high leaching potential for both As and Se.

Ash materials were also ranked according to the % of total As and % of total Se that leached in each assay. The ranking of the ashes with high percentages and ashes with low percentages were not as consistent between the tests. For example, all four tests categorized FA2 as high % leachable As and three out of four tests ranked FA4 and FGD2 as low %leachable As (Supplementary Fig. S14). However, three ash materials (FA4, FA6, and FGD1) appeared in both high- and low-risk categories. For Se, three out of four tests categorized FA2 as high % leachable Se, and there was little agreement (only two out of four tests) on the lowest leaching potential ashes (Supplementary Fig. S15). Four ash materials appeared in both the low and high categories for %leachable Se (FA2, FA4, FA6, and FGD1). The inconsistency of rankings based on % leachable Se and As highlight the importance of environmental conditions for understanding the degree of soluble Se and As in coal ash.

Future directions for predicting disposal risks

Results of the ash rankings based on leachable As and leachable Se (per g ash) were generally consistent between the tests despite the relative simplicity of the protocols. This result suggests that a 24-h single point leaching test of leachable As and leachable Se content could give a good first estimate of leaching potential and may present a way to identify ash samples for more in depth risk assessment. Yet, to develop a true understanding of the magnitude of potential leaching, it is crucial to select a leaching test that adequately mimics the ash disposal or spill scenario.

Our results demonstrate that geochemical conditions greatly impact the overall amount of contaminant leached for both As and Se, and the selection of just one test to assess leaching potential could result in an underestimate of leaching if that test is not representative of disposal conditions. Current

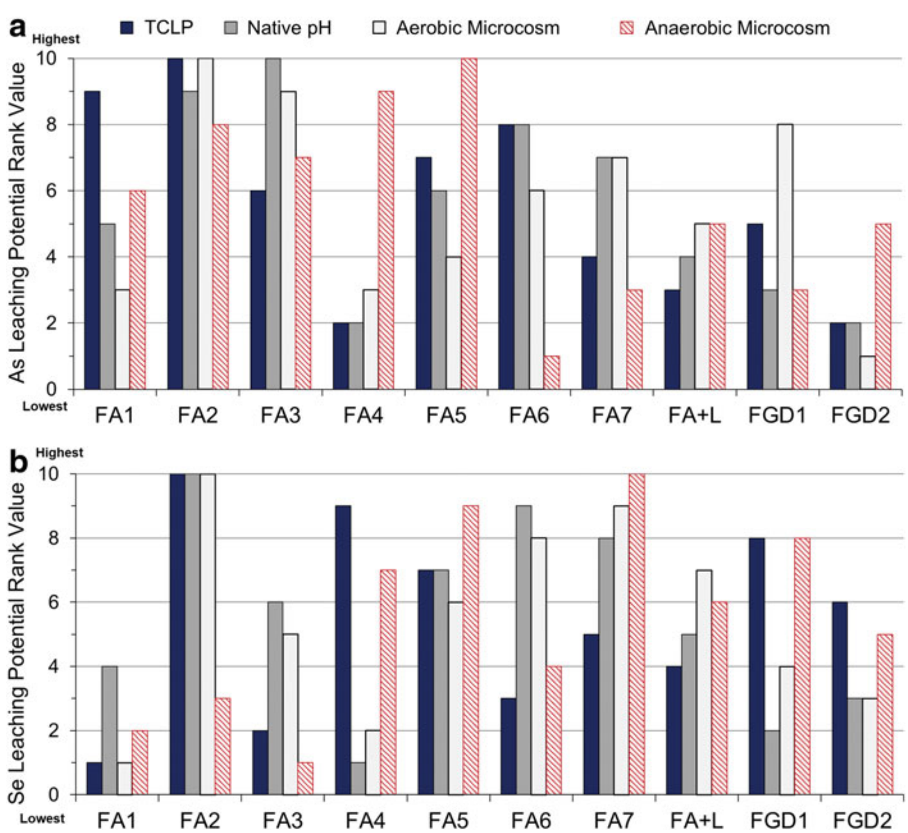


FIG. 6. Comparison of 10 coal ash samples tested in leaching studies (TCLP, DI water leaching, and sediment/ash microcosm tests). Ash samples were assigned integer values between 1 and 10 based on **(a)** leachable arsenic per g of ash; and **(b)** leachable selenium per g of ash at the 24 h time point for each leaching test.

disposal options for coal ash consist of wet storage in impoundments and dry landfilling in either monofills or, less-frequently, in mixed compartments with municipal waste. Each of these disposal scenarios presents a unique geochemical environment that varies from site to site. Given these complexities, perhaps the best approach for assessing coal ash disposal risk is to move toward a situational framework. Just as the National Pollution Discharge Elimination System (NPDES) permits in the United States are written specifically for individual outfalls from power plants, a coal ash disposal plan could also be tailored for the specific conditions of the coal ash disposal sites. In this way, disposal requirements could be written for specific elements of interest given the typical coal source, combustion parameters, air pollution capture devices of the particular plant, and disposal track for solid wastes. Site-specific, situational risk assessments present the best option for ash materials, especially for contaminants such as As and Se that are known to undergo multiple biogeochemical transformations that influence mobility and exposure.

Acknowledgments

We thank Kaitlyn Porter for her assistance with ICP-MS measurements. This work was supported by the National Science Foundation (CBET-1235661 and CBET-1510965). G.E.S. was partly supported by a doctoral scholarship from the Environmental Research and Education Foundation. The effort of A.L.P. was supported by Duke's Program in Environmental Health (ITEHP) Training Grant from the National Institute of Environmental Health Sciences (T32-ES021432).

Supporting Information

The supporting information contains additional descriptions of sample preparation and analysis, statistical data, additional figures on microcosm geochemistry, and correlations between the individual leaching tests.

Author Disclosure Statement

No competing financial interests exist.

References

Balistrieri, L.S., and Chao, T.T. (1990). Adsorption of selenium by amorphous iron oxyhydroxide and manganese dioxide. *Geochim. Cosmochim. Acta.* 54, 739.

Catalano, J.G., Huhmann, B.L., Luo, Y., Mitnick, E.H., Slavney, A., and Giammar, D.E. (2012). Metal release and speciation changes during wet aging of coal fly ashes. *Environ. Sci. Technol.* 46, 11804.

Chou, C.-L. (2012). Sulfur in coals: A review of geochemistry and origins. *Int. J. Coal Geol.* 100, 1.

Córdoba, P., Ochoa-Gonzalez, R., Font, O., Izquierdo, M., Querol, X., Leiva, C., López-Antón, M.A., Díaz-Somoano, M., Rosa Martinez-Tarazona, M., Fernandez, C., *et al.* (2012). Partitioning of trace inorganic elements in a coal-fired power plant equipped with a wet Flue Gas Desulphurisation system. *Fuel* 92, 145.

Deonarine, A., Bartov, G., Johnson, T.M., Ruhl, L., Vengosh, A., and Hsu-Kim, H. (2013). Environmental impacts of the Tennessee Valley Authority Kingston coal ash spill. 2. Effect of coal ash on methylmercury in historically contaminated river sediments. *Environ. Sci. Technol.* 47, 2100.

Finkelman, R.B. (1995). Modes of occurrence of environmentally-sensitive trace elements in coal. In D.J. Swaine and F. Goodarzi, Eds., *Environmental Aspects of Trace Elements in Coal*. Springer: Springer Netherlands, pp. 24–50.

Gadd, G.M. (2004). Microbial influence on metal mobility and application for bioremediation. *Geoderma* 122, 109.

Hower, J.C., Trimble, A.S., Eble, C.F., Palmer, C.A., and Kolker, A. (1999). Characterization of fly ash from low-sulfur and high-sulfur coal sources: Partitioning of carbon and trace elements with particle size. *Energ Sources* 21, 511.

Hulett, L.D., Weinberger, A.J., Northcutt, K.J., and Ferguson, M. (1980). Chemical species in fly ash from coal-burning power plants. *Science* 210, 1356.

Hutchinson, T.J., Basappa, L., Dikshit, A., Luo, Y., Catalano, J.G., and Giammar, D.E. (2012). Fate of metals in fly ash during aging in laboratory-scale ash impoundments. *Environ. Eng. Sci.* 29, 1085.

Izquierdo, M., and Querol, X. (2012). Leaching behaviour of elements from coal combustion fly ash: An overview. *Int. J. Coal Geol*. 94, 54.

Kolker, A. (2012). Minor element distribution in iron disulfides in coal: A geochemical review. *Int. J. Coal Geol.* 94, 32.

Kosson, D.S., Sanchez, F., Kariher, P., Turner, L.H., Delapp, R., and Seignette, P. (2009). *Characterization of Coal Combustion Residues from Electric Utilities—Leaching and Characterization Data*. EPA Office of Research and Development, Ed. National Risk Management and Research Laboratory, Research Triangle Park, NC.

Kosson, D.S., van der Sloot, H.A., Garrabrants, A.C., and Seignette, P. (2014). *Leaching Test Relationships, Laboratory-to-Field Comparisons and Recommendations for Leaching Evaluation Using the Leaching Environmental Assessment Framework (LEAF)*. Cincinnati, OH: Report US Environmental Protection Agency.

Liu, Y.-T., Chen, T.-Y., Mackebee, W.G., Ruhl, L., Vengosh, A., and Hsu-Kim, H. (2013). Selenium speciation in coal ash spilled at the Tennessee Valley Authority Kingston site. *Environ. Sci. Technol.* 47, 14001.

Luoma, S.N., and Presser, T.S. (2009). Emerging opportunities in management of selenium contamination1. *Environ. Sci. Technol*. 43, 8483.

Meij, R. (1994). Trace element behavior in coal-fired power plants. *Fuel Process. Technol.* 39, 199.

Redman, A.D., Macalady, D.L., and Ahmann, D. (2002). Natural organic matter affects arsenic speciation and sorption onto hematite. *Environ. Sci. Technol.* 36, 2889.

Ruhl, L., Vengosh, A., Dwyer, G., Hsu-Kim, H., Schwartz, G., Romanski, A., and Smith, S.D. (2012). The impact of coal combustion residue effluent on water resources: A North Carolina example. *Environ. Sci. Technol*. 46, 12226.

Schwartz, G.E., Redfern, L.K., Ikuma, K., Gunsch, C.K., Ruhl, L.S., Vengosh, A., and Hsu-Kim, H. (2016a). Impacts of coal ash on methylmercury production and the methylating microbial community in anaerobic sediment slurries. *Environ. Sci. Process. Impacts* 18, 1427.

Schwartz, G.E., Rivera, N., Lee, S.-W., Harrington, J.M., Hower, J.C., Levine, K.E., Vengosh, A., and Hsu-Kim, H. (2016b). Leaching potential and redox transformations of arsenic and selenium in sediment microcosms with fly ash. *Appl. Geochem*. 67, 177.

Sharma, V.K., McDonald, T.J., Sohn, M., Anquandah GAK, Pettine, M., and Zboril, R. (2015). Biogeochemistry of selenium. A review. *Environ. Chem. Lett*. 13, 49.

Sharma, V.K., and Sohn, M. (2009). Aquatic arsenic: Toxicity, speciation, transformations, and remediation. *Environ. Int*. 35, 743.

Smedley, P.L., and Kinniburgh, D.G. (2002). A review of the source, behaviour and distribution of arsenic in natural waters. *Appl. Geochem.* 17, 517.

Thorneloe, S.A., Kosson, D.S., Sanchez, F., Garrabrants, A.C., and Helms, G. (2010). Evaluating the fate of metals in air pollution control residues from coal fired power plants. *Environ. Sci. Technol.* 44, 7351.

Tratnyek, P.G., Reilkoff, T.E., Lemon, A.W., Scherer, M.M., Balko, B.A., Feik, L.M., and Henegar, B.D. (2001). Visualizing redox chemistry: Probing environmental oxidation–reduction reactions with indicator dyes. *Chem. Educ*. 6, 172.

United States Energy Information Administration. (2014). *Spot Coal Price Trends Vary Across Key Basins During 2013*. Available at: www.eia.gov/todayinenergy/detail.php?id=14631 (accessed August 31, 2017).

United States Environmental Protection Agency. (1992). *Method 1311: Toxicity Characteristic Leaching Procedure*. Washington, DC: United States Environmental Protection Agency.

United States Environmental Protection Agency. (2007). *Coal Combustion Waste Damage Assessments*. Available at: http://graphics8.nytimes.com/packages/pdf/national/07sludge_EPA.pdf (accessed August 31, 2017).

United States Environmental Protection Agency. (2012a). *Method 1313: Liquid Solid Partitioning as a Function of Extract pH using a Parallel Batch Extraction Procedure*. Washington, DC: United States Environmental Protection Agency.

United States Environmental Protection Agency. (2012b). *Method 1316: Liquid-Solid Partitioninig as a Function of Liquid-to-Solid Ratio in Solid Materials Using a Parallel Batch Procedure*. Washington, DC: United States Environmental Protection Agency.

United States Environmental Protection Agency. (2013a). *Method 1314: Liquid-Solid Partitioning as a Function of Liquid-Solid Ratio for Constituents in Solid Materials Using an Up-Flow Percolation Column Procedure*. Washington, DC: United States Environmental Protection Agency.

United States Environmental Protection Agency. (2013b). *Method 1315: Mass Transfer Rates of Constituents in Monolithic or Compacted Granular Materials Using a Semi-Dynamic Tank Leaching Procedure*. Washington, DC: United States Environmental Protection Agency.

United States Environmental Protection Agency. (2013c). *Technical Development Document for the Proposed Effluent Limitations Guidelines and Standards for the Steam Electric Power Generating Point Source Category*. Washington, DC: United States Environmental Protection Agency.

Vejahati, F., Xu, Z., and Gupta, R. (2010). Trace elements in coal: Associations with coal and minerals and their behavior during coal utilization—*A review. Fuel* 89, 904.

Veselská, V., Majzlan, J., Hiller, E., Peťková, K., Jurkovič, Ľ., Ďurža, O., and Voleková-Lalinská, B. (2013). Geochemical characterization of arsenic-rich coal-combustion ashes buried under agricultural soils and the release of arsenic. *Appl. Geochem.* 33, 153.

Wang, S., and Mulligan, C.N. (2006). Effect of natural organic matter on arsenic release from soilsand sediments into groundwater. *Environ. Geochem. Health* 28, 197.

Wang, T., Wang, J., Tang, Y., Shi, H., and Ladwig, K. (2009). Leaching characteristics of arsenic and selenium from coal fly ash: Role of calcium. *Energ Fuels* 23, 2959.

ATTACHMENT 28

ian.magruder@nremontana.com

From:	Tolaymat, Thabet <Tolaymat.Thabet@epa.gov>
Sent:	Thursday, June 11, 2020 6:32 AM
To:	ian.magruder@nremontana.com
Subject:	RE: Hydrologic Evaluation Landfill Performance (HELP) Model

Yes that is right. Let me know if you have any more questions.
Thabet

From: ian.magruder@nremontana.com <ian.magruder@nremontana.com>
Sent: Wednesday, June 10, 2020 5:40 PM
To: Tolaymat, Thabet <Tolaymat.Thabet@epa.gov>
Subject: RE: Hydrologic Evaluation Landfill Performance (HELP) Model

Thanks that does make sense. The point being that the modeled vertical slice of the landfill must actually be above the water table. The flux from groundwater on the bottom 20 ft would be modeled using a different technique. Do I Have that correct?

Ian Magruder
(406) 439-0049
northernrockiesengineering.com

From: Tolaymat, Thabet <Tolaymat.Thabet@epa.gov>
Sent: Wednesday, June 10, 2020 1:28 PM
To: ian.magruder@nremontana.com
Subject: RE: Hydrologic Evaluation Landfill Performance (HELP) Model

Ian
Good question, you are right but there are ways around it. It is difficult to say what you can do but if the landfill is 200ft deep and the bottom 20ft are below the groundwater, then you can change the simulated depth of the landfill in the HELP model to 180ft and assume that the bottom 20ft are not with the waste mass. That would give you the flux from the unsaturated waste mass. Then you would add on top of that the flux from the ground water passing through the bottom 20 ft of waste. Does that make sense?
Thabet

____

Thabet Tolaymat Ph.D., P.E.
USEPA Office of Research and Development
Center for Environmental Solutions and Emergency Response
Cincinnati Ohio 45232
(513) 487-2860

From: ian.magruder@nremontana.com <ian.magruder@nremontana.com>
Sent: Wednesday, June 10, 2020 3:19 PM
To: Tolaymat, Thabet <Tolaymat.Thabet@epa.gov>
Subject: Hydrologic Evaluation Landfill Performance (HELP) Model

Hello Thabet, I have a question about application of the HELP model. Is this model appropriate for modeling leachate flux to groundwater in a landfill where the bottom layer of the landfill is in contact with groundwater? I believe this would violate the free drainage assumption and another model should be used. Can you help with this question?

Ian Magruder
(406) 439-0049
northernrockiesengineering.com

ATTACHMENT 29

The Leaching Behavior of Arsenic from Fly Ash

Joel Burken
Missouri University of Science and Technology

Heng Ban
University of Pittsburgh

Report for 2004MO34B: The Leaching Behavior of Arsenic and Selenium from Fly Ash and Their Potential Impact on Water Quality

- Conference Proceedings:
  - Wang, T., Wang, J., Chusuei, C., and Ban, H. (2005) Release of Arsenic from Coal Fly Ash Surface. 229th ACS San Diego National Meeting, San Diego, California, USA (March, 2005).
  - Wang, T., Wang, J., Burken, J., and Ban, H. The Leaching Behavior of Arsenic from Fly Ash. 2005 World of Coal Ash, Lexington, Kentucky, USA (April, 2005).

Report Follows

The Leaching Behavior of Arsenic from Fly Ash

Tian Wang[1], Jianmin Wang[1], Joel Burken[1], and Heng Ban[2]

[1]University of Missouri – Rolla, Department of Civil, Architectural & Environmental Engineering, Rolla, MO 65409; [2]University of Alabama at Birmingham, Department of Mechanical Engineering, Birmingham, AL 35294

KEYWORDS: arsenic, fly ash, leaching

ABSTRACT

The Maximum Contaminant Level (MCL) for arsenic in drinking water will be reduced to 10 ppb from the current 50 ppb level effective January 2006. Fly ash contains arsenic and could be a potential source of arsenic release to the environment. Understanding the leaching behavior of arsenic from fly ash is significant in predicting the arsenic impact on the drinking water quality and in developing innovative methods to prevent arsenic leaching.

The physical-chemical characteristics of three bituminous coal fly ashes (AN/Col #1, AN/Col #2 and AN/NRT #2) were studied using titration method and XPS analysis. AN/Col #1 and AN/Col #2 were obtained from different units burning the same coal. AN/Col #1 employed SNCR (selective non-catalytic reduction) for NOx control, and AN/Col #2 did not. AN/NRT #2 was collected from the same unit as AN/Col #2, but a different, higher calcium coal. Three acid sites were found on the surfaces of the fly ash, but only the first acid site, site α, was considered to be responsible for arsenic adsorption. XPS data indicated that the major elements on ash surface are C, O, Al and Si. Minor and trace elements Ca, As, and Se were also detected. Batch results indicated that pH has significant effect on arsenic leaching. Between pH 3 and 7, arsenic leaching is at a minimum. When pH was less than 3 or greater than 7, a significant amount of arsenic was leached from fly ash. More arsenic was leached out from ash AN/NRT #2 than ashes AN/Col #1 and AN/Col #2. However, the arsenic leaching from AN/NRT #2 was reduced when pH was greater than 9, which may be caused by the precipitation with calcium and other cations. We developed an arsenic adsorption model based on chemical reactions among different arsenic species and surface sites to quantify arsenic partitioning in fly ash. The pH-independent adsorption constants (log K_s) for $H_2AsO_4^-$ and $HAsO_4^{2-}$ were determined to be 2.6 and 6.2 respectively. The approach developed in this research is useful for understanding and predicting the release of arsenic from fly ash and other solid materials.

INTRODUCTION

The USEPA has recently reduced the Maximum Contaminant Level (MCL) for arsenic in drinking water to 10 ppb from 50 ppb, and all drinking water systems must comply with this new standard by January 2006.[1] Fly ash contains various levels of elements including arsenic.[2,3] For bituminous coal fly ash, the arsenic concentration can range from 1 to 1000 ppm, depending on coal source and combustion technology.[4] In 2003, a total of 122 million tons of Coal Combustion Products (CCPs) were generated in the US, and 58% of the CCPs were fly ash.[5] The release of arsenic from fly ash could lead to concentrations in drinking water that are above the new MCL. Understanding the leaching behavior of arsenic from fly ash is significant in understanding the potential arsenic impact on the drinking water quality, and in developing innovative methods to prevent arsenic leaching.

According to previous research with leaching tests and XPS analysis, arsenic was confirmed to be enriched on ash surface.[6,7] Both As(III) and As(V) were detected in ash, but the latter was present in a much higher fraction.[7,8] Various leachants, including HNO_3, H_2SO_4, sodium citrate, geopolymer, and EDTA were used to leach the arsenic from fly ash.[7,9,10,11] It was reported that 78-97% of the total As can be removed from fly ash by leaching with 0.5 N H_2SO_4 or a 1 M sodium citrate at pH 5.[7]

Many factors can influence the leaching of arsenic from fly ash, including pH, solid to liquid ratio, leaching time, temperature, etc.[11,12] Research also suggested that $H_2PO_4^-$ can displace arsenate in fly ash and increase arsenic concentration in leachate.[13]

Several mechanisms were proposed to interpret arsenic interactions with fly ash and the surrounding environment. Van der Hoek et al. reported that the leaching of As from acidic ash was sorption controlled and that iron hydroxide was the probable controlling sorbent.[14] However, other study suggested that calcium arsenate is a probable host for arsenic in fly ash.[15]

A surface complexation model was used to quantitatively describe the adsorption of arsenic on acidic fly ash.[16, 17] However, the modeling results were strongly dependent on the initial assumptions, and only amorphous iron hydroxide was considered in modeling. These factors limited the application potential of the model on fly ash.

The objectives of this study are to investigate the physical-chemical characteristics of fly ash, evaluate the leaching behavior of arsenic from fly ash, demonstrate the relationship between the surface characteristics and arsenic adsorption, and quantify the arsenic adsorption behavior by fly ash.

THEORETICAL ASPECTS

Ash Surface Speciation

According to Wang, et al.,[18] there are three types of weak acid sites on the fly ash surface. The protonated form of the first acid site, site α, which has the lowest pK_a value, is positively charged. Therefore, protonated form of the site α is most likely the one to adsorb anionic metal ions. The speciation of this acid site can be expressed as:

$\underline{S}OH_2^+ = \underline{S}OH + H^+; K_H$ (1)

where K_H is the acidity constant of the surface site $\underline{S}OH_2^+$.

The positively charged surface site concentration can be expressed as:

$$[\underline{S}OH_2^{+}] = \alpha_+ S_T \quad (2)$$

where S_T is the total site α density, and $\alpha_+ = \frac{[H^+]}{[H^+] + K_H}$

As(V) Speciation

In water solution, As(V) may exist as the following species:

$H_3AsO_4 = H_2AsO_4^- + H^+$; $pK_{a1} = 2.26$; $[H_2AsO_4^{-}] = \alpha_1[As(V)]_D$ (3)

$H_2AsO_4^- = HAsO_4^{2-} + H^+$; $pK_{a2} = 6.76$; $[HAsO_4^{2-}] = \alpha_2[As(V)]_D$ (4)

$HAsO_4^{2-} = AsO_4^{3-} + H^+$; $pK_{a3} = 11.29$; $[AsO_4^{3-}] = \alpha_3[As(V)]_D$ (5)

Where α_1, α_2 and α_3 are the fractions of As(V) as $H_2AsO_4^-$, $HAsO_4^{2-}$, and AsO_4^{3-}, respectively. $[As(V)]_D$ is the total dissolved As(V) concentration.

As(V) Adsorption Reactions

Assuming that only the negatively charged arsenic species are adsorbed on the positively charged ash surface sites:

$\underline{S}OH_2^+ + H_2AsO_4^- = \underline{S}\text{-}H_2AsO_4 + H_2O; K_{S1};$ (6)

$\underline{S}OH_2^+ + HAsO_4^{2-} = \underline{S}\text{-}HAsO_4^- + H_2O; K_{S2};$ (7)

$\underline{S}OH_2^+ + AsO_4^{3-} = \underline{S}\text{-}AsO_4^{2-} + H_2O; K_{S3};$ (8)

Where K_{S1}, K_{S2} and K_{S3} are adsorption constants of the respective three negatively charged arsenic species. Assuming that the adsorption is in the linear range of the Langmuir isotherm, the concentration of adsorbed As(V) species can be calculated using the following equations:

$$[\underline{S} - H_2AsO_4] = K_{S1}\alpha_{S+}S_T\alpha_1[As(V)]_D \quad (9)$$

$$[\underline{S} - HAsO_4^{-}] = K_{S2}\alpha_{S+}S_T\alpha_2[As(V)]_D \quad (10)$$

$$[\underline{S} - AsO_4^{2-}] = K_{S3}\alpha_{S+}S_T\alpha_3[As(V)]_D \quad (11)$$

Therefore, the adsorption ratio of arsenic can be expressed as:

$$R = \frac{[As(V)]_{ads}}{[As(V)]_D + [As(V)]_{ads}} = \frac{\alpha_{S+} S_T (K_{S1}\alpha_1 + K_{S2}\alpha_2 + K_{S3}\alpha_3)}{1 + \alpha_{S+} S_T (K_{S1}\alpha_1 + K_{S2}\alpha_2 + K_{S3}\alpha_3)} \quad (12)$$

where $[As(V)]_{ads}$ is total concentration of adsorbed As(V) species.

MATERIALS AND METHODS

Fly Ash Samples

Three ash samples were used in this study. Samples AN/Col #1 and AN/Col #2 were respectively collected from Unit #1 (with SNCR) and Unit #2 (conventional) of a facility burning eastern bituminous coal. Their loss on ignition (LOI) were, respectively, 12.7% and 6.7%. Sample AN/NRT #2, with LOI of 9.8%, was collected from the Unit #2 of the same facility when it was burning a different higher calcium eastern bituminous coal. All these samples were collected from the cold side electrostatic precipitator (ESP).

Raw ash samples were used for basic leaching experiment. All samples were dried at 105 °C for at least 24 hours in an oven before the experiments. Washed ashes were used for surface characterization and arsenic partitioning experiment. The purpose of washing was to remove soluble materials to get a relatively clean surface for the experiments. For the arsenic partitioning experiment, a 0.2 M NaOH solution was used to perform ash washing to maximize the arsenic removal. For other experiments, ashes were washed with DI water. All washing was performed at the solid/liquid ratio of 1:5, and was repeated for 5 times. Aeration was used to agitate the ash – water mixture, and each washing lasted 20 hours. Washed ash was dried in an oven at 105 ^{0}C for at least 24 hours before use.

Batch Equilibrium Titration

A batch equilibrium titration method including mathematical models developed by Wang, et al.[18, 19] was employed in this study to determine the surface site density and acidity constant of the fly ash.

As(V) Partitioning Experiment

Batch method was employed for arsenic partitioning studies.[18] The solid/liquid ratio was 1/10. Ionic strength was adjusted with 0.01M using stock $NaNO_3$ solution. For this study, samples were divided into 4 groups, with 1, 2, 5 and 10 ppm As(V) addition, respectively. To make sure the adsorption is in the linear range, the total arsenic concentration should be less than 10 percent of the surface site concentration. The equilibrium time used in this study was 24 hours. After shaking, all samples were settled overnight, the supernatant was then collected for arsenic analysis. The final pH was measured using the rest of the mixture in the bottle.

Basic Leaching Experiment

Arsenic leaching from raw ash under various pH conditions was investigated using batch methods.[18] Ionic strength was not adjusted in this experiment. At least 10 pH values in the range between 2 - 12 were selected for leaching. Solid/liquid ratio of 1:10 was used in the experiment. Arsenic in the supernatants was analyzed after 24 hrs of shaking. The final pH in each bottle was also measured.

Surface Analysis

The XPS analysis was carried out using Kratos Axis 165 X-Ray Photoelectrons spectrometer. Mg Kα radiation (1253.6 eV) was employed to provide the x-ray beam. By measuring the photon electron energy in a high-resolution analyzer, information regarding the concentration and oxidation states of the surface elements can be determined.

Analytical Method

A graphite furnace atomic absorption spectrometer (AAnalyst 600, Perkin-Elmer Corp., Norwalk, Connecticut, USA) was used to determine arsenic concentrations in the solution. An Orion PerpHecT Triode pH electrode (model 9207BN) and a pH meter (perpHecT LoR model 370) were used for pH measurement.

Data Analysis

The non-linear regression program Kaleidagraph™ was used to conduct curve fitting for the determination of the surface acid characteristics and arsenic adsorption constants, based on the respective models we developed.

RESULTS AND DISCUSSION

Surface Acidity

The surface characteristics of three washed ash samples AN/Col #1, AN/Col #2 and AN/NRT #2 were investigated. AN/Col #1 and AN/NRT #2 were washed with DI water only. The AN/Col#2 was washed with both DI water and 0.2M NaOH solution. Figure 1 shows the titration and curve fitting results for all samples. Results indicated that all samples have three types of acid sites on their surface. Table 1 shows the site density and the acidity constant of each site. Since the protonated form of the site α is positively charged, it may be the most responsible site for adsorption of arsenic anions.

Table 1. Surface site density and acidity constant of washed ash samples AN/Col #1, AN/Col #2, and AN/NRT #2.

Sample	Washing Agent	Site	α	β	γ
AN/Col #1	DI water	Site density (10^{-5}mol/g)	32 ± 1	2.5 ± 0.8	8.6± 2.7
		Acidity constant (pK_H)	3.0 ± 0.1	8.4 ± 0.5	11.6 ± 0.4
AN/Col #2	DI water	Site density (10^{-5}mol/g)	23 ± 1	3.2 ± 0.1	11± 4
		Acidity constant (pK_H)	2.8 ± 0.1	8.3 ± 0.5	12.0 ± 0.4
AN/Col#2*	0.2M NaOH	Site density (10^{-5}mol/g)	25± 2	8.5± 1.3	11± 1
		Acidity constant (pK_H)	3.5 ± 0.1	7.0 ± 0.3	11.1 ± 0.1
AN/NRT #2	DI water	Site density (10^{-5}mol/g)	47 ± 2	2.5 ± 1.2	16 ± 20
		Acidity constant (pK_H)	3.4 ± 0.1	8.8 ± 1.1	12.1 ± 0.9

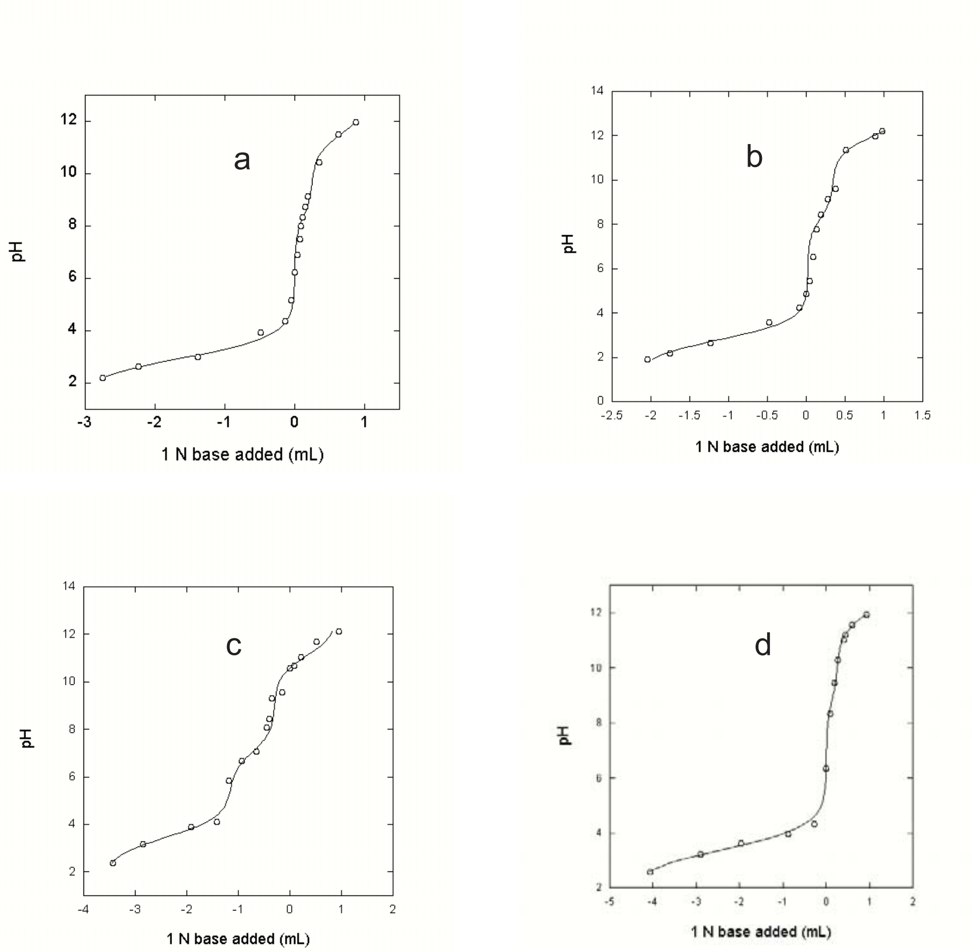


Figure 1 Titration and curve fitting results for washed ashes: (a) AN/Col #1; (b) AN/Col #2 (DI water washed); (c) AN/Col #2 (0.2M NaOH washed); and (d) AN/NRT #2. Ionic strength = 0.01 M ($NaNO_3$), temperature = 20 – 25 ^{0}C; equilibration time = 24 hours.

Surface Analysis with XPS

To obtain ash surface composition information and oxidation states of arsenic, the raw ash and washed ash of AN/Col #2 were scanned with XPS. Table 2 shows the relative amounts of each element detected on ash surface. It can be seen that C, O, Al, and Si are major elements on surface, while the amounts of Ca, As and Se are much lower. Quantitative change of these elements before and after washing is also observed. The increase of oxygen may be due to the surface contamination by oxygen in air. The decrease of carbon could be caused by the removal of carbon content during the washing process. For Se and Si, their concentrations on surface increased after washing, which suggests that these elements tend to be under the top layer of the ash surface. The amount of As and Al decreased, suggesting that these elements may be desorbed or dissolved in water during washing. It may also indicate that arsenic tends to be concentrated on the ash surface.

Table 2. Surface composition of ash AN/Col #2 based on XPS analysis.

Element		C	O	Al	Ca	Si	As	Se
Relative Amount (%)	AN/Col #2 Unwashed	7.88	60.8	16.2	0.016	15.1	0.0062	0.019
	AN/Col #2 Washed	3.43	66.4	10.8	0.016	19.3	0.0042	0.033

Effect of pH on Arsenic Leaching

Effect of pH on arsenic leaching from raw ash AN/Col #1 and AN/Col #2 was investigated using batch leaching methods. Figure 2 shows the soluble arsenic concentration as a function of pH. Figure 2 shows that more arsenic can be released from ash AN/Col #1 than from AN/Col #2. Results also indicate that arsenic can be released when pH is less than 3 or greater than 7, while in the pH range between 3 and 7, very little arsenic is released. This can be explained with arsenate speciation analysis.

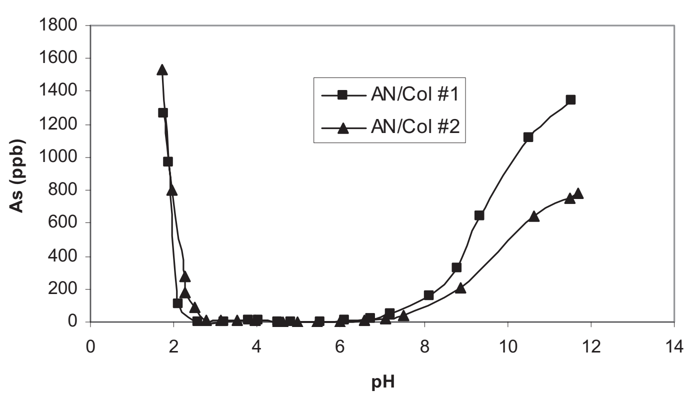


Figure 2. Basic leaching results for As from ash AN/Col #1 and AN/Col #2. Experimental conditions: S/L = 1:10; temperature = 20 – 25 ^{0}C; equilibration time = 24 hours.

Figure 3 shows the As(V) speciation diagram. When pH is very low (less than 2), the major arsenic species is the H_3AsO_4, which does not have charge. It appears that the neutral arsenic molecules are not easily adsorbed by ash surface. When pH is increased above 2, the total concentration of anionic arsenic species ($H_2AsO_4^-$ and $HAsO_4^{2-}$) is also increased. These anions can be strongly adsorbed by positively charged ash surface sites. When pH is further increased above 7, both the ash surface and arsenic are negatively charged, which results in the arsenic release.

Coal ash AN/NRT #2 was also investigated using batch leaching approach. This coal ash had a higher calcium content than the other two coal ashes. Figure 4 shows the leaching results under two S/L ratios. Results indicate that the leachate arsenic concentration for this ash is significantly greater than the other two ash samples. The leaching behavior of arsenic is similar to the other two ashes when pH is less than 9. However, the soluble arsenic concentration deceases with the increase of pH when pH is greater than 9, and increases again with the increase of pH when pH is greater than 11. This behavior may be caused by the precipitation of arsenate compounds. When pH increases, more arsenic is in the free arsenate ion form, which will form precipitates with many cations including calcium. Therefore, the total arsenic concentration decreases with the increase of pH when pH is greater than 9. If we further increase the pH above 11, free cation concentration will be decreased due to the formation of metal-hydroxides. Therefore, some precipitated arsenic can be dissolved due to the decrease of free cation concentration.

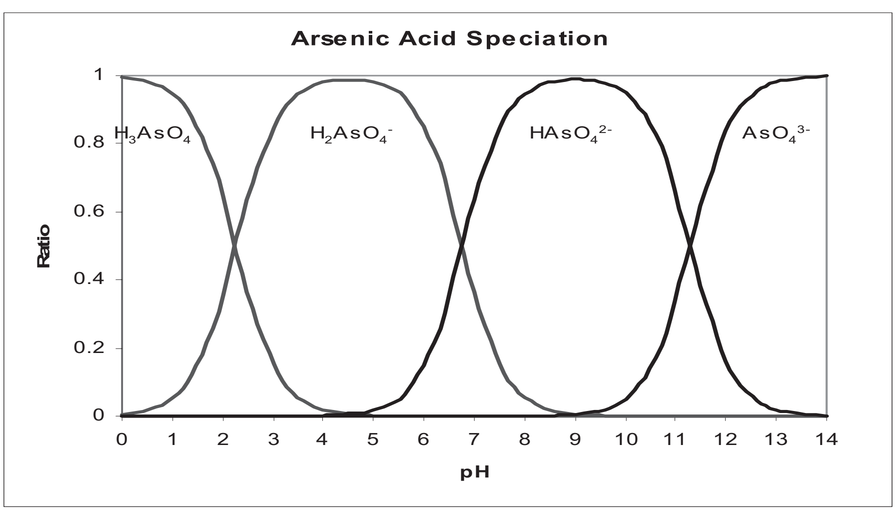


Figure 3. Speciation of arsenic acid.

Figure 4 also shows that, in alkaline pH range, the soluble arsenic concentration is high when the S/L ratio is low. This suggests that, under the low S/L conditions, the total cation concentration is low. Therefore, more arsenic is in soluble form under the saturation condition.

Leist reported that the calcium concentration in the leachate was mirrored in the arsenic concentration, suggestive of As-Ca precipitation.[20] To verify whether As-Ca correlation exists in our system, calcium concentrations in supernatants were measured. The results are also shown in Figure 4. Based on K_{sp} of $Ca_3(AsO_4)_2$ and dissolved calcium concentrations, the saturation concentrations of AsO_4^{3-} and total dissolved arsenic were calculated. However, our calculation results are about 10 times greater than experimental data, which indicates that some other factors may also present in the system affecting arsenic release. This will be investigated in our future studies.

Results also show that when pH is less than 9, the soluble concentrations of arsenic under two ash S/L ratios are overlap. This could be caused by joint effects of adsorption and precipitation. It is speculated that due to the arsenic speciation, there is less chance of precipitation under low pH. The details of this “overlap” phenomenon will be investigated in future.

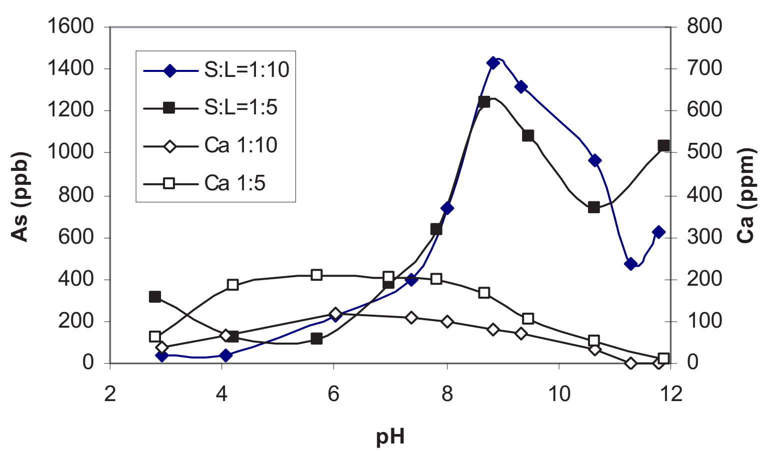


Figure 4. Basic leaching results for As & Ca from ash AN/NRT #2. Experimental conditions: S/L = 1:10; temperature = 20 – 25 ^{0}C; equilibration time = 24 hours.

As (V) Interactions with Washed Ash

In order to determine the significance of adsorption on arsenic leaching, an arsenic partitioning experiment was conducted using washed ash. In this experiment, the NaOH washed ash AN/Col #2 was used for arsenic partitioning studies. Different initial As(V) additions were used: 0, 1, 2, 5 and 10 ppm. Figure 6 shows the arsenic partitioning results. Results indicate that pH has the similar effect on soluble As (V) concentrations for systems containing washed ash and raw ash. The 0 ppm addition data indicate that the washed ash still contained some leachable arsenic. Results also show that, in a broad pH range, the soluble arsenic concentration is proportional to the arsenic addition, which indicates that the adsorption plays a major role on arsenic partitioning. However, when pH is greater than 9, the soluble arsenic concentration for the 10 ppm arsenic addition scenario decreases with the increase of pH. This could be caused by the arsenic precipitation with the cations but this explanation needs to be further verified. Compared with the basic leaching results in Figure 3, the higher percentage of As(V) is in soluble phase for the washed ash. This could be caused by the removal of other cations during the washing process.

Modeling for As(V) Partitioning

Equation 12 was used to model As(V) partitioning results. Previously determined parameters including the surface site density and acidity constant were applied to the model. For this study, only site α was considered, which is most possible to be the arsenic adsorption site. Since a certain amount of arsenic can be released from the ash with 0 ppm addition, a background concentration was estimated to calculate the total arsenic concentration in the system after arsenic addition. The arsenic uptake ratio R can be expressed as $[1 - M_d/(M_{add}+M_b)]$, where M_d, M_{add} and M_b are the dissolved, added and background arsenic concentrations, respectively. Considering that precipitation may occur at very high pH, only the data with pH condition of lower than 9 was used for curve fitting.

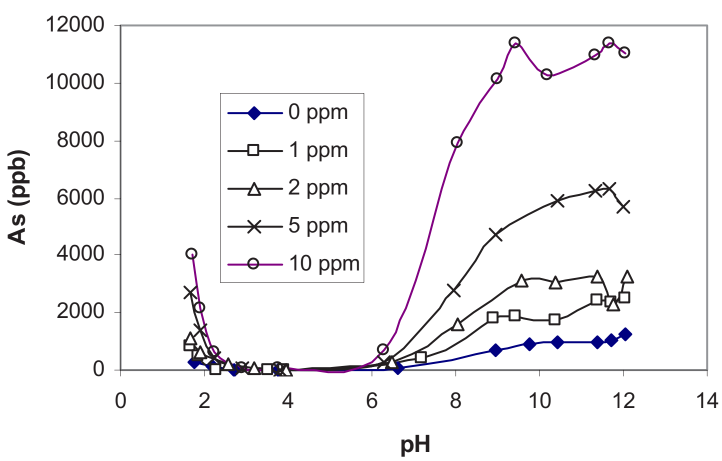


Figure 5. As(V) partitioning results for 0.2 M NaOH washed ash AN/Col #2. Experimental conditions: S/L = 1:10; ionic strength = 0.01M $NaNO_3$; temperature = 20 – 25 ^{0}C; equilibration time = 24 hours.

Based on the soluble arsenic concentrations in Figure 5, the amount of arsenic addition, and the estimated background arsenic concentration, the arsenic partitioning can be calculated. Figure 6 shows the arsenic partitioning (R) as a function of pH (points). It shows that, regardless of the amount of arsenic addition, the percentage of arsenic on the ash surface is constant for a given pH. It indicates that all experiments were conducted within the linear range of the Langmuir isotherm.

Kaleidagraph™ was used to perform the curve fitting and determine the adsorption constants of two species $H_2AsO_4^-$ and $HAsO_4^{2-}$. Because the species AsO_4^{3-} is significant only under very high pH conditions when the surface sites are negatively charged, the chance of AsO_4^{3-} adsorption by positively charged surface sites is minimum. Therefore, the adsorption of AsO_4^{3-} was not considered in the model. The solid curve in Figure 6 is the model result. Table 3 shows the calculated adsorption constants, their standard errors, and the correlation factor for the curve fitting. The good agreement between experimental data and the theoretical model indicates that this model is successful and practical for simulating arsenic partitioning under different pH conditions.

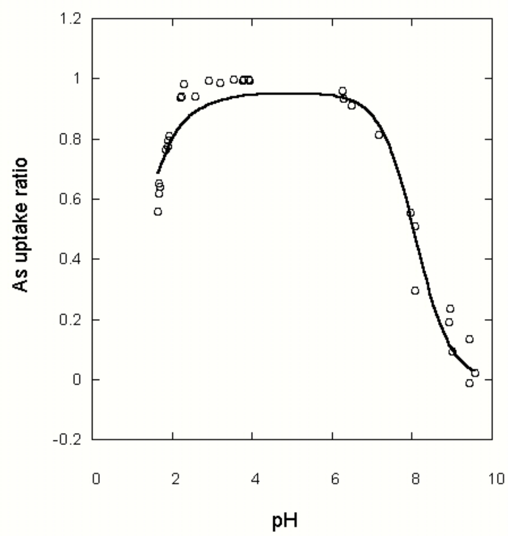


Figure 6. The adsorption results of As(V) onto washed ash AN/Col #2. Experimental conditions: metal concentrations = 1 - 10 mg/L; S/L = 1:10; ionic strength = 0.01M ($NaNO_3$); temperature = 20 – 25 ^{0}C; equilibration time = 24 hours.

Table 3 Adsorption constants between As(V) and ash AN/Col #2

Species	$logK_s$	Standard Error	R^2
$H_2AsO_4^-$	2.64	0.06	0.95
$HAsO_4^{2-}$	6.20	0.06	

CONCLUSIONS

Results indicate that there are three acid sites on ash surfaces, among which the first acid site is most likely responsible for adsorption of arsenic. The model developed in this study based on arsenic speciation analysis can be used to quantify the As (V) partitioning. The adsorption constants ($\log K_S$) for $H_2AsO_4^-$ and $HAsO_4^{2-}$ are determined to be 2.6 and 6.2, respectively. Results also indicate that adsorption and precipitation may concurrently exist to control arsenic leaching.

ACKNOWLEDGEMENTS

This work was supported by the Electric Power Research Institute (EPRI), by the Department of Interior (USDOI) through Missouri Water Research Center (MWRC) (Award Number 01HQGR0089), and by the Environmental Research Center for Emerging Contaminants (ERCEC) at the University of Missouri-Rolla (UMR). Assistance from Mr. Ken Ladwig, Project Manager at EPRI, was greatly appreciated. Conclusions and statements made in this paper are those of the authors, and in no way reflect the endorsement of the funding agencies.

REFERENCES

[1] www.epa.gov/safewater/ars/implement.html.

[2] Kim, A.G. and Cardone, C., Preliminary Statistical Analysis of Fly Ash Disposal in Mined Areas. Proc: 12th International Symposium on Coal Combustion By-Product Management and Use. American Coal Ash Association, 1997, 1, pp. 11-1 to 11-13.

[3] Kim, A.G. and Kazonich, G., Release of trace elements from CCB: Maximum extractable fraction. Proceedings 14th International Symposium on Management and Use of Coal Combustion Products (CCPs), 2001, 1, 20-1 to 20-15.

[4] EPRI, Chemical Characterization of Fossil Fuel Combustion Wastes", EPRI report EA-5321, 1987.

[5] American Coal Ash Association (ACAA), 2003 Coal Combustion Product (CCP) Production and Use Survey. http://www.acaa-usa.org.

[6] Xu, Yanhua; Nakajima, Tsunenori and Phki Akira., leaching of arsenic from coal fly ashes 1. arsenic pre-leaching with sodium gluconate solution. Toxicological and environmental chemistry, 2001, 81(1-2), pp. 55-68.

[7] Silberman, Dave; Harris, Wesley R. Determination of arsenic(III) and arsenic(V) in coal and oil fly ashes, International Journal of Environmental Analytical Chemistry, 1984, 17(1), pp. 73-83.

[8] Goodarzi, Fariborz; Huggins, Frank E. Monitoring the species of arsenic, chromium and nickel in milled coal, bottom ash and fly ash from a pulverized coal-fired power plant in western Canada, Journal of Environmental Monitoring, 2001, 3(1), pp. 1-6.

[9] Bankowski, P.; Zou, L.; Hodges, R., Reduction of metal leaching in brown coal fly ash using geopolymers, Journal of Hazardous Materials, 2004, 114(1-3), pp. 59-67.

[10] Sakaguchi, Yuka; Nakajima, Tsunenori; Takanashi, Hirokazu; Ohki, Akira, Analysis of coal fly ash by X-ray photoelectron spectroscopy, Sekitan Kagaku Kaigi Happyo Ronbunshu, 2002, 39, pp.133-134.

[11] Xu, Yanhua; Nakajima, Tsunenori; Phki Akira. Leaching of arsenic from coal fly ashes 2. arsenic pre-lleaching with sodium gluconate solution. Toxicological and environmental chemistry, 2001, 81(1-2), pp. 69-80.

[12] Praharaj, T.; Powell, M. A.; Hart, B. R.; Tripathy, S. Leachability of elements from sub-bituminous coal fly ash from India, Environment International, 2002, 27(8), pp. 609-615.

[13] Qafoku N.P., U. Kukier, M.E. Sumner, W.P. Miller, and D.E. Radcliffe. Arsenate displacement from fly ash in amended soils, Water, Air, and Soil Pollution, 1999, 114, pp.185-198.

[14] van der Hoek, E.E. Bonouvrie, P.A. and Comans, R.N.J. sorption of As and Se on mineral components of fly ash: relevance for leaching processes. Applied Geochemistry, 1994, 9, pp. 403-412.

[15] Yanger, J. identification of arsenic species in coal ash particles. electric poer research institure report TR-109002, Palo alto, CA, 1998, pp.167.

[16] Belzile, N., Tessier, A. Interactions between arsenic and iron oxyhydroxides in lacustrine sediments, Geochimica et Cosmochimica Acta ,1990, 54(1), pp. 103-9.

[17] Van der Hoek, Eline E., Comans, Rob N. J., Modeling Arsenic and Selenium Leaching from Acidic Fly Ash by Sorption on Iron (Hydr)oxide in the Fly Ash Matrix, Environmental Science and Technology, 1996, 30(2), pp. 517-23.

[18] Wang, Jianmin; Teng, Xinjun; Wang, Hao; Ban, Heng., Characterizing the Metal Adsorption Capability of a Class F Coal Fly Ash. Environmental Science and Technology, 2004, 38(24), pp. 6710-6715.

[19] Wang J.; Huang, C.P.; Allen, H.E., Surface Physical-chemical Characteristics of Sludge Particulates. Water Environ. Res, 2000,72 (5), pp. 545-553.

[20] Leist, M., The Fixation of Arsenic Wastes, PhD thesis, 2001, Victoria Univ., Melbourne. Australia.