Appendix B
Groundwater Upwelling Survey Reports

Data Report

Groundwater Upwelling Survey

Dundalk Marine Terminal – Baltimore, Maryland

April 2007

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LIST OF ACRONYMS

COPR	Chrome Ore–Processing Residue
DMT	Dundalk Marine Terminal
GPS	Global Positioning System
MDE	Maryland Department of Environment
MPA	Maryland Port Administration
NIST	National Institute of Standards and Technology
PARCC	Precision, Accuracy, Representativeness, Completeness, and/or Comparability
QA	Quality Assurance
RSD	Relative Standard Deviation

UNITS

C	degrees Celsius
ft	feet
%FS	percent full scale
mS/cm	millisiemens per centimeter

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1 INTRODUCTION

1.1 BACKGROUND

This data report describes the results of groundwater upwelling surveying near Dundalk Marine Terminal (DMT) in Baltimore, Maryland. The work was performed in support of a 2006 Consent Decree entered into among the Maryland Department of the Environment (MDE), the Maryland Port Administration (MPA), and Honeywell International Inc. (Honeywell).

1.2 SITE CHARACTERISTICS

DMT is a major maritime port operated by the MPA encompassing approximately 560 acres in the inner Harbor of Baltimore. Approximately 120 acres of DMT is constructed on land reclaimed from prior marshlands and the Patapsco River by means of fill composed primarily of chrome ore–processing residue (COPR). COPR fill may be in contact with groundwater. Groundwater flow from the site may serve to convey chromium into the Patapsco River.

1.3 OBJECTIVES OF THE PROJECT

The objective for this work was to identify potential groundwater upwelling locations. The results of the analysis will be used to help characterize the nature and extent of potential chromium releases from the DMT.

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2 PROJECT TECHNOLOGY AND METHODOLOGY

2.1 TECHNOLOGY DESCRIPTION

The primary technology utilized for the study was a screening probe for determining where groundwater may be discharging with an integrated porewater sampler for collecting subsurface samples from areas identified as potential discharge zones (the Trident Probe; Figure 2-1). The Trident probe is a direct-push, integrated temperature sensor, conductivity sensor, and porewater sampler developed to screen sites for areas where groundwater may be discharging to a surface water body (Figure 2-1; Chadwick et al., 2003). Spatial patterns in observed subsurface and surface water conductivity and temperature indicate areas where groundwater discharge may be occurring. The integral porewater sampler can be used to rapidly confirm the presence of freshwater or other chemical constituents. The pole-mounted global positioning system (GPS) receiver records the location of the push. Only the sensor component of the system was used during this survey.

2.2 SAMPLING DESIGN

The experimental design for the Trident survey at DMT focused on identifying potential groundwater discharge zones along the shoreline of the terminal. The sampling grid consisted of the 19 primary transects of 3 stations each, and 17 supplementary stations to further delineate potential groundwater discharge zones around the periphery of the terminal (Figure 2-2). Testing occurred at 100-foot intervals out from the periphery at each of those locations, beginning immediately adjacent to the terminal (i.e. at 0 feet, 100 feet, and 200 feet). Exact locations were adjusted depending on site conditions. At identified groundwater upwelling locations, additional samples were taken along and adjacent to the transect to better identify the upwelling area. Ancillary measurements of water levels were collected in two monitoring wells and in the harbor adjacent to DMT.

2.3 TRIDENT SENSOR SAMPLING

The Trident Probe survey was conducted in the harbor adjacent to DMT during the period extending from 12/8/06 – 12/11/06. A total of 74 Trident stations were sampled for subsurface temperature/conductivity contrast. At each station, average sensor readings were determined based on a minimum of nine replicate readings. The Trident sensor survey was conducted by inserting the probe into the seabed to a depth of approximately 2 ft from a small boat. Once on station with the probe inserted, data was collected from the probe (subsurface) and reference (surface water at 1 ft above the interface) conductivity and temperature sensors and the GPS using the TridentTalk software. Once the sensor readings had stabilized, the data was recorded by activating the “Log current data” button on the TridentTalk display. The real-time data was then reviewed in numeric format, and displayed spatially using the AGIS™ graphical information system software. The spatial AGIS™ display provided a capability for rapidly evaluating the most likely areas of groundwater discharge based on spatial patterns of subsurface temperature and conductivity and contrast between subsurface and surface water conditions. The resulting survey data were used to develop spatial maps indicating potential areas of groundwater discharge.

2.4 MONITORING WELL LEVEL LOGGING

Level loggers were installed in two monitoring well pairs and at a single location in the harbor to monitoring water level fluctuations during the study period. The level loggers were internal-recording Solinst™ units that were suspended within the well using a stainless steel wire. The level loggers were not vertically geo-referenced, so only relative variations were monitored. Levels were monitored at 10 minute intervals for the period extending from about 1300 12/8/06 to 1300 12/11/06. The monitoring well pairs included well EA-11S/EA-11M located on the southwestern corner of the terminal, and EA-7S/EA-7M located at the southwestern shoreline of the terminal.

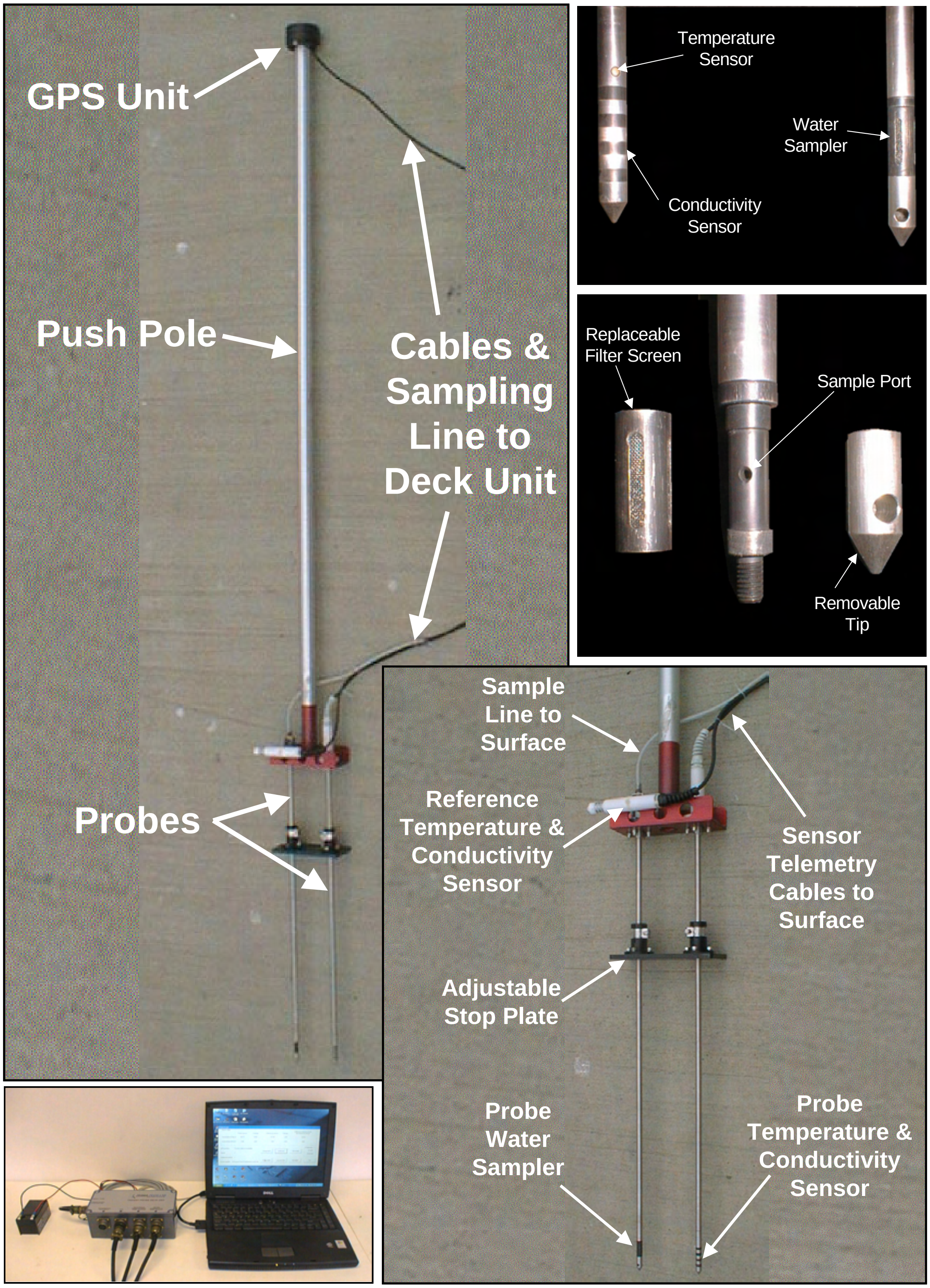

Figure 2-1. Complete Trident Probe showing sensor and water sampling probes, push-pole, GPS unit, expanded view of sensors and water sampler, and deck unit.

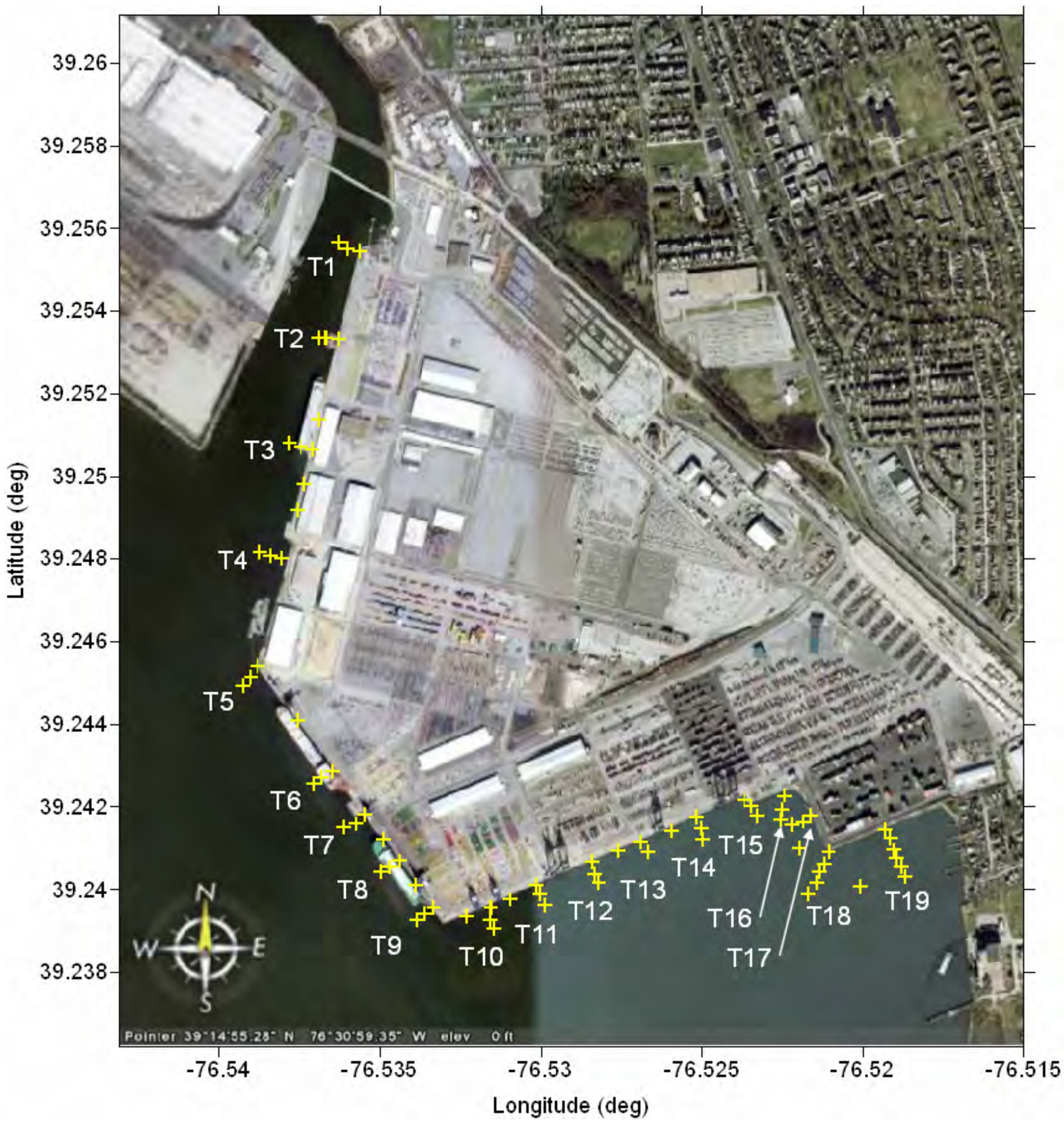

Figure 2-2. Sampling grid for the Trident Probe sensor survey offshore from DMT. Labels indicate transect numbers. Individual stations were designated 1,2,3… with increasing distance from shore. Intermediate transects were designated with fractional designations based on the relative position between adjacent primary transects (e.g. T3.5).

3 RESULTS

3.1 DATA QUALITY RESULTS

The quality assurance (QA) objective of this field investigation was to collect data of known quality. The QA processes included the application of: (1) appropriate field techniques; (2) appropriate analytical methods; and (3) measurement objectives for precision, accuracy, representativeness, completeness, and comparability (PARCC). Results for the QA objectives for the Trident measurements are summarized below.

Precision

Precision for the Trident sensors including temperature and conductivity was assessed on the basis of replicate analysis performed under controlled laboratory conditions prior to commencement of the survey. Sensor replicates consisted of a minimum of nine individual measurements for each standard. Results for the Trident laboratory precision were generated for replicate measurements of two separate National Institute of Standards and Technology (NIST) conductivity standards and two fixed temperature water baths monitored by a highly accurate digital oceanographic thermometer. Laboratory relative standard deviations (RSDs) for the Trident conductivity sensors ranged from 0.47 – 0.53% of full scale for the Probe, and 0.00 – 0.45% for the Reference (Table 3-1). RSDs for the Trident temperature sensors were 0.02 – 0.29% full scale for the Probe, and 0.05 – 0.22% for the Reference (Table 3-2). This range of variation is generally 2-3 orders of magnitude lower than the variations observed at the site.

Accuracy

For Trident temperature and conductivity sensors, accuracy was established by applying laboratory calibrations. Calibration curves for the Trident probe conductivity and temperature sensors are shown in Figure 3-1 and Figure 3-2. Calibration curves for the Trident reference conductivity and temperature sensors are shown in Figure 3-3 and Figure 3-4.

Representativeness

Representativeness is a qualitative expression of the degree to which sample data accurately represent the characteristics of a population, parameter variations at a sampling point, or an environmental condition that they are intended to represent. Representativeness was maximized by (1) selecting the appropriate number of samples and sampling locations, and (2) using appropriate and established sample collection, handling, and analysis techniques to provide information that reflects actual site conditions.

Completeness

Completeness assesses the amount of valid data obtained from a measurement system compared to the amount of data required to achieve a particular statistical level of confidence. The percent completeness was calculated as the number of samples yielding acceptable data divided by the total number of samples planned to be collected and multiplied by 100. Results for completeness were assessed for the Trident sensor data based on the number of stations where acceptable data was collected. Completeness for the Trident sensor data was 100%.

Comparability

Comparability is a qualitative parameter that expresses the degree of confidence that one data set may be compared to another. This goal was achieved through the use of (1) standardized techniques to collect and analyze samples, and (2) appropriate units to report analytical results. The comparability of the data was maximized by using standard analytical methods when possible, reporting data in consistent units, reporting data in a tabular format, and by validating the results against commonly accepted methodologies and target limits.

NIST Standard	Reps	Trident Probe			Trident Reference		
		Cond	StDev	RSD	Cond	StDev	RSD
(mS/cm)		(mS/cm)	(mS/cm)	(%FS)	(mS/cm)	(mS/cm)	(%FS)
0	9	0.233	0.050	0.53	0.000	0.000	0.00
9.86	9	9.422	0.044	0.47	9.722	0.044	0.45
		Slope	1.073		Slope	1.014	
		Offset	-0.250		Offset	0.000	

Table 3-1. Conductivity calibration results for the Trident Probe and Reference sensors. Conductivities reported in millisiemens per centimeter (mS/cm) and relative standard deviations reported as percent of full scale (%FS).

Temp. Standard	Reps	Trident Probe			Trident Reference		
		Temp.	StDev	RSD	Temp.	StDev	RSD
(C)		(C)	(C)	(%FS)	(C)	(C)	(%FS)
5	9	4.465	0.060	0.29	5.999	0.046	0.22
20	9	20.816	0.004	0.02	20.518	0.011	0.05
		Slope	0.917		Slope	1.033	
		Offset	0.904		Offset	-1.198	

Table 3-2. Temperature calibration results for the Trident Probe and Reference sensors. Temperatures reported in degrees Celsius (C) and relative standard deviations reported as percent of full scale (%FS).

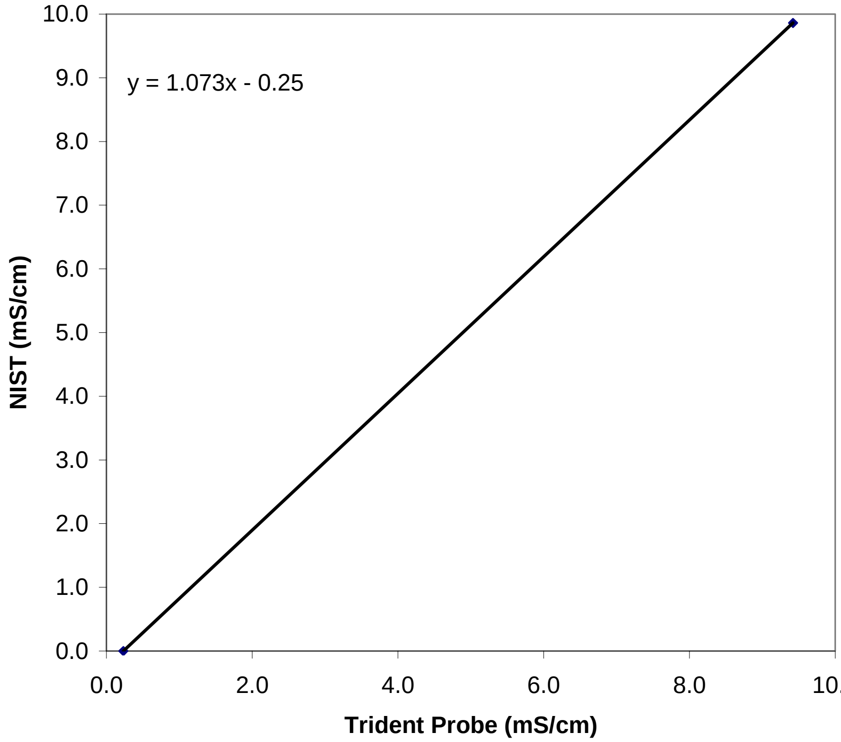

Figure 3-1. Trident probe conductivity sensor calibration.

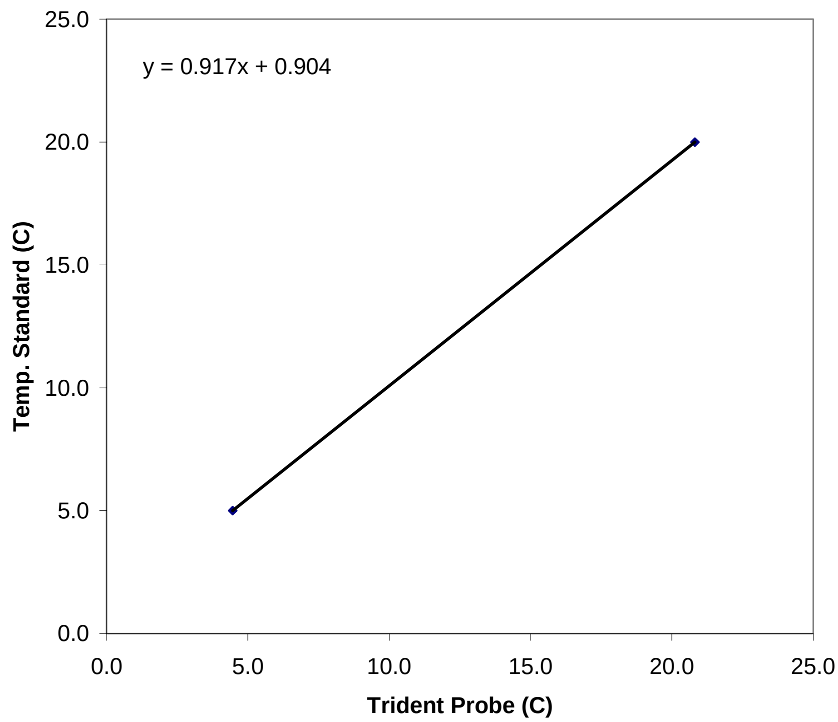

Figure 3-2. Trident probe temperature sensor calibration.

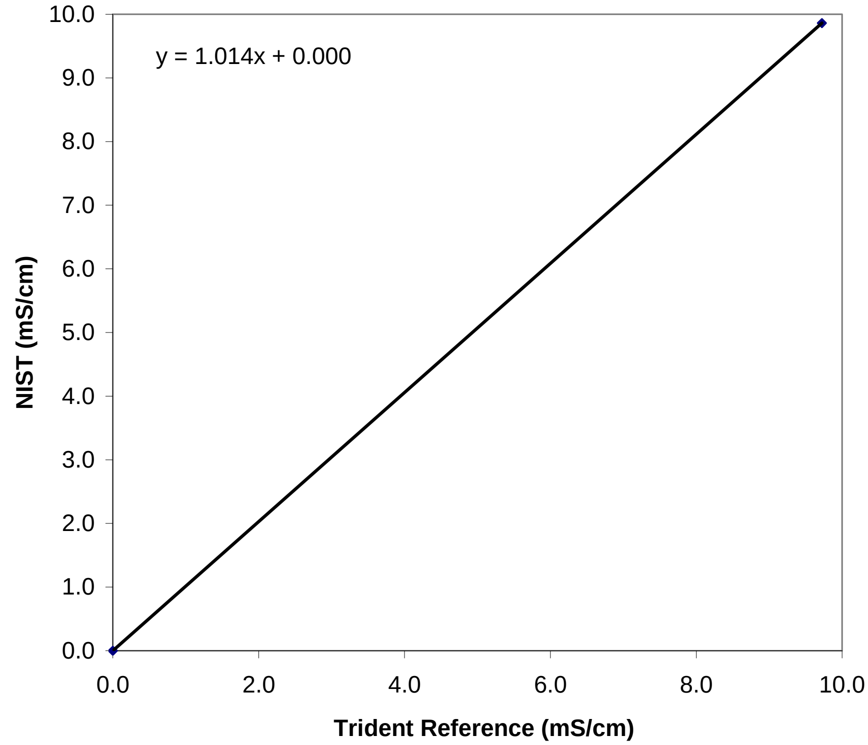

Figure 3-3. Trident reference conductivity sensor calibration.

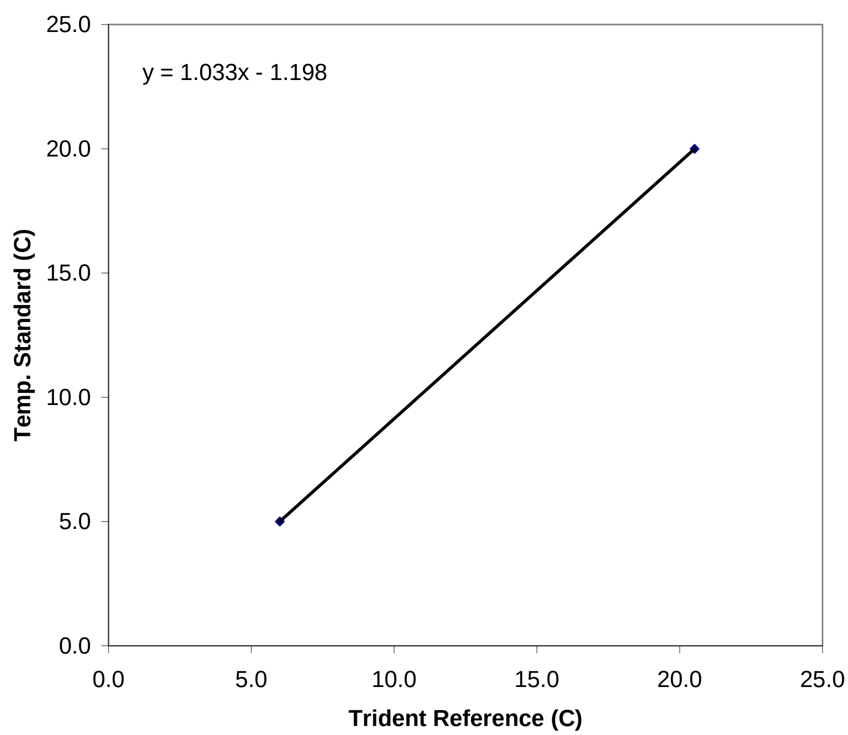

Figure 3-4. Trident reference temperature sensor calibration.

3.2 FIELD SAMPLING RESULTS

3.2.1 TRIDENT CONDUCTIVITY AND TEMPERATURE MAPPING

Horizontal Trident mapping of conductivity and temperature contrast at the groundwater – surface water interface was used to identify likely areas of groundwater discharge to the harbor area adjacent to the terminal. During the winter, groundwater in this region was expected to be warmer and fresher than the surface water. Trident measurements were performed at the stations shown in Figure 2-2. Complete results for the Trident conductivity and temperature mapping are given in Table 3-3 through Table 3-6, and statistics are summarized in Table 3-7. The results for subsurface conductivity and temperature for the offshore study area were classified and posted spatially with an aerial photo basemap in Figure 3-5 and Figure 3-6.

Subsurface conductivities ranged from 1.64 to 11.89 mS/cm, with the lowest values concentrated in the southeastern extent of the study area from transect 17-19. A smaller zone was identified along the western shore near transect 3. Isolated stations with relatively low conductivities (i.e. < 4 mS/cm) were also identified particularly in the stations along the southern shoreline between transects 12-15.

Subsurface temperatures in the offshore region varied by about 8 C, ranging from 8.38 C to 16.24 C. Cooler subsurface temperatures were observed in association with the low conductivity zone in the southeastern extent of the study area from transect 17-19. Warmer subsurface temperatures were generally observed in the near shore stations, particularly along the southern shoreline, but also in areas along the eastern and southeastern shores. There was a weak correlation between subsurface conductivity and temperature, with lower temperatures corresponding with lower conductivities (Figure 3-7).

Based on the subsurface conductivity and temperature mapping, potential groundwater discharge zones were identified (Figure 3-8). The zone in the southeast extent of the study area had the strongest low conductivity anomaly. While this corresponded with comparatively cooler subsurface temperatures, the subsurface temperatures in this zone were still generally warmer than the surface water by about 3-7 C. The spatial pattern of lower subsurface temperature associated with this zone could indicate groundwater discharge from a pathway other than the warm shallow groundwater source that appears to underlay the terminal. Alternatively, it was observed that the bottom depths in this zone were significantly shallower (Figure 3-9), and that the surface water itself had a lower conductivity and temperature characteristic (Figure 3-10 and Figure 3-11). Thus the signal in this area could also reflect the exchange of surface water into the high permeability sandy gravel substrate that was present at many of these stations. This explanation is consistent with the lower subsurface vs. surface water temperature and conductivity contrast in this zone. Other areas of low subsurface conductivity showed some overlap with warmer subsurface temperature, particularly along the southern shoreline. These anomalies were generally weaker, and limited in extent to fewer stations.

3.2.2 MONITORING WELL ELEVATIONS

Results for the EA-11 and EA-7 well pairs are shown in comparison to the tidal elevation in the harbor in Figure 3-12 and Figure 3-13, respectively. The level logger in EA-7M was set too deep and over-scaled the sensor so no data were obtained. The results generally indicate minimal response in the shallow wells, and significant response in the deeper well relative to the tidal variation in the harbor. This suggests that there is a low degree of groundwater-surface water interaction between the harbor and the shallow aquifer, while the connection between the harbor and the deeper aquifer appears to be stronger. In addition, this suggests relatively little connection between the shallow and deeper aquifers, although the data set is of limited extent and should not be viewed as representing the entire site.

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Station ID	Station Reps.	Date	Time (EST)	Long (deg. W)	Lat (deg. N)	Avg Probe Temp (C)	StDev Probe Temp (C)	Δ Temp (C)	Avg Probe Cond (mS/cm)	StDev Probe Cond (mS/cm)	Δ Cond (mS/cm)	Avg Ref Temp (C)	StDev Ref Temp (C)	Avg Ref Cond (mS/cm)	StDev Ref Cond (mS/cm)
T1-1	10	12/8/2006	15:13:01	76.53563	39.25545	15.351	0.014	6.841	5.405	0.067	-8.703	8.510	0.019	14.107	0.032
T1-2	9	12/8/2006	14:56:49	76.53602	39.25552	15.152	0.039	6.520	4.877	0.083	-9.130	8.631	0.045	14.007	0.078
T1-3	9	12/8/2006	14:45:35	76.53630	39.25567	15.541	0.002	6.245	4.948	0.053	-9.454	9.296	0.015	14.402	0.000
T2-1	9	12/8/2006	16:08:14	76.53628	39.25333	14.838	0.049	6.453	5.913	0.053	-0.736	8.385	0.036	6.649	0.053
T2-2	9	12/8/2006	15:49:04	76.53670	39.25335	12.576	0.018	4.072	6.760	0.087	-7.382	8.503	0.049	14.142	0.053
T2-3	9	12/8/2006	15:36:07	76.53690	39.25337	12.380	0.057	4.105	5.985	0.136	-7.909	8.275	0.021	13.894	0.000
T3-1	9	12/11/2006	15:44:24	76.53712	39.25067	14.582	0.022	4.797	3.989	0.078	-12.833	9.785	0.023	16.822	0.044
T3-2	9	12/11/2006	15:32:26	76.53747	39.25072	13.676	0.041	3.405	3.400	0.050	-15.100	10.270	0.031	18.500	0.000
T3-3	9	12/11/2006	15:19:34	76.53782	39.25080	12.701	0.022	2.635	4.889	0.105	-13.711	10.066	0.020	18.600	0.000
T4-1	10	12/9/2006	16:52:20	76.53807	39.24802	15.901	0.014	5.855	4.550	0.085	-11.950	10.046	0.005	16.500	0.000
T4-2	9	12/9/2006	16:37:01	76.53840	39.24808	15.611	0.076	5.583	4.233	0.112	-12.267	10.028	0.012	16.500	0.000
T4-3	9	12/9/2006	16:21:45	76.53875	39.24818	12.801	0.021	2.719	5.344	0.230	-10.956	10.082	0.004	16.300	0.000
T5-1	9	12/11/2006	14:09:57	76.53927	39.24493	14.954	0.045	4.831	4.300	0.000	-14.233	10.123	0.040	18.533	0.050
T5-2	9	12/11/2006	14:22:35	76.53902	39.24515	15.944	0.047	5.992	11.889	0.033	-5.033	9.952	0.038	16.922	0.067
T5-3	9	12/11/2006	14:33:53	76.53882	39.24542	15.346	0.027	5.612	4.311	0.033	-12.489	9.734	0.023	16.800	0.000
T6-1	9	12/9/2006	15:46:40	76.53650	39.24288	13.818	0.029	3.599	11.400	0.087	-4.400	10.220	0.002	15.800	0.000
T6-2	9	12/9/2006	15:30:02	76.53682	39.24273	13.758	0.027	3.678	3.944	0.053	-12.356	10.080	0.008	16.300	0.000
T6-3	10	12/9/2006	15:13:30	76.53708	39.24257	12.434	0.049	2.480	4.040	0.052	-12.360	9.954	0.016	16.400	0.000
T7-1	9	12/9/2006	14:40:13	76.53548	39.24182	16.237	0.042	5.802	8.700	0.240	-5.811	10.435	0.033	14.511	0.060
T7-2	9	12/9/2006	14:26:16	76.53575	39.24160	15.874	0.061	5.771	3.756	0.368	-11.978	10.103	0.031	15.733	0.050
T7-3	9	12/9/2006	14:13:33	76.53613	39.24152	12.274	0.056	2.179	5.778	0.685	-10.033	10.094	0.027	15.811	0.033

Notes: Probe = subsurface — C = degrees Celsius

Reference (Ref) = surface water — mS/cm = millisiemens per centimeter

Δ Temp = subsurface – surface water temperature — Δ Cond = subsurface – surface water conductivity

Table 3-3. Trident sensor results for transects 1-7.

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Station ID	Station Reps.	Date	Time (EST)	Long (deg. W)	Lat (deg. N)	Avg Probe Temp (C)	StDev Probe Temp (C)	Δ Temp (C)	Avg Probe Cond (mS/cm)	StDev Probe Cond (mS/cm)	Δ Cond (mS/cm)	Avg Ref Temp (C)	StDev Ref Temp (C)	Avg Ref Cond (mS/cm)	StDev Ref Cond (mS/cm)
T8-1	9	12/10/2006	9:39:55	76.53440	39.24070	14.254	0.019	4.517	3.911	0.033	-12.389	9.737	0.024	16.300	0.000
T8-2	9	12/10/2006	9:27:40	76.53472	39.24055	15.924	0.035	5.303	6.100	0.000	-12.889	10.621	0.032	18.989	0.033
T8-3	10	12/10/2006	9:12:03	76.53498	39.24043	14.703	0.041	4.478	7.930	0.048	-10.820	10.225	0.061	18.750	0.053
T9-1	9	12/10/2006	10:34:47	76.53335	39.23957	13.273	0.012	3.084	9.178	0.067	-8.611	10.189	0.004	17.789	0.033
T9-2	9	12/10/2006	10:17:08	76.53363	39.23943	13.235	0.042	2.575	5.122	0.044	-14.578	10.660	0.045	19.700	0.000
T9-3	9	12/10/2006	10:04:14	76.53388	39.23928	11.592	0.004	0.884	5.922	0.067	-13.911	10.708	0.020	19.833	0.071
T10-1	9	12/11/2006	9:43:58	76.53157	39.23957	15.341	0.060	5.325	4.200	0.000	-14.600	10.016	0.055	18.800	0.000
T10-2	9	12/11/2006	9:29:16	76.53158	39.23927	13.465	0.008	3.314	4.622	0.044	-14.078	10.151	0.014	18.700	0.000
T10-3	9	12/11/2006	9:06:35	76.53147	39.23905	14.205	0.013	3.904	3.989	0.078	-15.011	10.301	0.019	19.000	0.000
T11-1	9	12/11/2006	10:08:12	76.53015	39.24010	15.668	0.046	5.832	8.044	0.053	-9.956	9.835	0.033	18.000	0.000
T11-2	9	12/11/2006	10:18:24	76.53003	39.23990	12.098	0.072	2.541	4.633	0.050	-14.233	9.557	0.074	18.867	0.050
T11-3	9	12/11/2006	10:35:08	76.52988	39.23963	11.847	0.029	1.952	4.700	0.000	-13.856	9.895	0.055	18.556	0.053
T12-1	9	12/10/2006	11:28:46	76.52842	39.24068	14.469	0.043	3.875	3.900	0.071	-15.767	10.595	0.046	19.667	0.050
T12-2	9	12/10/2006	11:15:49	76.52835	39.24037	12.188	0.026	1.557	4.311	0.033	-15.378	10.630	0.036	19.689	0.033
T12-3	9	12/10/2006	11:03:47	76.52822	39.24017	13.738	0.025	3.200	4.256	0.073	-15.444	10.538	0.040	19.700	0.000
T13-1	9	12/9/2006	13:35:30	76.52692	39.24115	15.703	0.071	6.142	6.389	0.033	-8.111	9.561	0.030	14.500	0.000
T13-2	9	12/9/2006	13:19:38	76.52670	39.24093	10.994	0.017	1.349	5.000	0.071	-9.900	9.645	0.024	14.900	0.000
T13-3	9	12/9/2006	13:03:50	76.52670	39.24093	12.099	0.053	2.452	4.500	0.050	-10.400	9.647	0.018	14.900	0.000

Notes: Probe = subsurface; C = degrees Celsius

Reference (Ref) = surface water; mS/cm = millisiemens per centimeter

Δ Temp = subsurface – surface water temperature; Δ Cond = subsurface – surface water conductivity

Table 3-4. Trident sensor results for transects 8-13.

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Station ID	Station Reps.	Date	Time (EST)	Long (deg. W)	Lat (deg. N)	Avg Probe Temp (C)	StDev Probe Temp (C)	Δ Temp (C)	Avg Probe Cond (mS/cm)	StDev Probe Cond (mS/cm)	Δ Cond (mS/cm)	Avg Ref Temp (C)	StDev Ref Temp (C)	Avg Ref Cond (mS/cm)	StDev Ref Cond (mS/cm)
T14-1	10	12/9/2006	11:08:33	76.52517	39.24177	15.947	0.059	6.393	3.940	0.070	-10.960	9.554	0.048	14.900	0.000
T14-2	10	12/9/2006	10:53:17	76.52503	39.24150	14.085	0.039	4.419	4.410	0.032	-10.490	9.666	0.035	14.900	0.000
T14-3	9	12/9/2006	10:34:15	76.52500	39.24123	15.215	0.042	5.475	4.778	0.044	-10.122	9.739	0.019	14.900	0.000
T15-1	9	12/9/2006	10:01:09	76.52370	39.24218	16.008	0.046	6.258	3.811	0.033	-10.556	9.750	0.009	14.367	0.050
T15-2	9	12/9/2006	9:42:15	76.52347	39.24203	15.682	0.066	6.129	6.111	0.033	-8.467	9.553	0.023	14.578	0.044
T15-3	9	12/9/2006	9:24:12	76.52328	39.24180	15.833	0.066	6.385	11.656	0.113	-1.000	9.449	0.028	12.656	0.088
T16-1	9	12/9/2006	11:58:41	76.52245	39.24228	14.144	0.042	7.290	6.000	0.000	-7.000	6.854	0.101	13.000	0.000
T16-2	9	12/9/2006	11:49:40	76.52253	39.24195	12.820	0.056	6.069	8.478	0.067	-4.500	6.750	0.016	12.978	0.044
T16-3	9	12/9/2006	11:38:48	76.52255	39.24170	12.850	0.043	6.794	5.700	2.729	-7.222	6.056	0.018	12.922	0.044
T17-1	9	12/10/2006	12:09:32	76.52162	39.24180	9.855	0.008	2.921	2.922	0.044	-10.078	6.934	0.061	13.000	0.000
T17-2	9	12/10/2006	12:19:28	76.52187	39.24165	10.611	0.017	4.075	4.422	0.044	-8.578	6.536	0.003	13.000	0.000
T17-3	9	12/10/2006	12:29:36	76.52222	39.24157	11.439	0.016	4.977	4.311	0.033	-8.689	6.461	0.001	13.000	0.000
T18-1	10	12/10/2006	13:21:07	76.52107	39.24092	10.565	0.011	3.514	2.600	0.000	-10.480	7.051	0.010	13.080	0.042
T18-2	9	12/10/2006	13:30:50	76.52120	39.24063	12.692	0.026	5.109	2.622	0.044	-10.578	7.583	0.003	13.200	0.000
T18-3	9	12/10/2006	13:38:31	76.52138	39.24043	13.432	0.078	5.575	3.367	0.050	-9.833	7.857	0.005	13.200	0.000
T19-1	10	12/10/2006	14:39:52	76.51933	39.24145	10.651	0.009	3.451	1.640	0.052	-11.360	7.200	0.021	13.000	0.000
T19-2	9	12/10/2006	14:49:40	76.51915	39.24125	9.131	0.019	2.147	3.444	0.101	-9.556	6.984	0.001	13.000	0.000
T19-3	9	12/10/2006	14:58:35	76.51905	39.24097	10.491	0.030	3.436	3.100	0.000	-9.900	7.055	0.016	13.000	0.000

Notes: Probe = subsurface

Reference (Ref) = surface water

Δ Temp = subsurface – surface water temperature

C = degrees Celsius

mS/cm = millisiemens per centimeter

Δ Cond = subsurface – surface water conductivity

Table 3-5. Trident sensor results for transects 14-19.

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Station ID	Station Reps.	Date	Time (EST)	Long (deg. W)	Lat (deg. N)	Avg Probe Temp (C)	StDev Probe Temp (C)	Δ Temp (C)	Avg Probe Cond (mS/cm)	StDev Probe Cond (mS/cm)	Δ Cond (mS/cm)	Avg Ref Temp (C)	StDev Ref Temp (C)	Avg Ref Cond (mS/cm)	StDev Ref Cond (mS/cm)
T2.5-1	9	12/11/2006	16:16:06	76.53690	39.25138	14.804	0.068	5.019	4.767	0.050	-12.267	9.785	0.030	17.033	0.050
T3.5-1	9	12/11/2006	16:04:47	76.53738	39.24983	15.742	0.017	5.784	3.533	0.050	-11.844	9.958	0.020	15.378	0.083
T3.75-1	9	12/11/2006	16:27:35	76.53758	39.24920	15.131	0.122	5.602	5.033	0.087	-11.122	9.529	0.059	16.156	0.159
T5.5-1	9	12/11/2006	14:51:59	76.53757	39.24410	13.938	0.072	4.466	6.467	0.100	-10.333	9.472	0.070	16.800	0.000
T7.5-1	9	12/11/2006	13:42:30	76.53490	39.24122	14.400	0.041	4.803	5.967	0.132	-10.956	9.597	0.036	16.922	0.044
T8.5-1	9	12/11/2006	11:20:00	76.53390	39.24010	13.126	0.027	3.647	5.289	0.033	-10.756	9.480	0.016	16.044	0.053
T9.5-1	9	12/11/2006	13:28:20	76.53232	39.23937	15.804	0.021	5.735	7.878	0.044	-9.300	10.069	0.019	17.178	0.044
T10.5-1	9	12/11/2006	10:59:36	76.53098	39.23977	15.944	0.045	5.939	5.233	0.071	-12.611	10.006	0.065	17.844	0.133
T12.5-1	9	12/11/2006	13:10:24	76.52762	39.24095	15.958	0.014	5.918	3.933	0.050	-14.389	10.040	0.038	18.322	0.044
T13.5-1	9	12/11/2006	12:53:47	76.52597	39.24143	15.913	0.026	5.843	4.022	0.097	-13.978	10.070	0.027	18.000	0.000
T17.5-3	9	12/11/2006	11:46:39	76.52200	39.24102	10.513	0.023	5.049	5.122	0.044	-6.178	5.464	0.083	11.300	0.071
T18-4	10	12/10/2006	14:06:53	76.52145	39.24017	12.999	0.036	5.084	**3.510**	0.032	-9.690	7.915	0.001	13.200	0.000
T18-5	9	12/10/2006	13:57:25	76.52170	39.23990	14.026	0.043	6.006	6.556	2.544	-6.689	8.020	0.014	13.244	0.053
T18.5-5	9	12/11/2006	12:01:09	76.52008	39.24008	11.836	0.067	5.700	4.567	0.206	-7.867	6.136	0.022	12.433	0.050
T19-4	9	12/10/2006	15:12:38	76.51898	39.24078	8.513	0.001	1.286	**2.900**	0.000	-10.100	7.227	0.002	13.000	0.000
T19-5	9	12/10/2006	15:31:02	76.51882	39.24057	10.124	0.010	2.759	5.422	0.044	-7.667	7.365	0.003	13.089	0.033
T19-6	9	12/10/2006	15:45:29	76.51870	39.24033	8.384	0.003	0.900	**3.822**	0.044	-9.278	7.484	0.010	13.100	0.000

Notes: Probe = subsurface | C = degrees Celsius

Reference (Ref) = surface water | mS/cm = millisiemens per centimeter

Δ Temp = subsurface – surface water temperature | Δ Cond = subsurface – surface water conductivity

Table 3-6. Trident sensor results for supplemental stations.

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	Subsurface		Surface water	
	Probe Temp (C)	Probe Cond (mS/cm)	Ref Temp (C)	Ref Cond (mS/cm)
Average	13.61	5.16	9.18	15.60
Minimum	8.38	1.64	5.46	6.56
Maximum	16.24	11.89	10.71	19.83
Stdev	2.05	1.97	1.37	2.56

Table 3-7. Statistical summary for the Trident sensor survey.

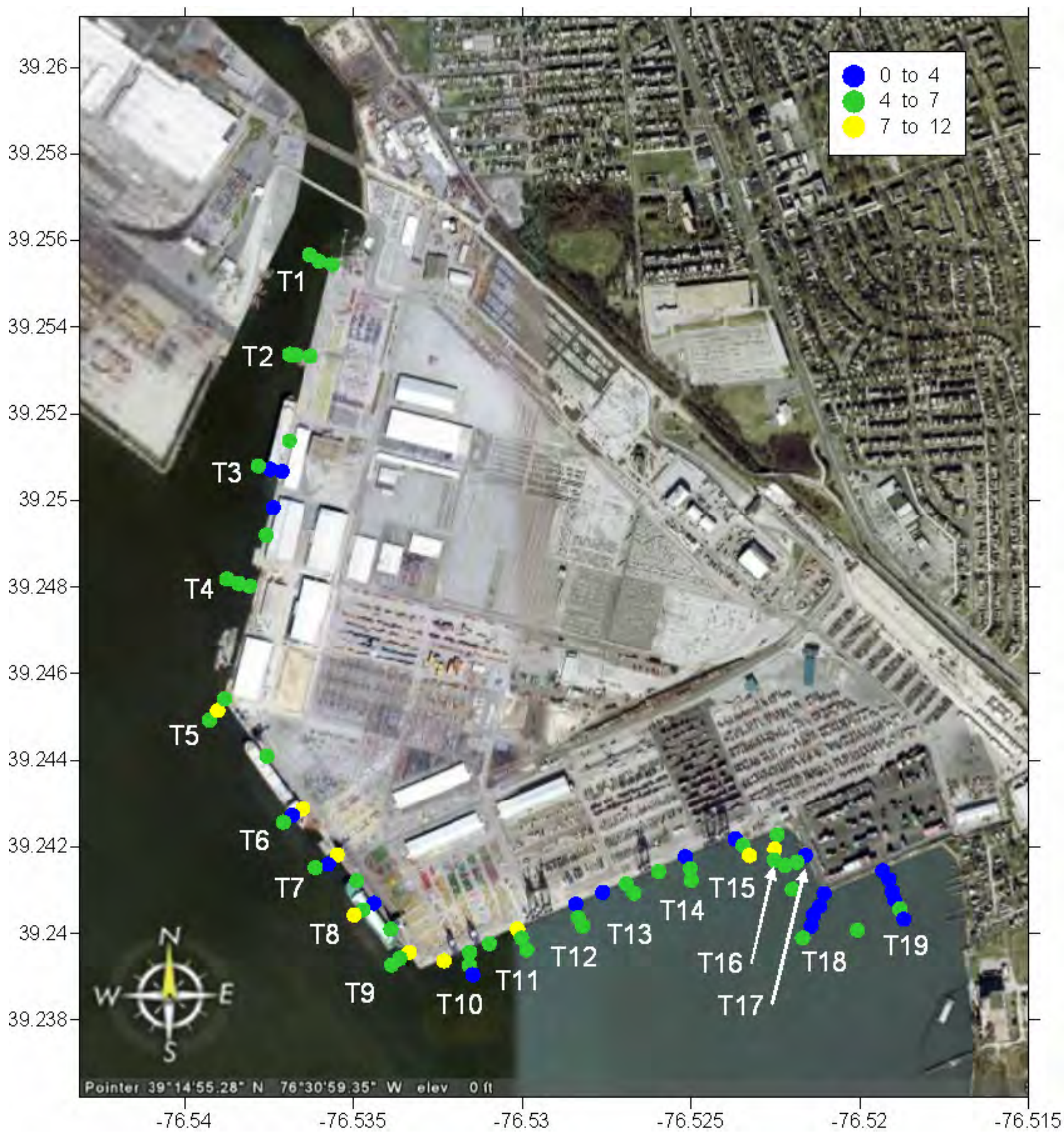

Figure 3-5. Trident subsurface conductivity distribution (mS/cm).

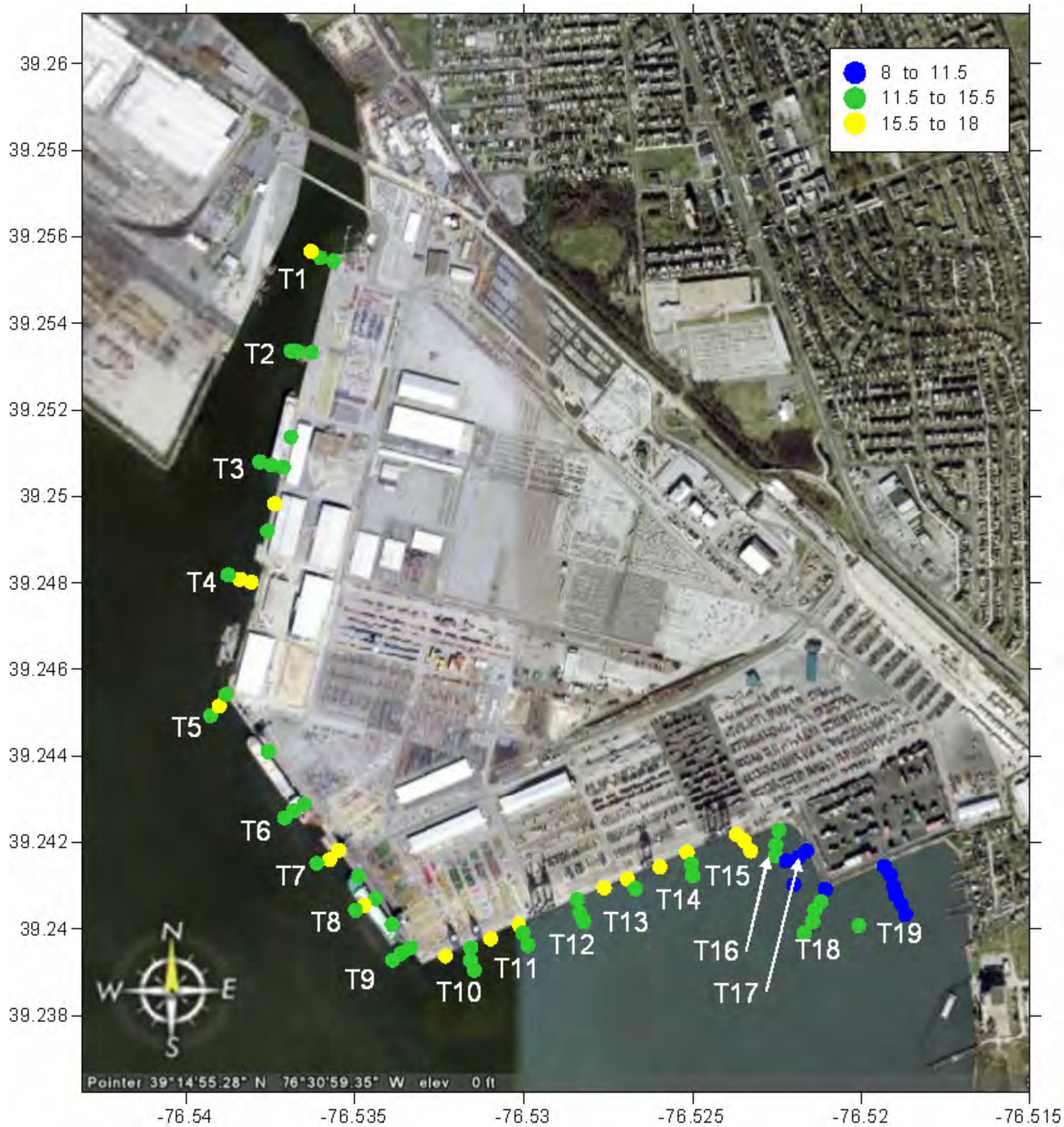

Figure 3-6. Trident subsurface temperature distribution (C).

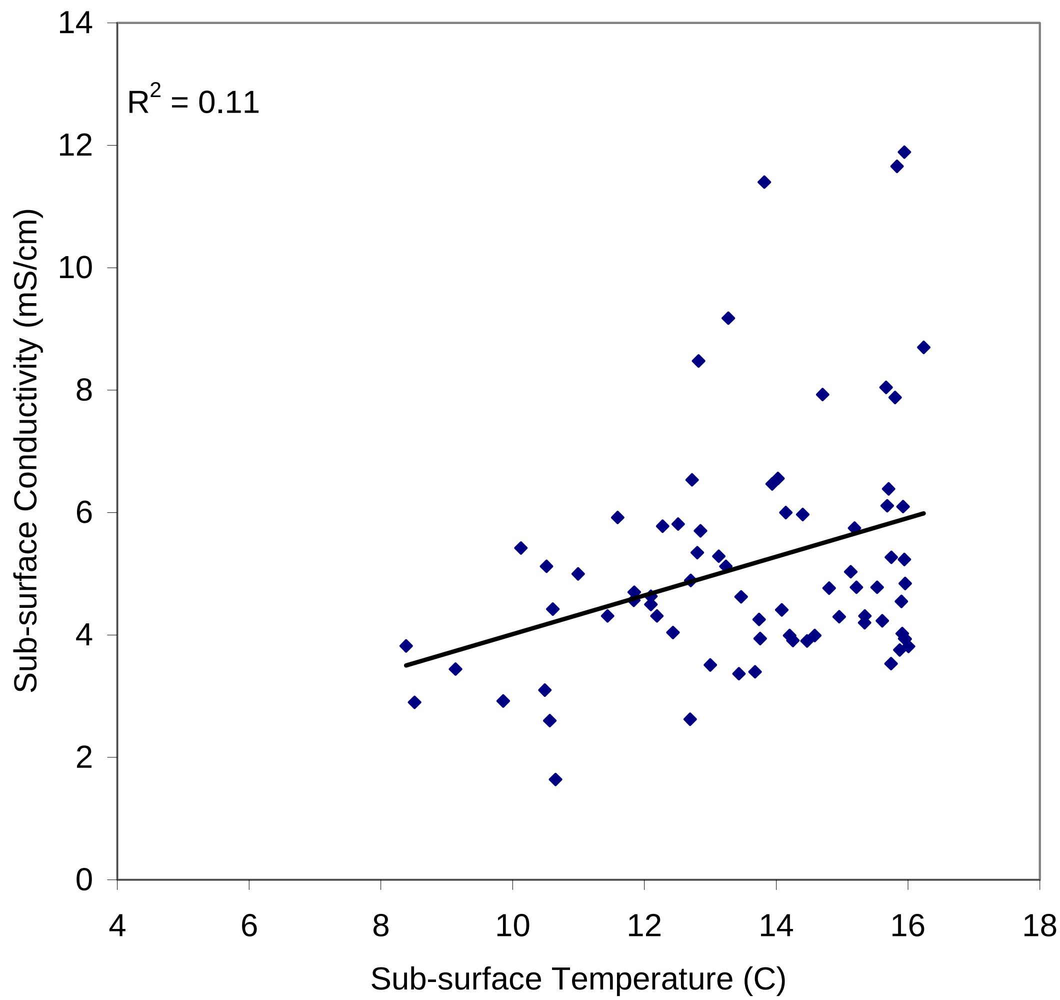

Figure 3-7. Relationship between subsurface conductivity and temperature.

Figure 3-8. Potential discharge zones based on Trident subsurface conductivity and temperature.

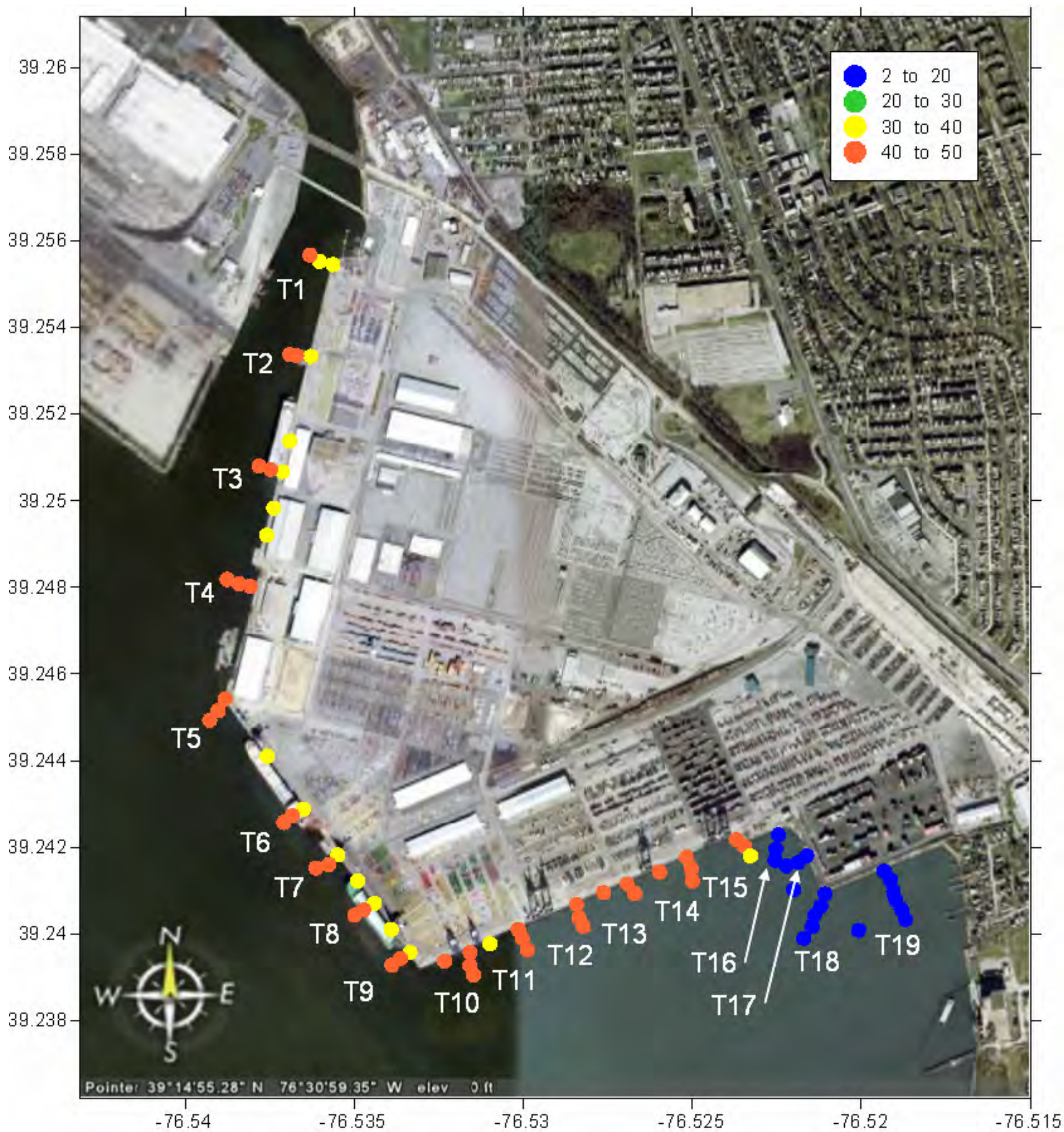

Figure 3-9. Bottom depth readings (ft) obtained during the Trident survey. Depths were measured by hand-held acoustic sounder and are not corrected for tidal variation.

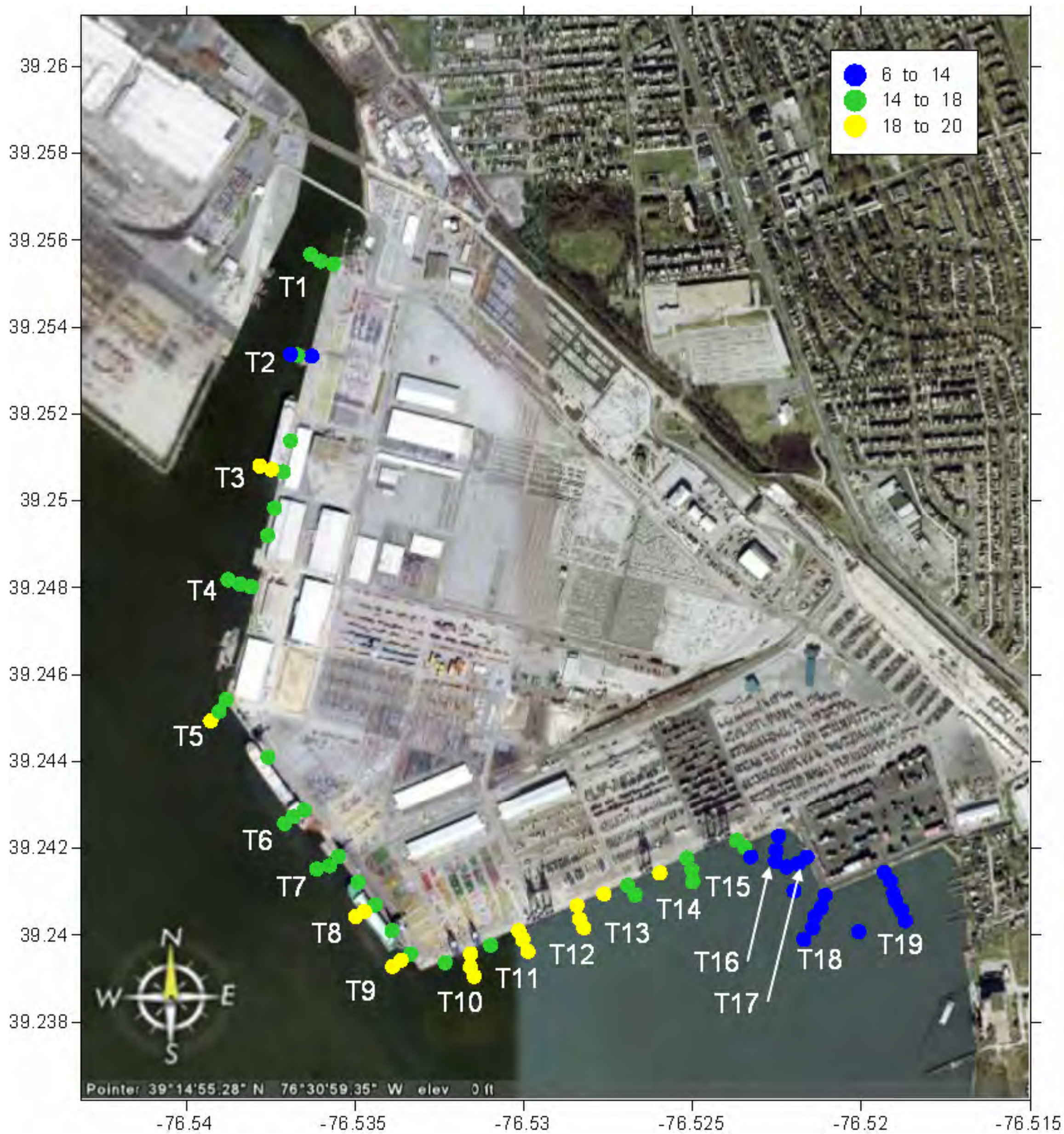

Figure 3-10. Trident reference sensor conductivity (mS/cm). Reference conductivities were measured within 1 ft of the bottom.

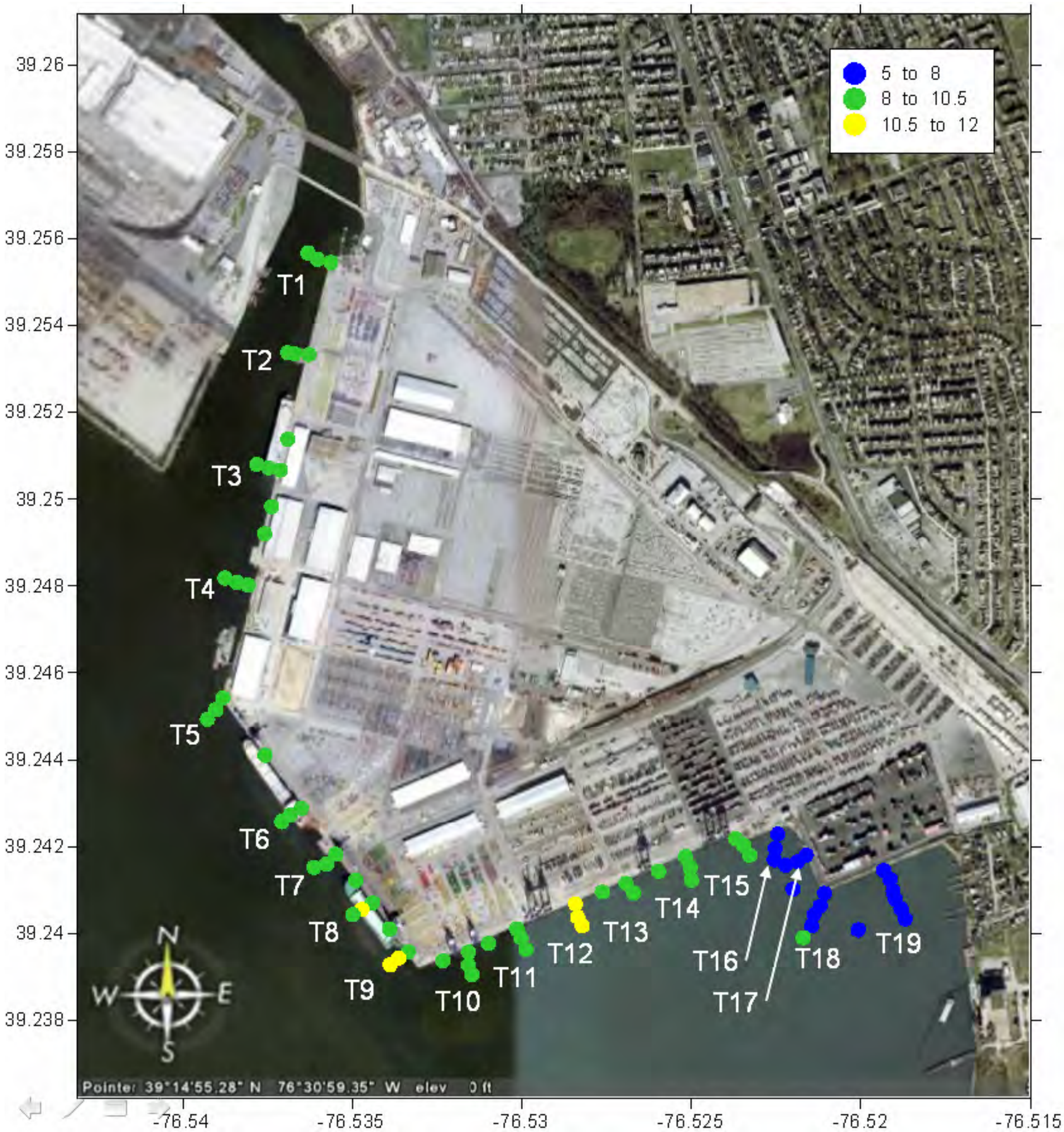

Figure 3-11. Trident reference sensor temperature (C). Reference temperatures were measured within 1 ft of the bottom.

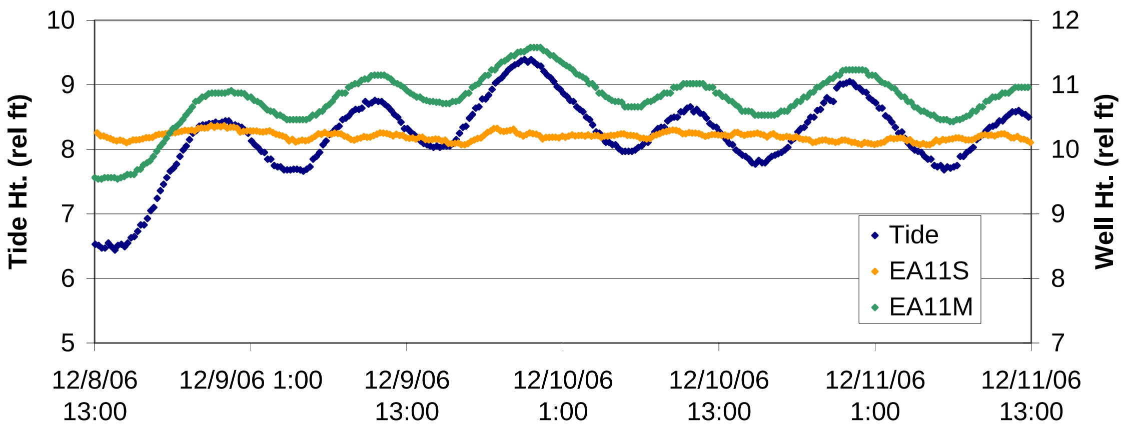

Figure 3-12. Level variation in monitoring well pair EA-11S/EA-11M compared to variations in the harbor tide.

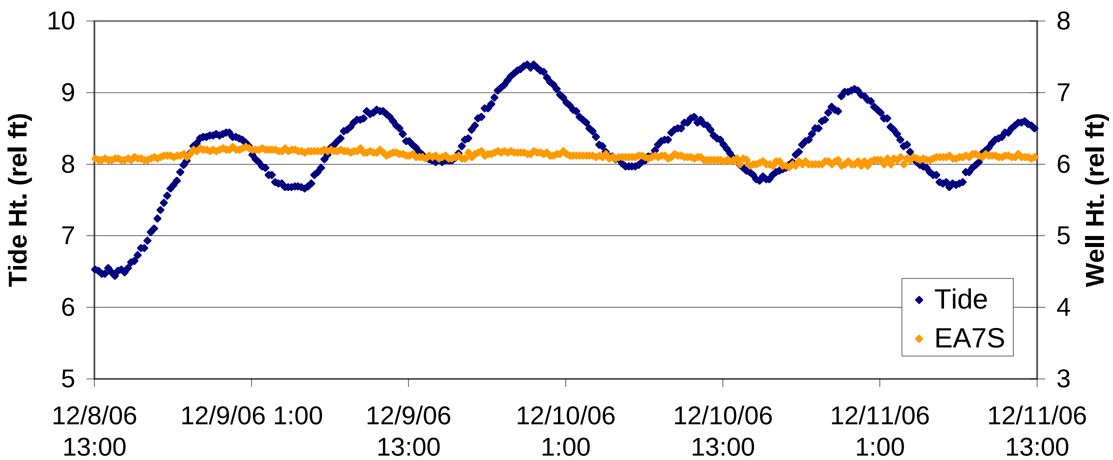

Figure 3-13. Level variation in monitoring well pair EA-7S compared to variations in the harbor tide.

4 REFERENCES

Chadwick, D.B., J. Groves, C. Smith, and R. Paulsen. 2003. Hardware description and sampling protocols for the Trident Probe and UltraSeep system: Technologies to evaluate contaminant transfer between groundwater and surface water. Technical Report #1902, SSC San Diego, United States Navy.

Data Report

Groundwater Upwelling Survey – Round 2

Dundalk Marine Terminal – Baltimore, Maryland

February 2008

Submitted to:

CH2M HILL

99 Cherry Hill Rd., Suite 200

Parsippany, NJ 07054

Submitted by:

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4741 Orchard Ave.

San Diego, CA 92107

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LIST OF ACRONYMS

COPR	Chrome Ore–Processing Residue
DMT	Dundalk Marine Terminal
GPS	Global Positioning System
MDE	Maryland Department of Environment
MPA	Maryland Port Administration
NIST	National Institute of Standards and Technology
PARCC	Precision, Accuracy, Representativeness, Completeness, and/or Comparability
QA	Quality Assurance
RSD	Relative Standard Deviation

UNITS

C	degrees Celsius
ft	feet
%FS	percent full scale
mS/cm	millisiemens per centimeter

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1 INTRODUCTION

1.1 BACKGROUND

This data report describes the results of groundwater upwelling surveying near Dundalk Marine Terminal (DMT) in Baltimore, Maryland. The work was performed in support of a 2006 Consent Decree entered into among the Maryland Department of the Environment (MDE), the Maryland Port Administration (MPA), and Honeywell International Inc. (Honeywell).

1.2 SITE CHARACTERISTICS

DMT is a major maritime port operated by the MPA encompassing approximately 560 acres in the inner Harbor of Baltimore. Part of DMT is constructed on land reclaimed from prior marshlands and the Patapsco River by means of fill composed primarily of chrome ore–processing residue (COPR). COPR fill is in contact with groundwater. The potential for transport of chromium via the groundwater pathway is being assessed as part of the Chromium Transport Study (CH2M HILL, 2008).

1.3 OBJECTIVES OF THE PROJECT

The objective for this work was to identify potential groundwater upwelling locations.

2 PROJECT TECHNOLOGY AND METHODOLOGY

2.1 TECHNOLOGY DESCRIPTION

The primary technology utilized for the study was a screening probe for determining where groundwater may be discharging (the Trident Probe; Figure 2-1). The Trident probe is a direct-push, integrated temperature sensor, conductivity sensor, and porewater sampler developed to screen sites for areas where groundwater may be discharging to a surface water body (Figure 2-1; Chadwick et al., 2003). Spatial patterns in observed subsurface and surface water conductivity and temperature indicate areas where groundwater discharge may be occurring. The pole-mounted global positioning system (GPS) receiver records the location of the push. Only the sensor component of the system was used during this survey.

2.2 SAMPLING DESIGN

The experimental design for the Trident survey at DMT focused on identifying potential groundwater discharge zones along the shoreline of the terminal. The sampling grid consisted of the 19 primary transects of 3 stations each, and 17 supplementary stations to further delineate potential groundwater discharge zones around the periphery of the terminal (Figure 2-2). Testing occurred at 100-foot intervals out from the periphery at each of those locations, beginning immediately adjacent to the terminal (i.e. at 0 feet, 100 feet, and 200 feet). Exact locations were adjusted depending on site conditions. At identified groundwater upwelling locations, additional samples were taken along and adjacent to the transect to better identify the upwelling area. Ancillary measurements of water levels were collected in two monitoring well pairs and in the harbor adjacent to DMT.

2.3 TRIDENT SENSOR SAMPLING

The Trident Probe survey was conducted in the harbor adjacent to DMT during the period extending from 10/29/07 – 11/2/07. A total of 74 Trident stations were sampled for subsurface temperature/conductivity contrast. At each station, average sensor readings were determined based on a minimum of nine replicate readings. The Trident sensor survey was conducted by inserting the probe into the seabed to a depth of approximately 2 ft from a small boat. Once on station with the probe inserted, data was collected from the probe (subsurface) and reference (surface water at 1 ft above the interface) conductivity and temperature sensors and the GPS using the TridentTalk software. Once the sensor readings had stabilized, the data was recorded by activating the "Log current data" button on the TridentTalk display. The real-time data was then reviewed in numeric format, and displayed spatially using the AGIS™ graphical information system software. The spatial AGIS™ display provided a capability for rapidly evaluating the most likely areas of groundwater discharge based on spatial patterns of subsurface temperature and conductivity and contrast between subsurface and surface water conditions. The resulting survey data were used to develop spatial maps indicating potential areas of groundwater discharge.

2.4 MONITORING WELL LEVEL LOGGING

Level loggers were installed in two monitoring well pairs and at a single location in the harbor to monitoring water level fluctuations during the study period. The level loggers were internal-recording Solinst™ units that were suspended within the well using a stainless steel wire. The level loggers were not vertically geo-referenced, so only relative variations were monitored. Levels were monitored at 15 minute intervals for the period extending from about 1730 10/31/07 to 1600 11/2/07. The monitoring well pairs included well EA-11S/EA-11M located on the southwestern corner of the terminal, and EA-58S/EA-7M located at the southwestern shoreline of the terminal.

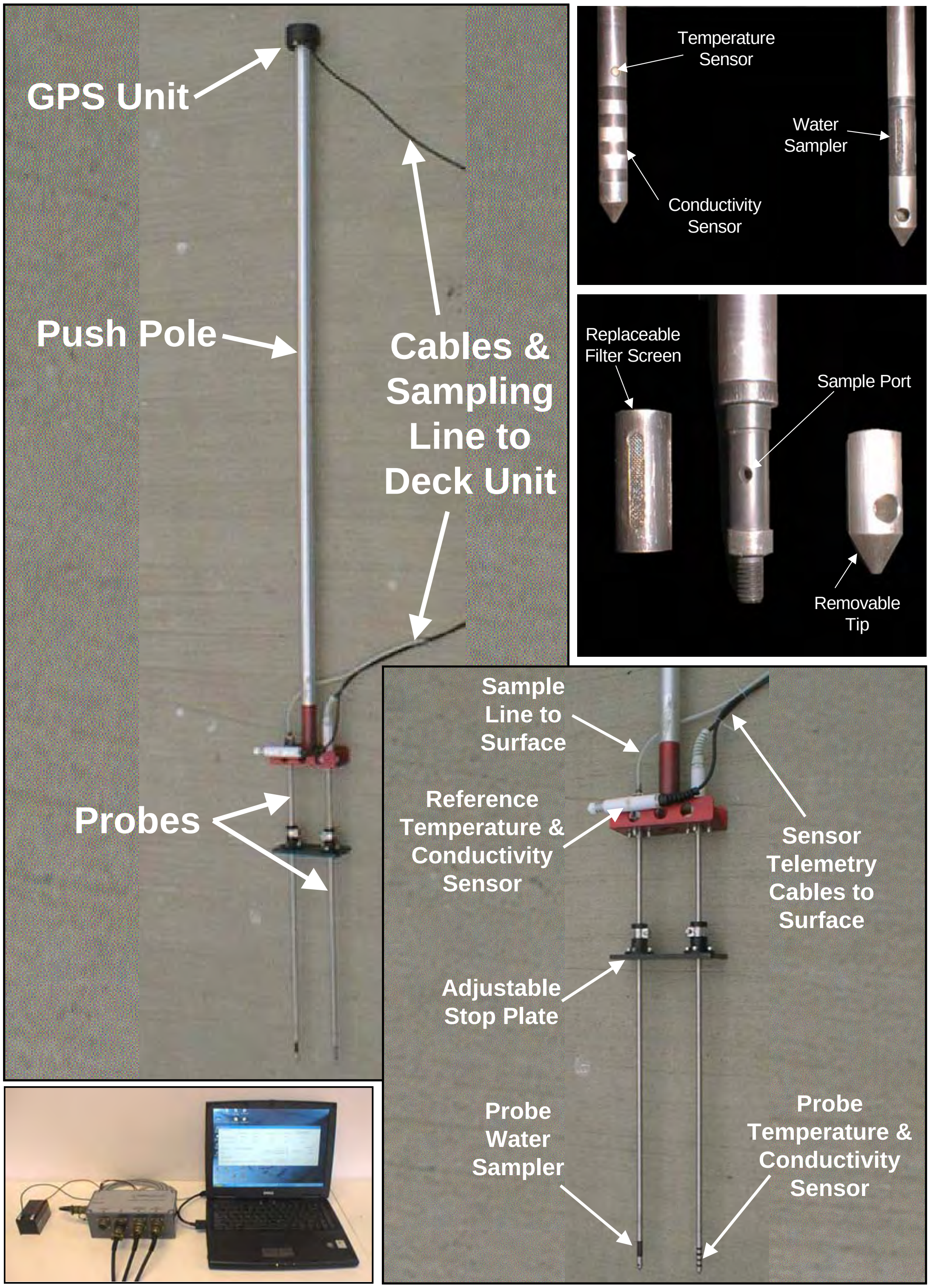

Figure 2-1. Complete Trident Probe showing sensor and water sampling probes, push-pole, GPS unit, expanded view of sensors and water sampler, and deck unit.

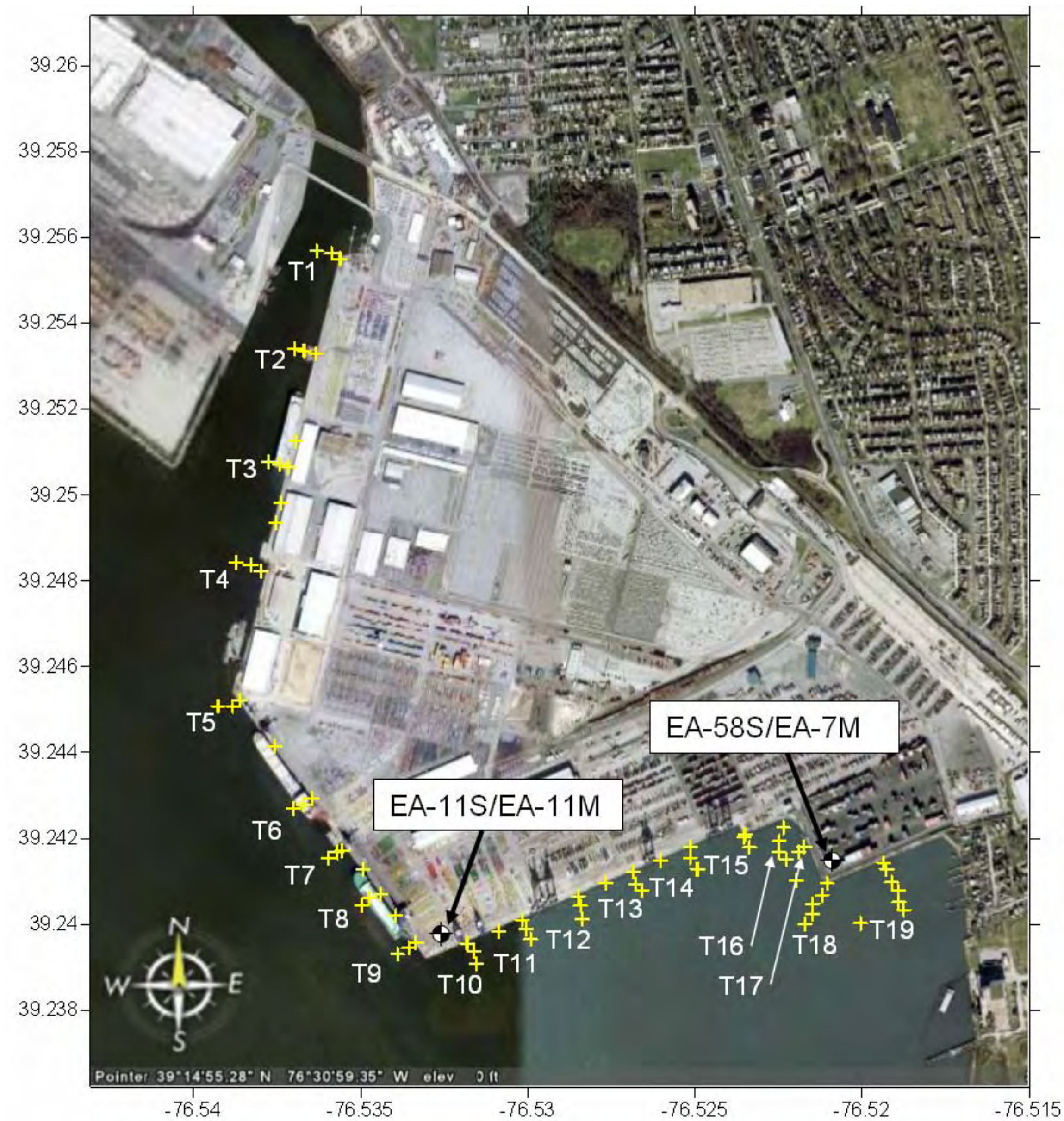

Figure 2-2. Sampling grid for the Trident Probe sensor survey offshore from DMT. Labels indicate transect numbers. Individual stations were designated A,B,C… with increasing distance from shore. Intermediate transects were designated with fractional designations based on the relative position between adjacent primary transects (e.g. T3.5).

3 RESULTS

3.1 DATA QUALITY RESULTS

The quality assurance (QA) objective of this field investigation was to collect data of known quality. The QA processes included the application of: (1) appropriate field techniques; (2) appropriate analytical methods; and (3) measurement objectives for precision, accuracy, representativeness, completeness, and comparability (PARCC). Results for the QA objectives for the Trident measurements are summarized below.

Precision

Precision for the Trident sensors including temperature and conductivity was assessed on the basis of replicate analysis performed under controlled laboratory conditions prior to commencement of the survey. Sensor replicates consisted of a minimum of nine individual measurements for each standard. Results for the Trident laboratory precision were generated for replicate measurements of two separate National Institute of Standards and Technology (NIST) conductivity standards and two fixed temperature water baths monitored by a highly accurate digital oceanographic thermometer. Laboratory relative standard deviations (RSDs) for the Trident conductivity sensors ranged from 0.00 – 0.21% of full scale for the Probe, and 0.00 – 0.03% for the Reference (Table 3-1). RSDs for the Trident temperature sensors were 0.02 – 0.25% full scale for the Probe, and 0.15 – 1.04% for the Reference (Table 3-2). This range of variation is generally 1-3 orders of magnitude lower than the variations observed at the site.

Accuracy

For Trident temperature and conductivity sensors, accuracy was established by applying laboratory calibrations. Calibration curves for the Trident probe conductivity and temperature sensors are shown in Figure 3-1 and Figure 3-2. Calibration curves for the Trident reference conductivity and temperature sensors are shown in Figure 3-3 and Figure 3-4.

Representativeness

Representativeness is a qualitative expression of the degree to which sample data accurately represent the characteristics of a population, parameter variations at a sampling point, or an environmental condition that they are intended to represent. Representativeness was maximized by (1) selecting the appropriate number of samples and sampling locations, and (2) using appropriate and established sample collection, handling, and analysis techniques to provide information that reflects actual site conditions.

Completeness

Completeness assesses the amount of valid data obtained from a measurement system compared to the amount of data required to achieve a particular statistical level of confidence. The percent completeness was calculated as the number of samples yielding acceptable data divided by the total number of samples planned to be collected and multiplied by 100. Results for completeness were assessed for the Trident sensor data based on the number of stations where acceptable data was collected. Completeness for the Trident sensor data was 100%.

Comparability

Comparability is a qualitative parameter that expresses the degree of confidence that one data set may be compared to another. This goal was achieved through the use of (1) standardized techniques to collect and analyze samples, and (2) appropriate units to report analytical results. The comparability of the data was maximized by using standard analytical methods when possible, reporting data in consistent units, reporting data in a tabular format, and by validating the results against commonly accepted methodologies and target limits.

NIST Standard		Trident Probe Sensor				
Raw NIST (mS/cm)	Temp (C)	Raw Probe (mS/cm)	Cal Probe (mS/cm)	Residual (mS/cm)	RPD (% FS)	RSD (% FS)
0	22.685	0.200	0.218	-0.218	2.21%	0.00%
0	22.675	0.200	0.218	-0.218	2.21%	
0	22.665	0.200	0.218	-0.218	2.21%	
0.998	22.443	1.100	1.19860	-0.201	2.03%	0.00%
0.998	22.429	1.100	1.19860	-0.201	2.03%	
0.998	22.421	1.100	1.19860	-0.201	2.03%	
9.86	23.22	9.033	9.843	0.017	0.18%	0.21%
9.86	23.2	9.000	9.807	0.053	0.54%	
9.86	23.144	9.033	9.843	0.017	0.18%	

Calibration Coefficients	
Slope	1.090

Min	0.18%	0.00%
Max	2.21%	0.21%
Avg	1.51%	0.11%

Full Scale	9.86

NIST Standard		Trident Reference Sensor				
Raw NIST (mS/cm)	Temp (C)	Raw Ref (mS/cm)	Cal Ref (mS/cm)	Residual (mS/cm)	RPD (% FS)	StDev Res (mS/cm)
0	21.886	0.003	0.003	-0.003	0.03%	0.00%
0	22.16	0.003	0.003	-0.003	0.03%	
0	22.306	0.003	0.003	-0.003	0.03%	
0.998	19.234	1.056	1.04106	-0.043	0.44%	0.02%
0.998	19.445	1.058	1.04304	-0.045	0.46%	
0.998	19.514	1.059	1.04402	-0.046	0.47%	
9.86	22.713	9.993	9.852	0.008	0.08%	0.03%
9.86	22.764	9.999	9.858	0.002	0.02%	
9.86	22.668	9.998	9.857	0.003	0.03%	

Calibration Coefficients	
Slope	0.986

Min	0.02%	0.00%
Max	0.47%	0.03%
Avg	0.18%	0.02%

Full Scale	9.86

Table 3-1. Conductivity calibration results for the Trident Probe and Reference sensors. Conductivities reported in millisiemens per centimeter (mS/cm) and relative standard deviations reported as percent of full scale (%FS).

NIST Temp Bath	Trident Probe Sensor				
(C)	Raw (C)	Cal (C)	Residual (C)	RPD (% FS)	RSD (% FS)
17.4	18.053	17.414	-0.014	0.05%	0.25%
17.4	18.132	17.498	-0.098	0.33%	
17.4	18.191	17.561	-0.161	0.54%	
24.9	24.876	24.690	0.024	0.08%	0.02%
24.9	24.875	24.689	0.025	0.08%	
24.9	24.865	24.678	0.035	0.12%	
29.8	29.840	29.984	-0.184	0.62%	0.20%
29.8	29.783	29.923	-0.123	0.41%	
29.8	29.726	29.863	-0.063	0.21%	

Calibration Coefficients	
Slope	1.066
Offset	-1.840

Min:	0.05%	0.02%
Max:	0.62%	0.25%
Avg:	0.27%	0.16%

Full Scale	29.8

NISTTemp Bath	Trident Reference Sensor				
(C)	Raw (C)	Cal (C)	Residual (C)	RPD (% FS)	RSD (% FS)
17.4	16.804	16.082	1.318	4.42%	0.15%
17.4	16.851	16.132	1.268	4.26%	
17.4	16.886	16.169	1.231	4.13%	
24.9	23.463	23.183	1.717	5.76%	1.04%
24.9	23.826	23.570	1.330	4.46%	
24.9	24.035	23.793	1.107	3.71%	
29.8	29.261	29.367	0.433	1.45%	0.16%
29.8	29.218	29.321	0.479	1.61%	
29.8	29.173	29.273	0.527	1.77%	

Calibration Coefficients	
Slope	1.005
Offset	0.632

Min:	1.45%	0.15%
Max:	5.76%	1.04%
Avg:	3.51%	0.45%

Full Scale	29.8

Table 3-2. Temperature calibration results for the Trident Probe and Reference sensors. Temperatures reported in degrees Celsius (C) and relative standard deviations reported as percent of full scale (%FS).

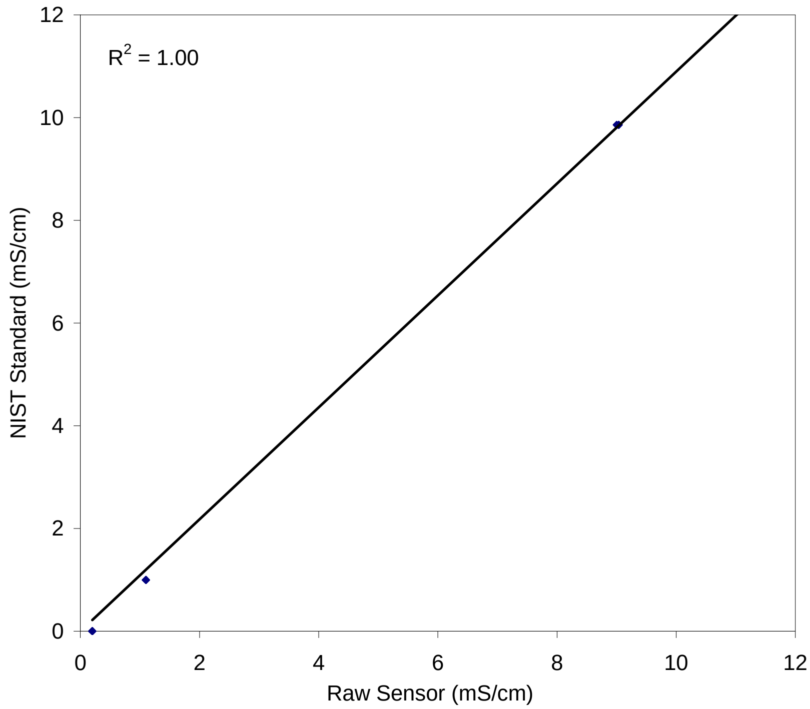

Figure 3-1. Trident probe conductivity sensor calibration.

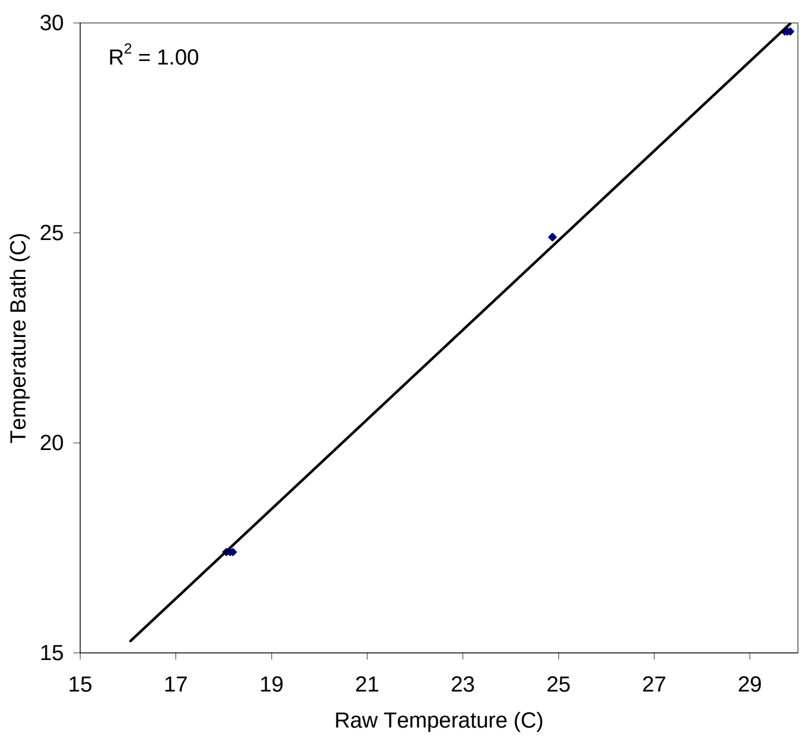

Figure 3-2. Trident probe temperature sensor calibration.

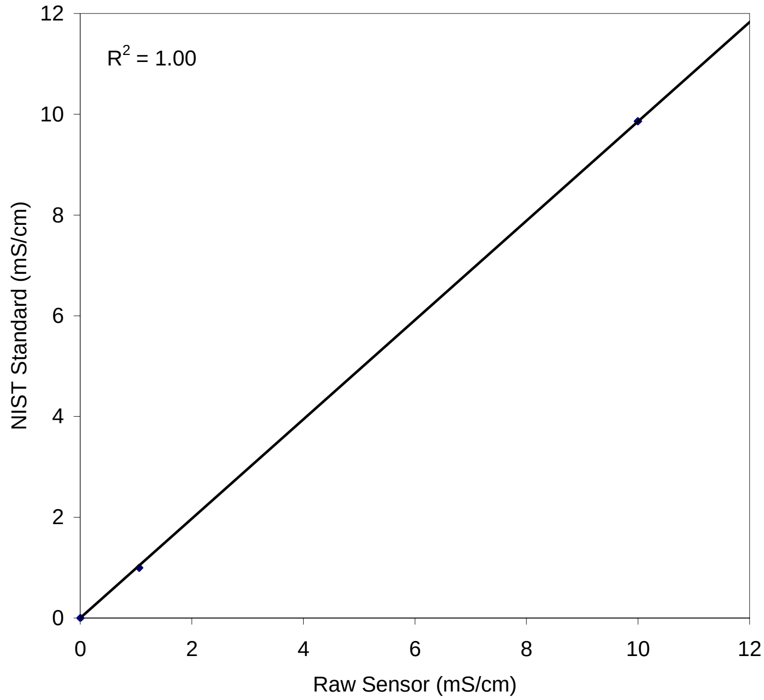

Figure 3-3. Trident reference conductivity sensor calibration.

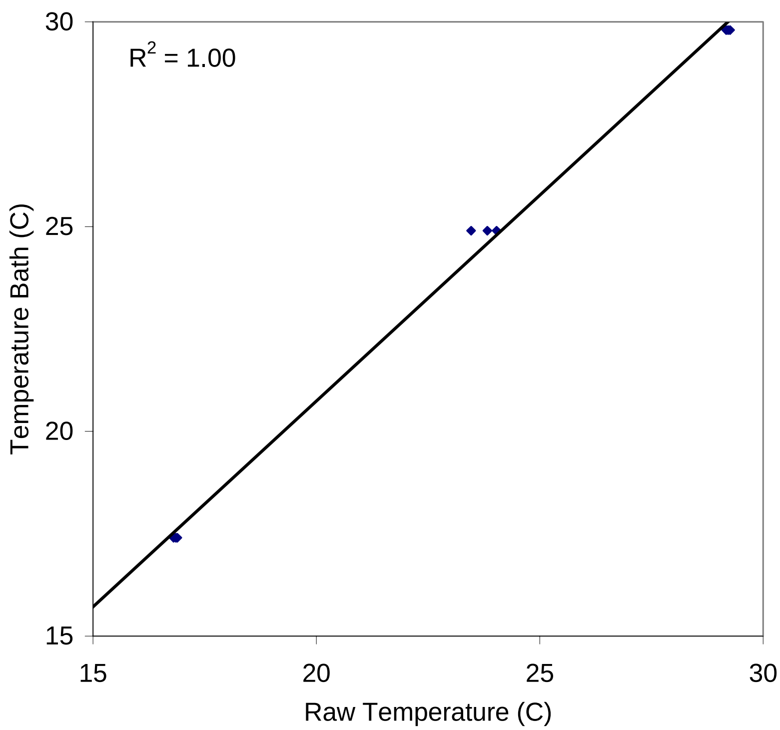

Figure 3-4. Trident reference temperature sensor calibration.

3.2 FIELD SAMPLING RESULTS

3.2.1 TRIDENT CONDUCTIVITY AND TEMPERATURE MAPPING

Horizontal Trident mapping of conductivity and temperature contrast was used to identify likely areas of groundwater discharge to the harbor area adjacent to the terminal. During the fall, groundwater in this region was expected to be warmer and fresher than the surface water. Trident measurements were performed at the stations shown in Figure 2-2. Complete results for the Trident conductivity and temperature mapping are given in Table 3-3 through Table 3-6, and statistics are summarized in Table 3-7. The results for subsurface conductivity and temperature for the offshore study area were classified and posted spatially with an aerial photo basemap in Figure 3-5 and Figure 3-6. Water depths and bottom type at each station are summarized in Table 3-8. Water depths were recorded with a hand-held acoustic sounder and are not corrected for tidal condition. Bottom type is generally gaged by the relative resistance during insertion of the Trident Probe and should be viewed as qualitative.

Subsurface conductivities ranged from 1.70 to 13.38 mS/cm, with a site-average of 6.77 mS/cm. This range is comparable to the observations from Round 1 in December 2006. Lowest subsurface conductivity values were concentrated in the southeastern portion of the study area from transect 17-19, both in the nearshore and offshore stations. Another zone with relatively low conductivities (i.e. < 4 mS/cm) was also identified along the southern shoreline between transects 12-14, predominately at the outer (B and C) stations. More isolated areas were identified along the western shore on transects 1 and 3, and along the southwestern shore on transects 6 and 8. These areas show a general correspondence to the low conductivity zones identified in Round 1.

Subsurface temperatures in the offshore region varied by only about 3 C, ranging from 17.18 C to 20.28 C with a site-average temperature of 19.28 C. Temperatures were generally about 4-5 C warmer than observed during Round 1, and the temperature range was considerably smaller. The general uniformity of temperatures across the site indicates that strong areas of contrasting groundwater discharge based on temperature were not observed. Relatively warmer temperatures were observed along the southern and southwestern shorelines in transects T6-T14, near the southeastern extent of the survey area on transect T18, and along the western shore at transects T2-T3. There was no significant correlation between subsurface conductivity and temperature, however there was a clustering of stations with low conductivity and warmer temperatures (Figure 3-7).

Based on the subsurface conductivity and temperature mapping, potential groundwater discharge zones were identified (Figure 3-8). Due to the weak temperature variation, conductivity differences probably provide the best indicator of potential discharge zones. Correspondence of these zones with warm temperature also tends to increase the likelihood of potential influence from groundwater discharge. The zone between T17 – T19 in the southeast extent of the study area had the strongest low conductivity anomaly. In this area, T18 also had elevated subsurface temperatures. Subsurface temperatures in this zone were generally warmer than the surface water by about 1-2 C. Other areas of low subsurface conductivity showed some overlap with warmer subsurface temperature, particularly along the southern shoreline on transects T10 and T12-T14, the western shoreline at T3, and the southwestern shoreline at T8. These conductivity anomalies were generally weaker than observed in the southeastern zone.

3.2.2 MONITORING WELL ELEVATIONS

Results for the EA-11 and EA-58/7 well pairs are shown in comparison to the tidal elevation in the harbor in Figure 3-9 and Figure 3-10, respectively. The results at both locations showed significant response in the deeper well relative to the tidal variation in the harbor. At EA-58S, the shallow well also showed a strong tidal response, while at EA-11S, the response was strongly attenuated. These results are similar to the findings from Round 1, except in Round 1 shallow well EA-7S was monitored and showed no significant tidal response. During Round 2 this well was substituted by EA-58S due to concerns that EA-7S was isolated by subsurface structural barriers. The suggests that there is a low degree of groundwater-surface water interaction between the harbor and the shallow aquifer near EA-11, while the connection between the harbor and the deeper aquifer appears to be stronger, as does the connection with the shallow aquifer near EA-58.

Station ID	Station Reps.	Date	Time (EST)	Long (deg. W)	Lat (deg. N)	Avg Probe Temp (C)	StDev Probe Temp (C)	Δ Temp (C)	Avg Probe Cond (mS/cm)	StDev Probe Cond (mS/cm)	Δ Cond (mS/cm)	Avg Ref Temp (C)	StDev Ref Temp (C)	Avg Ref Cond (mS/cm)	StDev Ref Cond (mS/cm)
T1-A	9	10/30/2007	16:50:33	-76.53562	39.25550	18.874	0.003	-0.858	4.467	0.071	-19.563	19.732	0.035	24.030	0.024
T1-B	10	10/30/2007	17:04:56	-76.53588	39.25562	18.172	0.018	-1.980	8.760	0.143	-12.932	20.151	0.009	21.692	0.116
T1-C	9	10/30/2007	17:17:11	-76.53632	39.25568	18.537	0.022	-1.497	5.678	0.083	-9.352	20.034	0.016	15.030	0.006
T2-A	10	10/31/2007	16:09:25	-76.53633	39.25330	18.717	0.006	-1.007	9.350	0.053	-6.162	19.724	0.022	15.512	0.056
T2-B	10	10/31/2007	15:57:41	-76.53670	39.25335	19.706	0.016	0.023	6.500	0.082	-18.681	19.683	0.018	25.181	0.021
T2-C	10	10/31/2007	15:44:13	-76.53698	39.25340	19.587	0.007	-0.189	5.690	0.129	-19.471	19.775	0.001	25.161	0.016
T3-A	9	11/1/2007	14:23:27	-76.53715	39.25065	19.572	0.001	0.484	5.300	0.050	-18.780	19.088	0.016	24.080	0.021
T3-B	10	11/1/2007	14:33:02	-76.53743	39.25072	19.799	0.010	0.552	4.210	0.057	-20.375	19.248	0.039	24.585	0.020
T3-C	9	11/1/2007	14:48:09	-76.53777	39.25078	19.724	0.004	0.373	4.733	0.112	-19.825	19.350	0.013	24.558	0.012
T4-A	10	11/1/2007	10:58:49	-76.53798	39.24823	18.408	0.003	-0.868	5.000	0.082	-19.257	19.276	0.013	24.257	0.016
T4-B	9	11/1/2007	11:35:57	-76.53830	39.24837	19.151	0.016	-0.259	8.122	0.130	-16.578	19.409	0.001	24.700	0.010
T4-C	10	11/1/2007	11:52:28	-76.53872	39.24842	19.597	0.003	0.215	11.410	0.378	-13.280	19.382	0.007	24.690	0.010
T5-A	10	11/1/2007	10:04:39	-76.53860	39.24522	19.269	0.004	0.509	8.940	0.097	-15.023	18.760	0.020	23.963	0.005
T5-B	10	11/1/2007	10:18:37	-76.53883	39.24508	18.489	0.009	-1.052	13.380	0.114	-5.867	19.541	0.043	19.247	0.454
T5-C	10	11/1/2007	10:32:01	-76.53927	39.24508	19.000	0.001	-0.141	8.130	0.048	-16.295	19.141	0.024	24.425	0.014
T6-A	10	10/30/2007	15:31:18	-76.53645	39.24292	19.949	0.007	0.634	11.330	0.048	-13.358	19.315	0.024	24.688	0.022
T6-B	9	10/30/2007	15:44:38	-76.53672	39.24278	19.509	0.006	-0.231	4.922	0.199	-20.742	19.740	0.007	25.664	0.014
T6-C	9	10/30/2007	15:57:14	-76.53703	39.24270	19.692	0.007	0.125	3.944	0.053	-21.784	19.566	0.017	25.728	0.014
T7-A	9	10/31/2007	11:01:26	-76.53557	39.24172	18.405	0.001	-1.336	8.356	0.053	-11.884	19.741	0.005	20.239	0.040
T7-B	10	10/31/2007	11:13:44	-76.53570	39.24167	18.437	0.006	-1.055	11.760	0.052	-9.555	19.491	0.024	21.315	0.117
T7-C	9	10/31/2007	11:32:20	-76.53598	39.24153	19.844	0.004	0.535	5.200	0.240	-20.046	19.309	0.012	25.246	0.005

Notes: Probe = subsurface; C = degrees Celsius

Reference (Ref) = surface water; mS/cm = millisiemens per centimeter

Δ Temp = subsurface – surface water temperature; Δ Cond = subsurface – surface water conductivity

Table 3-3. Trident sensor results for transects 1-7.

Station ID	Station Reps.	Date	Time (EST)	Long (deg. W)	Lat (deg. N)	Avg Probe Temp (C)	StDev Probe Temp (C)	Δ Temp (C)	Avg Probe Cond (mS/cm)	StDev Probe Cond (mS/cm)	Δ Cond (mS/cm)	Avg Ref Temp (C)	StDev Ref Temp (C)	Avg Ref Cond (mS/cm)	StDev Ref Cond (mS/cm)
T8-A	10	10/31/2007	9:57:18	-76.53442	39.24070	19.823	0.006	0.824	6.040	0.052	-18.404	18.999	0.009	24.444	0.012
T8-B	10	10/31/2007	10:09:27	-76.53475	39.24060	19.450	0.002	0.187	4.210	0.032	-20.499	19.264	0.016	24.709	0.014
T8-C	10	10/31/2007	10:22:37	-76.53497	39.24045	19.768	0.004	0.518	4.000	3.490	-20.915	19.250	0.019	24.915	0.018
T9-A	9	10/31/2007	9:06:35	-76.53335	39.23957	19.950	0.003	0.666	9.411	0.196	-15.470	19.285	0.007	24.881	0.037
T9-B	9	10/31/2007	9:18:34	-76.53357	39.23945	19.867	0.004	0.532	5.600	0.000	-19.542	19.335	0.017	25.142	0.041
T9-C	9	10/31/2007	9:31:14	-76.53390	39.23930	19.721	0.004	0.391	5.411	0.033	-19.824	19.330	0.024	25.235	0.023
T10-A	10	10/30/2007	9:22:17	-76.53182	39.23955	19.788	0.002	-0.202	6.230	0.048	-19.476	19.990	0.016	25.706	0.009
T10-B	10	10/30/2007	10:53:07	-76.53162	39.23938	19.716	0.001	-0.241	8.880	0.123	-16.963	19.957	0.004	25.843	0.022
T10-C	9	10/30/2007	11:10:53	-76.53155	39.23907	19.814	0.001	-0.083	4.900	0.000	-20.940	19.897	0.007	25.840	0.010
T11-A	10	10/30/2007	11:41:56	-76.53018	39.24010	19.264	0.008	-0.578	10.180	0.123	-13.308	19.843	0.020	23.488	0.371
T11-B	10	10/30/2007	11:54:53	-76.53005	39.23990	20.017	0.006	0.239	5.330	0.048	-20.379	19.779	0.007	25.709	0.010
T11-C	10	10/30/2007	12:18:41	-76.52992	39.23965	19.604	0.003	-0.067	6.050	0.053	-19.585	19.670	0.005	25.635	0.036
T12-A	10	10/30/2007	14:16:02	-76.52850	39.24065	19.847	0.002	0.281	5.860	2.059	-19.826	19.567	0.009	25.686	0.013
T12-B	9	10/30/2007	14:26:36	-76.52843	39.24043	19.666	0.012	0.233	5.900	0.000	-19.584	19.433	0.012	25.484	0.027
T12-C	9	10/30/2007	15:02:30	-76.52837	39.24013	19.790	0.001	0.439	3.811	0.033	-21.608	19.351	0.006	25.419	0.014
T13-A	10	10/29/2007	16:33:44	-76.52685	39.24122	18.945	0.015	-1.085	9.170	0.048	-15.036	20.030	0.019	24.206	0.041
T13-B	9	10/29/2007	16:46:10	-76.52678	39.24093	20.044	0.011	0.270	4.533	0.100	-21.502	19.774	0.054	26.036	0.036
T13-C	9	10/29/2007	16:57:45	-76.52658	39.24078	19.995	0.005	0.106	4.644	0.053	-21.358	19.889	0.021	26.002	0.012

Notes: Probe = subsurface; C = degrees Celsius

Reference (Ref) = surface water; mS/cm = millisiemens per centimeter

Δ Temp = subsurface – surface water temperature; Δ Cond = subsurface – surface water conductivity

Table 3-4. Trident sensor results for transects 8-13.

Station ID	Station Reps.	Date	Time (EST)	Long (deg. W)	Lat (deg. N)	Avg Probe Temp (C)	StDev Probe Temp (C)	Δ Temp (C)	Avg Probe Cond (mS/cm)	StDev Probe Cond (mS/cm)	Δ Cond (mS/cm)	Avg Ref Temp (C)	StDev Ref Temp (C)	Avg Ref Cond (mS/cm)	StDev Ref Cond (mS/cm)
T14-A	9	10/29/2007	15:26:39	-76.52515	39.24180	18.342	0.041	-1.748	8.489	0.060	-16.145	20.090	0.021	24.634	0.080
T14-B	10	10/29/2007	15:45:33	-76.52515	39.24155	19.713	0.003	-0.348	4.430	0.048	-21.467	20.061	0.010	25.897	0.012
T14-C	10	10/29/2007	16:02:47	-76.52493	39.24128	20.113	0.002	0.036	4.610	0.032	-21.192	20.077	0.006	25.802	0.012
T15-A	10	11/2/2007	9:30:19	-76.52350	39.24208	19.590	0.004	1.013	11.490	4.040	-9.458	18.578	0.010	20.948	0.042
T15-B	10	11/2/2007	12:30:00	-76.52354	39.24203	18.832	0.006	0.864	10.560	0.052	-12.505	17.968	0.036	23.065	0.042
T15-C	10	11/2/2007	12:40:00	-76.52337	39.24179	18.804	0.003	-0.123	10.750	0.053	-9.529	18.927	0.019	20.279	0.046
T16-A	10	11/2/2007	13:22:00	-76.52235	39.24225	19.393	0.008	2.215	7.900	0.047	-14.488	17.177	0.008	22.388	0.011
T16-B	10	11/2/2007	13:32:00	-76.52248	39.24193	18.908	0.023	2.011	6.660	2.024	-15.575	16.896	0.018	22.235	0.081
T16-C	10	11/2/2007	13:45:00	-76.52249	39.24168	18.638	0.009	1.781	8.010	0.032	-14.193	16.858	0.004	22.203	0.019
T17-A	10	11/2/2007	2:17:39	-76.52173	39.24180	17.182	0.004	0.183	3.800	0.000	-18.351	16.998	0.021	22.151	0.013
T17-B	10	11/2/2007	2:25:51	-76.52191	39.24168	18.159	0.010	1.236	5.600	0.000	-16.628	16.923	0.015	22.228	0.012
T17-C	10	11/2/2007	2:35:29	-76.52228	39.24151	17.829	0.011	0.861	4.600	0.000	-17.678	16.968	0.040	22.278	0.021
T18-A	10	10/29/2007	13:53:13	-76.52105	39.24095	19.277	0.011	0.808	3.320	0.042	-18.505	18.468	0.028	21.825	0.025
T18-B	10	10/29/2007	14:02:11	-76.52120	39.24068	20.023	0.020	1.444	5.770	2.028	-16.510	18.579	0.041	22.280	0.011
T18-C	10	10/29/2007	14:13:57	-76.52147	39.24047	20.281	0.016	1.711	5.050	2.662	-17.346	18.570	0.051	22.396	0.020
T19-A	10	10/29/2007	12:31:04	-76.51935	39.24143	19.426	0.001	1.344	1.700	0.000	-19.732	18.083	0.001	21.432	0.012
T19-B	10	10/29/2007	12:41:02	-76.51927	39.24128	19.244	0.035	1.376	2.600	0.000	-19.193	17.868	0.105	21.793	0.034
T19-C	10	10/29/2007	12:47:56	-76.51912	39.24098	19.479	0.021	1.472	3.210	0.032	-18.703	18.007	0.078	21.913	0.029

Notes: Probe = subsurface
C = degrees Celsius
Reference (Ref) = surface water
mS/cm = millisiemens per centimeter
Δ Temp = subsurface – surface water temperature
Δ Cond = subsurface – surface water conductivity

Table 3-5. Trident sensor results for transects 14-19.

Station ID	Station Reps.	Date	Time (EST)	Long (deg. W)	Lat (deg. N)	Avg Probe Temp (C)	StDev Probe Temp (C)	Δ Temp (C)	Avg Probe Cond (mS/cm)	StDev Probe Cond (mS/cm)	Δ Cond (mS/cm)	Avg Ref Temp (C)	StDev Ref Temp (C)	Avg Ref Cond (mS/cm)	StDev Ref Cond (mS/cm)
T2.5-A	10	10/31/2007	16:53:16	-76.53693	39.25125	19.456	0.002	-0.039	5.610	0.032	-19.281	19.496	0.044	24.891	0.075
T3.5-A	10	10/31/2007	16:37:41	-76.53738	39.24982	19.112	0.002	-0.275	12.140	0.306	-12.338	19.386	0.067	24.478	0.210
T3.5-B	9	11/1/2007	15:23:17	-76.53755	39.24935	18.251	0.002	-1.424	10.978	0.067	-5.902	19.675	0.006	16.880	0.065
T3.5-C	10	11/1/2007	15:21:30	-76.53753	39.24935	18.273	0.005	-1.350	11.200	0.047	-5.871	19.624	0.013	17.071	0.186
T5.5-A	9	10/30/2007	16:17:22	-76.53758	39.24415	19.380	0.030	0.338	7.811	0.105	-17.154	19.042	0.079	24.965	0.090
T7.5-A	9	10/31/2007	12:41:56	-76.53493	39.24128	19.812	0.024	0.783	8.344	0.053	-16.784	19.029	0.060	25.128	0.019
T8.5-A	9	10/31/2007	12:28:09	-76.53395	39.24020	19.628	0.010	0.466	5.900	0.000	-19.038	19.162	0.026	24.938	0.023
T10.5-A	9	11/2/2007	3:10:26	-76.53088	39.23984	19.371	0.002	0.661	9.600	1.387	-14.300	18.711	0.003	23.900	0.043
T12.5-A	9	11/1/2007	15:46:27	-76.52767	39.24097	19.664	0.002	0.528	5.833	0.050	-18.781	19.136	0.023	24.614	0.020
T14.5-A	10	10/29/2007	17:20:40	-76.52603	39.24148	19.204	0.007	-0.988	11.110	0.110	-8.230	20.192	0.013	19.340	0.022
T17.5-A	10	10/29/2007	14:58:38	-76.52197	39.24102	19.243	0.003	0.138	6.080	2.137	-16.257	19.105	0.017	22.337	0.030
T18-D	10	10/29/2007	14:22:44	-76.52150	39.24023	20.020	0.014	1.515	3.340	0.070	-18.924	18.505	0.038	22.264	0.018
T18-E	10	10/29/2007	14:34:18	-76.52172	39.24000	19.737	0.029	1.234	9.020	0.042	-13.268	18.503	0.035	22.288	0.016
T18.5-A	9	10/29/2007	13:29:09	-76.52005	39.24002	19.104	0.031	0.945	8.189	0.033	-14.093	18.159	0.101	22.282	0.049
T19-D	10	10/29/2007	12:55:33	-76.51893	39.24078	18.291	0.012	0.203	3.590	0.032	-18.370	18.089	0.066	21.960	0.020
T19-E	10	10/29/2007	13:02:19	-76.51890	39.24052	18.945	0.024	0.769	3.410	0.032	-18.661	18.176	0.080	22.071	0.075
T19-F	10	10/29/2007	13:10:00	-76.51875	39.24033	18.764	0.026	0.819	4.800	3.313	-17.310	17.945	0.109	22.110	0.042

Notes: Probe = subsurface | C = degrees Celsius

Reference (Ref) = surface water | mS/cm = millisiemens per centimeter

Δ Temp = subsurface – surface water temperature | Δ Cond = subsurface – surface water conductivity

Table 3-6. Trident sensor results for supplemental stations.

	Subsurface		Surface water	
	Probe Temp (C)	Probe Cond (mS/cm)	Ref Temp (C)	Ref Cond (mS/cm)
Average	19.28	6.77	19.07	23.32
Minimum	17.18	1.70	16.86	15.03
Maximum	20.28	13.38	20.19	26.04
Stdev	0.63	2.73	0.87	2.45

Table 3-7. Statistical summary for the Trident sensor survey.

Station	Water Depth (ft)	Bottom Type	Station	Water Depth (ft)	Bottom Type	Station	Water Depth (ft)	Bottom Type
T1-A	35.3	silt	T9-A	38.4	sand	T17-A	3.2	sand
T1-B	40.7	silt	T9-B	41.8	silt	T17-B	4.7	sand
T1-C	40.8	silt	T9-C	45	sand	T17-C	6.7	sand
T2-A	41.3	silt	T10-A	44.3	silt	T18-A	4.6	sand
T2-B	43.5	silty sand	T10-B	45.4	sand	T18-B	9.2	sand
T2-C	42.3	silty sand	T10-C	48	sand	T18-C	9.3	sand
T3-A	40.9	silt	T11-A	43.4	silt	T18-D	9.3	sand
T3-B	47.3	silty sand	T11-B	47.5	silty sand	T19-A	5.2	silty sand
T3-C	47	silty sand	T11-C	45.2	silty sand	T19-B	6.8	sand
T4-A	44.9	silt	T12-A	42.5	silt	T19-C	7.6	sand
T4-B	48.5	silty sand	T12-B	46.1	sand	T19-D	7.3	sand
T4-C	47.2	silty sand w/gravel	T12-C	45.3	silty sand	T19-E	7.1	sand
T5-A	44.9	silt	T13-A	43.5	silt	T19-F	7.2	sand
T5-B	42.7	silt	T13-B	46.8	silt	T2.5-A	39.4	silty sand
T5-C	37.2	silt	T13-C	44.5	silt	T3.5-A	37.8	silt
T6-A	34.4	silty sand	T14-A	42.2	silt	T3.5-B	39	silty sand
T6-B	45	sand w/gravel	T14-B	44.6	silt	T5.5-A	38.5	sand w/gravel
T6-C	47.8	sand	T14-C	43.6	silt	T7.5-A	38	silty sand
T7-A	34.9	silt	T15-A	31.9	silt	T8.5-A	35.9	silt
T7-B	39.1	silt	T15-B	38.1	silty sand	T9.5-A	42.9	silt
T7-C	42.1	sand	T15-C	37.1	silt	T10.5-A	43.3	silt
T8-A	36.7	sand	T16-A	4.3	silty sand	T12.5-A	45	silt
T8-B	41	sand w/clay	T16-B	6.3	sand	T14.5-A	43.4	silt
T8-C	40.7	sandy clay	T16-C	7.2	sand	T17.5-A	6.7	sand
-	-	-	-	-	-	T18.5-A	8.8	sand

Table 3-8. Water depths and bottom type for the DMT stations.

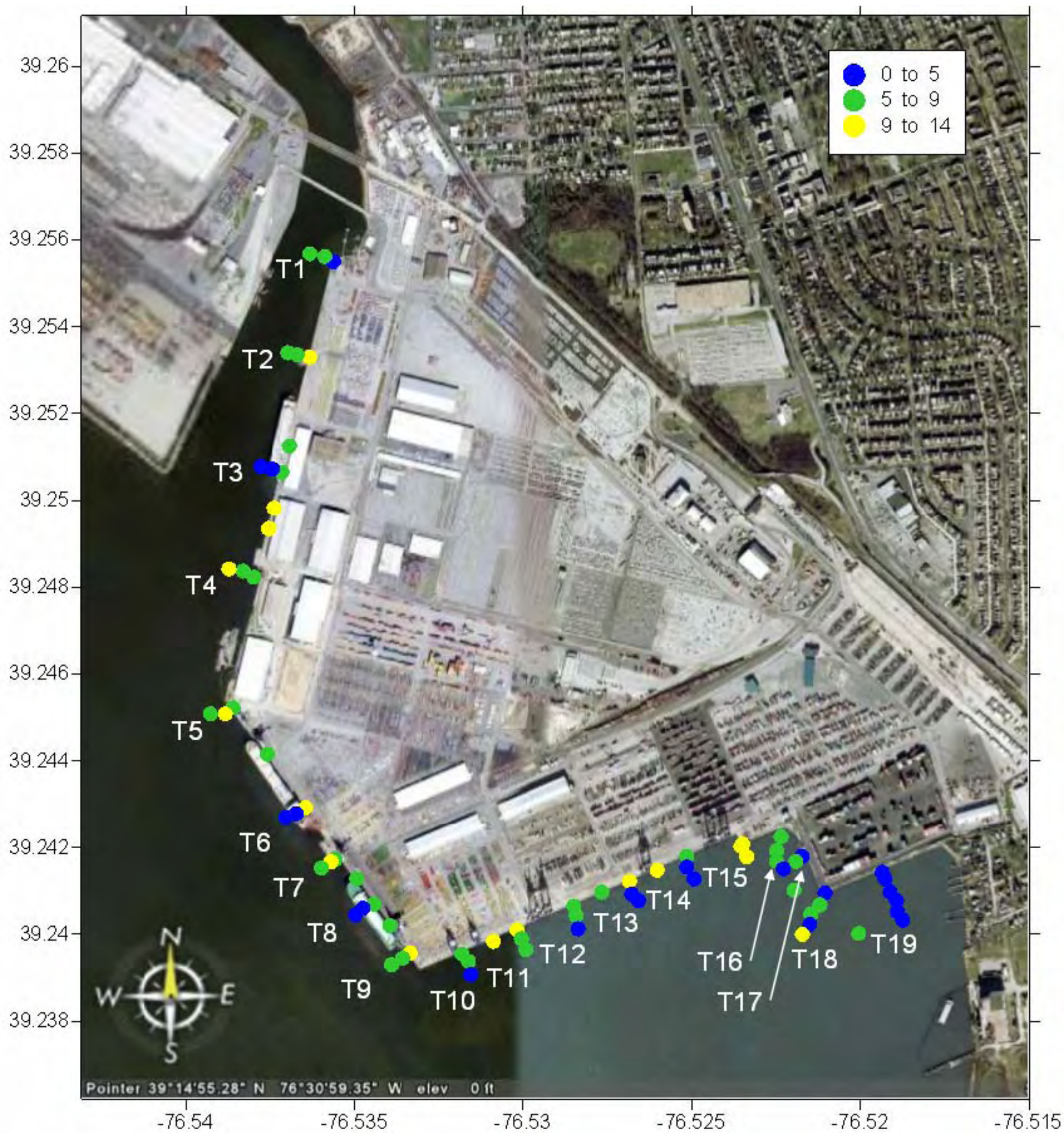

Figure 3-5. Trident subsurface conductivity distribution (mS/cm).

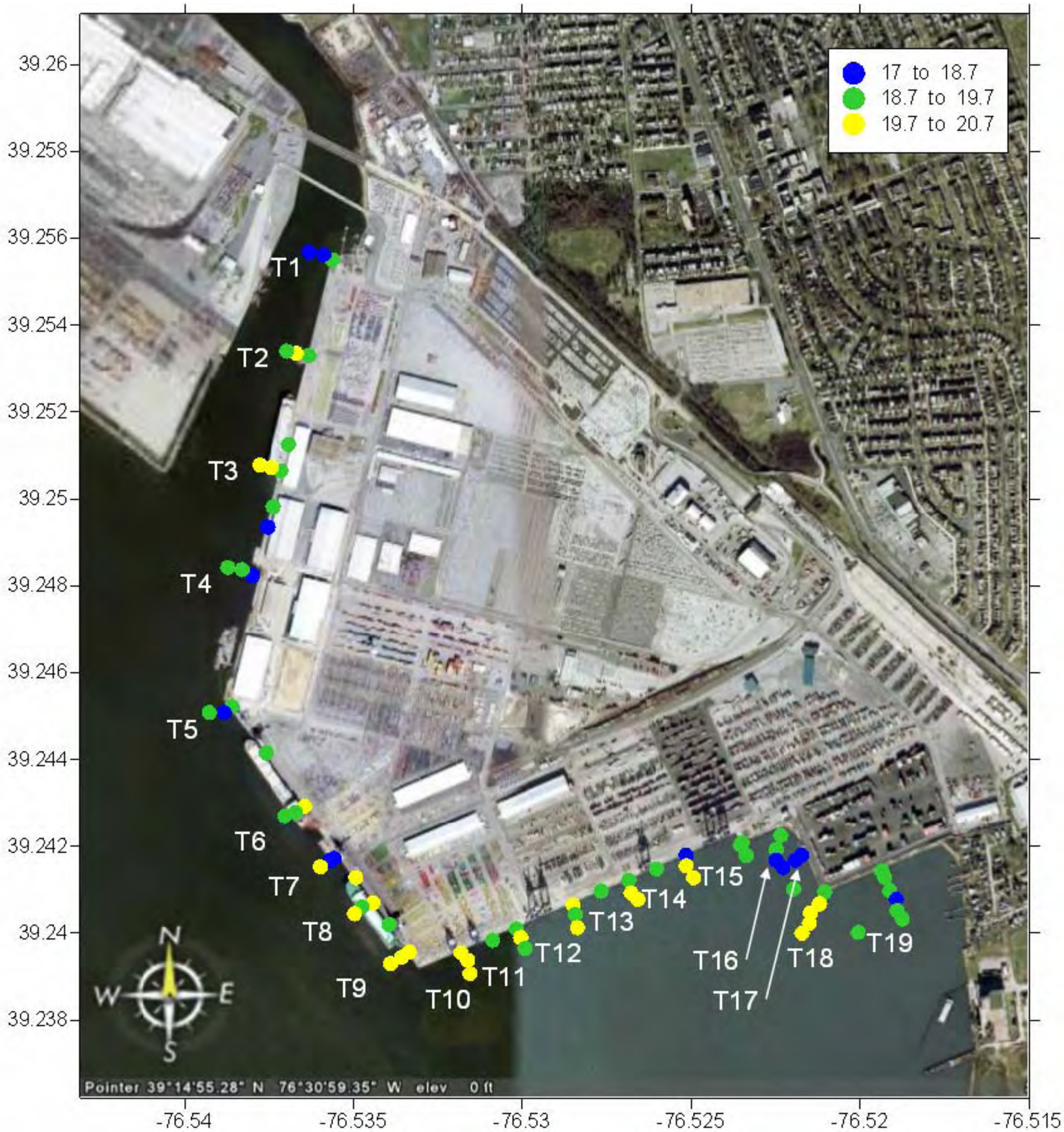

Figure 3-6. Trident subsurface temperature distribution (C).

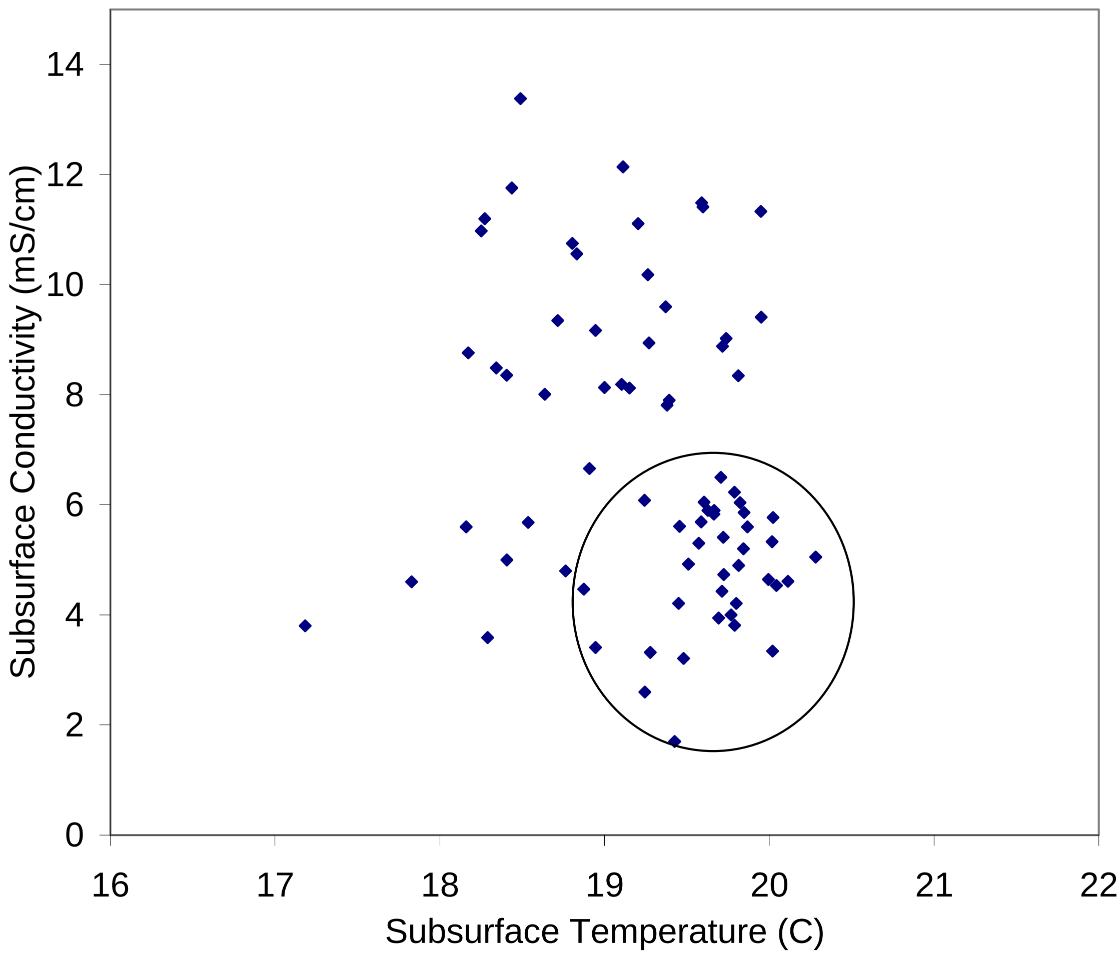

Figure 3-7. Relationship between subsurface conductivity and temperature. Circle indicates cluster of stations with relatively low conductivity and high temperature.

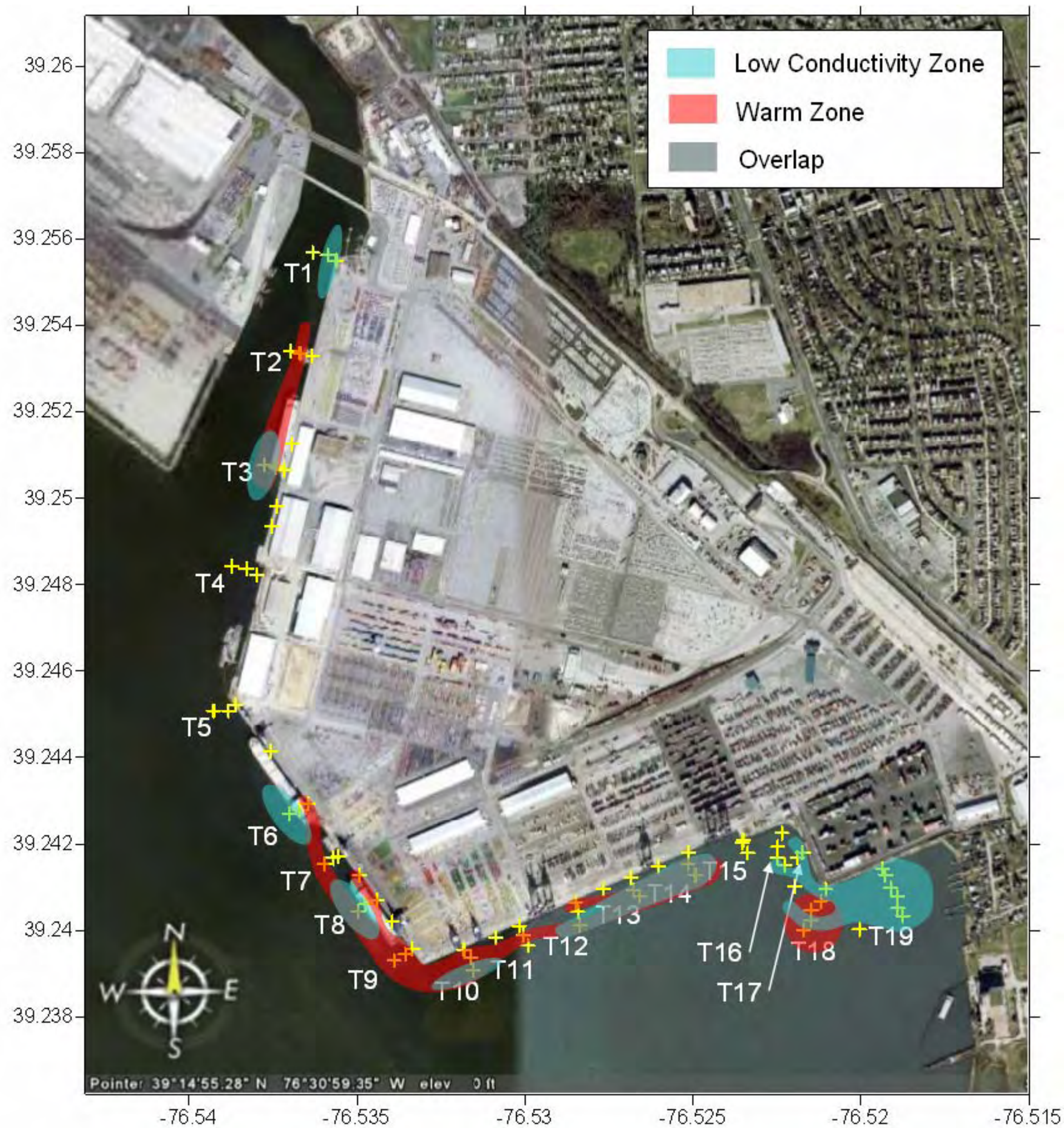

Figure 3-8. Potential discharge zones based on Trident subsurface conductivity and temperature.

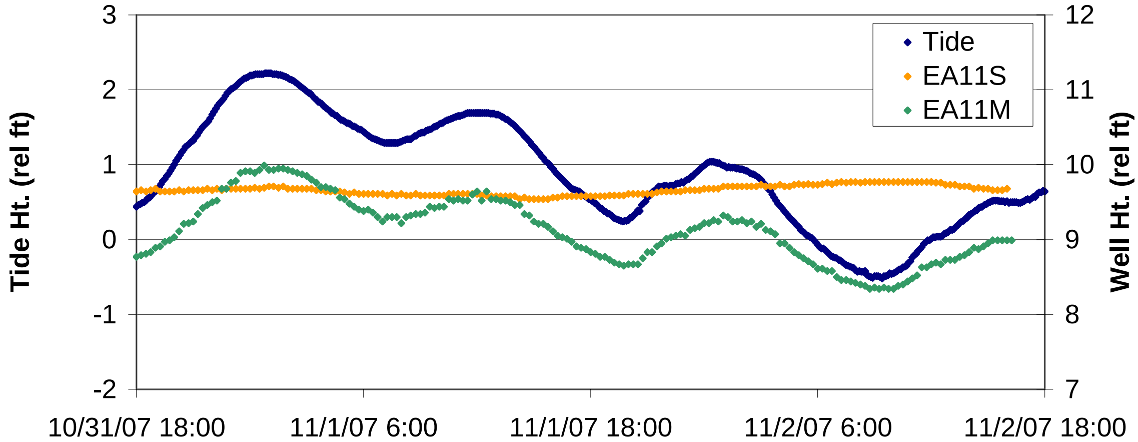

Figure 3-9. Level variation in monitoring well pair EA-11S/EA-11M compared to variations in the harbor tide.

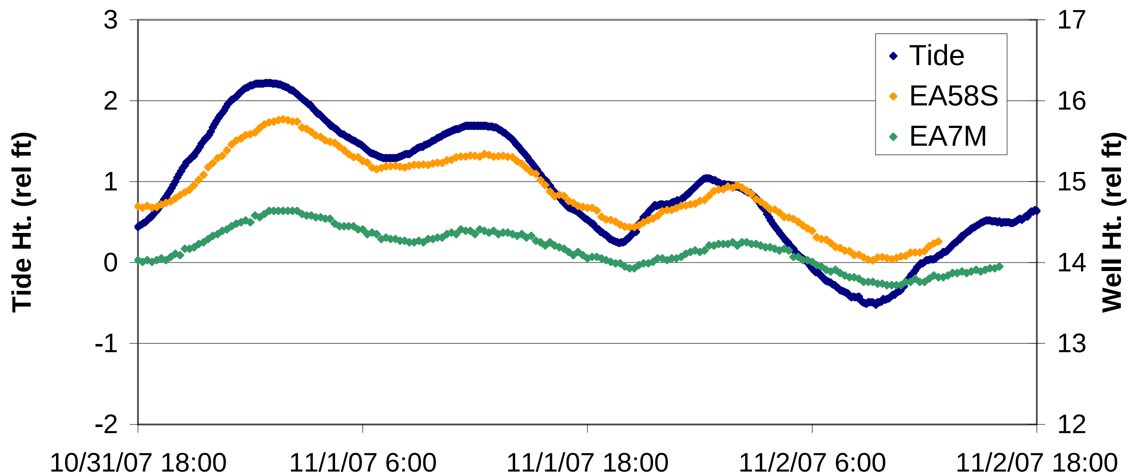

Figure 3-10. Level variation in monitoring well pair EA-58S/EA-7M compared to variations in the harbor tide.

4 REFERENCES

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