APPENDIX D
GEOPHYSICAL INVESTIGATION

BEA, Inc.

Project Number 6661

Geophysical Investigation

Ravenna Army Ammunition Plant
Ravenna, Ohio

August 1996

Prepared for:

Science Applications International Corporation
P.O. Box 2502, 800 Oak Ridge Turnpike
Oak Ridge, TN 37831

Prepared by:

Berkshire Environmental Associates, Inc.
409 Penn Avenue
Sinking Spring, Pennsylvania 19608-1109

Respectfully submitted,

Christopher E. Papadakis

Christopher E. Papadakis, P.G.
Geophysical Engineer

Environmental Resolutions

BEA, Inc.

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1.0 PROJECT OVERVIEW

Berkshire Environmental Associates, Inc. (BEA) performed an integrated near-surface geophysical survey between July 27th and July 30th, 1996 at the Ravenna Army Ammunition Plant in Ravenna, Ohio. The purpose of the geophysical investigation was to locate buried conductive materials and disposal trenches at the Landfill North of the Winklepeck Burning Grounds (RVAAP-19). The investigation integrated both time-domain and frequency-domain electromagnetic surveys.

2.0 GEOPHYSICAL THEORY AND INSTRUMENTATION

2.1 Time-Domain Electromagnetic Induction - EM-61

Time-domain electromagnetic induction (TDEM) is a non-intrusive exploration technique that uses an alternating magnetic field to induce eddy currents in buried conductive materials. The decay rate of these eddy currents is monitored after the alternating signal is switched off. The rate of decay is slower for metallic objects than in less electrically conductive materials, resulting in higher (voltage) readings over metallic targets. In addition, decay rates in deeper metal objects persist longer than for shallow objects. **BEA** utilized a Geonics EM-61 metal detector **(Figure 1)** which is capable of detecting metal targets at depths to 10 ft, while remaining insensitive to conductivity changes related to soil and dissolved ions.

2.2 Frequency-Domain Electromagnetic Induction - EM-31

Frequency-domain electromagnetic induction is used to map electrical conductivity variations related to buried materials and near-surface geologic variations. The method involves the generation of an alternating magnetic field which induces eddy currents to flow in conductive materials. These eddy currents produce a secondary magnetic field which is sensed and measured. The subsurface apparent electrical conductivity is derived by comparing the primary magnetic field with the measured secondary field and recorded in milliSiemens/meter, the inverse of resistivity. Quadrature data are sensitive to buried metal, soil changes, and near-surface drainage patterns. A second mode of data, (in-phase) is also collected. In-phase data are sensitive to ferrous and non-ferrous metal.

Recorded data represent a composite value for all geo-electric layers within the investigated zone. The depth of investigation is dependent on the spacing between the transmitter and receiver coils and their orientation. For this study, both quadrature and in-phase mode data were collected using a Geonics EM-31 terrain conductivity system in the vertical dipole mode (**Figure 2**). This geometry provides an effective exploration depth of ~15 ft below the land surface.

3.0 FIELD DESIGN

The survey limits of RVAAP-19 were established on July 27, 1996 during a field reconnaissance with representatives of **Science Applications International Corporation**. An irregular-shaped, 4 acre area had been brush hogged by an independent contractor and the survey limits were defined by distinct slope breaks and established stands of hardwood trees.

BEA designed, surveyed, and constructed a 20 x 20 ft control grid over the ~4 acre landfill. The control grid was extended into the woods along the perimeter of the brush-hogged area and vegetation was cleared from these areas to facilitate geophysical data collection. Additional vegetation cutting was performed along survey profiles in many interior areas to permit equipment access.

Both EM-61 and EM-31 data were collected on a 10 x 10 ft grid pattern in a generally north-south direction by bisecting the control grid. A total of 1,391 EM-61 and 1,605 EM-31 data stations were surveyed (**Figures 3** and **4**). The greater EM-31 coverage is due to the increased portability of the EM-31 and patches of dense vegetation which precluded EM-61 data collection in some areas. The geophysical data were digitally stored, downloaded to a computer and preliminary contour maps were generated in the field to locate anomalous areas due to subsurface metal and burial trenches. Anomalies identified with these preliminary maps were field-verified and those not associated with visible surface features were field-flagged.

As a means of evaluating the repeatability of the geophysical survey and assessing background conditions, **BEA** conducted 2 additional QA/QC measures: 1) at the end of the survey, two profile lines were recollected with both the EM-61 and EM-31 for comparison with initial recorded values; and 2) a 200 ft baseline was established outside RVAAP-19 and EM-61 and EM-31 data, collected on 10 ft centers, were recorded to document background conditions.

4.0 DATA INTERPRETATION

All EM-61 and EM-31 data were digitally stored, downloaded to a field computer, and files were reviewed for data completeness and integrity. Preliminary contour maps were generated in the field and interpreted for anomalous activity prior to field-flagging interpreted anomalies. Final contour maps were generated using SURFER (v.6.01) software.

4.1 EM-61

Data from the lower coil and the difference between the upper and lower coils were contoured (**Figures 5** and **6**). The lower coil is more sensitive to buried features than the upper coil, and the difference between the two coils is used to further confirm anomaly locations and characteristics.

The response measured on the lower coil was used in conjunction with the differential between the upper and lower coil to interpret the EM-61 data. Typically, strong "bulls-eye" anomalies on the lower coil map (**Figure 5**) not associated with known surface features indicate buried objects. Since no surface features were identified during the survey, all high-amplitude EM-61 responses in RVAAP-19 are interpreted as anomalous (**Figure 7**). Positive anomalies on the differential map (**Figure 6**) coincide with those identified on the lower coil map and support the interpretation of buried targets. The coordinates of field-flagged EM-61 anomalies are listed in **Table 1**.

Table 1
Coordinates of EM-61 Anomalies

Field-Flagged	Field-Flagged	Field-Flagged
(540,260)	(720,260)	(770-800,460)
(540,290)	(740,380)	(790,360-400)
(560,340)	(760,420)	(810-860,225)
(600-620,230)	(770,230)	(930,230)
(650,240)	(770,330-360)	(980,220)

4.2 EM-31

An examination of the ground conductivity and in-phase maps (**Figures 8** and **9**) reveals several high-amplitude responses. A strong correlation exists between the ground conductivity and in-phase maps. Since in-phase values are most sensitive to buried ferrous and non-ferrous metal, this correlation supports the interpretation of buried metal. In addition, negative EM-31 values, such as those centered near coordinates (610,230), (760,390), and (840,225) indicate metal targets.

The interpreted EM-31 anomalies (**Figure 10**) all occur east of profile line Y=210 and their location may define burial trenches. The chaotic ground conductivity values surrounding these interpreted anomalies is consistent with disturbed or backfilled areas. Undisturbed areas typically respond with gentle conductivity trends, while responses over disturbed or backfilled areas fluctuate due to buried conductive materials, inverted soil column, and near-surface drainage variations. As a result, most survey areas east of profile line Y=210 are interpreted as disturbed or filled.

4.3 QA/QC

A range of background EM-61 and EM-31 values was established by collecting data at 10 ft intervals along a 200 ft baseline positioned west of RVAAP-19. Recorded background values for the EM-61 ranged between -2.62 and 2.44 mV. Quadrature mode data ranged from 10.3 to 19.2 mS/m and in-phase values fell within a range of 7.7 and 8.1 ppt.

To evaluate the repeatability of the geophysical data, **BEA** recollected EM-61 and EM-31 data over two profiles. The two data sets were compared and the difference and percent change between the two data sets was calculated (**Appendix A**). In general, the repeatability for the EM-61 was less than anticipated; the percent change between duplicate lower sensor readings exceeded 50% in 36% of the cases. This compares to the EM-31 where 84% of the quadrature and 94% of in-phase data sets repeated within 10%.

The relationship between data repeatability and data reliability is not as simple as the calculated percent change between duplicated stations. Concern would arise if duplicated stations yielded anomalous values on one pass and background conditions on another. In comparing the EM-61 and EM-31 files, **BEA** found only 3 (1 EM-61 and 2 EM-31) cases (2.2% of total) where repeated values varied in such a way that only one value of the data pair exceeded, even marginally, an established anomaly threshold value. In this way, **BEA** considers the collected data to be ~97.8% reliable in resolving anomalous activity.

Differences between the two recorded values and the variation in repeatability for each EM system is attributed primarily to equipment position and sensitivity. In repeating the profile lines it is likely that neither the EM-61 nor the EM-31 was in the exact same location for both measurements. This explains some change in the data sets. The greater variations in EM-61 data are probably the result of the increased sensitivity of the EM-61 system. Therefore, small lateral changes in the position of the EM-61 could affect the recorded data more than the same lateral change with an EM-31.

5.0 CONCLUSIONS

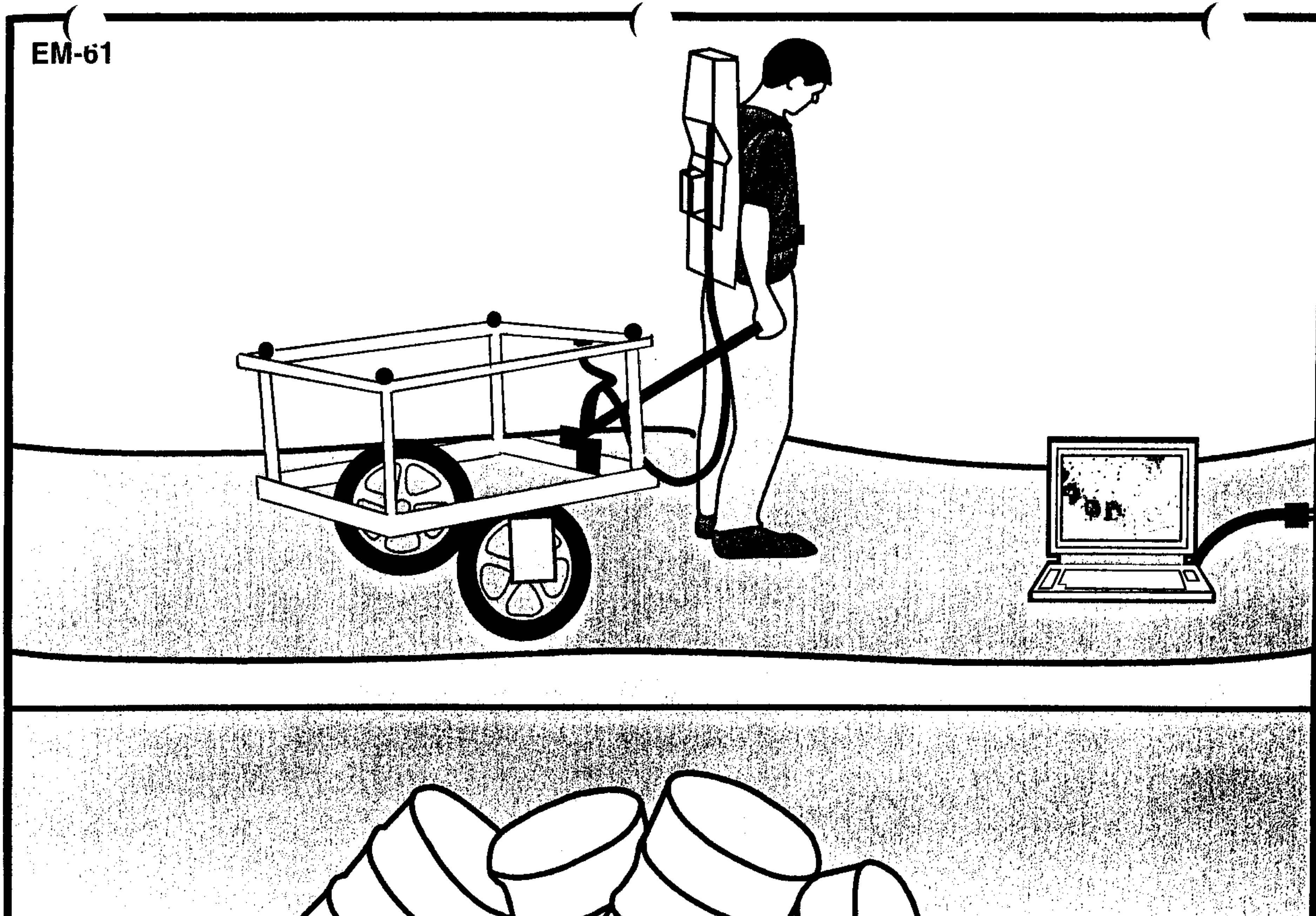
Between July 27th and July 30th, 1996, **BEA** performed an integrated near-surface geophysical survey at the Landfill North of the Winklepeck Burning Grounds, RVAAP-19, at the Ravenna Army Ammunition Plant in Ravenna, Ohio. The purpose of the geophysical investigation was to locate buried conductive materials and disposal trenches using time-domain (EM-61) and frequency-domain (EM-31) exploration techniques. The geophysical surveys covered ~4 acres and data were collected on a 10 x 10 ft grid pattern.

The geophysical surveys successfully mapped numerous anomalies interpreted as buried metal objects and appear to define burial trench areas (**Figures 7 and 10**). The coordinates of field-flagged EM-61 anomalies area listed in **Table 1** and correlate closely with interpreted EM-31 anomalies. Field-flagged anomalies are attributed to buried metal since field observations did not indicate the presence of surficial metal. **BEA** recommends that all interpreted anomalies be considered for excavation or physical inspection.

The QA/QC data evaluation revealed that EM-31 data is more repeatable than EM-61 values along the duplicated profiles (**Appendix A**). Although recorded data did vary on the repeated profiles, both values at a given point were classified as either anomalous or background conditions 97.8% of the time. This is important in evaluating the reliability of geophysical anomaly interpretations since repeatability variations had little overall affect on whether data fell above or below an established anomaly threshold value.

6.0 CLOSING

The field procedures and interpretative methodologies used in this project are consistent with standard, recognized practices in similar geophysical investigations. The correlation of geophysical responses with probable subsurface features is based on the past result of similar surveys although it is possible that some variation could exist at this site. This warranty is in lieu of all other warranties either implied or expressed. **BEA** assumes no responsibility for interpretations made by others based on work performed by or recommendations made by **BEA.**



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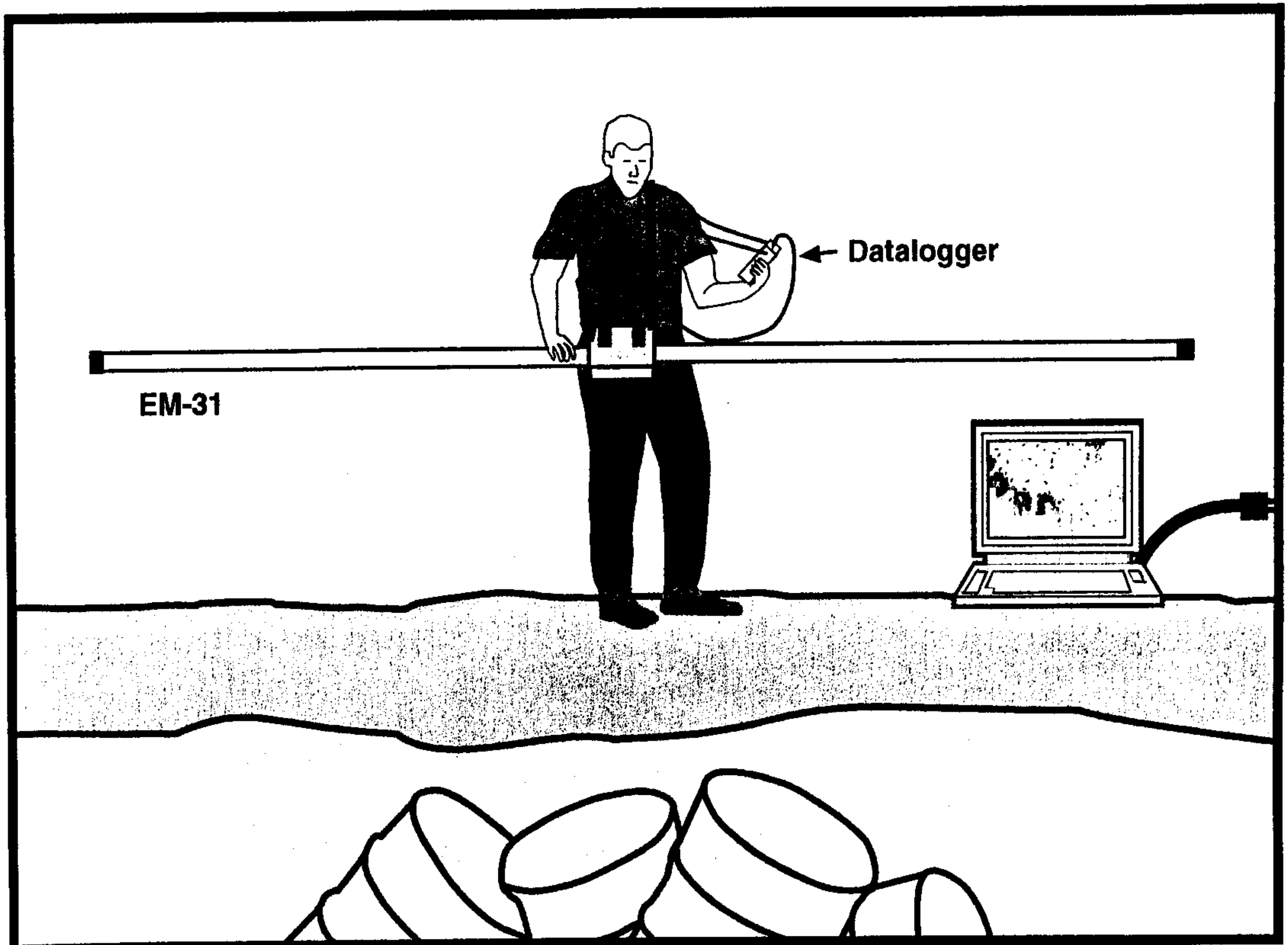
EM-61 Instrumentation — Figure 1



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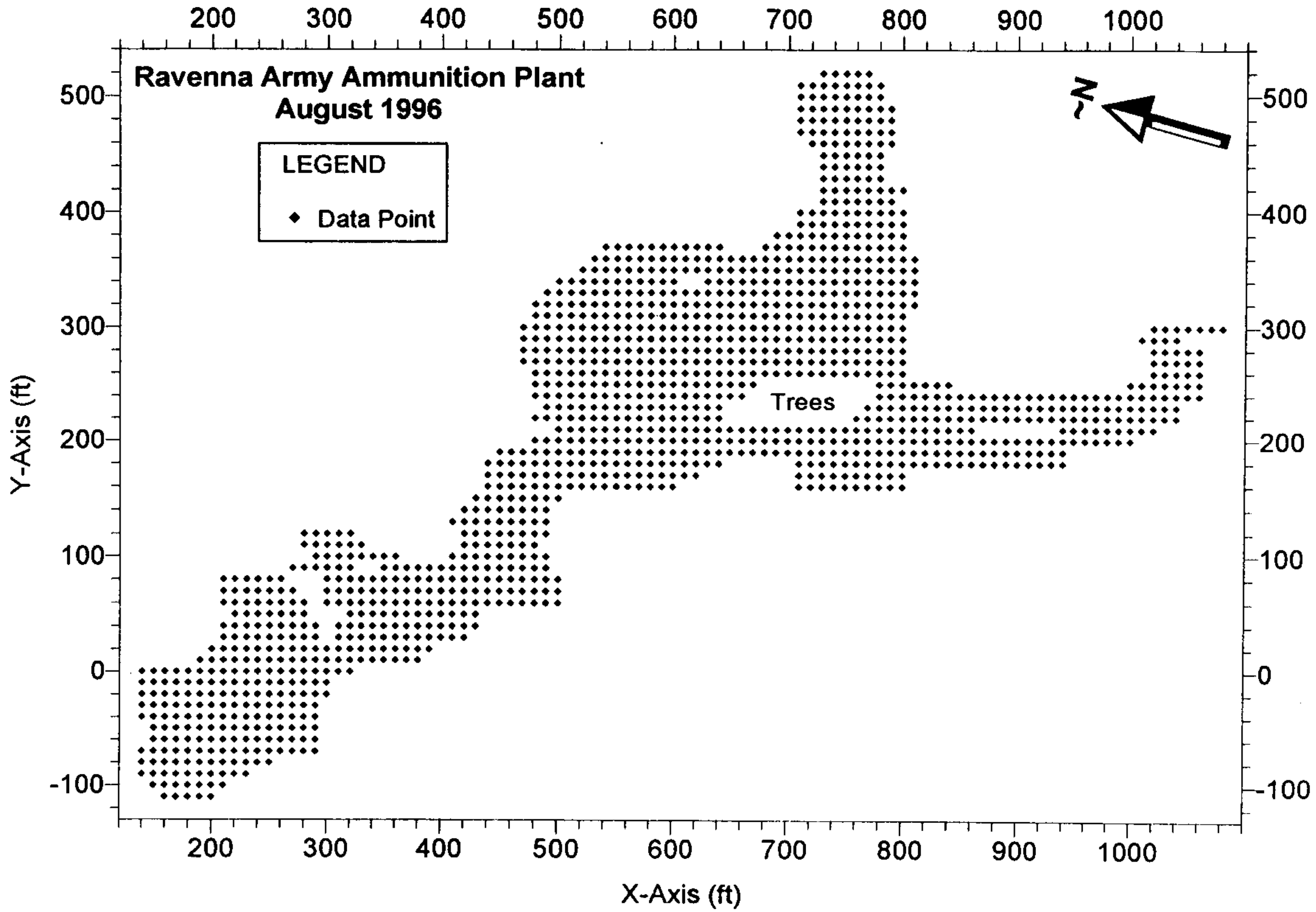
EM-31 Instrumentation

Figure 2



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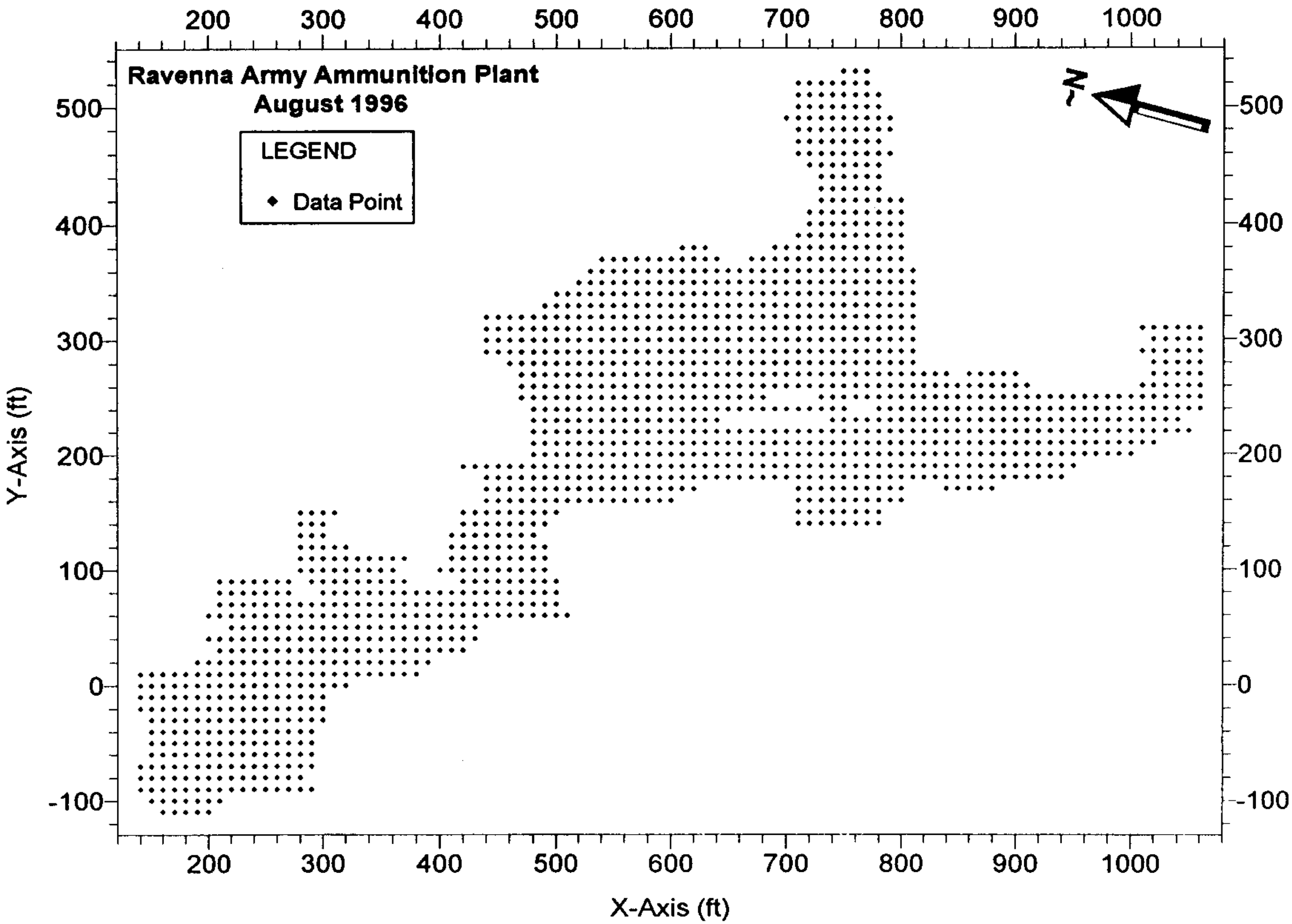
EM-61 Data Reference Map

Figure 3



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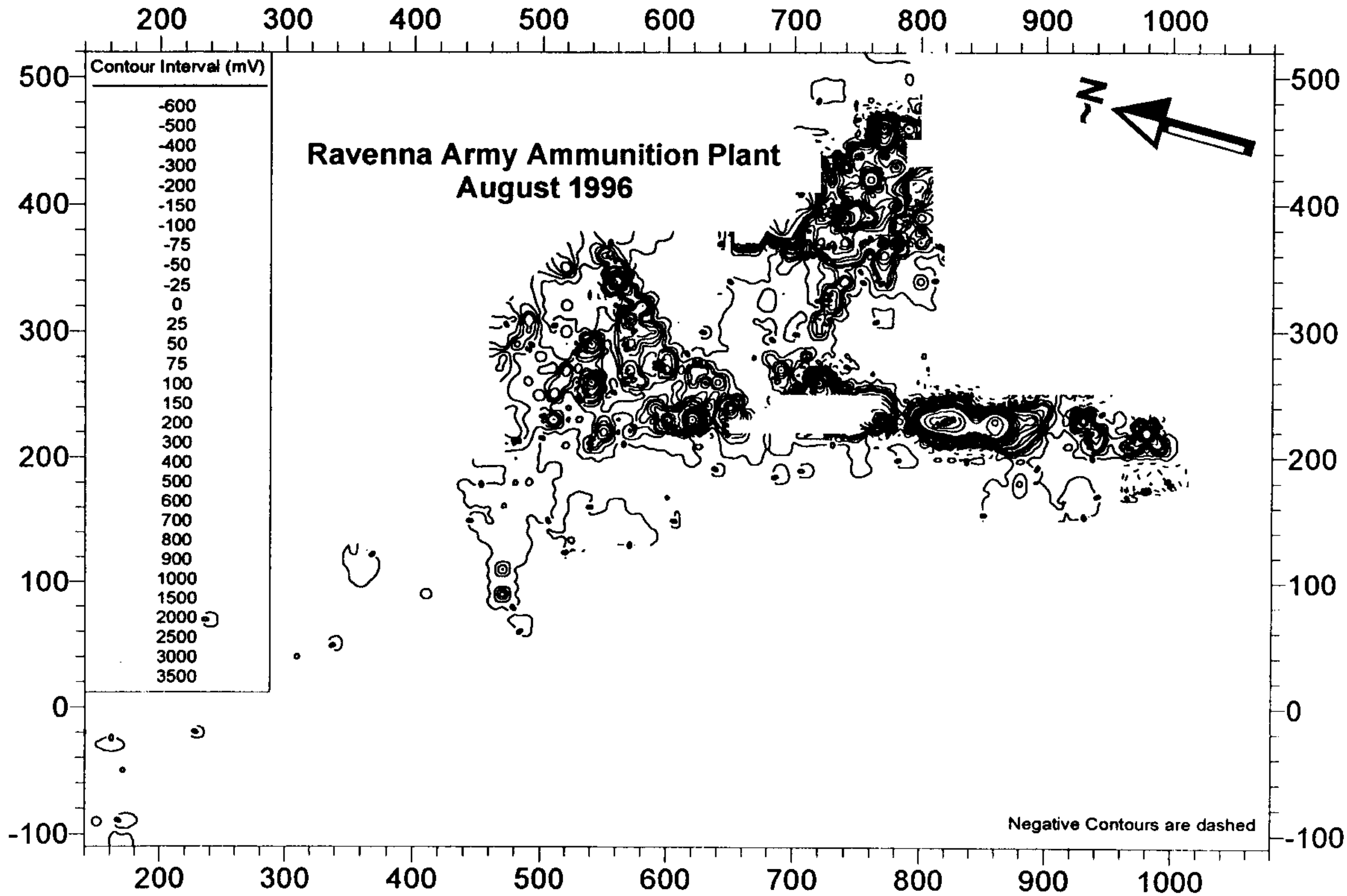
EM-31 Data Reference Map

Figure 4



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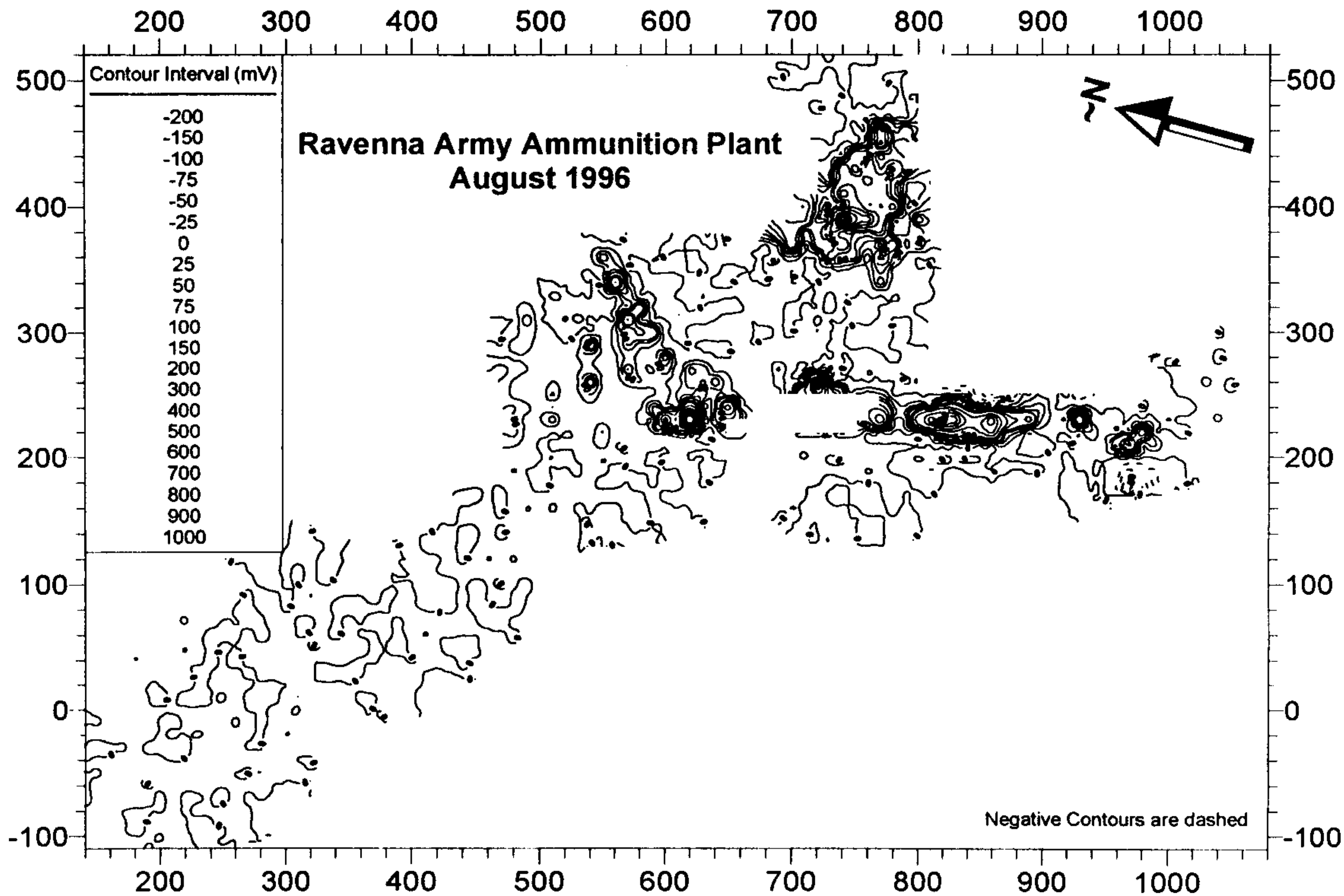
EM-61 Contour Map: Lower Coil

Figure 5



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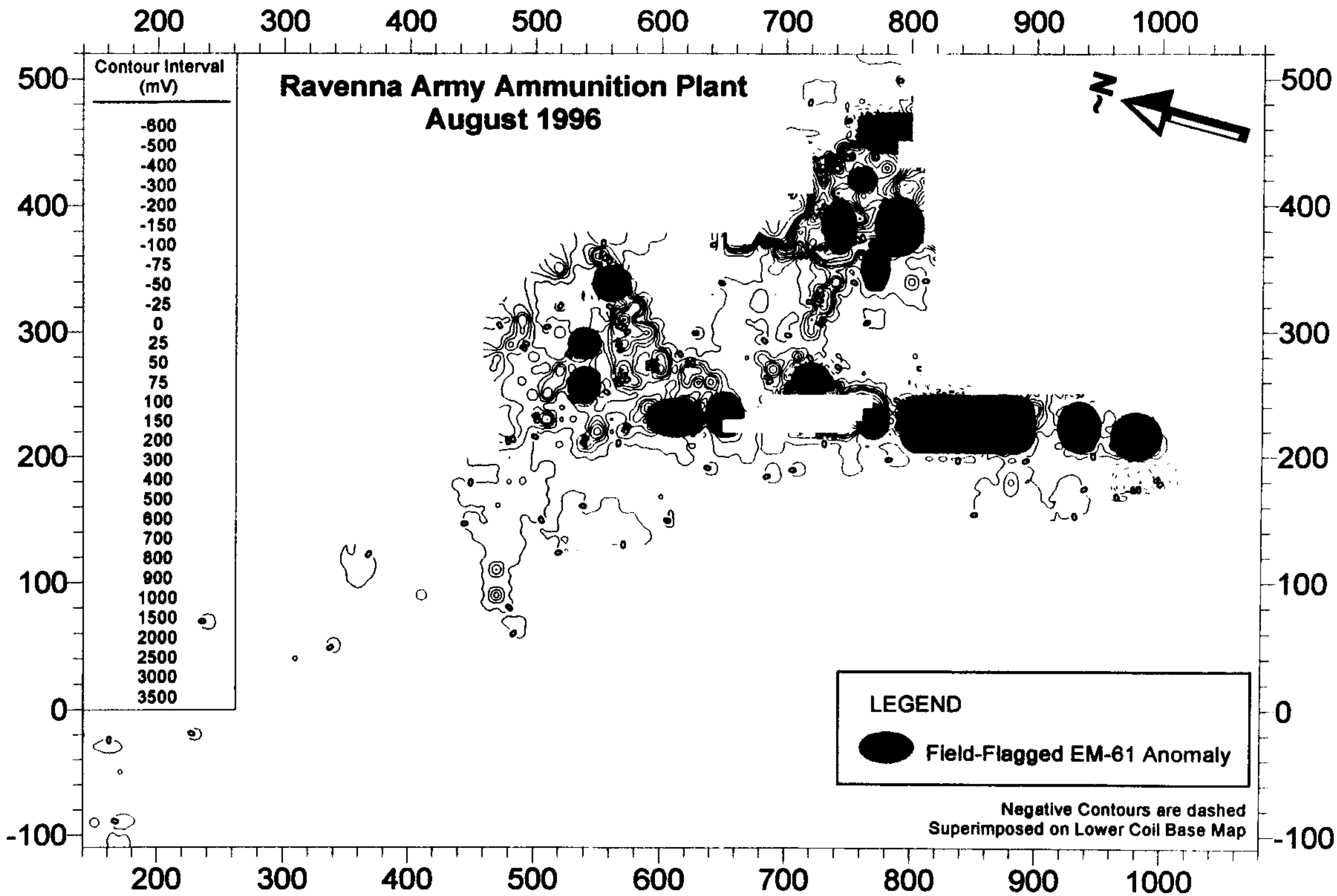
EM-61 Contour Map: Differential

Figure 6



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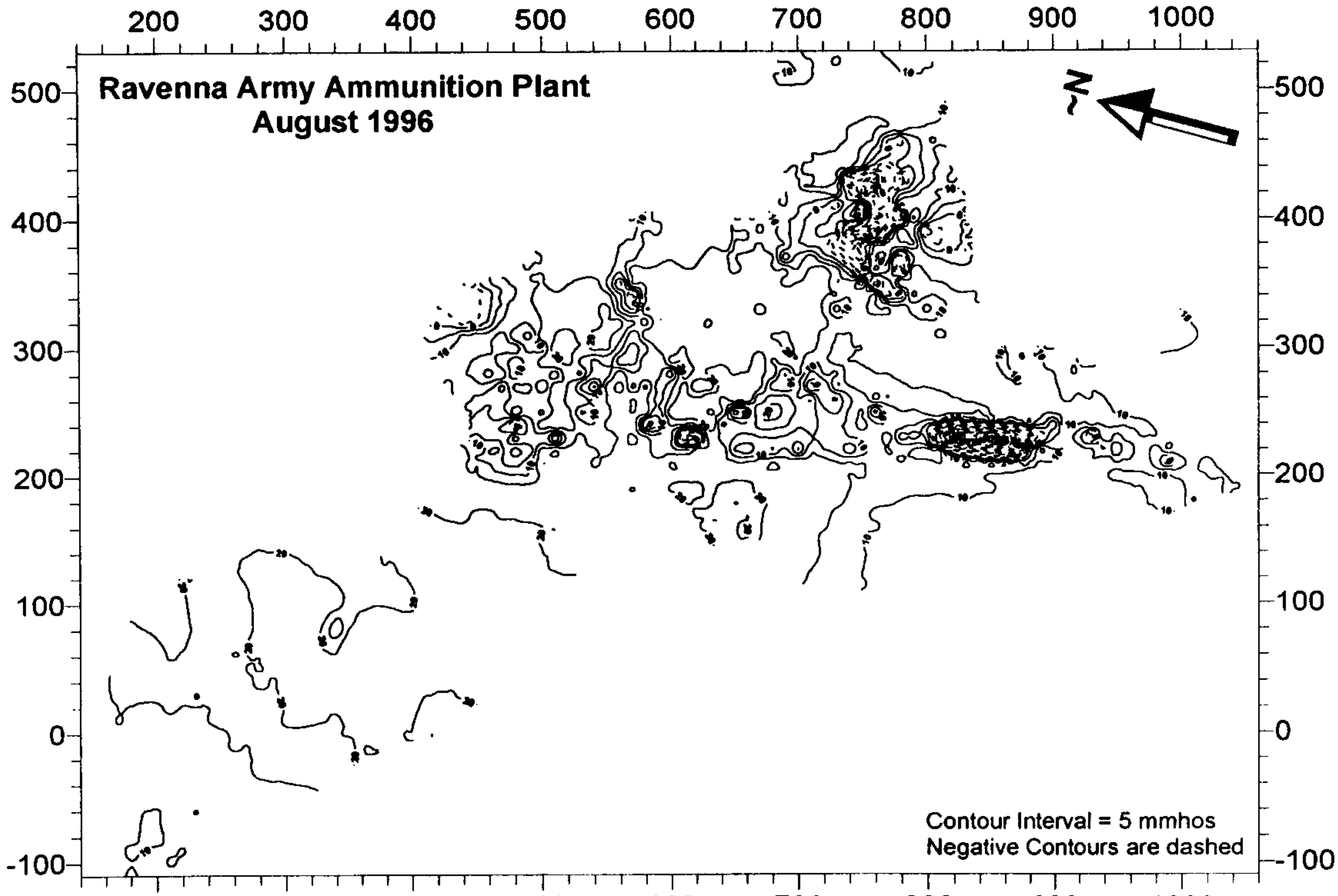
EM-61 Interpretation Map

Figure 7



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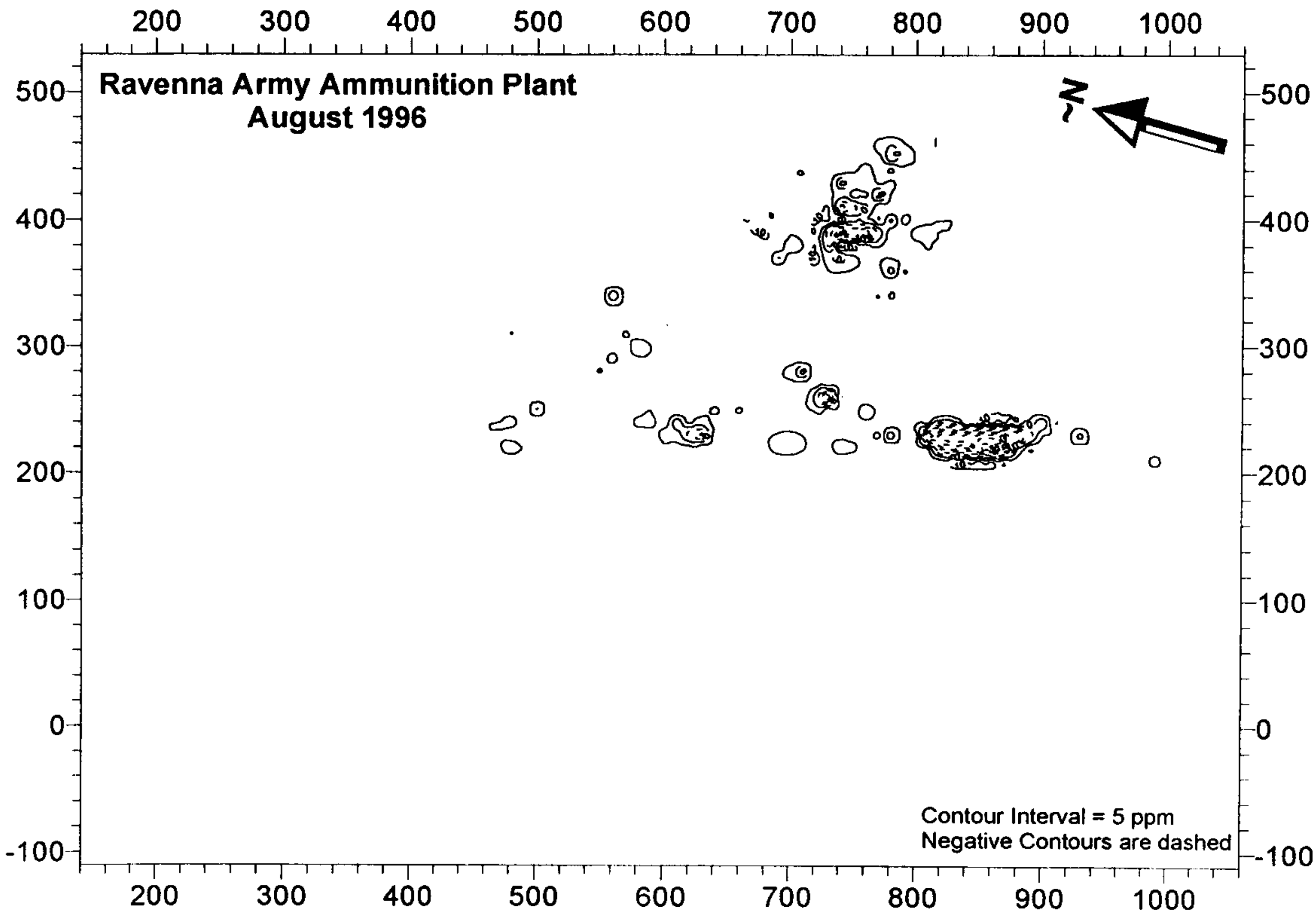
EM-31 Ground Conductivity Map

Figure 8



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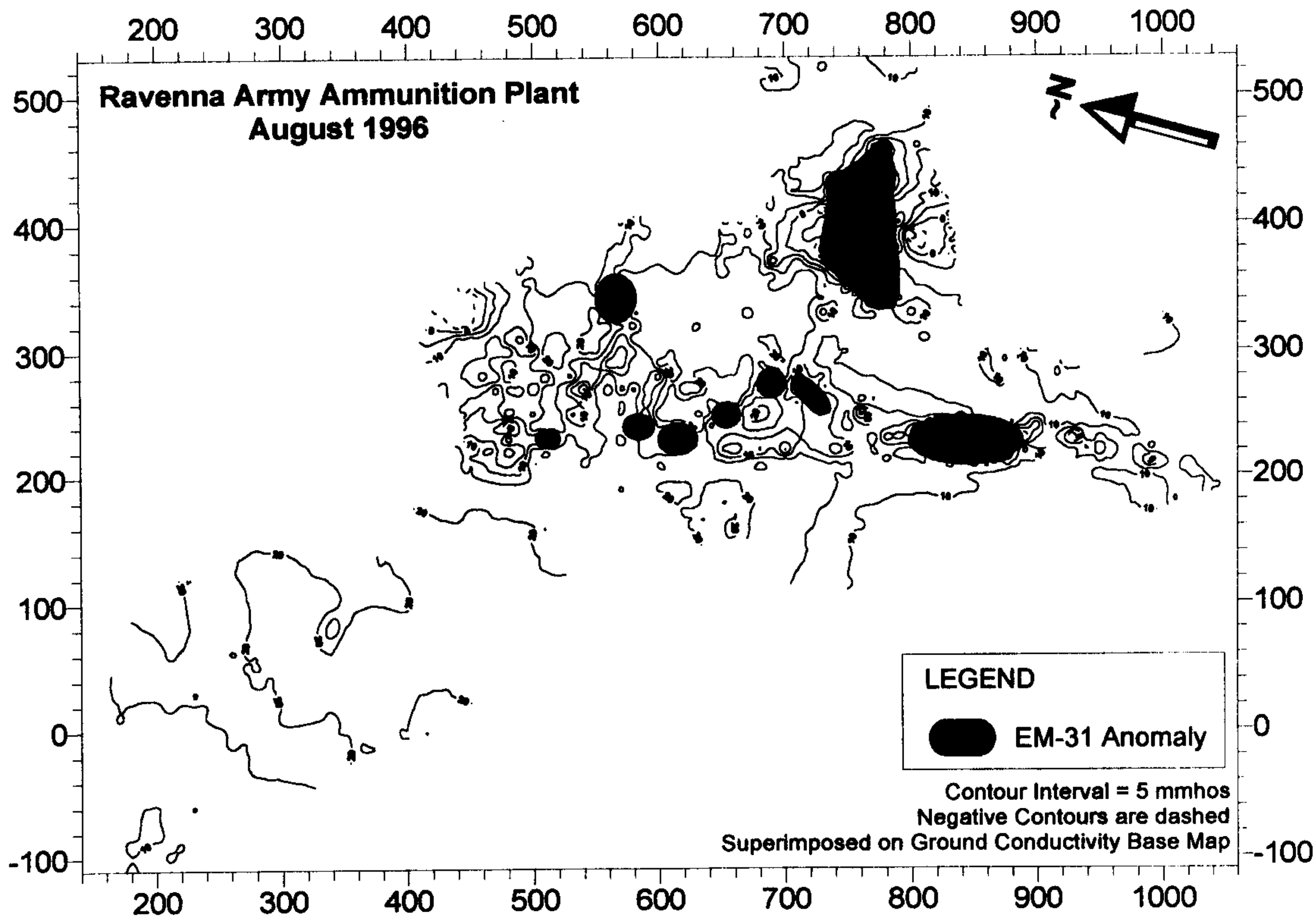
EM-31 In-Phase Contour Map

Figure 9



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EM-31 Interpretation Map

Figure 10

Appendix A

QA/QC Data Files

x	y	q 1	q 2	abs(q1-q2)	% change	ph 1	ph 2	abs(ph1-ph2)	% change
460	300	14.374	14.312	0.062	0.43	8.347	8.492	0.145	1.74
470	300	16.846	16.876	0.03	0.18	8.419	8.714	0.295	3.50
480	300	18.554	17.944	0.61	3.29	7.415	7.301	0.114	1.54
490	300	8.85	9.46	0.61	6.89	6.844	6.763	0.081	1.18
500	300	8.178	7.782	0.396	4.84	5.532	5.528	0.004	0.07
510	300	22.796	22.858	0.062	0.27	8.54	8.672	0.132	1.55
520	300	21.362	20.202	1.16	5.43	8.421	8.568	0.147	1.75
530	300	19.5	17.914	1.586	8.13	8.413	8.097	0.316	3.76
540	300	21.332	20.172	1.16	5.44	8.703	8.806	0.103	1.18
550	300	20.966	20.538	0.428	2.04	8.237	8.336	0.099	1.20
560	300	11.718	9.858	1.86	15.87	5.979	5.841	0.138	2.31
570	300	2.014	-1.19	3.204	159.09	7.584	7.188	0.396	5.22
580	300	8.85	6.714	2.136	24.14	0.314	1.637	1.323	421.34
590	300	15.686	16.022	0.336	2.14	5.065	4.996	0.069	1.36
600	300	16.51	18.86	2.35	14.23	8.084	8.766	0.682	8.44
610	300	20.264	18.554	1.71	8.44	8.505	8.672	0.167	1.96
620	300	16.816	16.968	0.152	0.90	8.248	8.516	0.268	3.25
630	300	16.632	15.96	0.672	4.04	8.224	8.338	0.114	1.39
640	300	15.564	15.686	0.122	0.78	8.251	8.534	0.283	3.43
650	300	16.388	16.906	0.518	3.16	8.549	8.588	0.039	0.46
660	300	17.212	17.212	0	0.00	8.678	8.928	0.25	2.88
670	300	19.532	19.47	0.062	0.32	8.762	9.064	0.302	3.45
680	300	18.524	19.134	0.61	3.29	8.426	8.492	0.066	0.78
690	300	20.386	20.202	0.184	0.90	8.72	8.898	0.178	2.04
700	300	19.44	19.5	0.06	0.31	8.635	8.707	0.072	0.83
710	300	18.158	19.532	1.374	7.57	8.158	8.641	0.483	5.92
720	300	11.596	10.102	1.494	12.88	8.522	8.613	0.091	1.07
730	300	16.296	16.662	0.366	2.25	7.456	7.663	0.207	2.78
740	300	15.258	14.466	0.792	5.19	8.336	8.264	0.072	0.86
750	300	14.984	14.16	0.824	5.50	8.132	8.277	0.145	1.78
760	300	12.756	12.36	0.396	3.10	8.101	8.119	0.018	0.22
770	300	12.818	12.36	0.458	3.57	8.082	8.138	0.056	0.69
780	300	12.542	11.628	0.914	7.29	7.912	8.035	0.123	1.55
790	300	11.718	12.42	0.702	5.99	8.007	8.149	0.142	1.77
800	300	12.36	12.208	0.152	1.23	8.027	8.176	0.149	1.86
810	300	11.414	11.596	0.182	1.59	8.044	8.352	0.308	3.83
810	310	9.46	9.888	0.428	4.52	8.105	8.044	0.061	0.75
800	310	10.498	10.438	0.06	0.57	8.196	8.016	0.18	2.20
790	310	11.078	10.62	0.458	4.13	8.292	8.149	0.143	1.72
780	310	11.596	11.444	0.152	1.31	8.242	8.224	0.018	0.22
770	310	11.23	11.138	0.092	0.82	8.319	8.055	0.264	3.17
760	310	12.084	11.596	0.488	4.04	8.176	8.046	0.13	1.59
750	310	12.786	13.032	0.246	1.92	8.283	8.255	0.028	0.34
740	310	15.106	14.588	0.518	3.43	8.387	8.408	0.021	0.25
730	310	15.014	14.77	0.244	1.63	8.336	8.174	0.162	1.94
720	310	12.818	12.604	0.214	1.67	8.108	7.974	0.134	1.65
710	310	19.166	16.754	2.412	12.58	8.711	8.11	0.601	6.90
700	310	17.762	18.128	0.366	2.06	8.568	8.533	0.035	0.41
690	310	20.446	19.684	0.762	3.73	8.661	8.762	0.101	1.17
680	310	20.142	20.264	0.122	0.61	8.694	8.669	0.025	0.29
670	310	17.272	17.212	0.06	0.35	8.819	8.641	0.178	2.02
660	310	16.662	17.12	0.458	2.75	9.064	9.051	0.013	0.14
650	310	16.204	15.748	0.456	2.81	8.573	8.626	0.053	0.62
640	310	16.144	15.534	0.61	3.78	8.325	8.084	0.241	2.89
630	310	15.198	15.076	0.122	0.80	8.376	8.555	0.179	2.14
620	310	15.228	14.892	0.336	2.21	8.424	8.178	0.246	2.92

610	310	16.144	15.96	0.184	1.14	8.492	8.494	0.002	0.02
600	310	19.012	20.568	1.556	8.18	8.797	8.707	0.09	1.02
590	310	19.806	19.684	0.122	0.62	8.244	8.009	0.235	2.85
580	310	18.158	16.144	2.014	11.09	8.586	8.503	0.083	0.97
570	310	6.44	4.7	1.74	27.02	4.439	0.966	3.473	78.24
560	310	17.426	18.28	0.854	4.90	8.13	8.975	0.845	10.39
550	310	20.722	21.088	0.366	1.77	8.512	8.546	0.034	0.40
540	310	21.18	20.508	0.672	3.17	8.689	8.568	0.121	1.39
530	310	18.342	17.518	0.824	4.49	8.536	8.174	0.362	4.24
520	310	21.76	21.454	0.306	1.41	8.724	8.7	0.024	0.28
510	310	20.05	20.356	0.306	1.53	8.683	8.742	0.059	0.68
500	310	17.944	17.212	0.732	4.08	7.467	7.087	0.38	5.09
490	310	3.388	0.794	2.594	76.56	8.619	7.98	0.639	7.41
480	310	6.44	10.56	4.12	63.98	4.871	4.139	0.732	15.03
470	310	17.272	14.77	2.502	14.49	9.082	8.9	0.182	2.00
460	310	12.908	13.55	0.642	4.97	8.312	8.393	0.081	0.97
450	310	12.726	13	0.274	2.15	8.334	8.264	0.07	0.84
Base Line Data									
x	q-base	ph-base							
0	13.366	7.959							
10	13.154	8.022							
20	12.664	7.99							
30	11.474	7.829							
40	11.078	7.765							
50	10.956	7.845							
60	10.314	7.757							
70	12.024	7.816							
80	11.872	7.807							
90	13.276	7.873							
100	14.862	7.963							
110	15.106	8.036							
120	15.534	7.875							
130	16.082	8.005							
140	16.938	7.893							
150	17.09	7.823							
160	17.12	7.849							
170	16.418	7.935							
180	17.578	7.873							
190	18.128	7.834							
200	19.196	8.075							

x	y	top 1	top 2	abs(top1-top2)	% change	bottom 1	bottom 2	abs(top1-top2)	% change	Base Line Data		
470	300	9.19	21.37	12.18	132.54	9.37	4.87	4.5	48.03	0	-0.93	-0.55
480	300	37.31	54.75	17.44	46.74	27.37	44.25	16.88	61.67	10	2.44	1.87
490	300	150.37	123	27.37	18.20	105.37	86.81	18.56	17.61	20	3	-0.18
500	300	29.25	25.31	3.94	13.47	17.62	18.19	0.57	3.23	30	-0.55	0.56
510	300	-0.55	-0.18	0.37	67.27	-1.3	-1.87	0.57	43.85	40	-1.87	0.19
520	300	47.62	74.25	26.63	55.92	49.87	82.31	32.44	65.05	50	-0.37	-0.93
530	300	-3.37	-1.12	2.25	66.77	-1.5	-1.12	0.38	25.33	60	-0.75	-0.75
540	300	3.19	3.37	0.18	5.64	0.19	1.69	1.5	789.47	70	-1.12	-0.55
550	300	37.12	89.62	52.5	141.43	28.69	73.5	44.81	156.19	80	2.06	0.56
560	300	112.31	99	13.31	11.85	70.69	66.37	4.32	6.11	90	0	-1.5
570	300	186.37	288.19	101.82	54.63	103.12	176.25	73.13	70.92	100	-1.3	-1.12
580	300	429.94	406.87	23.07	5.37	261	235.31	25.69	9.84	110	-1.68	-1.68
590	300	351.94	401.81	49.87	14.17	206.44	239.62	33.18	16.07	120	-1.87	-1.3
600	300	8.62	16.12	7.5	87.01	1.5	6	4.5	300.00	130	0.19	-1.3
610	300	-2.8	-0.18	2.62	93.57	-1.12	-1.87	0.75	66.96	140	-1.68	-1.3
620	300	-0.75	-1.87	1.12	149.33	-2.43	-1.12	1.31	53.91	150	-2.62	-0.75
630	300	5.62	29.62	24	427.05	2.81	20.81	18	640.57	160	-1.12	-1.3
640	300	-0.93	-1.12	0.19	20.43	-2.43	-1.12	1.31	53.91	170	-1.12	-1.5
650	300	25.31	28.31	3	11.85	21.75	28.31	6.56	30.16	180	-0.93	-1.3
660	300	1.12	-0.18	1.3	116.07	0.75	0.19	0.56	74.67	190	-2.62	-1.5
670	300	5.06	3.19	1.87	36.96	5.06	6.19	1.13	22.33	200	-1.12	-2.05
680	300	-1.5	0	1.5	100.00	0.19	0.19	0	0.00			
690	300	1.87	-1.87	3.74	200.00	0.94	-1.5	2.44	259.57			
700	300	-2.43	-2.8	0.37	15.23	-1.12	-0.93	0.19	16.96			
710	300	20.44	10.12	10.32	50.49	14.62	7.31	7.31	50.00			
720	300	112.87	100.5	12.37	10.96	87.94	78.56	9.38	10.67			
730	300	0.37	0.94	0.57	154.05	0	0.19	0.19				
740	300	-1.12	-2.05	0.93	83.04	-0.37	-0.93	0.56	151.35			
750	300	0.75	-0.37	1.12	149.33	-2.62	-1.87	0.75	28.63			
760	300	-1.12	-0.18	0.94	83.93	-2.05	-1.5	0.55	26.83			
770	300	1.5	-0.93	2.43	162.00	-2.62	-1.5	1.12	42.75			
780	300	-1.68	-3.93	2.25	133.93	-1.5	-0.93	0.57	38.00			
790	300	-2.8	-1.87	0.93	33.21	-1.3	-1.87	0.57	43.85			
800	300	0	2.06	2.06		-2.25	-2.62	0.37	16.44			
800	310	-1.12	-1.87	0.75	66.96	-1.87	-1.87	0	0.00			

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790	310	-2.05	-2.43	0.38	18.54	-1.5	-1.5	0	0.00			
780	310	-1.5	-2.43	0.93	62.00	-1.3	-1.3	0	0.00			
770	310	9.56	8.44	1.12	11.72	8.81	6.94	1.87	21.23			
760	310	-3	-3.55	0.55	18.33	-1.5	-1.12	0.38	25.33			
750	310	-2.25	-1.3	0.95	42.22	-1.5	-2.05	0.55	36.67			
740	310	-1.5	-2.05	0.55	36.67	-2.05	-1.68	0.37	18.05			
730	310	-0.18	0	0.18	100.00	-0.75	-0.75	0	0.00			
720	310	133.69	177.19	43.5	32.54	102.19	151.69	49.5	48.44			
710	310	2.25	12.37	10.12	449.78	0.56	6.37	5.81	1037.50			
700	310	-0.75	-3.37	2.62	349.33	-0.55	0.37	0.92	167.27			
690	310	3.94	-1.12	5.06	128.43	3.37	-0.37	3.74	110.98			
680	310	0.19	-0.18	0.37	194.74	-1.87	-0.18	1.69	90.37			
670	310	-0.37	-0.37	0	0.00	-0.55	-0.75	0.2	36.36			
660	310	13.5	10.12	3.38	25.04	11.25	11.06	0.19	1.69			
650	310	8.62	6.75	1.87	21.69	5.81	5.44	0.37	6.37			
640	310	-2.05	-2.25	0.2	9.76	-2.05	-2.05	0	0.00			
630	310	-5.62	-4.68	0.94	16.73	-4.12	-4.12	0	0.00			
620	310	-2.43	-3.55	1.12	46.09	-1.5	-1.5	0	0.00			
610	310	-2.62	-2.05	0.57	21.76	-1.87	-1.87	0	0.00			
600	310	-1.5	-2.43	0.93	62.00	-1.3	-2.05	0.75	57.69			
590	310	14.81	11.06	3.75	25.32	6.56	5.25	1.31	19.97			
580	310	118.5	132	13.5	11.39	62.81	75.19	12.38	19.71			
570	310	837.94	817.87	20.07	2.40	537.37	523.69	13.68	2.55			
560	310	21.19	35.06	13.87	65.46	12.19	21.19	9	73.83			
550	310	9.56	12.37	2.81	29.39	8.06	13.31	5.25	65.14			
540	310	-1.3	-2.05	0.75	57.69	-2.05	-2.05	0	0.00			
530	310	-0.37	-0.18	0.19	51.35	-1.68	0.37	2.05	122.02			
520	310	-1.87	-2.25	0.38	20.32	-2.05	-1.5	0.55	26.83			
510	310	-1.12	-0.18	0.94	83.93	0.19	-0.75	0.94	494.74			
500	310	3.75	2.44	1.31	34.93	0.94	1.12	0.18	19.15			
490	310	206.62	214.31	7.69	3.72	139.31	147.37	8.06	5.79			
480	310	3.94	4.87	0.93	23.60	0.75	1.5	0.75	100.00			

BEA, Inc.

409 Penn Avenue
Sinking Spring, Pennsylvania 19608
(610)670-5900
(610)670-5903 FAX
beainc@postoffice.ptd.net

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