ANNUAL GROUNDWATER MONITORING REPORT

HAZARDOUS WASTE MANAGEMENT UNITS 4, 5, 10, 13, 16 AND 39
CALENDAR YEAR 1999

RADFORD ARMY AMMUNITION PLANT
RADFORD, VIRGINIA

Submitted to:

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INTRODUCTION

This document represents a compilation of the annual groundwater monitoring reports for the permitted hazardous waste management facilities at the Radford Army Ammunition Plant (RFAAP) in Radford, Virginia. The units are designated as HWMU-4, HWMU-5, HWMU-10, HWMU-13, HWMU-16 and HWMU-39. The annual groundwater monitoring report for an additional unit, HWMU-7, is being submitted under separate cover. These reports have been compiled in accordance with 9 VAC 20-60-570, sections E.1.b.2 and 3.

The reports present the following set of information for each unit: basic information and unit identification, a description of the groundwater monitoring plan, a discussion of groundwater movement, an updated potentiometric map, a table of groundwater elevations and detailed statistical evaluations of the analytical data. In general, the reports evaluate the analytical data from the four 1999 quarterly sampling events; these data were submitted previously to the VDEQ in quarterly monitoring reports for the units.

SIGNATURE/CERTIFICATION

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I certify that I have prepared or supervised preparation of the attached reports, that they have been prepared in accordance with industry standards and practices, and that the information contained herein is truthful and accurate to the best of my knowledge.

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HWMU-4 ANNUAL GROUNDWATER MONITORING REPORT

CALENDAR YEAR: 1999
REPORT DATE: March 1, 2000

Prepared for the Virginia Department of Environmental Quality - Waste Division (VDEQ-WD) in accordance with 9 VAC 20-60-570.

A. WASTE MANAGEMENT UNIT INFORMATION

UNIT NAME: Hazardous Waste Management Unit 4 (HWMU-4)
OWNER/OPERATOR: United States Army / Alliant TechSystems, Inc.

UNIT LOCATION: Radford AAP Main Plant Area, Radford, Virginia

CLASS: Hazardous Waste Management Unit
TYPE: Former Acid and Wastewater Equalization Basin

B. GROUNDWATER MONITORING PLAN

MONITORING NETWORK
UPGRADIENT WELL: 4P3
DOWNGRADIENT WELLS: 4W2B, 4W4B, 4MW7, 4WC9B, 4WC21, 4WC22, 4WC23, 4WC32, 4WC41, 4WC42, 4WC43, 4W5A, 4W6A, 4W7A
OBSERVATION WELL: 4WC8B
(static water level measurements only)

MONITORING STATUS: Groundwater Quality Assessment Program

DATA COLLECTION STATUS:

Quarterly Event	March 5, 8 and 31, 1999
Quarterly Event	May 26-27, 1999
Quarterly Event	July 23, 1999
Quarterly Event	November 5, 1999

C. GROUNDWATER MOVEMENT

The monitoring wells at HWMU-4 are screened entirely within either carbonate bedrock, weathered carbonate bedrock residuum or alluvium, or across the interfaces between two of the listed strata. The static water level measurements gathered during the 1999 quarterly monitoring events are summarized in **Table 1** (**Appendix A**). Groundwater fluctuations ranged from 0.8 to 7 feet annually. As shown on the HWMU-4 Potentiometric Surface Map for Fourth Quarter 1999 (**Appendix B**), groundwater movement beneath the site is generally to the northeast.

For the purposes of this report, Darcian flow conditions were assumed for the alluvium, residuum, and karst carbonate bedrock beneath HWMU-4. As a result, the groundwater

velocities were calculated by multiplying the hydraulic conductivity (determined from previously conducted slug tests) by the average hydraulic gradient across the site, and dividing by an assumed effective porosity for the aquifer materials. The average hydraulic gradient was determined by superimposing three evenly spaced flow line vectors over the Potentiometric Surface Map, measuring their lengths, calculating the head differential over the distances measured, and dividing the head differential by the length of the flow line vectors. The three calculated gradients were then averaged to a single value. Using this method, the average groundwater hydraulic gradient across the site based on Fourth Quarter 1999 groundwater elevations was calculated to be 0.054 ft/ft. Historical slug test data for the site yielded an average hydraulic conductivity of 1.18×10^{-5} ft/second. This value is consistent with literature values for karst carbonate rock and for clayey, silty sand and gravel alluvium and residuum (Domenico and Schwartz, 1990).

The estimated groundwater velocity across the site was calculated to be approximately 0.14 ft/day or 51 ft/year, based on the following:

- an average hydraulic conductivity of 1.18×10^{-5} ft/second;
- an average hydraulic gradient of 0.054 ft/ft; and
- an assumed effective porosity of 0.40, based on a representative range of porosities for karst carbonate rock, weathered residuum, and clayey, silty sand and gravel alluvium (Domenico and Schwartz, 1990).

The actual groundwater flow velocities in the carbonate bedrock may vary as much as one to two orders of magnitude from the velocity presented above, depending on water level conditions and the distribution of karst conduits.

D. STATISTICAL EVALUATIONS

D.1 HWMU-4 GROUNDWATER BACKGROUND CONCENTRATIONS

Background concentrations were calculated for each constituent in the groundwater monitoring program using the 1996-1999 quarterly analytical data from upgradient well 4P3. The background concentration calculations were based on site wide 95% confidence, 95% coverage upper prediction intervals. When adjusted for multiple comparisons of the background data, the minimum required false positive rate was well below 1%. A 99% confidence level (0.01 false positive rate) was used for all individual comparisons. These coverage limits were only achieved for constituent data on which parametric prediction intervals were performed. In cases where non-parametric prediction intervals were computed to determine the background levels, the confidence level and error rate were calculated based on the number of background data points available and number of future comparisons. Because the upper control limit of a non-parametric interval cannot be adjusted for multiple comparisons and an inadequate number of background data, the number of resampling events required was adjusted to account for the high error rates inherent in those situations. No confidence levels were defined in cases where the background data were 100% non-detected; the detection limits of such constituents were used to define their respective background levels.

D.2 HWMU-4 STATISTICAL ANALYSIS

Statistical evaluations were performed for HWMU-4 as specified in VHWMR 9 VAC 20-60-570. The statistical evaluations were performed in accordance with the procedures and guidance provided in the following documents:

- Virginia Hazardous Waste Management Regulations, 9 VAC 20-60-790 H and I;
- VDEQ Guidance for statistical analysis titled "Data Analysis Plan," undated;
- Interim Final Guidance for Statistical Analysis of Groundwater Monitoring Data at RCRA Facilities, USEPA, April 1989;
- Addendum to Interim Final Guidance for Statistical Analysis of Groundwater Monitoring Data at RCRA Facilities, USEPA, July 1992; and
- Statistical Methods for Groundwater Monitoring, Gibbons, R.D., 1994.

Statistical threshold values were computed for the 32 constituents for which HWMU-4 is currently monitored based on the concentrations of those constituents in upgradient (background) well 4P3. The 1996-1999 quarterly monitoring data for well 4P3 were used for this purpose. Comparison statistical analyses were performed for all constituents which were detected in any downgradient well during Fourth Quarter 1999.

D.2.1 Background Data and Statistical Comparisons

Statistical analyses were performed using the 1996-1999 quarterly analytical results from upgradient well 4P3 as background data. Based on the percentage of non-detects and the distribution of the background data, methods of statistical comparisons varied. Background average, standard deviation and other descriptive statistical data were computed for all constituents and are presented in **Appendix C**.

The constituents listed below were 100% non-detected in the background data. The background threshold levels (BTLs) for these constituents were established as equal to their detection limits (DLs). Detections of these constituents in the downgradient wells during Fourth Quarter 1999 were compared to these BTLs.

Background Threshold Level (BTL) = Detection Limit (DL)				
Parameter	**Sample Size**	**% Non-Detects**	**DL (µg/l)**	**BTL (µg/l)**
Antimony	15	100	3	3
Mercury	15	100	0.2	0.2
Bis(2-ethylhexyl)phthalate	15	100	10	10
Chloromethane	15	100	0.3	0.3
Di-n-butylphthalate	15	100	5	5
trans 1,2-Dichloroethene	15	100	0.1	0.1
Diethyl phthalate	15	100	5	5
2,4-Dinitrophenol	15	100	50	50
Diphenylamine	15	100	10	10

Background Threshold Level (BTL) = Detection Limit (DL)				
Parameter	**Sample Size**	**% Non-Detects**	**DL (µg/l)**	**BTL (µg/l)**
Methylethyl ketone	15	100	1.1	1.1
Toluene	15	100	0.1	0.1
Trichloroethene	15	100	0.1	0.1
Xylene	15	100	0.1	0.1

Non-parametric prediction intervals were computed for all of the constituents for which the data from background well 4P3 satisfied one of the following two criteria, per VDEQ regulations and guidance as well as USEPA guidance:

- Percentage of non-detects was greater than or equal to 50 and less than 100; or
- Percentage of non-detects was less than 50, but data was not normally distributed.

Non-parametric upper prediction limits (UPL) were computed for 15 constituents which met one of the above two criteria. The background threshold levels for these constituents were set as equal to their UPLs. The confidence level and false positive rate were calculated based on the number of background data points available and number of future comparisons. For all constituents except specific conductivity, the confidence level was determined to be equal to 0.915, and the false positive rate was equal to 0.085. For specific conductivity, the confidence level was determined to be equal to 0.867, and the false positive rate was equal to 0.133. Since the upper control limit of a non-parametric interval cannot be adjusted for multiple comparisons and inadequate number of background data, the number of resampling events required was adjusted to account for the high error rates inherent in those situations. The number of confirmation resamples required for all constituents is 2. The background and relevant statistical data for these constituents are summarized below. Associated statistical computations are presented in **Appendix C**.

BTL = Upper Prediction Limit of Non-parametric Prediction Interval w/false positive rate=0.085 (false positive rate=0.133 for specific conductivity)				
Parameter	**Sample Size**	**% Non-Detects**	**DL (µg/l)**	**BTL (µg/l)**
TOC	15	67	1000	1425
Arsenic	15	80	1	5
Barium	15	0	2	348
Beryllium	15	67	0.2	3.5
Cadmium	15	60	0.1	0.8
Chromium	15	27	1	22
Copper	15	27	1	27
Nickel	15	87	15	22
Silver	15	80	0.2	0.7
Vanadium	15	67	4	31
Zinc	15	33	05	139
Chloroform	15	87	0.1	1.6

BTL = Upper Prediction Limit of Non-parametric Prediction Interval w/false positive rate=0.085 (false positive rate=0.133 for specific conductivity)				
Parameter	**Sample Size**	**% Non-Detects**	**DL (µg/l)**	**BTL (µg/l)**
Dichloromethane	15	93	0.2	1.3
Vinyl chloride	15	93	0.1	0.1
Specific conductivity	11	0	1 µS/cm	3393 µS/cm

The following constituents exhibited normally distributed background data with less than 25% non-detects. One sided parametric prediction intervals were computed on the background data for all of these constituents. The UPLs for these constituents were set as their respective BTLs, with one exception. For pH, a two-sided parametric prediction interval was computed; therefore, the BTL for pH consisted of a range between the lower prediction limit (LPL) and the upper prediction limit. The background concentration calculations were based on site wide 95% confidence, 95% coverage upper prediction intervals. When adjusted for multiple comparisons of the background data, the minimum required false positive rate was well below 1% (0.01). A 99% confidence level (0.01 false positive rate) was used for all individual comparisons, which with the most conservative assumptions provided a site-wide false positive rate of <0.05 for all constituents. The background and relevant statistical data for these constituents are summarized below. The prediction interval computations for these constituents are presented in **Appendix C**.

BTL = UPL of one-sided Prediction Interval (exception pH) w/site-wide false positive rate>0.05 (individual comparisons false positive rate=0.01) BTL for pH = LPL – UPL of two-sided Prediction Interval				
Parameter	**Sample Size**	**% Non-Detects**	**DL (µg/l)**	**BTL (µg/l)**
TOX	15	20	5	17.9
Cobalt	15	20	1	16
Lead	15	20	1	24.7
pH	11	0	0.1 pH units	5.6 to 8.6 pH units

D.2.2 Results of Statistical Comparisons

The following table lists the constituents which were detected during the Fourth Quarter 1999 event at concentrations exceeding their respective background threshold levels (BTLs), and the downgradient wells in which they were detected.

Parameter	Monitoring Well(s)
Lead	4W6A
Chloroform	4W5A
Vinyl chloride	4W6A
TOX	4WC32

Any HWMU-4 target constituents not listed above were not detected in the downgradient monitoring wells at concentrations exceeding their respective BTLs.

HWMU-5 ANNUAL GROUNDWATER MONITORING REPORT

CALENDAR YEAR: 1999
REPORT DATE: March 1, 2000

Prepared for the Virginia Department of Environmental Quality - Waste Division (VDEQ-WD) in accordance with 9 VAC 20-60-570.

A. WASTE MANAGEMENT UNIT INFORMATION

UNIT NAME: Hazardous Waste Management Unit 5 (HWMU-5)
OWNER/OPERATOR: United States Army / Alliant TechSystems, Inc.

UNIT LOCATION: Radford AAP Main Plant Area, Radford, Virginia

CLASS: Hazardous Waste Management Unit
TYPE: Former Neutralization Pond

B. GROUNDWATER MONITORING PLAN

MONITORING NETWORK
UPGRADIENT WELL: 5W8B
DOWNGRADIENT WELLS: 5W5B, 5W7B, 5WC21, 5WC22, 5WC23, S5W5, S5W7, 5W9A, 5W10A, 5W11A
OBSERVATION WELL: S5W6
(static water level measurements only)

MONITORING STATUS: Groundwater Quality Assessment Program

DATA COLLECTION STATUS:

Quarterly Event	March 11, 1999
Quarterly Event	May 26, 1999
Quarterly Event	July 20, 1999
Quarterly Event	November 4, 1999

C. GROUNDWATER MOVEMENT

The monitoring wells at HWMU-5 are screened entirely within either weathered carbonate bedrock residuum or alluvium, or across the weathered residuum/carbonate bedrock interface. The static water level measurements gathered during the 1999 quarterly monitoring events are summarized in **Table 2** (**Appendix A**). Groundwater fluctuations ranged from 1.3 to 3 feet annually. As shown on the HWMU-5 Potentiometric Surface Map for Fourth Quarter 1999 (**Appendix B**), groundwater movement beneath the site is generally to the northeast.

For the purposes of this report, Darcian flow conditions were assumed for the alluvium, residuum, and karst carbonate bedrock beneath HWMU-5. As a result, the groundwater

velocities were calculated by multiplying the hydraulic conductivity (determined from previously conducted slug tests) by the average hydraulic gradient across the site, and dividing by an assumed effective porosity for the aquifer materials. The average hydraulic gradient was determined by superimposing three evenly spaced flow line vectors over the Potentiometric Surface Map, measuring their lengths, calculating the head differential over the distances measured, and dividing the head differential by the length of the flow line vectors. The three calculated gradients were then averaged to a single value. Using this method, the average groundwater hydraulic gradient across the site based on Fourth Quarter 1999 groundwater elevations was calculated to be 0.028 ft/ft. Historical slug test data for the site yielded an average hydraulic conductivity of 5.25×10^{-5} ft/second. This value is consistent with literature values for karst carbonate rock and for clayey, silty sand and gravel alluvium and residuum (Domenico and Schwartz, 1990).

The estimated groundwater velocity across the site was calculated to be approximately 0.32 ft/day or 116 ft/year, based on the following:

- an average hydraulic conductivity of 5.25×10^{-5} ft/second;
- an average hydraulic gradient of 0.028 ft/ft; and
- an assumed effective porosity of 0.40, based on a representative range of porosities for karst carbonate rock, weathered residuum, and clayey, silty sand and gravel alluvium (Domenico and Schwartz, 1990).

The actual groundwater flow velocities in the carbonate bedrock may vary as much as one to two orders of magnitude from the velocity presented above, depending on water level conditions and the distribution of karst conduits.

D. STATISTICAL EVALUATIONS

D.1 HWMU-5 GROUNDWATER BACKGROUND CONCENTRATIONS

Background concentrations were calculated for each constituent in the groundwater monitoring program using the 1996-1999 quarterly analytical data from upgradient well 5W8B. The background concentration calculations were based on site wide 95% confidence, 95% coverage upper prediction intervals. When adjusted for multiple comparisons of the background data, the minimum required false positive rate was well below 1%. A 99% confidence level (0.01 false positive rate) was used for all individual comparisons. These coverage limits were only achieved for constituent data on which parametric prediction intervals were performed. In cases where non-parametric prediction intervals were computed to determine the background levels, the confidence level and error rate were calculated based on the number of background data points available and number of future comparisons. Because the upper control limit of a non-parametric interval cannot be adjusted for multiple comparisons and an inadequate number of background data, the number of resampling events required was adjusted to account for the high error rates inherent in those situations. No confidence levels were defined in cases where the background data were 100% non-detected; the detection limits of such constituents were used to define their respective background levels.

D.2 HWMU-5 STATISTICAL ANALYSIS

Statistical evaluations were performed for HWMU-5 as specified in VHWMR 9 VAC 20-60-570. The statistical evaluations were performed in accordance with the procedures and guidance provided in the following documents:

- Virginia Hazardous Waste Management Regulations, 9 VAC 20-60-790 H and I;
- VDEQ Guidance for statistical analysis titled "Data Analysis Plan," undated;
- Interim Final Guidance for Statistical Analysis of Groundwater Monitoring Data at RCRA Facilities, USEPA, April 1989;
- Addendum to Interim Final Guidance for Statistical Analysis of Groundwater Monitoring Data at RCRA Facilities, USEPA, July 1992; and
- Statistical Methods for Groundwater Monitoring, Gibbons, R.D., 1994.

Statistical threshold values were computed for the 40 constituents for which HWMU-5 is currently monitored based on the concentrations of those constituents in upgradient (background) well 5W8B. The 1996-1999 quarterly monitoring data for well 5W8B were used for this purpose. Comparison statistical analyses were performed for all constituents which were detected in any downgradient well during Fourth Quarter 1999.

D.2.1 Background Data and Statistical Comparisons

Statistical analyses were performed using the 1996-1999 quarterly analytical results from upgradient well 5W8B as background data. Based on the percentage of non-detects and the distribution of the background data, methods of statistical comparisons varied. Background average, standard deviation and other descriptive statistical data were computed for all constituents and are presented in **Appendix D**.

The constituents listed below were 100% non-detected in the background data. The background threshold levels (BTLs) for these constituents were established as equal to their detection limits (DLs). Detections of these constituents in the downgradient wells during Fourth Quarter 1999 were compared to these BTLs.

Background Threshold Level (BTL) = Detection Limit (DL)				
Parameter	**Sample Size**	**% Non-Detects**	**DL (µg/l)**	**BTL (µg/l)**
Antimony	16	100	3	3
Arsenic	16	100	1	1
Selenium	16	100	1	1
2,6-Dinitrotoluene	16	100	0.08	0.08
Benzene	16	100	0.1	0.1
Bis(2-ethylhexyl)phthalate	16	100	10	10
Chloromethane	16	100	0.3	0.3
Di-n-butylphthalate	12	100	5	5
1,2-Dichloroethane	16	100	0.1	0.1

Background Threshold Level (BTL) = Detection Limit (DL)				
Parameter	**Sample Size**	**% Non-Detects**	**DL (µg/l)**	**BTL (µg/l)**
trans-1,2-Dichloroethene	16	100	0.1	0.1
Diethylphthalate	16	100	5	5
Diphenylamine	16	100	10	10
Tetrachloroethene	16	100	0.1	0.1
Toluene	16	100	0.1	0.1
1,1,2-Trichloroethane	16	100	0.5	0.5
Trichlorofluoromethane	16	100	0.5	0.5
Vinyl chloride	16	100	0.1	0.1
Xylene	16	100	0.1	0.1

Non-parametric prediction intervals were computed for all of the constituents for which the data from background well 5W8B satisfied one of the following two criteria, per VDEQ regulations and guidance as well as USEPA guidance:

- Percentage of non-detects was greater than or equal to 50 and less than 100; or
- Percentage of non-detects was less than 50, but data was not normally distributed.

Non-parametric upper prediction limits (UPL) were computed for 20 constituents which met one of the above two criteria. The background threshold levels for these constituents were set as equal to their UPLs. The confidence level and false positive rate were calculated based on the number of background data points available and number of future comparisons. For all constituents except specific conductivity, the confidence level was determined to be equal to 0.943, and the false positive rate was equal to 0.057. For specific conductivity, the confidence level was determined to be equal to 0.897, and the false positive rate was equal to 0.103. Since the upper control limit of a non-parametric interval cannot be adjusted for multiple comparisons and inadequate number of background data, the number of resampling events required was adjusted to account for the high error rates inherent in those situations. The number of confirmation resamples required for all constituents is 2. The background and relevant statistical data for these constituents are summarized below. Associated statistical computations are presented in **Appendix D**.

BTL = Upper Prediction Limit of Non-parametric Prediction Interval w/false positive rate=0.057 (false positive rate=0.103 for specific conductivity)				
Parameter	**Sample Size**	**% Non-Detects**	**DL (µg/l)**	**BTL (µg/l)**
Beryllium	16	56	2	0.7
Cadmium	16	38	0.1	0.4
Cobalt	16	38	1	7
Copper	16	56	1	18
Lead	16	75	1	10
Mercury	16	88	0.2	0.9
Nickel	16	75	15	106
Silver	16	88	0.2	2.3
Thallium	16	88	1	2
Vanadium	16	69	4	17
Zinc	16	44	5	75
2,4-Dinitrotoluene	16	94	0.08	0.18
Acetone	16	94	10	89
Chloroform	16	81	0.3	0.5
Dichloromethane	16	94	0.7	0.4
Methylethyl ketone	16	94	1.1	21.3
Trichloroethene	16	88	0.1	0.8
TOC	16	75	1000	253000
TOX	16	50	5	13.4
Specific Conductivity	11	0	1 µS/cm	580 µS/cm

The following constituents exhibited normally distributed background data with less than 25% non-detects. One sided parametric prediction intervals were computed on the background

data for all of these constituents. The UPLs for these constituents were set as their respective BTLs, with one exception. For pH, a two-sided parametric prediction interval was computed; therefore, the BTL for pH consisted of a range between the lower prediction limit (LPL) and the upper prediction limit. The background concentration calculations were based on site wide 95% confidence, 95% coverage upper prediction intervals. When adjusted for multiple comparisons of the background data, the minimum required false positive rate was well below 1% (0.01). A 99% confidence level (0.01 false positive rate) was used for all individual comparisons, which with the most conservative assumptions provided a site-wide false positive rate of 0.05 for all constituents. The background and relevant statistical data for these constituents are summarized below. The prediction interval computations for these constituents are presented in **Appendix D**.

BTL = UPL of one-sided Prediction Interval (exception pH) w/site-wide false positive rate<0.05 (individual comparisons false positive rate=0.01) BTL for pH = LPL – UPL of two-sided Prediction Interval				
Parameter	**Sample Size**	**% Non-Detects**	**DL (µg/l)**	**BTL (µg/l)**
Barium	16	0	2	142.4
pH	11	0	0.1 pH units	3.9 to 6.8 pH units

D.2.2 Results of Statistical Comparisons

The following table lists the constituents which were detected during the Fourth Quarter 1999 event at concentrations exceeding their respective background threshold levels (BTLs), and the downgradient wells in which they were detected.

Parameter	Monitoring Well(s)
Arsenic	5W5B, 5WC23, S5W5, 5W9A, 5W10A, 5W11A
Beryllium	5W7B, 5WC21, S5W5
Cadmium	5WC21, 5WC23
Cobalt	5W7B, 5WC21, 5WC22, 5WC23, 5W11A
Copper	5W7B, 5WC21, S5W5
Lead	S5W5
Nickel	5WC21
Selenium	5W5B, 5W7B, 5WC21, S5W5
Vanadium	S5W5
Zinc	5W7B, 5WC21
Chloroform	5W7B
Trichloroethene	5W5B, 5WC21, 5WC22, 5WC23,
pH	5W7B, 5WC21, 5W9A
Specific Conductivity	5W5B, W7B, 5WC21, 5WC22, 5WC23, S5W5, 5W9A, 5W11A

Any HWMU-5 target constituents not listed above were not detected in the downgradient monitoring wells at concentrations exceeding their respective BTLs.

HWMU-10 ANNUAL GROUNDWATER MONITORING REPORT

CALENDAR YEAR: 1999
REPORT DATE: March 1, 2000

Prepared for the Virginia Department of Environmental Quality – Waste Division (VDEQ-WD) in accordance with 9 VAC 20-60-570.

A. WASTE MANAGEMENT UNIT INFORMATION

UNIT NAME: Hazardous Waste Management Unit 10 (HWMU-10)
OWNER/OPERATOR: United States Army / Alliant TechSystems, Inc.

UNIT LOCATION: Radford AAP Main Plant Area, Radford, Virginia

CLASS: Hazardous Waste Management Unit
TYPE: Closed Equalization Basin for the Biological Treatment System

B. GROUNDWATER MONITORING PLAN

MONITORING NETWORK
UPGRADIENT WELL: 10D4
DOWNGRADIENT WELLS: 10MW1, 10DDH2, 10D3, 10D3D
OBSERVATION WELLS: 10DG-1
(static water level measurements only)

MONITORING STATUS: Groundwater Quality Assessment Program

DATA COLLECTION STATUS:

Quarterly Event	March 16, 1999
Quarterly Event	May 28 and June 4, 1999
Quarterly Event	July 23, 1999
Quarterly Event	November 8, 1999

C. GROUNDWATER MOVEMENT

The monitoring wells at HWMU-10 are screened either across the alluvium/limestone bedrock interface or entirely within bedrock. The static water level measurements gathered during the 1999 quarterly monitoring events are summarized in **Table 3** (**Appendix A**). Groundwater fluctuations did not appear to exceed 2 to 3 feet annually, although individual wells tapping karst conduits could have experienced dramatic fluctuations following storm events. As shown on the HWMU-10 Potentiometric Surface Map for Fourth Quarter 1999 (**Appendix B**), groundwater movement beneath the site is generally to the north towards the New River.

For the purposes of this report, Darcian flow conditions were assumed for the alluvium and karst limestone bedrock beneath HWMU-10. As a result, the groundwater velocities were

calculated by multiplying the hydraulic conductivity (determined from previously conducted slug tests) by the average hydraulic gradient across the site, and dividing by an assumed effective porosity for the aquifer materials. The average hydraulic gradient was determined by superimposing three evenly spaced flow line vectors over the Potentiometric Surface Map, measuring their lengths, calculating the head differential over the distances measured, and dividing the head differential by the length of the flow line vectors. The three calculated gradients were then averaged to a single value. Using this method, the average groundwater hydraulic gradient across the site based on Fourth Quarter 1999 groundwater elevations was calculated to be 0.016 ft/ft. Historical slug test data for the site yielded an average hydraulic conductivity of 4.9×10^{-4} ft/second. This value is consistent with literature values for karst limestone and for clayey, silty sand and gravel alluvium (Domenico and Schwartz, 1990).

The estimated groundwater velocity across the site was calculated to be approximately 1.69 ft/day or 617 ft/year, based on the following:

- an average hydraulic conductivity of 4.9×10^{-4} ft/second;
- an average hydraulic gradient of 0.016 ft/ft; and
- an assumed effective porosity of 0.40, based on a representative range of porosities for karst limestone and for clayey, silty sand and gravel alluvium (Domenico and Schwartz, 1990).

The actual groundwater flow velocities in the limestone bedrock may vary as much as one to two orders of magnitude from the velocity presented above, depending on water level conditions and the distribution of karst conduits.

D. STATISTICAL EVALUATIONS

D.1 HWMU-10 GROUNDWATER BACKGROUND CONCENTRATIONS

Background concentrations were calculated for each constituent in the groundwater monitoring program using the 1996-1999 quarterly analytical data from upgradient well 10D4. The background concentration calculations were based on site wide 95% confidence, 95% coverage upper prediction intervals. When adjusted for multiple comparisons of the background data, the minimum required false positive rate was approximately 1%. Therefore, a 99% confidence level (0.01 false positive rate) was used for all individual comparisons. These coverage limits were only achieved for constituent data on which parametric prediction intervals were performed. In cases where non-parametric prediction intervals were computed to determine the background levels, the confidence level and error rate were calculated based on the number of background data points available and number of future comparisons. Because the upper control limit of a non-parametric interval cannot be adjusted for multiple comparisons and an inadequate number of background data, the number of resampling events required was adjusted to account for the high error rates inherent in those situations. No confidence levels were defined in cases where the background data were 100% non-detected; the detection limits of such constituents were used to define their respective background levels.

D.2 HWMU-10 STATISTICAL ANALYSIS

Statistical evaluations were performed for HWMU-10 as specified in VHWMR 9 VAC 20-60-570. The statistical evaluations were performed in accordance with the procedures and guidance provided in the following documents:

- Virginia Hazardous Waste Management Regulations, 9 VAC 20-60-790 H and I;
- VDEQ Guidance for statistical analysis titled "Data Analysis Plan," undated;
- Interim Final Guidance for Statistical Analysis of Groundwater Monitoring Data at RCRA Facilities, USEPA, April 1989;
- Addendum to Interim Final Guidance for Statistical Analysis of Groundwater Monitoring Data at RCRA Facilities, USEPA, July 1992; and
- Statistical Methods for Groundwater Monitoring, Gibbons, R.D., 1994.

Statistical threshold values were computed for the 27 constituents for which HWMU-10 is currently monitored based on the concentrations of those constituents in upgradient (background) well 10D4. The 1996-1999 quarterly monitoring data for well 10D4 were used for this purpose. Comparison statistical analyses were performed for all constituents which were detected in any downgradient well during Fourth Quarter 1999.

D.2.1 Background Data and Statistical Comparisons

Statistical analyses were performed using the 1996-1999 quarterly analytical results from upgradient well 10D4 as background data. Based on the percentage of non-detects and the distribution of the background data, methods of statistical comparisons varied. Background average, standard deviation and other descriptive statistical data were computed for all constituents and are presented in **Appendix E**.

The constituents listed below were 100% non-detected in the background data. The background threshold levels (BTLs) for these constituents were established as equal to their detection limits (DLs). Detections of these constituents in the downgradient wells during Fourth Quarter 1999 were compared to these BTLs.

Background Threshold Level (BTL) = Detection Limit (DL)				
Parameter	**Sample Size**	**% Non-Detects**	**DL (µg/l)**	**BTL (µg/l)**
Silver	16	100	0.2	0.2
Cyanide	16	100	10	10
2,6-Dintrotoluene	16	100	0.08	0.08
Bromodichloromethane	16	100	0.2	0.2
Chloromethane	16	100	0.3	0.3
Di-n-butylphthalate	16	100	5	5
trans 1,2-Dichloroethene	16	100	0.1	0.1
Trichloroethene	16	100	0.1	0.1
Trichlorofluoromethane	16	100	0.5	0.5

Non-parametric prediction intervals were computed for all of the constituents for which the data from background well 10D4 satisfied one of the following two criteria, per VDEQ regulations and guidance as well as USEPA guidance:

- Percentage of non-detects was greater than or equal to 50 and less than 100; or
- Percentage of non-detects was less than 50, but data was not normally distributed.

Non-parametric upper prediction limits (UPL) were computed for 11 constituents which met one of the above two criteria. The background threshold levels for these constituents were set as equal to their UPLs. The confidence level and false positive rate were calculated based on the number of background data points available and number of future comparisons. For all constituents, the confidence level was determined to be equal to 0.975, and the false positive rate was equal to 0.025. Since the upper control limit of a non-parametric interval cannot be adjusted for multiple comparisons and inadequate number of background data, the number of resampling events required was adjusted to account for the high error rates inherent in those situations. The number of confirmation resamples required for all constituents is 1. The background and relevant statistical data for these constituents are summarized below. Associated statistical computations are presented in **Appendix E**.

BTL = Upper Prediction Limit of Non-parametric Prediction Interval w/false positive rate=0.025				
Parameter	**Sample Size**	**% Non-Detects**	**DL (µg/l)**	**BTL (µg/l)**
Arsenic	16	81	1	2
Mercury	16	94	0.2	0.2
Nickel	16	94	15	26
Selenium	16	94	1	2
Thallium	16	75	1	3
2,4-Dinitrotoluene	16	94	0.08	0.13
Chloroform	16	25	3.5	21.5
Methylethyl ketone	16	94	1.1	8.2
Xylene	16	94	0.1	3.0
TOC	16	94	1000	84275
TOX	16	44	5	77.5

The following constituents exhibited normally distributed background data with less than 25% non-detects. One sided parametric prediction intervals were computed on the background data for all of these constituents. The UPLs for these constituents were set as their respective BTLs, with one exception. For pH, a two-sided parametric prediction interval was computed; therefore, the BTL for pH consisted of a range between the lower prediction limit (LPL) and the upper prediction limit. The background concentration calculations were based on site wide 95% confidence, 95% coverage upper prediction intervals. When adjusted for multiple comparisons of the background data, the minimum required false positive rate was approximately 1% (0.01). Therefore, a 99% confidence level (0.01 false positive rate) was used for all individual comparisons, which with the most conservative assumptions provided a site-wide false positive rate of 0.05 for all constituents. The background and relevant statistical data for these

constituents are summarized below. The prediction interval computations for these constituents are presented in **Appendix E**.

BTL = UPL of one-sided Prediction Interval (exception pH) w/site-wide false positive rate=0.05 (individual comparisons false positive rate=0.01) BTL for pH = LPL – UPL of two-sided Prediction Interval				
Parameter	**Sample Size**	**% Non-Detects**	**DL (µg/l)**	**BTL (µg/l)**
Barium	16	0	2	183.7
Chromium	16	0	1	18.5
Copper	16	13	1	11.3
Lead	16	19	1	10.6
Zinc	16	19	5	86
Specific conductivity	12	0	1 µS/cm	417 µS/cm
pH	12	0	0.1 pH units	5.6 to 8.0 pH units

D.2.2 Results of Statistical Comparisons

The following table lists the constituents which were detected during the Fourth Quarter 1999 event at concentrations exceeding their respective background threshold levels (BTLs), and the downgradient wells in which they were detected.

Parameter	Monitoring Well(s)
Arsenic	10DDH2
Bromodichloromethane	10MW1
Specific Conductivity	10DDH2, 10D3, 10D3D, 10MW1

Any HWMU-10 target constituents not listed above were not detected in the downgradient monitoring wells at concentrations exceeding their respective BTLs.

HWMU-13 ANNUAL GROUNDWATER MONITORING REPORT

CALENDAR YEAR: 1998
REPORT DATE: March 1, 2000

Prepared for the Virginia Department of Environmental Quality - Waste Division (VDEQ-WD) in accordance with 9 VAC 20-60-570.

A. WASTE MANAGEMENT UNIT INFORMATION

UNIT NAME: Hazardous Waste Management Unit 13 (HWMU-13)
OWNER/OPERATOR: United States Army / Alliant TechSystems, Inc.

UNIT LOCATION: Radford AAP Main Plant Area, Radford, Virginia

CLASS: Hazardous Waste Management Unit
TYPE: Waste Propellant Burning Ground

B. GROUNDWATER MONITORING PLAN

MONITORING NETWORK
UPGRADIENT WELLS: 13MW1, 13MW2
DOWNGRADIENT WELLS: 13MW3, 13MW4, 13MW5, 13MW6, 13MW7

MONITORING STATUS: Groundwater Quality Assessment Program

DATA COLLECTION STATUS:

Quarterly Event	March 13, 1999
Quarterly Event	May 27 and June 4, 1999
Quarterly Event	July 27, 1999
Quarterly Event	November 8, 1999

C. GROUNDWATER MOVEMENT

The static water level measurements gathered at HWMU-13 during the 1999 quarterly monitoring events are summarized in **Table 4** (**Appendix A**). Groundwater fluctuations ranged from 1.5 to 5 feet annually. As shown on the HWMU-13 Potentiometric Surface Map for Fourth Quarter 1999 (**Appendix B**), groundwater movement beneath the site is generally to the south toward the New River.

For the purposes of this report, Darcian flow conditions were assumed for the alluvium and karst carbonate bedrock beneath HWMU-13. As a result, the groundwater velocities were calculated by multiplying the hydraulic conductivity (determined from previously conducted slug tests) by the average hydraulic gradient across the site, and dividing by an assumed effective porosity for the aquifer materials. The average hydraulic gradient was determined by superimposing three evenly spaced flow line vectors over the Potentiometric Surface Map,

measuring their lengths, calculating the head differential over the distances measured, and dividing the head differential by the length of the flow line vectors. The three calculated gradients were then averaged to a single value. Using this method, the average groundwater hydraulic gradient across the site based on Fourth Quarter 1999 groundwater elevations was calculated to be 0.005 ft/ft. Historical slug test data for the site yielded an average hydraulic conductivity of 6.56×10^{-5} ft/second. This value is consistent with literature values for karst carbonate rock and for clayey, silty sand and gravel alluvium (Domenico and Schwartz, 1990).

The estimated groundwater velocity across the site was calculated to be approximately 7.08×10^{-2} ft/day or 26 ft/year, based on the following:

- an average hydraulic conductivity of 6.56×10^{-5} ft/second;
- an average hydraulic gradient of 0.005 ft/ft; and
- an assumed effective porosity of 0.40, based on a representative range of porosities for karst carbonate rock and clayey, silty sand and gravel alluvium (Domenico and Schwartz, 1990).

The actual groundwater flow velocities in the carbonate bedrock may vary as much as one to two orders of magnitude from the velocity presented above, depending on water level conditions and the distribution of karst conduits.

D. STATISTICAL EVALUATIONS

D.1 HWMU-13 GROUNDWATER BACKGROUND CONCENTRATIONS

Background concentrations were calculated for each constituent in the groundwater monitoring program using the 1996-1999 quarterly analytical data from upgradient wells 13MW1 and 13MW2. The background concentration calculations were based on site wide 95% confidence, 95% coverage upper prediction intervals. When adjusted for multiple comparisons of the background data, the minimum required false positive rate was approximately 1%. Therefore, a 99% confidence level (0.01 false positive rate) was used for all individual comparisons. These coverage limits were only achieved for constituent data on which parametric prediction intervals were performed. In cases where non-parametric prediction intervals were computed to determine the background levels, the confidence level and error rate were calculated based on the number of background data points available and number of future comparisons. Because the upper control limit of a non-parametric interval cannot be adjusted for multiple comparisons and an inadequate number of background data, the number of resampling events required was adjusted to account for the high error rates inherent in those situations. No confidence levels were defined in cases where the background data were 100% non-detected; the detection limits of such constituents were used to define their respective background levels.

D.2 HWMU-13 STATISTICAL ANALYSIS

Statistical evaluations were performed for HWMU-13 as specified in VHWMR 9 VAC 20-60-570. The statistical evaluations were performed in accordance with the procedures and guidance provided in the following documents:

- Virginia Hazardous Waste Management Regulations, 9 VAC 20-60-790 H and I;
- VDEQ Guidance for statistical analysis titled "Data Analysis Plan," undated;
- Interim Final Guidance for Statistical Analysis of Groundwater Monitoring Data at RCRA Facilities, USEPA, April 1989;
- Addendum to Interim Final Guidance for Statistical Analysis of Groundwater Monitoring Data at RCRA Facilities, USEPA, July 1992; and
- Statistical Methods for Groundwater Monitoring, Gibbons, R.D., 1994.

Statistical threshold values were computed for the 65 constituents for which HWMU-13 is currently monitored based on the concentrations of those constituents in upgradient (background) wells 13MW1 and 13MW2. The 1996-1999 quarterly monitoring data for the background wells were used for this purpose. Comparison statistical analyses were performed for all constituents which were detected in any downgradient well during Fourth Quarter 1999. Downgradient wells 13MW5 and 13MW7 were not sampled during Fourth Quarter 1999; therefore, comparison statistical analyses were performed for all constituents which were detected in wells 13MW5 and 13MW7 during Third Quarter 1999.

D.2.1 Background Data and Statistical Comparisons

Statistical analyses were performed using the 1996-1999 quarterly analytical results from upgradient wells 13MW1 and 13MW2 as background data. Based on the percentage of non-detects and the distribution of the background data, methods of statistical comparisons varied. Background average, standard deviation and other descriptive statistical data were computed for all constituents and are presented in **Appendix F**.

The constituents listed below were 100% non-detected in the background data. The background threshold levels (BTLs) for these constituents were established as equal to their detection limits (DLs). Detections of these constituents in the downgradient wells during Fourth Quarter 1999 (Third Quarter 1999 for wells 13 MW5 and 13MW7) were compared to these BTLs.

Background Threshold Level (BTL) = Detection Limit (DL)				
Parameter	**Sample Size**	**% Non-Detects**	**DL (µg/l)**	**BTL (µg/l)**
Mercury	32	100	0.2	0.2
2,4-Dinitrotoluene	32	100	0.08	0.08
2,6-Dinitrotoluene	32	100	0.08	0.08
1,1,1-Trichloroethane	32	100	0.3	0.3
1,1-Dichloroethene	32	100	0.3	0.3
2,4,6-Trinitrotoluene	32	100	10	10
2,4-Dinitrophenol	32	100	50	50
2-Nitrodiphenylamine	32	100	10	10
Acetone	32	100	10	10
Benzene	32	100	0.1	0.1

Background Threshold Level (BTL) = Detection Limit (DL)				
Parameter	**Sample Size**	**% Non-Detects**	**DL (µg/l)**	**BTL (µg/l)**
Butyl benzyl phthalate	32	100	5	5
Cyanide	32	100	10	10
Cyclonite	32	100	10	10
Diethylene glycol dinitrate	32	100	10	10
Diethyl ether	32	100	10	10
Diethyl phthalate	32	100	5	5
Dimethyl ether	32	100	10	10
Di-n-butylphthalate	32	100	5	5
Di-n-propyladipate	32	100	10	10
Diphenylamine	32	100	10	10
Ethanol	32	100	10	10
Ethyleneglycol monoethylether	32	100	10	10
Homocyclonite	32	100	10	10
Nitrite	32	100	10	10
Nitrocellulose	32	100	10	10
Nitroglycerin	32	100	10	10
Nitroguanidine	32	100	10	10
N-Nitrosodiphenylamine	32	100	5	5
o-Nitroaniline	32	100	50	50
Resorcinol	32	100	10	10
Tetryl	32	100	10	10
Triethylene glycol dinitrate	32	100	10	10
Trimethyloethane trinitrate	32	100	10	10
Vinyl chloride	32	100	0.1	0.1

Non-parametric prediction intervals were computed for all of the constituents for which the data from the background wells satisfied one of the following two criteria, per VDEQ regulations and guidance as well as USEPA guidance:

- Percentage of non-detects was greater than or equal to 50 and less than 100; or
- Percentage of non-detects was less than 50, but data was not normally distributed.

Non-parametric upper prediction limits (UPL) were computed for 22 constituents which met one of the above two criteria. The background threshold levels for these constituents were set as equal to their UPLs. The confidence level and false positive rate were calculated based on the number of background data points available and number of future comparisons. For all constituents except specific conductivity, the confidence level was determined to be equal to 0.991, and the false positive rate was equal to 0.009. For specific conductivity, the confidence level was determined to be equal to 0.981, and the false positive rate was equal to 0.019. Since the upper control limit of a non-parametric interval cannot be adjusted for multiple comparisons and inadequate number of background data, the number of resampling events required was

adjusted to account for the high error rates inherent in those situations. The number of confirmation resamples required for all constituents is 1. The background and relevant statistical data for these constituents are summarized below. Associated statistical computations are presented in **Appendix F**.

BTL = Upper Prediction Limit of Non-parametric Prediction Interval w/false positive rate=0.009 (false positive rate=0.019 for specific conductivity)				
Parameter	**Sample Size**	**% Non-Detects**	**DL (µg/l)**	**BTL (µg/l)**
Antimony	32	97	3	6
Arsenic	32	91	1	3
Boron	32	44	50	220
Cadmium	32	69	0.1	0.2
Lead	32	31	1	14
Magnesium	32	0	200	93600
Nickel	32	81	15	48
Selenium	32	53	1	5
Silver	32	81	0.2	2.4
Sodium	32	0	100	18700
Zinc	32	25	5	118
Ammonia	32	81	100	600
Chloride	32	0	1000	30500
Fluoride	32	0	100	300
Phenols	32	94	10	20
Sulfate	32	0	1000	88000
Bis (2-ethylhexyl)phthalate	32	94	10	27
Toluene	32	94	0.1	0.2
Xylene	32	94	0.1	2.1
TOC	32	81	1000	8625
TOX	32	75	5	25.5
Specific conductivity	22	0	1 µS/cm	6870 µS/cm

The following constituents exhibited normally distributed background data with less than 25% non-detects. One sided parametric prediction intervals were computed on the background data for all of these constituents. The UPLs for these constituents were set as their respective BTLs, with one exception. For pH, a two-sided parametric prediction interval was computed; therefore, the BTL for pH consisted of a range between the lower prediction limit (LPL) and the upper prediction limit. The background concentration calculations were based on site wide 95% confidence, 95% coverage upper prediction intervals. When adjusted for multiple comparisons of the background data, the minimum required false positive rate was approximately 1% (0.01). A 99% confidence level (0.01 false positive rate) was used for all individual comparisons, which with the most conservative assumptions provided a site-wide false positive rate of 0.05 for all constituents. The background and relevant statistical data for these constituents are summarized below. The prediction interval computations for these constituents are presented in **Appendix F**.

BTL = UPL of one-sided Prediction Interval (exception pH) w/site-wide false positive rate=0.05 (individual comparisons false positive rate=0.01) BTL for pH = LPL – UPL of two-sided Prediction Interval				
Parameter	**Sample Size**	**% Non-Detects**	**DL (µg/l)**	**BTL (µg/l)**
Aluminum	32	6	2	5709
Barium	32	0		202.9
Calcium	32	0		110068
Chromium	32	0		65.3
Copper	32	13	100	22.1
Iron	32	0	200	7183
Manganese	32	0	100	145.4
Nitrate	32	0		947.4
pH	22	0	0.1 pH units	6.3 to 7.8 pH units

D.2.2 Results of Statistical Comparisons

The following table lists the constituents which were detected during the Fourth Quarter 1999 event at concentrations exceeding their respective background threshold levels (BTLs), and the downgradient wells in which they were detected.

Parameter	Monitoring Well(s)
Calcium	13MW6
Sodium	13MW6
Fluoride	13MW3, 13MW5, 13MW6, 13MW7
Nitrate	13MW3, 13MW4, 13MW5, 13MW7
Sulfate	13MW3, 13MW5, 13MW6, 13MW7
TOX	13MW3, 13MW4

Any HWMU-13 target constituents not listed above were not detected in the downgradient monitoring wells at concentrations exceeding their respective BTLs.

HWMU-16 ANNUAL GROUNDWATER MONITORING REPORT

CALENDAR YEAR: 1999
REPORT DATE: March 1, 2000

Prepared for the Virginia Department of Environmental Quality - Waste Division (VDEQ-WD) in accordance with 9 VAC 20-60-570.

A. WASTE MANAGEMENT UNIT INFORMATION

UNIT NAME: Hazardous Waste Management Unit 16 (HWMU-16)
OWNER/OPERATOR: United States Army / Alliant TechSystems, Inc.

UNIT LOCATION: Radford AAP Main Plant Area, Radford, Virginia

CLASS: Hazardous Waste Management Unit
TYPE: Former Hazardous Waste Landfill

B. GROUNDWATER MONITORING PLAN

MONITORING NETWORK
UPGRADIENT WELL: 16C1
DOWNGRADIENT WELLS: 16-1, 16-2, 16-3, 16-5, 16WC1A, 16WC1B, 16WC2B, 16MW8, 16MW9, 16SPRING
OBSERVATION WELLS: 16WC2A, 16C3, 16CDH3
(static water level measurements only)

MONITORING STATUS: Groundwater Quality Assessment Program

DATA COLLECTION STATUS:

Quarterly Event	March 17 and 19, 1999
Quarterly Event	June 2, 4 and 25, 1999
Quarterly Event	July 26, 1999
Quarterly Event	November 9, 1999

C. GROUNDWATER MOVEMENT

The monitoring wells at HWMU-16 are screened entirely within either carbonate bedrock or weathered carbonate bedrock residuum, or across the residuum/bedrock interface. The static water level measurements gathered at HWMU-16 during the 1999 quarterly monitoring events are summarized in **Table 5** (**Appendix A**). Groundwater fluctuations ranged from 0.5 to 3 feet annually. As shown on the HWMU-16 Potentiometric Surface Map for Fourth Quarter 1999 (**Appendix B**), groundwater movement beneath the site is generally to the northeast.

For the purposes of this report, Darcian flow conditions were assumed for the weathered residuum and karst carbonate bedrock beneath HWMU-16. As a result, the groundwater

velocities were calculated by multiplying the hydraulic conductivity (determined from previously conducted slug tests) by the average hydraulic gradient across the site, and dividing by an assumed effective porosity for the aquifer materials. The average hydraulic gradient was determined by superimposing three evenly spaced flow line vectors over the Potentiometric Surface Map, measuring their lengths, calculating the head differential over the distances measured, and dividing the head differential by the length of the flow line vectors. The three calculated gradients were then averaged to a single value. Using this method, the average groundwater hydraulic gradient across the site based on Fourth Quarter 1999 groundwater elevations was calculated to be 0.086 ft/ft. Historical slug test data for the site yielded an average hydraulic conductivity of 7.87×10^{-5} ft/second. This value is consistent with literature values for karst carbonate rock and for clay and silt residuum (Domenico and Schwartz, 1990).

The estimated groundwater velocity across the site was calculated to be approximately 1.67 ft/day or 610 ft/year, based on the following:

- an average hydraulic conductivity of 7.87×10^{-5} ft/second;
- an average hydraulic gradient of 0.086 ft/ft; and
- an assumed effective porosity of 0.35, based on a representative range of porosities for karst carbonate rock and clay and silt residuum (Domenico and Schwartz, 1990).

The actual groundwater flow velocities in the carbonate bedrock may vary as much as one to two orders of magnitude from the velocity presented above, depending on water level conditions and the distribution of karst conduits.

D. STATISTICAL EVALUATIONS

D.1 HWMU-16 GROUNDWATER BACKGROUND CONCENTRATIONS

Background concentrations were calculated for each constituent in the groundwater monitoring program using the 1996-1999 quarterly analytical data from upgradient well 16C1. The background concentration calculations were based on site wide 95% confidence, 95% coverage upper prediction intervals. When adjusted for multiple comparisons of the background data, the minimum required false positive rate was well below 1%. A 99% confidence level (0.01 false positive rate) was used for all individual comparisons. These coverage limits were only achieved for constituent data on which parametric prediction intervals were performed. In cases where non-parametric prediction intervals were computed to determine the background levels, the confidence level and error rate were calculated based on the number of background data points available and number of future comparisons. Because the upper control limit of a non-parametric interval cannot be adjusted for multiple comparisons and an inadequate number of background data, the number of resampling events required was adjusted to account for the high error rates inherent in those situations. No confidence levels were defined in cases where the background data were 100% non-detected; the detection limits of such constituents were used to define their respective background levels.

D.2 HWMU-16 STATISTICAL ANALYSIS

Statistical evaluations were performed for HWMU-16 as specified in VHWMR 9 VAC 20-60-570. The statistical evaluations were performed in accordance with the procedures and guidance provided in the following documents:

- Virginia Hazardous Waste Management Regulations, 9 VAC 20-60-790 H and I;
- VDEQ Guidance for statistical analysis titled "Data Analysis Plan," undated;
- Interim Final Guidance for Statistical Analysis of Groundwater Monitoring Data at RCRA Facilities, USEPA, April 1989;
- Addendum to Interim Final Guidance for Statistical Analysis of Groundwater Monitoring Data at RCRA Facilities, USEPA, July 1992; and
- Statistical Methods for Groundwater Monitoring, Gibbons, R.D., 1994.

Statistical threshold values were computed for the 54 constituents for which HWMU-16 is currently monitored based on the concentrations of those constituents in upgradient (background) well 16C1. The 1996-1999 quarterly monitoring data for well 16C1 were used for this purpose. Comparison statistical analyses were performed for all constituents which were detected in any downgradient well during Fourth Quarter 1999. Downgradient wells 16WC1B and 16MW8 were dry during Fourth Quarter 1999; therefore, comparison statistical analyses were performed for all constituents which were detected in well 16WC1B during Second Quarter 1999 and in well 16MW8 during Third Quarter 1999.

D.2.1 Background Data and Statistical Comparisons

Statistical analyses were performed using the 1998 quarterly analytical results from upgradient well 16C1 as background data. Based on the percentage of non-detects and the distribution of the background data, methods of statistical comparisons varied. Background average, standard deviation and other descriptive statistical data were computed for all constituents and are presented in **Appendix G**.

The constituents listed below were 100% non-detected in the background data. The background threshold levels (BTLs) for these constituents were established as equal to their detection limits (DLs). Detections of these constituents in the downgradient wells during Fourth Quarter 1999 (Second Quarter 1999 for well 16WC1B and Third Quarter 1999 for well 16MW8) were compared to these BTLs.

Background Threshold Level (BTL) = Detection Limit (DL)				
Parameter	**Sample Size**	**% Non-Detects**	**DL (µg/l)**	**BTL (µg/l)**
Antimony	16	100	3	3
Arsenic	16	100	1	1
Mercury	16	100	0.2	0.2
Selenium	16	100	1	1
Bromoform	16	100	0.3	0.3
Carbon tetrachloride	16	100	0.2	0.2
Chlorobenzene	16	100	0.1	0.1

Background Threshold Level (BTL) = Detection Limit (DL)				
Parameter	**Sample Size**	**% Non-Detects**	**DL (µg/l)**	**BTL (µg/l)**
Chloromethane	16	100	0.3	0.3
Cyanide	16	100	10	10
Di-n-butyl phthalate	16	100	5	5
1,4-Dichlorobenzene	16	100	0.1	0.1
1,2-Dichloroethane	16	100	0.1	0.1
trans-1,2-Dichloroethene	16	100	0.1	0.1
1,1,2,2,-Tetrachloroethane	16	100	0.1	0.1
1,1,2-Trichloroethane	16	100	0.5	0.5
Trichloroethene	16	100	0.1	0.1
1234678-HPCDF	16	100	0.0615	0.0615
1234789-HPCDF	16	100	0.0709	0.0709
123478-HXCDF	16	100	0.039	0.039
123678-HXCDF	16	100	0.0377	0.0377
123789-HXCDF	16	100	0.0415	0.0415
234678-HXCDF	16	100	0.0428	0.0428
12378-PECDF	16	100	0.0439	0.0439
23478-PECDF	16	100	0.0417	0.0417
2378-TCDF	16	100	0.0485	0.0485
OCDF	16	100	0.1307	0.1307

Non-parametric prediction intervals were computed for all of the constituents for which the data from the background wells satisfied one of the following two criteria, per VDEQ regulations and guidance as well as USEPA guidance:

- Percentage of non-detects was greater than or equal to 50 and less than 100; or
- Percentage of non-detects was less than 50, but data was not normally distributed.

Non-parametric upper prediction limits (UPL) were computed for 23 constituents which met one of the above two criteria. The background threshold levels for these constituents were set as equal to their UPLs, with one exception. For pH, a two-sided nonparametric prediction interval was computed; therefore, the BTL for pH consisted of a range between the lower prediction limit (LPL) and the upper prediction limit. The confidence level and false positive rate were calculated based on the number of background data points available and number of future comparisons. For all constituents except specific conductivity and pH, the confidence level was determined to be equal to 0.943, and the false positive rate was equal to 0.057. For specific conductivity and pH, the confidence level was determined to be equal to 0.910, and the false positive rate was equal to 0.090. Since the upper control limit of a non-parametric interval cannot be adjusted for multiple comparisons and inadequate number of background data, the number of resampling events required was adjusted to account for the high error rates inherent in those situations. The number of confirmation resamples required for all constituents is 2. The background and relevant statistical data for these constituents are summarized below. Associated statistical computations are presented in **Appendix G**.

BTL = Upper Prediction Limit of Non-parametric Prediction Interval w/false positive rate=0.057 (false positive rate=0.090 for specific conductivity and pH) BTL for pH = LPL – UPL of two-sided Prediction Interval				
Parameter	**Sample Size**	**% Non-Detects**	**DL (µg/l)**	**BTL (µg/l)**
Beryllium	16	81	0.2	0.7
Cadmium	16	75	0.1	6.1
Chromium	16	38	1	13
Cobalt	16	69	1	5
Copper	16	50	1	48
Lead	16	50	1	11
Nickel	16	94	15	16
Silver	16	75	0.2	2.2
Thallium	16	75	1	6
Vanadium	16	88	4	151
Zinc	16	56	5	296
2,4-Dinitrotoluene	16	94	0.08	0.1
2,6-Dinitrotoluene	16	75	0.08	1.67
1,1-Dichloroethane	16	0	0.2	9.5
Ethylbenzene	16	94	0.1	0.7
Methylethyl ketone	16	94	1.1	11.2
Toluene	16	94	0.1	0.2
1,1,1-Trichloroethane	16	13	0.3	9.2
Vinyl chloride	16	94	0.1	0.1
Xylene	16	88	0.1	1.4
TOC	16	75	1000	478750
Specific conductivity	12	0	1 µS/cm	6610 µS/cm
pH	12	0	0.1 pH units	6.2 to 8.3 pH units

The constituents tetrachloroethene and total organic halides (TOX) exhibited normally distributed data (excluding non-detects) with between 25% and 50% non-detects in the background well. The mean and standard deviation of the background data for these constituents were adjusted using Cohen's Maximum Likelihood Estimator Method (1959, 1961). One-sided parametric prediction intervals were then computed based on the adjusted mean and standard deviation. The computed Upper Prediction Limits were set as the BTLs. The background and relevant statistical data are summarized below. Cohen's adjustment computations and prediction interval computations are presented in **Appendix G**.

BTL = Upper Prediction Limit of Prediction Interval w/site wide false positive rate=0.05				
Parameter	**Sample Size**	**% Non-Detects**	**DL (µg/l)**	**BTL (µg/l)**

BTL = Upper Prediction Limit of Prediction Interval w/site wide false positive rate=0.05				
Parameter	**Sample Size**	**% Non-Detects**	**DL (µg/l)**	**BTL (µg/l)**
Tetrachloroethene	16	25	0.1	0.9
TOX	16	25	5	46.2

The following constituents exhibited normally distributed background data with less than 25% non-detects. One sided parametric prediction intervals were computed on the background data for all of these constituents. The UPLs for these constituents were set as their respective BTLs, with one exception. The background concentration calculations were based on a site wide 95% confidence, 95% coverage upper prediction intervals. When adjusted for multiple comparisons of the background data, the minimum required false positive rate was well below 1% (0.01). A 99% confidence level (0.01 false positive rate) was used for all individual comparisons, which with the most conservative assumptions provided a site-wide false positive rate of >0.05 for all constituents. The background and relevant statistical data for these constituents are summarized below. The prediction interval computations for these constituents are presented in **Appendix G**.

BTL = UPL of one-sided Prediction Interval (exception pH) w/site-wide false positive rate>0.05 (individual comparisons false positive rate=0.01)				
Parameter	**Sample Size**	**% Non-Detects**	**DL (µg/l)**	**BTL (µg/l)**
Barium	16	0	2	173
Dichlorodifluoromethane	16	6	0.3	32.1
Trichlorofluoromethane	16	0	0.5	8.4

D.2.2 Results of Statistical Comparisons

The following table lists the constituents which were detected during the Fourth Quarter 1999 event (Second Quarter 1999 event for well 16WC1B and Third Quarter 1999 event for well 16MW8) at concentrations exceeding their respective background threshold levels (BTLs), and the downgradient wells in which they were detected.

Parameter	Monitoring Well(s)
Barium	16-1, 16-2, 16-3, 16-5, 16MW9, 16WC1A, 16WC2B, 16Spring
Chromium	16MW9
Cobalt	16WC1A
Mercury	16WC1B
Selenium	16-5
Toluene	16WC2B
pH	16MW8

Any HWMU-16 target constituents not listed above were not detected in the downgradient monitoring wells at concentrations exceeding their respective BTLs.

HWMU-39 ANNUAL GROUNDWATER MONITORING REPORT

CALENDAR YEAR: 1999
REPORT DATE: March 1, 2000

Prepared for the Virginia Department of Environmental Quality - Waste Division (VDEQ-WD) in accordance with 9 VAC 20-60-570.

A. WASTE MANAGEMENT UNIT INFORMATION

UNIT NAME: Hazardous Waste Management Unit 39 (HWMU-39)
OWNER/OPERATOR: United States Army / Alliant TechSystems, Inc.

UNIT LOCATION: Radford AAP Main Plant Area, Radford, Virginia

CLASS: Hazardous Waste Management Unit
TYPE: Closed Incinerator Spray Pond

B. GROUNDWATER MONITORING PLAN

MONITORING NETWORK
UPGRADIENT WELLS: 39MW1, 39MW4
DOWNGRADIENT WELLS: 39MW3, 39MW5, 39MW6

MONITORING STATUS: Groundwater Quality Assessment Program

DATA COLLECTION STATUS:

Quarterly Event	March 22, 1999
Quarterly Event	May 28, 1999
Quarterly Event	July 27, 1999
Quarterly Event	November 8, 1999

C. GROUNDWATER MOVEMENT

The monitoring wells at HWMU-39 are screened within carbonate bedrock. The static water level measurements gathered at HWMU-39 during the 1999 quarterly monitoring events are summarized in **Table 6** (**Appendix A**). Groundwater fluctuations ranged from 1 to 1.5 feet annually. As shown on the HWMU-39 Potentiometric Surface Map for First Quarter 1999 (**Appendix B**), groundwater movement beneath the site is generally to the northeast.

For the purposes of this report, Darcian flow conditions were assumed for the karst carbonate bedrock beneath HWMU-39. As a result, the groundwater velocities were calculated by multiplying an assumed hydraulic conductivity by the average hydraulic gradient across the site, and dividing by an assumed effective porosity for the aquifer materials. The average hydraulic gradient was determined by superimposing three evenly spaced flow line vectors over the Potentiometric Surface Map, measuring their lengths, calculating the head differential over

the distances measured, and dividing the head differential by the length of the flow line vectors. The three calculated gradients were then averaged to a single value. Using this method, the average groundwater hydraulic gradient across the site based on First Quarter 1999 groundwater elevations was calculated to be 0.016 ft/ft. A representative range of hydraulic conductivities for karst limestone yielded an assumed hydraulic conductivity of 3.28×10^{-4} ft/second (Domenico and Schwartz, 1990).

The estimated groundwater velocity across the site was calculated to be approximately 1.51 ft/day or 551 ft/year, based on the following:

- an assumed hydraulic conductivity of 3.28×10^{-4} ft/second;
- an average hydraulic gradient of 0.016 ft/ft; and
- an assumed effective porosity of 0.30, based on a representative range of porosities for karst carbonate rock (Domenico and Schwartz, 1990).

The actual groundwater flow velocities in the carbonate bedrock may vary as much as one to two orders of magnitude from the velocity presented above, depending on water level conditions and the distribution of karst conduits.

D. STATISTICAL EVALUATIONS

D.1 HWMU-39 GROUNDWATER BACKGROUND CONCENTRATIONS

Background concentrations were calculated for each constituent in the groundwater monitoring program using the 1998-1999 quarterly analytical data from upgradient wells 39MW1 and 39MW4. The background concentration calculations were based on site wide 95% confidence, 95% coverage upper prediction intervals. When adjusted for multiple comparisons of the background data, the minimum required false positive rate was approximately 1%. A 99% confidence level (0.01 false positive rate) was used for all individual comparisons. These coverage limits were only achieved for constituent data on which parametric prediction intervals were performed. In cases where non-parametric prediction intervals were computed to determine the background levels, the confidence level and error rate were calculated based on the number of background data points available and number of future comparisons. Because the upper control limit of a non-parametric interval cannot be adjusted for multiple comparisons and an inadequate number of background data, the number of resampling events required was adjusted to account for the high error rates inherent in those situations. No confidence levels were defined in cases where the background data were 100% non-detected; the detection limits of such constituents were used to define their respective background levels.

D.2 HWMU-39 STATISTICAL ANALYSIS

Statistical evaluations were performed for HWMU-39 as specified in VHWMR 9 VAC 20-60-570. The statistical evaluations were performed in accordance with the procedures and guidance provided in the following documents:

- Virginia Hazardous Waste Management Regulations, 9 VAC 20-60-790 H and I;

- VDEQ Guidance for statistical analysis titled "Data Analysis Plan," undated;
- Interim Final Guidance for Statistical Analysis of Groundwater Monitoring Data at RCRA Facilities, USEPA, April 1989;
- Addendum to Interim Final Guidance for Statistical Analysis of Groundwater Monitoring Data at RCRA Facilities, USEPA, July 1992; and
- Statistical Methods for Groundwater Monitoring, Gibbons, R.D., 1994.

Statistical threshold values were computed for the 39 constituents for which HWMU-39 is currently monitored based on the concentrations of those constituents in upgradient (background) wells 39MW1 and 39MW4. The 1998-1999 quarterly monitoring data for wells 39MW1 and 39MW4 were used for this purpose. Downgradient wells 39MW5 and 39MW6 were dry during Fourth Quarter 1999; therefore, comparison statistical analyses were performed for all constituents which were detected in wells 39MW5 and 39MW6 during Third Quarter 1999. Comparison statistical analyses were performed for all constituents which were detected in downgradient well 39MW3 during Fourth Quarter 1999.

D.2.1 Background Data and Statistical Comparisons

Statistical analyses were performed using the 1998-1999 quarterly analytical results from upgradient wells 39MW1 and 39MW4 as background data. Based on the percentage of non-detects and the distribution of the background data, methods of statistical comparisons varied. Background average, standard deviation and other descriptive statistical data were computed for all constituents and are presented in **Appendix H**.

The constituents listed below were 100% non-detected in the background data. The background threshold levels (BTLs) for these constituents were established as equal to their detection limits (DLs). Detections of these constituents in the downgradient wells during Third or Fourth Quarter 1999 were compared to these BTLs.

Background Threshold Level (BTL) = Detection Limit (DL)				
Parameter	**Sample Size**	**% Non-Detects**	**DL (µg/l)**	**BTL (µg/l)**
Antimony	15	100	60	60
Thallium	15	100	1	1
Mercury	15	100	0.2	0.2
gamma-BHC	15	100	2	2
2,4-D	15	100	1	1
2,4,5-TP silvex	15	100	1	1
Di-n-butylphthalate	15	100	5	5
Diethylphthalate	15	100	5	5
Endrin	15	100	2	2
Methoxychlor	15	100	2	2
Phenols	15	100	10	10
Resorcinol	15	100	10	10

Background Threshold Level (BTL) = Detection Limit (DL)				
Parameter	**Sample Size**	**% Non-Detects**	**DL (µg/l)**	**BTL (µg/l)**
Toxaphene	15	100	2	2

Non-parametric prediction intervals were computed for all of the constituents for which the data from the background wells satisfied one of the following two criteria, per VDEQ regulations and guidance as well as USEPA guidance:

- Percentage of non-detects was greater than or equal to 50 and less than 100; or
- Percentage of non-detects was less than 50, but data was not normally distributed.

The background threshold levels for these constituents were set as equal to their UPLs. The confidence level and false positive rate were calculated based on the number of background data points available and number of future comparisons. For all constituents except specific conductivity, the confidence level was determined to be equal to 0.979, and the false positive rate was equal to 0.021. For specific conductivity, the confidence level was determined to be equal to 0.976, and the false positive rate was equal to 0.024. Since the upper control limit of a non-parametric interval cannot be adjusted for multiple comparisons and inadequate number of background data, the number of resampling events required was adjusted to account for the high error rates inherent in those situations. The minimum number of confirmation resamples required for all constituents is 1. The background and relevant statistical data for these constituents are summarized below. Associated statistical computations are presented in **Appendix H**.

BTL = Upper Prediction Limit of Non-parametric Prediction Interval w/false positive rate=0.021 (false positive rate=0.024 for specific conductivity)				
Parameter	**Sample Size**	**% Non-Detects**	**DL (µg/l)**	**BTL (µg/l)**
Arsenic	15	60	1	7
Beryllium	15	67	0.2	2.4
Cadmium	15	73	0.1	0.4
Chromium	15	0	1	71
Lead	15	47	1	65
Nickel	15	73	15	63
Selenium	15	40	1	4
Silver	15	93	0.2	0.7
2,4-DNT	15	93	0.08	0.14
2,6-DNT	15	93	0.08	0.11
Alpha emission	15	33	1 pCi/l	53 pCi/l
Radium	15	87	1 pCi/l	5 pCi/l
Fluoride	15	53	100	380
Sulfate	15	7	1000	100000
Coliform	15	53	2 MPN/ml	30 MPN /l
TOC	15	47	1000	1775

BTL = Upper Prediction Limit of Non-parametric Prediction Interval w/false positive rate=0.021 (false positive rate=0.024 for specific conductivity)				
Parameter	**Sample Size**	**% Non-Detects**	**DL (µg/l)**	**BTL (µg/l)**
TOX	15	60	5	23
Specific conductivity	14	0	1 µS/cm	3900 µS/cm

The following constituents exhibited normally distributed background data with less than 25% non-detects. One sided parametric prediction intervals were computed on the background data for all of these constituents. The UPLs for these constituents were set as their respective BTLs, with one exception. For pH, a two-sided parametric prediction interval was computed; therefore, the BTL for pH consisted of a range between the lower prediction limit (LPL) and the upper prediction limit. The background concentration calculations were based on a site wide 95% confidence, 95% coverage upper prediction intervals. When adjusted for multiple comparisons of the background data, the minimum required false positive rate was approximately 1% (0.01). A 99% confidence level (0.01 false positive rate) was used for all individual comparisons, which with the most conservative assumptions provided a site-wide false positive rate of 0.05 for all constituents. The background and relevant statistical data for these constituents are summarized below. The prediction interval computations for these constituents are presented in **Appendix H**.

BTL = UPL of one-sided Prediction Interval (exception pH) w/site-wide false positive rate=0.05 (individual comparisons false positive rate=0.01) BTL for pH = LPL – UPL of two-sided Prediction Interval				
Parameter	**Sample Size**	**% Non-Detects**	**DL (µg/l)**	**BTL (µg/l)**
Barium	15	0		215
Iron	15	0		69502
Manganese	15	7		4047
Sodium	15	0		17004
Beta emission	15	20	1 pCi/l	133 pCi/l
Chloride	15	7		9139
Nitrate	15	7		2056
pH	14	0	0.1 pH units	5.8 to 8.6 pH units

D.2.2 Results of Statistical Comparisons

The following table lists the constituents which were detected during the Third or Fourth Quarter 1999 events at concentrations exceeding their respective background threshold levels (BTLs), and the downgradient wells in which they were detected.

Parameter	Monitoring Well(s)
Barium	39MW5, 39MW6
Sodium	39MW3
Alpha emission	39MW6
Fluoride	39MW5, 39MW6
Total Organic Carbon (TOC)	39MW6

Any HWMU-39 target constituents not listed above were not detected in the downgradient monitoring wells at concentrations exceeding their respective BTLs.

APPENDIX A

TABLES

APPENDIX B

FIGURES

APPENDIX C

HWMU-4 STATISTICAL ANALYSIS RESULTS

APPENDIX D

HWMU-5 STATISTICAL ANALYSIS RESULTS

APPENDIX E

HWMU-10 STATISTICAL ANALYSIS RESULTS

APPENDIX F

HWMU-13 STATISTICAL ANALYSIS RESULTS

APPENDIX G

HWMU-16 STATISTICAL ANALYSIS RESULTS

APPENDIX H

HWMU-39 STATISTICAL ANALYSIS RESULTS