Cost and Performance Summary Report
In Situ Chemical Oxidation Using Fenton's Reagent at Naval Submarine Base Kings Bay, Site 11, Camden County, Georgia

Summary Information [1,2,3,4,6,7,8,10,11]

Naval Submarine Base (NSB) Kings Bay encompasses more than 16,000 acres near the Georgia-Florida border in Camden County, GA. Commissioned in 1978, the base originally served as a forward refit site for submarine squadrons. In 1980, the base was designated as U.S. Atlantic Fleet home port to the next generation of ballistic submarines. NSB Kings Bay also maintains and operates administration and personnel support facilities. Site 11 is the location of a former 25-acre landfill at NSB Kings Bay, known as the Old Camden County landfill, that was operated by the county during the mid-1970s to 1980. A variety of wastes from the local Kings Bay community and the Navy were disposed of in the landfill, including solvents and municipal waste. Waste was disposed using the trench method wherein trenches were dug, backfilled with waste, and covered with fill. In the early 1990's, a RCRA Facility Investigation (RFI) identified groundwater contamination in the area of the landfill. A tetrachloroethene (PCE) plume was determined to be migrating towards a subdivision located several hundred yards from the perimeter of the landfill. As an interim measure, the Navy installed pumping wells to hydraulically contain the plume at the perimeter of the landfill.

Results of additional site investigations conducted to delineate the source of contamination determined that the PCE source was 120 feet long by 40 feet wide and was found in the 30 to 40 foot horizon below ground surface (bgs). In addition, PCE degradation products including trichloroethene (TCE), dichloroethene (DCE), and vinyl chloride (VC), were detected in the groundwater. Total chlorinated aliphatic compounds (CACs), the sum of PCE and its degradation products TCE, DCE, and VC, were detected at concentrations of more than 9,000 micrograms per liter (µg/L) in the groundwater within the landfill source area. PCE concentrations in this area were detected as high as 8,500 µg/L. Because PCE concentrations were as much as 5 percent (%) of the pure solubility phase, the presence of dense non-phase aqueous liquids (DNAPL) was inferred. On March 18, 1994, NSB Kings Bay entered into a Corrective Action Consent Order with the Georgia Environmental Protection Division to address prior releases of hazardous constituents from Site 11.

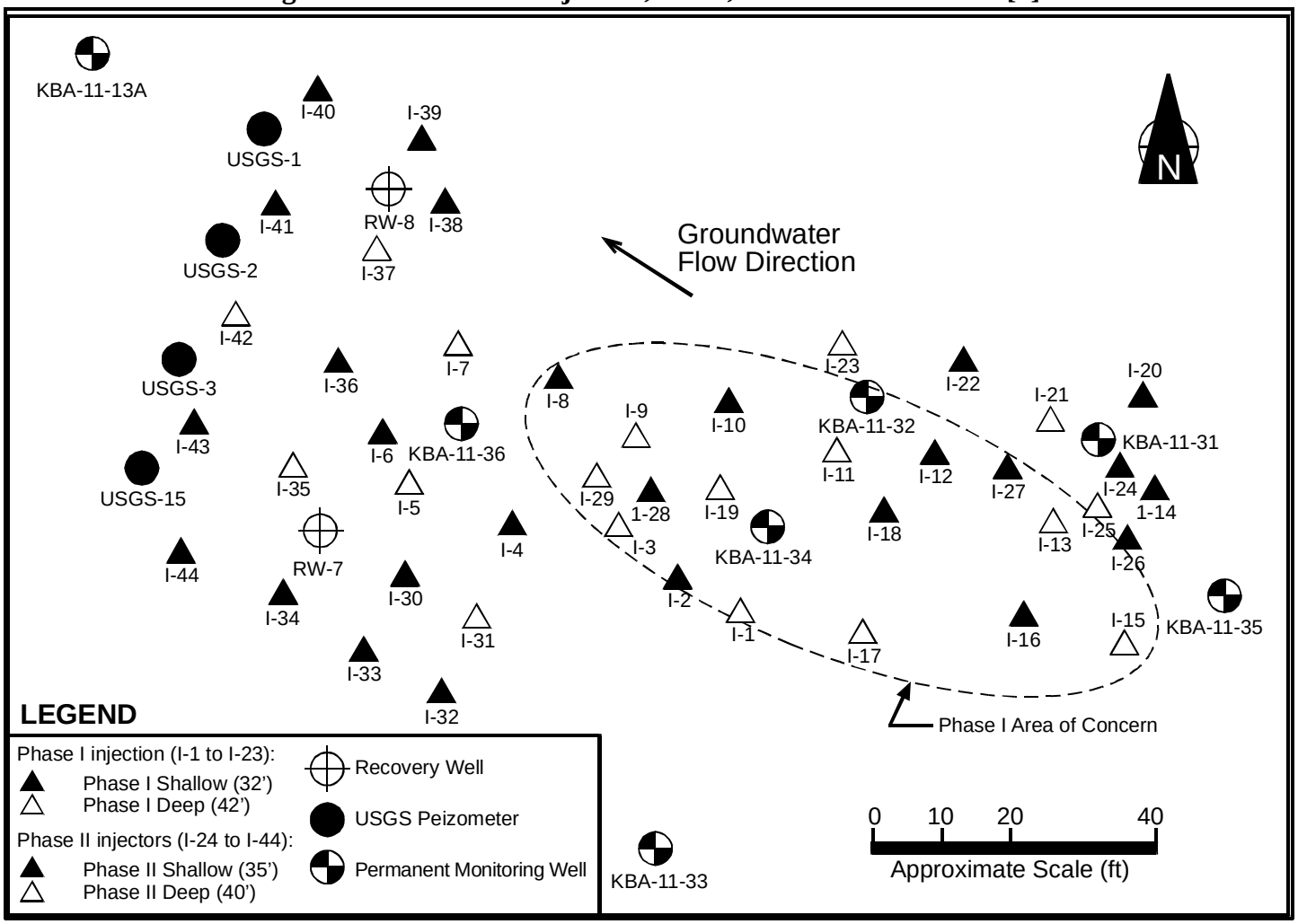
The Navy selected *in situ* chemical oxidation using Fenton's reagent for this site based on its successful use by the U.S. Department of Energy (DOE) in remediating chlorinated solvent contaminated groundwater at the Savannah River site. The Navy's approach to the cleanup of Site 11 was to use *in situ* chemical oxidation to reduce groundwater contaminant concentrations in the source area followed by natural attenuation to address residual contamination. Modeling results indicated that if the concentrations of total CACs in the source area were reduced to 100 ug/L, natural attenuation would address residual contamination, achieving compliance levels in the groundwater plume prior to reaching the facility's boundaries.

Figure 1 shows the PCE source area (area of concern) for the cleanup, and the location of the injection and other wells at the site. Phases 1 and 2 of the remediation have been completed. The first phase was conducted from November 1998 to May 1999 and the second phase was conducted from June 1999 to August 1999. Following Phase 2, elevated total CACs concentrations (1,700 ug/L) were found near injector I-14 (to the east of the area of concern) indicating the presence of a previously unidentified contamination source area. The soil in this area has been excavated and the Navy is planning to use chemical oxidation to polish the groundwater in this area. Chemical oxidation of the I-14 area had not begun at the time of this report. Therefore, this report addresses Phases 1 and 2 of the remediation at Site 11.

The volume of groundwater treated during the Phase 1 was estimated to be 78,989 gallons based on a treatment volume of 1,778 cubic yards and a porosity of 22%. Information on the volume of groundwater treated during Phase 2 was not provided.

RCRIS Facility ID:	GA4170090001
Type of Action:	RCRA Corrective Action
Lead:	Southern Division Naval Facilities Engineering Command (NAVFAC)
Oversight:	State of Georgia Environmental Protection Division

Figure 1 – Location of Injectors, Wells, and Area of Concern [7]



Timeline [1,2,3,8,10]

Early 1990's	RCRA Facility Investigation detects PCE contamination. Hydraulic containment installed.
March 18, 1994	NSB entered into a Corrective Action Consent Order with the state
Mar - Sept 1997	Additional investigation to delineate source of contamination at Site 11
Sept - Oct 1998	Installation of treatment system
Nov 2 - 21, 1998	Phase 1 treatment - first injection
Feb 8 - 14, 1999	Phase 1 treatment - second injection
June 3 - 11, 1999	Phase 2 treatment - first injection
July 12 - 15, 1999	Phase 2 treatment - second injection
August 1999	Phase 2 completed

Factors That Affected Cost or Performance of Treatment [2,5]

The shallow soils in the region of NSB Kings Bay consist of fine sands interbedded with silty and/or clayey fine sands and some medium sands. The water table is encountered at 6 feet bgs and there is an unconfined surficial aquifer that is approximately 90 feet thick. Site 11 is located within a zone of high transmissivity and the hydraulic conductivity is estimated to be 30 feet per day (ft/d). Groundwater flow direction is generally northwest.

Groundwater samples were collected prior to treatment to determine the conditions at the site and to evaluate whether the conditions were suitable for use of the Geo-Cleanse® process. The key matrix characteristics that affect the cost or performance of this technology and the values measured for each are presented below. According to the technology vendor, Site 11 was suitable for remediation using the Geo-Cleanse® process, as the conditions at the site were within the "optimal" ranges for hydraulic conductivity, pH, alkalinity, total dissolved iron, and depth of contamination. The optimal ranges for the Geo-Cleanse® process for these parameters are shown in parentheses.

Matrix Characteristics [2,5]

Parameter	Value
Soil Classification:	Fine to medium quartz sand
Clay Content and/or Particle Size Distribution:	Fine sands interbedded with silty and/or clayey fine sands
Hydraulic Conductivity:	30 ft/day (optimal > $3x10^{-5}$ ft/day)
pH:	4 to 6 (optimal < 6)
Alkalinity:	< 200 mg/L (optimal < 200 mg/L)
Total Dissolved Iron:	> 10 mg/L (optimal > 5 mg/L)
Depth/Thickness of Zone of Interest:	30 to 40 feet bgs (optimal > 5 ft bgs)
Non-Aqueous Phase Liquids:	DNAPL presence inferred because PCE detected at five times solubility

Treatment Technology Description [2,4 5,7,8,9]

For the remediation of Site 11, the Geo-Cleanse® process, a patented in situ chemical oxidation technology using Fenton's reagent, was used. The Fenton's reagent consisted of hydrogen peroxide (50%) and an equivalent volume of ferrous iron catalyst that were injected into the subsurface under pressure. Fenton's reagent generates a strong hydroxyl free radical that oxidizes chlorinated organic contaminants to carbon dioxide, water, and chloride. Residual hydrogen peroxide decomposes to oxygen and water, and soluble ferrous ion catalyst amendments precipitate as ferric iron compounds. The Geo-Cleanse® injection process is designed so that the reaction with the site contaminants does not occur until the chemicals have reached the desired zone of treatment and the dispersion and diffusion of the reagent through the aquifer are maximized.

As shown in Figure 1, for Phase 1, there were 23 injectors (I-1 through I-23) installed in and around the area of concern, including deep (42 ft bgs) and shallow (32 ft bgs) injectors. During Phase 1, there were two injections of Fenton's reagent into the subsurface, totaling 12,045 gallons. From November 2-21, 1998, 8,257 gallons of solution were injected. From February 8-14, 1999 3,788 gallons of solution were injected. During Phase 2, the system was expanded to add 21 injectors (I-24 through I-44), including deep (40 ft bgs) and shallow (35 ft bgs) injectors there were two injections of Fenton's reagent into the subsurface, totaling 11,247 gallons. From June 3-11, 1999, 8,283 gallons of solution were injected. From July 12-15, 1999, 2,964 gallons of solution were injected.

Groundwater samples were collected from the monitoring wells, recovery wells, and injectors and analyzed for total CACs, including PCE, TCE, DCE, and VC. During the injections, groundwater quality parameters (pH, alkalinity, iron, chloride, and peroxide) were monitored. A photo-ionization detector (PID) was used for head space readings of groundwater samples to provide a semi-quantitative measure of CACs over time. Off gases from the monitoring wells and injectors were routinely monitored for carbon dioxide, oxygen, and VOCs.

Listed below are the key operating parameters at Site 11 that affected cost or performance and the values measured for each.

Operating Parameters [2,4]

Parameter	Value
pH:	4 to 6
Amount of Fenton's Reagent Injected:	11/98 - 12,045 gallons 2/99 - 3,788 gallons 6/99 - 8,283 gallons 7/99 - 2,964 gallons
Fenton's Reagent components:	50% Hydrogen Peroxide Ferrous Iron Catalyst
Number of Injectors	23 used for Phase 1 21 added for Phase 2 for a total of 44
Air injection rates	3 cfm per injector

Performance Information [2,4,6,7,8,9]

The cleanup goal for the RCRA corrective action at Site 11 was established by the state at 100 µg/L for total CACs. Total CACs were defined as the sum of PCE, TCE, cis-1,2 DCE, and VC concentrations in groundwater. The 100 µg/L value was derived using natural attenuation groundwater modeling. Table 1 presents a summary of the total CAC results for Phases 1 and 2, described below. Data are presented for samples collected from the monitoring and recovery wells and from the injectors, which were completed in the same manner as the monitoring wells.

Phase 1

The first injection was performed from November 2-21, 1998. Samples collected at the end of January 1999 (about two months after the injection) showed total CAC concentrations had been reduced to below the cleanup goal in five of the seven monitoring wells, including well KBA-11-34 located within the source area where concentrations had been reduced by >97% to 90 ug/L. However, total CAC concentrations remained above the cleanup goal in downgradient monitoring wells (426 ug/l in well KBA-11-36 and 152 ug/L in well KBA-11-13A). The downgradient recovery wells were not sampled in January. Seven of the injectors were sampled in January, with one (I-4 located near downgradient well KBA-11-36) showing total CAC concentrations of 265 ug/L, above the cleanup goal.

The second injection was performed from February 8-14, 1999. Samples collected in May 1999 (about three months after the injection) showed that total CACs had been reduced to below the cleanup goal in the two recovery wells (RW-7 and RW-8), but remained at or above the cleanup goal in the two downgradient wells (KBA-11-36 and KBA-11-13A). In addition, concentrations of total CACs in well KBA-11-31 (east of the area of concern) increased from levels below the cleanup goal to 204 ug/L. Of the 43 injectors sampled in May 1999, 15 showed total CAC concentrations above the cleanup goal, including nine injectors located downgradient of the area of concern where concentrations ranged from 113 (injector I-39) to 1,080 ug/L (injector I-40). As a result, a second phase of treatment was performed.

Phase 2

The first injection of Phase 2 was performed from June 3-11, 1999. Samples collected on June 21, 1999 showed total CAC concentrations below the cleanup goal in both recovery wells and in all but one monitoring well (downgradient well KBA-11-13A at 350 ug/L). In addition, total CAC concentrations were above the cleanup goal in two downgradient injectors (I-39 at 246 ug/L and I-41 at 357 ug/L). The second injection of Phase 2 was performed from July 12-15, 1999. Samples collected in August 1999 (about one month after the injection) showed total CAC concentrations remaining below the cleanup goal in all wells except for downgradient well KBA-11-13A (290 ug/L). The total CAC concentration was primarily DCE (240 ug/L).

In addition, total CAC concentrations were below the cleanup goal in all injectors sampled in August, with the exception of injector I-14 at 1,700 ug/L. As discussed above, the Navy has determined that there is a previously unknown source of contamination in this area and is addressing the cleanup of the area separate from the Site 11 area of concern. Data on this cleanup were not available at the time of this report.

Performance Data Quality [2]

The majority of the performance data were obtained by field analytical methods and portable instruments such as a PID. Confirmation samples were analyzed using standard laboratory analysis methods. Information on the specific quality assurance/quality control procedures used during this application were not provided in the references used for this report. However, no exceptions or issues with data quality were noted in the available references.

Table 1. Naval Submarine Base Kings Bay Geo-Cleanse® Treatment Results - Total CACs (μg/L) - [4,7]

Location	Prior to Treatment		Phase 1 Treatment							Phase 2 Treatment				
	9/17/98	10/30/98	Reagent Injection - Nov 2 - 21, 1998	11/24/98	12/22/98	1/27/99	Reagent Injection - Feb. 8-14, 1999	2/18/99	3/15/99	5/20/99	Reagent Injection - June 3-11, 1999	6/21/99	Reagent Injection - July 12-15, 1999	7/26/99	8/16/99
KBA-11-31	17	8		17	30	31		45	34	**204**		6		4	7
KBA-11-32	133	168		16	25	31		17	26	31		19		13	12
KBA-11-33	0	0		0	0	0		0	0	0		0		0	0
KBA-11-34	3,558	9,074		**219**	93	90		9	65	86		10		24	16
KBA-11-35	0	0		0	0	0		0	0	0		19		1	2
KBA-11-36	512	424		75	**416**	**426**		6	54	**100**		0		17	30
KBA-11-13A	262	156		**138**	**266**	**152**		**187**	**178**	**440**		**350**		**323**	**290**
RW-7	NS	946		**392**	NS	NS		**135**	86	83		13		13	18
RW-8	NS	150		**177**	NS	NS		**139**	NS	69		31		12	6
I-1	NS	9		NS	0	NS		NS	0	0		4		NS	
I-2	NS	NS		NS	**299**	8		53	**233**	35		17		2	15
I-3	NS	NS		NS	1	NS		NS	58	NS		NS		8	22
I-4	NS	NS		**333**	**931**	**265**		99	90	19		33		16	30
I-5	NS	NS		NS	NS	NS		1	0	0		3		NS	NS
I-6	NS	NS		NS	NS	NS		2	2	0		0		NS	NS
I-7	NS	NS		NS	NS	NS		**213**	87	**245**		13		16	17
I-8	NS	NS		NS	29	NS		NS	7	10		5		NS	NS
I-9	NS	NS		NS	48	14		NS	23	20		75		NS	NS
I-10	NS	NS		NS	35	29		NS	23	25		0		NS	NS
I-11	NS	NS		NS	71	NS		29	10	4		9		8	5
I-12	NS	NS		37	78	45		25	44	27		22		8	13

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I-13	NS	NS		NS	35	14		79	18	8		8		NS	NS
I-14	NS	NS		NS	NS	NS		NS	**3,800**	**5,885**		62		**136**	**1,700**
I-15	NS	NS		NS	NS	NS		NS	0	0		0		NS	NS
I-16	NS	0		NS	71	33		NS	**140**	17		**212**		0	56
I-17	NS	NS		NS	0	NS		NS	4	23		51		NS	NS
I-18	NS	NS		NS	16	NS		NS	99	**187**		0		15	31
I-19	NS	NS		NS	**100**	NS		112	11	41		18		3	10
I-20	NS	NS		NS	NS	NS		NS	0	4		6		NS	NS
I-21	NS	NS		NS	NS	NS		NS	**223**	**121**		**116**		**100**	14
I-22	NS	NS		NS	NS	NS		NS	72	74		5		NS	NS
I-23	NS	NS		NS	NS	NS		NS	18	37		50		NS	NS
I-24	NS	NS		NS	NS	NS		NS	NS	49		13		NS	NS
I-25	NS	NS		NS	NS	NS		NS	NS	**434**		9		0	1
I-26	NS	NS		NS	NS	NS		NS	NS	562		73		12	18
I-27	NS	NS		NS	NS	NS		NS	NS	**1,622**		29		4	34
I-28	NS	NS		NS	NS	NS		NS	NS	88		5		14	26
I-29	NS	NS		NS	NS	NS		NS	NS	**158**		12		33	41

Table 1. Naval Submarine Base Kings Bay Geo-Cleanse® Treatment Results - Total CACs (μg/L) - [4,7]

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	9/17/98	10/30/98	Reagent Injection - Nov 2 - 21, 1998	11/24/98	12/22/98	1/27/99	Reagent Injection - Feb. 8-14, 1999	2/18/99	3/15/99	5/20/99	Reagent Injection - June 3-11, 1999	6/21/99	Reagent Injection - July 12-15, 1999	7/26/99	8/16/99
I-30	NS	NS		NS	NS	NS		NS	NS	**268**		17		6	17
I-31	NS	NS		NS	NS	NS		NS	NS	16		28		NS	NS
I-32	NS	NS		NS	NS	NS		NS	NS	0		11		NS	NS
I-33	NS	NS		NS	NS	NS		NS	NS	0		21		NS	NS
I-34	NS	NS		NS	NS	NS		NS	NS	9		13		NS	NS
I-35	NS	NS		NS	NS	NS		NS	NS	**233**		0		7	13
I-36	NS	NS		NS	NS	NS		NS	NS	51		27		NS	NS
I-37	NS	NS		NS	NS	NS		NS	NS	**188**		46		17	18
I-38	NS	NS		NS	NS	NS		NS	NS	74		32		13	18
I-39	NS	NS		NS	NS	NS		NS	NS	**113**		**246**		5	6
I-40	NS	NS		NS	NS	NS		NS	NS	**1,080**		37		23	66
I-41	NS	NS		NS	NS	NS		NS	NS	**636**		**357**		38	50
I-42	NS	NS		NS	NS	NS		NS	NS	35		36		NS	NS
I-43	NS	NS		NS	NS	NS		NS	NS	**409**		30		8	5
I-44	NS	NS		NS	NS	NS		NS	NS	**137**		33		27	19

(1) Total = Total chlorinated aliphatic compounds (CACs) - PCE, TCE, DCE, and VC
NS = Not Sampled
Bold - above cleanup goal

Cost Information [1,4]

Bechtel served as the Navy's prime contractor for the remediation of Site 11. Bechtel contracted with Geo-Cleanse, the technology vendor, to perform the application of the Geo-Cleanse® process at the site.

According to Geo-Cleanse, the proposed total cost for Phase 1 of the application of the Geo-Cleanse® process at NSB Kings Bay was approximately $223,000, which included costs for reagents, mobilization, onsite treatment time, injection and monitoring equipment, documentation, and injector construction oversight and materials. The cost provided by Geo-Cleanse did not include costs for drilling, water and power supplies, oversight, and analytical laboratory services, or other costs incurred by the prime contractor, Bechtel. Actual costs were not reported. In addition, no cost data were provided for Phase 2 or for project costs other than those provided by Geo-Cleanse.

Observations and Lessons Learned [1,2,10]

After two phases of treatment using the Geo-Cleanse® process, total CAC concentrations had been reduced to below the cleanup goal of 100 ug/L in all but one well located downgradient of the area of concern. The total CAC concentrations in this well were primarily DCE. The first phase of treatment (two injections) reduced total CAC concentrations to below the cleanup goal in five of the seven monitoring wells, including a reduction of >97% in the well located within the source area.

In August 1999, elevated concentrations of total CACs concentrations were found in injector I-14 (to the east of the area of concern), indicating the presence of an additional contamination source area in the shallow soil. The soil in this area has been excavated and the Navy is planning to use chemical oxidation to polish the groundwater in this area.

On March 23, 1999, NSB Kings Bay received a letter from the Georgia Department of Natural Resources indicating that the data provided by the Navy supported the Navy's contention that the Interim Measures at Site 11 were reducing the contamination at the site. The letter also stated that NSB Kings Bay had adequately responded to all of the conditions of the March 18, 1994 Consent Order.

In June, 1999 NSB Kings Bay received the Georgia Chamber of Commerce Award for Environmental Excellence. The project's success was attributed, in part, to the exchange of technology and ideas between government agencies (DOE and DoD).

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6. E-mail from Clifton Casey, Southern Division, NAVFAC to Richard Weisman, Tetra Tech EM Inc., Comments on Kings Bay Draft Report. September 29, 1999.

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8. Telephone Conversation. Mark Gage, Bechtel, with Richard Weisman, Tetra Tech EM Inc., Kings Bay Response to Additional Questions. October 19, 1999.

9. Telephone Conversation. Dan Bryant, Geo-Cleanse, with Richard Weisman, Tetra Tech EM Inc., Kings Bay Response to Additional Questions. September 2, 1999.

10. E-mail from Billy Hendricks, State of Georgia Environmental Protection Division, to Richard Weisman, Tetra Tech EM Inc., Comments on Kings Bay Draft Report. October 5, 1999.

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