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FINAL DESKTOP SUDIT TECHNICAL MEMORANDUM SUMMARY OF PERCHLORATE SITE 67 WITH TRANSMITTAL NSWC INDIAN HEAD MD
3/25/2011
TETRA TECH NUS

3003

TETRA TECH

March 25, 2011

NOR-01037
Project Number 2622

NAVFAC Washington
Attn: Mr. Joe Rail, P.E. (Code OPB1E)
Washington Navy Yard, Building 212
1314 Harwood Street, SE
Washington, DC 20374-5018

Ref: CLEAN Contract No. N62470-08-D-1001
Contract Task Order JU11

Subject: Final Desktop Audit Technical Memorandum
Summary of Perchlorate at Site 67 – Hog-Out Facility
Naval Support Facility Indian Head, Indian Head, Maryland

Dear Mr. Rail:

Tetra Tech is pleased to submit two copies of the desktop audit technical memorandum entitled *Summary of Perchlorate at Site 67 – Hog-Out Facility* (enclosed). An electronic version (PDF) is provided on CD with each hard copy. All Team comments on the draft version were incorporated into this final version.

Additional copies were distributed as shown below. Please contact me at 757-466-4908 or ed.corack@tetratech.com if you have any questions or need additional copies.

Respectfully,

Tetra Tech

Ed Corack, P.E.
Project Manager

Enclosures

c: Mr. Nicholas Carros, NAVFAC Washington, NSF-IH (2 copies)
Mr. Dennis Orenshaw, EPA Region 3 (2 copies)
Mr. Curtis DeTore, MDE (2 copies)
Mr. John Trepanowski, Tetra Tech (cover letter only)
Mr. Garth Glenn, Tetra Tech (cover letter only)
Mr. Scott Nesbit, Tetra Tech (1 PDF CD only)
Admin Record – Mr. Glenn Wagner, Tetra Tech (1 copy)
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TETRA TECH

TECHNICAL MEMORANDUM

DATE: March 25, 2011

TO: Indian Head Installation Restoration Team

FROM: Tetra Tech NUS, Inc.

SUBJECT: **Final Desktop Audit**
Summary of Perchlorate at Site 67 – Hog-Out Facility
Naval Support Facility Indian Head (NSF-IH), Indian Head, MD
CLEAN Contract No. N62470-08-D-1001, Contract Task Order JU11

INTRODUCTION

This technical memorandum (tech memo) summarizes the following activities and documents for Site 67 – Hot-Out Facility at NSF-IH in Indian Head, MD. The tech memo also serves to provide general information and discussion on perchlorate contamination and the site, and suggest a path forward.

- **Activity: 2002 Pilot Test.**
  Document: Naval Ordnance Safety and Security Activity (NOSSA) (2004) *Field Demonstration of In Situ Perchlorate Bioremediation at Building 1419.*

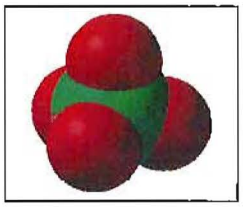
- **Activity: 2006 Technology Demonstration Plan.**
  Document: Environmental Security Technology Certification Program (ESTCP) (2006a) *Evaluation of Potential for Monitored Natural Attenuation of Perchlorate in Groundwater: Technology Demonstration Plan for Building 1419 Site, Naval Surface Warfare Center, Indian Head, MD.*

- **Activity: 2008 Perchlorate Attenuation Guidance.**
  Document: ESTCP (2008) *Natural Attenuation of Perchlorate in Groundwater: Processes, Tools, and Monitoring Techniques.*

SITE 67 – HOG-OUT FACILITY

Site 67 – Hog-Out Facility is located on the southeast side of NSF-IH bordering Mattawoman Creek (**Figure 1**). The site is described as perchlorate-contaminated groundwater resulting from historical site practices at Building 1419 (**Figure 2**), which consisted of cleaning out (hogging out) solid propellant from various devices, including rockets and ejection seat motors (Tetra Tech, 2009). The 2-acre grassy site contains a small drum storage building. Direct dumping of the hog-out wastewater occurred from the 1960s to the mid-1990s (Tetra Tech, 2009). Wastewaters at the site now are drummed and disposed appropriately (NSF-IH, 2006).

PERCHLORATE



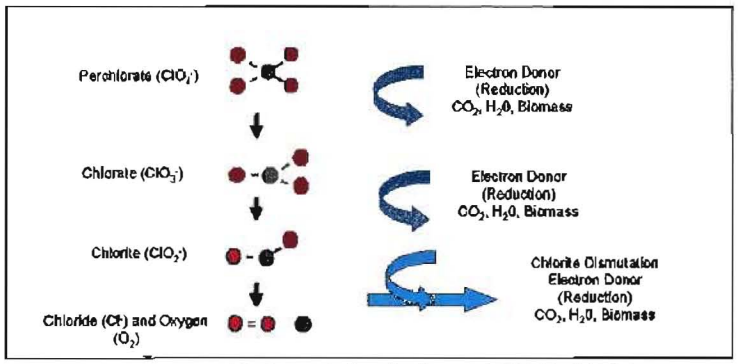
Perchlorate Anion (ITRC, 2005)

Perchlorate (ClO_4^-) is composed of a chloride atom bonded to four oxygen atoms. Perchlorate is usually found as the anion component of a salt and is released when the solid salts of ammonium (NH_4ClO_4), sodium ($NaClO_4$), or potassium perchlorate ($KClO_4$) and perchloric acid ($HClO_4$) dissolve in water (ESTCP, 2008; Motzer, 2001). Perchlorate has been manufactured since the 1890s and is most commonly found as a manufactured compound (ITRC [Interstate Technology and Regulatory Council], 2005). Ammonium perchlorate is used as an oxidizing agent for solid propellant rockets and missiles. Other common uses for perchlorate are shown below (ITRC, 2005). Considering these uses, other contaminants typically are found with perchlorate such as volatile organic compounds (VOCs), halogenated solvents, explosive compounds (e.g., trinitrotoluene [TNT]; hexahydro-1,3,5-trinitro-1,3,5-trizine [RDX]; and octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine [HMX]), nitrate, and sulfate (ESTCP, 2008; ITRC, 2002). Other contaminants may originate from specific types of rocket motors (e.g., polycyclic aromatic hydrocarbons [PAHs] from jet-assisted takeoff [JATO] motors) (Maryland Department of Environment [MDE], 2010).

Chemical and Electrical Uses	Explosive and Propellant Uses	Miscellaneous Uses
cathodic protection systems	military devices	steel plate bonding
brine separation	geoseismic devices	Li-ion batteries
chlorate/chlorite	chemical cutter	enamel paints
manufacturing	ordnance	fertilizer
cloud seeding	tracer bullets	laundry bleach
dielectric for transformers	solid rocket motor	pharmaceutical
electroplating	rocket motor	diagnosis/treatment
	airbags	pool sanitizer
	ejection seats	
	fireworks	

Perchlorate contamination in soil and groundwater primarily results from the production of the compound for aerospace and military applications, the testing of rockets and munitions, and the periodic removal and replacement of solid fuels in rockets (Strategic Environmental Research and Development Program [SERDP], 2002). The removal and replacement procedure, referred to as hog-out, is required periodically because solid perchlorate fuels have a limited usable life. Solid propellant is initially washed from the casing using high-pressure water, then the solid fuel is replaced or the casing is discarded. The improper disposal of this wastewater, which contains high concentrations of perchlorate and other salts, as well as the disposal techniques traditionally used during manufacturing and testing results in substantial perchlorate contamination (SERDP, 2002). Perchlorate salts are highly soluble in water, dissociating completely to perchlorate anions that are nonvolatile, highly mobile, and chemically stable in aqueous systems (groundwater and surface water) under normal conditions. However, "solid perchlorate salts like ammonium perchlorate and highly concentrated solutions of perchlorate, known as brine, can behave similarly to dense non-aqueous phase liquid (DNAPL) when released into an aquifer system. As such, the perchlorate tends to sink through the water column until the mass reaches a low permeability confining layer (Motzer, 2001) where it persists causing secondary or recurring perchlorate contamination (ITRC, 2002) (ESTCP, 2008)."

Perchlorate biodegradation occurs in a somewhat similar manner as reductive dechlorination,[1] but through a different metabolic mechanism. Indigenous chlorate-reducing bacteria and associated enzymes in the aquifer utilize a substrate (electron donor) under favorable anaerobic conditions to convert perchlorate to chlorate, chlorite, and finally chloride (SERDP, 2002; ESTCP, 2006b and 2006c).[2] From ESTCP (2006a):



Perchlorate Biodegradation Pathway (ESTCP, 2006a)

> Work by Coates et al. (1999), Chaudhuri et al. (2002), and Bender et al. (2002) indicates that the *Dechloromonas sp.* and *Dechlorosoma sp.* represent the primary chlorate- and perchlorate-reducing bacteria in the environment, but more than 30 different strains of perchlorate-reducing microbes have been identified (EPA, 2005). The rate-limiting step in the three-step degradation process is the conversion of perchlorate to chlorate by a perchlorate reductase enzyme. Subsequent conversion of chlorate to chlorite is also catalyzed by a perchlorate reductase enzyme. Chlorite removal by the chlorite dismutase enzyme is the final step in perchlorate reduction.

Perchlorate respiration also is similar to denitrification, where bacteria utilize a substrate and reduce nitrate as the terminal electron acceptor to nitrogen gas (SERDP, 2002). The other natural attenuation mechanisms (advection, dispersion, diffusion, and sorption) also affect (i.e., decrease) perchlorate concentrations.

2002 PILOT TEST

The perchlorate biodegradation field demonstration (pilot test) methodology and results are presented in the NOSSA (2004) document. A brief summary of the previous SERDP-funded field and lab work in 2000 is introduced prior to the pilot study presentation.

2000 SERDP Study

The "2000 SERDP Study" included collecting sediments and groundwater from perchlorate-contaminated aquifers at multiple facilities, including NSF-IH (samples were collected from Building 1190 and Building 1419 [Site 67]) (SERDP, 2002; NOSSA, 2004). The objective of the study was to "develop a biological treatment technology for in situ remediation of perchlorate in subsurface environments." Four key factors were hypothesized to contribute to the persistence of perchlorate at various sites:

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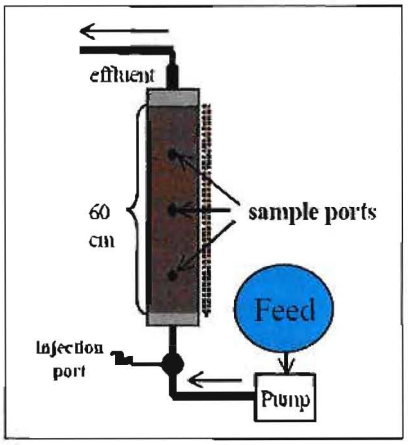
[1] The primary pathway for biodegradation of chlorinated volatile organic compounds (VOCs) occurs under anaerobic conditions via reductive dechlorination. During this biotic process, the chlorinated VOCs are used as an electron acceptor by dechlorinating / dehalogenating bacteria in the presence of a carbon source (electron donor), and a chlorine atom is removed and replaced with a hydrogen atom (EPA, September 1998). If the bacteria are able to obtain metabolically useful energy from reductive dechlorination, the process is also referred to as halorespiration (ESTCP, 2006c).

[2] Perchlorate biodegradation can occur under strict anaerobic conditions as well as facultative anaerobic conditions (ESTCP, 2006a and 2006b). Facultative anaerobic microorganisms are capable of both aerobic respiration under low oxygen tension and fermentation when anaerobic conditions prevail. This metabolic versatility suggests a variety of indigenous perchlorate-reducing microbial populations exist.

- Absence of an appropriate substrate (electron donor) for growth of indigenous perchlorate-degrading bacteria.
- Presence of alternative electron acceptors for bacterial respiration, including oxygen, nitrate, and nitrite in groundwater.
- Lack of an indigenous population of bacteria capable of perchlorate reduction.
- Unfavorable environmental conditions for activity of indigenous perchlorate degraders.



Aquifer Microcosm (SERDP, 2002)

The mixed sediment and groundwater aquifer samples were subjected to microcosm studies. No perchlorate was detected in the Building 1190 samples (so perchlorate was added to these samples for the studies), whereas perchlorate was detected at 45 milligrams per liter (mg/L) (or 45,000 micrograms per liter [µg/L]) in the homogenized samples from Building 1419. Various electron donors were tested for efficacy: methanol, ethanol, acetate, benzoate, lactate, sucrose, molasses, ethanol with yeast extract, hydrogen gas, and propane. A specific enrichment culture (bacteria), *Dechlorospirillum sp.*,[3] was also inoculated into one sample. All samples were incubated at 15 degrees Celsius (°C) and analyzed at 11, 20, 36, and 71 days for perchlorate via U.S. Environmental Protection Agency (EPA) Method 314.0. The tests showed perchlorate degradation in the Building 1090 samples, but not in the Building 1419 samples, despite confirming the presence of active indigenous cultures (and one sample was inoculated with *Dechlorospirillum sp.*). It was observed that the pH of the samples from Building 1190 was at 7, while the pH of the samples from Building 1419 was at 4.3.

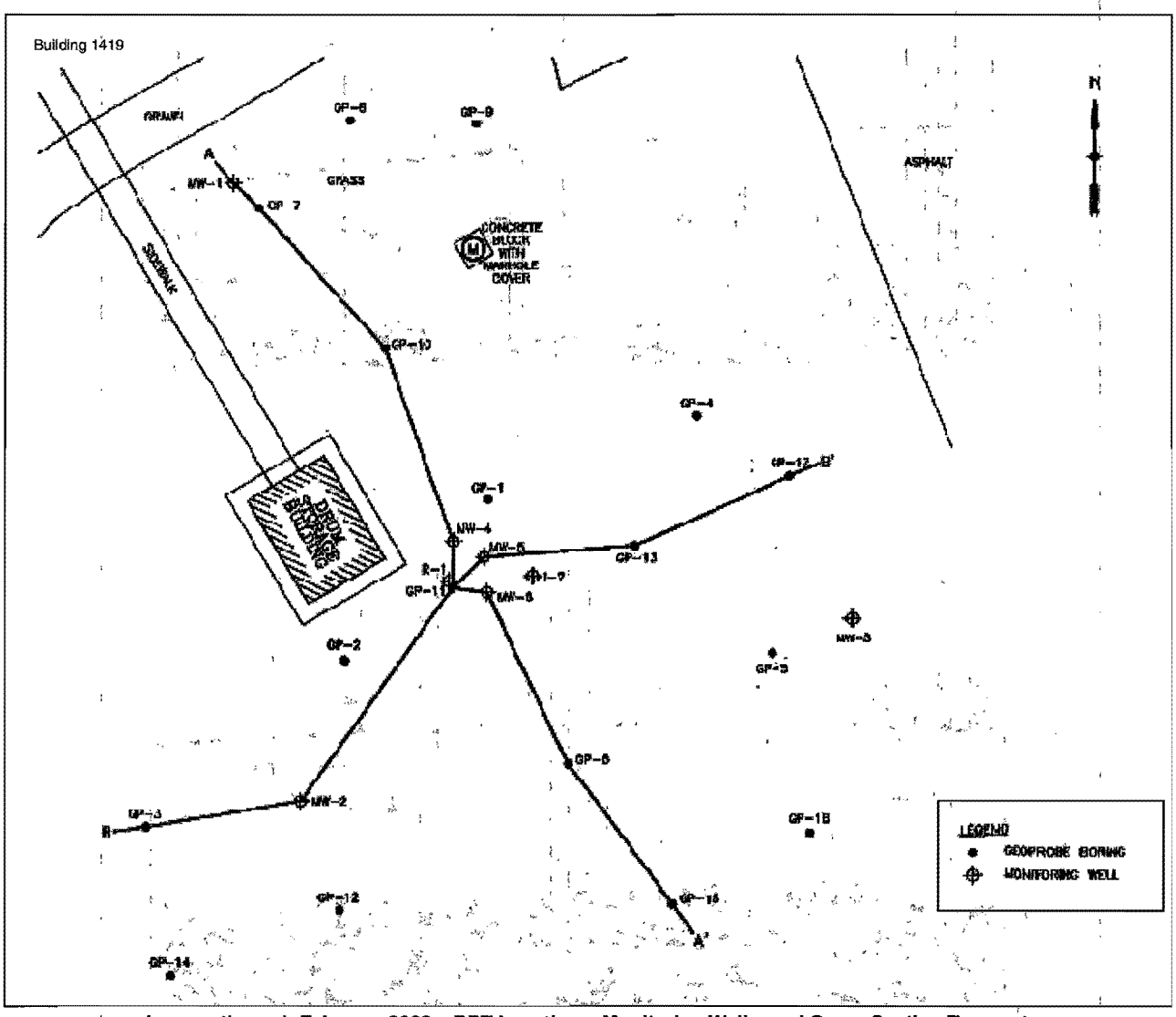
The study concluded that there may be a pH below which perchlorate biodegradation is physiologically inhibited, or that some other geochemical factor (e.g., heavy metal toxicity or trace metal unavailability) prevents perchlorate biodegradation at low pH. Once the Building 1419 samples were buffered in follow up tests (pH was increased to 7), perchlorate degradation was observed. The overall results from the 2000 SERDP Study revealed the following:

1. Perchlorate-degrading bacteria are widely distributed in groundwater aquifers.
2. These organisms can be stimulated to biodegrade perchlorate under anoxic conditions using a variety of different electron donors, although the most effective donors vary on a site-specific basis.
3. Perchlorate biodegradation is inhibited in aquifers where the pH is naturally below approximately 5.5. However, the indigenous bacteria exist / can survive at the lower pH (prior to stimulation and pH adjustment).

[3] This culture was isolated from a perchlorate fluidized bed treatment system in use in California at the time.

2002 NOSSA PILOT TEST

Based on the success of the 2000 SERDP Study, the NOSSA field-pilot demonstration proceeded at Site 67 to evaluate the potential for in situ treatment of perchlorate in the shallow aquifer. Seventeen Geoprobe® (i.e., direct push technology [DPT]) borings were installed in January 2002 to collect soil lithology and groundwater samples approximately 300 feet (ft) upgradient of Mattawoman Creek. After logging the soil, temporary wells were installed to collect groundwater samples. Six larger soil borings also were installed in January through February 2002 to accommodate six new permanent groundwater monitoring wells (locations were based on the perchlorate results from the DPT samples).



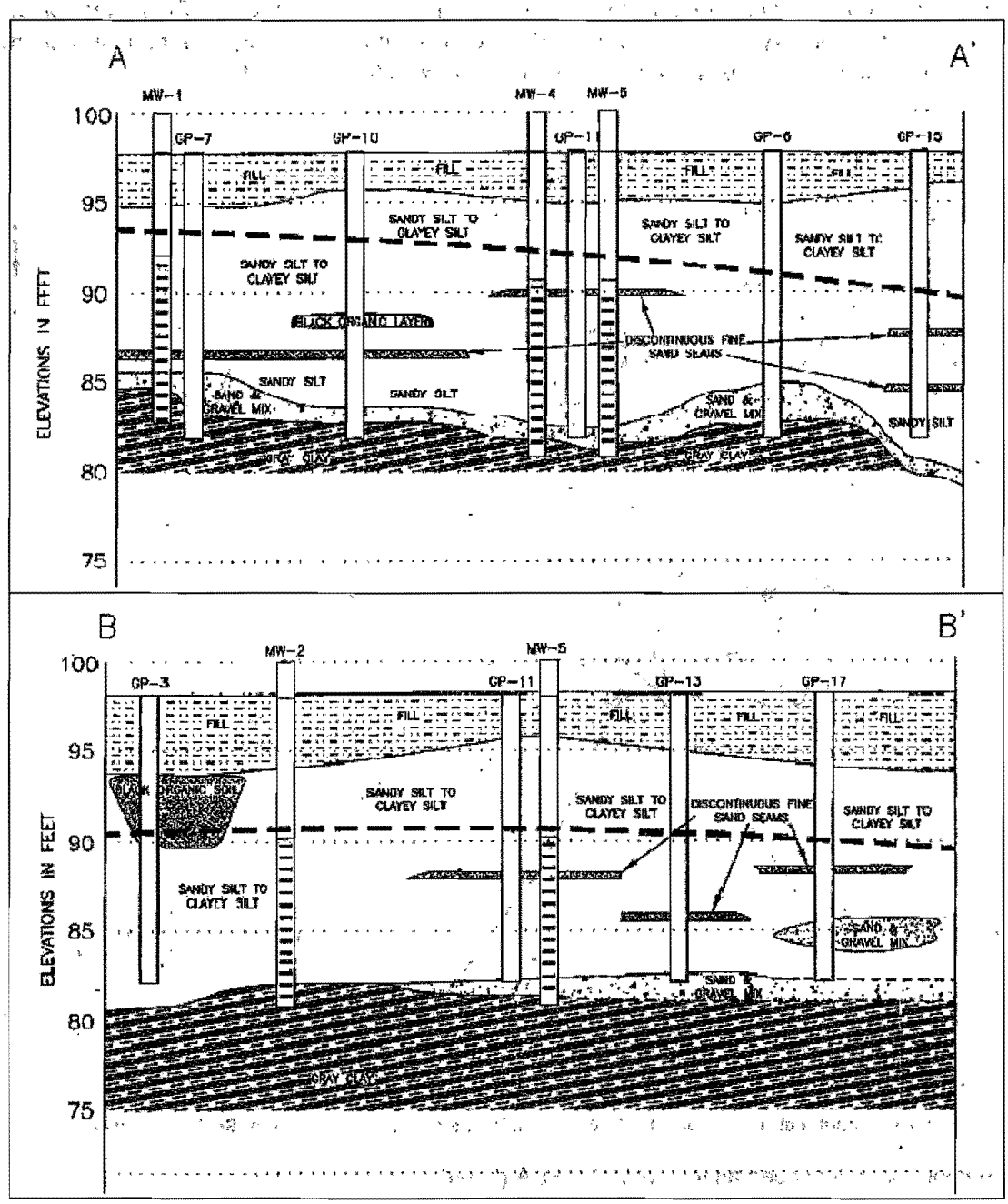
January through February 2002 – DPT Locations, Monitoring Wells, and Cross-Section Transects

The site geology was described as follows in NOSSA (2004):

> The top 2 to 4 ft of soil consisted of fill material including organic material, gravel, and silty sand. The underlying 11 to 13 ft consisted of mottled light to olive brown clay to sandy silts. The clay and sand fraction of the silts varied horizontally and vertically. Fine grained sand seams 1 to 2 inches in thickness were seen in many of the boring locations, but these seams were not continuous from boring to boring. At a depth of approximately

15 ft below ground surface (bgs), a 1- to 1.5-ft-thick layer of sand and gravel was encountered. This layer was found to be continuous throughout the area near the test plot. The sand and gravel layer is underlain by a gray clay layer, which extends to a depth of at least 20 ft bgs, the deepest extent of the [DPT and monitoring well] borings.

Interpretive cross-sections A-A' and B-B' are provided below from NOSSA (2004).



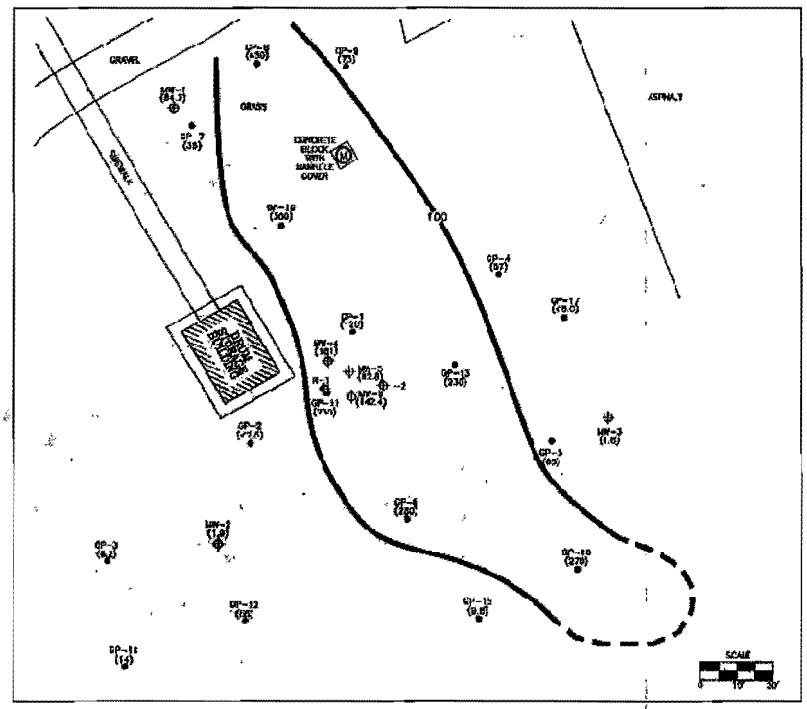
Water level gauging was performed to determine water table conditions and surficial aquifer groundwater flow at the site. Groundwater flow generally followed topography southeast toward Mattawoman Creek, with an average hydraulic gradient of 0.023. Depth to the water table ranged from 6.5 to 10.3 ft bgs. Slug tests were performed on three monitoring wells nearest the planned test plot area. Using the Bower-

Rice unconfined aquifer method, the average hydraulic conductivity (K) was determined to be 0.012 ft per minute.

A varying step pump test was performed for 12 hours with sustained pumping rates of 0.15 to 0.2 gallons per minute (gpm). Based on the data, K estimates ranged from 0.011 to 0.044 ft per minute. Using a hydraulic conductivity of 0.02 ft per minute and an assumed effective porosity of 25 percent, the estimated groundwater velocity at the site is calculated at 970 feet per year. The pump test was followed with an injection test, which showed the aquifer could receive 1.2 gpm at less than 3.5 pounds per square inch (psi) pressure.

The groundwater samples from each of the 17 DPT temporary wells were analyzed for perchlorate, nitrate, sulfate, pH, and dissolved oxygen (DO). Perchlorate concentrations ranged from less than (<) 2.5 (nondetect [ND]) to 430 mg/L, nitrate (as nitrogen) ranged from < 0.2 (ND) to 14 mg/L, sulfate ranged from 56 to 280 mg/L, pH ranged from 4.2 to 8.1, and DO ranged from < 0.2 (ND) to 1.5 mg/L. The highest perchlorate and nitrate concentrations occurred at GP-8, where no DO was detected and the pH was 4.6.

The groundwater samples from each of the six permanent monitoring wells were analyzed for perchlorate, pH, and DO. In the monitoring well groundwater samples, perchlorate ranged from 1.6 to 142 mg/L, pH ranged from 4.1 to 6.8, and DO ranged from 1.1 to 6.6. The highest perchlorate concentration occurred at monitoring well MW-6, where DO was 1.33 mg/L and pH was 5. The combined perchlorate results showed a shallow, narrow plume of perchlorate.

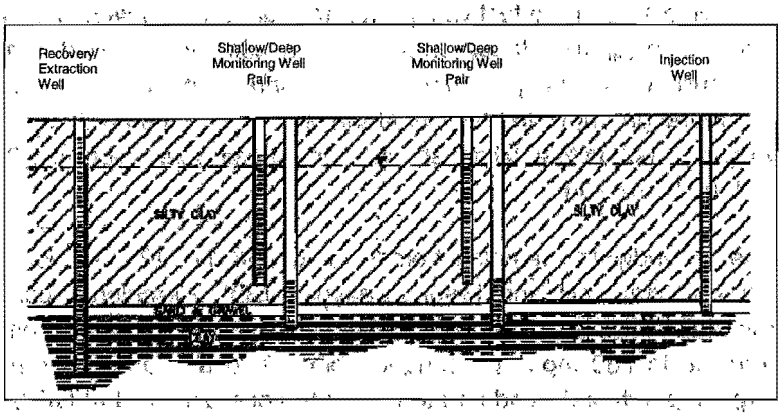


January through February 2002 Groundwater Perchlorate Distribution

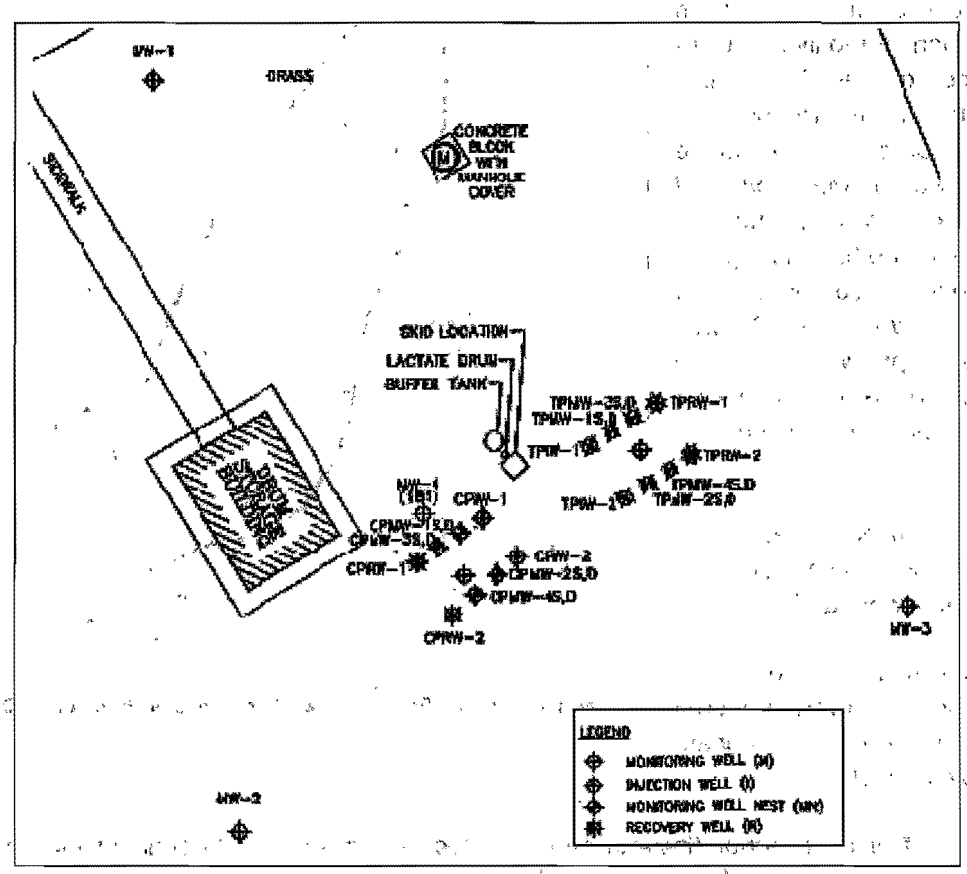
The results were used to design the field demonstration. The objectives of the demonstration were as follows:

1. Demonstrate that the aquifer can be effectively buffered using a mixture of carbonate and bicarbonate.
2. Show that electron donor (lactate) can be effectively distributed throughout the contaminated aquifer using a groundwater extraction-injection design.
3. Demonstrate that perchlorate and nitrate can be biodegraded in the buffered aquifer using lactate as an electron donor, with minimal reduction of sulfate.
4. Quantify the time required for perchlorate biodegradation and the levels of degradation achievable.

5. Identify key design and operational factors that influence full-scale application of in situ perchlorate bioremediation at this and other sites.



The test plot and control plot layouts of injection, extraction (for recirculation), and monitoring wells were initially determined using "a simple single-layer numeric model," which was calibrated with the pump test data. The final layout of each plot consisted of two injection wells and two extraction wells installed 12 ft apart in each of the plots, with two sets of shallow/deep monitoring wells installed between the injection and extraction wells. The plots were set up 20 ft away from each other. The injection wells were installed at the clay layer interface while the extraction wells were keyed 4 ft into the clay layer.



Test Plot (TP) and Control Plot (CP) Recirculation Cell Layouts

Prior to the full-scale demonstration, a tracer test using sodium bromide was used to confirm the hydraulic connectivity between the injection, extraction, and monitoring wells. The results confirmed connectivity between all wells in the test plot where the buffer and electron donor were added to the aquifer.

During the full-scale demonstration, test plot water was amended with electron donor and buffer periodically (approximately once per week) during the recirculation/reinjection process. Sixty percent (by

weight) of food-grade sodium lactate syrup (neutral pH) was added along with 6.7 percent food-grade sodium carbonate and/or sodium bicarbonate. The ratio of carbonate to bicarbonate varied throughout the test. The pH and alkalinity of the test plot water were monitored throughout the study. By the end of the test, a total of 58 kilograms (kg) of lactate (24 gallons of 60 percent lactate) was added to the aquifer in the test plot.

Over 20,000 gallons of groundwater were recirculated through each plot during the demonstration (140 to 180 gallons per day through each cell). Excessive rainfall during the test caused elevated water table conditions, which required an early system shut down at day 111 because the aquifer could not accept the injected/recirculated material. Despite the early shut down, samples were still collected at day 140 to complete the originally planned test duration.

Baseline groundwater samples were collected from the test plot and control plot monitoring wells at 10 weeks and 1 week prior to system startup. During system operation, samples were collected in the test plot at 2, 3, 7, 10, 15, and 20 weeks, and from the control plot at 2, 7, 15, and 20 weeks. Each sample was analyzed for pH and alkalinity, lactate, perchlorate, nitrate, and sulfate. Nitrate and sulfate levels were monitored because nitrate reduction occurs prior to perchlorate reduction and sulfate reduction occurs after perchlorate reduction. Thus, these parameters served as aquifer condition and reduction indicators.

The pH and alkalinity increased throughout the test duration in the test plot due to the buffer addition. There was no appreciable increase in these parameters in the control plot. Lactate samples in the test plot demonstrated effective distribution of the electron donor: The sample data showed initial increases in lactate concentrations followed by decreases as the aquifer biota consumed the lactate at increasing rates.

Perchlorate concentrations within the test plot showed a steady decline throughout the demonstration, decreasing by 95 percent to 99 percent in all but one well. The one well in question was thought to be affected by groundwater flow patterns from outside the test plot area. There was "no consistent reduction in perchlorate levels in any of the wells in the control plot during the demonstration period." Further:

> The data from the demonstration clearly show that the addition of buffer and electron donor to the test plot stimulated the microbial reduction of perchlorate in the aquifer. Losses of perchlorate to dilution or any other abiotic process would have been observed in both plots.

It was stated that this particular study was one of the first successful field demonstrations of in situ perchlorate bioremediation in a groundwater aquifer, the first conducted on the East Coast of the U.S., the first performed in an acidic aquifer, and the first to show perchlorate levels above 200 mg/L can be treated in situ. NOSSA (2004) concluded that the acidic aquifer was effectively buffered using both carbonate and bicarbonate, and that the recirculation cell design provided effective distribution of both buffer and electron donor. The data from the demonstration suggested that in situ bioremediation is "a viable option for perchlorate treatment in aquifers containing localized, high concentrations of the oxidant... [including] source areas from hog-out operations, demolition and open burn areas, and other regions where perchlorate or perchlorate-laden fuels are discharged.

2006 TECHNOLOGY DEMONSTRATION PLAN

The work plan and design for additional field studies and guidance development at Site 67 is presented in the ESTCP (2006) *Technology Demonstration Plan* prepared by Solutions-IES. Site 67 was selected

from among several candidate sites for the demonstration after three levels of site evaluation were conducted. The overall goals of the project were as follows:

1. Provide managers with the tools needed to evaluate whether monitored natural attenuation (MNA) may be appropriate for management of perchlorate releases on their site(s).

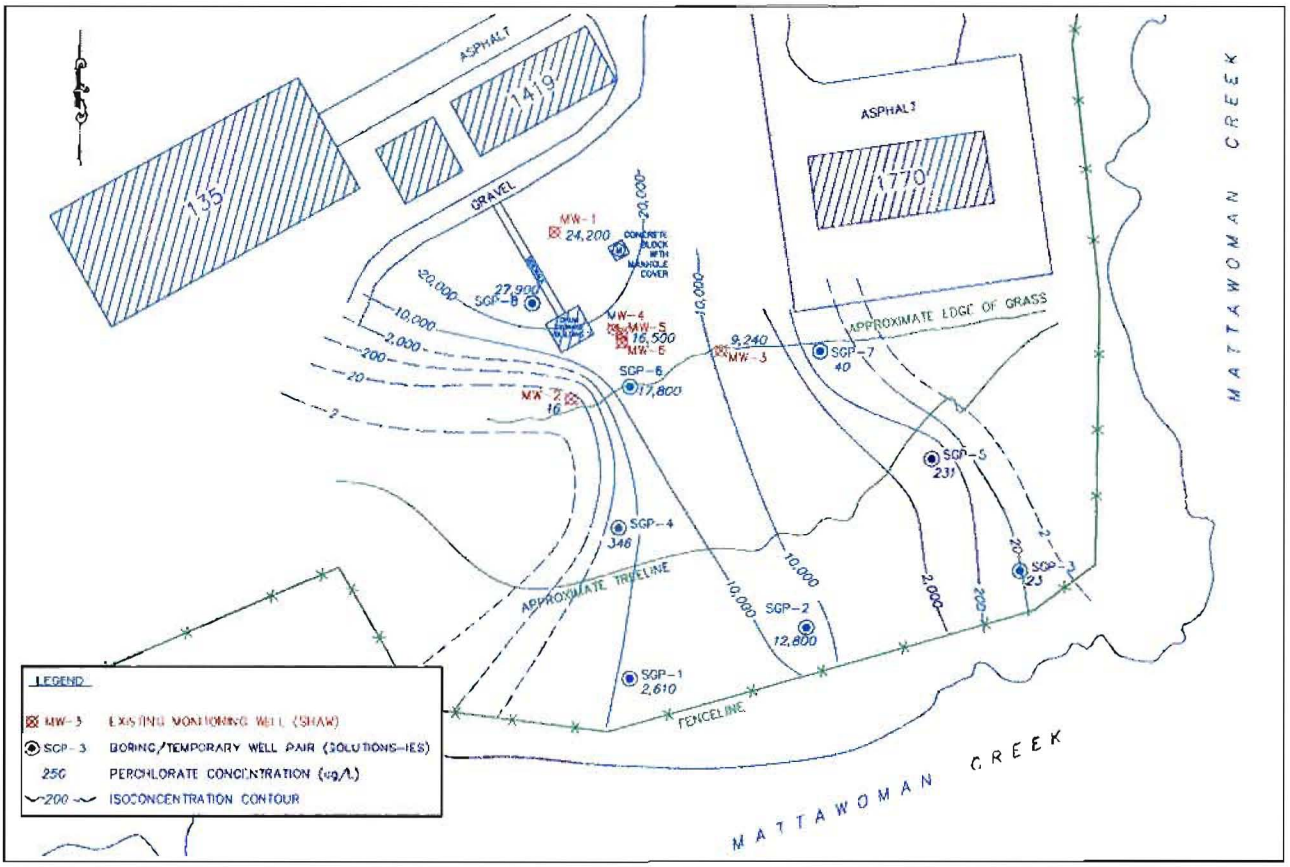
2. Demonstrate to regulatory agencies that perchlorate MNA is effective for controlling adverse impacts to the environment.

The project objectives were to evaluate MNA's efficacy at remediating perchlorate in groundwater, and to evaluate innovative tools to determine if biodegradation is occurring and at what rates. That is, to develop lines of evidence for MNA of perchlorate and to test these in the field to verify if they will be adequate for use in a protocol. The following lines of evidence were defined for evaluation:

- Using existing and new monitoring wells, determine the horizontal and vertical distribution of perchlorate and mass flux with distance.
- Observe changes in groundwater bio-geochemistry as supporting evidence for attenuation.
- Confirm and obtain additional microbiological evidence for the in situ activity of perchlorate-degrading organisms using an analysis for chlorite dismutase[4] and in situ biodegradation study results.
- Identify changes in isotopic composition of perchlorate as an indicator of biodegradation.

To support development of the Technology Demonstration Plan, ESTCP collected groundwater samples from existing monitoring wells at Site 67 in 2005, followed by the installation of seven new soil borings for lithology collection and groundwater sampling from temporary monitoring wells. Site lithology and groundwater flow was determined to be consistent with previous findings documented in NOSSA (2004). In addition, specific capacity tests were performed on two existing monitoring wells. Groundwater sample data did not clearly indicate a source area for the perchlorate release, but suggested that perchlorate was discharging to the mudflat adjoining Mattawoman Creek in excess of 10 mg/L (10,000 µg/L). The mudflat area, extending over 400 ft from the shoreline, submerged under 2 ft of water during high tide, and exposed during low tide, would be the focus of the biodegradation study.

[4] The specificity of chlorite dismutase could be useful as an indicator of perchlorate biodegradation and, therefore, provide supporting evidence for MNA of perchlorate.



2005 Perchlorate Isoconcentration Contour Map – Shallow Groundwater

The study would consist of installation of approximately eight new shallow/deep monitoring well pairs onsite, six new monitoring wells within the mudflat area, and a set of biocolumns (i.e., in situ columns to estimate the biodegradation rate as perchlorate migrates upward through the surficial mudflat sediments containing organic carbon) within the mudflat area. Specific capacity tests would be performed on all new wells to obtain additional hydraulic conductivity data.

Soil samples would be collected from all borings advanced in the mudflats to be tested for total organic carbon (TOC). Baseline and performance monitoring groundwater samples would be collected. All groundwater samples would be tested for perchlorate, TOC, chloride, nitrate, sulfate, and methane. A subset of the samples also would be tested for iron, manganese, ammonia, alkalinity, chlorite dismutase, and a specific chloride isotope ("$\delta^{37}Cl$").

2008 PERCHLORATE ATTENUATION GUIDANCE

Site 67 is presented as a case study in the ESTCP (2008) perchlorate attenuation guidance document prepared by Solutions-IES.

GUIDANCE/PROTOCOL

The document discusses background information on MNA, perchlorate, and tools and techniques for evaluating perchlorate attenuation (e.g., field and laboratory methods, geochemical and microbial indicators, etc.). The document points out that as of 2008 (Nzengung et al., 2008):

The biodegradation pathways are well understood and the microorganisms involved in perchlorate biodegradation are known, they can use a variety of different organic substrates as electron donors, are relatively ubiquitous in soil and groundwater environments, and function as strict or facultative anaerobes. This suggests that natural attenuation of perchlorate should occur at many sites (Cooley et al., 2005), and that MNA can be effective in managing the risks posed by perchlorate contamination of groundwater under favorable conditions.

A three-tier approach for the assessment of natural attenuation of perchlorate is defined as follows (similar to EPA [1999]):

- **Tier 1 – Spatial and temporal distribution of perchlorate** (plume stability and geometry, shrinking plume, and reduction in concentrations).
- **Tier 2 – Bio-geochemical conditions for perchlorate biodegradation** (indicator parameters to demonstrate favorable conditions—similar to evaluating favorable conditions for biodegradation of chlorinated VOCs—pH near neutrality; no or low DO; negative oxidation-reduction potential [ORP]; presence of available organic carbon [electron donor]; methane [reducing, methanogenic conditions]; nitrate [denitrification conditions]; iron [reducing environment], and increasing chloride).
- **Tier 3 – Microbiological indicators of perchlorate biodegradation** (similar to evaluating biodegradation of chlorinated VOCs, but different daughter products [chlorate, chlorite, and chloride], bacteria, and specific enzymes [perchlorate reductase and chlorite dismutase]).

SITE 67 CASE STUDY PRESENTATION

The case study for Site 67 is appended to the ESTCP (2008) guidance document. The case study reviews the 2005 pre-demonstration results and presents the subsequent sampling results and findings. The study confirmed general groundwater flow southeast through the site, and that groundwater flow direction offsite varies daily and seasonally according to tide levels in Mattawoman Creek. At high tide, water flows downward through the mudflat sediments into the aquifer, whereas at low tide, the groundwater flows up through the "organic rich sediments before discharging to the surface as a series of small springs and seeps."

Perchlorate concentrations were measured as high as 93 mg/L near Building 1419 and over 10 mg/L at the bank of the creek. However, concentrations decrease over 99 percent as groundwater migrates upward through the mudflat sediments. Bio-geochemical conditions showed conducive conditions for perchlorate biodegradation. Specifically, TOC and methane concentrations increase and ORP values decrease as groundwater migrates upward through the mudflat sediments.

Both macrocosm (in situ) and microcosm (laboratory) studies were performed. The macrocosm results showed 40 percent reduction in perchlorate in 2 weeks. The microcosm results showed perchlorate reduction to below detection limits in less than 2 months. First-order biodegradation rates were estimated at 24 to 61 per year. Enzyme analysis showed that chlorite dismutase gene was present in the mudflat sediments, indicating the capability of perchlorate biodegradation by indigenous microbial communities. Molecular analysis showed that perchlorate reductase genes were also present, which are involved in the degradation of perchlorate to chlorate and chlorite. "In general, higher numbers of gene copies were reported in locations with lower perchlorate concentrations, suggesting that perchlorate is biodegrading as a result of perchlorate reductase activity."

In summary, the results of the three-tier assessment for perchlorate attenuation at Site 67 were as follows:

- **Tier 1** – Perchlorate concentrations decrease with time and distance due to biodegradation, dilution, and dispersion.
- **Tier 2** – Most ideal geochemical conditions coincide with greatest perchlorate reduction.
- **Tier 3** – Greatest perchlorate reduction occurs where highest population of perchlorate-reducing bacteria indicators are measured.

Therefore, MNA likely is an acceptable final remedy for the site. However, additional sampling should be performed to create a more robust temporal dataset for Tiers 1 and 2. Further, additional sampling locations are necessary to fully delineate the perchlorate plume and define the source area.

PATH FORWARD FOR SITE 67

Based on the research, lab results, field results, conclusions, and guidance presented in NOSSA (2004) and ESTCP (2006a and 2008), it is expected that perchlorate concentrations at Site 67 will continue to decline via multiple natural attenuation mechanisms (e.g., biodegradation and dilution). However, groundwater concentrations of perchlorate may not reach an appropriate cleanup level[5] in a reasonable timeframe (not considering land use) via natural attenuation only.

While perchlorate contamination in the surficial aquifer is evident at the site, the soil medium and other potential contaminants in all media require investigation. Therefore, a Remedial Investigation (RI) is recommended by the Navy to completely characterize the site. A Feasibility Study (FS) likely will be required to evaluate remedial alternatives for site cleanup.

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[5] The cleanup level for perchlorate (and any other contaminants) will be developed in the Feasibility Study (FS). Note that the U.S. Environmental Protection Agency (EPA) issued an Interim Drinking Water Health Advisory of 15 µg/L for perchlorate in January 2009.

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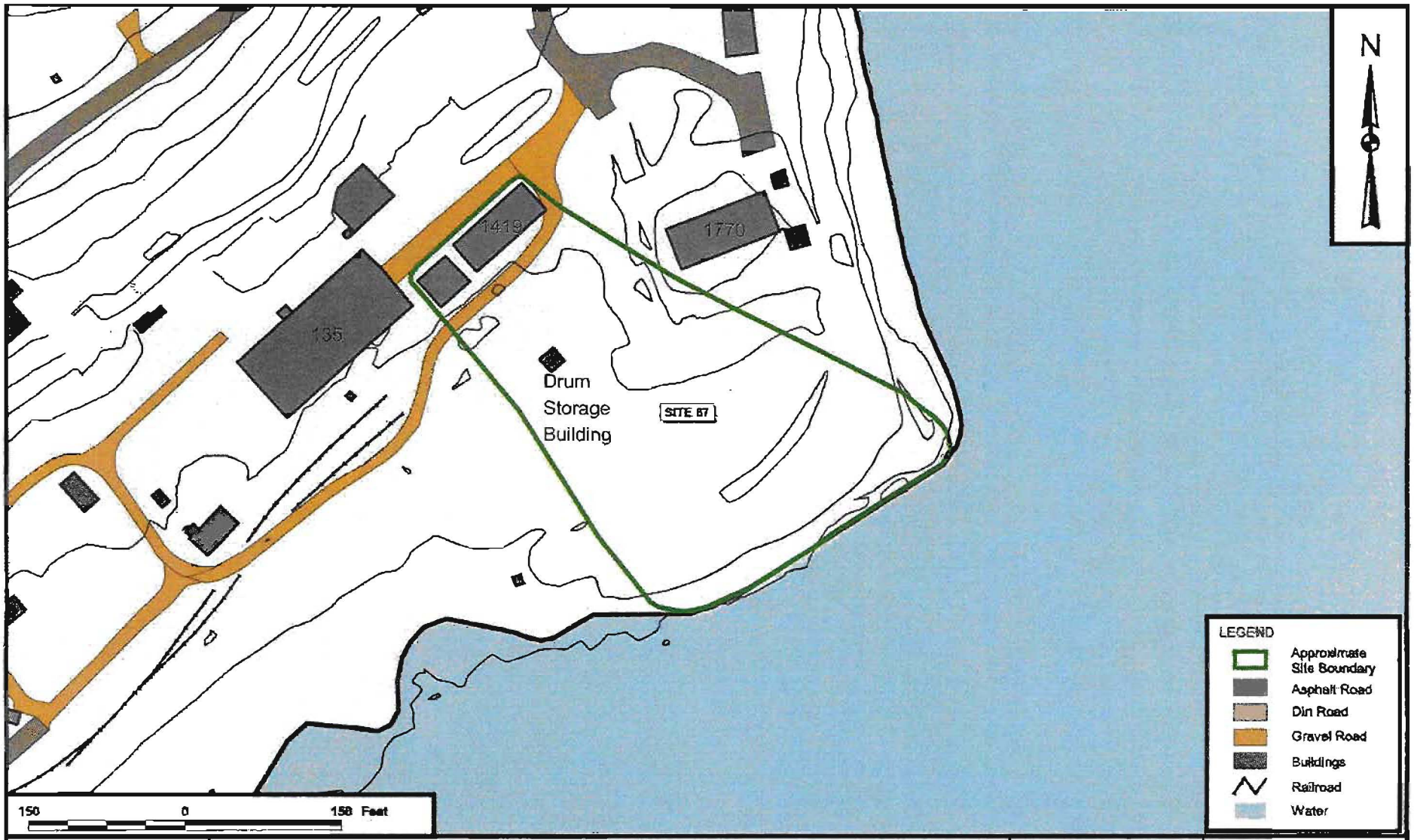
P:\GIS\INDIANHEAD_NSWC\APR\SITEMANAGEMENTPLAN.APR UPDATED CRP-SITE LOCATIONS-MAIN SITE LAYOUT 06/09/08 SS

DRAWN BY K. PIELA	DATE 7/26/02	Tetra Tech NUS, Inc.	CONTRACT NUMBER 2193 / OWNER NUMBER —
CHECKED BY K. TURNBULL	DATE 6/09/08	Site Location Map Naval Support Facility Indian Head - Main Area Indian Head, Maryland	APPROVED BY GJL / DATE 12/29/06
COST/SCHEDULE-AREA			APPROVED BY — / DATE —
SCALE AS NOTED			DRAWING NO. Figure 1 / REV 0



DRAWN BY K. PERLA	DATE 6/22/06	Tetra Tech NUS, Inc.	CONTRACT NUMBER 2193 / OWNER NUMBER —
CHECKED BY GJL	DATE 12/29/06	Site 67 - Hog-Out Facility Naval Support Facility Indian Head Indian Head, Maryland	APPROVED BY GJL / DATE 12/29/06
COST/SCHEDULE-AREA			APPROVED BY — / DATE —
SCALE AS NOTED			DRAWING NO. Figure 2 / REV 0

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