WHITE STREET LANDFILL

Phase II Assessment of Corrective Measures

Greensboro, North Carolina
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EXECUTIVE SUMMARY

The White Street Landfill of Greensboro North Carolina, contains three distinct phases, I, II, and III, which operated under Permit Nos. 41-03 (Phase I & II) and 41-12 (Phase III). Phase II of the landfill is an active construction, demolition, and debris landfill on top of a closed municipal solid waste (MSW) cell. The Phase II portion of the landfill was included under Permit No. 41-03. The Facility is located at the end of White Street in the City of Greensboro, North Carolina (reference **Figure 1**). The NCAC 2L Groundwater Quality Standards (2L standard) for several target constituents have been exceeded in Phase II of the facility near the north-northwestern property boundary. The nearest downgradient receptor north-northwest of the facility is Buffalo Creek.

A Nature and Extent Report has been completed by S&ME describing the nature of the primary constituents of concern within Phase II exceeding their respective 2L standards, where the exceedances occurred within the compliance network, and to what extent the 2L standards were exceeded. Several organic compounds including the volatile organic compounds: Methylene chloride, cis-1,2-dichloroethene, 2-butanone, benzene, 1,2-dichloroethane, trichloroethene, 1,2-dichloropropane, and vinyl chloride as well as the inorganic constituents: cadmium, chromium, nickel, thallium, and vanadium have exceeded the 2L standards and/or DENR Groundwater Protection Standards (GPS) within the White Street Landfill compliance monitoring well network. The results of the Nature and Extent Study indicated that organic constituents; tetrachloroethene, and vinyl chloride, as well as inorganic constituents; thallium and vanadium, exceeded the 2L standards and/or DENR GPS values within the Nature and Extent Study (NES) wells at the north-northwestern property boundary near Buffalo Creek.

Several potential solutions or corrective measures could be implemented to address the migration of groundwater contaminants beyond the compliance boundaries.

Techniques such as Air Stripping, Subterranean Physical Barriers, Bioremediation, Pump and Treat, Trash Removal/Excavation, and Natural Attenuation, could be considered as possible effective corrective measures. Of these potential measures, the Facility will choose the most feasible method which will achieve the combined goals of protection of human health and the environment with a reasonable allocation of City resources.

1.0 INTRODUCTION

1.1 Purpose

The purpose of an Assessment of Corrective Measures (ACM) is to document the potential corrective measure options and recommend, with public input, measures that are appropriate for the facility based on the magnitude of the constituents of concern. Constituents of concern have been identified through the White Street Landfill Facility Assessment Monitoring Program and the ongoing Alternate Source Determination and Nature and Extent Investigation awaiting approval by the NCDENR. As per 15A NCAC 13.B1635 of the North Carolina Department of Environment and Natural Resources, Division of Waste Management (NCDENR-DWM) whenever it is demonstrated that one or more constituents listed in Appendix II has been detected at a statistically significant level exceeding the 2L standards and/or DENR GPS, the owner or operator shall initiate assessment of corrective action measures (ACM). Under the Assessment Groundwater Monitoring Program, a statistically significant level is determined by a point comparison of the compliance data directly to the 2L standard or DENR GPS.

This Assessment of Corrective Measures has evaluated "The performance, reliability, ease of implementation, and potential impacts of appropriate potential remedies, including safety impacts, cross-media impacts, and control of exposure to any residual contamination; the time required to begin and complete the remedy; the costs of remedy implementation; and the institutional requirements such as State and Local permit requirements or other environmental or public health requirements that may substantially affect implementation of the remedy(s)," as per 15A NCAC 13.B1635 of the NCDENR DWM.

1.2 General

1.2.1 Location

The White Street Landfill is owned and operated by the City of Greensboro, North Carolina. The landfill is located at the north end of White Street in northeastern Greensboro. The White Street Landfill is accessed off of White Street and Phase II is regulated under Solid Waste Management Permit (SWMP) No# 41-03. Phase II of the Facility is bounded by rural properties and Rankin Mill Road to the east, Phase III areas to the south and Buffalo Creek to the north and west.

1.2.2 Physical Site Characteristics

The natural topography surrounding the waste management units at the Facility is best characterized as gradual to moderately sloping with small drains and small hollows truncating the slopes and feeding the unnamed tributaries of Buffalo Creek. Surface runoff in the undisturbed areas of the landfill will generally mimic the slope gradients and follow the drains and small hollows to the creek. Infiltration and percolation into the upper soil horizon is expected to be moderate due to the sandy loam content within this stratum. Percolation within the waste management units is expected to be light since the

landfill has been capped with a compacted low permeability clay layer. However, in areas where weathering and erosion have thinned or removed the upper soil horizon such that the lower soil horizon is exposed at the surface, vertical percolation rates may be higher as this soil horizon often has a greater sand and gravel content. The nearest surface water body to the waste management units is Buffalo Creek. The shortest distance between any of the waste management units and Buffalo Creek is between the stream and the northeast corner of the Phase II disposal area located adjacent to the stream at the northeast property boundary. This stream is also approximately 350 feet away from the northern edge of the waste management units of the landfill. This stream will be the primary receptor of all surface water runoff from the landfill.

Reference **Figure 1** for the White Street Landfill Overall Base Map. **Figure 2** depicts the locations of existing compliance and the NES monitoring wells for Phase II at the Facility.

2.0 NATURE AND EXTENT STUDY

2.1 Nature and Extent Summary

A Nature and Extent Report was submitted to the NC DENR in August of 2007 documenting the exceedance of the 2L standards and/or DENR GPS at Phase II of the White Street Landfill.

As a result of several network compliance monitoring wells exceeding the North Carolina established NCAC 2L groundwater standard and/or DENR GPS, Phase II of the White Street Landfill as defined under NC DENR Permit #41-03 has installed seven non-network shallow monitoring wells, with one deep monitor wells. The wells are designated II-2B, II-7B (deep monitor well), II-9, II-10, II-11, II-12, and II-13. The following is a summary of the parameters of concern detected in the Nature and Extent Study wells during this investigation:

- The results of the Nature and Extent Study sampling indicated that there are exceedances of tetrachloroethene, and vinyl chloride above the established NCAC 2L standard in NES well II-2B.
- Analytical results have detected 2-butanone, tetrachloroethene, and vanadium in NES well II-7B at concentrations which exceed the respective NCAC 2L groundwater standard and/or NC DENR GPS. However, the detected concentrations of vanadium have been demonstrated to be the result of naturally occurring vanadium in the in-situ soils which is influencing groundwater quality in the uppermost aquifer at the Facility.
- The only constituent detected in NES well II-9 at a concentration above the NCAC 2L standard is vinyl chloride.
- No constituents of concern have been detected in NES monitoring well II-10.

- The metal thallium was detected in the groundwater sample from NES well II-11 at a concentration which exceeds the recently established NC DENR GPS for thallium set at 0.28 μg/L. No other constituents of concern were detected above the method detection limit in NES well II-11.
- Thallium, exceeded the established NC DENR GPS in NES well II-12. There were no other constituents of concern detected above the NCAC 2L standard and/or DENR GPS in NES well II-12.
- There were no constituents of concern detected above the NCAC 2L standard in NES well II-13.

The nature of impact to the hydrogeologic regime at the White Street Landfill Facility is primarily from low level organic constituents. However, the metal thallium also exceeds the recently promulgated DENR GPS of 0.28 μg/L set by DENR for thallium. The concentrations of the organic constituents of concern observed in the NES wells during this study are close to their respective NCAC 2L standard.

The lateral extent of contaminant migration away from the landfill is defined by Buffalo Creek which truncates the primary component of groundwater flow in the uppermost prevalent aquifer along the northern Facility boundary. This creek also represents the primary receptor of impact from constituents migrating away from the landfill and is expected to be the primary local discharge point for the uppermost prevalent aquifer. The vertical extent of contaminant migration has been observed to be limited to a low level impact from tetrachloroethene at a concentration close to the NCAC 2L standard in NES well II-7B.

3.0 RISK ASSESSMENT

Methylene Chloride:

Methylene chloride exceeded the 2L standard for this constituent only once during the monitoring history of the White Street Landfill, in only one well. During the routine October 1998 groundwater monitoring event, methylene chloride was detected solely in compliance monitoring well II-7 at a reported concentration of 64 μg/L which exceeds the 2L standard of 5 μg/L for this constituent. Methylene chloride has not exceeded the 2L standard in any other groundwater samples from any other compliance or NES monitoring well since the October 1998 monitoring event.

Methylene chloride undergoes slow hydrolysis in water. The experimental half-life reported for the hydrolysis reaction, at neutral conditions, is approximately 18 months at 25 degrees Celsius (Dilling et al. 1975). Therefore, if a continual release of methylene chloride were occurring from the Phase II, methylene chloride would likely be continually detected in one or more groundwater monitoring wells in multiple groundwater monitoring events.

Since this constituent was only detected in one compliance well during one groundwater monitoring event, it is unlikely that the single detection of methylene chloride in compliance well II-7 represents a substantial release from the Phase II. Additionally, no 2B surface water standard has been established under the codes set forth in 15A NCAC 02B.0100, .0200, & .0300 for methylene chloride. Based on these finding's and the fact that there are no downgradient receptor wells prior to reaching the Buffalo creek, the level of risk posed to human health and aquatic life from the single detection of methylene chloride is expected to be low.

Cis-1,2-dichloroethene:

Cis-1,2-dichloroethene was also only detected in one groundwater monitoring well at concentrations which exceeded the 2L standard for this constituent, for the monitoring history of Phase II. During the January 5, 1996, September 25, 1996, and October 16, 1998 routine groundwater monitoring events, cis-1,2-dichloroethene was detected solely in compliance well II-7 at reported concentrations of 110 μg/L , 160 μg/L, and 200 μg/L respectively. Cis-1,2-dichloroethene has not been detected a concentrations exceeding the 2L standard since the October 1998 monitoring event in any compliance or NES monitoring well it should be noted that 1998 corresponds with the closing of Phase II to the receipt of MSW. Shortly there after the landfill was capped and methane gas recovered alliuites were initiated.

Cis-1,2-dichloroethene has been detected at low level concentrations sporadically in monitoring well II-7 and recently in compliance well II-2 but at levels significantly less than the 2L standard. Therefore it is plausible that a low level release of this constituent may have occurred. However, the release from the Facility appears to have been a slug type release based on the trend of decreasing concentrations of this constituent in groundwater samples from compliance well II-7 and the current downward trend in concentration of cis-1,2-dichloroethene in the vicinity of II-7 is expected to continue. The observed trend of decreasing concentrations is thought to be related to the 1998 capping of the MSW and subsequent activation of methane gas recovery. Both measures can be considered corrective measures.

The trend of a decreasing concentration of cis-1,2-dichloroethene in compliance well II-7, with the appearance and continual detection of this constituent in compliance well II-2 since the September 22, 2004, may also suggest that the contaminant plume in the vicinity of compliance well II-7 has migrated to the northeast within the hydrogeologic regime beneath Phase II. This is further supported by the appearance of low level concentrations of other constituents of concern in compliance well II-2 coupled with a decreasing trend of these constituents in compliance well II-7. Compliance well II-2 is hydrogeologically cross gradient from compliance well II-7.

1,2-dichloroethylene, is a highly flammable, colorless liquid with a sharp, harsh odor. It is used to produce solvents and in chemical mixtures.

Cis-1,2-Dichloroethene evaporates rapidly into air. In the air, it takes about 5-12 days for half of it to break down. Most cis-1,2-dichloroethene in the soil surface or bodies of water will evaporate into air. Cis-1,2-Dichloroethene can travel through soil or dissolve in water in the soil and therefore it can contaminate groundwater. In groundwater, it takes about 13-48 weeks to break down. There is a slight chance that cis-1,2-dichloroethene will break down into vinyl chloride, a different chemical which is believed to be more toxic than 1,2-dichloroethene. With the note worthy reduction in

concentrations of cis-1,2-dichloroethene in compliance well II-7, the only compliance well in which cis1,2-dichloroethene has exceeded the 2L standard in the history of monitoring groundwater quality at the White Street Landfill, it is reasonable to conclude that cis1,2-dichloroethene is not continually being released from the Facility. Furthermore, the original slug type release of this constituent is thought to be naturally remediated and may be breaking down into vinyl chloride which was recently detected in compliance well II-2.

No15A NCAC 2B surface water standard has been established for cis1,2-dichloroethene. Based on the data discussed above which appear to suggest that the release of cis1,2-dichloroethene was a slug type release and is not a continual release from the Facility, and given the low levels of this constituent detected since the October 1998 monitoring event within the uppermost pervasive monitored aquifer at the Facility, the risk to human health as well as the aquatic life in Buffalo Creek is expected to be low.

<u>2-Butanone:</u>

2-Butanone is a manufactured chemical but it is also present in the environment from natural sources. It is a colorless liquid with a sharp, sweet odor. It is also known as methyl ethyl ketone (MEK). 2-Butanone is produced in large quantities. Nearly half of its use is in paints and other coatings because it will quickly evaporate into the air and it dissolves many substances. It is also used in glues and as a cleaning agent. 2-Butanone occurs as a natural product. It is made by some trees and found in some fruits and vegetables in small amounts. It is also released to the air from car and truck exhausts.

2-Butanone was not one of the primary constituents of concern in that it was not detected in the compliance groundwater monitoring well network. Rather, the only occurrence of 2-Butanone in the monitoring history of the White Street Landfill occurred in NES monitoring well II-7B during the first monitoring event completed on this well following it's installation on September 13, 2001. The reported concentration of 2-Butanone during this sampling event, 680 μg/L, exceeded the 2L standard set for this compound at 170 μg/L. Since this constituent has not been detected occurred in any other groundwater sample from any other groundwater monitoring well in the monitoring history of the Facility, this result is suspected of being the result of laboratory and/or sampling error. This result may have occurred due to vehicle exhaust being present close to the sample containers. Even if this result is in fact valid, because it has not been detected in any compliance groundwater monitoring well and because it was a single detection, the risk

to human health or the environment from this detection of 2-butanone is believed to be low.

Benzene:

Benzene is highly flammable and is formed from both natural processes and human activities. Benzene is widely used in the United States; it ranks in the top 20 chemicals for production volume. Some industries use benzene to make other chemicals which are used to make plastics, resins, and nylon and synthetic fibers. Benzene is also used to make some types of rubbers, lubricants, dyes, detergents, drugs, and pesticides. Natural sources of benzene include volcanoes and forest fires. Benzene is also a natural part of crude oil, gasoline, and cigarette smoke.

While benzene has been detected in four compliance groundwater monitoring wells at reported concentrations exceeding the 2L standard, the detection of benzene at the White Street Landfill has primarily centered around compliance monitoring well II-7. Benzene was detected in the groundwater samples collected from compliance well II-1 during the March 25, 1995 and July 6, 1994 groundwater monitoring events at reported concentrations of 5.4 and 6.5 μg/L respectively. Both of these concentrations exceed the 2L standard of 1 μg/l for benzene. However, benzene has not been detected above the reportable quantitation limit in compliance well II-1 since the July 6, 1994 sampling event.

Benzene was also detected above the 2L standard in compliance well II-6 during the September 25, 1996 with a reported concentration of 5.2 μg/L. However, benzene has not been detected again above the quantitation limit in well II-6 since this event.

Most of the detections of benzene at the White Street Landfill have occurred in groundwater monitoring well II-7 from the July 11, 1995 groundwater monitoring event through the October 16, 1998 groundwater monitoring event. However, benzene has not been detected above the quantitation limit in well II-7 since the October 16, 1998 sampling event. The release of benzene from the Facility appears to have been a slug type release based on the results that show this constituent has not been quantified in groundwater samples from compliance well II-7 since the October 1998 sampling event.

It should be noted that 1998 corresponds with the closing of Phase II to the receipt of MSW. Shortly there after the landfill was capped and methane gas recovered alliuites were initiated.

The only reported concentration of benzene detected in any compliance or NES monitoring well since the October 1998 monitoring event occurred in compliance well II-2 during the most recent April 12, 2007 groundwater monitoring event. Benzene was detected at a reported concentration of 1.4 μg/L in well II-2 during this event which is

above the 2L standard of 1 μg/L for benzene. To date, this has been the only detection of benzene in monitoring well II-2. The trend of the disappearance of benzene in compliance well II-7 may be related to the 1998 capping of MSW in Phase II and the subsequent activation of methane gas recovery. Both measures can be considered corrective measures. However, the appearance of benzene in compliance well II-2 during the most recent April 12, 2007 groundwater monitoring event, may also suggest that the contaminant plume in the vicinity of compliance well II-7 has migrated to the northeast within the hydrogeologic regime beneath Phase II. This is further supported by the appearance of low level concentrations of other constituents of concern in compliance well II-2 coupled with a decreasing trend of these constituents in compliance well II-7. Compliance well II-2 is hydrogeologically cross gradient from compliance well II-7.

With the reduction in concentration of benzene in the compliance monitoring wells in which it was detected, it is reasonable to conclude that benzene is not continually being released from the Facility.

Based on the data discussed above which appear to suggest that the release of benzene was a slug type release and is not a continual release from the Facility, and given the low levels of this constituent detected since the October 1998 monitoring event within the uppermost pervasive monitored aquifer at the Facility, the risk from levels of benzene reported in the compliance monitoring data from the White Street Landfill to human health as well as the aquatic life in Buffalo Creek is expected to be low.

1,2-Dichloroethane:

The compound 1,2-dichloroethane has only been detected in compliance monitoring well II-7 since monitoring history at the landfill began. In groundwater samples collected from monitoring well II-7, 1,2-dichloroethane has only been detected twice, once during the March 17, 1995 and once during the October 16, 1998 groundwater monitoring events. However, both of the reported concentrations during these two events, 25 μg/L and 9.2 μg/L respectively, were above the 2L standard of 0.38 μg/L for this constituent. The compound 1,2-dichloroethane has not been detected in any compliance groundwater monitoring well since the October 1998 sampling event. It should be noted that 1998 corresponds with the closing of Phase II to the receipt of MSW. Shortly there after the landfill was capped and methane gas recovered alliuites were initiated, measures can be considered corrective measures.

The most common use of 1,2-dichloroethane is in the production of vinyl chloride which is used to make a variety of plastic and vinyl products including polyvinyl chloride (PVC) pipes, furniture and automobile upholstery, wall coverings, house wares, and automobile parts. It is also used to as a solvent and is added to leaded gasoline to remove lead.

The Department of Health and Human Services (DHHS) has determined that 1,2-dichloroethane may reasonably be expected to cause cancer. The EPA has determined that 1,2-dichloroethane is a probable human carcinogen and the International Agency for Cancer Research (IARC) considers it to be a possible human carcinogen.

The constituent 1,2-dichloroethane breaks down very slowly in both surface water and groundwater. Since 1,2-dichloroethane is not continually being detected in the compliance monitoring network and has not been detected since the October 1998 groundwater monitoring event, it is reasonable to conclude that a continual release of 1,2-dichloroethane from the Facility is not occurring.

The primary risk from the release of 1,2-dichloroethane to Buffalo Creek is aquatic life. While no information relating directly to the study of the effects of 1,2-dichloroethane on fish were found by S&ME for the preparation of this report, in laboratory animals, breathing or ingesting large amounts of 1,2-dichloroethane have also caused nervous system disorders and liver, kidney, and lung effects. Animal studies also suggest that 1,2-dichloroethane may damage the immune system.

However, since there have been no detections of 1,2-dichlorethene since 1998 in any compliance or NES monitoring wells, the release of 1,2-dichloroethene is not ongoing. Therefore the risk to human health and the environment for the release of 1,2-dichloroethane from the Facility is expected to be low.

Trichloroethene:

Trichloroethene is a colorless liquid with a characteristic, slightly sweet odor. It is used as a solvent in a variety of applications. A major use of trichloroethene is in metal degreasing; other significant uses are in textile cleaning, solvent extraction processes and as a carrier solvent. It is no longer used as a grain fumigant and is now only occasionally used in anesthesia. For practical use, trichloroethene requires the addition of stabilizers (up to 2%). The limited toxicity data available show LC50 values for aquatic biota in the mg/liter range. Trichloroethene is degraded in biological and abiotic systems. The detection of trichloroethene at the White Street Landfill has been isolated to samples collected from II-7 and one sample from II-2 collected during the April 24, 2006 groundwater monitoring event.

Based on the calculated hydraulic conductivities for the Facility and the fact that Trichloroethene has been present in monitoring wells II-7 for several years based on historical monitoring data, it is likely that the release of Trichloroethene from the Facility has reached the creek. Additionally all of the reported concentrations of trichloroethene (TCE), detected in the groundwater samples from compliance wells II-7 and II-2 exceed both the 2L standard for groundwater, as well as the North Carolina 2B surface water standard. However, the trends in the data indicated a dramatic decline in TCE concentrations in compliance well II-7 since the October 1998 sampling event with only

two detections close to the 2L standard having occurred since the October 1998 sampling event. As discussed earlier, this trend corresponds with the installation of an active gas remediation system at the Facility and the capping of the Phase II portion of the landfill.

S&ME completed a drinking water well receptor survey within a quarter mile radius of compliance wells II-2 and II-7 where the primary constituents of concern have impacted groundwater quality. The results of this receptor survey show that there are five (5) drinking water wells within a quarter mile radius of compliance wells II-2 and II-7. These wells are on the opposite side of Buffalo Creek, which is a local hydraulic divide, for the uppermost prevalent aquifer. Additionally, all five of the drinking water wells are at topographically higher elevations than compliance wells II-2 and II-7. S&ME does not have well construction information for the drinking water wells and therefore we do not know if the drinking water wells are set in the same aquifer as the compliance monitoring wells II-2 and II-7.

Based on these results, the level of risk posed to human health from the release of Trichloroethene is expected to be low. The primary risk of impact from this release will be aquatic life in the receiving creek. Since the toxicity data available show Lethal Concentration of 50% of the Population (LC50) values for aquatic biota in the mg/liter range, the associated risk to aquatic life from the levels of Trichloroethene shown at the creek (180 µg/L predilution based on the Nature and Extent Study) are also expected to be low.

<u>1,2-Dichloropropane:</u>

1,2-Dichloropropane, which was detected in wells II-1 and II-7 at concentrations in exceedance of the 2L standard, was not detected in any other nature and extent study well. 1,2-Dichloropropane (DCP) has only been sporadically detected in these two wells and has not been detected in any compliance well since the October 1998 groundwater monitoring event. The release from the Facility appears to have been a slug type release. The trends in the data indicated a dramatic decline in TCE concentrations in compliance well II-7 since the October 1998 sampling event. As discussed earlier, this trend corresponds with the installation of an active gas remediation system at the Facility and the capping of the Phase II portion of the landfill.

Literature suggests that if injected into soil DCP will be primarily lost by volatilization. The fate of DCP in groundwater is unknown. However, if released to surface water, DCP will be lost by volatilization with half-lives ranging from approximately 6 hours for a river to 10 days for a lake. Absorption to soil and bioconcentration in fish will not be significant.

North Carolina has not established a 15A 2B surface water standard for DCP. Since the primary receptor of the migrating constituent plume from the Phase II is Buffalo Creek, it is reasonable to predict that Buffalo Creek (Creek) will be a discharge point for the

uppermost aquifer. Therefore, if low levels of DCP enter the Creek, the half life is expected to be approximately 6 hours until it will be lost by volatilization. Additionally, the bioconcentration in fish is not expected to be significant. Therefore the risk to human health and the environment from the isolated detections of low levels of DCP in compliances wells II-1 and II-7 is low.

Tetrachloroethene:

Literature suggests that Tetrachloroethene is one of the most important chlorinated solvents worldwide and has been produced commercially since the early 1900s. Most of the tetrachloroethene produced is used for dry cleaning garments; smaller amounts are used in the production of chlorofluorocarbons and for degreasing metals. Five studies of people exposed to drinking-water contaminated with tetrachloroethene have been reported. In four of these, no consistent pattern of risk for any specific cancers was observed. In the fifth study, in Massachusetts, United States, although the increase in the relative risk for leukemia was significant, the result was based on only two cases. No consistent evidence for an elevated risk for leukemia was seen in the cohort studies. Tetrachloroethene shows only low acute toxicity in humans and in experimental animals.

The release of tetrachloroethene at the Facility is centered primarily around compliance monitoring well II-7 where it has been consistently detected in groundwater samples collected from this well since it was installed. The reported concentrations from this well have also been above the 2L standard, however, it is important to note, there has been a declining trend in the concentrations of tetrachloroethene in well II-7 since the October 1998 sampling event. As with the other primary constituents of concern discussed above, this decline in the concentration of tetrachloroethene corresponds with the installation of an active gas remediation system and the capping of the Phase II portion of the landfill.

In the April 12, 2007 groundwater monitoring event, tetrachloroethene was also detected in compliance well II-2 and in NES well II-7B at reported concentrations in exceedance of the 2L standard. As stated earlier, this may be indicative of a shift in the path of the primary component of flow moving away from well II-7 toward well II-2. It is also likely that the release of tetrachloroethene has migrated to the creek along the northwestern Facility boundary in the vicinity of compliance well II-7. However, the concentration of tetrachloroethene in deep monitoring well II-7B is low and close to the 2L standard.

The reported concentrations of tetrachloroethene in compliance wells II-7 and II-2 are all above the 15A 2B surface water stand and for this constituent. Based on the above finding and the concentrations detected in monitor wells the primary risk of impact from this release will be aquatic life in the receiving creek. Based on the results of S&ME's receptor survey and the fact that there are no known potable uses of Buffalo Creek in the vicinity of the landfill, the risk to human health is expected to be low.

Vinyl Chloride:

Vinyl chloride has detected in both compliance well II-2 and NES well II-2B in the April 12, 2007 and July 11, 2007 groundwater monitoring events respectively at reported concentrations exceeding the 2L standard. Vinyl chloride was also detected in compliance well II-1 during the March and July 1994 monitoring events and in NES well II-9 during the May 11, 2005 groundwater monitoring event.

Vinyl chloride is a synthetic chemical obtained either by hydrochlorination of acetylene or by halogenation of ethylene (ILO, 1983; Budavari, 1989). Under normal conditions of temperature and pressure, vinyl chloride is a colorless gas with mild ethereal odor. It is usually handled under pressure as a colorless liquid. Vinyl chloride is used for the production of vinyl chloride homo-polymer and co-polymer resins; these have many applications. It was formerly considered for use as an anesthetic agent, but was finally abandoned for this purpose because of cardiac arrhythmias during anesthesia. It has also been used as a refrigerant, an extraction solvent, a propellant, and for the production of methyl chloroform (ECETOC, 1988). EPA has issued a maximum contaminant level of 2 ppb for vinyl chloride in drinking water.

Again, based on the hydraulic conductivities of the site and the sampling results of the Nature and Extent Study, it is likely that the release of vinyl chloride has reached the creek. However, there is no drinking water or other receptors wells between the landfill and the creek. The creek is a local hydraulic divide for the uppermost prevalent aquifer and exists between a release from the landfill and the five receptor wells within a ¼ mile radius on the other side of the creek. Based on the factor and the concentrations detected in monitoring wells the level of risk to human health is expected to be low. The primary risk of impact from this release will be aquatic life in the receiving creek. The reported concentrations of vinyl chloride in compliance well II-2 and NES well II-2B which was 3.2 μg/L is close to North Carolina's surface water standard of 2 μg/L for vinyl chloride.

Inorganics:

With the exception of thallium, each of the metals listed in the constituents of concern were demonstrated to be naturally occurring in the in-situ soil at the Facility in the ASD completed by S&ME. The ASD demonstrated that the elevated levels of the metals portion of the primary constituents of concern are due to influence from the natural occurrence of these metals in the native residual soil and not the result of a release from the Facility. In accordance to the North Carolina Solid Waste Management Regulations, naturally occurring conditions are not 2L exceedanes. Additionally, many of the metals of concern are shown as an exceedance because the State of North Carolina has not established a 2L standard for these metals.

Pure thallium is a bluish-white metal that is found in trace amounts in the earth's crust. In the past, thallium was obtained as a by-product from smelting other metals; however, it has not been produced in the United States since 1984. Currently, all the thallium is obtained from imports and from thallium reserves.

The Department of Health and Human Services, the International Agency for Research on Cancer, and the Environmental Protection Agency (EPA) have not classified thallium as to its human carcinogenicity. Thallium enters the environment primarily from coal-burning and smelting, in which it is a trace contaminant of the raw materials. It stays in the air, water, and soil for a long time and is not broken down. Some thallium compounds are removed from the atmosphere in rain and snow. It's absorbed by plants and enters the food chain. It builds up in fish and shellfish. Therefore, the primary risk of impact from this release will be aquatic life in the receiving creek. North Carolina has not established a 2B surface water standard for thallium. Since thallium build-up in fish and shellfish is cumulate, the level of risk to aquatic life from thallium is considered to be moderate.

Nickel has continually been detected in groundwater samples collected from compliance well I-5 at reported concentrations above the 2L standard. The results of S&ME's ASD demonstrated that nickel is in fact naturally occurring in the in-situ soils at the Facility. But the levels of nickel in the groundwater samples from well I-5 are higher than would be expected purely from influence of the overlying in-situ soils at the Facility. However, well I-5 is not a property boundary well and is located well within the Facility boundary. Since nickel was not detected in any other compliance or NES wells along the Facility boundary, nickel has not left the Facility and is therefore not considered a risk to potential receptors.

4.0 POTENTIAL METHODS OF GROUNDWATER CORRECTIVE MEASURES

The following corrective measures were examined so as to present possible feasible solutions to the City of Greensboro, the governing body complying with the conditions of the NCDENR DWM Permit Nos. 41-03, 41-12, and No. 41-03.), and to those potentially effected by the off-site contaminate migration (residents of City of Greensboro). Each of the corrective measures listed here are considered feasible; however, only a select few will have the greatest effect on the potential contaminate migration given the patterns of the sampling analysis, and the environmental conditions of the impacted area. The selection of a remedy is controlled by the geologic and hydrogeologic conditions at the site, and the risks associated with the release. More aggressive remedial alternatives tend to have a higher capital cost for implementation. The aggressiveness of the selected remedy is usually controlled by the level of risk(s) to downgradient receptors from the associated release. If there is a high level of risk to receptors, the situation may dictate a more aggressive remedial technology be implemented due to the immediate need to reduce risk to the receptors. Conversely, sites with low risk to downgradient receptors may not require such aggressive technology since contaminate levels may more closely approximate regulatory clean-up goals and time budgets would allow for remediation over a longer period.

The goal of the corrective measures process is to restore groundwater quality to the level of the standard, or as closely there to as is economically and technologically feasible. The NCDENR DWM indicates that remediation will be complete when concentrations of the constituents of concern are less than the 2L standard for three consecutive years when

measured in all points within the plume that lie at and beyond the groundwater compliance monitoring well network. Therefore, the objective of corrective action for this ACM is to reduce the concentrations of the constituents of concern to levels below the 2L standards within the plume of contamination at points lying at and beyond the compliance well network. The following methods were selected for evaluation as an appropriate remedy for corrective action at the White Street Landfill. Most of these are listed in the Examples of Approved Groundwater Corrective Measures for Solid Waste Management Facilities in the memo issued by State of North Carolina Department of Environment and Natural Resources, Division of Waste Management, Solid Waste Section, March 2007.

- In Situ Air Sparging / Vapor Extraction
- Subterranean Physical Barriers
- In Situ Enhanced Bioremediation
- Groundwater Pump and Treat with Ex Situ Treatment
- Monitored Natural Attenuation

	Treatment Train	Residuals	Operation & Maintenance; Capital Expenses	Availability	Reliability	Time	Cost	Halogenated VOCs
Air Sparging	N	V	Not O&M or CAP intensive	3	3	1	3	2
Physical Barrier	N	N	CAP	3	3	1	3	1
Enhanced In Situ Bioremediation	N	N	O&M; CAP for injection points & chemicals	3	2	*	3	*
Groundwater Pump & Treat	Y	L	Not O&M or CAP intensive	3	3	1	1	2
Monitored Natural Attenuation	N	N	Not O&M or CAP intensive	3	2	*	3	2

Residuals: L = liquid, V = vapor, S = solid, N = none

Availability: 3 = > 4 vendors

Reliability: 1 = Low reliability & high maintenance; 2 = Average reliability & average maintenance; 3 = High reliability & low maintenance.

Time to treat 1 M gal: 1 = > 10 years; 2 = 3 to 10 years; 3 = < 3 years.

Cost: 1 = > $10/1kgal; 2 = $3 to $10/1kgal; 3 = < $3/1kgal.

Capable of degrading Halogenated Volatile Organic Contaminants: * = contaminant dependant; 2 = limited; 3 = effective.

4.1 In Situ Air Sparging / Soil Vapor Extraction

4.1.1 Method Description

Air sparging is an in situ technology in which air is pushed through a contaminated aquifer. Air bubbles traverse horizontally and vertically through the pores and voids in the soil column, creating an underground air stripper that removes contaminants by volatilization. These air bubbles carry the contaminants that have volatilized to a vapor extraction system. Vapor extraction is implemented in conjunction with air sparging to remove the generated vapor-phase contamination. This technology is designed to operate at high flow rates to maintain increased vapor movement in groundwater and soil.

This technology requires the installation and use of sparging (injection) wells to introduce the hydrocarbon free air into the subsurface. The introduction points for the air are set typically into the saturated zone below the lowest level of contamination.

According to the EPA Seminar Publication: *Site Characterization for Subsurface Remediation (1991)*, Soil Vacuum Extraction (SVE) utilizes forced air venting, or in situ air stripping. This technique involves extraction of air and contaminates from unsaturated soil. In contrast to a static equilibrium soil system where evaporation of the chemical is equal to the condensation of the chemical, with SVE, clean air is injected or passively flows in the unsaturated zone. Volatile chemicals then partition from soil water into soil air, with relative partitioning based on the air/water partition coefficient (Kh) or Henry's Law constant and the vapor-laden air is removed using vacuum extraction wells.

Typically, components of SVE consist of vacuum extraction wells, air inlet wells, and vapor monitoring wells distributed across a contaminated site, and a blower(s) to control air flow. Extraction Wells may be placed vertically or horizontally, although vertical alignment is typical for deep contamination zones and for residues in radial flow patterns. Schematics of SVE Systems and a gas extraction well are presented in **Figures 3** and **4**. SVE systems may include vapor phase treatment prior to discharge to the atmosphere depending on state air discharge regulations and contaminant concentrations.

4.1.2 Performance and Reliability

The effectiveness of SVE at a site prior to installation is difficult to predict due to the fact that movement of VOCs through the soil is controlled in part by diffusion and is, therefore, directly affected by the properties of the soil in which the system is installed. These properties which ultimately control the effectiveness of an SVE system include permeability, porosity, grain size distribution, moisture content, organic content, and bulk density. However, SVE technology has been demonstrated to be effective at numerous contaminated sites, but is sensitive to minute permeability changes, which can result in non-uniform air flow and localized stripping.

There are two factors on which the effectiveness of Air Sparging primarily depends. The first is vapor/dissolved phase partitioning of the parameters within the soil, and the second is the permeability of the soil.

The equilibrium distribution of a particular organic parameter between the dissolved phase and the vapor phase is determined by the vapor/dissolved-phase partitioning of the parameters. Therefore, vapor/dissolved-phase partitioning is a significant factor in determining the rate at which dissolved phase parameters can be transferred to the vapor phase.

The permeability of the soil determines the rate at which air can be injected into the saturated zone. Therefore, soil permeability is the second significant factor in determining the transfer rate of constituent mass from the dissolved phase to the vapor phase.

Air Sparging (AS) has been shown to be moderately effective for the chlorinated hydrocarbons which constitute the primary constituents of concern at the Landfill. This success can be attributed to the fact that chlorinated VOCs are often very volatile and possess high solubility constants. As AS operations proceed and concentrations of dissolved constituents are reduced, the reduction rate of constituent mass slows. Soil characteristics determine the flow path of vapors within the vadose zone. Therefore soil characteristics can greatly influence the ease or difficulty with which vapors can be controlled and extracted using SVE. Both injection and extraction gaseous flow paths will follow the zones of least resistance within the soil, typically found in course-grained zones. This preferential flow pattern could result in stripped vapors traveling large lateral distance from the injection point which could result in contaminant laden sparge vapors migrating outside the vapor extraction control area.

A properly designed AS system should prevent further migration of contaminant parameters beyond the Facility property boundary and should reduce the constituents of concern to concentrations at least equal to their respective GPS.

4.1.3 Associated Receptor Impacts From AS Systems

Impacts to other receptors from a properly designed Air Sparging System would center around the contaminant laden vapors extracted from the subsurface. The extracted vapor would require periodic testing and if VOC concentrations warranted it or if required by regulation, a secondary treatment system to reduce VOC emissions to the outside air would be installed. The secondary treatment system would typically employ activated carbon absorption to remove chlorinated VOCs from the air stream. With this type of secondary treatment, the activated carbon must be periodically recharged.

4.1.4 Remediation Timeframe

This technology is readily available from multiple vendors. An AS system could be installed at the Facility within 1 to 1.5 years. Published research indicates that Air Sparge systems are capable to remediate 1 million gallons of groundwater impacted with chlorinated hydrocarbons in less than 3 years. Given the concentrations of these constituents identified at the Facility boundary during the NES operations, the GPS at the landfill boundary might be obtained within 5 to 10 years. However, this type of system would have to continuously operate for the entire post closure care of the Facility or as long as the Facility continues to release groundwater contaminant parameters in sufficient quantities to exceed the established GPS within the facility monitoring network.

4.1.5 Implementation Requirements

The design methods and construction of an AS system will require some additional site characterization, especially pertaining to the on site soil characteristics. Additionally, a pilot study would be proposed in order to determine the effectiveness of this type of system within the existing subsurface conditions at the site prior to installation and implementation. The fundamental design element is the radius of influence of the wells. Typical designs employ a 15 to 25 foot radius of influence per vertical well. Horizontal wells could also be employed to increase the systems efficiency and reduce the remediation timeframe. However, horizontal wells are more costly.

4.1.6 Remedy Costs

For all remedies discussed in the following sections, the ranges of costs presented in this report are based on other cases studies and/or similar projects as well as S&ME experience with these remedial technologies. The presented cost ranges only represent typical costs for the specific remediation being discussed. These costs DO NOT represent actual cost based on specific or exact design criteria specific to the Facility as the design phase of the Assessment of Corrective Measures process follows the submittal and subsequent approval of this report by the NC DENR and is completed under the Corrective Action Plan phase of this process. These costs are only intended to present the reader with generalized ranges of costs to implement the specific technology on a "typical" project. The actual costs incurred for this project may vary depending on the specific site conditions encountered as well as engineering design criteria specific to this project.

Costs associated with an Air Sparge system include site characterization, design costs, permitting costs, construction and construction oversight costs, and monitoring costs. The following costs are estimated for implementation of an AS system:

Design Costs:

Site Characterization.....$50,000 – $75,000

Engineering.....$25,000 - $50,000

Permitting.....$5,000 - $10,000

Equipment Costs (Treatment Building):

(including carbon adsorption treatment unit).....$60,000 - $100,000

Well Installation Costs:

Vertical AS Wells .....$150,000 - $200,000
Vertical SVE Wells.....$50,000 - $75,000
Horizontal AS Wells .....$200,000 - $250,000
Horizontal SVE Wells..... $75,000 - $125,000
Power line installation..... $20,000 - $25,000

Total Estimated Remedy Implementation Costs: .....$635,000 – $910,000

Actual costs are dependant on the total number, type, and depth of wells. The annual operation and maintenance costs including carbon recharge is estimated to be $25,000 to $50,000.

4.1.7 Institutional Controls & Requirements

The City of Greensboro may require permits for construction activities. Additionally an air discharge permit may be required, and the NC DENR Division of Waste Management will require modification to the Facility's operating permit.

4.2 Subterranean Physical Barriers

4.2.1 Method Description

Cut-off wall technology or a slurry wall physical containment technique involves installing barriers to groundwater flow. Alternate physical barrier technologies involve grout curtains, sheet pilings, block displacement, and synthetic membranes. Reference **Figure 5** for a basic schematic of the physical barrier technology. The rational behind installing a physical barrier is to divert either uncontaminated groundwater away from waste sites or contaminated water away from clean areas (Ehrenfield and Bass, 1984). These containment systems also provide for temporary containment while groundwater is removed and treated, and aquifer material is decontaminated.

The physical barrier can be utilized in at least two different approaches. The physical barrier could be placed upgradient of the contamination zone to help limit the amount of water migrating to a sensitive or offsite area. A second possible approach is to place the physical barrier downgradient of the contamination zone, and use in conjunction with a pump and treat system (as documented in Section 4.4).

There are three primary types of physical barriers that have been demonstrated to be effective at stopping groundwater migration and flow. These include: bentonite slurry walls, sheet piling, and synthetic membranes.

Slurry walls made of bentonite contain the groundwater, thus treating no particular target group of contaminants. Slurry walls are used to contain contaminated groundwater,

divert contaminated groundwater from drinking water intake, divert uncontaminated groundwater flow, and/or provide a barrier for the groundwater treatment system.

These subsurface barriers often consist of a vertically excavated trench that is filled with a slurry. The slurry hydraulically shores the trench to prevent collapse and form a filter cake to reduce groundwater flow. Most slurry walls are constructed of a soil, bentonite, and water mixture; walls of this composition provide a barrier with low permeability and chemical resistance at low cost. Other wall compositions, such as sheet piling, cement, bentonite, and water may be used if greater structural strength is required or if chemical incompatibilities between bentonite and site contaminants exist.

Slurry walls are typically placed at depths less than 50 ft and generally are 2 to 4 feet thick. The most effective application of the slurry wall for site remediation or pollution control is to base (or key) the slurry wall 2 to 3 ft into a low permeability layer such as a clay or bedrock. This “keying in” provides for an effective foundation with minimum leakage potential.

Sheet piling has been used for civil engineering applications for years. A sheet pile barrier can be made from a variety of materials: wood, recast concrete, and steel. Steel is the most common material because of its high durability, low cost, and high flexibility. Sheet pilings are constructed by driving individual sections of interlocking steel sheets into the ground with impact or vibratory hammers to form an impermeable barrier. The retaining steel pile walls flex from water or lateral earth pressure which tightens the interlocks making the connection more water resistant.

Synthetic membranes used for vertical cutoff walls are generally made from high density polyethylene; however, other polymers have been used. Membrane sheets can be continuous, but usually finite length panels that interlock are preferred. The final depth of installation is a function of the ability of the trenching technique.

Synthetic membranes are typically installed in much the same way as the bentonite slurry wall and sheet piling. Trenching machine installation involves the excavation of an unsupported trench with the membrane lowered vertically in the trench and progressively unrolled.

4.2.2 Performance and Reliability

Slurry walls are a full-scale technology that has been used for decades as a long-term solution for controlling groundwater seepage and flow. The technology has demonstrated its effectiveness in containing more than 95% of uncontaminated groundwater; however, in contaminated groundwater applications, certain contaminant types may degrade the slurry wall components and reduce the long term effectiveness.

A key factor in installing an effective slurry wall is to anchor the base of the wall in either competent bedrock or a clay with very low permeability. Slurry walls have been used for decades, so the equipment and methodology are readily available and well known; however, the process of designing the proper mix of wall materials to contain specific contaminants is less well developed. Excavation and backfilling of the trench is critical and requires experienced contractors.

Sheet piling and synthetic membrane barriers remove the potential for breakdown form contaminant parameters. Also, no excavation is necessary to install a sheet piling wall.

Factors that may limit the applicability and effectiveness of physical barriers include the following:

- The technology only contains contaminants within a specific area
- Soil-bentonite backfills are not able to withstand attack by strong acids, bases, salt solutions, and some organic chemicals (other slurry mixtures can be developed to resist specific chemicals)
- There is the potential for the slurry walls to degrade or deteriorate over time
- Noise and vibration during installation
- Process may not be suitable for soils containing large cobbles and boulders
- Depth limitations
- Keying into rock is not possible with Sheet Piling technology

The following factors, at a minimum, must be assessed to design effective soil-bentonite slurry walls: maximum allowable permeability, anticipated hydraulic gradients, required wall strength, availability and grade of bentonite to be used, boundaries of contamination, compatibility of wastes and contaminants in contact with slurry wall materials, characteristics (i.e., depth, permeability, and continuity) of substrate into which the wall is to be keyed, characteristics of backfill material (e.g., fines content), and site terrain and physical layout.

Advantages of physical barrier technology in groundwater remediation include the following:

- High level of effectiveness in containing/diverting groundwater associated with all of these technologies
- With sheet piling no excavation is required
- Sheet piling can be removed later if required or desired
- With sheet piling technology, topography and depth to groundwater have little impact
- Diffusive transponder is reduced
- Irregular enclosure shapes are possible
- Continuity of impermeability
- Various methods of installation provide flexibility in design to meet site specific needs.

Intensive geotechnical evaluation of the location where the physical barrier is to be installed must be performed. The key factor in evaluating the effectiveness of a physical barrier is the ability of the system to contain the plume. Therefore, additional geotechnical work, aquifer tests, groundwater monitoring well installation, and groundwater sampling and analysis are needed to optimize the design.

Performance of a properly designed and installed physical barrier is expected to reduce constituents of concern in downgradient areas which are downgradient of the physical barrier itself. The physical barrier will prevent transport of additional constituents of concern past the Facility Boundary and will allow natural attenuation to continue to remediate impacted groundwater from areas downgradient of the physical barrier.

Physical barrier systems require no regular maintenance to continue operating as designed; they also do not require experienced operator oversight or frequent operational changes to be effective. However, they do require regular monitoring to insure that leaks are not occurring due to poor seals or deterioration of the barrier itself. Additionally, bentonite slurry walls may at some point need to be replaced.

4.2.3 Associated Receptor Impacts

Depending on the installation method, a large volume of diverted groundwater may need to be disposed of. If the physical barrier is installed downgradient of the waste management units, constituent impacted groundwater will have to be disposed of and/or treated. This could be accomplished by pumping to remove the groundwater mound which will develop behind the wall, then diverting the impacted groundwater to the already installed leachate collection system between the waste management units and the creek. Additionally, depending on the exact location, wetlands and stream channels may be impacted.

4.2.4 Remediation Time Frame

The remediation timeframe for a physical barrier system will depend on the placement of the barrier itself. If the physical barrier can be placed between the waste disposal areas and the compliance boundary along the creek, the remediation goals would be achieved at the compliance boundary in a relatively short period of time (estimated 3 to 5 years); however, there would be on going maintenance to manage the water impounded behind the barrier. If the site conditions do not allow the placement of the physical barrier between the Facility Boundary and the waste disposal area boundary, it is likely that achieving remediation goals at the compliance boundary will take longer. If this becomes the case and physical barrier technology is still pursued as a means of corrective action, the physical barrier could be place upgradient of the waste management units in an effort to reduce downgradient influx of clean groundwater into the waste units. Cutting off or reducing groundwater migration into the waste units will reduce intermixing of groundwater with leachate, reduce leachate production and dramatically reduce landfill mass. This scenario will assist and promote natural attenuation within the waste management units as well as impacted areas of the hydrogeologic regime in the

downgradient areas. However remedial goals will take longer to achieve given this scenario. For multiple reasons, this scenario is not applicable at Phase II of the Facility.

4.2.5 Implementation Requirements

Prior to installing any of the types of physical barriers discussed above, an extensive site characterization must be performed in the area of proposed installation in order to determine: the depth to bedrock, the geotechnical qualities of the soil, competency of bedrock, fines content of the soil, and a cross sectional map of both the saturated and vadose zones of the subsurface. The design of the physical barrier must incorporate compensations for the difficulties presented by the site characteristics in order to design and install a successful physical barrier. Additionally, a pilot study may be required to ensure the effectiveness of the proposed physical barrier. For an effective and successful physical barrier, the fundamental design elements include completely capturing the zone(s) of impact within the aquifer and "keying in" to competent bedrock or a very low permeability clay such that migration will be stopped and not leak below and through the base of the physical barrier. Therefore, the physical barrier will need to be installed to bedrock to prevent plume deflection into lower portions of the uppermost aquifer. Depth to bedrock at the Facility varies between 30 to 50 feet below ground surface.

4.2.6 Remedy Costs

Costs associated with a physical barrier system include site characterization, design costs, permitting costs, construction and construction oversight costs, and monitoring costs. For the Facility, the estimated cost for designing and installing a physical barrier system are as follows:

Design Costs:
- Site Characterization.....$50,000 - $75,000
- Engineering Costs.....$30,000 - $50,000
- Permitting Costs.....$5,000 - $10,000

Materials Costs:
- Barrier Materials.....$40,000 - $80,000

Construction Costs:
- Construction of Physical Barrier.....$200,000 - $265,000
  (range: $15 - $20 per ft²)
- Construction Oversight & Documentation .....$35,000 - $50,000

Contingencies:..... $54,000 – $79,500

Total Estimated Remedy Implementation Costs: .....$415,000 - $609,500

If replacement of the physical barrier is required at some point in the future, the replacement cost is estimated at $200,000 to $400,000. Annual monitoring costs associated with the physical barrier system are estimated at $10,000 to $20,000 annually.

4.2.7 Institutional Controls & Requirements

The City of Greensboro may require permits for construction activities. A North Carolina National Pollution Discharge Elimination System (NPDES permit may be required to dispose of constituent impacted groundwater which is diverted and subsequently captured for treatment. Also the DENR Division of Waste Management will require modification to the Facility operating permit.

4.3 In Situ Enhanced Bioremediation

4.3.1 Method Description

The basic premises of microbial ecology are related to bioremediation in that many organic compounds can be used by microorganisms as a source of carbon and energy. Many of the compounds that are considered hazardous can be degraded in the subsurface if the concentrations are not toxic to the microorganisms and the appropriate environmental parameters can be established. Biodegradation is a process in which indigenous or inoculated microorganisms (i.e., fungi, bacteria, and other microbes) degrade (metabolize) organic contaminants found in the soil and/or groundwater. In the presence of sufficient oxygen (aerobic conditions), microorganisms will ultimately convert many organic constituents to carbon dioxide, water, and microbial cell mass. In the absence of oxygen (anaerobic conditions), the constituents will ultimately metabolize to methane, limited amounts of carbon dioxide, and trace amounts of hydrogen gas. Bioremediation is based on the understanding of the carbon cycle and extrapolation of compound mineralization in other environments to the subsurface. Environmental factors, such as pH, oxidation-reduction potential, and temperature, may play a role in determining the potential for bioremediation. Halogenated compounds generally tend to persist in aerobic environments, but continued research is providing evidence that biological alternatives to these compounds may exist. Under anaerobic conditions, several chlorinated compounds have been shown to undergo transformation. For example, tetrachloroethene (PCE) has been shown to be dechlorinated under environmental conditions that support the growth of anaerobic bacteria. This process is known as reductive dechlorination as follows:

$$\text{PCE} \rightarrow \text{TCE} + \text{Cl} \rightarrow \text{DCE} + \text{Cl} \rightarrow \text{CE} + \text{Cl}$$
$$\rightarrow CO_2 + \text{Cl}$$

The compounds produced are trichloroethene (TCE), the isomers of dichloroethene (DCE), and chloroethene (CE). The removal of the chlorine atoms enhances the potential for aerobic microorganisms to degrade the daughter products. DCE has a greater potential for aerobic degradation than does PCE.

Material can be introduced into the aquifer through the use of infiltration galleries (reference **Figure 6** and **Figure 7**, Brenoel and Bround, 1985; Thomas and Ward, 1996). Infiltration galleries facilitate all movement of the microbiological solution though the

unsaturated zone and the saturated zone, resulting in potential treatment of the source material that may be trapped in the pore spaces of the unsaturated zone.

The rate of bioremediation is enhanced by increasing the concentration of electron acceptors and/or nutrients in the groundwater. Groundwater naturally contains low concentrations of oxygen because of the minimal reaeration resulting from flow beneath the surface. The subsurface is typically nutrient starved as well.

Enhanced biodegradation is similar to natural attenuation, except that chemicals and/or bacteria are introduced to the contaminated media to enhance the biodegradation process.

Figures 5, 6, & 7: Physical Barrier Design, Bioremedation Design Schematic I, and Bioremedation Design Schematic II

4.3.2 Performance and Reliability

Bioremediation techniques have been successfully used to remediate soils, sludges, and groundwater contaminated with chlorinated solvents, pesticides, and other organic chemicals. Biodegradation can be effective for remediating low-level residual contamination in conjunction with source removal. If properly designed, monitored, and maintained, enhanced bioremediation is a reliable remedial alternative that can rapidly destroy contaminants in the subsurface. A key advantage of the in situ process is that it allows soil to be treated without being excavated and transported, resulting in less disturbance of the site activities and significant cost savings over methods involving excavation and transportation. Also, both contaminated groundwater and soil can be treated simultaneously. In situ processes generally require linger time periods however, and there is less certainty about the uniformity of treatment because of the inherent variability in soil and aquifer characteristics and difficulty in monitoring progress.

Factors that may limit the applicability and effectiveness of the process include the following:

- Clean-up goals may not be attained if the soil matrix prohibits contaminant-microorganism contact.
- The circulation of water-based solutions through the soil may increase contaminant mobility and necessitate treatment of underlying groundwater.
- Preferential colonization by microbes may occur causing clogging of nutrient and water injection wells
- Preferential flow paths may severely decrease contact between injected fluids and contaminants throughout the contaminated zones. The system should not be used for clay, highly layered, or heterogeneous subsurface environments because of oxygen (or other electron acceptor) transfer limitations.

- High concentrations of heavy metals, highly chlorinated organics, long chain hydrocarbons, or inorganic salts are likely to be toxic to microorganisms
- Bioremediation slows at low temperatures.
- Unless the primary and secondary sources or contaminates are treated or removed, repeated treatments will be required to achieve and maintain compliance with clean-up goals.

For this Facility, enhanced bioremediation would likely involve the injection of hydrogen release compounds (HRC) to treat chlorinated organic compounds. HRC, in the form of a polyactate ester, would be injected into the affected aquifer using a series of direct push probes. The polyactate ester will release lactic acid as it is hydrated, which will be metabolized by indigenous anaerobic microbes and will produce low concentrations of dissolved hydrogen. The dissolved hydrogen is then used by reductive dehalogenator organisms that strip the chlorine atoms from the chlorinated hydrocarbons as part of their metabolism.

4.3.3 Associated Receptor Impacts

Enhanced bioremediation would not present a significant risk to other environmental receptors. A minor impact could result form the generation of contaminated purge water. This purge water would have to be disposed of.

4.3.4 Remediation Timeframe

The success of enhanced biodegradation is ultimately dependent upon soil properties and the biodegradability of the contaminants. It is estimated that within one to six months an observable decrease in constituent concentration should be observed. The timeframe for an observable decrease in concentrations to be observed at all points within the plume is difficult to predict but estimated to be three to six years. Based on the monitoring results, follow-up injections of hydrogen release compounds would likely be required since the source is long-term.

4.3.5 Implementation Requirements

In order to determine the suitability of Enhanced Bioremediation (EB) at the site, a laboratory scale testing which would include a treatability study should be conducted prior to field implementation. If the results of the laboratory model show favorable treatability results, a field scale pilot study would be completed in order to ensure that existing site conditions are conducive to EB. Finally, an application plan for the HRC would be developed. The injection wells would then be installed which will require field work. Once the injection wells are installed, injection of the HRC will be performed. Regular monitoring activities will also be performed to monitor the progress of the EB Program. Reinjections will likely be required on a periodic basis until the GPS exceedances within the downgradient compliance wells have ceased. This will occur once landfill mass has been sufficiently reduced.

4.3.6 Remedy Costs

Enhanced bioremediation will require expenditures for engineering design, capitol costs to purchase the HRC, installation, monitoring and evaluation costs. The estimated costs for employing an enhanced bioremediation system at the landfill include the following:

Limited Site Characterization	$30,000 - $40,000
Design Costs:	
Engineering Costs	$25,000 - $35,000
Permitting Costs	$5,000 - $10,000
Equipment Costs:	
HRC	$150,000 - $250,000
Construction Costs:	
Additional Wells as required	$50,000 - $75,000
HRC application and oversight	$10,000 - $20,000
Contingencies:	$40,500 - $64,500
Total Estimated Remedy Implementation Costs:	**$310,500 – $494,500**

Depending on the final design of the monitoring network and the determined appropriate monitoring frequency, annual monitoring and reporting costs for an enhanced bio-remediation system are estimated at $20,000 to $30,000 per year until remediation goals are met. If additional injections of hydrogen release compounds are required, these costs, which include supplies, subcontractors, and oversight are estimated at $50,000 - $100,000 per event.

4.3.7 Institutional Controls & Requirements

If enhanced bioremediation is the selected method to restore groundwater quality at the Facility, NC DENR will require a major permit amendment to the landfill operating permit.

4.4 Groundwater Pump & Treatment

4.4.1 Method Description

Conventional groundwater pumping is used for cleanup of both organics and inorganics in groundwater. The system, consisting of appropriate access wells for groundwater extraction, removes contaminants that are dissolved in the groundwater for treatment at the surface. Groundwater removed from the aquifer is then treated and disposed of.

Pump and treat systems can best be described when broken into its two basic components: the pumping system and the treatment system. Pumping systems may be used for plume containment and plume recovery for above ground treatment. Groundwater pumping systems utilize the principle that groundwater flows in response to a hydraulic gradient, i.e., a drop in hydraulic pressure created by the combined effects of elevation, fluid density, and gravity (reference **Figures 8 and 9**). The pumped

contaminated groundwater that is withdrawn from an aquifer can be treated by various methods, depending on the type(s) of contamination. Treatment methods may include one or more of the following: (1) physical processes, such as adsorption onto activated carbon or resins, ion exchange, reverse osmosis, filtration, or transfer to the gaseous phase by air stripping; (2) chemical processes, such as neutralization, coagulation, precipitation, oxidation, or reduction reactions, which involve inactivating or immobilizing contaminants with chemical agents; or (3) biological processes, using conventional wastewater treatment methods such as suspended growth (i.e., activated sludge, lagoons, waste stabilization ponds, and fluidized bed reactors) and freed film (i.e., trickling filters and totation biological contractors) processes (Thomas *et al*., 1987) Extracted groundwater may also be sent off site for treatment at an existing Publicly Operated Treatment Works (POTW).

When pump and treat remediation is selected, a decision needs to be made about the use of wells and drains (U.S. EPA, 1990). If the hydraulic conductivity is sufficiently high to allow flow to wells, then wells are recommended. For low permeability material, drains may be required. Wells can be categorized as extraction, injection, or a combination. Injection wells reduce cleanup time required by flushing chemicals into extraction wells. Design and management decisions concerning extraction wells include whether to use continuous pumping, pulsed pumping, or pumping combined with containment. While continuous pumping maintains an inward hydraulic gradient, pulsed pumping allows maximum concentrations to be pumped and requires only minimum volumes of pumping. The pump and treat technique can also be used with the physical barrier technique documented in Section 4.2.

Groundwater pump and treat systems are expensive to install and relatively expensive to operate. They also require regular maintenance and sampling. Pump and treat is a viable option for landfills; however, the expense and the uncertain timeframe for achieving remedial goals often necessitate the use of a pilot study to better predict the effectiveness of a pump and treat system for a particular site.

4.4.2 Performance and Reliability

Groundwater pump and treatment technology is relatively simple to design and operate, uses standard equipment available from many sources (reducing costs), and can treat all types of dissolved (mobile) contamination. It allows flexibility in meeting various cleanup goals (e.g., mass reduction versus plume spread). It can be implemented quickly and is compatible with adjunct technologies (e.g., vacuum extraction or in situ air stripping) for overall cost effectiveness.

The recovery well network must be designed to capture water from the center (high concentration area) of the plume for rapid mass removal and from the leading edge of the plume to minimize plume spread.

The design can be based on standard groundwater models. Simplicity of concept and flexibility in meeting various cleanup objectives (many different contaminant types, balanced optimization based on mass reduction and plume spread, etc.) are significant strengths of groundwater pump and treat, and this technology will continue to be an important tool in cleanup activities. Unfortunately, pump and treat has several important limitations, including generation of substantial amounts of secondary waste water, high energy costs for pumping and moving large volumes of water, indiscriminate removal of all groundwater components, potential impacts on groundwater resources, and slow progress toward terminal regulatory goals due to technical limitations. Additionally, the performance of pump and treat to remediate an aquifer containing VOCs is moderate to poor if the goals of the remediation are to reduce the contaminant levels in the already impacted portion of the aquifer; the extraction process for the organic contaminants becomes diffusion controlled (residual to dissolved) once saturated components of the dissolved phase contamination have been removed from the aquifer.

The chemical characteristics of the contaminants to be removed are critical to the success or failure of pump and treat. The solubility and partitioning coefficients (Kd and/or Kow) of the contaminants for soil and water must be considered to assess the feasibility of such a system. Groundwater pump and treat is most effective on compounds with low partitioning coefficients and high solubility (i.e., most chlorinated hydrocarbons).

4.4.3 Associated Receptor Impacts

A pump and treatment system should not present a significant risk to other environmental receptors. This is due to the fact that for the case in point, treatment of the extracted constituent laden groundwater would not take place on site. Instead the extracted groundwater would be sent to a Publicly Operated Treatment Works. If however, onsite treatment were mandated, perhaps due to permitting issues, air-stripping and/or activated carbon adsorption system could be employed. The use of activated carbon would necessitate regular rejuvenation of contaminated carbon which would result in cross media impacts.

4.4.4 Remediation Timeframe

The remediation timeframe for a pump and treat system will depend on the location and placement of the extraction points. If the extraction points are placed between the waste disposal area and the Facility boundary, the remediation goals will be achieved at the compliance boundary in a relatively short period of time (estimated at 3 to 5 years of operation). However, if site conditions impede placement of the extraction wells between the waste disposal areas and the Facility boundary, it is likely that it will take longer for the pump and treat system to achieve remedial goals. Points within the capture zone of the pump and treat system will take the longest to reach remedial goals, since natural attenuation would be relied upon to attenuate these contaminants. The pump and treat system would be designed to control further releases from the landfill and would therefore have to be operated until the landfill meets the remedial goals.

4.4.5 Implementation Requirements

In order to implement a pump and treat system a number of extraction wells will have to be installed. For this type of remedial technology, the fundamental design components include the number of extraction wells, placement of the extraction wells, pumping rates, and managing the extracted groundwater at the surface. In order to assist in designing this type of system, it is often useful to construct an analytical groundwater flow model or site numerical flow model to optimize the number, location, and pumping rate of the extraction wells.

The extracted groundwater will be collected and pumped to the local Public Water Treatment Works via the existing force main which runs across the Facility Property approximately 4,500 feet southwest of compliance wells II-7 and II-2.

4.4.6 Remedy Costs

The associated costs to install and maintain a pump and treat system would include: design, permitting, capital costs for pumps and equipment, procurement, construction, and construction oversight costs, and operation and maintenance costs. Continuous pump and treat is an energy intensive operation. This type of system would require regular inspection and maintenance. There are also costs associated with transport and treatment of the extracted groundwater. The estimated costs to install, operate, and maintain a pump and treat system are as follows:

Design Costs:
- Pilot Test .....$15,000 - $20,000
- Engineering Costs .....$20,000 - $40,000
- Permitting Costs.....$5,000 - $10,000

Equipment Costs:
- Collection system, pumps, piping, controls, etc. .$50,000 - $100,000
- Transfer piping and lift station.....$135,000 - $160,000

Construction Costs:
- Extraction well and system installation .....$40,000 - $80,000
- Construction oversight and documentation .....$30,000 - $60,000
- Power supply to the site .....$5,000 - $10,000

Contingencies: .....$45,000 – $72,000

Total Estimated Implementation Costs: .....$345,000 – $552,000

The estimated annual maintenance and upkeep costs for a pump and treat system is $30,000. This number assumes that the local waste water treatment plant will not charge the City of Greensboro for accepting the additional influx and/or treatment for the collected groundwater from the pump and treat system.

4.4.7 Institutional Controls and Requirements

Implementation of a pump and treat system may require several permits for operation. Discharge of impacted groundwater to a sewer system may require a POTW permit in lieu of the discharge permit. Treated groundwater would require a discharge permit from the DENR Division of Waste Management to be discharged, and the operating permit for the landfill would require modification by the DENR Division of Waste Management.

4.5 Monitored Natural Attenuation

4.5.1 Method Description

Natural Attenuation is the reduction in mass or concentration of a chemical in groundwater over time or distance from the source of contamination due to naturally occurring physical, chemical, and biological processes. These naturally occurring physical, chemical, and biological processes include: dispersion, dilution, sorption, volatilization, biodegradation/biotransformation, and abiotic degredation/transformation. There are two types of mechanisms of natural attenuation; non-destructive and destructive mechanisms. Non-destructive mechanisms result in reduction in groundwater concentrations with no mass loss of contaminants from the system. Non-destructive mechanisms include dispersion, dilution from recharge, sorption, and volatilization. In the sorption process contaminant mass is transferred to aquifer solids. During volatilization contaminant mass is transferred to the surrounding atmosphere. Destructive mechanisms of natural attenuation results in mass loss of contaminants from the system. Destructive mechanisms include aerobic biodegradation, anaerobic biodegradation, cometabolism, abiotic oxidation/reduction reactions, and hydrolysis. The affects of the natural attenuation process can be seen over increased distance from a continuous contaminant source in a tapered linear relationship when compared with source concentrations. With increasing distance from a slug release contaminant source, the relationship between attenuation and contaminant concentrations will be represented by a bell curve plot of groundwater quality data over time throughout the natural attenuation process. For the City of Greensboro Landfill Phase II, it has not yet been determined if the contaminant plume is still in a growth phase, stable phase, or if the plume has already reached its peak and is now a shrinking plume. Plume behavior at the Facility would be determined during the MNA process.

Monitored Natural Attenuation is considered as an appropriated remedy for corrective measures at a Facility if the site meets the following criteria:

1. The groundwater flow is not in a direction of a public or private drinking water supply
2. The groundwater flow velocity, based on monitoring well conductivity tests, does not suggest the contaminated groundwater flow as quickly leaving the property boundary, as further suggested by:
   a) The site has a relatively high clay content and low sand content.
   b) The site does not have a steep upgradient hydraulic head.
   c) The site has well drained soil, without many preferred groundwater flow pathways.

d) The constituents exceeding 2L standard do not spontaneously change over short periods of time.

Biodegradation will be the primary reduction process of landfill mass during the natural attenuation process. Biodegradation involves biologically mediated oxidation/reduction reactions and is fundamentally an electron transfer process. Electrons are transferred from more reduced compounds to more oxidized compounds. Energy released is used by microbes to sustain metabolism and growth. Redox chemistry is a good analogy of this process in that electron donors are what microbes "eat" and electron acceptors are what microbes "breath" (Barden & Wiedemeier 1997). Electron donors include natural organic carbon, fuel hydrocarbons, and most importantly for this case, landfill leachate constituents.

The constituents of concern at the Landfill include the organic parameters, Tetrachloroethene, Trichloroethene, and Vinyl Chloride. Research has shown that chlorinated solvents which include Tetrachloroethene, and Trichloroethene, all biodegrade via halorespiration (Barden & Wiedemeier 1997). Tetrachloroethene and Trichloroethene have also been shown to degrade through cometabolism. Finally, Vinyl Chloride, an anthropogenic Cl-ethene, will biodegrade through aerobic respiration and iron (III) reduction. Based on the years of groundwater monitoring analytical data coupled with the various studies throughout the groundwater monitoring history of the Facility including the previously discussed Nature and Extent Study, the primary substrate at the Facility should contain a sufficient quantity of anthropogenic organic carbon to support biodegradation of the chlorinated solvents of concern. In addition, there is likely native organic carbon in trace amounts which will further enhance biodegradation rates of these constituents. However, exact analysis of existing native organic carbon has not been studied to date. The dominant thermal electron-accepting process through which biodegradation takes place is:

Aerobic Respiration	Dentrification	Iron (III) Reduction	Sulfate Reduction	Methanogenesis

Time ----------►

◄---------- Distance From Source

(After: Bower and McCarty, 1984)

The geochemical content of the uppermost monitored aquifer will evolve over time due to the biodegradation process. Based on the above equation, with increased time, a decrease in electron acceptors such as dissolved oxygen, nitrate, FE(III), SO^{2-}_4 and CO_2 will occur close to the source as a result of the metabolic processes intrinsic to the hydrogeologic regime at the site. Conversely there will be an increase in degradation/transformation products including dissolved iron, methane, ethane, ethane, and chloride. If additional lines of evidence for natural attenuation are needed, microbiological indicators can be analyzed and included in the study if warranted. The effectiveness and magnitude of the natural attenuation process can be demonstrated

through inclusion of these constituents during the routine groundwater sampling and subsequent analytical analysis. Monitoring these indicators as well as noting reductions in the concentrations of the landfill constituents of concern over time will be essential for mapping and gauging a successful natural attenuation process over time.

MNA can result in complete mineralization of contaminants to innocuous products. Although considered a "passive" technique, it allows for continuing use of infrastructure and can be very cost effective.

An evaluation of the risks posed to human health and the environment at the landfill is included in this report. Based on the risk evaluation it may be concluded that MNA would be an appropriate remedial measure for the landfill.

This process would involve sampling the appropriate property boundary groundwater monitoring wells for the constituents found over the 2L standard. After an appropriate amount of samples have been taken, assumptions may be drawn concerning the constituent magnitude concentration trend (increasing, decreasing, or static) in order to reevaluate the Dispersion and Natural Attenuation process effectiveness. The objectives for a monitored natural attenuation groundwater remediation program include the following:

- Demonstrate that natural attenuation is occurring
- Be protective of human health and the environment
- Monitor natural attenuation and environmental impact; and
- Restore groundwater at the edges of the plume to below the 2L standard and GPS

4.5.2 Performance and Reliability

MNA is a proven remedial alternative and can successfully restore groundwater quality and return monitored constituents to within 2L standard levels. MNA has been used at many different types of sites to treat both impacted groundwater and soils. MNA is an adequate stand alone remedy in cases where there is no identified risk to human health or the environment, and/or when proactive remediation is not likely to be more effective than MNA at restoring groundwater quality.

MNA performance differs at every site and is dependant on the individual site conditions. Therefore, performance of MNA is typically determined by long term monitoring for the monitored contaminant parameters, daughter products if any, and other indicators of attenuation such as electron acceptors (oxygen, sulfate, nitrate, and ferrous iron) and waste products (ethane, ethane, methane, chloride, carbon dioxide, etc.).

4.5.3 Associated Receptor Impacts

There are no major remediation-related impacts associated with MNA, since MNA results in the destruction of the contamination. Minor impacts would include the generation of contaminated purge water, which would have to be disposed into the local POTW.

4.5.4 Remediation Timeframe

The timeframe for achieving objectives should be reasonable compared to other alternatives. The existing and historical data can be used as a predictor of future result. Based on the historical groundwater data, it is reasonable to believe that the GPS can reasonably be obtained in 15+ years based on case study literature. It is believed that MNA has already been occurring and is evidenced by the daughter products such as vinyl chloride already present in the compliance and NES groundwater monitoring wells.

4.5.5 Implementation Requirements

In order to implement MNA at the Facility a performance monitoring program PM designed to address the higher level of uncertainty regarding the mass contaminants and predictive analyses will be required. Per the EPA Office of Solid Waste and Emergency Response (OSWER) Directive (1999), performance monitoring to evaluate the remedy effectiveness and to ensure protection of human health and the environment is a critical element of all response actions. The monitoring program will have to be designed to incorporate the following:

Demonstrate that natural attenuation is occurring according to expectations;

- Detect changes in environmental conditions that may reduce the efficacy of any of the natural attenuation processes;
- Identify any potentially toxic and/or mobile transformation products;
- Verify that the plume(s) is not expanding
- Verify no unacceptable impact to downgradient receptors
- Detect new releases of contaminants to the environment that could impact the effectiveness of the natural attenuation remedy;
- Demonstrate the efficacy of institutional controls that were put in place to protect potential receptors; and
- Verify attainment of remediation objectives.

The City of Greensboro would implement the PM program through a Corrective Action Plan which would be prepared and submitted to DENR upon approval of the ACM. The existing monitoring network plus the NES wells would be utilized for the PM program. Monitoring wells MW-13 and MW-14, the upgradient wells, would allow determination of geochemical conditions in the groundwater prior to entering the source area. Monitoring wells II-2 and II-7 are located in the plume and will be utilized to collect data for bioremediation rate calculations. Additional wells may be required along the downgradient Facility Boundary to define the edge of the plume and act as sentinel wells. These wells would be monitored and evaluated to determine if bioremediation is working as well as to determine if triggers have been exceeded.

4.5.6 Remedy Costs

The costs associated with MNA would include preparing the performance Monitoring Plan, installing additional monitoring wells as required, sampling and analysis costs, data evaluation, and reporting costs. Based on the existing site conditions, the estimated implementation costs for MNA are as follows:

Initial Start-Up Costs:

Pilot study and base line data collection:.....$20,000 - $40,000

Design Costs:

Engineering Costs .....$10,000 - $20,000

Permitting Costs.....$0 - $5,000

Construction Costs:

Additional Wells as needed .....$30,000 - $40,000

Contingencies:.....$9,000 - $15,750

Total Estimated Remedy Costs: .....$69,000 – $120,750

Depending on the final design, the size MNA groundwater monitoring network, and the determined monitoring frequency, the annual monitoring and reporting costs associated with MNA are estimated at $20,000 to $40,000 per year until remediation goals are achieved.

4.5.7 Institutional Requirements

The Waste Division at DENR will require modification to the operating permit for the landfill.

4.6 Maintaining a Consistent Contour with pre-1988 Waste Area

Maintaining a consistent contour across the pre-1988 waste area entails basic maintenance to those areas where ditches, slumps, and sinkholes have formed from trash decomposition. Maintenance would involve filling or grading over only those anomalous surface deficiencies that facilitate the influx of water into the waste trenches.

Maintaining a consistent contour would involve a continuous process of inspection and backfilling on a semi-annual or annual basis for any existing or potential surface water collection locations followed by timely addition of backfill soil and reseeding.

This process will reduce landfill mass by reducing vertical percolation of rain water into the waste mass through leaching.

Estimated annual costs to ensure a consistent contour on the landfill cap is $5,000 per year.

5.0 ASSESSMENT OF POTENTIAL METHODS OF GROUNDWATER CORRECTIVE MEASURES

The primary concern or the most serious possible threat to the environment extends from the organic compounds: tetrachloroethene, trichloroethylene, and vinyl chloride repeatedly exceeding the 2L Standards in the network wells, II-2 and II-7.

It is important to consider the topographic, hydrogeologic, and physical setting conditions from monitoring wells II-2 and II-7 to Buffalo Creek and farther downgradient when considering one particular corrective measure over another. The soils in the vicinity of II-7 are composed of a sandy clayey silt overlying a micaceous clayey silt which are moderately drained soils. The soils in the vicinity of II-2 are classified as clayey silts and silty clays which are also moderately drained soils. The soils farther downgradient closer to the creek reside in the floodplain of this tributary and can be considered saturated or hydric wetland soil.

5.1 Air Sparging or SVE Method

The air sparging or SVE method is specifically designed to evacuate the air filled pore spaces in the soil above the water table. The water table is shallow in the vicinity of II-7 and II-2 and, therefore, SVE would require an extensive pilot study prior to implementation. It is likely that other remedies would be more efficient and cost effective for the selected remedy based on existing site conditions.

5.2 Subterranean Physical Barriers

5.2.1 Downgradient Physical Barrier

The cut-off wall or physical barrier technology may be able to provide flow containment to the groundwater exceeding the 2L standard. However, the waste management units are so close to the creek that if implemented as the selected remedy, a physical barrier would have to be installed into the flood plain areas of the creek. The limits of waste almost extend to the alluvial flood plain deposit of the creek and therefore there is very limited access to install a physical barrier between the waste management units along the northwestern facility boundary and the creek. Application of this technology would involve excavation into either the waste management units or the flood plain of the creek. Excavation into the waste management units would likely cause a high level of short term impact to the creek which could extend into long term impact and would require the methods discussed in the trash removal and excavation portion of this report. Excavation into the flood plain areas of the creek may require special permitting for impacting protected waters of the U.S. and special design techniques would have to be employed to insure the effectiveness of the physical barrier at stopping further downgradient migration. This would be very difficult due to the fact that the barrier would have to be built in a constantly saturated alluvial deposit.

5.2.2 Upgradient Physical Barrier

An upgradient physical barrier at this Facility is impractical because the highest elevation upgradient from the compliance monitoring wells is the top of the waste. Therefore, an upgradient physical barrier could not be used at this Facility.

Even if a physical barrier were attempted as a remedy to contain the release from the landfill by ignoring the complications discussed above, given the physical size of the disposal area alone (45 acres) the physical barrier would be required to be of a significant scale and would not eliminate the migration of groundwater from beneath the waste management unit.

5.3 Bioremediation or Injection Methods

Bioremediation or injection methods could be employed in the vicinity of II-7 to the vicinity of II-2 or farther downgradient. This method which utilizes a hydraulic pumping system described in Section 4.3, could be effective to remediate the in situ VOC's. In general, hydraulic control systems are less costly and time consuming to install than physical containment structures such as slurry walls. Well systems also are more flexible, because pumping rates and well locations can be altered as the system is operated over a period of time.

However, most all bioremediation techniques assume there is an ability to control environmental factors conducive to biodegradation. Conditions such as pH and temperature would be crucial to the applicability of the bioremediation system.

This method would be most effective if used at a point source, however, the source has not been exactly pinpointed within the entire waste management unit. Therefore, it is likely that other remedies would be more efficient and cost effective for meeting the remedial goals at the landfill. Also there is a need for repeat re-injection for this remedy and is thus cost prohibitive.

5.4 Pump and Treat

The attributes of the pump and treat system are very similar to the bioremediation and injection method. However, the method of treatment would not be in situ, rather the contaminated water would be pumped out of the ground, and then pumped off site to the local waste water treatment facility and treated physically, chemically, or biologically. The pump and treat systems may also allow for variable hydrogeological (i.e. seasonal water elevations changes) conditions similar to the bioremediation. One advantage over the injection of biodegrading solutions, however, is the temperature and pH, for example, do not have to be held relatively constant with the pump and treat system. The pump and treat process can be used quite effectively in combination with Monitored Natural Attenuation.

This remedy, coupled with a Monitored Natural Attenuation Program might prove to be the most viable option for achieving the remedial goals and returning constituent concentration to within their respective 2L standard and/or GPS values. Again however, extensive additional site characterization will be required before implementation of a pump and treat system.

5.5 Dispersion, Natural Attenuation, and Continued Monitoring

Monitored Natural Attenuation (MNA) would be an appropriate method of restoring groundwater quality at the Facility based on the existing hydrogeologic conditions as well as the previously discussed risk assessment and analysis. Additional studies, such as a benthic study of the creek in both up and downgradient areas of the zone of influence by the Facility, could be coupled with the MNA to monitor impact to the aquatic life of the stream. The economic and existing water quality value of the creek upgradient of the Facility could also be evaluated to determine the impact, if any, the Facility is having on surficial water quality standards. Surface water quality could be monitored and the results compared to the existing 2B surface water standards. MNA could be the central component of the Facility's selected remedy while incorporating one or more of the other feasible treatment options previously discussed such as maintaining a consistent contour over the waste management units. The dispersion, natural attenuation, and continued monitoring option would be economically feasible and within the resources of the City of Greensboro. Implementing a constant groundwater monitoring event program could also establish the concentration trend over time.

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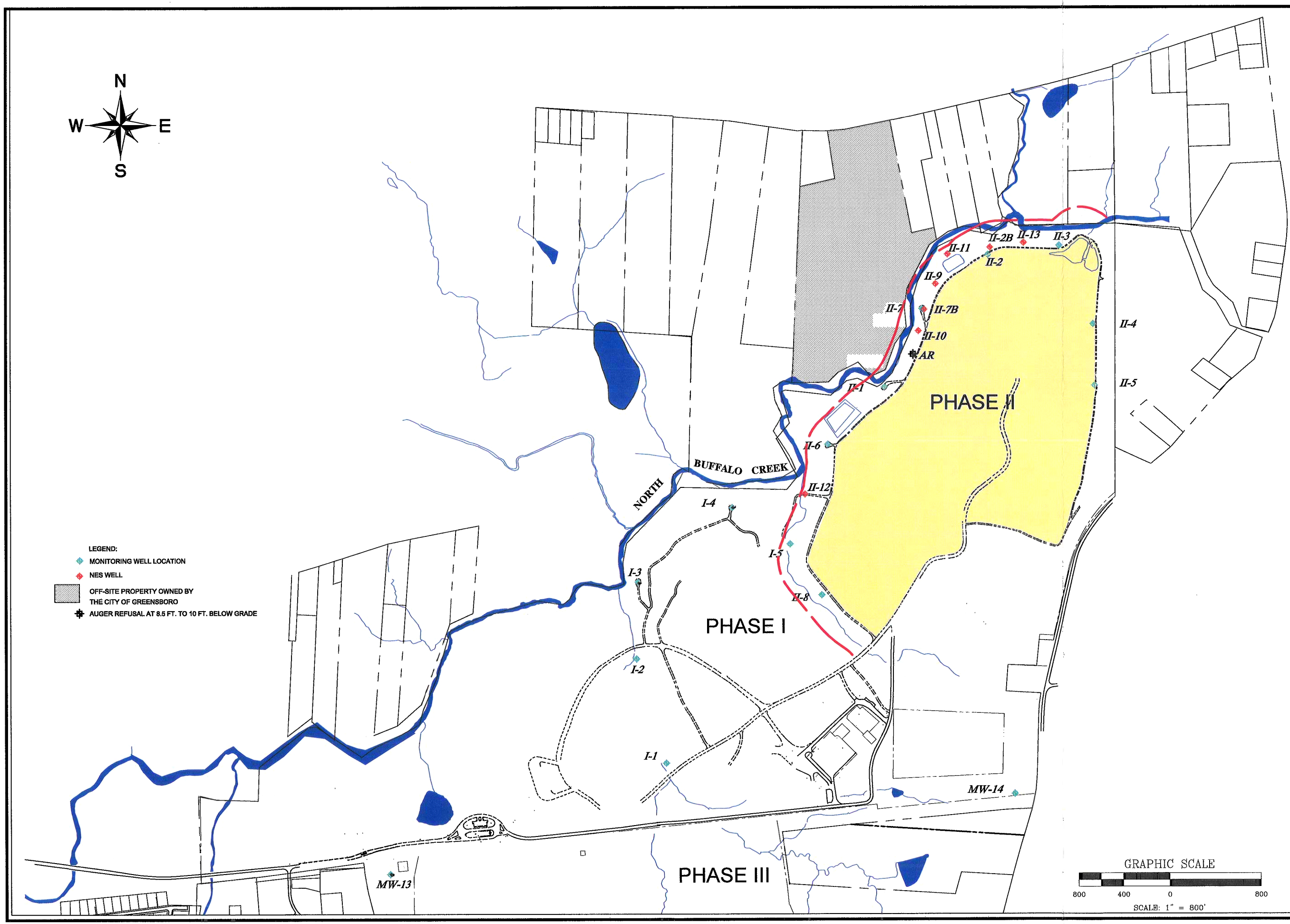
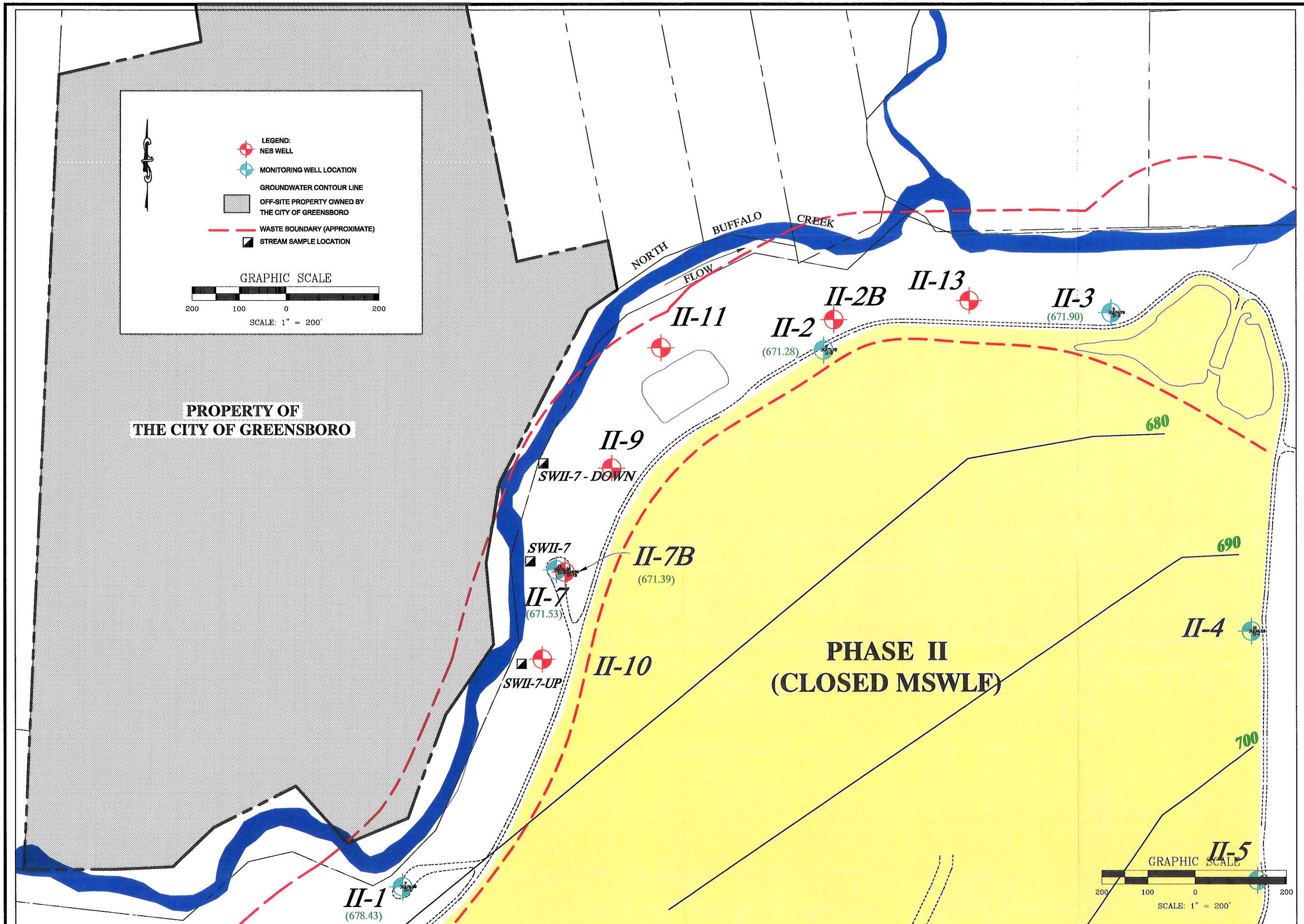
FIGURES



SITE BASE MAP
PHASE II
WHITE STREET LANDFILL
GREENSBORO, NORTH CAROLINA

SCALE: AS SHOWN	DRAWN BY: DSB/RDM	CHECKED BY: DRL	
JOB NO. 1584-98-081	DATE: JUNE 2005	FIGURE NO. 1	

S&ME
ENVIRONMENTAL SERVICES
ENGINEERING · TESTING



DETAILED SITE MAP
PHASE II
WHITE STREET LANDFILL
GREENSBORO, NORTH CAROLINA

SCALE: AS SHOWN	DRAWN BY: DSB/RDM
JOB NO. 1584-98-081B	DATE: JUNE 2005
CHECKED BY: EQBH	FIGURE NO. 2

S&ME
ENVIRONMENTAL SERVICES
ENGINEERING · TESTING

SVE Schematics

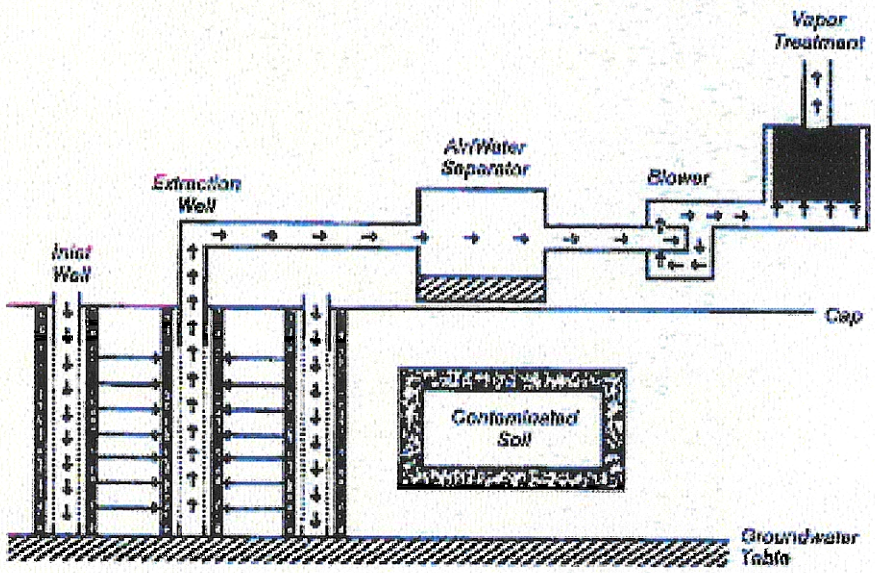


Figure 3: Typical components of a soil vacuum extraction system (from Hutzler et al., 1990).

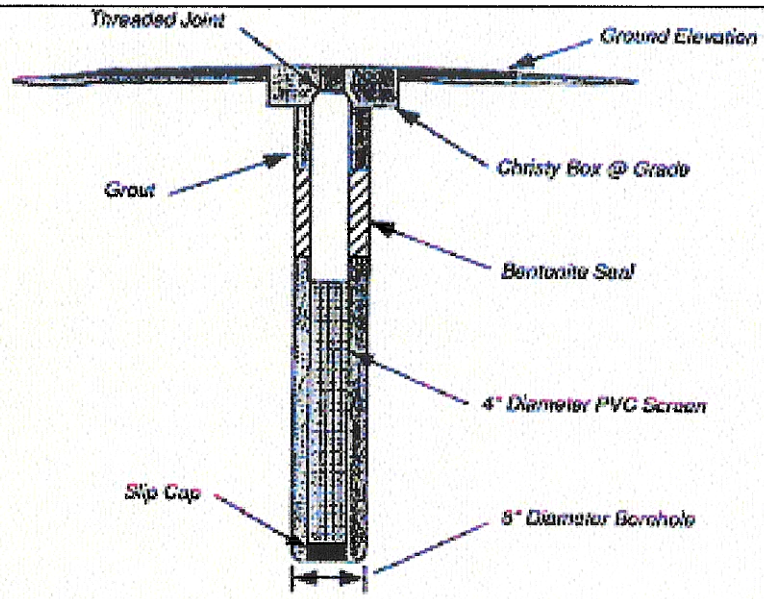


Figure 4: Schematic of a gas extraction well used in a soil vacuum extraction system (from DiGiulio, 1989).

Physical Barrier and Bioremediation Schematics

Physical Barrier

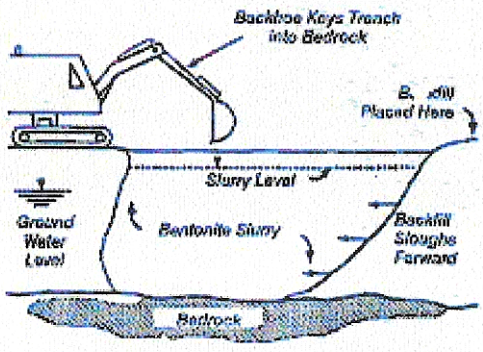


Figure 5: Schematic of the preparation of a slurry wall for physical containment of contaminated ground water or for diversions of clean water around a contaminated subsurface (from U.S. EPA, 1985).

Bioremediation

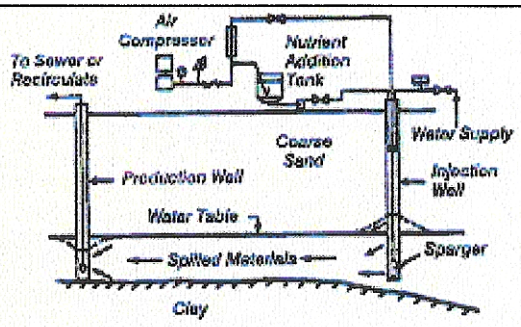


Figure 6: Typical schematic for aerobic subsurface bioremediation (from Thomas and Ward, 1989).

Bioremediation

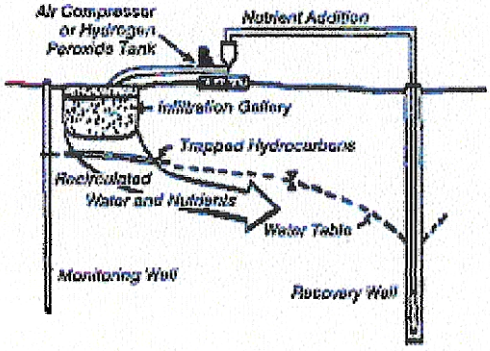


Figure 7: Use of infiltration gallery for recirculation of water and nutrients in in situ bioremediation (from Thomas and Ward, 1989).

Pump and Treat Schematics

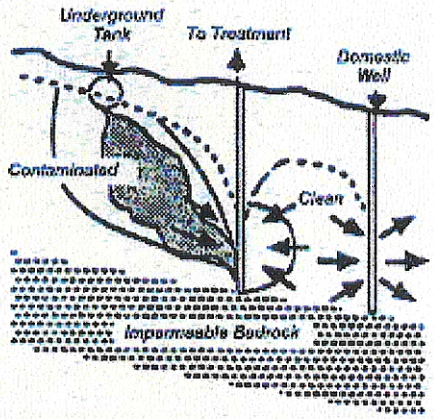


Figure 8: Cross-sectional view of pump-and-treat system (from U.S. EPA, 1985).

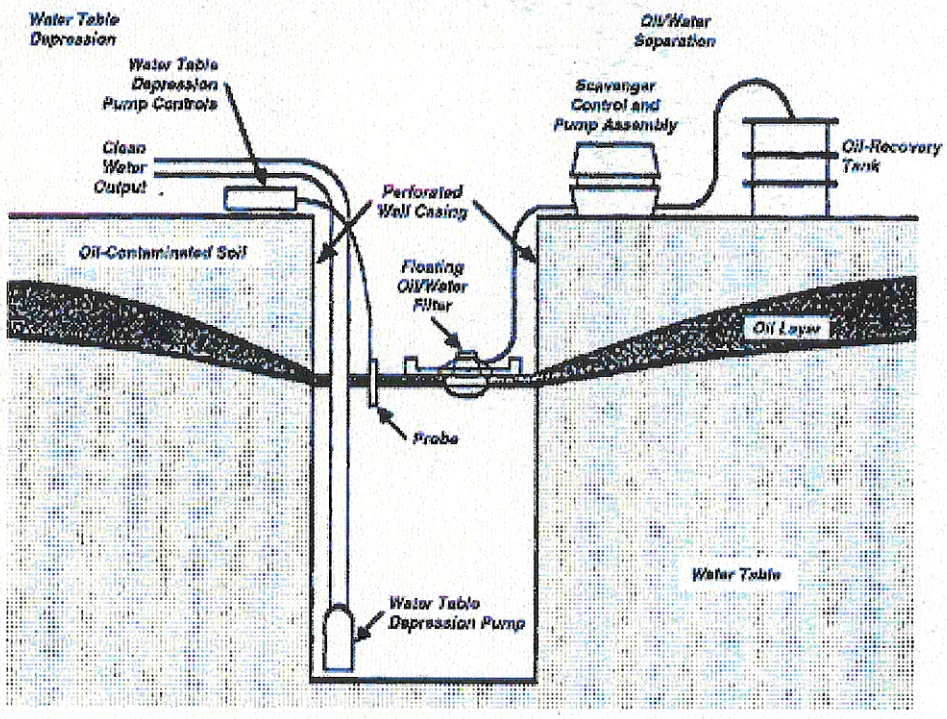


Figure 9: Product recovery using a watertable depression pump and a floating oilwater filter (from Nyer, 1985).