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1.0 Introduction

El Dorado Chemical Company (EDCC) is investigating options for groundwater remediation of nitrate. GBM^c and Associates (GBM^c) has performed a review of *in-situ* remediation alternatives to address nitrate impacted groundwater. The purpose of this report is to present *in-situ* remediation options and recommend a methodology to achieve nitrate remediation of the groundwater at EDCC.

2.0 Site Conceptual Model

The conceptual model of the site is a simplified description of the groundwater system based on site investigation and characterization information. This initial conceptual model for the nitrate impacted groundwater at EDCC includes information regarding the site background, hydrogeology, geochemistry, and fate and transport. The conceptual model is a useful tool for determining remedial objectives, considering appropriate data collection activities, selecting remediation technologies, and developing design criteria for remediation systems. As additional site specific information and data are collected, the conceptual model should be refined and basically evolve during the course of site activities.

2.1 Site Background

In December 1997, a report was completed by Woodward-Clyde for the purpose of developing risk based target monitoring levels for nitrate. A groundwater monitoring program was developed and implemented in 2001 and monitoring has continued to the present.

Nitrate is in the aqueous phase in both the vadose and saturated zone of the subsurface. Nitrate, as ammonium nitrate, has a solubility of approximately 70g/100g of water at 21°C. Nitrate does not tend to adsorb to subsurface materials, has a low probability of retardation onto soil colloids, and tends to move at virtually the same speed as the groundwater. Although nitrate is stable in groundwater, conversion of nitrate to nitrogen gas can occur due to microbial activity in the subsurface.

Based on available groundwater data, there appears to be two different areas of nitrate impacted groundwater. The first being the shallow groundwater in the vicinity of the production area. In this area, the nitrate concentrations at the source zone range from approximately 600 mg/L to 1,200 mg/L (nitrate as N). The second area where nitrate appears to have impacted the shallow groundwater is in the vicinity of Lake Kildeer. Nitrate concentrations in this area are below 100 mg/L (nitrate as N).

2.2 Hydrogeology

The 2003 Annual Groundwater Report, prepared by Environmental Management Services, Inc., provides a description of the site geology. As stated in the report, the local shallow subsurface consists of interbedded sand, silty sand, silt and clay with more clay in the northern area of the property and more sand to the south. The permeable Cockfield Formation is underlain by the Cook Mountain Formation. The Cook Mountain Formation, 50 to 200 feet thick, serves as a confining layer between the Cockfield Formation and the Sparta Aquifer.

Appendix C of the 1997 report completed by Woodward-Clyde provided hydrology and geological information for the Cockfield formation. Based on slug tests conducted in monitoring wells MW-EDC-4, MW-EDC-13, and MW-EDC-18, the hydraulic conductivity of the Cockfield formation ranged from 4.0×10^{-4} cm/sec to 8.26×10^{-4} cm/sec. The average hydraulic conductivity calculated from these slug tests was 6.61×10^{-4} cm/sec or 1.87 ft/day. The groundwater flow direction is typically in a southeast direction. Based on a hydraulic gradient of 4.4×10^{-3} ft/ft and assuming an effective porosity of 0.30, the groundwater seepage velocity is approximately 0.027 ft/day, where seepage velocity was calculated using the following equation:

$$V = Ki/n_e$$

V = seepage velocity
K = hydraulic conductivity
i = hydraulic gradient
n_e = effective porosity

The depth to groundwater varies across the site and typically ranges from approximately 1 to 9 feet below ground surface. An exception is monitoring well MW-EDC-2 where groundwater is just below ground surface or produces artesian flow. Another exception is monitoring well MW-EDC-17 where groundwater is about 25 feet below ground surface.

Table 2.1. Hydrogeology of the subsurface environment at EDCC.

Formation	Parameter	Value/Description
Cockfield Formation	Hydrogeologic Unit	sand, silty sand, interbedded clay
	Formation Thickness	200 ft
	Groundwater Flow Direction	southeast
	Depth to Groundwater	1 to 9 ft below ground surface
	Hydraulic Conductivity	1.87 ft/day
	Hydraulic Gradient	4.4×10^{-3} ft/ft
	Porosity	0.30
	Seepage Velocity	0.027 ft/day
Cook Mountain Formation	Hydrogeologic Unit	Clay
	Formation Thickness	50 to 200 ft
	Vertical Hydraulic Conductivity	3×10^{-4} to 9×10^{-6} ft/day

Note: Information presented in Table 2.1 is based on data and information from the following reports: "Development of Risk-Based Target Monitoring Levels", Woodward-Clyde, December 1997; and "2003 Annual Ground Water Report", Environmental Management Services, April 2004.

2.3 Geochemistry

Table 2.2 provides a list of geochemical data that is useful for evaluating the applicability of *in-situ* remediation alternatives, especially technologies that depend on microbial activity in the subsurface (e.g., biodenitrification, natural attenuation, phytoremediation, etc.). Much of the geochemical data has not been developed at this time.

Table 2.2. Geochemical parameters for evaluating remediation alternatives.

Parameter	Reason for Analysis
Nitrate	A decrease in concentration of nitrate may indicate bioremediation or other attenuation mechanisms are occurring.
Nitrite	Nitrite is an intermediate product that is formed during the transformation of nitrate to nitrogen gas.
Alkalinity	Due to microbial respiration production of carbon dioxide, an increase in alkalinity compared to background can be expected.
Dissolved Oxygen	Dissolved oxygen concentrations must be suppressed, approximately < 2 mg/L, in order for conditions to be favorable for denitrification to occur.
pH	Effective pH ranges for microbial activity can vary considerably, but are typically in the range of 6.0 to 8.5. Bioremediation may occur at lower pH values, but may result in slower degradation rates or may require a lag time for microbial populations to become acclimated and established.
Redox	The Redox, or oxidation reduction potential, will indicate the constituents being used by microbial populations as an electron acceptor. Nitrate will be an electron acceptor near a Redox of 750 mV.
Dissolved Manganese	If dissolved manganese is present, indicates Redox may be too low and Mn is serving as an electron acceptor.
Dissolved Iron	If iron is being used as an electron acceptor, (i.e., Fe^{3+} converted to Fe^{2+}), dissolved iron concentrations will increase compared to upgradient concentrations.
Phosphorus	Phosphorus needs to be available for microbial metabolism. However, addition of phosphorus is typically not required in field applications, but may be necessary for bench scale testing.
Total Organic Carbon	TOC analysis will indicate the availability of naturally occurring carbon sources that are needed as an electron donor for microbial activity.

2.4 Fate and Transport

Nitrate is fairly stable in groundwater and is transported through the subsurface at the same rate as groundwater flow. Dispersion and dilution will decrease the nitrate concentration, but do not change the mass of nitrate in the groundwater. Nitrate can be utilized by microbes through assimilation, which is the incorporation of nitrate into biomass. However, the main transformation process that affects the fate of nitrate in the subsurface is denitrification.

Under anaerobic conditions, nitrate can be used as an alternative electron acceptor by specific groups of microorganisms. Denitrifying bacteria combine the oxidation of organic matter with the reduction of nitrate, as shown in the reaction below:

$$C_6H_{12}O_6 + 4NO_3 \rightarrow 6CO_2 + 6H_2O + 2N_2$$

The reaction shown above depicts the complete mineralization reaction for nitrate. Typically, transformation of contaminants in groundwater is sequential with various intermediates appearing before the contaminant is completely mineralized. The generally accepted sequence for the mineralization of nitrate is:

$$NO_3 \rightarrow NO_2 \rightarrow NO \rightarrow N_2O \rightarrow N_2$$

The intermediates are short lived, however in some cases it is possible to detect an increase in nitrite due to denitrification of nitrate.

3.0 *In-situ* Treatment Alternatives

The main advantage of *in-situ* treatment is the cost savings resulting from not having to pump the groundwater to the surface. Another advantage of *in-situ* treatment technologies is the limited generation or transfer of remediation wastes. However, disadvantages of *in-situ* treatment are that it may require longer time periods to achieve clean up goals and variability in the subsurface may result in less certainty about the uniformity of treatment. A brief overview of *in-situ* treatment alternatives that are potentially applicable for nitrate remediation is provided in the following sections.

3.1 Monitored Natural Attenuation

Natural subsurface processes such as dilution, volatilization, biodegradation, adsorption, and chemical reactions may reduce contaminant concentrations to acceptable levels. Consideration of monitored natural attenuation usually requires modeling, evaluating contaminant degradation rates and pathways, and predicting contaminant concentration at down gradient receptor points, especially when the plume is still expanding or migrating. The primary objective of site modeling is to demonstrate that natural processes of contaminant degradation will reduce concentrations below regulatory standards or risk-based levels before potential exposure pathways are completed. The goal of the monitored natural attenuation program is to confirm that the plume is shrinking or stable, and that contaminant degradation is proceeding at rates consistent with meeting cleanup objectives. The monitored natural attenuation program includes the development of a sampling and analysis plan that defines sampling requirements and establishes goals and objectives of the monitored natural attenuation program.

3.2 Enhanced *In-situ* Biodenitrification

Enhanced *in-situ* bioremediation systems stimulate the biodegradation of certain contaminants by manipulating conditions that affect microbial populations in the subsurface. Microbes responsible for bioremediation generally require a source of carbon, an electron donor, an electron acceptor, appropriate nutrients, and a suitable temperature and pH range.

Enhanced *in-situ* biodenitrification is a remediation technology where a carbon source is introduced to a nitrate contaminated aquifer. In the absence of oxygen and the presence of a carbon source, bacteria can utilize nitrate as an electron acceptor during respiration. Since most aquifers are aerobic, indigenous aerobic bacteria utilize the introduced carbon as a carbon source and oxygen as the electron acceptor. Oxygen in the aquifer becomes depleted, forming an anaerobic aquifer. When this occurs and an abundant carbon source is present, indigenous denitrifying bacteria proliferate and reduce nitrate to nitrogen gas through anaerobic respiration.

3.3 Phytoremediation

The US EPA's Phytoremediation Resource Guide defines six types of phytoremediation mechanisms, including phytoaccumulation, phytodegradation, phytostabilization, phytovolatilization, rhizodegradation, and rhizofiltration. The phytoremediation mechanisms applicable to nitrate remediation include phytodegradation, phytostabilization, and rhizodegradation.

- Phytodegradation, also called phytotransformation, is the breakdown of contaminants taken up by plants through metabolic processes within the plant, or the breakdown of contaminants external to the plant through the effect of compounds, such as enzymes, produced by the plants. Pollutants are degraded, used as nutrients, and incorporated into plant tissues.

- Phytostabilization is the use of certain plant species to immobilize contaminants in soil and groundwater through absorption and accumulation by roots, adsorption onto roots or precipitation within the root zone, and physical stabilization of soils. This process reduces the mobility of the contaminant and prevents migration in groundwater. Depending on the type of trees, climate, and season, trees can act as organic pumps and establish hydraulic control of the groundwater.

- Rhizodegradation, also called phytostimulation, is the breakdown of contaminants in the soil through microbial activity that is enhanced by the presence of the rhizosphere. Natural substances released by the plant roots (e.g., sugars, alcohols, and acids) contain organic carbon that is utilized by microorganisms. Rhizodegradation is aided by the way plants loosen the soil and transport oxygen and water to the area. The plants also enhance biodegradation by other mechanisms such as breaking apart clods and transporting atmospheric oxygen to the root zone.

3.4 NitrEl

The NitrEL system is an electrochemical water treatment process that reduces nitrate concentrations in contaminated drinking water, groundwater and industrial process wastewater streams by converting the nitrate directly to nitrogen gas. NitrEl is a fairly new technology with a limited number of applications at field scale groundwater remediation sites. However, the NitrEL system has been utilized at a highly contaminated groundwater site and was reported to remove greater than 90% of the nitrate and up to 70% of the dissolved ammonia. The NitrEL system uses an electrochemical cell to remove nitrate and ammonia from water. The process is based on electrochemical redox reactions that convert the nitrate and ammonia to nitrogen gas. The *in-situ* application utilizes a "fence" of electrodes inserted into the ground and groundwater flows through the treatment zone created by the electrodes.

The cathodic reactions that predominate in the cell are a function of electrode material and cell operating parameters, such as current density and electrode potential. Cell operating conditions can be controlled to promote the desired reaction. The reduction of nitrate to nitrogen gas can only occur in combination with oxidizing reactions. Various species are oxidized at the anode, including ammonia, to provide electrons for the reduction reactions.

3.5 Permeable Reactive Barrier

A permeable reactive barrier (PRB) is a continuous, *in-situ* permeable treatment zone designed to intercept and remediate a contaminant plume. The treatment zone may be created directly using reactive materials such as iron or indirectly using materials designed to stimulate secondary processes, such as by adding carbon substrate and nutrients to enhance microbial activity. The “barrier” is not intended to convey the idea of a barrier to groundwater flow but as a barrier to contaminants. PRBs are designed to be more permeable than the surrounding aquifer materials so that contaminants are treated as groundwater readily flows through without significantly altering groundwater hydrogeology.

PRBs may be used as a containment remedy or as a source zone remedy. For example, a PRB installed near the downgradient site boundary may be designed to protect downgradient properties or receptors such as surface waters or potable wells. Alternatively, a PRB installed near the source zone may be designed to reduce the mass of contaminant by a given percent with the idea that natural attenuation or some other remedy will address the downgradient residual contamination.

PRBs are installed as permanent, semi-permanent, or replaceable units across the ground water flow path of a contaminant plume. PRBs can be installed as a funnel-and-gate system, trench system, or a series of injection points. The funnel-and-gate system has impermeable walls that direct the contaminant plume through a gate containing the reactive media. A trench is installed across the entire path of the plume and is filled with the reactive media. A series of injection points may be set up to create a treatment zone for groundwater to flow through.

3.6 Ex-situ Alternative

Although the purpose of this report is to review *in-situ* treatment alternatives, an ex-situ treatment option may be applicable. The main advantage of ex-situ treatment is that it generally requires a shorter time period, and there is potentially more certainty about the uniformity of treatment because of the ability to monitor and continuously mix the groundwater that is pumped to the surface for treatment. However, ex-situ treatment requires pumping of groundwater, leading to increased costs and engineering for equipment, possible permitting issues, and material handling. An ex-situ treatment alternative may need to be considered as part of a contingency plan in the event that the *in-situ* treatment does not perform as expected. Alternatively, the ex-situ treatment may be chosen as the primary treatment mechanism to reduce nitrate concentrations at the source zone.

EDCC is in the process of reviewing wastewater treatment alternatives for process water and storm water prior to discharge through an NPDES permitted outfall. The wastewater treatment system will include treatment of nitrate and ammonia to meet NPDES permit limitations. Ex-situ treatment of groundwater in the wastewater treatment system would be a valid treatment alternative or may be part of a contingency plan if an *in-situ* treatment alternative is implemented. However, the wastewater treatment system for the process water and storm water will need to be designed to handle the additional hydraulic and contaminant load resulting from groundwater remediation activity. Other ex-situ treatment systems have not been reviewed, based on the assumption that an existing wastewater treatment system would provide the most economical ex-situ treatment alternative.

Table 3.1. Treatment alternative advantages and disadvantages.

Treatment Alternative	Advantages	Disadvantages
Monitored Natural Attenuation	• Less intrusive than most remediation technologies as few surface structures are required • May be applied to all or part of a given site, depending on-site conditions and cleanup objectives • Natural attenuation may be used in conjunction with, or as a follow-up to, other remedial measures • Overall cost will potentially be lower than other remediation technologies, depending on monitoring time frame and parameters that are required to be analyzed	• Time frames for complete remediation may be long • Responsibility must be assumed for long-term monitoring and its associated cost, including the possibility of implementing institutional controls • Natural attenuation is subject to natural and anthropogenic changes in hydrogeologic conditions • Aquifer heterogeneity may complicate site characterization • Intermediate products of biodegradation can be more toxic than the original compound (e.g., nitrite)
Enhanced *In-situ* Biodenitrification	• Less intrusive than most remediation technologies as few surface structures are required • May be applied to all or part of a given site, depending on-site conditions and cleanup objectives	• Clogging of injection wells may occur due to excessive growth of microorganisms (i.e., biofouling) • Preferential flow paths may decrease contact between injected fluids and contaminants throughout the contaminated zone • Intermediate products of biodegradation can be more toxic than the original compound
Phytoremediation	• Relatively low installation and maintenance costs • May provide hydraulic control as well as contaminant degradation • Plants and/or trees are aesthetically acceptable	• Time frame for plants to reach mature age • Limited effective depth of treatment, depth of the treatment zone is determined by the type of plant used • High concentrations of contaminants may be toxic to plants • Intermediate products of biodegradation can be more toxic than the original compound
NitrEl	• Modular and adaptable to a variety of site conditions and nitrate concentrations • Constant rates of denitrification that are not affected by acidity, aeration, temperature, or nutrient availability	• Relatively new technology with limited full scale application • Operation and maintenance cost • Cost of power requirements to operate system
Permeable Reactive Barrier	• May be applied in the source zone or at downgradient locations • Hydraulic control may be possible	• Installation and maintenance costs • Operational problems may arise due to difficulty of controlling groundwater hydrology
Wastewater Treatment System	• Hydraulic control may be possible • Potential for shorter cleanup time frame • Utilize existing wastewater treatment system	• Groundwater must be pumped to surface • Permitting issues • Capital cost for pumping and material handling equipment • Operation and maintenance

4.0 Potential Remediation System

Based on the site conceptual model and available remediation technologies, the following sections provide site specific information for enhanced *in-situ* biodenitrification, phytoremediation, pump and treat, and monitored natural attenuation. The NitrEl option was not considered further because of the limited field application of the new technology and because power requirements could potentially be cost prohibitive. The PRB option is not specifically discussed for this site, because the enhanced *in-situ* biodenitrification option can be implemented in a manner equivalent to a PRB. The costs provided are rough estimates only and are meant to be used for the purpose of comparing the potential cost of available technologies. Refined cost estimates will require additional site specific data and may include information obtained from pilot scale testing of selected remediation technologies.

4.1 Enhanced *In-situ* Biodenitrification

Enhanced *in-situ* biodenitrification may be considered for treatment of the source zone in the vicinity of the production area and in the vicinity of Lake Kildeer. The advantages of this technology are that it is non-intrusive, low maintenance requirements, and potential of relatively fast time frame for achieving remediation. However, the cost of this technology may be prohibitive for reaching target cleanup goals if used as a stand alone treatment.

Implementation of enhanced *in-situ* biodenitrification would require supplying a carbon source to the groundwater environment. Different carbon amendments are available, such as ethanol, acetate, and sugar. Although cost and availability are important factors in selecting a carbon source, engineering factors also need to be considered such as design of a delivery system, monitoring requirements, and the potential for biofouling. Biofouling can occur at the injection point and results in clogging the injection well due to excessive microbial growth. Clogging of the injection point decreases the effectiveness of biodenitrification by limiting the bioavailability of the carbon source. Some carbon sources are more likely to produce clogging than others due to the potential for production of excess biomass. Strategies for controlling or correcting biofouling are available and can be applied as needed, but will increase the overall cost of remediation.

Regardless of the carbon source chosen, it is important to determine the amount of carbon required to stimulate denitrification in the groundwater. The amount of carbon required for some commonly used carbon amendments in denitrification are shown in Table 4.1. Carbon requirements are based on stoichiometry. However additional carbon is consumed due to cell synthesis and deoxygenation. The additional carbon consumed has been reported to be an excess of approximately 20% to 40% of the stoichiometric requirement.

Table 4.1. Carbon amendment requirements for denitrification.

Carbon Source	Carbon Source Consumed in Denitrifying 1 mg NO_3-N	
	Based on Stoichiometry (mg)	Field Application Estimates (mg)
Methanol	1.91	2.3 to 2.7
Acetate	2.64	3.2 to 3.7
Ethanol	1.37	1.6 to 1.9
Acetone	1.30	1.5 to 1.8
Sucrose	2.55	3.1 to 3.6

Another carbon source to be considered is HRC® (Hydrogen Release Compound), which is a commercially available carbon source offered by Regenesis. This product is designed specifically for groundwater remediation and has been utilized at various sites to enhance *in-situ* bioremediation of groundwater contaminants, including nitrate. HRC® is specifically designed to slowly release lactic acid when contacted with water and is an advantage over other carbon sources because biofouling is less likely to occur. Another advantage of this product is that it may be more acceptable to regulatory agencies for injection into the groundwater due to the past history and use of HRC® at other sites.

Regenesis has provided a site specific evaluation using HRC® to treat nitrate at the source zone in the vicinity of the production area at EDCC. The cost of enhanced *in-situ* biodenitrification as a stand alone treatment technology may be prohibitive due to the large amount of HRC® required to reach target clean up goals. The cost of the HRC® material alone would be approximately $4,000,000. However, partial treatment using HRC® at the production area or in the vicinity of Lake Kildeer may be combined with phytoremediation and/or monitored natural attenuation as a more economically feasible remediation alternative.

HRC® Pilot Test: $20,000
HRC® Full Scale: $4,000,000 to $6,000,000 (complete treatment of source zones)
HRC® Full Scale: $500,000 to $1,500,000 (partial treatment of source zones)

4.2 Phytoremediation

Phytoremediation may be considered for application in the vicinity of Lake Kildeer in combination with enhanced *in-situ* biodenitrification or as a stand alone treatment technology. Planting and maintaining vegetation (e.g., hybrid poplar, willow, cottonwood, etc.) in the vicinity of the lake may provide long-term nitrate treatment and hydraulic control in this area. Currently, there is a fairly good stand of pine trees in the vicinity of Lake Kildeer. A pilot scale study may need to be conducted to determine if alternative trees, such as hybrid poplar or willow, can achieve treatment goals through phytoremediation mechanisms.

The cost of phytoremediation will depend on design parameters and the type of plants selected. Design parameters will greatly affect the cost of implementing phytoremediation, for example the length and width of the required planting area will determine the number of plants needed and the total acreage of site area that will require preparation for planting. Estimated costs associated with implementing phytoremediation in the vicinity of Lake Kildeer are provided below, but may vary based on design parameters.

Plant Price Range: $2 to $10 per cutting/pole, $20 to $40 per bare root tree
Plants: $20,000 (assumes 4,000 cuttings at $5 each)
Design Services: $15,000 to $35,000
Site Preparation: $30,000 to $60,000
Planting: $40,000 to $80,000
Annual O&M: $5,000 to $15,000

4.3 Ex-situ Treatment

EDCC is in the process of considering wastewater treatment alternatives for process water and storm water, which would include a nitrate treatment component. Since a wastewater treatment system will possibly be available to treat nitrate, it may be cost effective to install an extraction well system within the source zone at the production area and pump groundwater to the wastewater treatment system. During development of the wastewater treatment system, the design should include consideration for additional hydraulic and treatment capacity for nitrate contaminated groundwater.

Estimated costs associated with implementing a pump and treat option are provided below, but will vary based on design parameters. Design of the groundwater recovery system will depend on the target cleanup goals and time frame for reaching the target cleanup goals. Confirmation of the hydraulic conductivity of the subsurface environment will be required to assist with design of the recovery system and will affect the number of wells required, potential pumping rates, and radius of influence of each well.

Extraction System:	$50,000 to $600,000
Treatment System:	No capital cost if treatment system already in place, but increase in wastewater treatment system O&M (e.g., carbon source).

4.4 Monitored Natural Attenuation

Enhanced *in-situ* biodenitrification, phytoremediation, and/or pump and treat are potential remediation alternatives. However, monitored natural attenuation may be implemented as a stand alone treatment alternative or utilized in combination with another technology. Site conditions are favorable for implementing monitored natural attenuation, most importantly because nitrate contamination is not currently affecting or threatening potential downgradient receptors. An important factor for implementing monitored natural attenuation is elimination of additional contaminant loading at the source zone.

A monitored natural attenuation program would include development of a sampling and analysis plan that would provide a basis for collecting comprehensive groundwater data at the site. Groundwater monitoring information would not only determine the natural attenuation capacity of the subsurface environment, but could provide insight into the effectiveness of enhanced *in-situ* biodenitrification, phytoremediation, and/or pump and treat technologies, if implemented. The monitoring program could also provide information regarding the need to continue source zone reduction, detect downgradient migration of nitrate, and assist with determining if a contingency plan needs be implemented.

The major costs associated with monitored natural attenuation include sampling and analysis plan development, monitoring well installation (if additional wells needed), groundwater sampling, analytical testing, modeling, and reports. Estimation of the cost will depend on the site specific sampling and analysis plan that is developed, which will outline requirements such as monitoring frequency, sampling parameters, analytical requirements, and other variables that will affect cost. Estimated costs associated with implementing monitored natural attenuation are provided below.

Sampling and Analysis Plan:	$8,000 to $16,000
Groundwater Monitoring:	$15,000 to $45,000 annually (Estimate may vary based on sampling frequency, required monitoring parameters, and analytical costs.)
Modeling and Reports:	$10,000 to $30,000 annually (Estimate may vary based on monitoring, modeling, and reporting requirements.)

5.0 Summary

EDCC is investigating options for groundwater remediation of nitrate. An initial conceptual model for the nitrate impacted groundwater at EDCC has been developed and applicable *in-situ* remediation technologies have been reviewed. Based on current information, monitored natural attenuation is the treatment system recommended for remediation of nitrate impacted groundwater at EDCC. The remediation plan for the site should be developed to provide flexibility and allow for remediation process optimization as additional information becomes available during site activities. In addition to monitored natural attenuation, a pump and treat system at selected locations may be a viable alternative to reduce nitrate concentrations at the source zone, if necessary. However, this recommendation is based on the assumption that a wastewater treatment system to treat process water and storm water will be available to treat excess recovered groundwater. Enhanced *in-situ* biodenitrification and phytoremediation may also be applicable treatment technologies, but cost may limit the applicability of these technologies to treatment in the vicinity of Lake Kildeer. In addition, a contingency plan should be developed and available for implementation in the event that the selected remediation system does not perform as expected.

During the upcoming groundwater sampling events, additional groundwater parameters should be evaluated (e.g., redox, dissolved oxygen, dissolved iron, total organic carbon, etc.) to assist with the development of information regarding the applicability of monitored natural attenuation (see Table 2.2). Hydraulic conductivity values for the shallow groundwater are based on data and information provided in previous reports by Woodward-Clyde. Additional testing may need to be conducted to confirm the hydraulic conductivity of the shallow groundwater. The hydraulic conductivity will have a considerable affect on the design and cost of treatment technologies.

Review of Nitrate Remediation Options

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