
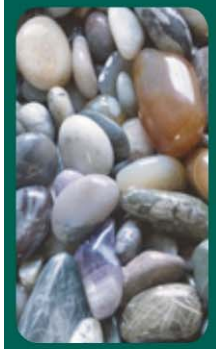

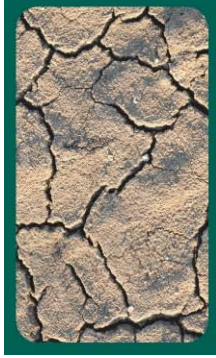

THE USE OF MONITORED NATURAL ATTENUATION TO MANAGE ENVIRONMENTAL RISK AT A SITE CONTAMINATED BY PETROLEUM HYDROCARBONS

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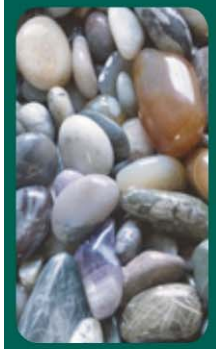
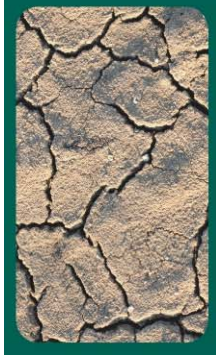
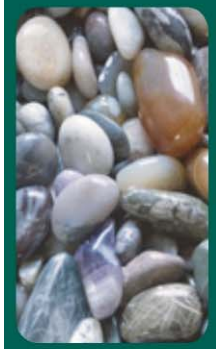
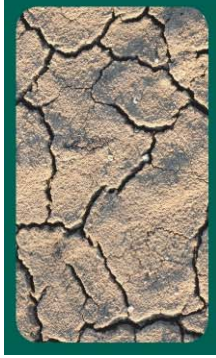




Outline

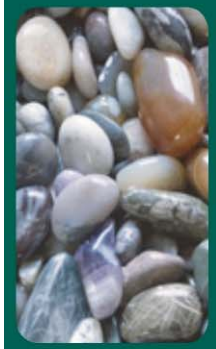
- Introduction
- Site Description
- Background Information
- Site Geology and Hydrogeology
- Hydrocarbon Plume Distribution
- Monitored Natural Attenuation (MNA)
- MNA Results
- Conclusions

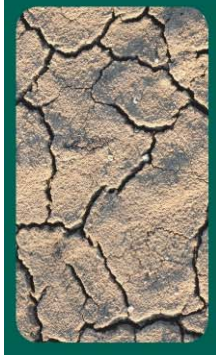





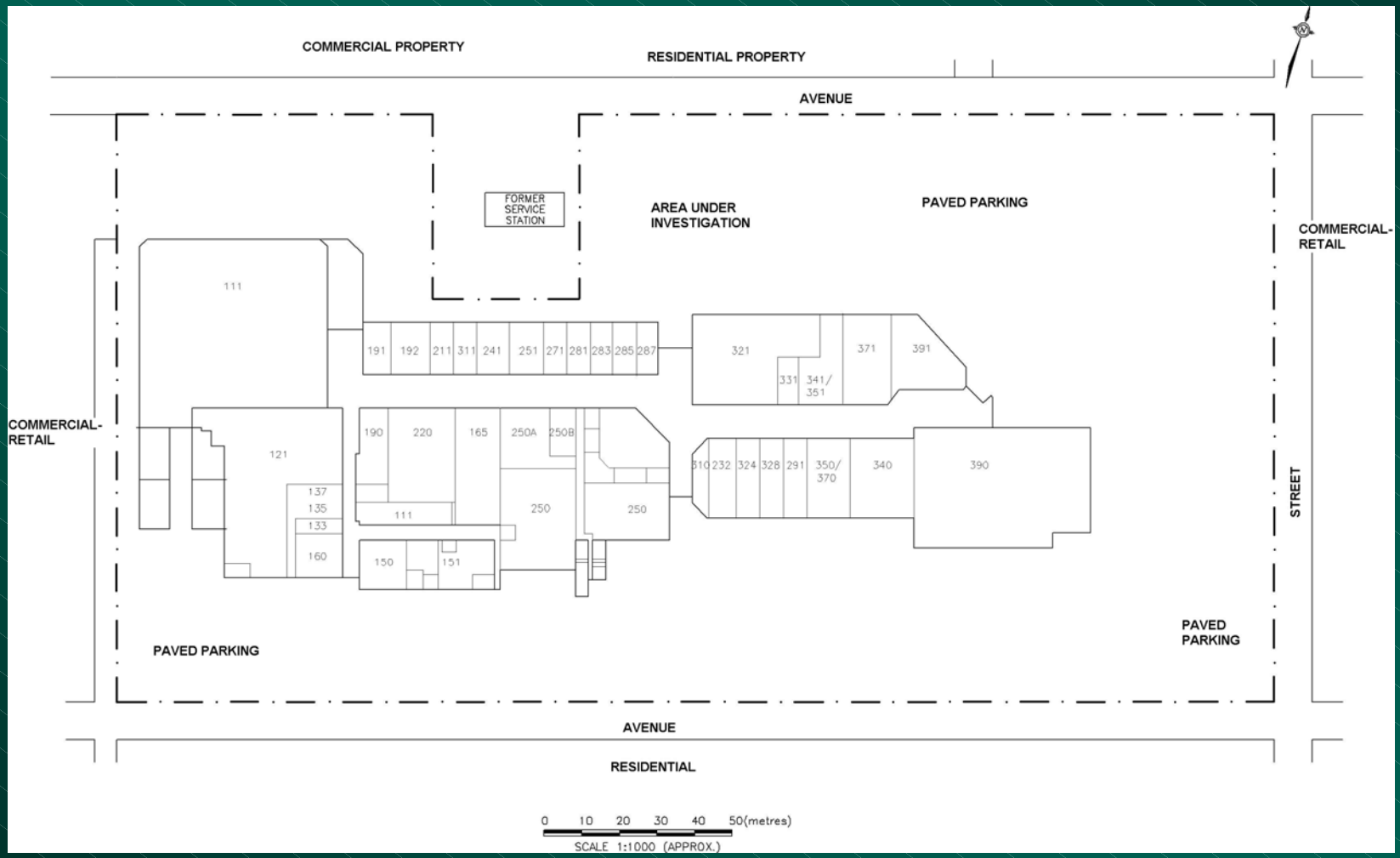
Introduction

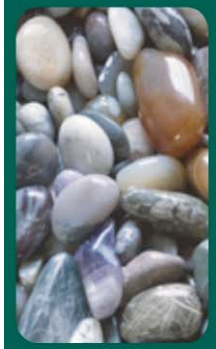
- Golder was retained by Adason Properties Limited (now Great West Life Realty Advisors Inc.) in 1999 to assess a hydrocarbon contaminated site and implement a risk management plan.
- Six-stage iterative process:
  - Problem definition;
  - A site-specific risk assessment;
  - Examining options for addressing risks;
  - Selecting the preferred options;
  - Implementing the preferred options; and
  - Evaluating the action.

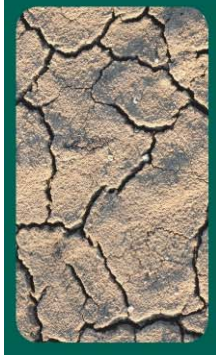




Site Description

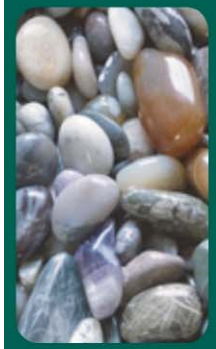


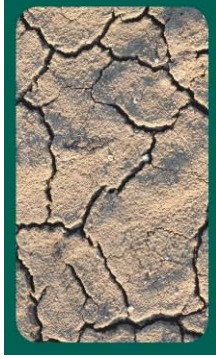





Background Information

- The former service station property operated as an auto repair facility from 1972 to 1983 (no gasoline service).
- Underground storage tanks (USTs) were installed in 1983 at the service station and operated to 1990.
- In 1990, the USTs were replaced. During the replacement of the USTs, visible hydrocarbon contamination was reportedly observed.

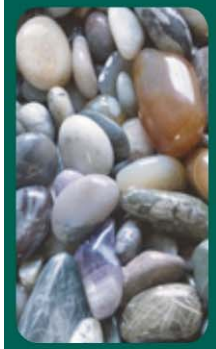


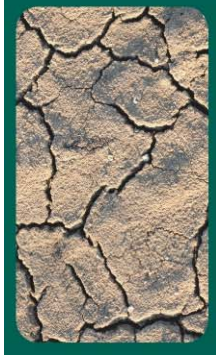
Background Information

- In August/September 1999 Golder was retained to monitor the removal of the USTs and associated petroleum hydrocarbon impacted soil from the service station property.
- Approximately 5,000 tonnes of contaminated soil was excavated and removed from the service station property.
- Following the removal of the impacted soil, residual hydrocarbon impacts remained on the service station

Background Information

Background Information





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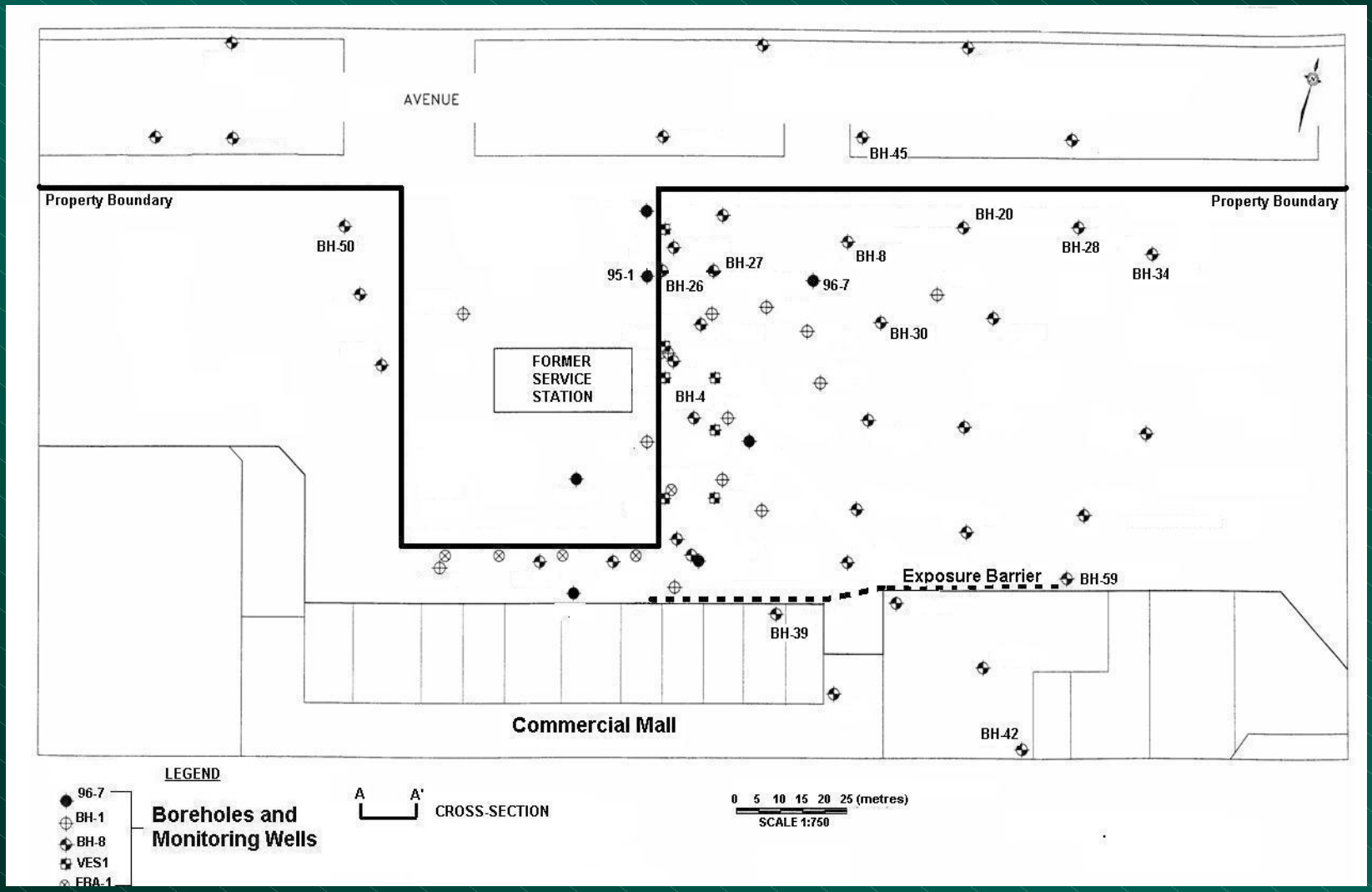
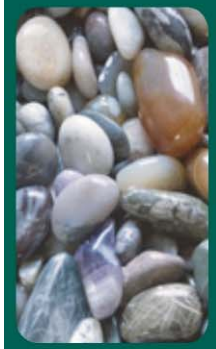
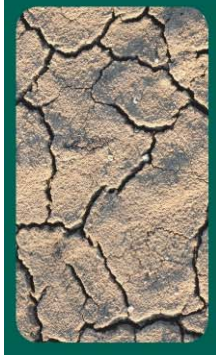


Background Information

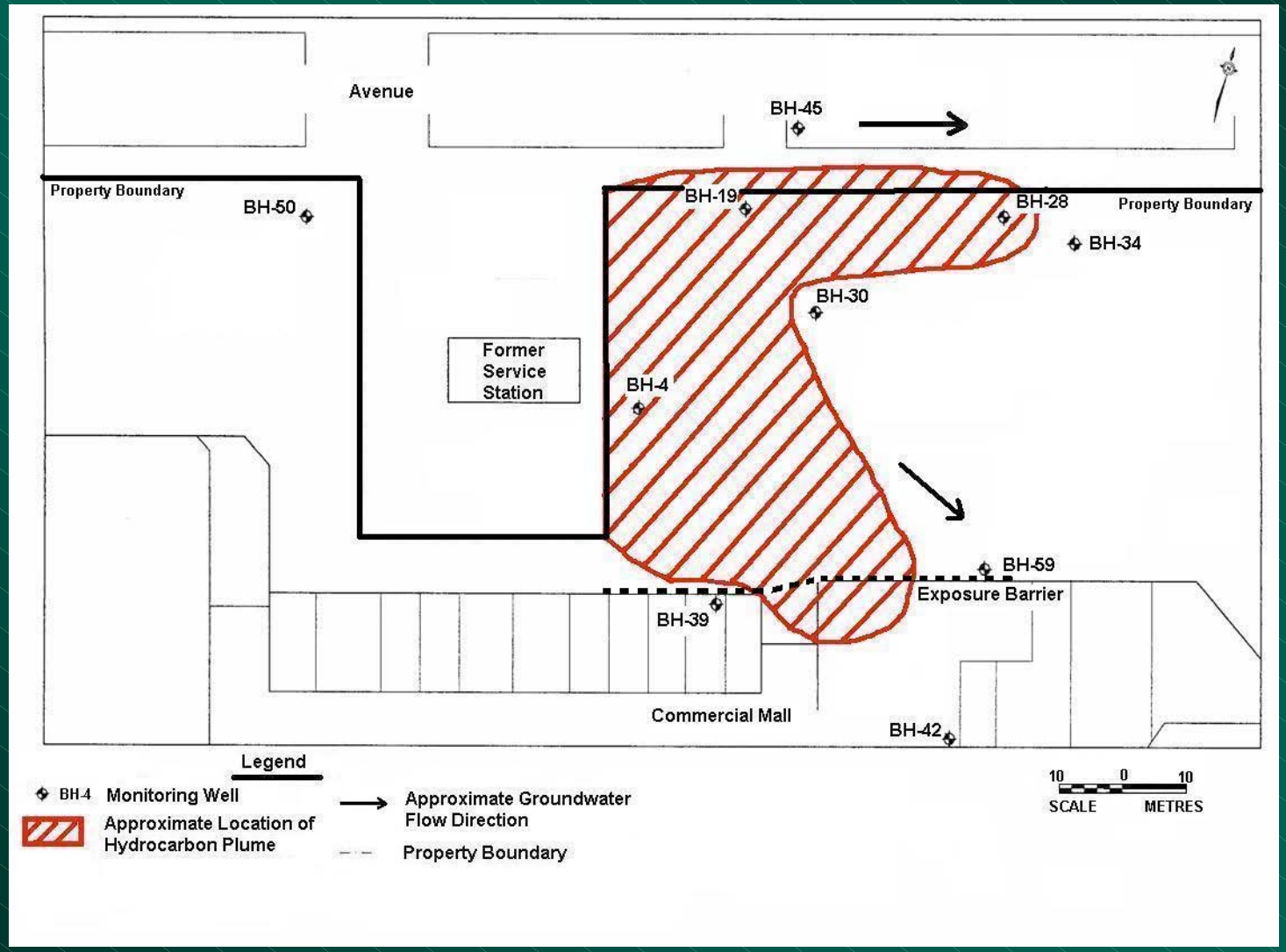



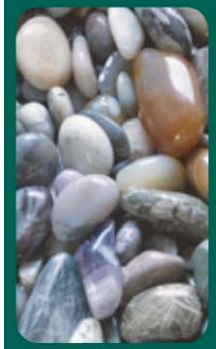


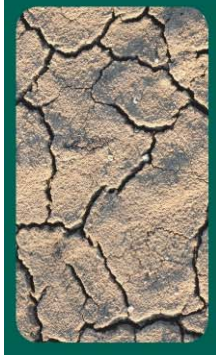
Site Geology and Hydrogeology

- Sub-surface stratigraphy consists predominantly of silty sand with inter-bedded silty clay.
- Water table has been measured at depths ranging from 1.9 to 4 metres below ground surface.
- Groundwater velocity ranges from approximately 2 to 5 m/year.

Hydrocarbon Plume Distribution

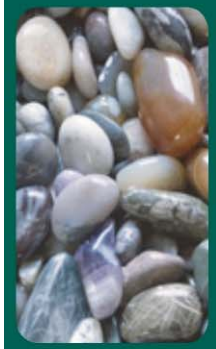


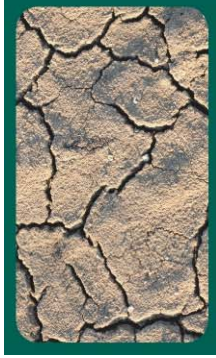





Site-Specific Risk Assessment

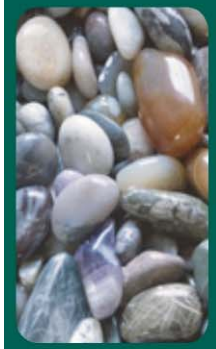
- In the fall of 2000, a Site-specific risk assessment was completed - no risks to human health were predicted.
- As a result of the depth and location of the hydrocarbon plume, monitored natural attenuation (MNA) was selected as the preferred risk management strategy for the Site.

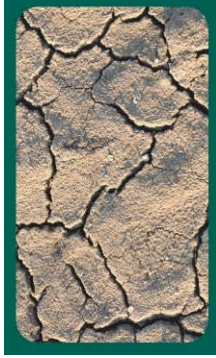





Monitored Natural Attenuation (MNA)

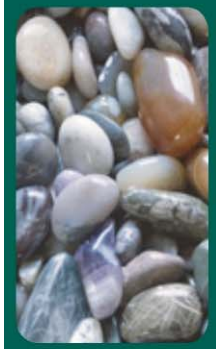
- Refers to a variety of physical, chemical, or biological processes that, under favorable conditions, act without human intervention to reduce the mass, toxicity, mobility, volume, or concentration of contaminants in soil or groundwater (US EPA, 1999).

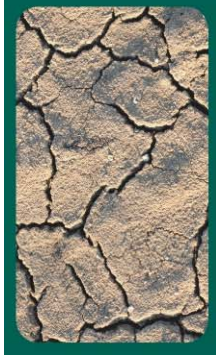





Monitored Natural Attenuation (MNA)

- The processes for MNA include: biodegradation; dispersion; dilution; sorption; volatilization; chemical or biological stabilization; transformation; or destruction of contaminants.
- MNA can reduce the potential risk posed by site contaminants by:
  1) destructive biodegradation and chemical reaction;
  2) reducing concentrations; or
  3) reducing mobility or bioavailability.

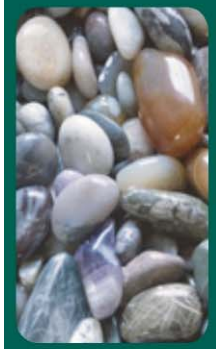


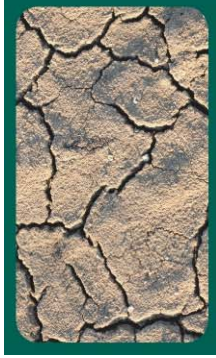
MNA Process of Biodegradation

- One of the most important components of Natural Attenuation.
- Biodegradation is an electron transfer process.
- Energy released is used by microbes to sustain metabolism and growth.
  - For example:

$$\underset{\text{Benzene}}{C_6H_6} + \underset{\text{Oxygen}}{7.5O_2} \rightarrow \underset{\text{Carbon Dioxide}}{6CO_2} + \underset{\text{Water}}{3H_2O}$$

Michael B. and T. Wiedemeier, 2000. Natural Attenuation for Remediation of Contaminated Sites Short Course.

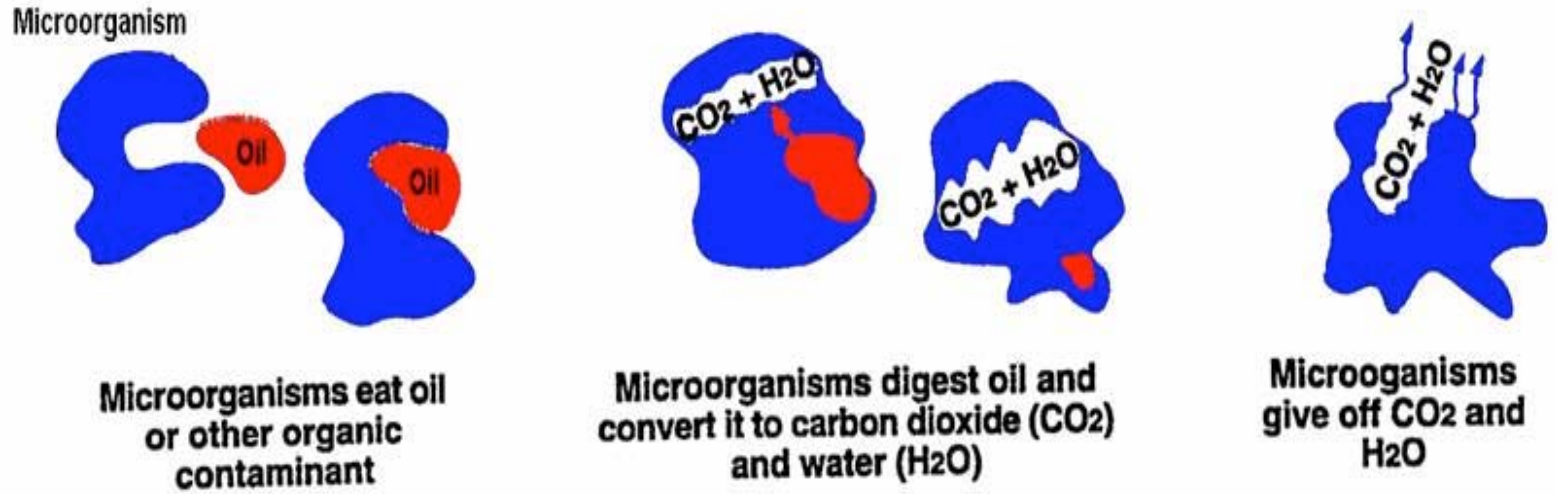





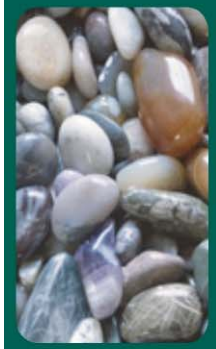
MNA Process of Biodegradation

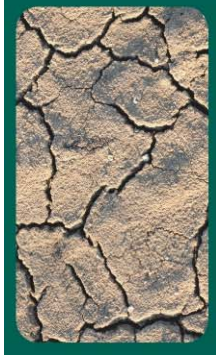
- Biodegradation can be understood in terms of redox chemistry
  - Electron donors are what microbes “eat”
    - Natural organic carbon
    - Organics such as fuel hydrocarbons
  - Electron acceptors are what microbes “breath” (respiration)
    - Naturally occurring
    - Oxygen (O_2), nitrate (NO_3), iron (Fe^{3+}), sulphate (SO_4) and carbon dioxide (CO_2).

MNA Process of Biodegradation



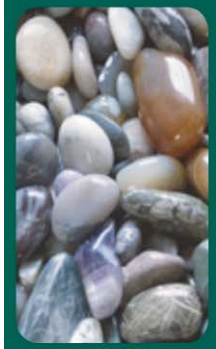
US EPA, 1996. A Citizen's Guide to Natural Attenuation

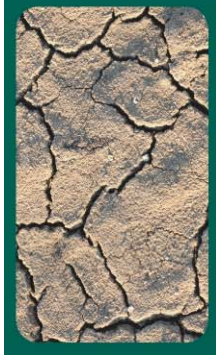





Geochemical Patterns Associated with Microbial Respiration

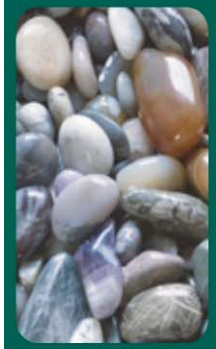
- Aerobic respiration
- Denitrification (nitrate reduction)
- Iron reduction
- Sulfate reduction
- Methanogenesis (CO_2 reduction)

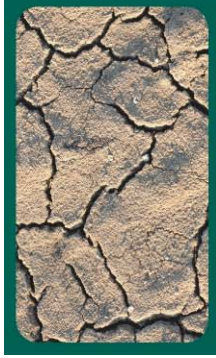





MNA Program

- The MNA program for the site involves sampling selected wells semi-annually (spring and fall) for a period of three years to:
  - Demonstrate the progressive natural attenuation of petroleum hydrocarbon contaminants in groundwater; and
  - Determine if MNA will degrade the hydrocarbon concentrations in the groundwater to concentrations below the applicable criteria.

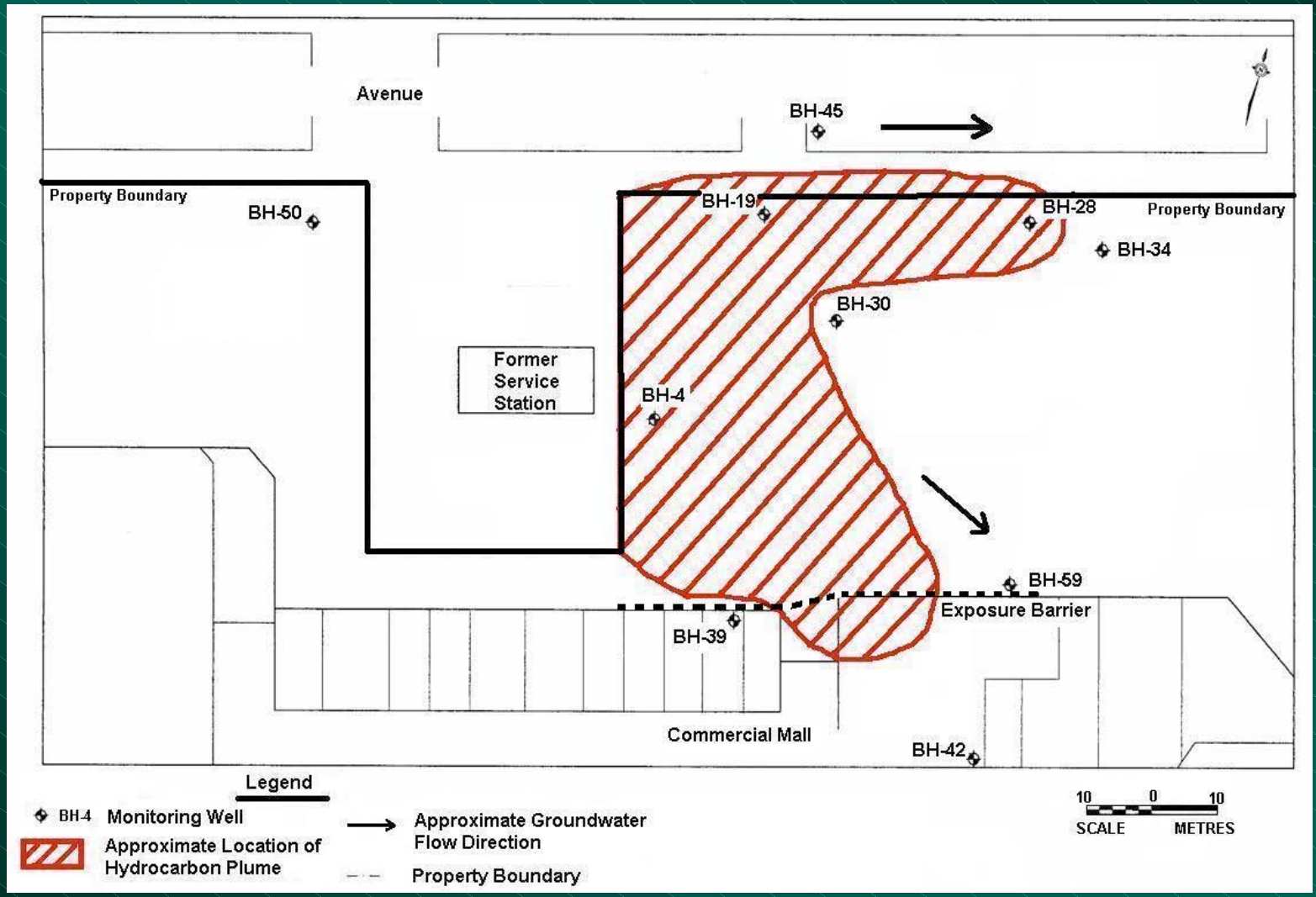


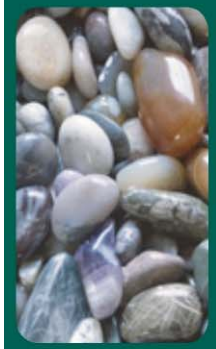
MNA Program

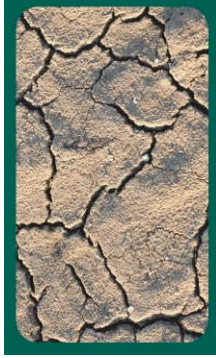
- The occurrence of natural attenuation is typically evaluated based on the following two lines of evidence consisting of:
  1. The documented loss of contaminants at the field scale supported by time series groundwater monitoring data; and
  2. Contaminant and geochemical analytical data that provide an indication of the degradation process (and estimate the magnitude) are required and supported by a survey of available electron acceptors used by bacteria for the biological oxidation of hydrocarbons.

Michael B. and T. Wiedemeier, 2000. Natural Attenuation for Remediation of Contaminated Sites Short Course.

Location of MNA Wells

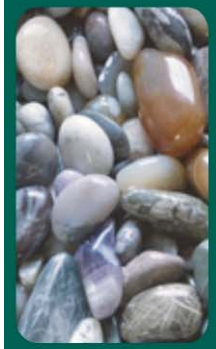


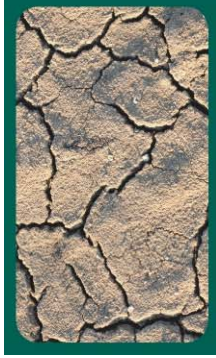





MNA Sampling Plan

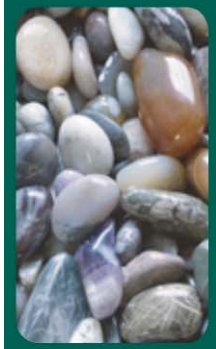
- Collection of field parameters consisting of: dissolved oxygen (DO), oxidation/reduction potential (ORP), pH, conductivity and temperature.
- Chemical analysis of nitrate, dissolved iron (ferrous iron), alkalinity, sulphate, carbon dioxide, methane, benzene, toluene, ethylbenzene and xylenes (BTEX), total volatile hydrocarbons and total extractable hydrocarbons.

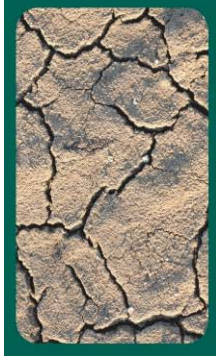





MNA Results

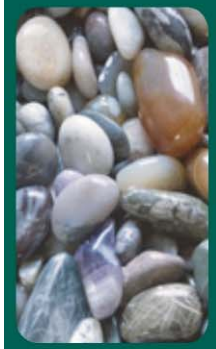
- Several lines of evidence support the progress of the degradation of petroleum hydrocarbons within groundwater at the Site. These include:
  - Reducing concentrations of hydrocarbon parameters with time;
  - Minor decreases in dissolved oxygen within the plume and downgradient of the plume. However, the plume is considered to be anaerobic due to the low concentrations (typically less than 2 mg/L) of naturally occurring oxygen in the groundwater;

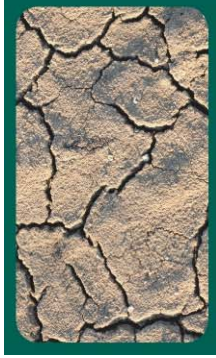





MNA Results

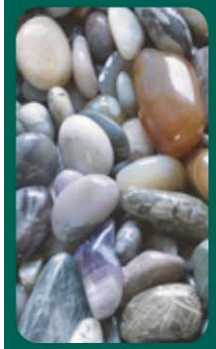
- Minor increasing concentrations of methane (methanogenesis). However, low concentrations of methane suggest that methanogenesis is not a significant process degrading hydrocarbons;
- Decreasing values of nitrate (through nitrate reduction) measured within and downgradient of the plume. However, this is a minor process due to the low concentrations of naturally occurring nitrate in the groundwater (typically below 5 mg/L);

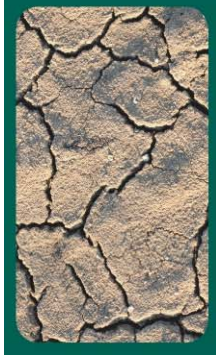





MNA Results

- Decreasing values of sulphate (through sulphate reduction) within and downgradient of the plume; and
- Substantial increases in ferrous (II) iron within and downgradient of the plume.

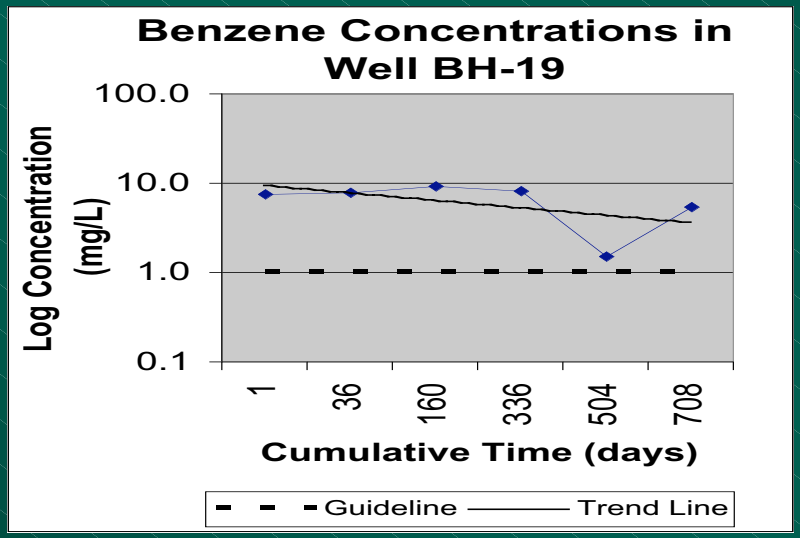



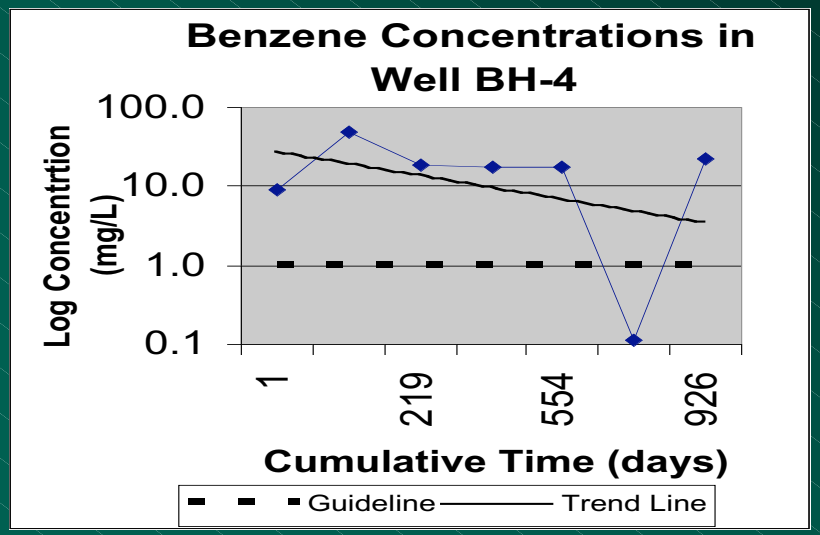


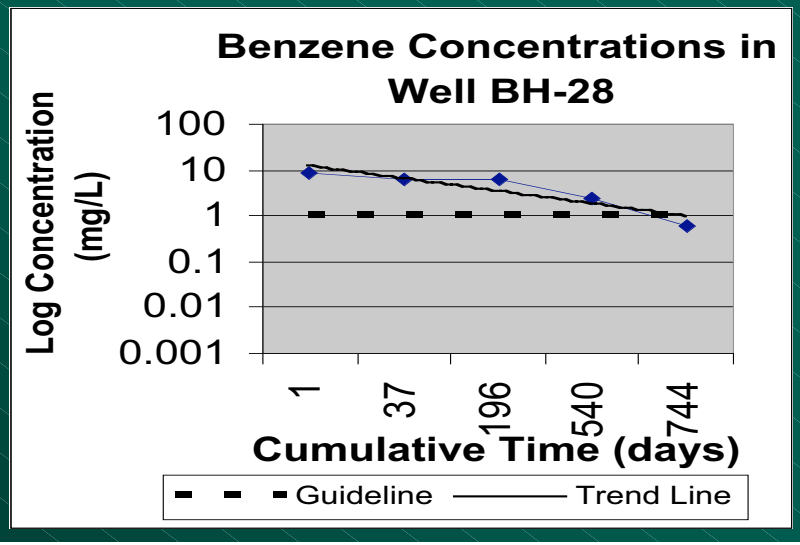
MNA Results

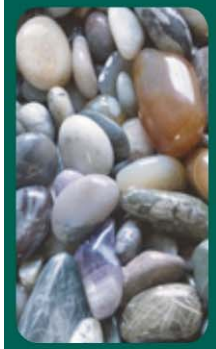
- Historical concentrations of toluene, ethylbenzene and xylenes measured in all 10 wells used for MNA have continually been below the AENV 2001 guidelines for a commercial site having coarse grained soil.
- Hydrocarbon results will be focused on benzene concentrations.

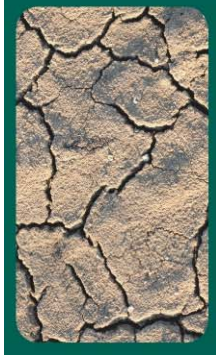
Results - Wells Within the Plume



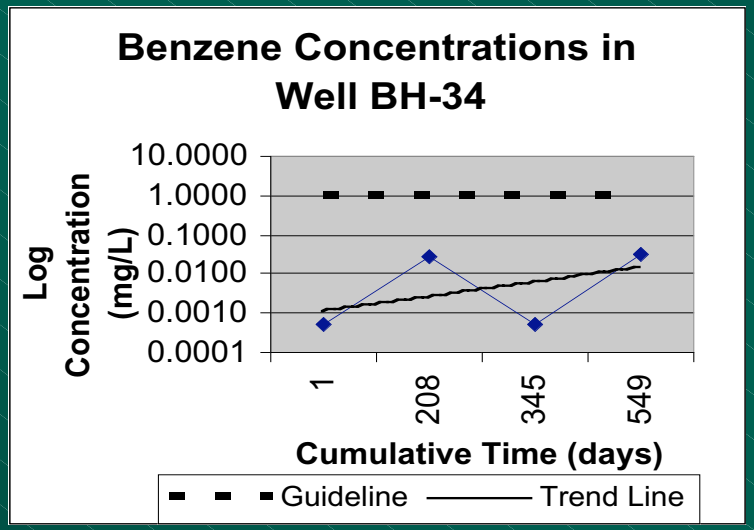


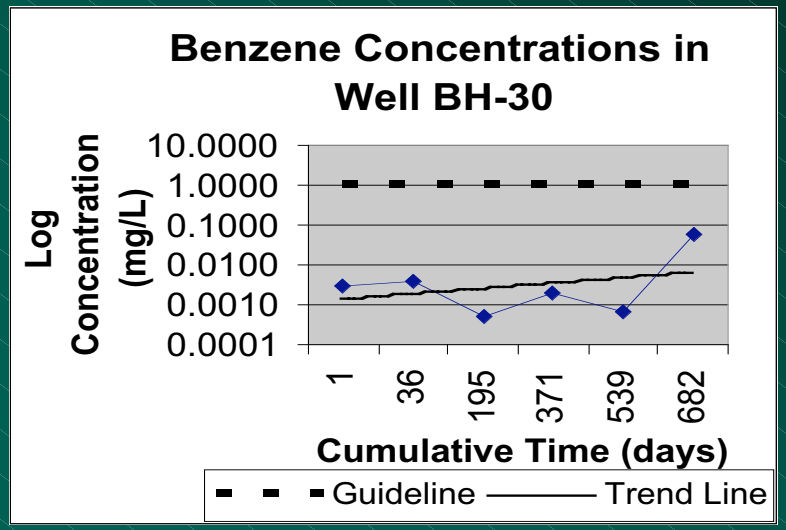


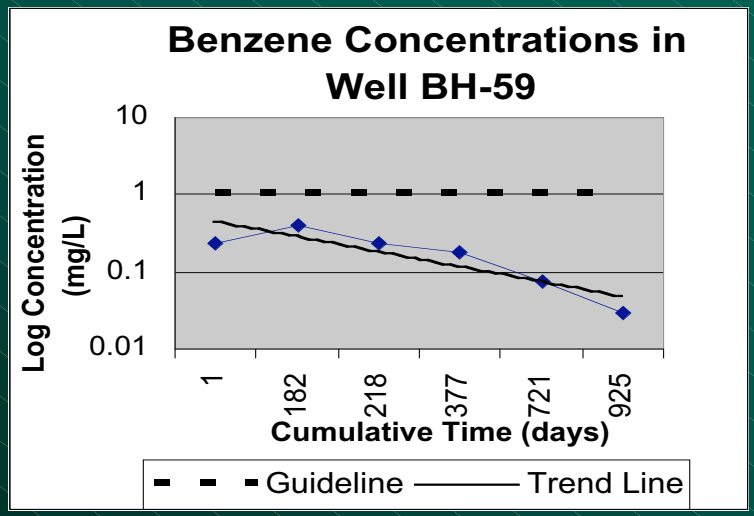



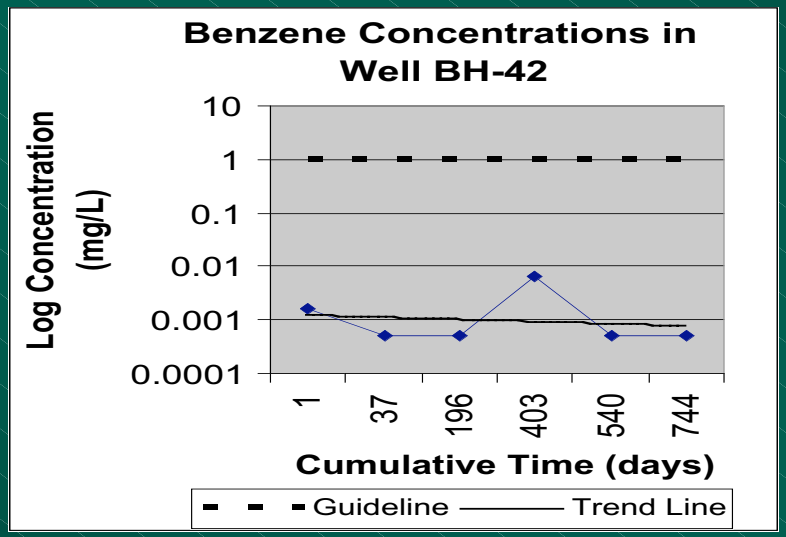


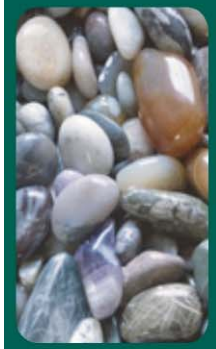
Results - Wells Downgradient of the Plume

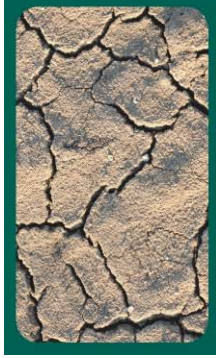






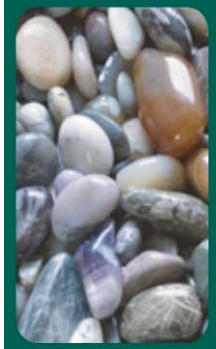


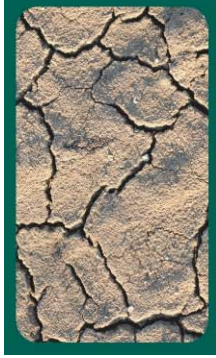





MNA Results

- Concentrations of hydrocarbon parameters are generally decreasing suggesting that the plume is shrinking.
- The time series data do not fit a first-order decay regression analysis which is likely an indication that the plume is being remediated at a very slow rate, which can be indicative of anaerobic plumes.

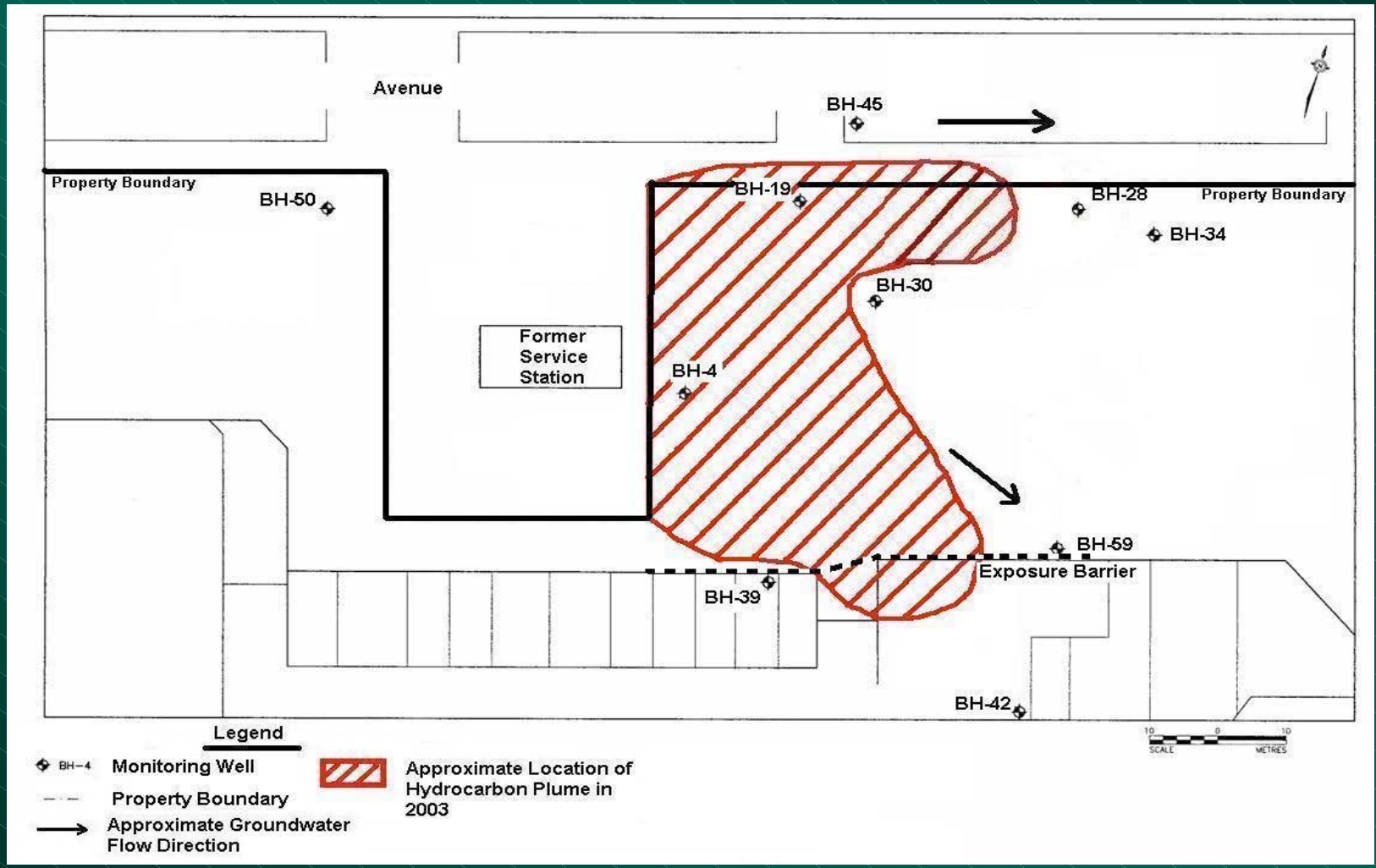



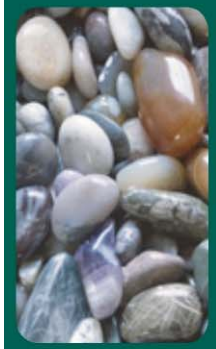


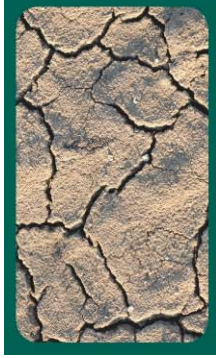
MNA Results

- Although MNA is acting to reduce the hydrocarbon concentrations below the applicable criteria at the edges of the plume, elevated concentrations of benzene ranging from 5 to 22 mg/L still exist within the central portion of the plume.

Plume Distribution Spring 2003

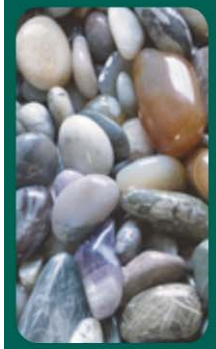


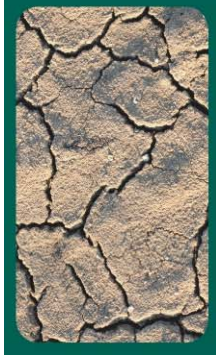





Conclusions

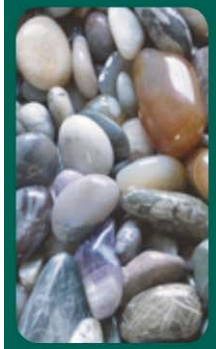
- Semi-annual monitoring for the first two and-a-half years of MNA data has been presented.
- Based on the low background oxygen concentrations, the plume is considered to be anaerobic.
- Iron reduction and sulphate reduction are the two main processes occurring to breakdown hydrocarbons in groundwater.

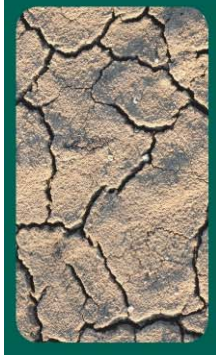





Conclusions

- Concentrations of hydrocarbon parameters are generally decreasing suggesting that the plume is generally shrinking.
- Benzene concentration trend lines do not fit a first-order regression analysis, which is likely an indication that the plume is being remediated at a very slow rate.



Conclusions

- After 2.5 years of monitoring, benzene concentrations close to the former source area are still 22 times higher than the benzene criteria of 1 mg/L. However, the current benzene concentration at this location is less than half of the maximum measured concentration of 50 mg/L.
- As a result of the decreasing hydrocarbon concentrations, environmental risk at the Site can be managed with monitored natural