TECHNOLOGY SELECTION FOR GASOLINE-IMPACTED GROUNDWATER

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Abstract

A key to cost-effective remediation of dissolved gasoline constituents is selection of the appropriate technology for a given site. Through the authors collective experience remediating scores of gasoline release sites, we offer some general guidelines on selecting the most appropriate and least-cost solutions. This paper focuses on ex situ treatment technologies associated with extraction of dissolved gasoline constituents. Technologies include air sparging/soil vapor extraction (AS/SVE) followed by off-gas treatment, and groundwater extraction followed by ex-situ treatment. Ex-situ groundwater treatment options include air stripping, granular activated carbon (GAC) adsorption, and bioreactor treatment. How to decide? The decision is site-specific, depending on such factors as contaminant types and concentrations, groundwater and soil vapor extraction rates, soil heterogeneity, depth to groundwater, groundwater flow rate, proximity to receptors, required cleanup concentrations, site access, and utilities. Often, total remediation costs are minimized by switching technologies as extracted concentrations decrease. Tracking contaminant mass loadings and actual monthly remediation costs, along with estimated monthly costs for alternative technologies, can provide a useful tool to help decide when to switch technologies. Three sites were examined. An AS/SVE case study confirmed the common rule of thumb that vapor treatment should be switched from catalytic oxidation to GAC when petroleum hydrocarbon concentrations fall to approximately 200 parts per million. A second case study of groundwater extraction and treatment of petroleum hydrocarbons indicated that at mass loadings of 1.5 pounds per day or more, air stripping followed by vapor-phase GAC was more cost-effective, whereas at mass loadings lower than this, direct GAC adsorption was more cost-effective. A third case study, of groundwater extraction and treatment at a site where MTBE is the primary contaminant, found that at mass loadings greater than 5,000 gpm-µg/L, bioreactor treatment was more cost-effective than GAC adsorption; whereas at lower mass loadings, GAC adsorption was more cost-effective.

Introduction

Effective cost management of groundwater remediation systems involves several key components including:

- Selecting the optimal remediation strategy;
- Selecting the appropriate extraction and ex situ treatment equipment (type and size); and
- Knowing when to change remediation technology and/or equipment.

Selecting the optimal remediation strategy and equipment is based on a site-specific conceptual model and pilot testing at the site. All too often, it is assumed that a remediation technology that worked well at one site will work just as well at another, which may not be the case if subsurface conditions or the nature of the contamination is different. Using an ineffective remediation system often results in long cleanup times and/or excessive costs.

Over time, as properly selected, situated, and sized remediation equipment operates (and assuming the sources of contamination have been properly identified and controlled), the size of the dissolved plume should shrink and extracted concentrations should decrease. At some point in time, the initial remediation system may no longer be the most cost-effective. One example would be an air sparging/soil vapor extraction (AS/SVE) system that initially removes large quantities of volatile organic compounds (VOCs) from the subsurface. A thermal or catalytic oxidizer for off-gas treatment may be optimal at first, but over time as extracted concentrations decrease, vapor-phase GAC treatment may become more cost-effective.

This paper examines the operation and maintenance (O&M) costs over time of several existing ex situ treatment systems and plots these along with O&M costs for alternative technologies suited for lower concentrations or mass loadings to determine whether system modifications could be anticipated based on contaminant concentrations or mass loading rates. (Mass loading is water or air extraction flow rate times the total concentration of VOCs in the extracted stream.) This is a useful way to determine when a new ex situ treatment technology is warranted.

This paper focuses on ex situ treatment technologies associated with AS/SVE and pump and treat systems used to extract dissolved gasoline constituents after free product has been removed. Contaminant extraction technologies are generally employed when dissolved concentrations are elevated, and in situ technologies are typically employed when dissolved concentrations are lower (although there are many exceptions to this). Three sites are discussed below. These sites are all being remediated by large oil companies that own a wide selection of remediation equipment that can be deployed to sites as needed. Thus, the cost calculations below do not include capital costs. The method below would need to be modified to include capital costs of new equipment for sites that do not have readily available equipment on hand and would need to purchase the equipment. One way to do this would be to amortize the capital cost over the length of time the equipment is anticipated to be needed and add those costs to the monthly O&M costs.

Remediation Systems Examined

Air Sparging/Soil Vapor Extraction System – Petroleum Hydrocarbons Only

AS/SVE is the process of injecting ambient air into the aquifer through injection wells, and then removing air from the vadose zone for aboveground treatment. AS/SVE is effective at removing dissolved gasoline hydrocarbons. AS/SVE is marginally effective for removing very low concentrations of ether oxygenates such as methyl tertiary butyl ether (MTBE). AS/SVE is not effective for tertiary buytl alcohol (TBA) at any concentration unless the mechanism is biostimulation, i.e., adding oxygen to stimulate TBA-degrading microorganisms that are already present in the aquifer.

Selection of the most cost-effective ex situ treatment technology for the VOCs removed by AS/SVE depends on the mass loading, and in the case of vapor-phase GAC, on the constituents present. Because vapor treatment equipment is sized for a relatively narrow range of flow rates, mass loading can be approximated simply by the total VOC concentration. Typical ex situ VOC treatment systems are thermal or catalytic oxidizers and vapor-phase GAC. A general rule of thumb often used is that for concentrations greater than 2,000 parts per million by volume (ppmv), a thermal oxidizer is best; for concentrations between 200 and 2,000 ppmv, a catalytic oxidizer (catox) is best; and for concentrations <200 ppmv, granular activated carbon (GAC) adsorption is best (unless fuel oxygenates like MTBE or TBA are present). ERI has moved away from thermal oxidizers due to their high capital costs and initial O&M costs. In cases where initial vapor concentrations would exceed 2,000 ppmv, ERI instead uses a catox, introducing dilution air to bring the vapor concentrations to below 2,000 ppmv during initial operation and then gradually reducing the amount of dilution air as extracted concentrations decrease with time.

The AS/SVE site selected for review is an operating gasoline station in Central California at which the primary contaminants are petroleum hydrocarbons. Low concentrations of MTBE are also present but are too low to drive the remediation. The site conceptual model reveals an estimated 30,000 pounds of hydrocarbons initially present in the soil. Depth to groundwater is approximately 110 feet. Concentrations of dissolved petroleum hydrocarbons were initially up to 5,100 micrograms per liter (µg/L), and MTBE concentrations in groundwater were up to 100 µg/L. AS/SVE was used to address both soil and groundwater at this site. The particular remediation system consists of an air sparge injection system and a multi-stage regenerative blower for soil vapor extraction. Extracted VOCs were treated by an electric catox.

O&M data for the catox system included: vapor extraction flow rates in standard cubic feet per minute, influent total petroleum hydrocarbon gasoline (TPHg) concentrations in milligrams per cubic meter, from which were calculated hydrocarbon mass extraction rates (or mass loadings) as total pounds of hydrocarbons extracted per day or month, and O&M costs per month including technician labor (at billing rates to the client), utilities (electricity), mileage, and miscellaneous maintenance/repair costs.

Information on this site is summarized on Figures 1a, b, and c. The actual O&M costs over time for vapor treatment using catox are plotted on Figure 1a. Estimated monthly costs for GAC treatment are also plotted on Figure 1a. The hydrocarbon mass loading rates were used to calculate the mass of vapor-phase GAC that would be required to adsorb the extracted hydrocarbons and meet the air discharge permit requirements. GAC costs were estimated at $1.35/pound of GAC, and the GAC was assumed to have an adsorptive capacity of 17 pounds of hydrocarbon adsorbed per 100 pounds of GAC (based on experience at other sites). Labor costs for GAC were estimated based on client-driven unit prices.

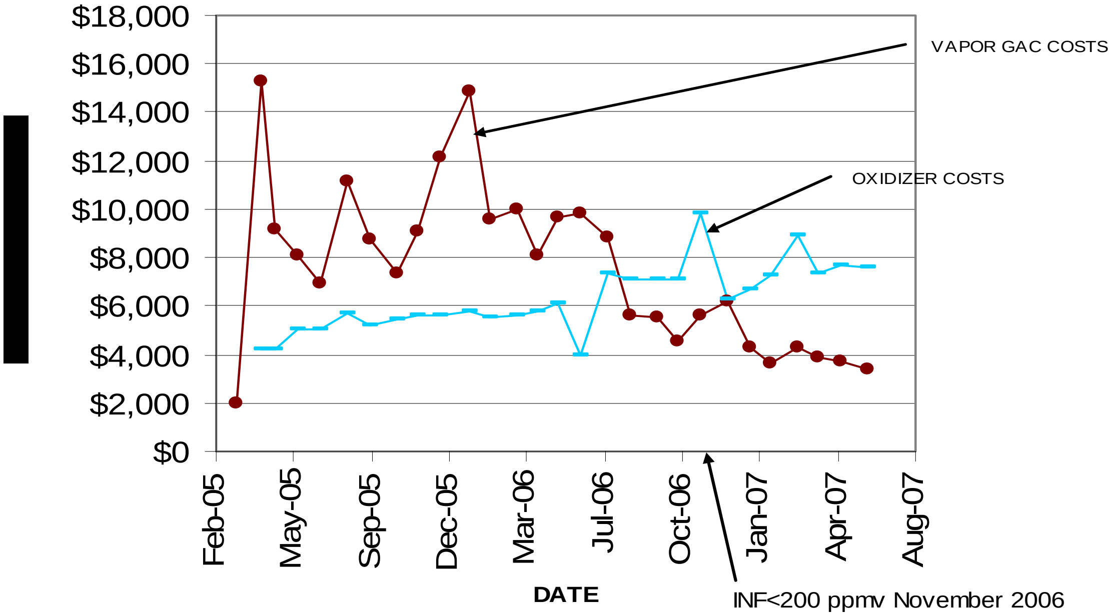
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Figure 1a. Monthly O&M Costs for AS/SVE Offgas Treatment by Catox vs. GAC

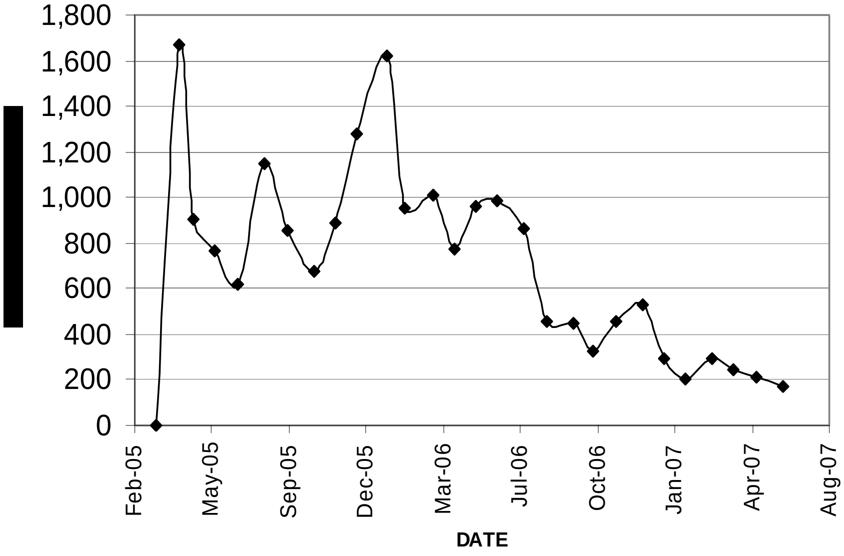
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Figure 1b. Monthly Mass Loading of Gasoline Hydrocarbons at AS/SVE Site.

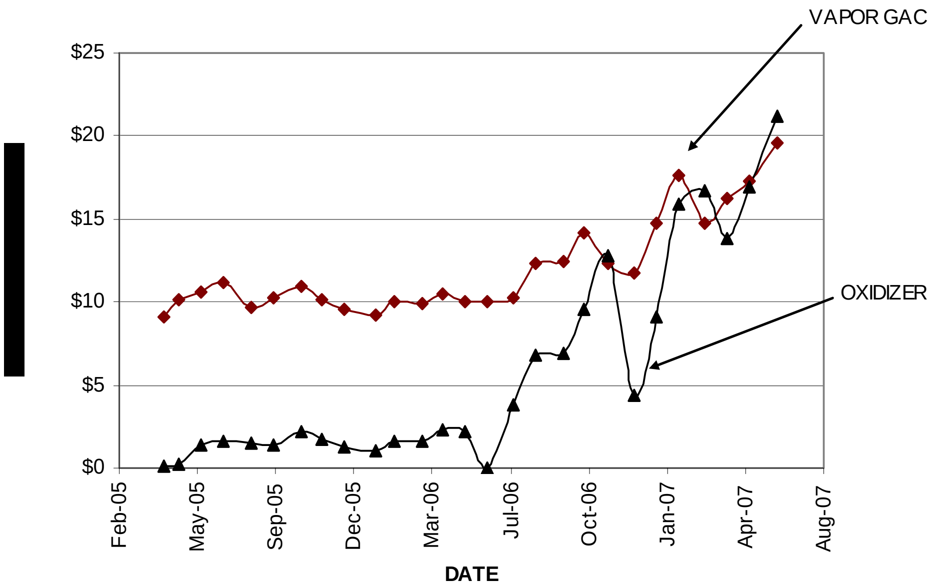

Figure 1c. O&M Costs per Pound of Gasoline Hydrocarbons Removed at AS/SVE Site

Figure 1a indicates that initially GAC treatment would have been more expensive than catox treatment. However, around August 2006, the influent hydrocarbon concentrations, and thus the hydrocarbon mass loading, had dropped and from that point on, GAC was more cost-effective. The equipment at this site however was not switched to GAC. The reason is that space for remediation equipment was extremely limited. There was room for a catox but not for GAC vessels. This illustrates the fact that other considerations besides cost-effectiveness enter into decision-making on treatment technologies, and a “cookbook” approach cannot be used. Site-specific considerations such as access may be more compelling.

Figure 1a also notes the point at which the influent TPHg concentrations fell below 200 ppmv. This occurred around November 2006. This is reasonably similar to the switchover point of August 2006 indicated by Figure 1a. Thus, at this site, as well as at over 50 other ERI sites, the 200 ppmv rule of thumb mentioned above has been confirmed to be relatively accurate.

Figure 1b shows the monthly hydrocarbon mass loading over time. Fluctuations in the data are caused by variable flow rates and hydrocarbon concentrations, partially caused by operational modifications such as turning wells on and off over time, as well as fluctuations in the up versus down time for the system month to month. Even though mass loadings are now much reduced from initial values, AS/SVE continues to extract significant mass from the subsurface, and site groundwater concentrations still significantly exceed treatment goals.

Catox and GAC O&M costs per pound of hydrocarbons extracted are also plotted in Figure 1c. Costs per pound of hydrocarbon can be calculated by simply dividing the data points in Figure 1a by the data points in Figure 1b. Several ERI clients have recently requested such evaluations. The data were examined and found to be not particularly useful for indicating when to switch remediation technologies. ERI has found similar evaluations at other sites, including the two other sites discussed below, to be inconclusive. Therefore, the paper does not pursue these types of calculations further.

Pump and Treat System – Petroleum Hydrocarbons only

Pump and treat systems are used at sites with gasoline hydrocarbon contaminated groundwater (with little if any fuel oxygenates contamination) rather than AS/SVE when plume control is required to prevent actual or potential off-site contaminant migration. This case study evaluates a pump and treat system designed to remediate TPHg in groundwater. MTBE and other oxygenates are not present at concentrations requiring remediation. Initially air stripping followed by vapor-phase GAC, along with liquid GAC for effluent polishing, was used for aboveground treatment of the extracted groundwater. Actual costs over time were compared with estimated costs of direct liquid-phase GAC treatment (i.e., without prior air stripping) to determine if and when it made sense to switch treatment technologies.

At this California site, TPHg as measured in groundwater samples from monitoring wells was present at concentrations up to 236,000 µg/L, while MTBE concentrations were up to 2,000 µg/L. Other oxygenates concentrations were very low. The publicly owned treatment works to which the treated groundwater is discharged does not have a limit for MTBE. Remediation system influent TPHg concentrations ranged up to 2,100 µg/L.

Flow rate and concentration data were gathered for this site. The stripping/vapor-phase GAC actual operating costs included technician labor costs, treatment system utility costs (estimated as 20% of the monthly site electric bills), mileage, and miscellaneous maintenance/repair costs. The liquid-phase GAC costs were estimated using the actual mass extraction rates and an estimated adsorptive capacity of liquid-phase GAC of 3 pounds of TPHg per 100 pounds of GAC and GAC replacement costs at $1.65 per pound of GAC (client prices). Vapor-phase GAC (with a replacement cost of approximately $1.35 per pound) will typically adsorb 17 pounds of hydrocarbons for every 100 pounds of GAC (depending on influent concentrations and bed contact time). By moving TPHg from groundwater to air and then removing it with vapor GAC, instead of direct liquid-phase GAC adsorption, there is a 17:3 reduction in the amount of GAC required for treatment. Information on the site is summarized in Figures 2a and b.

Figure 2a indicates that, except during approximately the first half of 2006, direct liquid-phase GAC was more cost-effective than air stripping followed by GAC. The site was switched to direct liquid-phase GAC in early 2007. Reflected in Figures 2a and 2b is that few groundwater extraction wells were operated when the remediation system was started in February 2005. As mass removal rates decreased with time, additional wells were installed and brought on line starting in late 2005, resulting in a dramatic increase in GAC usage. The use of the air stripper in the first half of 2006 resulted in a significant savings in O&M costs for that period. Figures 2a and 2b show that at a TPHg mass loading of approximately 45 pounds per month (or 1.5 pounds per day) or more, air stripping followed by GAC is more cost-effective than direct GAC adsorption, whereas at lower mass loadings, direct GAC adsorption is more cost-effective. ERI has found this to be the case at at least a dozen other sites.

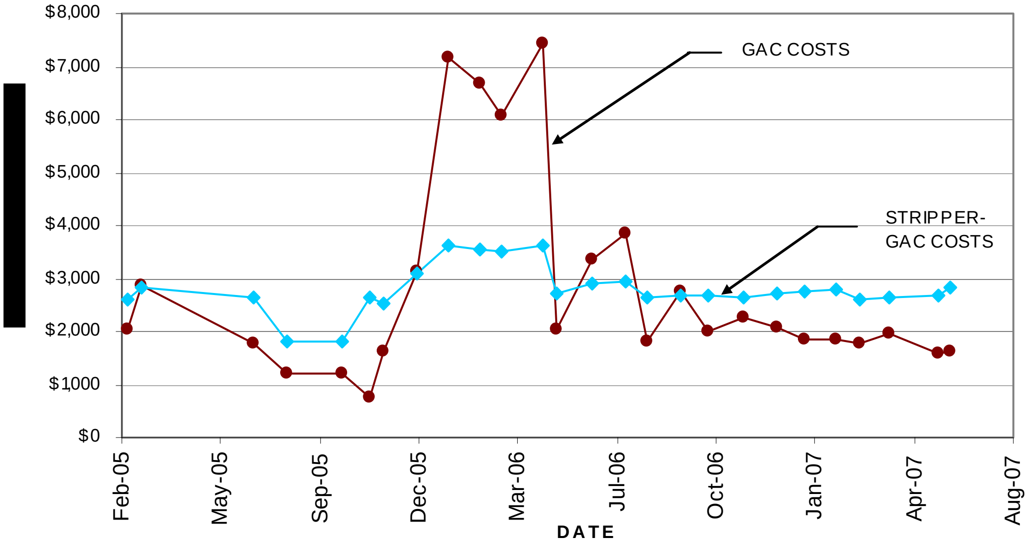
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Figure 2a. Monthly O&M Costs for Air Stripping/GAC vs. Liquid-Phase GAC

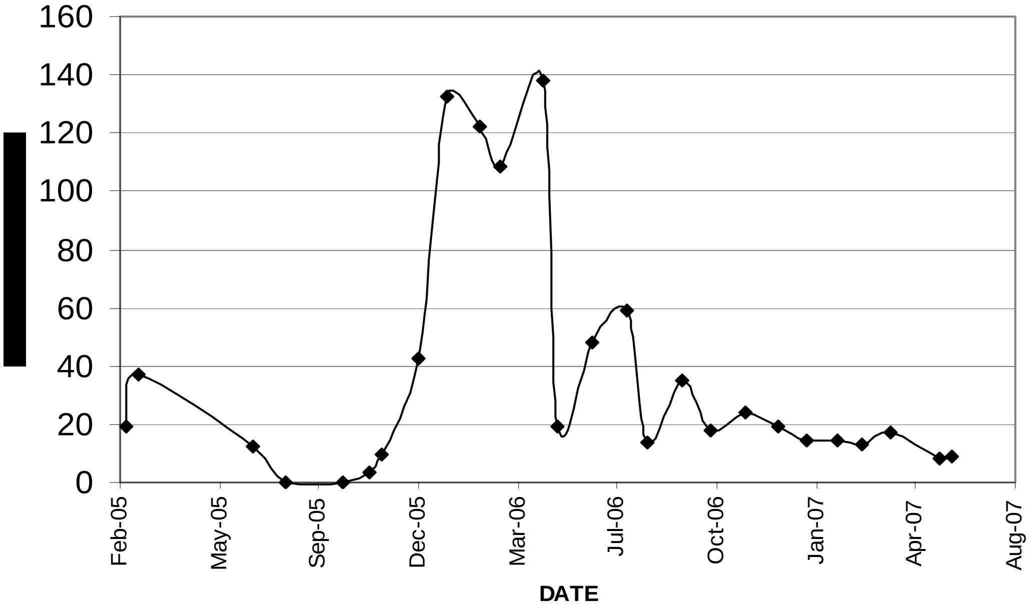
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Figure 2b. Monthly Gasoline Hydrocarbon Mass Loading at Pump and Treat Site

Pump and Treat System – Oxygenates Only

The selected site is a currently operating gasoline station in California that initially had dissolved concentrations of up to 115,000 µg/L of MTBE and up to 55,000 µg/L of TBA. Petroleum hydrocarbons were not a concern at this site, and there was no discharge limit for TBA. The MTBE could be adsorbed onto GAC; or alternatively, a bioreactor followed by GAC polishing could be used. This site was initially remediated using a bioreactor with GAC polishing, and was later switched to direct GAC adsorption.

O&M costs for a bioreactor tend to be fairly constant. GAC vessels are in place downstream to ensure that if there is an upset in the bioreactor, MTBE/TBA will not be discharged in the water effluent. Typically very little GAC is used, and GAC changeouts are infrequent if needed at all. (For more information on bioreactors, see a paper presented at this same conference by Joseph O'Connell and Ellen Moyer titled "MTBE and TBA Remediation Using Fluidized Bed Bioreactors.") O&M information for this site is summarized on Figures 3a and 3b.

As shown in Figure 3a, the monthly O&M indicate that until about May 2004, bioreactor treatment was generally was more cost-effective than direct GAC adsorption, and after that time, direct GAC adsorption was more cost-effective.

Figure 3b presents data on the instantaneous mass loading in gallons per minute – micrograms per liter (gpm-µg/L) which is calculated by directly multiplying water flow rate times total VOC concentration. (These gpm-µg/L units can easily be converted to units of pounds per day or pounds per month using the appropriate conversion factors). Figures 3a and 3b indicate that the switchover mass loading at this site is approximately 5,000 gpm-µg/L; a bioreactor is optimal for mass loadings higher than that and direct GAC adsorption is optimal for mass loadings lower than that. This change was made at the site in mid 2004 and direct GAC adsorption continues to be used. Another MTBE bioreactor site was similar; bioreactor treatment was switched to GAC when influent concentrations were approximately 200 µg/L and flow rates were approximately 20 gpm, or when the mass loading was 4,000 gpm-µg/L.

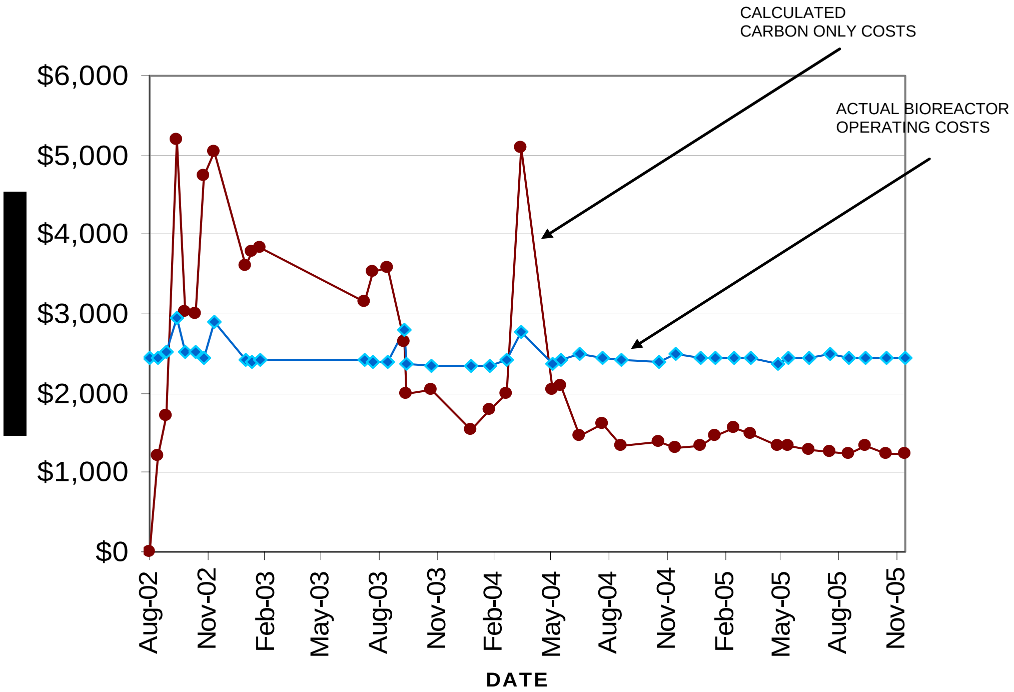
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Figure 3a. Monthly O&M Costs for Bioreactor/GAC vs. GAC Treatment

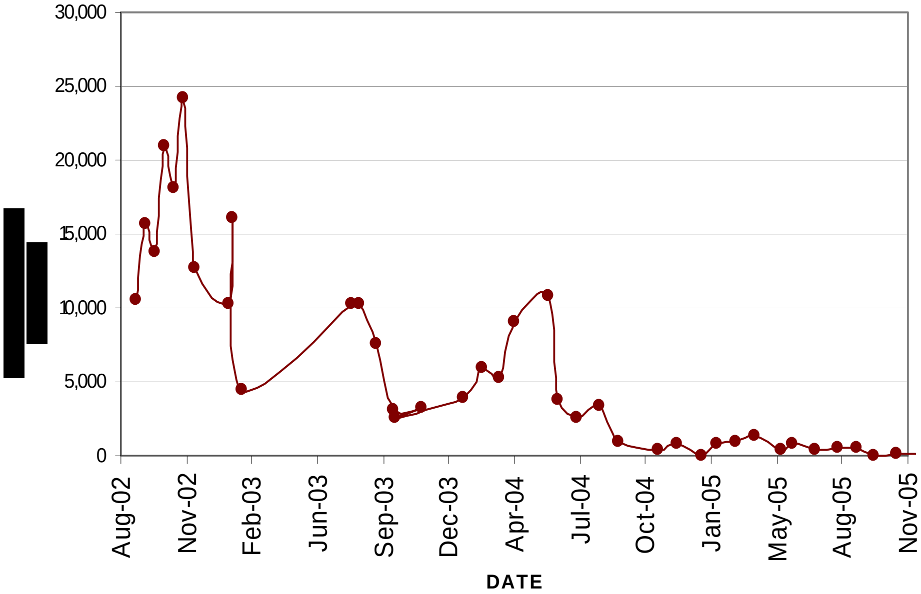
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Figure 3b. Instantaneous MTBE Mass Loading at Bioreactor Site

Conclusions

A key to optimizing remediation and minimizing costs is to know (in advance, if possible) when remediation technologies should be changed as contaminant concentrations at the site decrease. This paper examined O&M costs relative to contaminant mass loading rates at three sites to determine when ex situ treatment technologies at three sites should be switched. The paper focused on ex situ treatment technologies (catox, vapor-phase GAC, air stripping/vapor-phase GAC, liquid-phase GAC, and bioreactor treatment) associated with AS/SVE and groundwater extraction and treatment.

It is important to keep in mind that equipment switchover points will be site-specific, depending on such factors as contaminant types and concentrations, groundwater and soil vapor extraction rates, soil heterogeneity, depth to groundwater, groundwater flow rate, proximity to receptors, required cleanup concentrations, site access, and utilities. It is also important to keep in mind that the three sites studied all are being remediated by large oil companies that own a wide selection of remediation equipment that can be deployed to sites as needed. Thus, the cost calculations did not include capital costs, only O&M costs. With these caveats understood, the following conclusions are offered:

- Tracking contaminant mass loadings and actual monthly remediation costs, along with estimated monthly costs for alternative technologies, can provide a useful tool to help decide when to switch technologies.

- Tracking cost per pound of hydrocarbon extracted did not prove useful for this decision-making.

- An AS/SVE case study confirmed the common rule of thumb that vapor treatment should be switched from catox to GAC when petroleum hydrocarbon concentrations fall to approximately 200 parts per million. AS/SVE is useful for remediating petroleum hydrocarbons at site where plume control is not required. AS/SVE is not effective for MTBE/TBA remediation.

- A second case study of groundwater extraction and treatment of petroleum hydrocarbons (at a site requiring plume control) indicated that at mass loadings of 1.5 pounds per day or more, air stripping followed by vapor-phase GAC was more cost-effective, whereas at mass loadings lower than this, direct GAC adsorption was more cost-effective. ERI has found similar results at approximately a dozen other sites.

- A third case study, of groundwater extraction and treatment at a site where MTBE is the primary contaminant, found that at mass loadings greater than 5,000 gpm-µg/L, bioreactor treatment was more cost-effective than GAC adsorption; whereas at lower mass loadings, GAC adsorption was more cost-effective. This was similar to another MTBE bioreactor site where the bioreactor was removed when the mass loading fell to about 4,000 gpm-µg/L and the extracted water has since been treated by direct GAC adsorption.

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David A. Klemme, P.E., is Environmental Resolutions, Inc.'s Principal Engineer. He has a B.S. in Mechanical Engineering and a Professional Certificate in Environmental Site Assessment and Remediation. He has approximately 12 years of experience assessing and remediating soil and groundwater contamination and has managed the remediation of over 75 sites. His focus is the development of designs and specifications for soil and groundwater remedial systems; pilot testing; permitting; system construction, installation, and startup; operations and maintenance; regulatory compliance; system performance evaluations; and site closure.

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