Case history of a "Brownfields" site in Wichita, Kansas USA: innovative approaches to groundwater remediation

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Abstract

At the Gilbert-Mosley Site in Wichita, Kansas USA, the groundwater has been contaminated by chlorinated solvents from past industrial activities. Over 3 billion gallons of groundwater have concentrations of tetrachloroethene (PCE) and trichloroethene (TCE) above drinking water standards (maximum contaminant levels [MCLs]). The contamination covers an area of approximately 2,220 acres. To address the Site's environmental conditions, a Corrective Action Decision (CAD) was approved by the Kansas Department of Health and Environment (KDHE) contained several innovative items, including: (1) alternate cleanup levels (ACLS) above MCLS; (2) containment of the contamination migration instead of aquifer restoration; and (3) use of bioremediation to treat the groundwater. Overall the approaches were viewed as potentially more cost effective than conventional remediation methods. Although all anticipated approaches were not implemented, the overall project was very effective in achieving goals and cost significantly less than typical groundwater remediation projects of similar size. The major cost savings resulted from (1) use of ACLS (vs MCLS), which reduced the amount of groundwater requiring cleanup by 40 percent and (2) efficiencies achieved by combining several contaminated plumes from many sources into one treatment system. In addition, the treatment system will include many enhancements resulting in recreational and educational benefits to the citizens of Wichita.
1 Introduction

In 1990, the City of Wichita, Kansas faced a dilemma plaguing cities across the USA. The Central Business District was declining, aggravated by a weakening regional oil and gas industry and a slump in the real estate market. Through public initiative and private investment, the City of Wichita (City) sought to revitalize its downtown. However, plans for revitalization abruptly ceased later in the year as a result of a report from KDHE. The report indicated that the groundwater under downtown Wichita was contaminated with chlorinated solvents. The groundwater plume was more than four miles long and a mile-and-a-half wide, and extended beneath some 8,000 parcels of land, including more than 550 businesses and thousands of residential properties. The area was named the Gilbert-Mosley Site after the intersection of two streets near the center of the area. The knowledge of this groundwater contamination created concern from environmental, public health and safety, and economic perspectives. Faced with their own questions of liability, banks immediately stopped lending to business and home buyers in the area. Without action, property values within the area were predicted to plummet by 40 percent. Unless a solution was developed quickly, the federal government would invoke Superfund, aggravating what already promised to be a long and costly problem.

The City decided to take the initiative and develop a plan to cleanup the Site. A unique partnership between the public and private sectors was established, involving intergovernmental partnerships with local, state, and federal government support, along with participation from the private sector — banks, responsible parties (industry), and the real estate community. The plan's fundamental premise would be the City's acceptance of responsibility for the cleanup of the Gilbert-Mosley Site in exchange for funding commitments from public and private sector partners. With City government in a leadership role, the following actions were taken:

- The State of Kansas and the City of Wichita established an agreement with the State's environmental agency (KDHE) who were acting on behalf of the U.S. Environmental Protection Agency (EPA).
- A primary party, responsible in part for the contamination, signed an agreement with the City to pay for its share of the contamination.
- The City developed a program agreed to by a majority of the local lending institutions to reestablish lending in this area by using a certificate of release from liability issued by the City.
- Authored amendments to Kansas State law that were adopted by the Kansas Legislature to allow for the use of Tax Increment Financing (TIF) for environmental conditions.
- Created a citizen involvement process for community input and awareness of the project.
- Secured a qualified consultant for the job.
- Adopted City Ordinances (institutional controls) to protect citizens from contaminated groundwater and related environmental conditions.
As a result of the above actions, life in the Gilbert-Mosley area returned to normal. Over 4,000 requests for "Certificates of Release" have been received, not only from property owners within the Gilbert-Mosley Site, but from many on the fringes of the Site, suggesting that the "Certificate" is a good method for removing potential liability. Overall, the following have been accomplished:

- Wichita's citizens have been protected from groundwater contamination.
- The City's tax base has been preserved.
- The property values in the Gilbert-Mosley area have been preserved and restored.
- The environment has been protected for future generations.
- To the extent that they can be identified, those responsible for the pollution are paying to clean it up. The remaining costs are being covered by the TIF.

In addition to the above positive socioeconomic benefits, many technical innovations have been implemented. The remainder of this paper describes the technical aspects of the project, including innovative approaches to remediation.

2 Site Hydrology

Figure 1 shows the location of the Gilbert-Mosley Site, the Site boundaries, and the various contamination plumes (A-F). The current Site is approximately 3,850 acres in size, covers an area approximately 4.4 miles long from north to south, and varies in width from 1.1 to 2.1 miles from west to east.

The Site is situated within the Arkansas River floodplain. The topography of the Site has low relief. The Arkansas River is the most prominent surface water feature and flows towards the south near the western border of the Gilbert-Mosley Site and then turns east, south of the Site. Chisholm Creek, which runs between I-135, is present at the eastern boundary of the Site.

The geology of the study area primarily consists of Arkansas River Valley alluvium and associated terrace deposits overlying the Wellington Formation bedrock. The Wellington Formation is primarily a gray and blue shale of Permian Age. The alluvial sediments consist of interbedded gravels, sands, silts, and clays. The alluvial sediments have a thickness of between 24 and 54 feet and averages 30 feet on the Site.

Groundwater depths in the alluvial range from 16 to 20 feet across the Site and average 18 feet below ground surface. Groundwater levels in the alluvial aquifer fluctuate seasonally and may vary as much as 3 feet, depending on the proximity to the Arkansas River, their flow levels, and the amount of precipitation received. General groundwater flow is to the south, with a gradient between 0.0007 and 0.0014 feet/foot across the Site. The hydraulic conductivity ranges between 380 and 707 feet per day. An average groundwater velocity for the Site as determined from the calibrated flow model ranges from 1.2 to 1.7 feet per day.
3 Problem Definition and Remediation Approach

The present boundaries of the Gilbert-Mosley Site and plume extents were developed as a result of a series of site investigations that have been conducted privately and by KDHE since 1986. In January 1991, the City selected CDM to conduct the Remedial Investigation and Feasibility Study (RI/FS) investigation. The Final RI was approved in January 1994 and the Final FS was approved in April 1994. After a public meeting, the Final CAD (similar to EPA Record of Decision) was signed on September 30, 1994.

The groundwater contamination above MCLS covers an area of approximately 2,220 acres (see Figure 1). Over 20 individual sources have been identified. Typical regulatory mandated solutions or Record of Decisions (RODs) for groundwater contamination contain the following components:

<table>
<thead>
<tr>
<th>Component</th>
<th>Specified Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cleanup Level</td>
<td>MCLS</td>
</tr>
<tr>
<td>Goal of Remediation</td>
<td>Restoration of aquifer to drinking water quality</td>
</tr>
<tr>
<td>Treatment Method</td>
<td>Pump-and-treat</td>
</tr>
</tbody>
</table>

Given the magnitude of the contamination, the large number of sources, and the questionable ability to restore aquifers to MCLs, the City and CDM proposed a new approach. The rationale for the new approach was provided to KDHE in May 1993 in a document titled *Gilbert-Mosley Site Preferred Alternative*. The document addressed each of the typical components of a ROD. The rationale used in 1993 is summarized in the following sections.

Cleanup Levels and the Goal of Remediation: In the early and mid-1990s, the first of a series of documents became available that evaluated the effectiveness of groundwater remediation systems currently in use at a variety of sites ([1], [2], [3]). Conclusions from these reports include:

- In the majority of the cases, the pumping systems were able to achieve containment of the dissolved phase contaminant plume and the extraction systems were effective in reducing the mass of contamination from the aquifer.
- When extraction systems were started up, contaminant concentrations dropped rapidly but then leveled off (tailing effect). The plateau concentrations were above remediation goals (e.g., MCLs).
- Cleanup times and cost were severely underestimated.
- The chemical nature of contaminants and/or the geological conditions of the Site can prevent pump-and-treat systems from restoring aquifers to health-based standards in a relatively short time.

The Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) requires the attainment of MCLs "where such goals are relevant and appropriate under the circumstances of the release or threatened release." Neither CERCLA nor the National Contingency Plan (NCP) require aquifer restoration per se; however, EPA has construed the MCL language to generally obligate restoration of any aquifer that is a potential drinking water source. The NCP does
allow for a waiver if the solution is "technically impracticable." Since 1993, guidance has been issued concerning the technical impracticability (TI) of groundwater restoration [4]. The document provides specific guidance concerning the evaluations to be performed to document TI. At Gilbert-Mosley, large areas exist with low concentrations of contaminants. These levels are above MCLs but below the concentrations typically achieved during pump-and-treat remediation. Given the historical record of sites not achieving MCLs and the low concentrations observed, restoration of the Gilbert-Mosley Site to MCLs may be technically infeasible.

Overall, the emphasis of any groundwater remediation should be on containment (vs restoration), institutional controls, realistic goals, natural attenuation (if applicable), and frequent re-evaluation of remediation goals. At the Gilbert-Mosley Site, a unique combination of approaches to remediation goals was proposed in 1993. First is the recognition that aquifer restoration to MCLs is not achievable in a reasonable time frame. To design a system for the sole purpose of showing an aquifer may not be restored to MCLs (i.e., to prove technical impracticability) is not a cost-effective approach. The alternative approach, to contain the contamination at higher levels and implement higher remediation goals with frequent evaluation, is cost-effective. In fact, the goal proposed ($10^{-4}$ additional cancer incidents) falls within EPA's range of acceptable risk levels. To further minimize any risk to human health, strict institutional controls and public education will be implemented to prevent future groundwater usage in all areas with contaminant concentrations above MCLs. Remediation to MCLs is also protective of human health, but it is not achievable and it is not cost-effective.

Method of Treatment: The previous reports clearly document the ineffectiveness of conventional pump-and-treat technology to cleanup contaminated groundwater to MCLs. Besides a basic change in the goal of remediation and the level of cleanup (containment vs restoration, and $10^{-4}$ goals vs MCLs), better treatment technologies are also needed. These technologies may include: Soil vapor extraction, air sparging, addition of surfactants or co-solvents (i.e., chemical enhancements), in situ chemical oxidation, monitored natural attenuation (MNA), reactive barrier walls (e.g., reductive iron), and in situ bioremediation.

4 KDHE and EPA decision

After reviewing the RI data and the technical evaluations in the 1993 Preferred Alternatives (summarized above) and receiving public comments, KDHE (with EPA's approval) issued a CAD, which is equivalent to an EPA ROD. The CAD contained the following components:

Institutional Controls: Establish institutional controls within the defined boundaries of the Gilbert-Mosley Site. The City of Wichita staff must propose an ordinance to the City Council to prohibit the connection of newly-constructed private water wells for private or public drinking water purposes. In addition, a public educational program should be initiated to discourage the use of
groundwater contaminated above the MCLs within the Site. These items have been implemented by the City.

Hydraulic Containment: Establish hydraulic containment to prevent further migration of contaminated groundwater. Groundwater contaminated above KDHE's ACLs would be targeted for containment. Any recovered groundwater would be treated to MCLs for the contaminants of concern. Hydraulic containment could be terminated once the ACLs have been achieved and sustained over a one-year period.

Monitoring: Establish compliance monitoring wells at the zero line (i.e., the area where groundwater contamination is below MCLs) to monitor for the chemicals of concern on a quarterly basis or other frequency as determined by KDHE. If any one of the compliance monitoring wells exceed the federal MCLs, additional remediation would be required. Long-term monitoring would be required at the compliance and selected monitoring wells for a minimum period of 10 years of annual monitoring following termination of hydraulic containment.

Source Control: Individual source control activities must be established at all identified source areas to eliminate and/or reduce the toxicity, mobility, and volume of waste/contaminants at the Site. Source controls will be determined on an individual basis following an appropriate source investigation. Source control has been implemented by Coleman (in 1993) and the City (at one site in 1998).

Bioremediation Demonstration: A microcosm study and a field demonstration would be performed at the Site to demonstrate the efficiency and economics of microbiological enhancement. The pilot demonstration was completed in 1995.

The CAD describes KDHE’s selection of ACLs at the Site. The levels proposed in the Preferred Alternative (10^-4) were modified based upon consideration of appropriate factors including: exposure factors, uncertainty factors, and concerns regarding cumulative effects of multiple contaminants. The ACLs include chemical-specific 10^-5 excess carcinogenic risk concentrations, or federal MCLs, whichever are greater, to address the uncertainties associated with cumulative risk factors. KDHE’s ACLs, the 10^-5 chemical-specific risk levels, and the MCLs are provided in Table 1.

<table>
<thead>
<tr>
<th>Contaminant</th>
<th>MCLs</th>
<th>10^-5 Chemical-Specific Risk Levels</th>
<th>KDHE’s ACLs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trichloroethene</td>
<td>5.00</td>
<td>21.00</td>
<td>21.00</td>
</tr>
<tr>
<td>Tetrachloroethene</td>
<td>5.00</td>
<td>14.00</td>
<td>14.00</td>
</tr>
<tr>
<td>1,2-Dichloroethene*</td>
<td>70.00</td>
<td>36.50</td>
<td>70.00</td>
</tr>
<tr>
<td>Vinyl Chloride</td>
<td>2.00</td>
<td>0.25</td>
<td>2.00</td>
</tr>
</tbody>
</table>

* Not a carcinogen (based on a Hazard Index of 1.0).
5 Application of the CAD

The CAD addresses the three components of concern evaluated in the Preferred Alternative document. The application of the CAD results in the following modifications to a typical ROD.

Cleanup Level: ACLs were selected versus MCLs for the cleanup criteria. Even though KDHE selected a $10^{-5}$ level (vs the $10^{-4}$ recommended), the area of contamination needing to be addressed was reduced from 2,220 acres to 1,350 acres (see Figure 1). The volume of contaminated water requiring treatment was reduced from 3 billion gallons to 1.8 billion gallons. This is almost a 40 percent reduction.

Goal or Results of Remediation: Containment was selected versus aquifer restoration as the ultimate goal of the remediation. As a result, remediation systems can be installed at the leading edges of the plumes versus within the plumes. The systems will also be installed near the ACL limits instead of the MCL limits.

Cleanup Method: Innovative treatment methods vs conventional pump-and-treat methods were selected by the City as the potential treatment methods. In situ bioremediation or in situ reductive iron walls were initially selected for groundwater contaminated with TCE, DCE, and VC. The innovative methods allow for flexibility in the future if newer and better technologies become available.

6 Progress Since the CAD

Since signing of the CAD in 1994, CDM, the City, and KDHE have worked to:

- Provide better delineation of the ACL extents of the groundwater plumes
- Conduct pilot scale studies to evaluate in situ bioremediation
- Monitor the downgradient extent of the groundwater plumes
- Better identify and characterize the source areas within the Site
- Collect data necessary for remedial design and groundwater modeling efforts
- Conduct groundwater modeling for the remedial design
- Perform preliminary designs for downgradient groundwater remediation systems

After collection of pre-design data in 1995 (groundwater samples to define the ACL extent and pilot plant evaluation of in situ bioremediation), a draft Preliminary Design Report was completed in March 1996. The report evaluated two remedial alternatives to establish hydraulic containment. These two alternatives were a pump-and-treat option and an innovative alternative option, which consisted of reactive iron walls and in situ bioremediation. The innovative options were evaluated in order to provide alternatives with less operation and maintenance and potential overall cost reductions. After input from a Citizens Technical Advisory Committee and KDHE, the City decided to implement full-scale demonstrations of the reactive iron wall and in situ bioremediation technologies at Plumes D and C, respectively (Figure 1).
An investigation program to acquire the data needed for the design of the remediation systems was conducted in July through September 1996 and was reported to KDHE in meetings in October 1996. Based on results of the 1996 investigation programs, KDHE concluded that hydraulic containment of Plume D was already in place via Chisholm Creek (Figure 1). Since the requirement of the CAD that a remediation system "establish hydraulic containment to prevent further migration of contaminated groundwater..." was met, no remediation of the downgradient end of Plume D was considered necessary by KDHE. As a result, the implementation of the full-scale demonstration of the reactive iron wall technology at Plume D and in situ bioremediation on Plume C was not completed.

In order to proceed with remediation on the other plumes, the City and CDM submitted Plume Remediation Investigation Work Plans for each of the other plumes (A, B, E, and F) to KDHE in 1996 and 1997. Investigations associated with these work plans were conducted from October 1997 to March 1998. Based on the new data collected, the City issued a RI/FS addendum in February 1999 for Downgradient Plume Remediation. The FS addendum evaluated four technologies in detail: monitored natural attenuation, pump-and-treat, reactive iron walls, and in situ bioremediation. The four technologies were modified by combining them into the following alternatives:

- Alternative 1 Monitored Natural Attenuation (MNA)
- Alternative 2a Pump-and-Treat Downgradient
- Alternative 2b Enhanced Pump-and-Treat
- Alternative 3a Iron Walls and Downgradient Pump-and-Treat
- Alternative 3b Iron Walls and Monitored Natural Attenuation
- Alternative 4 In situ Bioremediation

A summary of the evaluation and estimated costs for a combined treatment system for Plumes A, B, and E are provided in Table 2. Based on input from a major responsible party, a Citizens Technical Advisory Committee, and KDHE, Alternative 2a, Enhanced Pump-and-Treat, was selected. The major reasons for this selection follow:

- MNA was not effective in meeting the requirements of the CAD and had extremely long cleanup times. Although PCE and TCE do degrade anaerobically in the site groundwater, the degradation rates are very slow and the degradation does not proceed beyond cis-1,2-DCE. These phenomena exist due to the limited electron donors (carbon) and excess electron acceptors (sulfate).
- Iron walls and in situ bioremediation are new technologies that lack long-term performance data. The technologies are also the most expensive.
- Pump-and-treat at only the downgradient end of the plume allows lateral expansion ("smearing") of the ACL extent and takes a long time.
- Enhanced pump-and-treat includes additional pumping wells in the plume to prevent lateral smearing and decrease cleanup times.

The enhanced pump-and-treat alternative was approved by KDHE in October 1999. After submittal of preliminary, intermediate, and final design reports,
KDHE approved the final design in October 2000. The Remedial Action Work Plan was approved in March 2001 and construction commenced in April 2001. The treatment system will start treating water in June 2002. A summary of the treatment system components follow:

- Thirteen extraction wells
- 5.6 miles of high-density underground pipe
- One treatment building with a hydraulic venturi and stripper system
- Design flow rate of 860 gallons per minute (gpm) (maximum of 1,155 gpm)

The locations of the treatment building, extraction wells, and underground piping are shown on Figure 1. The treated effluent water will be discharged through a series of ponds and meandering creeks to enhance the park setting. The treatment building will be architecturally enhanced to serve as a display and education center. Features will include an educational wing and aquarium. The costs for the Plume ABE basic treatment system (without enhancements) follow:

- Capital Costs: $5,300,000
- Average Annual O&M $213,000
- Net Present Value $13,800,000

Net present value is for the projected clean-up time of 60 years plus 10 years of post remediation monitoring.

7 Conclusions

The unique approach by the City of Wichita to this "Brownfields" type project have resulted in many benefits, including restoration of property values and redevelopment of portions of the Gilbert-Mosley Site. Several innovative technical approaches to remediate the groundwater at the Gilbert-Mosley Site were also originally anticipated. A summary of approaches actually implemented follow:

- The use of ACLs (vs MCLs) has reduced the amount of groundwater requiring cleanup by 40 percent. Although about 10 percent less than originally anticipated, the cost savings have been significant (millions of dollars).
- Containment at the downgradient end of the plumes only was shown to be ineffective in completely controlling contaminant migration. Additional extraction wells within the plumes were necessary and helped reduce cleanup times significantly.
- Use of innovative remediation techniques (in situ bioremediation and iron walls) were determined to be more expensive than pump-and-treat alternatives. In addition, the responsible parties favored more conventional technology versus innovative technologies with no long-term performance history.

Overall, the approaches and treatment methods implemented have been the most cost-effective available. In addition, the costs have been significantly less than typical groundwater remediation projects of similar size. The cost savings have resulted from use of ACLs and combination of several plumes from many
sources into one treatment system. In addition, the enhancements to the treatment system will result in increased benefits to the citizens of the City including recreational and education facilities. The project has been a true "Brownfields" success story that serves as a model for future sites.
<table>
<thead>
<tr>
<th>Alternative</th>
<th>Cleanup Time (Years)</th>
<th>Net Capital Cost (Millions)</th>
<th>Net Present Value</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Measured Natural</td>
<td>Phases A: 90</td>
<td>$0.08/ $0.30</td>
<td>$7.45/ $12.1</td>
<td>Very low capital cost</td>
<td>Very long cleanup time</td>
</tr>
<tr>
<td>2. Pump and Treat</td>
<td>Phases B: 80</td>
<td>$2.25</td>
<td>$10.1</td>
<td>Easy to implement</td>
<td>Does not contain high concentrations</td>
</tr>
<tr>
<td></td>
<td>Phases C: 100</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2a. Pump-and-Treat</td>
<td>Phases A: 40</td>
<td>$3.47</td>
<td>$11.6</td>
<td>Low capital cost</td>
<td>Low capital cost</td>
</tr>
<tr>
<td></td>
<td>Phases B: 40</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>Phases C: 70</td>
<td></td>
<td></td>
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<tr>
<td>2b. Iron Walls with</td>
<td>Phases A: 50</td>
<td>$10.1</td>
<td>$14.6</td>
<td>Shortest cleanup time for Phases A and B</td>
<td>High capital cost</td>
</tr>
<tr>
<td>Pump and Treat</td>
<td>Phases B: 50</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>Phases C: 70</td>
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<tr>
<td></td>
<td>Phases A: 90</td>
<td>$8.5</td>
<td>$10.8</td>
<td>Shortest cleanup time for Phases A and overall</td>
<td>High capital cost</td>
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<tr>
<td></td>
<td>Phases B: 90</td>
<td></td>
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</tr>
<tr>
<td></td>
<td>Phases C: 70</td>
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</tr>
<tr>
<td></td>
<td>Phases A: 90</td>
<td>$10.5</td>
<td>$29.6</td>
<td>Most VOCs destroyed in situ</td>
<td>No surface treatment</td>
</tr>
</tbody>
</table>

Table 2: Plume ABE Remediation, Comparison Summary of Remediation Alternatives
References


