MORE BANG FOR THE BUCK: A MULTI-TECHNOLOGY APPROACH FOR THE REMEDIATION OF PETROLEUM CONSTITUENTS AT MULTIPLE SITES

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ABSTRACT

The challenge—design a multi-technology remedial system to aggressively and simultaneously treat petroleum constituents in soil and groundwater, and have it be pre-designed to effectively operate at multiple sites. There were two initial sites; both are active pipeline pump stations located in northern Illinois. The products of release consisted of unknown quantities of diesel, gasoline, and jet fuels, with free-phase product conditions observed at one site. The areas of impact ranged from 0.7 to 2.7 acres with off-site mitigation of impact required at both locations. The sites have similar geology, with one having vertical fractures within the water-bearing glacial till zone causing preferential pathways. Technologies chosen were vacuum-enhanced groundwater extraction, soil vapor extraction, and soil flushing using infiltration galleries with design considerations for future augmentation of the system for bio-enhancing chemical injection. Groundwater effluent treatment was designed to meet both surface discharge and re-injection criteria. The entire system is successfully controlled using a PC platform with remote telemetry. System construction began at the larger of the two sites in October 1997, with system start-up in late January 1998.

Key words: *remediation, multi-technology, petroleum, groundwater, infiltration*

INTRODUCTION

The intent of this paper is to show how multi-technologies were integrated to create a remedial system to aggressively mitigate petroleum products released to the subsurface. The design was not merely for one system at one site, but for a system adaptable for multi-site applications. The challenge was to seamlessly combine multi-technologies with the flexibility to add or subtract technologies as needed. The goal was to achieve and/or maintain cost efficiencies in construction, operation, maintenance, and modifications made to meet changing site conditions at the first site for carryover to the second site.

It is not the intent of this paper to present a technical discussion of design elements for the various technologies being utilized. This is a demonstration of "hands-on" approach to design, implementation, and operation, which also sought direct "hands-on" involvement of the site owner. The partnership and interaction between the site owner and the remediation contractor was essential to the success of this project. By relying on the strengths of various individuals and organizations, the goals and challenges of this project are being successfully achieved.

THE SITES

Geographical Settings

Site "A", which is currently under remediation, is the location of the Explorer Pipeline (EPL) Decatur Station, located along County Road 1900E, Christian County, Illinois. The subject site generally consists of a square-shaped parcel of land approximately 3.9 acres in size. The site includes a control building and

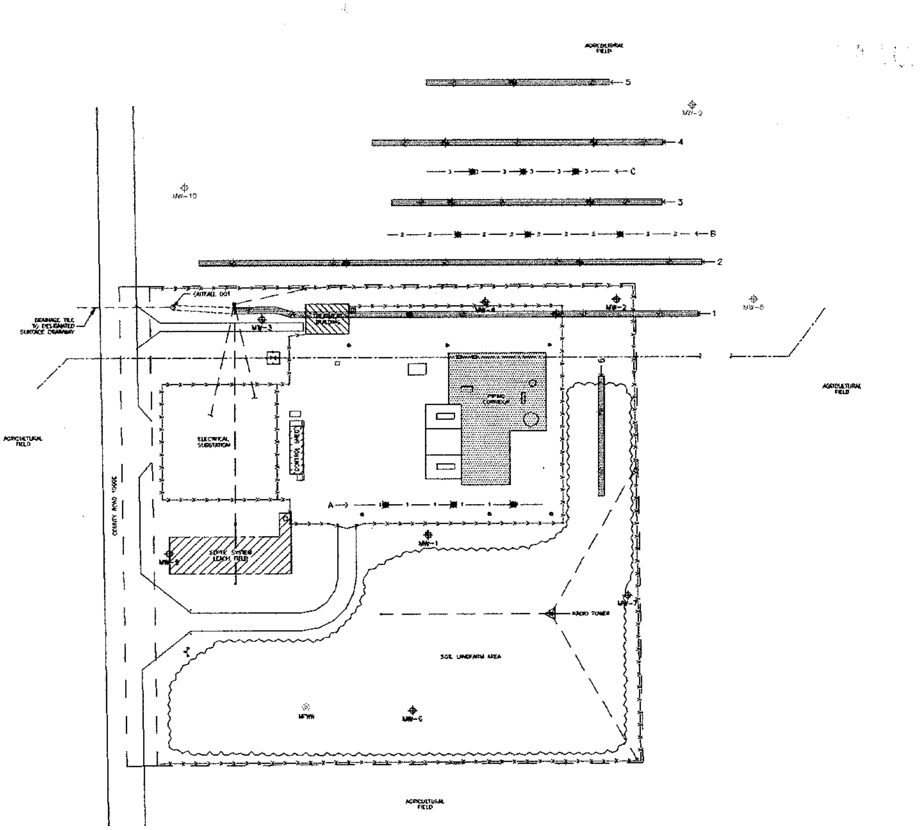


Figure 1. Site "A" Remedial Layout

pipeline pumping equipment located within a fenced enclosure. An electrical substation and a radio tower are also located on the subject property. The site is bordered by County Road 1900E to the west, and agricultural fields to the north, south, and east. Adjacent property usage within a one-mile radius of the site includes agricultural fields with a few scattered rural residences. Reference attached Figure 1 for site layout.

Site "B" is the current location of the EPL Chatsworth Station, located near the intersection of County Road 3500E and 200N, Livingston County, Illinois. The subject site generally consists of a rectangular-shaped parcel of land approximately 6.47 acres in size. The subject property includes a control building and pipeline pumping equipment located within a fenced enclosure. An electrical substation and a radio tower are located on the property. The site is bordered by County Road 3500E to the east, County Road 200N to the south, and agricultural fields to the north and west. Agricultural fields are located east and south of the subject site across County Road 3500E and 200N, respectively. Adjacent property usage within a one-mile radius of the site includes agricultural fields with a few scattered rural residences. Reference Figure 2 for site layout.

Geological History

Site "A" is situated in a physiographic province of Illinois referred to as the Springfield Plain. The Springfield Plain is characterized by

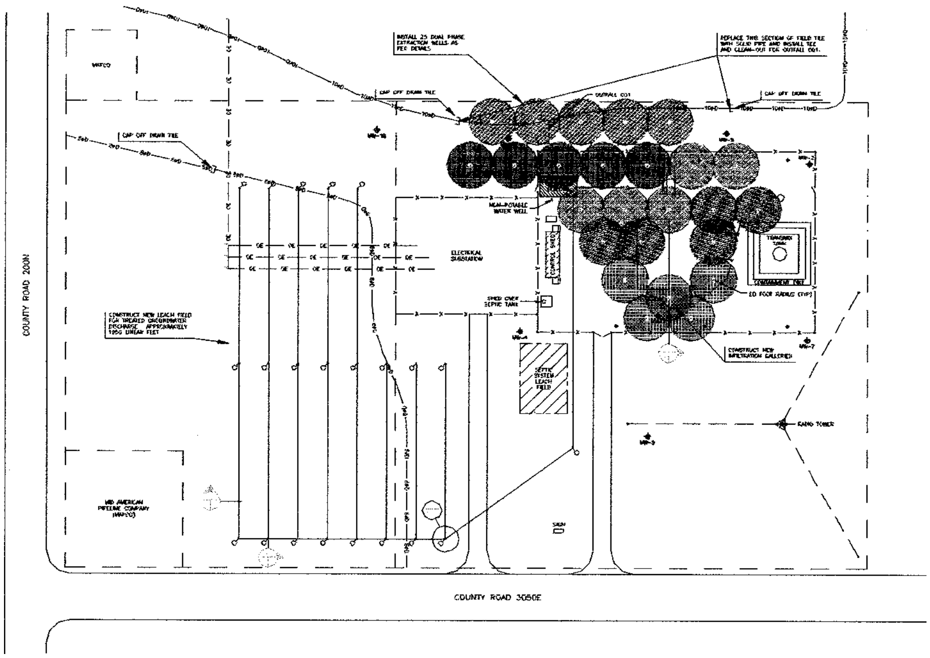


Figure 2. Site "B" Remedial Layout

the presence of an Illinoian Age glacial till plain, which at the location of the subject site, does not appear to have undergone significant erosion/dissection. The subject site and immediately surrounding areas are of low relief. The direction of primary drainage across the site could not be visually estimated.

The subject site and surrounding area is underlain by approximately eight feet of loess, a wind-blown glacial sediment consisting predominantly of clayey silt. The loess is underlain by the Radnor Till Member of the Glasford Formation, an Illinoian Age glacial till generally described as a mostly gray, compact, silty till with a little gravel, sand, and silt in some places. The Radnor Till, as observed in soil borings drilled for monitoring well installation, consisted of gray silty clay with trace sand. The total thickness of glacially derived unconsolidated sediments overlying bedrock at this site is likely on the order of 100 to 200 feet.

The Radnor Till is likely underlain by bedrock of the Pennsylvanian Age Bond Formation. The Bond Formation generally consists of a high percentage of limestone and calcareous clays and shales, and may locally contain minor siltstone and sandstone beds. Gray shales constitute the greatest portion of the formation; however, thick channel sandstones may be present locally.

Site "B" is situated in a physiographic province of Illinois referred to as the Bloomington Ridged Plain. The Bloomington Ridged Plain is characterized by prominent glacial topography typical of late Wisconsinan glaciation. This topography generally consists of numerous rough-surfaced morainic ridges that may be 50 to 100 feet high, one to two miles wide, and continuous for 50 to 100 miles. Morainic ridges are generally separated by inner-morainic areas with more subdued, undulating topography, commonly described as swell-swale or rolling topography. The subject site is located on the Gifford Moraine, a Woodfordian Age terminal glacial moraine. The direction of primary drainage across the site was visually determined to be in a westerly direction.

The subject property is underlain by approximately three feet of loess, a wind-blown glacial sediment consisting predominantly of clayey silt. The loess is underlain by the Snider Till, a member of the Wedron Formation; a Wisconsinan Age glacial till described as a gray silty clayey till which generally exhibits a coarse blocky structure (Lineback, 1979). The blocky structure of the Snider Till generally produces higher *in situ* permeabilities and hydraulic conductivities than observed in other Wisconsinan Age glacial till deposits. The Snider Till is likely underlain by older silt and glacial till deposits (Wisconsinan through Illinoian).

The total thickness of glacially derived unconsolidated sedimentary materials underlying the site likely ranges between 200 and 400 feet. Unconsolidated materials blanketing the site and surrounding areas are likely underlain by bedrock of the Pennsylvanian Age Carbondale Formation. The Carbondale Formation consists of interbeded sandstone, limestone, shale, and coal units.

Hydrogeologic Conditions

In general, groundwater at Site “A” was encountered at depths ranging between seven and 14 feet below ground surface. Shallow groundwater below the facility appears to flow in a radial direction north to northeast from the site. The results of hydraulic conductivity testing indicated conductivities in a range between 7.1 x 10^{-6} centimeters per second (cm/sec) and 1.3 x 10^{-5} cm/sec. However, these hydraulic conductivity values did not appear consistent with the actual impact plume migration rate that has occurred. Test pits were excavated on site, revealing the glacial till unit (clay diamicton) underlying the site was highly fractured, resulting in significant secondary permeability. This condition was not reflected in the above-referenced hydraulic conductivity testing due to apparent smearing of the fractures during soil boring advancement and/or borings placed between fracture sets.

Site “B” groundwater was encountered at depths generally ranging between three and one-half and four feet below ground surface. Shallow groundwater below the facility appears to flow in a general southwesterly direction. The hydraulic conductivity values obtained from on-site testing were in the range of 4.7 x 10^{-6} and 2.0 x 10^{-5} cm/sec., respectively. It should be noted that an approximate 12-inch gravelly sand lense was encountered in one of the monitoring wells tested, which likely resulted in the apparent discrepancy observed for hydraulic conductivity values obtained.

Berg Classification

In Illinois, sites are additionally assessed for their relationship to groundwater and the associated groundwater hazard posed by the site. The subject sites and surrounding one (1) mile radii is mapped by Berg et al. (Plate 1, Potential for Contamination of Shallow Aquifers from Land Burial of Municipal Wastes) as occurring within Area E. Berg describes Area E as being characterized by uniform, relatively impermeable silty or clayey till or other fine-grained materials extending from the land surface to more than 50 feet in depth. Berg states that sites with characteristic Area E geology exhibit a low potential for contamination of underlying aquifers.

TECHNOLOGY OVERVIEW

Development

The rudimentary technologies for remediating petroleum hydrocarbons have been around for years. Whether it is a simple pump-and-treat system, soil vapor extraction (SVE), or one of the newer *in situ* bioremediation enhancement applications, empirical data exist to aid in system design. As such, full-scale pilot testing is not usually necessary based on a cost-to-benefit ratio.

Terracon has a long history in remediation design, implementation, and operation. We have compiled empirical data on the performance of various remedial technologies, including hybrid systems that have and are operating in the geological matrix of the central United States where our case study sites reside. The remedial technologies selected were developed from Terracon's experience on what has worked well on other similar sites. Basic geological and hydrogeologic data were collected during the assessment phase of the projects.

Initially the sites were assessed and corrective action measures were developed separately. EPL was not under regulatory mandate to clean up these sites. However, EPL elected to enroll in the Illinois Site Remediation Program (SRP), a voluntary cleanup program, as a means to obtain regulatory closure for each site while maintaining control over how and when cleanup would be implemented. Under the program, EPL requested and was granted approval to conduct remediation at the two sites consecutively rather than concurrently. This was the catalyst that bought the two sites together. By using the flexibility of the SRP, EPL and Terracon tailored an approach for the cleanup of one site while monitoring the other. Approval from the regulators was granted because the plan detailed the remediation of both sites up front, using the same system components, providing a significant capital cost-saving measure. EPL also provided the assurance that the technologies employed would aggressively mitigate the first site in a manageable time frame. A detailed monitoring plan for the second site was made part of the remedial plans, with EPL's assurance that if conditions changed at Site B, requiring immediate corrective actions, such actions would be implemented.

Soil Mitigation

Impacted soil at both sites would be treated using soil vapor extraction (SVE) technology. In addition, the soils within the smear zone, which are found to be the major contributor to impact re-leaching to the groundwater, would be mitigated by taking advantage of groundwater remediation, lowering the shallow groundwater table to expose the soils to SVE. The exposed semi-saturated soils will begin to dry, creating air channels, and thus expanding the area of influence for vapor extraction.

In addition to SVE, soil flushing will also be used to mitigate soil impact. Soil flushing removes residual chemical constituents trapped in soils. Soil flushing can occur naturally through surface water infiltration (i.e., rainfall). To enhance this process, a network of infiltration galleries was designed. The galleries are located within the capture zone of the groundwater extraction system, creating a closed loop. The infiltration system can also be used to introduce bio-remedial nutrients, oxygenaters, and/or oxidizers if needed, to enhance the natural biodegradation process.

Groundwater Remediation

Impacted groundwater will be extracted and treated above grade at both sites. The groundwater extraction will be accomplished using jet-pump technology. The principle of jet pumping is using one fluid to entrain another. Specifically, stored untreated extracted water will be forced through a series of jet pumps, also called eductors, under high pressure. As the high-pressure water stream passes through the eductor, suction (vacuum) is created and fluids in the trench are drawn up the lift tube and carried off (entrained) with the high-pressure return stream. The return stream of fluids flow back to the treatment building for processing. As long as there is water pumping through the eductor, a vacuum will be maintained in the lift pipe. As the area becomes dewatered, water and/or air will be drawn up the suction tube, thus creating a self-priming pumping system without the need of expensive water-level control sensors. Another advantage of the eductor system is the ability to bury it and forget (i.e., maintenance free). This was critical for each site due to groundwater impact off site and the adjacent property owner's desire to continue to grow crops on the land without the need to plant and work around surface structures (i.e. manholes and vaults) typical of conventional groundwater extraction methods. The eductor system also had cost-saving advantages over electrical submersible pumps due to the on-site requirements for wiring to meet explosive rating classifications.

To improve groundwater extraction efficiencies, vacuum was added to the technology matrix. Compared to conventional groundwater extraction systems, a groundwater extraction process, which uses and/or is enhanced by vacuum, increases hydraulic conductivity (flow) from the well by one to three times. The increase in flow is caused by the creation of a negative pressure gradient near the recovery well, overcoming the capillary forces which tend to hold the water trapped in the soil voids. This breakdown of capillary tension also causes a deepening or flattening of the cone of depression and over time creates a larger radius of influence. However, empirical data has indicated that while the enlarged area of influence is maintained, the higher flow rates diminish over time as the area of influence stabilizes.

As outlined above, one technology can be piggybacked on to another to make a third. By sharing components, cost savings are achieved over buying individual component for each technology. Sizing of the various components required forethought as to how each technology was going to interact with the other.

BEST VALUED REMEDIAL DESIGN

Under Illinois regulatory programs, corrective active plans (CAPs) are not required to include detailed plans and specifications. As such, CAPs can be presented in a conceptual format. This allows flexibility in the implementation of the proposed technologies including procurement of capital equipment, construction methodologies, and fabrication of the system. Changes can readily be made without the need for costly revisions and addendums typical of detailed plan and specification packages and/or re-submittals to regulatory authorities for approval. EPL and Terracon chose to work under a CAP to provide the flexibility necessary to accomplish the multi-site design.

How does such a process come together? The answer is best valued remedial design (BVRD). BVRD blends traditional engineering design, design build (DB), quality base selection (QBS), and cost control concepts and practices. Specifically for these projects, Terracon, the design professional, and EPL, the site owner, became the first members of the BVRD matrix. The conceptual CAP was driven just a much by EPL goals and objectives which included continuous operations, minimal disruption to adjacent landowners, cost control, and minimization of the time required for the remediation as site-specific geology, hydrogeology, and environmental concerns. As the design and implementation process proceeded, site-specific system components that were applicable and/or feasible took into account EPL current and future facility needs. An example was the design and positioning of the remediation building, which will be used in the future for operations and maintenance. The remedial sites, being Department of Transportation (DOT) regulated facilities, added additional implementation requirements for contractors working on the site. EPL, having extensive construction experience and lists of approved contractors, was also involved in selection of construction methodology alternatives and QBS for construction contractors.

Terracon took responsibility for QBS selection of the remedial system installer, which mainly focused on experience in logic control systems applicable to custom multi-technology applications. The remedial contractor would also be the prime contractor, responsible for subcontractor contracting and coordination. Terracon took on the role of design engineer/ construction manager and eventually the system operator.

Once the remedial contractor was selected, they were also brought into the BVRD matrix. Terracon, together with EPL and the remedial contractor, worked through final construction and implementation methodologies. Each alternative was analyzed for its effectiveness and then cost. Once the team worked through construction and implementation methods, remedial technologies, and developed a subcontractor list, the remedial contractor with oversight from Terracon prepared a detailed project cost proposal for EPL. This process included demonstrating QBS and/or cost-competitive pricing of major remedial components and subcontractor services. One aspect of subcontractor selection was the goal to hire local contractors, specifically the electrical subcontractor. Low cost was not seen as important as having local support for the system, as these sites are in rural areas and are not manned by EPL on a full-time basis. Additional cost savings for EPL were achieved through separate contracting, avoiding contractor markups, and establishing cost procurement limits where vendor invoices would be direct-billed to EPL over set amounts.

As presented above, BVRD was an essential element in the success of this project. It does not work for all projects and requires the development of a partnership which fosters trust between all the project stakeholders. As an environmental design professional, BVRD requires the consideration of non-technical elements during the pre-design and design stages of the project, which can assist in the overall effectiveness of the design and generate possible life cycle cost savings.

THE SYSTEM

Site "A"

Site "A" was selected for active remediation first, based on level impact and associated risk factors. As indicated earlier, this site presented a unique hydrogeologic problem from secondary permeability generated from fractures in the water-bearing soils. The installation of dual-phase recovery wells as originally planned was deemed unfeasible due to the probability of either not intersecting fractures and/or having the fractures sealed off during well installation. Other methods had to be selected; through BVRD, the team considered other alternatives such as directional horizontally drilled wells and different types of trench recovery systems.

For site "A," a trench recovery system was selected as the most effective approach. Through construction costing of two different construction methodologies, continuous trenching and conventional excavation, conventional trench excavating was the most economical. This remained true even considering potential problems that can be encountered in digging trenches into groundwater tables. The change from recovery wells to recovery trenches also required re-evaluation of the groundwater extraction methodology. The remedial contractor was responsible for presenting the innovative approach for groundwater extraction using jet-pumping technology that was employed at this site—another example of how BVRD benefited the project design.

Contractor Selection

Terracon selected JNC Limited (JNC), Davenport, Iowa, as the general remedial system installer for the remedial system. JNC was responsible for the procurement of system components and on-site installation/fabrication. The remedial system's programmable logic controller was manufactured by Mississippi Valley Liquid System (MVLSI), a wholly owned subsidiary of JNC Limited. JNC contracted with and was responsible for subcontractors who performed site excavating activities, building construction, and electrical installation services.

The following subcontractors were selected based on experience in their respective fields, proximity to the site, availability, and cost:

- Excavating—Bodine Excavating—Decatur, Illinois
- Electrical—Hart Electric—Decatur, Illinois
- MGC Construction—Decatur, Illinois

The on-site contractors, as well as Terracon employees, followed Department of Transportation (DOT) facility safety and drug testing protocols and were pre-qualified and/or approved to work at/on EPL facilities within "safety sensitive areas."

Soil Mitigation Technology

Impacted soils present above and below the shallow groundwater table were treated by lowering the shallow groundwater table to a maximum depth of approximately 11 feet below ground surface (bgs) and using soil vapor extraction (SVE) technology. The depth of extraction was based on site geology and shallow groundwater elevations. Vacuum was applied to each recovery trench through a series of horizontally installed perforated piping embedded in the top portion of the recovery trench granular backfill. The horizontal piping consisted of alternating sections of perforated and non-perforated sections, with the longer recovery trench runs having two separate vacuum lines to help balance and uniformly distribute the vacuum applied to the soils. The vacuum is applied to the recovery trenches by three positive, displacement blower units. Each unit has the capacity to generate approximately 10 inches of mercury (Hg) at an air flow rate on the order of 300 cfm. The blower units are connected to a combination manifold and mist/particle separator. The manifold system will allow for multiple-zone operation and allow one or more blowers to be used on a given zone.

As stated earlier, soil-flushing technology was employed using infiltration galleries and/or cyclic operation of the groundwater extraction system. The design criteria used for sizing the infiltration galleries was based on physicochemical properties of soil (Freeze and Cherry, 1979, and Krishnayya et al., 1988), and anticipated flow rates from the groundwater extraction system. The required square feet (sqft) of seepage area need for the projected GPD was determined using an estimated percolation rate for the site and design criteria set by Illinois Administrative Codes. The infiltration system can also be retrofitted for the introduction of bioremedial nutrients, oxygenaters, and/or oxidizers.

Groundwater Mitigation Technology

Impacted groundwater was extracted and treated above grade. The groundwater was extracted through a series of extraction trenches. The placement of extraction trenches was based on design assumptions and the areal extent of soil and groundwater impact. The extraction network consisted of six extraction trenches, connected to form six operational zones. The psychical mechanics of groundwater extraction was accomplished using jet-pump technology. The principle of jet pumping consists of using one fluid to entrain another. Specifically, stored untreated extracted groundwater is forced through a series of jet pumps, called eductors, under high pressure. The eductors, which are spaced along each recovery/eductor trench, have suction or lift tubes suspended in the center of the trench to withdraw groundwater to the specified depth (i.e., approximately 11 feet bgs). As the high-pressure water stream passes through the eductor, suction (vacuum) is created and fluids in the trench are drawn up the lift tube and carried off (entrained) with the high-pressure return stream. The return stream of fluids flow back to the treatment building for processing. As long as there is water pumping through the eductor, a vacuum will be maintained in the lift pipe. As the trench becomes dewatered, water and/or air will be drawn up the tube, thus maintaining a self-priming pumping system.

The groundwater extraction system is operated on a continual basis. However, the different recovery/eductor trenches can be activated in a cyclic manner (also known as pulsing the system). As mentioned above, the individual operation zones will allow for various remedial disciplines to be used in the mitigation of the dissolved groundwater impact.

Free-Phase Separated Product Recovery

The jet-pump technology employed for groundwater extraction was a total fluids process, and as such, free-phase separated product (FPSP), if present, will be recovered as part of the groundwater extraction. In addition, negative pressure produced through the vacuum-enhanced system will aid in the recovery of FPSP by overcoming the capillary forces, which tend to hold the FPSP trapped in the soil voids. Soil flushing activities will help the recovery of FPSP as well. FPSP was separated and collected in the oil/water separator. Accumulated product was periodically transferred to the pump station's trans-mix tank, which stores other petroleum products handled by this facility.

Due to the SVE system (vacuum enhancement) being employed at this site, FPSP drawn to the recovery trenches may become vaporized. During early stages of site mitigation, the SVE system was not used due to the possibility of high concentrations of petroleum vapors being present in the exhaust stream of the blowers. These concentrations could exceed permissible discharge limits and require off-gas treatment. As impact levels are reduced, the SVE system will be gradually phased in so permissible discharge limits are not exceeded.

Landfarming

Included in the CAP was a proposal to landfarm soils on site, including excess soils from excavated trenches. State approval was obtained and contaminated soils were successfully landfarmed on site. In general, the landfarming consisted of the following activities:

- Excavated soils were spread approximately six to eight inches thick over a designated area in the southwest quadrant of the subject property (i.e., east and south of the main facility compound).
- Soils were periodically aerated using earth-moving equipment following spreading activities.
- The soils were periodically sampled to assess the progress of soil treatment.
- Grasses and other vegetation, through natural seeding and mechanical application, were then allowed to grow.

System Controller

What makes multi-technology applications work are programmable logic controllers. The MV2100 Control System, manufactured by MVLSI, Davenport, Iowa, was selected to handle the complex operational and alarm sequences planned for this system. The MV2100 control system is custom built for each remedial system. Though each system is customized, MVLSI uses standardized components, board layouts, and communication software to make it easier to operate, maintain, and troubleshoot multiple systems. The system includes motor controls, control relays, alarms, sensors, and monitoring/metering equipment. The system uses analog and I/O input/output boards in a standard PC configuration. The system's logic program is written using Boolean expression in the form of Boolean functions and operators. A Windows-based communication program is used for remote telemetry. The remote telemetry screen is identical to the on-site display screen, including operational commands, which simplifies training.

Data is downloaded as a common delineated file for easy data manipulation. Arrays of alarm/monitoring sensors are incorporated into the system to prevent the discharging of non-treated groundwater to the environment. A Radio Shack Autodialer has been interrogated into the alarm sequence to call system operators in the event of a system upset.

The MV2100 control system has also allowed us to equip the remedial building with sensors to warn of hazardous conditions (i.e., explosive vapors). The sensors are also interrogated into a system which will activate ventilators to evacuate vapors in the building and, if vapor levels continue to rise, will shut down the remedial system and electric power. This allows us to fabricate the system without the need for an explosion-proof system, except for the building ventilation fan. The control system is housed in a sealed cabinet with an outside, air-supplied blower to maintain a positive air pressure within the cabinet. This hazardous condition monitoring system greatly reduces initial installation costs and exhibits long-term savings when system maintenance and modifications issues are considered.

Operational Sequencing

The dual-phase extraction zones and infiltration galleries operate on a cyclic basis. Cyclic operation of the various remedial components are based on system performance, engineering judgment, and the results of periodic analytical testing. Changes in the cyclic operation are made manually, using electronically operated valving controlled by the logic controller. The logic controller is programmed to prevent an improper operational sequence from being performed, such as the filling of an infiltration gallery without having a down-gradient extraction zone in operation for fluid recapture.

Extracted water and air are separated, with the air stream being directly discharged to the atmosphere and the water processed through the groundwater treatment system. The entire process is controlled through liquid level and flow sensors wired to the logic controller. Treated groundwater is discharged to either a surface drainageway or the infiltration galleries, depending on how the sequences are selected for the extraction and infiltration gallery zones. FPSP is processed manually on an as-needed basis.

Construction/Operating Permits

Although the CAP was approved, a number of permits still had to be acquired and access to adjacent property was obtained. In order to construct and operate the remedial system, the following permits were obtained from various divisions of the IEPA:

- IEPA Division of Water Pollution Control
  Construct/Operate permit.
  Permit No.1997-EA-4377
  Expiration Date—September 30, 2002
- IEPA Air Division Construction permit.
  Application No. 97070046
  I.D. No. 021808AAB
  Expiration Date—December 4, 2002
- IEPA National Pollutant Discharge Elimination System (NPDES) Surface Drainage Discharge permit.
  Permit No.IL0072311
  Expiration Date—January 31, 2003
- IEPA Wastewater Operator Certification
  Program-Bureau of Water
  Service Agreement approved between
  EPL and the
  Class K-WR system operator(s).
  FSP# G-3540-A
  Expiration Date—April 30, 1999
- Off-Site Property Access was obtained for the Gordon farmstead by EPL.

Construction

The following is a generalized sequence of construction events that took place for installation of the remedial system:

- Major remedial system components were ordered by JNC starting in late September 1997.
- A pre-construction meeting was held on site, October 1, 1997.
- Site preparation work began on October 22, 1997, which included fence removal, landfarm area setup, and system layout.
- Excavation of infiltration galleries, eductor trenches, and connecting pipe corridors followed. Underground piping installation and backfilling operations were performed concurrently with excavating activities. Underground component work was completed by mid-November 1997.
- Excavated soils were initially stockpiled near the excavations and later transferred to the landfarming area.
- Building construction and interior remedial component work was performed during the period of late November 1997 through the end of January 1998.
- System troubleshooting and trial batch runs were started on January 28, 1998.
- Completion of expanded system startup testing protocols was completed in May 1998.

Remedial Operations

Following construction, receipt of regulatory agency operational permits, and before direct surface discharge and/or injection of treated effluent, a trial batch test was performed. The trial batch test consisted of running the remedial system at design parameters and containerizing the effluent generated by the system. During system testing, influent (IF) and effluent (EF) water samples were collected and analyzed. Effluent discharge that did not meet effluent quality parameters was retreated following modifications to the treatment system to correct effluent quality problems. Once design and effluent discharge criteria were met, the system was restarted and operated continually with direct effluent discharge to either the infiltration galleries and/or the surface drainage outfall.

As part of operational permit requirements for the startup of a treatment system, sampling of the effluent waters was conducted twice per week, followed by weekly sampling over a three-month period.

Construction/Startup Followup Issues

During system troubleshooting and system startup, problems were identified in the eductor system. The eductor system for trenches 1 and 2 failed to maintain adequate operating pressure and shortly after system startup, the eductor system in trenches 3 and 6 failed to return water. Due to a very wet spring and summer, repairs to these systems could not be performed in a timely manner. Auxiliary pumping equipment was installed in trenches 1 and 6 to dewater the site while repairs were made. As of this reporting date, trench 2 remains off-line. It was discovered that the scheduled 80 PVC 3/8-diameter, threaded-transition connection on several eductor assemblies had broken. The exact cause for the breakage is unknown. The eductor assemblies were retrofitted to accept a steel-threaded connector where repairs were needed.

Problems were also found and remedied concerning effluent water quality out of the air-stripping tower. Terracon and JNC could not isolate a specific cause for the poor effluent quality. The final solution was the installation of a larger blower unit. This new blower exceeds tower design modeling by 150 to 200 percent.

Other problems and/or modifications that were made to the system were as follows:

- Infiltration gallery conductance-type, water-level control probes required replacing with mechanical and/or pressure-type control devices when it was discovered the facility's in-ground cathodic protection system caused interference with the conductance signals to the control panel.
- Additional water filters/strainers were required on the eductor system due to higher-than-anticipated suspended solids in the groundwater and bacterial growth in the batch holding tanks.
- Auxiliary carbon units were added to the effluent discharge stream from the air stripper due to higher-than-anticipated naphthalene levels recorded in the influent groundwater. This also required modifications to the air-stripper transfer pumping system to handle the higher flow pressures through the carbon vessels. Carbon polishing was discontinued in late 1998 and units removed in early 1999.
- Mechanical water-level control probes were replaced with conductance type devices in the oil/water separator and air-stripping tower sumps to overcome rapid fouling problems caused by poor groundwater quality.
- Additional water flow meters were installed and/or repositioned to better record and monitor system flow rates.

- To simplify maintenance of the eductor system, modifications were made to the eductor piping and SVE vacuum lines inside the building to utilize these components for backflushing of the eductor system.
- With the second time loss of extraction trench #1, the infiltration gallery sump well installed in extraction trench #1 was retrofitted initially with an aboveground centrifugal pumping system. This pumping system was later changed over to a submersible unit and is used as the sole extraction method for trench 1.
- A second settling tank was added between the silt separator and the oil/water separator to aide in emulsified product separation. The tank was plumbed to allow for gravity flow between the two units and fitted with an emergency E-high water, level-flow switch.
- Additional eductors were replaced in the fall of 1999. Eductors were found to be damaged by external corrosion. It is believed, since the site has cathodic protection, the eductors are acting as sacrificial anodes.

As depicted above, a remedial system is like a living entity which undergoes changes. These changes, in many cases, are not a reflection of poor design. A poor design would be a system that does not allow for changes to occur.

SYSTEM PERFORMANCE SUMMARY

System Components

The remedial system began full-time operation on February 19, 1998. The major system components include the following:

- Six recovery/eductor trenches with SVE enhancement;
- Three infiltration galleries;
- One silt and oil/water separator;
- Two batch tanks;
- One counter air-flow stripping tower;
- Three auxiliary carbon polishing units (no longer in service or on site);
- One discharge holding tank;
- One effluent discharge water distribution system; and
- One programmable logic controller with remote telemetry and an automatic message dialer unit that sends out a pre-recorded message to three locations, informing system operators of an operational upset alarm.

Untreated groundwater, stored in the two batch tanks, is used for the eductor (i.e., jet pump) feed water. Treated groundwater is discharged either to the permitted infiltration galleries or through an existing public drainage way under an NPDES permit. Off-gas from the groundwater air-stripping tower and SVE system is vented, untreated, to the atmosphere, as allowed under the operating permits. FPSP, if collected, is temporarily stored within an approved petroleum aboveground storage tank for disposal by EPL. Reference Figure 3 for Site A remedial flow diagram and Figure 4 for system component layout.

System Operators

Treatment system operation is under the direct and active field supervision of a certified, Class “K-WR,” Industrial Treatment Plant Operator(s) in accordance with State of Illinois Rules and Regulations, Title 35, Subtitle C,

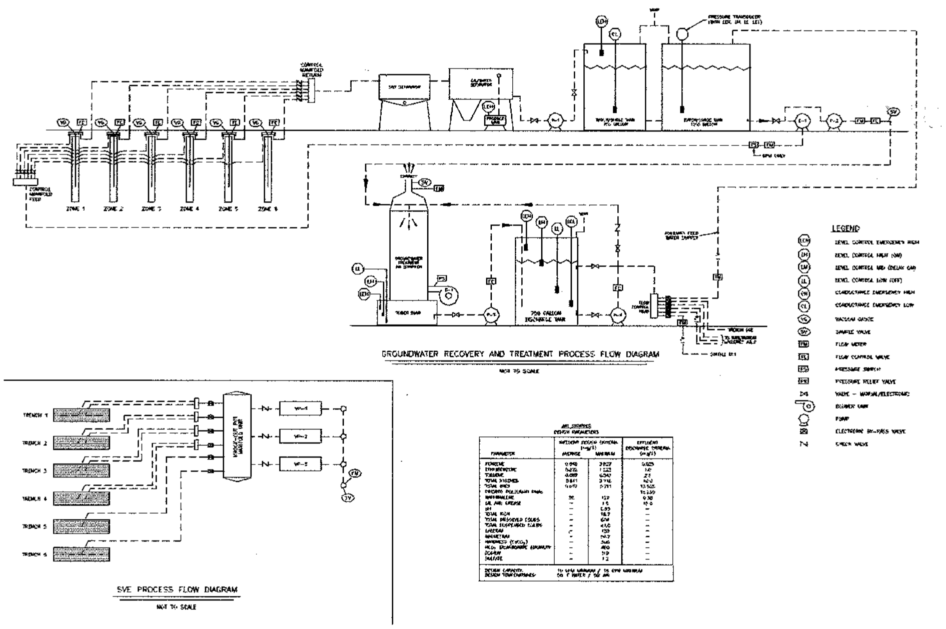


Figure 3. Site "A" Remedial Flow Diagram

Chapter 1, Part 312. The Class "K-WR" operators for this system are Mr. James R. Buckhahn and Mr. John W. Cameron. The system operators can from time to time utilize local contractors that were involved in the system installation to perform emergency site visits for system-upset response or other conditions requiring a quicker response. During such an event, the system operator can be remotely monitoring and/or controlling system operations. The ability to use the local contractors is a direct benefit of the BVRD process.

Operational Monitoring and Maintenance

Terracon system operators perform and/or supervise personnel in the operational monitoring and maintenance (O&M) of the remedial system. O&M includes, at a minimum, weekly remote monitoring and twice per month (i.e., bimonthly) site visits. During site visits, required sampling of treatment waters is performed as well as routine system component maintenance. On a quarterly basis, in conjunction with a bimonthly site visit, groundwater monitoring well network gauging and analytical sampling will occur. The O&M schedule may be modified in the future based on system performance and/or regulatory guidelines. Additionally, EPL personnel have assisted with monitoring and maintenance between site visits by the system operators.

System Performance

Remedial system process flow rates for the individual operating systems are routinely collected from on-site or remote telemetry monitoring. This data is used to evaluate system operational performance and in the preparation of required regulatory submittals (e.g., NPDES monthly reports).

Through the period ending April 2000, approximately 5,900,000 gallons of water have been extracted and treated at this facility. Approximately 5,720,000 gallons of treated

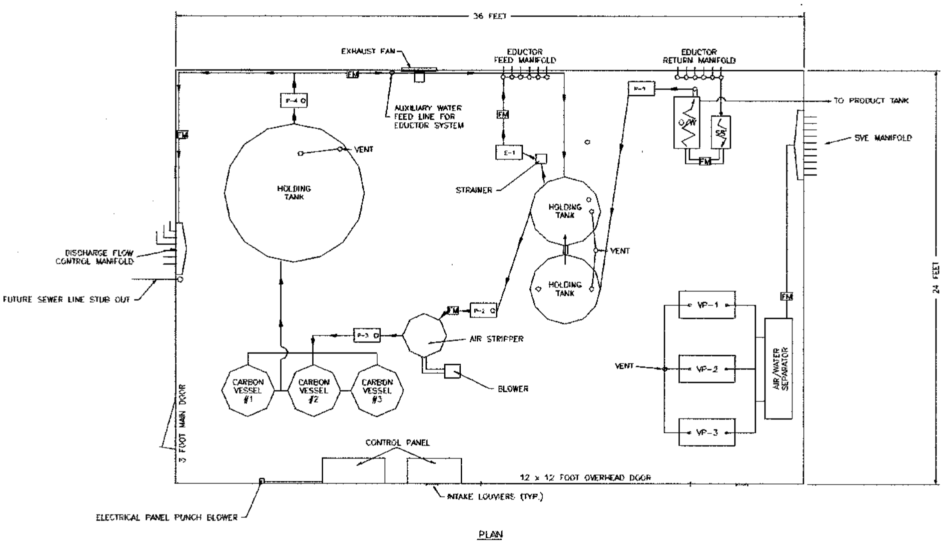


Figure 4. Site "A" Remedial Layout

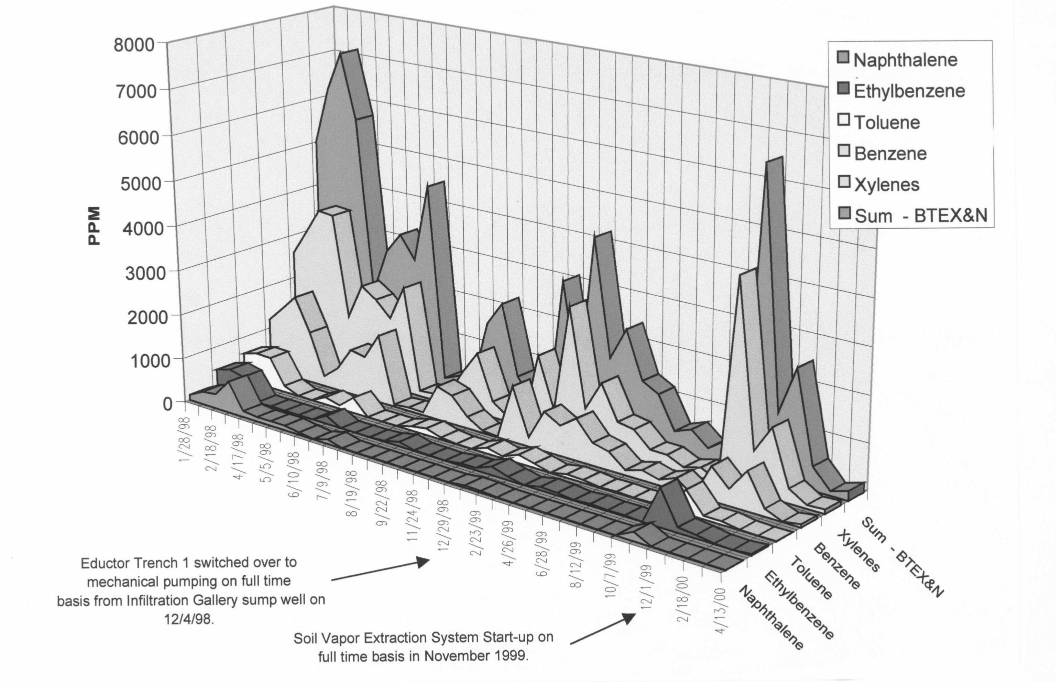
water have been discharged to the surface drainage-way via Outfall 001, with approximately 180,000 gallons of water being re-injected through the infiltration gallery network. The shallow aquifer is yielding on average approximately 8,800 gallons of water per day. Up until the winter of 1999, the site was yielding on average 13,000 gallons per day, which was a flow of approximately 1.5 times more than the anticipated long-term yield. It is our opinion that these higher yields may have been due to the fractures in the glacial till unit (clay diamicton) underlying the site, resulting in an apparent significant secondary permeability and aquifer storage capacity. These water-filled fractures were observed in a test pit excavated near MW-4 following the 1995 assessment activities (reference CAP, June 5, 1997). As such, it was difficult to maintain a draw down of the water table to sufficient depths to use of the infiltration gallery system. In November 1999 the aquifer yield dramatically dropped off and has remained constant at levels more typical of the site's geology.

Prior to the winter of 1999, the SVE system had only been run for two, one-hour test runs (October 29 and December 15, 1998) due to the sustained high groundwater table across the site. Since November 1999, the SVE system has been run on a continuous basis. On average, the SVE draws 890 CFM. For the one month of operation in 1999, approximately 1.5 tons of VOC were extracted.

The remedial system has been operational for a total of approximately 800 days. During this reporting period, the system has been operational approximately 93% of the time. Overall, the system has been operational approximately 88% of the time, inclusive of system maintenance, troubleshooting activities, and system upsets.

Treatment System Analytical Results

Discharges from the groundwater treatment system have been in compliance with permit limitations since the system has been operational. Overall, influent concentrations have dropped 83% since the start of remedial



Eductor Trench 1 switched over to mechanical pumping on full time basis from Infiltration Gallery sump well on 12/4/98.

Soil Vapor Extraction System Start-up on full time basis in November 1999.

Figure 5. Site "A" Influent Chart

operations. Prior to operating the SVE and infiltration galleries, the influent concentrations had dropped 93%. Reference Figure 5 for a graphical depiction of influent concentrations over time.

Site Monitoring

Water-level measurements and analytical samples are obtained from the monitoring well network on a periodic basis. Selected recovery/eductor trenches are also sampled as part of site-monitoring activities.

Changes have been observed in constituent concentrations in the site-monitoring wells from pre-remedial activities. In general, average concentrations of dissolved petroleum constituents (BTEX) have shown an approximately 45% reduction from pre-remedial conditions. When Naphthalene is included in the calculations, the percent overall reduction is 22%. The significant difference between the overall percent reduction when Naphthalene is added is due to a two to three times increase in concentration for this compound following system start-up. Reference Table 1 for average monitoring well analytical results over time.

Keeping It Running

No matter how simplistic or complex a remedial system is, if it does not run, it cannot do its job in mitigating the site. A well-maintained system is the first critical step in keeping a system running. If money was never an issue, this would not be a problem; however, operational costs are typically scrutinized and are cut to the bare bones. Optimization of maintenance expenditures requires some forethought that is enhanced by the BVRD process, which helps bring those less technical issue to the board in the design/implementation phase. Additionally, experience and the knowledge of the designer, as well as the ideas of all the stakeholders, are incorporated into the system's design and installation. Examples of implemented forethought can be as simple as installing quick-disconnect fittings at pumps or installing additional pipe and valving to backflush various system components. On a multi-technology system, making alternate uses of equipment can also greatly expedite routine maintenance functions. At Site "A," additional piping and valving were added to the groundwater treatment system transfer pump and the SVE system to use these pumps for backflushing of the eductor system. Multi-technology systems also have another hidden asset to get the system running. As mentioned earlier, extraction trench #1 became inoperable when another break occurred in the eductor piping. Since extraction trench #1 was designed with an infiltration gallery sump, it was a simple retrofit to make it into an extraction well to de-water the trench until the eductor piping could be repaired. The retrofit also included some minor programming changes to allow the new extraction well to work automatically.

Just keeping a system running is not always sufficient. Changing or unanticipated site

Table 1. Average Monitoring Well Analytical Results

Compounds	**Pre-remedial**		**Active Remediation**			
Date	8/16/95	10/9/96	6/9/98	9/22/98	12/15/98	7/15/99
Benzene	1996	1939	1313	1410	1086	1127
Toluene	2078	130	574	408	381	313
Ethylbenzene	1186	408	588	548	330	457
Total Xylenes	2881	913	1900	1782	1224	1433
Naphthalene	------	50	111	153	88	85
Reductions*			**Overall**	**Overall**	**Overall**	**Overall**
Benzene			33%	28%	45%	43%
Toluene			48%	63%	65%	72%
Ethylbenzene			26%	31%	59%	43%
Total Xylenes			0%	6%	36%	24%
Naphthalene			-124%	-207%	-76%	-71%
BTEX&N			-3%	-16%	26%	22%
BTEX			27%	32%	51%	45%

Legend

Reductions "Overall" is based on average chemical compound concentrations obtained from selected sampling points during a given sampling event as compared to the average concentration between the two pre-remedial sampling events, without Naphthalene.

Reductions "Period" represents changes in concentrations between samping events.

Negative percentages (-#%) indicate a rise in concentration for a given compound, either "Overall" or for the "Period".

conditions often require changes in the system to optimize remedial efforts. Multi-technical systems are ideally suited to meet changing remedial needs of a site. At Site “A,” the higher-than-anticipated groundwater flow caused by the fractures in the water-bearing soils required changes to accelerate groundwater extraction rates. This is being accomplished by switching out some pumping equipment and installing a larger submersible pump to extraction trench #1. The cost for this modification will be small relative to the overall life cycle cost. All of the replacement equipment, except for the submersible pump in extraction trench #1, was sized, keeping in mind the additional equipment needed for Site “B”’s remedial system.

SITE “B”

Site “B” has been monitored on a yearly basis as per protocols established in the regulatory approved CAP. Monitoring has not indicated the need to accelerate remedial activities at this time. Deactivation of Site “A” may occur by the end of 2000. With the CAP in place, EPL has the flexibility to start construction of on-site components at Site “B” any time between now and deactivation of Site “A,” since the design work has already been completed.

Table 2 is a summary of dissolved groundwater constituents which have been detected in the following monitoring wells, as exceeding (i.e., Above) or not exceeding (i.e., Below) their respective remedial objectives over time.

Site “B” will use recovery wells with infiltration galleries rather than extraction trenches. The recovery well network will include 25 dual-phase extraction wells connected to form five operational zones. A series of three infiltration galleries will be installed within the radius of influence of the dual-phase recovery wells, creating a closed-loop system. Groundwater will be extracted using the same jet-pump technology as at Site “A.” The groundwater treatment system, vacuum pumps, control manifolds, and programmable controller will be moved from Site ”A” to Site “B.”

We will use the knowledge obtained from Site “A” in improving installation and operational practices for Site “B.” One such lesson will be the way the eductors are installed. Installation

Table 2. Site Conditions Over Time

Well #	**MW-1**			**MW-3**			**MW-6**			**MW-9**		
Date	1996	6/98	5/99	1996	6/98	5/99	1996	6/98	5/99	1996	6/98	5/99
Benzene	**A**	**A**	**A**	**A**	**A**	**A**	**A**	**A**	**A**	**A**	**A**	**A**
Toluene	B	B	B	**A**	B	B	**A**	B	**A**	B	B	B
Ethylbenzene	B	B	B	B	B	**A**	**A**	B	**A**	B	B	**A**
Xylenes	B	B	B	B	B	B	**A**	B	B	B	B	B
Naphthalene	**A**	B	B	**A**	**A**	**A**	**A**	**A**	**A**	**A**	**A**	**A**

A—Above
B—Below

techniques will be changed for the eductors to avoid the breaking pipe problems which have plagued Site "A."

SUMMARY

Multi-technologies can be effectively combined together to aggressively mitigate impacted sites. The key component to the integration of multi-technologies is the programmable logic control. Through BVRD, you can also design and implement a cost-effective system for the life cycle of the system while developing a trust with all parties involved. When you design a system, use empirical data. Why re-invent the wheel? And think long term, utilizing the collective knowledge of all the stakeholders. The design should include maintenance considerations and flexibility for change, as it is more likely than not that changes to the system will need to be made. In the final analysis, can your system adapt?

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