Table 6-1

Remediation Activities and Available Technologies

Activity	Medium	Containment with LNAPL recovery	Soil vapor extraction	In situ air sparging	Subsurface Heating	Six-phase heating	Recirculating wells	SEAR	Chemical oxidation	Monitored natural attenuation	Institutional Controls
Containment	Groundwater	P									
	Free-phase LNAPL	P									
Source removal	Residual immobile LNAPL, vadose		P	P	P	h		h	h	m	
	Free-phase LNAPL	P	P	P	P	P		P	P	m	
	Residual immobile LNAPL, saturated zone			P	P	P	m	P	P	m	
Vapor control	Soil vapor		P							P	
Dissolved hydrocarbon removal	Groundwater			P	P	P	P		P	P	
Exposure Prevention	Groundwater, LNAPL										P

P = This technology is potentially applicable for the activity listed.

m = This technology contributes to the activity listed, but only in a minor way.

h = This technology may be potentially applicable for the activity listed, but only if performed at high water table.

Note: Empty cells mean that the technology is not applicable to this activity.

Table 6-2
Summary Screening of Technologies

Technology	Description	Considered for further Evaluation	Rationale
Containment	Containment pumping, barrier walls, natural attenuation.	Yes	Proven effective at full scale at this site; essential to prevent migration of contaminants.
Soil vapor extraction (SVE)	Extraction of soil vapor, causing stripping of vadose hydrocarbons and enhanced biodegradation.	Yes	Proven effective at full scale to remove or biodegrade hydrocarbons from the vadose zone at this site.
In situ air sparging (IAS)	Injection of air below the water table, causing stripping of hydrocarbons and enhanced biodegradation	Yes	Proven effective in removing hydrocarbons from the saturated zone at nearby site; complements SVE
Thermal enhancements other than Six-Phase Heating	Injection of heated air or steam to reduce viscosity, and enhance stripping of hydrocarbons.	No	Very permeable formation causes large heat losses; energy-intensive; bypasses lenses of tight soil; unproven at this site.
Six-Phase Heating (SPH)	Resistive heating with electrodes in hexagonal pattern; boils water, driving off dissolved hydrocarbons and LNAPL	No	Very permeable formation causes large heat losses; energy-intensive; requires very large number of large diameter borings.
Groundwater Circulating Wells (GCWs)	In situ stripping of groundwater, removes volatiles with exhausted air.	No	Poorly compatible with vertically fluctuating LNAPL layer; expensive infrastructure; does not remove LNAPL; unproven at this site.
Surfactant-Enhanced Aquifer Remediation (SEAR)	Surfactant flooding to mobilize LNAPL.	Yes	The only technology that has the potential to rapidly and thoroughly remove free-phase and residual LNAPL.
In Situ Chemical Oxidation (ISCO)	Injection of oxidant to destroy hydrocarbons in situ.	No	According to site-specific lab tests, poorly compatible with site permeability and pH, very costly.
Monitored Natural Attenuation (MNA)	Sorption, dispersion, and biodegradation	Yes	Essential in final polishing of the site; complements containment.
Institutional Controls	Official notification, government controls, legal instruments that restrict access to the site.	Yes	Will be used in any case to prevent exposure to the contaminants.

Table 7-2

Estimated Time from Present Needed for the Groundwater Benzene Concentration to Drop Below the MCL (5μg/L)

Alternative	Initial Source Removal Technology	Time after Initial Source Removal (Years)	Duration of Initial Source Removal (Years)	Total Duration (Years from Present)
1	None	458	0	458
2	SVE	294	12	306
3	SVE + IAS	233	10	243
4	SVE + SEAR	93	8	101

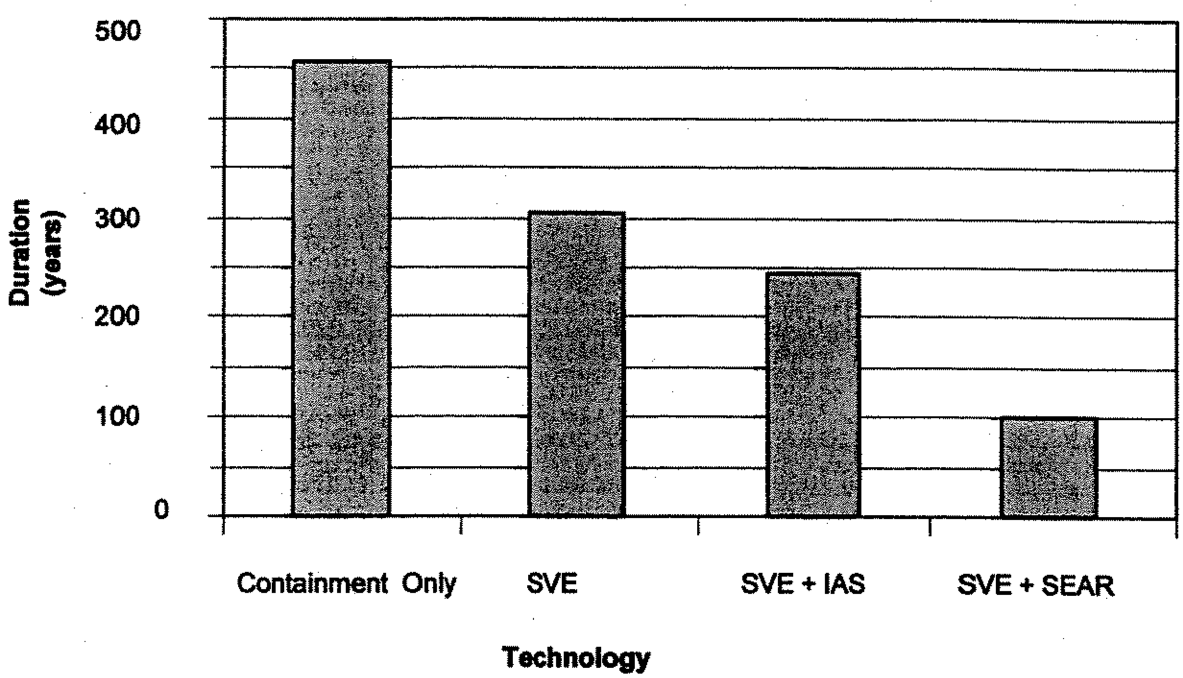

Figure 7-5

Projected Durations from Present to 5 μg/L Benzene, versus Technology

Table 7-5

Remedy Selection Decision Factor Grading Scale

Remedy Selection Factor	Grade	Grade Points	Grade Definition
Effectiveness and Useful Life	Excellent	3	Completely prevents the potential for future migration through rigorous treatment, containment, or both. Excellent ability to perform intended function through design or performance standards. Unlimited useful service life.
	Good	2	Limited potential for migration due to less rigorous treatment or containment. May not fully address contamination. Good ability to perform intended function through design or performance standards. Prolonged useful service life.
	Fair	1	Incomplete or limited treatment. Limited ability to perform intended function through design or performance standards. Limited useful service life.
	Poor	0	No reduction in toxicity, mobility, or volume. Poor ability to perform intended function through design or performance standards. Inadequate useful service life.
Reliability and O&M requirements	Excellent	3	Highly effective and proven treatment. Minimal risk of failure, or failure would have insignificant impact on receptors. Little or no operation and maintenance required.
	Good	2	Effective treatment, used in similar conditions and applications. Low risk of failure or failure would have little impact on receptors. Operation and maintenance requirements are straightforward and/or infrequent.
	Fair	1	Innovative approach or technology. Operation and maintenance requirements are complex and/or frequent. Risk of failure or failure would have significant impact on receptors.
	Poor	0	Developmental or unproven approach. High risk of failure or failure would adversely impact receptors. O&M requirements are stringent.
Implementability	Excellent	3	No significant construction or regulatory issues. Technology, regulatory climate, and internal climate favorable. Benefits of treatment can be observed immediately. Expedites the timing of remedial activity implementation.
	Good	2	Site conditions do not interfere with constructability. Technology and climate mostly favorable. Some issues may require additional testing, evaluation, and negotiation. Remedial activity implementation is swift, and benefits of treatment are quickly apparent.
	Fair	1	Site conditions have some effect on constructability. Innovative approach or technology. Some regulatory hurdles. Remedial activity implementation and/or observable treatment benefits may be delayed.
	Poor	0	Site conditions adversely affect constructability. New or developmental technology or approach. Extensive regulatory and/or community input is required. Extensive negotiations may delay technology implementation, or technology takes a long time to produce beneficial effects.

Table 7-5 (Continued)

Remedy Selection Factor	Grade	Grade Points	Grade Definition
Safety	Excellent	3	Minimal material handling or waste management activities. Waste handling/management performed under controlled conditions. Little or no threat to workers or nearby communities during implementation.
	Good	2	Some material handling/waste management. Activities well controlled. With proper controls, no threat to workers or nearby communities during implementation.
	Fair	1	Rigorous yet controlled material handling and waste management. Some risk of short-term release or exposure. Some potential threat to workers or nearby communities during implementation.
	Poor	0	Extensive material handling or waste management activities. Potential for short-term releases or exposures. Can pose a threat to workers or nearby communities during implementation.
Environmental effects (short and long term)	Excellent	3	Large (90-100%) reduction in toxicity or mobility. Waste is managed and contained so as to minimize future releases and optimize short-term efficacy. Eliminates contact and migration potential.
	Good	2	Reasonable (risk-based) reductions in toxicity or mobility. Short-term exposure risk is restricted. Reduces exposure risk by limiting contact and migration potential.
	Fair	1	Some reduction of toxicity or mobility, but not wholly effective for the contaminants of concern. Contact and/or migration potential if containment systems or other engineering controls fail. Some risk of short-term release or exposure.
	Poor	0	No reduction in toxicity or mobility. Will result in a release if the containment systems or other engineering controls fail. Contact and/or migration potential is persistent.
Human Health effects (short and long term)	Excellent	3	Large (90-100%) reduction in toxicity or mobility. Waste is managed and contained so as to minimize future releases and optimize short-term efficacy. Eliminates contact and migration potential.
	Good	2	Reasonable reductions in toxicity or mobility. Short-term exposure risk is restricted. Reduces exposure risk by limiting contact and migration potential.
	Fair	1	Some reduction of toxicity or mobility, but not wholly effective for the contaminants of concern. Contact and/or migration potential if containment systems or other engineering controls fail. Some risk of short-term release or exposure.
	Poor	0	No reduction in toxicity or mobility. Will result in a release if the containment systems or other engineering controls fail. Potential for short-term releases or exposures. Contact and/or migration potential is persistent.

Table 7-5 (Continued)

Remedy Selection Factor	Grade	Grade Points	Grade Definition
Institutional Concerns	Excellent	3	Community in full support of technology. Technology, regulatory climate, and internal climate favorable. No significant construction or regulatory issues. Expedites the timing of remedial activity implementation.
	Good	2	Public support for proposal is available. Technology and climate mostly favorable. Some issues may require additional testing, evaluation, and negotiation.
	Fair	1	Some community relations issues. Innovative approach or technology. Some regulatory hurdles.
	Poor	0	Community dislikes alternative. New or developmental technology or approach. Will require extensive regulatory negotiation. Remedial activity implementation may be delayed.
Construction Cost	None	None	Construction cost of implementing remedy.
O&M Cost	None	None	O&M cost of implementing remedy.

7.5.5 Environmental Effects (Short- and Long-Term)

For all alternatives, the mobile LNAPL and dissolved hydrocarbons are contained, so the efficacy of containment is not a differentiator, but it implies that no alternative should get a score below 2. Alternative 1 removes only free phase LNAPL and has no direct impact on benzene; of all the alternatives, it leaves the most LNAPL and benzene in the ground so it will be given a score of 2. Alternatives 2 and 3 have more impact on benzene and LNAPL but not to the point of warranting a higher score, so they also will be assigned a score of 2. Alternative 4 is the only one with the potential of removing most of the LNAPL and thus the source of benzene, so it will be given a score of 3.

7.5.6 Human Health Effects (Short- and Long-Term)

The scoring for this criterion will follow the same reasoning as for the environmental effects, i.e., a 2 for Alternatives 1, 2, and 3, and a score of 3 for Alternative 4.

Table 7-6
Composite Evaluation of Alternatives

Alternative No.	Effectiveness and Useful Life	Reliability and O&M Requirements	Implementability	Safety	Environmental Effects	Human Health Effects	Institutional Concerns	Present Worth Cost ($ millions)	Final Score
1	2	2	3	2	2	2	3	50	16
2	2	1	2	1	2	2	2	90	12
3	2	1	1	1	2	2	1	107	10
4	2	0	0	0	3	3	0	150	8

7.7 Conclusions

The estimated remediation times and estimated costs for the four alternatives are shown in Table 7-7.

Table 7-7
Estimated Remediation Times and Costs for Four Alternatives

Alternative No.	Present Worth Cost ($ millions)	Estimated Remediation Time
1	50	458 years
2	96	306 years
3	107	243 years
4	150	101 years

The four alternatives that have been developed comprise a range of approaches from continued containment (Alternative 1) to the most aggressive (Alternative 4). An analysis of these alternatives indicates that even with the most aggressive approach, it will take at least a century to meet the final cleanup goals. Practically speaking, it is not possible to return the aquifer to its maximum beneficial use in a reasonable time period.

B.0 Cost Inputs

B.1 Financial Assumptions

The discount rate (i) was set at 5%/year, the inflation rate (i_i) at 3%/year. From these numbers, an effective discount rate (i_e) of 1.94% was calculated using the equation

$i_e = (i-i_i) / (1+i_i)$.

B.2 Fixed Costs

Several short-term operations now taking place at the site will have to continue in the near future and be completion. On the Island, bioventing will continue and be followed by monitored natural attenuation. Under East Hooven, three horizontal wells are in operation; they will be operated in SVE mode until this becomes uneconomical, after which they will be operated at a reduced flow for bioventing. The costs and durations assumed are summarized in Table B-1.

Table B-1

Fixed Costs

Location	Islands		Hooven	
Technology	Bioventing	MNA	SVE	Bioventing
Annual Cost	$40,000	$20,000	$100,000	$40,000
From	Year 0	Year 8	Year 0	Year 8
Until	Year 7	Year 14	Year 7	Year 14
Present worth*	$0.26MM	$0.11MM	$0.65MM	$0.23MM

* Present worth of costs at 1.94% effective discount rate.

The total present worth of these fixed costs is $1.25 million.

B.3 P&T Costs

The annual operating cost of the P&T system without free-product recovery is estimated in Table B-2.

Table B-2

Present Annual O&M Cost of the P&T System

Item	Annual Cost
Electrical (Wells)	$63,333
Electrical (GAC FBR)	$60,000
GAC FBR Consumables	$62,000
Maintenance labor	$117,000
NPDES fees	$6,000
Well rehabilitation, 9 wells	$33,000
Effluent monitoring	$12,000
Groundwater monitoring	$125,000
Non-P&T payroll	$200,000
Other utilities, O&M	$20,000
Consulting	$150,000
Total annual cost	$848,333

The alternatives have projected operating times that range from decades to centuries. During this time, it is likely that the GAC FBR water treatment facility will have to be replaced. It was assumed that the GAC FBR facility would have a life expectancy of 25 years and that the first replacement would have to occur in 10 years since the present facility was built 15 years ago. A new GAC FBR facility is estimated to cost $2.3 million.

B-4 Free-Product Recovery

As discussed in Section 4.4, the rate of free-product recovery since 1989 has oscillated based on water levels and shows no clear trend. LNAPL recovery will continue as long as substantial amounts can be recovered, but will be focused on the western edge of the facility, along S. R. 128. For the purpose of this cost analysis, we assumed that free-product recovery would continue for 16 years. The cost of disposing of the recovered free product is $0.67/gallon.

For Alternatives 1 (P&T only) and 2 (SVE), an annual free-product recovery of 60,000 gallons was estimated. This is the historical average for the past decade. The initial recovery rate in the 1985-1989 time frame was much higher, but has not reoccurred since.

In the case of Alternative 3, we assumed that the SVE + IAS system would remove some free product, leaving only 45,000 gallons per year to be recovered via the production wells. Finally, the SEAR + SVE system in Alternative 4 was assumed to remove a substantial amount of free product, leaving only 30,000 gallons per year for recovery via the production wells.

B-5 Cost of Initial Remediation

The capital and O&M costs of SVE, SVE + IAS, and SEAR + SVE were estimated (see Appendix B) and are summarized in Table B-3.

Table B-3

Estimated Costs of Initial Remediation

Alternative	Initial Remediation Technology	Capital Cost	O&M Cost	Duration of Initial Remediation	Present Worth of O&M
		$ millions	$ millions/yr	years	$ millions
1	None	0	0	0	0
2	SVE	18.74	2.24	12	23.77
3	SVE + IAS	24.78	3.56	10	32.08
4	SEAR + SVE	89.76	2.24 (*)	8	16.45

(*) Only O&M for SVE; O&M of SEAR incorporated in capital cost.

Note that, due to the complexity of the SEAR cost estimate, SEAR was assumed to be instantaneous for cost purposes, so its capital and O&M costs are combined in the capital cost column. The present worth of O&M for SEAR reflects only the cost for SVE operation during 8 years.