Table 10-8
Potentially Applicable Remedial Technologies and Process Options for DNAPL Contamination and/or Contaminated Fractured Bedrock
Casmalia Resources Superfund Site
Casmalia, CA

General Response Action	Remediation Technology	Process Option	Description	Effectiveness	Implementability	Relative Capital/Operation & Maintenance Costs	Summary of Screening
Containment	Hydraulic Ground Water Barrier	Ground Water Pumping	Ground water extraction to establish capture zone and restrict ground water flow and contaminant migration in the down gradient direction. Treatment of extracted groundwater may be required for disposal.	Ineffective for cleanup of DNAPLs in fractured bedrock because of insufficient hydraulic interconnectedness, the presence of flow restrictions(e.g., partially-closed fractures), and matrix diffusion into the surrounding rock.	Even closely-spaced extraction wells or trenches would not be able to intersect all of the factures that contain or potentially contain DNAPLs to depths of approximately 150 ft bgs. Groundwater extraction is only appropriate as a component of existing source control features (e.g., PSCT and PCT), but will not achieve cleanup goals due to the presence exisiting chemical sources.	High capital. High O&M.	Not effective at reducing VOC concentrations down gradient from the extraction barrier. Extraction could continue for hudreds of years without reaching cleanup goals. This technology is typically ineffective for DNAPLs in fractured bedrock.
	Fluids Extraction	High Vacuum Extraction	Extraction of total fluids via a high vacuum pump. Pump applies a vacuum to the subsurface drawing out fluids and vapor. The extracted groundwater provides hydraulic containment and the extracted vapors remove VOC's and provide a vapor containment.	Not applicable for DNAPL cleanup in deep fractured rock. Only marginally effective on Upper HSU at Casamlia due to the low permeability of weathered bedrock. Not effective on remediating non-volatile chemicals.	Requires groundwater and vapor flow into well, which is not possible in bedrock.	Low capital. Moderate O&M.	Not effective at reducing non-volatile chemcials, limited radius of influence in fine-grained soils. This technology is typically ineffective for DNAPLs in fractured bedrock.
	Physical Ground Water Barrier	Low Permeability Wall	Construction of a low-permeability vertical barrier to restrict ground water flow and contaminant migration in the down gradient direction. Long-term monitoring of containment structure required.	This technology has been proven to be effective for containing impacted NAPLs and ground water or providing a barrier for ground water treatment systems at the Casmalia site. May need to be implemented in association with additional active treatment technologies to reduce contaminant mass. Does not address contaminants downgradient of wall.	DNAPLs have been observed in isolated areas to depths of approximately 150 feet bgs, which is beyond the depths that slurry walls can be installed using reliable installation methods within bedrock materials. Impervious barrier methods, in concert with groundwater extraction, are only appropriate as a component of an existing source control feature (e.g., P/S Landfill Clay Barrier and RAP Trenches).	High capital. Low O&M.	Does not reduce toxicity or contaminant mass. Does not address areas downgradient of wall.
In Situ Ground Water Treatment	Thermal Treatment	Steam Heating	Involves the installation of a series of steam injection wells. Steam is generated in a boiler and injected at the wells, which gradually raises the temperature of the ground water and soil, thereby enhancing the mobility and volatility of contaminants. This technology commonly uses an SVE system to control buildup of volatilized contaminants and non-condensable gases, as well as ground water extraction.	The low permeability and insufficient hydraulic interconnectivity of the fractured bedrock will inhibit proper flow and distribution of steam, making this technology ineffective.	Consistent steam flow would be impossible to achieve in the low permeability fractured bedrock.	High capital. High O&M.	Neither effective nor implementable for DNAPLs in deep fractured bedrock. Dependence on complete vapor distribution and recovery make this technology typically ineffective for DNAPLs in fractured bedrock.
		Electrically Induced Heating	Electrical current is generated between electrodes installed in the subsurface, which gradually raises the temperature of ground water, thereby enhancing the mobility and volatility of contaminants. This technology also requires an SVE system to control buildup of volatilized contaminants and non-condensable gases.	Effective only for VOCs. Effective capture of VOCs requires implementation of SVE, which would be ineffective in weathered or unweathered bedrock.	Complete steam recovery would be impossible to achieve in the low permeability fractured bedrock; creation of steam without a clear connection to a vapor recovery system could drive contaminants deeper and farther into the fractured system.	High capital. High O&M.	Dependance on complete vapor recovery make this technology typically ineffective for DNAPLs in fractured bedrock.
		Radio Frequency Heating	Involves using electromagnetic energy to heat the soil and groundwater, thereby enhancing the mobility and volatility of contaminants. This technology also requires an SVE system to control buildup of volatilized contaminants and non-condensable gases.	Effective only for VOCs. Effective capture of VOCs requires implementation of SVE, which would be ineffective in weathered or unweathered bedrock.	Complete steam recovery would be impossible to achieve in the low permeability fractured bedrock, creation of steam without a clear connection to a vapor recovery system could drive contaminants deeper and farther into the fractured system.	High capital. High O&M.	Dependance on complete vapor recovery make this technology typically ineffective for DNAPLs in fractured bedrock.
	Physical Treatment	In-Well Air Stripping	In-well aerators perform air stripping of ground water within the well. Ground water is not removed from the well, but is circulated between an upper and lower screen in the well. Volatile compounds enter the vapor phase and are recovered and treated by a vapor extraction system.	Effective for VOCs, SVOCs and fuels. Cost effective in areas with deep water tables because impacted ground water does not have to be pumped to surface. Relies on adequate groundwater flow within an induced recirculation cell. Not effective for fractured bedrock.	Low permeability and fractured nature of soils would significantly reduce amount of ground water treated and the radial influence of the wells, increasing the number of recirculation wells required.	High capital. Moderate O&M.	Dependance on complete vapor recovery make this technology typically ineffective for DNAPLs in fractured bedrock.

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		Air Sparging	Air is injected into the saturated zone to induce mechanical stripping and volatilization of contaminants. SVE is required to capture vapor phase contaminants.	Effective for VOCs and fuels in permeable media. Low permeability of fractured bedrock would limit contact with the injected air. Biodegradation of VOCs would not be enhanced, and could be hindered, by increase in oxygen concentration.	Relies on mass removal via vapor extraction. Consistent vapor flow would be impossible to achieve in the low permeability fractured bedrock.	High capital. Moderate O&M.	Dependance on complete vapor recovery make this technology typically ineffective for DNAPLs in fractured bedrock.
	Chemical Treatment	Chemical Oxidation	Injection of a dilute solution of an oxidant such as potassium permanganate, sodium per sulfate, or Fenton's Reagent, into the contaminated zone to directly oxidize VOCs.	Requires direct contact with affected media, and therefore not effective in the fractured bedrock areas. Also requires low oxidant demand of native soils, yet native rock is an organic-rich marine claystone that would likely have high oxidant demand.	Low permeability of Upper HSU and fractured bedrock in Lower HSU will affect the ability to inject adequate volume of oxidant and create direct contact in all locations.	Moderate capital. Low O&M.	Need for complete contact and low soil oxidant demand make this technology typically ineffective for DNAPLs in fractured bedrock.
		Ozone Sparging	Sparging of gas-phase ozone to oxidize VOCs in situ. Implemented similarly to air sparging with the addition of ozone to the sparged air. Typically combined with soil vapor extraction. Typically most applicable for high concentration and recalcitrant contaminants.	Ozone can be effective at oxidizing VOCs in groundwater. Delivery of ozone may be prohibitive due to low-permeability of Upper HSU and fractured bedrock in the Lower HSU. Short-lived ozone requires good distribution for adequate effectiveness.	Technology is implemented in a similar manner as air sparging, and has similar implementation issues.	High capital. High O&M.	Dependence on complete vapor distribution and recovery make this technology typically ineffective for DNAPLs in fractured bedrock.
		Zero-Valent Iron Permeable Reactive Barrier	Placement of zero-valent iron into the contaminated zone to destroy VOCs through chemically-mediated reductive dechlorination. The zero-valent iron is placed in the form of a reactive barrier wall perpendicular to ground water flow direction. Placement of the zero-valent iron may be performed using dug trenches or through high-pressure slurry	Effective for complete destruction of halogenated VOCs on contact. Not effective on hydrocarbons or non-chlorinated contaminants. Requires specific background geochemistry to prevent premature oxidation of iron.	Most commonly implemented as a reactive barrier wall, treating contaminants passing through wall. Trenching not possible to depths of 148 feet, where DNAPLs have been observed. Hydraulic fracturing is possible to those depths in unconsolidated deposits, but not within fractured	High capital. Low O&M.	Will not treat all chemicals of concern. This technology is typically ineffective for DNAPLs in fractured bedrock. Would not significantly improve contaminant migration in Upper HSU beyond existing hydraulic barriers/control features (e.g., PSCT).
	Biological Treatment	Enhanced Anaerobic Bioremediation	Injection of a carbon source (electron donor) material into the contaminated zone to stimulate degradation of polychlorinated VOCs through reductive dechlorination. Typical injectates include acetate, lactate, and food-grade oils. Can be supplemented with addition of specific degrading microbes to enhance overall effectiveness.	Effective for chlorinated VOCs, but daughter compounds such as dichloroethene and vinyl chloride are much more difficult to dechlorinate and may increase toxicity. Low permeability in Upper HSU and fractured bedrock in Lower HSU would reduce migration of carbon source and limit effectiveness.	Low permeability of fractured bedrock may limit ability to inject carbon source.	High capital. Low O&M.	Low permeability would limit injection of carbon source, and actions could produce more toxic byproducts (e.g., vinly chloride) with partial breakdown, making this technology typically ineffective for DNAPLs in fractured bedrock.
		Enhanced Aerobic Bioremediation	Injection of oxygen or oxygen-releasing material into or up gradient of the contaminated zone to enhance degradation of organic compounds through aerobic respiration.	Effective for non-halogenated VOCs, SVOCs, and fuels. More effective for dichloroethene and vinyl chloride. Not effective for chlorinated VOCs.	Low permeability of fractured bedrock may limit ability to inject oxygen.	High capital. Low O&M.	May be effective for fuel hydrocarbons in Upper HSU, but not effective for chlorinated VOCs. This technically is typically ineffective for DNAPLs in fractured bedrock.

Notes:
This table is not intended to be a comprehensive screening analysis. A more comprehensive analysis will be presented in the forthcoming Feasibility Study.