Table A-9.A. Steam injection

Technology	Steam injection	Steam is injected into wells to heat the formation and LNAPL. Steam injection induces a pressure gradient that pushes ahead of it, in sequence, a cold water (ambient temperature) front, a hot water front, and a steam front through the LNAPL zone. In the unsaturated zone, a steam and condensation front develops. The mobilized LNAPL and groundwater are recovered from extraction wells, and volatilized LNAPL is collected via vapor extraction wells. Pressure cycling can be used to remove the volatile fractions preferentially, by a process similar to distillation.	
Remediation process	Physical mass recovery	Yes	Cold water front flushes some of the remaining mobile LNAPL from pores. Hot water and steam fronts reduce viscosity of LNAPL increasing mobility and recoverability.
	Phase change	Yes	The steam front volatilizes the VOCs contained in the LNAPL.
	In situ destruction	Yes	Not generally important at steam temperatures for LNAPLs. LNAPL may undergo thermal degradation or hydrous pyrolysis but with limited effect.
	Stabilization/ binding	No	N/A
Objective applicability	LNAPL saturation	Yes	Enhances LNAPL fluid flow by reducing LNAPL viscosity, and volatilizes lighter constituents, reducing LNAPL saturations to below residual saturation achieved by standard hydraulic methods.
		Example performance metrics	Reduced LNAPL transmissivity; reduction or elimination of measurable LNAPL in wells.
	LNAPL composition	Yes	Abate accumulation of unacceptable constituent concentrations in soil vapor and/or groundwater from an LNAPL source.
		Example performance metrics	LNAPL composition change; soil VOC concentrations to below regulatory standard; soil vapor plume concentrations to below regulatory standard.
Applicable LNAPL type	All LNAPL types, though higher-viscosity and/or lower-volatility LNAPL takes longer to treat and/or achieves less remedial effectiveness.		
Geologic factors	Unsaturated zone	Permeability	Steam injection is effective only in relatively permeable materials (hydraulic conductivity >10^{-5} cm/sec), where there is less resistance to flow. More effective in stratified LNAPL settings, where a low-permeability layer can help to control steam distribution. Care must be taken to understand where the condensate goes—in permeable settings it may migrate downward to the water table.
		Grain size	Steam injection can achieve more effective saturation reduction in coarser-grain materials.
		Heterogeneity	Steam injection is more efficient in permeable pathways, but LNAPL is also distributed mainly in these pathways. Strata that do not readily accept steam are heated via heat conduction from the more permeable zones where steam does flow.
		Consolidation	High consolidation may reduce pore sizes, permeability, and injection feasibility. Steam may readily flow in fractures in rock, which is likely where the LNAPL concentrations are greatest.
	Saturated zone	Permeability	Steam injection is effective only in relatively permeable materials (hydraulic conductivity >10^{-5} cm/sec), where there is less resistance to flow. More effective in stratified LNAPL settings, where a low-permeability layer can help to control steam distribution.
		Grain size	Steam injection can achieve more effective saturation reduction in coarser-grained materials.

		Heterogeneity	Steam injection is more efficient in permeable pathways, but LNAPL is also distributed mainly in these pathways. Strata that do not readily accept steam are heated via heat conduction from the more permeable zones where steam does flow.
		Consolidation	High consolidation may reduce pore sizes, permeability, and injection feasibility. Steam may readily flow in fractures in rock, which is likely where the LNAPL concentrations are greatest.