Table A-9.C. Technical implementation considerations for steam injection

Data requirements	Site-specific data for technology evaluation	Site size and soil characteristics	Steam injection is most suited to large, deep sites, and sites with significant groundwater flow.
		Groundwater characteristics	Steam injection is most applicable in high permeability soils with significant groundwater flow.
		LNAPL characteristics	Chemical properties (composition, vapor pressure, boiling point, viscosity, etc.).
		LNAPL depth	Lateral extent and vertical depth needed to estimate total soil volume to be heated, steam-generation needs, etc.
		LNAPL location	Open area preferred. Under building, in the shallow zone, near utilities, or any other obstructions to injection well placement need special consideration.
		Off-gas treatment	Concentrations and types of contaminants affect loading and off-gas technology selection. Water and NAPL separation and treatment required.
	Bench-scale testing	Bench scale testing is only required for some SVOCs.	
		Soil characteristics	Permeability, moisture, classification, achievable reductions in LNAPL concentrations as a function of steam flushes.
		LNAPL characteristics	LNAPL viscosity reduction as a function of temperature.
		Groundwater geochemistry	N/A
	Pilot-scale testing	Pilot testing is not generally required.	Limited steam injection testing may be performed by the vendor to determine the relationship between injection pressure and steam flow rate.
		Injection/ extraction well spacing	Based on permeability, steam injection rate, injection pressure, and desired breakthrough time. Determine placement of injection and extraction wells, plus screen depth, length and spacing. Determine actual steam migration pattern in subsurface.
		Injection rates	Determine required injection pressure and rate to ensure overall coverage and minimize short-circuiting to the surface.
		Injection pressures	Injection pressure must be less than the overburden pressure to ensure short-circuiting to the surface does not occur.
		Off-gas treatment	Selection of off-gas treatment depends on contaminant mass and extraction rate, regulations, etc. A pilot study is generally not required to determine off gas treatment.
	Full-scale design	Injection rates	Normally estimated by numerical modeling in conjunction with minimal steam injection pilot testing, further adjustments made during operations depending on observations of subsurface temperatures.
		Injection pressures	Injection pressure must be less than the overburden pressure to ensure short-circuiting to the surface does not occur.
		Off-gas treatment	Selection of off-gas treatment depends on contaminant mass and extraction rate, regulations, etc.
	Performance metrics	Achieve temperature goal throughout treatment area.	Temperatures are measured throughout the treatment area and compared with an energy balance for the site to ensure that the entire treatment area is heated to the target temperature.
		Effluent measurements	Mass recovery rate and cumulative mass recovered over time are tracked to determine when mass recovery diminishes.
		Groundwater concentrations	Groundwater concentrations are expected to increase initially, than decrease as mass remaining in the subsurface diminishes.
		Soil concentrations	Soil concentrations will decrease as the mass remaining in the subsurface decreases.
Modeling tools/applicable models		Thermal vendors will run their own models of the system.	

Further information	EPA. 1998. Steam Injection for Soil and Aquifer Remediation. EPA/540/S-97/505. https://www.epa.gov/sites/production/files/2015-06/documents/steaminj.pdf
	USACE. 2009. Engineering and Design: In Situ Thermal Remediation. EM-1110-1-4015. https://clu-in.org/download/techfocus/thermal/EM_1110-1-4015.pdf