Containment and Groundwater Modification

Team 3: Ajia, Amina, Darren, David, Domenico, Nicole, and Sruthi

Overview

Groundwater zone contamination.
More difficult to treat than surface water contamination
Plume can spread to undesirable lengths and locations.
“dissolved” or “free-phase”
<u>Containment</u> = important in-situ step.
Prevent the problem from escalating
Followed by other treatment methods.
<u>Groundwater Modification</u> = in-situ for the most part

Type 1: Isolation/Containment

- Passive vs Active

1) SLURRY WALLS

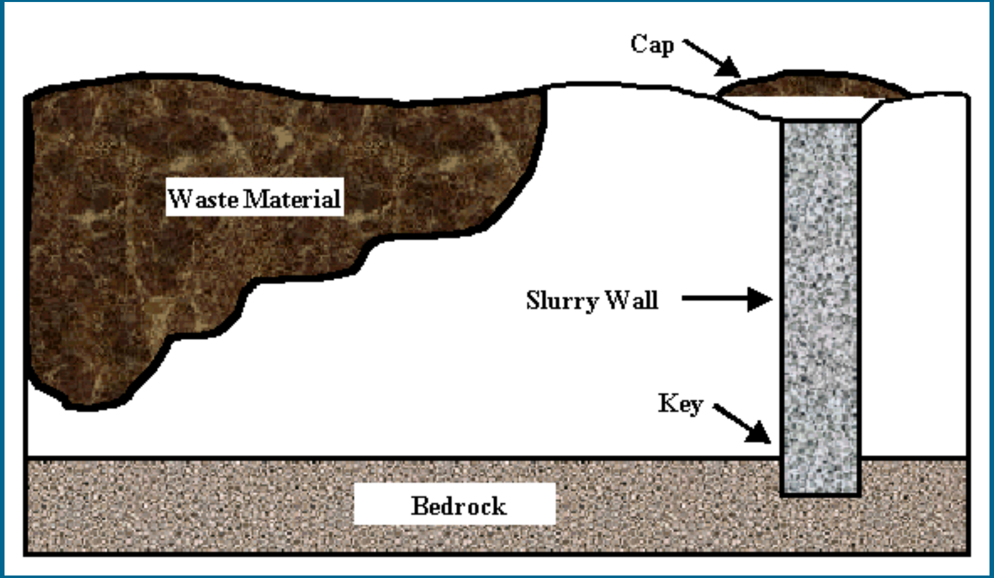
High plasticity, low K

Sometimes 360° around

Sometimes capped on top

Floating OR Keyed in

Plume may react with wall



Type 1: Isolation/Containment

1) Slurry Walls…

2) Soil Mixing

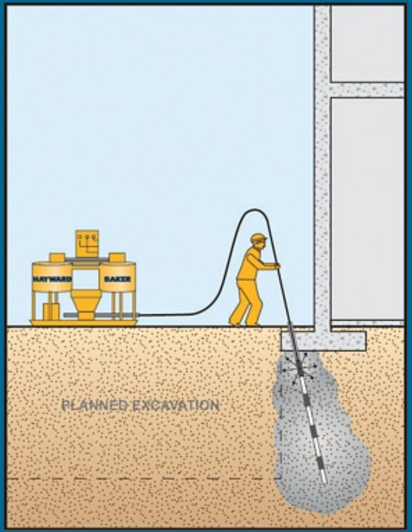
Penetration: fill in voids

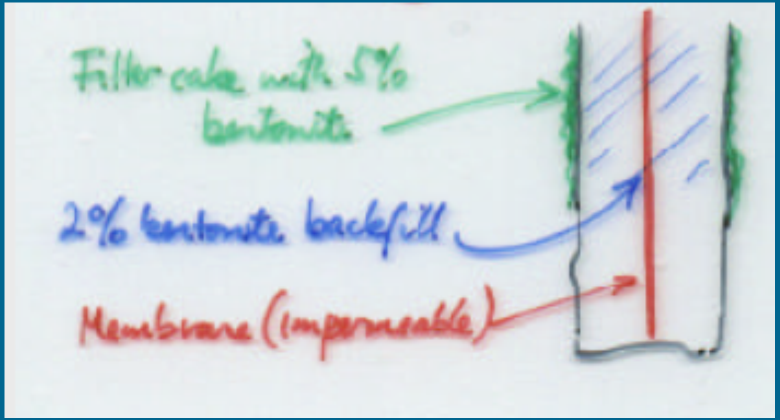
1-3 m

Jet Grouting: destroy fabric

0.3-2 m

K: 10^-5 to 10^-8 cm/s





Type 1: Isolation/Containment

3) Sheet Piling

Joints are sealable

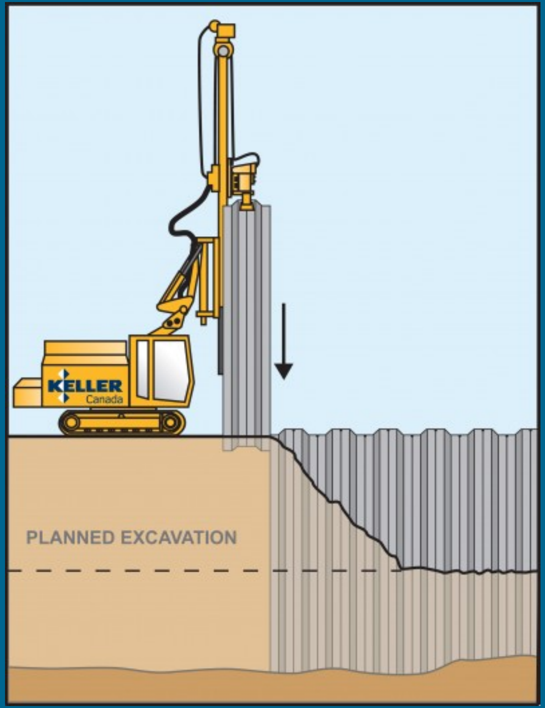
Risk: May crack aquicludes

Material costs

4) Active Controls

AFTER Containment,

Pump and treat



Type 2: Stabilization/Solidification

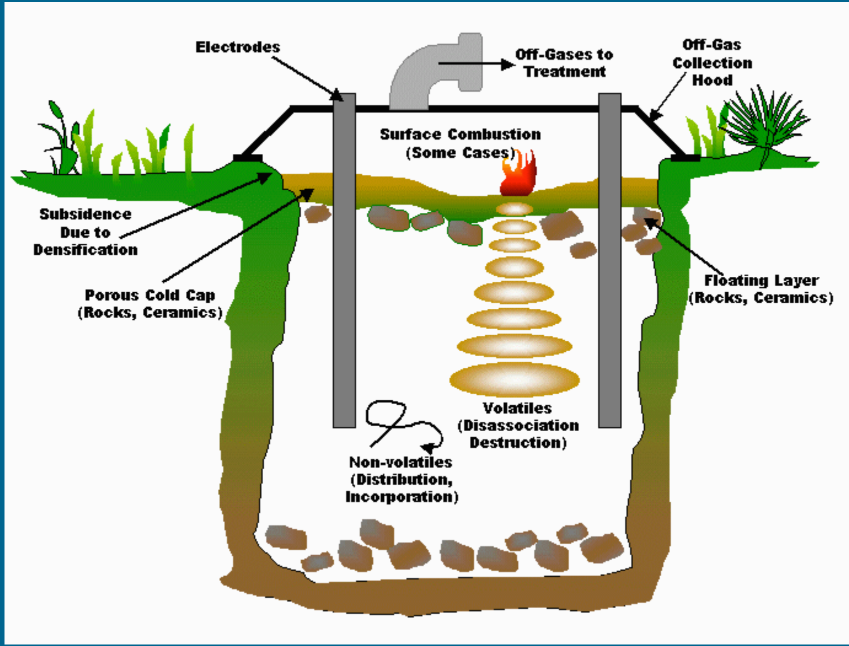
Stabilization: in-situ transformation
(toxicity or solubility)

Solidification: creating solid mass to be
taken out

In Situ Vitrification

electric current + heat to melt soil

becomes glass like material and traps
contaminants



Type 2: Stabilization/Solidification

Micro -encapsulation: trap contaminants in crystalline structure

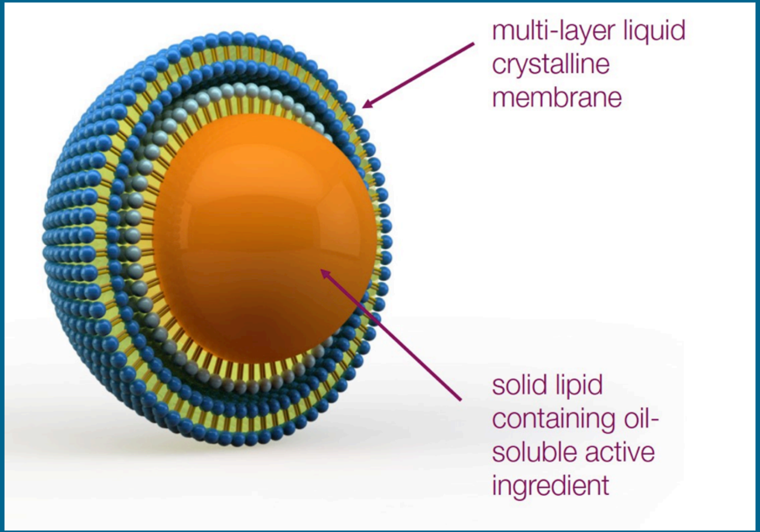
(microscopic pores)

Or, **Macro -encapsulation:** trap on a solid surface

Organic vs **Inorganic**

Underlying mechanism: *ADSORPTION*

Strength + Durability



Type 3: Permeable Treatment Walls

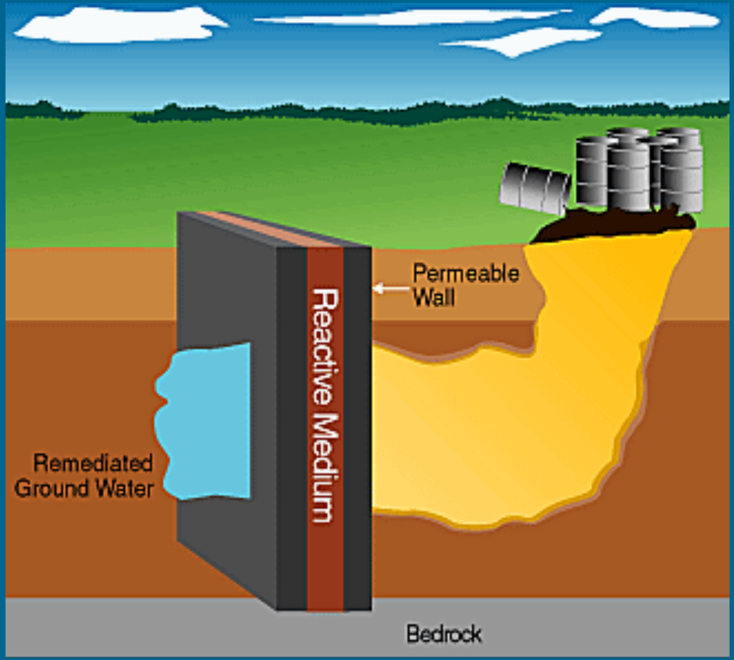
Precipitation: Dissolved contaminant can react and "precipitate out" as a solid. It is pH-dependent.

METALS, hydroxides, sulfides, silicates, carbonates, phosphates

Detoxification: change contaminant into less toxic form

Ex: Cr+6 -> Cr+3

Biodegradation: Bacteria

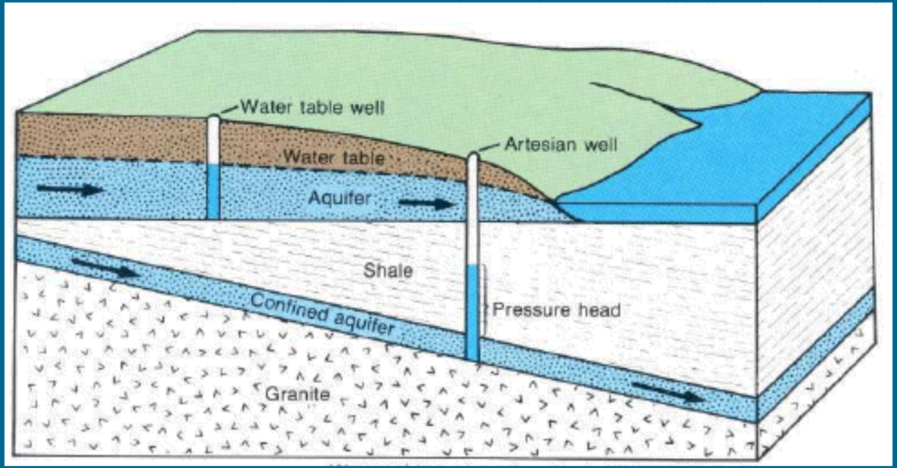


Permeable reactive barriers have the potential to lower the cost and increase the effectiveness of groundwater cleanup.

Influencing Factors

Things to consider:

- Location
    - Aquifer
    - Public/Private Wells
    - Impermeable layer
- Contaminant Composition
- Material (ex. Fly Ash)
- Stress-deformation Analysis



http://www.waterincrisis.com/pages/aquifers_mn1/aquifers.html

Influencing Factors

LNAPL:

- Control the migration, not containment
- Treatment wall

DNAPL:

- May be used with other methods
- Isolate the contaminant
- Prevent lateral migration

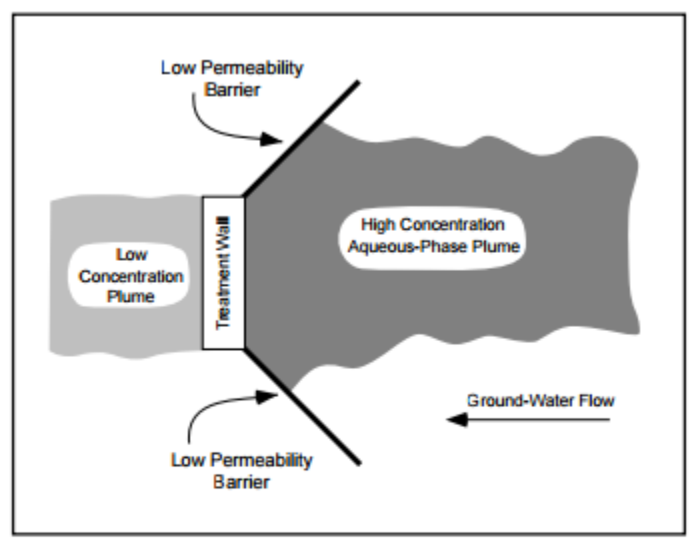


Image reproduced from the EPA (Newell et al., 2015).

Influencing Factors

Slurry Walls:

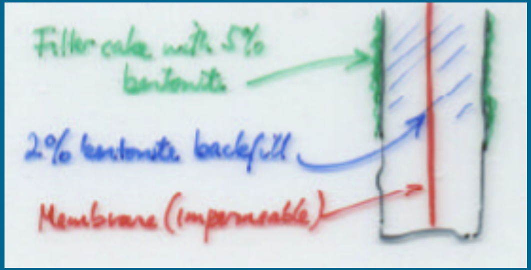
Bentonite Soil

Low conductivity with about 5-7% bentonite

High plasticity resists fractures

Backfill typically 2% bentonite

Sheet piles, geomembranes, or concrete cut-off as impermeable membrane



Bentonite Concrete

Brittle and may fracture

Influencing Factors

Type	Advantages
Cement-bentonite (CB)	Strength, low compressibility Can be used on steep slopes with unstable soil Hydraulic conductivity around 10^{-6} cm/s
Soil-bentonite (SB)	Lower hydraulic conductivities than CB Cheaper than CB Hydraulic conductivity typically around 10^{-7} cm/s, but as low as 5.0×10^{-9} cm/s
Soil-cement-bentonite (SCB)	Similar to CB in strength and SB in hydraulic conductivity
Plastic concrete (PC)	Stiffer and stronger than cement-bentonite Preferred type of cutoff wall for deep walls (clam-shell or hydromill is used to excavate the trench)
Mix-in-place	Soil is not excavated
Composite slurry	Improved impermeability and resistance
Grouting	Can be used for barrier construction by injecting grout into holes or to seal fractures in impermeable layers

Table reproduced from the EPA (1992).

Influencing Factors

Penetration and Jet Grouting:

- Penetration
    - Support/stabilization
- Jet
    - Soil/Slurry mix
    - Overlay columns
- Conductivity of grout mix about 10^-5 to 10^-8 cm/s

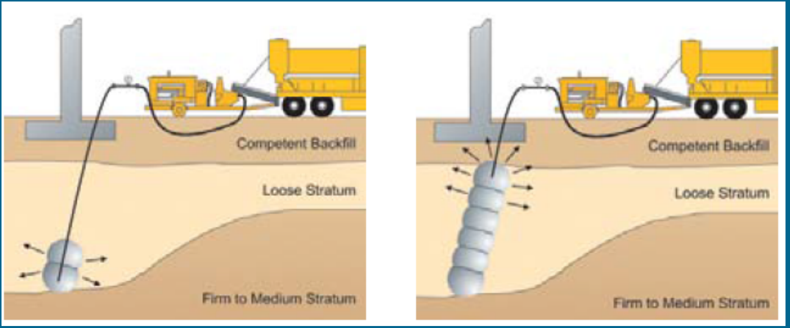


Image courtesy of Keller Ground Engineering (2017).

Influencing Factors

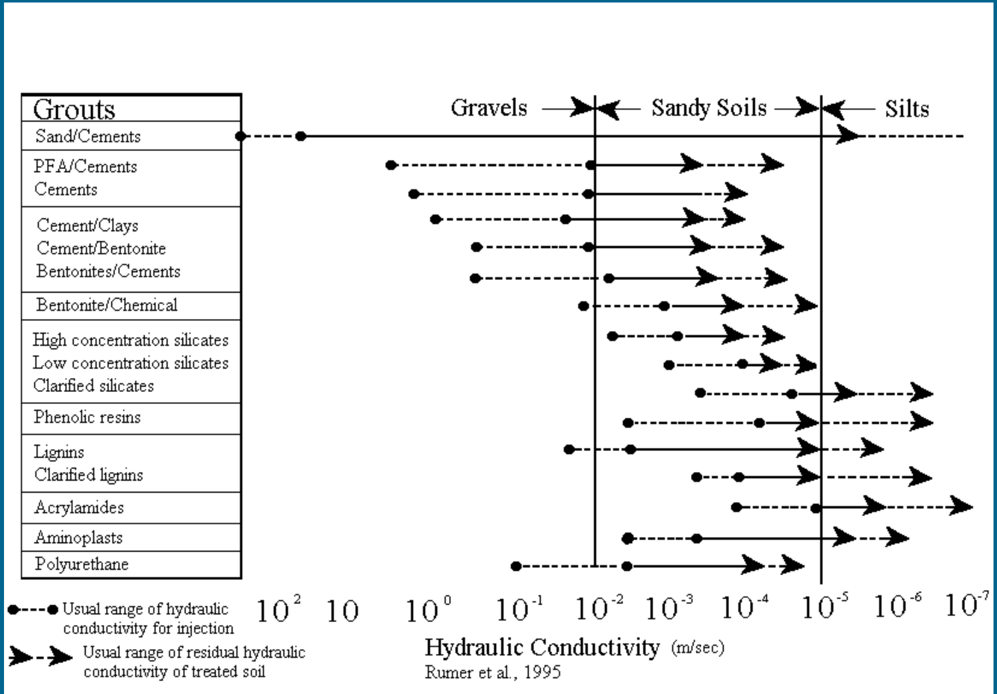


Figure reproduced from Pearlman (1999).

Influencing Factors

Effects of pH on the system:

- Acidic
  - Strong inorganics (pH < 1)
  - Bentonite dissolution
    - Silica
    - Aluminum
- Basic
  - Strong (pH > 11)
  - Change the porosity

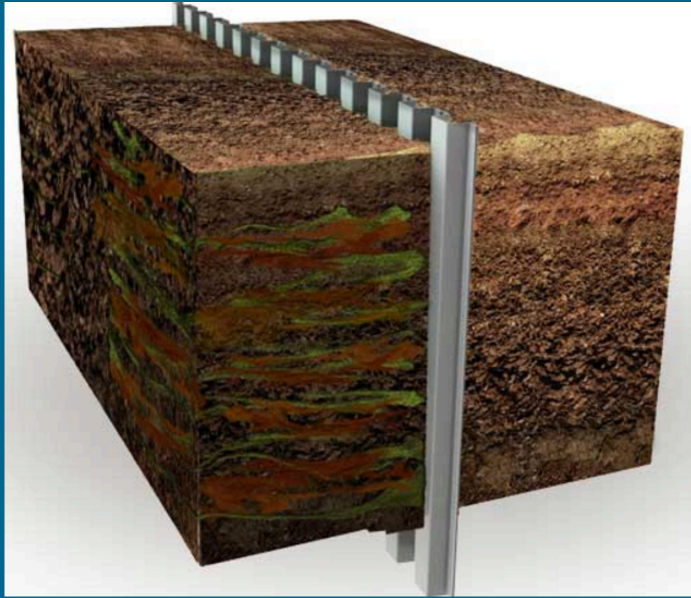


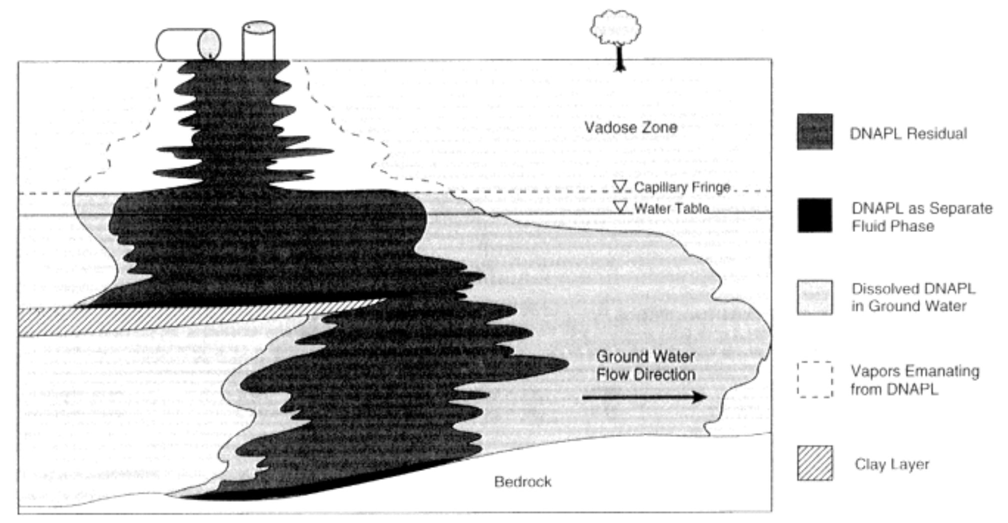
Image courtesy of CMI Sheet Piling (2017).

Influencing Factors

Other Factors:

- Some compounds may shrink the clay particles
  - Inorganic salts
  - Some organics
- Freezing/thawing of the ground
- Difficult to evaluate effectiveness
- Only controls lateral migration

Field Implementation



https://www.nap.edu/read/2311/chapter/4#52

Impermeable Boundaries

1. Encompass DNAPL source area with barrier

OR

1. Dissolved plume is locally arrested with barriers

Implement through slurry walls, sheet piles, jet gravity, or pumping

Field Implementation

http://cmisheetpiling.com/applications/cut-off-containment/

Sheet Piles

Types:

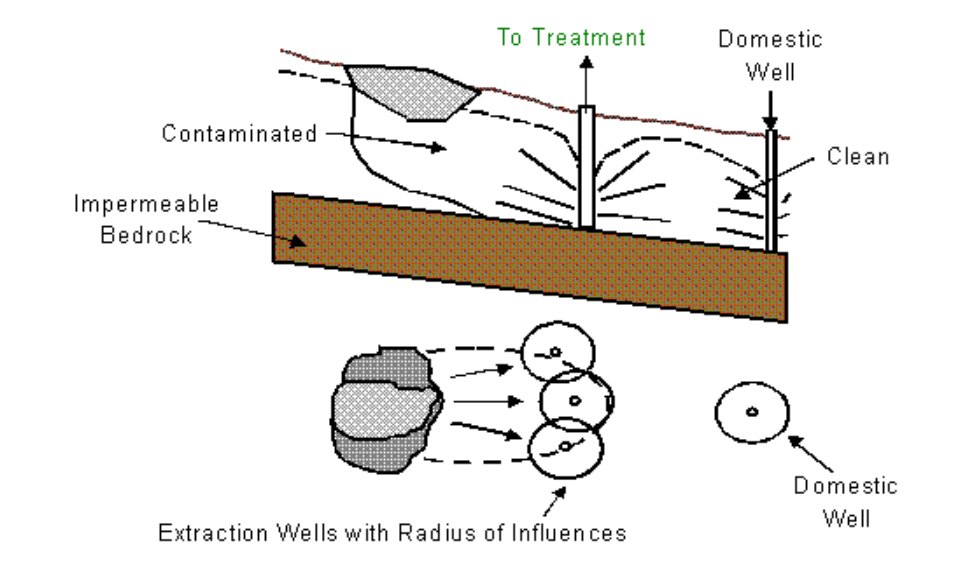
- Steel
- Reinforced concrete

Formed by connecting the joints of adjacent sheet pile sections in sequential installation.

Field Implementation

Pumping

Removes dissolved contaminants from the subsurface and prevent migration of contaminants



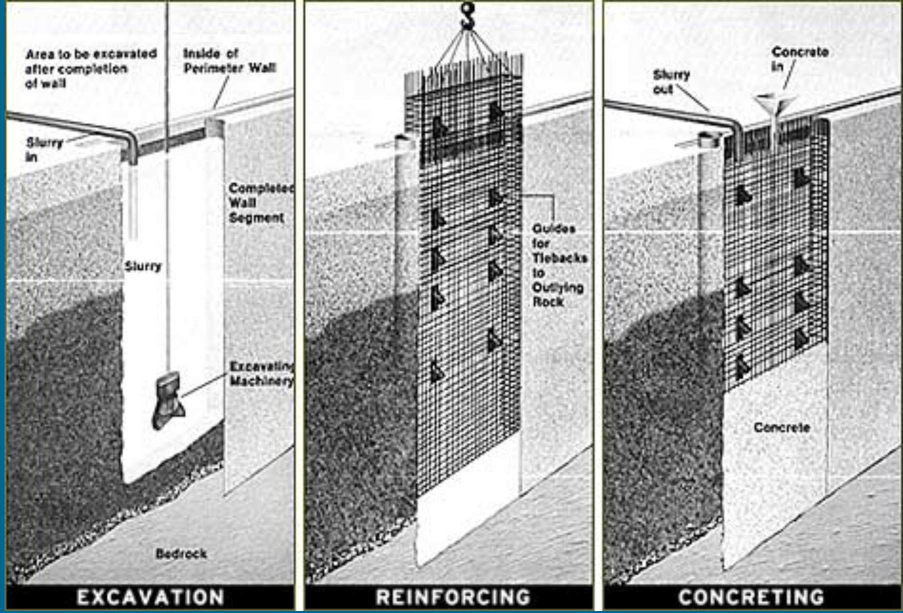
https://frtr.gov/matrix2/section4/4-48.html

Uses a hydraulic barrier to prevent offsite migration of contaminant plumes

- Wells and piezometers are used to monitor the groundwater extraction system effectiveness

Field Implementation

Slurry Wall



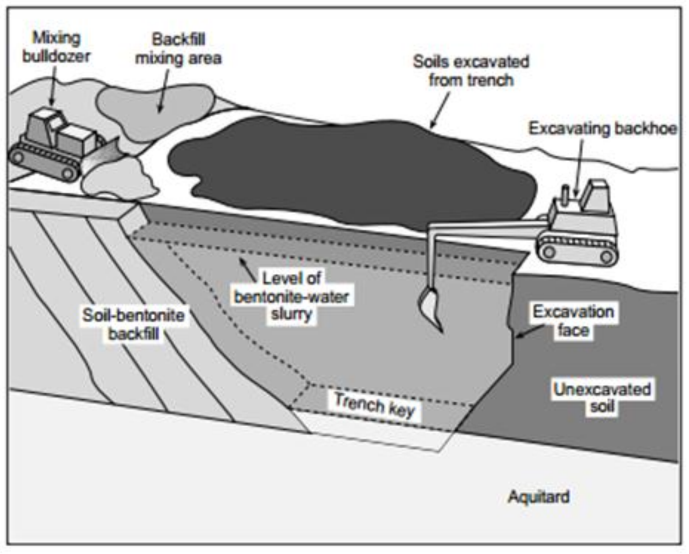
Specifics:

- Usually 2-4 feet thick
- Maximum of 200 feet deep
- Uses backfill of weathered shales, sand, clays, tills

Types of Slurry Walls:

- Soil-bentonite, cement-bentonite, soil-cement-bentonite, and a combination or use of composite systems

http://www.geo-solutions.chttp://www.geoengineer.org/education/web-based-class-projects/39-web-bas
technologies/impermeable-barriersom/slurry-bentonite



Field Implementation

Slurry Wall

Construction of Soil-Bentonite Wall:

- Excavate soils contaminated with DNAPL and dispose or treat to clean
- Typically excavated with a long reach excavator under a bentonite water slurry
- Once the trench is completely excavated, dry bentonite, borrow soils, bentonite slurry and any other necessary additives are mixed together and added to the trench
- When the backfill operation is complete, the soil-bentonite backfill consolidates

http://www.cetco.com/en-us/applications/drilling-products/slurry-walls

Field Implementation

Slurry Wall

Construction of Soil-Bentonite Backfill:

- Backfill may be blended using a variety of equipment.
- Most common method is to mix batches of backfill alongside the slurry trench using a small excavator/bulldozer
- The resultant mix should look like wet concrete (low to moderate slump) and is placed into the trench

Field Implementation

Slurry Wall

Construction of Soil-Bentonite Backfill:

Specifics:

- Permeability range: 10^-6 to 10^-8 cm/sec
- Low strength → will remain soft (in range of 300 psf) for design life

https://theconstructor.org/geotechnical/jet-grouting-procedure-advanta

Field Implementation

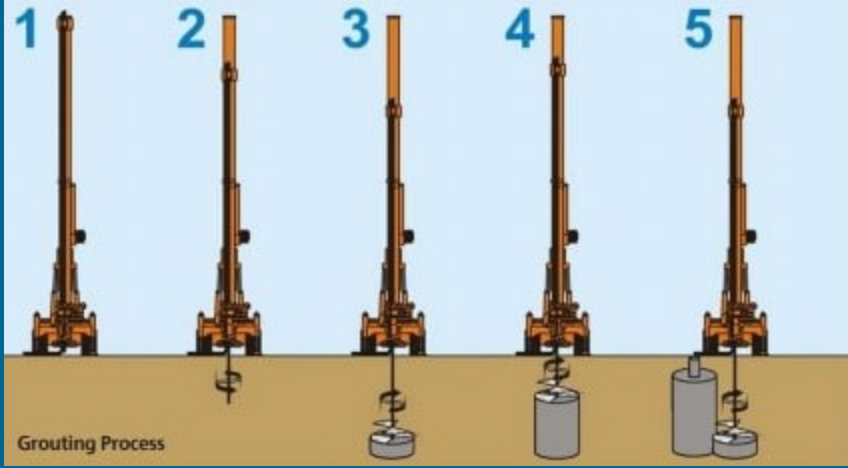
Gravity

Specifics:

- Particulate grouts include: clay, lime, fly ash, cement
- Chemical grouts include: Bitumen, resins, silicates
    - Low viscosity is proportional to high penetration
- Jet Grouting: operate at 1-2 rpm, 1-2 ft^3/min, and 6,000 psi injection pressure

Video; http://www.haywardbaker.com/solutions/techniques/jet-grouting https://theconstructor.org/geotechnical/jet-grouting-procedure-advantages/14470/

Field Implementation



Gravity

Implementation of Jet Grouting:

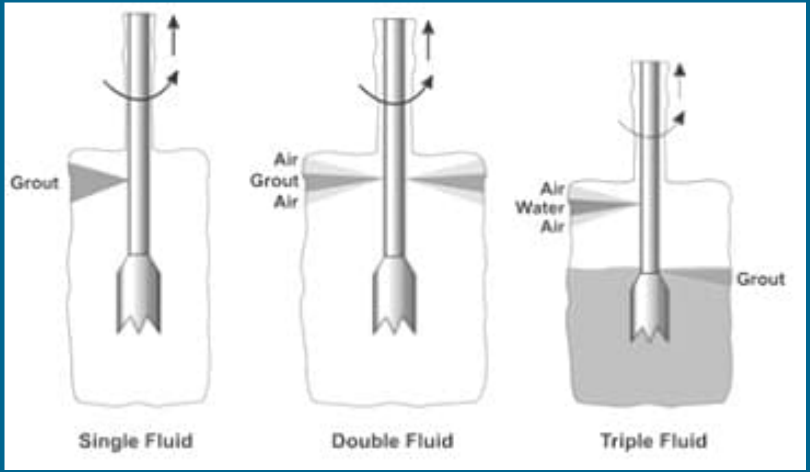
1. Soil treatment area is chosen and a hole is drilled to the required depth
    a. 10-20 cm range
2. Jet grouting string is place over drill hole
    a. 7-10 cm diameter string
3. String is raised and rotated slowly to seal the whole column surface with soil and the injected fluid system

Field Implementation

Gravity

Types of Jet Grouting Systems:

1. Single Fluid System: grout
2. Double Fluid System: Air + grout
3. Triple Fluid System: Water, air, and grout

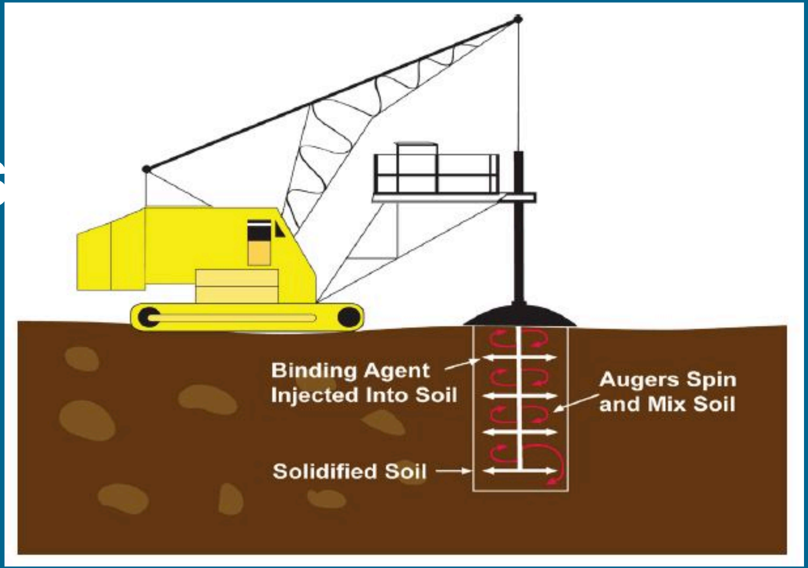


https://theconstructor.org/geotechnical/jet-grouting-procedure-advantages/14470/

https://www.youtube.com/watch?v=D_ncFvBljvk

Field Implementation

Stabilization and Solidification (SS



http://www.geoengineer.org/education/web-based-class-projects/geoenvironmental-remediation-technologies/stabilization-solidification?showall=1&limitstart=

- Involves mixing a binding reagent into the contaminated media or waste
- This treatment relies on changes to the physical properties of the waste as the cement solidifies the waste
- Large concentrations of oils and greases (>20%) may prevent the hydration of cement

Field Implementation

Stabilization and Solidification

<u>Types of Stabilization Methods:</u>

1. In-situ stabilization: injection of stabilizing compounds into the soil

2. Ex-situ stabilization: involves excavation and backfilling

Field Implementation

<u>Common Field Implementation Steps</u>

In-situ Remediation

Also called in-situ soil mixing or auger mixing

There are three specific types of in-situ soil mixing:

1. Deep soil mixing (DSM)
2. Shallow soil mixing (SSM)
3. Backhoe stabilization

- Performed using a large diameter (3-12 ft)

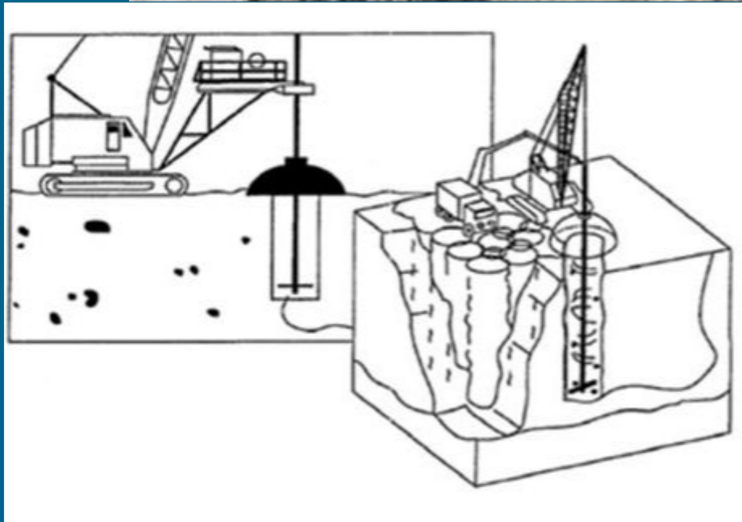
http://www.geo-solutions.com/soil-insitu-soil-stabilization-solidification http://www.geo-solutions.com/soil-insitu-soil-stabilization-solidification

Field Implementation

Common Field Implementation Steps

General In-situ Remediation Steps:

1. Addition of reagent
2. Mixing with backhoe until stabilization
3. Setting for 24-48 hours
4. Off-gas treatment to collect hazardous vapors



http://www.geoengineer.org/education/web-based-class-projects/geoenvironmental-remediation-technologies/stabilization-solidification?showall=1&limitstart=

Field Implementation

Common Field Implementation Steps

General In-situ Remediation Steps:

- Portland cement is the most common reagent, but others include blast furnace slag, fly ash, cement kiln dust, and bentonite.

Field Implementation

<u>Common Field Implementation Steps</u>

Ex-situ Remediation

- Provide better control over reagents, mixing, and sampling

Important considerations:

- Swelling during mixing
- Generation of harmful odors, dust, and organic vapors

Field Implementation

<u>Common Field Implementation Steps</u>

Ex-situ Remediation: Mobile Mixing

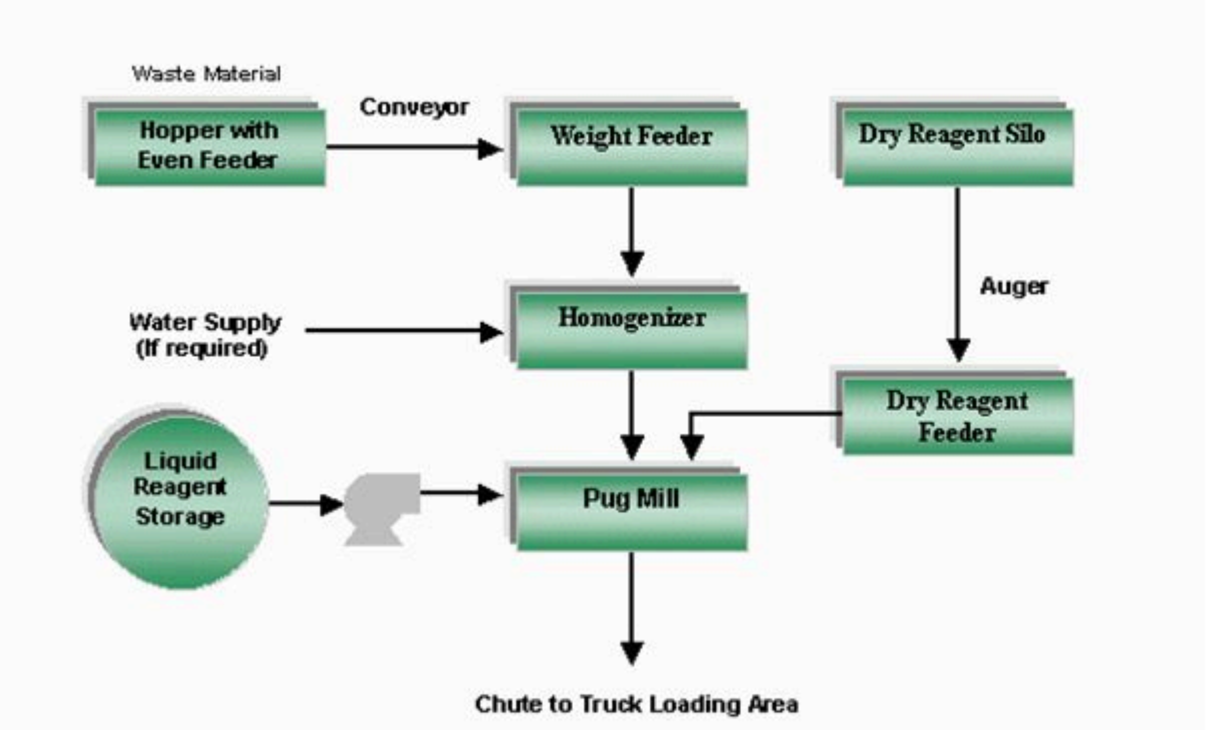
Typical procedure of mobile mixing includes:

1. Excavation to remove contaminated waste
2. Classification of wastes
3. Mobile plant setup and mixing
4. Off-gas treatment to collect hazardous vapors
5. Final disposal

http://www.geoengineer.org/education/web-based-class-projects/geoenvironmental-remediation-technologies/stabilization-solidification?showall=1&limitstart=

Field Implementation

Typical mobile mixing plant schematic.



Field Implementation

Common Field Implementation Steps

Ex-situ Remediation: In-Drum Mixing

Typical procedure of mobile mixing includes:

1. Evaluation/identification of contents in each drum
2. Evaluation of drum condition and head space
3. Preparation of materials handling location
4. Addition and mixing of SS chemicals
5. Placement of drums in a secure area for curing

Field Implementation

Permeable Treatment Walls

Highly specialized type of slurry wall construction, which can be an economical alternative for applying chemical reagents to contaminated groundwater

- Can be installed using the biopolymer slurry trenching (BP Trench) method, shallow soil mixing or conventional open-cut trenching

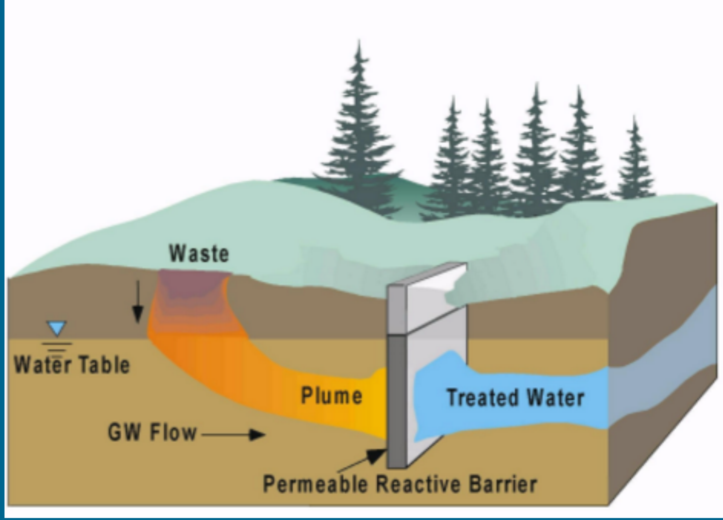
http://www.geo-solutions.com/permeable-reactive-barriers

Field Implementation

Permeable Treatment Walls

- Permeability of the application is controlled so the wall exhibits a hydraulic conductivity similar to the surrounding native soils, allowing groundwater to flow naturally through the barrier

- Chemical reagents are added to the installation at the time of construction within the barrier or injected later through the well installed for that purpose

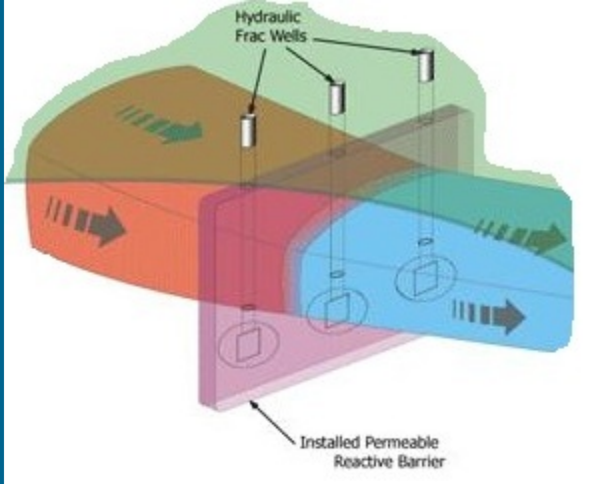


Typical reagents include:

- Zero valent iron, activated carbon, peat moss, etc

Field Implementation

Permeable Treatment Walls



Zero Valent Iron Treatment:

- Treats contaminants such as organic halogenated hydrocarbons, inorganics, and metals
- Reaction degrades or precipitates out contaminants

Permeable Treatment Wall Construction:

- Vertical hydrofracturing
- Ideal in urban areas

Case Study #1 : Soil-Bentonite Cutoff Wall through an Abandoned Coal Mine

- Approximately 18 acre superfund site in Grove City, PA
  - Abandoned strip mine
  - Adjacent to deep mine and highwall
  - Partially flooded
- Surrounding area is mostly agricultural, some residential area 250m north
- Mine operated between 1900’s and 1940’s
- Used as a disposal site from 1950’s to 1978
  - Foundry sand, slag, and scrap metal

Case Study #1

Added to NPL in 1984

Contaminants found:

- benzo(a)pyrene
- dibenzo(a,h)anthracene
- chromium
- Lead
- Nickel
- TCE and vinyl chloride

Case Study #1

EPA concluded site had contaminated groundwater

Most of the waste deposited below water table

Onsite waste material considered to be a dermal contact risk

Contaminated groundwater migration considered to be a future risk

Case Study #1

Remedial Objectives:

- Prevent migration of contamination through groundwater
- Prevent infiltration of surface water into contaminated area
- Prevent contact with contaminated materials

EPA preferred RCRA compliance landfill

- Would have achieved objectives but estimated cost of $26 million
- Included excavating and stockpiling waste onsite while RCRA cell was completed elsewhere
- Cost would be high due to requiring a dewatering system and wastewater treatment

Case Study #1

Alternative remedial action proposed by the engineer

- Soil-bentonite slurry wall around contaminated area
- Low permeability GCL cap
- Extraction wells installed inside the slurry cutoff wall collect groundwater and send to onsite treatment system

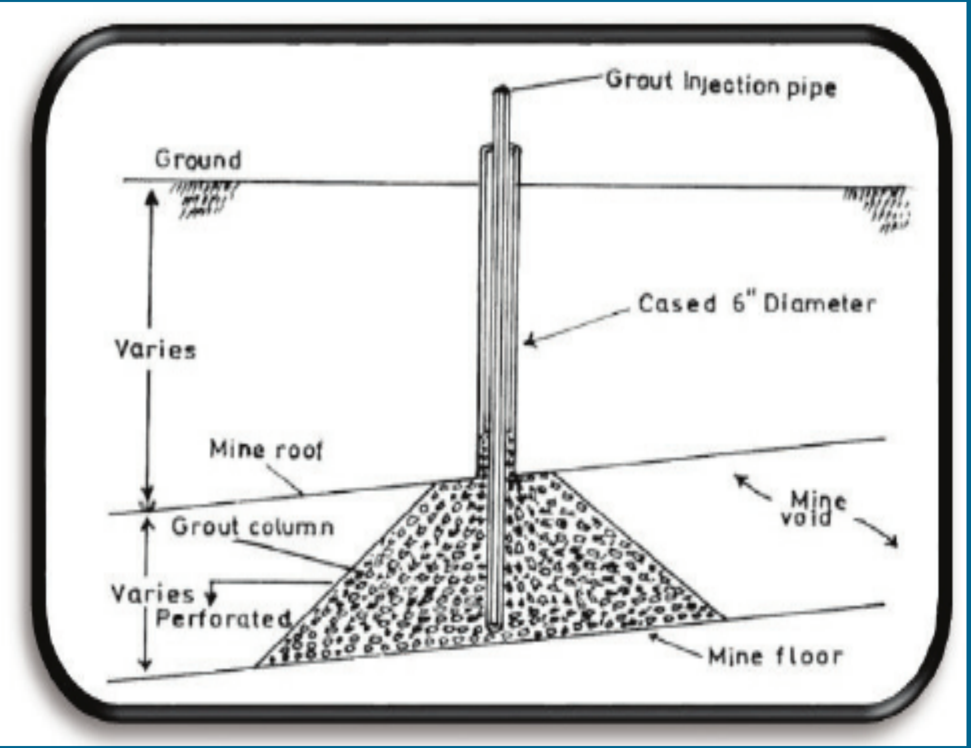
Estimated cost $10 million

EPA would not approve unless conditions were met

- Verification of coal seam underclay along entire slurry wall location

Case Study #1

- Site was not ideal for slurry wall technique due to presence of mine voids as high as 8 ft
- Mine grouting was the technique selected to fill the voids
  - Contains the slurry wall
  - Protects slurry wall and cap from damage in case of subsidence



Case Study #1

- Three parallel lines of grouting were installed using air rotary drilling ri and grout mixture prepared to 10 psi minimum strength

- Slurry wall was keyed into either Brookeville Coal Underclay or Homewood sandstone

    - Formations helped create confining zon

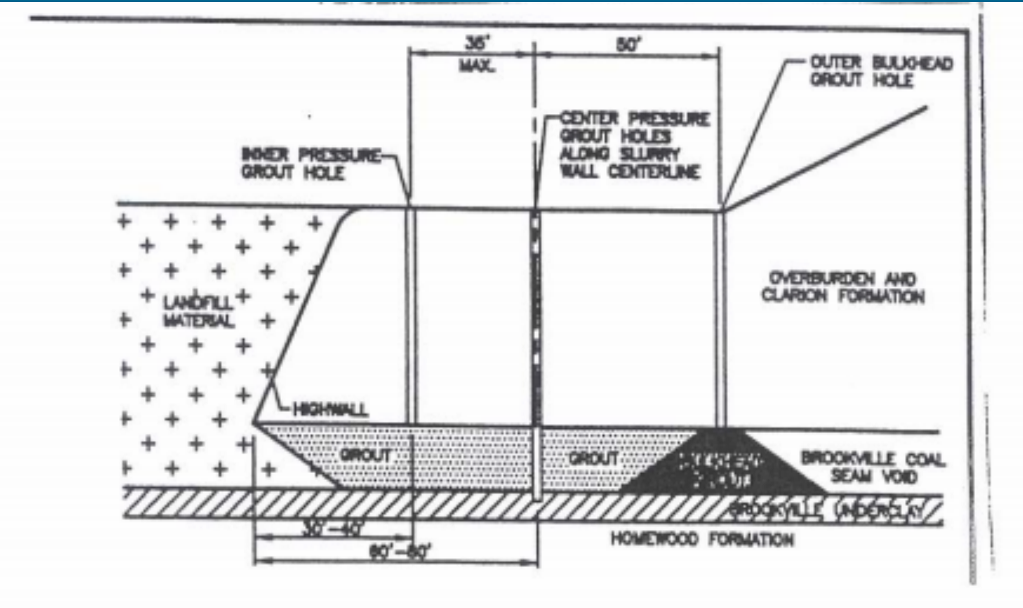


FIGURE 3

Case Study #1

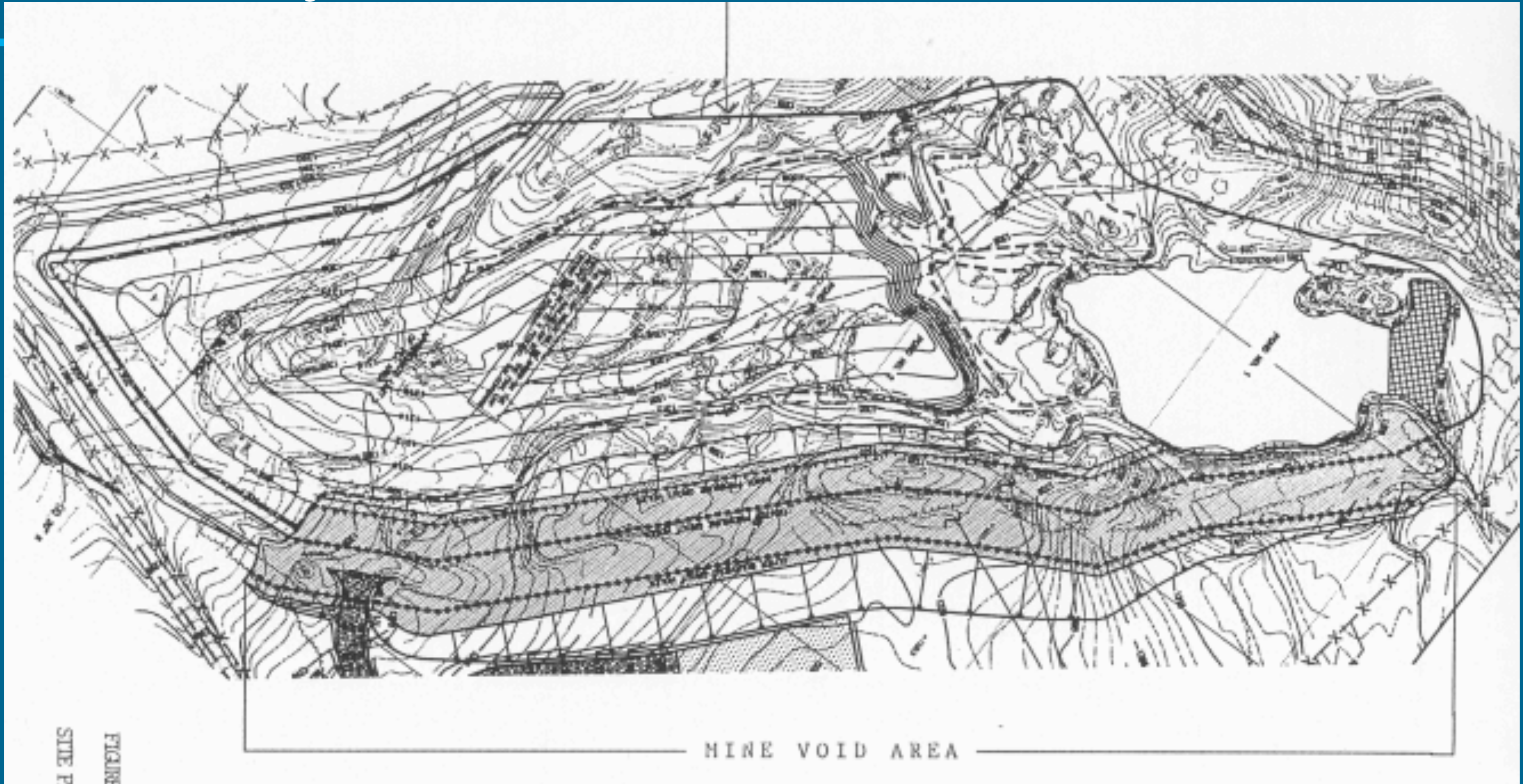
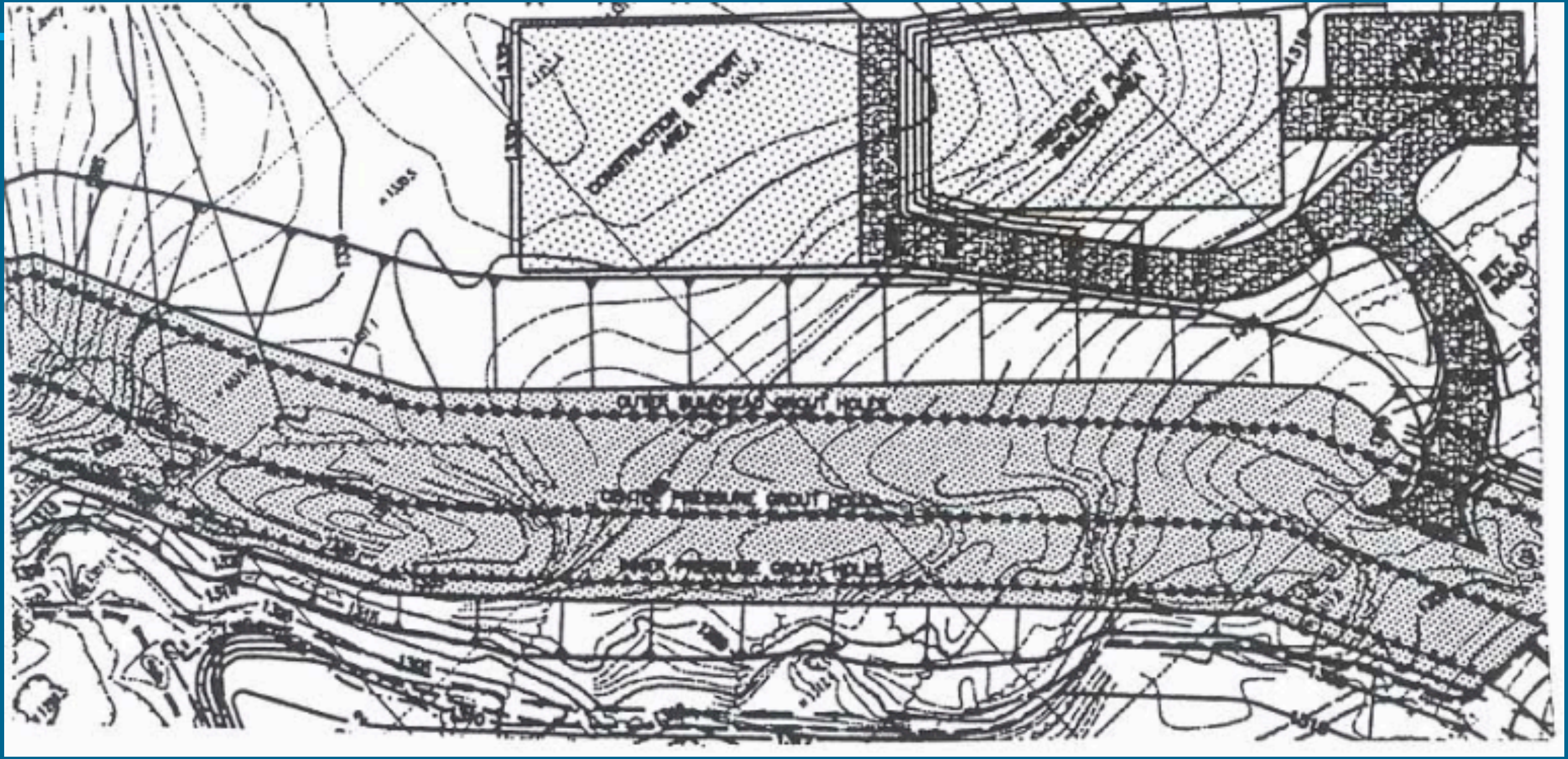


FIGURE 1
SITE PLAN

Case Study #1


CONSTRUCTION SUPPORT AREA
TREATMENT PLANT BUILDING AREA
OUTER BULKHEAD GROUT HOLES
CENTER PRESSURE GROUT HOLES
INNER PRESSURE GROUT HOLES

Case Study #1

Project was completed from 1995-1997

Remediation costs were reduced by 60% due to onsite containment versus removal to off site RCRA landfill

Project illustrated ability of slurry cutoff walls to be an effective option through areas with voids such as mines


Diamond Rd

Case Study 2: Design and Construction of a Slurry Wall around Superfund Site

Ellis Street Site

June - October, 1987

Mountain View, California (“Silicon Valley”)

Total Area: 1000 ft by 840 ft

Groundwater level 20 ft below, 50 ft above sea level

Owned by Raytheon Company, Semiconductor Division

Placed on EPA NPL list due to presence of contaminants in the ground/groundwater

Operating facility, equipment sensitivities to vibrations and dust

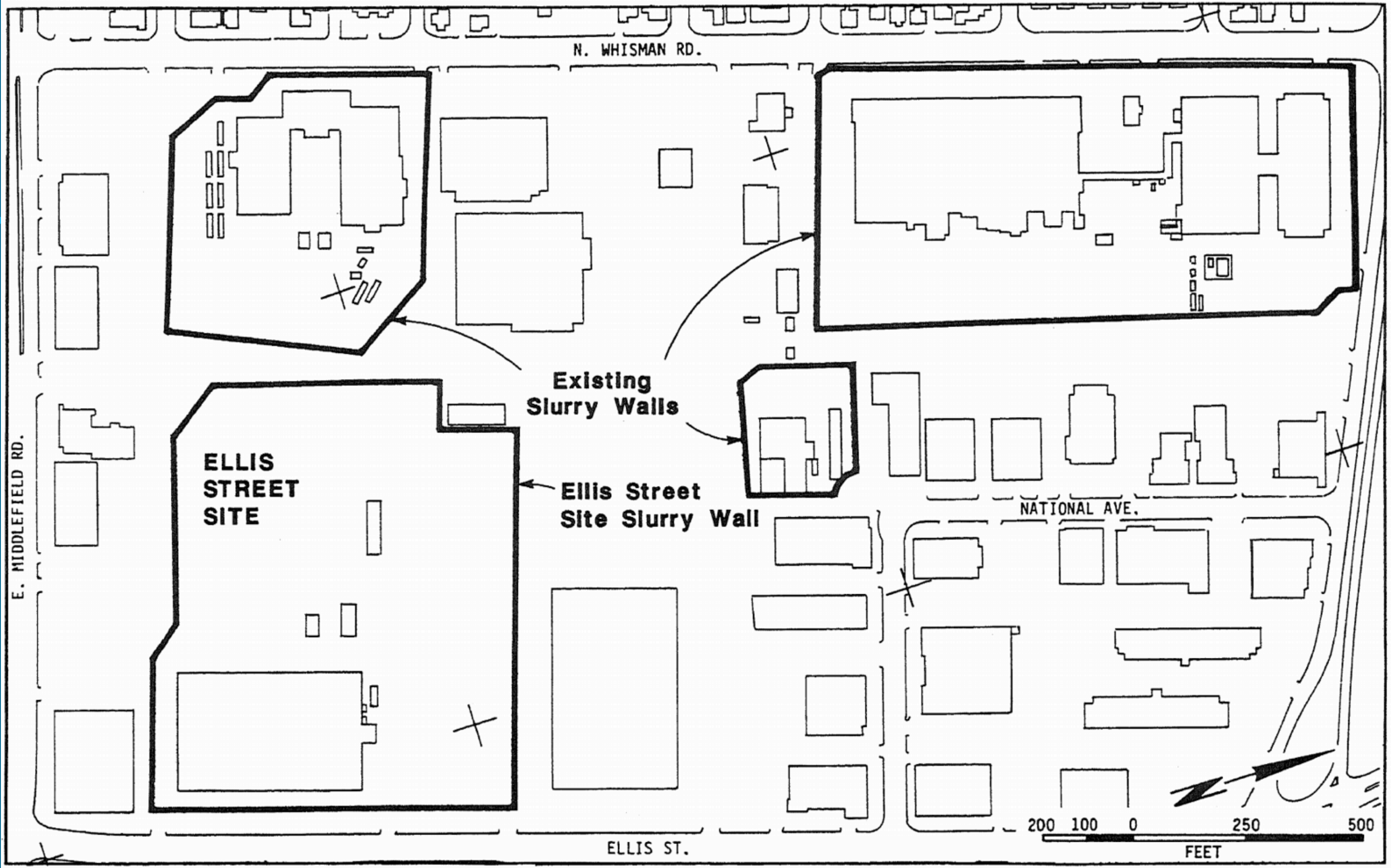


FIGURE 1. Site Vicinity Map

Case Study 2

Investigation:

200 boreholes, 100 monitoring and extraction wells

Soil consistency: medium dense to dense interbedded clays, silts, sands and gravels

Contaminants:

- Trichloroethylene (TCE)
- 1, 2-dichloroethylene (1, 2-DCE)
- <37 ppm in soil, <200 mg/L in groundwater

Remedial Objectives:

Case Study 2

Slurry Wall with Pumping from within Contained Area

- Maintain inward and upward hydraulic gradients
- Halt further migration of contaminants
- Protect underlying aquifer system
- Facilitate the removal of saturated soils
- Allowed facilities to remain operational during all stages of construction

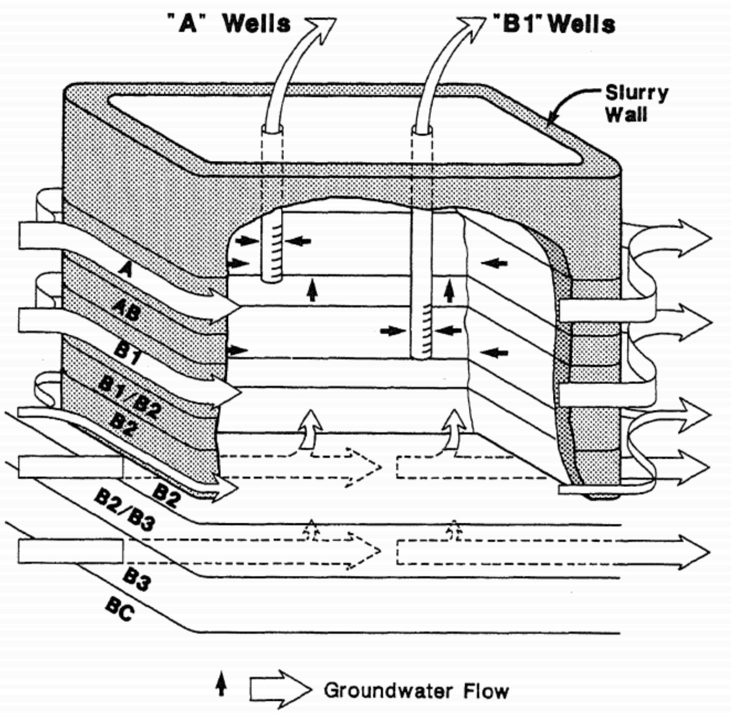


FIGURE 3. Slurry Wall Schematic

Case Study 2

Design

Total perimeter: 3400 ft

Max. hydraulic conductivity: 1.0 * 10^{-7} cm/s

Utility Protection

15 ft clearance under utility bridge

Slurry wall 30 ft from property boundary

Monitoring wells

Bentonite Slurry Wall

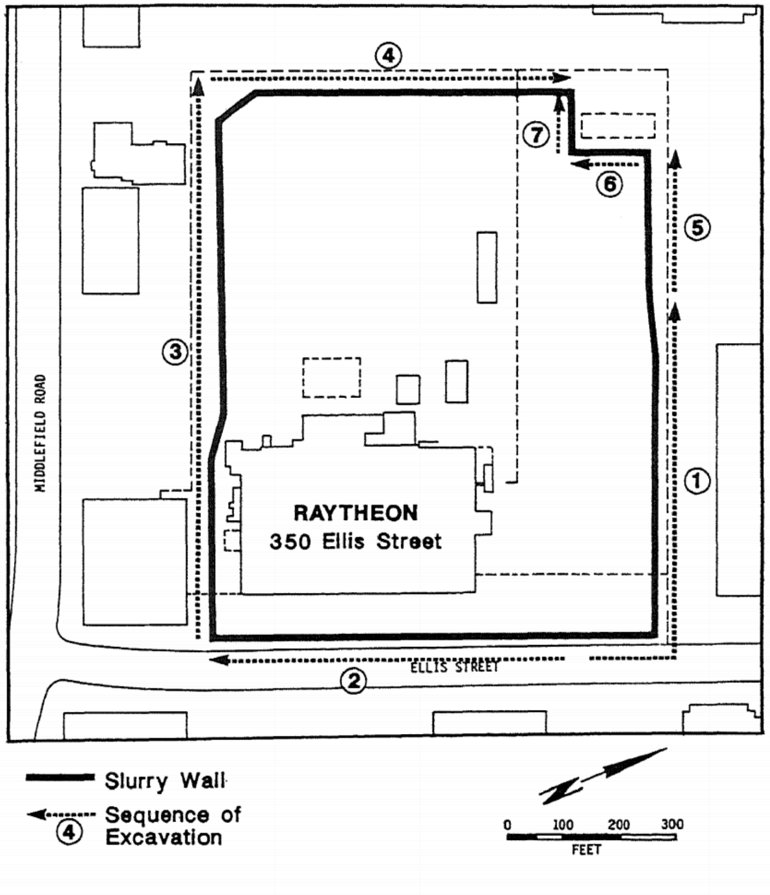
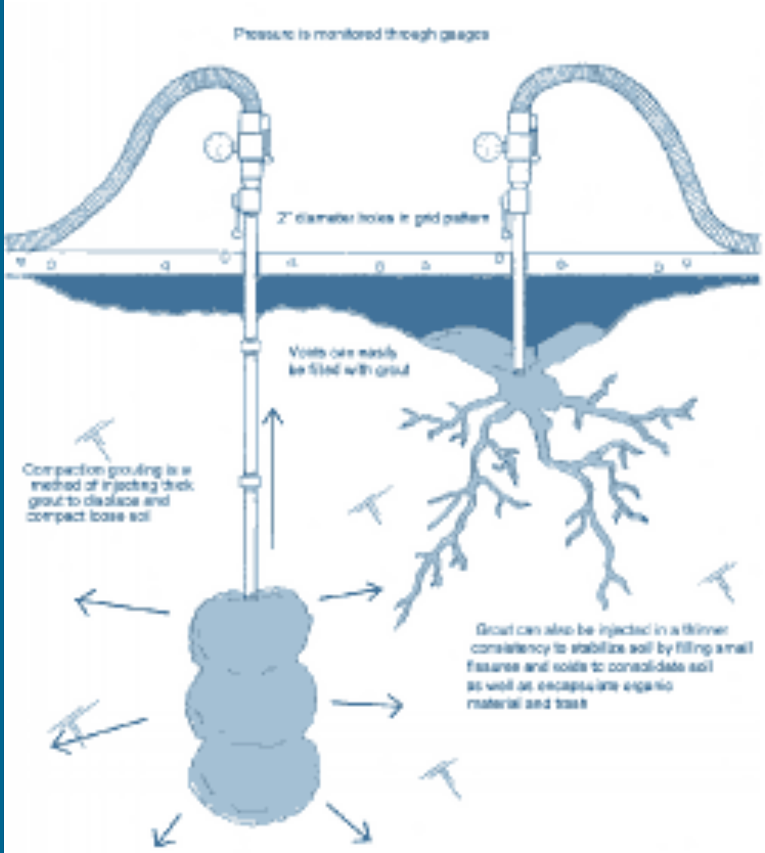


FIGURE 4. Slurry Wall Excavation Sequence

Case Study 2

Effects and Results

- Met specified permeability
- Water levels in pumped aquifers decreased upon completion
- Prevention of further off-site contamination
- No disruption to facility operations or production
- Successful completion in more restrictive setting

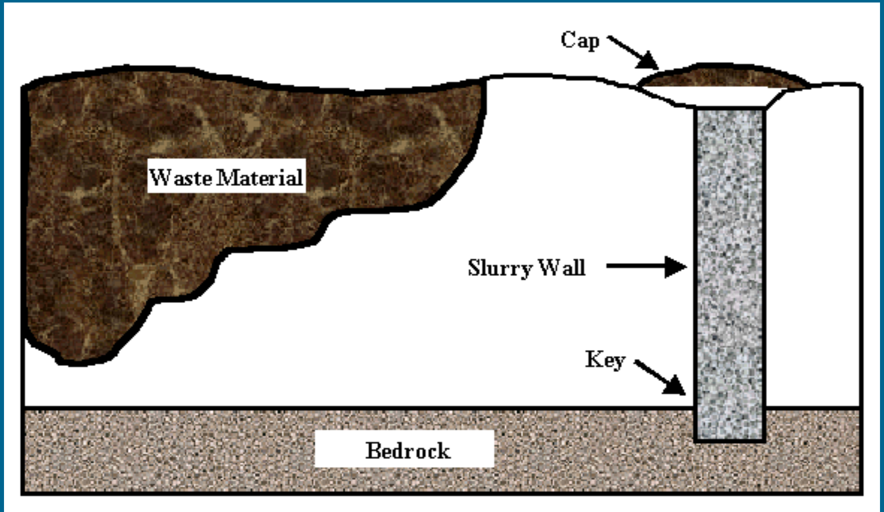


Pressure is monitored through gauges
2" diameter holes in grid pattern
Voids can easily be filled with grout
Compaction grouting is a method of injecting thick grout to displace and compact loose soil
Grout can also be injected in a thinner consistency to stabilize soil by filling small fissures and voids to consolidate soil as well as encapsulate organic material and trash

Applicability and Limitations

Slurry Walls

- Does not treat or destroy contaminant
- Test and monitoring necessary
- Seismic activities and pressure effect
- Groundwater control
- Designing



Applicability and Limitations

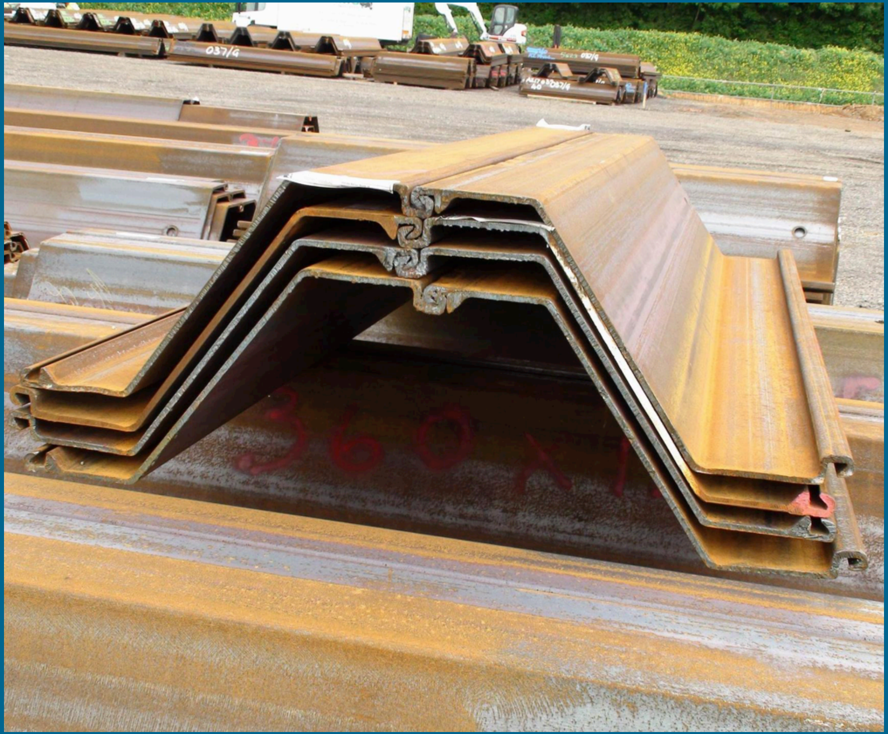
Applicabilities of slurry walls

- Does not target a particular group of contaminant
- Deals with a wide variety of contaminant
- Deals with large waste mass

Applicability and Limitations

Sheet Piling

- Susceptible to salts and acids
- Interlock leakage
- High cost
- Installation difficulties



Applicability and Limitations

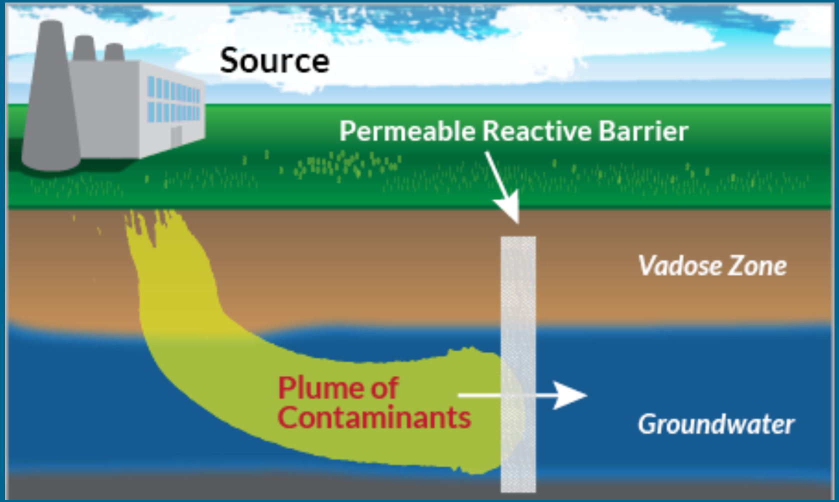
Applicabilities of sheet piling

- Easy replacement
- Depth advantage
- Quick installation
- Little waste material during installation
- Reduced diffusion transport

Applicability and Limitations

Permeable Treatment Walls

- Ensuring total capture can be difficult
- Time consuming/Monitoring system
- Reduced effectiveness over long-term
- Reactive material leach
- Installation difficulties (Sheet piles)



Applicability and Limitations

Applicability of PRBs

- Wide range of contaminants
- No loss of ground water
- Little to no energy requirement

Availability- Slurry Wall

- Cement Bentonite- common form of vertical barriers in Europe
  - Seepage control especially
- Soil Bentonite- most used technique for contamination for the US
- Soil-Cement-Bentonite- mix of the two above and not nearly as popular as either.

Cost- Slurry Wall

Cement- Bentonite wall ranges from $10-20/ft^2

- 2 ft wide barrier of less than 100 ft

Soil-Bentonite wall ranges from $5-7/ft^2

- Costs not including cost needed for
  - Chemical analyses
  - Feasibility test
  - Compatibility test

Availability- Grouting

Best used in lower permeability soils

Different … bilities of soil

Permeability (cm/sec)	Groutability
$\leq 10^{-6}$	Ungroutable
10^{-5} to 10^{-6}	Groutable with difficulty by grouts with viscosity < 5 cP Ungroutable with grouts having viscosity > 5 cP
10^{-3} to 10^{-6}	Groutable with low viscosity grouts, but difficult with grouts with a viscosity > 10 cP
10^{-1} to 10^{-3}	Groutable with all commonly used chemical grouts
$\geq 10^{-1}$	Requires suspension grouts or chemical grouts containing a filler material

Availability- Grouting

Jet Grouting

- Done at high Pressure
- Single
    - Uses existing soil and grout to create impermeable wall
- Double
    - Uses air and grout
    - Clears jet stream of soil and groundwater
- Triple

Availability- Grouting

Permeation grouting

- Done at low pressure
- Best used if you do not want to change structure of soil
- Applicable for rock
- Viable for both short and long term applications

Cost- Jet Grouting

Mobilizing Equipment

Over $35,000 per rig

Labor and materials

$320/m^3 of improved ground

Handling, removal, and disposal of waste slurry

System dependant

Slurry Produced is 60-100% of volume of treated soil

Cost- Permeation Grouting

Mobilizing Equipment

Microfine cement grout$15,00-25,000

Sodium silicate grout- Over $25,000

Installing Sleeve Port

$50 per meter of pipe

Labor and grout materials

Microfine- $120/$m^3$ of treated ground

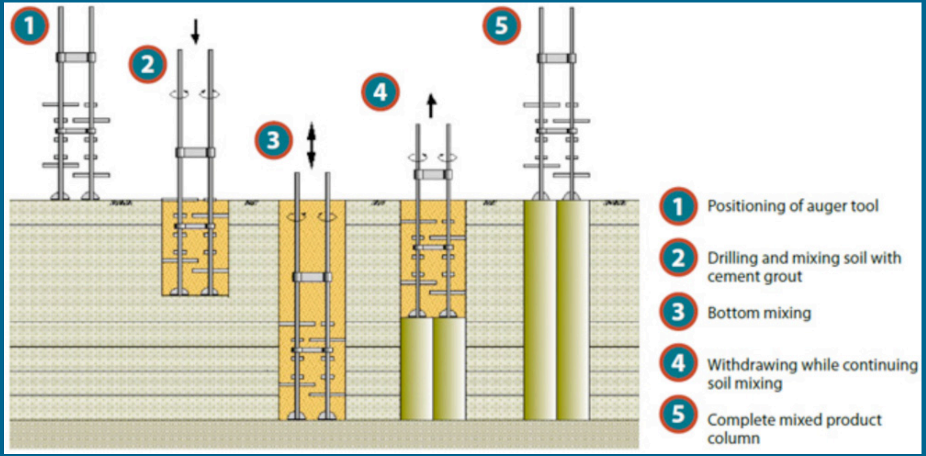
Availability- In Situ Soil Mixing

With regard to soil type

- High in clean granular soils
- Low in clayey soils

Best if you do not want to move soil

Very few in the United States



Cost- In Situ Soil Mixing

$100,000 for rig and grout plant

Grout materials and mixing

- $100/m^3 of improved ground for shallow mixing (<8 m)
- $200/m^3 of improved ground for deep mixing (8-30 m)

Discarding of waste soil-cement

- About 30% of treated volume

Availability & Cost Permeable Treatment Wall

Best for

Shallow deposits (0-70 ft)

Unconfined aquifer systems in unconsolidated deposits

If reactive material is more conductive than the aquifer

Average capital cost

$460,000