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25 Years of Technology Innovation: 1990-2015

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The Starting Point

- Innovative Treatment Technologies: Technologies whose routine use is inhibited by lack of data on performance and cost.
- 1990 Mandates/Drivers
  - Preference for treatment (Superfund Amendments and Reauthorization Act or SARA)
    - Move away from "dig and haul," capping
    - Permanence
  - Land Disposal Restrictions – In Situ
  - Very limited menu of treatment options
    - Soil: Incineration, maybe solidification
    - Groundwater: Pump and treat

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Early Cleanups in Superfund

- Superfund Law Enacted in 1980 in response to a need to protect citizens from the dangers posed by abandoned or uncontrolled hazardous waste sites
- Superfund was a powerful law that resulted in immediate action at many priority sites
- The challenge was new, and the need for action prevailed
- Technical solutions were few, and we applied what we knew

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Technology Innovation Directions: c 1990

- Treatment, soil (surface, vadose zone)
- Groundwater treatment, very limited options
- Characterization, *not so much*
- Bioremediation
  - Exxon-Valdez
  - Natural attenuation, *hmmm….*
- Ex-situ treatments
  - Soil washing
  - Solvent extraction
  - Thermal desorption
  - Bioreactors

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The Starting Point

- Superfund Remedies: Early Years (1982-1985)

	Containment	Treatment
Soil Remedies	75%	25%
	Pump & Treat	**In-Situ Treatment**
Groundwater remedies	90%	3%

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RD&D: Many Options

- U.S. EPA: Superfund Innovative Technology Evaluation (SITE) Program
- Department of Energy, EM-50
- Department of Defense
- State programs
- Non-profit, private sector
  - NETAC
  - PERF
- Cost and performance information at a premium

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FRTR Direction: 1990's

- Sharing information, information resources
- Better information for decision makers
- Demonstration projects
- Information exchange
- Public-private partnerships
  - Remediation Technology Development Forum
  - Clean Sites
  - Technology testing centers
- Leveraging investment
- Biggest focus on remediation

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Evolution of Technology: 1995-2005

- Treatment trains
- Platforms vs. individual technologies
- Greater focus on groundwater, broader use of alternative technologies
  - RD&D money, a shrinking pie
- Emerging concepts
  - Triad
  - Optimization
  - Reuse, land revitalization
- Building library of cost and performance information, case studies

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Evolution of Technology: 2005-Present

- Big growth in Brownfields, land revitalization directions
- Maturation of Triad concepts: approach vs. technologies
- Maturation of optimization
  - Beyond RSE, LTMO
  - Beyond pump and treat
- Growth and maturation in source treatment
  - Thermal approaches
  - Oxidation

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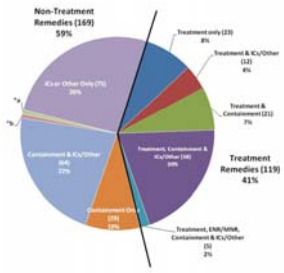
Superfund Remedies for Sources[1] (2009–2011)



- Remedies often selected and applied in combination
- For example, over 30% of treatment remedies were selected with other types of remedies
- We now have a rich mix of remedies available and mature consulting and engineering sector to implement them

1. Sources inc ude soil, sed ment, solid waste NAPL

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In Situ Source Treatment Technologies at Superfund Sites

Technology	Total 2009-2011	Percent 2009-2011
In Situ		
Soil Vapor Extraction	25	14%
Chemical Treatment	17	10%
Solidification/Stabilization	11	6%
Multi-Phase Extraction	9	5%
In Situ Thermal Treatment	7	4%
Bioremediation	5	3%
Subaqueous Reactive Cap	2	1%
Flushing	1	1%
Fracturing	1	1%
Phytoremediation	1	1%
Total In Situ	**79**	**45%**

- About 45% of treatment remedies for source control are currently in situ (in place)
- We are seeing fewer developments in new technologies, and more innovation in design, construction and operation of commercial technologies
- More aggressive remedies used to tackle source areas (such as in situ thermal treatment, chemical oxidation)
- Often coupled with groundwater remedies, treatment and non-treatment

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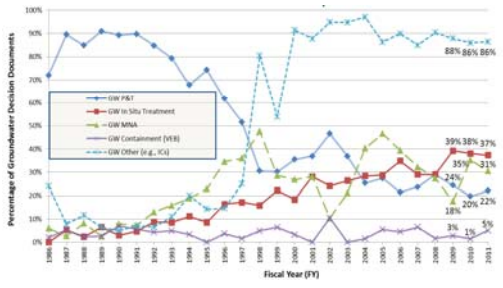
Trends in Superfund Groundwater Remedies Selection (1986–11)

Total Groundwater Decision Documents = 1,912



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Groundwater Remedy Types Recently Selected in Superfund

Remedy Type and Technologies	Total (FY09–11)	Percent (FY09–11)
Groundwater Pump and Treat	**44**	**12%**
In Situ Treatment of Groundwater	**78**	**21%**
Bioremediation	49	13%
Chemical Treatment	27	7%
Air Sparging	14	4%
Permeable Reactive Barrier	8	2%
In-Well Air Stripping	2	1%
Multi-Phase Extraction	2	1%
MNA of Groundwater	**56**	**15%**
Groundwater Containment (VEB)	**6**	**2%**
Engineered (Constructed) Wetland	**3**	**1%**
Other Groundwater	**177**	**49%**
Institutional Controls	173	48%
Alternative Water Supply	13	4%
Engineering Controls	2	1%

- Groundwater pump and treat still common, but we see more in situ treatment remedies
- Monitored natural attenuation is used either alone or in combination
- Concept of "adaptive management" gaining ground: Actively monitoring operating systems to determine optimal transition time and place between remedy components

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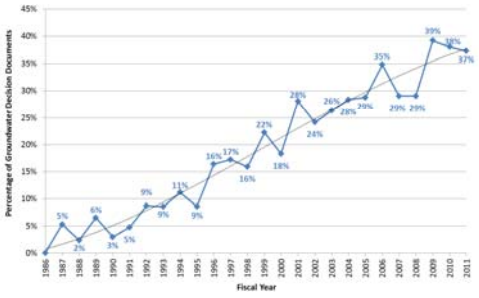
In Situ Groundwater Treatment: Increasing Use in Superfund



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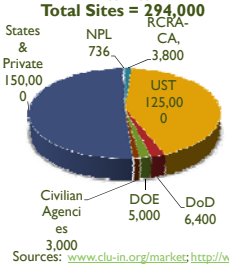
U.S. Contaminated Site Programs: We Still a Lot of Remediation Work to Do

Estimated Number of Contaminated Sites (USEPA 2004), United States cleanup horizon, 2004 – 33

Total Sites = 294,000



- We have made great progress cleaning up contaminated sites but…
  - National Academies of Sciences estimates 126,000 sites across U.S. still have contaminated groundwater, and their closure expected to cost at least $110 billion to $127 billion
  - We continue to invest over $8 billion a year in remediation (USEPA, EBJ)
  - We have opportunity to take lessons learned over the past decades, and apply innovations and best management practices to future sites

Sources: www.clu-in.org/market; http://www.nationalacademies.org/ http://www.ebiusa.com/

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Evolution of Technology: Moving Forward

- High resolution site characterization approaches
  - Many data points
  - An evolving conceptual site model
  - Data management tools and visualization of data
- Green and Sustainable Remediation
  - Approaches
  - Components
  - Energy use, GHGs and climate change adaptation
- Addressing complexity of sites/"big" sites
- Bioavailability

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Moving Forward

- Focusing and pursuing site cleanup needs
  - Specifics are important
    - Beyond contaminant/media
    - Clearly stating need
    - Providing performance metrics in statement of need
    - Characterization tools – focus on decisions, decisonmakers
  - Need a path forward
    - If we decide we need it, what are we going to do about it?
    - Funding options
      - Map
      - Leverage
    - Path to site use

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Example of Needs Statement
Monitoring Technologies c. 2007

- **Air Emissions Monitoring** -Continuous emissions monitors for thermal hazardous waste treatment systems; remote sensing for fence-line monitoring of fugitive emissions
- **Characterizing and Monitoring Mining Sites-** Monitoring technologies for mining waste sites
- **Contaminated Sediment Characterization-** Sampling and analytical technologies for potentially contaminated sediment
- **Field Methods -** Screening for dioxin contamination; detection of perchlorate in water-pesticides and their degradation products; MTBE in groundwater
- **Indoor Air Quality-** Monitoring vapor intrusion into buildings
- **In-Situ Monitoring Systems-** Sensor technologies for long term monitoring of groundwater, treatment system performance; leak detection for small municipal landfills
- **Laboratory Analytical Methods-** New monitoring methods for total cyanides and cyanide speciation
- **Monitoring Effectiveness of In-Situ Remedies-** Monitors of natural attenuation and other in-situ systems
- **Non-invasive Subsurface Chemical Detection Systems-** Technologies for locating and monitoring DNAPL contamination; technologies for mercury and heavy metals in soils
- **Underground Storage Tanks-** Leak detection methods for underground storage tanks and pipes