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# Leveraging Artificial Intelligence and Large Language Models for Enhanced Decision-Making in Environmental Remediation

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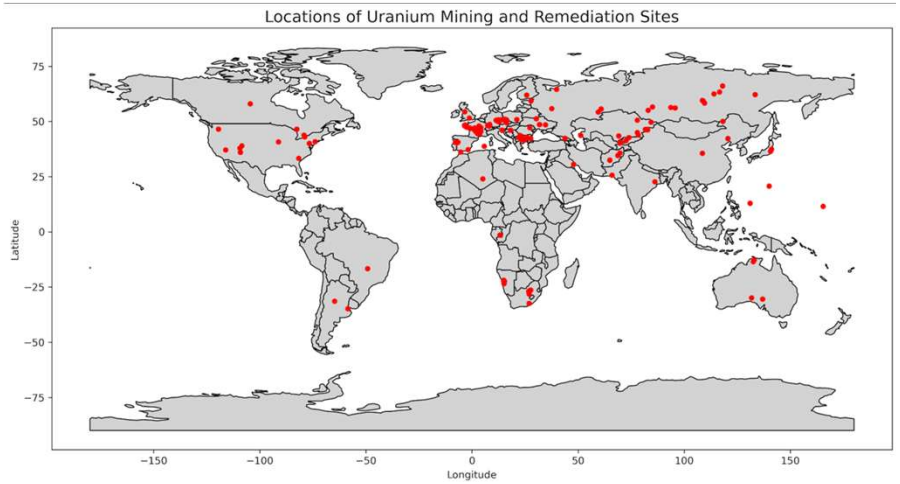
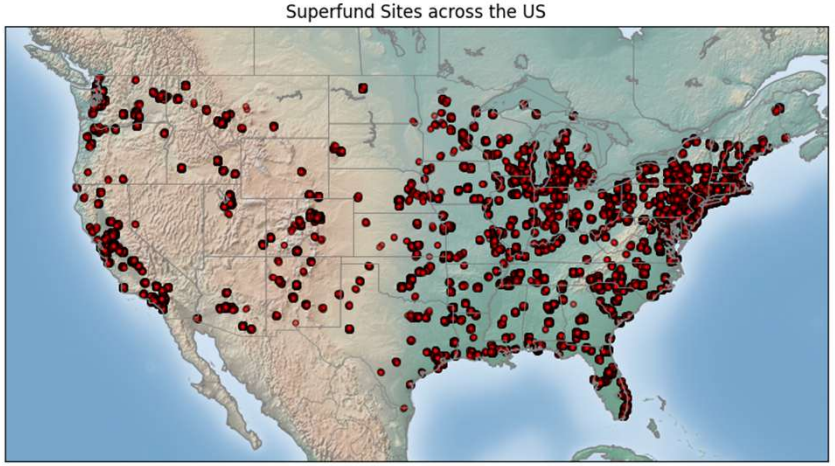
# Radioactively Contaminated Sites




*An example subset of data from the preliminary REMPOR database (550+ sites in 58 MSs)*




*An example dataset from US Environmental Protection Agency's (EPA's) Superfund Data Reports (1900+sites)*

Contaminates Superfund Sites in the **National Priorities List (NPL)** during 1981-2024

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# Remediation of Radioactively Contaminated Sites

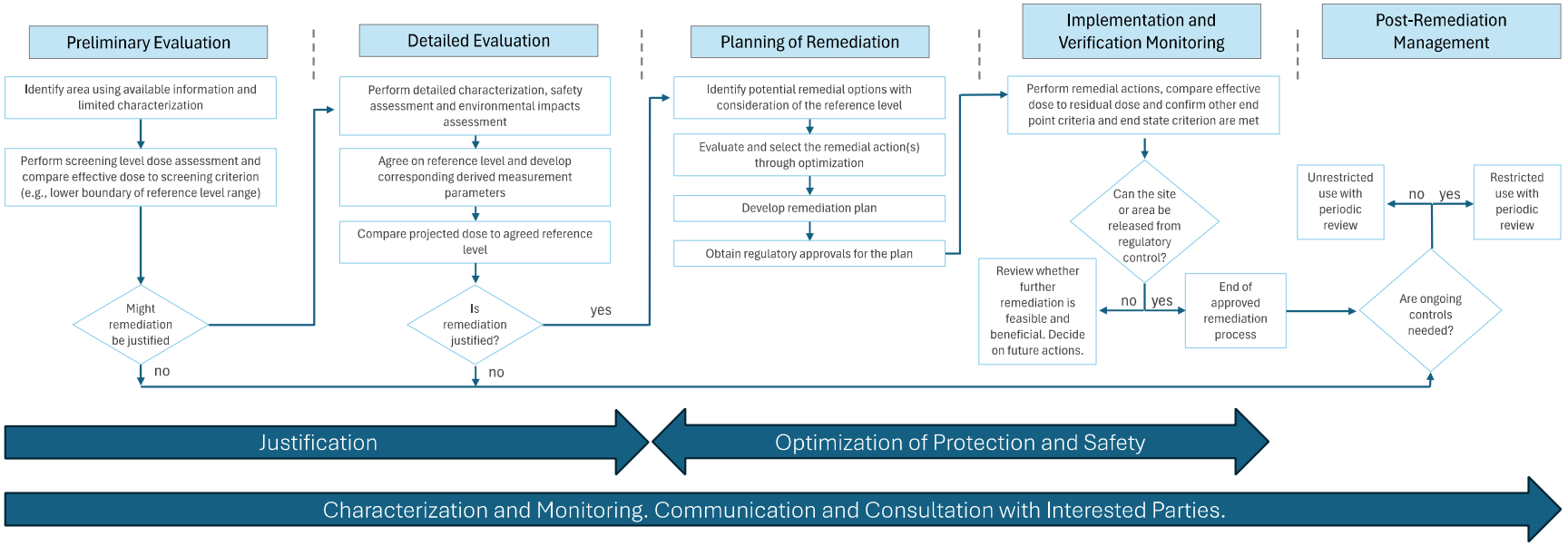
- Remediation is a complex and multi-phase process, depending on:
  - Technical and non-technical factors
  - Technological and operational factors
  - National legal/regulatory/policy frameworks
- Primary goal:
  - Reduce the risks to human and environmental health through combination of remedial actions and engineered or institutional controls
- Secondary goal:
  - Return the site and the contaminated media to productive use (e.g., business, recreation, or natural ecosystem, human consumption)
- Regulations/policies drive remediation through:
  - Defining acceptable end states, regulatory standards, reference levels
  - Specifying required remedial actions and timeframes

*Remediation, as defined by the IAEA, means any measures that may be carried out to reduce radiation exposure from existing contamination of land areas through actions applied to the contamination itself (the source) or to exposure pathways to humans*[1]

[1] *INTERNATIONAL ATOMIC ENERGY AGENCY, IAEA Safety Glossary, IAEA, Vienna (2007).*

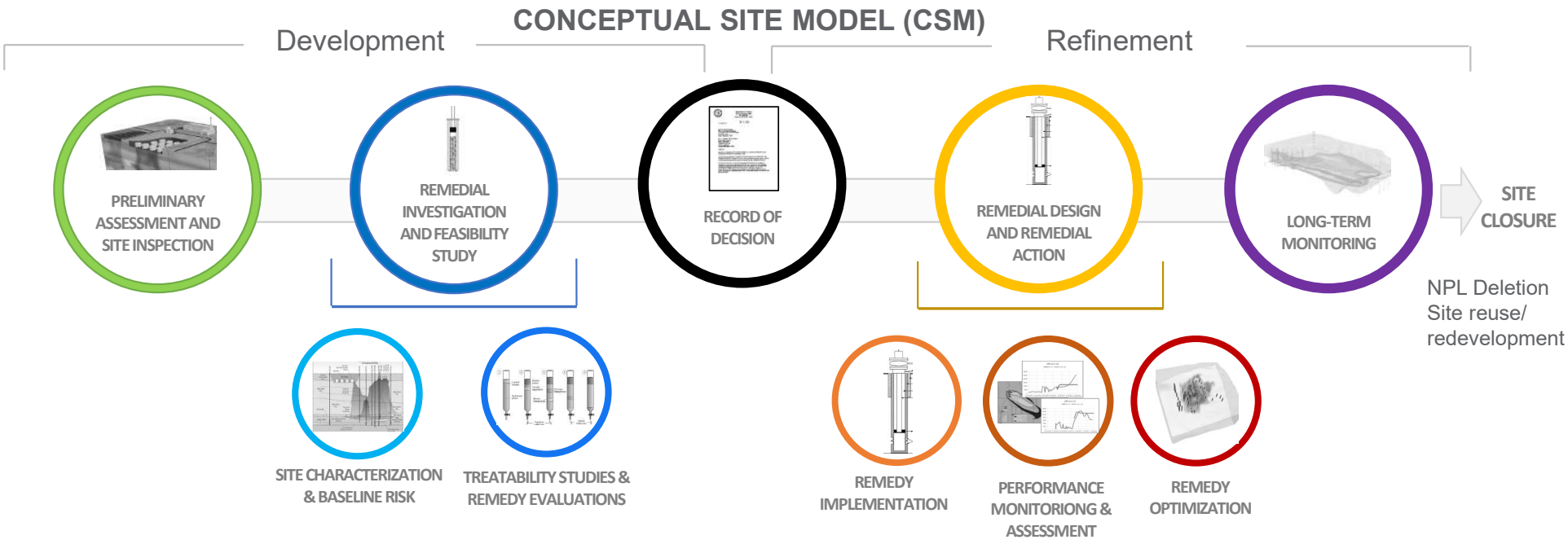
# IAEA Remediation Process

- The main principles of the remediation process depends upon radiation protection, through stepwise evaluation of justification, optimization of protection and safety, and the use of reference levels




*Representative scheme for the phases involved in the remediation of a contaminated area (IAEA General Safety Guide No. GSG-15)*
*IAEA, 2022, Remediation Strategy and Process for Areas Affected by Past Activities or Events*

# CERCLA Remediation Process

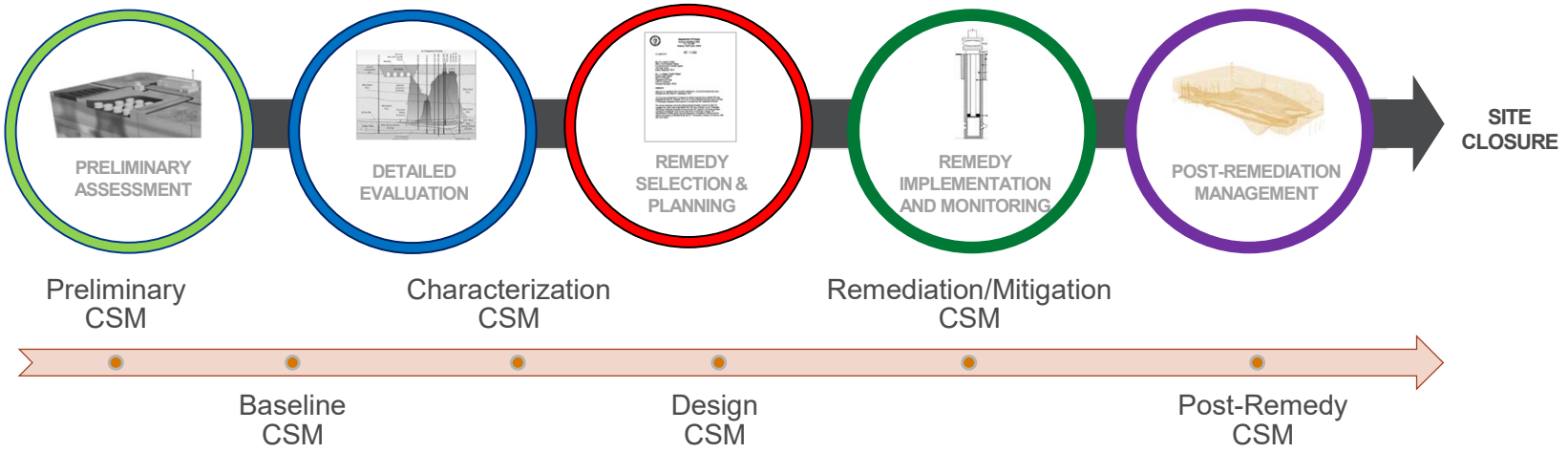



- Contaminant extent & distribution, and subsurface properties
- Features and processes that control contaminant mobility/risk
- Technology development, screening, and testing
- Technical basis for remedy selection

- Technology maturation and implementation
- End-state driven remedy optimization
- Technical approach for remedy performance monitoring & assessment
- Long-term monitoring approaches and technologies

# Conceptual Site Model (CSM)

- An iterative, 'living representation' of a site that represents the physical, chemical and biological processes that control the fate and transport of contaminants and their actual or potential impacts to human and/or other receptors
- Serves as the framework for incorporating new data during characterization and remediation
- Supports key remedial decisions related to project elements, such as cumulative risk, remedy selection, remedy implementation, site completion, and site reuse




USEPA, 2011, Environmental Cleanup Best Management Practices: Effective Use of the Project Life Cycle Conceptual Site Model

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# CSM Data

## Historical Operations

- Site infrastructure
- Operational history
- Disposal practices
- Spills
- Releases
- Production capacity/inventory

## Physical Features

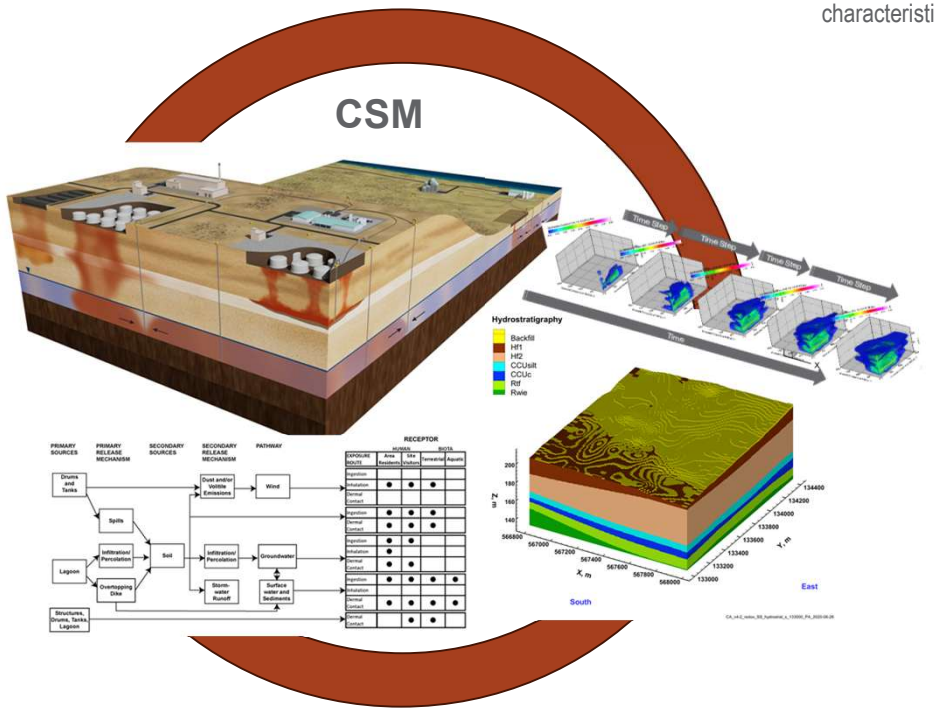
- Location of the site
- Current infrastructure
- Topography
- Weather patterns
- Surface water features
- Prevailing wind direction

## Geology

- Regional geology
- Site-specific geological features
- Geologic formations and characteristics

## Receptors & Exposure Pathways

- Potentially impacted communities
- Ecological receptors
- Environmental media impacted
- Exposure pathways




## Hydrology & Hydrogeology

- Surface water elevations
- Groundwater depth
- Subsurface flow and transport properties
- Aquifer piezometric surfaces
- Vertical and lateral flow patterns

## Radioactive Contamination

- Contaminants
- Inventory
- Spatial and temporal distribution of contaminants
- Source identification
- Contaminant geochemistry
- Transport properties
- Attenuation characteristics

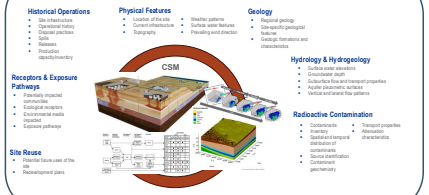
## Site Reuse

- Potential future uses of the site
- Redevelopment plans

# Decision-making in ER

- **Data intensive process**

**Site Data**



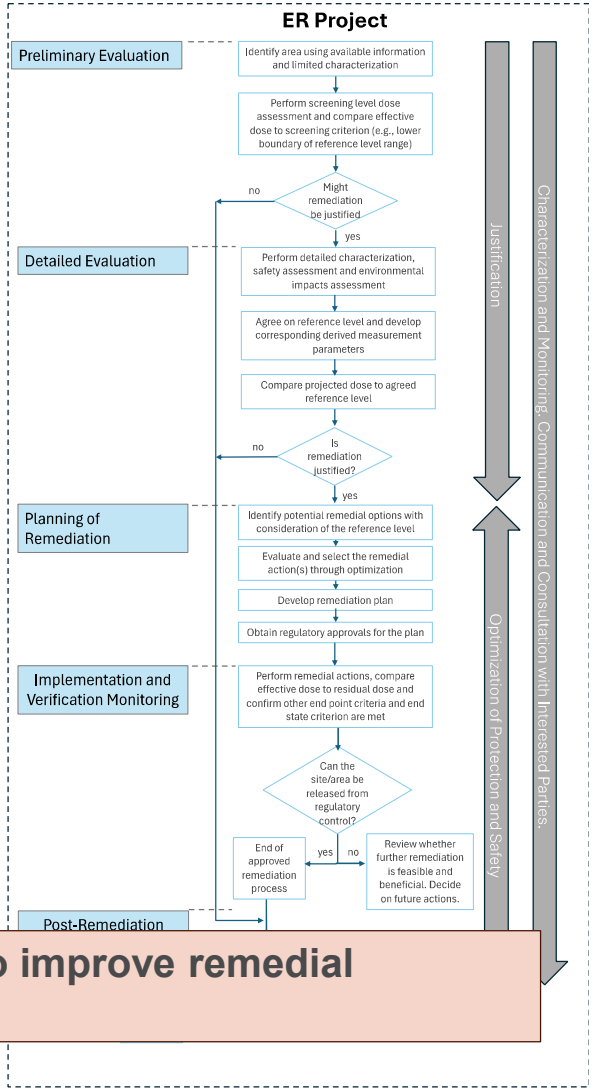

**Technology-Specific Considerations**

- Operational characteristics
- Performance data
- Cost and implementability
- Waste management issues
- Commercial availability

REGULATORY END-STATE

STAKEHOLDER ACCEPTENCE

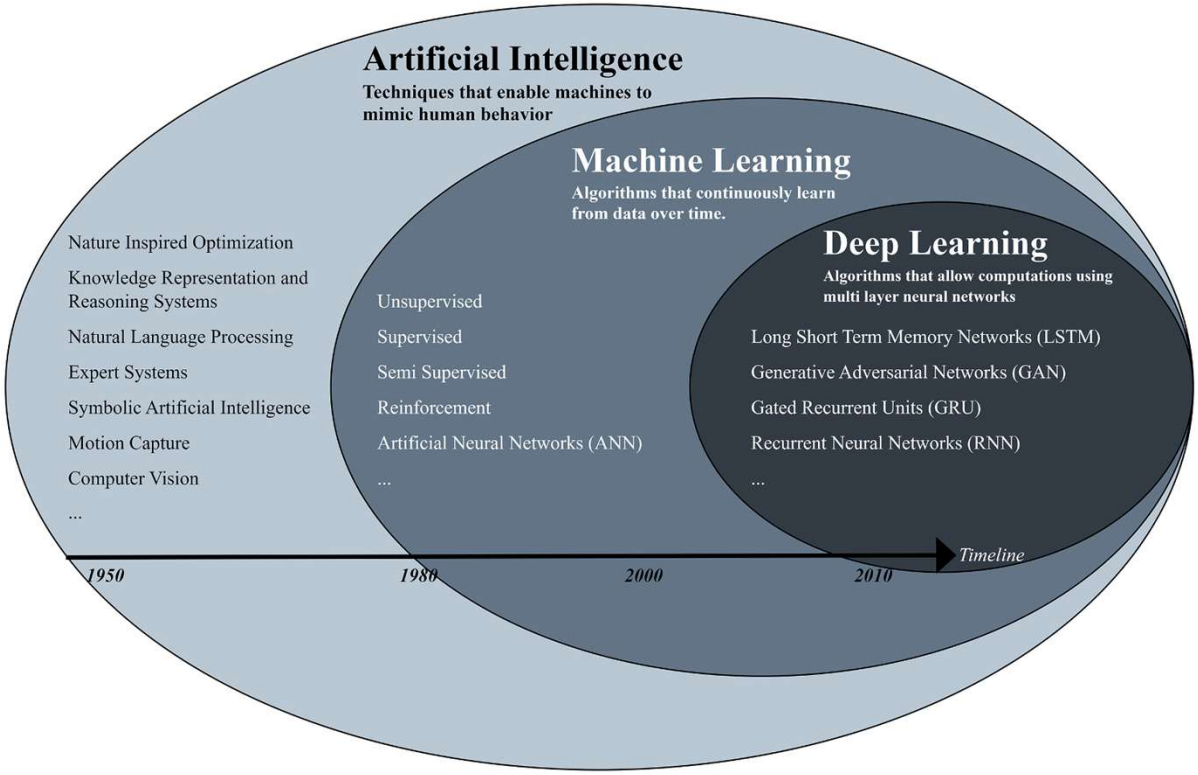
AVAILABLE RESOURCES




**Can we leverage the historical knowledge and ER data to improve remedial decision-making?**

# AI/ML/DL

- AI emerged in 1950s focusing on rule-based systems for knowledge representation
- ML was developed in the late 1980s specifically on certain optimizations where algorithms can learn from the data to improve the prediction accuracy and decision-making capacity
- DL is further developed as a newer subset to ML in early 2010s to enhance the ability of neural networks in understanding and processing complex data sets




*AI: Artificial Intelligence*
*ML: Machine Learning*
*DL: Deep Learning*

Janga et al. 2023, *Integrating artificial intelligence, machine learning, and deep learning approaches into remediation of contaminated sites: A review. Chemosphere 345 (2023) 140476*

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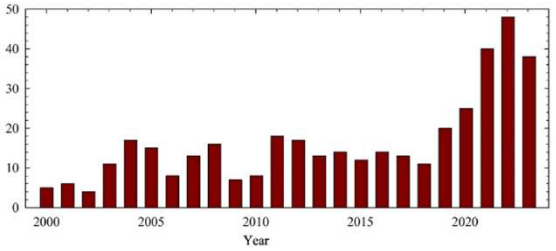
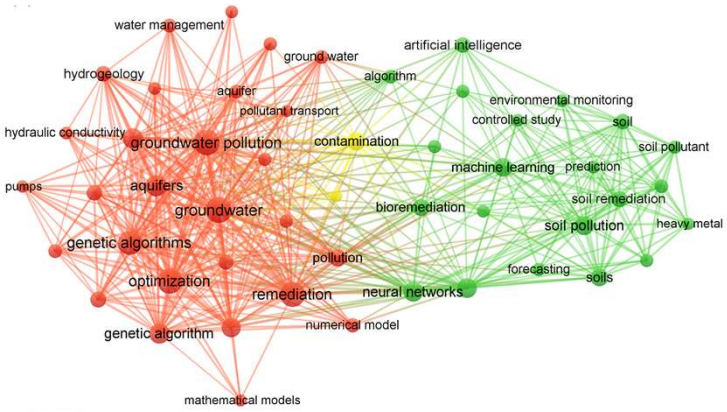
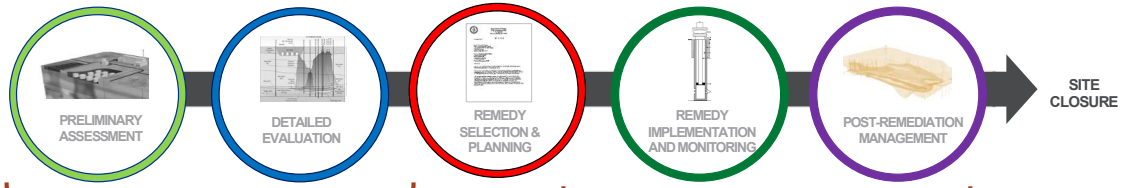
Number of publications between 2000-2023




# AI/ML/DL in Remedial Decision-making

- AI/ML/DL involves creating mathematical models to facilitate predictions and decisions
  - Uses training data
- AI/ML/DL can
  - Assimilate large datasets
  - Capture the principal features identifying interactions, organizations, and patterns from variables
  - Improve predictions




AI/ML/DL for **site characterization planning** or **remedy alternative identification**

AI/ML/DL for **remedy monitoring and performance verification/optimization**

AI/ML/DL for r**emedy selection**

Janga et al. 2023, *Integrating artificial intelligence, machine learning, and deep learning approaches into remediation of contaminated sites: A review. Chemosphere 345 (2023) 140476*

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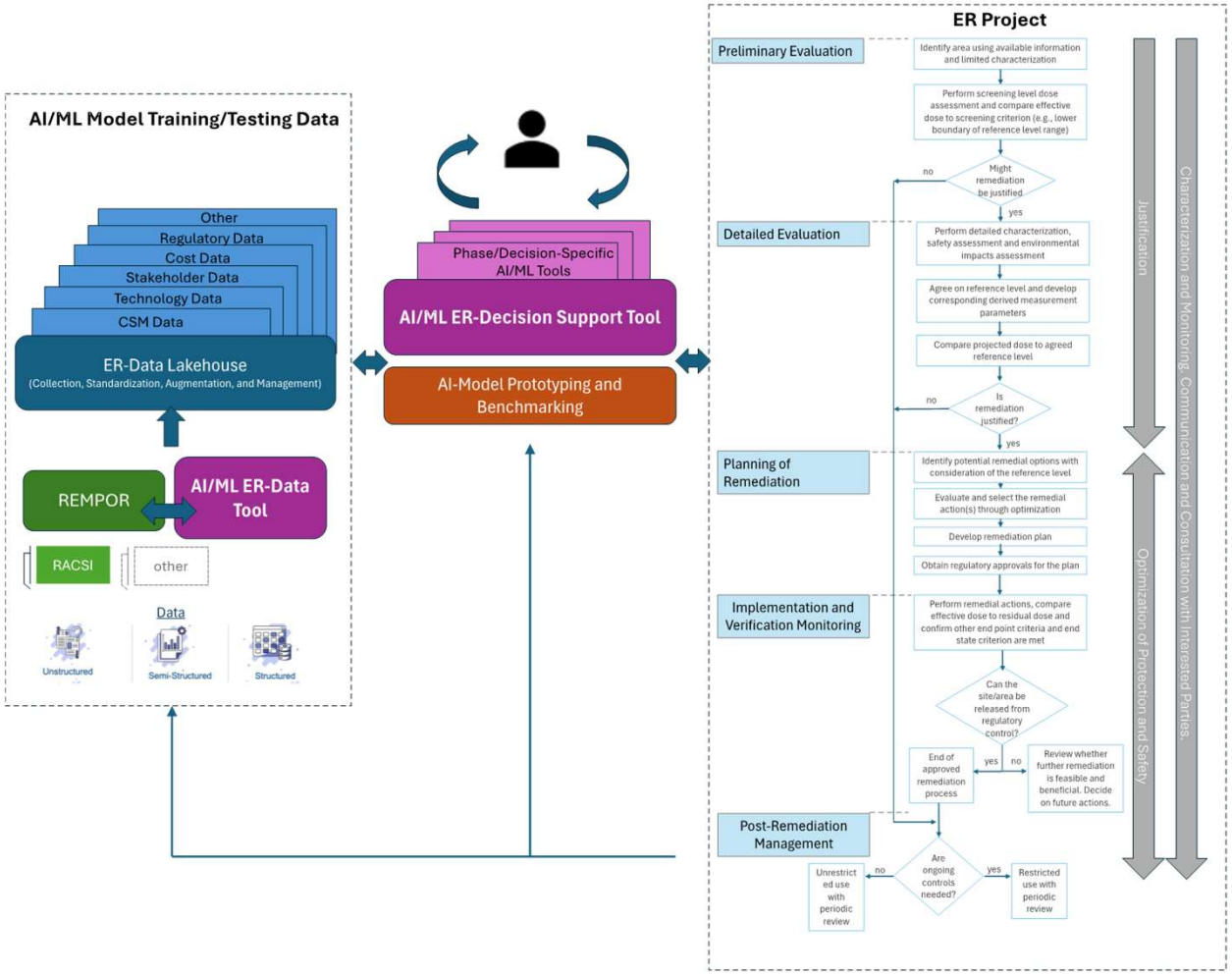
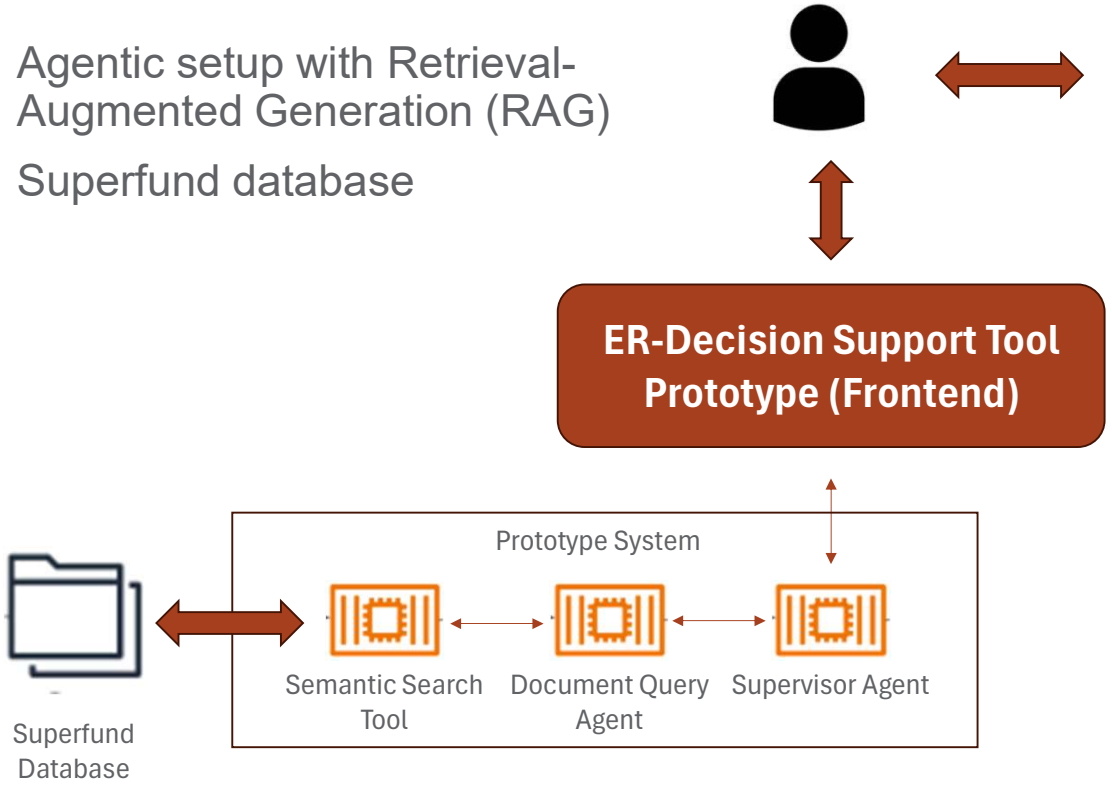
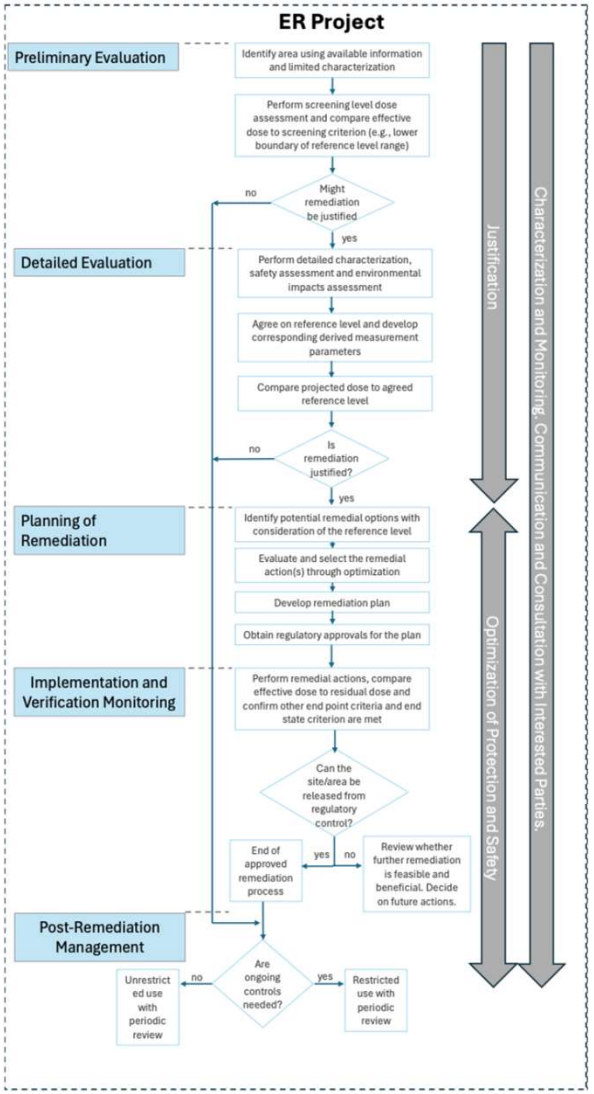
# Vision for Deployment



# PILOT Approach: Document Query Agent

- Agentic setup with Retrieval-Augmented Generation (RAG)
- Superfund database



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# Summary

- Remediation processes are complex, multi-phase, and iterative. They are governed by:
  - National regulations/policies
  - Assessed human health and environmental risk
- CSMs are a critical tool to support iterative and complex nature of the remediation processes and decision-making
- Selection of appropriate remedy technologies depends on
  - A robust and up-to-date CSM
  - Accurate identification of relevant actual and/or perceived risks
  - Identified end-states
  - Availability of feasible technologies
- AI/ML approaches can support decision-making in environmental remediation, leveraging existing data
  - A pilot approach is being kicked off to develop an agentic solution initially focusing on a capability for document query

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# Thank you