Advances in Adaptive Management for Cleanup of Complex Sites

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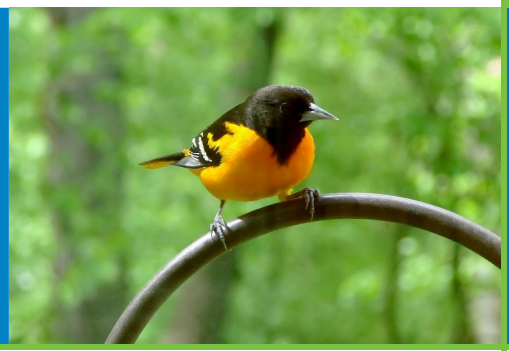

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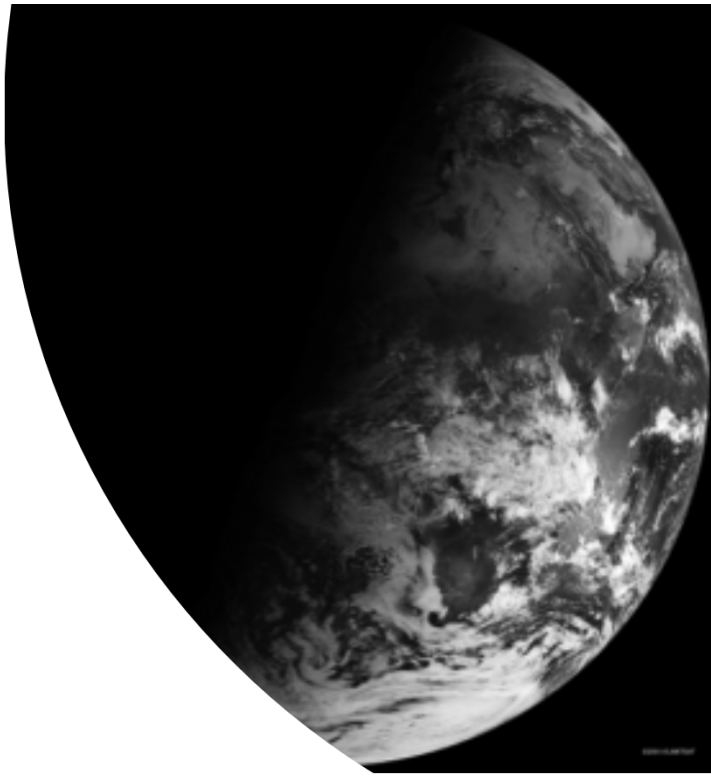
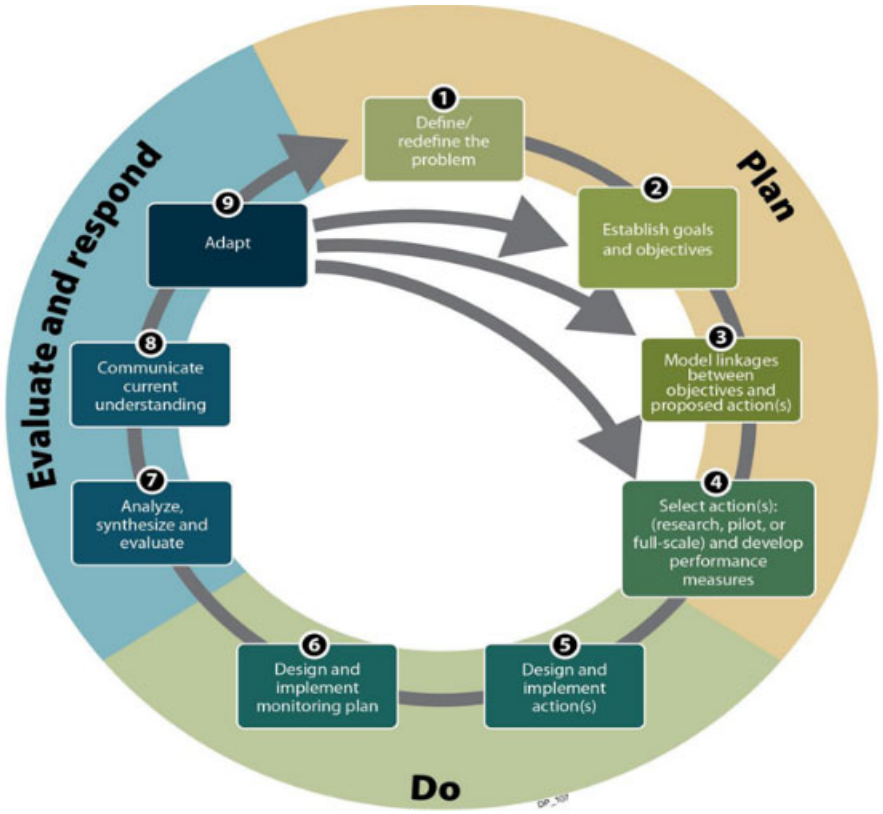
Problem: Complex Site Management



- Significant challenges with complex site cleanup
  - Conceptual site models (CSM) complex and expensive
  - Multi-technology cleanup approaches likely
  - Long-term management as sites transition to different phases (i.e. active to passive)
  - Stringent cleanup goals, including restoration
  - Significant uncertainty when decisions are made
- How can cost-effective decisions be made over the course of the remedy life cycle?

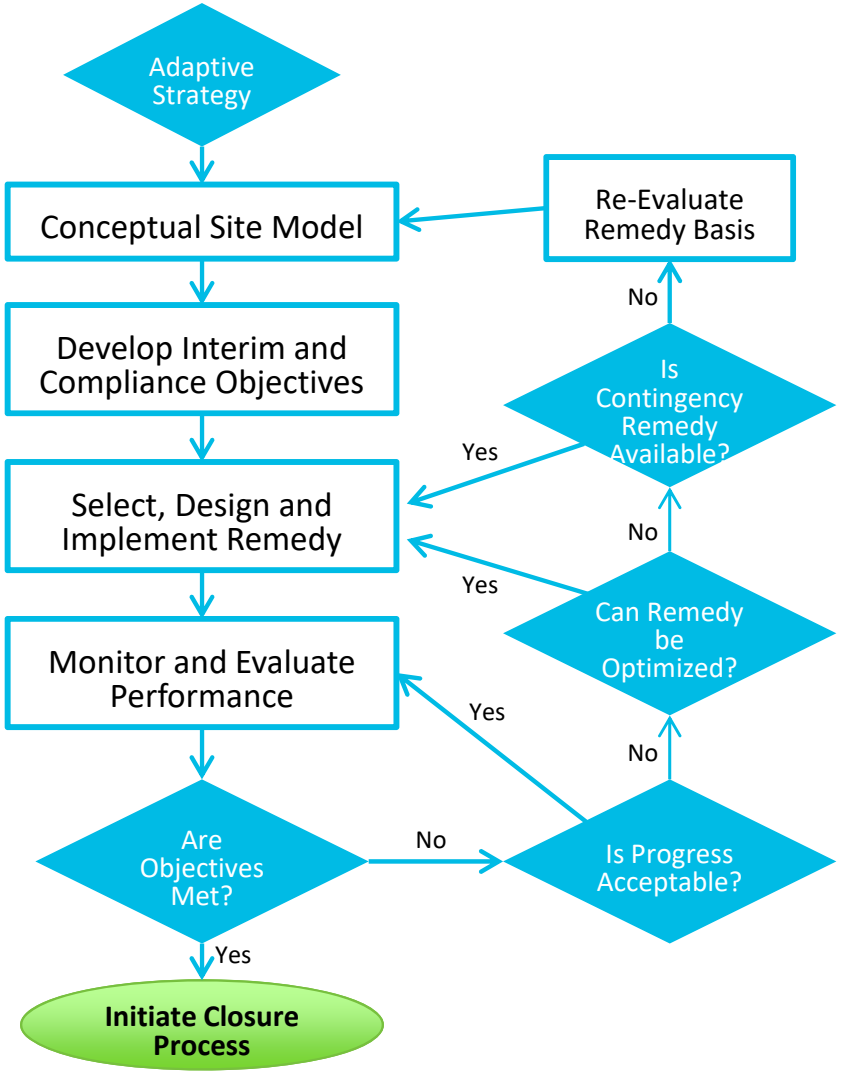
Solution: Adaptive Site Management

- ***Acknowledge complexity*** of working systems
- ***Account for uncertainties*** when making remediation decisions
- ***Develop decision framework for adaptive approach***
  - Identify key decision points in the remedy life cycle
  - Understand potential for feedback at each decision point
- ***Assess and mitigate risk*** to bound impacts on outcomes for planning
  - Technical risks
  - Schedule risks
  - Cost risks

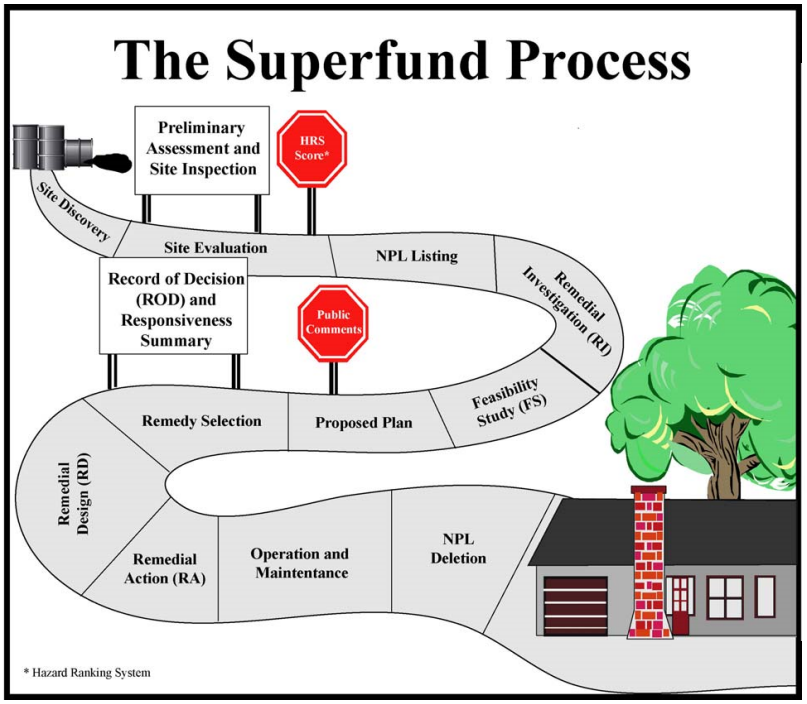


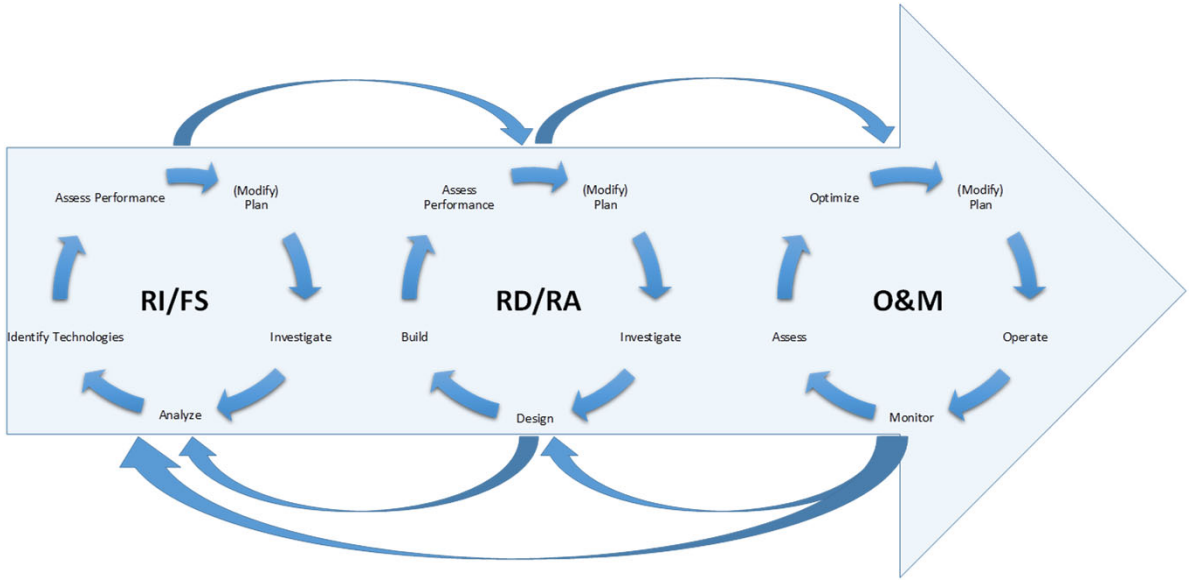
Remedy Flexibility

- Interim Objectives with Clear Remedy Transition
  - Active ⇒ Passive
  - Active ⇒ Long Term Monitoring
- Technology Tool Box Approach
- Developing Contingency Plan



Superfund Remedial Site Management

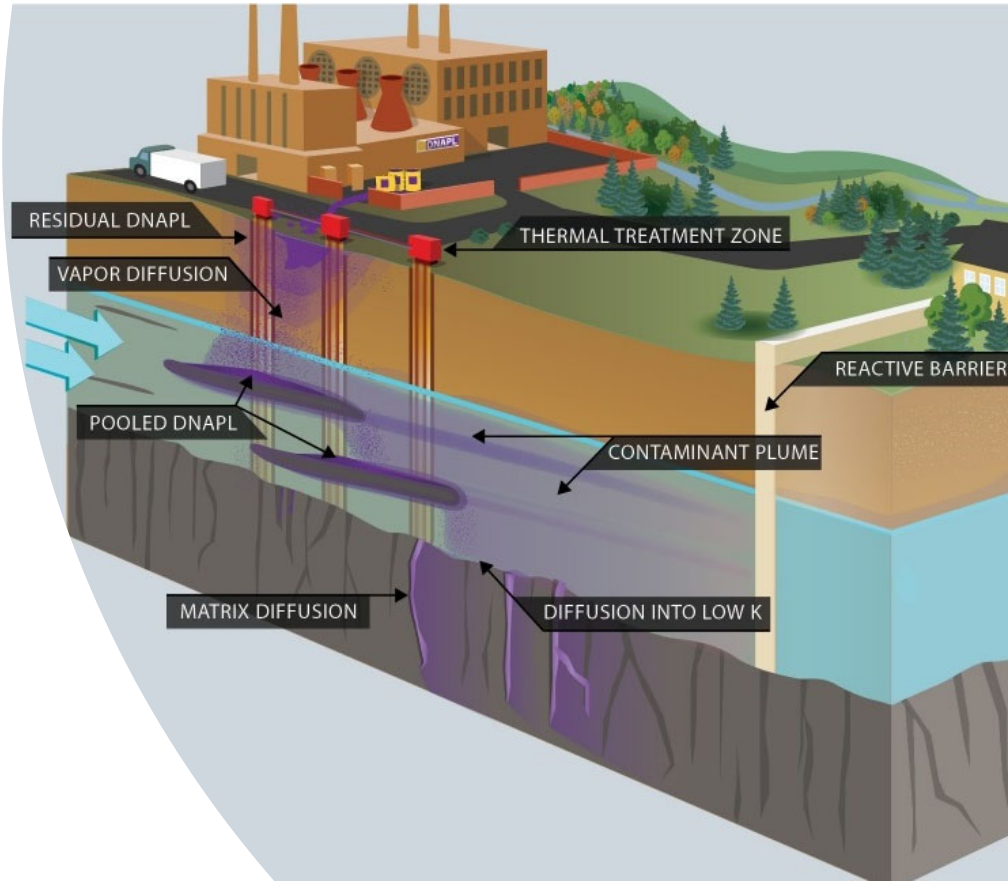




https://www.epa.gov/superfund/about-superfund-cleanup-process

Sites for Adaptive Management

- Sites that are not conducive to final remedy selection in the short-term.
- Large and/or complex sites where targeted activities may reduce project uncertainties and demonstrate continued site progress.
- Sites with complete exposure pathways that would benefit from targeted actions to reduce or mitigate exposure.
- Sites with uncertainty in the CSM that may benefit from a multi-phase remedy.
- Sites that have responsible parties motivated to expedite RD/RA completion activities.



Approaches for Adaptive Management and Risk Evaluation

- Multiple-criteria decision analysis
  - Identify decision inputs
  - Rank and score decision criteria
  - Incorporate multiple scenarios to assess uncertainty and quantify risks
- Risk register
  - Identify risk elements with potential to limit project success
  - Rank and score project risks
  - Develop risk mitigation plan

Tools for Multiple-Criteria Decision Analysis

- Multi-Attribute Global Inference of Quality (MAGIQ)
- Multi-attribute utility theory (MAUT)
- Multi-attribute value theory (MAVT)
- **Multi-Objective Dragonfly Algorithm (MODA)**
- Multi-Objective Genetic Algorithms (GA)
- New Approach to Appraisal (NATA)
- Nonstructural Fuzzy Decision Support System (NSFDSS)
- [illegible]
- [illegible]
- [illegible]
- Sub-Structured Neural Network (SSANN)
- Superiority and inferiority ranking method (SIR method)
- Technique for the Order of Prioritisation by Similarity to Ideal Solution (TOPSIS)
- Value analysis (VA)
- Value engineering (VE)
- VIKOR method[52]
- Fuzzy VIKOR method[53]
- Weighted product model (WPM)
- Weighted sum model (WSM)
- Aggregated Indices Randomization Method (AIRM)

- **Analytic hierarchy process (AHP)**
- Analytic network process (ANP)
- Balance Beam process
- Best worst method (BWM)[44][45]
- Brown–Gibson model
- Characteristic Objects MeThod (COMET)[46][47]
- Choosing By Advantages (CBA)

Measuring Attractiveness by a Categorical Based Evaluation Technique (MACBETH)

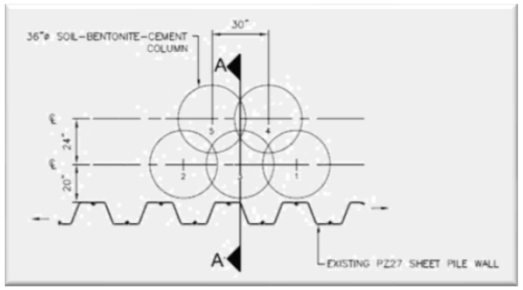
- Dominance-based rough set approach (DRSA)
- ELECTRE (Outranking)
- Evaluation Based on Distance from Average Solution (EDAS)[48]
- Evidential reasoning approach (ER)
- Goal programming (GP)
- Grey relational analysis (GRA)
- Inner product of vectors (IPV)
- Measuring Attractiveness by a categorical Based Evaluation Technique (MACBETH)
- Simple Multi-Attribute Rating Technique (SMART)
- Stratified multi criteria decision making method (SMCDM)[49]
- Markovian Multi-Criteria Decision Making [50] [51]

Case Example: Hunters Point Shipyard

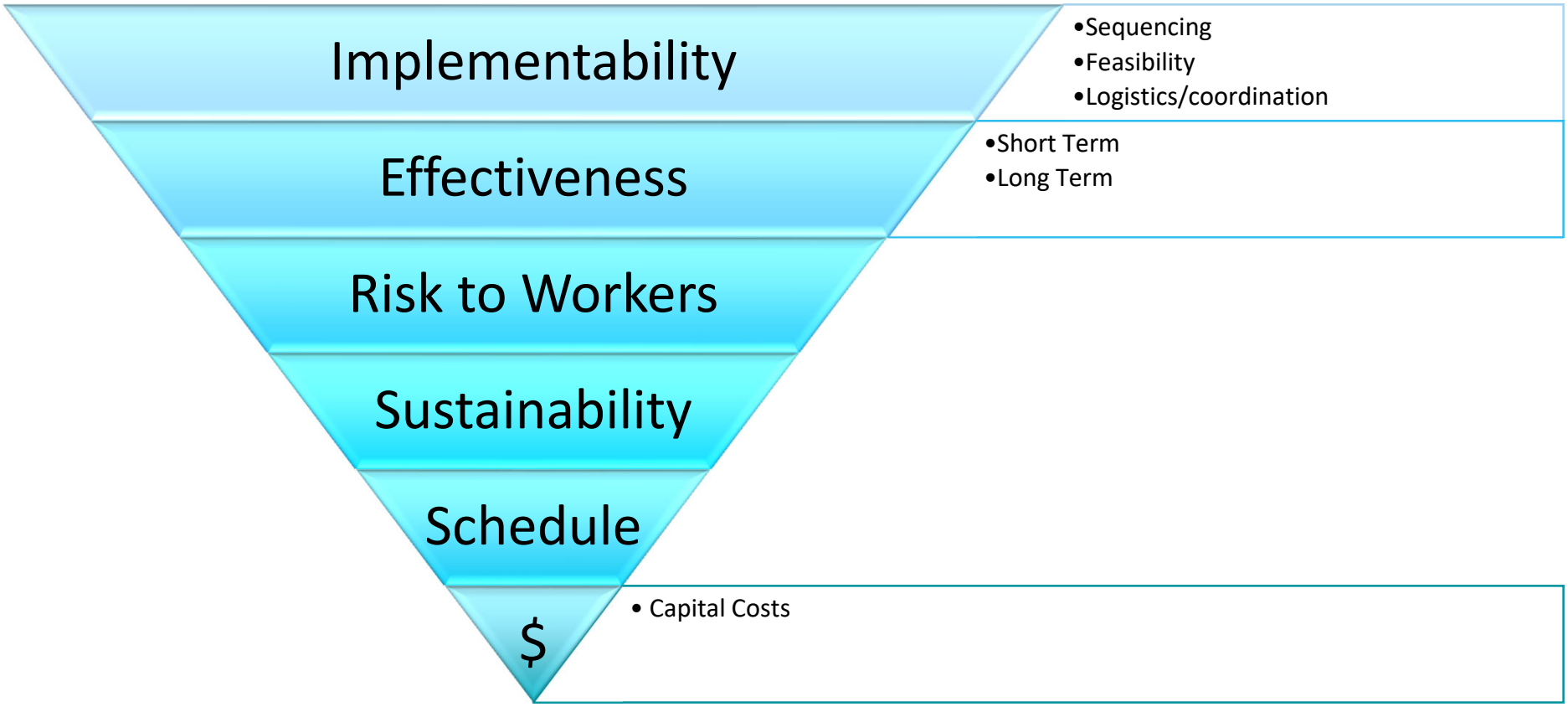
- Evaluation of multi-technology treatment for former nonaqueous phase liquid (NAPL) ponds
- Adaptive ROD specified NAPL technologies
  - *in situ* thermal remediation (ISTR) and
  - *in situ* solidification and stabilization (ISS)
- Pilot Testing
- Criterium Decision Plus (CDP) support tool used to evaluate NAPL remediation scenarios and develop a remedial strategy to achieve remedial goals
  - Treat mobile NAPL
  - Prevent mass discharge via groundwater to surface water (San Francisco Bay)

TPH, PCBs, PAHs, aryl phosphates

Pilot Testing: In Situ Solidification/Stabilization & Thermal

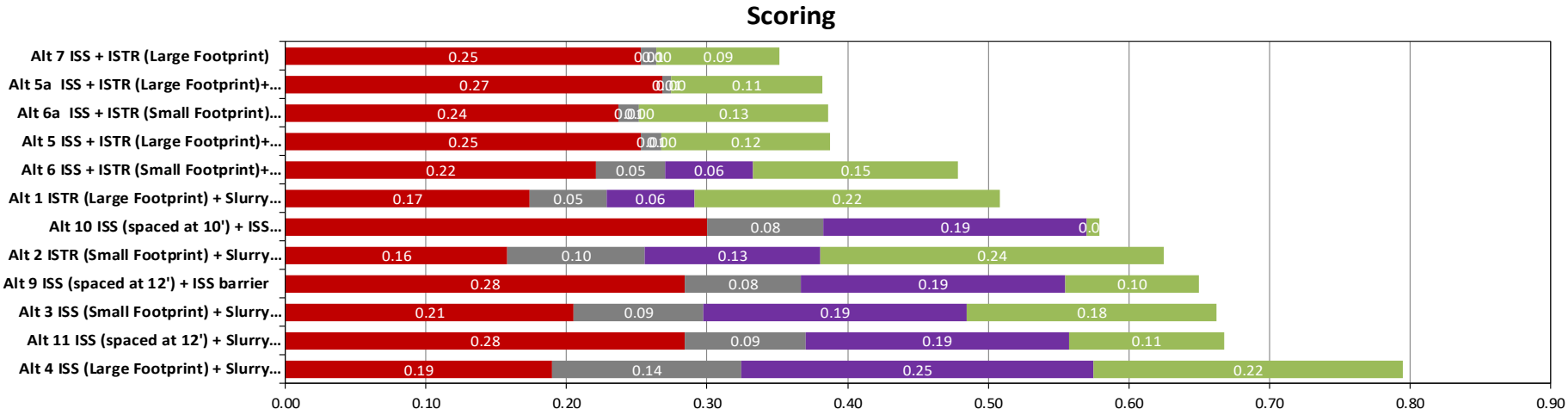


Decision Criteria for NAPL Treatment Strategy



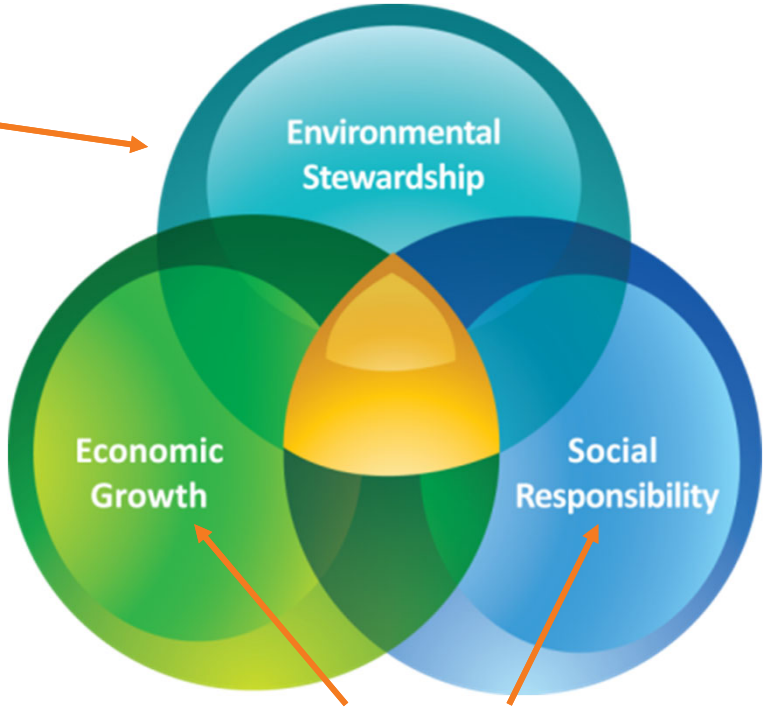
Evaluate Multiple Technology Combinations

- **Criterium Decision Plus (CDP)** – multi-criteria decision making software using the Analytic Hierarchy Process and the Simple Multi-Attribute Rating Technique
  - Long-Term Effectiveness (red)
  - Short-Term Effectiveness (grey)
  - Implementability (purple)
  - Cost (green)



Green and Sustainable Remediation (GSR) Assessment

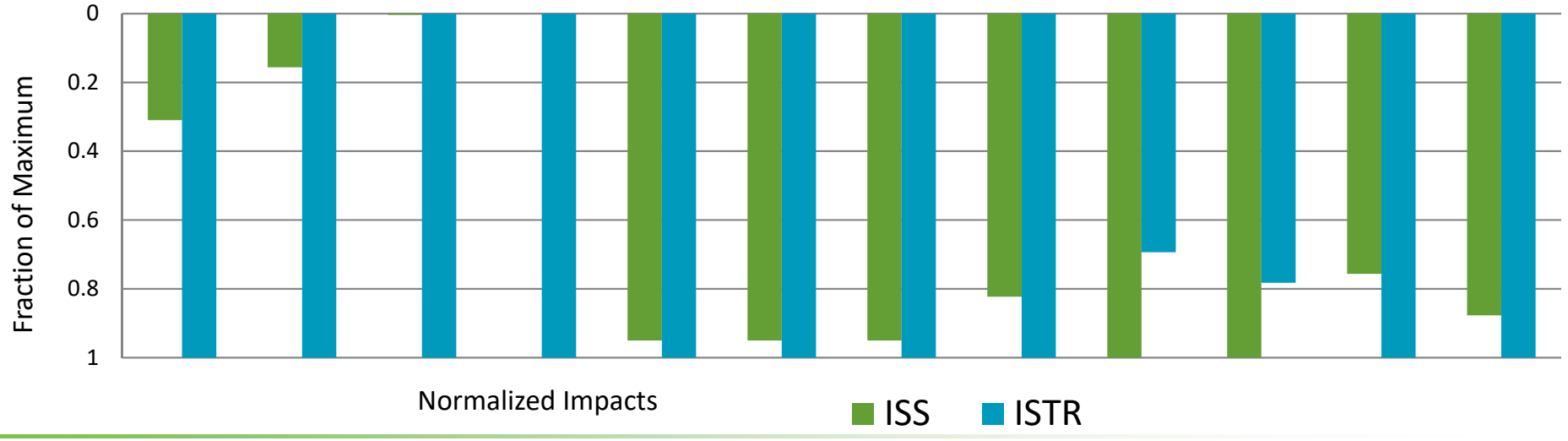
SiteWise™ *environmental footprint tool*



Global Monetized Impacts

GSR Environmental Footprint Analysis: SiteWise™

	Usage			Emissions							Accident Risk	
	Energy	Water	Elec	GHG	Onsite NOx	Onsite SOx	Onsite PM10	Total NOx	Total SOx	Total PM10	Fatality	Injury
ISS	Low	Low	Low	Med	High	High	High	High	High	High	Low	Low
ISTR	High	High	High	High	High	High	High	High	Med	High	Low	Low

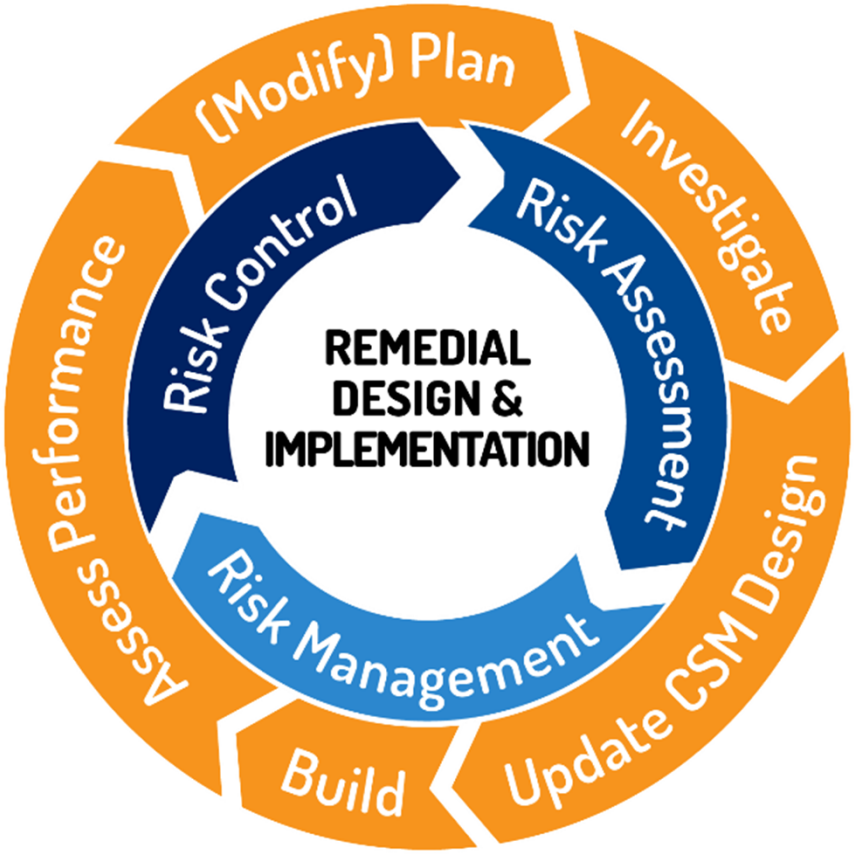


Summary of Decision Criteria Evaluation

Objective	Metric	ISTR+Slurry Wall	ISS+Slurry Wall
Risks to Community or Workers	Qualitative [hazardous materials and process hazards]	Moderate	Low
Environmental Footprint	Numeric [SiteWise]	High	Moderate
	Global Monetized Impacts	High	Low
Schedule	Numeric [Time to implement remedy]	3 Years	2 Years
Implementation	Qualitative [complexity of implementation]	Difficult	Moderately Difficult
Capital cost	Capital cost ($M)	$14.7	$13.7
CDP Score	Numeric [CDP]	0.52	0.81

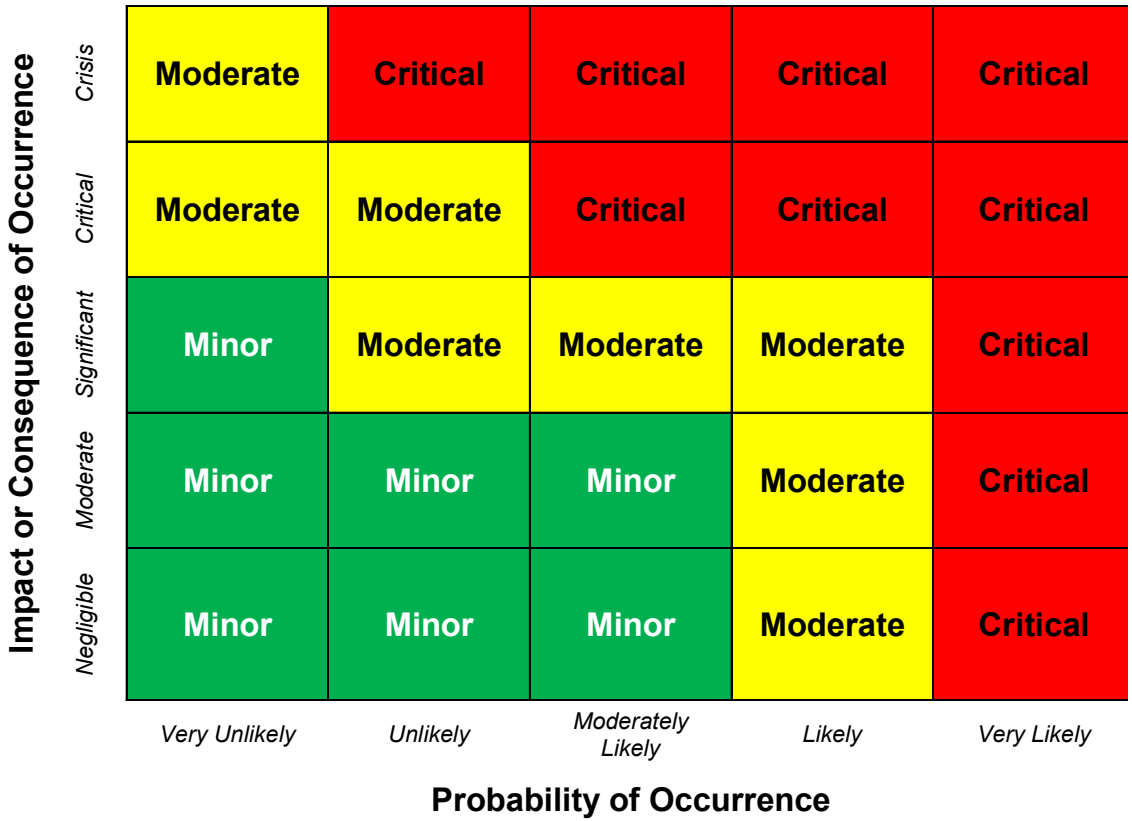
Tools for Identifying and Managing Project Risks

- Technical Risks
  - Flawed conceptual site model
  - Inaccurate assumptions during remedial investigation, design, implementation
- Cost Risks
- Schedule Risks



Managing Uncertainty and Risk

- Risk register
  - Identify risk types
  - Assess risk impact
  - Assess the risk probability of occurring
  - Provides quantitative means to score the risk
- Mitigation plan for risk
  - Includes contingency



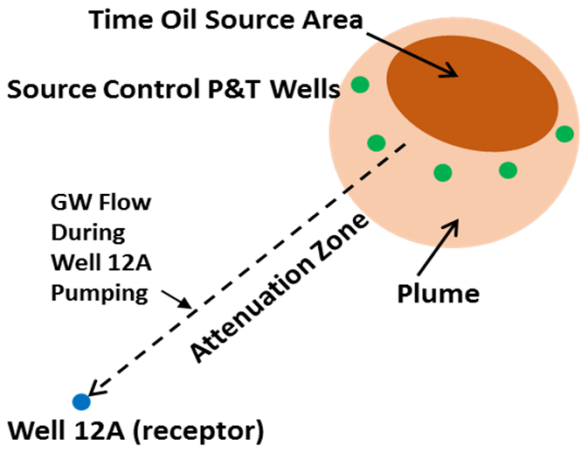
Summary of Risks: Achieving RAOs

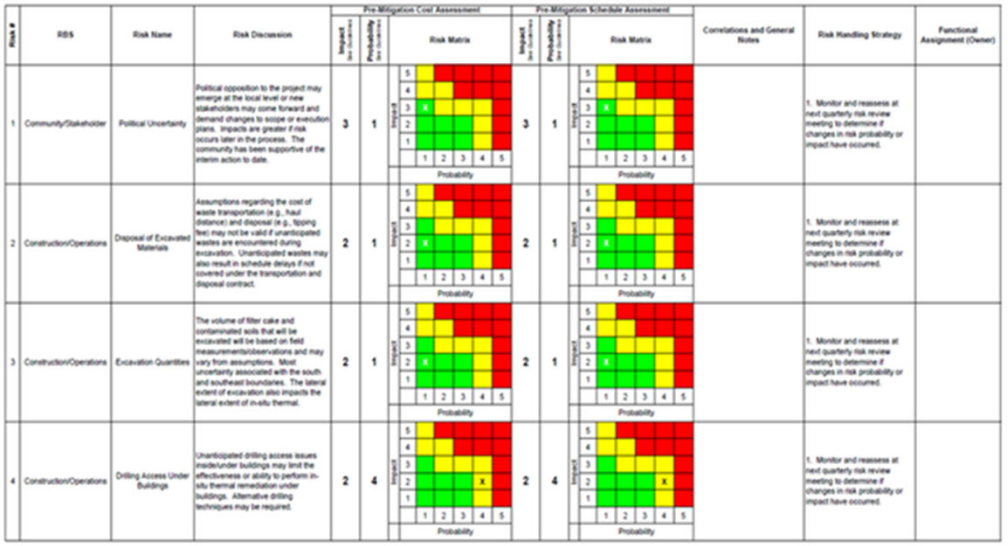
Model to determine mass flux objectives

- Source strength
- Aquifer attenuation capacity
- Used active pump and treat system data to model and assess objectives
- **Result**: Realistic performance goals for active treatment of a DNAPL site, compatible with the overall remedy management approach to protect the receptor

Identified and prioritized key uncertainties, which informed:

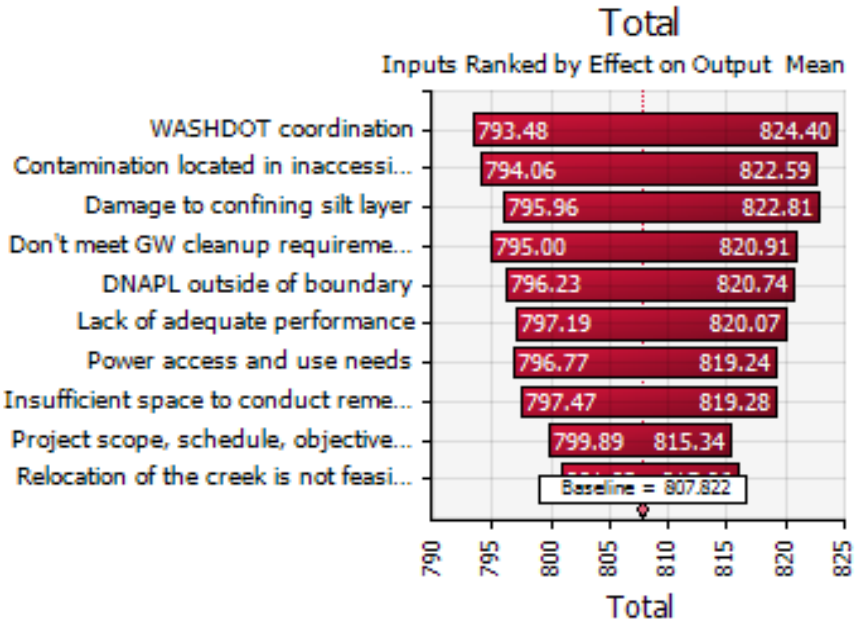
- ✓ Design sampling needs
- ✓ Scope and role remedy decision in site strategy
- ✓ Necessity for remedial action contracting flexibilities



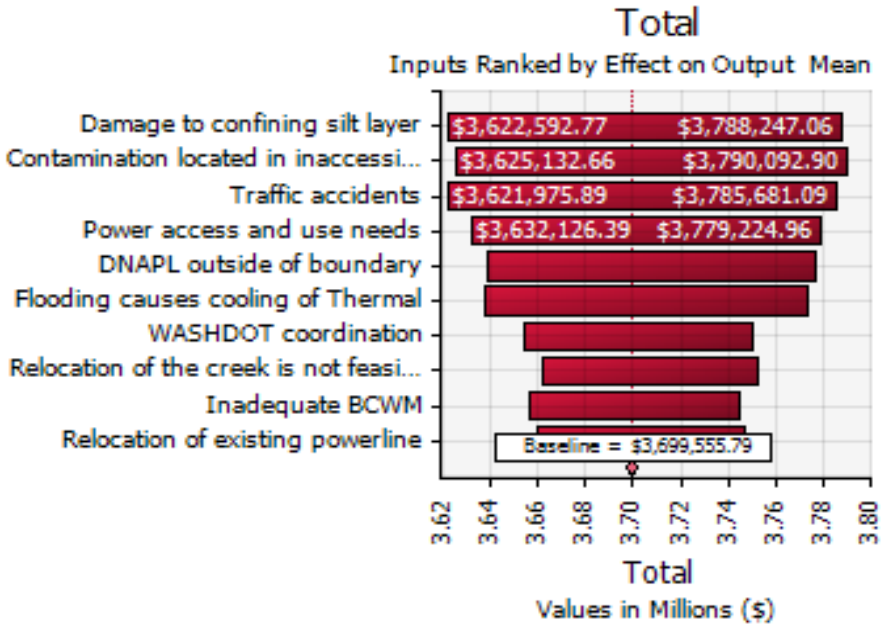


Summary of Risks: Thermal Treatment of a DNAPL Site

- Summary of Schedule Risks

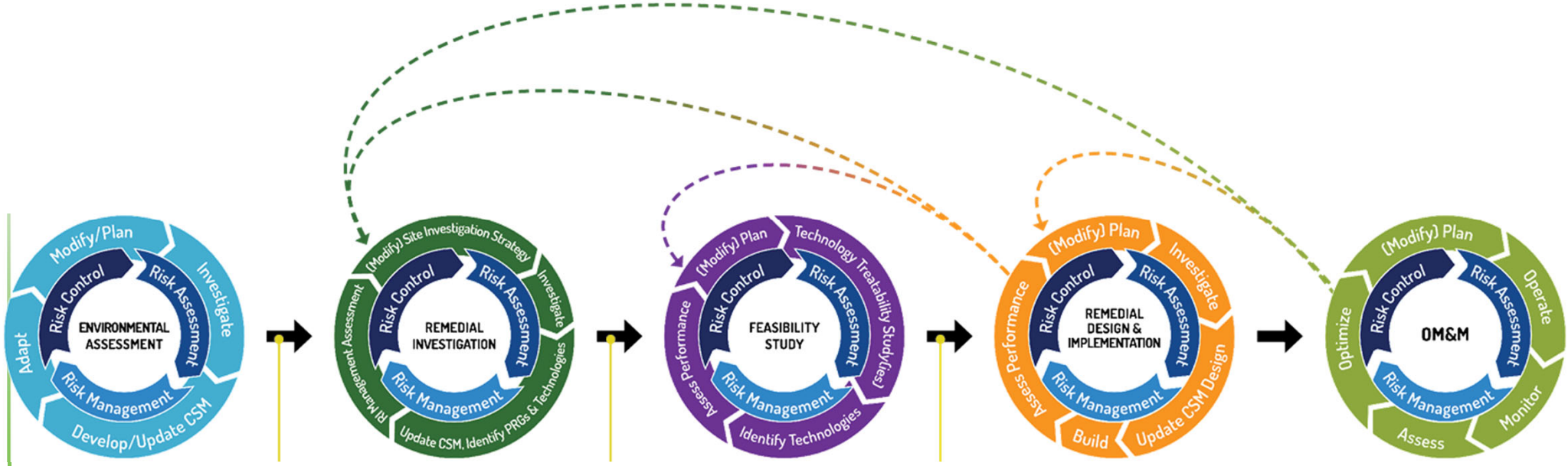


- Summary of Cost Risks



Conclusions

- Effective adaptive management –evaluate/mitigate project risk.
- Adaptive management incorporated throughout project life cycle.



Transitional Decision Points

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