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Collaborative Development of Remediation Portfolios:

Toward Risk Reduction at the Tuba City Mill Site

2021 RemPlex Summit

Authors: Team from the Department of Energy Network of National Laboratories for Environmental Management and Stewardship

Tuba City Site

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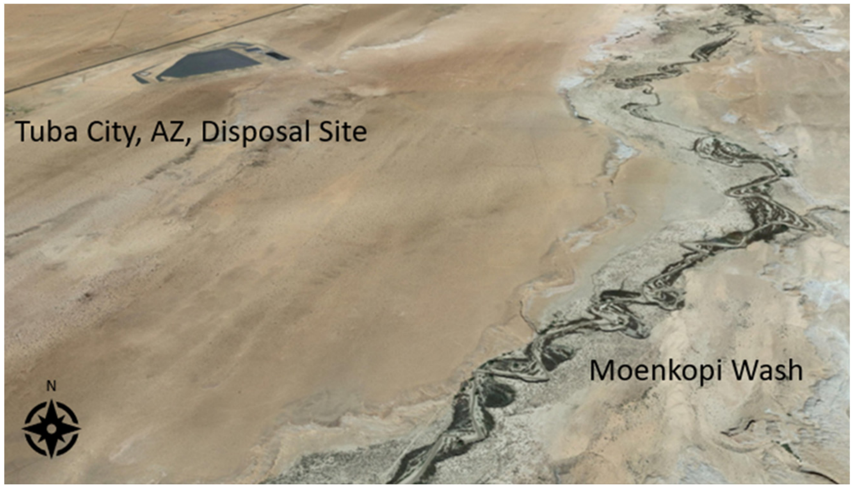
Synopsis

- Tuba City is a "Complex Site", necessitating a combined remedy strategy – "Adaptive Site Management"
- Stakeholder values key to developing potential remedy portfolios to achieve remedial objectives and maximize value to both DOE and the community
- Collaborative technically-focused process envisioned by Carmelo Melendez to address risk drivers at former Tuba City mill site
  - Residual sources (amount, character, location, projected source flux over time)
  - Attenuation processes and plume dynamics
  - Characterization opportunities and efficiencies to meet Groundwater Corrective Action Plan (GCAP) goals and data quality objectives (DQOs)
  - Innovative strategies to mitigate stakeholder and regulatory risks and maximize the value of DOE actions



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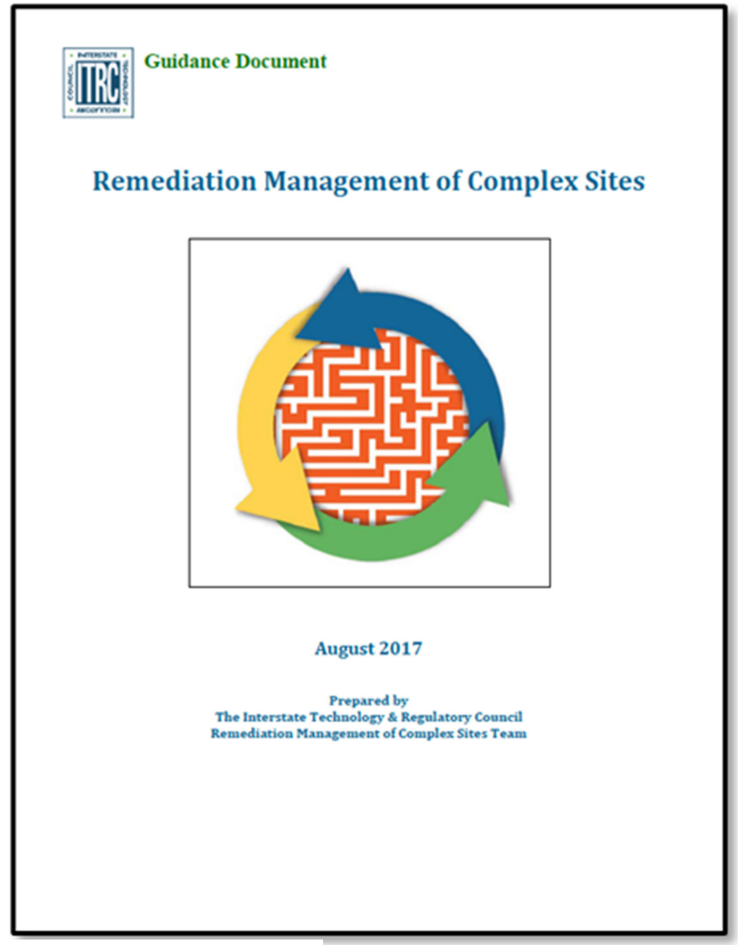
Challenges at "Complex Sites"

Current Management Strategy:
Traditional regulatory and management of environmental challenges uses a **linear "study, select, design, build, and operate" paradigm.** For example, this is inherent in to standard CERCLA feasibility study approach

Emerging Management Strategy:
For Complex Sites, Years of experience has led to the recognition that the **significant uncertainty inherent in environmental cleanup** requires more flexible, iterative approaches.

Key topics:
What is a complex site? What will improve success is remediating complex sites? How can we measure risk reduction and performance of remediation at complex site? …


ITRC Guidance Document

Remediation Management of Complex Sites

August 2017

Prepared by
The Interstate Technology & Regulatory Council
Remediation Management of Complex Sites Team

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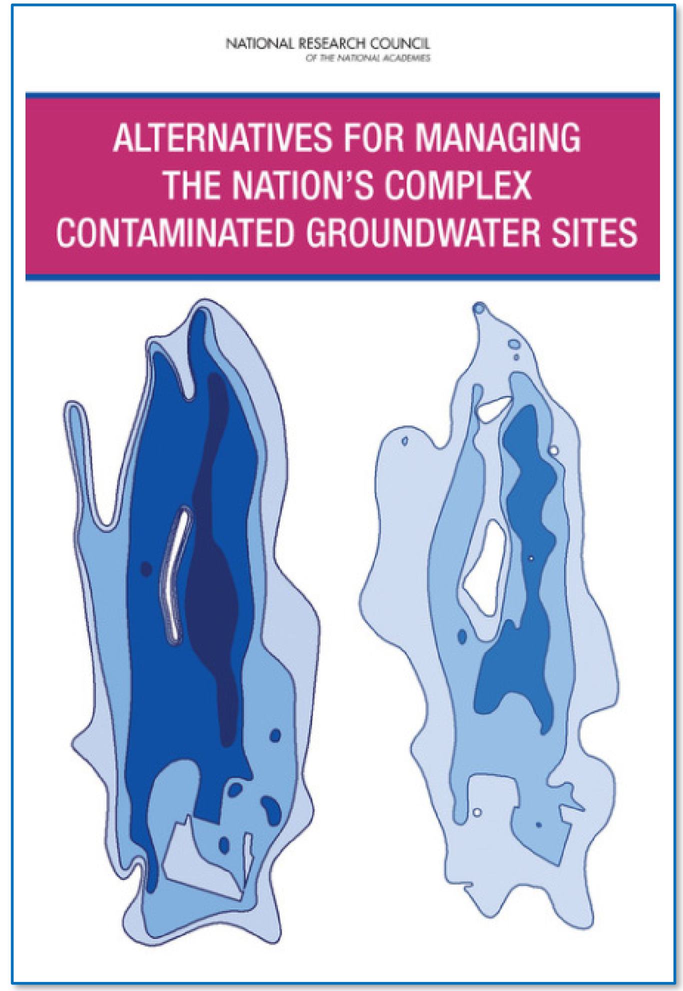
Complex Sites: History and Lessons Learned

Observations:

- Achieving MCLs throughout the aquifer unlikely at most complex groundwater sites in a time frame of 50-100 years.
- Individual technologies are generally not effective at addressing the different target zones within the contaminant plume

Most Effective Solution:

- Developed a combined remedy where technologies are optimally used to address key sub-objectives or target contamination zones
- Use interim and sequenced technologies in an organized and strategic manner – adjust based on performance metrics
- Adaptive Site Management

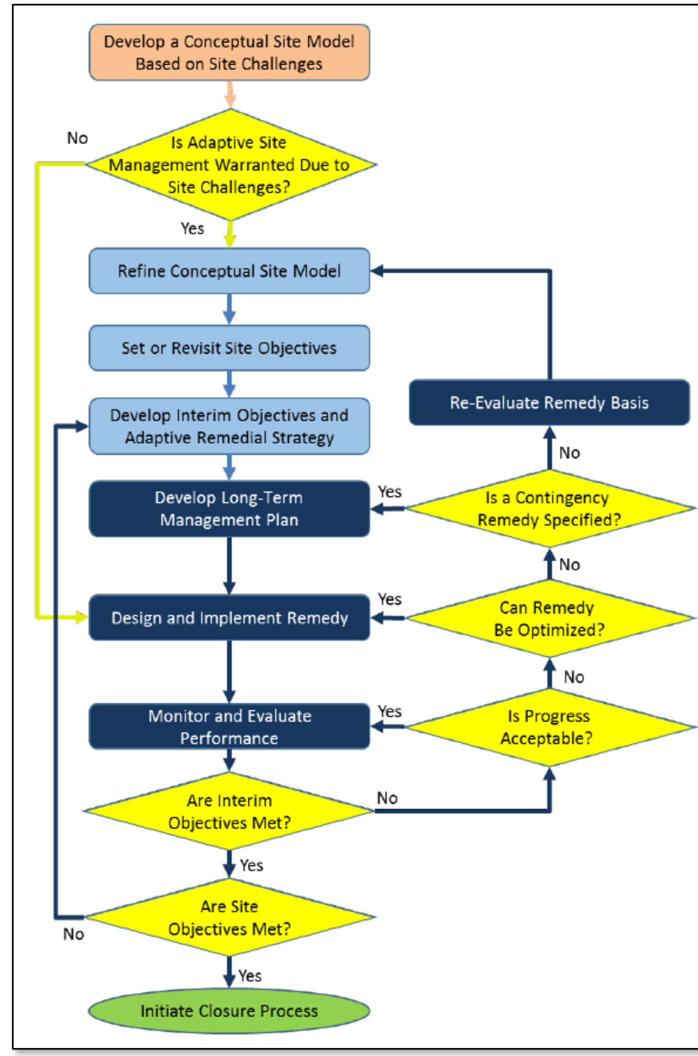


Complex Sites: Remedy Development

Adaptive Site Management

- Useful for sites with significant uncertainty
- Iterative process; periodic evaluations
- Periodic refinement of CSM
- Based on Targeted, Interim and Ultimate Objectives
    - Relies on the DQO process
    - Can dovetail with planned (e.g. five-year reviews)

- Example of a typical combined remedy
    - Plume control (limit growth of existing plume)
    - Source mass flux reduction (control or removal)
    - Document natural attenuation or deploy enhanced attenuation
    - Develop metrics for implementation of technologies and transition to an agreed end state



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Complex Sites: Characteristics

Technical Challenges	Examples
Geologic conditions	• Geologic heterogeneity/preferential flow paths • Faults • Fractured bedrock • Karst geology • Low-permeability media
Hydrogeologic conditions	• Extreme or variable groundwater velocities • Fluctuating groundwater levels • Deep groundwater contamination • Surface water and groundwater interactions and impacted sediment
Geochemical conditions	• Extreme geochemistry (such as unusually high or low pH or alkalinity, elevated electron acceptors, extreme redox conditions) • Extreme groundwater temperatures
Contaminant-related conditions	• Light or dense nonaqueous phase liquids (LNAPL or DNAPL) • Recalcitrant contaminants • High contaminant concentrations or multiple contaminants • Emerging contaminants
Large-scale site	• Location and extent of contamination • Number, type and proximity of receptors • Depth of contamination • Extensive or comingled plumes

Nontechnical Challenges	Examples
Site objectives	• Societal expectations and social acceptability • Changing site objectives • Adopting site objectives that differ from promulgated screening levels or closure criteria (such as MCLs)
Managing changes that may occur over long time frames	• Phased remediation • Future use • Site management • Multiple responsible parties • Staff turnover/Loss of institutional knowledge • Litigation
Overlapping regulatory responsibilities	• Federal and state cooperation • Changing laws and regulation • Financial responsibility • Orphan sites • Contaminants without regulatory criteria or guidance (such as emerging contaminants)
ICs	• Tracking and managing ICs • IC enforcement • Long-term management of institutional controls
Changes in land use	• Changing land use or water use • Multiple owners • Site access
Funding	• Lack of funding (state, federal, or private industry) • Politics that alter funding/program priorities • Unwilling or unknown RPs

In addition to the nontechnical challenges listed, accounting for **stakeholder perspectives** is a significant challenge at some sites.

Complex Sites: Characteristics – Tuba City A

Technical Challenges	Examples
Geologic conditions ☑	• Geologic heterogeneity/preferential flow paths ☑ • Faults • Fractured bedrock ☑ • Karst geology • Low-permeability media ☑
Hydrogeologic conditions ☑	• Extreme or variable groundwater velocities • Fluctuating groundwater levels • Deep groundwater contamination ☑ • Surface water and groundwater interactions and impacted sediment
Geochemical conditions ☑	• Extreme geochemistry (such as unusually high or low pH or alkalinity, elevated electron acceptors, extreme redox conditions) ☑ • Extreme groundwater temperatures
Contaminant-related conditions ☑	• Light or dense nonaqueous phase liquids (LNAPL or DNAPL) • Recalcitrant contaminants ☑ • High contaminant concentrations or multiple contaminants ☑ • Emerging contaminants
Large-scale site ☑	• Location and extent of contamination ☑ • Number, type and proximity of receptors • Depth of contamination ☑ • Extensive or comingled plumes ☑ ☑

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Complex Sites: Characteristics – Tuba City B

Nontechnical Challenges	Examples
Site objectives ☑	• Societal expectations and social acceptability ☑ • Changing site objectives ☑ • Adopting site objectives that differ from promulgated screening levels or closure criteria (such as MCLs) ☑
Managing changes that may occur over long time frames ☑	• Phased remediation ☑ • Future use ☑ • Site management • Multiple responsible parties • Staff turnover/Loss of institutional knowledge • Litigation
Overlapping regulatory responsibilities ☑	• Federal and state cooperation ☑ • Changing laws and regulation ☑ • Financial responsibility • Orphan sites • Contaminants without regulatory criteria or guidance (such as emerging contaminants)
ICs ☑	• Tracking and managing ICs • IC enforcement • Long-term management of institutional controls ☑
Changes in land use ☑	• Changing land use or water use • Multiple owners • Site access ☑
Funding ☑	• Lack of funding (state, federal, or private industry) • Politics that alter funding/program priorities ☑ • Unwilling or unknown RPs

☑ In addition to the nontechnical challenges listed, accounting for stakeholder perspectives is a significant challenge at some sites. ☑

Risk Reduction Strategy

- LM Site Risk Ranking Index
  - Human Health
  - Stakeholder Concerns
  - Regulatory Compliance
  - Institutional Controls (ICs)
  - Site complexities impacting remediation
- Tuba City scored as high risk for all factors, and ranked as the second highest risk site in LM's portfolio (over 100 sites nationwide)
- Address risk through collaboration with NNLEMS and stakeholders
- Develop actionable recommendations

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Risk Reduction Strategy

- Risk Reduction Framework
  - What are we doing
    - to effectively reduce risk, that we should continue?
    - that is not effectively reducing risk, that we should stop?
  - What are we not doing
    - that has potential to reduce risk, that we should start?
- Risk Reduction Recommendations Criteria
  - Actionable in the next 1 to 5 years
  - Consensus-driven
  - Directly address one or more of the four risk ranking factors
  - Include mature technologies, which are matched to site conditions
  - Reduce uncertainties (site characterization recommendations)
  - Promote long-term stability and attainment of the end state (remedies)

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Collaboration Process

- Tuba City Collaboration Working Group
  - LM, NLN, LM Support (LMS) Contractor
  - Navajo and Hopi agencies
  - US NRC
  - Local community leaders, Navajo Nation Council Delegate
- Subgroups
  - End State / Stakeholders / Institutional Controls
  - Site (hydrogeological) and Contaminant Source Characterization
  - Hydrologic Boundary Conditions and Remedy Evaluation
- The working group and subgroups focused on actions and technologies to preserve the quality and quantity of groundwater in the Navajo Aquifer – a "portfolio" approach

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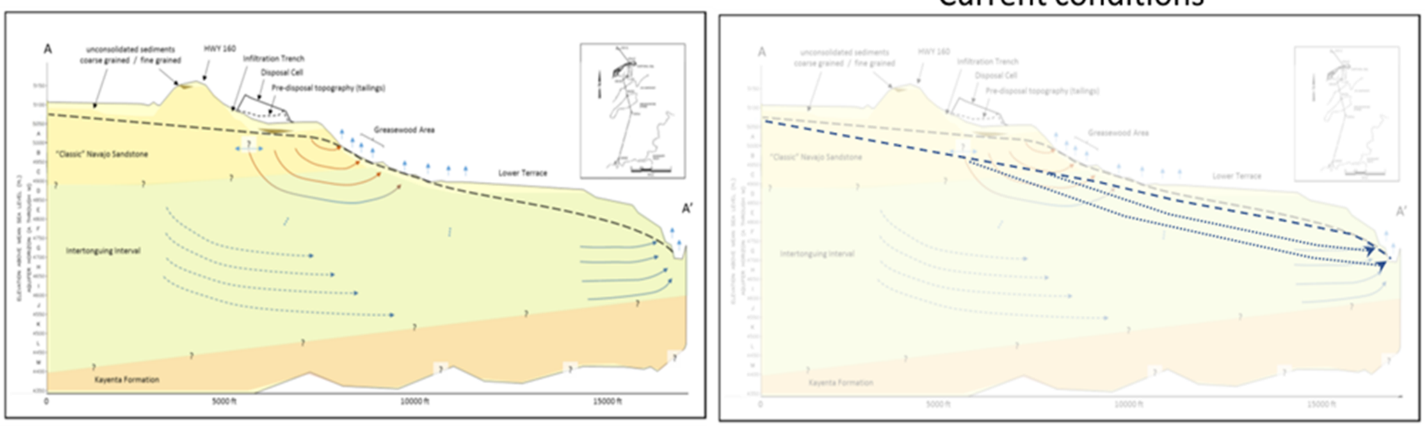
Summary of some key attributes Tuba City

- Overlies extensive Navajo “N” Aquifer and groundwater movement toward Moenkopi Wash
- During mill operations, groundwater beneath the site mounded and water levels may have been higher beneath the site (middle terrace) and in the nearfield area of the lower terrace

During mill operation

Current conditions

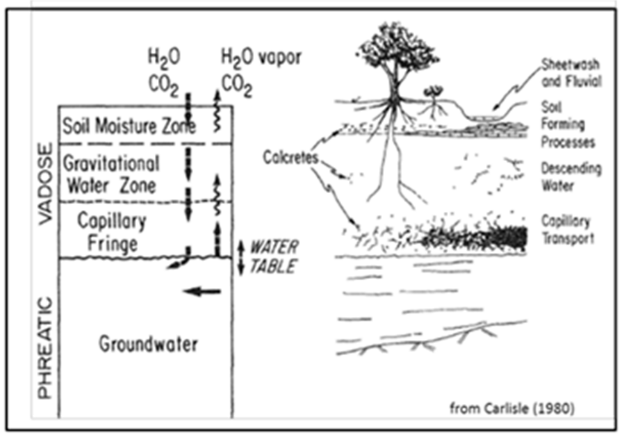


- Also ... many past detailed geochemical scoping models, plant/greenhouse studies, operating data from P&T, multispectral satellite imagery, ET studies, geological studies, technical reviews, high-resolution spectral gamma overflights…

Where do contaminants go?

Linkage of hydrological and geochemical framework…

a)



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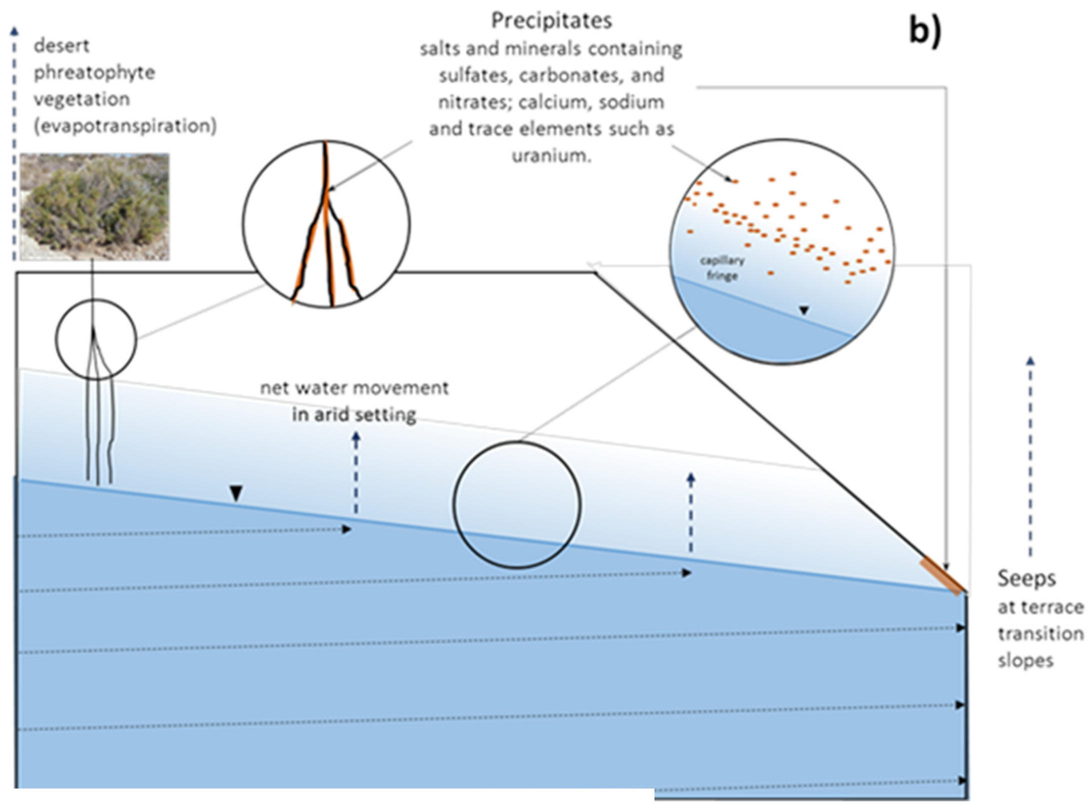

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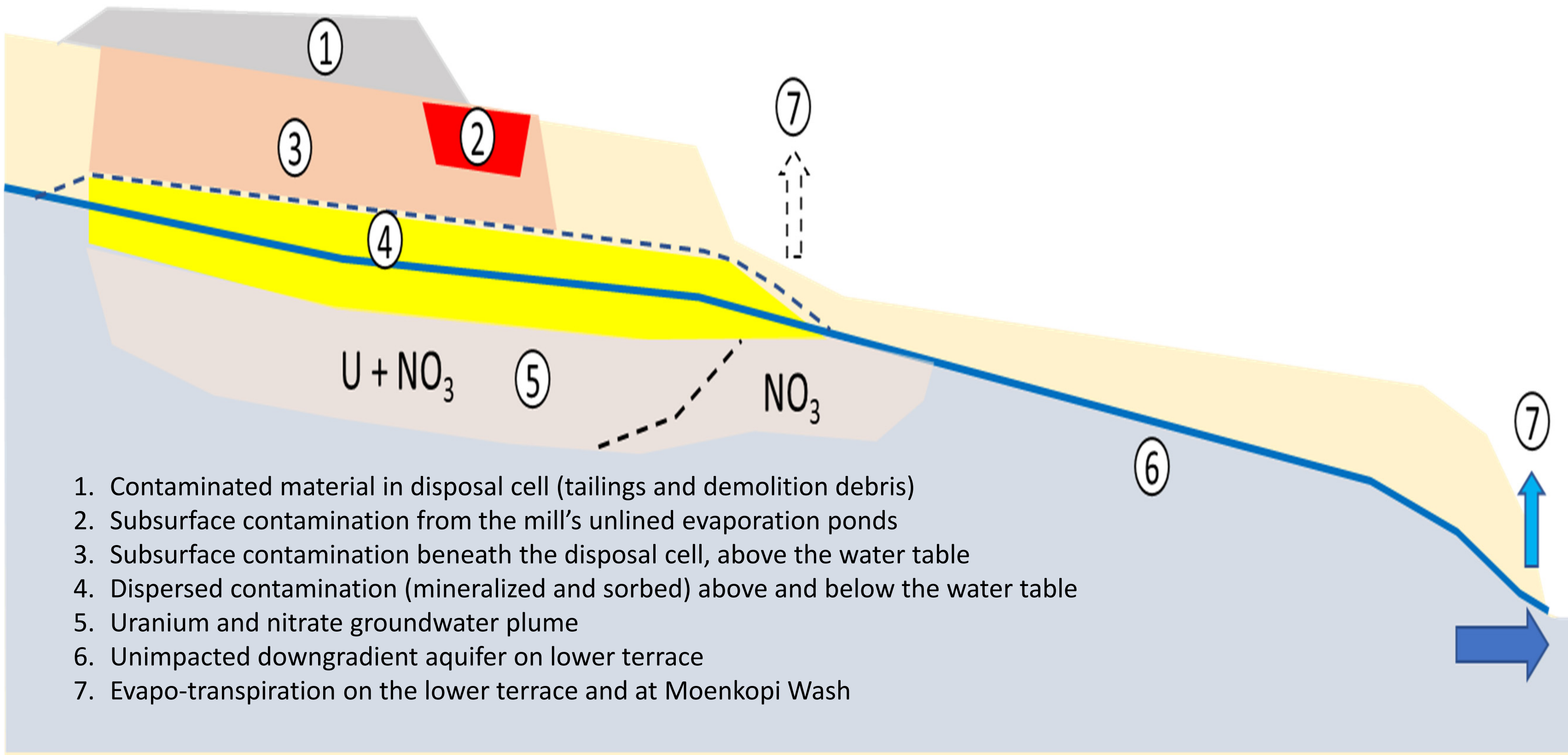
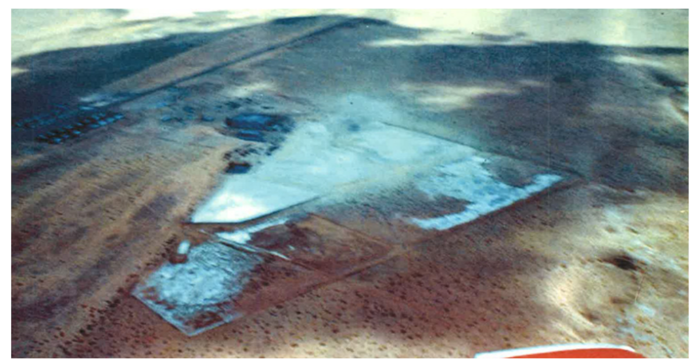
Site Specific Conceptual Model – Key to Remedy Evaluation

- Multiple source zones exist, and no standalone remedy will be as effective as a combination of remedies



Remedy Options for Protection of Groundwater Quantity and Quality (1)

- Pump-and-Treat to address the existing plume
  - Re-purpose downgradient injection wells as extraction wells
  - Lease/purchase mobile treatment system, return treated water to aquifer
- Surface infiltration barriers to address contaminant migration
  - Low permeability barrier over former mill pond area
  - Vegetated evapo-transpiration cover for the disposal cell
- Excavation
  - Remove soil contaminated by mill ponds



Remedy Options for Protection of Groundwater Quantity and Quality (2)

- Contaminant Source Isolation by Groundwater Bypass
  - Passively lower the water table, leaving the contaminated zones “high and dry”
- Contaminant Immobilization by In Situ Sequestration
  - Decrease uranium flux (from solid to dissolved form), through reactive barriers in the unsaturated subsurface and aquifer
- Contaminant (nitrate) Degradation by In Situ Reduction
  - Create a reducing environment in the high concentration area of the nitrate plume, cutting off plume migration through source control

Remedy Options for Protection of Groundwater Quantity and Quality (3)

- Contaminant Mobilization and Capture
  - In situ recovery (ISR mining) technique for contamination bound in the aquifer
  - Soil flushing for contamination bound in the unsaturated subsurface
- Natural Attenuation
  - Groundwater flow and contaminant transport modeling
  - Determine if natural attenuation mechanisms and capacity are sufficient
  - Control the plume, through combination of active and natural passive means
- Alternate Water Supply
  - Repurpose the coal slurry pipeline for delivery of potable water from Black Mesa to the Moenkopi Villages and Tuba City

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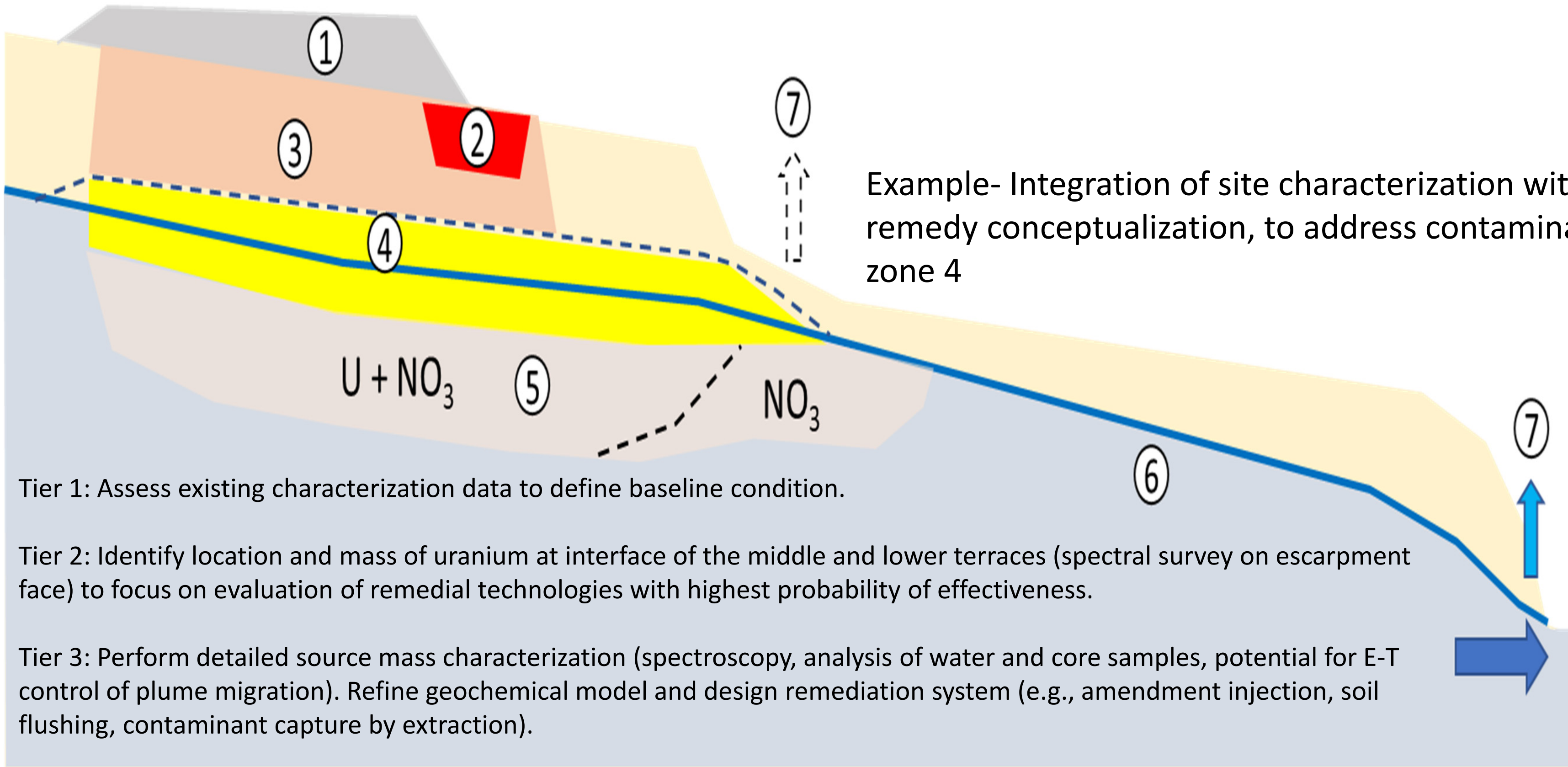
Site Characterization Synopsis

- Tiered Approach to Data Collection and Modeling (minimum but sufficient)



Example- Integration of site characterization with remedy conceptualization, to address contaminant zone 4

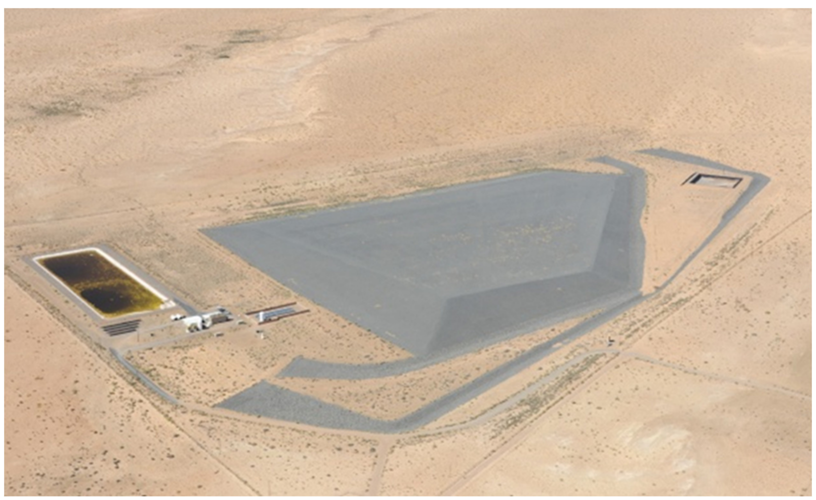
Tier 1: Assess existing characterization data to define baseline condition.

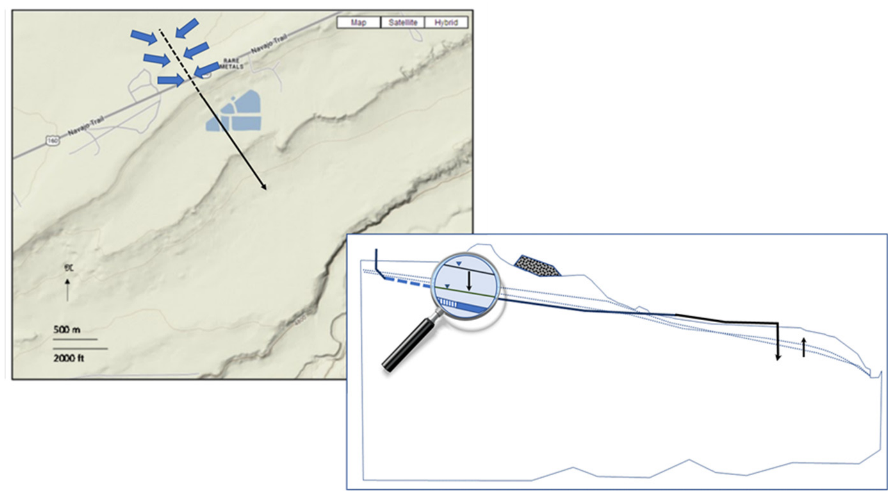
Tier 2: Identify location and mass of uranium at interface of the middle and lower terraces (spectral survey on escarpment face) to focus on evaluation of remedial technologies with highest probability of effectiveness.

Tier 3: Perform detailed source mass characterization (spectroscopy, analysis of water and core samples, potential for E-T control of plume migration). Refine geochemical model and design remediation system (e.g., amendment injection, soil flushing, contaminant capture by extraction).

Remedy Portfolios

- Portfolio Development
  - Provide a spectrum of alternatives, emphasizing synergistic groupings of recommended technologies
  - Address all contaminant zones
  - Identify decision points in the site characterization effort
  - Integrate remedial strategies with stakeholder interests
    - Prioritize contaminant removal before developing alternatives that leave contamination in place
    - Perform near-term actions that will limit contaminant migration, while characterization work is in progress and until the long-term remedy is implemented
    - Implement a long-term strategy that is sustainable and will preserve the intrinsic value of the aquifer





Example Remedy Portfolios

Short-term plume containment and source removal	Assumptions
P&T to provide plume containment while characterization, modeling and other remedial activities are being implemented	P&T for tens of years is acceptable and technically effective at halting migration of nitrate and uranium.
Source removal (excavation, vadose zone soil flushing, in situ recovery)	Source material is removable, easy to excavate and/or located in areas of good hydraulic conductivity.
Institutional controls to restrict drilling of domestic and/or agricultural supply wells in the area of the plume	ICs are acceptable, durable and enforceable.

Groundwater bypass and source immobilization	Assumptions
Plume containment (P&T) until new water table is established	P&T for tens of years is acceptable and technically effective at halting migration of nitrate and uranium.
Passively lower the water table to minimize contact with contaminants	Groundwater bypass flow (gravity) can be effectively established, and accounts for potential impacts to existing NTUA supply wells.
Aboveground/vadose zone source immobilization (ET cell cover, infiltration barrier, in situ reduction/sequestration)	Potential for recontamination must be controlled.
Aboveground/vadose zone source removal (excavation)	Potential for recontamination must be controlled.
Institutional controls to restrict well drilling until new water table level is established	ICs may not be needed, after groundwater is effectively isolated from contaminant source.

Conclusions

- Data gaps in site hydro-geochemical conditions, coupled with recognition of multiple contaminant source zones, led to development of remedy portfolios.
- Remedy conceptualization was integrated with site and source data collection recommendations and with stakeholders' preferred end state (protection of groundwater quality and quantity).
- Remedy portfolios can be refined (or modified or discarded) as characterization efforts progress.
- Development of the groundwater corrective action plan will follow NRC guidance for characterization, hazard assessment, remedial alternatives evaluation and engagement with stakeholders.
- The LM / National Lab Network collaboration laid a foundation to benefit future of groundwater remediation and stakeholder engagement at the Tuba City site.

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