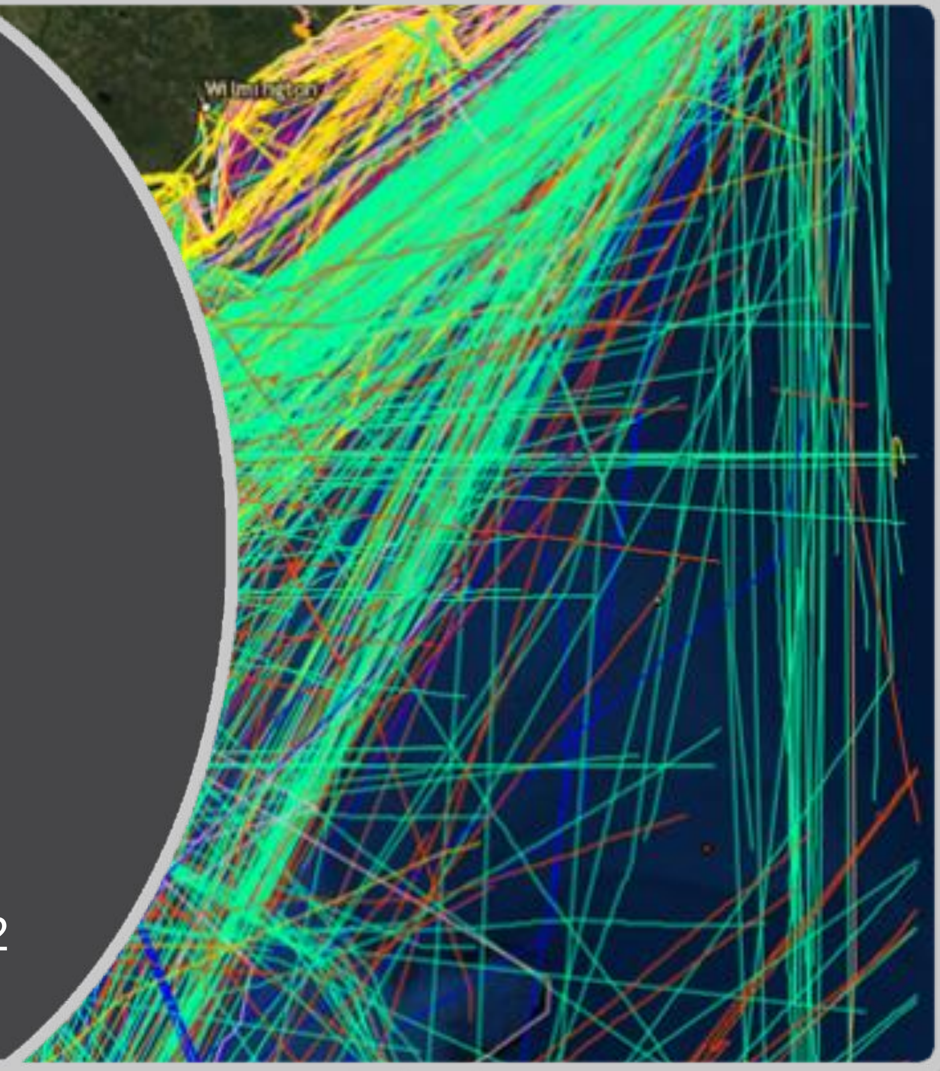
Risk Management Framework for Coal Combustion Residue Impoundments



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NETL FY22 FECM Spring R&D Project Review, May 2022

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U.S. ARMY

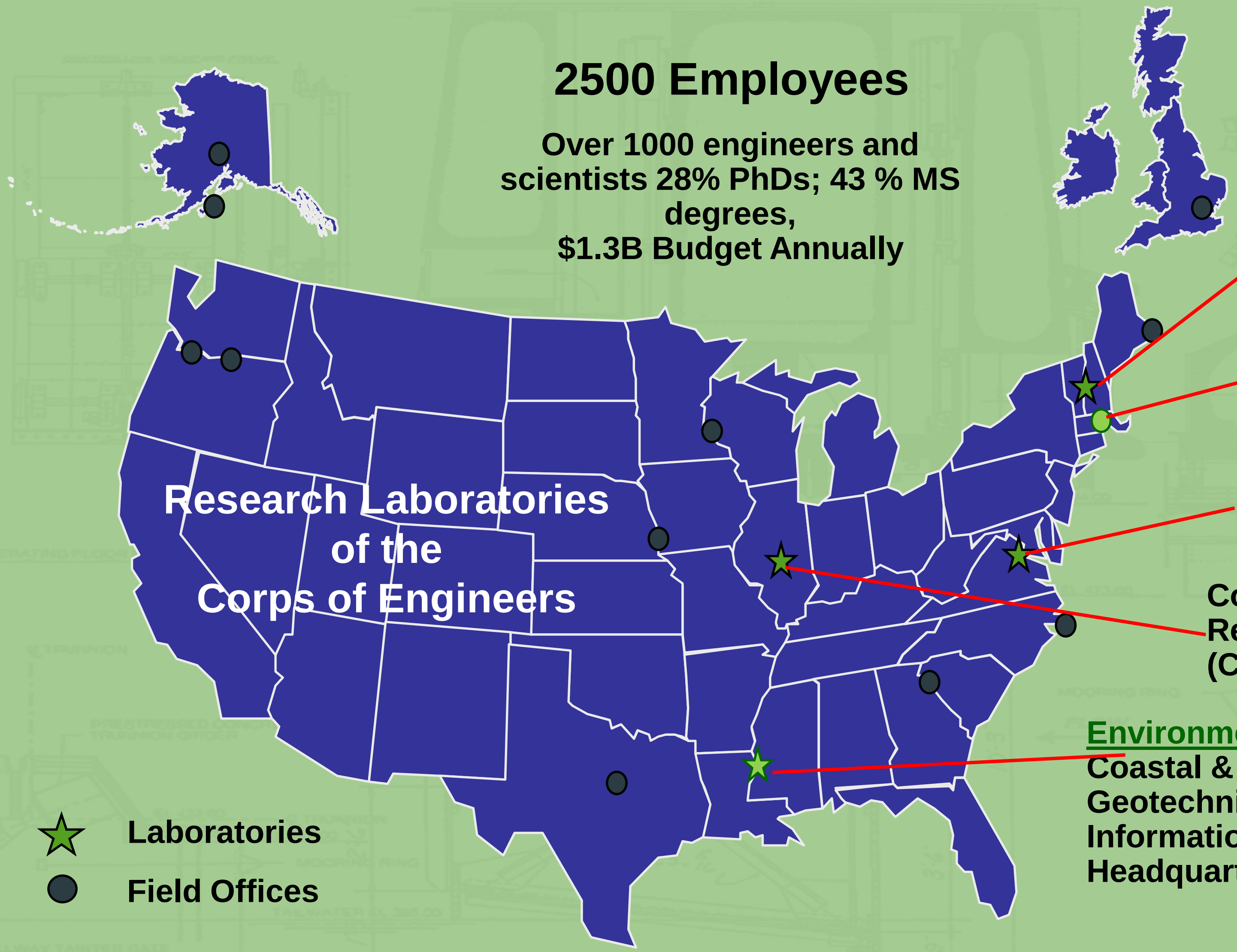
US Army Corps of Engineers

ERDC ENGINEER RESEARCH & DEVELOPMENT CENTER

US Army Engineer Research and Development Center

2500 Employees

Over 1000 engineers and scientists 28% PhDs; 43 % MS degrees,
$1.3B Budget Annually



Cold Regions Research Engineering Laboratory (Hanover, NH)

Risk and Decision Science Team Boston, MA)

Topographic Engineering Center (Alexandria, VA)

Construction Engineering Research Laboratory (Champaign, IL)

Environmental Laboratory
Coastal & Hydraulics Laboratory
Geotechnical & Structures Laboratory
Information Technology Laboratory
Headquarters (Vicksburg, MS)

★ Laboratories
● Field Offices

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Decision Science

- Systematic (repeatable) and transparent process for making a decision
- Includes risk analysis, cost-benefit analysis, resilience analysis
- Uses methods from operations research, e.g., optimization
- Reduce cognitive burden of decision making
- Best = alternative that has the most utility, as defined by the decision-makers
- Often include expert judgements

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CCR Impoundment Background

- There is A LOT of coal ash
  - 2nd most abundant waste material in the U.S. (ACS 2016)
  - 735+ active surface impoundments (NARUC 2020)
  - Approx. 1.5 billion (to 2 billion) tons of ash are “stockpiled” in the U.S. (ACS 2016)
  - The average size of impoundments is 50 acres, with a depth of 20 feet, some more than 5 million cubic yards (NARUC 2020)
- On-site surface impoundments containment is common but is not permanent disposal
  - Use time exceeds design life; many designed without modern engineering expertise; often adjacent to surface water bodies; EPA structural assessments have found many to be unsound (NARUC 2020)

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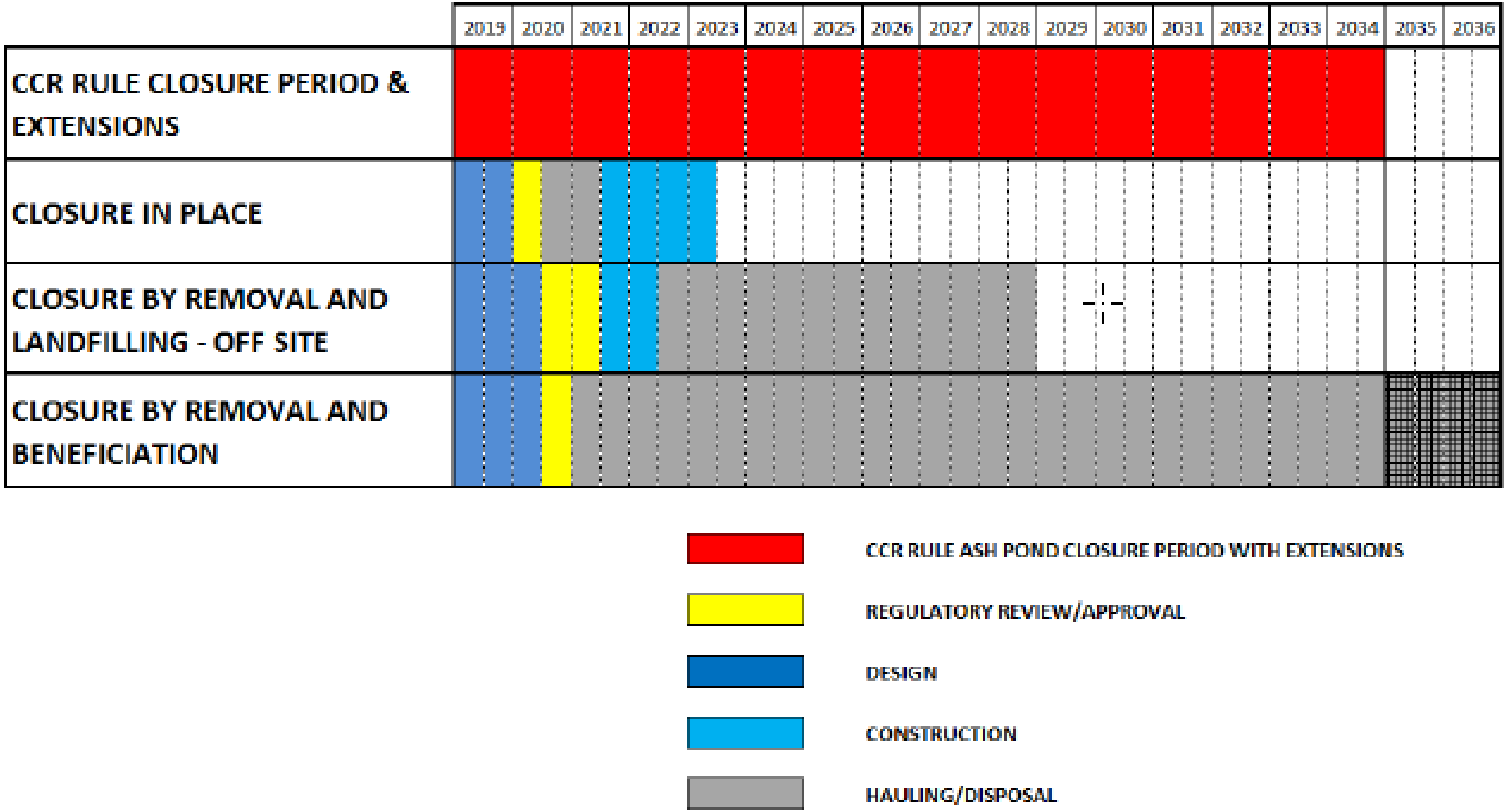
Alternative Options

Do Nothing/ Do Not Close

- **Vary by:**
  - **Risk**
  - **Cost**
  - **Benefit**

Quantify in order to guide alternative selection



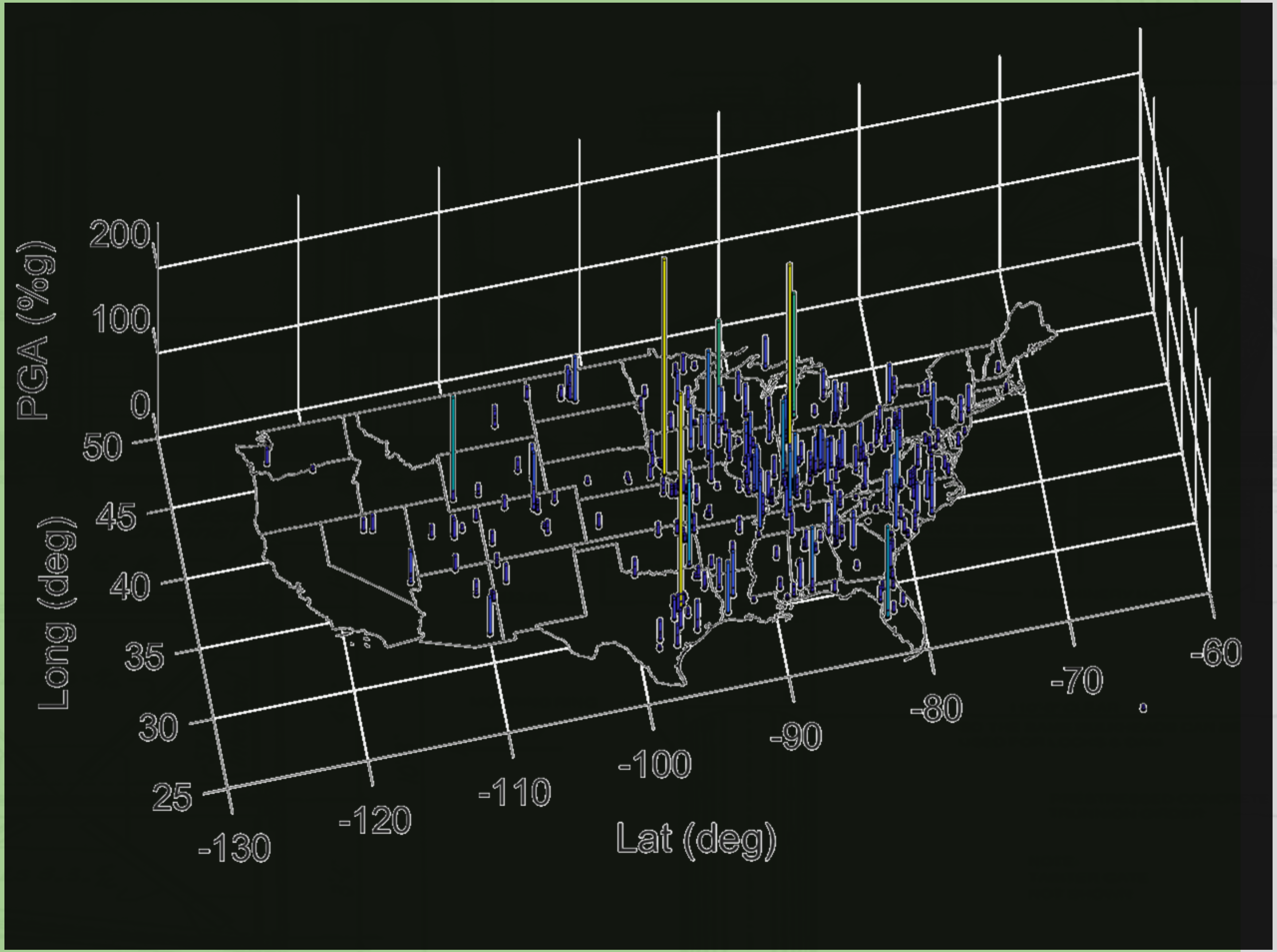
Kulasingam and Bove, 2018 Workshop on Current Issues in Ponded CCPs, Richmond, VA

Risk Management Framework for CCP Impoundments

Can we develop a framework to characterize how risks associated with CCP impoundments could change if we conduct by-product generation?

To answer questions such as:

1) Is it “worth” it to do by-product generation at a specific impoundment?
2) Which impoundments are most suitable for by-product generation?



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Risk Assessment of CCR Impoundments

Systematic process to comprehend the nature of risk (express and evaluate risk) with the available knowledge

Risk = hazard x exposure x effects
and/or
Risk = threat x vulnerability x consequences

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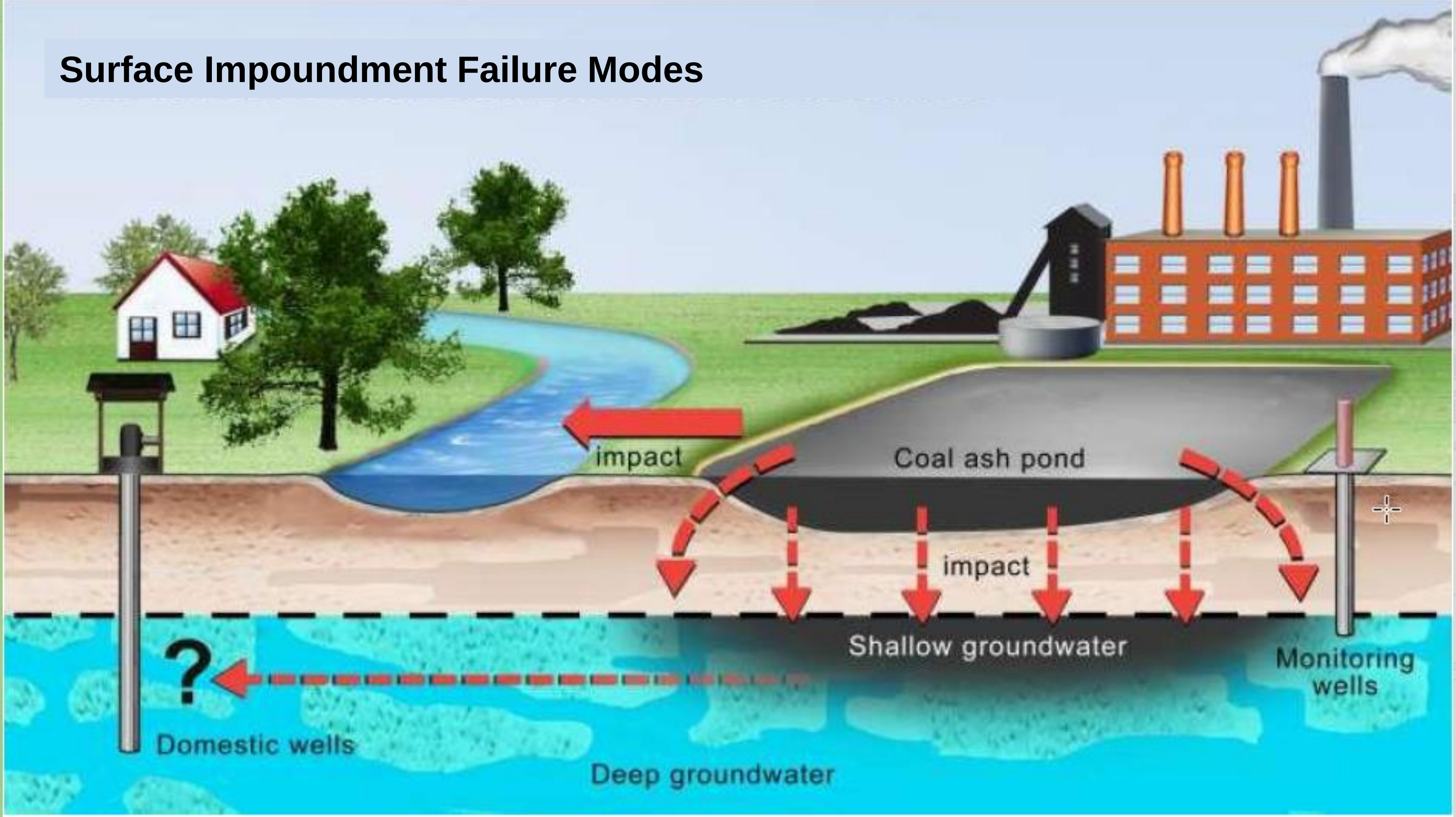
Base-Line Risk Posed by On-site Surface Impoundment due to Multiple Failure Modes

- Exposure to leached CCR constituents via seepage to ground and surface water through earthen containment
- Exposure to spilled CCR material via rapid release from impoundment failure

Surface Impoundment Failure Modes



Harkness, J.S., Sulkin, B. and Vengosh, A. (2016). **Evidence for Coal Ash Ponds Leaking in the Southeastern United States**
Environmental Science & Technology, 50 (12), 6583-6592 DOI: 10.1021/acs.est.6b01727
Via Phys.org

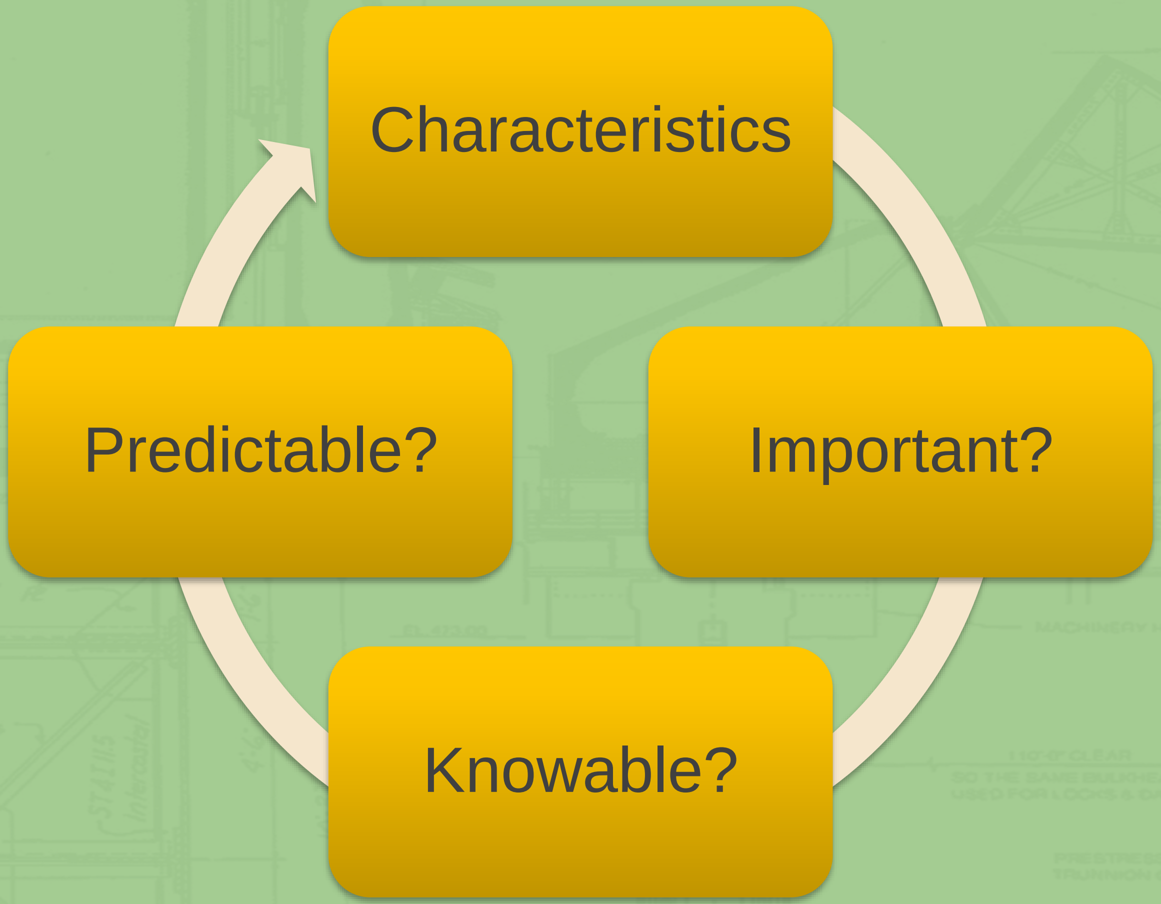
Identifying Indicators of Risk

Likelihood

- Historical incidents
- EPA assessment
- Engineering principles
- Laboratory testing
- Sampling/ Monitoring

Consequence

- Historical incidents
- EPA assessment
- Presence, sensitivity of receptors



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Potential Indicators of Risk

- Baseline Risk
  - Leach Probability
    - Age
    - Volume
    - Liner Status
    - Coal Combusted
    - Technology during active addition
  - Breach Probability
    - Safety Factors
    - Physical condition
    - Load return periods
  - Consequences
    - Surface water bodies
    - Habitats
    - Population Density
    - Disadvantaged Status

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Change in risk with respect to the baseline of each alternative

	Current Physical State	Current Chemical State	Δ Physical due to Management Alt	Δ Chemical due to Management Alt
Physical Failure (Acute Spill)	Does the physical state point to the risk of a physical failure?	Does the chemical state point to the risk of a physical failure?	Does alt. change things physically in a way that changes the risk of a physical failure?	Does alt. change things chemically in a way that changes the risk of a physical failure?
Chemical Failure (Chronic Leaching)	Does the physical state point to the risk of a chemical failure?	Does the chemical state point to the risk of a chemical failure?	Does alt. change things physically in a way that changes the risk of a chemical failure?	Does alt. change things chemically in a way that changes the risk of a chemical failure?

Survey Methodology

- 6 detailed CCR impoundment case studies
  - Representative of range of characteristics
- Survey questions to elicit expert judgement on
  - Which characteristics are most indicative of risk
  - Best management options
  - Information gaps
- Web-based roll out on EDX

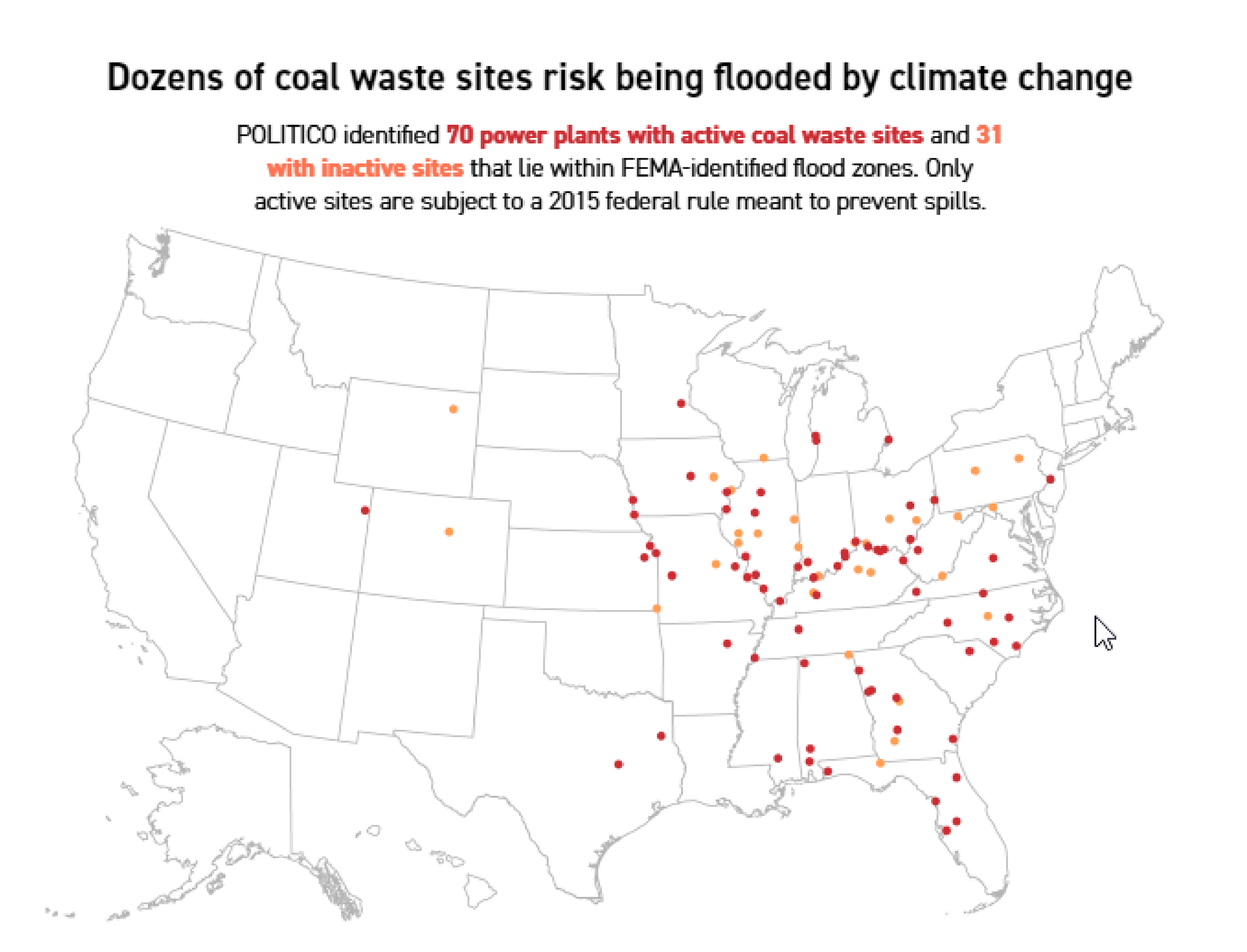

Figure from: https://www.politico.com/story/2019/08/26/toxic-waste-climate-change-worse-1672998

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Case Studies

Groundwater samples from Environmental Integrity Project

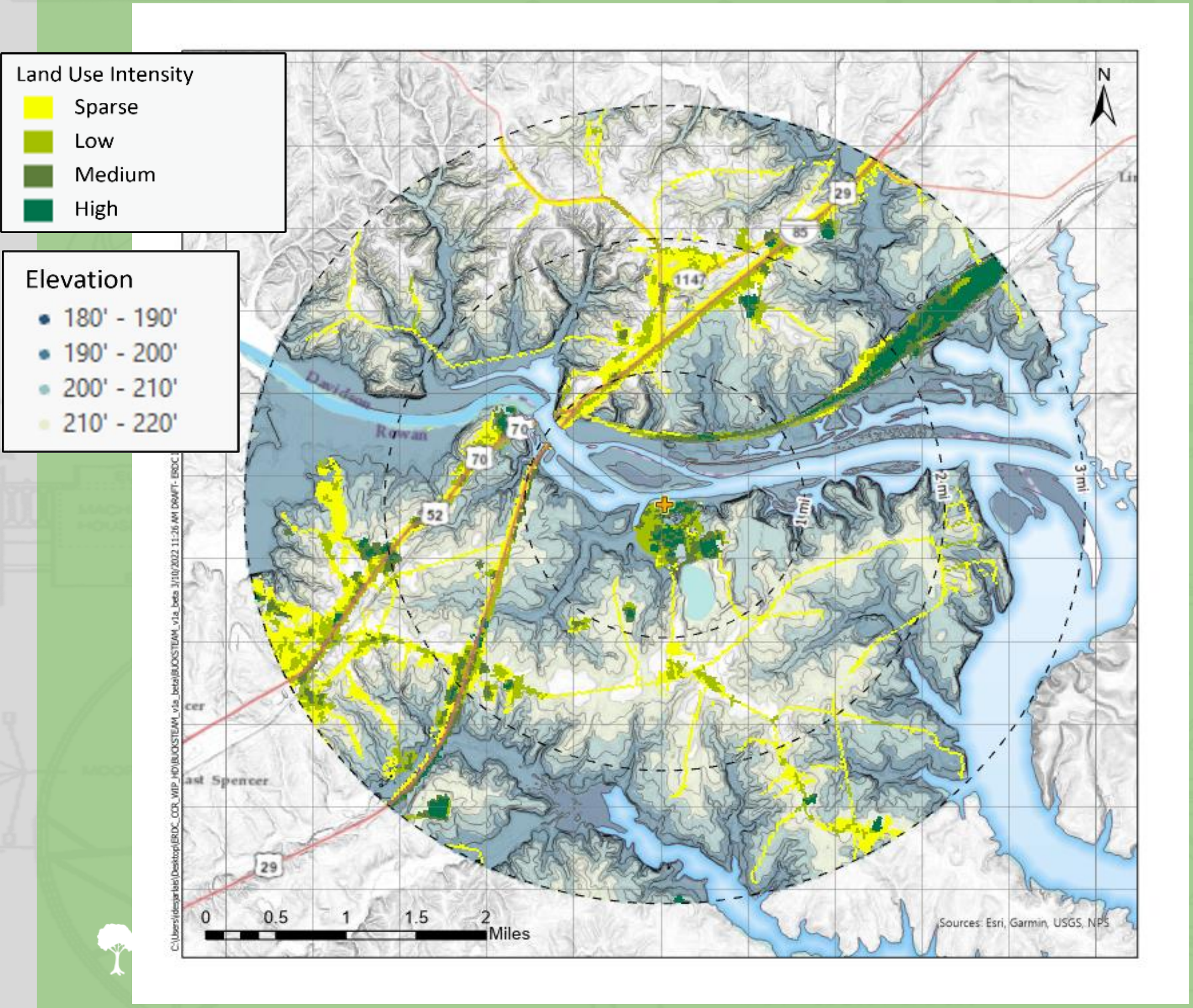
Groundwater Pollutant	Ratio of Observed Concentration to Safe Concentration
Antimony	<1
Arsenic	<1
Barium	<1
Beryllium	<1
Boron	<1
Cadmium	<1
Chromium	<1
Cobalt	12
Fluoride	<1
Lead	<1
Lithium	9
Mercury	<1
Molybdenum	1
Radium	<1
Selenium	<1
Sulfate	1
Thallium	<1

Structural Inspection required by EPA

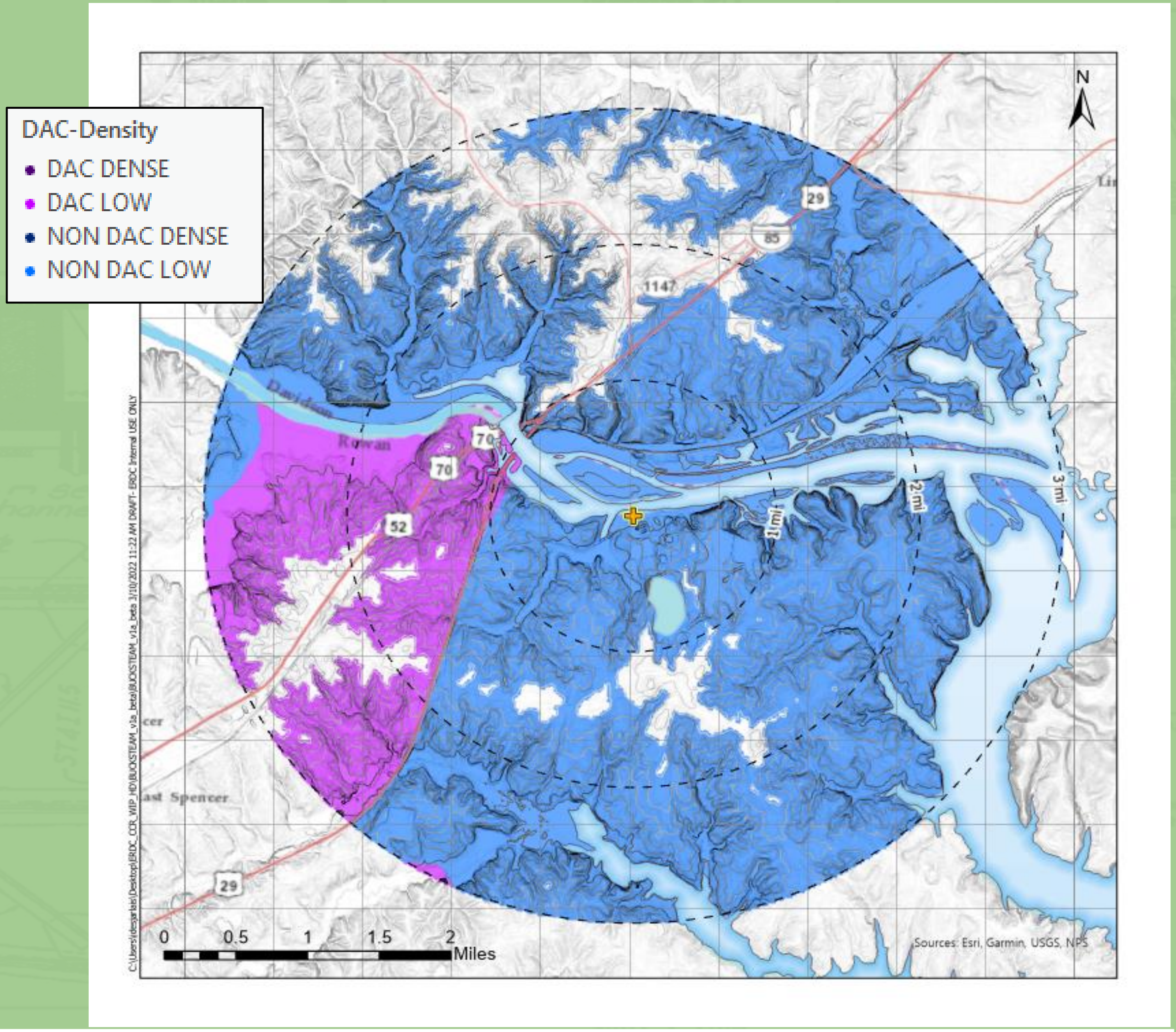
Category	Risk Factor	Unit	Basin 1
Physical Condition of Pond Embankment	Does embankment foundation condition comply with EPA?	Y/N	Y
	Does slope protection/vegetation condition comply with EPA?	Y/N	Y
	Does dike compaction condition comply with EPA?	Y/N	Y
	Does spillways condition comply with EPA?	Y/N	Y
	Does hydraulic structures condition comply with EPA?	Y/N	Y
	Does inundation due to water body comply with EPA?	Y/N	Y
Safety Factors against EPA Compliance Loads	Long-term maximum storage pool safety factor for critical cross-section*	SF/SF_{min}*	1.97/1.5
	Maximum surcharge pool safety factor for critical cross-section*	SF/SF_{min}*	1.91/1.4
	Seismic loading safety factor for critical cross-section*	SF/SF_{min}*	1.50/1.0
	Liquefaction loading safety factor for critical cross-section*	SF/SF_{min}*	NA**
EPA Compliance Load return periods	Long-term maximum storage pool exceedance return period*	years	100
	Maximum surcharge pool exceedance return period*	years	100
	Seismic loading exceedance return period*	years	2,500
	Liquefaction loading exceedance return period*	years	2,500

Case Studies

Surrounding land use and elevation relative to impoundment



Population density and disadvantaged community (DAC) status surrounding the impoundment



Survey Items

A. General CCR Impoundment Characteristics

1. Age of the impoundment
2. Volume of CCR in the impoundment
3. Liner status (lined or unlined)
4. Observed concentrations of CCR in groundwater

B. Safety Factor Ratios

1. status of compliance with EPA minimum embankment condition in your recommendation?
2. safety factor ratio for the long-term minimum storage pool loading condition
3. safety factor ratio for the maximum surcharge pool loading condition
4. safety factor ratio for the seismic loading condition
5. safety factor ratio for the liquefaction loading condition

C. Return periods

1. Return period for the long-term minimum storage pool loading condition
2. return period for the maximum surcharge pool loading condition
3. return period for the seismic loading condition
4. return period for the liquefaction loading condition

D. Surrounding Environment and Land Use

1. Surrounding topography
2. Surrounding land use intensity
3. Proximity to surface water bodies
4. Potential risk to the environment
5. Demographic composition of nearby populations

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Overall expert recommendation

Management Option Assessment

Given your review of the [add name of case study site], which management option do you recommend?

- Maintain current status
- CCR Removal
- Cap in Place
- Other (propose a management approach not listed above):

Assesses level of agreement among sampled experts

General CCR Impoundment Management

1. Any of the management alternatives are inherently better than others?
2. Should current regulations be adjusted for considering potential human health and environmental risks posed by CCR impoundments?
3. Any information not provided in the cases that you feel should be included to improve recommendations for CCR impoundment management?
4. Do you foresee different or elevated risks associated with beneficial re-use of CCR as compared to closure-by-removal?

Provides qualitative data for discussion and future evaluations

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Societal Risk Evaluation Scheme (SRES)

- *"What matters in expert judgments of CCR impoundments?"* and provides first-level data to serve as foundational criteria upon which future evaluations and decisions could be based. The criteria constitute categories and contain sub-criteria that are individually quantifiable.
- "*How much does each of these criteria matter?*" as some criteria may be more important than others and may hold distinct levels of importance as reported by top field experts.
- "*How confident are you in your judgment of each criteria?*" Such data allows researchers and decisionmakers to readily identify areas of information deficiencies where experts report higher levels of uncertainty in their evaluation– this signals opportunity for improving future research trajectories and informing data needs.
- "*How does each CCR impoundment score according to the criteria*?" Criteria scores are tracked, both in expert evaluations of the criteria themselves as well as expert levels of confidence in their response, to create comparative assessments.

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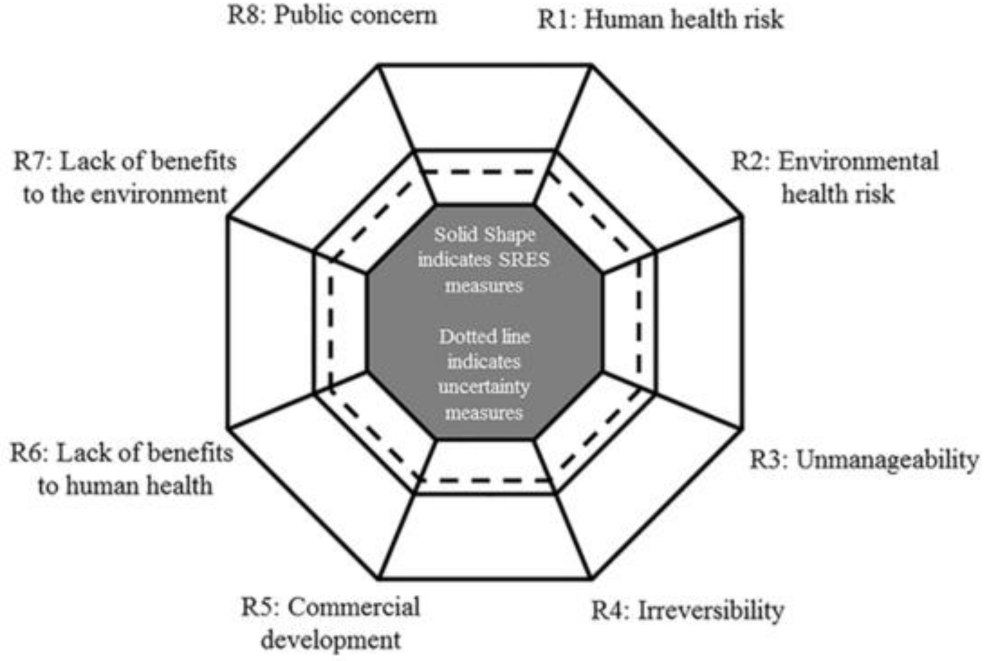
SRES output

- Aggregate mean scores of each criteria across the sample of stakeholder respondents are plotted onto circumradii to provide a single visual depiction of the risk footprint of each case.
- Each spoke of the circumradius corresponds to the SRES measures with the center point being equal to a score of zero.
- The shaded area represents experts' judgment of criteria, while the dotted line reports the level of confidence (expert uncertainty) as reported by the sample of stakeholders.
- This comparative evaluation of expert-derived criteria importance is a primary deliverable and outcome of the project

Fig 2. Example of SRES Octagonal Plot of Risk and Uncertainty



Cummings CL, Kuzma J (2017) Societal Risk Evaluation Scheme (SRES): Scenario-Based Multi-Criteria Evaluation of Synthetic Biology Applications. PLOS ONE 12(1): e0168564. https://doi.org/10.1371/journal.pone.0168564
https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0168564

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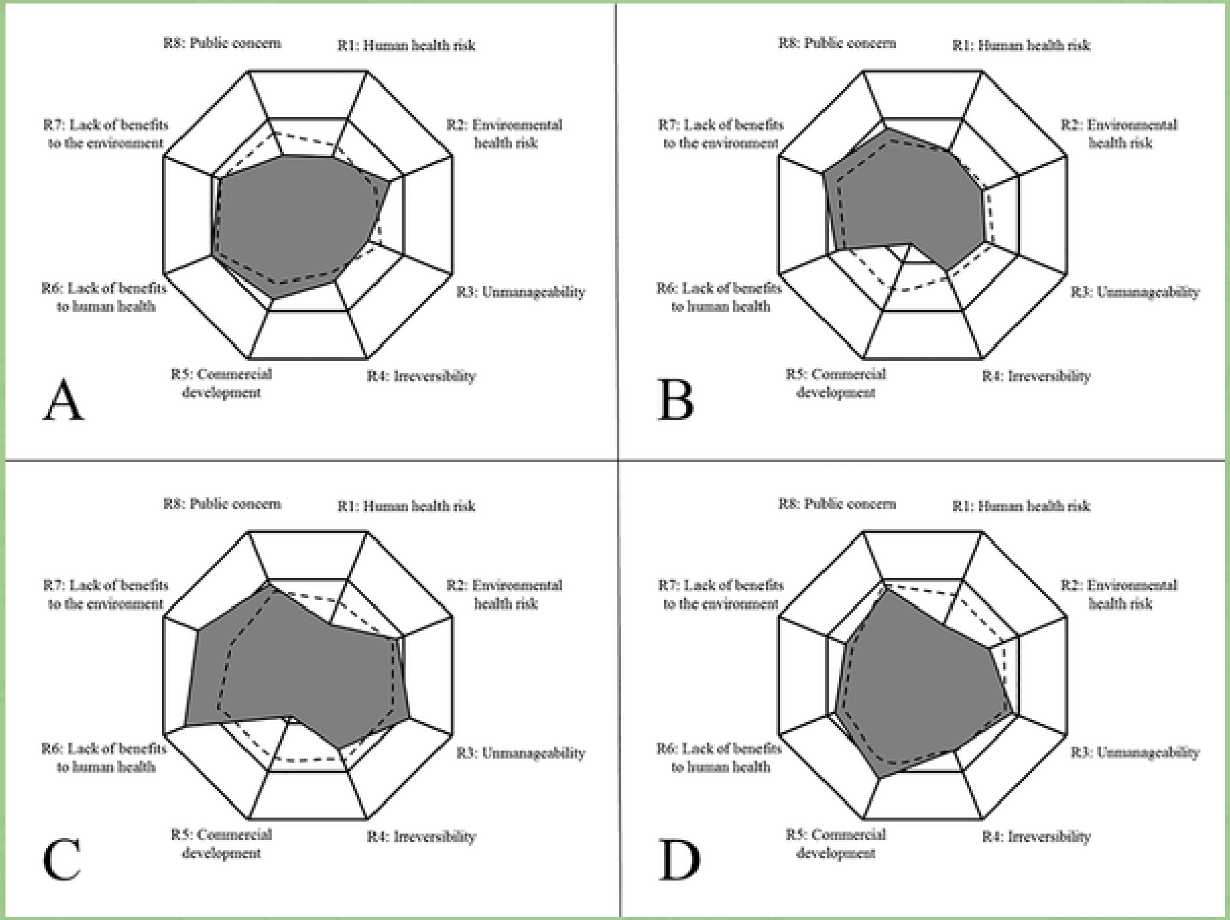
Comparative Evaluation

- When all values are plotted, they can be summarized for each CCR impoundment to provide comparative models which provide holistic and granular points of comparison of expert judgment and uncertainty.

- These expert-derived risk comparisons are another deliverable and outcome of the project.



Cummings CL, Kuzma J (2017) Societal Risk Evaluation Scheme (SRES): Scenario-Based Multi-Criteria Evaluation of Synthetic Biology Applications. PLOS ONE 12(1): e0168564. https://doi.org/10.1371/journal.pone.0168564
https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0168564

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Questions and Comments are Very Welcome!

Follow up:

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Extra Slides

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Table ES.1 GLMRIS Evaluation Criteria Summary

GLMRIS Alternatives	GLMRIS Alternatives Evaluation Criteria†											
			Effects of GLMRIS Alternatives									
	Effectiveness at Preventing Interbasin Transfer (at time of implementation)	Implementation (years)	Negative CAWS Environmental Impacts	Negative Water Quality Impacts (CAWS)	Negative Water Quality Impacts (Lake Michigan)	Water Quality Mitigation Measures Cost[4]	FRM (net change in EEAD – an annual impact)	FRM Mitigation Measures Cost[4]	Commercial Cargo Cost Impacts (annual cost)	Non-Cargo Navigation Impacts	Complexity of Regulatory Compliance	Cost of the ANS Control and Mitigation Measures[4]	Nonstructural & OMRR&R Costs (annual)[4]
No New Federal Action – Sustained Activities	★	The No New Federal Action – Sustained Activities Alternative assumes that any currently funded ANS prevention actions are maintained to include the operation of the existing electric barrier in Romeoville, IL. All alternatives below are actions in addition to the No New Federal Action – Sustained Activities Alternative. For complete details on this alternative, please review Section 3.8.											
Nonstructural Control Technologies	★★	0	L	L	L	N/A	$0	N/A	Likely minimal[3]	L	L	$–[5]	$68 M
Mid-System Control Technologies without a Buffer Zone – Flow Bypass[2]	★★★	25	M	L	L	N/A	$1.1 M	$9,100 M	$0.75 M	L	M	$15,500 M	$210 M
Technology Alternative with a Buffer Zone[2]	★★★	10	H	L	L	$1,600 M	$0.6 M	$2,000 M	$0.50 M	M	M	$7,800 M	$220 M
Lakefront Hydrologic Separation[2]	★★★★	25	H	M	Improves[1]	$500 M	$66.0 M	$14,500 M	$210 M	H	H	$18,300 M	$160 M
Mid-System Hydrologic Separation[2]	★★★★	25	L	H	H	$12,900 M	$1.1 M	$24 M	$250 M	M	H	$15,500 M	$140 M
Hybrid – Mid-System Separation Cal-Sag Open[2]	★★★	25	H	M	M	$8,300 M	$28.1 M	$1,900 M	$7.30 M	M	H	$15,100 M	$180 M
Hybrid – Mid-System Separation CSSC Open[2]	★★★	25	M	H	M	$4,300 M	($26.4 M)	$145 M	$8.80 M	M	H	$8,300 M	$160 M

Decision Science for Risk Management

Traditional risk analysis is not possible for data-poor and emerging/ evolving risks.

CAMP Model
Simplified, Standardized Risk

Risk = Probability of failure (Engineering assessment) × Consequence of failure (Mission impact assessment)

Probability of failure — Engineering assessment	Consequence of failure — Mission impact assessment
Facilities condition index: From BUILDER Lifecycle projections, actual condition, and functionality assessment (safety, ADA, FSDCs, space/capacity, etc.)	**Built infrastructure:** MDI + MAJCOM mission impact **MDI**—Improved to represent a steady-state understanding of Commander's mission priorities in two ways: a. Fix inconsistent CatCode alignment b. Allow for case-by-case within CAMP process **MAJCOM mission impact**—To account for exceptional requirements and issues that aren't accurately captured by MDI. MAJCOM priorities will be weighted by PRV just as they were in the previous AFCAMP cycle.
Pavement condition index: From PAVER Condition, FOD potential, skid potential, and structural index	
Utilities condition index: Not SMS-based Remaining service life (from standard tables) and performance (documented breaks/outages)	
Natural infrastructure: From EQ programming guide Environmental/regulatory compliance	**Natural infrastructure:** From EQ programming guide Mission impact, risk on public health and/or the environment, and stakeholder concern

Air Force Comprehensive Asset Management Plan (AFCAMP)

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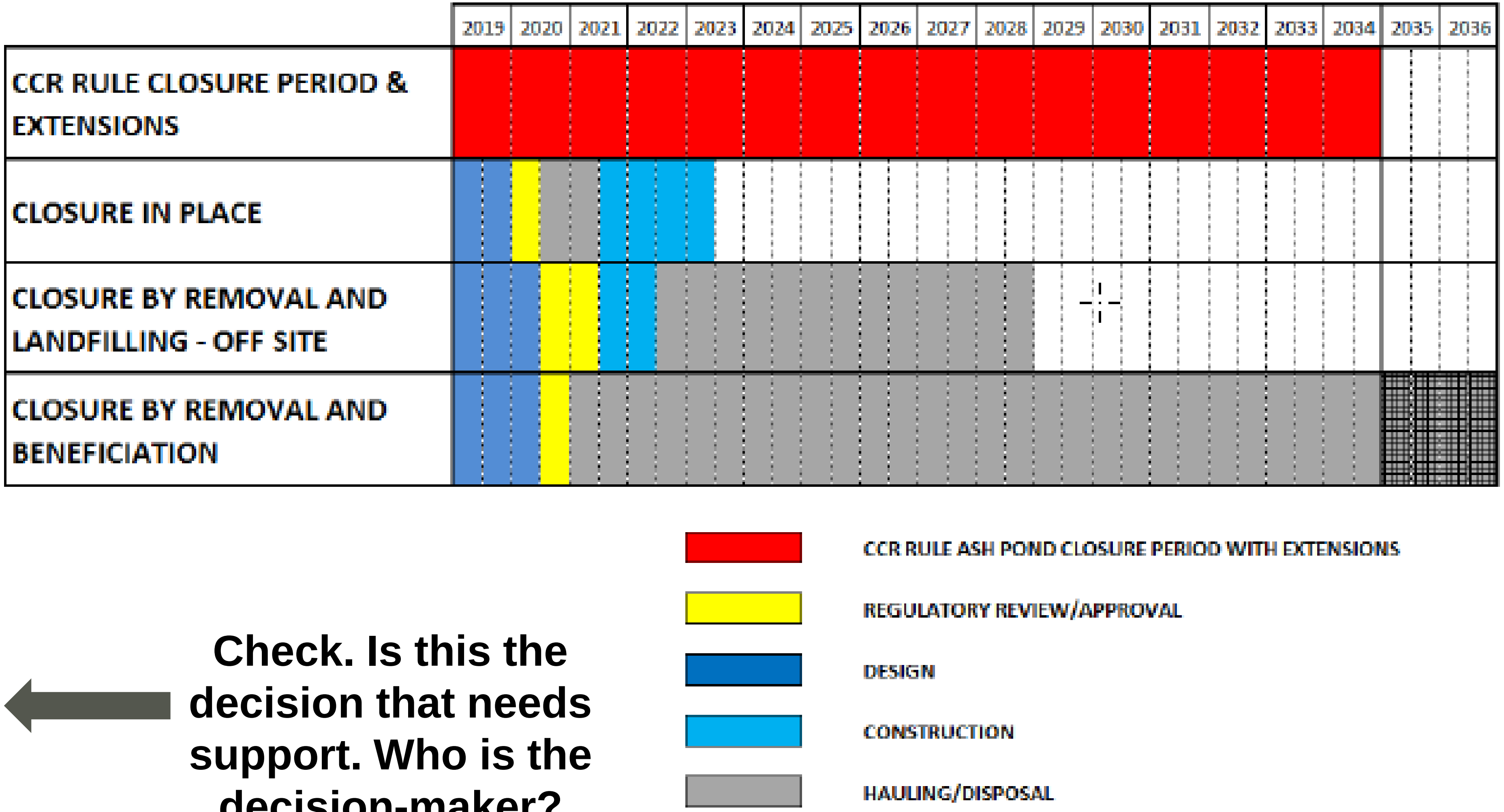
Alternative Options

Do Nothing/
Do Not Close

- Vary by:
  - Risk/ Cost
  - Benefit

- Quantify in order to guide alternative selection



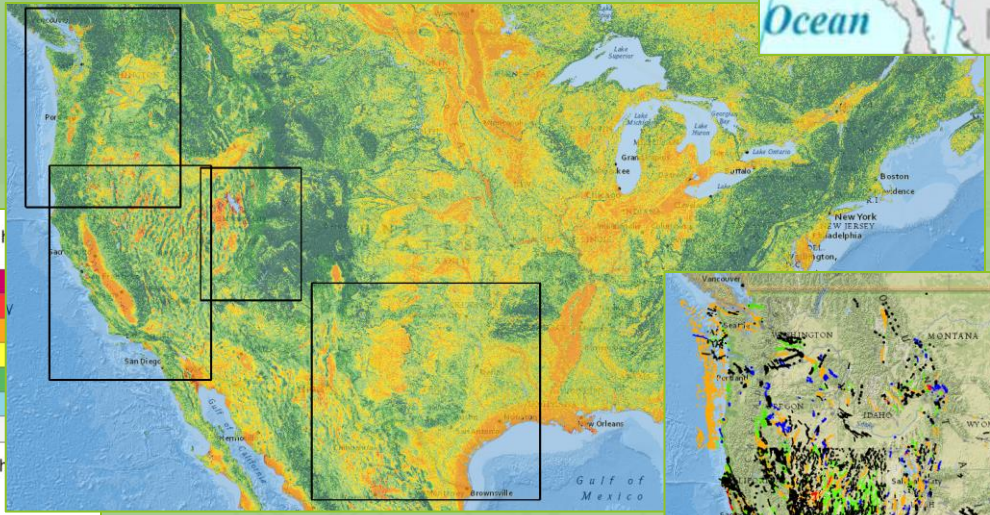
Check. Is this the decision that needs support. Who is the decision-maker?

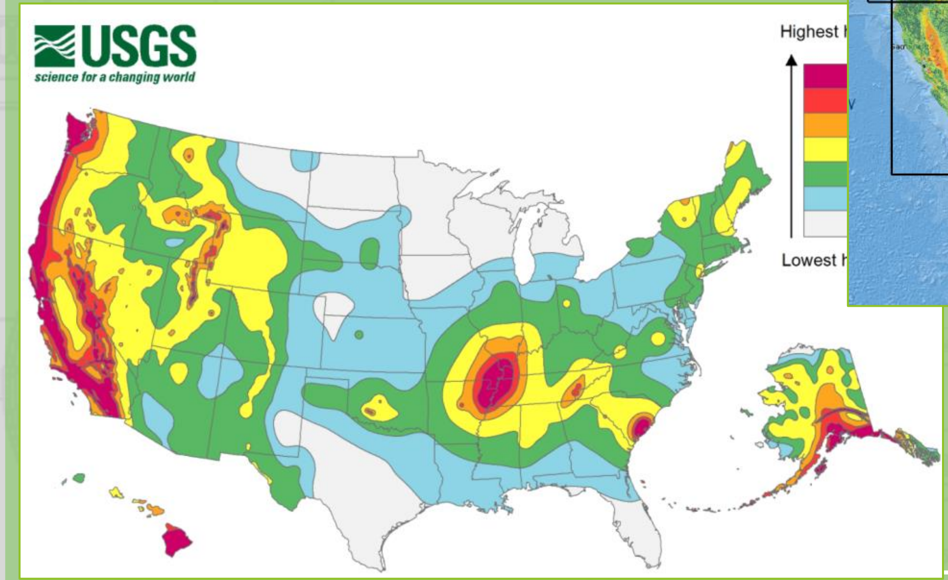
Kulasingam and Bove, 2018 Workshop on Current Issues in Ponded CCPs, Richmond, VA

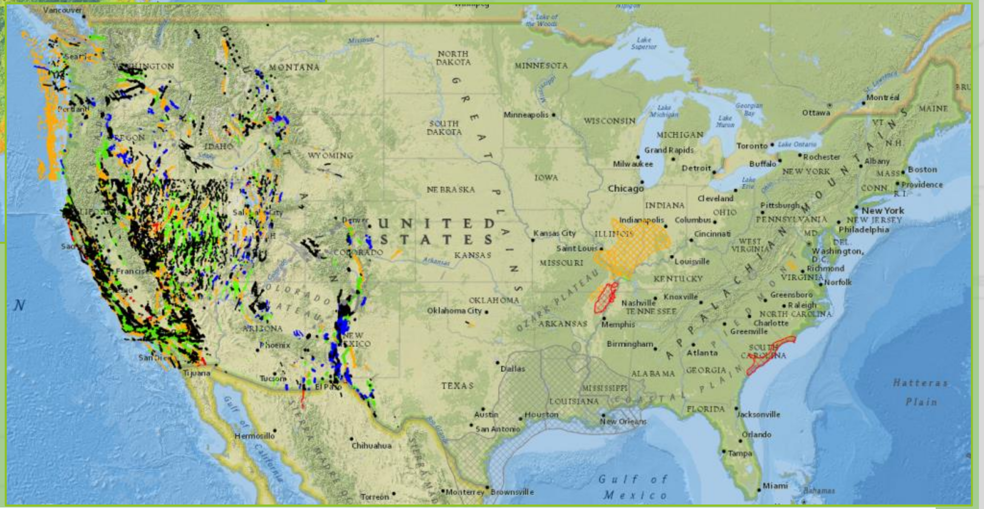
AECOM

Ex. Geographic-Dependent Risk Drivers

- USGS Seismic Hazard Maps (2018)[1]
- USGS V_{s30} maps based on topographic slope[2]
- USGS fault maps[3]
- FEMA flood plain maps[4][5]
- **Proximity to Receptors





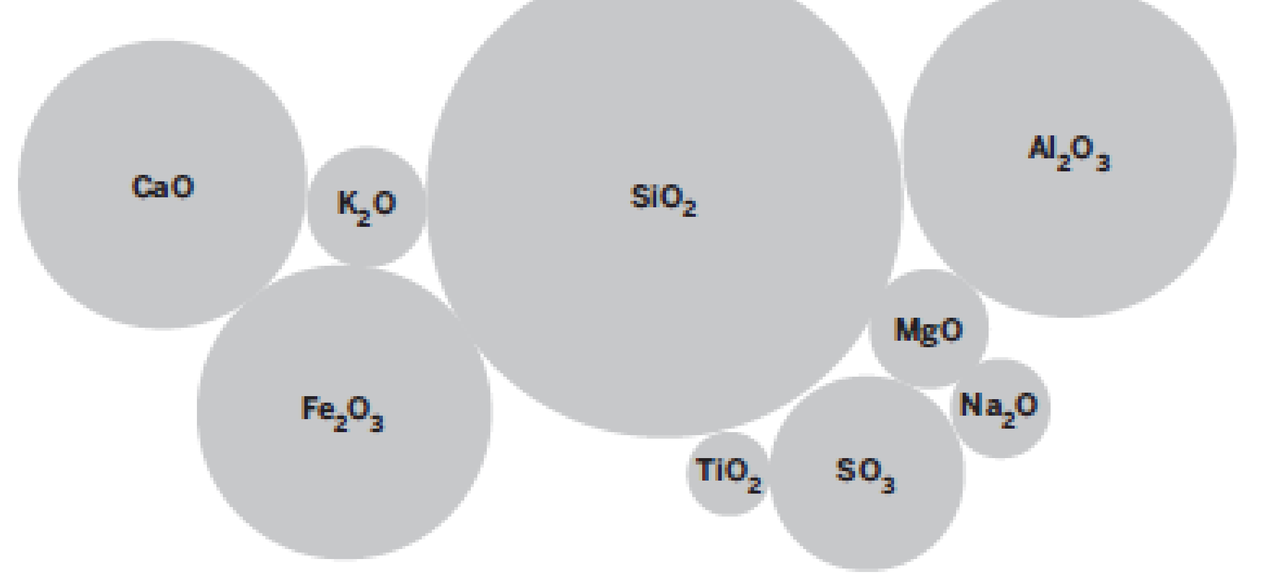


Map Sources in Notes

Indicators Development
Chemical Failure: Establish Baseline and Δ Constituents

- **Location criteria – Aquifer proximity, surface water body/wetland proximity**
  - **Seepage through the dam/dyke is another major route to both ground and surface waters (Santamarina et al. 2019; Schmitt USGS**
- **Site/Pond-specific details – Current use, history, liner status, GW flow, volume**
- **Origin of coal**
  - **Bituminous coal ash leach significantly more As and Se than sub-bituminous coal ash (Wang et al. 2009); sulfur content; pH**
- **Mixing, Redox Environment**
  - **Emory River/TVA ash clean up site as reference for leachability and/or analog for pond environment**

Fly ash relative composition



Trace elements[a]: Ba, Sr, B, Mn, Zn, V, Cr, As, Pb, Ni, Cu, Mo, Tl, Be, U, Se, Sb, Cd, Hg

NOTE: Circles represent mean concentrations for various fly ash samples, for example, SiO_2 = 215,000 mg/kg.
a In order of relative abundance. SOURCE: Electric Power Research Institute

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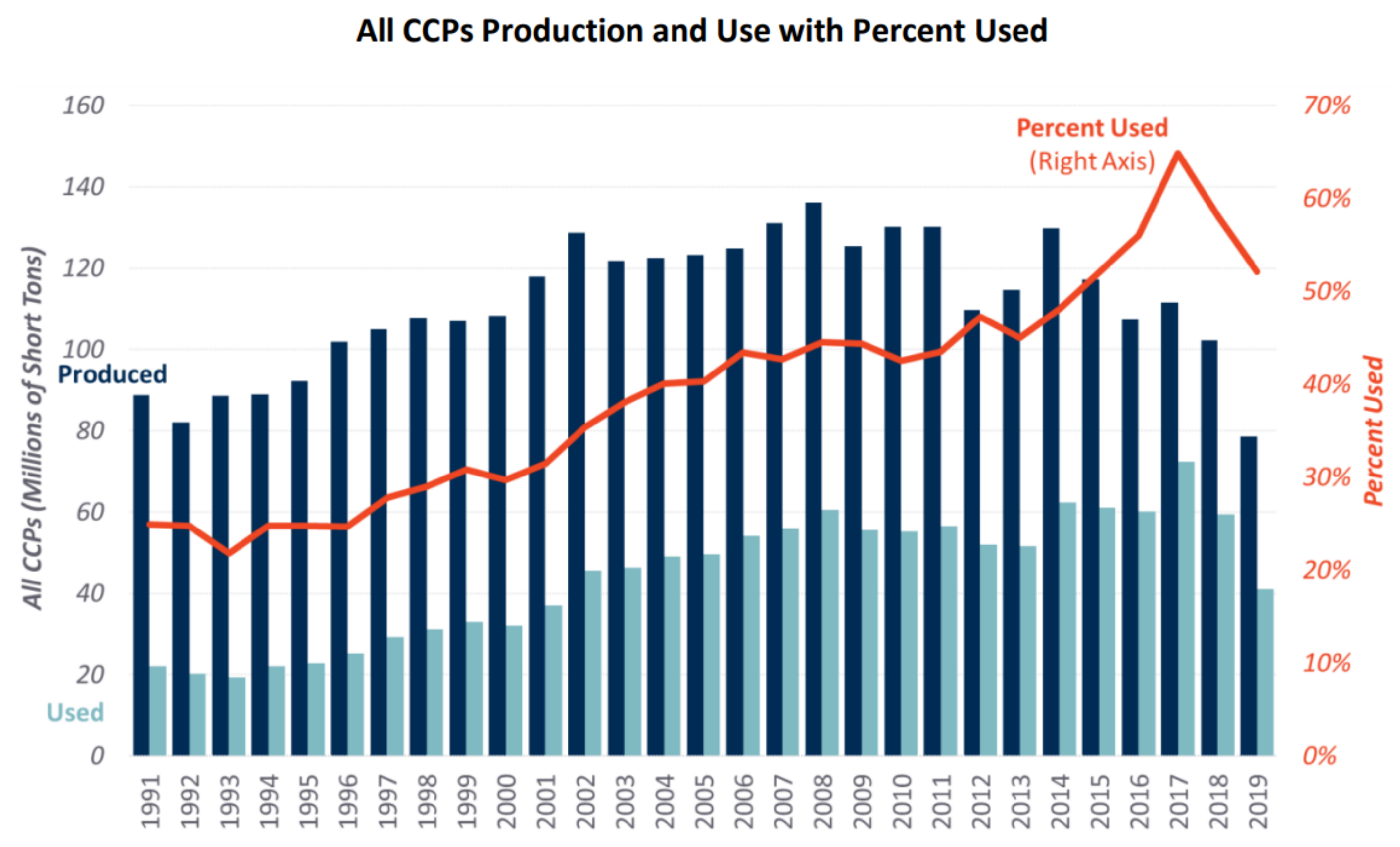
Context & Motivation

Supply and Demand Uncertainty

- Looming shortage of coal ash due to coal combustion phase-out?
- Approx. 1.5 billion (to 2 billion) tons of ash are “stockpiled” in the U.S. (ACS 2016)
- Surface impoundments currently receive more than 1/3 of CCR (NARUC 2020)

Derive Value from CCR already in impoundments/landfills

- Offset cost of regulatory compliance
- Growing interest in discovery of more valuable materials
- Changing liability



source: https://acaa-usa.org/wp-content/uploads/coal-combustion-products-use/2019-Charts.pdf

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Consequences of failure

- The EPA final rule on Coal Ash Impoundments rates the potential consequences of failure or mis-operation of an impoundment based on the Hazard Potential Rating

  – Derived from the rating system used for dams

  – Includes three possible ratings:

    - **High:** failure or mis-operation will probably cause **loss of human life**.
    - **Significant:** failure or mis-operation results in no probable loss of human life, but can cause **economic loss, environmental damage, disruption of lifeline facilities**, or impact other concerns.
    - **Low:** failure or mis-operation results in no probable loss of human life and low **economic and/or environmental losses**. Losses are principally limited to the surface impoundment owner's property.

Consequences of failure (cont.)

- **Based on this, the following metrics of consequences are defined for prioritized sites, along with some associated key factors:**
  - **Loss of human life**
    - Volume of CCR released
    - Proximity, relative location (i.e., downgrade or upgrade) and size of surrounding population
  - **Environmental damage**
    - Aquatic habitat damage
    - Aquatic wildlife displacement
  - **Disruption of Critical Facilities**
    - Location of schools, hospitals, or other critical infrastructures within five miles down gradient
  - **Economic Losses**
    - Economic damages to owner
    - Economic damages to surrounding community