2025 RemPlex Global Summit

A Long Way to Go: Envisioning PFAS Groundwater Remediation Across Thousands of Sites

November 2025

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How Should We Approach PFAS Site Cleanup?

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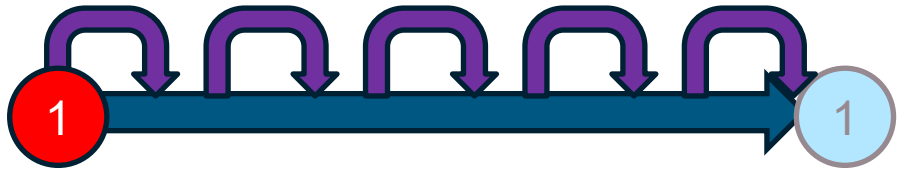
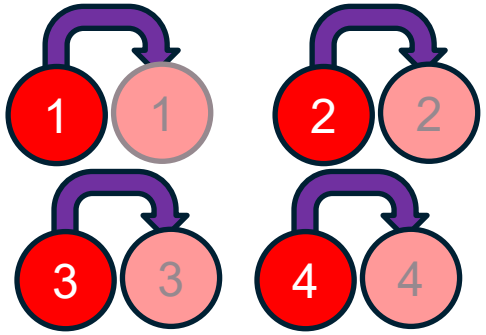
Three Prioritization Scenarios

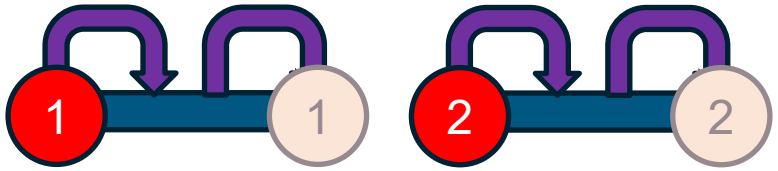
- *Intensive: Do it Right the First Time*



- *Efficient: Work Fast, Move on*



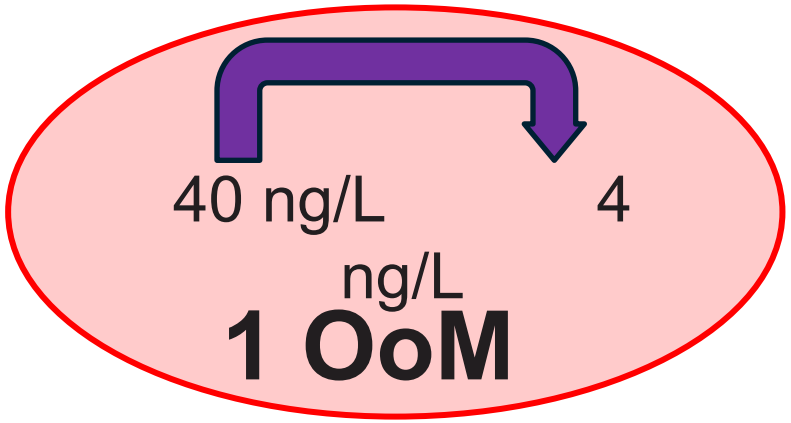
- *Standard: Middle of the Road*

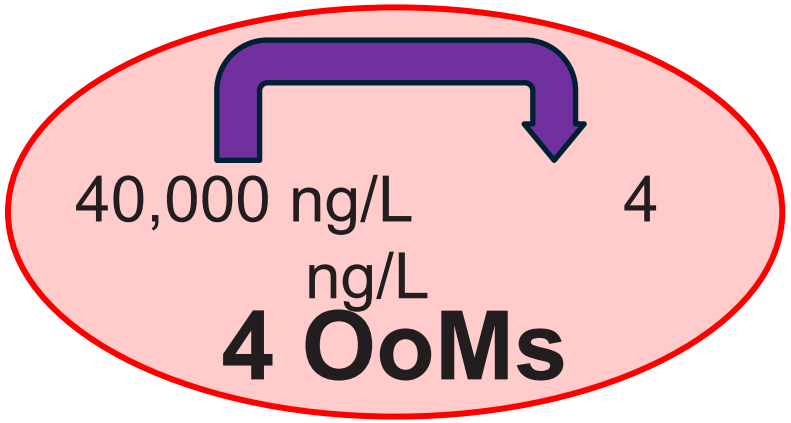


Can we forecast which Prioritization Scenario reduces risk the *most-est the fastest*?

Key Assumptions and Disclaimers

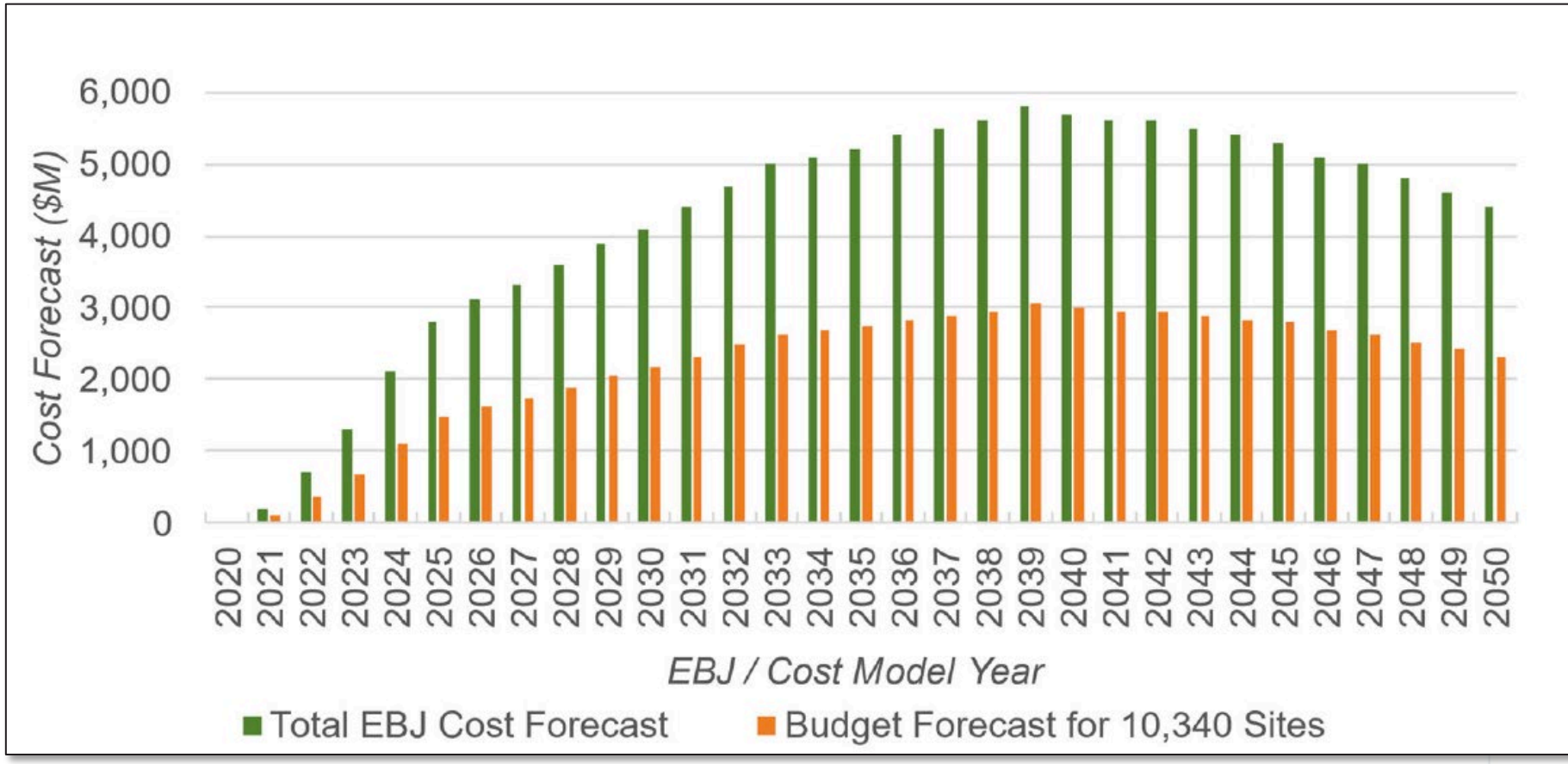
1. We use Environmental Business Journal's "*PFAS Working Model*":
   - $67 billion remediation spending over 30 years for ~10,000 key PFAS sites
2. Risk is proportional to concentration
3. Remediation cost & performance based on Order of Magnitude (OoMs)
4. Queue of 10,000 PFAS sites (modeled as 100 tranches)
5. But we can decide if we remediate efficiently vs. intensively*
6. **The forecasts you are about to see are likely going to be wrong….**





Environmental Business Journal "PFAS Working Model"

- ***~10,000 key PFAS remediation sites*** *(e.g., AFFF, manufacturing, superfund, refineries)*
- *Estimated remediation cost between* ***$1 and $95 million per site***
- *PFAS remediation spend for these sites:* ***$67 Billion over next 30 years***



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https://ebionline.org/environmental-business-journal-2/

Risk is Proportional to PFAS Concentration

- **Navy 26 AFFF Sites Plume-a-thon Study (Kulkarni et al., 2025)**

Maximum PFOS Concentration in Plume & OoMs	*(ng/L)*	*OoMs**
Minimum	76	1.3
25th Percentile	2,000	2.7
Median	**17,800**	**3.6**
75th Percentile	80,000	4.3
Maximum	3,700,000	6.0

*OoMs to get to 4 ng/L

Order-of-Magnitude Framework for Remediation

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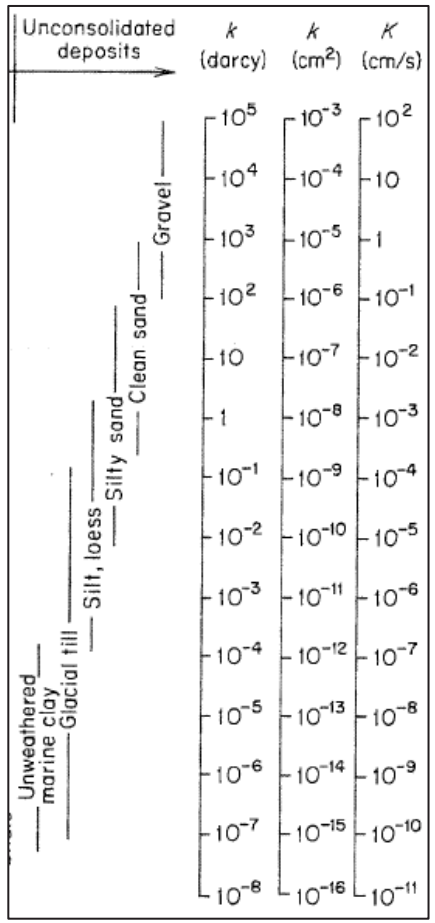
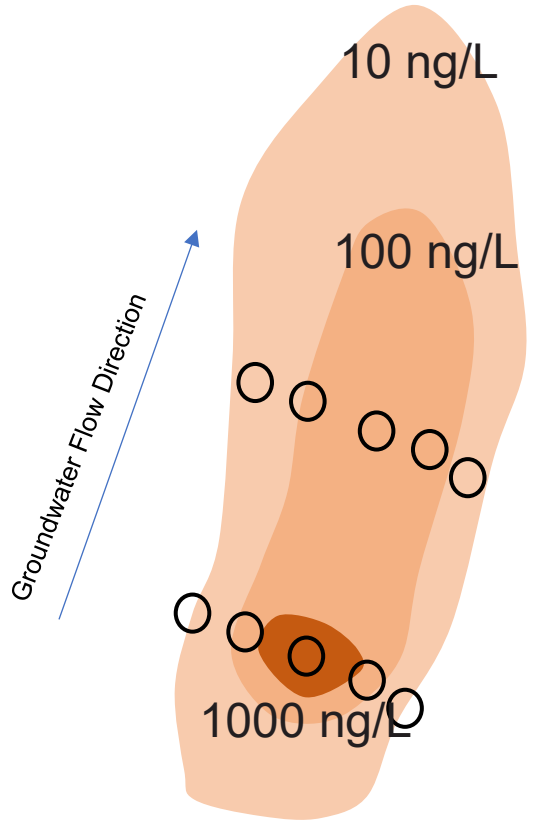
Remediation people live in an OoM world



Freeze and Cherry, 1979



PFAS Plume Map

This Forecast:

Remediation performance goes up by an order of magnitude for each remediation level

This Remediation Level…	Reduces PFAS Concentrations by This Many OoMs
Efficient	1 OoM (90%)
Standard	2 OoMs (99%)
Intensive	3 OoMs (99.9%)

EFFICIENT:

- *Contain to 1000 ng/L contour*
- *No source removal*

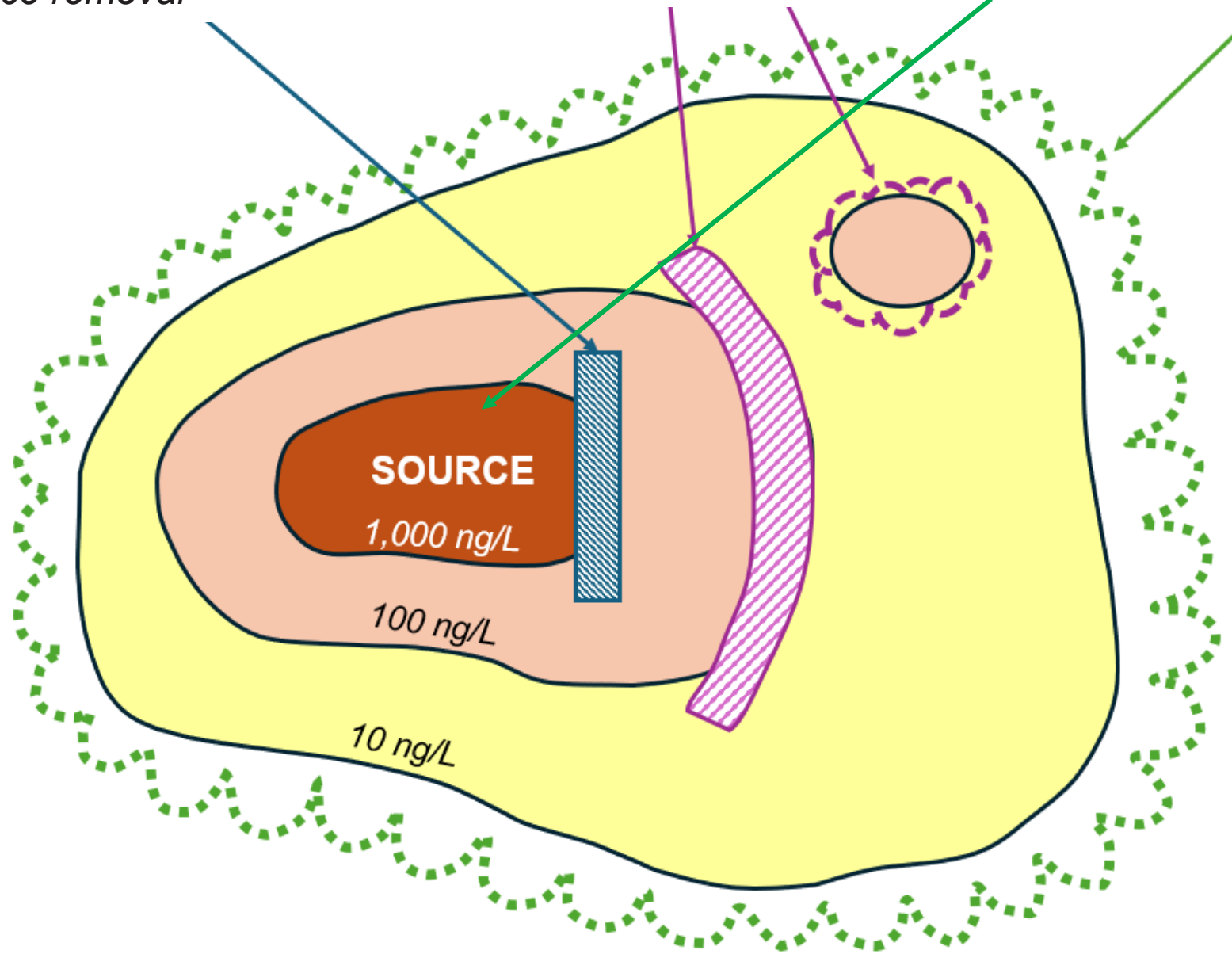
STANDARD:

- *Contain to 100 ng/L contour*
- *Hot spot source removal*

INTENSIVE:

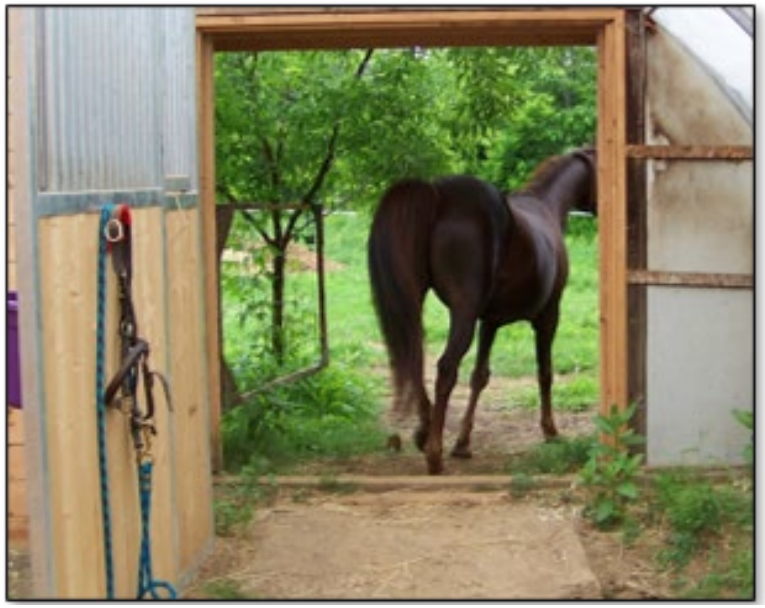
- *Contain to 10 ng/L contour &*
- *Full source removal*

Examples of three remediation levels

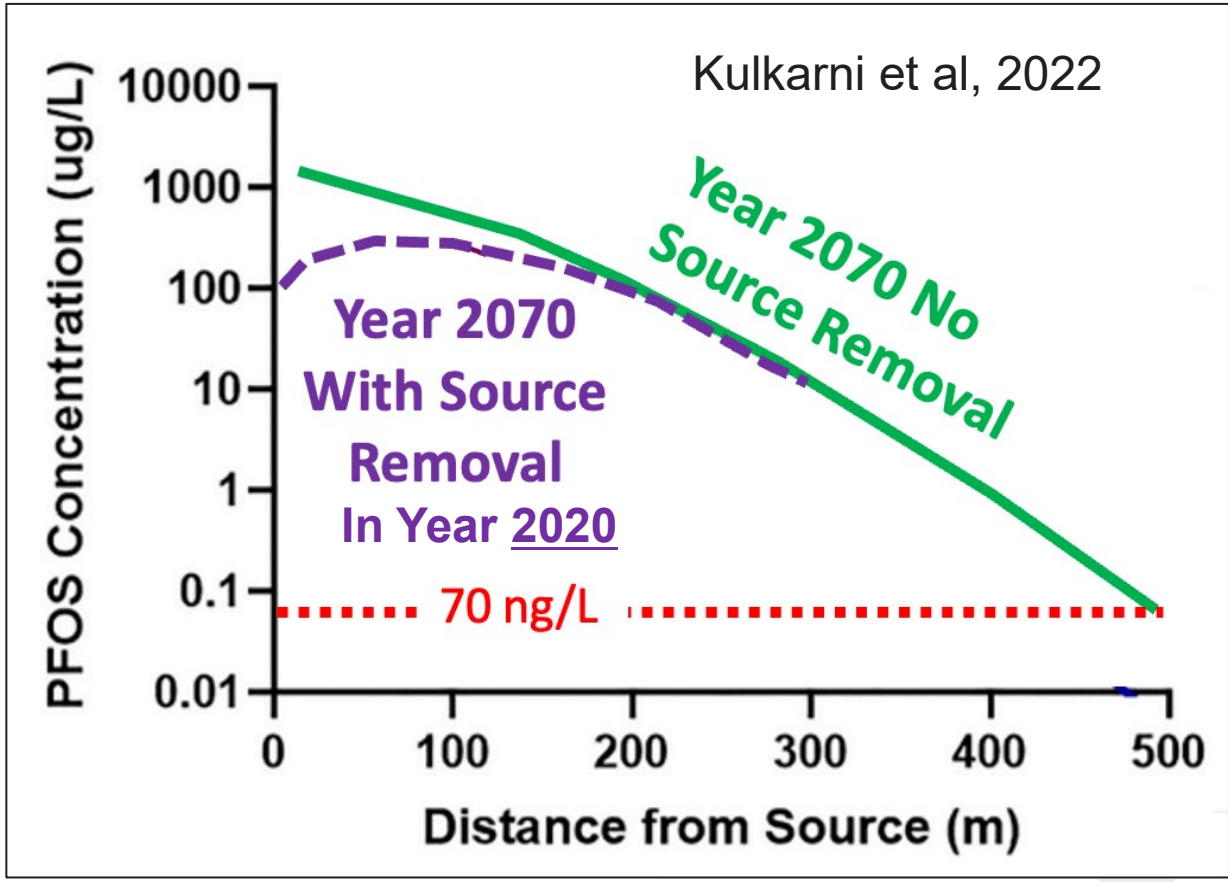


Containment vs. Mass Removal

- PFAA plumes not likely degrading in groundwater
- Source remediation may not decrease risk at downgradient edge of the plume



”Has the horse already left the barn?”



Types of PFAS Sites, Concentrations, and Remediation Cost

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Key Site Types (EBJ, 2024)	Category	# Sites	Median Conc./Risk *(ng/L)*	Remediation Cost *(Efficient/Std./Intensive)* *(Million $ per site)*
DOD AFFF Sites Airports: Major Refineries NPL: Superfund Airports: Regional Manufacturing Sites Using PFAS RCRA Corrective Action	**Major**	700	20,000	$ 9.5 / **$30** / $95
	Moderate	4700	5,000	$2.2 / **$7** / $22
DOD Other Fire/Emergency Response Sites Civilian Agencies	**Minor**	4900	1,000	$ 0.9 / **$3** / $9

Remediation Prioritization Forecast Model

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- Key features:
  - Semi-random queue of ~10,000 Major, Moderate, Minor Sites
  - We choose which strategies by site type
  - Randomized site concentrations
  - Remediation budget per year
  - Total risk magnitude
- How many sites can be addressed annually?
- Which strategies are more effective for risk reduction?

Site Group	Site Type (Major, Moderate, or Minor)	Randomized Log10 PFAS Risk	Initial Risk	Remediation Type: Efficient	Conc. Reduction	Remediation Cost: Efficient
		(log10 ng/L)	*(ng/L)*	*(-)*	*(OoMs)*	*($Mil/100 Sites)*
1	Moderate	3.7	5,012	Efficient	1.0	222
2	Minor	3.0	1,000	Efficient	1.0	95
3	Moderate	2.8	581	Efficient	1.0	222
4	Minor	3.0	916	Efficient	1.0	95
5	Moderate	4.0	9,901	Efficient	1.0	222

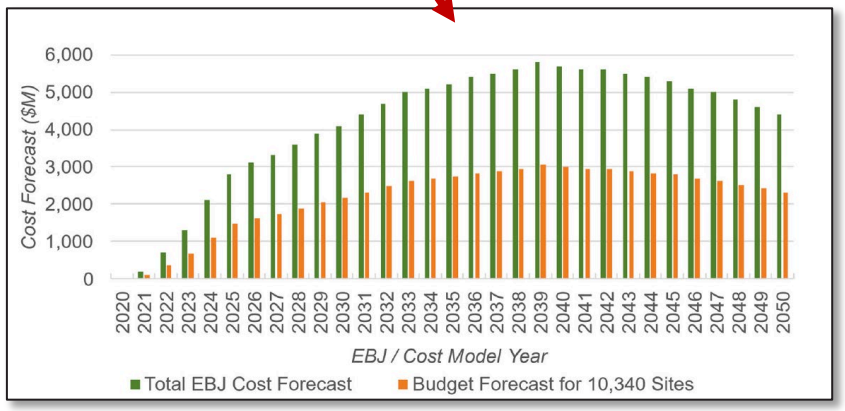
Model Year	1	2	3	4
Funds Available	57	229	402	574
Funds Spent	57	229	402	574

Site Group	Total Cost ($M)	Spend Yr 1	Spend Yr 2	Spend Yr 3	Spend Yr 4
Group 1	222	57.4	164.1	0.0	0.0
Group 2	95	0.0	65.3	29.6	0.0
Group 3	222	0.0	0.0	221.5	0.0
Group 4	95	0.0	0.0	94.9	0.0
Group 5	222	0.0	0.0	55.5	166.0

Site Group	Risk, Yr 1	Risk, Yr 2	Risk, Yr 3	Risk, Yr 4
	ng/L	*ng/L*	*ng/L*	*ng/L*
Group 1	*2,761*	*501*	*501*	*501*
Group 2	*1,000*	*205*	*100*	*100*
Group 3	*581*	*581*	*58*	*58*
Group 4	*916*	*916*	*92*	*92*
Group 5	*9,901*	*9,901*	*5,558*	*990*

ative Risk Proxy for 10,000 PFAS Remediation Sites er Next 30 Years

- **Intensive** remediation for Site 1 then Site 2 then Site 3 then Site 4…
- Spend each year until "*after the money is gone*."*



* Talking Heads, 1980

Relative Risk Proxy for 10,000 PFAS Remediation Sites Over Next 30 Years

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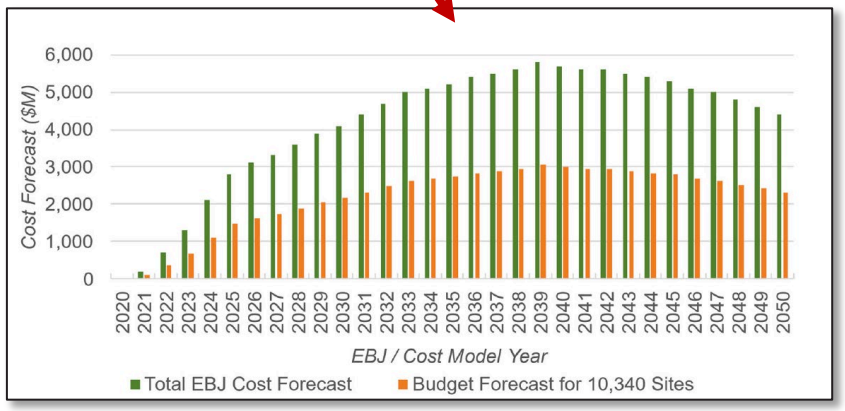

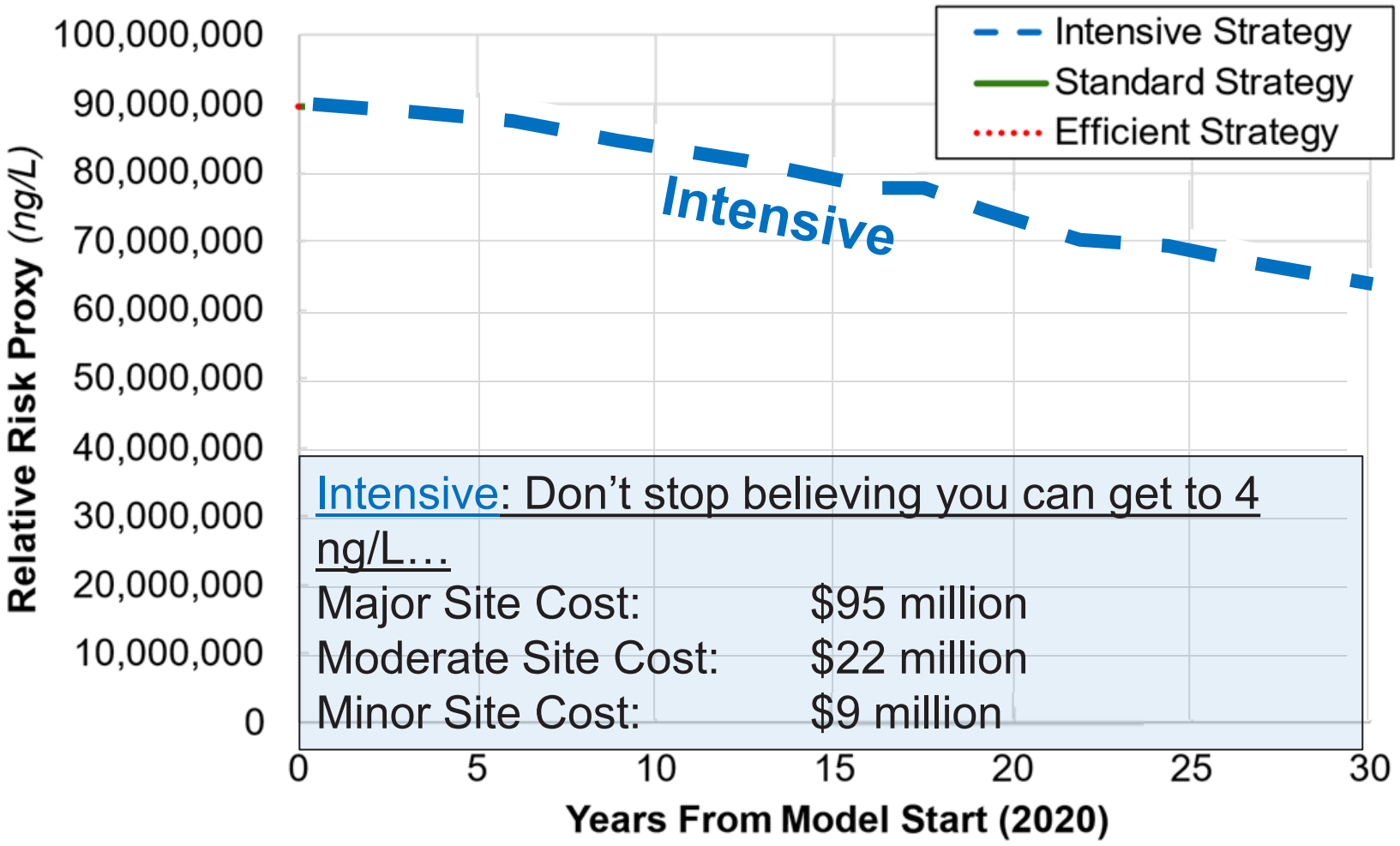

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Relative Risk Proxy for 10,000 PFAS Remediation Sites Over Next 30 Years

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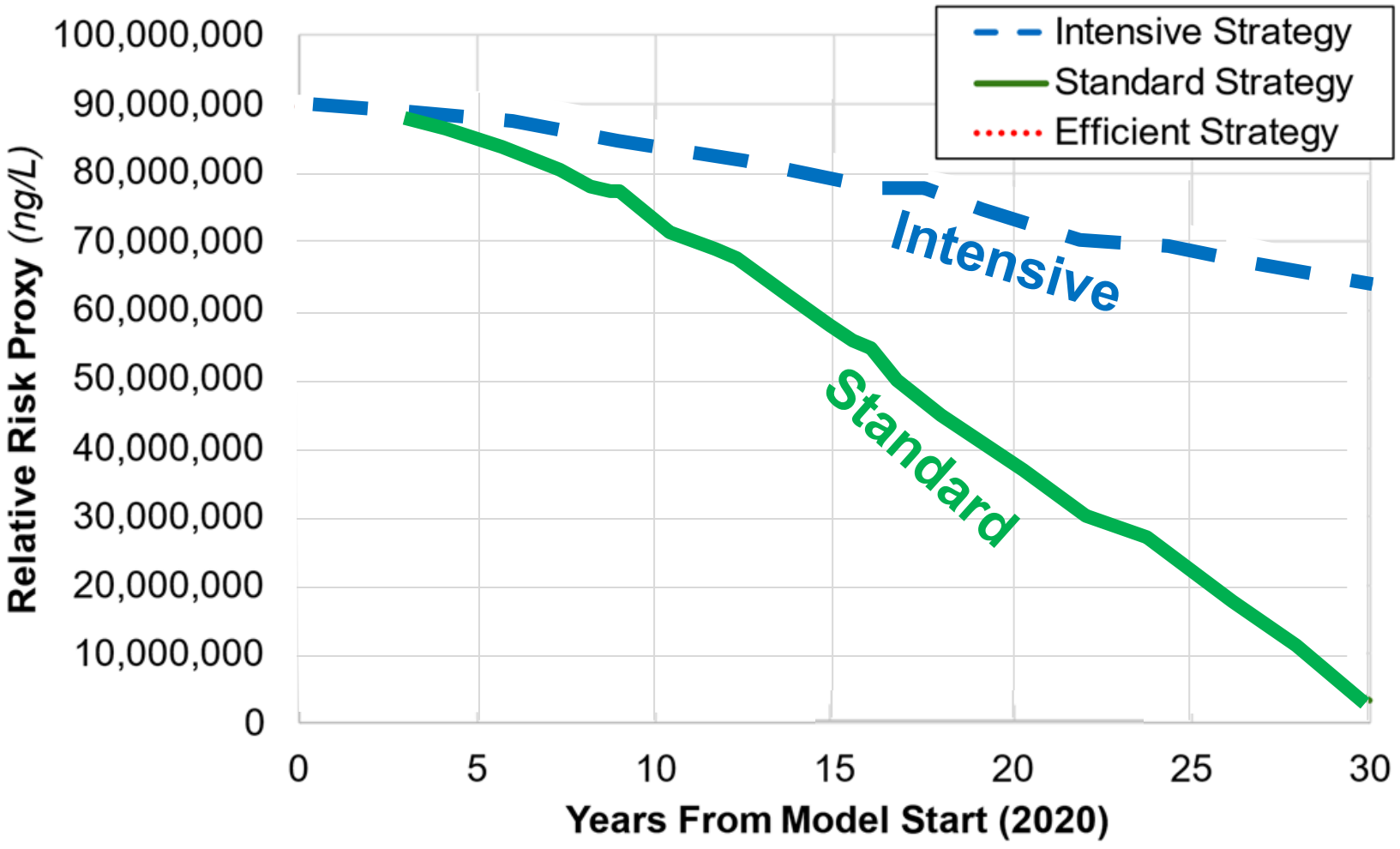
- **Intensive** remediation for Site 1 then Site 2 then Site 3 then Site 4…
- **Standard** Strategy for all sites

Standard: Hybrid contain, remove
Major Site Cost: $30 million
Moderate Site Cost: $7.0 million
Minor Site Cost: $3 million



Relative Risk Proxy for 10,000 PFAS Remediation Sites Over Next 30 Years

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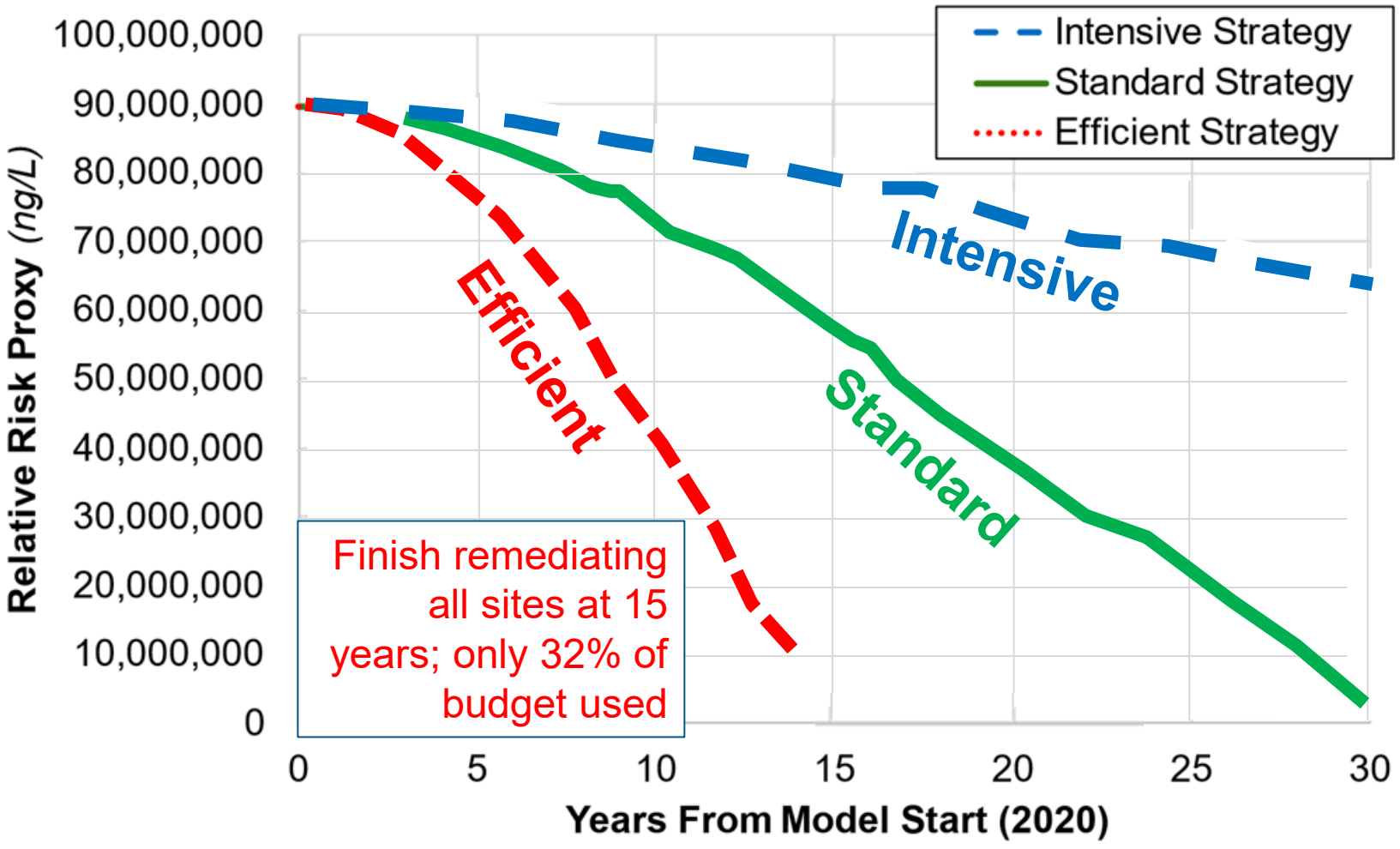
- **Intensive** Strategy until the money is gone
- **Standard** Strategy for all sites
- **Efficient** Strategy until there are no more sites in the 10,000 site queue



Efficient: Focus on containment

Major Site Cost:	*$9.5 million*
Moderate Site Cost:	*$2.2 million*
Minor Site Cost:	*$0.9 million*

Discussion

This forecasts suggests we should focus on containing PFAS for the next 15 years, then work on mass removal?

- Could this possibly be right?
- Where could it be wrong?
- But is this useful?

- Are there better strategies?

https://commons.wikimedia.org/wiki/File:Crystal_ball_by_Ron_Bodoh.JPG

Discussion

Two more scenarios (and then I promise I will stop):

"Throw More Money At It"

"Technology Changes Everything"

Relative Risk Proxy for 10,000 PFAS Remediation Sites Over Next 30 Years

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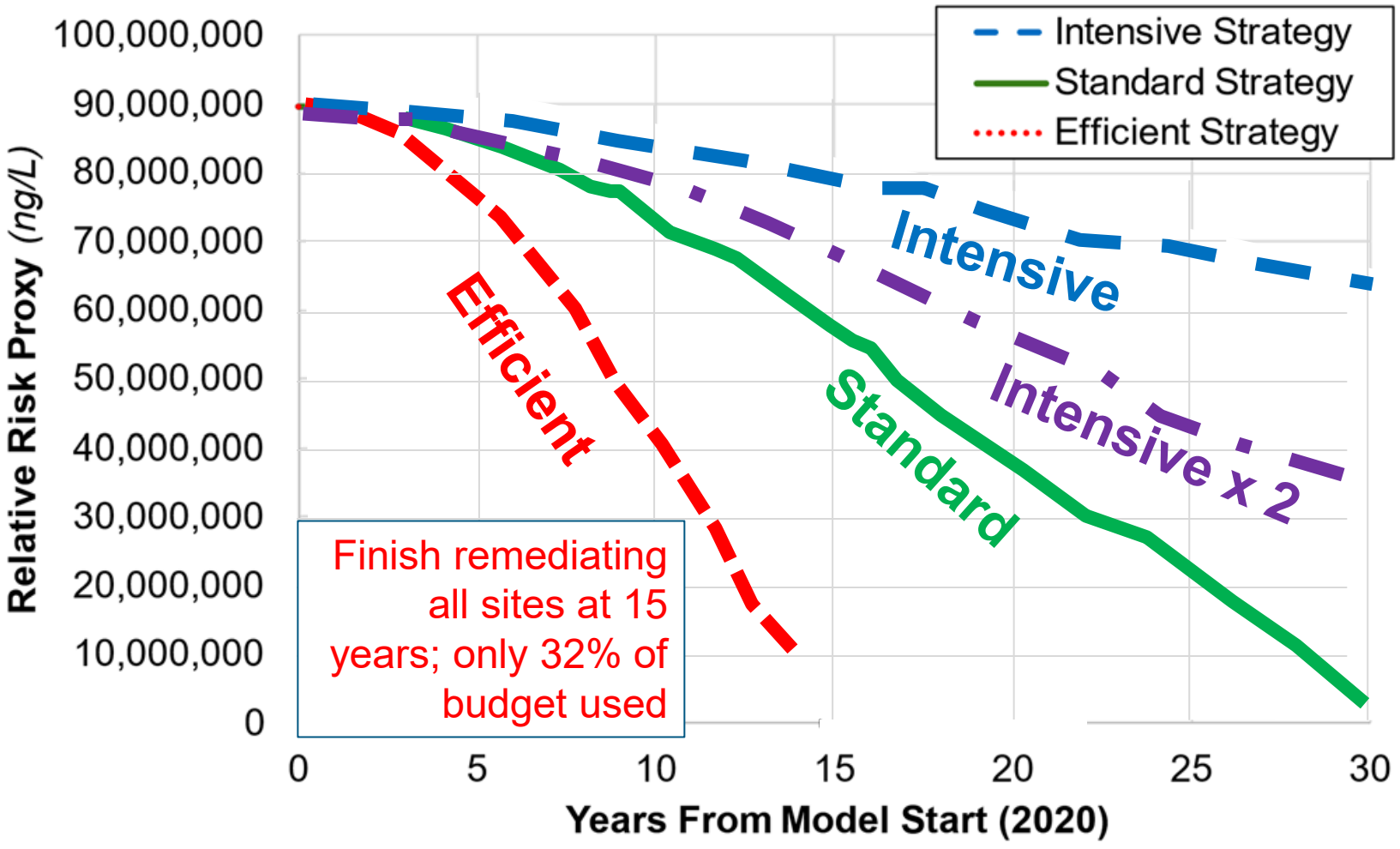
Intensive but we…

Double the Annual Remediation Budget



Relative Risk Proxy for 10,000 PFAS Remediation Sites Over Next 30 Years

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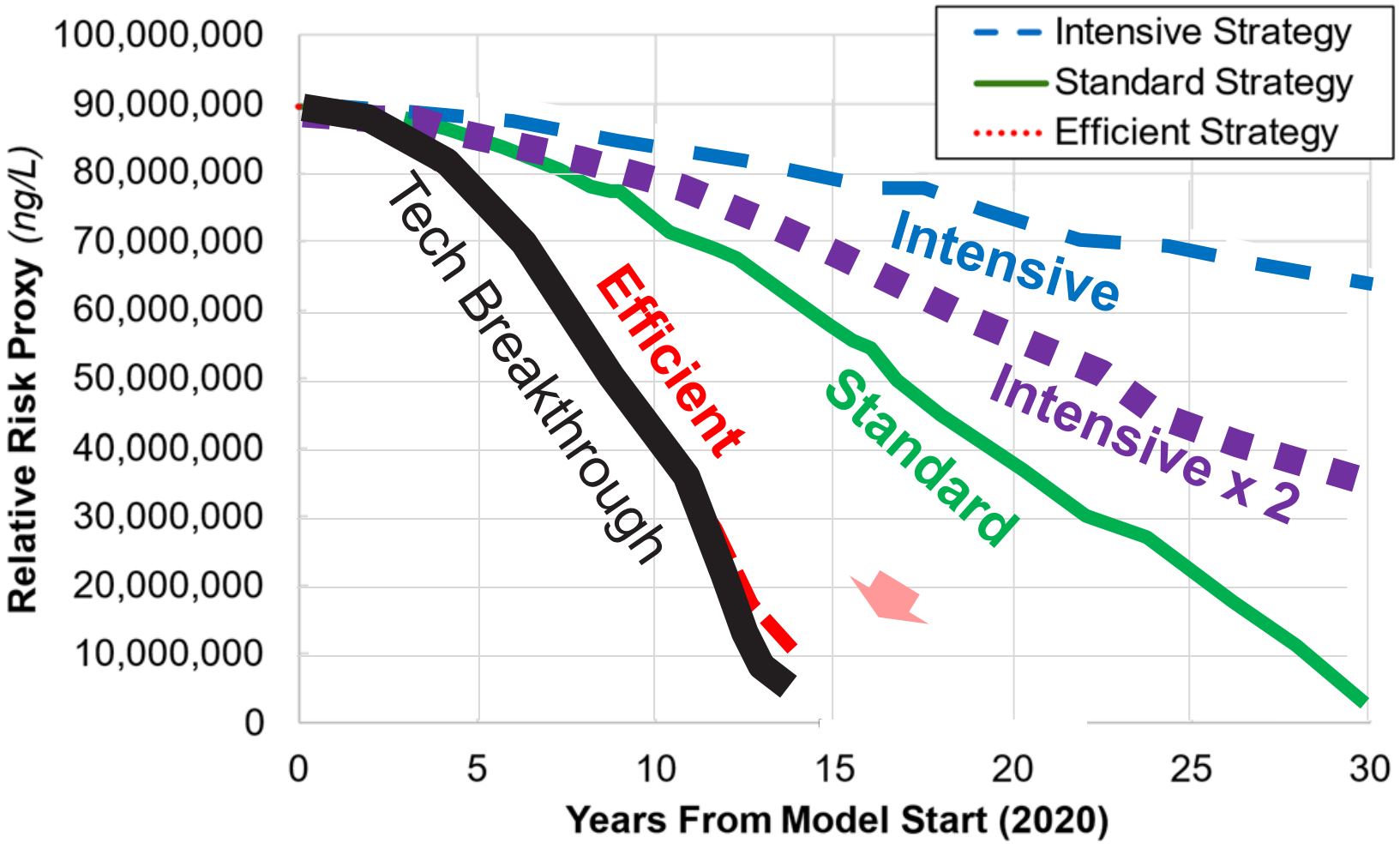
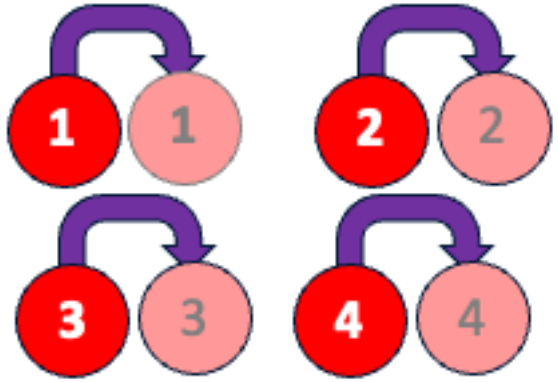
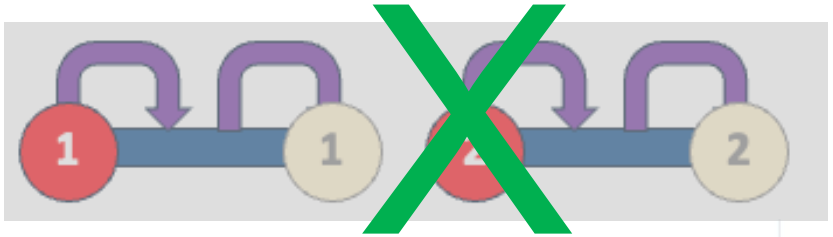
- **Efficient Scenario**
- **Improve the Technology** w/10x more removal for Efficient scenario, starting in 10 years *("J. Cook Scenario")*



Conclusions

- We have a long way to go…
- If forecast is correct, **efficient** strategy is best way
- But what do you think?





https://commons.wikimedia.org/wiki/File:Snowy_forest_path_at_sunset.jpg

Questions?

Remediation Journal

WILEY

COMMENTARY OPEN ACCESS

A Long Way to Go: Challenges and Strategies for Managing PFAS in Groundwater

Charles J. Newell[1] | John S. Cook[1] | David T. Adamson[1] | Paul B. Hatzinger[2]

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QUESTIONS?

Contact Us

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EBJ 2024 Working Model on Estimated Number of U.S. Sites with PFAS Contamination

Site Category	Sites	% PFAS contamination	Est. Sites PFAS contamination	Avg $mil remediation costs	Total $mil remediation costs	System Upgrade Cost* $mil
Soil/Groundwater Remediation						
NPL: Superfund	1,850	20-30%	463	10.0	4,625	
RCRA Corrective Action	4,000	20-30%	1,000	5.0	5,000	
RCRA UST	140,000	2-4%	4,200	1.0	4,200	
DOD AFFF Sites	360	100%	360	40.0	14,400	
DOD Other	4,400	60-80%	3,080	3.5	10,780	
DOE	5,000	10-15%	600	5.0	3,000	
Civilian Agencies	3,000	25-30%	810	2.0	1,620	
State Sites	110,000	5-10%	8,800	0.5	4,400	
PFAS Manufacturing Sites	60	100%	60	400	24,000	
Manufacturing Sites Using PFAS	3,600	70-90%	2,880	6.5	18,720	
Pulp & Paper	240	70-80%	180	10.0	1,800	
Other Manufacturing Sites	330,000	2-3%	8,250	0.5	4,125	
Chromium/Electroplating	4,400	30-50%	1,760	1.0	1,760	
Refineries	130	80-90%	104	20.0	2,080	
Landfills: Active	3,100	70-80%	2,325	4.0	9,300	
Landfills: Closed	8,600	50-60%	4,730	2.0	9,460	
Airports: Major	260	80-90%	221	20.0	4,420	
Airports: Regional	1,200	30-40%	396	7.5	2,970	
Airports: Commercial/Private	17,540	3-5%	702	6.0	4,210	
Biosolids/Landfarming 503 Permits	2,500	70-80%	1,875	2.5	4,688	
Biosolids/Landfarming: Small	5,000	5-20%	625	0.2	125	
Fire/Emergency Response Sites	1,200	80-90%	1,020	3.0	3,060	
Remediation Totals	**646,440**	**7%**	**44,440**	**3.1**	**138,742**	
Water/Wastewater Treatment						
Wastewater: POTWs 10 MGD+	500	90-95%	460	90		41,400
Wastewater: POTWs <10 MGD	15,000	20-50%	4,500	7.5		31,500
Water Utilities: Urban	4,000	65-80%	2,800	15.0		42,000
Water Utilities: Rural	50,000	10-20%	7,500	1.5		11,250
Private Water Sources/Wells	100,000	5-10%	7,000	0.2		1,540
Water/Wastewater Totals	**169,500**	**8%**	**22,260**	**5.7**		**127,690**

*Source: Environmental Business International Inc., Environmental Business Journal. 2024 EBJ PFAS model using site count estimates from EPA, ITRC, US Census, US DOT FAA, and others; a consensus of '% PFAS contamination' and average site costs from a survey and interviews with remediation experts. *Water/wastewater treatment system cost is capex and estimated opex for 20-year O&M*

Salvatore et al. 2022: 57,000 sites

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DOE	5,000	10-15%	600	5.0	3,000	

DoD Remediation Cost:
~$25 Billion