U.S. EPA "State of VI Science" Workshop

Selecting Sampling Strategies for Efficient & Economical Vapor Intrusion Site Assessment & Long-Term Management – forming Soil Gas Safe Communities

Economic Analyses of Long-Term Stewardship: Balancing Investigation, Mitigation and Remediation Decisions

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Presentation archived at https://iavi.rti.org/

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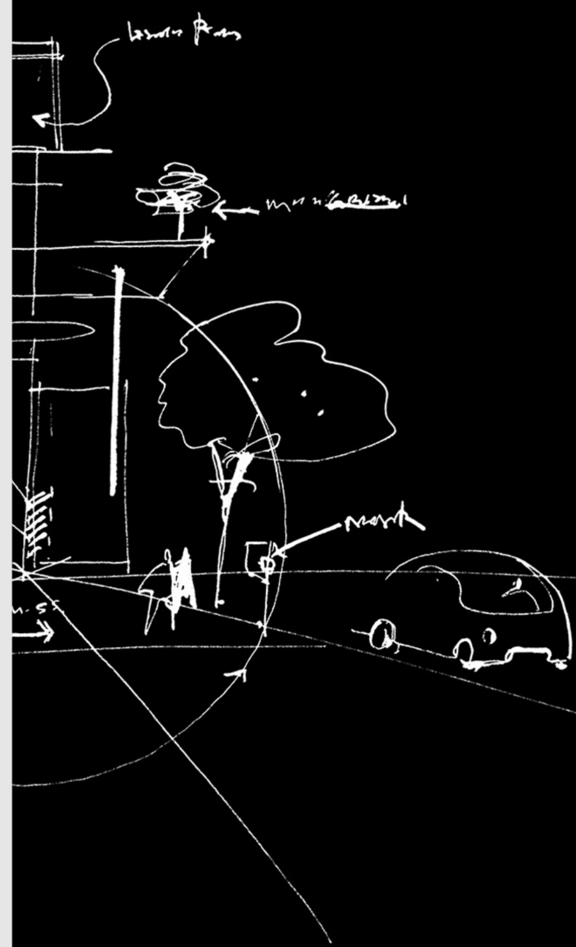
Agenda

Economic Analysis of VI Choices

- Available data sources and methods for cost estimation
- Monitoring vs. mitigation costs
- Building specific mitigation with subslab depressurization (SSD) vs. Soil Vapor Extraction (SVE) costs
- Decision making at various project stages
- Account for long term stewardship

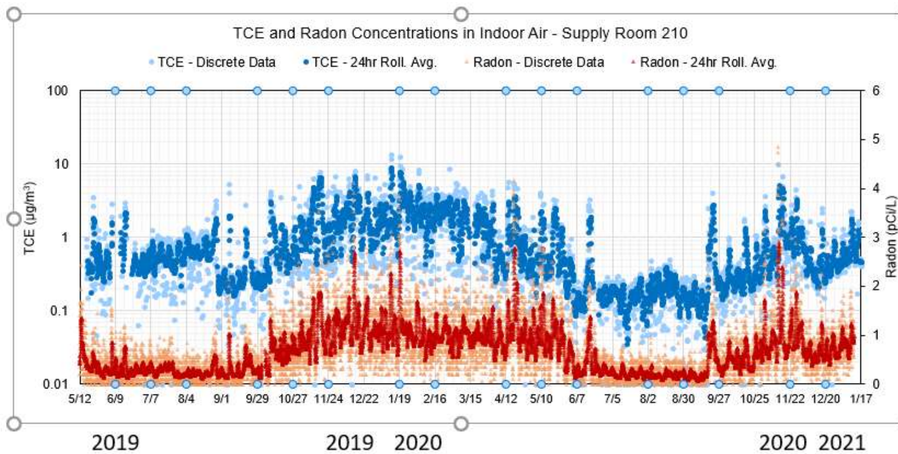


VI Site Assessment Challenges

- Indoor concentrations vary strongly with building envelope specific characteristics
- Tens of thousands of sites to assess
- A large number of buildings and zones within individual buildings often need to be assessed (10’s to 1,000’s)
- Indoor concentrations change widely over time (1 to 2 orders of magnitude)
- Site decision making typically requires a multiple lines of evidence (sampling multiple media)

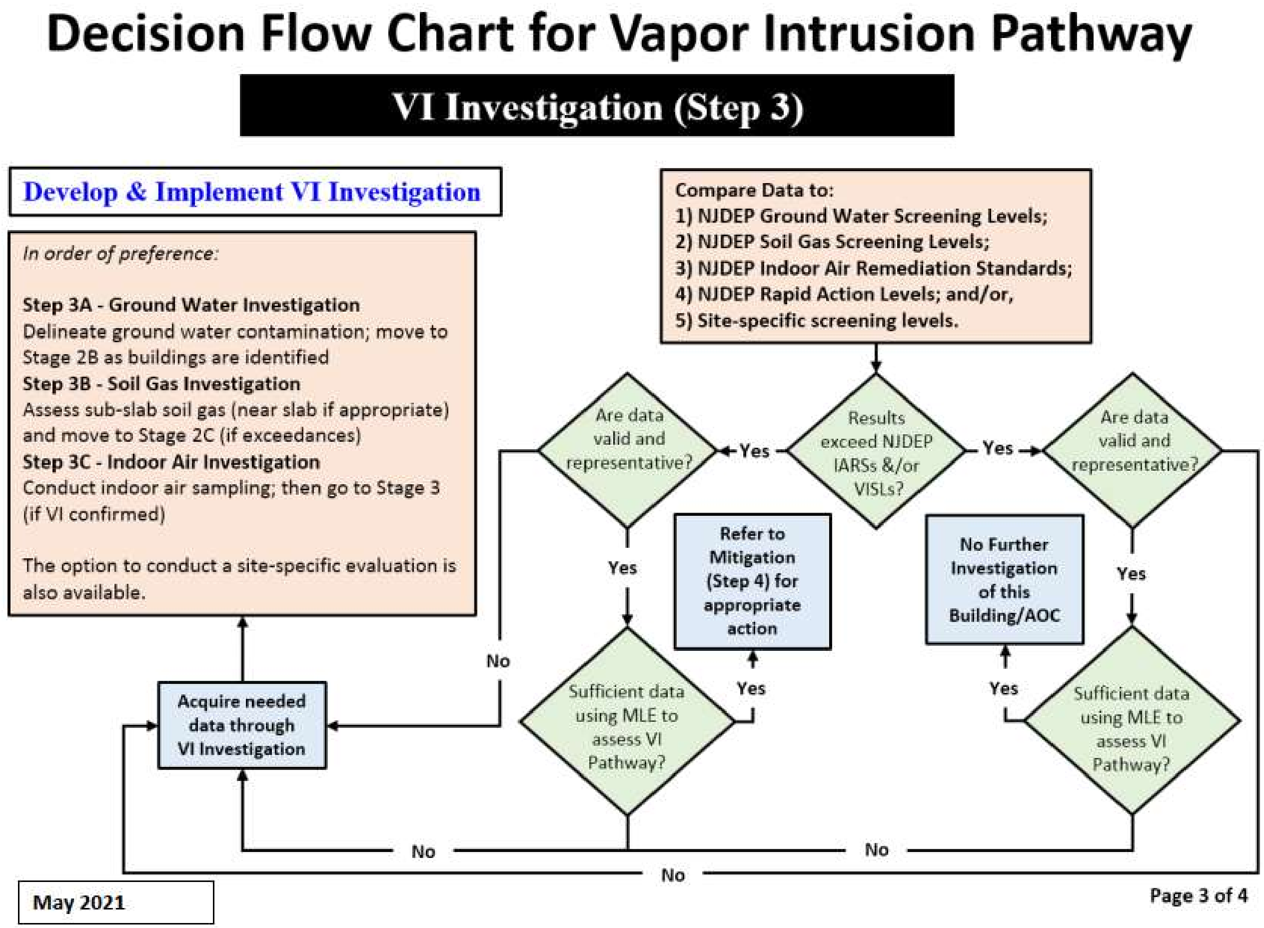
Aerial image a DC dry cleaner site, reprinted from “Technical Support Document for U.S. EPA’s Final Rule: Addition of a Subsurface Intrusion Component to the Hazard Ranking System” ; Appendix D.

Data graph from a VA industrial building reprinted Lutes et. all AEHS presentation 2021 “Eighteen Months of High Resolution Indoor and Subslab Temporal Observations from an Industrial Building”



Decision Points at Various Project Stages

- Which media to sample and how many?
- Whether to preemptively mitigate after some site delineation with external soil gas sampling but before indoor sampling in every building?
- Mitigate after some indoor VOC sampling?
- Individual house mitigation systems and/or vadose zone remediation/mitigation on neighborhood scale



Part of NJ 2021 Guidance Flow Chart

Current Limitations on Decision Making

- Decision makers most often lack quantitative models that could be used to select the near-optimum site investigation and mitigation strategy

- Experience-based intuition and group consensus-based decision-making methods are much more commonly employed than quantitative or systematic decision-making tools (Clayton, 2017). Near-optimum decisions are likely the result of a combination of quantitative and intuitive methods.

- We have good experience-based intuition on some things – for example should I buy a new car this year or keep fixing my old clunker? This presentation aims to strengthen our understanding of the tradeoffs in VI decisions.

Real World Cost Cases for Residential VI Mitigation – Regulated Sites

Region	Reference	# Buildings	Total $	$/building	Notes
New England	DiLorenzo, 2014	43	$1.4M	$30K	Stone foundations, multiple additions
Southwestern U.S.	Minchak, 2018	13 buildings, 21 Systems	$815K	$62.7K	Significant building envelope repairs, multiple systems in some structures
Pompton Lakes N.J.	Borough of Pompton Lakes, Undated	Numerous	NA	$8.8K	Install and first year testing, typical home allowance.

A common error is to directly apply low mitigation costs associated with the radon mitigation systems installed as part of a property transfer to more highly regulated VI situations.
"Radon mitigation typically costs between $771 and $1,179" realestate.usnews.com

This Presentation Builds on Previously Presented Analyses

CH2MHILL.

Nonresidential Building: Vapor Intrusion Lifecycle Cost Analysis

Chris Lutes, CH2M HILL, Raleigh N.C.

*Presented at EPA Workshop at AEHS 2015: **Long-Term Evidence-Based Protection & Sustainability in Residential, Commercial, and Industrial Buildings***

https://iavi.rti.org/assets/docs/WorkshopsAndConferences/07_Lutes_Commercial%20Building%20Mitigation%20Economic%20AnalysisCL_JDM7.pdf

Groundwater Monitoring&Remediation

Cost Comparison of Soil Vapor Extraction and Subslab Depressurization for Vapor Intrusion Mitigation

by Christopher Lutes, Lloyd Stewart, Robert Truesdale, Jose De Loera, John H. Zimmerman and Brian Schumacher

Lutes, Christopher, et al. "Cost Comparison of Soil Vapor Extraction and Subslab Depressurization for Vapor Intrusion Mitigation." *Groundwater Monitoring & Remediation* 42.4 (2022): 43-53.

Non-residential Building Vapor Intrusion (VI) Lifecycle Cost – When Is Preemptive Mitigation a Good Value?

Christopher Lutes (Christopher.Lutes@ch2m.com) (CH2M, Raleigh, NC, USA)
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https://www.researchgate.net/profile/Chris-Lutes/publications

Economic Analyses of Vapor Intrusion Investigation, Mitigation and Remediation Decisions – What's Been Done and How Can it Help You?

Christopher C. Lutes, Jeffrey D. Minchak, Keri E. Hallberg, and Laurent C. Levy Paper #1164201
Jacobs; 111 Corning Rd Suite 200, Cary, NC 27518
Presented at: A&WMA's 115th Annual Conference & Exhibition San Francisco, CA June 27 – June 30, 2022

What's Behind the Curtain?

- A spreadsheet calculation of costs for a hypothetical case (composite of experience)
- Broken out by tasks as an engineering professional would do when estimating costs:
  - Project management
  - Diagnostic Test
  - Design
  - Construction and oversight
  - Startup
  - Operations and Maintenance; Monitoring
- Further broken down into labor hours, individual materials items, analytical costs etc.
- Uses professional judgment, informed by regulatory guidance and vendor prices where available
- Not intended to be exact/binding estimate, but to illustrate the general trend of the tradeoffs and identify the sensitive parameters.

Notional Base Case Building Assumptions (Lutes & Minchak 2015)

- Commercial building: 7,200 square ft, 30 years old, Northern California, major metropolitan area
- Slab on grade, one floor, three tenants; single style of construction
- Not believed to be the primary release location
- Overall site is reasonably well understood – PCE in gw at 500 µg/l at 15 ft bls (aerobic case, TCE not expected to be driver). Source treatment just beginning 200 ft. upgradient, expected to require 30 years to reach VISLs
- Previous data on this specific building consists of one round of 24-hour indoor air sampling, at two locations, in summer. Results gave compound ratios potentially suggestive of vapor intrusion.
- Indoor air concentrations observed in one round of sampling were substantially greater than ambient concentrations.
- Indoor air concentrations in one round of sampling (normal HVAC conditions) were at roughly 50% of the value at which state would definitely require long term mitigation.

Situation: Single Commercial Building
Choice: Mitigate Early or Monitor and Hope to Avoid Mitigation???

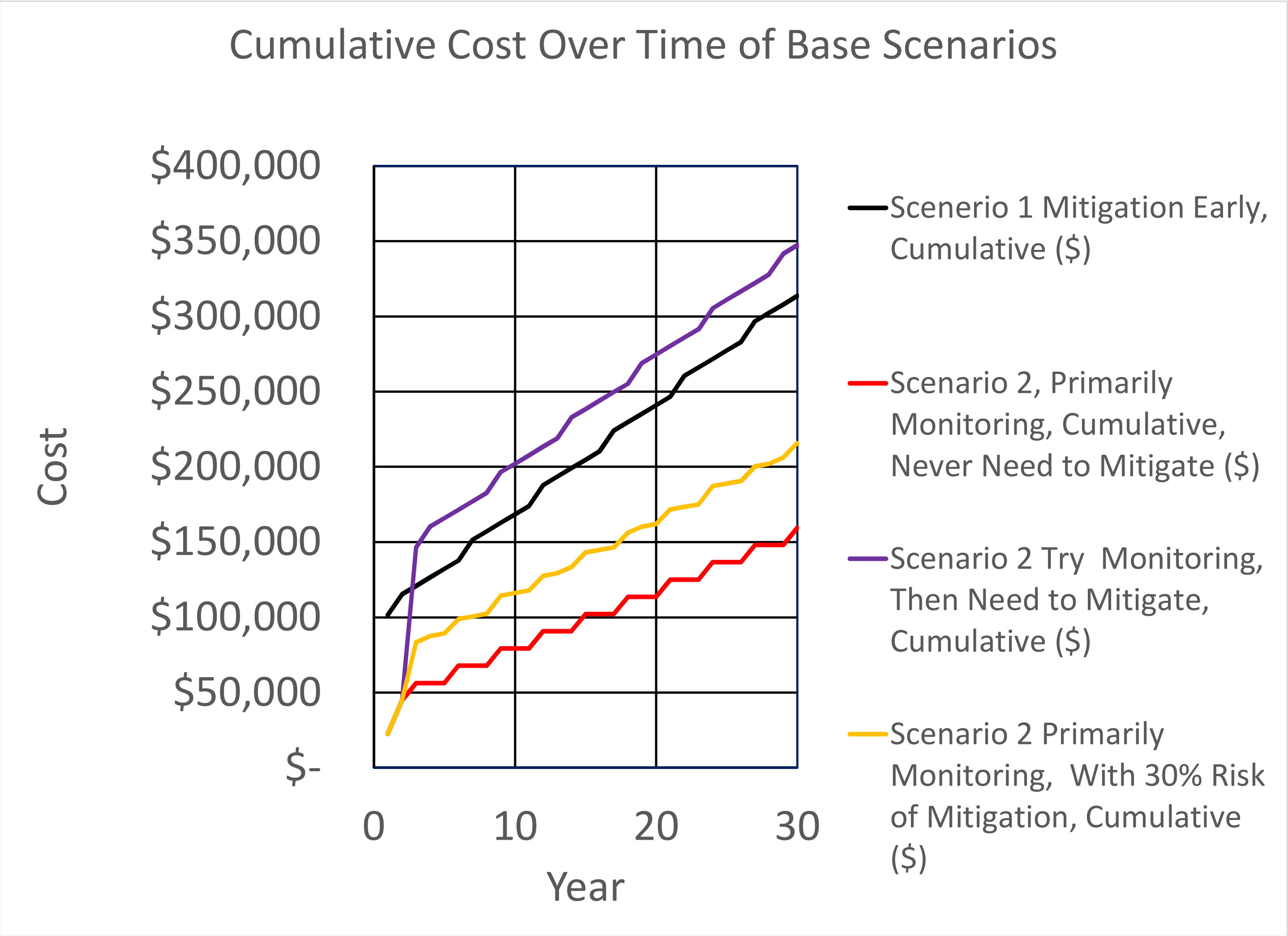
From: Lutes and Minchak 2016

Red= Base Case Black = Alternatives

- <u>Scenario 1: Mitigation Early</u>
  - Implement vapor intrusion mitigation with SSD immediately,
  - Monitor effectiveness sufficiently to verify adequate performance for chronic risk protection over all climatic conditions.
  - Long term monitoring for 30 years.
  - No change to building HVAC system.
- <u>Scenario 2: Primarily Monitoring</u>
  - Four rounds of monitoring to better define seasonal variability;
  - Intensive building survey to locate and eliminate potential indoor sources.
  - Mitigate if necessary.
  - If Ok after 2 years monitor once every 3 years

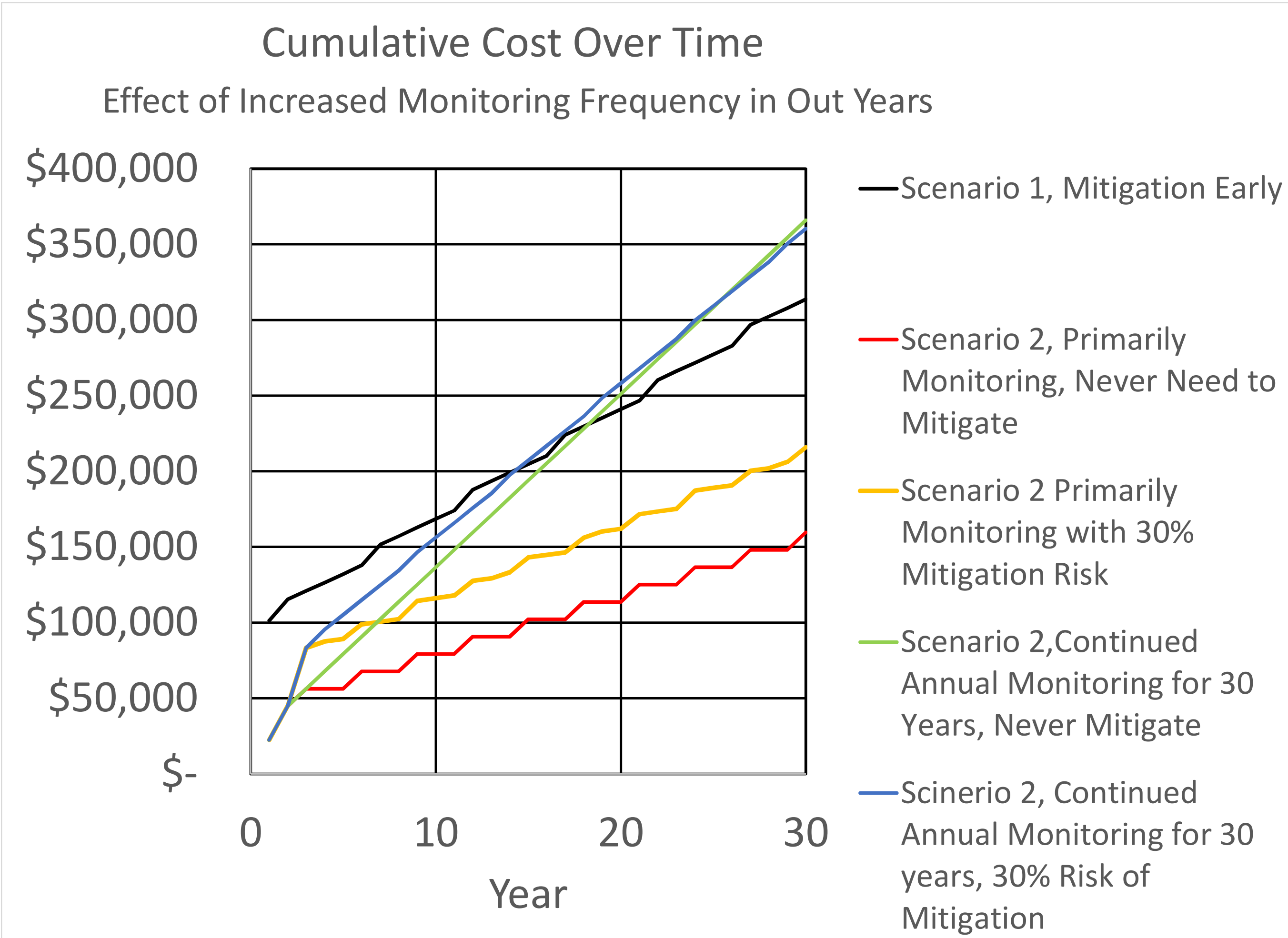
- Long term monitoring frequency without mitigation
  - Annual
  - Every 3 years
  - Every 5 years
- Long term sampling frequency after passing initial post mitigation monitoring
  - Every 3 years
  - Every 5 years
- Building size (scales number of samples, size of fan, extraction points, capital cost etc.)
  - 7,000 sq ft
  - 35,000 sq ft
  - 175,000 sq ft
- Building Complexity: 1, 3, 10 occupied suites/foundation additions
- System Intensity (based on soils permeability and heterogeneity)
  - 45 ft ROI; 0.14 HP of blower per 1,000 sq. ft.
  - 15 ft ROI; 0.5 HP of blower per 1,000 sq. ft.

Base Scenarios, Cumulative Costs; With and Without Mitigation



Key Point: Assume four rounds of monitoring in first year was considered sufficient, then every three years thereafter. In that case monitoring in a situation that has a 30% risk of needing mitigation is less expensive than going to mitigation early.

Sensitivity to Changing Monitoring Frequency in Scenario 2 (Going to Annual Monitoring in Out years



Key Point: Assume four rounds of monitoring in first year was considered sufficient, then annual thereafter if you didn't mitigate. But VOC monitoring on mitigated building was every 5 years.
In that case the mitigation early strategy eventually saves money.

Mitigation Early vs. Monitoring Conclusions –

From Lutes and Minchak 2015/2016

- There are cases, where the economic tradeoff between a "mitigation early" and "monitoring until you have to mitigate" strategy is a close one.
- Going to mitigation early can raise the ultimate life cycle cost if there is a reasonable chance that monitoring will lead to a decision not to mitigate. But if you are almost certain to have to mitigate anyway, then several rounds of monitoring plus mitigation is more expensive.
- If you have to monitor annually for the long term without mitigation (to handle temporal variability), then mitigation is less expensive in the long term.
- Monitoring and mitigation have very different annual cash flows.
- The cost advantage of trying monitoring first is greater for larger, simple buildings (few suites/foundations)
- Note: A different analysis using the concept of "equivalent protection" to evaluate needed number of samples using a different tool, suggests mitigation first often wins. (Lutes, C. A.J. Kondash and C. Holton "Results and Interpretation of Sampling Strategy and Equivalent Protection Cost Effectiveness Analyses" oral presentation at 2022 Workshop https://iavi.rti.org/assets/docs/07_Lutes_Results_SSA_EPCEA.pdf)

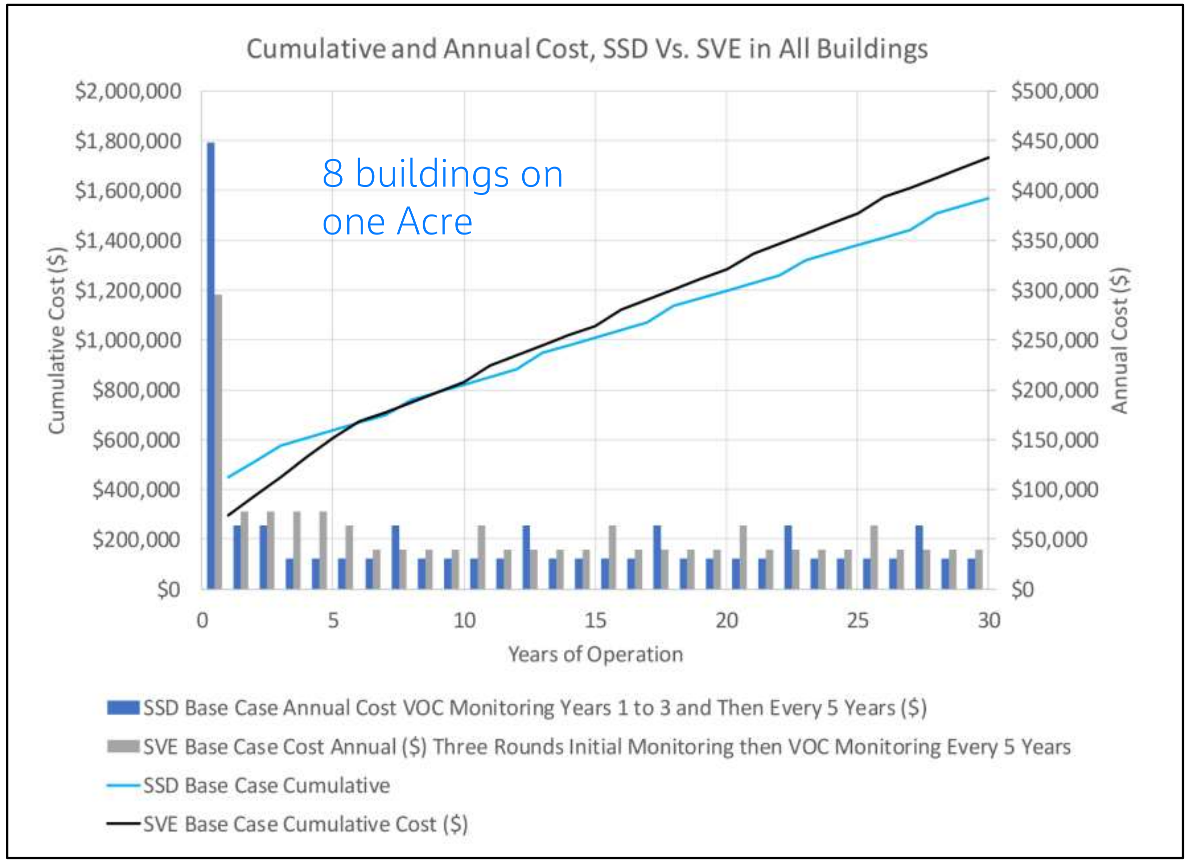
Situation: Multiple Commercial Buildings Close Together Over Source Choice: Mitigate Buildings Individually (SSD) vs. SVE

Lutes, Christopher, et al. "Cost Comparison of Soil Vapor Extraction and Subslab Depressurization for Vapor Intrusion Mitigation." *Groundwater Monitoring & Remediation* 42.4 (2022): 43-53.

- SVE performance and economics based on EPA funded field study
  - Stewart, Lloyd, Chris Lutes, Robert Truesdale, Brian Schumacher, John H. Zimmerman, and Rebecca Connell. "Field Study of Soil Vapor Extraction for Reducing Off-Site Vapor Intrusion." *Groundwater Monitoring & Remediation*. 40, no. 1 (2020): 74-85.
  - Fairly large SVE system: 20 HP blower, two 2000 lb vapor phase carbon modules, 4,000 lbs GAC used per year; 370 to 460 CFM
  - Eight buildings protected totaling 32,000 ft^2 on a total land area of 110,000 ft^2 (almost all paved)
  - assumes the SVE operation transitions from remediation to VI mitigation as the primary goal after 4 years using a subset of screens
  - Assumes the SVE effectiveness for VI monitored with three rounds indoor air (20 locations) plus a round every 5 years, and annual differential pressure
- Uses the Lutes & Minchak 2015 and 2016 mitigation costs scaled and applied to the eight buildings individually, and then summed.
  - Pressure field extension testing, plus three rounds of VOC monitoring in indoor air after installation, VOC monitoring in off-gas
  - Long term stewardship includes annual flow rate monitoring and differential pressure rechecks, indoor air every 5 years
  - No air emissions control on SSD

Base Case Results: SSD vs. SVE Costs

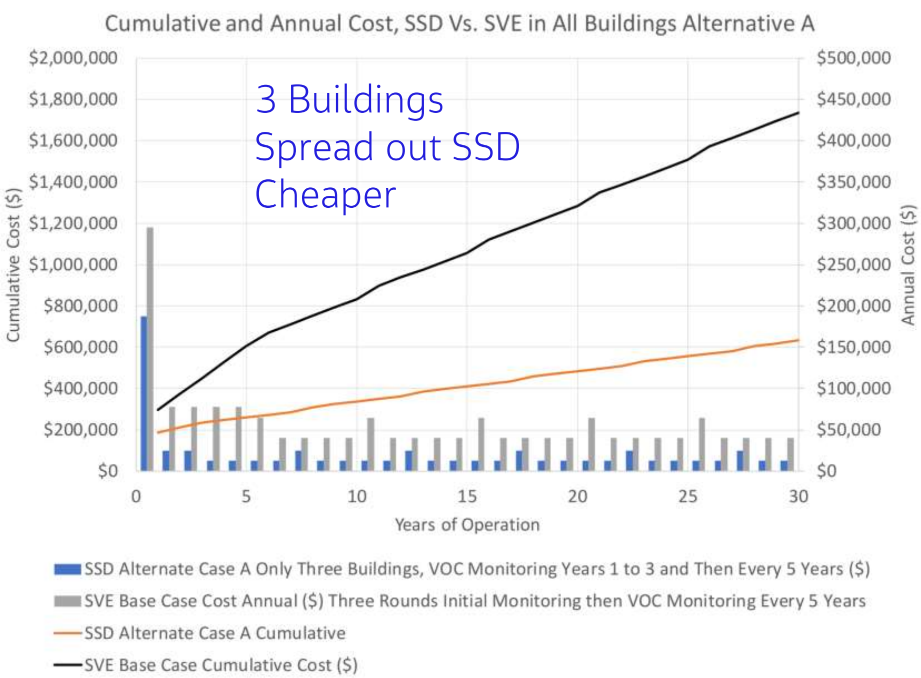
- SVE Capital $295K < SSD capital $448K
- SVE operational costs in early years when being used for mass removal are higher than SSD
- Costs equal after 6 years
- Total over 30 years SSD ($1,567K) modestly better cumulative then SVE ($1,733K)
- SSD benefits from the assumption of no off gas treatment
- But SVE provides additional source removal benefits

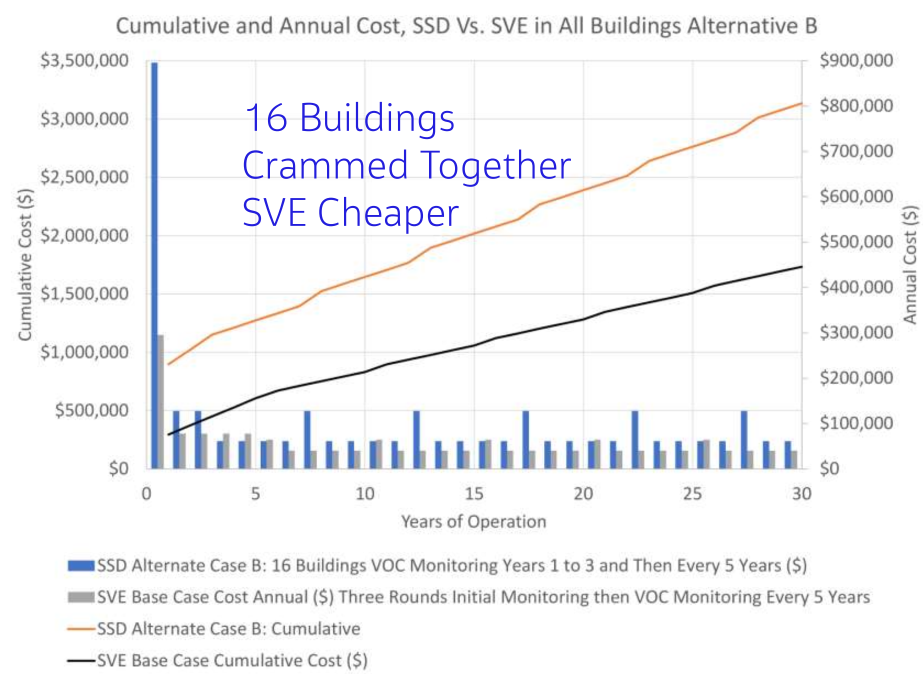


Sensitivity Analysis of Situation: Multiple Commercial Buildings Close Together Over Source; Choice: Mitigate Buildings Individually (SSD vs. SVE)

Analyses included in published paper Red= Base Case Black = Alternatives

- Keep land the same, change percent of land area covered with buildings
  - 16% (only 3 of the 8 original buildings assumed to exist) = Alternate A
  - 30% (the 8 original buildings exist)
  - 58% (16 buildings now exist) = Alternative B





Limitations/Critiques of 2022 GWMR Analysis

- Although realistically representing a difference in how systems are often treated, analyzing SSD without offgas control is an “unfair” advantage for that technology.
  - Thus, we revised in this presentation to include an offgas control for SSD option.
- The EPA pilot site was a source zone with strong mass in soil and groundwater, thus the SVE blower and Granular Activated Carbon (GAC) was bigger than needed for long term continuous service, what would the results be like over a dilute plume?
  - Thus, we considered a thought experiment involving “relocating” the same buildings to place them over a dilute plume. A down-sized solar SVE system was costed.
- Would the results have been different if the buildings were residential instead of commercial?
  - Thus, residential buildings of the same footprint and foundation style but with more suites/apartments considered.

Photos To Show Building Style – Not from Actual Test Site

Photos reprinted from https://www.tri-c.edu/workforce/public-safety/simulated-scenario-village.html
https://www.nps.gov/places/wohlner-s-neighborhood-grocery.htm?utm_source=place&utm_medium=website&utm_campaign=experience_more&utm_content=small

LC0

Estimated SSD Cost Impact of Changes from Commercial and Residential No GAC to Residential with GAC

Commercial vs. Residential No GAC	
Commercial 1st Year Cost	$448,000
Residential 1st Year Cost	$497,000
Change	+11%
Commercial Subsequent years cost (3 years)	$94,000
Residential Subsequent years cost (3 years)	$108,000
Change*	+14%

Residential No GAC vs. Residential with GAC	
Residential no GAC 1st Year Cost	$497,000
Residential+ GAC 1st Year Cost	$521,000
Change	+5%
Residential no GAC Subsequent years cost (3 years)	$108,000
Residential + GAC Subsequent years cost (3 years)	$143,000
Change**	+32%

Commercial No GAC vs. Residential with GAC	
Commercial 1st Year Cost	$448,000
Residential+ GAC 1st Year Cost	$521,000
Change	+16%
Commercial Subsequent years cost (3 years)	$94,000
Residential + GAC Subsequent years cost (3 years)	$143,000
Change**	+52%

Notes:

* Cost of sampling at residential locations is higher than at commercial locations. More samples are collected at residential buildings based on number of residential units of each building (2 per unit).

** Cost increase is due mainly to GAC replacement (assumed to happen every 3 years)

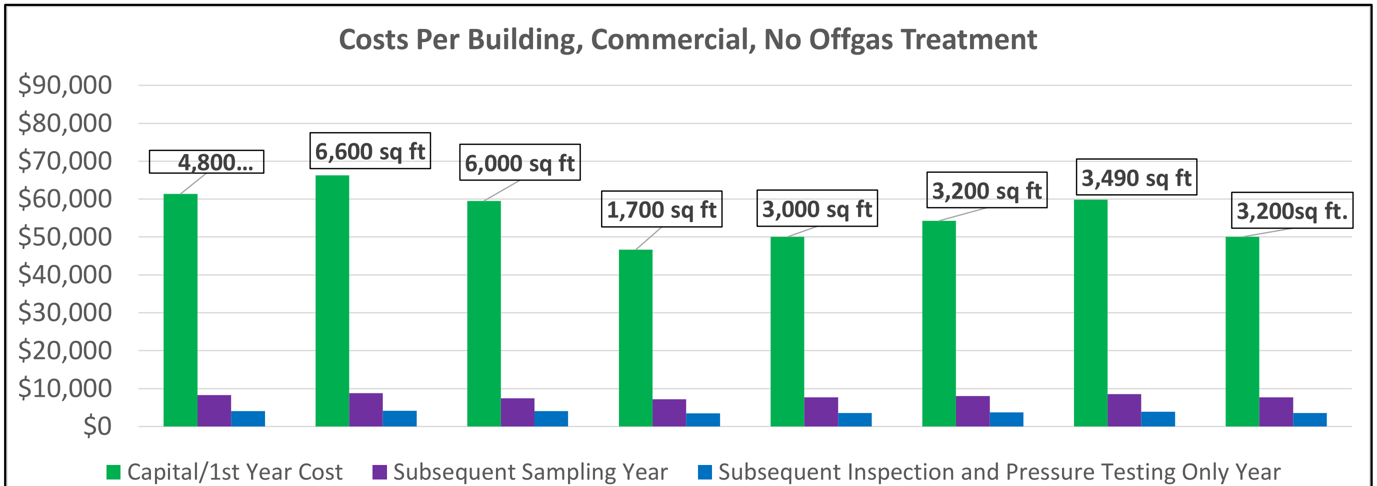
Slide 18

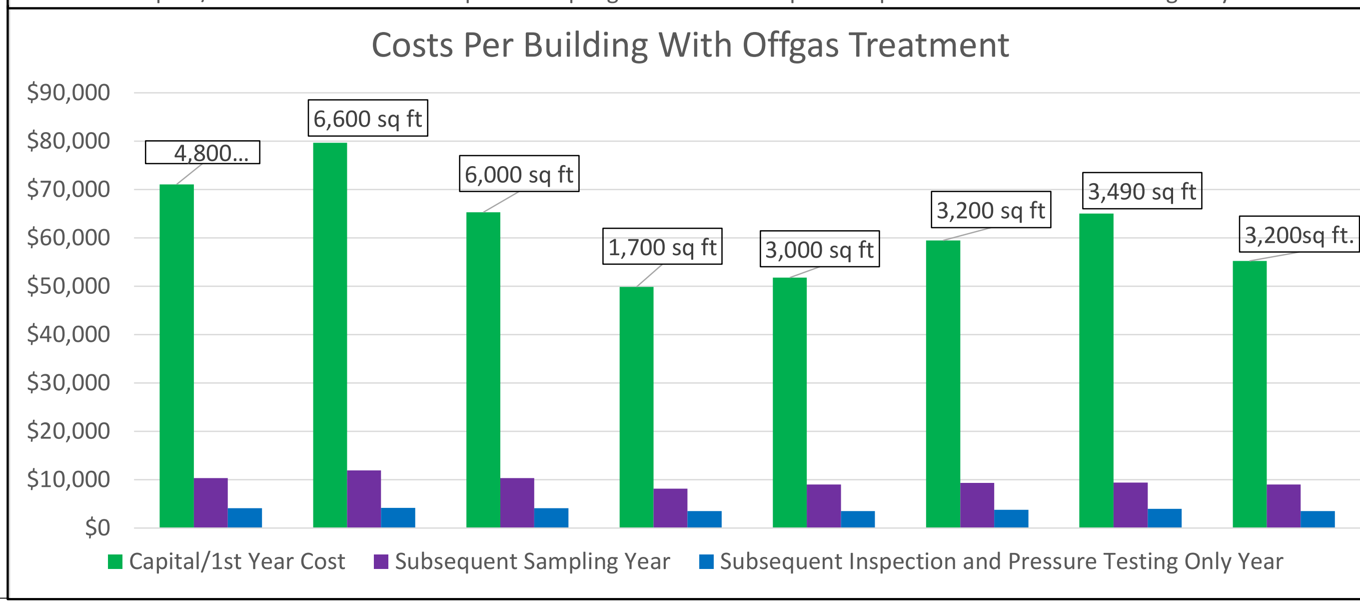
LC0 Elsy I am changing this number, I also reordered the blocks

Lutes, Christopher, 2023-03-16T00:20:05.616

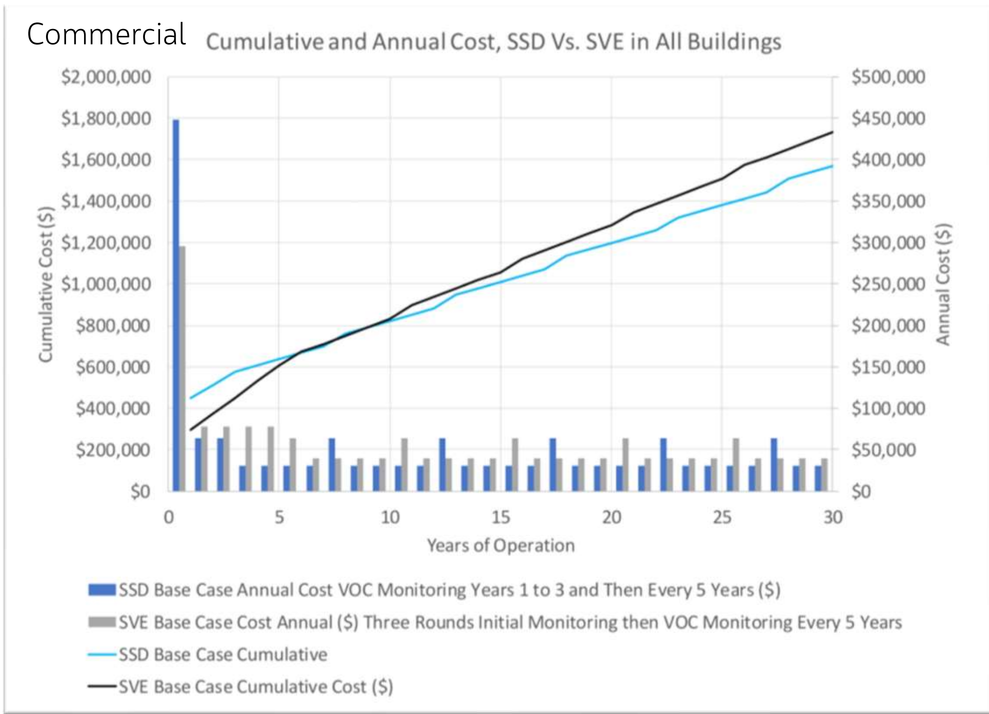
Estimated Cost Impact of Changes from Commercial No GAC to Residential with GAC

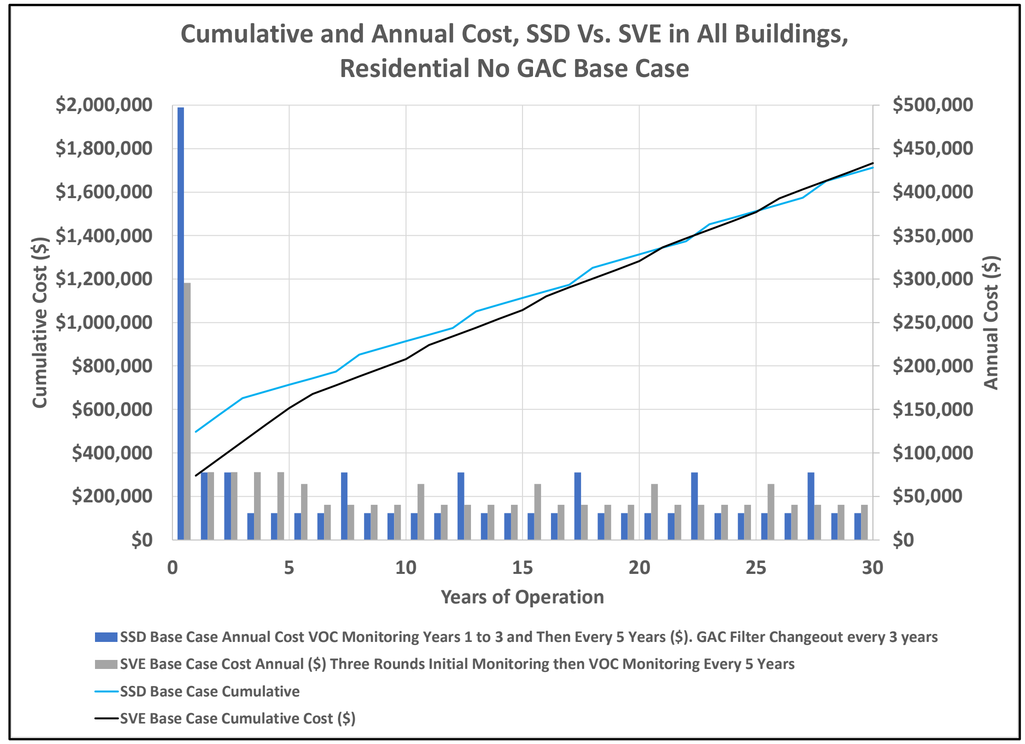
- Changes shown per building
- Bars represent capital, and subsequent sampling years vs. inspection only years





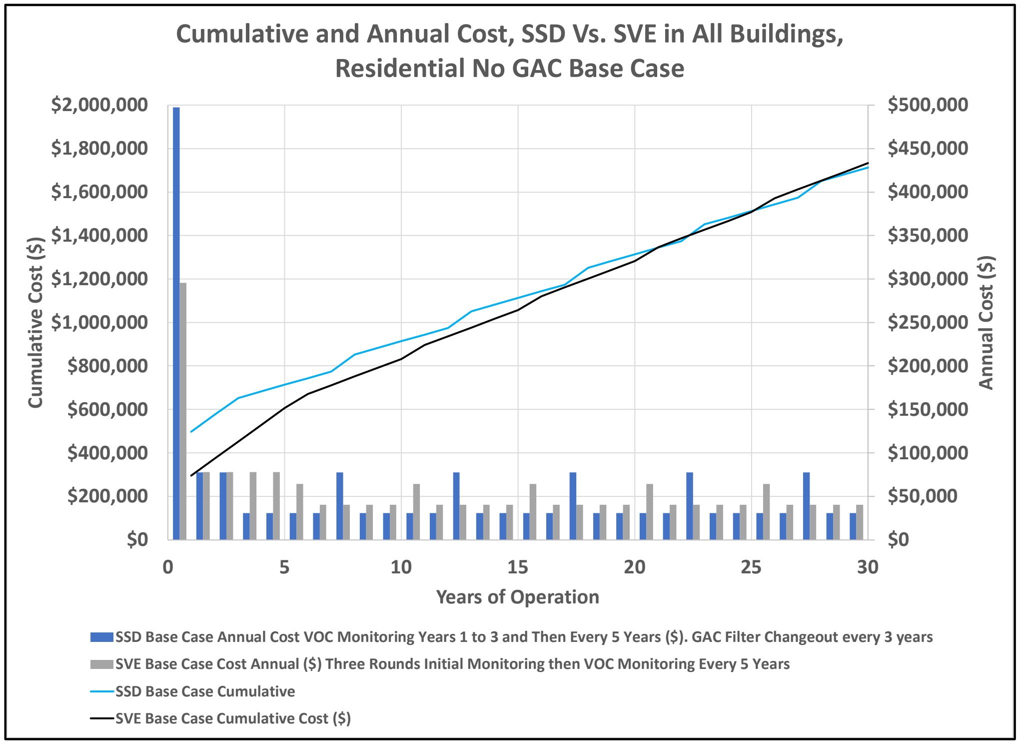
Impact of Going from Commercial Without GAC to Residential without GAC: Source Zone SVE as In Previous Paper

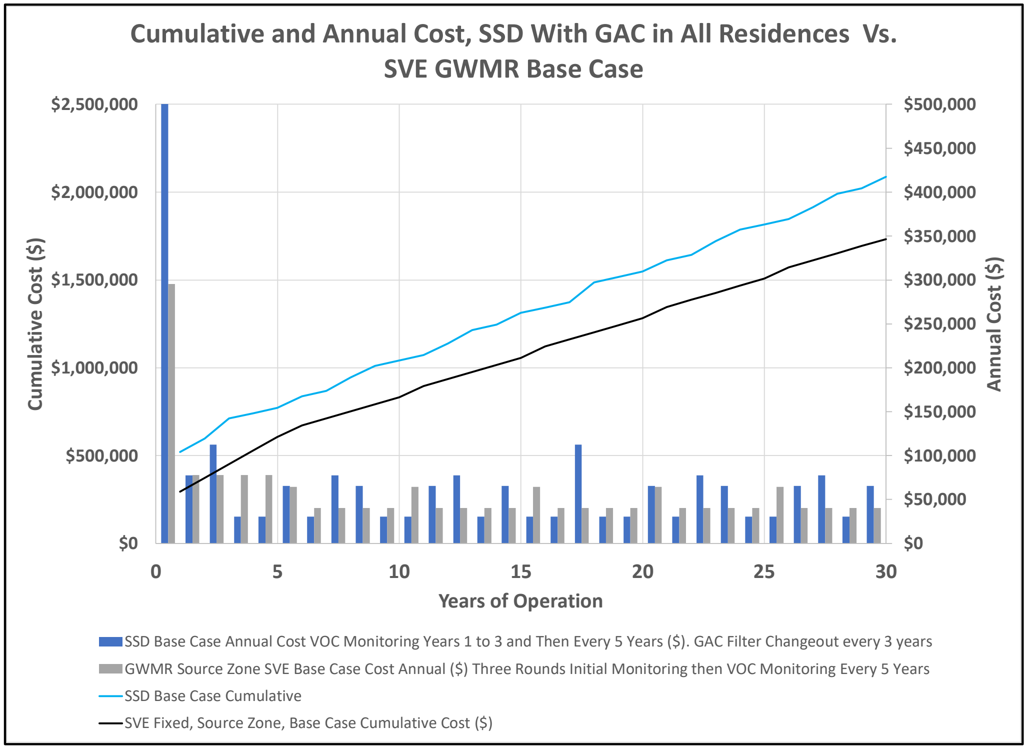




Commercial to Residential Change Raises SSD Cost slightly (more suites, Leads to Essentially a Tie)

Impact of Going from Residential Without GAC to Residential with GAC; Source Zone SVE as In Previous Paper



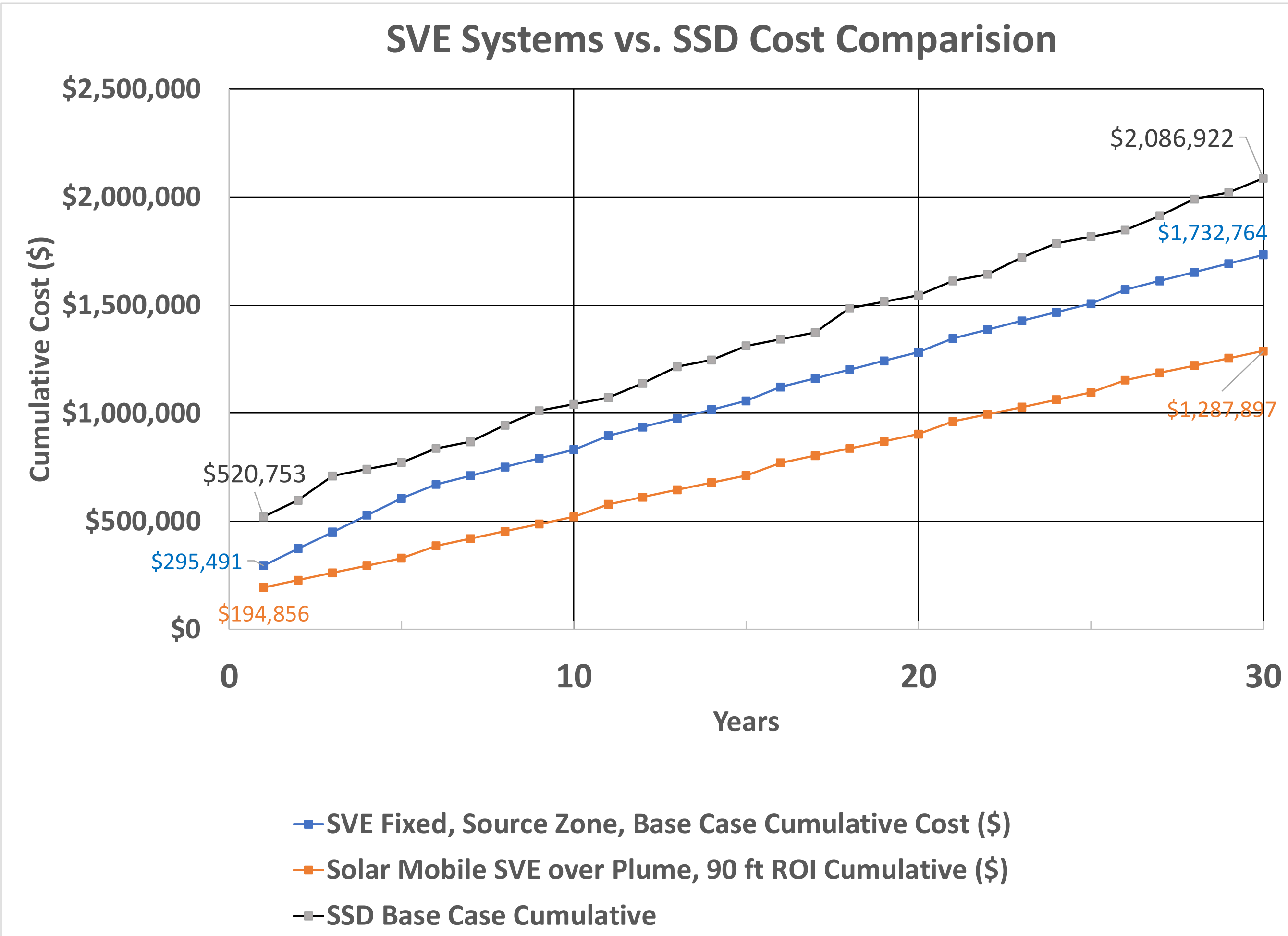


Adding offgas treatment to SSD makes SVE the cheaper alternative

New Option Analysis –Mobile Solar Powered Shallow SVE – System Introduced in Bo's Previous Talk

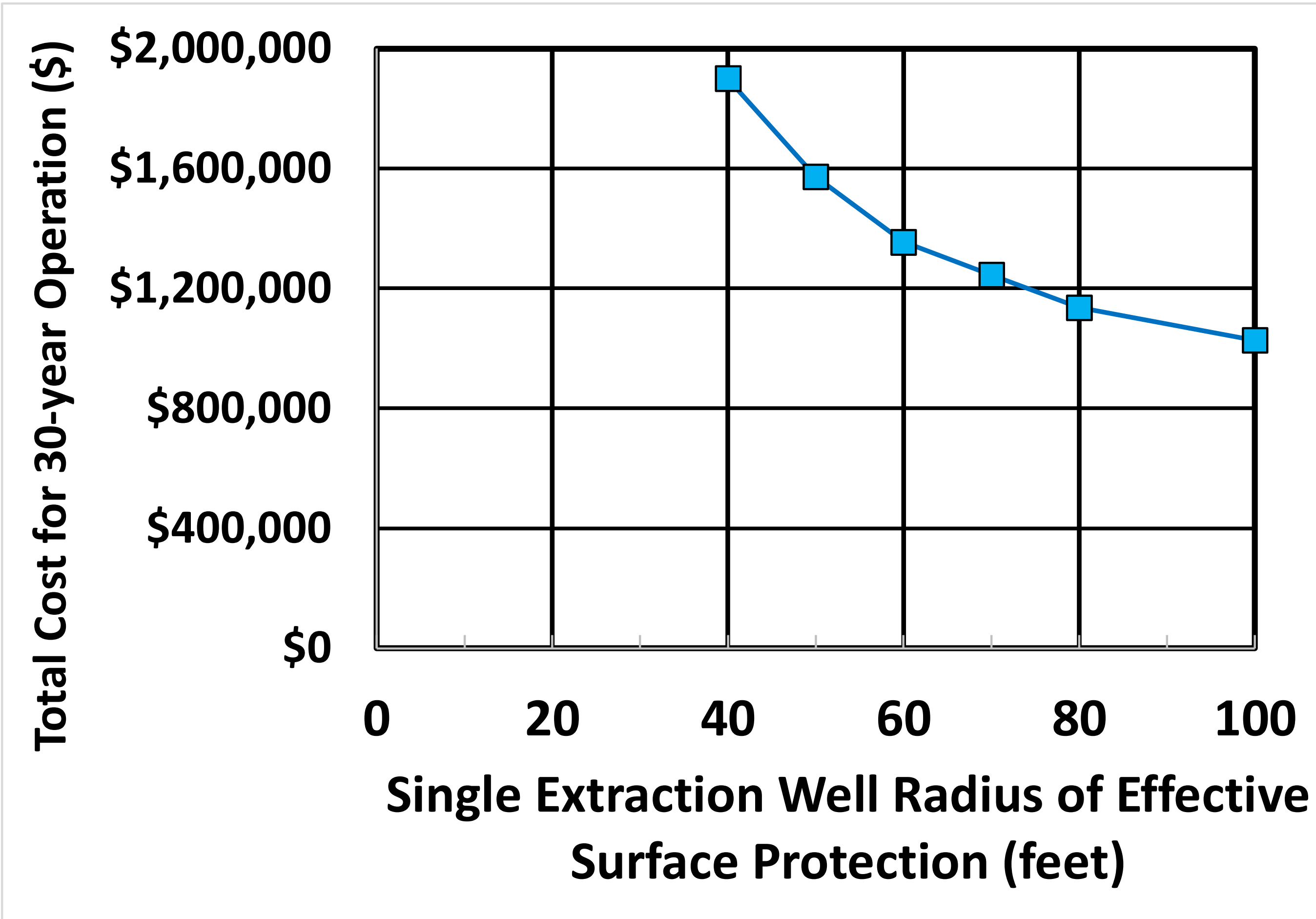
- Elements of estimate include:
  - Development of design basis through a one day pilot test with 1 HP rented system, 24 vapor samples
  - Design and purchase of trailer mounted SVE system with 5 HP Blower, controls, telemetry and solar power. Includes 2 * 200 lb carbon beds. Includes drilling three extraction wells and installing 2 multidepth sample ports.
  - Initial flushing and operational period; one week on each of several extraction wells with sample analysis; prepare site specific O&M plan
  - Operates one month on each well, only during periods when solar is sufficient
  - Annual Operating Cost, Quarterly sampling of sentinel wells
- Assumptions in Long Term Cost Analysis
  - First year includes short design pilot test, deploy SVE system, initial flushing & operation, Soil Gas and Offgas Monitoring
  - Subsequent years are routine mobile operations, with soil gas and offgas monitoring
  - Subslab monitoring only in buildings in years 1, 6, 11, 16, 21, 26…..

Impact of Changing from Fixed Source Zone SVE to Mobile Solar SVE



Key Point: Mobile, solar SVE over plume less expensive, even in capital cost, as compared to fixed source zone SVE.

Mobile Solar Soil Gas Sampling – Life Cycle Cost as Function of Radius of Influence – 1 Acre Site as in GWMR



Mobile Solar SVE – Life Cycle Cost as Function of Acreage

- Assumes a constant 90 ft ROI
- w/o subslab but with external soil gas and offgas monitoring

Size	Number of Extraction Wells	Design + Capital Cost ($K)	10 Year Cumulative Cost ($K)	30 Year Cumulative Cost($K)
1 Acre (as in 8 bldg. case)	2	$114	$465K	$1,136
7 Acres	12	$253	$1,301	$3,240

What Happens if I Don't Separately Attack the Original Source?

- It depends on the time for the "news of cleanup" to arrive at the downgradient location, but your grandchildren will save money in mitigation or downgradient SVE if you cut operating duration by attacking the source.
- Costs here are constant dollar, without inflation, without net present value
- Does not account completely for equipment wearing out, buildings going beyond economic life or environmental standards changing

	SSD in 8 Buildings (as in GWMR)	Solar, Mobile SVE over Plume
10 Year Cumulative Cost ($K)	$1,042K	$521K
30 Year Cumulative Cost ($K)	$2,087K	$1,288K
100 Year Cumulative Cost ($K)	$5,645K	$4,030K

"There is general agreement among practicing remediation professionals, however, that there is a substantial population of sites, where, due to inherent geologic complexities, restoration within the next 50-100 years is likely not achievable." National Academy of Sciences "Alternatives for Managing the Nations Complex Contaminated Groundwater Sites", 2012

Conclusions

- Simple spreadsheet models have been developed here to compare:
  - Strategies that rely primarily on monitoring vs. Strategies that employ mitigation early
  - Strategies that focus on building specific mitigation vs. strategies that focus on area SVE
- The balance between mitigation early vs. monitoring to refine risk estimate before mitigating turns on how many rounds you need to be confident.
- In the source zone case, 8 buildings an acre, SSD without GAC exhaust treatment is slightly cheaper than SVE. But if SSD needs to have GAC then SVE is cheaper.
- When the same source zone has only 3 buildings then SSD cheaper. With 16 buildings SVE is much cheaper. Building density matters.
- Changing building from commercial to residential primarily matters for SSD if number of ground floor suites changes.
- A mobile solar powered SVE system over a plume provides a significant cost advantage in the 1 acre, 8 building case vs. fixed, source zone SVE.
- The single mobile solar powered unit with the assumptions used here could serve up to 7 acres downgradient.

For more information:

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Thanks for your interest!

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One Possible Approach: Multi-Criteria Decision Analysis

- Incorporate technical information and stakeholder preferences to identify optimal outcomes
  - Determine **Alternatives** for evaluation
  - Define **Criteria** for decision-making
  - Experts measure and **Score** how well alternatives achieve criteria
  - Stakeholders subjectively **Weight** importance of criteria independent of alternatives
  - Scores and weights combined to give **Overall Values**, used to select optimal alternative
  - Overall values compared to with life cycle **Costs**

Multi-Criteria Decision Analysis (cont.)

Decision Criteria

Maximize Protection | Minimize Disruption | Minimize Time to Implement | Minimize Time to Reduce Source

Subjective Stakeholder Weights of Criteria (0-100; least to most important)

Criteria	Martin	Sylvia	Annette	Emil	Lena	Chao	Geometric Mean
Maximize health protection	70	100	80	80	90	100	**86**
Minimize occupant disruption	100	85	20	85	100	60	**67**
Minimize time to implement	100	90	100	35	20	40	**54**
Minimize time to remediate	90	65	80	80	70	70	**75**

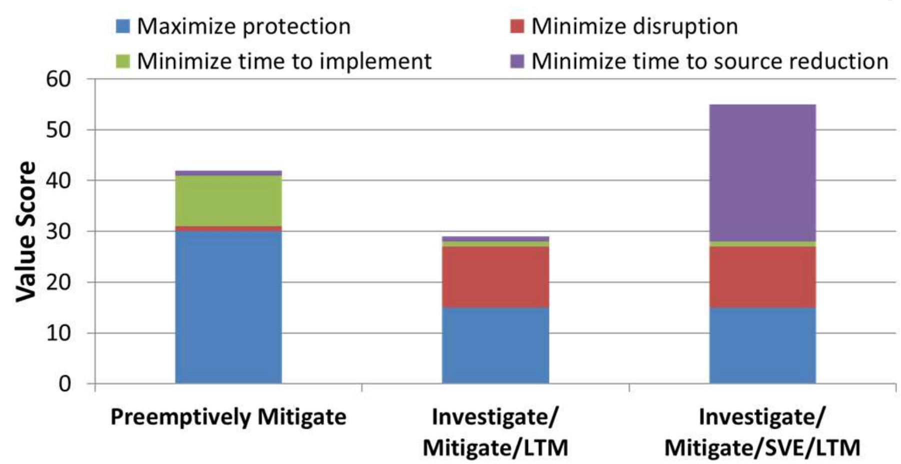
Martin - Facility RPM
Sylvia - Community Representative
Annette - Federal regulator
Emil - State regulator
Lena - Facility public health SME
Chao - Regulatory public health SME

Objective Expert Scores of Alternatives

Scores and Weights Combined

Alternative 3 has highest value score, but cost not considered

Overall Value Scores



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VI Economics Analyses – Sampling Strategies

- Kram et al. (2016) - analysis comparing cost associated with continuous monitoring of VOC concentrations using on-site gas chromatography-electron capture detection (GC-ECD) instrumentation against cost associated with more conventional approaches (e.g., multiple discrete sampling events using canisters). Argued in favor of the on-site GC-ECD in most cases.

Vs

- Nocetti et al. (2019) developed a decision model using a variety of factors to assess the cost and effectiveness of different sampling strategies and recommend long-duration sampling to reduce uncertainty
- An economic analysis sponsored by the U.S. Environmental Protection Agency (USEPA) compared the cost of random or seasonal sampling-based assessment approaches to those that where sampling is driven by a low cost, continuously measured indicator or tracer (I&T), such as differential temperature or radon (Schuver, 2015, 2021; Lutes 2022a). Results:
  - I&T beneficial to make sample number manageable, reduce cost.
  - Sometimes a preemptive mitigation decision forced by a stringent action level actually reduced cost vs. sampling enough to resolve a "grey area" case confidently.

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