Considerations for Conducting Ecological Risk Assessments (ERAs) at Per- and Polyfluoroalkyl Substances (PFAS) Sites

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Jason Conder, Geosyntec
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Summer 2024

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Information in this presentation is current as of 7 May 2024.

EXWC: Engineering and Expeditionary Warfare Center
NAVFAC: Naval Facilities Engineering Systems Command

Additional Disclaimer: Jason Speicher/Navy

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Speaker Introduction

Jason Speicher, MBA
Biologist
NAVFAC Atlantic

- ERA SME for NAVFAC Atlantic
- Provide SME support to both active (ERN) and closed (BRAC) Navy facilities
- Provide policy and guidance support to Navy management
- Member of the SERDP/Environmental Security Technology Certification Program's Technical Advisory Committee for research associated with PFAS and contaminated sediments
- Member of Navy's Emerging Chemicals Workgroup
- Former steering committee member for the USEPA Ecological Soil Screening Level (Eco-SSL) effort
- Currently working with various Navy and DoD researchers on efforts to fill knowledge gaps for toxicity and bioaccumulation associated with PFAS

BRAC: Base Realignment and Closure
DoD: Department of Defense
ERA: ecological risk assessment
ERN: Environmental Restoration
MBA: Master of Business Administration
NAVFAC: Naval Facilities Engineering Systems Command
PFAS: per- and polyfluoroalkyl substances
SERDP: Strategic Environmental Research and Development Program
USEPA: United States Environmental Protection Agency

Speaker Introduction

Jason Conder, PhD
Principal
Geosyntec Consultants

PhD: Doctor of Philosophy

- PhD Environmental Toxicologist and Chemist
- Environmental risk assessor certified by the International Board of Environmental Risk Assessors
- Working with the Navy as a consultant for over 15 years
- Professional focus on PFAS site investigation and risk assessment
- Various PFAS projects since ~2005
  - 9 peer-reviewed papers on PFAS (chemistry, ecotoxicology, risk assessment)
  - US DoD Frequently Asked Questions PFAS
  - US DoD Guidance for PFAS ERA
  - Several ongoing risk assessments for PFAS
  - Working with DoD on several PFAS ecorisk, ecotoxicology, and passive sampling projects

Speaker Introduction

Jennifer Arblaster, MRM
Senior Scientist
Geosyntec Consultants

- Master of Environmental Resource Management
- ERA, sediment site assessment, and food web modelling expertise
- Professional focus on PFAS site investigation and risk assessment since 2014
- Various PFAS projects, including the following
  - US DoD Guidance for PFAS ERA
  - Working with DoD on three PFAS aquatic toxicity research projects
  - Several site-specific risk assessments and site investigations for PFAS

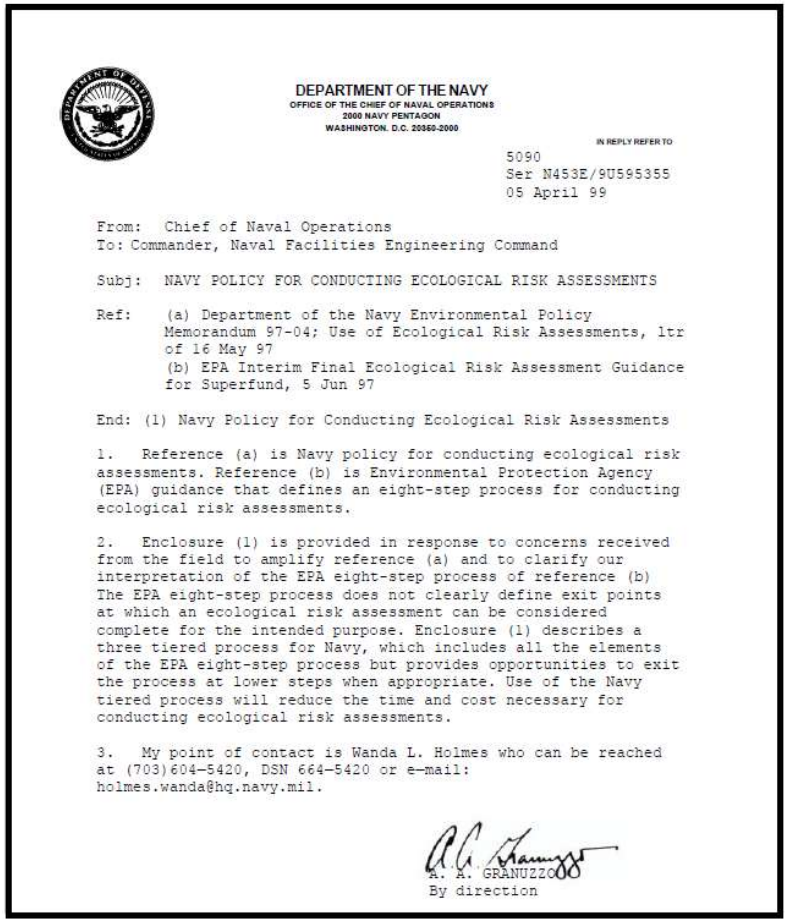
MRM: Master of Environmental Resource Management
US: United States

Presentation Overview

- ERA 101
- ERA for PFAS: *Preface*
- PFAS CSM Considerations and Planning
- Planning for Tier 1 SERA and Tier 2 BERA PFAS ERAs
- PFAS Exposure and Effects Estimation
- PFAS Exposure and Effects Estimation Case Studies
- PFAS Risk Management
- Summary Closing Statements

Navy Guidance for Ecological Risk Assessments (ERAs)

- DoD NERP and Navy NERP Guidance provide basis for completing risk assessments under the CERCLA and RCRA processes
- Existing DoD and Navy policy and standard practice/guidance mirrors USEPA ERA Guidance (1997)
  - Navy ERA Policy (1999) provides tiered process
- NAVFAC (2022) guidance should be followed for ERAs at CERCLA and RCRA sites



DEPARTMENT OF THE NAVY
OFFICE OF THE CHIEF OF NAVAL OPERATIONS
2000 NAVY PENTAGON
WASHINGTON, D.C. 20350-2000

IN REPLY REFER TO
5090
Ser N453E/9U595355
05 April 99

From: Chief of Naval Operations
To: Commander, Naval Facilities Engineering Command

Subj: NAVY POLICY FOR CONDUCTING ECOLOGICAL RISK ASSESSMENTS

Ref: (a) Department of the Navy Environmental Policy Memorandum 97-04; Use of Ecological Risk Assessments, ltr of 16 May 97
(b) EPA Interim Final Ecological Risk Assessment Guidance for Superfund, 5 Jun 97

End: (1) Navy Policy for Conducting Ecological Risk Assessments

1. Reference (a) is Navy policy for conducting ecological risk assessments. Reference (b) is Environmental Protection Agency (EPA) guidance that defines an eight-step process for conducting ecological risk assessments.

2. Enclosure (1) is provided in response to concerns received from the field to amplify reference (a) and to clarify our interpretation of the EPA eight-step process of reference (b) The EPA eight-step process does not clearly define exit points at which an ecological risk assessment can be considered complete for the intended purpose. Enclosure (1) describes a three tiered process for Navy, which includes all the elements of the EPA eight-step process but provides opportunities to exit the process at lower steps when appropriate. Use of the Navy tiered process will reduce the time and cost necessary for conducting ecological risk assessments.

3. My point of contact is Wanda L. Holmes who can be reached at (703)604-5420, DSN 664-5420 or e-mail: holmes.wanda@hq.navy.mil.

A. A. GRANUZZO
By direction

CERCLA: Comprehensive Environmental Response, Compensation, and Liability Act
NERP: Navy Environmental Restoration Program
RCRA: Resource Conservation and Recovery Act

What is ERA?

"…a process that evaluates the likelihood that adverse ecological effects are occurring or may occur as a result of exposure to one or more stressors"

-USEPA (1997)

- ERAs are often part of a larger process that seeks to answer the following questions
  - Are chemicals at a particular site causing adverse effects to ecological resources?
  - Should action be taken to address effects?
  - What should be done (where, how, when)?
    - "To dig, or not to dig, that is the question"

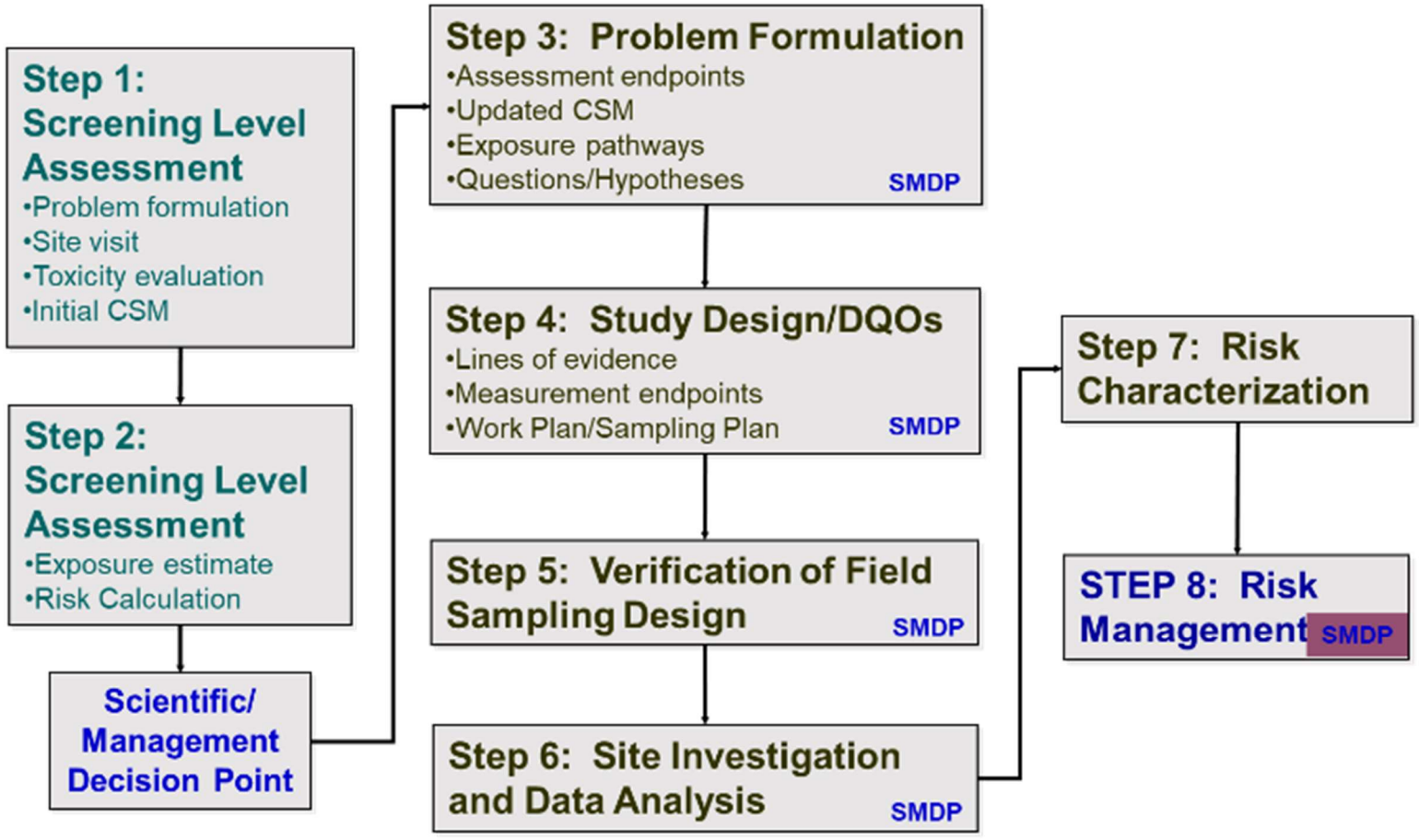
(Pixabay n.d.)

Guiding Principles of ERA

- "The dose makes the poison"
  - Paracelsus, 1500s
- "First, do no harm"
  - Auguste François Chomel, early 1800s (not Hippocrates)
- "A thing is right when it tends to preserve the integrity, stability and beauty of the biotic community. It is wrong when it tends otherwise"
  - Aldo Leopold, *A Sand County Almanac*, 1947
- "Don't do anything stupid"
  - Glenn Suter (USEPA), *Ecological Risk Assessment for Contaminated Sites*, 2000

ERA Overview: CERCLA

1997 USEPA Superfund Guidance for ERA (aka ERAGs)



CSM: conceptual site model
ERAG: Ecological Risk Assessment Guidance
SMDP: Scientific Management Decision Point

ERA Overview: NAVFAC

RPM Input and Risk Management Consideration
Step 8: Risk Management

Tier 1. Screening Ecological Risk Assessment (SERA): Identify pathways and compare exposure point concentrations to benchmarks

Step 1: Site Visit; Pathway Identification/Problem Formulation; Toxicity Evaluation
Step 2: Exposure Estimate; Risk Calculation (SMDP)
Proceed to Exit Criteria for SERA

SMDP: Exit Criteria for the SERA
1) Site passes SERA: A determination is made that the site poses acceptable risk and shall be closed out for ecological concerns.
2) Site fails SERA: Pathways complete and potential unacceptable risk.

Proceed to Tier 2 or Interim Cleanup

Tier 2. Baseline Ecological Risk Assessment (BERA)

Step 3a: Refinement of Conservative SERA Exposure Assumptions
Proceed to Exit Criteria for Step 3a

SMDP: Exit Criteria Step 3a
1) If re-evaluation of the conservative exposure assumptions (SERA) support an acceptable risk determination, then exit the ecological risk assessment process.
2) If re-evaluation of the conservative exposure assumptions (SERA) do not support an acceptable [illegible] continue the BERA process.

Proceed to Step 3b

Step 3b: Problem Formulation—Toxicity Evaluation; Assessment Endpoints; Conceptual Model; Risk Hypothesis (SMDP)
Step 4: Study Design/DQO—Lines of Evidence; Measurement Endpoints; UFP-SAP (SMDP)
Step 5: Verification of Field Sampling Design (SMDP)
Step 6: Site Investigation and Data Analysis (SMDP)
Step 7: Risk Characterization
Proceed to Exit Criteria for BERA

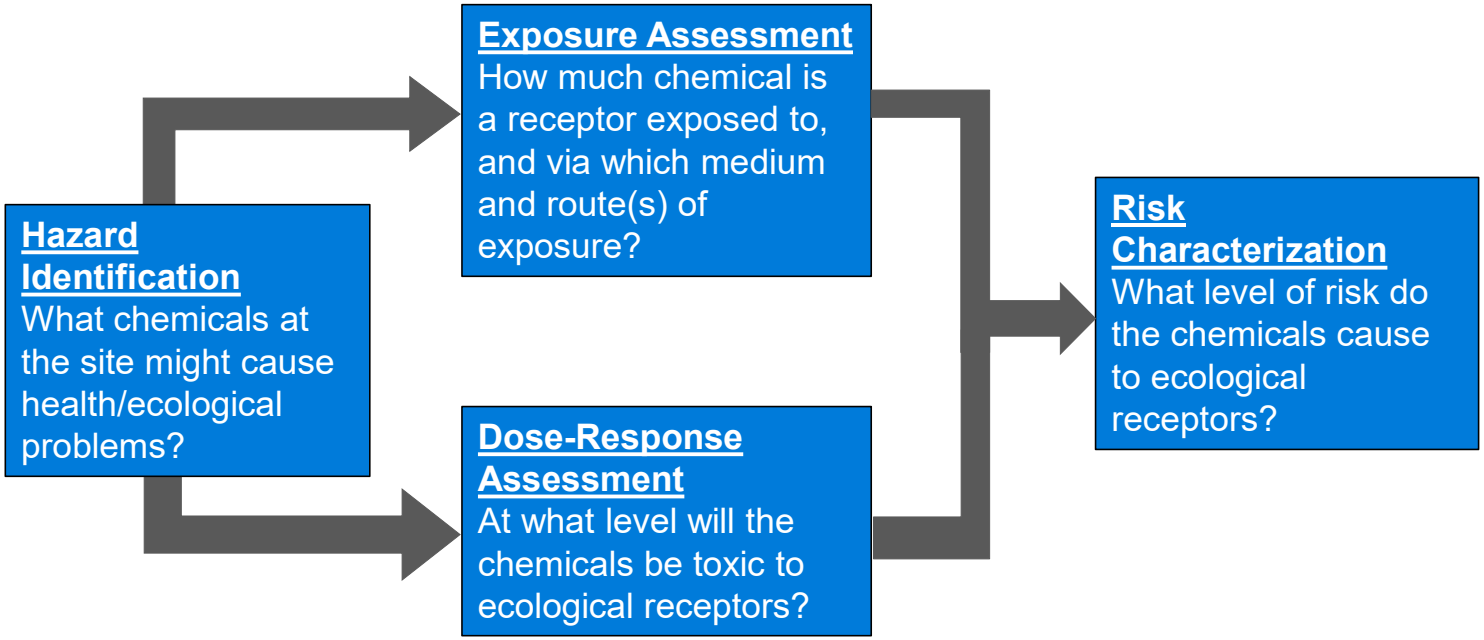
SMDP: Exit Criteria for the BERA
1) If the site poses acceptable risk, then no further evaluation and no remediation from an ecological perspective is warranted.
2) If the site poses unacceptable ecological risk and additional evaluation in the form of remedy development and evaluation is appropriate, proceed to third tier.

Tier 3. Evaluation of Remedial Alternatives (RAGS C)

a. Develop site-specific risk based cleanup values
b. Qualitatively evaluate risk posed to the environment by implementation of each alternative (short-term) impacts and estimate risk reduction provided by each (long-term) impacts; provide quantitative evaluation where appropriate. Weigh [illegible] maining CERCLA Nine Evaluation [illegible] ring and site closeout.

Just a different framing of the same key technical steps!

Four Basic Scientific Parts to Any Risk Assessment



Tier 1 Screening Ecological Risk Assessment (SERA)

- SERA
  - Do we need an ERA?
  - What receptors are exposed (and how)?
- Which chemicals?
- Does a conservative evaluation indicate potential risk?

Tier 1. Screening Ecological Risk Assessment (SERA): Identify pathways and compare exposure point concentrations to benchmarks

Step 1: Site Visit; Pathway Identification/Problem Formulation; Toxicity Evaluation
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1) Site passes SERA: A determination is made that the site poses acceptable risk and shall be closed out for ecological concerns.
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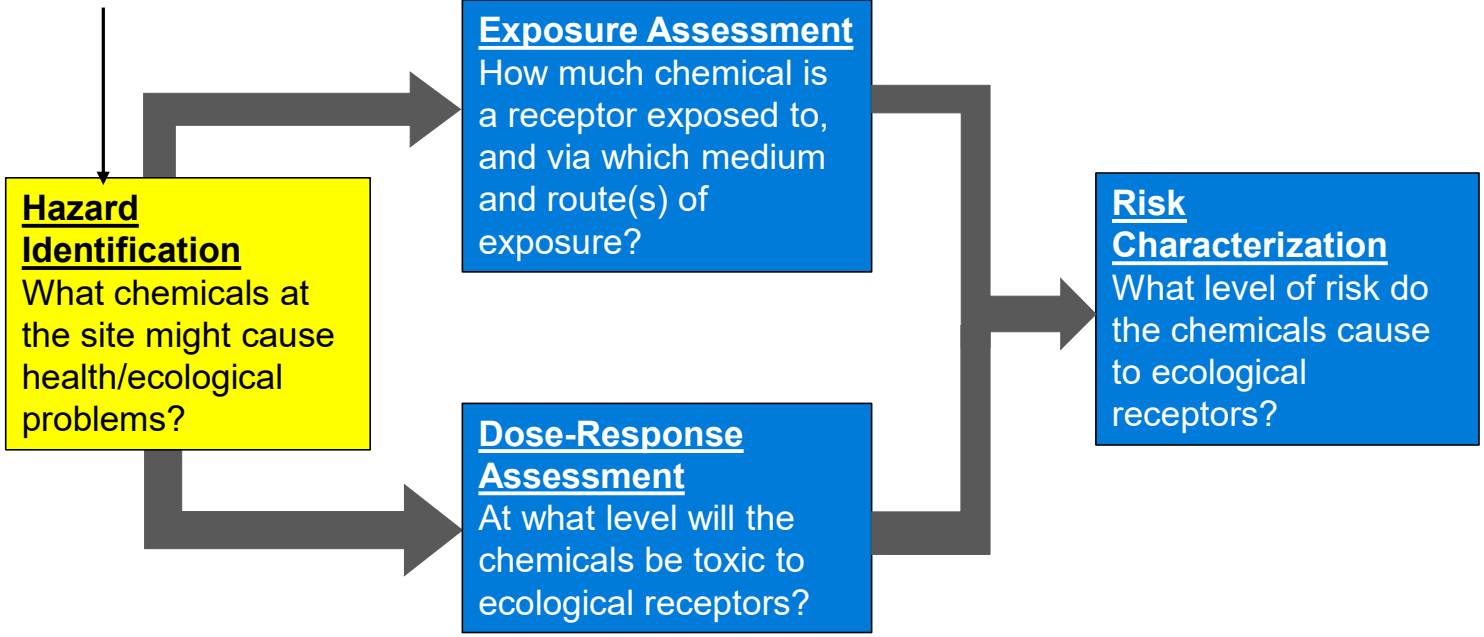
Proceed to Tier 2 or Interim Cleanup

(NAVFAC 2022)

Tier 1 SERA, Step 1: Overview

Tier 1 SERA, Step 1:
Planning and Exposure Pathways

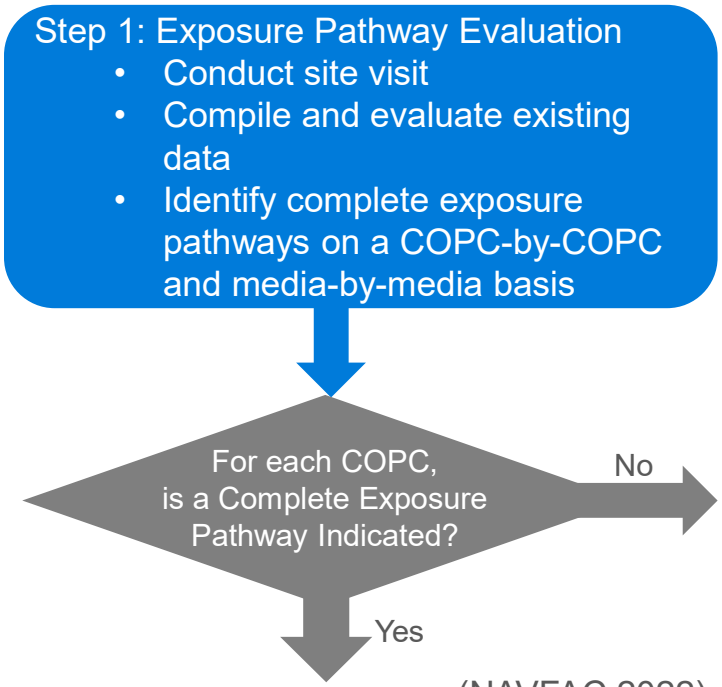


Tier 1 SERA, Step 1: Planning

- Define objectives clearly and early
- Determine technical requirements
  - Sampling methods, lab methods, data evaluation plan
- Identify risk assessment expertise
- Initiate early discussions between risk assessors, RPMs, and other technical staff (engineers, geologists)
- Coordinate early with regulators and other stakeholders
- Conduct a site visit
  - RPMs should scope for the Ecological Risk Assessor to visit the site

COPC: chemical of potential concern
RPM: remedial project manager

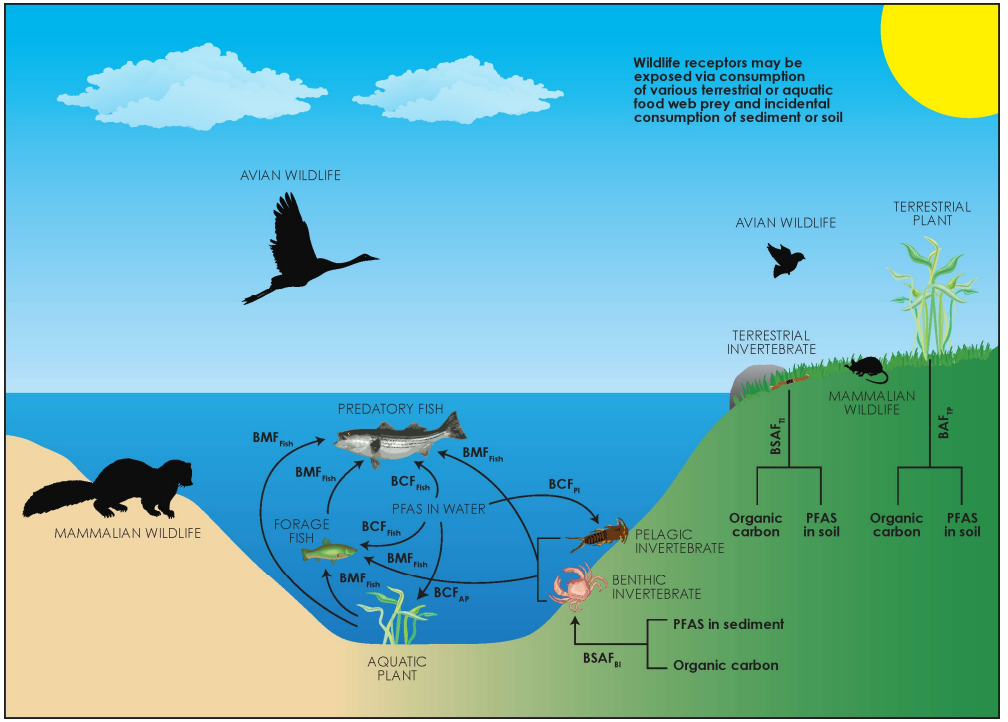
Objectives and requirements get more complex with each tier



(NAVFAC 2022)

Tier 1 SERA, Step 1: Exposure Pathways

- What are your potential exposure pathways?
  - To have a risk, you must have a potential exposure
  - In ERAs, we evaluate current exposure, not hypothetical future exposure
- What are your potential ecological receptors?
  - Terrestrial receptors
  - Aquatic receptors
  - Any Threatened or Endangered Species
- What are we trying to protect?
  - Assessment versus Measurement endpoints



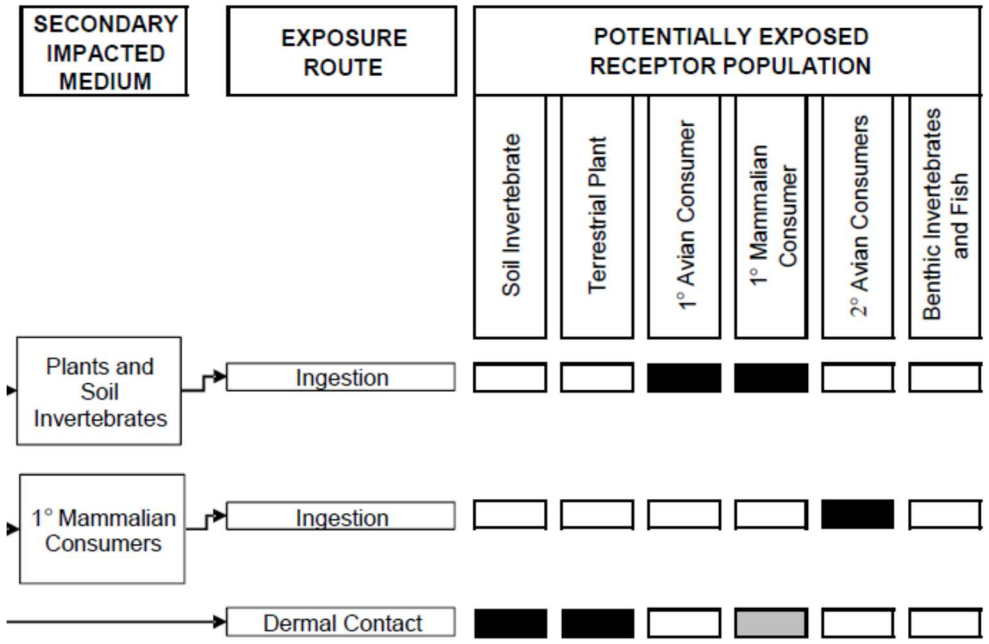
Generic CSM
(Conder et al. 2020)

Tier 1 SERA, Step 1: Conceptual Site Models (CSMs)

- Do we need an ERA?
- What are the exposure pathways?
- **A CSM helps you organize**

☑ Chemicals
☑ Valued ecological receptors
☑ Exposure pathways

Notes:
- Complete exposure pathway that will be quantitatively evaluated.
- Potentially complete, but insignificant pathway.
- Incomplete exposure pathway; no evaluation or management action is necessary.



KEY POINT

CSMs provide a road map to which pathways require quantified assessment.

(Conder n.d.)

Tier 1 SERA, Step 1: Data Planning

- What abiotic data will you need to determine exposure to chemical concentrations in the Tier 1 SERA?
  - Soil, surface water, sediment (sediment porewater)?
  - What data do I have, and can it be used?
  - Will my data quality be adequate for conducting a Tier 1 SERA?
  - How much data do I need?

- Key data goal: EPC
  - A single number representing a concentration of a chemical (in soil, water, etc.) at your site
    - Tier 1 SERA, Step 1: maximum concentrations in abiotic media
    - Tier 2 BERA, Step 3a: 95 UCLs: USEPA's ProUCL tool is a good resource for calculating 95 UCLs
- In Step 1, EPCs can be compared to screening values and used in exposure models

BERA: baseline ecological risk assessment
EPC: exposure point concentration
SERA: screening ecological risk assessment
UCL: upper confidence limit

Tier 1 SERA, Step 1: Screening

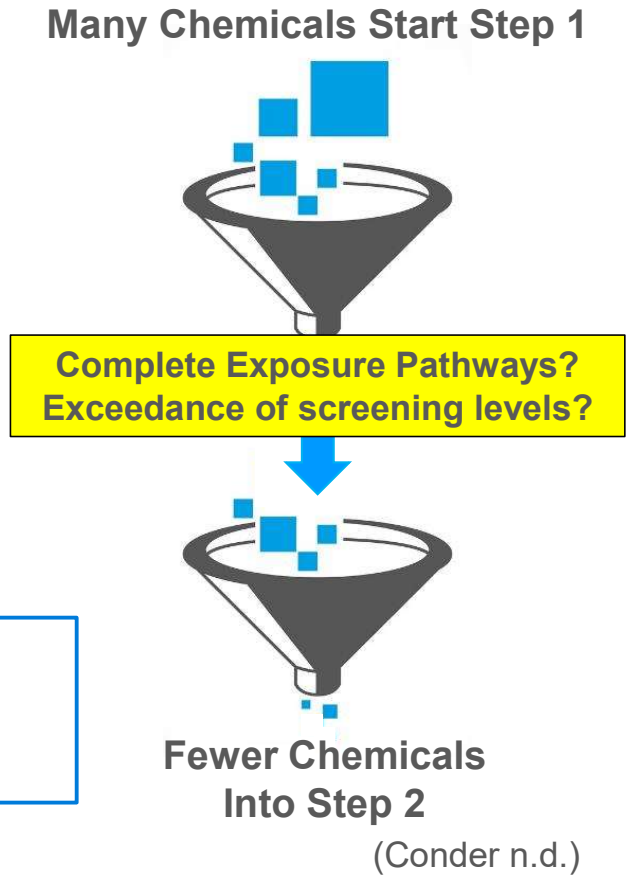
- In Step 1, in addition to considering complete exposure pathways, EPCs are often compared to conservative screening values
- Chemicals that exceed conservative screening values proceed to Tier 1 SERA, Step 2

Basis of Screening Levels
- Established screening values (USEPA AWQC, Eco-SSLs, Biological Technical Assistance Group Region 3, Oak Ridge National Laboratory values)
- Literature-based values

KEY POINT

The Tier 1 SERA is a conservative screen intended to eliminate chemicals with no complete exposure pathways and eliminate chemicals present at "safe" concentrations.

AWQC: ambient water quality criteria
Eco-SSL: ecological soil screening level



(Conder n.d.)

Tier 1 SERA, Step 2: Overview

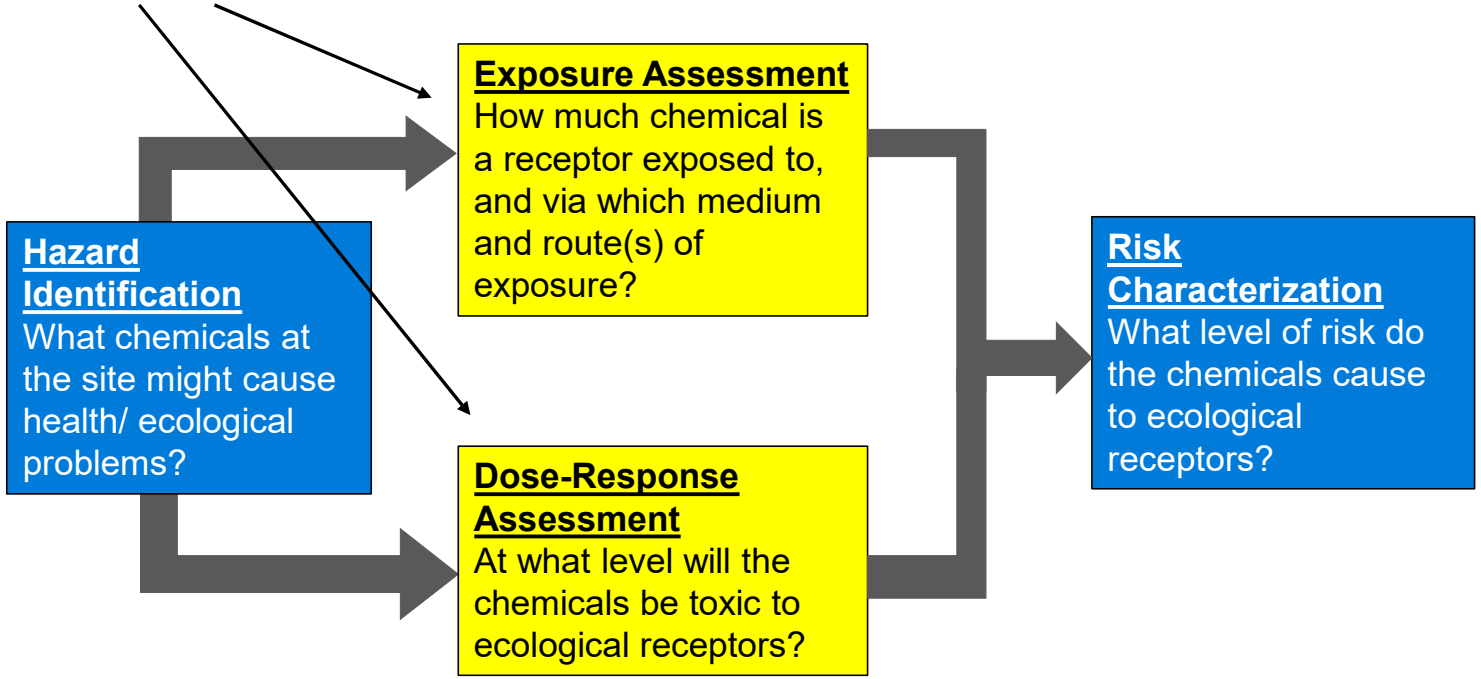
Step 2: Conduct Exposure/Dose Estimation and Risk Calculation for Remaining COPCs

- Estimate exposure and dose using conservative assumptions
- Compile COPC-specific screening values
- Estimate risk potential using hazard quotient approach

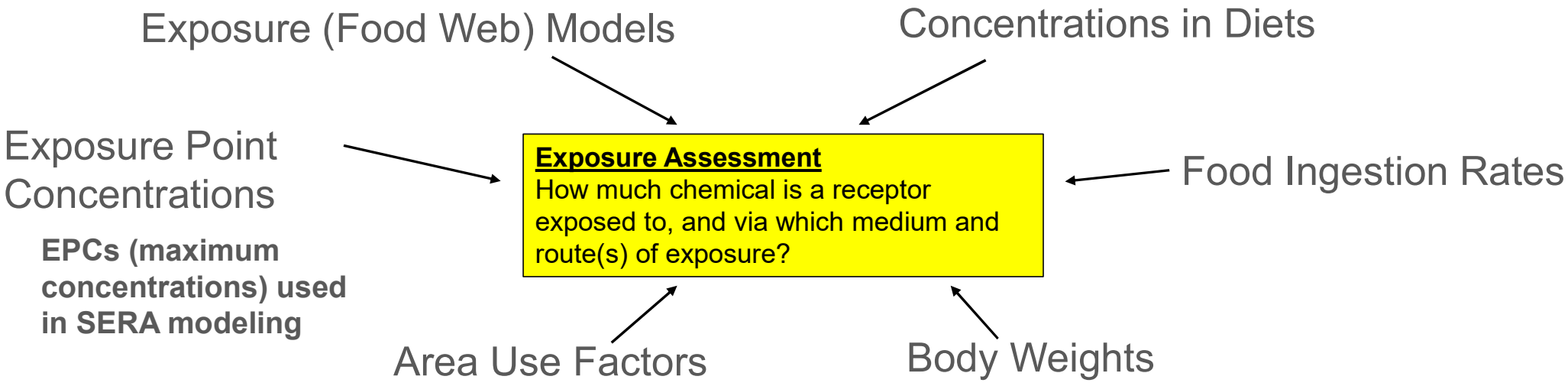
(NAVFAC 2022)

Tier 1 SERA, Step 2: Overview

Tier 1 SERA, Step 2:
Exposure and Effects Calculations



Tier 1 SERA, Step 2: Exposure Assessment



KEY POINT

Exposure Assessment quantifies the amount of a chemical that receptors are exposed to (internal dose, or external media concentration).

(Conder n.d.)

Where Do Ecorisk Exposure Models Come From?

- In their most basic form, ecorisk models are a series of several Excel spreadsheets that use site EPCs to estimate site-specific exposures to selected representative ecological receptors
- Eco-Risk Assessors usually operate these models

$$DI = [\Sigma(Ci \times Fi \times FIR) + (Cs \times SIR)] \times AUF \times (1/BW)$$

Where:

- DI = daily intake (dose) (mg/kg*day)
- Ci = concentration in food item i (mg/kg; wet weight)
- Fi = fraction of diet comprised of food item i (unitless)
- FIR = food ingestion rate (kg/day; wet weight)
- Cs = concentration in soil (or sediment) (mg/kg; dry weight)
- SIR = soil (or sediment) ingestion rate (kg/day; dry weight)
- AUF = area use factor (unitless, max of 1) = Home range ÷ Site Area
- BW = body weight (kg)

kg: kilogram
mg: milligram

(Conder n.d.)

Example: ERA Model Tool for Aquatic Ecosystems

Table 1: Exposure Factors for Selected Receptors

Table 2: Bioaccumulation Parameters

Table 3: Site-specific Data Entry and Food Web Model

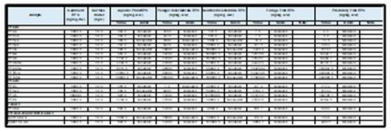
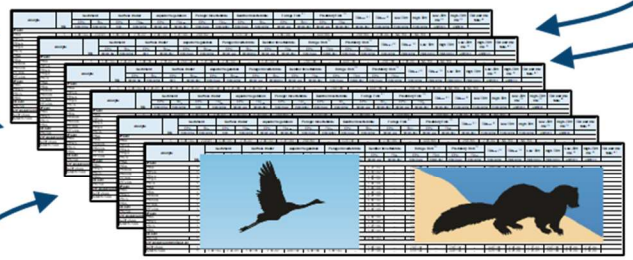


Table 4: Exposure Point Concentrations for All Media

Table 5: Toxicity Reference Values - Birds



Tables 8-13: Exposure Assessment and Hazard Characterization *(up to 5 wildlife species, 1 per table)*

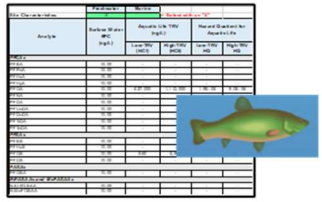


Table 7: Direct Contact Exposures Assessment and Hazard Characterization *(aquatic life)*

Table 6: Toxicity Reference Values - Mammals

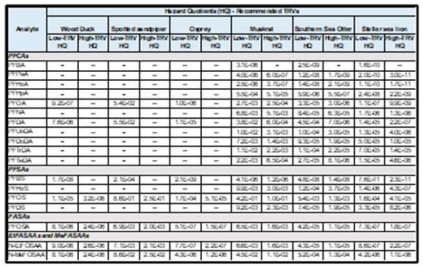
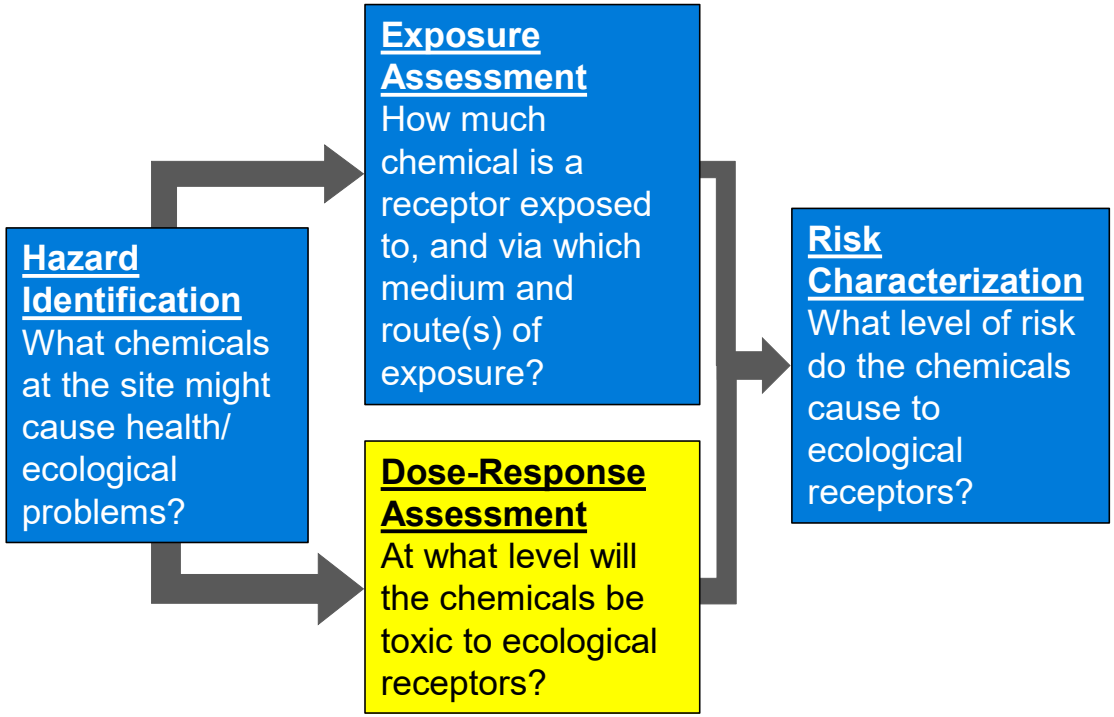


Table 14: Hazard Quotient Summary

(Conder 2020)

Tier 1 SERA, Step 2: Effects Assessment

- Predicted exposures from the models divided by the Toxicity Reference Value (TRV) to calculate a Hazard Quotient (HQ)
  - HQ ≤ 1 = acceptable risk
  - HQ > 1 = potentially unacceptable risk (i.e., more work to do)



$$\text{Hazard Quotient} = \frac{\text{Exposure Value}}{\text{Toxicity Reference Value}}$$

Where do TRVs Come From?

- TRVs
  - Are also known as Screening Ecotoxicity Value (NAVFAC 2022 term), toxicity benchmark, no observed effect concentrations, lowest observed effect concentration, water quality criteria, etc.
  - Are based on dose response

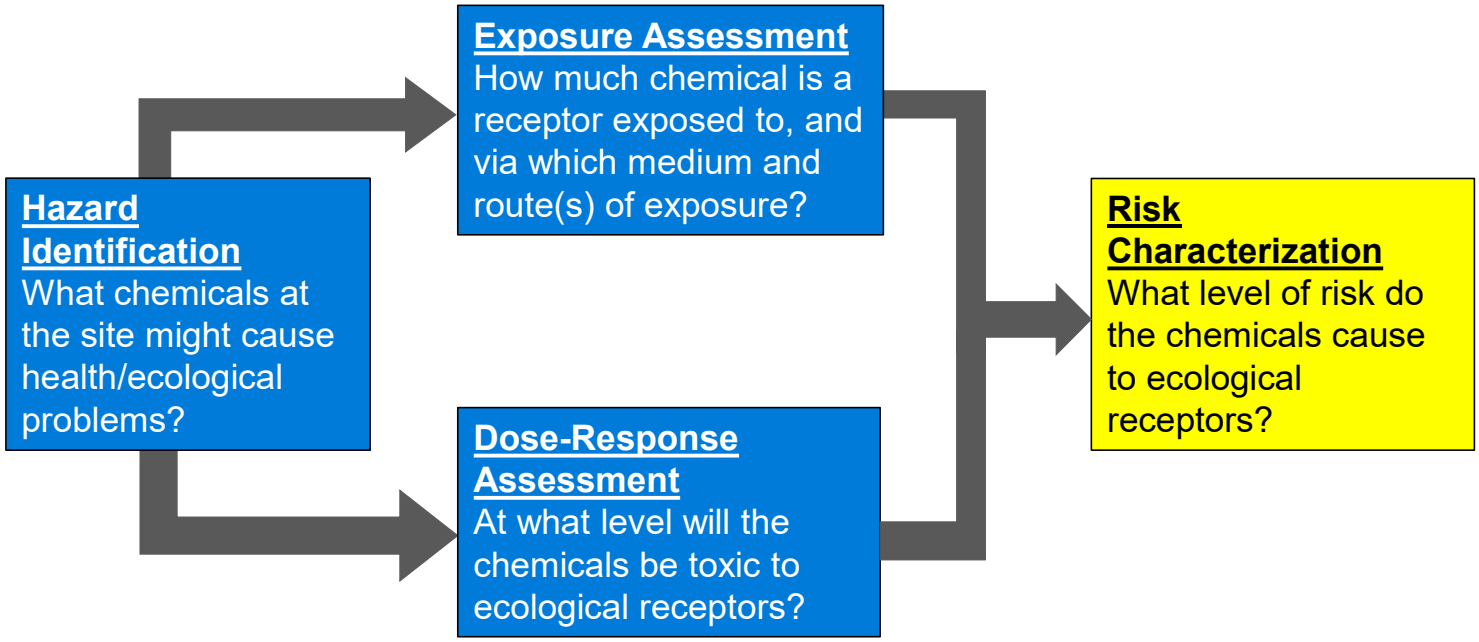
KEY POINT

The Dose-Response Assessment describes the relationship between the level of exposure and the likelihood and/or severity of an adverse effect.

- TRVs are usually derived from controlled experiments in which a laboratory organism is exposed to several doses of a chemical
  - Values obtained from peer-reviewed literature (usually)
  - USEPA and state environmental agencies may have preferred lists
    - Examples: USEPA Ecological Soil Screening Levels, AWQC

Tier 1 SERA, Step 2: Risk Characterization

- HQs are > 1, but
  - Communicate the uncertainties
  - Provide more detail on the assessment
  - Remind yourself and your readers that ERAs are conservative and hypothetical exercises
  - What's the predicted ecological outcome?



HQs > 1?: Common Misperceptions

(Pixabay n.d.)

(Pixabay n.d.)

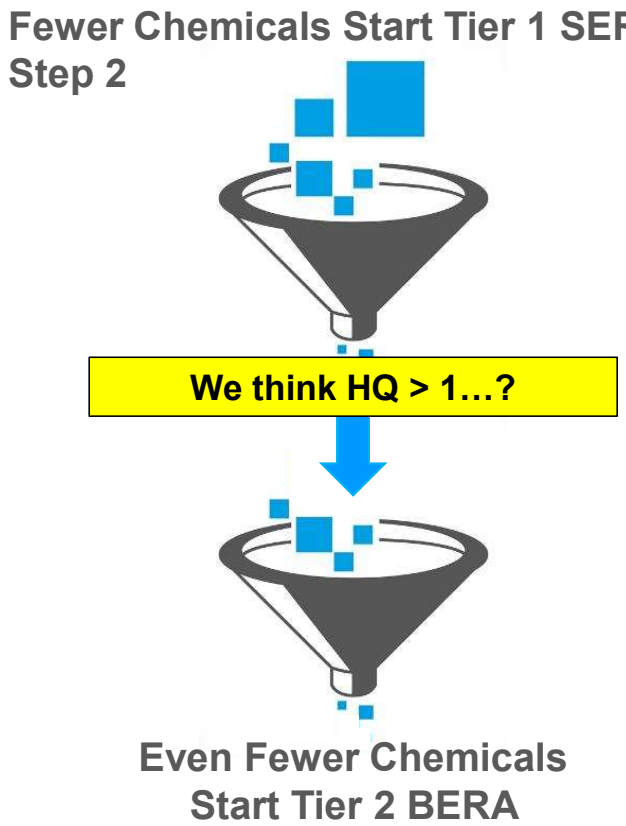
HQs > 1?: Reality






(Conder n.d.)

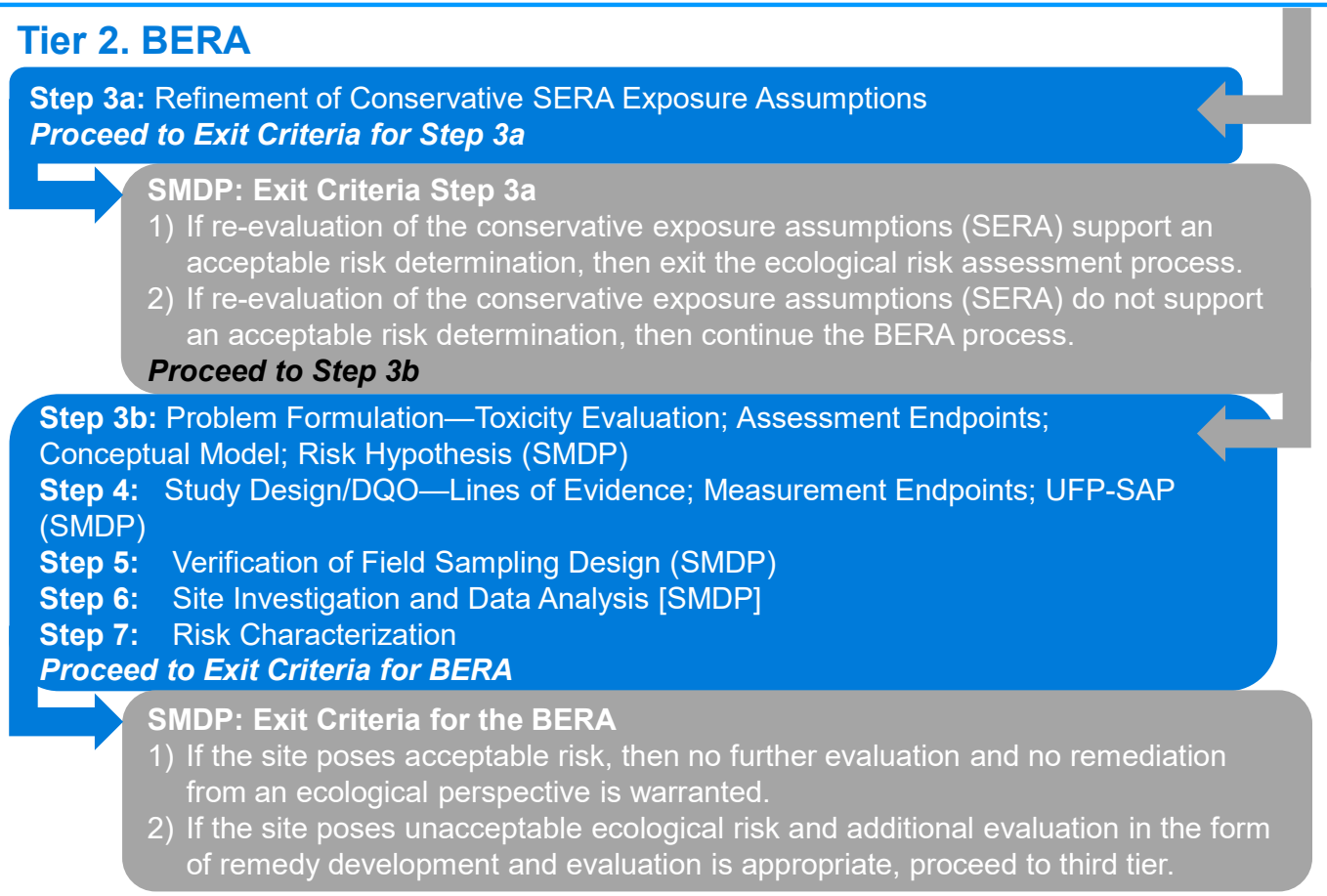
Tier 1 SERA, Step 2: Proceeding to Tier 2 Baseline Ecological Risk Assessment (BERA)



(Conder n.d.)

Tier 2 BERA

- BERA
  - Does a ~~conservative~~ more realistic evaluation indicate potential risk?
  - If potential risk is indicated, should we collect more data?

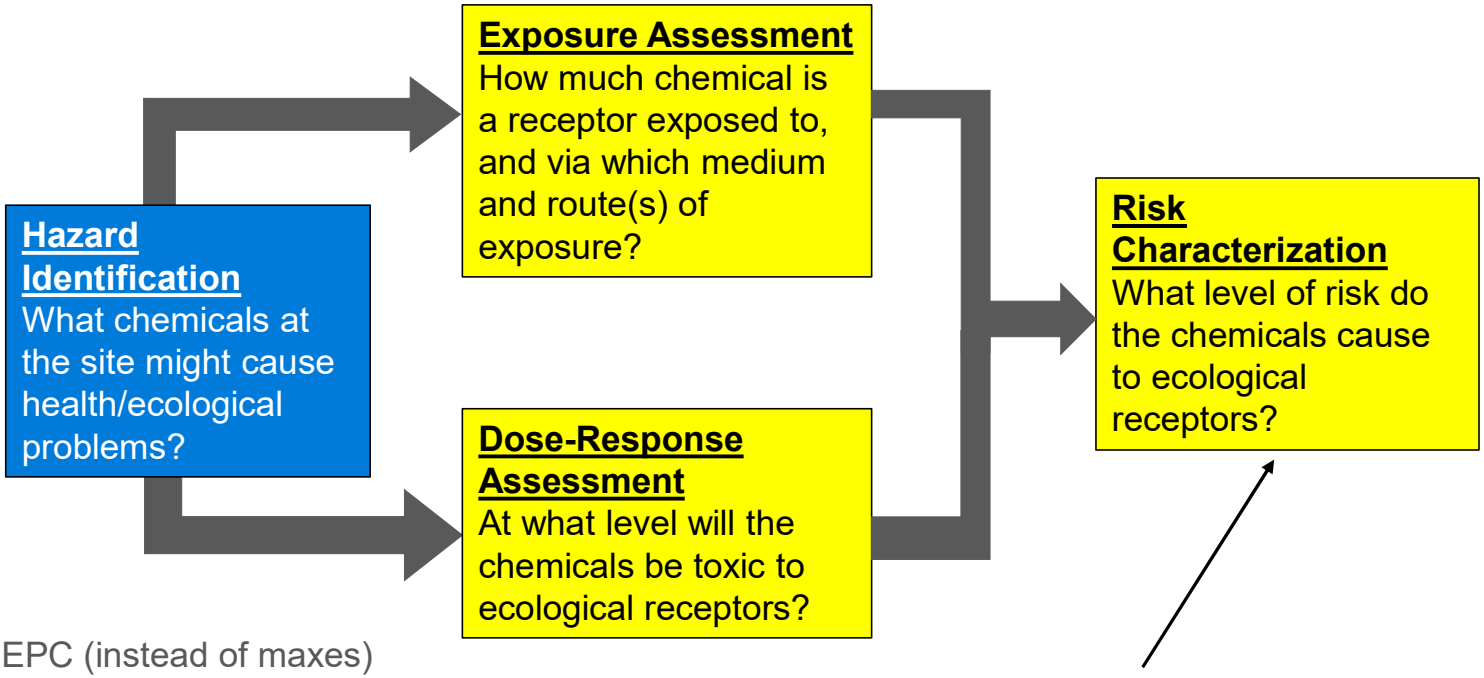


DQO: data quality objective
UFP-SAP: Uniform Federal Policy Sampling and Analysis Plan

(NAVFAC 2022)

Tier 2 BERA, Step 3a: Overview

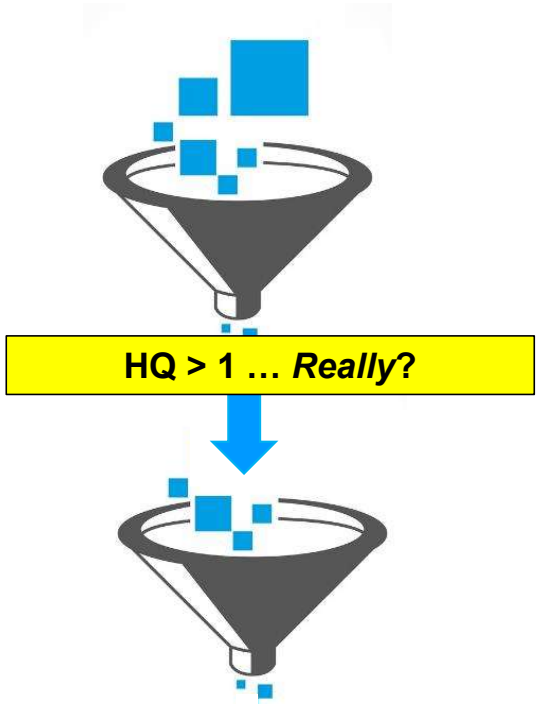
Tier 2 BERA, Step 3a:
Exposure and Effects calculations ***again***, but using less conservative* model assumptions to reduce uncertainty with site-specific considerations



*Examples
- 95 UCLs as the EPC (instead of maxes)
- Assume the animals don't stay at the site 100% of the time
- Digestive availability that is not 100%

And more risk characterization ***again***

Tier 2 BERA, Step 3a: Proceeding to Tier 2 BERA



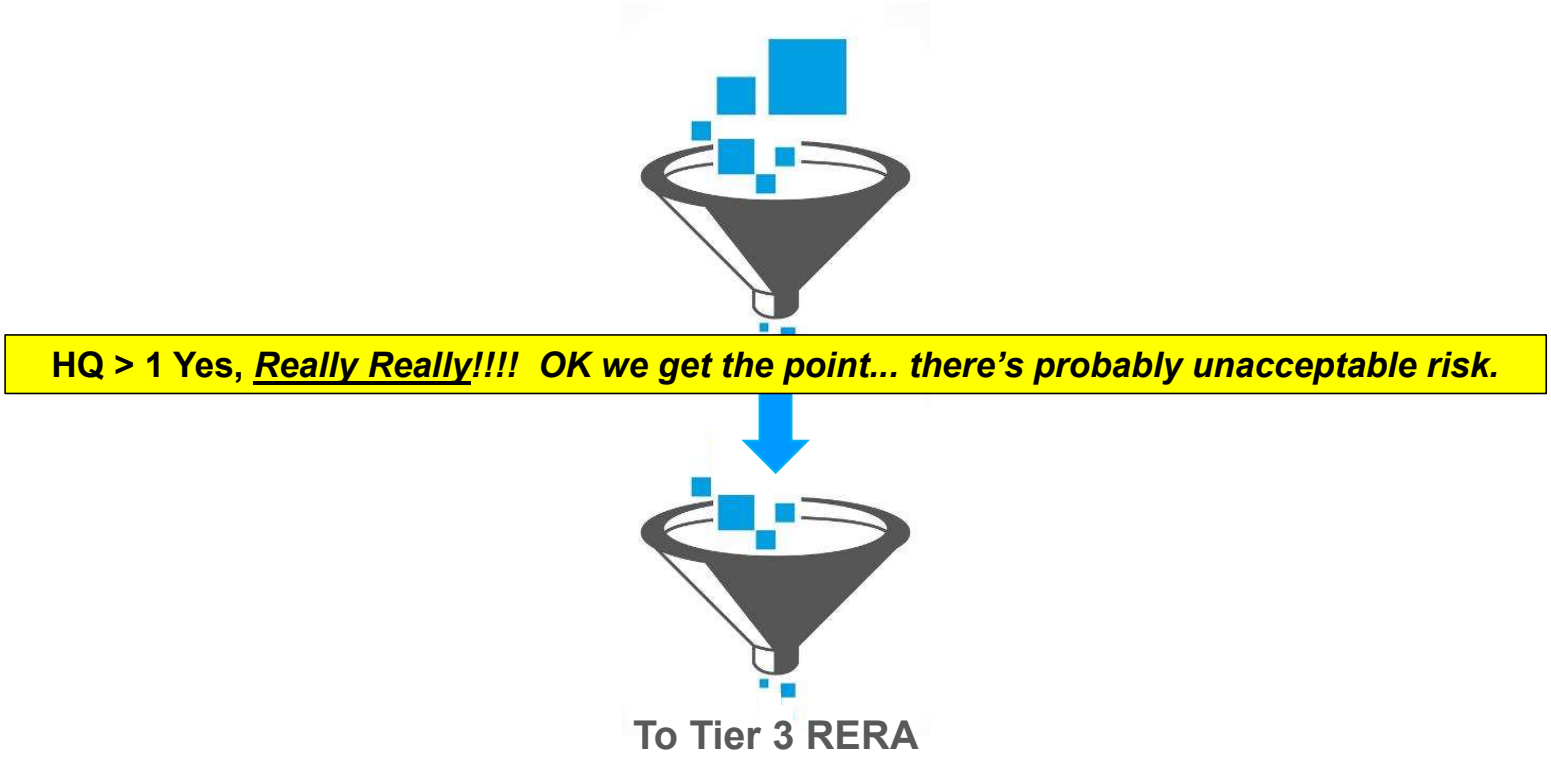
To Tier 2 BERA, Step 3b

(Conder n.d.)

Tier 2 BERA: Step 3b and Beyond

- Making your risk assessment model more site-specific
- Collect more data and re-run HQs
- Examples of additional data collection
  - Measure concentrations of chemicals in wildlife diet items
  - Conduct toxicity testing
  - Evaluate site-specific bioavailability to refine exposure assessment
    - Total organic carbon, porewater passive sampling; simultaneous extracted metals/acid-volatile sulfide (AVS-SEM) for metals, etc.
  - Evaluate the predictions of the risk assessment model: Put the Eco in the Ecorisk!
    - Focused species surveys (wildlife studies)
    - Benthic invertebrate and aquatic census studies
    - Compare results to reference areas (if possible)

Tier 2 BERA: Proceeding to Tier 3 Risk Evaluation of Remedial Alternatives (RERA)



(Conder n.d.)

Tier 3 RERA

- RERA
  - Where do we remediate, how, and what's the cleanup goal?
    - Use existing models and data from the BERA
  - What's the risk to ecological receptors and habitat from a remediation?
    - Don't let the cure be worse than the disease

Tier 3. Evaluation of Remedial Alternatives (RAGS C)

a. Develop site-specific risk based cleanup values.
b. Qualitatively evaluate risk posed to the environment by implementation of each alternative (short-term) impacts and estimate risk reduction provided by each (long-term) impacts; provide quantitative evaluation where appropriate. Weigh alternative as appropriate. Plan for monitoring and site closeout.

(Pixabay n.d.)

RAGS C: Risk Assessment Guidance for Superfund Part C

NAVFAC
Naval Facilities Engineering Systems Command
EXWC Engineering and Expeditionary Warfare Center

ERA 101 Knowledge Check

Do You Need an ERA?

CSM Example: US Army Reserve Center

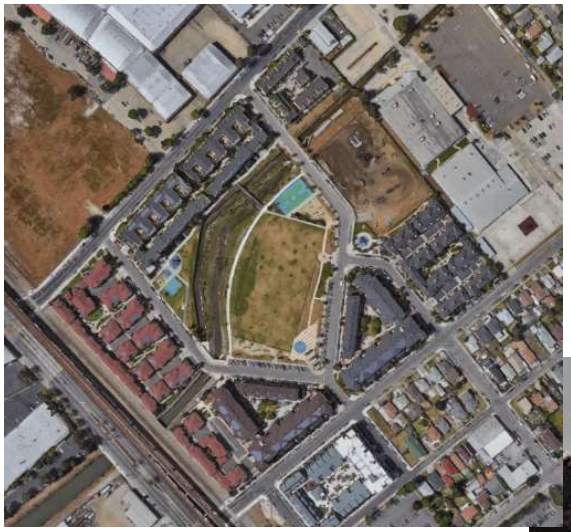
- US Army Reserve Center, Marine Corps Air Station Miramar, San Diego
- 0.1 km^2 shrubland habitat
- Metals (copper, lead) present in soil due to light industrial activity

☑ Chemicals
☑ Valued ecological receptors
☑ Exposure pathways

km^2: square kilometer

(Google Earth 2023)

CSM Example: Oakland Gardens



- Impacted soil (metals, pesticides)
- Impacted groundwater (pesticides)
- Impacted stormwater (metals)

(Google Earth 2023)

CSM Example: Oakland Gardens

- Chemicals present, but no significant habitat and no valued wildlife (managed [mowed] grass lawn)

☑ Chemicals
☐ Valued ecological receptors
☐ Exposure pathways

- BUT….
- What if a groundwater plume emerges at a surface water body?

☑ Chemicals
☑ Valued ecological receptors
☑ Exposure pathways

(Google Earth 2023)

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PFAS Risk Assessment: What We Know So Far

- Off-site issues are often most important
- Concentrations of PFAS at many sites can trigger concerns
- Quantifying the risk of PFAS background exposures is challenging
- There is much left to learn about PFAS—a lot of uncertainties and unanswered questions
  - Most current knowledge is based on select PFCAs and PFSAs, like PFOA and PFOS

Short-chain PFCAs				Long-chain PFCAs				
PFBA	PFPeA	PFHxA	PFHpA	PFOA	PFNA	PFDA	PFUnA	PFDoA
PFBS	PFPeS	PFHxS	PFHpS	PFOS	PFNS	PFDS	PFUnS	PFDoS
Short-chain PFSAs		Long-chain PFSAs						

(Conder n.d.)

- Site-specific risk assessment and decision-making criteria are ongoing now and still being developed
  - In many cases, there is no time to wait for a perfect understanding or final regulatory directives

PFCA: perfluoroalkyl carboxylic acid
PFOA: perfluorooctanoic acid
PFSA: perfluorosulfonic acid
PFOS: perfluorooctanesulfonic acid

Risk-based Decisions Work for PFAS

- PFAS obey the laws of physics
- "The dose makes the poison" (don't forget Paracelsus)
- We don't have to reinvent the wheel
- We still can (and should) use risk assessment to make decisions

Paracelsus
(1493-1541)
Founder of Toxicology
Portrait by Quentin Matsys

PFAS ERA Resources

- Ecological risk of PFAS is a rapidly growing research area, and there are many resources available
- Critical resources for ERAs for PFAS

1. SERDP Projects on Ecotoxicity of PFAS
   - Specific projects, workshops, tools and trainings are available
   - Conder et al. (2020), Devine et al. (2020) are important references for Tier 1 SERAs
2. Ecological Risk Assessment for Per- and Polyfluorinated Alkyl Substances (PFAS)
   - Special Issue in Integrated Environmental Assessment and Management in 2021
3. ITRC PFAS Guidance Chapter 9 - Site Risk Assessment
4. Navy EWC Issue Papers on PFAS ESVs (available internally)

ESV: ecological screening value
EWC: electronic warfare center

ITRC: Interstate Technology Regulatory Council

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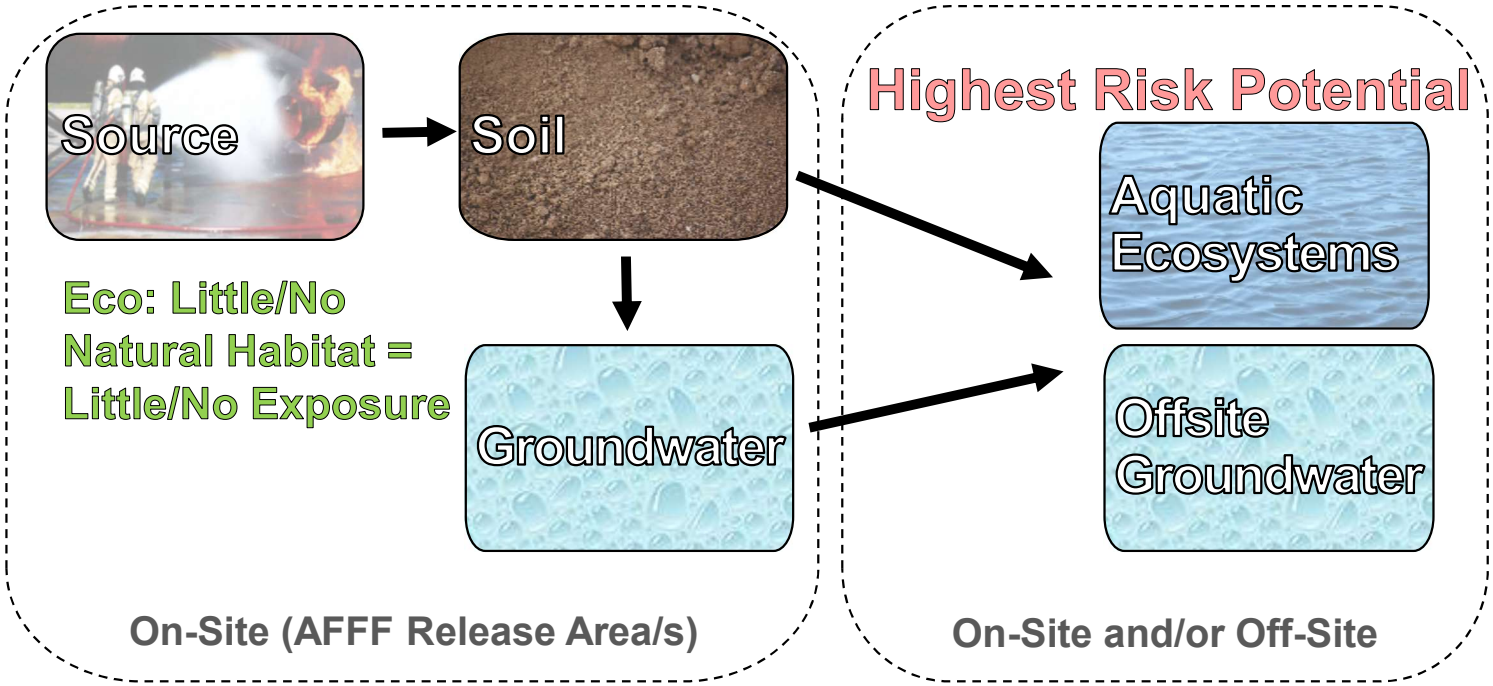
Considerations for PFAS Ecological CSMs

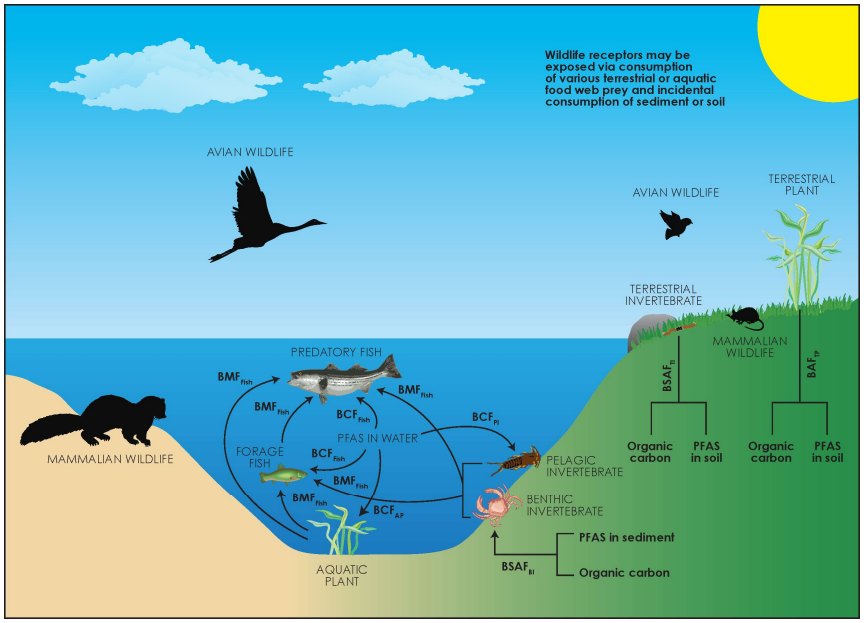


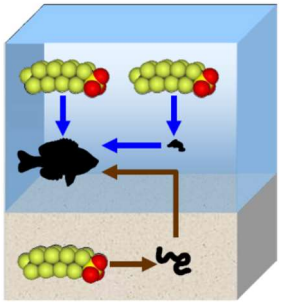
AFFF: aqueous film forming foam

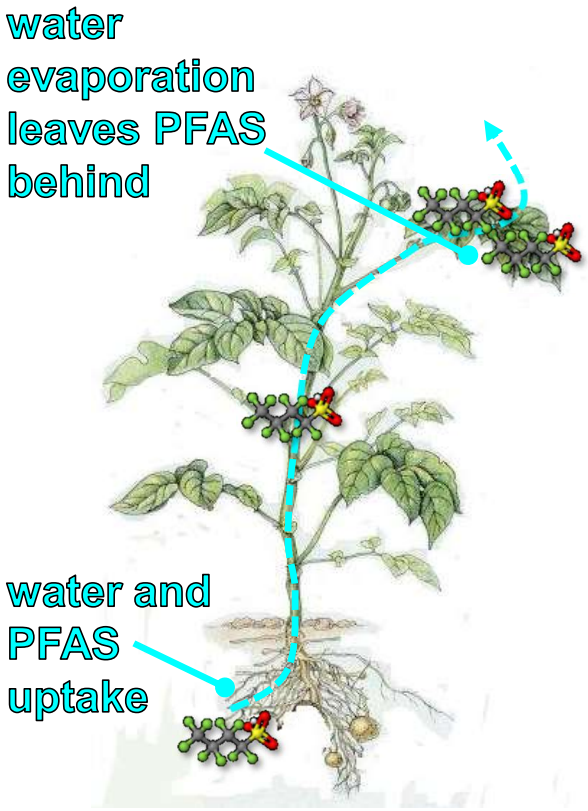
(Conder n.d.)

Bioaccumulation Exposures Are Important for Ecological Risks

- PFAS bioaccumulate into ecological food webs
  - Aquatic life (e.g., fish and invertebrates)
  - Soil life (e.g., earthworms, insects, plants)
- PFAS tends to bind to proteins, not lipids, so models we often rely upon to predict bioaccumulation are not useful for PFAS





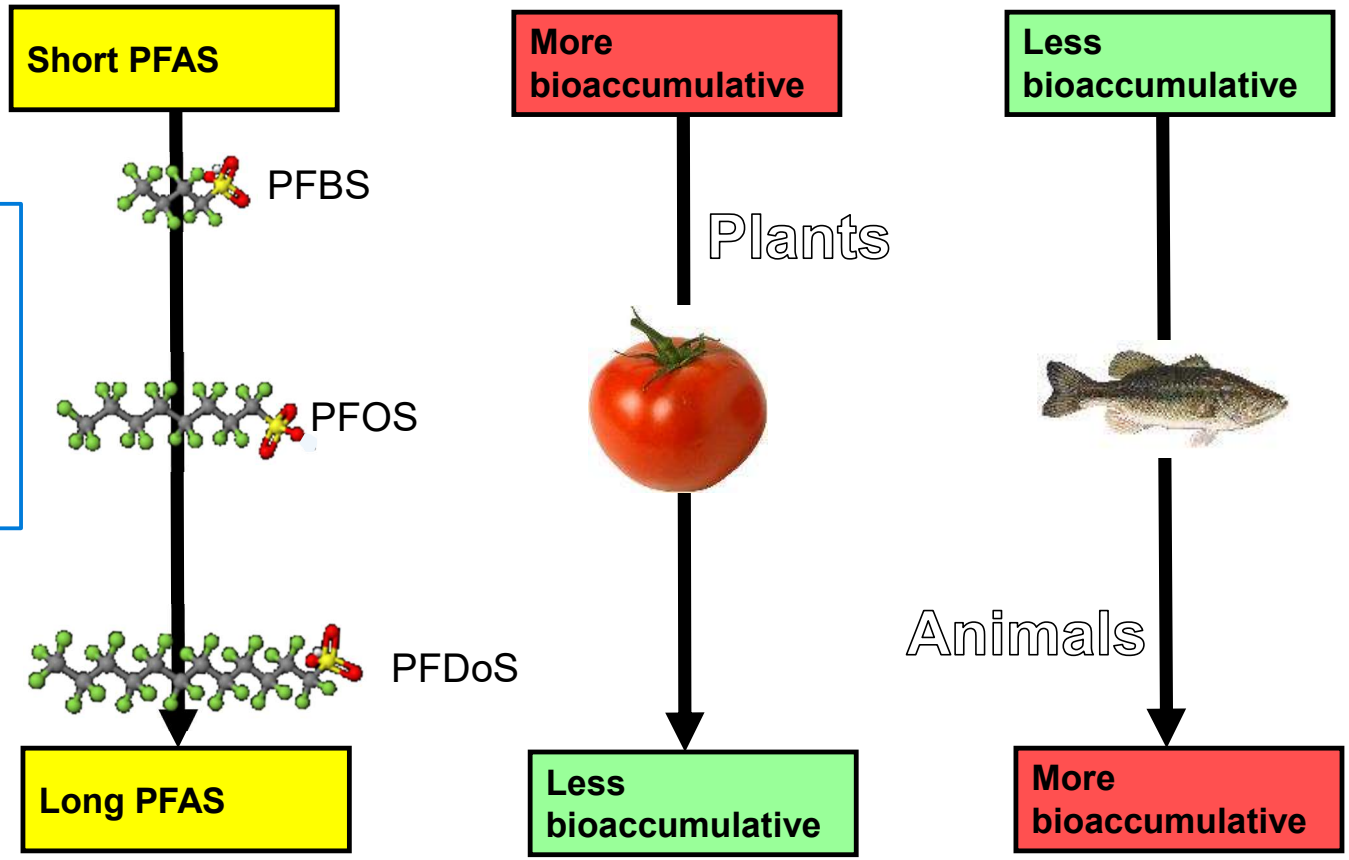


(Conder n.d.)

Chemical Size Affects Bioaccumulation

KEY POINT

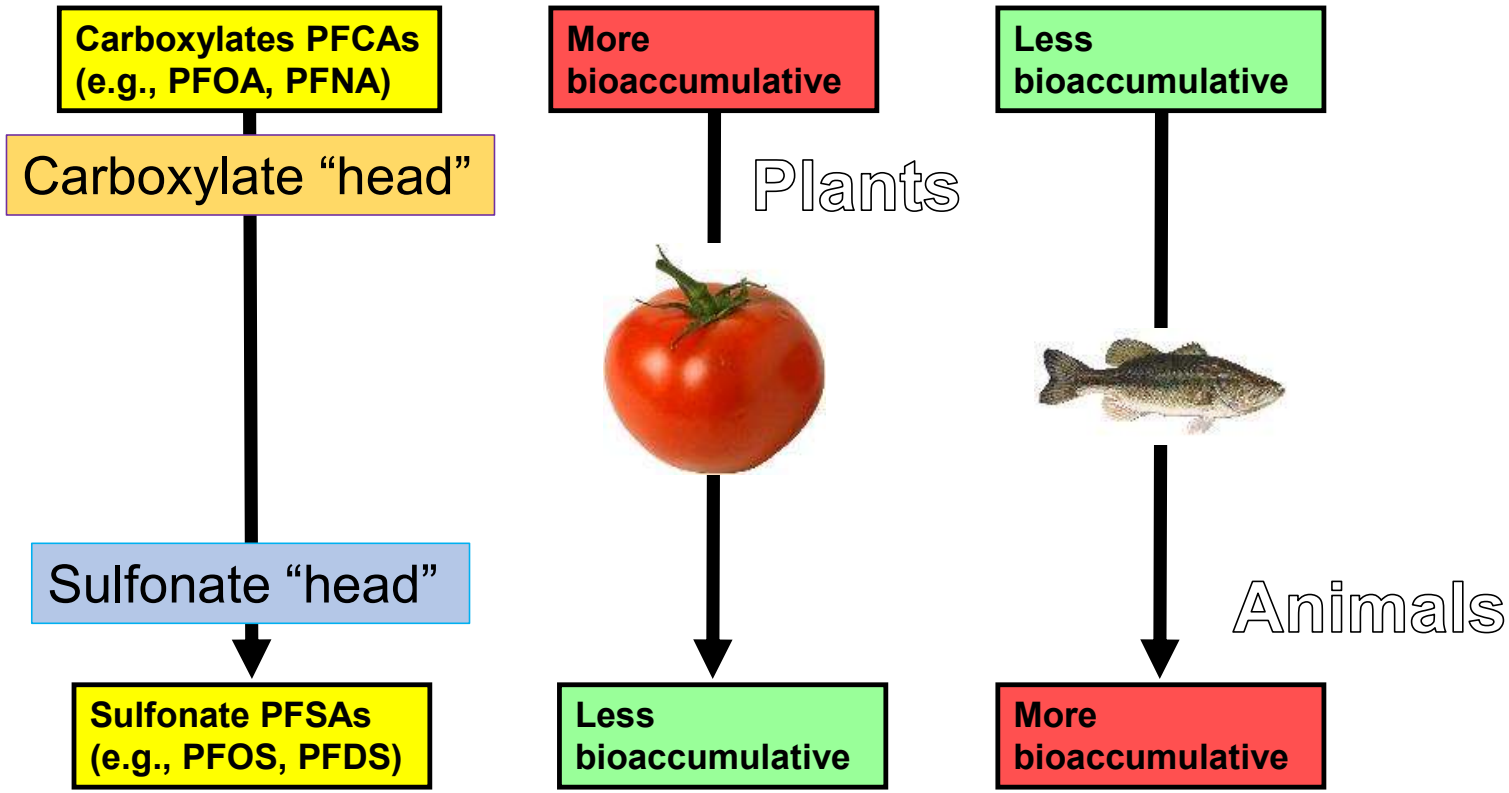
Short-chain PFAAs accumulate in plants more. Long-chain PFAAs accumulate in animals more.



PFAA: perfluoroalkyl acid
PFBS: perfluorobutanesulfonic acid
PFDoS: perfluorododecane sulfonic acid

(Conder n.d.)

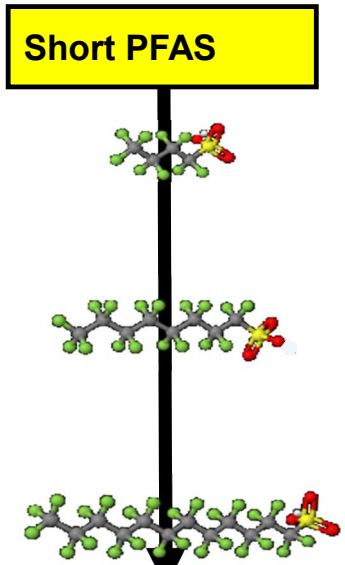
Chemical Type Affects Bioaccumulation



PFDS: perfluorodecane sulfonate
PFNA: perfluorononanoate

(Conder n.d.)

Chemical Type Affects Bioaccumulation



Short PFAS

Long PFAS

Carboxylates PFCAs (e.g., PFOA, PFNA)

Carboxylate "head"

Sulfonate "head"

Sulfonate PFSAs (e.g., PFOS, PFDS)

More bioaccumulative

Plants

Less bioaccumulative

Less bioaccumulative

Animals

More bioaccumulative

KEY POINT

Long-chain PFSA = most bioaccumulative in animals
Short chain PFCAs = most bioaccumulative in plants

(Conder n.d.)

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Planning for ERAs during the RI

- Beware of science projects
  - PFAS are still relatively new to many regulators and consultants
  - Beware of extra questions/bloated investigations because of natural curiosity
  - Stick to clear DQOs within the regulatory-driven risk assessment
- Consider which PFAS to include
  - ERAs not possible for full PFAS list for 1633; focus on PFSAs, PFCAs, and select PFAS with ecotox information
  - Remember data gaps for PFAS are frequently updated (e.g., marine toxicity, toxicity data for more PFAS); include areas of potential data gaps to reduce uncertainties

KEY POINT

Data gaps are unavoidable but should not prevent risk assessment.

RI: remedial investigation

Sampling for ERAs for Tier 1 SERA / Tier 2 BERA

Consider data needed for all aspects of RI

- Recommendations for PFAS sampling
  - Terrestrial
    - Definitely: soil (measure organic carbon too)
    - Possibly: soil invertebrates, plants, and other biota (usually latter stages of BERA)
    - Usually not: groundwater, soil gas, air
  - Aquatic
    - Definitely: sediment (measure organic carbon too), surface water
    - Possibly: sediment porewater; benthic and pelagic invertebrates, plants, fish, and other biota (usually latter stages of BERA)
- Consider background sampling in a reference area
    - Important Reminder: CERCLA does not allow clean up below background
- Avoid developing PFAS chemistry approaches (e.g., total organofluorine methods, TOP assay, PIGE)
    - These methods do not have a clear DQOs for evaluating risk
    - These methods are considered screening methods with potential use in identifying areas to collect definitive data or as sensitivity analyses around ERA results on definitive data

PIGE: particle-induced gamma ray emission
TOP: total oxidizable precursor

PFAS Ecological Screening Values (ESVs)

- Sources of screening values for abiotic environmental media
  - Zodrow et al. 2021; Devine et al. 2020 (SERDP Project ER18-1653)
  - Conder et al. 2020 (SERDP Project ER18-1614)
  - Grippo et al. 2021 (Argonne National Laboratory under agreement with AFCEC)
    - Focused on eight PFAS commonly found in AFFF
    - Soil and surface water ecological screening values (ESVs) only
    - Grippo et al. (2021) involved review by USEPA's Office of Water and Ecological Risk Assessment Team
  - Amphibians: Sepulveda 2023 (SERDP Project ER-2626); Pandelides et al. 2023 (ET&C)

AFCEC: Air Force Civil Engineer Center
ET&C: Environmental Toxicology and Chemistry

PFAS ESVs, Continued

- Grippo et al. for screening of soil and surface water (USEPA collaboration)
- Zodrow et al. and Conder et al. to supplement Grippo et al.
- USEPA published Draft Freshwater AWQC for PFOA and PFOS for protection of aquatic life in April 2022:
  - Can consider these values in Tier 1 SERA, if requested by regulator agencies, with notation that they are not Final AWQC (i.e., ARARs)
  - Draft freshwater chronic values:
    - PFOS: 8,400 ng/L
    - PFOA: 94,000 ng/L

TABLE ES-3 Summary of Results and Data Gaps for PFAS Soil and Surface Water ESVs

	Soil ESVs (mg/kg)				Surface Water ESVs (µg/L)[d]			
					Freshwater			Marine
PFAS	Terrestrial Plants	Terrestrial Invertebrates	Terrestrial Mammals	Terrestrial Birds	Aquatic Life[b]	Aquatic-Dependent Mammals[c]	Aquatic-Dependent Birds	Aquatic Life[b]
PFBA	—[a]	—	2.98	—	64.6	8,370	—	—
PFHxA	—	—	6.20	—	28.8	2,210	—	—
PFOA	79.5	22.4	3.84	—	307	1,580	—	6.12
PFNA	—	10	0.0242	—	16.4	2.08	—	—
PFDA	—	—	0.0677	—	2.94	0.66	—	—
PFBS	—	100	0.817	15.8	400	5,710	88,600	—
PFHxS	—	10	0.0028	—	65.3	5.50	—	—
PFOS	40.2	48.1	0.0087	0.0386	22.6	0.117	2.57	3.96

[a] Dash (—) indicates a data gap – data not available.
[b] Chronic ESV values; PFOA and PFOS are Tier I ESVs; the remaining are Tier II ESVs.
[c] The lower of the aquatic-dependent mammal or bird value is selected as the Aquatic-Dependent Wildlife ESV.
[d] The surface water values should only be used when the water column is relatively quiescent and sediments at the site are relatively undisturbed; the derived ESVs do not consider the antagonistic, additive or synergistic effects of other PFAS or other aquatic contaminants in combination with individual PFAS chemicals.

Screening Values Soil and SW
(Grippo et al. 2021)

ANL: Argonne National Laboratory
ARAR: applicable or relevant and appropriate requirements
ng/L: nanograms per liter
SW: surface water

KEY POINT

Ecological screening levels are available for many PFAS and receptors, but use wisely.

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Quiz/Discussion Time: EPCs

EPC Quiz

What is the most appropriate EPC to use in a Tier 1 SERA?

a) Minimum
b) Maximum
c) Average
d) 95UCL
e) What's an EPC again?

EPC Quiz

What is the most appropriate EPC to use in a Tier 2 BERA?

a) Minimum
b) Maximum
c) Average
d) 95UCL
e) Ok really, what's an EPC again?

PFAS Ecotoxicology Overview

- Demonstrated effects of PFAS in laboratory studies (mostly from study of PFCAs and PFSAs like PFOA and PFOS)
  - Animals
    - Mortality and growth effects
    - Reproductive effects (decreased reproductive output)
    - Organ-specific effects (e.g., changes in liver, kidney)
    - Immunological effects
    - Endocrine system effects (e.g., thyroid)
    - Tumors (e.g., liver, testicular, pancreatic)
  - Plants
    - Mortality and growth effects
- Field studies at AFFF sites that document a clear cause-and-effect link to PFAS exposures and effects remain elusive (need for more study)

Animal PFAS mode of toxic action for apical endpoints used in ecological risk assessments (i.e., mortality, growth, reproduction) currently under study

- Aquatic life: could be narcosis (effects biological membranes)
- Mammals: general narcosis, effects on fatty acids, other biochemical pathways in liver

Effects and Exposure of PFAS: Soil and Aquatic Life (Non-Wildlife Receptors)

- Aquatic toxicity data (fish, invertebrates) for some compounds
  - Most direct toxic effects occur at concentrations much higher than other concerns (e.g., drinking water)
- Plants and soil invertebrates relatively insensitive to PFAS
  - Effects occur in the milligram per kilogram (mg/kg) range (higher than other concerns)
- In both Tier 1 and Tier 2, use EPCs in soil, water, and sediment with these screening levels (i.e., use as TRVs) to calculate HQs

(Pixabay n.d.)

$$Hazard\ Quotient = \frac{EPC}{TRV}$$

Effects and Exposure of PFAS: Wildlife (Birds and Mammals)

- Wildlife tend to be most sensitive ecological receptors (especially for PFOS)
  - Focus on small animals (high site fidelity, high dietary exposure)
    - Tend to drive decisions for most bioaccumulative chemicals
  - Modeling exposure to carnivorous and wider-ranging wildlife is more complicated, but is not expected to drive risk
- Field studies have shown mixed results
  - Custer et al. (2012, 2014) note decreased hatching success in a wild population of tree swallows,
    - Other chemicals complicate the direct casual link to PFAS (see Custer [2021] additional analysis)
  - Other studies have found minimal or no reproductive effects in birds, including under much higher PFAS exposures

(Pixabay n.d.)

Exposure Assessment for PFAS: Wildlife

- Typical Tier 1 SERA and Tier 2 BERA exposure model approach can be used to estimate PFAS daily doses for wildlife

Site Measurements (or Model Predictions)

Assumptions and Modeling

Chemical in Soil (ng/g) → Accidental Soil Ingestion Rate (g/day)

Chemical in Food (ng/g) → Food Ingestion Rate (g/day)

Predicted chemical dose (ng/day)

$$DI = [\Sigma(Ci \times Fi \times FIR) + (Cs \times SIR)] \times AUF \times (1/BW)$$

Where:

- DI = daily intake (dose) (mg/kg*day)
- Ci = concentration in food item i (mg/kg; wet weight)
- Fi = fraction of diet comprised of food item i (unitless)
- FIR = food ingestion rate (kg/day; wet weight)
- Cs = concentration in soil (or sediment) (mg/kg; dry weight)
- SIR = soil (or sediment) ingestion rate (kg/day; dry weight)
- AUF = area use factor (unitless, max of 1) = Home range ÷ Site Area
- BW = body weight (kg)

- Food samples often hard to come by
  - Often start by predicting what's in the food using concentrations of chemicals in soil, sediment, and/or water (i.e., food web models)

g/day: gram per day
ng/day: nanogram per day
ng/g: nanogram per gram

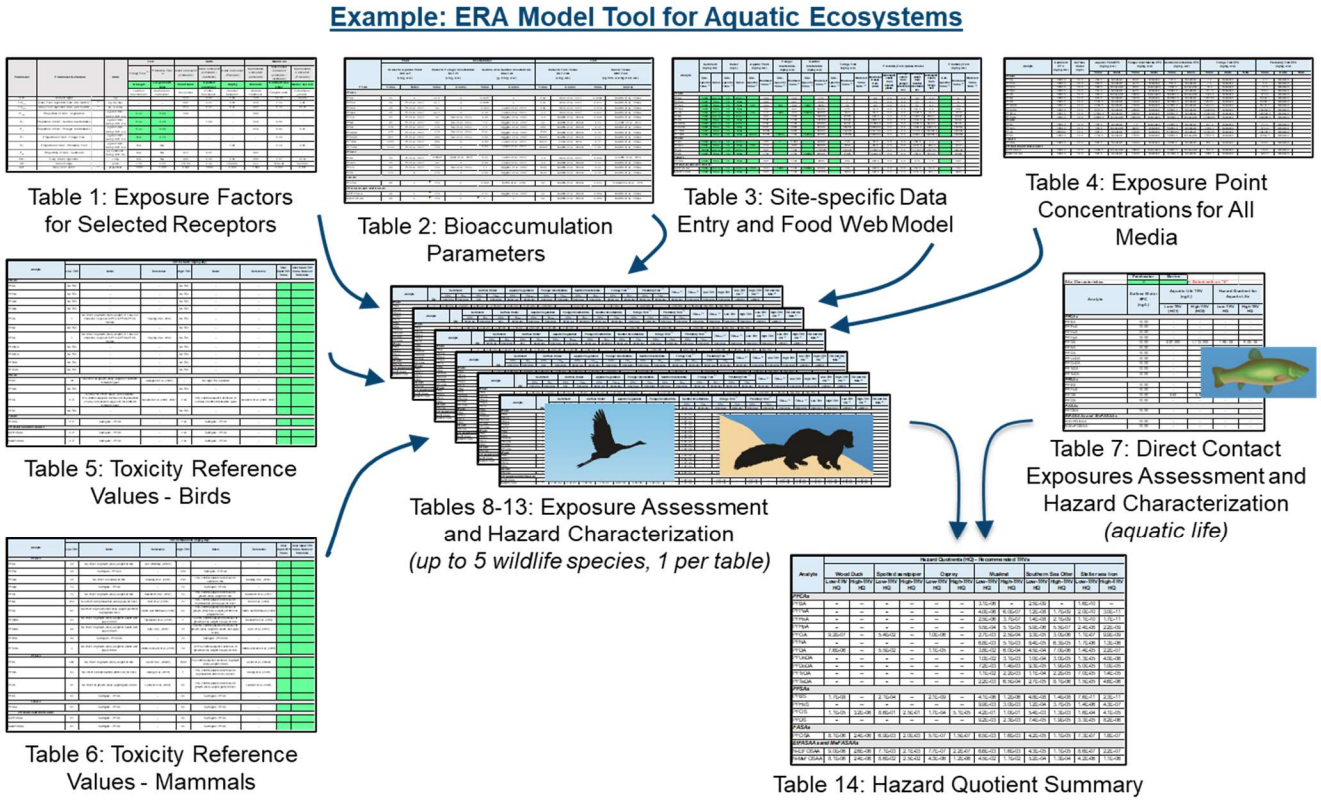
Bioaccumulation Modeling Needs and Resources For PFAS

- Site-specific data needs are as follows
  - Concentration of PFAS in water and sediment (aquatic); soil (terrestrial)
  - Organic carbon content in sediment and soil
- Uptake factors to estimate PFAS concentrations in wildlife diet items are available
  - Conder et al. (2020)—SERDP Project ER18-1614 and modeling tool
  - Update with peer-reviewed literature as appropriate
  - Mechanistic models (similar to Gobas models for lipophilic organics) recently developed (Sun et al., 2022)
- Bioaccumulation modeling for PFAS also comes in handy for human health risk assessments

SERDP PFAS Food Web Modeling Tool for Excel

- Available as Excel files, with “how to” instructions and technical support for models
- Free PFAS ecorisk food web models (SERDP Project ER18-1614)

https://tinyurl.com/PFAS-Risk-Tools



PFAS Wildlife Toxicity Benchmarks

- PFAS mammalian laboratory toxicity studies primarily limited to a handful of the PFCAs and PFSAs
- PFAS avian laboratory toxicity studies even more limited
- Several resources for wildlife TRVs (i.e., SEVs in Navy terms) for PFAS
  - Conder et al. (2020)—SERDP Project ER18-1614 (included in SERDP PFAS food web modeling tool)
  - Grippo et al. (2021)—Argonne National Laboratory under agreement with AFCEC
  - Narizzano et al. (2022)—Mammalian TRVs NAVFAC white papers to support refinement TRVs for mammals (PFOS and PFHxS) and birds (PFOS)
    - Review and Summary Issue Paper Preparation funded by NAVFAC; the Navy Emerging Chemicals Workgroup currently completing internal review of the draft Issue Papers, with plans to finalize and incorporate into ERA process

PFHxS: perfluorohexanesulfonic acid
SEV: screening ecotoxicity value

Tier 2 BERA, Step 3b: Advanced PFAS Investigations

- Many traditional advanced ERA methods are applicable to PFAS
  - Toxicity testing, passive sampling, benthic community assessment, tissue analysis, etc.
  - Refer to usual guidance for these tests
- Focus on the 'Eco' in the ERA
  - Consider how site communities compare to reference; are impacts indicated?
- Focus on specific DQOs that add risk management value and not on undertaking multiyear research projects without clear goals and objectives

Risk Characterization and Communication

- Follows bioaccumulation/exposure modeling and TRV selection for wildlife and standard ERA approaches
  - Hazard Quotient (HQ) = Predicted Dose ÷ TRV
- For Aquatic life/terrestrial plants or invertebrates
  - HQ = Exposure ÷ ESV
- HQ ≤ 1 indicates effects are unlikely to occur; HQ > 1 indicates additional evaluation and possible management could be needed
  - However, examine predicted doses relative to the effect and magnitude of the effect associated with the TRV

KEY POINT

Communicate risks specifically; focus on the level of potential impact and to which receptors.

PFAS-specific Ecological Risk Uncertainties

1. PFAS Mixtures
   - Multiple HQs for multiple PFAS
2. PFAS Detected at Site, but no ESVs/TRVs
   - Especially a challenge for many PFAS with marine aquatic life and birds
3. PFAS 'Dark Matter'
   - PFAS that may be present but cannot be detected

Recommendations

1. Mixtures?
   - Acknowledge as uncertainty
   - Modeling sensitivity analysis ideas
     - Could sum HQs (Hazard Index), but not yet supported
2. No TRVs?
   - Acknowledge as uncertainty
   - Modeling sensitivity analysis ideas
     - Still estimate exposure and qualitatively compare to PFOS or other PFAS with values
     - Develop surrogate PFAS by selecting similar chain-length and functional group where able
3. PFAS Dark Matter
   - Acknowledge as uncertainty
   - No good quantitative approach to estimate site concentrations, uptake factors, or TRVs
   - Resist overly conservative assumptions or arbitrary uncertainty factors
   - May need to support risk assessment modeling (conducted with measurable PFAS) with ecological investigations

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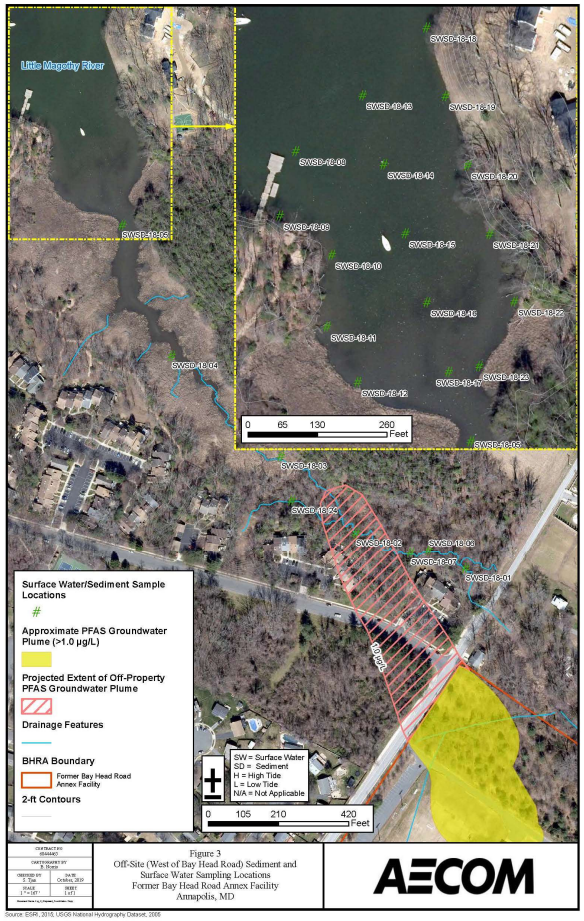
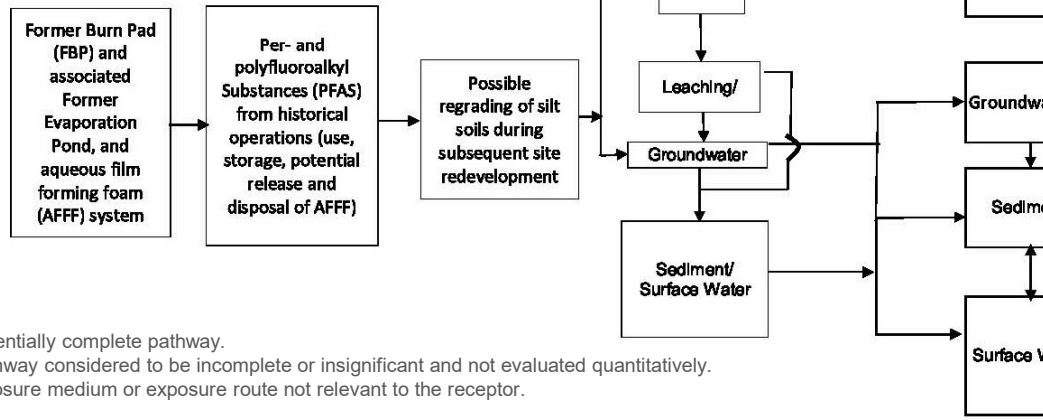
Bay Head Road Annex (2019)

- Former Navy Site with a burn pad used for testing fire retardant materials for shipboard use
- Suspected use of AFFF to extinguish controlled fires performed at site
- Limited/minimal on-site habitat
- CSM development
  - Impacted media included soil and groundwater, which emerged at the Little Magothy River
  - PFAS detected in surface water and sediment downstream
  - CSM considered direct exposures to soil, sediment and surface water (plants, invertebrates and wildlife) and bioaccumulation into wildlife diet items

(AECOM 2020)



Bay Head Road Annex: CSM



Exposure Media	Potential Exposure Route	Terrestrial Plant Community	Soil Invertebrate Community	Amphibian/ Fish/Aquatic Invertebrate Community	Benthic Invertebrate Community	Avian and Mammalian Communities
		Potential Ecological Receptors/Exposure Pathways				
Surface Soil	Incidental Ingestion	—	⌘	—	—	⌘
	Dermal / Direct Contact	⌘	⌘	—	—	⊛
	Bioaccumulation (Diet)	—	⊛	—	—	⌘
Subsurface Soil	Incidental Ingestion	—	⊛	—	—	⊛
	Dermal / Direct Contact	⊛	⊛	—	—	⊛
Groundwater	Dermal / Direct Contact	—	—	—	—	—
	Incidental Ingestion	—	—	—	—	—
Sediment	Incidental Ingestion	—	—	⊛	⌘	⌘
	Dermal / Direct Contact	—	—	⊛	⌘	⊛
	Bioaccumulation (Diet)	—	—	⊛	⌘	⌘
Surface Water	Incidental Ingestion	—	—	⌘	⌘(a)	⌘
	Dermal / Direct Contact	—	—	⌘	⌘(a)	⊛
	Bioaccumulation (Diet)	—	—	⌘	⌘(a)	⌘

Notes:
⌘ Potentially complete pathway.
⊛ Pathway considered to be incomplete or insignificant and not evaluated quantitatively.
□ Exposure medium or exposure route not relevant to the receptor.

(a) The high solubility potential of PFOS and other long-chain PFAS results in a high capacity for uptake from the water-column into aquatic tissues as well as into benthic organism tissues at the sediment-surface water interface.

Ecological Site Model
Former BHRA Annapolis, Maryland
(AECOM 2020)

BHRA: Bay Head Road Annex

Tier 1 SERA Screening

- Tier 1 results were as follows
  - Compared maximum concentrations to available screening levels
    - Various jurisdictions used, as this ERA pre-dated the recommended resources here
  - Concentrations in soil, surface water and sediment were below ESVs protective of direct exposure (HQ < 1), but HQs were above 1 for wildlife
- Tier 1 indicated complete exposure pathways for additional evaluation
  - Terrestrial birds and mammals exposure to PFOS in soil
  - Aquatic birds and mammals exposure to PFOS and PFOA in surface water

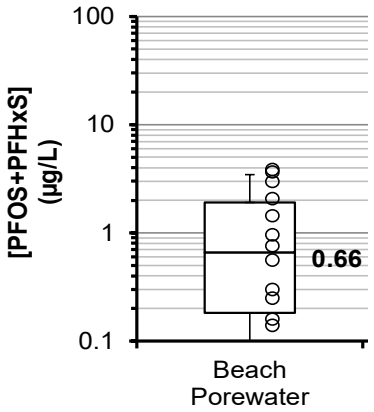
Tier 2 BERA: Step 3a Refinements

- Step 3a Refinements
  - 95UCLs instead of max
  - Spatial considerations of ESV exceedances
  - Run food web model using no-effect and low-effect TRVs to provide risk management range
- Step 3a Results
  - 95UCL for PFOS in soil was below ESV for birds; HQ for mammals > 1, but driven by two locations with high PFOS and low risks in majority of site area
  - Considering low risk levels outside of hotspots and uncertainty in ESV, soil pathway was considered complete but insignificant
  - Surface water no-effect HQs < 1 for great blue heron, osprey, otter and mink; no-effect HQ was > 1 for the belted kingfisher (HQ = 5.2), but the low-effect HQ was < 1
  - Calculate risk-based concentrations for surface water; use as remedial goals

Australia Site

- Former industrial site with AFFF impacts from storm water discharge to a small beach area
- Not a US Navy Site, but great example of more advanced Tier 2 BERA work

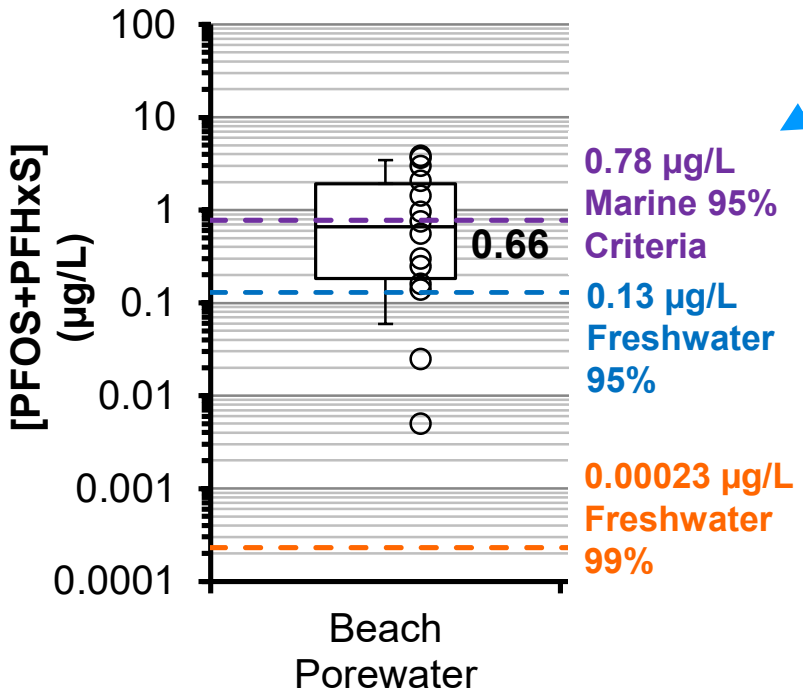
- Complete exposure pathways
  - Aquatic birds nesting or feeding on shore; food web models indicated minimal risks
  - On-shore benthic community



(Geosyntec 2020)

µg/L: microgram per liter

So Now What?



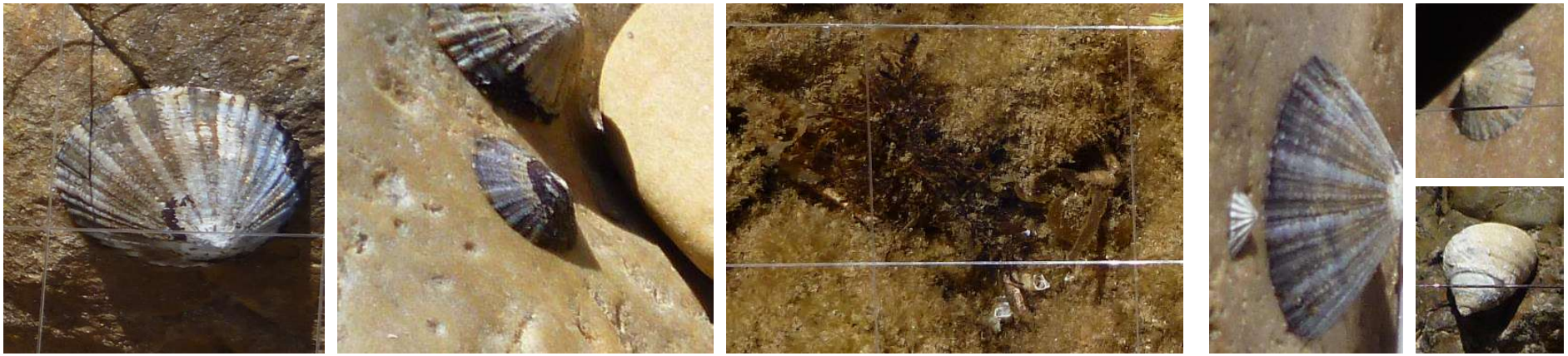
(Geosyntec 2020)

Concentrations in beach porewater that exceed screening criteria for aquatic life protection

- Could measure concentrations of PFAS in invertebrates, but no good criteria to compare to understand risk of adverse effects to aquatic life
- Could also do laboratory aquatic toxicity testing, but unclear what to test and species to use
- Other options?

Putting the Eco in the Ecological Risk Assessment

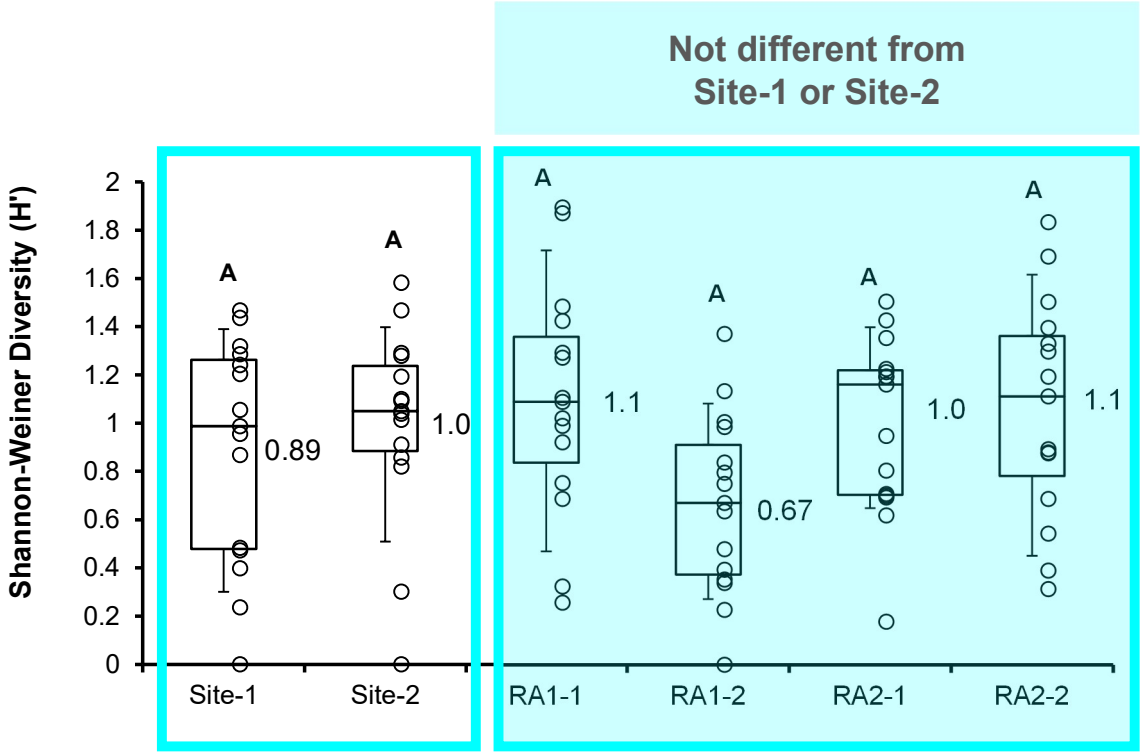
- Key ecological resource: intertidal invertebrate and algal community
  - Exposed to PFAS during storm events and from beach porewater
  - Important food source for wildlife
  - Can be evaluated through intertidal survey



(Geosyntec 2020)

Intertidal Survey: Community Results

- Diversity (site similar to all Reference Areas [RA1 and RA2])
- Other community census metrics indicated same conclusion: **Community at site not impacted**
  - Pielou's Evenness (J')
  - Species Richness
  - Swartz's Dominance Index (SDI)
- Uplands PFAS source managed, beach area left intact



Note: No statistical differences

(Geosyntec 2020)

Presentation Overview

- ERA 101
- ERA for PFAS: *Preface*
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- PFAS Exposure and Effects Estimation Case Studies
- PFAS Risk Management
- Summary Closing Statements

Beyond the ERA: Risk Management

- If stakeholders agree that chemicals need to be managed at the site, ERA is also used to help identify management approaches
- Usually occurs after the full ERA (but sometimes is included as a final section in an ERA)
- Key ERA activities include the following
  - Cleanup levels
  - Cleanup delineation
  - Other analyses to manage risk/exposures
  - Long-term monitoring

Cleanup Levels

- Often, use the ERA models to calculate the concentrations in soil, sediment, or water that should be reached to ensure HQ values are 1 or less
- Wildlife Preliminary Remedial Goals (PRGs) can be back-calculated from site-specific food web models
- But “don’t do anything stupid”
  - Are your cleanup levels achievable?
  - Are your cleanup levels above ambient anthropogenic background?
  - Are your cleanup levels measurable (above analytical limits of reporting/detection)?

PFAS Tier 3 Challenges

- Unlike many “traditional” chemicals, PFAS exposure in aquatic systems occur from both sediment, water and diet
- Determining which media to set a PRG for can be a challenge: which abiotic media is driving risk?

ERA Support in Remedial Planning

- Risk assessors should help in applying cleanup levels spatially at the site to identify areas that should be considered for management (soil and sediment)
- As RPMs, consider the following
  - How to spatially apply a clean up level (e.g., geostatistical analysis, point by point, surface weighted average concentrations (SWACs))
  - Spatial variability of the data and the home ranges of wildlife receptors
  - Be iterative: start with highest areas of risk and evaluate how small areas of remediations impact site-wide risk estimates
  - Environmental benefit versus habitat destruction/alteration
  - Law of diminishing returns: plot a curve of areas remediated versus predicted exposure/risk

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Summary Closing Statements

- Focus on your customers and the decision-making process
  - Resist overly simplistic explanations and conclusions as much as possible
  - However, ultimately your ERA will result in a binary management action ("To dig or not to dig, that is the question")
- Communicate effectively and clearly about your assessment, its assumptions, its sources of data, and model parameters
- Do what is right by the ecology
  - Protect from the adverse effects of chemicals
  - Protect from unnecessary remediation ("First, do no harm")
- "Don't do anything stupid"

KEY POINT

An ERA is an ERA, whether its for PFAS or not.

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Questions