United States Environmental Protection Agency

Causal Assessment, Stressor Identification & CADDIS

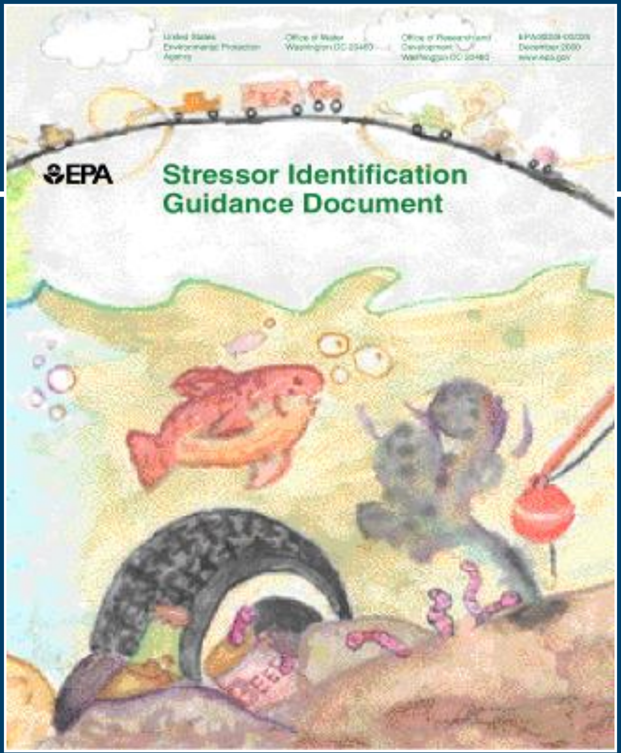
Sue Norton & Kate Schofield



Office of Research and Development
National Center for Environmental Assessment

CWA 303(d) Training Workshop
June 1, 2017

General outline for course



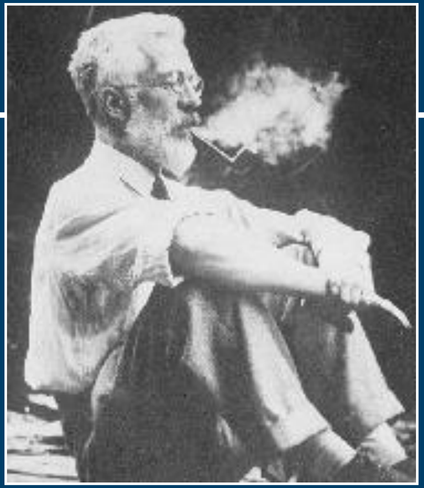
- Describe EPA’s approach to causal assessment
  - Introduction to philosophical foundations of causation
  - Step-by-step walk through Stressor Identification process
- Introduction to the Causal Analysis/Diagnosis Decision Information System

www.epa.gov/caddis

Causal assessment, Stressor Identification & CADDIS

- **Causal assessment**
  - Process to determine likely cause of an observed effect
- **Stressor Identification (SI)**
  - Method for determining most likely cause of observed biological impairments in aquatic systems
- **CADDIS**
  - Causal Analysis/Diagnosis Decision Information System
  - Website that provides information, methodology and tools to help users implement SI and conduct causal assessments of biological impairment

Three tiers of causal assessment



- **General** – Can C cause E?
  - Can smoking cause lung cancer?
  - Can Chemical Z cause fish lesions?
- **Contextual** – Under what conditions can C cause E?
  - Does smoking cause lung cancer when certain genetic factors are also present?
  - Does Chemical Z cause fish lesions only when it exceeds a particular concentration?
- **Specific** – Did C cause E in this case?
  - Did smoking cause lung cancer in Ronald Fisher?
  - Did Chemical Z cause fish lesions in my stream?

Why is specific causation important?

- Biological assessments are commonly used to identify if streams are impaired.
- In many cases, causes of impairment are unknown.
- To fix the problem, you have to know what to fix.

Causes of Impairment for 303(d) Listed Waters (2013)

Rank	Impairment Group
1	Pathogens
2	Metals (other than Hg)
3	Nutrients
9	Cause unknown
14	Cause unknown: impaired biota
29	Cause unknown: fish kills

The Exercise River

Why use a formal method?

Because we make mistakes about causality…

- We form initial impressions quickly, based on readily available information. This can result in:

Overweighting chance events	Every time I wash my car it rains.
Having biases	All pollution is caused by industry.
Being "educationally" predisposed	Hydrologists think hydrology.
Relying on intuition and past experience	I have a hunch that it's nitrogen. Last time I saw this, it was nitrogen.

Why use a formal method?

Because we make mistakes about causality…

- We gather information that supports our initial impression.

HYPOTHESIS TENACITY

- We confidently reach conclusions based on incomplete information.

WYSIATI
"what you see is all there is"

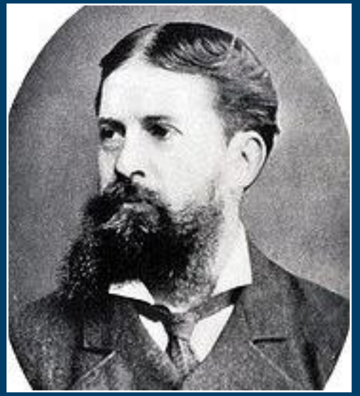
"Science is a way of trying not to fool yourself. The first principle is that you must not fool yourself – and you are the easiest person to fool." [Feynman 1964]

Establishing causation

- Causation is one of the most difficult and controversial concepts in philosophy.
- A **randomized, replicated, controlled** experiment is the **ONLY** reliable method for establishing causation...
- ...but environmental studies rarely randomize, replicate, or control exposures.





Our causal assessment approach

THE GOOD…

- Provides formal method that allows defensible & transparent evaluation
- Identifies causal relationships that may not be immediately apparent
- Minimizes biases and other lapses of logic
- Helps identify all available evidence
- Increases confidence that remedial or restoration effects can improve biological condition

Our causal assessment approach

…THE BAD…

- Conducting causal assessments is not necessarily easy or straightforward.
- Mechanisms driving biological impacts can be complex.
- The method relies on data – quantity and quality matter.
- Ultimately, a "smoking fish" may not be found, or multiple stressors may remain as likely causes.

Our causal assessment approach

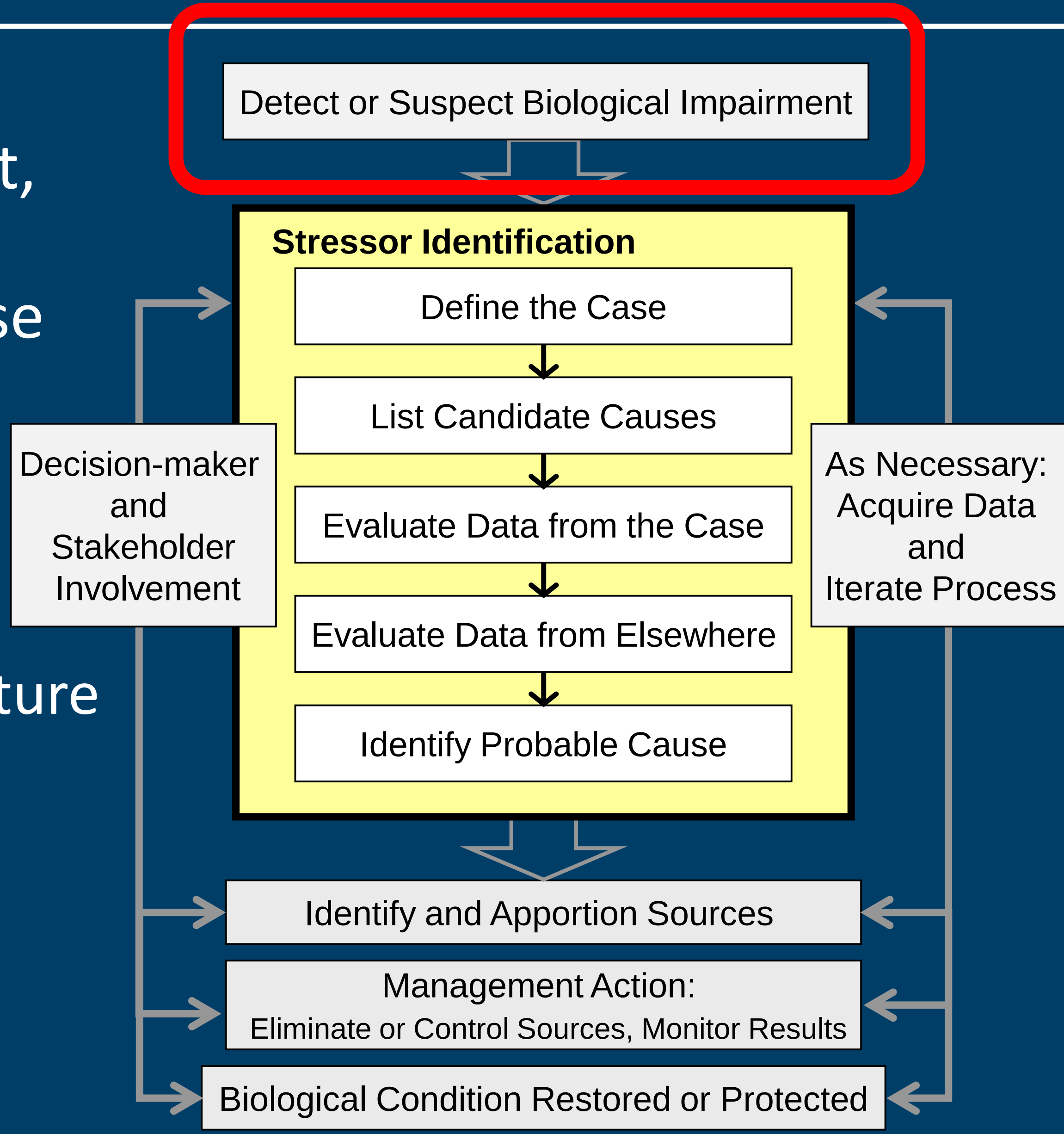
…AND BACK TO THE GOOD

- Even when one likely cause is not identified, a causal assessment can narrow the universe of possible causes and point to promising data and analyses.

1. ~~Low dissolved oxygen~~
2. Gill damage
3. Nitrate exposure
4. Infections
5. ~~High pH~~
6. ~~pH fluctuations~~
7. ~~Ammonia toxicity~~
8. Other, unspecified toxic substances
9. ~~Inadequate food resources~~

What triggers a causal assessment?

- Detection of a biological impairment, with no obvious or readily apparent cause
  - Fish kills
  - Organismal anomalies
  - Community structure changes
  - Low biotic index values
  - Violation of biocriteria

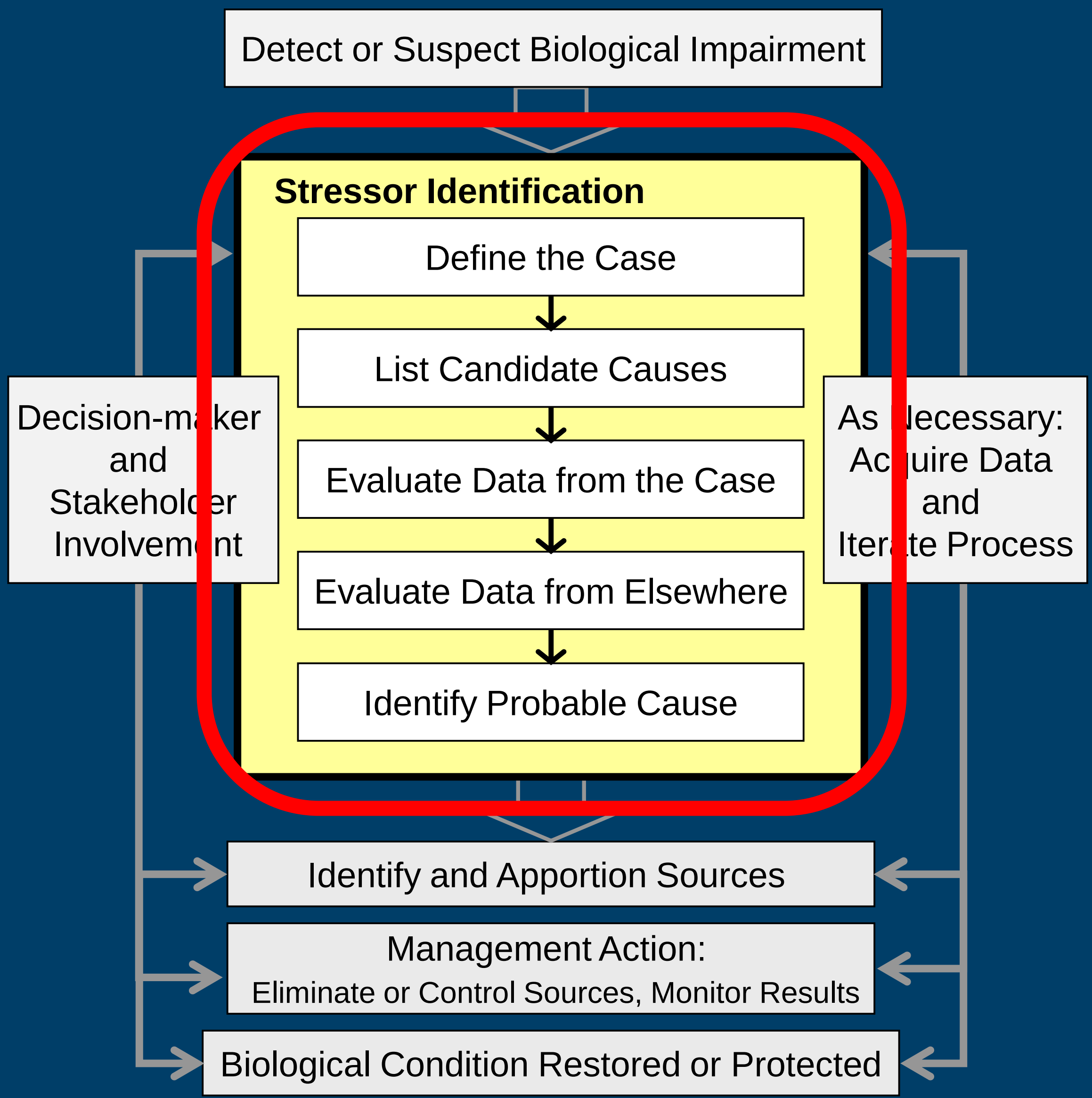


Before initiating a causal assessment…

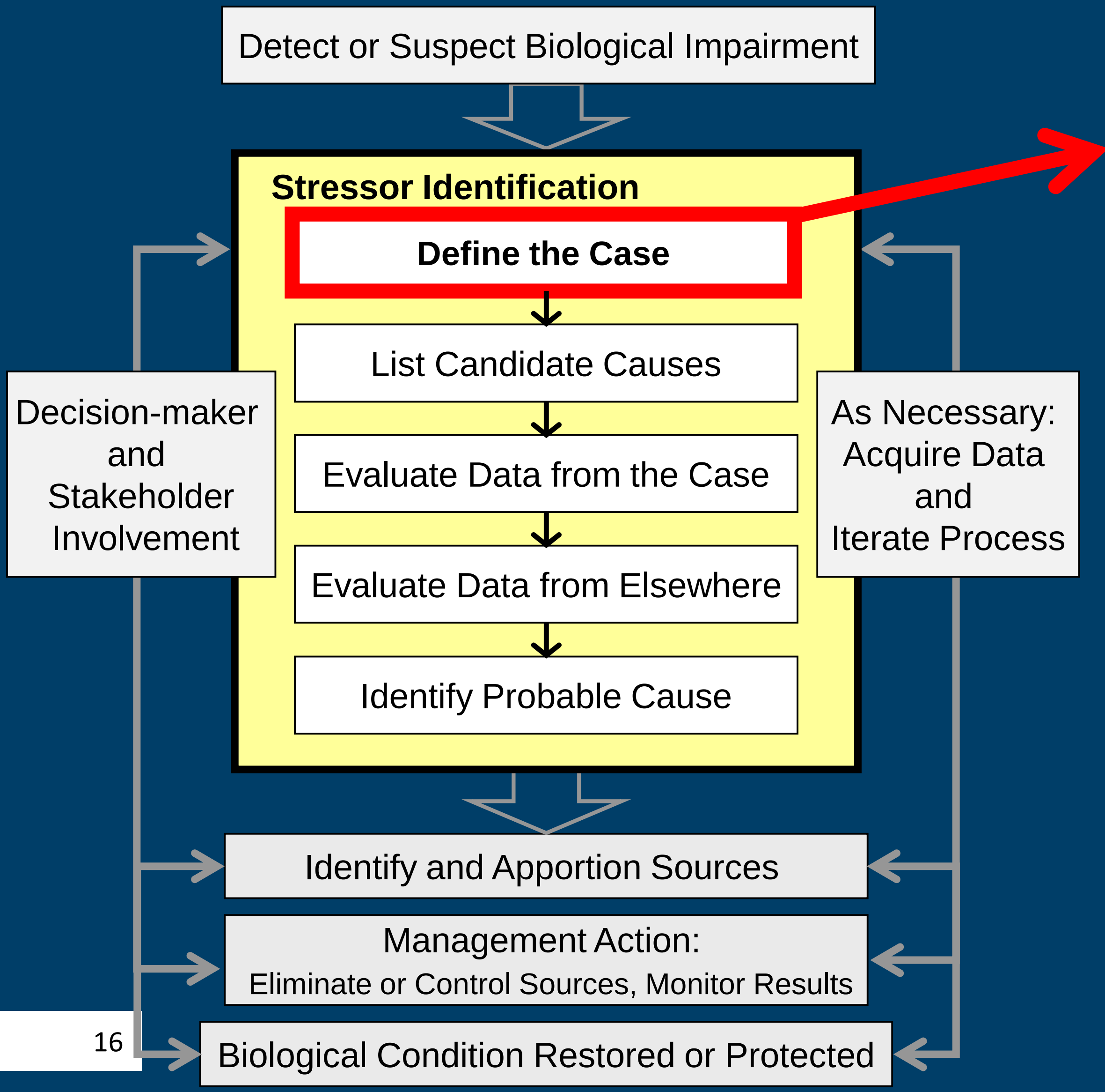
- Verify the biological effects
  - Is there anecdotal information?
  - Was the appropriate reference/comparison site used?
  - Were the appropriate statistics used?

- Verify that there is no identified or apparent cause
  - Usual suspects may not be present.
  - May be lots going on in watershed, but not clear which factors are contributing, to what degree.
  - Others may need to be convinced of cause.

That brings us to Stressor Identification…



Step 1 – Define the case



- What specific biological effects were observed?
- Where and when did they occur?
- Where are the effects absent or different (i.e., where are comparison sites located)?

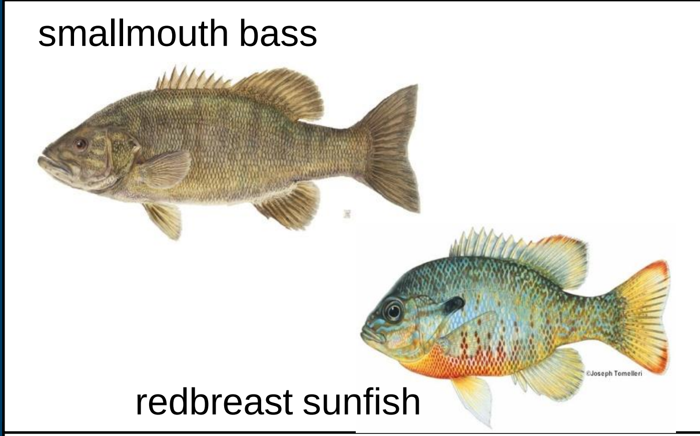
Step 1 – Define the case

- Describe the undesirable biological effect
  - Describe biological measure(s) that triggered causal assessment (i.e., the impairment)
- Specify the effects of interest
  - May be the same as the impairment, but better if more specific

SPECIFICITY	EXAMPLES
coarse	failure to meet biological criteria
↓	↓ sensitive taxa ↓ EPT taxa
specific	↓ *Paraleptophlebia* absence of brook trout

Step 1 – Define the case

- Establish the spatial and temporal frames
  - Where were effects observed?
  - When were effects observed?
  - Again, be as specific as possible



March–May 2006

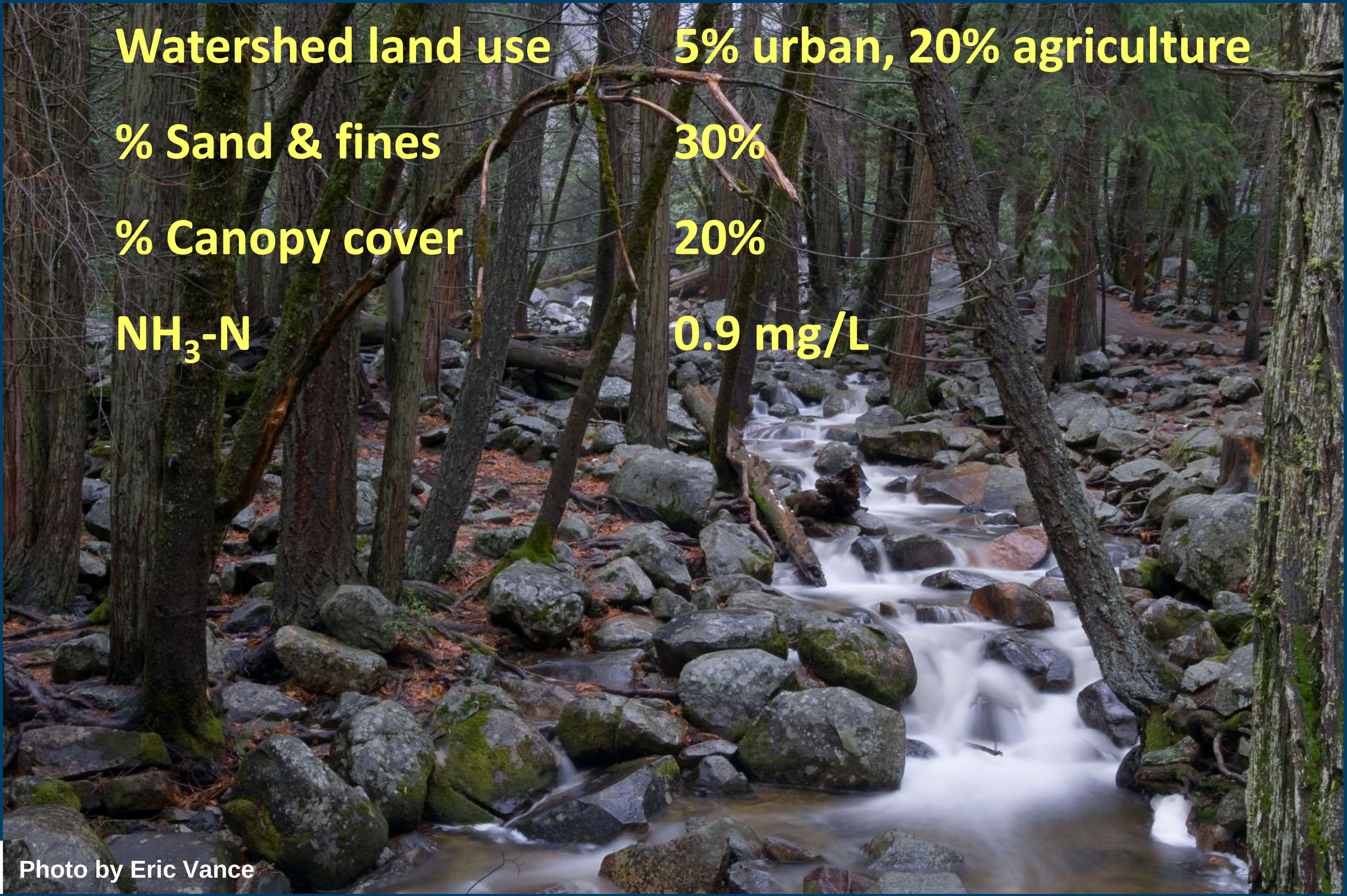
Acute phase noted by sudden death (mid-March)

Chronic phase noted by lesions preceding death (March–May)

Step 1 – Define the case

- Establish comparison sites
  - Comparison sites may:
    - Lack the effect
    - Lack a particular source or stressor
    - Have well-characterized sources, stressors, or effects
  - Comparison ≠ reference
    - Comparison sites need not be highest quality
  - Usually identified using best professional judgment, but this is area of active research to find better ways
- Consider the management context and any other constraints

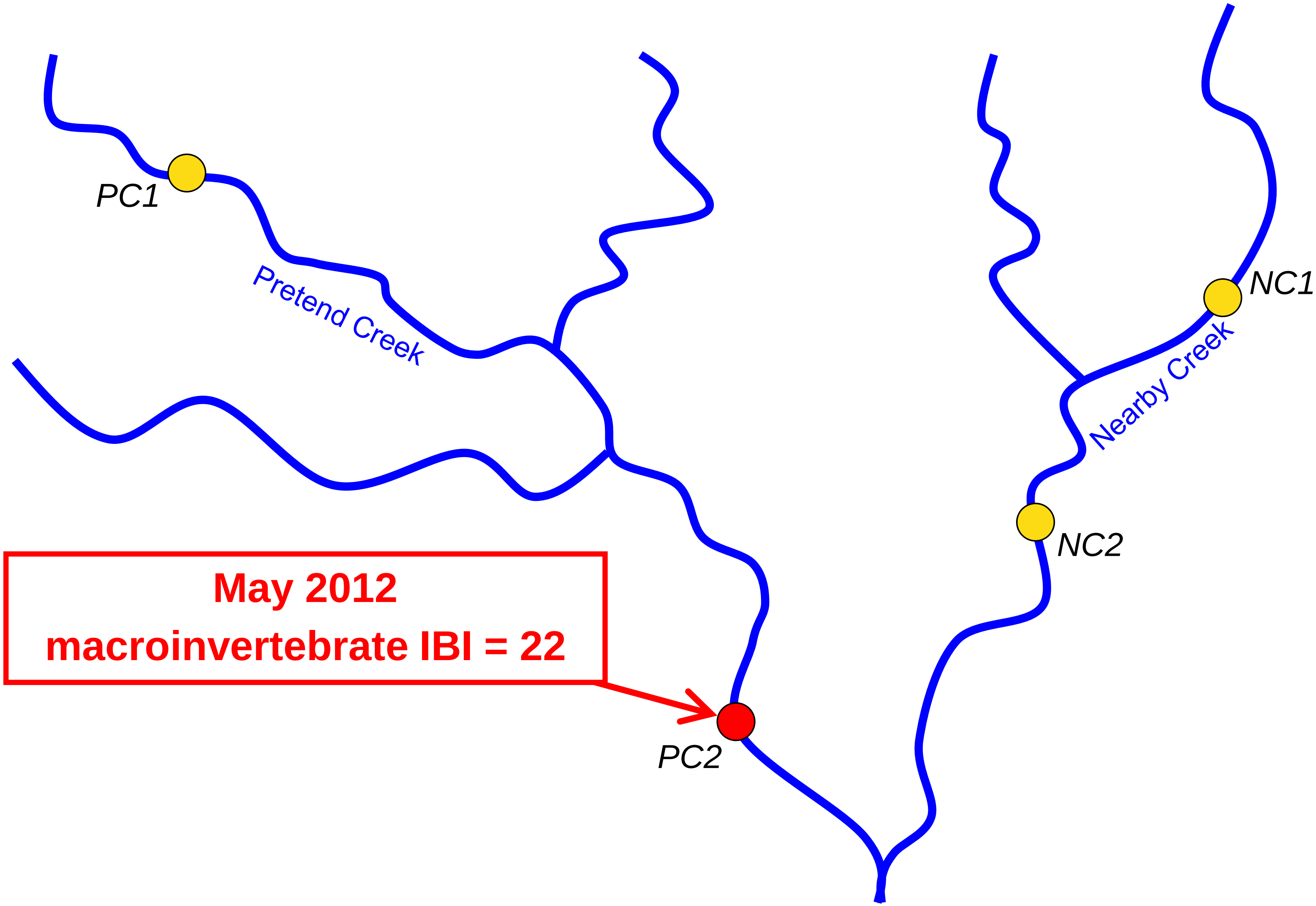
Case study – Pretend Creek



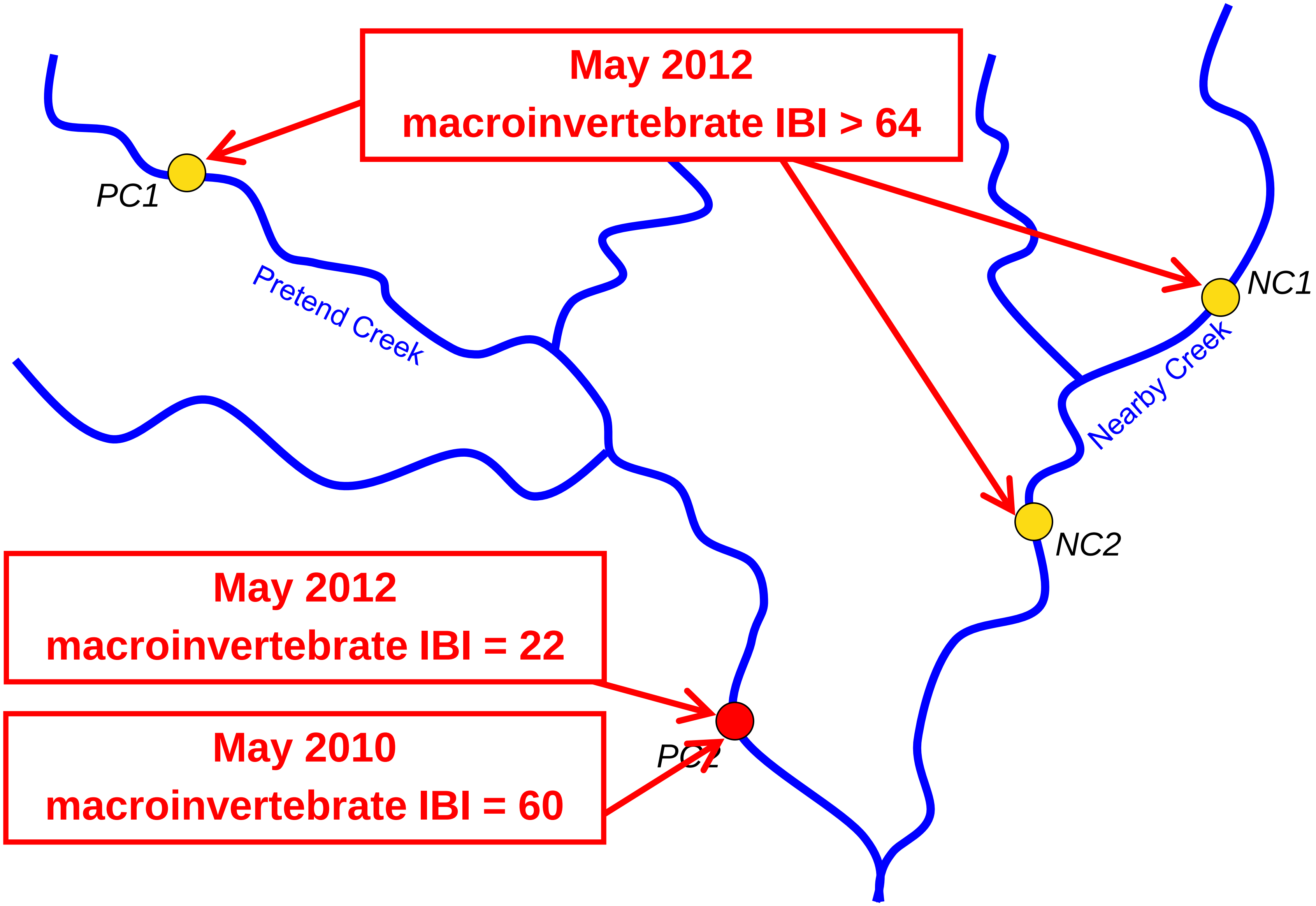
Watershed land use	5% urban, 20% agriculture
% Sand & fines	30%
% Canopy cover	20%
NH_3-N	0.9 mg/L

Photo by Eric Vance

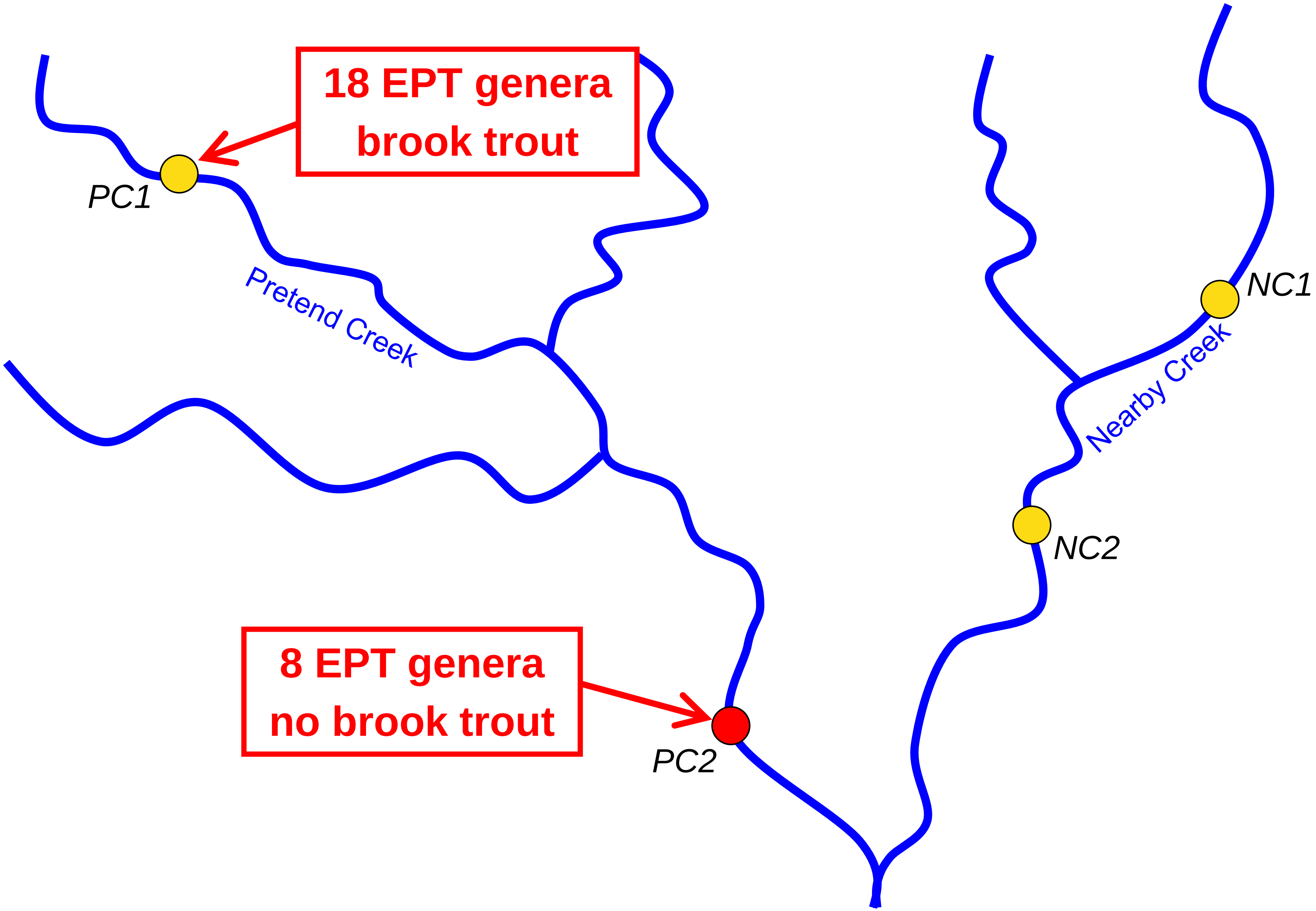
Pretend Creek's causal assessment trigger?



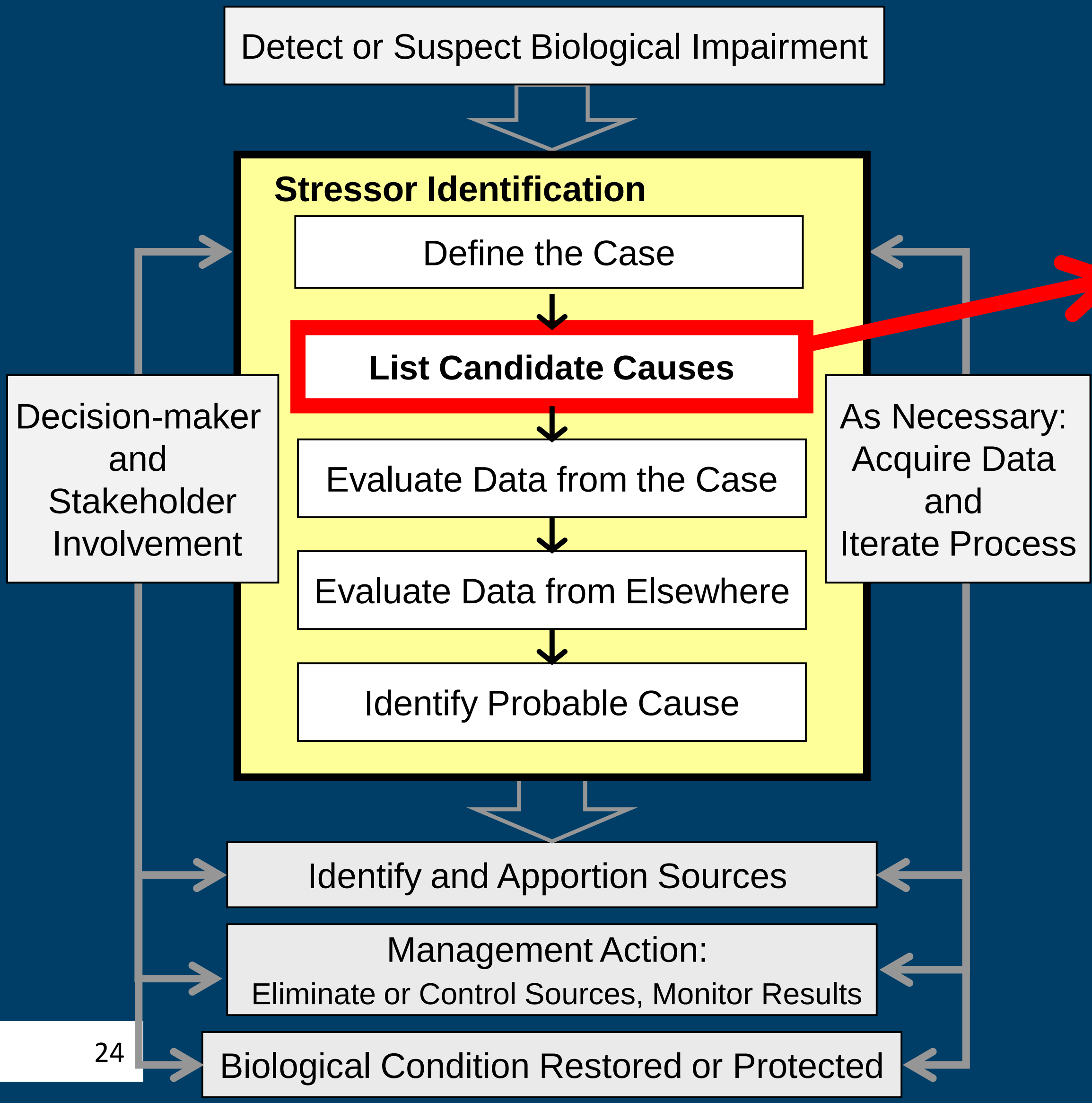
Defining the case at Pretend Creek



Defining the case at Pretend Creek



Step 2 – List candidate causes



- Generate an initial list
- Gather information on potential sources, stressors, and exposures
- Develop conceptual diagram
- Develop the "final" list

Step 2 – List candidate causes

- Generate the initial list of candidate causes
  - Hypothesized causes of effect(s)
  - Sufficiently credible to be analyzed
  - Focus on proximate stressor (stressor directly contacting or co-occurring with organisms)
  - Causes may include sources, mechanisms of action, or several causes acting together
  - In developing list, use:
    - Observations and available data from site
    - Information on known or potential sources
    - Existing knowledge from site, region, and elsewhere
    - Stakeholder input

Common aquatic stressors

CHEMICAL

- Dissolved oxygen
- Herbicides
- Pesticides
- Persistent toxic substances (e.g., PCBs, PAHs)
- Endocrine disruptors
- Metals
- Nutrients
- pH
- Suspended solids
- Salinity

PHYSICAL

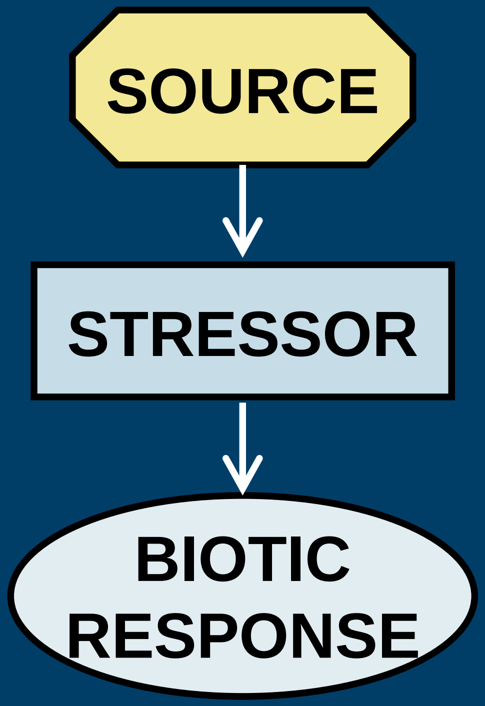
- Water temperature
- Bed sediment load
- Habitat destruction
- Habitat fragmentation
- Hydrologic alteration

BIOLOGICAL

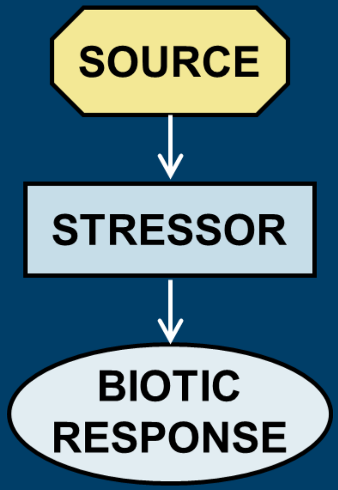
- Interspecies competition
- Invasive species
- Overharvesting
- Pathogens and parasites
- Predation

Step 2 – List candidate causes

- Make a map
  - Potential pollution sources (point, non-point)
  - Other factors that may affect candidate causes
- Make a conceptual diagram
  - Diagram showing hypothesized cause-effect linkages among sources, stressors, and biological effects
  - Used for:
    - Brainstorming
    - Analysis framework
    - Communication tool



Advice for developing a conceptual diagram



- Think about causal pathways.
  - How do sources lead to stressors?
  - How do stressors lead to biological effects?
- Be as specific as possible.
  - You do not need data for every component in your diagram.
  - Try to identify potential data sources and types of evidence.
  - Think about general vs. specific impairments.
- Be thorough and inclusive.
  - You can always eliminate things later one, so do not want to limit initial brainstorming and potentially miss something important.

CADDIS Volume 2: Sources, Stressors & Responses



Pilfer from CADDIS!

Deciding which pathways to consider in a causal assessment—that is, listing candidate causes as described in Step 2 of the process—sets the framework for causal assessment. This section of CADDIS provides background information on commonly encountered sources, stressors, and responses for use in deciding which candidate causes to consider, as well as developing cases for or against those candidate causes in the actual assessment.

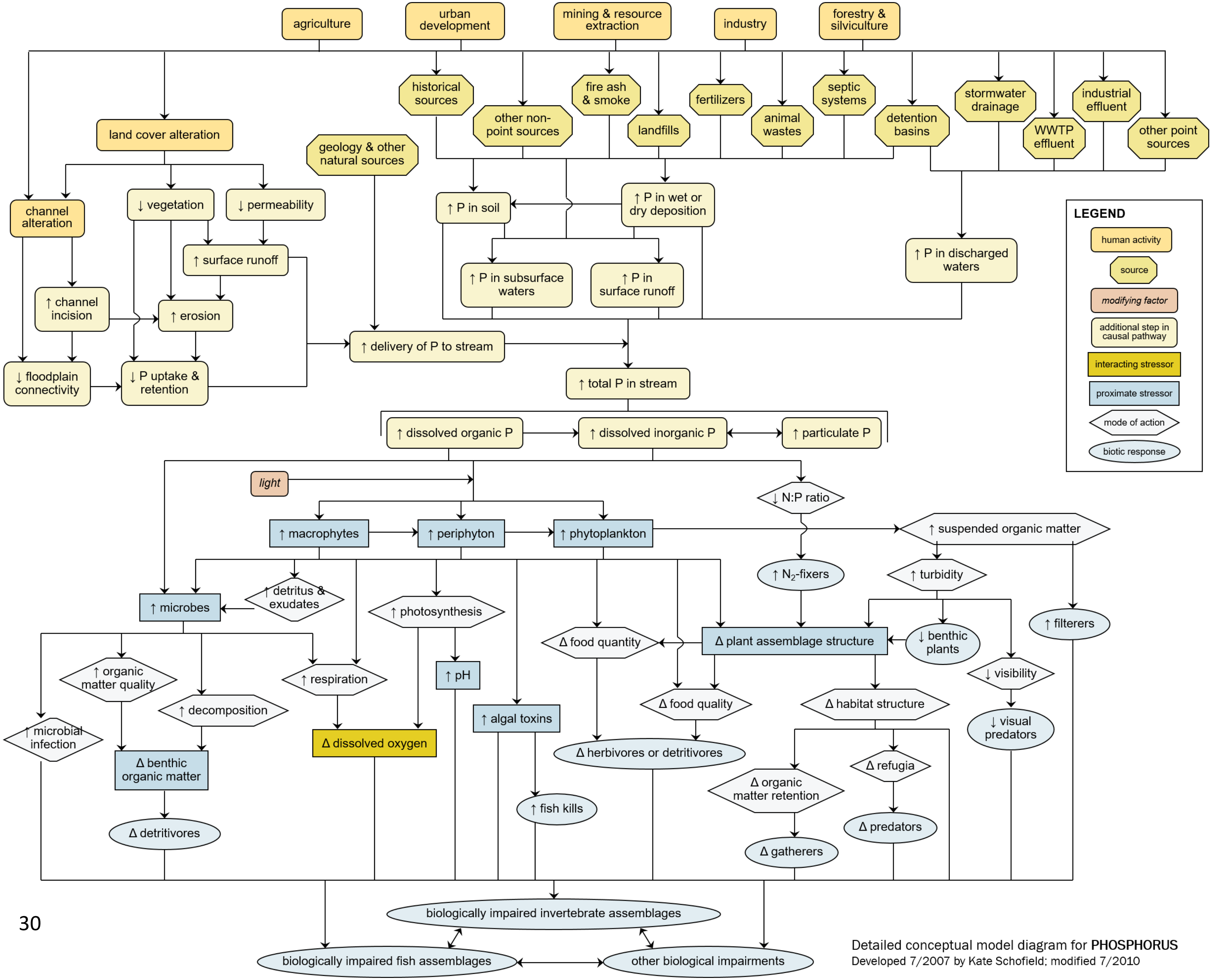
Each stressor module is organized into five sections, or tabs:

- **Introduction** provides a summary overview of the stressor, including a checklist of evidence that suggests including a given stressor in your assessment (i.e., listing it as a candidate cause).
- **When to List** provides more detailed information on the sources, activities, site evidence, and biologial responses that suggest inclusion as a candidate cause.
- **Ways to Measure** details different methods for quantifying the stressor.
- **Conceptual Diagrams** illustrates hypothesized causal linkages among the stressor, its sources, and associated biotic responses.
- **References** lists the references cited throughout the module.

In addition, some stressor modules have a **Literature Reviews** tab, which presents an annotated bibliography of key references providing general background information, particularly regarding stressor-response relationships.

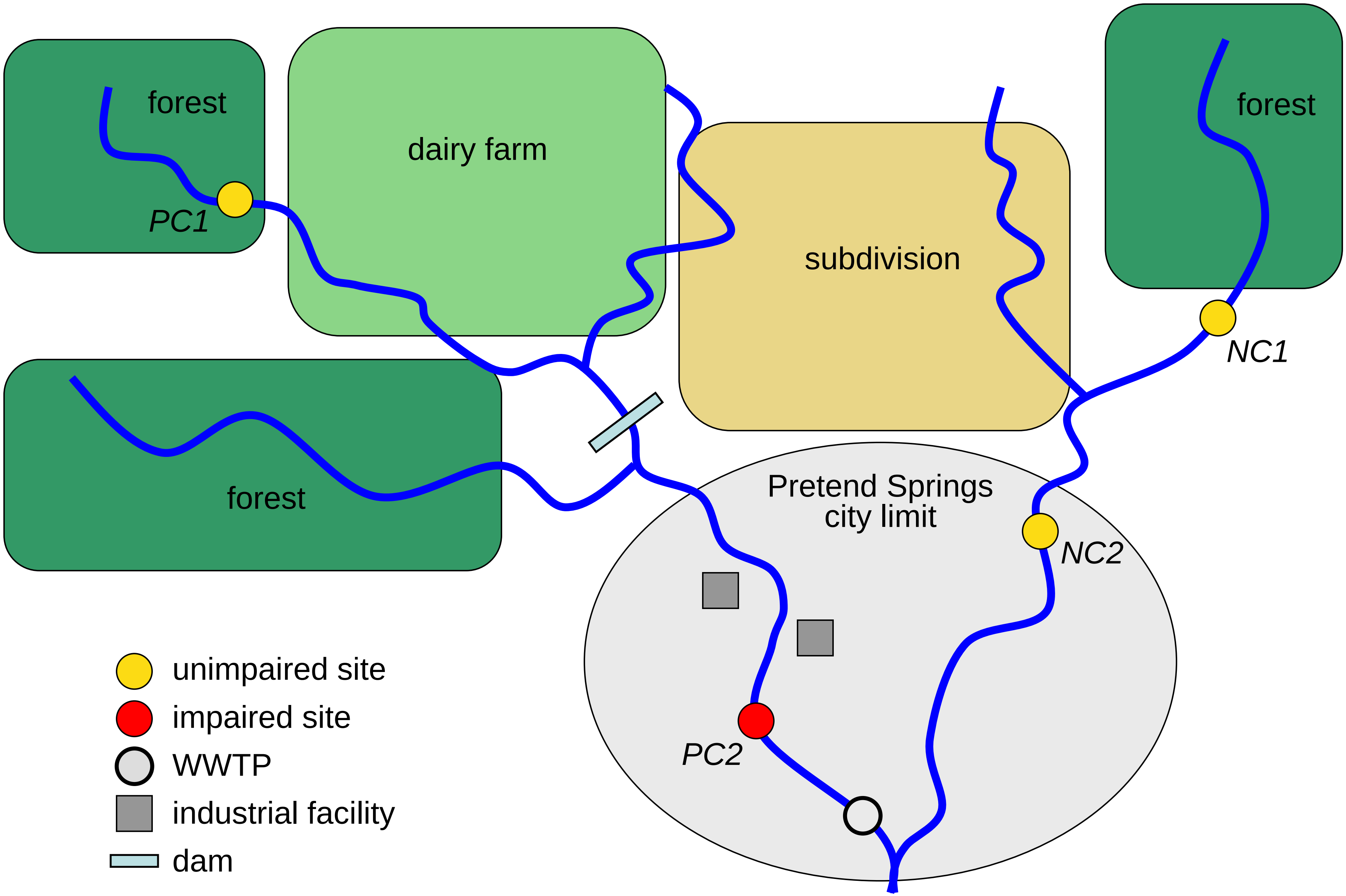
The source module for urbanization contains similar summary information on effects of urban development on stream ecosystems, but it is presented in a different format. The module is organized using a simple schematic of how urbanization affects streams. Users can click on any shape in the schematic to navigate through the module and focus on areas of interest; within each section (i.e., under each shape) the user can click on additional topic boxes for more detailed information.

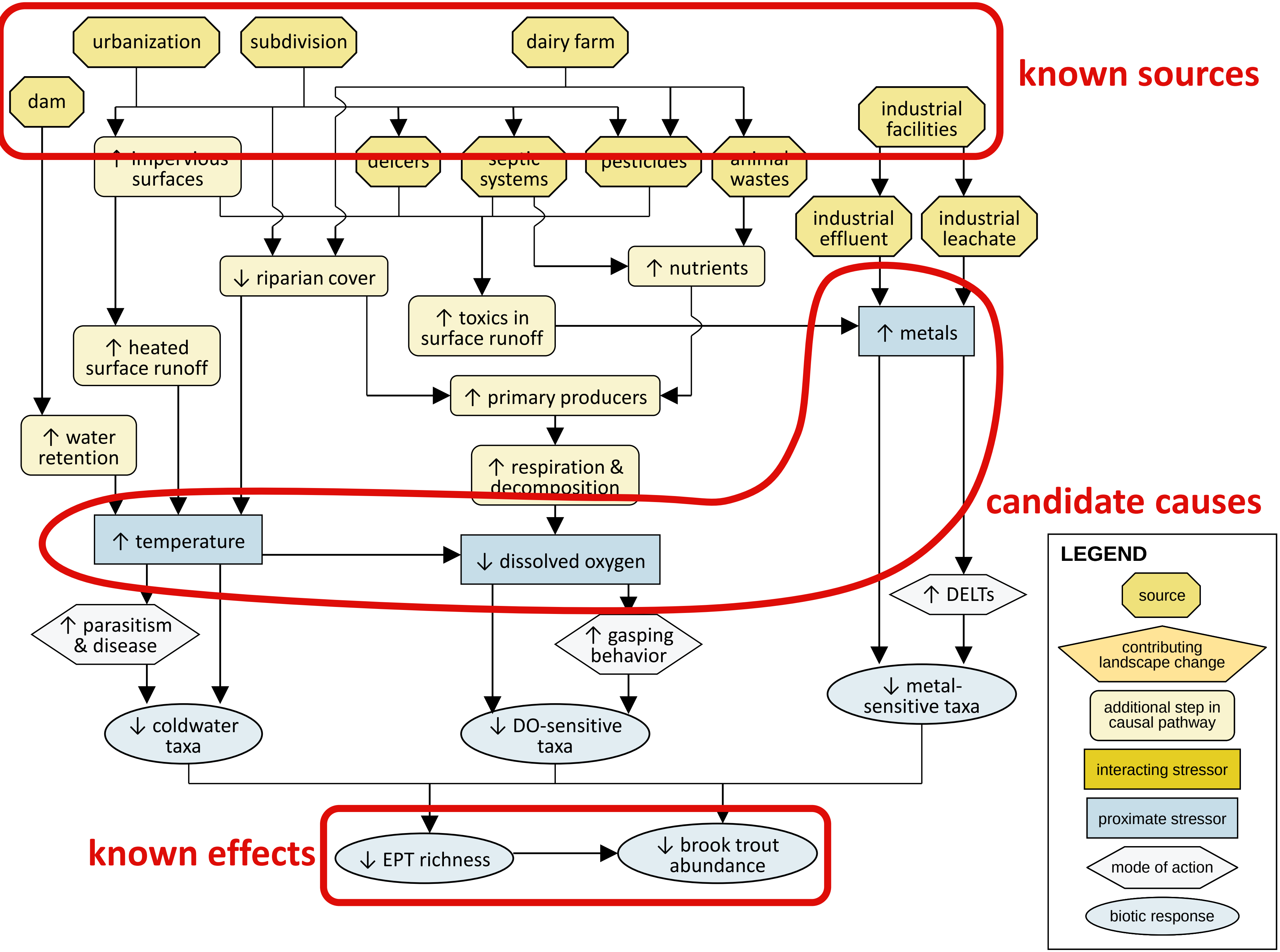
Ammonia	Insecticides	pH	Temperature
Dissolved Oxygen	Ionic Strength	Physical Habitat	Unspecified Toxic Chemicals
Flow Alteration	Metals	Sediments	Urbanization
Herbicides	Nutrients		



Detailed conceptual model diagram for **PHOSPHORUS**
Developed 7/2007 by Kate Schofield; modified 7/2010

Listing candidate causes at Pretend Creek

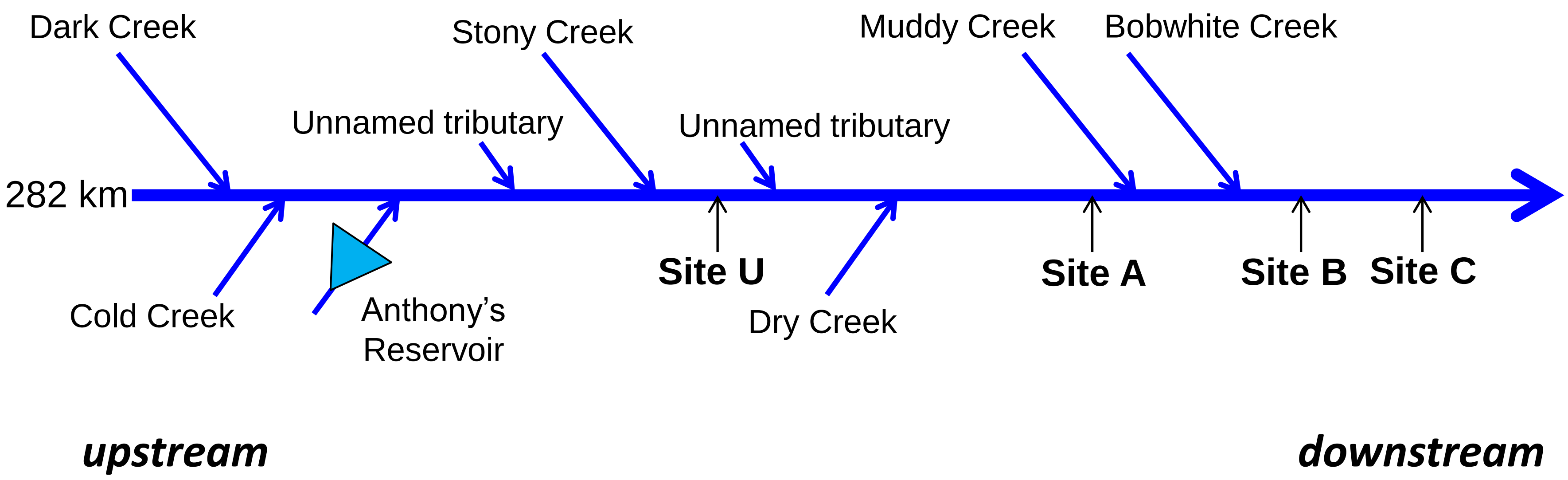




known sources
urbanization
subdivision
dairy farm
dam
industrial facilities
↑ impervious surfaces
deicers
septic systems
pesticides
animal wastes
industrial effluent
industrial leachate
↓ riparian cover
↑ nutrients
↑ toxics in surface runoff
↑ metals
↑ heated surface runoff
↑ primary producers
↑ water retention
↑ respiration & decomposition
candidate causes
↑ temperature
↓ dissolved oxygen
↑ DELTs
↑ parasitism & disease
↑ gasping behavior
↓ metal-sensitive taxa
↓ coldwater taxa
↓ DO-sensitive taxa
known effects
↓ EPT richness
↓ brook trout abundance
LEGEND
source
contributing landscape change
additional step in causal pathway
interacting stressor
proximate stressor
mode of action
biotic response

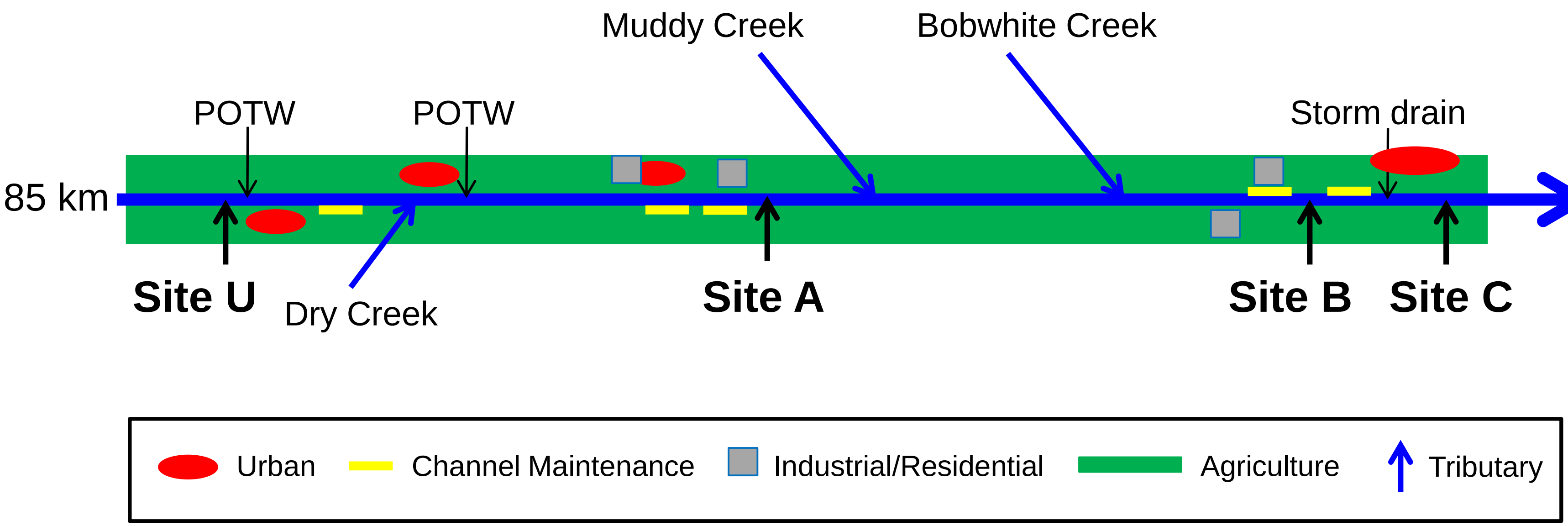
The Exercise River

The Exercise River – Defining the case

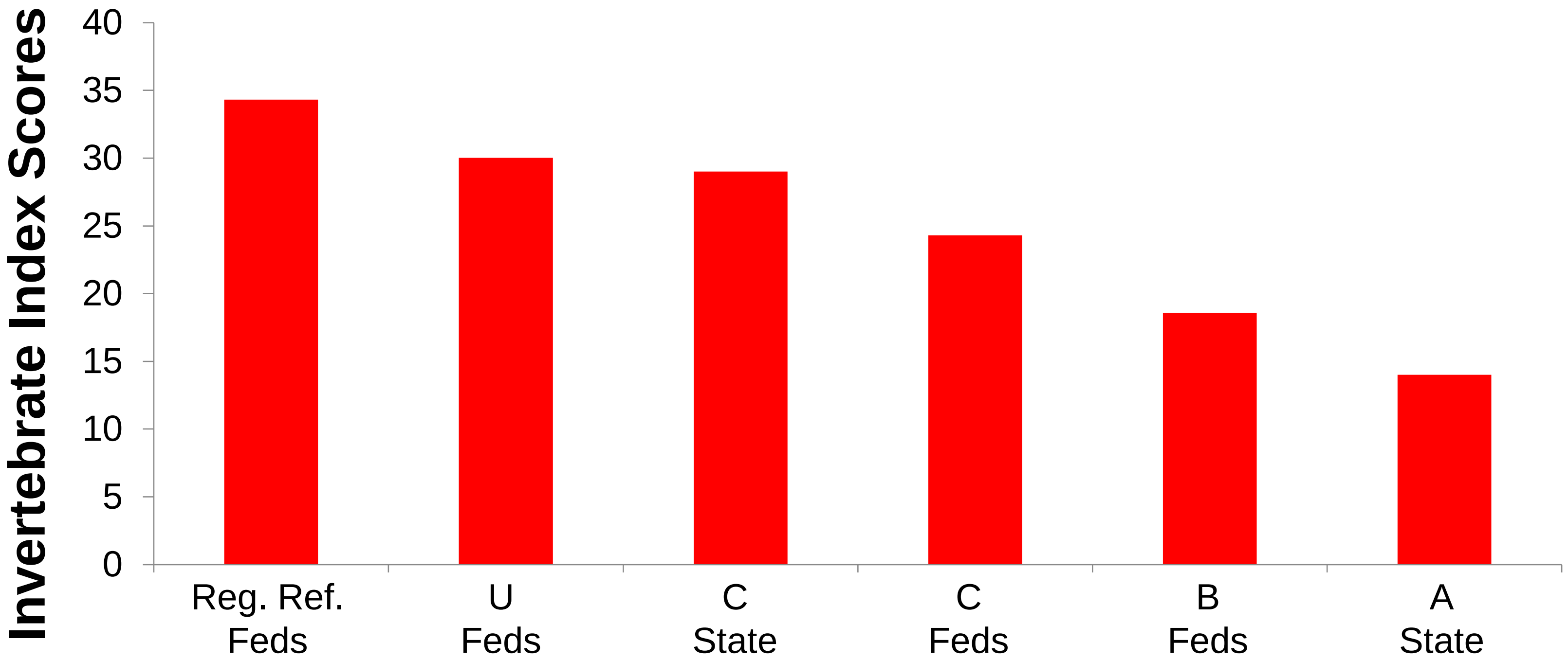


The Exercise River – Defining the case

Schematic of Sources



The Exercise River – Defining the case

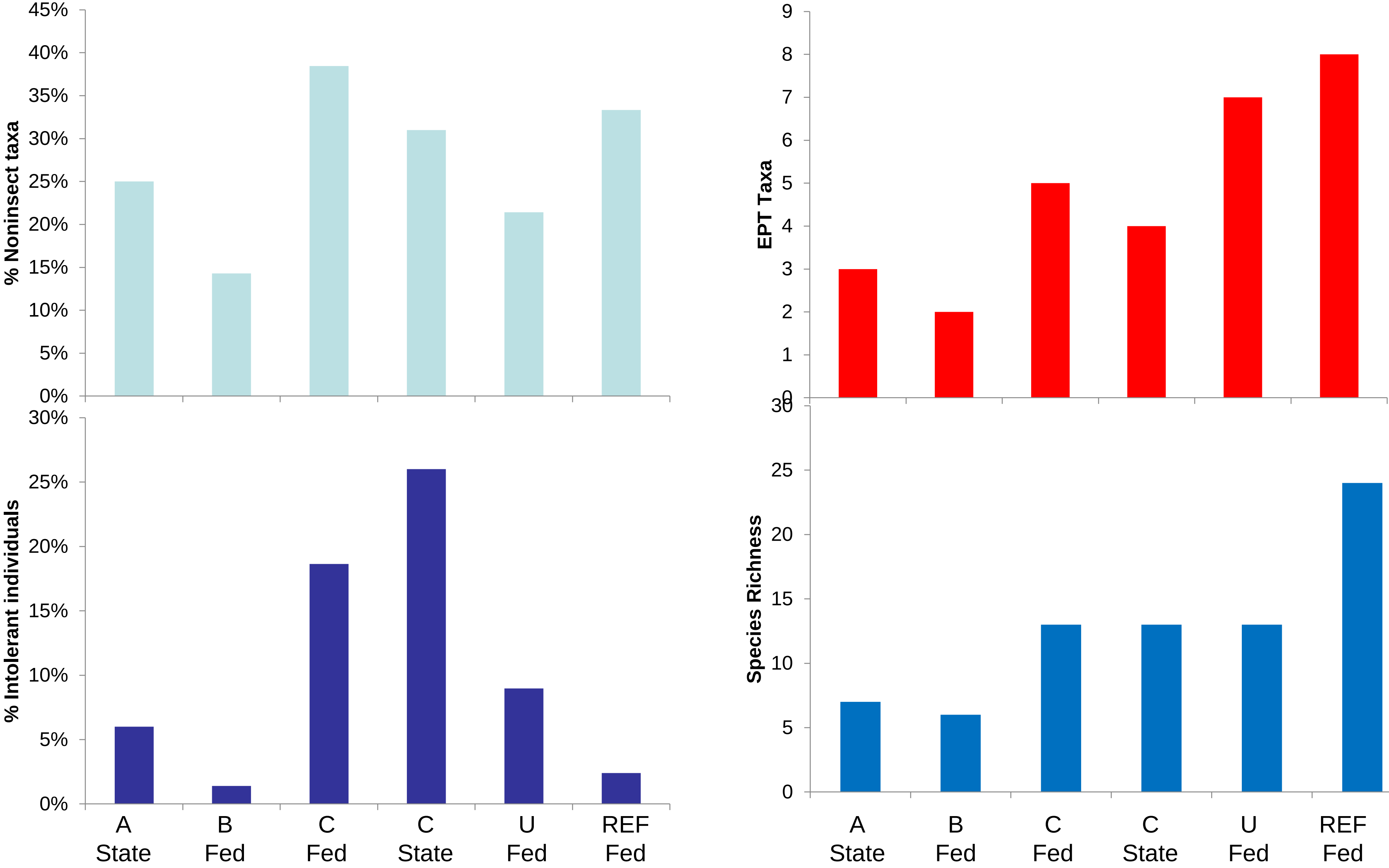


	REF	U	C	C	B	A
Program	Feds	Feds	State	Feds	Feds	State
Index Score	34	30	29	24	19	14
Sampling Date	14 May	26 May	6 Jun	25 May	26 May	6 Jun

The Exercise River – Defining the case

- What are the affected sites?
  - Site A, Site B
- What are the comparison sites?
  - Site U (upstream reference)
  - Site C
  - Out-of-basin reference
- What specifically changed (biologically)?
  - ANSWER?

The Exercise River – Defining the case



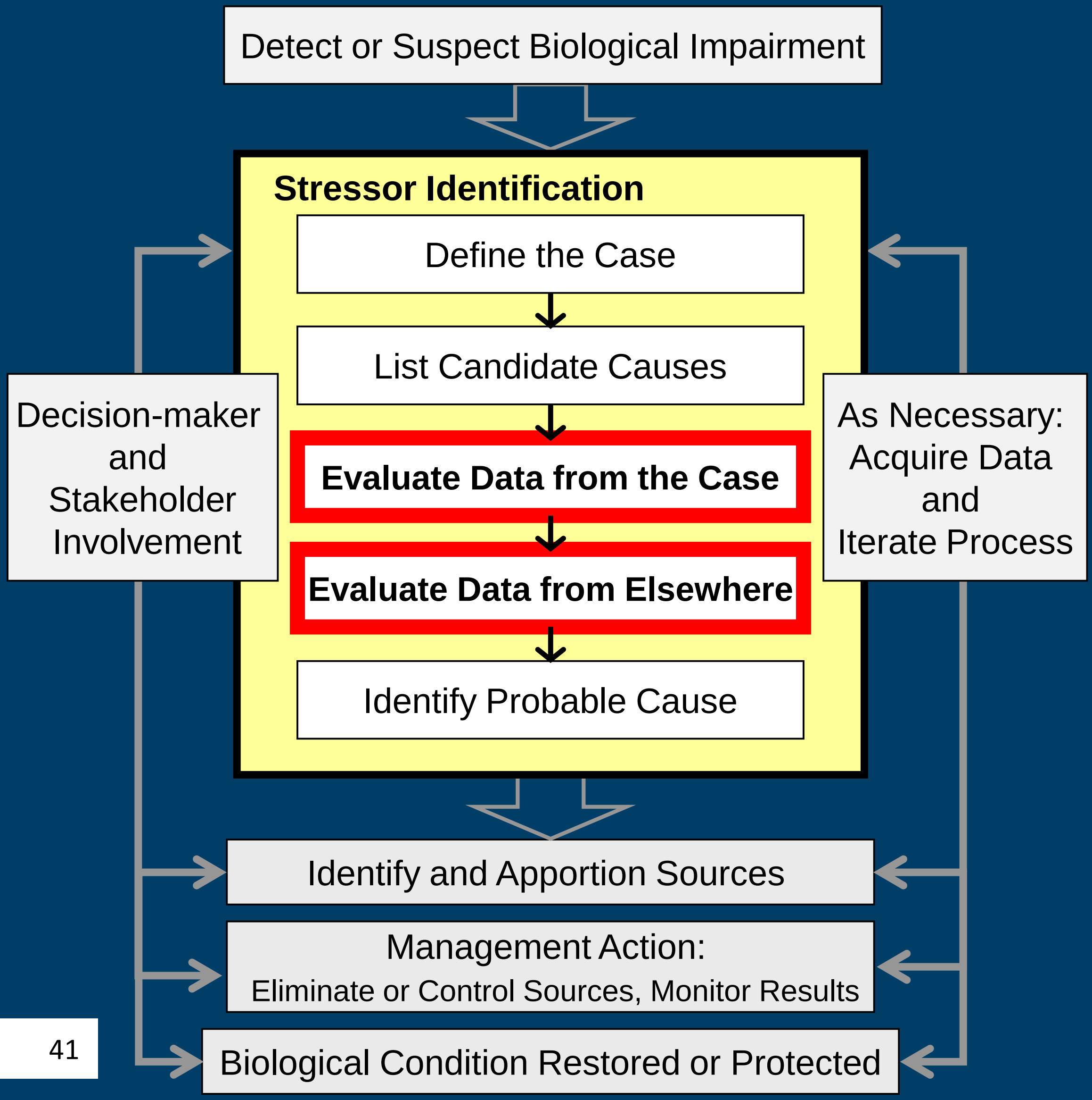
The Exercise River – Defining the case

Count (RA%)	A	B	C	C	U	Ref
	State	Feds	Feds	State	Feds	Feds
Chironomidae	178 (36%)	312 (63%)	262 (52%)	22 (37%)	134 (38%)	51 (10%)
Oligochaeta	246 (49%)	168 (34%)	21 (4%)	3 (5%)	12 (3%)	21 (4%)
Tricorythodes	2 (<1%)	3 (1%)	61 (12%)	7 (12%)	68 (19%)	217 (43%)
Centroptilum	29 (6%)	7 (1%)	136 (27%)	11 (19%)	32 (9%)	12 (2%)
Acentrella	0 (0%)	0 (0%)	0 (0%)	1 (2%)	63 (18%)	11 (2%)
Hydropsyche	0 (0%)	0 (0%)	0 (0%)	0 (0%)	2 (1%)	70 (14%)
Total Count	497	498	500	59	356	500

The Exercise River – Listing candidate causes

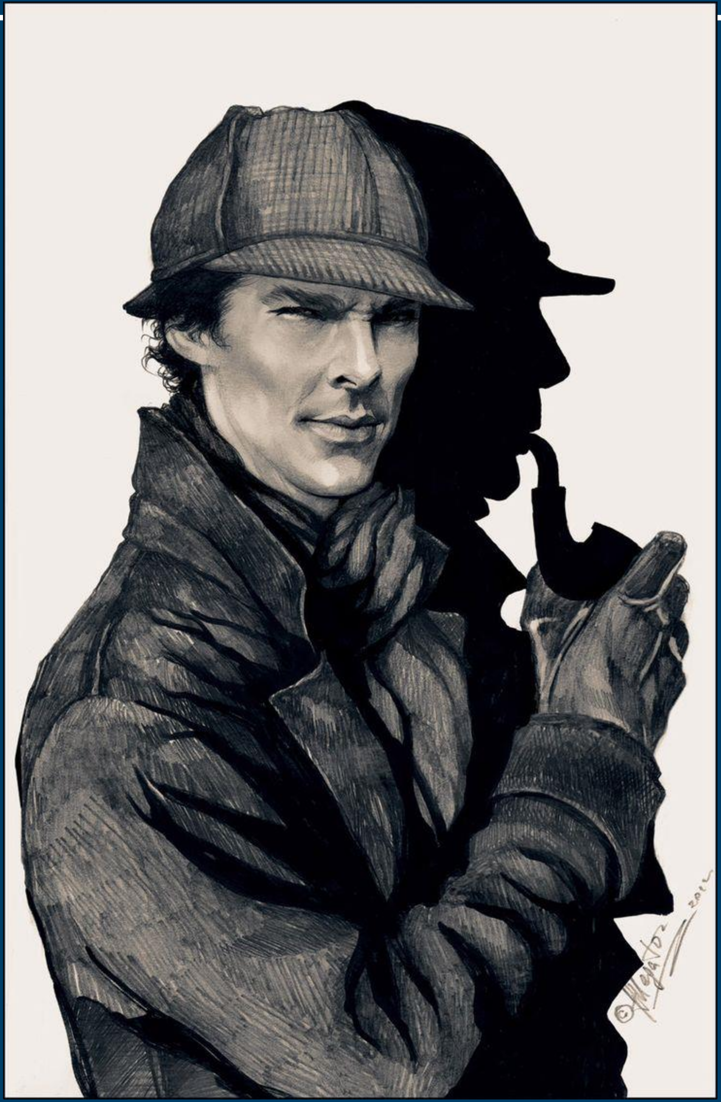
1. Increased sediments
2. Increased ionic strength
3. Increased pesticides
4. Decreased dissolved oxygen
5. Increased metals
6. Nutrient enrichment and toxicity
7. Flow alteration
8. Physical habitat alteration

Steps 3 & 4 – Evaluating the data



Let’s talk about evidence…

- What is evidence?
  - Available information that indicates whether belief or proposition is valid.
  - If Cause X produced Effect Y, then we would expect to observe Result Z.
  - Information used to determine whether we actually observe Result Z is a piece of evidence.
  - Individual pieces of evidence are combined into the overall body of evidence.



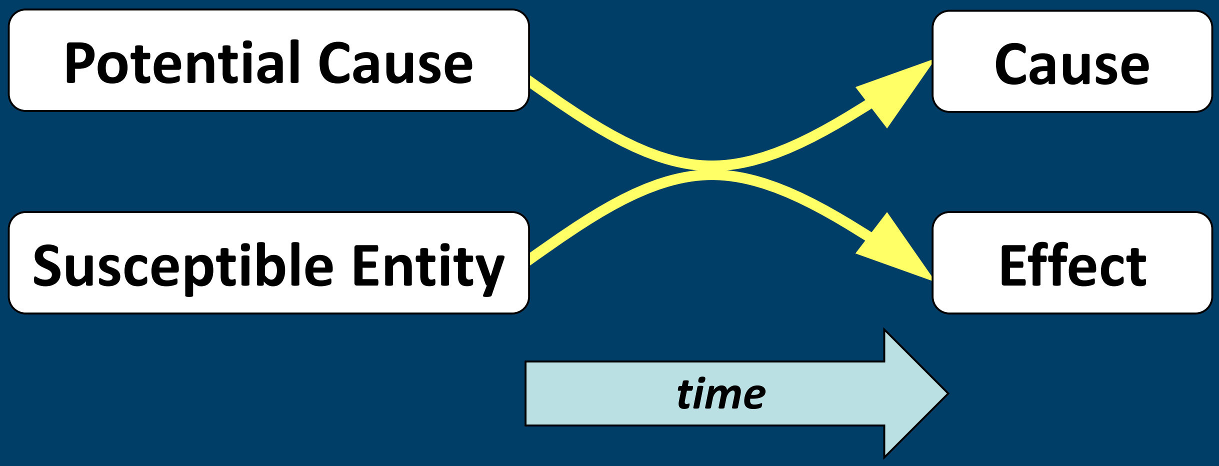
An example

- **<u>IF</u>** effluent from a WWTP discharge caused the observed effect on macroinvertebrates, **<u>THEN</u>** we would ***expect*** that this effect would have occurred only after effluent was first discharged.

- Data showing when WWTP began discharging, relative to when effect was observed, are a ***piece of evidence***.
  - Evidence ***supports*** argument for effluent as cause if effect was observed after, but not before, discharge began.
  - Evidence ***weakens*** the argument for effluent as cause if effect was observed both before and after discharge began.

What are our expectations based on?

- Causal relationships exhibit certain fundamental characteristics:
  - Time order
  - Co-occurrence, interaction, sufficiency
  - Alteration
  - Antecedence



Causal characteristics

Characteristic	Description	Expect To Observe
Co-occurrence	The cause co-occurs with the susceptible entity in space and time.	The presence of both the cause and the effect and the potential for exposure.
Sufficiency	The intensity, frequency, and duration of the cause are adequate, and the entity is sufficiently susceptible to produce the type and magnitude of the effect.	Enough of the cause and a sufficiently susceptible entity that can result in the level of the observed effect.
Time order	The cause precedes the effect.	Change in the entity after interaction with the cause and not before.
Interaction	The cause interacts with the entity in a way that can induce the effect.	Signs of initiation of the change by the causal agent such as contact or uptake.
Alteration	The entity is altered by interacting with the cause.	Changes in the entity attributable to or at least appropriate to the cause.
Antecedence	The causal relationship is a result of a larger web of antecedent cause-and-effect relationships.	Earlier events that led to the particular causal event.

Where does evidence come from?

Type of Investigation

Source of Samples

	Field observations	Field experiments	Laboratory experiments	Models
From the case under investigation				
From other cases				

No piece of evidence is perfect –
so want to develop as many pieces of evidence as possible.

"From the case" vs. "from elsewhere"

- "**From the case**" = data collected from affected location and nearby comparison sites
  - Most relevant evidence
  - Best chance of isolating causal processes, minimizing confounding factors
- "**From elsewhere**" = data collected from other field locations, the laboratory, or process models
  - Compare data from the case to data from elsewhere to derive pieces of evidence

Types of evidence in CADDIS

Data from the case

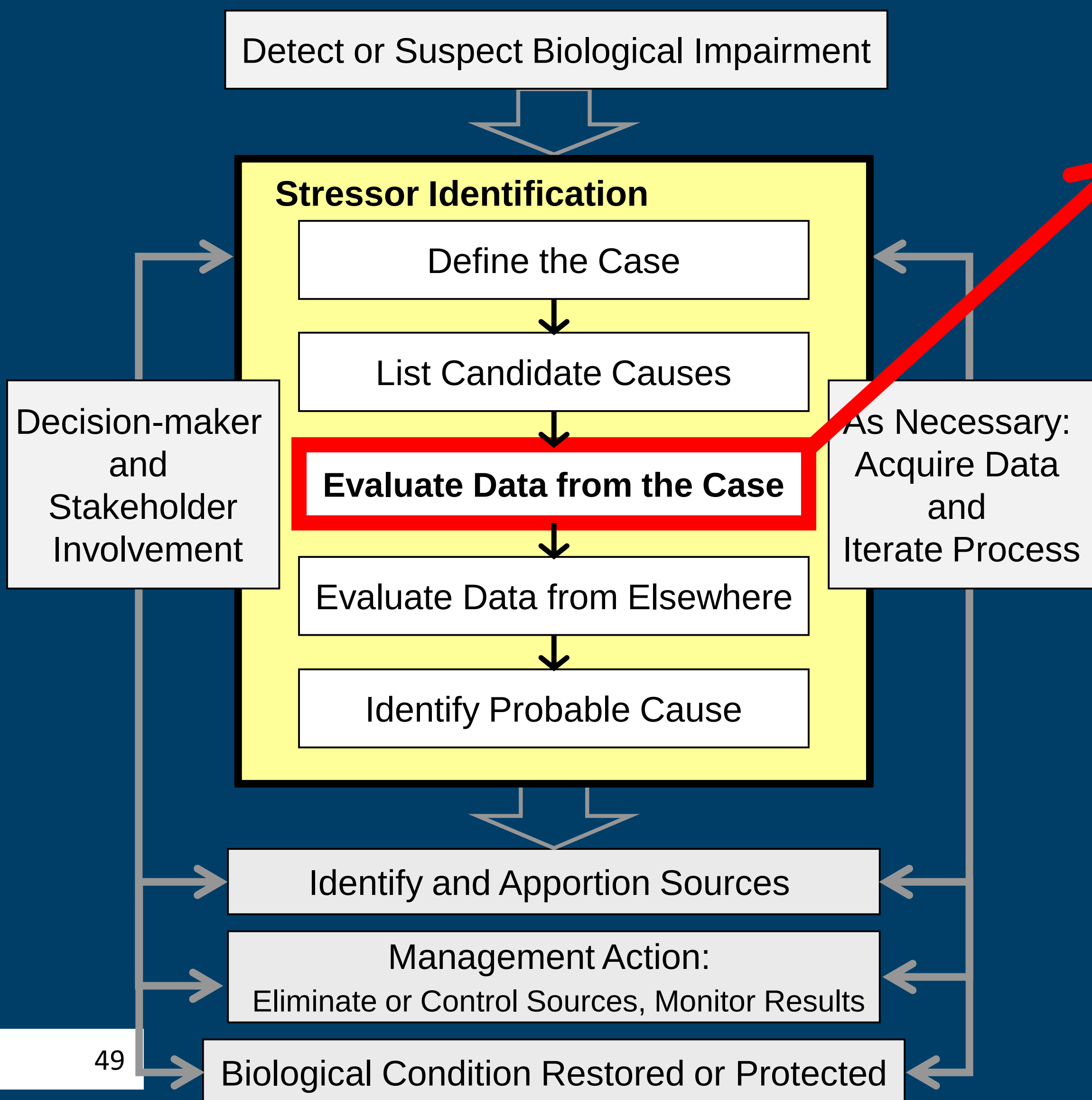
- ***Spatial/temporal co-occurrence***
- Evidence of exposure or biological mechanism
- ***Causal pathway***
- ***Stressor-response relationships from the field***
- Manipulation of exposure
- Laboratory tests of site media
- Temporal sequence
- Verified predictions
- Symptoms

Data from elsewhere

- ***Stressor-response relationships from other field studies***
- ***Stressor-response relationships from laboratory studies***
- Stressor-response relationships from ecological simulation models
- Mechanistically plausible cause
- Manipulation of exposure at other sites
- Verified predictions
- Analogous stressors

italics indicates commonly available types of evidence

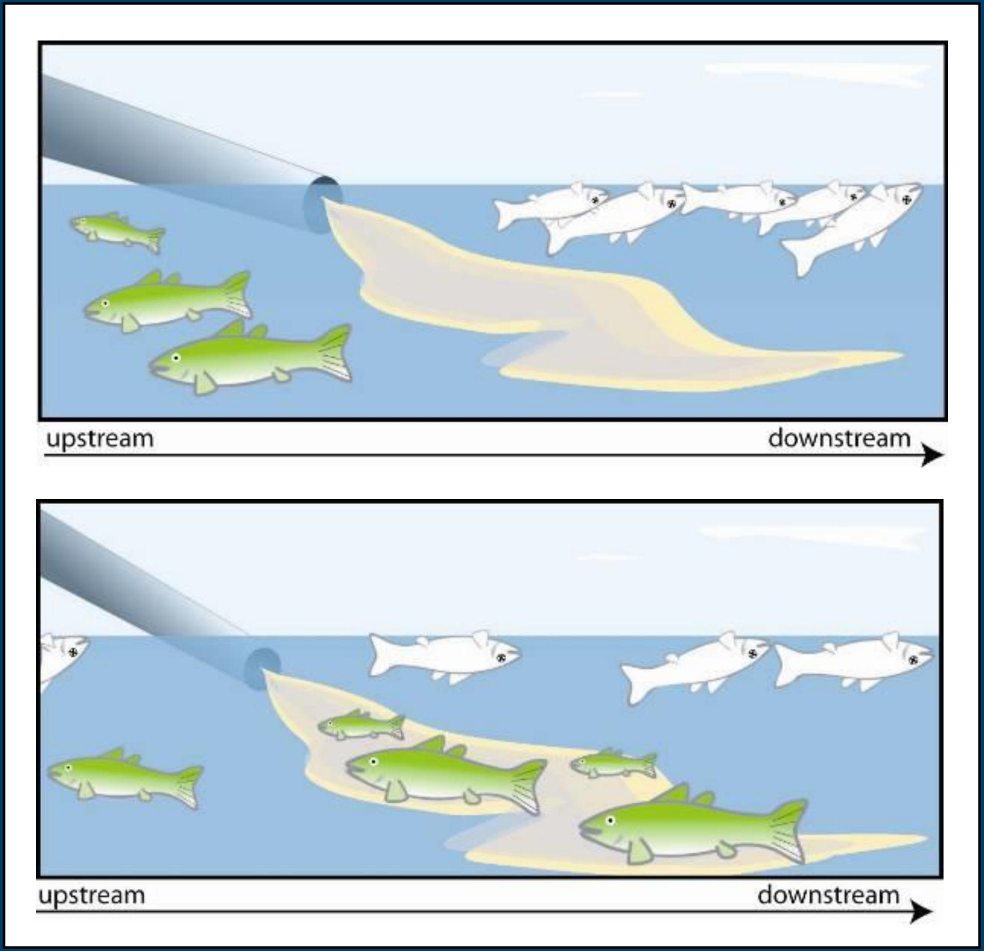
Step 3 – Evaluating data from the case



- Co-occurrence
- Stressor-response associations from field
- Causal pathway
- Lab tests of site media

- Exposure or mechanism
- Manipulation
- Temporal sequence
- Verified predictions
- Symptoms

Spatial / temporal co-occurrence



SUPPORTS

Impairment occurs where or when exposure to stressor occurs

WEAKENS

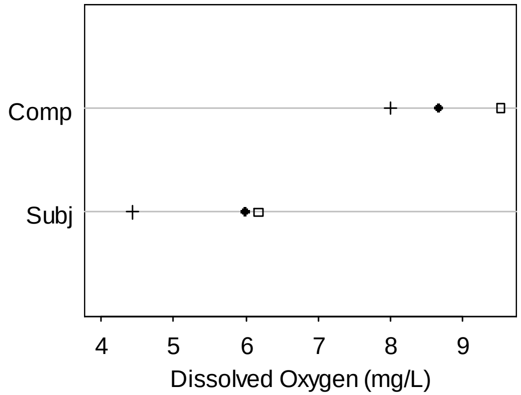
Impairment does not occur where or when exposure to stressor decreases

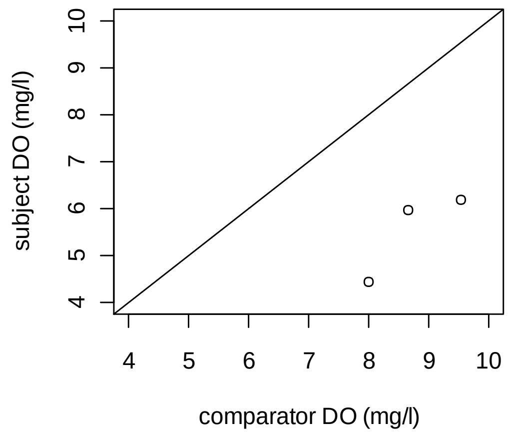
Example plots

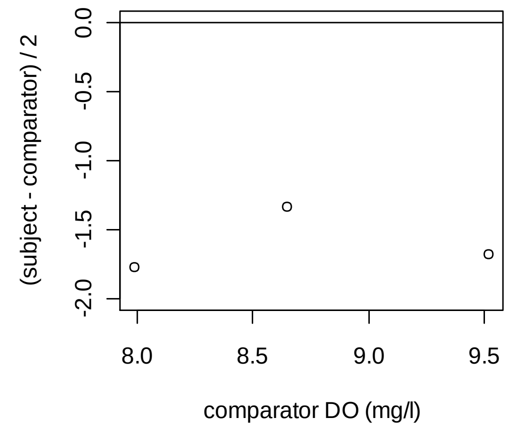
dot plots

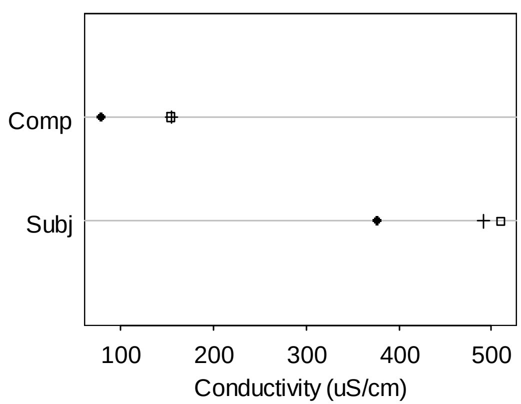
q-q plots

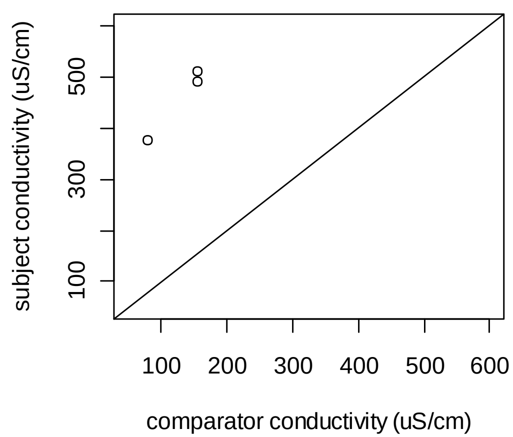
mean difference plots

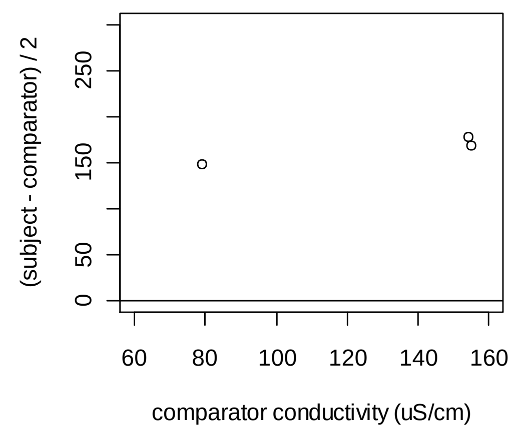












Issues and recommendations

- Only use measures of proximate stressor
  - Other measures considered under “Causal pathway” evidence
- Simple comparison – is exposure to proximate stressor greater where/when effect occurs?
- Don’t consider whether magnitude is sufficient
  - Sufficiency considered under other types of evidence (e.g., “Stressor-response relationships from elsewhere” evidence)
- Consider uncertainty and variability, but do not rely on statistical tests

Why no hypothesis tests?

SCENARIO 1

- DO measured upstream & downstream over 9 months
  - Upstream mean = 9.3 mg/L
  - Downstream mean = 8.4 mg/L
- Difference significant at $P<0.05$

SCENARIO 2

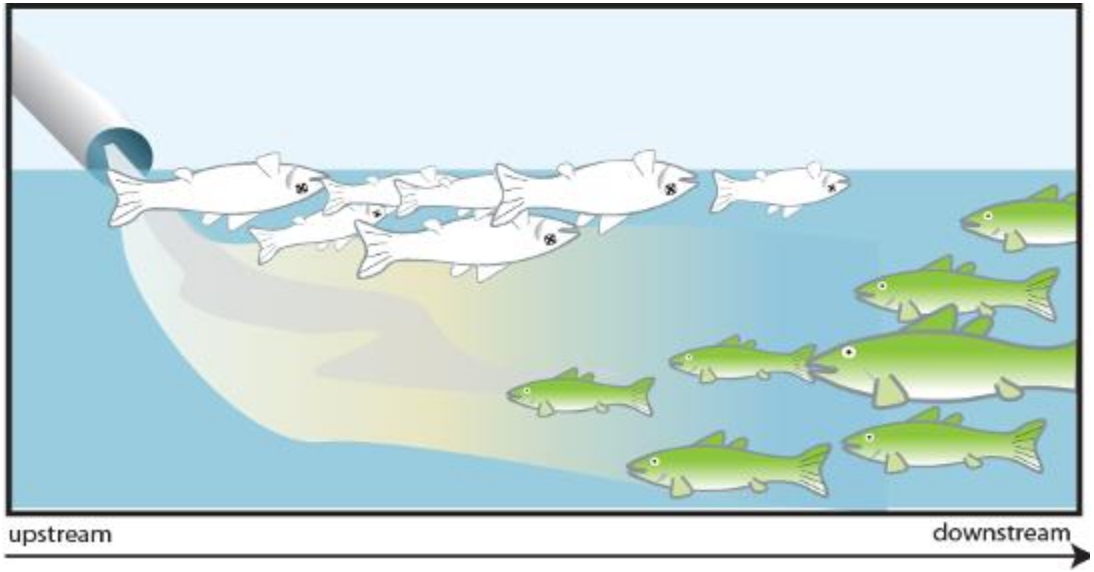
- DO measured upstream & downstream over 3 months
  - Upstream mean = 7.9 mg/L
  - Downstream mean = 4.2 mg/L
- Difference **not** significant at $P<0.05$

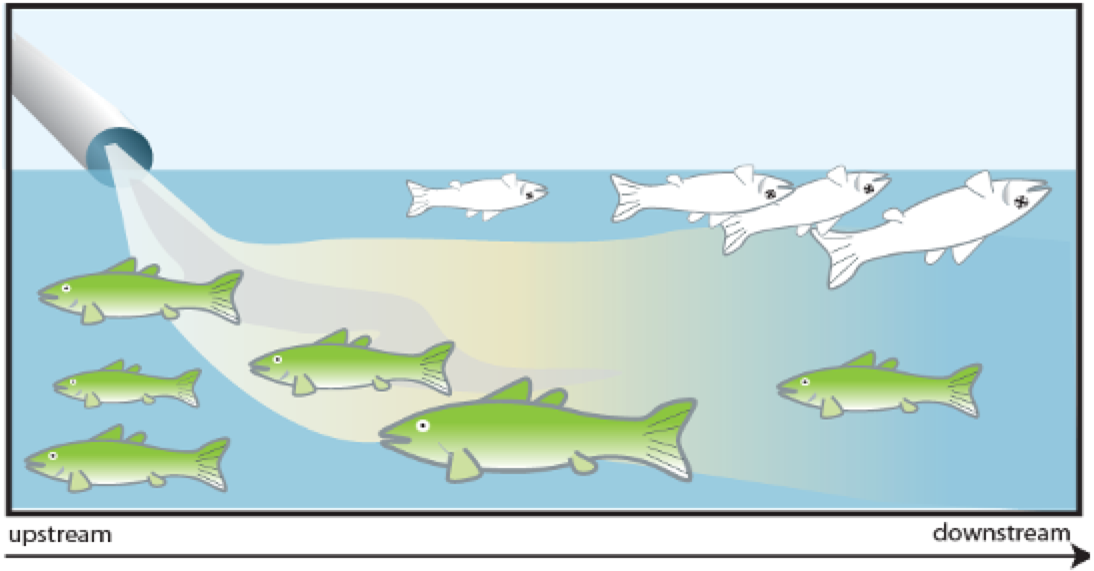
Which scenario presents a stronger case for DO causing impairment?

Use caution in interpreting differences

- Look at **magnitude** and **consistency** of differences, rather than statistical significance
- Statistical significance detects differences exceeding natural variance
  - Does not detect stressor effects
  - Does not equal biological significance
  - Small *n* = limited power to detect differences
- Can use statistics, but also use your head
  - Think about relationship between minimum detectable difference (power) and biologically relevant difference

Stressor-response from the field





SUPPORTS

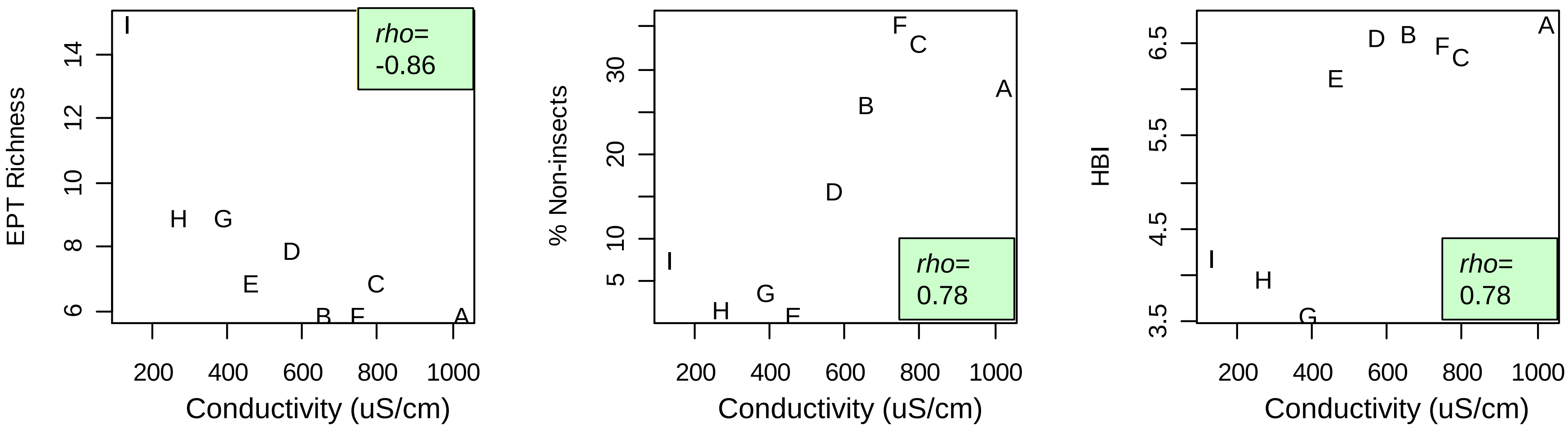
Impairment decreases as exposure to stressor decreases

WEAKENS

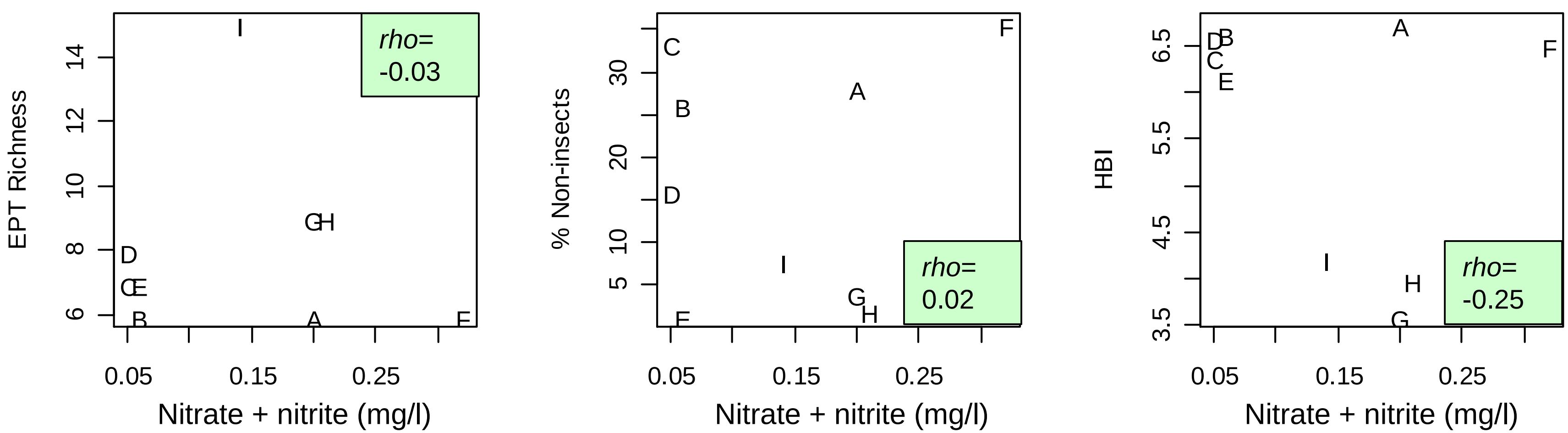
Impairment increases as exposure to stressor decreases

Example plots

SUPPORT

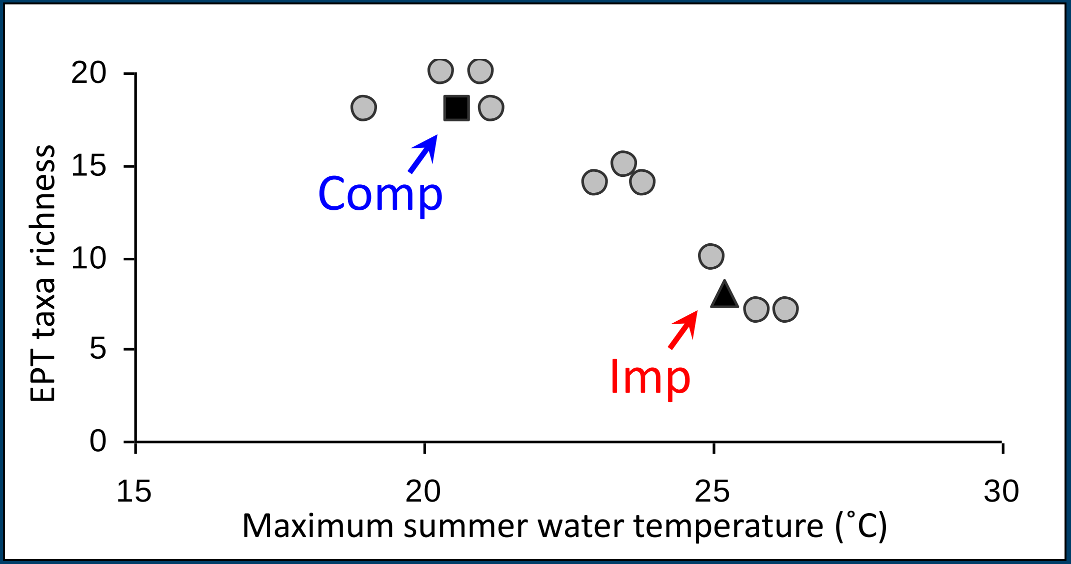


WEAKEN

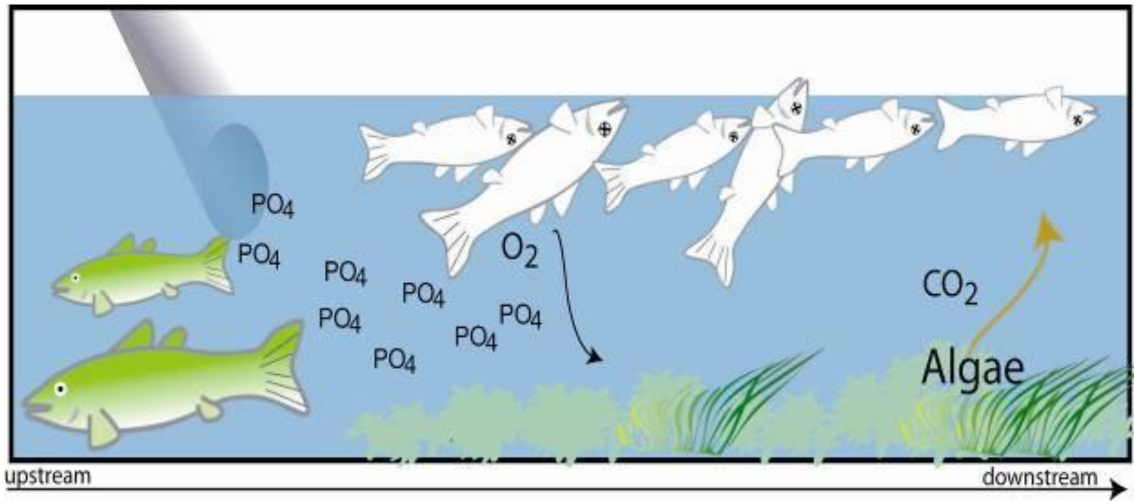


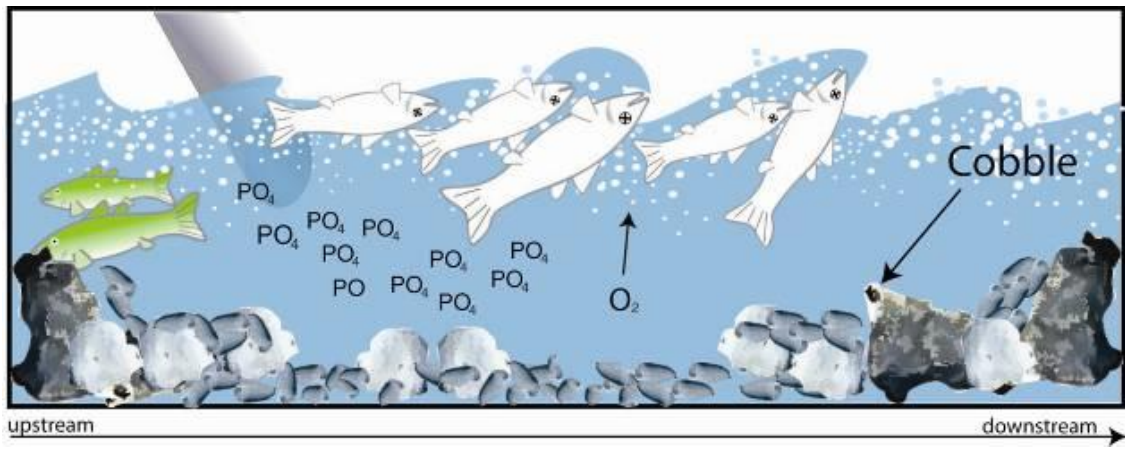
Interpreting correlations

- Correlations and slopes quantify degree of association between stressor and response in group of sites – but say nothing about where observations from impaired site fall within that relationship
- Only evaluate S-R from field for stressors with supporting evidence for co-occurrence
- Visually confirm that association supports case by identifying impaired and comparison sites on scatterplots



Causal pathway





SUPPORTS

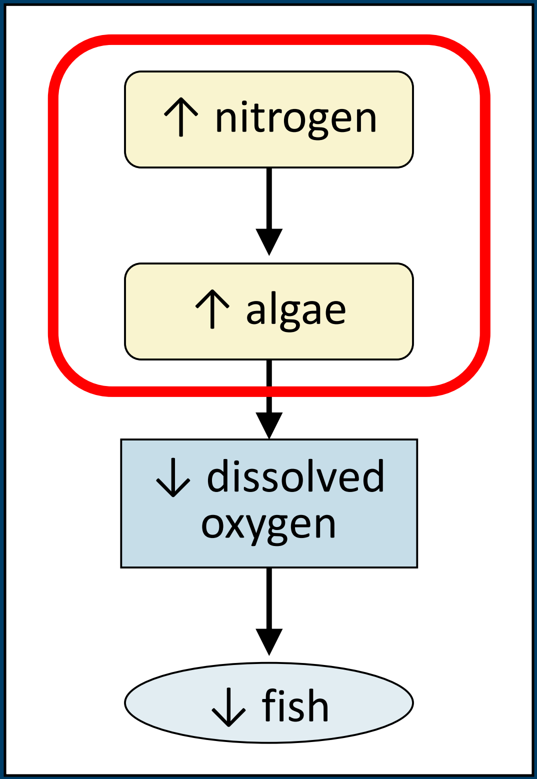
Steps in causal pathway observed and coincide with impairment

WEAKENS

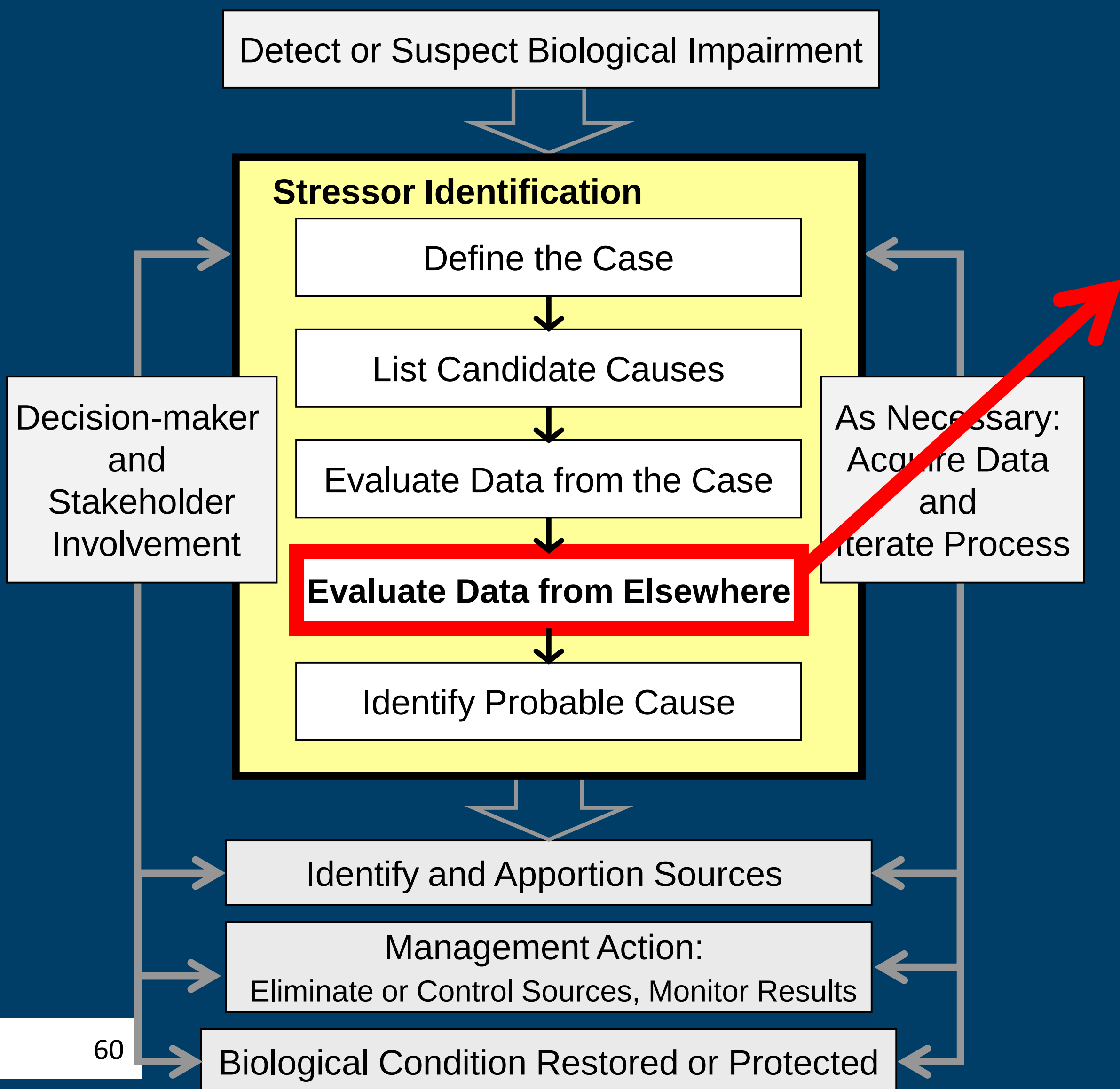
Steps in causal pathway not observed or do not coincide with impairment

Issues and recommendations

- Causal pathway similar to spatial/temporal co-occurrence, but uses data from entire causal chain
- When in doubt, assume a step exists
- Evidence of a missing step is powerful; evidence of many intermediate steps increases confidence
- May be able to eliminate one pathway, but rarely can eliminate all pathways



Step 4 – Evaluating data from elsewhere



- Spatial co-occurrence compared with regional reference sites
- Stressor-response relationships from lab, other field studies, or ecosystem models

---

- Mechanistically plausible cause
- Manipulation
- Temporal sequence
- Verified predictions
- Symptoms

Extrapolating "from elsewhere" to your site

Use care when extrapolating from test systems → your system!

OTHER FIELD STUDIES

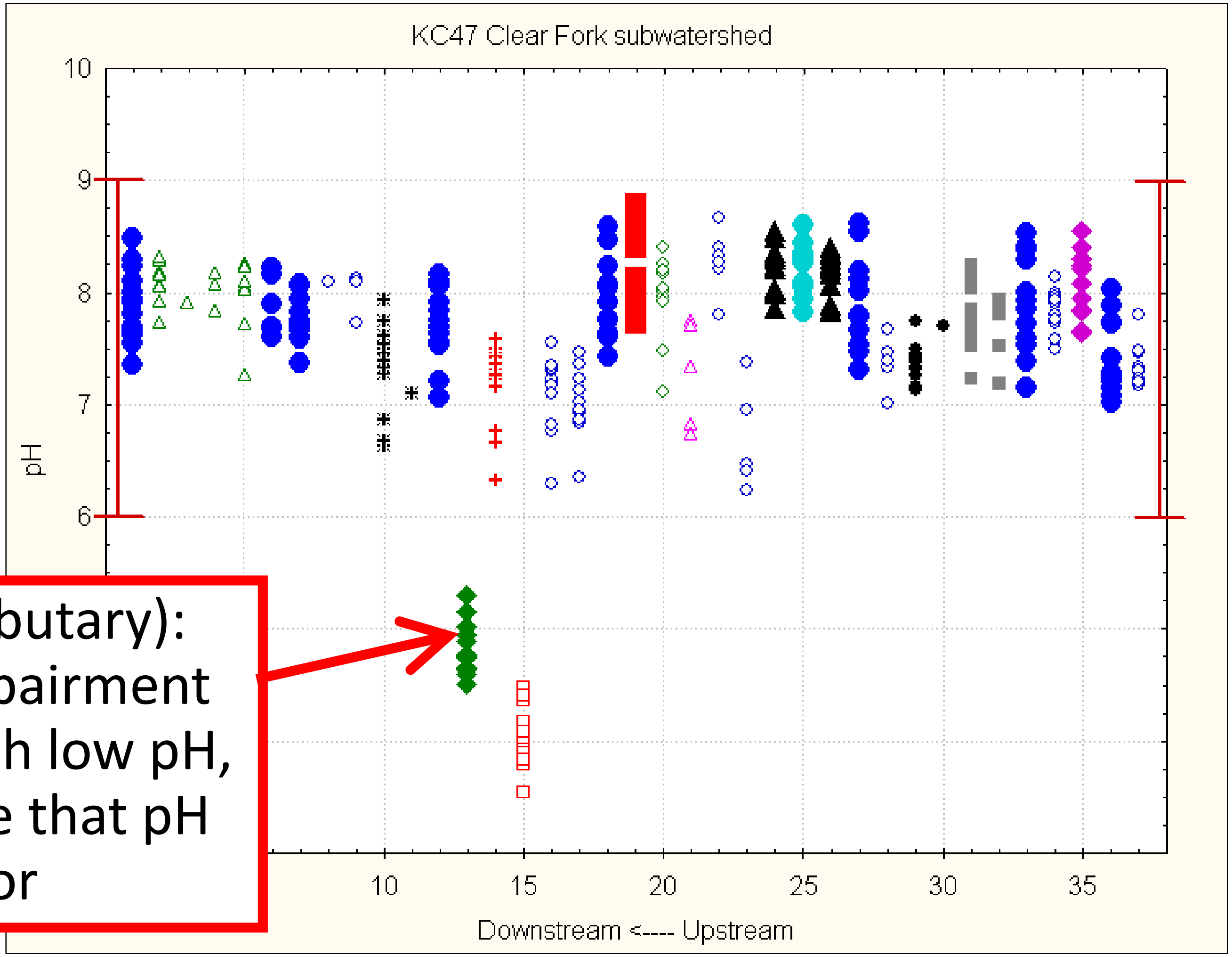
- taxa differ (EPT ≠ EPT)
- co-varying stressors
- confounding factors

LAB STUDIES

- different test organisms
- single-stressor exposures
- not representative of field conditions
- no biotic interactions
- criteria often protective, not effects-based

Spatial co-occurrence and regional reference sites

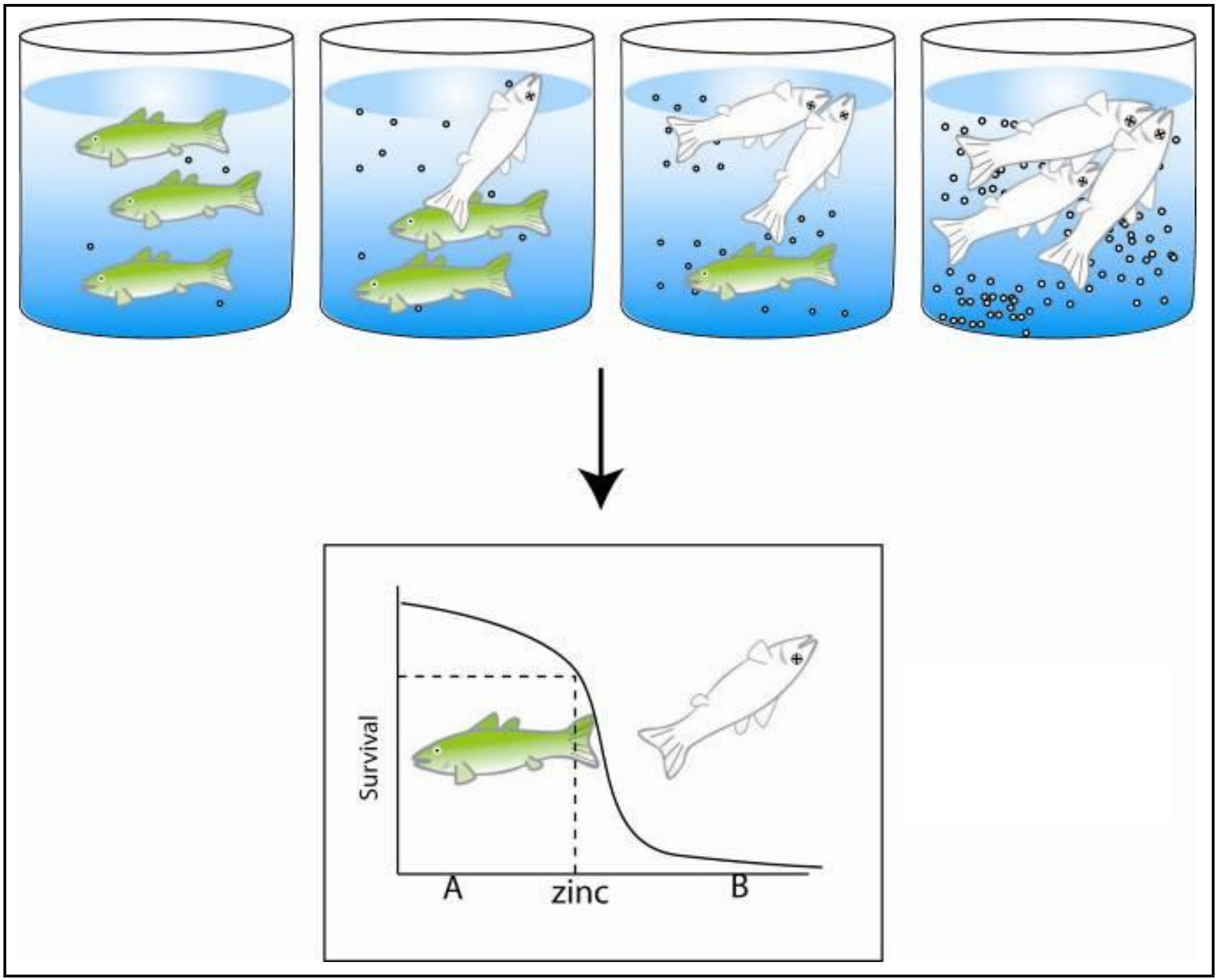
pH in Clear Fork, West Virginia and its tributaries



"Normal" pH range (from state-wide database)

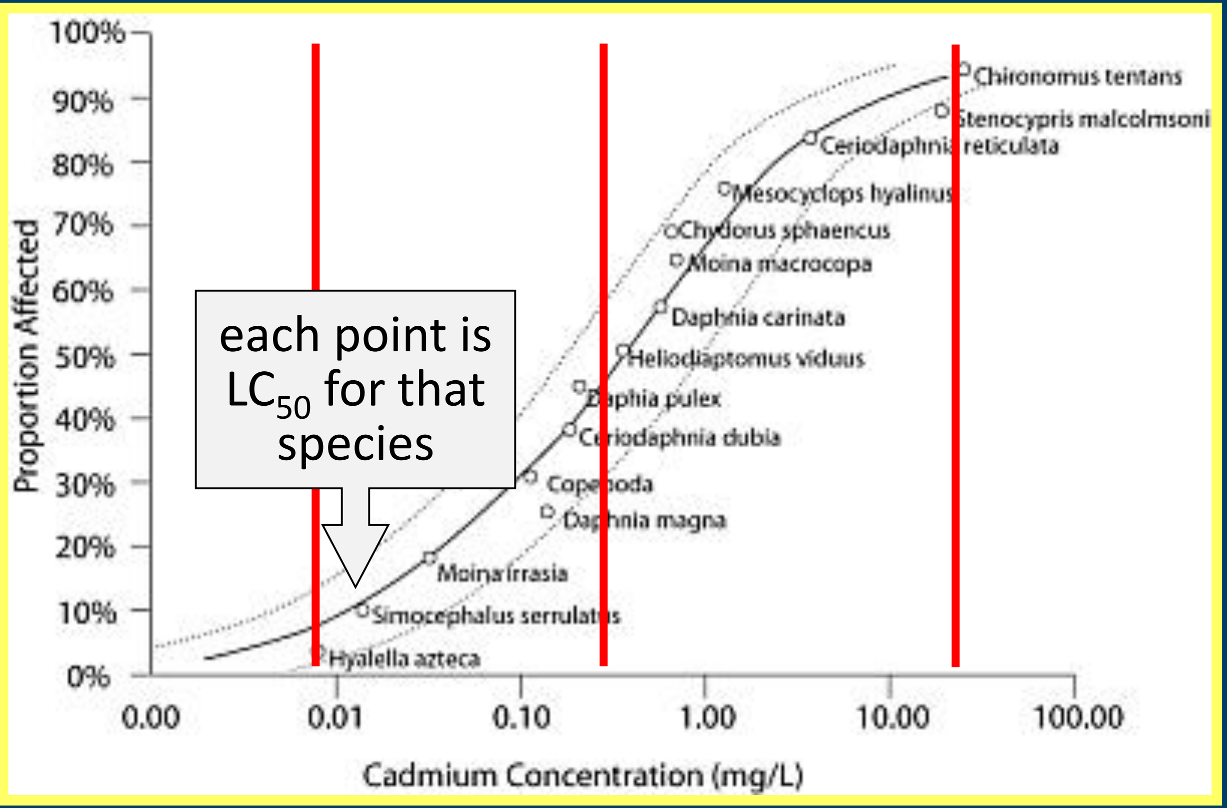
Coal Fork (tributary): biological impairment co-occurs with low pH, supports case that pH is causal factor

Stressor-response relationships from lab studies



Species Sensitivity Distributions (SSDs)

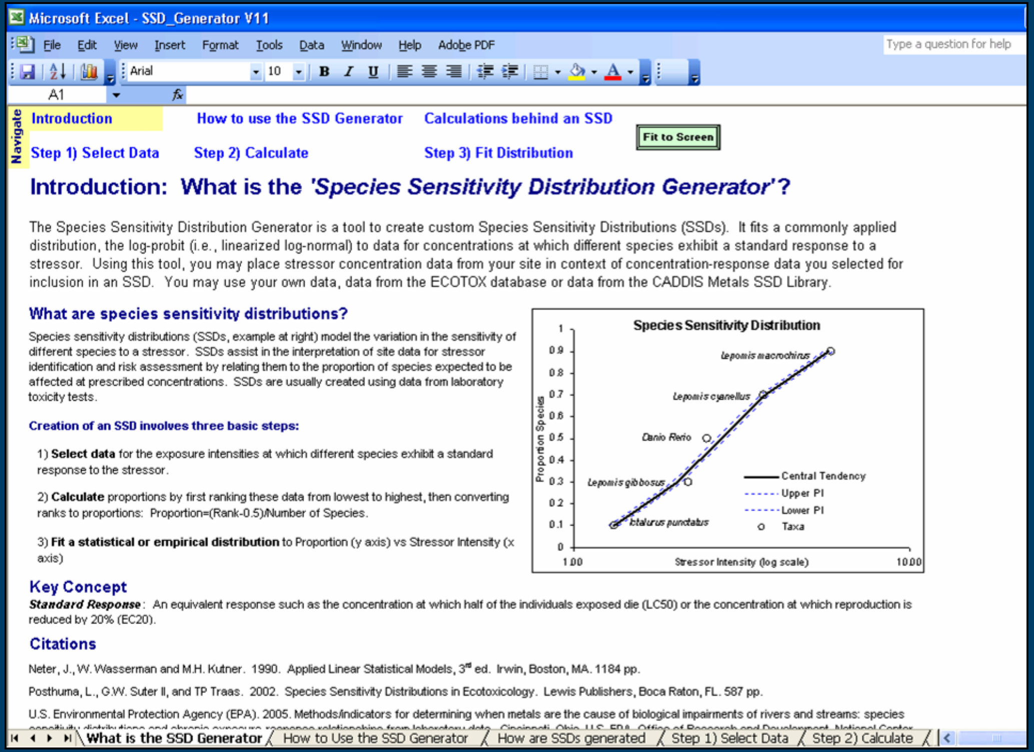
- Represent relative sensitivities of organisms to stressor of interest
- Basis for US National Ambient Water Quality Criteria



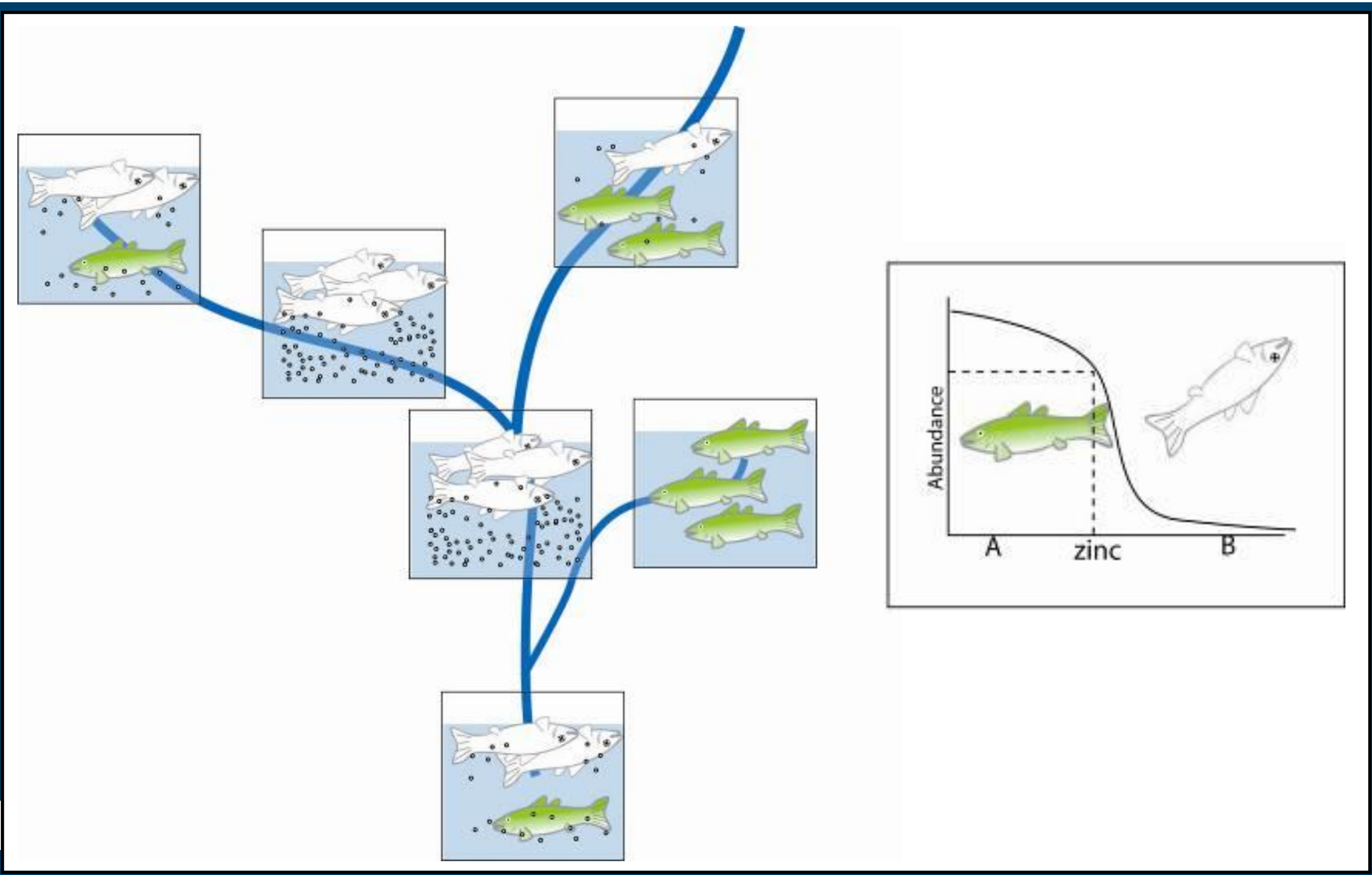
- Can be used in many ways (e.g., to predict taxa richness declines expected at impaired site)

Species Sensitivity Distributions (SSDs)

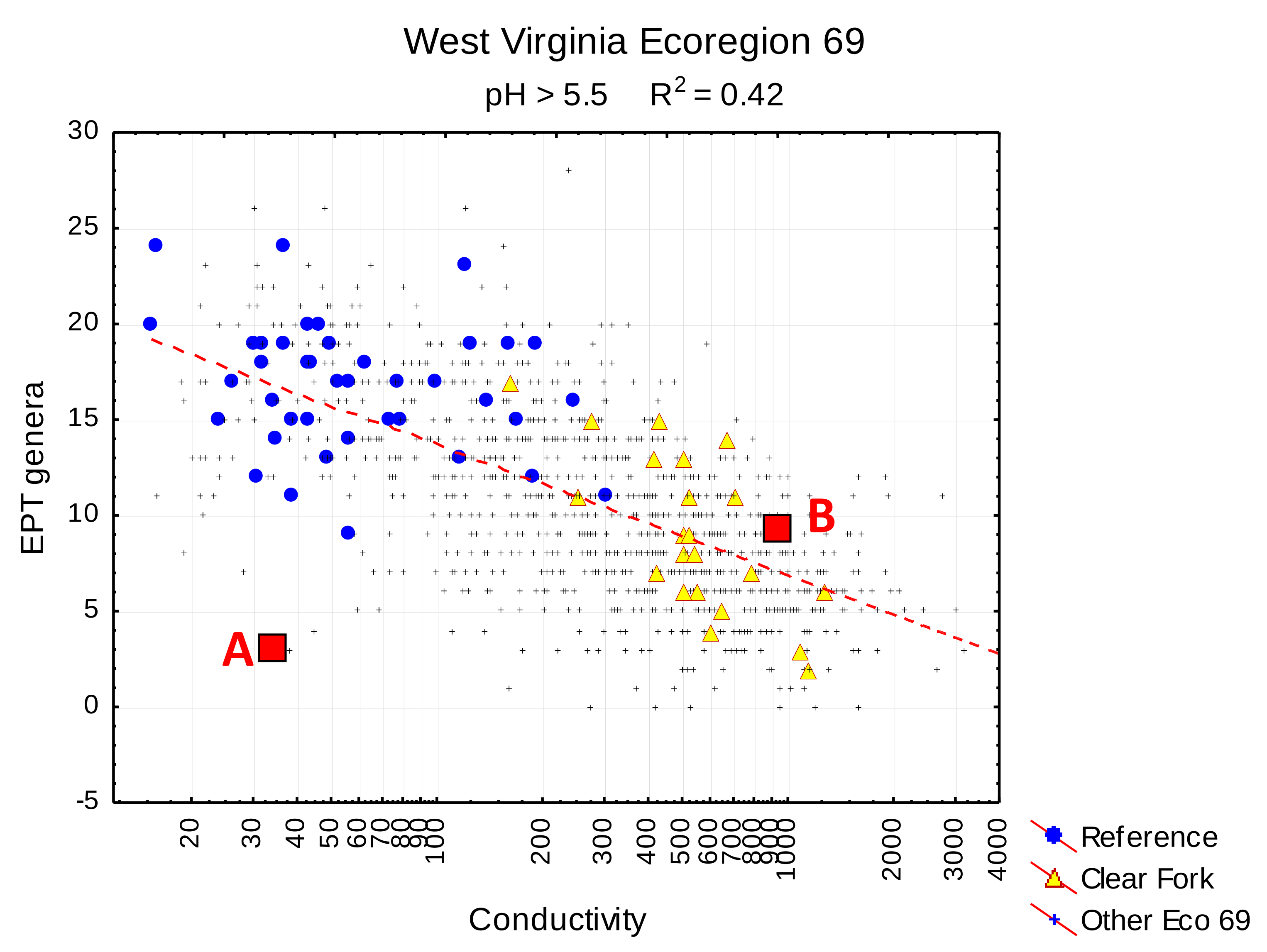
- Constructed in 3-step process
  - List stressor-effect levels (e.g., LC50s, LOELs)
  - Order from lowest to highest exposure
  - Plot and fit a curve or interpolate
- Download the SSD generator from CADDIS
  - Calculates and plots proportion of species affected at different exposure levels in lab toxicity tests



Stressor-response relationships from other field studies



Stressor-response relationships from other field studies



Issues and recommendations

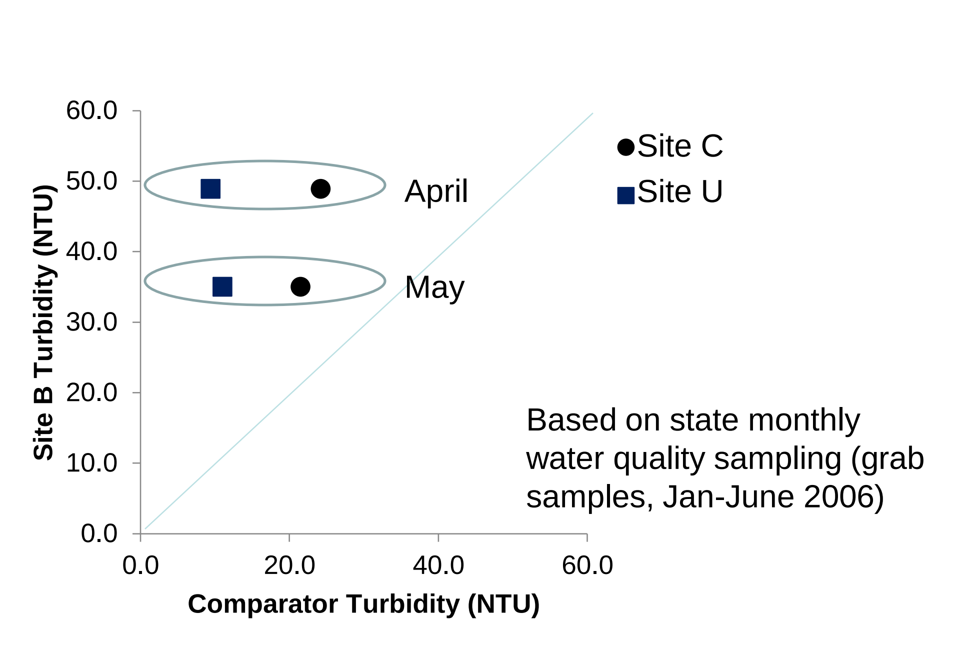
- Beware interpretation of parameter estimates when multiple stressors co-vary
- Some treatment of confounding factors is usually necessary
  - Bundle stressors using PCA
  - Trimming
  - Stratification
  - Propensity scores

The Exercise River – List of candidate causes

1. Increased sediments
2. Increased ionic strength
3. Increased pesticides
4. Decreased dissolved oxygen
5. Increased metals
6. Nutrient enrichment and toxicity
7. Flow alteration
8. Physical habitat alteration

The Exercise River – Evaluating data

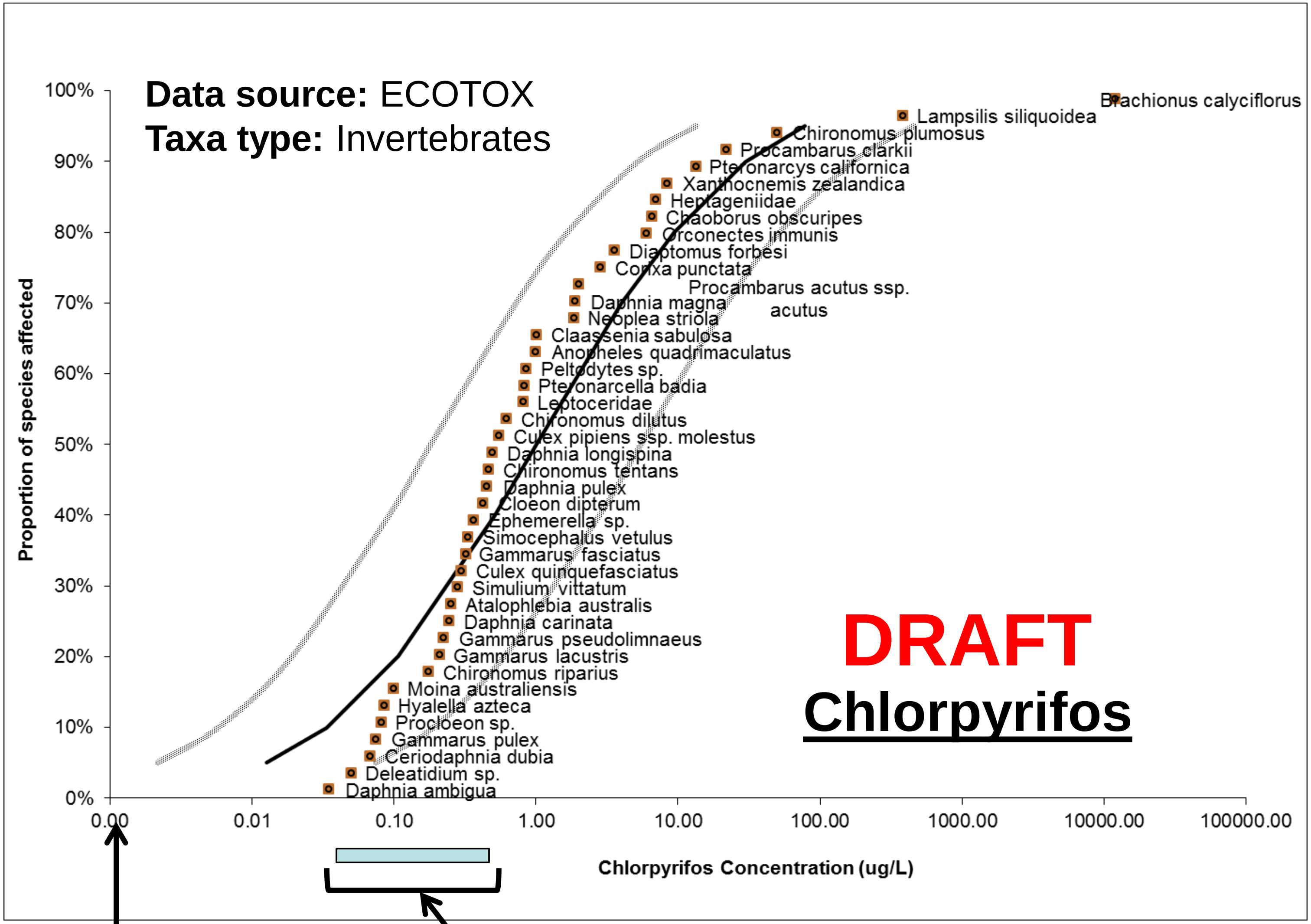
- To which candidate cause are the data relevant?
- How do NTU compare between comparison and impaired sites?
- Does this evidence support or weaken the case for the relevant candidate cause?
- How would you judge the quality of this piece of evidence?



The Exercise River – Evaluating data

- To which candidate cause are the following data relevant?
- How do maximum concentrations at Sites A and B compare to the SSD?
- Does this evidence support or weaken the case for the relevant candidate cause?
- How would you judge the quality of this piece of evidence?

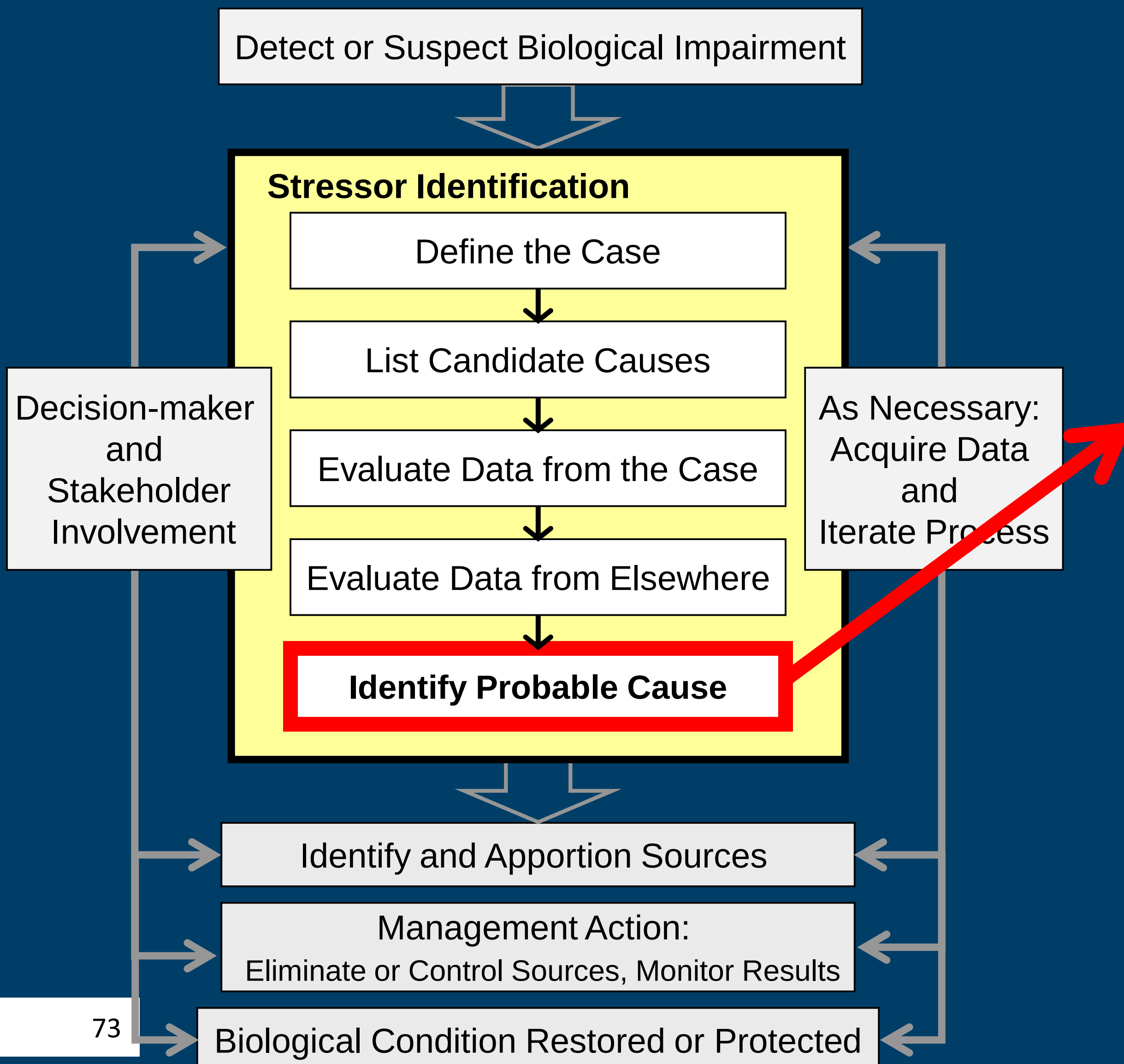
The Exercise River – Evaluating data



Observed max concentration 2006 at Sites A and B (0.001 ug/L)

Observed concentration range in Example River (previous years)

Step 5 – Identify probable cause



- Weigh the evidence for each cause
  - Eliminate if possible
  - Diagnose if possible
- Compare evidence across all causes

Step 5 – Identify probable cause

- Weigh each piece of evidence using a scoring system
- Weigh body of evidence for each candidate cause
- Compare evidence across candidate causes
- Identify candidate cause(s) that are best supported by available evidence
- Identify candidate cause(s) that are not supported by available evidence

The CADDIS scoring system

+++	convincingly supports (or weakens - - -)
++	strongly supports (or weakens - -)
+	somewhat supports (or weakens -)
0	neither supports nor weakens
R	refutes
D	diagnoses
NE	no evidence

General principles for scoring evidence

- First **+** or **–** or **0**
  - Based on logical implication of evidence that passes basic quality and relevance test
- Second **+** or **–**
  - Based on strength of association (e.g., large differences)
- Third **+** or **–**
  - Based on reliability of association (e.g., high sample sizes, excellent study design, control of confounders)
- Each type of evidence has strengths and weaknesses, which are reflected in the CADDIS scoring system

Example of evidence scoring table

Summary Table of Scores

Type of Evidence	Finding	Interpretation	Score
Types of Evidence that Use Data from the Case			
Spatial/Temporal Co-occurrence	The effect occurs where or when the candidate cause occurs, **OR** the effect does not occur where or when the candidate cause does not occur.	This finding *somewhat supports* the case for the candidate cause, but is not strongly supportive because the association could be coincidental.	+
	It is uncertain whether the candidate cause and the effect co-occur.	This finding *neither supports nor weakens* the case for the candidate cause, because the evidence is ambiguous.	0
	The effect does not occur where or when the candidate cause occurs, **OR** the effect occurs where or when the candidate cause does not occur.	This finding *convincingly weakens* the case for the candidate cause, because causes must co-occur with their effects.	- - -
	The effect does not occur where and when the candidate cause occurs, **OR** the effect occurs where or when the candidate cause does not occur, and the evidence is indisputable.	This finding *refutes* the case for the candidate cause, because causes must co-occur with their effects.	R

Scoring the evidence for all candidate causes

Scoring summary table	Metals	NH_3	Flow	Silt	Low DO	Temp	Food	Episodic Mix
Types of Evidence that Use Data from the Case								
Spatial/Temporal Co-Occurrence	+	-		+	- - -	+		+
Evidence of Biological Mechanism	+	+	+	-	+	+	-	+
Causal Pathway		-	+	-	-	+	-	+
Stressor-Response from the Field	+	-		-	+	+		
Manipulation of Exposure								+ + +
Verified Predictions								+ + +
Types of Evidence that Use Data from Elsewhere								
Stressor-Response from Other Field	- -	+						
Stressor-Response from Laboratory	+ +	-			-	+		

Weighing the evidence

- Weigh the body of evidence for each candidate cause
  - Evaluate quantity and quality of evidence
  - Identify compelling evidence
  - Evaluate consistency and credibility of evidence

Consistency of Evidence	All available types of evidence support the case for the candidate cause.	+ + +
	All available types of evidence weaken the case for the candidate cause.	- - -
	All available types of evidence support the case for the candidate cause, but few types are available.	+
	All available types of evidence weaken the case for the candidate cause, but few types are available.	-
	The evidence is ambiguous or inadequate.	0
	Some available types of evidence support and some weaken the case for the candidate cause.	-

Scoring summary table	Metals	NH_3	Flow	Silt	Low DO	Temp	Food	Episodic Mix
Types of Evidence that Use Data from the Case								
Spatial/Temporal Co-Occurrence	+	-		+	- - -	+		+
Evidence of Biological Mechanism	+	+	+	-	+	+	-	+
Causal Pathway		-	+	-	-	+	-	+
Stressor-Response from the Field	+	-		-	+	+		
Manipulation of Exposure								+ + +
Verified Predictions								+ + +
Types of Evidence that Use Data from Elsewhere								
Stressor-Response from Other Field	- -	+						
Stressor-Response from Laboratory	+ +	-			-	+		
Evaluating Multiple Types of Evidence								
Consistency of Evidence	-	-	+	-	-	+	-	+ + +

Comparing evidence and forming conclusions

- Compare the evidence across candidate causes, even when there is a "smoking gun"
  - Determine if there is more than one likely cause
  - Determine your level of confidence in the results
- Identify cause(s) best supported by the evidence
- Classify causes (e.g., likely, unlikely, uncertain)
- Refine your hypotheses
  - Consider multiple causes
  - Revisit conceptual diagrams

The Exercise River – Scoring evidence and forming conclusions

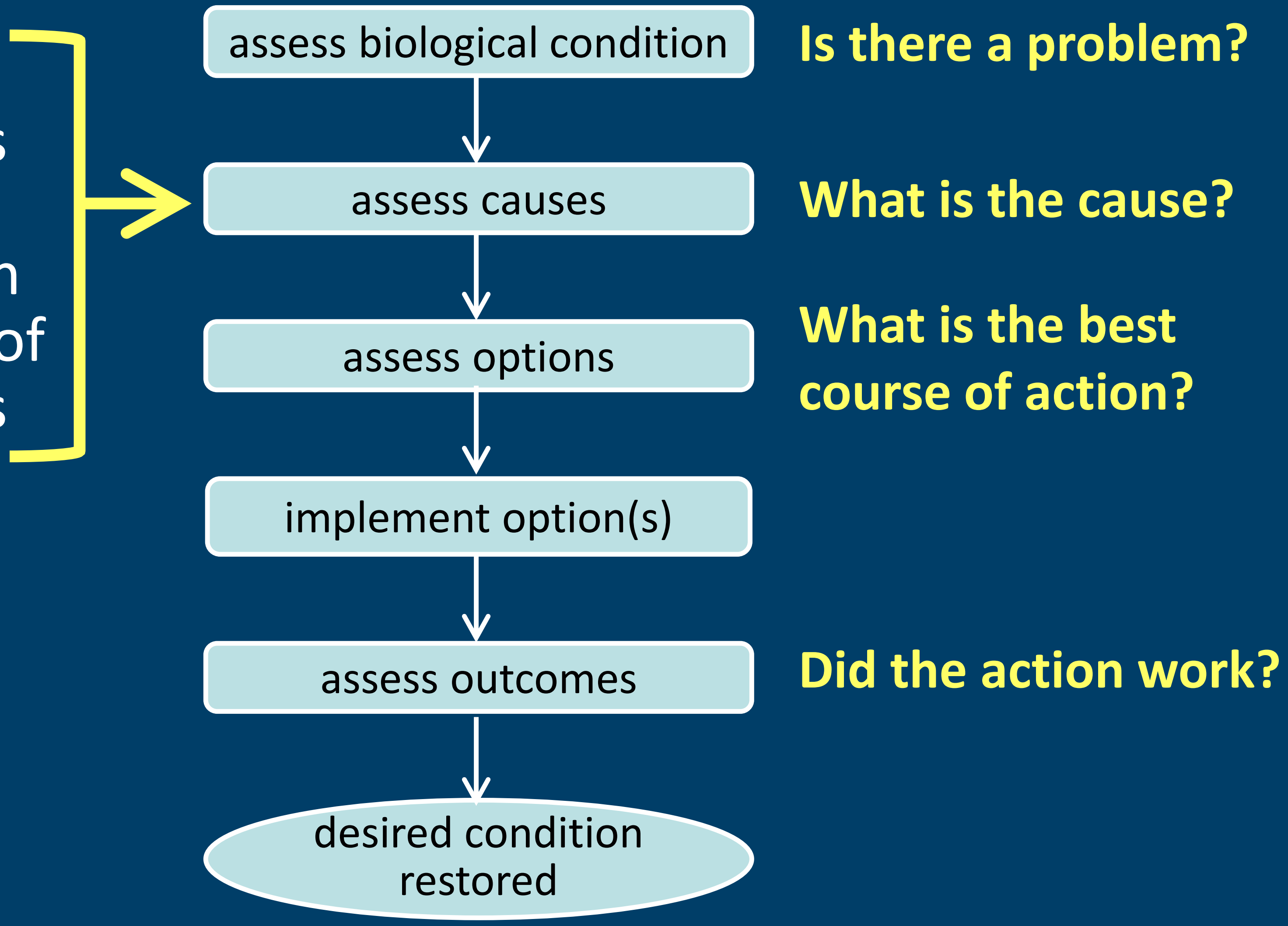
- Using the scoring table on the following slide
  - Score each candidate cause for consistency
  - Determine which candidate causes are likely contributors, unlikely contributors, and which are too uncertain to call

The Exercise River – Scoring evidence and forming conclusions

Site A compared with Site C	Decreased DO	Increased Pesticides	Metals	Increased Nutrients	Increased Ionic Strength	Increased Sediment (Bed)	Increased Sediment (Susp)	Altered Flow Regime	Altered Physical Habitat
Types of Evidence that Use Data from the Case									
Spatial/Temporal Co-Occurrence	-	**NE**	**NE**	+	---	---	+	-	-
Causal Pathway	**0**	+	**0**	**0**	**0**	-	+	**0**	+
Stressor-Response from the Field	-			-	-	-	++	+	
Laboratory Test of Site Media		-	-						
Temporal Sequence				---	---		+		
Types of Evidence that Use Data from Elsewhere									
Stressor-Response from Other Field Studies							+		
Stressor-Response from Laboratory		+	+						
Evaluating Multiple Types of Evidence									
Consistency of Evidence									

What comes after the causal assessment?

Causal assessments are typically conducted in a sequence of assessments

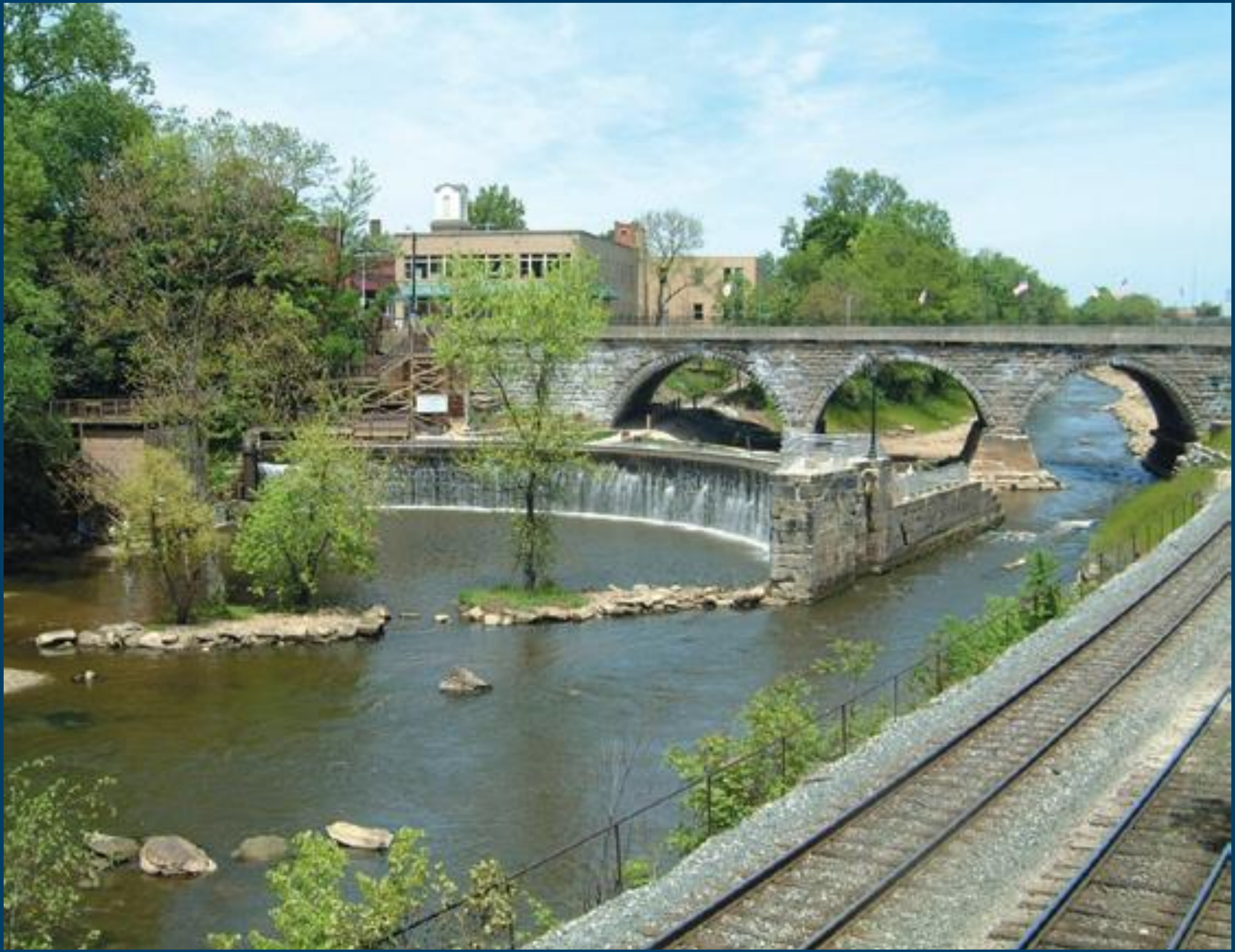


The Kent Dam removal

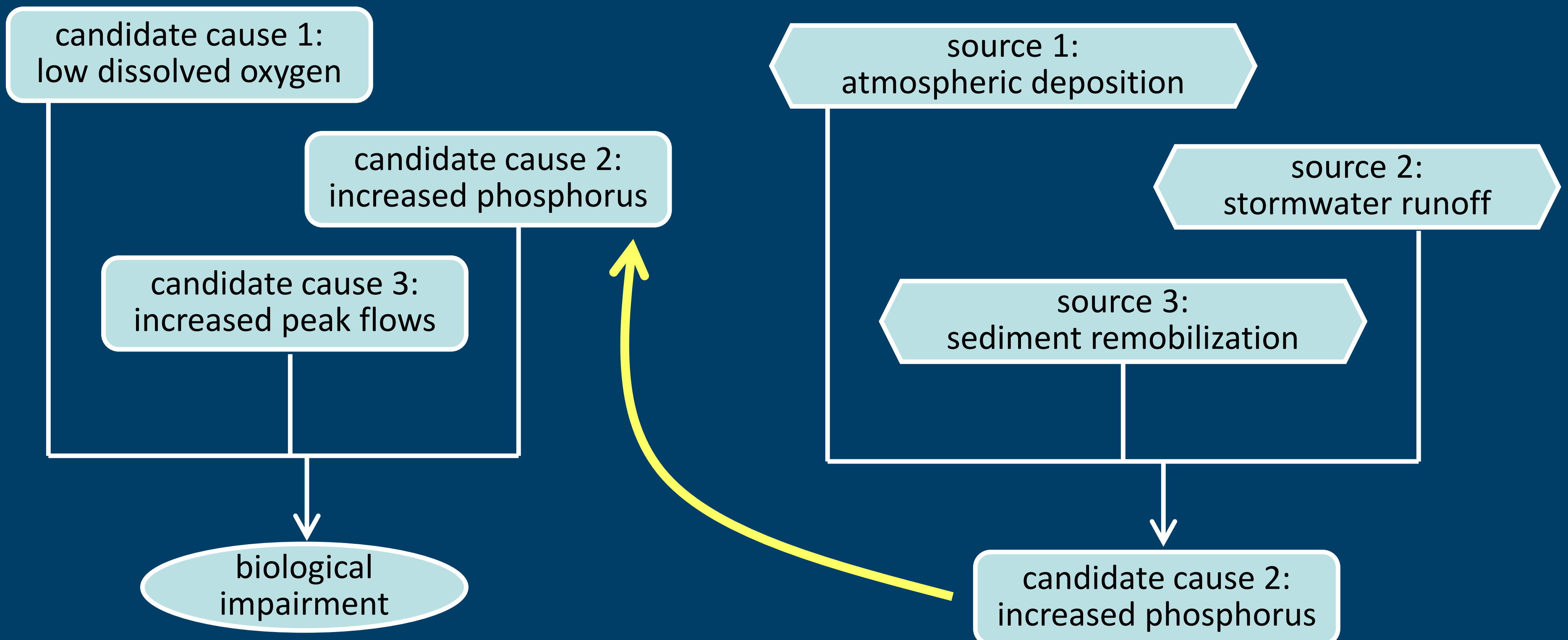
Tuckerman and Zawiski 2007

- assess biological condition
- ↓ assess causes
- ↓ assess options
- ↓ implement option(s)
- ↓ assess outcomes
- ↓ desired condition restored

Index	Fish	Dissolved Oxygen	Habitat
Warm Water Criteria	40	4 (avg)	60
Pre- Remediation	28.0	0-3 (minimums)	51.0
Post-Remediation	**44**	**5-7 (range)**	**79.5**



Causal assessment applied more broadly…



Español | 中文: 繁體版 | 中文: 简体版 | Tiếng Việt | 한국어

EPA United States Environmental Protection Agency

LEARN THE ISSUES | SCIENCE & TECHNOLOGY | LAWS & REGULATIONS | ABOUT EPA

ALL EPA THIS AREA Advanced Search

SEARCH

CADDIS: The Causal Analysis/Diagnosis Decision Information System

Contact Us Share

1 2 3 4 5 6

Quick Finder

CADLit	Causal Assessment Background	ICD Application
CADStat	Getting Started with Data Analysis	Step-by-step Guide
Case Studies		

The **Causal Analysis/Diagnosis Decision Information System, or CADDIS**, is a website developed to help scientists and engineers in the Regions, States, and Tribes conduct causal assessments in aquatic systems. It is organized into five volumes:

- **Volume 1: Stressor Identification** provides a step-by- impairment in a particular system, based on the U.S. EPA's in conducting a complete causal assessment, learning abo causal assessment theory, start with this volume.
- **Volume 2: Sources, Stressors & Responses** provide stressors, and biotic responses in stream ecosystems. If y specific summary information (e.g., for urbanization, physi start with this volume.
- **Volume 3: Examples & Applications** provides examp you are interested in reading completed causal assessmen worksheets are completed, or examining example applica volume.
- **Volume 4: Data Analysis** provides guidance on the use If you are interested in learning how to use data in your ca
- **Volume 5: Causal Databases** provides access to litera assessments. If you are interested in applying literature-b this volume.

Vol 1: Stressor Identification

Vol 2: Sources, Stressors & Responses

Vol 3: Examples & Applications

Vol 4: Data Analysis

Vol 5: Causal Databases

Top Three Questions

1. What's new in the 2010 release of CADDIS?
2. How do I cite CADDIS?
3. Where can I view a site map for CADDIS?

CADDIS Navigation

CADDIS Home

Volume 1: Stressor Identification

Volume 2: Sources, Stressors & Responses

Volume 3: Examples & Applications

Volume 4: Data Analysis

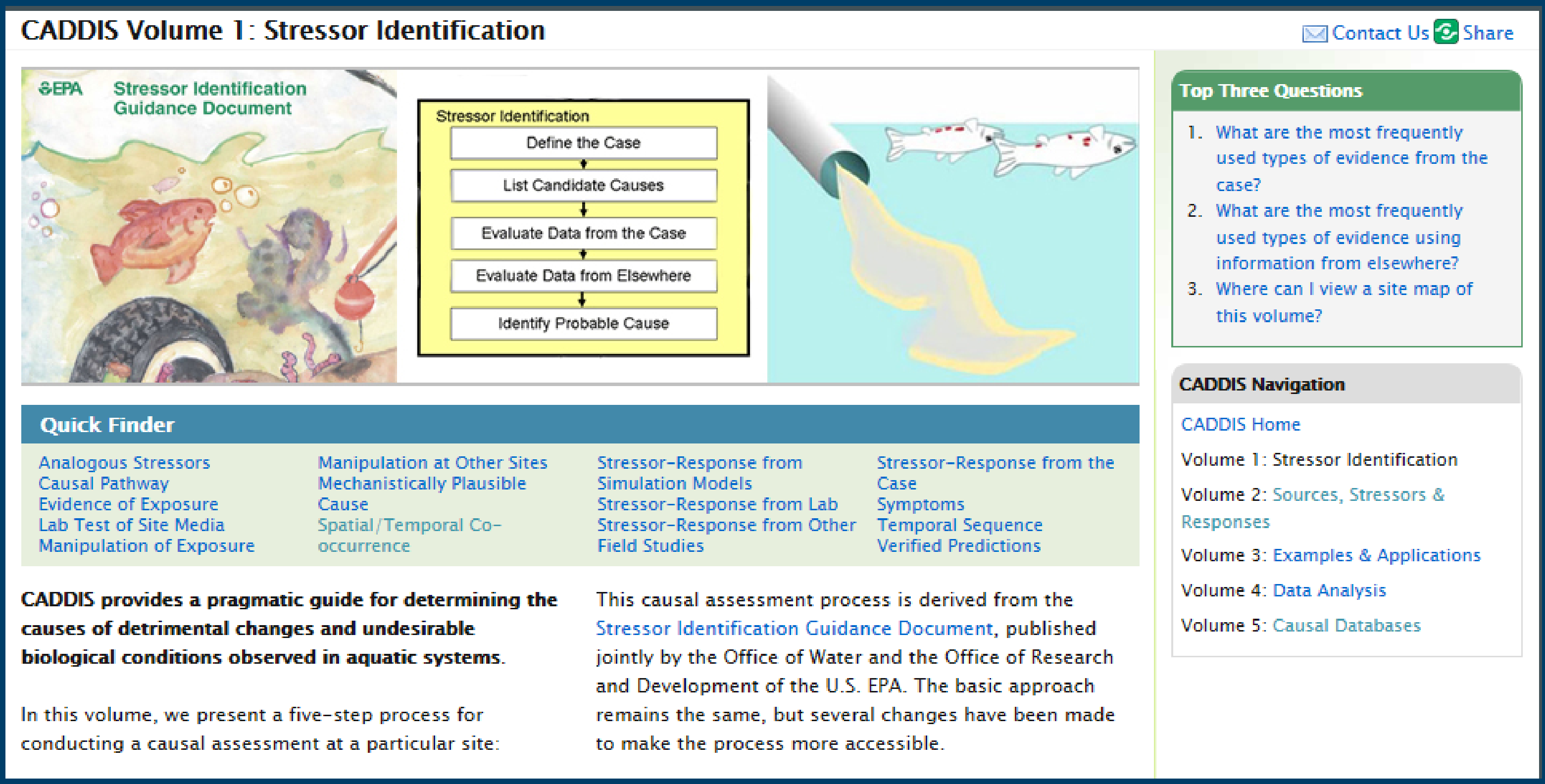
Volume 5: Causal Databases

Recent Additions

Basic Information	Publications	Authors & Contributors
Recent Additions	Glossary	Site Map
Frequent Questions	Related Links	

Vol 1: Stressor Identification

- Step-by-Step Guide
- Causal Assessment Background


CADDIS Volume 1: Stressor Identification

Contact Us Share

EPA Stressor Identification Guidance Document

Stressor Identification
Define the Case
List Candidate Causes
Evaluate Data from the Case
Evaluate Data from Elsewhere
Identify Probable Cause

Top Three Questions

1. What are the most frequently used types of evidence from the case?
2. What are the most frequently used types of evidence using information from elsewhere?
3. Where can I view a site map of this volume?

Quick Finder

Analogous Stressors
Causal Pathway
Evidence of Exposure
Lab Test of Site Media
Manipulation of Exposure
Manipulation at Other Sites
Mechanistically Plausible Cause
Spatial/Temporal Co-occurrence
Stressor-Response from Simulation Models
Stressor-Response from Lab
Stressor-Response from Other Field Studies
Stressor-Response from the Case
Symptoms
Temporal Sequence
Verified Predictions

CADDIS provides a pragmatic guide for determining the causes of detrimental changes and undesirable biological conditions observed in aquatic systems.

In this volume, we present a five-step process for conducting a causal assessment at a particular site:

This causal assessment process is derived from the Stressor Identification Guidance Document, published jointly by the Office of Water and the Office of Research and Development of the U.S. EPA. The basic approach remains the same, but several changes have been made to make the process more accessible.

CADDIS Navigation

CADDIS Home
Volume 1: Stressor Identification
Volume 2: Sources, Stressors & Responses
Volume 3: Examples & Applications
Volume 4: Data Analysis
Volume 5: Causal Databases

CADDIS Volume 1: Stressor Identification

Step 1: Define the Case

Overview | In-Depth Look | Results and Next Steps

The first step of the Stressor Identification (SI) process is to define the subject of the analysis (i.e., the case), by determining the geographic scope of the investigation and the effects that will be analyzed. The case definition sets the foundation for the rest of the causal analysis: it influences the information that will be assembled, the causes that will be considered, and the way in which conclusions will be presented. For this reason, it is important to get input from managers and stakeholders at this early stage of the process.

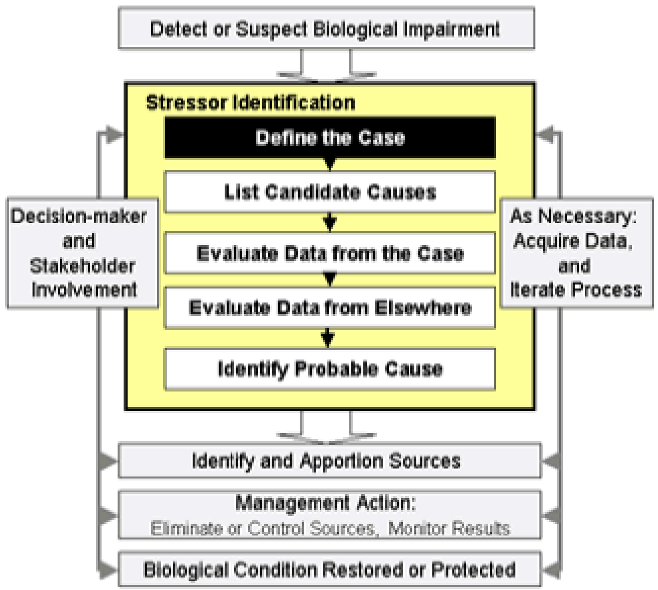


Figure 1-1. Illustration of where Step 1: Define the Case fits into the Stressor Identification process.

Causal analysis is triggered by the observation of a biological effect, including:

- Kills of fish, invertebrates, plants, domestic animals, or wildlife;
- Anomalies in any life form, such as tumors, lesions, parasites, or disease;
- Changes in community structure, such as loss of species or shifts in species abundance (e.g., increased

CADDIS Home

Stressor Identification
- Introduction
- Step 1: Define the Case
- Step 2: Candidate Causes
- Step 3: Data from the Case
- Step 4: Data from Elsewhere
- Step 5: Identify Probable Causes
- Types of Evidence
- Scores
- Causal Assessment Background

Sources, Stressors & Responses

Examples & Applications

Data Analysis

Causal Databases

You are here: EPA Home » CADDIS » Stressor Identification » Step 3: Evaluate Data from the Case: In-Depth Look » Spatial/Temporal Co-occurrence

Step 3: Evaluate Data from the Case

Overview | In-Depth Look | Results and Next Steps

Spatial/Temporal Co-occurrence

Concept

The biological effect must be observed where and when the cause is observed, and must not be observed where and when the cause is absent.

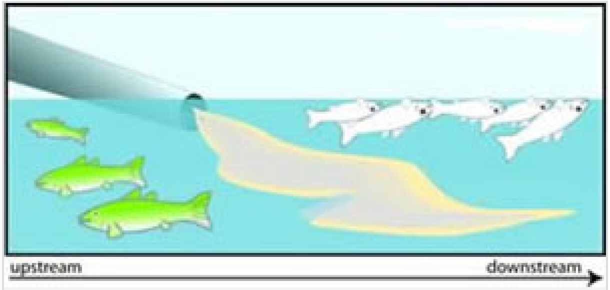


Figure 3-1a. Spatial/Temporal Co-occurrence with Upstream/Downstream Comparisons, Supports. The impairment (dead fish) occurs downstream of the source of the causal agent (effluent) but not upstream. [general explanation of illustration]

Additional illustrations

Examples

Consider increased suspended solid concentrations as a candidate cause of reduced aquatic invertebrate abundance. What findings support or weaken the case for increased suspended solids as the cause, based on spatial/temporal co-occurrence?

- Supporting evidence (spatial co-occurrence) – Suspended solid concentrations are higher at the impaired site(s) than at unimpaired reference sites.
- Supporting evidence (temporal co-occurrence) – Suspended solid concentrations are episodic, and insect abundance decreases during periods with high suspended solids.

Related Links

On this page
- Concept
- Examples
- How do I analyze the data?
- What evidence would support or weaken the case for a candidate cause?
- How do I score the evidence?
- Helpful tips

Types of evidence
- Spatial/Temporal Co-occurrence
- Evidence of Exposure or Biological Mechanism
- Causal Pathway
- Stressor-Response Relationships from the Field
- Manipulation of Exposure
- Laboratory Tests of Site Media
- Temporal Sequence
- Verified Predictions
- Symptoms

Back to Evaluate Data from the Case: In-Depth Look

Vol 2: Sources, Stressors & Responses

CADDIS Volume 2: Sources, Stressors & Responses

Contact Us Share

Deciding which pathways to consider in a causal assessment—that is, listing candidate causes as described in Step 2 of the SI process—sets the framework for causal assessment. This section of CADDIS provides background information on commonly encountered sources, stressors, and responses for use in deciding which candidate causes to consider, as well as in developing cases for or against those candidate causes in the actual assessment.

Each stressor module is organized into five sections, or tabs:

- **Introduction** provides a summary overview of the stressor, including a checklist of evidence that suggests including a given stressor in your assessment (i.e., listing it as a candidate cause).
- **When to List** provides more detailed information on the sources, activities, site evidence, and biologial responses that suggest inclusion as a candidate cause.
- **Ways to Measure** details different methods for quantifying the stressor.
- **Conceptual Diagrams** illustrates hypothesized causal linkages among the stressor, its sources, and associated biotic responses.
- **References** lists the references cited throughout the module.

Top Three Questions

1. What are sources, stressors & responses?
2. Is there additional literature-based information available for these sources, stressors & responses?
3. Can I view a site map of this volume?

CADDIS Navigation

CADDIS Volume 2: Sources, Stressors & Responses

Contact Us Share

CADDIS Home

Stressor Identification

Sources, Stressors & Responses

SOURCES
- Urbanization

STRESSORS
- Ammonia
- Dissolved Oxygen
- Flow Alteration
- Herbicides
- Insecticides
- Ionic Strength
- Metals
- Nutrients
- pH
- Physical Habitat
- Sediments
- Temperature
- Unspecified Toxic Chemicals

RESPONSES

You are here: EPA Home » CADDIS » Sources, Stressors & Responses » Ammonia: Introduction

Ammonia

Introduction | When to List | Ways to Measure | Conceptual Diagrams | Literature Reviews | References

Figure 1. Landfill settling pond.

Courtesy of U.S. EPA Region 10: The Pacific Northwest, KPC Photo Gallery.

Ammonia (NH_3) is a common toxicant derived from wastes (Figure 1), fertilizers, and natural processes. Ammonia nitrogen includes both the ionized form (ammonium, NH_4^+) and the unionized form (ammonia, NH_3). An increase in pH favors formation of the more toxic unionized form (NH_3), while a decrease favors the ionized (NH_4^+) form. Temperature also affects the toxicity of ammonia to aquatic life. Ammonia is a common cause of fish kills, but the most common problems associated with ammonia relate to elevated concentrations affecting fish growth, gill condition, organ weights, and hematocrit (Milne et al. 2000). Exposure duration and frequency strongly influence the severity of effects (Milne et al. 2000).

Ammonia in sediments typically results from bacterial decomposition of natural and anthropogenic organic matter that accumulates in sediment. Sediment microbiota mineralize organic nitrogen or (less commonly) produce ammonia by dissimilatory nitrate

Related Links

On this page
- Checklist of sources, site evidence and biological effects

Other sources/stressors/responses
- pH
- Temperature
- Nutrients

Databases
- ICD
- CADLit

Examples
- Case studies

Authors: G.W. Suter II, S.M. Cormier, K. Schofield, M. Bowersox, H. Latimer

Vol 3: Examples & Applications

CADDIS Volume 3: Examples & Applications

Contact Us Share

Quick Finder

Assemble Data from Case
Assemble Data from Elsewhere
Causal Pathway
Consistency of Evidence
Define the Case
Evidence of Exposure or Mechanism
Explanation of Evidence
Identify Probable Cause
List Candidate Causes
Mechanistically Plausible Cause
Spatial Co-occurrence with Regional Reference Sites
Stressor-Response from Field
Stressor-Response from Lab
Summary of Scores from Case
Summary of Scores from Elsewhere
Verified Prediction with PECBO
Verified Prediction with Traits

This volume provides examples that illustrate different aspects of a causal analysis.

- The **Analytical Examples** section provides examples illustrating the use of different data analyses to inform particular types of evidence. If you are interested in seeing how data analysis techniques can be applied in causal assessment, start with this section.
- The **Worksheets** section provides examples from the Little Scioto River in Ohio, one of the first Stressor Identification-based causal analyses conducted. These examples are presented as "worksheets" that one might complete as one conducts a causal analysis, so this section is a good place to start if you are planning on

Top Three Questions

1. Where are examples of completed case studies?
2. How do I determine if a stressor co-occurs with the effect?
3. Where can I get a site map for this volume?

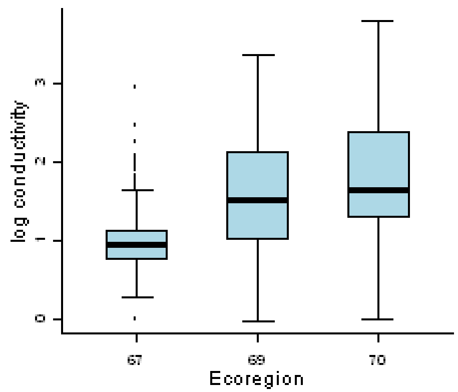
CADDIS Navigation

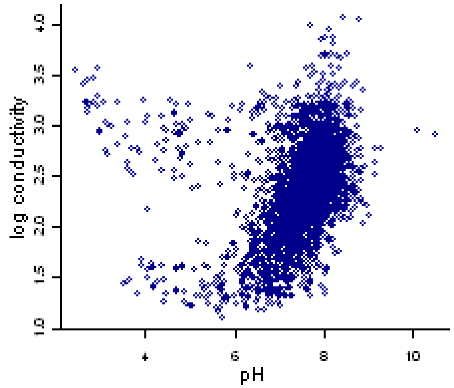
CADDIS Home
Volume 1: Stressor Identification
Volume 2: Sources, Stressors & Responses
Volume 3: Examples & Applications
Volume 4: Data Analysis
Volume 5: Causal Databases

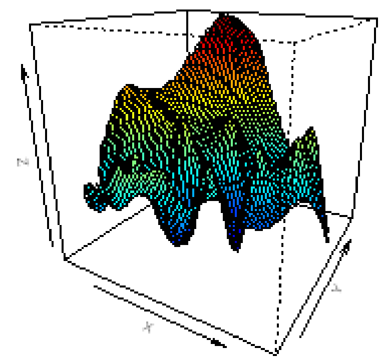
Vol 4: Data Analysis

CADDIS Volume 4: Data Analysis

Contact Us Share







Quick Finder

Autocorrelation
Classification and Regression Trees
Conditional Probability
Confidence Intervals
Confounding
Controlling for Natural Variability
Correlation Analysis
Interpreting Statistics
Multivariate Data Exploration
PECBO
Propensity Scores
Quantile Regression
Regression Analysis
Scatterplots
Spatial Analysis and GIS
SSDs
Tests of Significant Difference
Traits

This volume of CADDIS was developed as a reference for users seeking information on different analytical techniques that can be applied to causal analysis.

Data analysis is a key phase of a causal assessment. In many cases, statistical analyses can be used to inform different types of evidence and strengthen confidence in the results of causal assessments.

- **Selecting an Analysis Approach**: initial guidance for selecting appropriate analyses that can inform different phases of a causal analysis.
- **Getting Started**: things to think about before you start analyzing data.
- **Basic Principles & Issues**: basic concepts to keep in mind while analyzing observational data.
- **Exploratory Data Analysis**: techniques for becoming familiar with your data.

Top Three Questions

1. Where can I download CADDIS software?
2. How can I analyze my data?
3. Can I view a site map of this volume?

CADDIS Navigation

CADDIS Home

Volume 1: Stressor Identification

Volume 2: Sources, Stressors & Responses

Volume 3: Examples & Applications

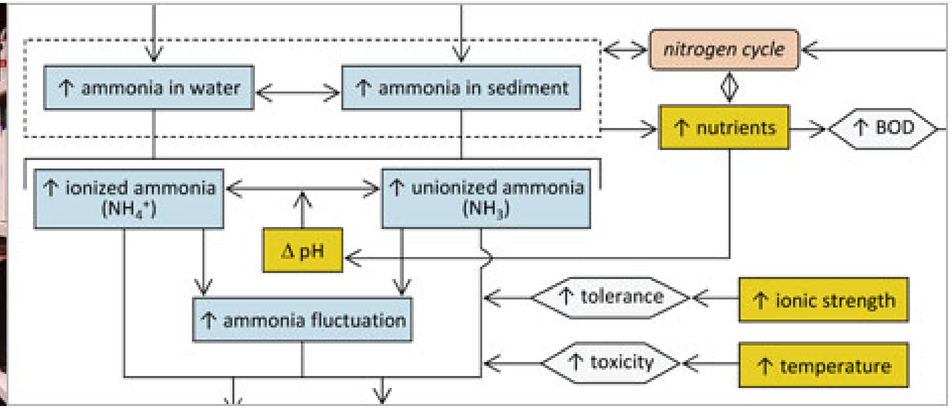
Volume 4: Data Analysis

Volume 5: Causal Databases

Vol 5: Causal Databases

CADDIS Volume 5: Causal Databases

Contact Us Share



Quick Finder

CADLit Advanced Search	CADLit User Guide	ICD Quick Start Instructions	Viewing ICDs
CADLit Keyword Search	ICD Application	ICD User Guide	Editing ICDs

This section of CADDIS provides two tools (at right) to help users access and apply literature-based evidence in their causal assessments. These tools are designed for users interested in finding and compiling scientific literature (peer-reviewed and other) to support or weaken the cases for particular causal pathways.

A key part of causal assessment is taking what has been learned about causal pathways in other systems and using that knowledge to inform the current assessment. In the Stressor Identification process, this application of previous research typically occurs in Step 2: List Candidate Causes and Step 4: Evaluate Data from

- The **Interactive Conceptual Diagram (ICD) application** uses conceptual diagrams as an organizing framework to provide supporting literature for linkages among different sources, stressors, and responses. Users can view literature linked to existing diagrams by clicking on diagram shapes, as well as create and populate their own diagrams with supporting literature.
- The **CADDIS Literature Resource (CADLit)** contains information on stressor-response associations reported in the peer-reviewed scientific literature. Currently, the stressors

Top Three Questions

1. How do I access the ICD application?
2. How do I access CADLit?
3. Can I view a site map of this volume?

CADDIS Navigation

CADDIS Home

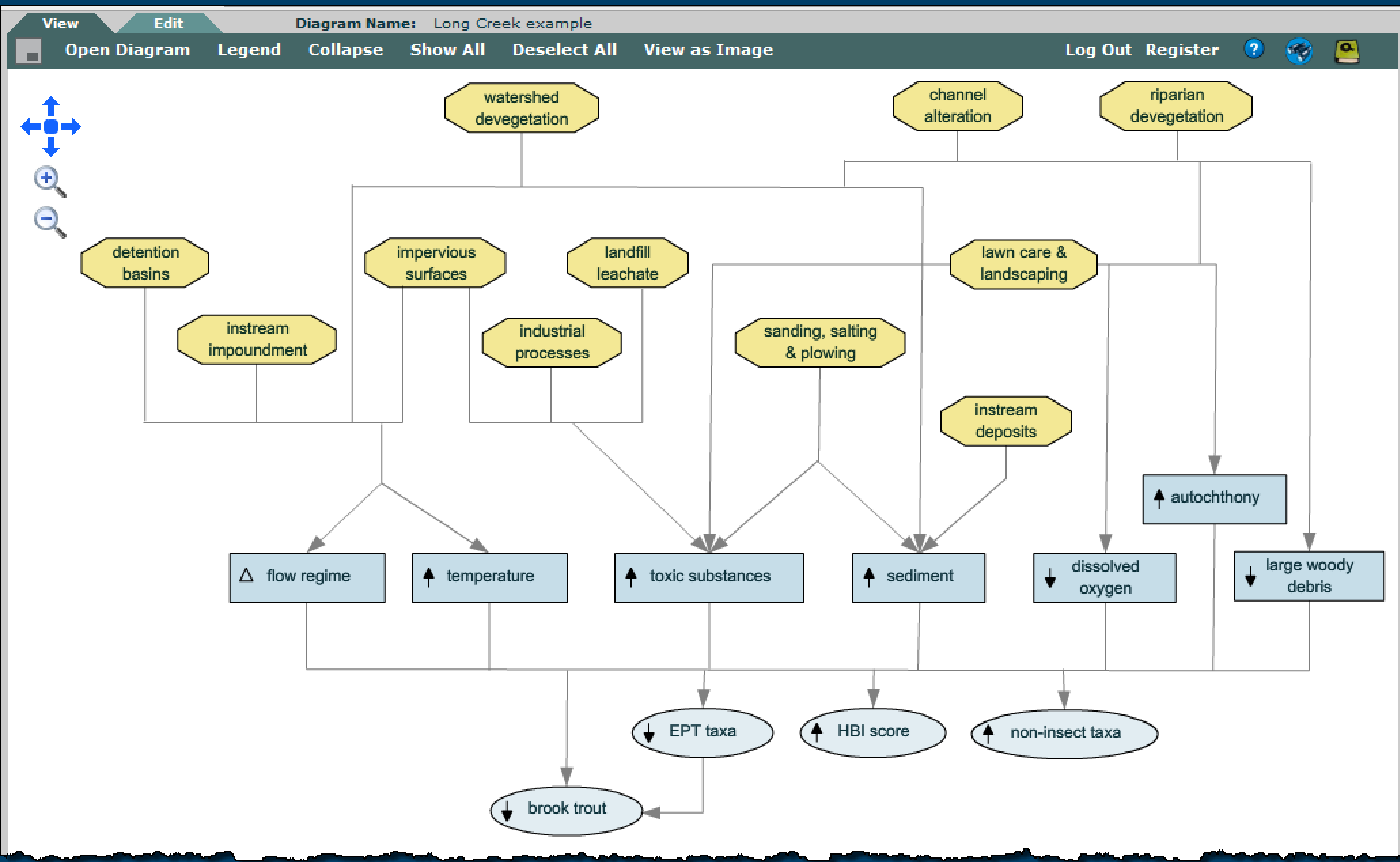
Volume 1: Stressor Identification

Volume 2: Sources, Stressors & Responses

Volume 3: Examples & Applications

Volume 4: Data Analysis

Volume 5: Causal Databases


View
Edit
Diagram Name: Long Creek example
Open Diagram
Legend
Collapse
Show All
Deselect All
View as Image
Log Out
Register
watershed devegetation
channel alteration
riparian devegetation
detention basins
impervious surfaces
landfill leachate
lawn care & landscaping
instream impoundment
industrial processes
sanding, salting & plowing
instream deposits
autochthony
flow regime
temperature
toxic substances
sediment
dissolved oxygen
large woody debris
EPT taxa
HBI score
non-insect taxa
brook trout

CADDIS Volume 5: Causal Databases

Contact Us Share

- CADDIS Home
- Stressor Identification
- Sources, Stressors & Responses
- Examples & Applications
- Data Analysis
- Causal Databases
  - ICDs
  - CADLink
  - Login to CADLink

You are here: EPA Home CADDIS Causal Databases CADLink

CADLink

Search the Database

CADLink is a database of literature-based evidence—that is, evidence extracted from the scientific literature, typically peer-reviewed publications. It contains information on the cause-effect relationships evaluated in each publication, along with relevant details such as study design, location, and analytical results. This evidence can be used to develop and evaluate the causal pathways included in environmental assessments.

Users can search for information in the database via an Oracle Application Express (APEX) interface. The database can also be used with CADDIS' Interactive Conceptual Diagram (ICD) tool, which allows users to link entries to specific causal pathways shown in user-developed conceptual model diagrams. In the future, registered users will be able to input new information into the database.

Please note that this is a beta (test) version of the CADLink database. We welcome your feedback on potential improvements as we continue development; please contact us with any problems you encounter or to suggest changes.

CADLink replaces CADLit, the original CADDIS literature database. CADLit information can be searched and downloaded via the CADLink APEX interface, but data can no longer be entered into CADLit.

Username: betatester
Password: cadlink2016

CADDIS Volume 4: Data Analysis

Contact Us Share

- CADDIS Home
- Stressor Identification
- Sources, Stressors & Responses
- Examples & Applications
- Data Analysis
  - Selecting an Analysis Approach
  - Getting Started
  - Basic Principles & Issues
  - Exploratory Data Analysis
  - Basic Analyses
  - Advanced Analyses
  - Download Software
- Causal Databases

You are here: EPA Home » CADDIS » Data Analysis » Download Software: CADStat

Download Software

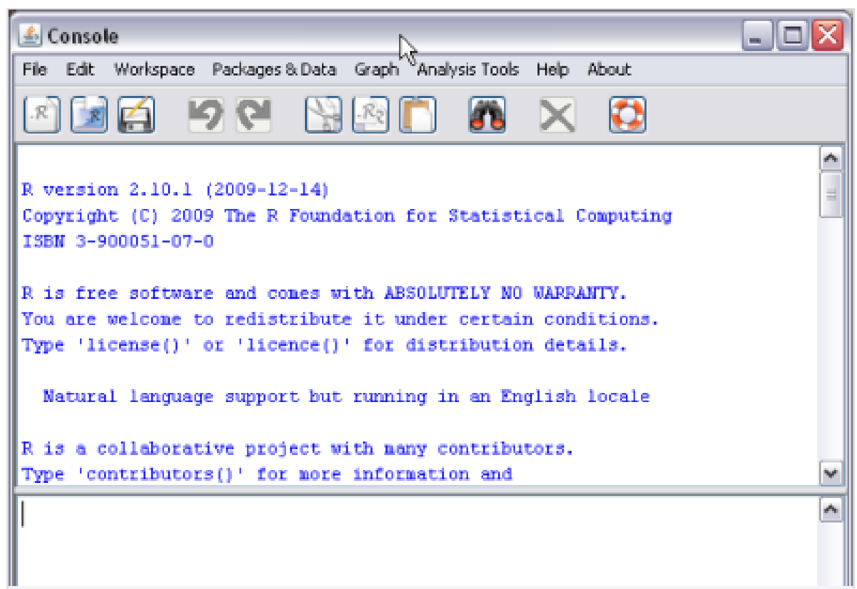
Overview | CADStat | SSD Generator | R Command Line Tut

> ***CADStat lives!***
> - Available for download from CRAN
> - Contact Sue Norton for installation instructions

CADStat

NOTICE: CADStat is currently inoperable because of R

CADStat is a menu-driven package of several data visualization and statistical methods. It is based on a Java Graphical User Interface to R (JGR EXIT Disclaimer). Methods in this package include: scatterplots, box plots, correlation analysis, linear regression, quantile regression, conditional probability analysis, and tools for predicting environmental conditions from biological observations. Download CADStat installation instructions (PDF) (2 pp, 169K, About PDF) for directions on how to obtain this free program.



Contact us

Sue Norton norton.susan@epa.gov

Kate Schofield schofield.kate@epa.gov