Stressor Identification Methods Used for Impaired Waters in the Chesapeake Bay Watershed States

DRAFT Report to the Chesapeake Bay Program
Non-tidal Water Quality Workgroup

by

Adam Griggs
Claire Buchanan

Interstate Commission on the Potomac River Basin
51 Monroe St PE-08
Rockville, MD 20850

August 7, 2012

Chesapeake Bay Program
A Watershed Partnership

ICPRB Report 12-05

This report can be downloaded from the Publications tab of the Commission's website, www.potomacriver.org. To receive hard copies of the report, please write

Interstate Commission on the Potomac River Basin
51 Monroe St., PE-08
Rockville, MD 20850
or call 301-984-1908.

Disclaimer
The opinions expressed in this report are those of the authors and should not be construed as representing the opinions or policies of the U. S. Government, the U. S. Environmental Protection Agency, the several states, or the signatories or Commissioners to the Interstate Commission on the Potomac River Basin. No official endorsement should be inferred.

Suggested citation for this report
Griggs, A. and C. Buchanan. 2012. Stressor Identification Methods Used for Impaired Waters in the Chesapeake Bay Watershed States: DRAFT Report to the Chesapeake Bay Program Non-tidal Water Quality Workgroup. ICPRB Report 12-05.

Table of Contents

Executive Summary iii

Introduction 1

Objective 2

EPA 2000 Stressor Identification Guidance 2

Current State Stressor Identification Approaches 3

Virginia 3

Maryland 4

Pennsylvania 5

Delaware 5

West Virginia 6

New York 7

Summary of State Approaches 8

CADDIS (The Causal Analysis/Diagnosis Decision Information System) 9

A Common Approach for Chesapeake Bay Watershed 9

Literature Cited 11

Executive Summary

Section 303(d) of the federal Clean Water Act (CWA) directs each state to identify and list waters for failing to meet water quality standards. For each impaired water body, the state is required to either establish a Total Maximum Daily Load (TMDL) of the specified substance that the waterbody can receive without violating water quality standards, or demonstrate via a Water Quality Analysis (WQA) that water quality standards are being met. Each state employs its own measure of aquatic life and the standards that support the aquatic life designated uses. When biology is deemed to be impaired, yet no state water-quality standards are violated or another stressor immediately apparent, the agency must attempt to identify the stressor or stressors causing the impairment.

To identify stressors, most states follow the EPA 2000 Stressor Identification Guidance at some level. Several states have developed additional tools to assist in their stressor identification processes. Maryland Department of the Environment (MDE) has developed the Biological Stressor Identification method (BSID), New York State Department of Environmental Conservation (NYSDEC) has developed the Impact Source Determination method (ISD), and several states have developed either formal or informal suites of stressor thresholds under a variety of methods that help identify stressors using numeric criteria. Other states rely heavily upon best professional judgment and field observations of the catchment to identify stressor sources. Overall, there is a general lack of consistency in stressor identification methods among the jurisdictional agencies, and for many, the process is an iterative process that must be repeated for each TMDL that is addressing biological impairments.

The EPA 2000 guidance outlines a formal data-driven iterative approach that instructs states to develop causal pathways, consider the scientific evidence, and support or refute causal models to identify most probable stressors. The guidance provides a framework for developing defensible stressor identifications; however, it does not provide conceptual models or potential screening thresholds. Superseding the 2000 guidance is the Causal Analysis/Diagnosis Decision Information System or CADDIS. Built upon the same data-driven, weight-of-evidence approach outlined in the 2000 guidance, CADDIS goes several steps further in providing numerous conceptual models of stressor-response, examples of stressor identification practices, and a collection of scientific literature that is helpful in constructing and supporting stressor-effect models.

The jurisdictional agencies could benefit from a CADDIS-type evaluation of stressors specific to the ecoregions of the Chesapeake Basin. Assimilation of recent and available stressor-response analysis results and the development of stressor-response thresholds tailored to the streams and rivers of this area would produce excellent screening tools when identifying causal stressors and degradation. Different levels of stressor-response thresholds, indicating the range of conditions from least- to most-degraded, would also be helpful in overall assessments of state waters and provide benchmarks for anti-degradation policies. It would also support the eventual quantification of tiers of aquatic life uses.

Introduction

The Clean Water Act requires each state to establish standards that support "fishable swimmable" waters. To accomplish this, states assign one or more designated uses to each water body, such as recreation, drinking water, fisheries, or aquatic life, and develop numeric or narrative standards for each use. States then collect chemical, physical, and biological data to decide if a water body meets the standards and supports its designated use. A water body is impaired if it does not fully support one of its designated uses or violates a state water-quality standard. Many pollutants however do not have numerical water quality standards. Stressor thresholds for sediment or flow alteration, or certain chemical stressors such as nutrients, can be difficult to quantify. For this and other reasons, biological data have become increasingly important aspects of monitoring programs in recent years. These data convey the health of important aquatic communities such as periphyton, underwater and emergent plants, aquatic insects (macroinvertebrates), and fish. Healthy aquatic communities are diverse, resilient, and vigorous and maintain desirable levels of productivity. A waterbody impacted by anthropogenic activities tends to lose these attributes. If biological condition is impaired, a body of water is added to the states' Integrated Report. To address the impairment, development of a Total Maximum Daily Load (TMDL) may be required. In order to develop a TMDL, one must consider the available evidence and identify the cause of impairment.

Relating biological degradation to a specific cause can be complicated. Natural mechanisms introduce variability into biological communities. Further, a causative pollutant may not be readily apparent or a water body may experience multiple stressors from different sources. Pollutants or physical stressors compromise an aquatic community by excluding organisms sensitive to a particular pollutant or deviation in natural stream condition. The principal cause of degradation is the stressor that most affects aquatic communities or that supersedes the influence of other stressors. Alleviating or removing the cause of the principal stressor often allows another unrelated principal stressor to emerge. Different abatement efforts may be needed to address a succession of principal stressors as a stream recovers. Overall, biological condition should improve as each stressor diminishes. On the other hand, if restoration efforts address less important stressors first, there may be little or no biological improvement.

The EPA Stressor Guidance Document (EPA 2000) and subsequent, web-based Causal Analysis/Diagnosis Decision Information System (CADDIS) outline a general process for identifying the stressors harming aquatic life. State agencies in the Chesapeake Bay region typically use their individual water quality criteria and screening thresholds to eliminate unlikely stressors and identify causal stressors when planning watershed TMDLs. Approaches range from standardized, risk-based protocols to the field biologist's best professional judgment. A common approach that is applicable anywhere in the Chesapeake watershed could assist state resource agencies in their own efforts and help prioritize corrective management actions on broader, interstate scales.

Objective

The purpose of this report is to summarize the approaches used by Chesapeake jurisdictions to identify stressors when planning TMDLs, and to compare these approaches to the EPA CADDIS approach. The report summarizes the approaches currently used by New York, Pennsylvania, Delaware, West Virginia, Maryland, Virginia, and the District of Columbia. It compares the various screening thresholds and criteria used to identify possible stressors of impaired systems. It also evaluates the results of two recent ICPRB projects for their possible application. Finally, the report reviews the Causal Analysis/Diagnosis Decision Information System (CADDIS) website that evolved from the USEPA *Stressor Identification* guidance document (EPA 2000). A table listing state criteria and existing and possible screening thresholds is the basis for exploring possible watershed-wide approaches.

EPA 2000 Stressor Identification Guidance

In 2000, the EPA office of Research and Development, and the then-named office of Water jointly released the Stressor Identification Guidance Document (USEPA 2000). The SI guidance is intended for use by states to assist in identifying stressors causing biological impairment in aquatic ecosystems, and to provide a systematic structure for weighing and presenting scientific evidence. The accurate identification of a stressor is key to the development of pollution abatement strategies that will result in improved biological community condition. The process applies most specifically to Category 5 waters of the Integrated Report where biological condition is impaired but a specific stressor is not known or readily identifiable. The process can assist in identifying waterbodies and pollutants for 303(d) listing, however it is not suitable for calculating loads and prescribed reductions under TMDLs.

The process is an iterative, weight-of-evidence approach that is framed upon the available scientific data. For this reason, a complete, high-quality ecological dataset is necessary for the application of the process and the correct identification of causative

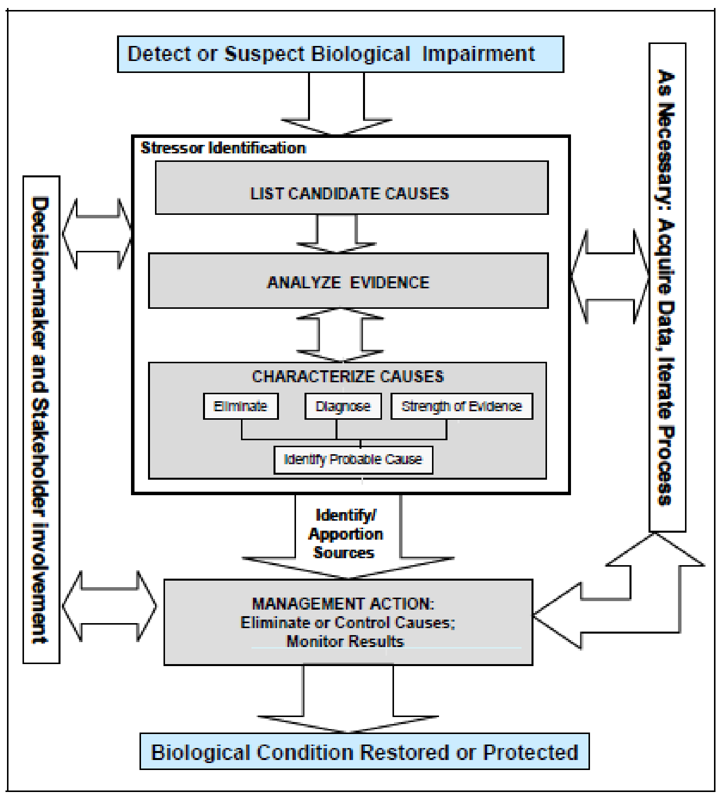


Figure 1 A conceptual model of the SI process in the context of management and restoration (EPA 2000).

stressors. In some cases, collection of additional data may be necessary to fill gaps in space, time, hydrograph, or parameters of concern.

The first step in the SI process is the listing of candidate causes and the development of conceptual models that may explain the observed biological deficit (See Figure 1). Careful explanation of the biological impairment and investigation of known causes from the particular case, prior experience, or the scientific literature help to develop these candidate cause and effect relationships. The second step in the process involves analyzing the available evidence to either support or eliminate the candidate causes. All aspects of ecological data may prove useful in this examination. Data are organized by their association to either support or refute a causative model. In the third and final step, the evidence to either support or eliminate causal scenarios is compared until sufficient confidence in a particular scenario is reached. If the evidence is inconclusive, the process can help guide additional data collection efforts and the process repeated until the stressor(s) is confidently identified.

Current State Stressor Identification Approaches

Virginia

The Virginia Department of Environmental Quality (VADEQ) is drafting a guidance manual for identifying stressors and developing TMDLs. A presentation by VADEQ biologist Jason Hill outlines the proposed stressor identification approach. There is also a 2007 review of VADEQ methods for TMDL development written by the Virginia Academic Advisory Committee (AAC).

VADEQ employs a stressor identification approach for streams that is generally consistent the EPA 2000 *Stressor Identificatio*n guidance document. Available water-chemistry data drive the process and a weight-of-evidence approach considers known pollutant sources and field observations in upstream catchments. Virginia has numeric standards for temperature, dissolved oxygen, pH, dissolved metals, dissolved organics, and ammonia-toxicity. A stream is declared impaired if these water quality parameters fail the standards. Other pollutants such as nutrients, sediment metals and organics, TP, TN, conductivity (surrogate for total dissolved solids) and environmental conditions such as heavy sediment deposition, flow alteration, and poor habitat quality currently do not have numeric standards although most have screening thresholds. Impairment of aquatic life use is generally required to list streams as degraded by these pollutants or environmental conditions. Virginia uses one of two multi-metric macroinvertebrate indexes to assess aquatic life use: the Coastal Plain Macroinvertebrate Index (CPMI) (Maxted et al. 2000) applied to streams in the Coastal Plain and the Virginia Stream Condition Index (VSCI) applied to streams in the Piedmont, Ridges, Valleys, and Appalachian Plateau regions. Biometric scores falling below a set of ecoregion-specific thresholds indicate a stream reach is impaired.

To assist in stressor identification, VADEQ has developed elimination and weight-of-evidence thresholds for identifying the contributing or most-probable stressors. The thresholds were developed using a variety of techniques, including change-point analyses, quantile regressions, relative and attributable risk approaches, and conditional probabilities. These analyses led to three classifications for each parameter: non-stressor, possible stressor, and most probable stressor. Virginia recently created or adopted new screening tools that provide additional evidence for classifying potential stressors. They are VADEQ's relative bed-stability calculations (performed across the state since 2008) and percentile-based thresholds to identify unstable streambeds caused by abundant sands and fines.

The 2007 AAC paper highlighted the strengths and weaknesses of eight completed TMDLs and offered a list of six general recommendations to guide future efforts to identify stressors. Strengths included the documents' organizational structure, communicability to stakeholders, and well-presented descriptions of sources, pathways, and causes of impairment. Weaknesses included incomplete descriptions or explanations of stressor-pathways, unconventional naming of stressors, lack of historical land-use context in explaining sources, disorganized structure, lack of citations from scientific literature, lumping of stressors into single categories without justification, and inadequate explanation of methods for establishing reference condition or selecting percentile values.

Maryland

The support of the aquatic life uses in Maryland is determined by using fish and macroinvertebrate indices of biotic integrity (IBI), developed by the Maryland Department of Natural Resources (MDNR). In order to identify sources of biological impairment, water chemistry, point-source, and land-use data are considered to identify a most likely stressor. State water-quality standards, best professional judgment, or other conclusive evidence can be used to identify a most-probable stressor for listing. However, if data does not point toward a known stressor, the waterbody may be listed for a biological impairment.

For biological impairments, the Maryland Department of the Environment (MDE) Science Services Administration (SSA) has developed the Biological Stressor Identification method (BSID) tool to "systematically and objectively" determine the most probable contributing stressors. The BSID is a "case-control, risk-based approach" that is designed to systematically and objectively determine the most probable cause and source of impairment. The analysis estimates the strength of association between stressors and biological communities, and the likelihood of improvement of the biological condition if a stressor were removed. The estimates are based upon the ratio of a stressor's presence observed in predefined case groups and control groups. The case group includes other sites in the hydrologic unit of assessment with degraded biological condition and the control group is comprised of sites with good biological condition and similar physiographic characteristics to the subject. Observation of stressor association within case groups provides individual stressor-thresholds that are predicted to be harmful to aquatic life. The case and control groups, and the stressor-risk thresholds were originally identified using Maryland biological Stream Survey (MBSS) Round 2 data. Both non-stress thresholds and potential stressor thresholds were developed for a suite of physical habitat, water chemistry, land use, and acid source measures (See Appendix A, Table 1). Most numerical thresholds were identified by observing the 90th percentile concentration of a given stressor among a control group in each of the three major Maryland ecoregions. Values above the 90th percentile of the control group are assumed to be contributing to aquatic life degradation. Once the BSID is applied, stressors are identified as either probable or unlikely causes of impairment in the 8-digit HUC unit of assessment. The results of the BSID tool are considered in a weight-of-evidence approach to update or reinforce listings in the integrated report and are a valuable tool for identifying causative stressors.

Pennsylvania

The Pennsylvania Department of Environmental Protection (PADEP) categorizes the health of Pennsylvania's flowing waters by their ability to support aquatic life use designations. PADEP employs both systematic and probabilistic sampling designs to sample benthic macroinvertebrates. The In-stream Comprehensive Evaluation protocol (ICE) is the currently employed sampling program and is a modification of the EPA's Rapid Bioassessment Protocol III (RPB-III). All biological surveys are performed using a d-frame net and include habitat surveys and in-situ measurements of pH, dissolved oxygen, specific conductivity, and alkalinity. Aquatic life use-support is determined by measuring the biological integrity of a waterbody through a suite of freestone and limestone IBIs (PADEP 2009). If a waterbody is found to be impaired, as measured by the applicable IBI, it is summarily added to Category 5 of the Integrated Report and scheduled for TMDL development. Separate TMDLs are developed for each contributing stressor. Generally, stressors are identified in a manner consistent with the EPA 2000 St*ressor Identification* guidance, in that it is an iterative, weight-of-evidence approach that considers the available water chemistry data, however, PADEP has not produced or adopted a formal stressor identification guidance or methodology. Since many water quality constituents are not routinely collected, greater emphasis is placed on the identification of sources in the upstream catchment. PADEP heavily weighs the biologists' understanding of watershed's land use, point sources and historical record. Field biologists observe the upstream catchment in order to identify sources and most-probable stressors based on best professional judgment while in the field. These observations can include windshield surveys of the catchment, useful in identifying pollutant types and sources. Recently, DEP biologists have worked to identify source-specific thresholds for several land-use and source types; however this work is in progress and the results are not currently being used in stressor identification efforts (PADEP 2012).

Delaware

The Delaware Department of Natural Resource Conservation (DDNREC) is the agency charged with protection of water resources in the state of Delaware. The Watershed Assessment Section under the Division of Watershed Stewardship performs routine monitoring and assessment of streams and wetlands. As in other states, measures of aquatic life help determine if waters are meeting aquatic life designated uses and those waters found to not be fully supportive of designated uses are scheduled for TMDL development. The DDNREC has promulgated a suite of state water quality standards for use in determining impairments in streams and rivers. These standards may vary by class of waters such as Antidegradation of waters of Exceptional Recreational or Ecological Significance (ERES). In the absence of national numeric nutrient criteria, DDNREC has used target thresholds of 3.0 mg/l for total nitrogen and 0.2 mg/l for total phosphorus as indicators of excessive nutrient levels in the streams (DDNREC 2004).

Delaware, however, has not needed to engage in significant stressor identification exercises as nearly all TMDLs have identified nutrients and bacteria as primary pollutants in their waters. In the few cases where a water quality standard or nutrient target thresholds have not been violated, Identification of stressors for aquatic life impairments required for the development of TMDLs has been performed largely by outside contractors. According to personal communication, the EPA 2000 Stressor Identification guidance serves as the basis for the stressor identification methods therein (DNREC 2012).

West Virginia

The West Virginia Department of Environmental Protection (WVDEP) has developed the West Virginia Stream Condition Index (WVSCI) to measure the integrity of aquatic communities in West Virginia's rivers and streams, which serves as the basis for biological assessment. The WVSCI includes six biological metrics that measure aspects of the macroinvertebrate community at any given site and was calibrated for a long-term biological index period extending from April - October. The benchmarks of aquatic integrity were developed using an observed reference pool and the index is not classified by region or season. When the WVSCI determines a biological impairment, and a causative stressor is not readily known, a stressor identification process is employed.

The SI process used by WVDEP closely resembles the2000 EPA SI guidance (EPA 2000) and is described in the draft TMDL report for the streams of the Elk River and Lower Kanawha River Watersheds (WVDEP 2011). As in the 2000 EPA guidance, the three main steps include: Developing a list of candidate stressors from known and suspected causes and pathways present in the watershed; analyzing available evidence related to each potential cause; and evaluation of the available data in an organized manner to characterize, eliminate, and compare strength of evidence for each candidate cause of the water quality impairment. WVDEP has produced a conceptual model of candidate causes that is employed during the SI process (See Figure 2). This conceptual model includes sources, stressors, and potential pathways of impact that result in shifted macroinvertebrate communities. West Virginia state water-quality standards serve as candidate stressor thresholds, including numeric criteria for aluminum, dissolved oxygen, iron, selenium, pH, and fecal coliform bacteria. For pollutants that do not currently have numerical water-quality standards, candidate thresholds have been identified that are useful in weighing evidence of causal stressor impairments. Thresholds for candidate stressors were identified by observing five best-fit lines among stressors and the West Virginia Stream Condition Index (WVSCI). Elimination and strength-of-evidence thresholds were developed for most numeric stressors and are provided in Appendix A, Table 2.

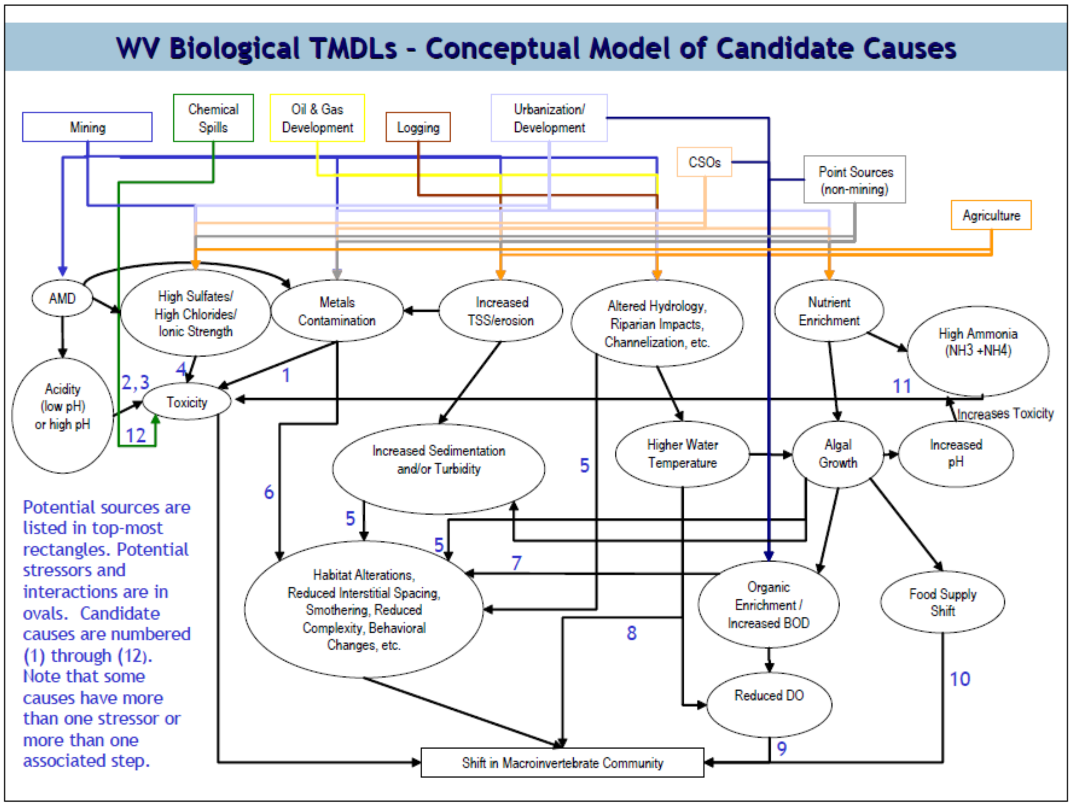


Figure 2 WVDEP conceptual model of candidate causes.

New York

A document titled *Standard Operating Procedure: Biological Monitoring of Surface Waters in New York State* outlines procedures for all facets of aquatic assessment in New York, including monitoring, sample and data processing, source identification, listing, and TMDL development (). A formal approach known as the Impact Source Determination (ISD) procedure is referenced on page 54 of the SOP manual and forms the basis of stressor identification in this state. The ISD works by comparing the taxa collected in a macroinvertebrate sample with that of established model communities that have been observed across both natural and anthropogenic stressor classifications. In a manner similar to a Percent Model Affinity or RIVPACS approach, sample-model agreements above 50% indicate likely similarity of the stream-stressor classification. There are six overall impact-source classes including (1) nonpoint nutrients, (2) siltation, (3) toxic, (4) organic, (5) complex, and (6) impoundments. There are several model communities under each stressor type and multiple “natural” community classes as well. The suite of model communities has been revised and expanded over the years and included some 62 model classifications as of 2002. The development of the ISD method is described in further detail in Riva-Murray et al. 2002.

New York has also developed a nutrient biotic index (NBI) to help identify eutrophic macroinvertebrate communities. Separate NBIs were developed by examining the weighted-average distributions of 164 macroinvertebrate taxa across total phosphorous and nitrate gradients. Taxa were assigned nutrient tolerance values (0-10) and indices were calculated following the Hilsenhoff approach (Hilsenhoff 1987). The resulting NBI-P and NBI-N were correlated with corresponding phosphorous and nitrate concentrations. A three-tiered scale of eutrophication was developed that related the NBI-N and NBI-P values to nutrient concentrations and allowed for the identification of thresholds of impairment falling between the oligotrophic, heterotrophic, and eutrophic boundaries.

Summary of State Approaches

In general, there is a wide range of approaches employed for identifying stressors causing aquatic life impairments in the Chesapeake Basin States. With the exception of the Maryland BSID method and the New York ISD procedures, most states' processes for stressor are iterative, data-driven, weight-of-evidence approaches that generally follow the EPA 2000 stressor identification guidance document. This means that for each waterbody with a biological impairment, the SI process is repeated and analyses are performed to identify candidate stressors.

The states that have developed candidate stressor thresholds have a valuable screening tool that allows for faster implementation of the SI process. Thresholds, when developed appropriately, should allow a state agency to quickly eliminate and identify candidate stressors. Most helpful are those thresholds that include "elimination", "possible stressor", and "likely stressor" thresholds. It should be of note that among the states that have developed these stressor thresholds, the methods of development have varied greatly, and in-turn, the thresholds for determining stress or non-stress vary. The Tables in Appendix 1 demonstrate overall poor agreement in stressor thresholds across a variety of stressor types between the Maryland BSID and West Virginia's SI thresholds. For example, Maryland's "possible stressor" threshold for total phosphorous (TP) is > 0.06 mg/L in the Highlands and Piedmont while the West Virginia "Exclusion", "Possible", and "Definite" TP thresholds are < 0.13139 mg/L, 0.193 – 0.2829 mg/L, and > 0.51 mg/L respectively. Similarly, Maryland's specific conductivity threshold is > 500 µS in the Highlands for a possible stressor while West Virginia's "Possible" threshold is 767 – 1064.9 µS. It should be noted that neither of the state's thresholds were developed in a stressor-response fashion, and rather were identified using correlative associations. The observed correlations were also based upon the biological index in use for the state, which vary in the metrics and thresholds that constitute them. The Indexes, while excellent screening tools for overall impairment, may not necessarily be sensitive to all stressors. If an index is not sensitive to a particular stressor, and the stressor thresholds developed by observing the index, than certain stressor thresholds may be inflated. An example of this limitation may be Total Nitrogen (TN) in the Maryland B-IBI. There has been some evidence indicating that the MBSS Piedmont and Coastal Plain IBIs are not particularly sensitive to nutrient gradients (Mandel et al. 2011). The BSID development only found a biologically significant threshold in the Ridge and Valleys region, and failed to do so in the Piedmont, or Coastal Plain. The value of 3.0 mg/L TN found in the Ridge and Valleys was therefore substituted for use in the other regions.

While the PA DEP methods allow for greater flexibility in pursuit of SI, and incorporates invaluable observations and best professional judgment from biologists in the field to a large extent, the process could benefit from a more formalized SI procedure. Overall, the iterative processes employed by most state agencies likely consume valuable agency resources while identifying the probable stressors for each listed waterbody for which a stressor is unknown. Customized numerical stressor thresholds could assist in rapidly identifying probable and least probable stressors that could assist in evaluation of available water quality data.

CADDIS (The Causal Analysis/Diagnosis Decision Information System)

The EPA published the "Stressor Identification Guidance Document" in 2000 to help scientists and engineers identify causes of stream impairment in a scientifically defensible and convincing manner. CADDIS was developed to supersede the SI guidance and provide additional tools for its implementation. The original CADDIS process has been considerably expanded and migrated to the EPA CADDIS website as an online application. The online application consists of five "volumes" corresponding to the five steps in the process. Appendix B of this report provides an annotated site map of the website with links to each page. Volume 1 leads the user through the stressor identification process in a painstaking but logical step-by-step manner, and has numerous links to supporting materials. The volume also includes a thought-provoking discussion of the philosophical foundation for causal analysis. Volume 2 provides a comprehensive review of the information needed to decide which stressors are candidates, and a robust process for building the case for or against each candidate stressor. Fifteen stressor-based conceptual diagrams illustrate all the possible connections documented in the literature between anthropogenic sources, stressors, and biological responses. Appendix C of this report contains downloaded images of the diagrams. A source-based module for urbanization explains the numerous, inter-related pathways through which urbanization can affect streams. Volume 3 provides analytical examples, actual worksheets, case studies, and relationships that have been established between some stressors and biological responses. Volume 4 discusses at length the basic and advanced statistical methods that can be useful in causal analysis. Volume 5 contains a database of literature and an interactive conceptual diagram (ICD) application, complete with User's Guide. The ICD application gives the analyst a powerful tool for tailoring individual conceptual diagrams to specific cases and evaluating the strength of likely sources and stressors.

A Common Approach for Chesapeake Bay Watershed

The learning curve to become familiar with the CADDIS website and skilled at performing the stressor identification steps is somewhat steep. If the process is done correctly, however, a scientifically defensible list of the stressor(s) impairing a stream site is identified. The generic CADDIS process could be modified to include screening thresholds and criteria specific to streams and rivers in the Mid-Atlantic physiographic regions. The result would be a consistent approach for identifying stressors of stream biological communities across the Chesapeake Bay watershed.

A CADDIS process customized to the Chesapeake Bay watershed should focus on detecting stress and degradation in the watershed's streams and rivers rather than on impairment. The process does not quantify impairment of the Aquatic Life Use designation, as this is the responsibility of the individual states and tribes. States in the Chesapeake Bay watershed have evolved different and sometimes multiple ways of defining use impairment, and a biological community classified as "impaired" in one state can be "unimpaired" in a neighboring state (USEPA 2008). Some states have also encoded definitions of impairment in their water quality standards making them difficult to change. By using ecoregion- or stream-type-specific thresholds of stress and degradation instead of the state-specific impairment criteria, the CADDIS process could be applied anywhere in the Chesapeake Bay watershed. The customized CADDIS process would be one of several tools available to state and regional agencies for developing watershed TMDLs.

Another advantage of such a tool is it can be used to detect the agents of stress and degradation in a watershed before state-defined levels of impairment are observed. If the tool is applied to the States' routine water quality monitoring data, States can in theory track changes in the multiple stressors at a site that correspond to degradation in biological metrics. This would allow them to alleviate or remove the cause(s) of the principal stressor and correctly anticipate which stressors may become most influential as stream conditions improve. Multiple stressor threshold levels would also be helpful for Antidegradation policies and implementation.

Recently, there has been a wealth of effort applied to identifying stressor thresholds in a stressor-response fashion among the Chesapeake jurisdictions. Several states, the ICPRB, and the EPA have recently worked to identify certain stressor thresholds for ionic strength, nutrients, flow alteration, and chlorides among others (Mandel et al. 2011, Haywood et al. 2012). By aggregating the available best science of the region and performing stressor-response identification analyses for remaining undeveloped stressor thresholds, a powerful screening tool could be readily assembled that would greatly assist states in their stressor-identification and overall waterbody assessment efforts.

Literature Cited

DDNREC. 2004. Total Maximum Daily Loads (TMDLs) Analysis for Buntings Branch, Delaware. Watershed Assessment Section, Delaware Department of Natural Resources and Environmental Control, Dover, DE.

DDNREC. 2012. Personal Communication with Lawrence Pomatto, Delaware DDNREC, Division of Watershed Stewardship.

Haywood, C., C. Buchanan, H. Moltz, J. Palmer, A. Griggs, O. Devereux, and K. Bencala. 2012. Middle Potomac River Watershed Assessment: Potomac River Sustainable Flow and Water Resources Analysis, Section 729 Watershed Assessment. Draft ICPRB report submitted to US Army Corps of Engineers May 2012.

Hilsenhoff, W.L. 1987. An improved biotic index of organic stream pollution. Great Lakes Entomologist 20:31-40.

MDE. 2009. Maryland Biological Stressor Identification Process. Maryland Department of the Environment, Baltimore, MD.

Maxted, J., M. Barbour, J. Gerritsen, V. Poretti, N. Primrose, A. Silvia, D. Penrose, and R. Renfrow. 2000. Assessment framework for mid-Atlantic coastal plain streams using benthic macroinvertebrates. Journal of American Benthological Society, 19 (1): 128-144

NYSDEC. 2009. Standard Operating Procedure: Biological Monitoring of SurfaceWaters in New York State. New York State Department of Environmental Conservation, Division of Water, Albany, NY.

PADEP. 2012. Personal Communication with Brian Chalfant, Pennsylvania Department of Environmental Protection, Bureau of Watershed Management, Harrisburg, PA.

PADEP. 2009. A Benthic Index of Biotic Integrity for Wadeable Freestone Riffle-Run Streams in Pennsylvania. Pennsylvania Department of Environmental Protection, Harrisburg, Pennsylvania.

Smith, A. J., R. W. Bode, and G. S. Kleppel. 2007. A Nutrient Biotic Index (NBI) for Use with Benthic Macroinvertebrate Communities. Ecological Indicators 7:371-386.

Southerland, M. T., G. M. Rogers, M. J. Kline, R. P. Morgan, D. M. Boward, P. F. Kazyak, R. J. Klauda, and S. J. Stranko. 2005. New Biological Indicators to Better Assess the Conditions of Maryland Streams. CBWP-MANTA-EA-05-13. Maryland Department of Natural Resources, Annapolis, MD.

Southerland, M., J. Volstad, E. Weber, R. Morgan, L. Currey, J. Holt, C. Poukish, and M. Rowe. 2007. Using MBSS Data to Identify Stressor for Streams that Fail Biocriteria in Maryland. Maryland Department of the Environment, Baltimore, MD.

WVDEP. 2011. Total Maximum Daily Loads for Streams in the Elk River and Lower Kanawha River Watersheds, West Virginia. West Virginia Department of Environmental Protection, Charleston, WV.

USEPA. 2008. 2007 Chesapeake Bay Health and Restoration Report. US EPA Chesapeake Bay Program Office. Annapolis, MD.

USEPA. 2010. Using Stressor-Response Relationships to Derive Numeric Nutrient Criteria. EPA-820-S-10-001. U.S. Environmental Protection Agency. Washington, DC.

Appendix A – Tables of State Stressor Identification Thresholds

Table 1. Thresholds identifying possible stressors in the Maryland Biological Stressor Identification (BSID) tool.

	Potential Stressor	Ecoregions Highlands	Piedmont	Coastal Plain
Rapid Habitat Assessment	Bar Formation	P/A	P/A	P/A
	Channel Alteration	P/A	P/A	P/A
	Embeddedness	> 50%	> 50%	100%
	Epifaunal Substrate	0 - 10	0 - 10	0 - 10
	Erosion	mod - sev	mod - sev	mod - sev
	Bank Stability	poor	poor	poor
	Fines	P/A	P/A	P/A
	Channelization	P/A	P/A	P/A
	In-stream Condition	0 - 10	0 - 10	0 - 10
	Pool Quality	0 - 10	0 - 10	0 - 10
	Riffle Quality	0 - 10	0 - 10	0 - 10
	Velocity/Depth Diversity	0 - 10	0 - 10	0 - 10
	Concrete	P/A	P/A	P/A
	Beavers	P/A	P/A	P/A
	Riparian	none	none	none
	Shading	< 50%	< 50%	< 50%
Water Chemistry	Total Phosphorous (mg/L)	0.06	0.06	0.14
	Ortho-Phosphate (mg/L))	0.02	0.02	0.02
	Total Nitrogen (mg/L)	3.0	3.0	3.0
	Total Dissolved Nitrogen (mg/L)	3.0	3.0	3.0
	Dissolved Oxygen (mg/L)	< 5.0	< 5.0	< 5.0
	DO Saturation	< 60% or > 125%	< 60% or > 125%	< 60% or > 125%
	Ammonia (mg/L)	CCC	CCC	CCC
	pH	< 6.5 or > 8.5	< 6.5 or > 8.5	< 6.5 or > 8.5
	Acid Neutralizing Capacity (µeq/L)	< 50 , < 200	< 50 , < 200	< 50 , < 200
	Chlorides (mg/L)	50.0	50.0	50.0
	Conductivity (µS/cm)	500	300	300
	Sulfates (mg/L)	32.0	21.0	28.0
Land Use	Impervious Surface	5%	5%	10%
	High Intensity Urban	6%	10%	10%
	Urban (60 m buffer)	6%	6%	7%
	Low Intensity Urban	20%	50%	55%
	Low Urban (60 m buffer)	20%	35%	40%
	Transportation	4%	6%	6%
	Transportation (60 m buffer)	5%	5%	3%
	Total Agriculture	55%	55%	55%
	Total Agriculture (60 m buffer)	45%	45%	45%
	Cropland	25%	25%	25%
	Cropland (60 m buffer)	20%	20%	20%
	Pasture	35%	35%	35%
	Pasture (60 m buffer)	30%	30%	30%
	Barren	1%	1%	1%
	Barren (60 m buffer)	1%	1%	1%
	Forest	25%	15%	15%
	Forest (60 m buffer)	35%	35%	30%
Acid Sources	Atmospheric Deposition	P/A	P/A	P/A
	Acid Mine Drainage	P/A	P/A	P/A
	Organic Acid Source	P/A	P/A	P/A
	Agricultural Acid Source	P/A	P/A	P/A

Table 2 Stressor classification thresholds as developed by the West Virginia Deapartment of Environmental Protection is use for stressor identification.

Stressor Classification Thresholds

Parameter	**Exclusion**	**Equivocal**	**Weak**	**Possible**	**Likely**	**Definite**
Periphyton (Qual. Ranking)	0	1	2	3	4	5
Fecal coliform (counts/100mL)	< 150	150.1 - 400	400.1 - 1400	1400.1 - 1900	1900.1 - 2300	> 2300.1
Iron Flocculation (mg/L)	≤ 0.49	0.5 - 0.7669	0.767 - 1.0169	1.017 - 1.3669	1.367 - 1.8669	> 1.867
% Fines	≤ 34.9	35 - 44.9	45 - 49.9	50 - 59.9	60 - 69.9	> 70
RBP: Embeddedness	16 - 20	11 - 15	9 - 10	6 - 8	3 - 5	0 - 2
RBP: Sediment Deposition	16 - 20	11 - 15	9 - 10	6 - 8	3 - 5	0 - 2
RBP: Cover	16 - 20	11 - 15	9 - 10	6 - 8	3 - 5	0 - 2
RBP: Riparian Vegetation	16 - 20	11 - 15	9 - 10	6 - 8	3 - 5	0 - 2
RBP: Total	≥ 110.1	100.1 - 110	85.1 - 100	75.1 - 85	65.1 - 75	≤ 65
Sediment Index	90 - 100	80 - 89.9	70 - 79.9	60 - 69.9	50 - 59.9	≤ 49.9
Aluminum (mg/L)	< 0.1049	0.105 - 0.1819	0.182 - 0.2269	0.227 - 0.3069	0.307 - 0.4419	> 0.442
pH (low)	≥ 6.3	6.29 - 6.0	6.59 - 5.3	5.29 - 5.0	4.99 - 4.3	< 4.29
pH (high)	≤ 8.39	8.4 - 8.69	8.7 - 8.79	8.8 - 8.89	8.9 - 9.09	> 9.1
Conductivity (µmhos)	≤ 326.9	327 - 516.9	517 - 766.9	767 - 1074.9	1075 - 1532.9	> 1533
Sulfates	≤ 56.9	57 - 119.9	120 - 201.9	202 - 289.9	290 - 416.9	> 417
Chlorides (mg/L)	≤ 60.0	60.1 - 80.0	80.1 - 125.0	125.1 - 160	160.1 - 229.9	> 230
Dissolved Oxygen (mg/L)	> 7.0	6.99 - 6.3	6.29 - 5.4	5.39 - 4.4	4.39 -3.2	≤ 3.19
Temperature (°C)	< 25.69	25.7 - 26.69	26.7 - 27.69	27.7 - 28.89	28.9 - 30.59	> 30.6
Nitrite-Nitrate (mg/L)	< 0.6829	0.683 - 0.9829	0.983 - 1.549	1.55 - 2.0829	2.0830- 2.649	> 2.65
Total Nitrogen (mg/L)	< 2.1169	2.117 - 2.7329	2.733 - 3.3669	3.367 - 4.0329	4.033 - 4.9	> 5.0
Total Phosphorous (mg/L)	< 0.1319	0.132 - 0.1929	0.193 - 0.2829	0.283 - 0.369	0.37 - 0.509	> 0.51
Ammonia (mg/L)	< 0.99	1.0 - 1.09	1.1 - 1.19	1.2 - 1.349	1.35 - 1.649	> 1.65

Appendix B

Site Map for the US EPA
Causal Analysis/Diagnosis Decision Information System (CADDIS) Website

Downloaded 7/31/2012 from www.epa.gov/caddis/

U.S. EPA (Environmental Protection Agency). 2010. Causal Analysis/Diagnosis Decision Information System (CADDIS). Office of Research and Development, Washington, DC. Available online at http://www.epa.gov/caddis. Last updated September 23, 2010.

SITE MAP	COMMENTS
CADDIS Home Basic Information Recent Additions Frequent Questions Publications Glossary Related Links Authors & Contributors Site Map	CADDIS provides a on-line guide for pragmatically determining the causes of detrimental changes and undesirable biological conditions in aquatic systems. It provides a logical, step-by-step framework for Stressor Identification based on the U.S. EPA's Stressor Identification Guidance Document (2000), as well as additional information and tools that can be used in these assessments. The website is a work in progress, with new "modules" currently being developed and some sections being revised or expanded.
Volume 1: Stressor Identification **Step-by-Step Guide Introduction** Using the Step-by-Step Guide Guide Overview Fundamentals of Causal Analysis	Volume 1 provides a step-by-step guide for identifying probable causes of impairment. The other four volumes provide the details underlying each step, examples, advice on analysis methods, and downloadable software applications. Guide Overview is useful for getting oriented. Fundamentals briefly discusses the principles underlying causal analysis - explains how "refutation", "diagnosis", and "strength of evidence" are adapted and integrated in CADDIS.
Step 1: Define the Case Overview In-Depth Look Results and Next Steps	Step 1 helps the user in focusing and scoping out the causal analysis. A quantitative definition of biological impairment (or level of degradation) helps a lot to define the case, and observation of a biological impairment (degradation) triggers the causal analysis.
Step 2: Candidate Causes Overview In-Depth Look Results and Next Steps	Step 2 guides the user through the process of listing the possible (candidate) causes of impairment. It results in: - a list of candidate causes selected from a provided list, - a map showing possible sources and other geographic features, and - a conceptual model diagram of the candidate causes

Step 3: Data from the Case

In Step 3, the analyst looks at evidence and apparent associations at the impaired site.

Overview
In-Depth Look
- 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

Results and Next Steps

The section leads you through steps to develop consistent and credible evidence to a) eliminate improbably causes, b) refute or diagnose likely causes, and c) begin to build a defensible body of evidence for the most likely cause(s). Explains how to score (weight) the various pieces of evidence. Produces a summary of supporting data, analysis, and scores for each type of evidence that was evaluated. Evidence sorted into eliminated causes and diagnosed causes.

Step 4: Data from Elsewhere

Step 4 draws in evidence from elsewhere – i.e., not from the same location; may or may not be from the literature and/or the laboratory. Again, associations are evaluated and scored according to how much they support or weaken the case for a candidate cause.

Overview
In-Depth Look
- 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
- Analogous Stressors

Results and Next Steps

Step 5: Identify Probable Causes

Step 5 is the final step in the stressor identification process. It identifies the most probable cause(s) of impairment from the full list of possible causes. If done correctly, the process should have built a clear, reasonable and convincing argument as to why the identified stressor(s) are causing biological impairment.

Overview
Weigh Evidence for Each Case
- Consistency of Evidence
- Explanation of the Evidence

Compare Evidence Among Causes
Complete Causal Analysis

Types of Evidence

Summary tables of the different types of evidence

Scores

Supporting tables showing how to score the evidence

Causal Assessment Background

The Causal Assessment Background section explains philosophical system ("pragmatism") underlying the CADDIS method. Causation is a difficult and complex concept. Causal analysis needs a strong conceptual foundation that weighs the evidence with transparency and consistency and then diagnoses the cause(s) of impairment with sufficient certainty.

Our Causal Approach
Causal Concepts

Causal History
References

Volume 2 focuses on the links between anthropogenic sources, environmental stressors, and biological responses. It offers guidance on: a) when to include a stressor as a candidate in a case study, b) how to measure stressors, c) conceptual diagrams of all the source-stressor-response links, and d) references.

Volume 2: Sources, Stressors & Responses

Sources

Urbanization
What is urbanization?

- The urban stream syndrome
- Urbanization & biotic integrity
- Catchment vs. riparian urbanization

There is currently one source-based module in CADDIS: urbanization. The urbanization section goes into detail about how various anthropogenic activities relating to urban development bring about the stressors that affect biological communities. The urban-to-stressor links that are discussed here are illustrated in the conceptual diagrams (Appendix B). There are a lot of useful references in this section.

Riparian/Channel Alteration

- Riparian zones & channel morphology
- Urbanization & riparian hydrology
- Stream burial

Wastewater Inputs

- Combined sewer overflows (CSOs)
- Wastewater-related enrichment
- Reproductive effects of WWTP effluents

Stormwater Runoff

- Effective vs. total imperviousness
- Imperviousness & biotic condition
- Thresholds of imperviousness

Water/Sediment Quality

- Conductivity
- Nitrogen
- Pavement sealants

Temperature

- Heated surface runoff
- Temperature & biotic condition
- Urbanization & climate change

Hydrology

- Baseflow in urban streams
- Water withdrawals & transfers
- Biotic responses to urban flows

Physical Habitat

- Channel enlargement
- Road crossings
- Bed substrates & biotic condition

Energy Sources

- Terrestrial leaf litter
- Primary production & respiration
- Quantity & quality of DOC

Stressors

Ammonia

- Introduction
- When to List
- Ways to Measure
- Simple Conceptual Diagram
- Detailed Conceptual Diagram
- Literature Reviews
- References

Dissolved Oxygen

- Introduction
- When to List
- Ways to Measure
- Simple Conceptual Diagram
- Detailed Conceptual Diagram
- References

Flow Alteration

- Introduction
- When to List
- Ways to Measure
- Simple Conceptual Diagram
- Detailed Conceptual Diagram
- References

Herbicides

There are currently 15 stressor-based modules on CADDIS (see list on left). Modules under development include endocrine-disrupting chemicals and polycyclic aromatic hydrocarbons.

Each module

- explains how an individual stressor affects biological condition
- discusses evidence that supports including the stressor as a candidate cause of impairment
- discusses ways of measuring the stressor

Each module is illustrated in conceptual diagrams. These diagrams connect anthropogenic sources to proximal stressors and then to biological responses while also indicating modifying factors, interacting stressors, and mode of action (Appendix B). Interactive conceptual diagrams (ICDs) can be found in another location on the website (see below).

- Introduction
- When to List
- Ways to Measure
- Simple Conceptual Diagram
- Detailed Conceptual Diagram
- Literature Reviews
- References

Insecticides

- Introduction
- When to List
- Ways to Measure
- Simple Conceptual Diagram
- Detailed Conceptual Diagram
- References

Ionic Strength

- Introduction
- When to List
- Ways to Measure
- Simple Conceptual Diagram
- Detailed Conceptual Diagram
- References

Metals

- Introduction
- When to List
- Ways to Measure
- Simple Conceptual Diagram
- Detailed Conceptual Diagram
- References

Nutrients

Separate modules are provided for nitrogen and for phosphorus.

- Introduction
- When to List
- Ways to Measure
- Simple Conceptual Diagram
- Detailed Conceptual Diagram
- References

pH

Separate modules are provided for high pH and for low pH.

- Introduction

- When to List
- Ways to Measure
- Simple Conceptual Diagram
- Detailed Conceptual Diagram
- References

Physical Habitat

- Introduction
- When to List
- Ways to Measure
- Simple Conceptual Diagram
- Detailed Conceptual Diagram
- References

Sediment

- Introduction
- When to List
- Ways to Measure
- Simple Conceptual Diagram
- Detailed Conceptual Diagram
- References

Temperature

- Introduction
- When to List
- Ways to Measure
- Simple Conceptual Diagram
- Detailed Conceptual Diagram
- References

Unspecified Toxic Chemicals

- Introduction
- When to List
- Ways to Measure
- Simple Conceptual Diagram
- Detailed Conceptual Diagram
- References

Responses

Responses are the biological results of exposure to proximate stressors. Currently there are no response modules on CADDIS, but a module for fish DELTS (deformities, erosions, lesions and tumors) is now under development.

Volume 3: Examples & Applications

Volume 3 illustrates different aspects of the causal analysis steps with actual examples.

The analytical examples are:

1. Spatial Co-occurrence with Regional Reference Sites
2. Verified Prediction: Predicting Environmental Conditions from Biological Observations
3. Stressor-Response from Field Observations
4. Stressor-Response from Laboratory Studies
5. Verified Prediction with Traits

The Little Scioto worksheets give an actual example of the SI steps from start to finish. The example is very useful to review when starting a case study.

Analytical Examples

Overview
Example 1
Example 2
Example 3
Example 4
Example 5

Worksheets: Little Scioto

Overview
1. Define the Case
2. List Candiate Causes
3. Assemble Data from the Case
4. Spatial/Temporal Co-occurrence
5. Evidence of Exposure or Mechanism
6. Causal Pathway
7. Stressor-Response from the Field
    - Sediment
    - Riffle/pool
    - Dissolved oxygen
    - Ammonia
    - Metals
8. Summary of Scores from the Case
    - Increased % DELT
    - Increased Relative Weight
    - Decreased % Mayflies and Increased % Tolerant Macroinvertebrates
9. Assemble Data from Elsewhere
10. Stressor-Response from Laboratory Studies
11. Mechanistically Plausible Cause
12. Summary of Scores from Elsewhere
    - Increased % DELT
    - Increased Relative Weight
    - Decreased % Mayflies and Increased % Tolerant Macroinvertebrates
13. Consistency of Evidence
    - Increased % DELT
    - Increased Relative Weight
    - Decreased % Mayflies and Increased % Tolerant Macroinvertebrates
14. Explanation of Evidence
    - Increased % DELT
    - Increased Relative Weight

Decreased % Mayflies and Increa
15. Identify Probable Cause

Full Case Studies

State Examples

Galleries

Overview
Chronic Concentration-Response
SSDs
Field Stressor-Response
References

Links to fifteen case studies and several state examples that show how some analysts have used the SI process. Differences can be seen in how the reports were organized, how the data were analyzed, and how the results were presented.

Galleries contain

- The Metals Chronic Concentration-Response Gallery - links to plots and source data describing the response of aquatic organisms to chronic metal exposures
- The Metals Species Sensitivity Distribution (SSD) Gallery - links to SSD plots and ECOTOX database for a range of toxic metals
- The Field Stressor-Response Association Gallery –plots of stressor-response relationships (primarily for sediment and metals) computed from field data using linear regression, quantile regression, and conditional probability

---

Volume 4: Data Analysis

Selecting an Analysis Approach

How Can I Use My Data?
Establishing Differences from Expectations
Describing Stressor-Response Relationships

Getting Started

Assembling Data
Matching Data
Organizing Data
Data Quality
References

Basic Principles and Issues

Interpreting Statistics
  Interpreting Statistics: Details
Autocorrelation
  Autocorrelation: Details
Confounding
  Confounding: Details
References

Volume 4 describes different analytical techniques that can be applied in a causal analysis. Materials in the volume have been organized in topic areas and were written for users with varying backgrounds in statistics. Brief descriptions of each section's contents are:

Selecting an Analysis Approach: initial guidance for selecting appropriate analyses that can inform different phases of a causal analysis.

- Does the site differ from reference?
- What is the expected relationship between stressor and biological response?

Getting Started: things to think about before you start analyzing data.

- Smartly assemble a reliable data set
- Correctly match biological and environmental data in time and space
- Associate source to stressor and stressor to biological response
- Follow QA procedures

Basic Principles & Issues: basic concepts to keep in mind while analyzing observational data.

Exploratory Data Analysis

What is EDA?
Variable Distributions
Scatterplots
Correlation Analysis
Conditional Probability
Multivariate Approaches
  Multivariate Approaches: Details
Mapping Data
References

Exploratory Data Analysis (EDA): techniques for becoming familiar with your data.

- Identifies general patterns in the data including outliers and unexpected features.
- Can provide insights that may guide listing of possible candidate causes of impairment.

Basic Analyses

Tests of Significant Difference
Regression Analysis
  Regression Analysis: Details
Quantile Regression
  Quantile Regression: Details
Classification and Regression Tree (CART) Analysis
  CART Analysis: Details
References

Basic Analyses: "building block" statistical methods. Explains some fundamental methods, how to use them, how to interpret the results, and the general do's and do not's for each. Very useful refresher in these statistical methods. Also provides links to downloadable software (see below).

Advanced Analyses

Controlling for Natural Variability
Predicting Environmental Conditions From Biological Observations (PECBO)
  PECBO: Details
Analyzing Trait Data
Propensity Score Analysis
Species Sensitivity Distributions (SSDs)
References

Advanced Analysis for users with more than a basic understanding of statistics. Several interesting and powerful approaches are described and demonstrated.

Download Software

Overview
CADStat
SSD Generator
R Command Line Tutorial

Download Software include:

- CADStat – a menu-driven package based on a Java Graphical User Interface to R, for those inexperienced with programming
- SSD – a Microsoft Excel template
- R Command Line Tutorial – a primer for using R scripts

Volume 5: Causal Databases

ICDs

Introduction
ICD User Roles & Modes

Volume 5 currently contains two tools:

- interactive conceptual diagrams (ICDs) that can be used by analysts as an organizing framework to generate list of plausible stressors for an impaired site
- the CADDIS literature resource (CADLit) from the peer-reviewed scientific literature

Viewing ICDs
Editing ICDs

The fifteen detailed conceptual diagrams available on the CADDIS website are shown in Appendix B. An ICD application is required to view and manipulate the online versions of the diagrams.

CADLit

Introduction
Using CADLit

Currently, the stressors considered in CADLit include metals, sediment, and nutrients. Literature dealing with other stressors is being added. Includes keyword search and advanced search capabilities.

APPENDIX C

Detailed Conceptual Diagrams
Relating Sources to Stressors and Stressors to Biological Responses

Conceptual diagrams are visual representations of how a system works and are useful in identifying and listing candidate causes of stream biological impairment (Step 2 of the CADDIS approach). The diagrams provide a picture of how specific stressors may be linked to sources and biological effects. They illustrate *potential* linkages among stressors (or candidate causes) and their likely sources and effects based on scientific literature and professional judgment. Inclusion of a linkage indicates that the linkage *can* occur, not that it *always* occurs.

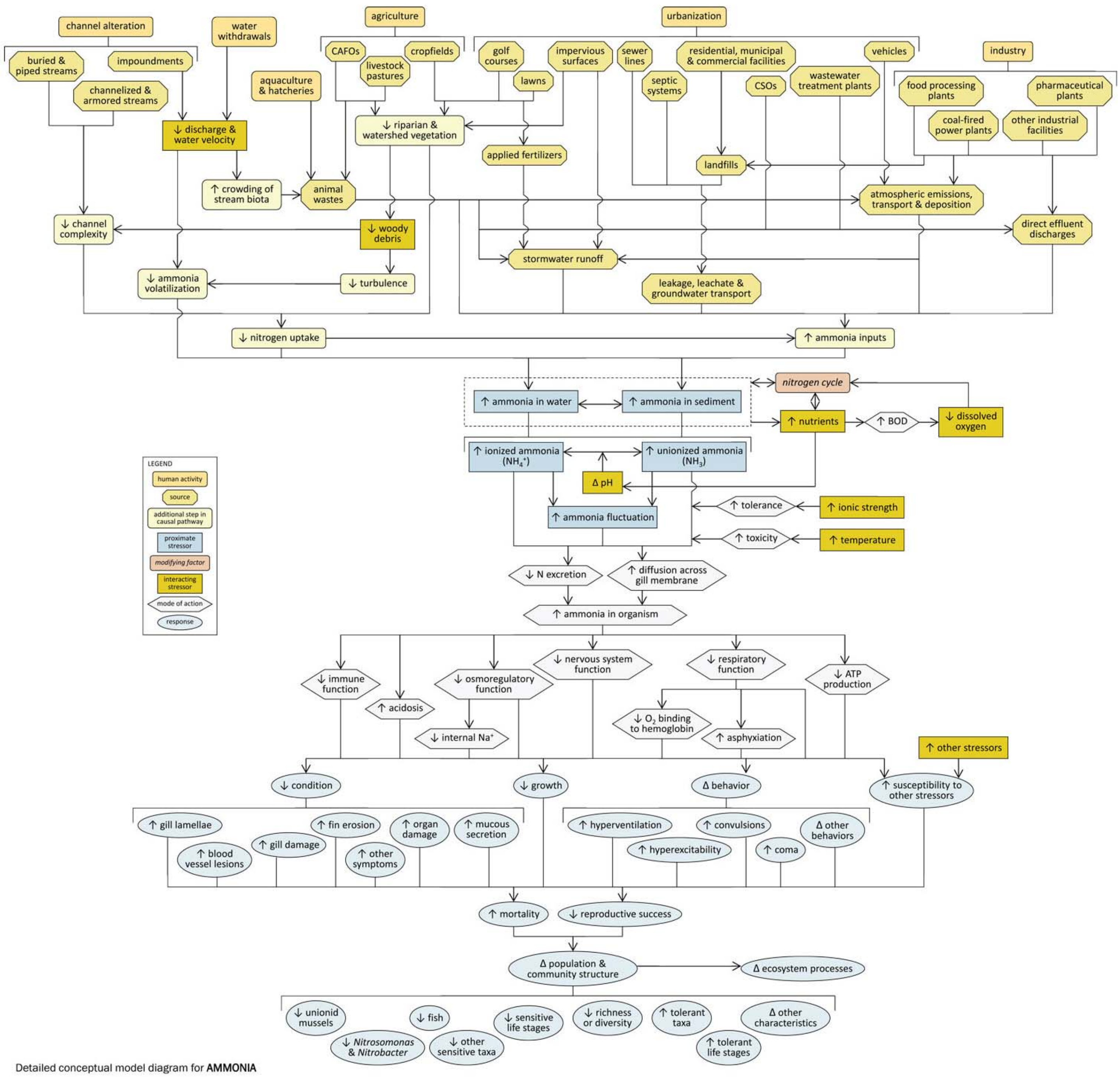
An interactive conceptual diagram application is available online at www.epa.gov/caddis/. The application provides:

1. **A set of U.S. EPA-constructed conceptual diagrams** illustrating human activities, associated sources and stressors, and potential biotic responses (collectively referred to as shapes), which can be used to search the ICD literature database for peer-reviewed scientific literature supporting linkages among selected shapes;
2. **An online graphical editor** that allows users to create new (or modify existing) interactive conceptual diagrams and link new or existing references to those diagrams;
3. **A collaborative workspace**, whereby users can grant other users the ability to view and/or revise diagrams they have created.

This appendix contains the full (detailed) conceptual diagrams completed to-date for sixteen stressors and available on the CADDIS website.

(ICD description adapted from http://www.epa.gov/caddis/cd_icds_intro.html .)

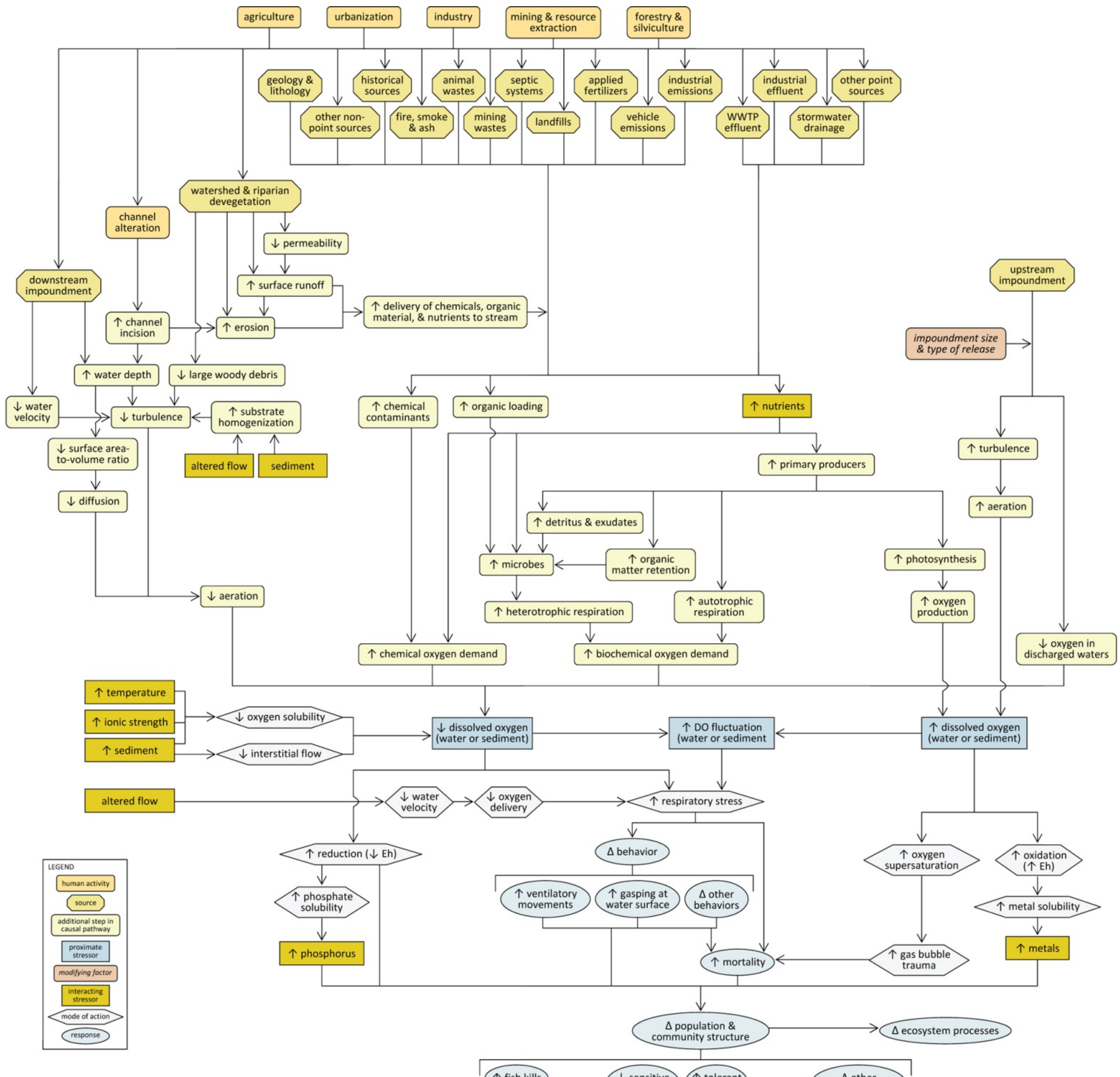
AMMONIA (NH_3)



Detailed conceptual model diagram for **AMMONIA**

From www.epa.gov/caddis/ssr_amm4d.html

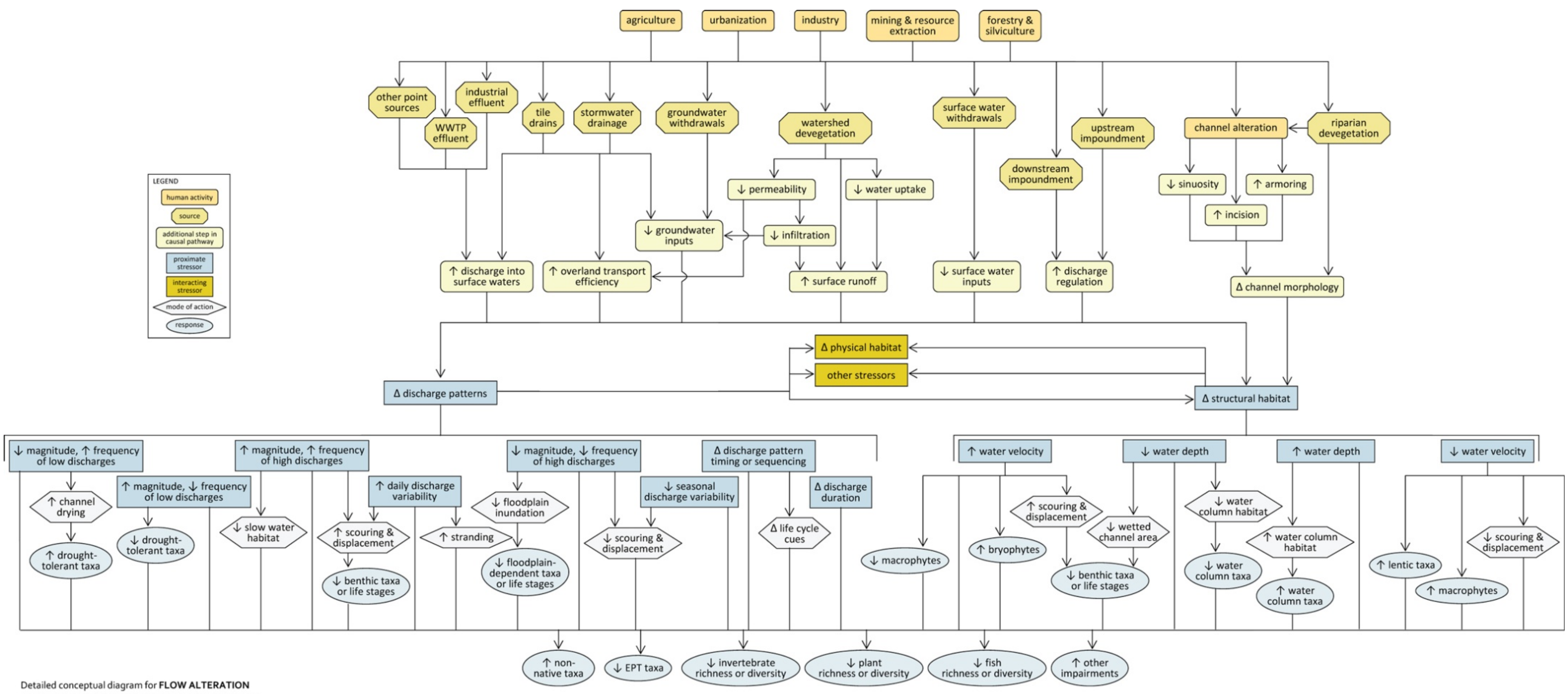
DISSOLVED OXYGEN



Detailed conceptual diagram for **DISSOLVED OXYGEN**
Developed 7/2007 by Kate Schofield & Suzanne Marcy; modified 6/2010

From www.epa.gov/caddis/ssr_do4d.html

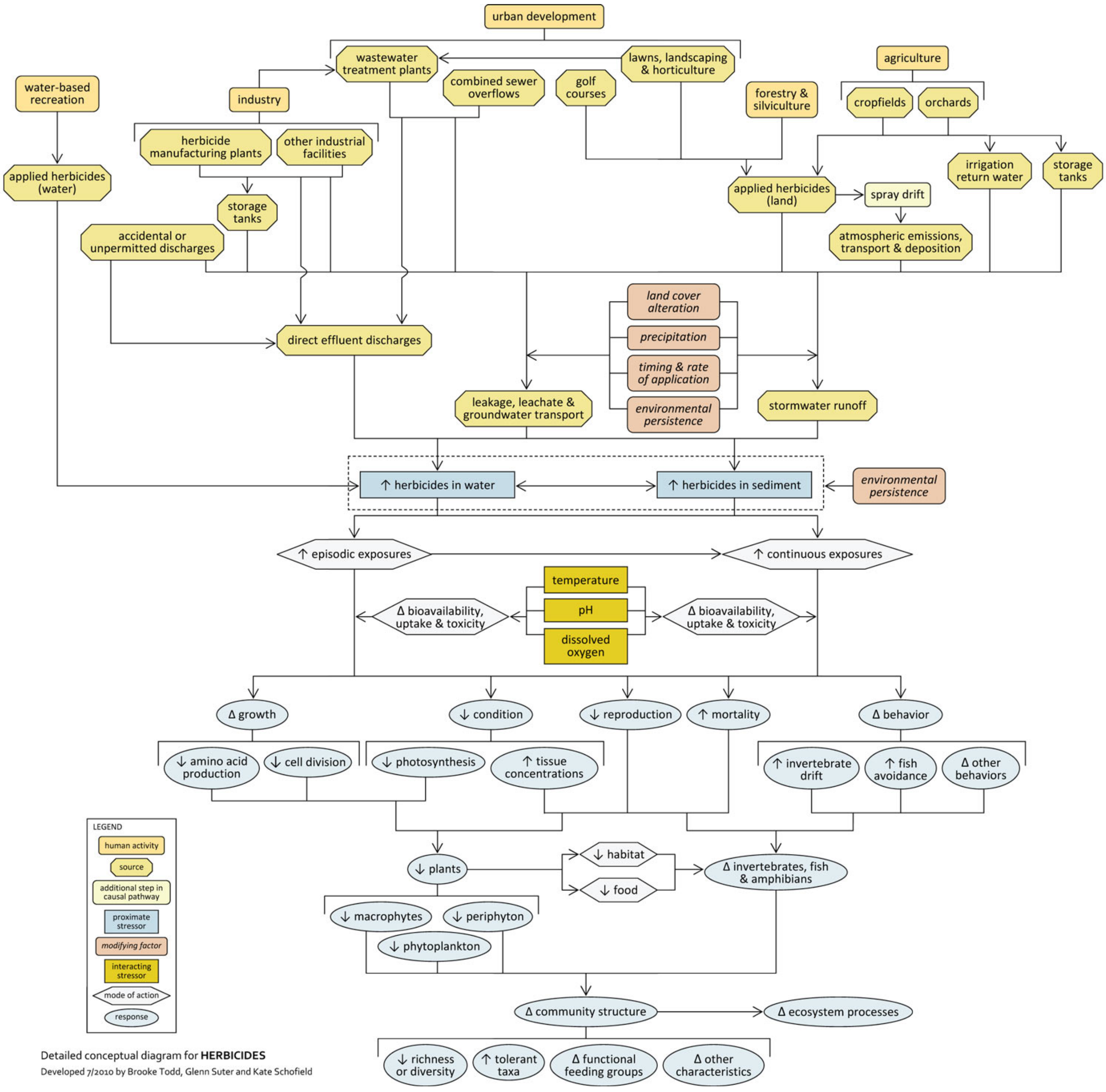
FLOW ALTERATION



Detailed conceptual diagram for **FLOW ALTERATION**
Developed 7/2007 by Kate Schofield & Rick Ziegler; modified 7/2010

From www.epa.gov/caddis/ssr_flow4d.html

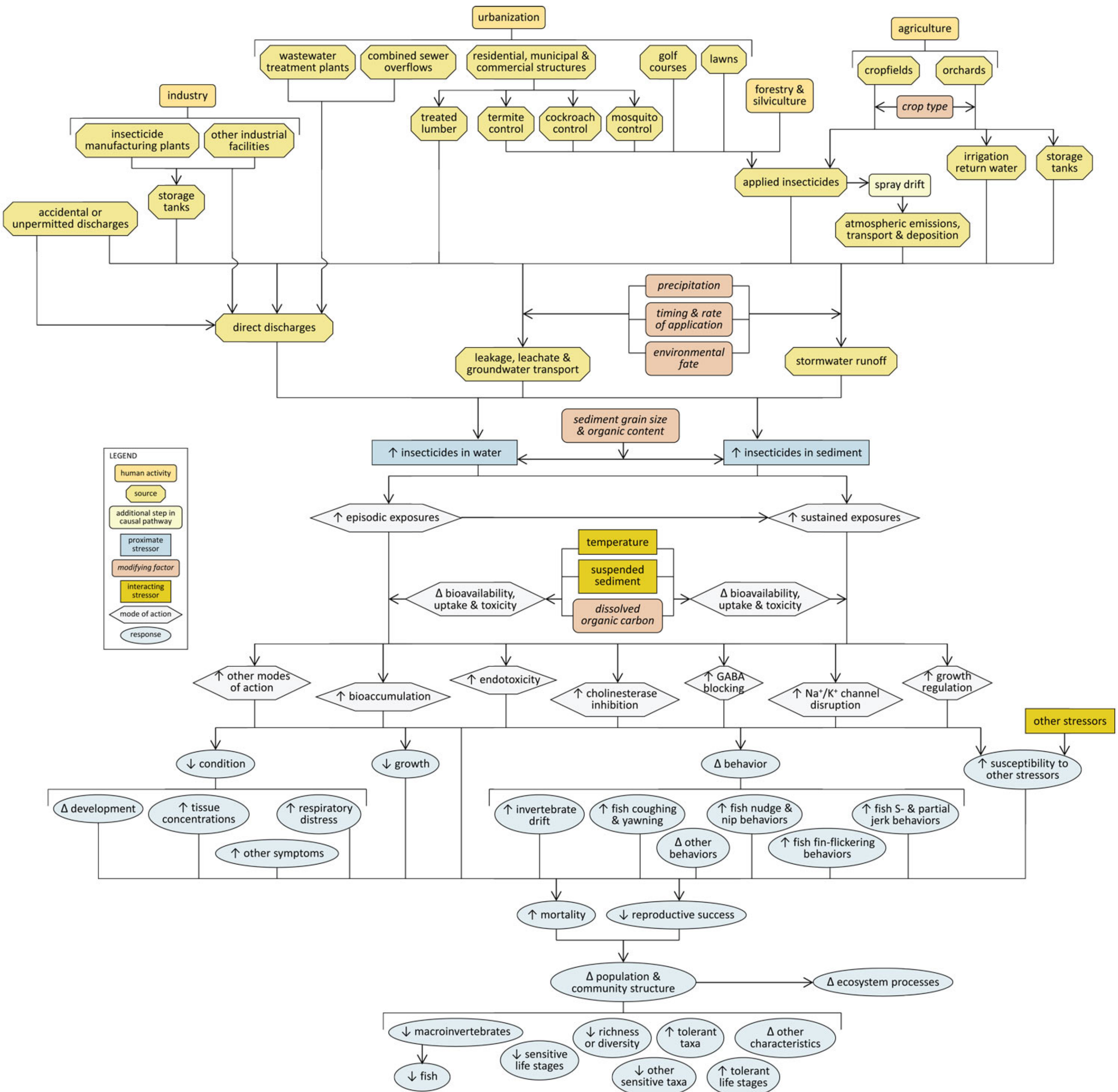
HERBICIDES



Detailed conceptual diagram for **HERBICIDES**
Developed 7/2010 by Brooke Todd, Glenn Suter and Kate Schofield

From www.epa.gov/caddis/ssr_herb4d.html

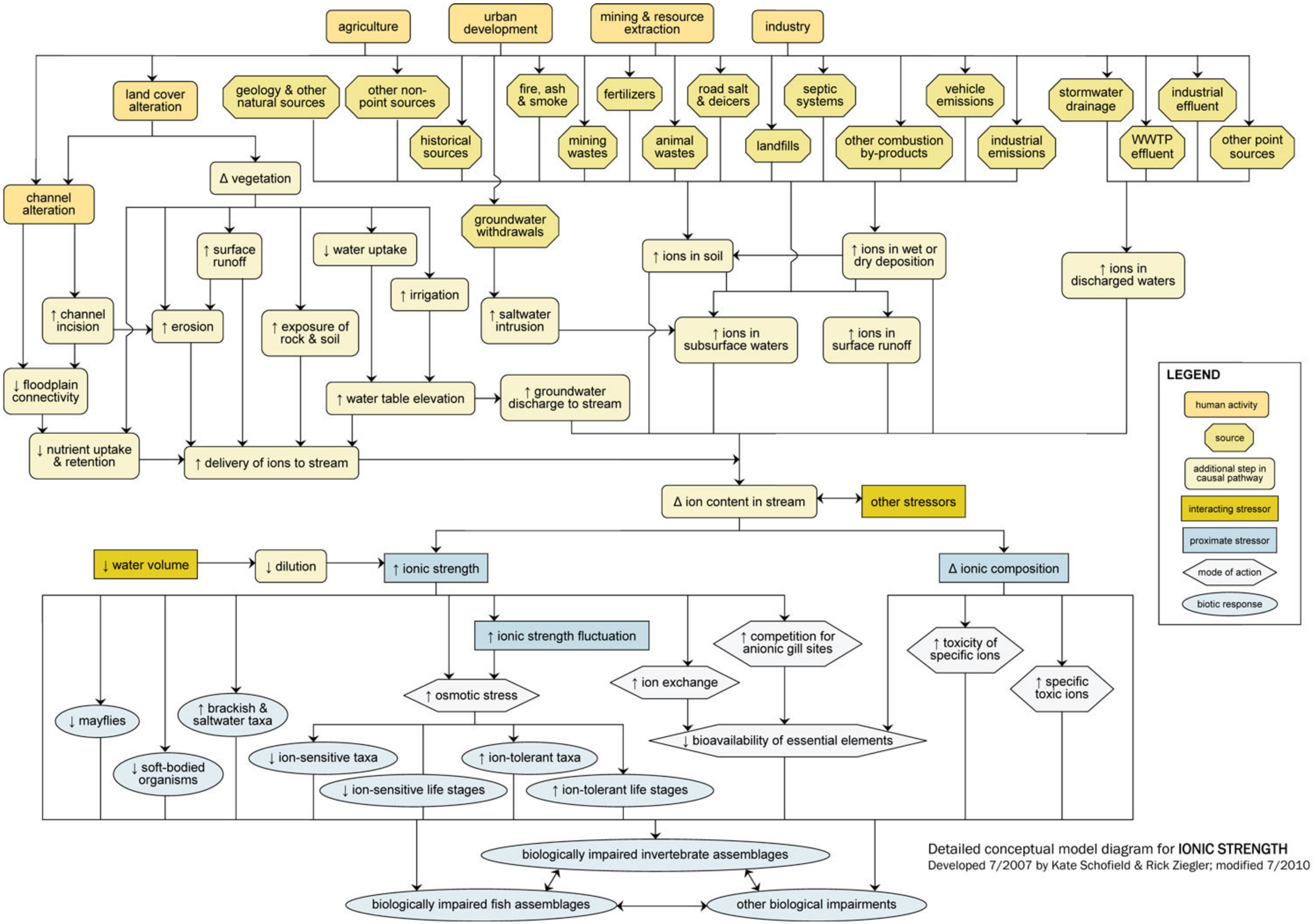
INSECTICIDES



Detailed conceptual model diagram for **INSECTICIDES**

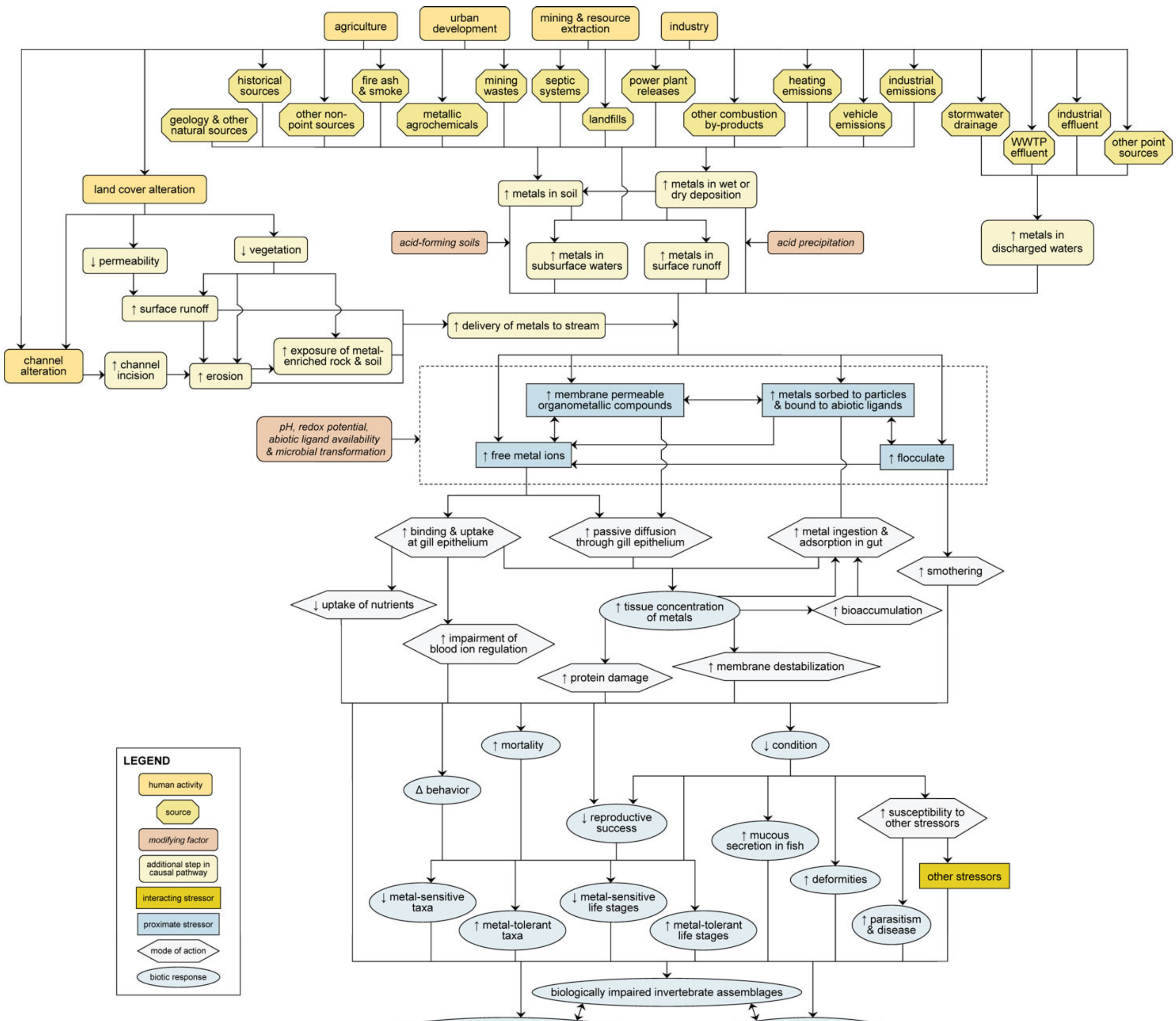
From www.epa.gov/caddis/ssr_ins4d.html

IONIC STRENGTH



From www.epa.gov/caddis/ssr_ion4d.html

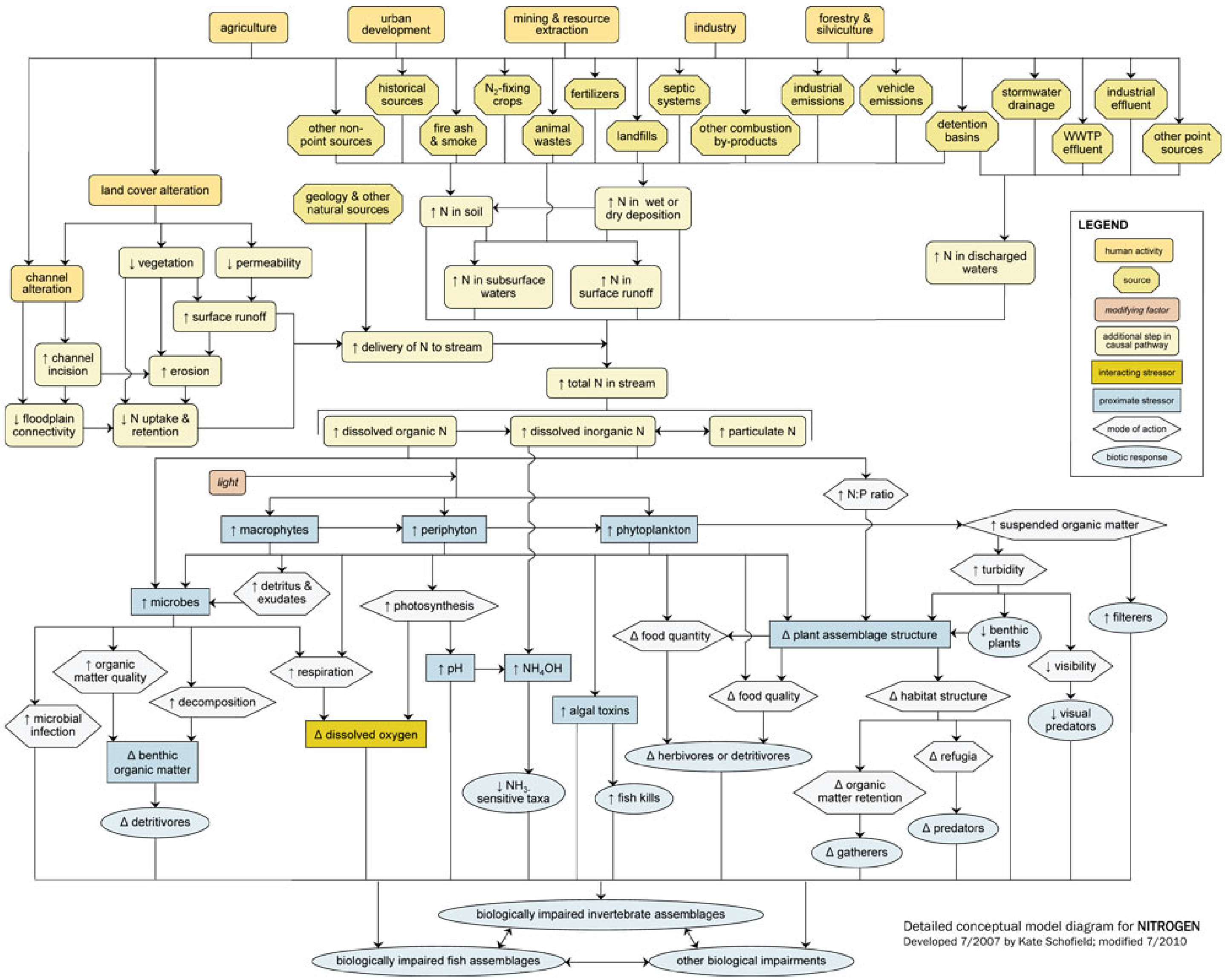
METALS



Detailed conceptual model diagram for **METALS**
Developed 7/2007 by Kate Schofield & Pat Shaw-Allen; modified 7/2010

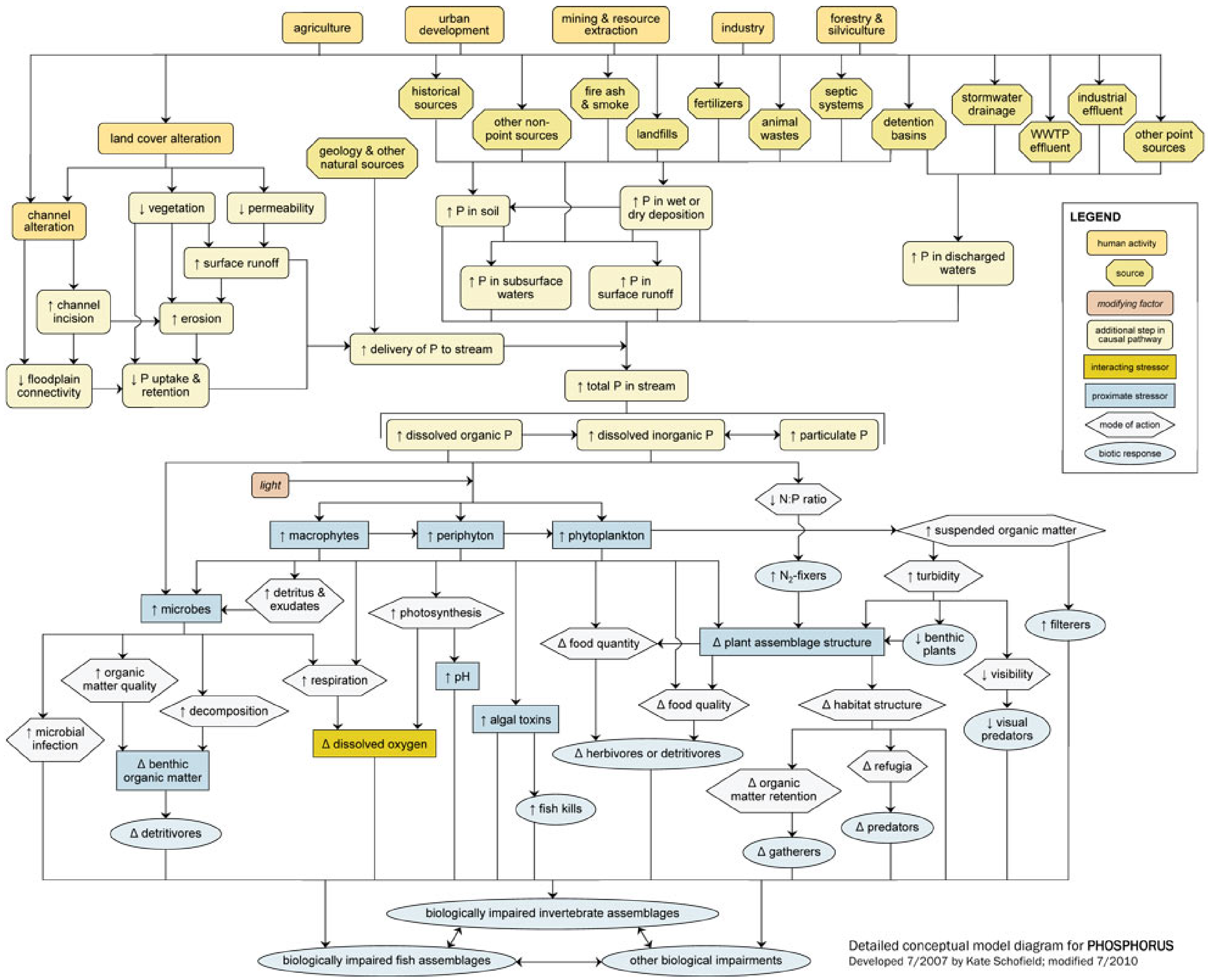
From www.epa.gov/caddis/ssr_met4d.html

NUTRIENTS - NITROGEN



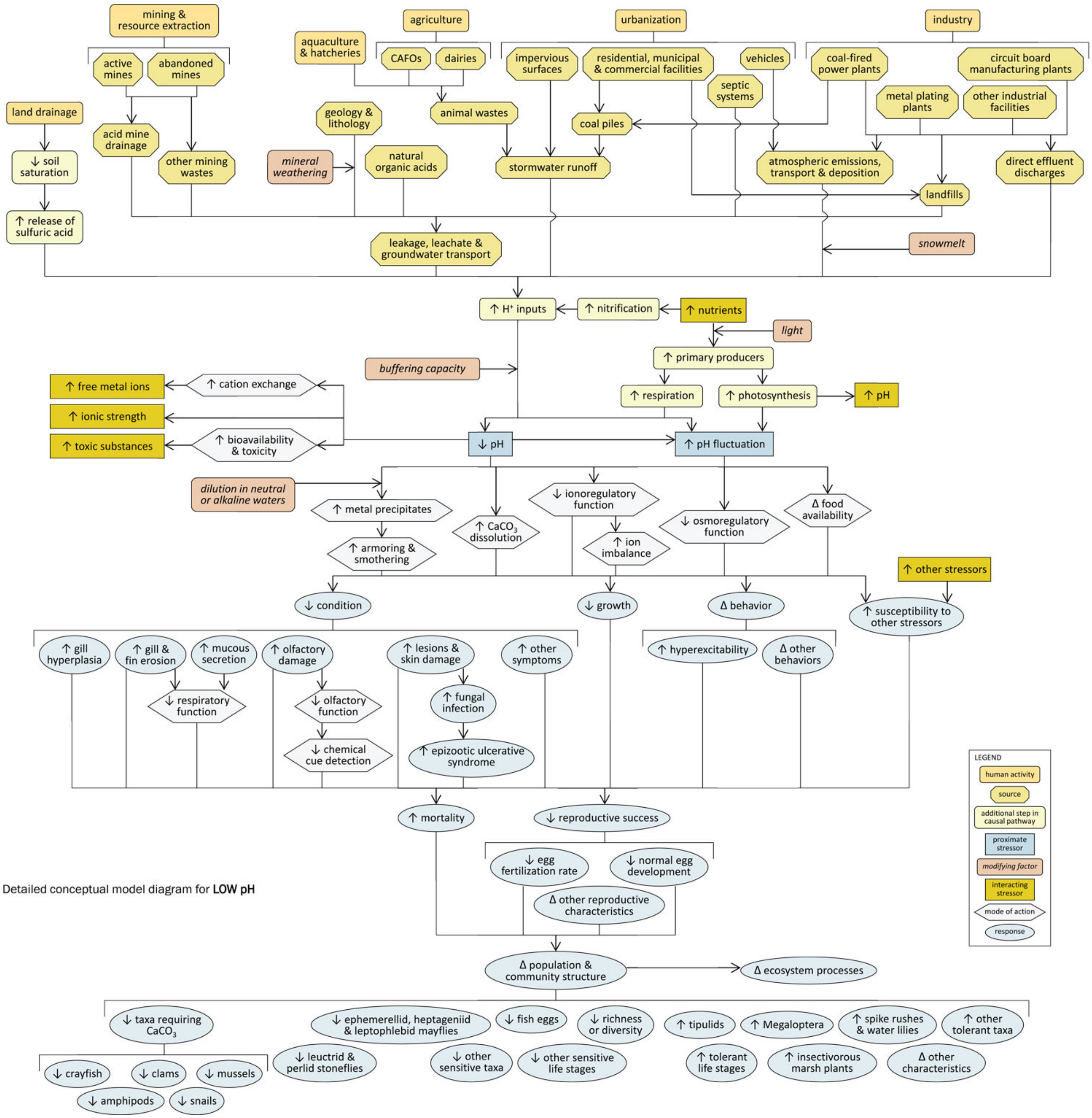
From www.epa.gov/caddis/ssr_nut4d_n.html

NUTRIENTS – PHOSPHORUS



From www.epa.gov/caddis/ssr_nut4d_p.html

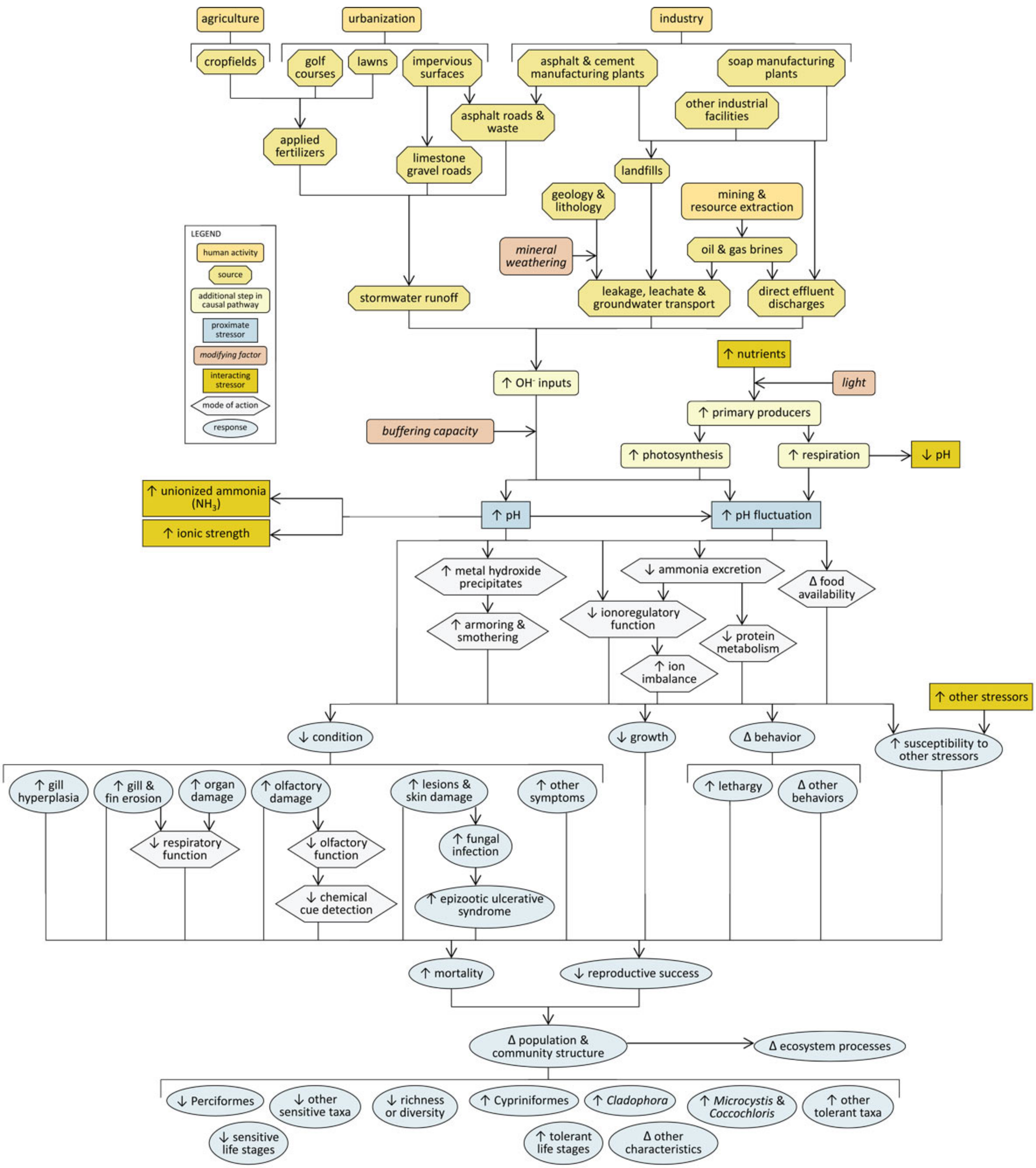
LOW pH



Detailed conceptual model diagram for **LOW pH**

From www.epa.gov/caddis/ssr_ph4d.html#lowph

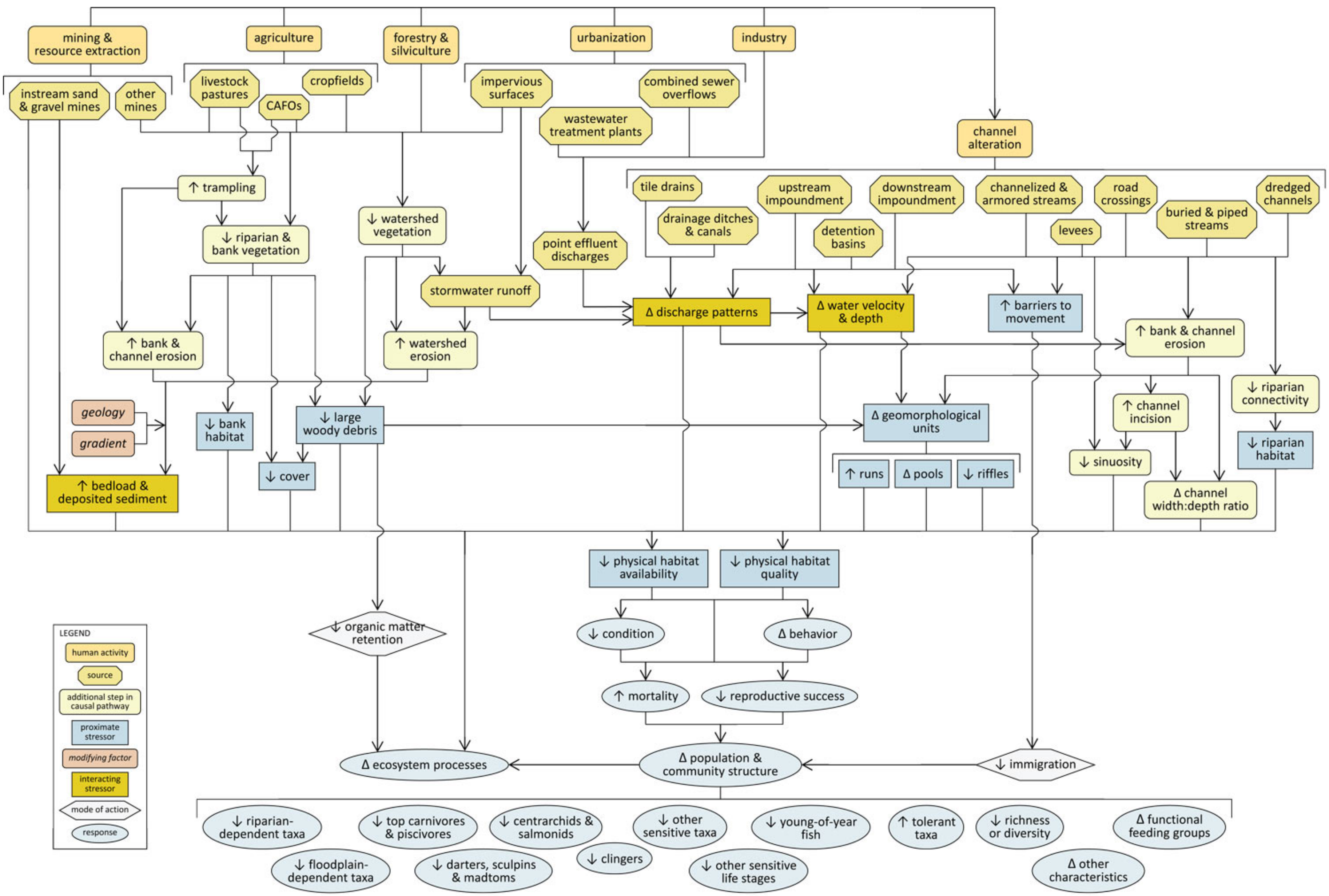
HIGH pH



Detailed conceptual model diagram for **HIGH pH**

From www.epa.gov/caddis/ssr_ph4d.html#highph

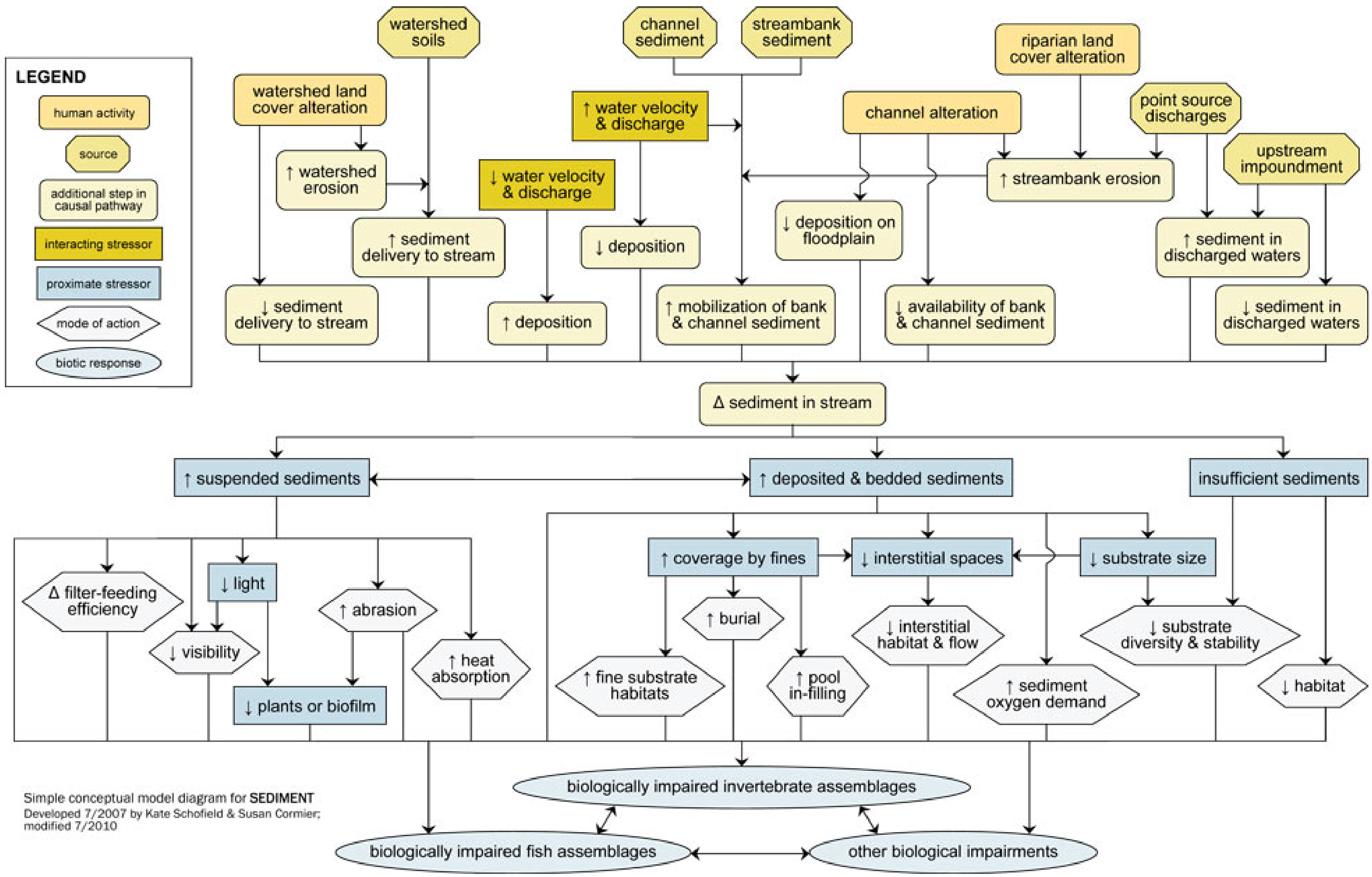
PHYSICAL HABITAT



Simple conceptual model diagram for **PHYSICAL HABITAT**

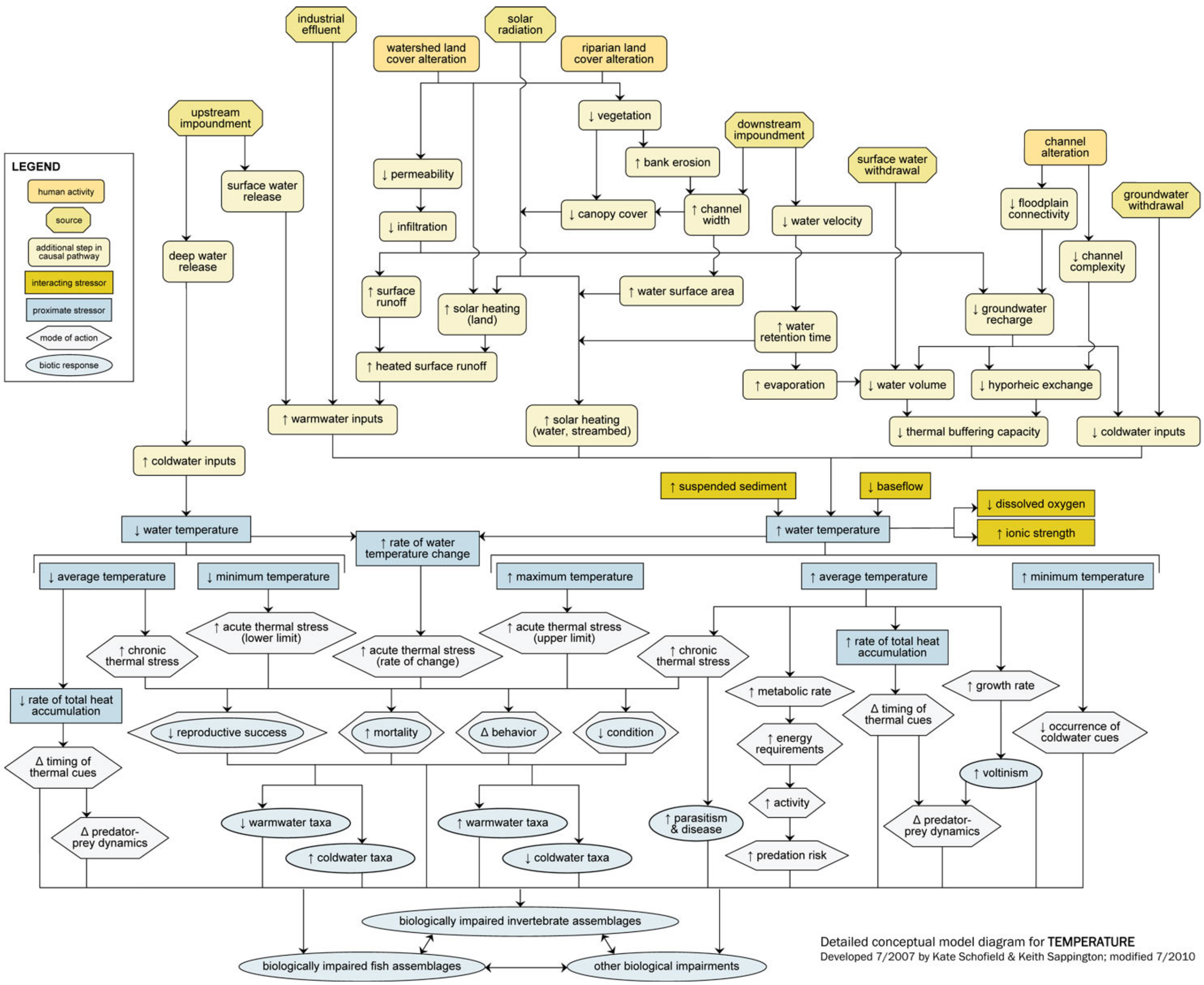
From www.epa.gov/caddis/ssr_phab4d.html

SEDIMENTS



From www.epa.gov/caddis/ssr_sed4s.html

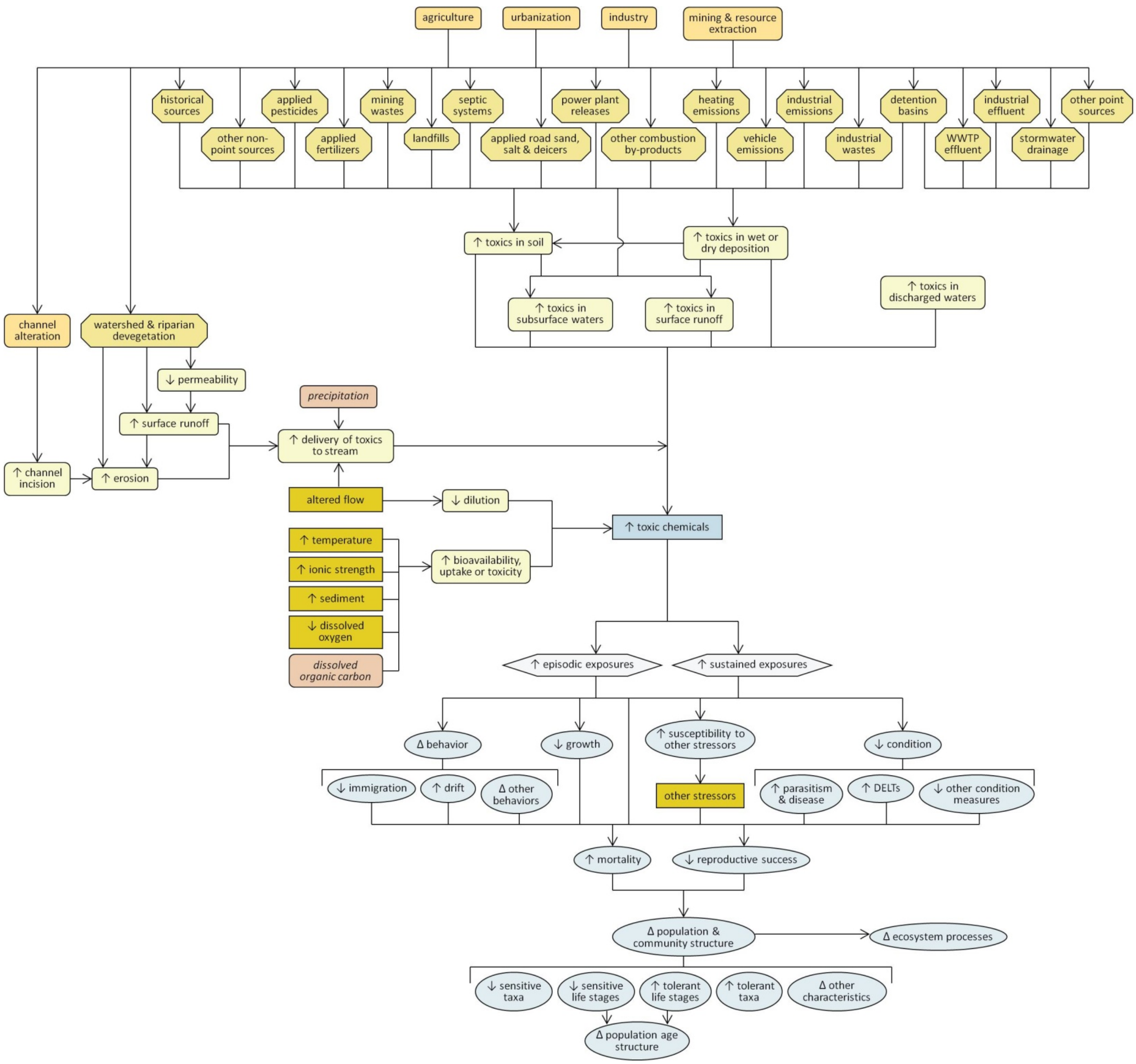
TEMPERATURE



Detailed conceptual model diagram for **TEMPERATURE**
Developed 7/2007 by Kate Schofield & Keith Sappington; modified 7/2010

From www.epa.gov/caddis/ssr_temp4d.html

UNSPECIFIED TOXIC CHEMICALS



From www.epa.gov/caddis/ssr_tox4d.html